MASSACHUSETTS INSTITUTE OF TECHNOLOGY
22.071/6.071 Introduction to Electronics, Signals and Measurement
Spring 2006

Lab6. Resistor Networks 2.

Experiment 1. Power rating of resistors.
Power rating is a very important characteristic of electronic devices. These devices may be complex electronic systems or simple electronic components such as resistors. Most of the resistors used in our laboratory are rated for ¼ Watt.
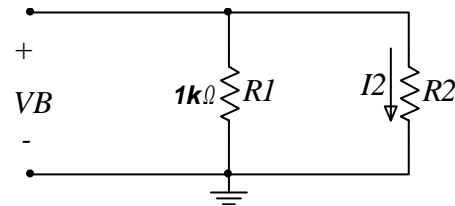Explain briefly the meaning and importance of this rating.

Draw the i-v space and indicate the region inside which you are able to safely operate your ¼ Watt resistors. For a 100Ω resistor indicate the region of operation.

Let's experiment with our resistors to see what actually happens when the stated power rating is exceeded.
Lets construct the circuit shown here →
Resistors R1 and R2 form a current divider network.
We will experiment with resistor R2 to determine the minimum resistance that it can have without violating the power rating. Violation of the power rating will simply result in the destruction of the component. (Be careful here. The resistor will get very hot and it will eventually burn with a very characteristic odor). Set the voltage VB to +15 Volts. Experiment and complete the table below. Start with R2=1k and decrease it until you violate the power rating or until you manage to destroy a resistor. (a set of test resistors could be 1kΩ, 100Ω, 50Ω, 30Ω, 10Ω, 5Ω, etc.) It is expected that you destroy at least one resistor in this experiment. Note that the +15 V power supply is limited to 500 mA.


| R2 (Ω)	I2 (mA) Calculated	Power (W) in R2 Calculated	Observation

Experiment 2.

Voltage Divider Thermometer.

We will use a thermistor device to construct a simple temperature measuring device. In Appendix A you may find a useful summary description of the thermistor characteristics. You may also find additional information posted on the Manuals and Data Sheets section of the class web site.

Construct the following circuit on your prototyping board and make the connections as indicated.
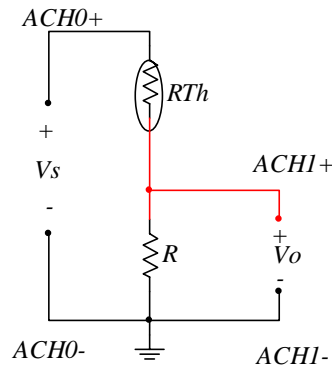

Here the symbol *RTh* indicates a thermistor. For the fixed resistor *R* use one of your 10kΩ laboratory resistors.

We need to keep track of both the voltage *Vs* and the output voltage *Vo*. Connect Vs to the +5 Volt supply. The resistance of the thermistor *RTh* changes as a function of temperature. The particular device that we use is called a 10kΩ thermistor. This, in the language of thermistors, means that the thermistor has a resistance of 10kΩ at 25 degrees Celsius. The

resistance versus temperature dependence is shown on the above plot. Note that the resistance decreases with increasing temperature and for this reason this is called a negative temperature coefficient (NTC) thermistor.
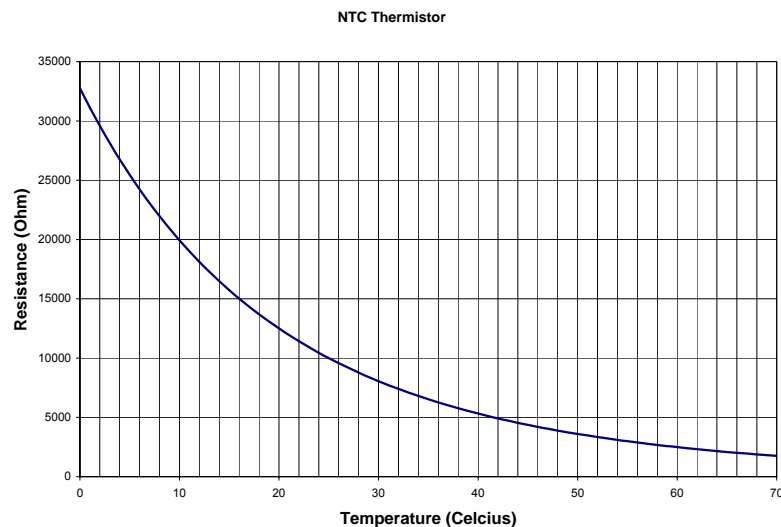
You are going to use a prepared instrument to perform these measurements. This instrument is called **Voltage Divider Thermometer** and it is internally pre-wired to the channels indicated above for the various signals. Download the instrument from the class web site and run it. The default interface looks like:

Start instrument   Stop instrument
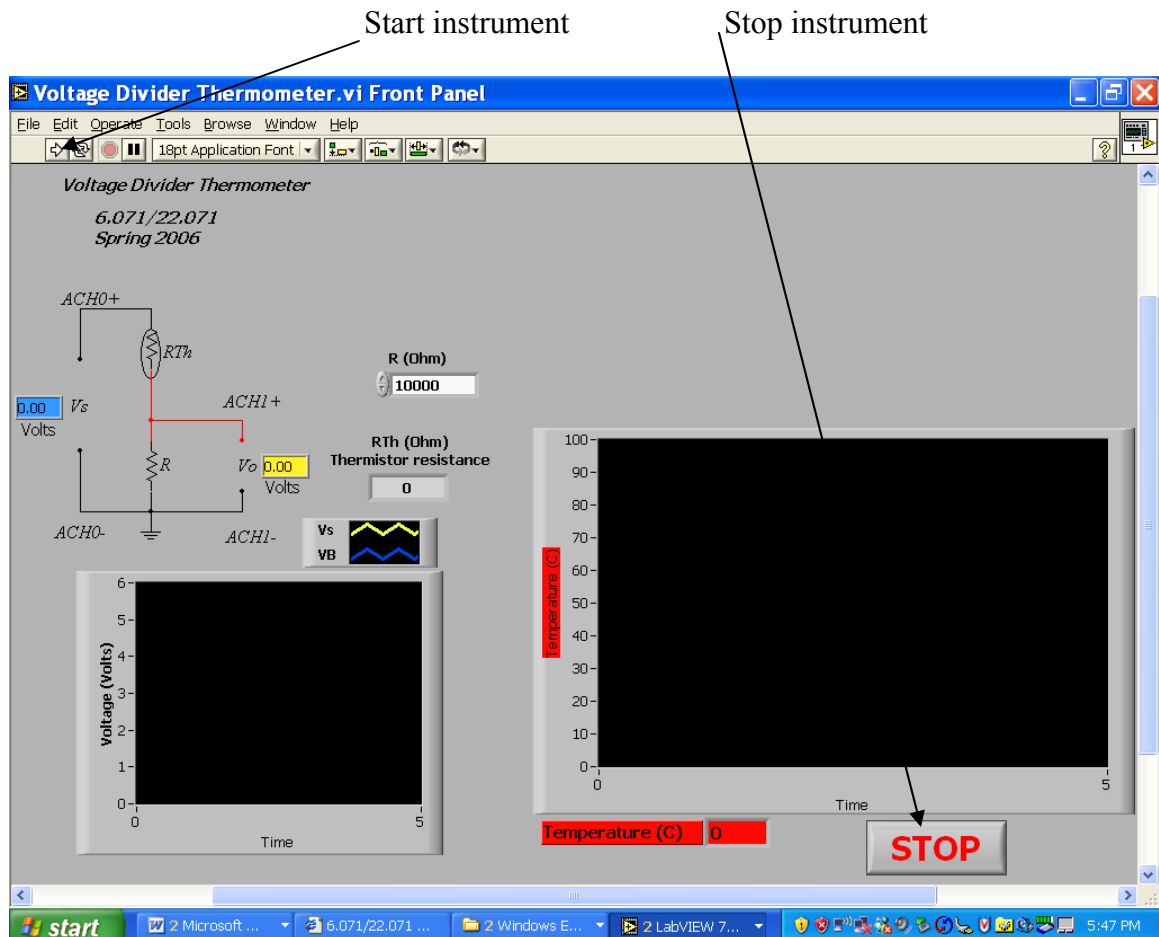
Courtesy of National Instruments. Used with permission.

Press the Start button on the upper right hand corner of the window. Observe the various outputs. Touch the thermistor with your hand. Does the temperature reading increase? How close to 37 C (the body temperature) can you get it?

Press the large STOP button located in the middle of the screen. This action will update the resistance versus temperature plot.

Express *RTh* as a function of the voltages *Vs* and *Vo* and the resistor *R*.

If the voltages are read into your computer by a 12 bit analog to digital converter and the fixed resistor has a tolerance of 5% , calculate the expected error in the estimation of *RTh*.

Assume that relationship between *RTh* and the temperature *T* is given by

$$T = A + \frac{B}{RTh} \tag{1.1}$$

where *A* and *B* are constants. Determine A and B so that the above function go through the points: (T,RTh)=(25.0C, 10.0kΩ), (35.0C, 6.5kΩ)

If the thermistor has a tolerance of 10% and all other processes are exact what is the estimated error in the measurement of the temperature?

Experiment 3.

Construct a heater and a temperature sensor. You will use this on Friday to measure the temperature coefficient of resistors.

For the assembly we will use nichrome wire as a heater, a thermistor as the temperature measuring device and a simple carbon film resistor. Nichrome is an alloy of Ni, Cr and Fe. The nichrome wire we are going to use has a resistance of 10 Ω/ft, or 32.8 Ω/m.

Wrap the resistor and thermistor with 1 foot of the nichrome wire and then pot the entire thing in thermally conductive grease and place a heat-shrink tube around it to contain the assembly. The cartoon and the schematic of the heater assembly is shown below.
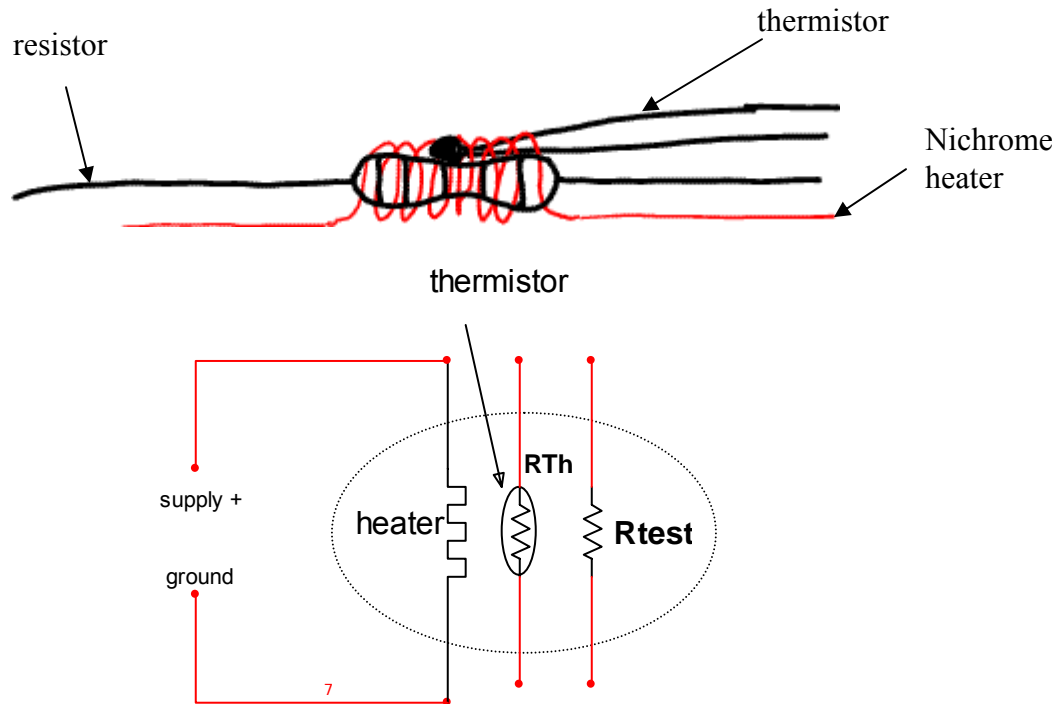
Before you proceed with supplying power and testing your heater connect the thermistor to the CURRENT HI and CURRENT LO in order to be able to measure its resistance as the temperature increases. Also connect supply+ to VOLTAGE HI and ground to VOLTAGE LO in order to measure the supply voltage.

We will heat the system with a maximum current of 0.5A through the nichrome heater. Adjust the voltage via the adjustable power supply (supply +)and observe the change in *RTh*.

What voltage is required to achieve a current of 0.5 A?

What is the maximum power dissipated by the heater?
What is the temperature as measured by the thermistor? (for this measure the thermistor resistance with your multimeter and look up the corresponding temperature from the thermistor data)
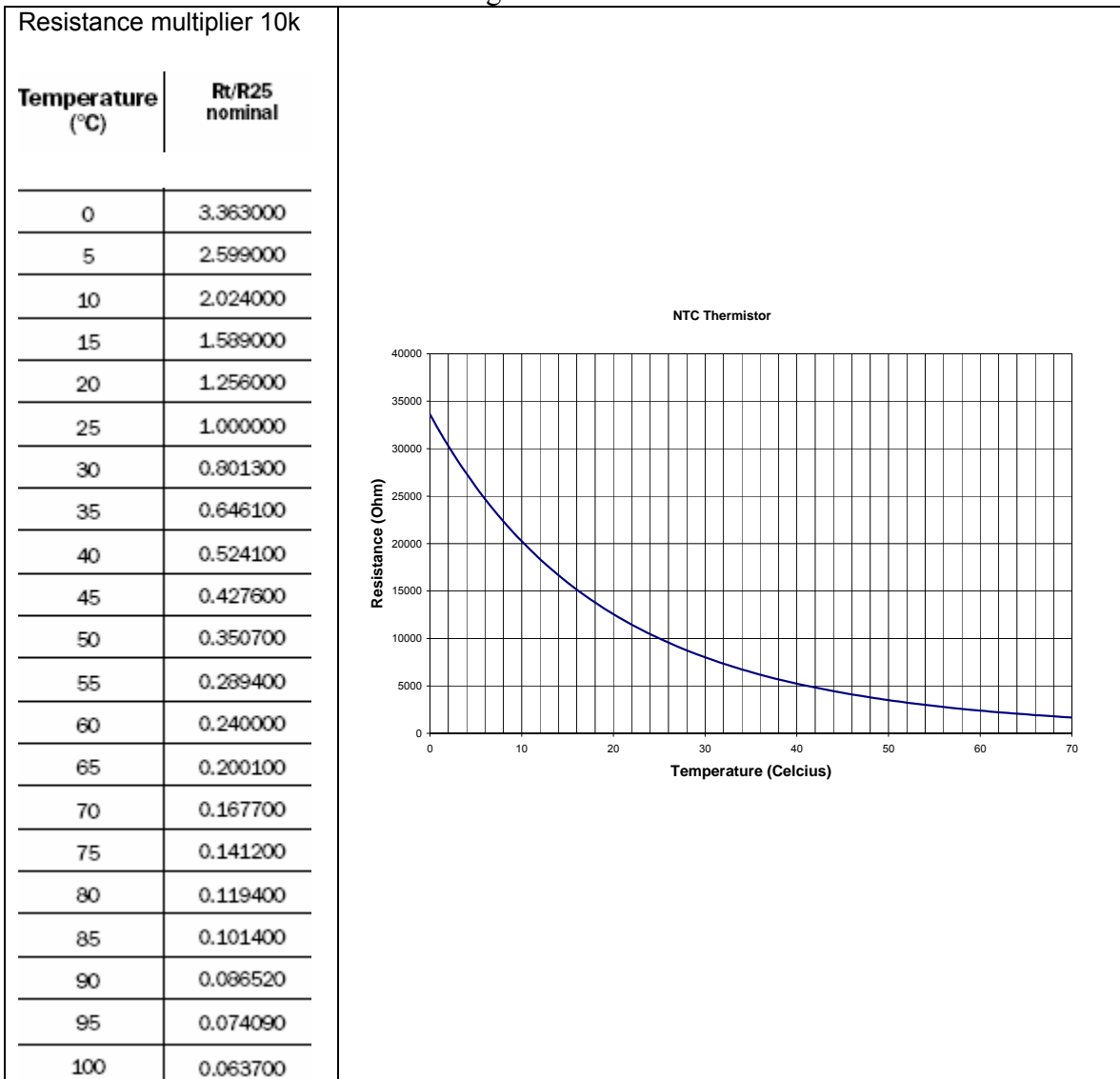
Appendix A.
 A glance at Thermistors

Thermistors are non-linear temperature dependent resistors with a high resistance temperature coefficient. They are advanced ceramics where the repeatable electrical characteristics of the molecular structure allow them to be used as solid-state, resistive temperature sensors. This molecular structure is obtained by mixing metal oxides together in varying proportions to create a material with the proper resistivity.

Two types of Thermistors are available: Negative Temperature Coefficient (NTC), resistance decreases with increasing temperature and Positive Temperature Coefficient (PTC), resistance increases with increasing temperature. In practice only NTC Thermistors are used for temperature measurement. PTC Thermistors are primarily used for relative temperature detection.

In this class we will use an NTC thermistor. The temperature versus resistance data of our thermistor is shown on the table and figure below.

Resistance multiplier 10k

Temperature (°C)	Rt/R25 nominal
0	3.363000
5	2.599000
10	2.024000
15	1.589000
20	1.256000
25	1.000000
30	0.801300
35	0.646100
40	0.524100
45	0.427600
50	0.350700
55	0.289400
60	0.240000
65	0.200100
70	0.167700
75	0.141200
80	0.119400
85	0.101400
90	0.086520
95	0.074090
100	0.063700

NTC Thermistor

For convenience we would like derive a mathematical expression which describes the behavior of the device. The Steinhart and Hart equation is an empirical expression that has been determined to be the best mathematical expression for resistance temperature relationship of NTC thermistors. The most common form of this equation is:

$$\frac{1}{T} = a + b(\ln R) + c(\ln R)^3 \qquad\qquad \text{Eq. 1}$$

Where T is in Kelvin and R in Ω. The coefficients a, b, c are constants which in principle are determined by measuring the thermistor resistance at three different temperatures T_1, T_2, T_3 and then solving the resulting three equations for a, b, c.

$$\frac{1}{T_1} = a + b(\ln R_1) + c(\ln R_1)^3$$

$$\frac{1}{T_2} = a + b(\ln R_2) + c(\ln R_2)^3$$

$$\frac{1}{T_3} = a + b(\ln R_3) + c(\ln R_3)^3$$

The parameters a, b, c for the thermistors provided with the lab kit in the temperature range between 0-50 degrees Celcius are:

$a = 1.1869 \times 10^{-3}$
$b = 2.2790 \times 10^{-4}$
$c = 8.7000 \times 10^{-8}$

The Steinhart and Hart equation may be used in two ways.

1) If resistance is known, the temperature may be determined from Eq. 1
2) If temperature is known the resistance is determined from the following equation:

$$R = \exp\left[\left(\beta - \frac{\alpha}{2} \right)^{1/3} - \left(\beta + \frac{\alpha}{2} \right)^{1/3} \right],$$

Where, $\alpha = \dfrac{a - \dfrac{1}{T}}{c}$ and $\beta = \sqrt{\left(\dfrac{b}{3c}\right) + \left(\dfrac{\alpha^2}{4}\right)}$

The non-linear resistance versus temperature behavior of the thermistor is the main disadvantage of these devices. However, with the availability of low cost microcontroller systems the non linear behavior can be handled in software by simply evaluating the Steinhart and Hart equation at the desired point.

The sensitivity of the thermistor, $\dfrac{dR}{dT}$, varies with temperature. For our thermistor the sensitivity as a function of temperature is shown on the following figure.

NTC Thermistor Sensitivity
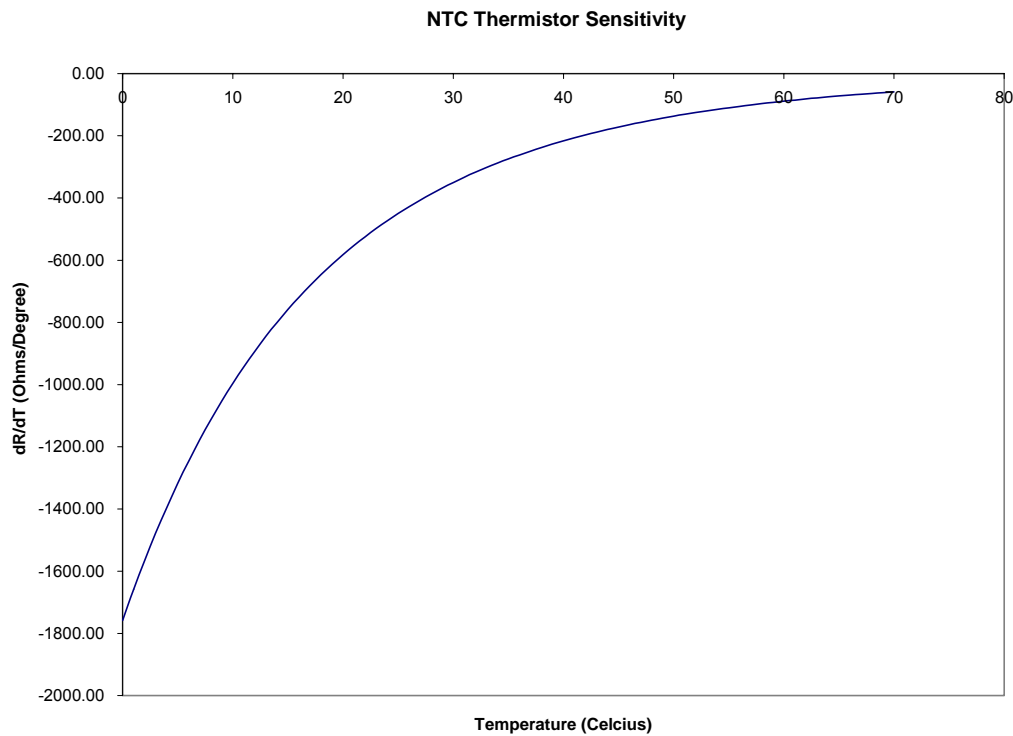
Note that the thermistor sensitivity decreases with increasing temperature. This is the primary reason for the small temperature measuring range of thermistors. Notice however that in temperature range of interest to biological and most environmental applications the sensitivity is greater than 100Ω/degree Celsius which results in the design of sensitive and robust systems.