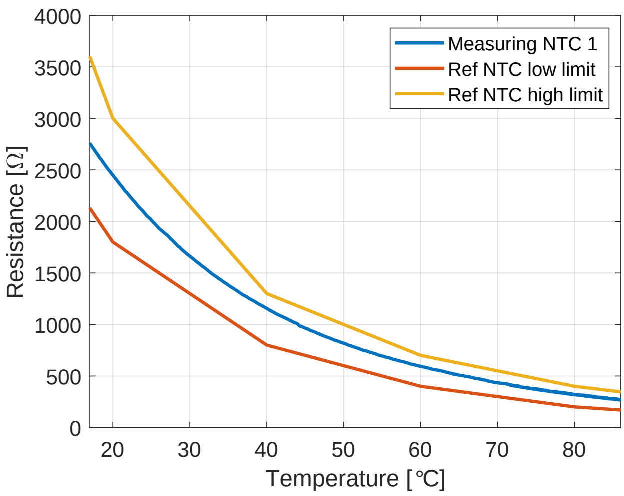
Automotive Sensors and Networks
Automotive temperature sensing

1 NTC sensors comparison

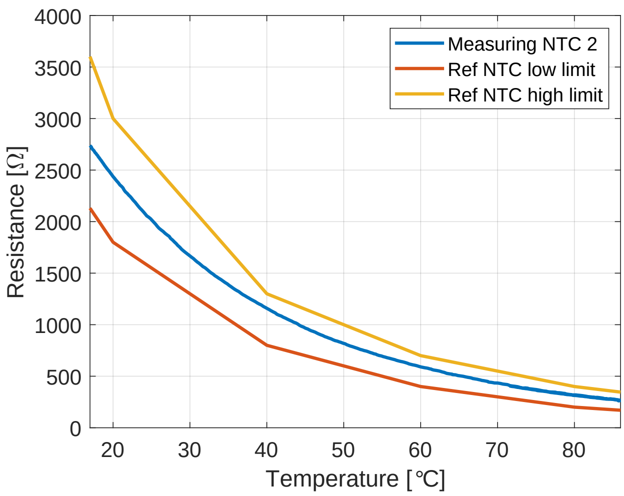
Measured characteristics of the two NTC sensors used in the laboratory experiment are shown in Figures 1a and 1b. Having a reference sensor from the manufacturer with its low and high limit characteristics values in Table 1, we have verified, that both NTC sensors' measurements are within the limits.

Temperature [°C]	−20	0	20	40	60	80	100
Low limit [kΩ]	10	4	1.8	0.8	0.4	0.2	0.1
High limit [kΩ]	20	7	3	1.3	0.7	0.4	0.22

Table 1: Low and high limits of a reference NTC sensor from the manufacturer.



(a) First NTC sensor



(b) Second NTC sensor

Figure 1: Measured characteristics of the two NTC sensors together with the reference sensor's limits.

2 Data extrapolation

In this section, we want to extrapolate the measured data to estimate the resistance of both NTC sensors in range between −20°C and 145°C. The NTC is a temperature-dependent resistor, whose resistance decreases with increasing temperature as the name - negative temperature coefficient - suggests. The decrease is exponential and can be described by the Steinhart-Hart equation. Using a simplified version of the Steinhart-Hart equation, we can write the resistance of the NTC as

$$R(T) = a \exp\left(\frac{b}{T+k}\right), \tag{1}$$

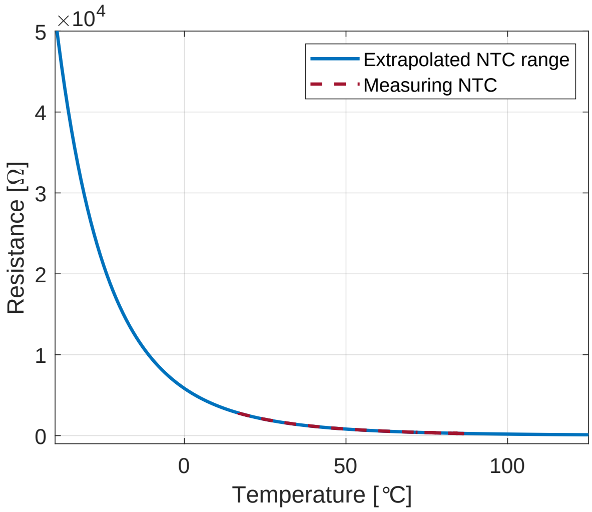
where T is temperature and B is sensitivity. The variable k is a transformation between kelvins and celsius, $k = 273.15$. The coefficients to be determined for the NTC are obtained using the `Curve Fitter` toolbox in MATLAB. The coefficients for the first NTC sensor are

$$a_1 = 0.0171, \quad b_1 = 3480. \tag{2}$$

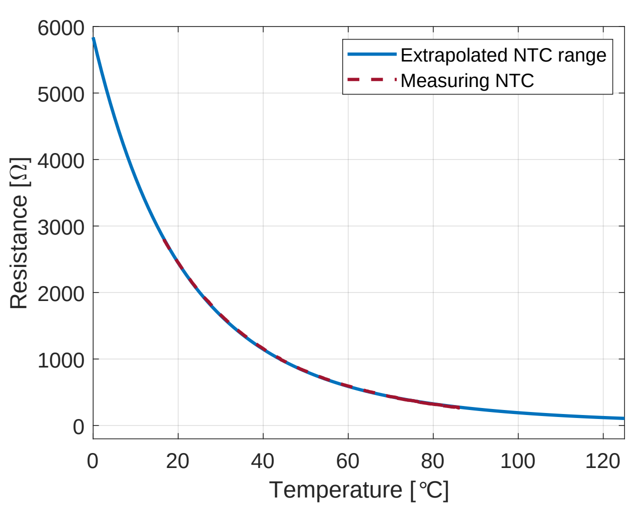
The measured data with the extrapolated characteristic are shown in Figure 2a with a detailed view in Figure 2b. As the coefficients a and b are almost the same for the second NTC sensor, that is

$$a_2 = 0.0172, \quad b_2 = 3478, \tag{3}$$

the extrapolation is not shown here.



(a) Temperature extrapolation



(b) Detail of the extrapolation

Figure 2: Extrapolated data estimating the resistance of the NTC sensor in range between $-20°$C and $145°$C.

3 EGR sensor characteristics

We heated a water bath in range between 17°C and 85°C and measured the EGR (exhaust gas) sensor characteristics placed in the bath. Reaching the latter temperature causes a short circuit of the sensor and the measurement drops to a zero resistance. When the bath is further heated to 95°C, we begin to add cold water to the reservoir causing the temperature to drop. The sensor's characteristic of such a process is shown in Figure 3.
Based on the measured data, we can see, that the sensor is a resistive metallic sensor made of a material, which has a lower thermal coefficient of resistance than copper. Resistive metallic sensors are another type of temperature sensors, which are used in automotive applications. To achieve a linear characteristic, the sensors use materials like platinum, nickel or copper and their characteristic is then given by the equation

$$R = R_0(1 + \alpha(t - t_{\mathrm{ref}})), \tag{4}$$

where R_0 is the resistance at the reference temperature t_{ref}, α is the temperature coefficient of resistance and t_{ref} is the reference temperature.

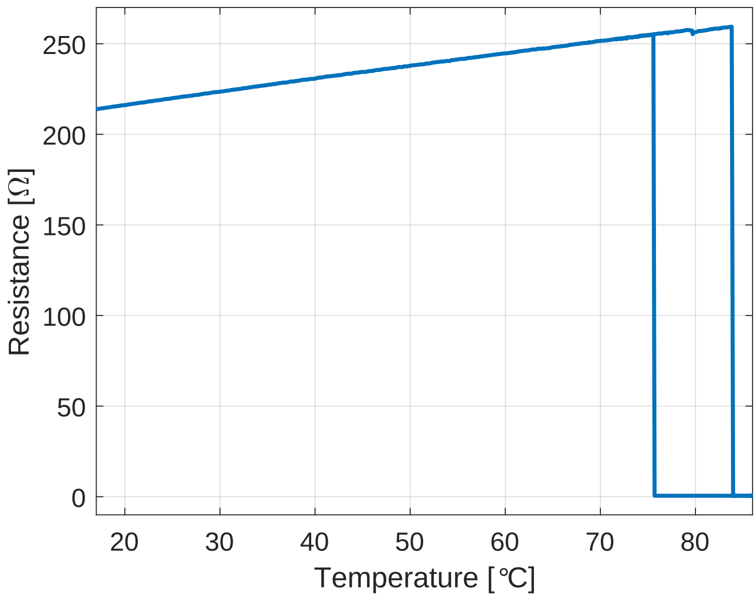


Figure 3: EGR sensor characteristics of heated water bath.

4 Voltage divider

A voltage divider is designed as a simple circuit consisting of two resistors connected in series. The divider serves as a linearizing circuit and is used to convert the resistance of the NTC sensor to a voltage. The output voltage of the divider is thus given by the equation

$$V_{\mathrm{out}} = \frac{R(T)}{R + R(T)} V_{\mathrm{in}}. \tag{5}$$

The input voltage V_{in} is 5 V and the resistance R is 1 kΩ. The resistance $R(T)$ is the resistance of the NTC sensor, which is temperature-dependent. We can see the output voltage of the divider plotted in Figure 4.

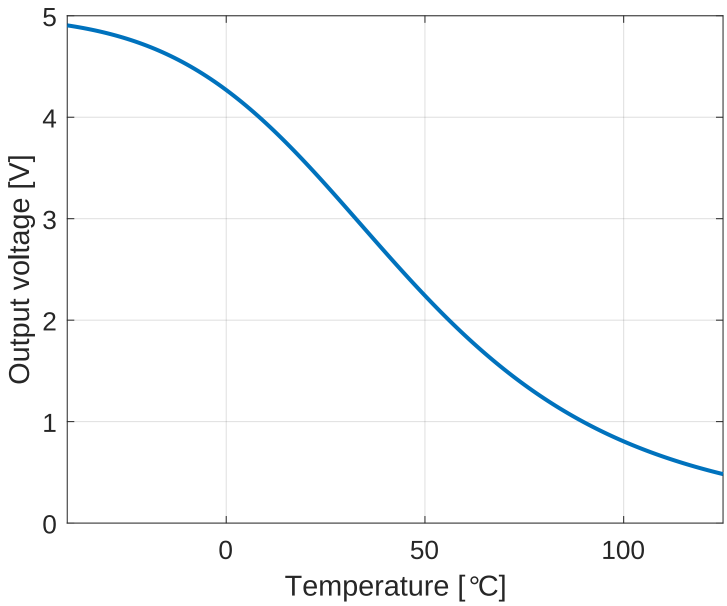


Figure 4: Output voltage of the voltage divider with the NTC sensor.

An AD converter is used to convert the analog voltage signal to a digital one. The required resolution of the AD converter corresponds to the smallest change in the temperature we measure, which is 1 °C, the smallest voltage change was measured to be approximately 0.01 V. Considering the voltage range of the AD converter, which is $0 - 5$ V, we need 500 steps to cover the whole voltage range. These presumptions lead to the conclusion that a 9-bit AD converter is required for the measurement.