NTC and PTC thermistors

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1 Introduction

This document aims to give a complete introduction to the world of thermistors. A thermistor, also called *thermally sensitive resistor*, is a device whose electrical resistivity is strictly bonded with the temperature. More precisely, there are two types of thermistors. The first one is called negative-temperature-coefficient (or **NTC**), meaning that its resistance changes in the opposite way of temperature: when the temperature raises, the resistance decreases, and vice-versa. The second type is the positive-temperature-coefficient thermistor (also known as **PTC**) which means that its resistivity increases if the environment gets hotter and is reduced when the temperature decreases.

Finish introduction.tex

2 Background

This chapter focuses on a brief explanation of the physics behind thermistors by introducing and discussing the structure of the atom and the most crucial information that is needed for a better understanding of the topic. Then the attention will be shifted to discussing a specific type of material, known as semiconductors, that are largely utilized for the creation of electric components as far as thermistors.

Finish Background introduction

2.1 Outermost orbit and valence electrons

As is common knowledge, everything is made out of atoms, every living creature and every unanimated object. An atom is made out of three subatomic particles. The protons (which have a positive electric charge) and the neutrons constitute the nuclei of the atom. The electrons, carrying a negative charge, orbit around the nucleus in distinct orbits.

By observing the figure 1, it is possible to distinguish two important types of electrons: the inner electrons, which orbit around the inner shells, and the valence electrons that orbit in the **valence shell** (also called the outermost orbit). These electrons are crucial for determining the properties of the material [4]. Particularly

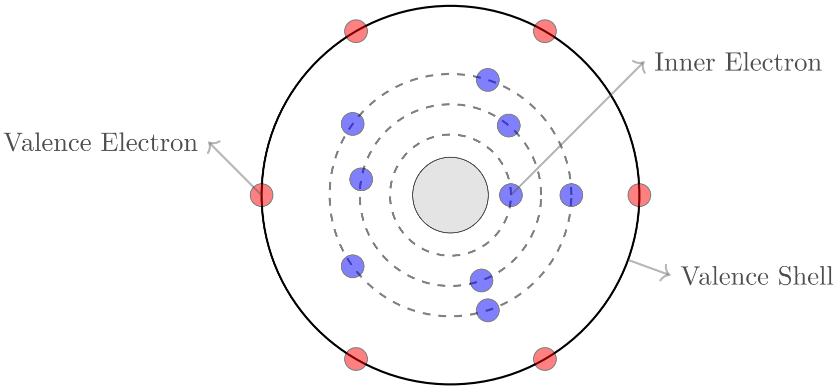

Figure 1: The orbits and electrons of an atom.

depending on how much energy these electrons have, a material is going to be a good conductor rather than a good insulator.

When the outermost orbit is incomplete, valence electrons are separable from the atom. In some cases, at room temperature, there is enough energy to remove these electrons from the orbit. This is the case for most conductive elements like metals (copper, silver and gold) which can easily propagate both electricity and heat. On the other hand, when a great amount of energy is needed to remove one valence electron from the valence orbit, the material is an insulator (also known as dielectric) like wood, glass or rubber [4].

2.2 Semiconductor materials

Other than conductors and dielectric elements there are other types of materials like semiconductors. This particular type of material is rather important to discuss because it is the key element in creating a thermistor. The peculiarity of a semiconductor element is that its conductivity stands between the inductors and the dielectric materials. The most common semiconductor materials are silicon and germanium but it is also used zinc, cadmium, boron and more [4]. These types of materials are highly popular because of their properties:

- They are light weight-wise and small dimension-wise;
- They are highly energy-efficient because they work with low voltage;
- Long-term degradation effects are insignificant.

Additionally, generally, the semiconductor materials are *negative temperature coefficient* meaning that their conductivity increases with the temperature, and so the resistivity of the element decreases non-linearly. But this also means that when the temperatures are extremely low (near zero Kelvin) their conductivity properties are comparable to a dielectric material (so their resistance is extremely high).

It is important to note that the semiconductors do not follow Ohm's law. More precisely the current increases much more than the voltage; this peculiarity is used for the BJT transistors. Furthermore, specifically because of the resistivity/temperature curve they are widely used in thermistors, rectifiers, Zener diodes, varistors and photovoltaic cells [4].

2.2.1 PTC and NTC materials

Add explanation for NTC and PTC material

Other types of materials

It is worth mentioning that the three types of material aforementioned are not the only ones. The *superconductors* are materials whose electrical resistivity reaches almost zero when the temperature is greatly below zero Celsius. These materials are usually metals or ceramics [4].

Moreover, there are *magnetic materials* that can differ in several types depending on their capability of being magnetized by magnetic fields. The diamagnetic and paramagnetic materials have a very low magnetic susceptibility (between 10^{-6} and 10^{-3}) meaning that they are not likely to propagate a magnetic field. Then there are the ferromagnetic and ferrimagnetic materials whose magnetic susceptibility depends on the magnetic field strength. Eventually, there are also antiferromagnetic materials whose susceptibility increases as the temperature increases but when the element reaches a critical temperature, the susceptibility starts decreasing again [4][5].

Furthermore, it is also important to mention the *ferroelectrics* which are a type of material whose natural electric polarization can be changed by the presence of an electric field [4][11].

2.3 History of thermistors

Insert history of thermistor

3 PTC thermistors

As aforementioned, a positive temperature coefficient thermistor (also called **positor**) is a thermally sensitive resistor that varies its resistivity as the temperature of the environment changes. Particularly because it is a positive coefficient, as the temperature increases, the resistivity of the semiconductor device increases as well.

The posistor's structure is rather simple: a PTC material is put between two metal foil electrodes. The overall resistance of the PTC thermistor is given by the PTC material (also called *bulk*), the electrode resistance (which can be omitted) and the interface resistance [10].

3.1 Charateristics

One of the most important properties of the PTC thermistor is the characteristic curve between the **resistance** R and the **temperature** T, which has to be converted from Celsius (or Fahrenheit) to Kelvin. Its curve is a positive exponential graph that respects the following equation [9][7]:

$$R = R_0 \, e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

Where R is the calculated resistance at the temperature T and R_0 is the resistance measured at temperature T_0. The coefficient β is the thermistor constant and it depends on the materials used to build it and on the thermistor dimensions. It is possible to obtain this value by measuring its resistance value at two different temperatures and computing the following equation [9].

$$\beta = \frac{\ln \frac{R_2}{R_1}}{\frac{1}{T_2} - \frac{1}{T_1}}$$

Using the previous equations, the curve can be plotted by writing down the equations using MATLAB, or other programming languages. Figure 3.1 shows how much the resistance increases as the temperature increases. In this case, the coefficient β has been calculated by assuming that when $T_1 = 358.15K = 85°C$, $R_1 = 40k\Omega$ and when $T_2 = 253.15K = -20°C$, $R_2 = 30\Omega$.

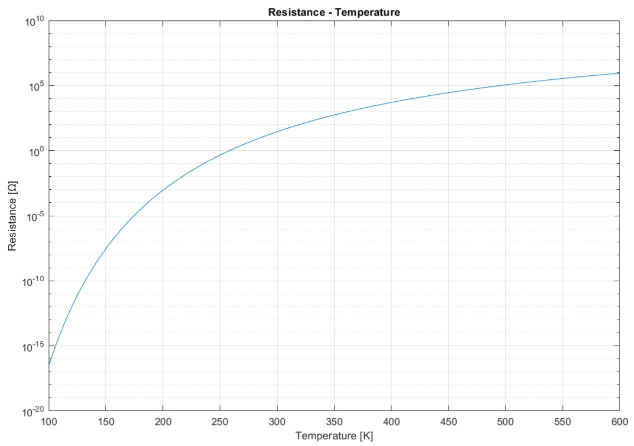

Figure 2: PTC resistance-temperature logarithmic curve, from -173°C to 326°C.

By restricting the plot between -13°C and 126°C it is more noticeable the exponential behavior of the posistor: the image 3.1 shows the limited exponential curve of the PTC thermistor.

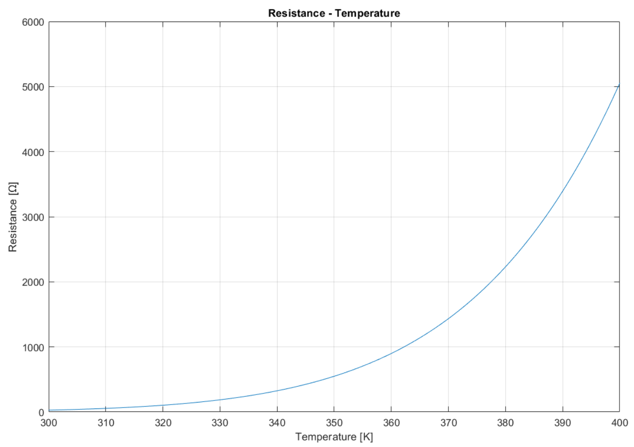

Figure 3: PTC resistance-temperature curve, limited between -13°C and 126°C.

In both of the plots the resistance value or the change ratio drastically increases as the environment gets hotter. Generally, the equation describes the behavior of the PTC thermistor in an interval of temperature: in the PTC materials there is a temperature, called **Curie point** where the resistance starts to rise exponentially in comparison with the temperature (as shown in figure 3.1 and 3.1); before the Curie temperature, the PTC thermistor does not increase drastically their resistance when the temperature raises. Generally, the Curie point in the PTC materials is between 50°C and 400°C [2].

Another important coefficient to know about is the **dissipation constant** δ which describes the power needed to increase the thermistor temperature by 1° Celsius through self-heating. The dissipation constant varies on the construction materials of the thermistor and the environment [9]. The constant δ is useful to describe the power dissipation of the thermistor when its temperature is T (at thermal equilibrium) and the ambient temperature is T_0:

$$P = VI = \delta(T - T_0)$$

By knowing the power dissipation it is then possible to plot the **current-voltage** relationship when the PTC thermistor is in a state of thermal equilibrium. Sure enough, by knowing the constant δ and the room temperature T_0, the power dissipation P can be obtained and then it is possible to calculate the voltage and the current relationship:

$$V = \sqrt{P \cdot R} \qquad\qquad I = \sqrt{\frac{P}{R}}$$

By setting $\delta = 4.5mW/°C$ and the room temperature $T_0 = 25°C = 298.15°K$, it is possible to plot some important relationship. Figure 3.1 describes the relationship between the current and the temperature in the PTC thermistor: as the temperature increases the current decreases; this is because when the temperature increases, also the resistance increases and, as such, the current flowing through will reasonably decrease.

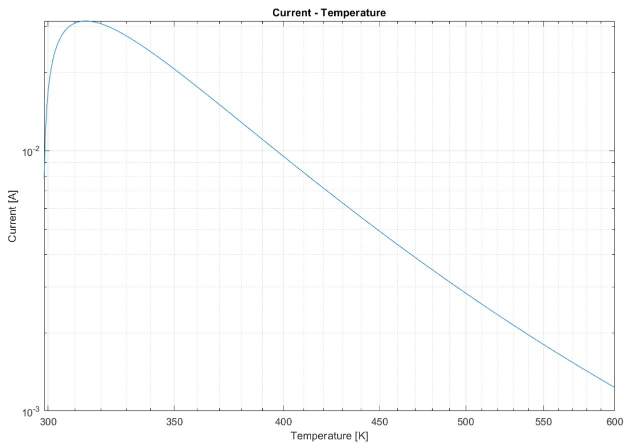

Figure 4: Corrent-temperature relationship of a PTC thermistor.

The relationship between the temperature and the voltage is shown in the image 3.1. Contrarily to the current-temperature relationship, here, as the temperature increases, the voltage of the thermistor rises as well because its resistivity intensifies.

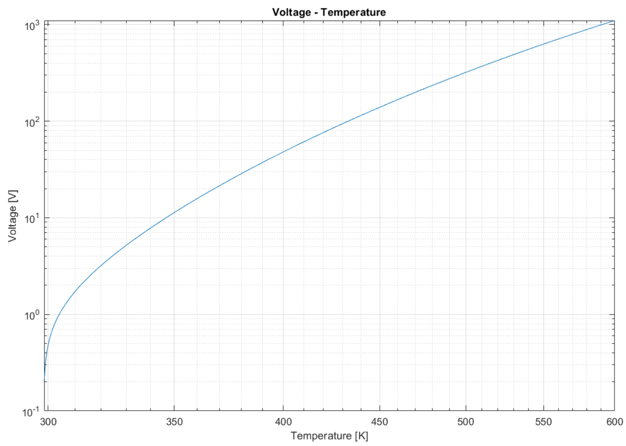

Figure 5: Voltage-temperature relationship of a PTC thermistor.

In the figure 3.1 there is the characteristic curve current-voltage of the PTC thermistor. The plot is an *insofar* curve: when the slope is positive there is a constant-resistance state meanwhile when the slope of the curve is negative there is a constant-power range [9].

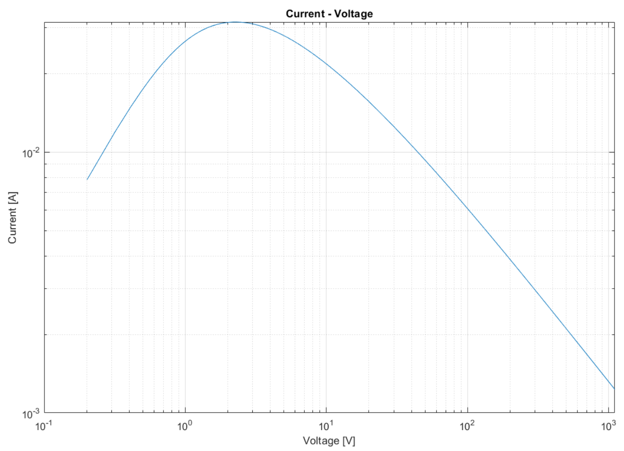

Figure 6: Current-voltage relationship of a PTC thermistor.

3.2 Applications

The applications of the posistors are remarkably important. One of the most popular uses of these devices is as *current limiters* to protect other devices. Sure enough, when there is an excess of current through a circuit it may result in a damaged component of the circuit, like the LED in figure 3.2; using a PTC thermistor prevents this from happening because when the current starts increasing through the thermistor, it will

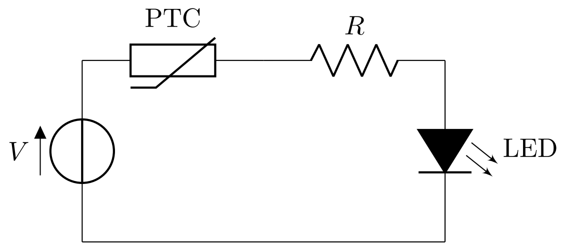

Figure 7: Current limiter PTC application

heat it making the resistance increase. When the resistance starts increasing the current flowing through it will decrease (as shown in figure 3.1) and the LED will be protected [9][8].

Other important applications are for the *temperature indicator*, when operating in parallel with a diode, or for *temperature control* purposes. In this case, the PTC posistor can control the power dissipated by another device that is connected in series [9][8]. The positive temperature coefficient thermistor may be also utilized to *measure the heating* consumption by a system. For example, it may be used to determine the fuel consumption in a vehicle or the heating consumption in a hot-water-based heating system [3]. Finally, the PTC thermister has found its way to space applications [6].

4 NTC thermistors

In contrast to the PTC thermistor, there is the negative-temperature-coefficient thermistor. This device reduces its resistivity when the temperature rises.

Make NTC introduction a little longer

4.1 Chrateristics

The NTC thermistor and the PTC thermistor, even though their functioning is opposite, have the same characteristic equation. As aforementioned, the equation that describes the behavior of the resistance R in relationship with the ambient temperature T is the following [1]:

$$R = R_0\, e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

Where R is the resistance at temperature T, which should be measured in Kelvin degrees, and R_0 is the resistance value measured at operating temperature T_0. The β coefficient describes the thermister constant which varies on temperature and materials used to build the device. It can be calculated using the same formula described in the PTC thermistors:

$$\beta = \frac{\ln \frac{R_2}{R_1}}{\frac{1}{T_2} - \frac{1}{T_1}}$$

By assuming that when $T_1 = 298.15K = 25°C$, $R_1 = 10k\Omega$ and when $T_2 = 358.15K = 85°C$. $R_2 = 1.4k\Omega$, it is possible to plot the resistance-temperature relationship of a negative temperature coefficient thermistor. As shown in figure 4.1, the curve shows that as the temperature rises, the resistance value decreases respecting the aforementioned equation.

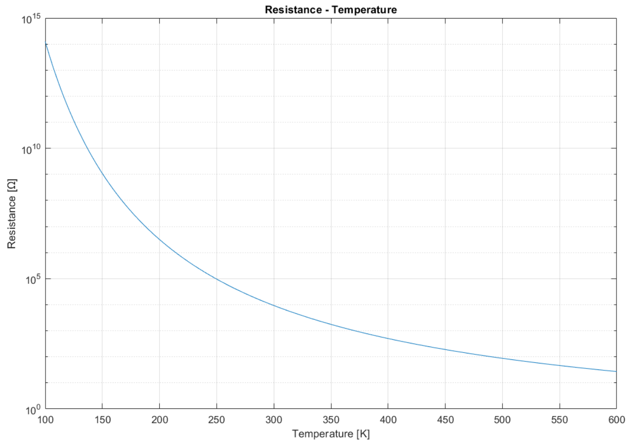

Figure 8: NTC resistance-temperature logarithmic curve, from -173°C to 326°C.

If the curve is restricted to more realistic temperature values (such as -13°C to 126°C), it's even more evident the inversely exponential curve which is described by the equation of the thermistor (figure 4.1).

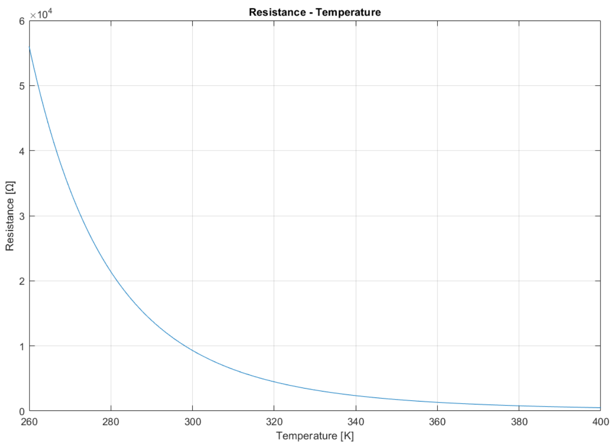

Figure 9: NTC resistance-temperature curve, limited between -13°C and 126°C.

4.2 Applications

As the posistor, also the NTC thermistor was used in space applications, specifically in the launch of the ETS-VI satellite and the H-II satellite [6].

5 Conclusions

References

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