Pspice Simulation Model from EPCOS
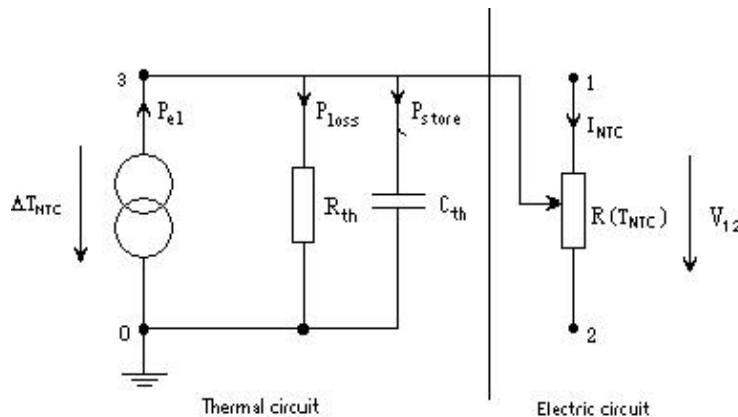
1. NTC thermistor model

Development of an NTC model for the "Pspice Design Center" circuit simulation program allows inclusion of NTC thermistors in the computer-aided design of modern electronic circuits.
An NTC thermistor is modeled under Pspice by its R/T curve, its heat capacity and its dissipation factor. Fig. 1 shows the structure of its equivalent circuit, consisting of a thermal and an electric circuit.
The electric circuit consists of a variable resistor $R(T_{NTC})$, connected by leads 1 and 2 to the circuit of the PSpice user. The voltage V_{12} corresponds to the voltage momentarily applied to the NTC, and the current I_{NTC} to the current flowing through it. The temperature T_{NTC} calculated in the thermal circuit defines the size of the resistance $R(T_{NTC})$.
The thermal circuit consists of a voltage-controlled current source, a variable resistance and a capacitance. The voltage here corresponds to the temperature of the NTC thermistor, the current to the thermal power released in the NTC thermistor ("heat current"), the capacitance to the heat capacity and the resistance to the thermal resistance R_{th} (inverse dissipation factor, $R_{th} = 1/G_{th}$). In this particular model the thermal resistance is temperature-dependent, the dissipation factor being taken as a linear function of temperature (all temperatures in °C):

$$G_{th}(T) = G_{th,0} + G_{th,1} * T$$

(1)

(Fig. 1: NTC thermistor model)

Electric circuit: the external voltage V_{12} is applied to nodes 1 and 2 and produces a current I_{NTC} that is computed self-consistently across the thermal circuit.
Thermal circuit: the electric power $P_{el} = I_{NTC} * V_{12}$ applied to the NTC is converted into thermal power and stored in part as thermal energy (corresponding to $P_{store} * t = C_{th} * T_{NTC}$) or given off to the ambient as thermal power loss (corresponding to $P_{loss} = T_{NTC} * G_{th}$).
The temperature of the NTC calculated from this is taken to compute the NTC resistance ($T_{NTC} = T + T_{amb}$, T_{amb} = ambient temperature).

## 2. Equivalence of thermal and electrical variables

This model for electrical-thermal simulation of NTC thermistors uses structural equality between electrical and thermal variables. This equivalence can be recognized by writing the power balance equation of the NTC thermistor:

Applied electric power (P_{el}) =
$\quad$ = Stored thermal power (P_{store}) + Dissipated thermal power (P_{loss})

or in formulas:

$$I_{NTC} * V_{12} = C_{th} * (dT_{NTC} / dt) + G_{th} * (T_{NTC} - T_{amb})$$

$$(2)$$

If you compare this expression to the following electric circuit (Fig. 2)
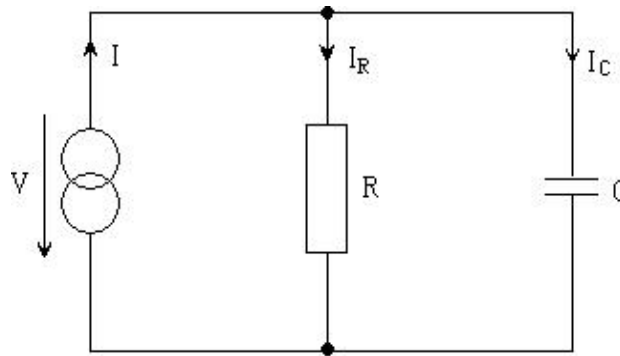
(Fig. 2: Circuit for current source, resistor and capacitor)

and deduce from this the differential equation for the current, you obtain:

$$I = C * (dV / dt) + V/R$$

$$(3)$$

Looking at equations (2) and (3) together, you see the previously mentioned equivalence between thermal and electrical variables. So in the thermal equivalent circuit diagram the released thermal power corresponds to the current I and the temperature difference $T = T_{NTC} - T_{amb}$ between component and ambient temperature to the voltage V. This difference between component and ambient temperature can be presented in the "Probe" submenu of Pspice as the voltage of node 3 of the NTC thermistor subcircuit.

3. Mathematic description of R/T curve

Borrowing from the Arrhenius model, the resistance is taken as an exponential function with a polynominal in the exponent, developing according to the inverse absolute temperature:

$$R(T) = R_{25} * \exp(b_0 + b_1 / T + ... + b_4 / T^4)$$

$$(4)$$
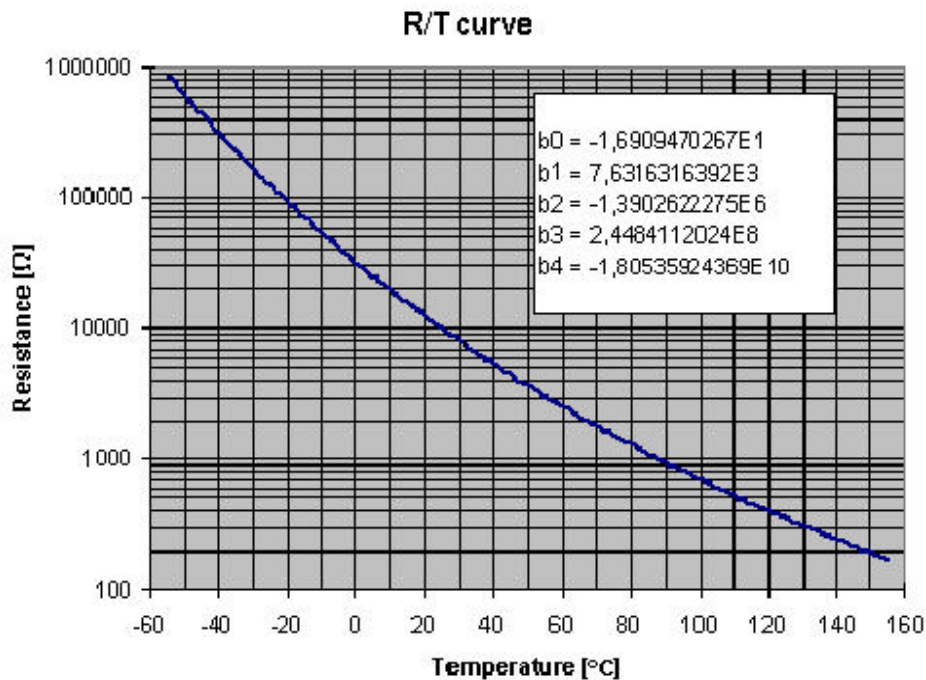
R/T curve

(Fig. 3: R/T curve of NTC with coefficients)

Taking a fourth-order polynominal produces as accurate as possible a reproduction of the nominal curve in a temperature range from -55 to 200°C. The user can also allow for different manufacturing tolerances by entering a tolerance by which R_{25} changes in the model (refer to 1999 data book for notes on tolerances).

4. Limits of model

Both electrical and thermal data were determined from experimental figures with the aid of least-square methods. Resulting from the fact that you can interpolate with fits but not extrapolate, the stored data only apply in the measured range: the electrical characteristics from -55 to +200°C and the thermal ones between 85 and 150°C (component temperature).
The following peculiarity of the thermal characteristics should be observed: thermal conductivity was measured under standard conditions (ambient temperature 25°C, length of wires 25 mm (clamped), still air, surrounding air volume > 1000 times component's own volume, etc). So the thermal values saved in the characteristics are for precisely this case. By altering the wire length, removal of heat through contacts, encapsulation of the component, a changed thermal environment when it is installed, etc, the thermal values can change and thus the resulting component temperatures too.
In this connection it should also be mentioned that under certain conditions (if the VI curve intersects with the resistance line at three points), two stable temperature states are possible. Mathematically speaking, transition from two stable states to just one is a case of "structural instability". Through slight changes of external parameters (eg voltage on component, ambient temperature, etc) one of these states can develop abruptly (ie of the order of the cooling time constants c) into the other, or in actual fact status 1 becomes steady-state, although simulation predicts status 2. In such cases it is advisable to make a sensitivity study.