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A simple analog behavioural model for NTC thermistors including selfheating effect

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Abstract

In this paper, a model is presented to simulate loaded, as well as unloaded thermistors with negative temperature coefficients. This analog behavioural model (ABM) is particularly suitable for the steady-state large signal time-domain analysis and design of NTC thermistor circuits, making it possible to simulate complete static current-voltage characteristic of a thermistor element, including the effect of selfheating.

Keywords: NTC thermistors; Analog behavioural modeling; Circuit simulation; PSPICE

1. Introduction

Although semiconductor device temperature is a function of the amount of power dissipated, in most circuit simulation software, the temperature of all devices is set to a user defined value prior to simulation. In fact, device electrical parameters also change with temperature, resulting in modification of power dissipated by device, therefore causing an alteration in the operation temperature. Thermal feedback effects on various semiconductors and their analysis using SPICE circuit simulation packages were reported in literature [1–4]. Theoretical bases of thermistor problem were studied by various researchers [5–7]. A modeling approach (without implementing SPICE) was reported for thermistor simulation applications in [8]. A measuring system for generating the static voltage versus current characteristics of various resistance sensors was described in [9].

Negative temperature coefficient thermistors (NTCTs) are thermally sensitive semiconductor resistors which exhibit a large decrease in resistance as temperature increases. In some cases NTC element is treated as a fixed resistor whose resistance R_T varies with ambient temperature, T_A

$$R_T = R_N \exp\left(\frac{\beta}{T_A} - \frac{\beta}{T_N}\right) \tag{1}$$

where β is the material constant, and R_N the resistance at the nominal temperature T_N, in Kelvin. However, when a current flows through the NTC thermistor, it will heat up by power dissipation. In the following analysis, we neglect the effect of geometry of the thermistor itself. Self-heating effect can be described by,

$$P = \frac{\mathrm{d}H}{\mathrm{d}t} = \delta(T - T_A) + C_{th}\frac{\mathrm{d}T}{\mathrm{d}t} = VI \tag{2}$$

Here dH/dt is the change of stored thermal energy with time, δ the dissipation factor of NTCT, C_{th} = heat capacity of NTCT, T = instantaneous thermistor body temperature, T_A = ambient temperature, V, I, P are the instantaneous NTCT voltage, current and power, respectively. After same time a constant electrical power is applied to the thermistor, a steady state will be reached where the power is dissipated by thermal conduction or convection, therefore dT/dt = 0 and,

$$I = \left(\frac{\delta(T - T_A)}{R_{NTC}}\right)^{1/2} \tag{3a}$$

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or

$$V = (\delta(T - T_A)R_{NTC})^{1/2} \tag{3b}$$

which yield the parametric description of the *V*/*I* curves that are calculated for different (constant) ambient temperatures. The linear part of log–log plotted *V*/*I* characteristic curve of NTCT is used when this element is employed as a temperature sensor. Beyond a certain limit, *V*/*I* characteristic behaves in non-linear fashion, first reaching a maximum and than displaying a negative resistance behaviour. There are many applications which are based upon the static *V*/*I* NTCT characteristic. (a) Applications where δ is varied (which is exploited in flow meters, vacuum manometers, liquid level control, and gas chromatography). (b) Applications where the electrical parameters of the circuit are varied. (c) Applications where the ambient temperature is varied which can be due to radiation absorbed by the thermistor, such as in microwave power measurement. Considering the cost of physical realization in these wide variety of applications, as well as the time spent in their design, it is apparent that, a model which helps to simulate NTCT steady-state response including selfheating (i.e., simulating complete static *I*–*V* characteristic, rather than partial formulations) will be advantageous. Motivated by this fact, a model is presented in this paper to simulate the NTC thermistor behaviour including the effect of selfheating in dc operating point analysis.

2. Modeling of NTC thermistors

In conventional circuit analysis software, an unloaded NTCT can be modelled with a look-up table, or an expression can be used to describe how the resistance varies with temperature by implementing an analog behavioural model (ABM). Here, procedure is to sense the current (*I*) and then generate the voltage *V* (=*IR)* with a voltage source. For example, to sense current, recent versions of PSPICE uses a voltage source which is set to 0 V, so there's no effect on the output voltage. The other source, which is connected in series to the first one, generates the voltage across the "resistor" based on the sensed current times the desired resistance. The important aspect of this source is that its output voltage can be described by an equation. The "resistor" described above is extended to include the characteristic equation of the NTCT and the sensor's temperature, to create the NTCT model. The sensor's temperature and the voltage nodes are included symbolically in the characteristic equation in volts (represents degrees celsius), and in the sub-circuit statement, respectively. For example, the subcircuit NTC given below defines the resistance of a 1 kΩ NTCT (with β = 3060), as follows:

```
.subckt NTC 1 2 5 6
eth 1 3 value = {i(vs) × 1k × exp(3060/(v(5, 6)+273) −
3060/(298))}
vs 32 dc 0
.ends
```

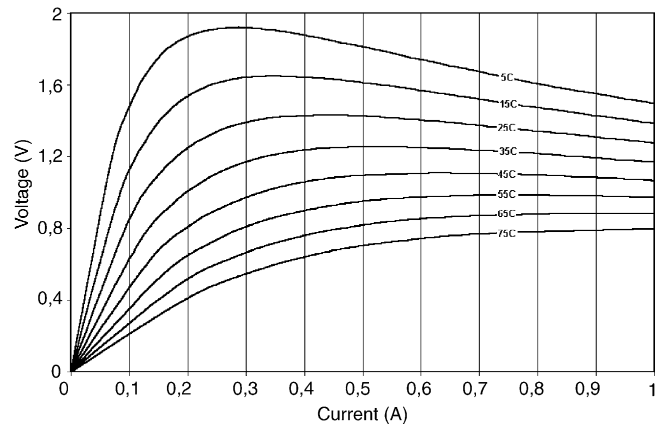

Fig. 1. Typical linear scaled *I*–*V* characteristics for a NTCT (S-237-10, [10]), at various ambient temperatures. These curves are constructed using the manufacturer data for δ = 17 mW/K.

As one can see, nodes 5 and 6 have been added in the sub-circuit statement. The ambient temperature, *V*(5, 6) is included in the characteristic equation, also. This is the sensor's temperature in volts (but it represents degrees celsius). Finally, characteristic equation has been included in the "eth" statement to create the NTCT model.

However, if the element operates in its non-linear *I*/*V* region, this model is insufficient to completely describe a NTCT.

3. Electrically loaded NTC thermistor

As long as data of a given NTCT are in hand, it is possible to compute the characteristic.

I–*V* curves at different ambient temperatures as shown in Fig. 1, and modify a PSPICE model described above, to represent steady state selfheated NTCT behaviour. The temperature change due to selfheating can be given as,

$$\Delta T = T_X - T_A = \frac{IV}{\delta} \tag{4}$$

Here temperature circuit is modified by the addition of a selfheating temperature equivalent of voltage source whose value is made equal to the change in voltage. This is shown in Fig. 2

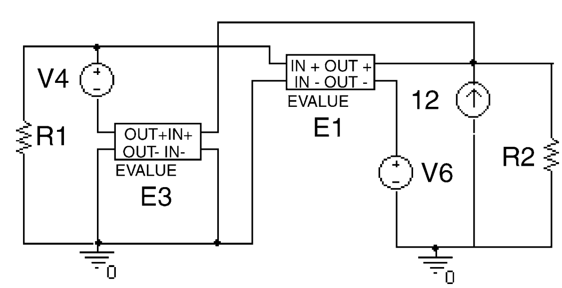

Fig. 2. Complete PSPICE ABM for NTCT with selfheating effect. VALUE($E1$)= $I(V6)\,R_N \exp[\beta/(V\%IN1+,\ \%IN1-) + 273) - \beta/298]$, VALUE($E3$)= $I(V6)(V\%IN3+, \%IN3-)/\delta$.