Extension of Nodal Voltage Method with the Thermosensing

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***Abstract*—Most of the electronic circuit simulation program contains a components's thermal behavior modeling. Unfortunately in most cases this modeling, or simulation depends on the ambient temperature of suspected electronic devices. This modelings can't use of electronic parts's or or circuit's self warming.**
The proposed option, methodology is particularly useful for the simulation of high performance circuits. In this article, we supplement this thermal simulation methods so, that it can not only to take into account the ambient temperature, but also to warm the part itself.
For the demonstration of simulation we use pSpice based MICROCAP software environment.

I. Introduction

On Fig. (1) is seen a typical application of a high power switching-mode semiconductor circuit. Fig. (2) illustrate a typical input and output signals of suspected (in this case typical theoretical application) circuit [6] [7].
Voltage generator (U_g) drives direct, with 5V, (U_{pp}), gate (G) of F_t transistor (red color of Fig. (2). If gate-source (S) voltage (U_{GS}) greater then threshold voltage of gate U_{TH}, then transistor saturate and drain (D) voltage (U_D) goes down (blue color of Fig. (2) from power voltage (U_P). Meanwhile, on R_D, I_D current is flowing [15] [3].

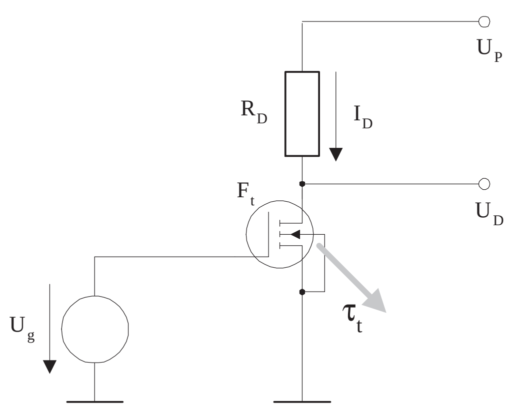

Fig. 1. Typical application of a high power switching-mode semiconductor circuit. ($U_P = 12V$, $R_D = 100\Omega$.) Time function of transistor's dissipation is τ_t.

II. Thermal Behavior of Self Heated Semiconductor

If the F_t turned ON, it's dissipation depends on channel resistance (R_{DS}), and drain current (I_D). So we get time function of dissipation power according equation (1);

$$p_{F_t}(t) = R_{DS} \cdot I_D(dt)^2. \quad (1)$$

We use differential equation (2) for the description of semiconductor's warming process or heat-work of suspected device;

$$Pdt = cm\tau + S\alpha\tau dt, \quad (2)$$

where c is average specific heat of semiconductor body, m is the mass of heating body, τ is temperature difference of environment and semiconductor device, α is a specific heat transfer factor. We put on the value P constant. Equation (2) solve for P, result is in equation (3)

$$P = cm\frac{d\tau}{dt} + S\alpha\tau. \quad (3)$$

On right side of equation (2) are two components; $S\alpha\tau$ is the quantity which heating environment, and time function of

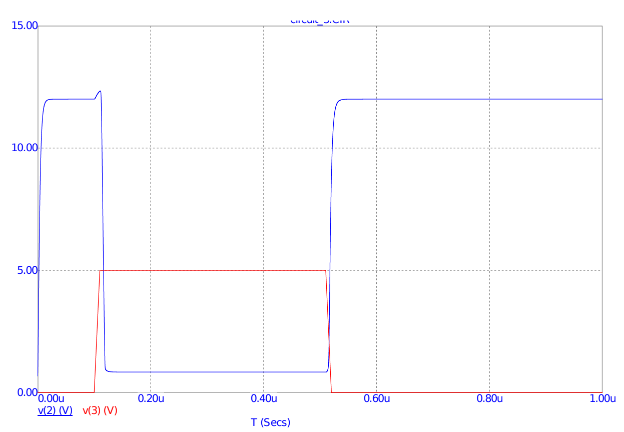

Fig. 2. Typical input and output signals of Fig. (1)'s circuit.

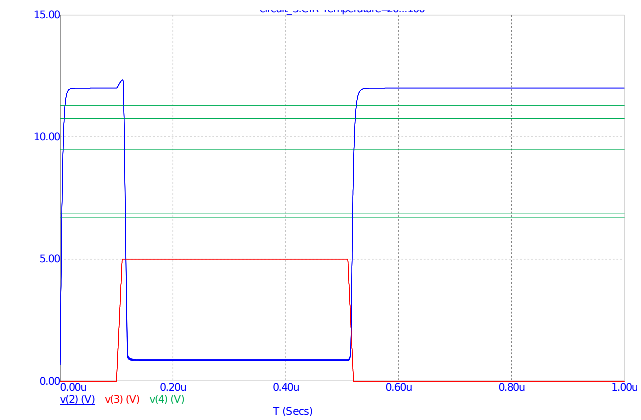

Fig. 3. Output signals of Fig. (1)'s circuit, parameterized in environmental temperature. $\Delta T is 20^{\circ}C$, green lines.

expression of $cm\frac{d\tau}{dt}$ gives thermal-work value what heating semiconductor's body itself.

If P constant, from equation 3, we get equation 4;

$$\tau(t) = \tau_0 e^{\frac{-t}{T}} + \tau_m(1 - e^{\frac{-t}{T}}); \tag{4}$$

where $T = \frac{cm}{S\alpha}$ time-constant of heating, $\tau_m = \frac{P}{S\alpha}$ Is the heat-balanced overheating, $\tau_0 = \tau(t = 0)$ is the initial value of the function.

III. The Usual Temperature Simulation

On Fig. (3) is seen a environmental temperature modeling of switching mode high power transistor circuit (Fig. 2). It follow the well used heuristical approach, according which $U_{TH}(\Delta T) \simeq -3mV/^{\circ}C$. Exact value of course depends on real type of a semiconductor.

Is seen on Fig. (3) that output characteristics isn't very dependent of ambient temperature, however it is change from $20^{\circ}C - 120^{\circ}C$.

It can be seen that by conventional simulation we are not really able to model the effect of thermal changes in the semiconductor [14]. This is especially true of the thermal processes on the chip and their effects [11]. If need to take into account the impact of the warming of its assets in other techniques must be used.

IV. Extend of Nodal Methods

The electronic circuit simulation programs use the nodal potential method. In case of active and passive components, they also use a replacement network. Generally, one branch consists of a voltage generator and branch resistance or impedance (Fig. 4).

We want to determine the voltage of each point (U_p) of the circuit use of equation 5:

$$U_p = R_e \sum_{i=1}^{n} I_n; \tag{5}$$

where I_n is the branch currents, R_e is parallel sum of branch resistors [5] [2]. By using the Milmann rule we get the equation 6:

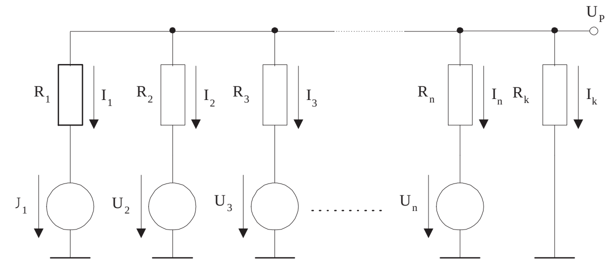

Fig. 4. Interpretation of nodal potential in a general case.

$$U_p = \frac{\sum_{i=1}^{n} \frac{U_i}{R_i}}{\sum_{i=1}^{k} \frac{1}{R_i}}; \tag{6}$$

thus, we get a direct correlation between branch voltage generators and branch resistors.

If the temperature change is to be taken into account when determining the value of the nodal potential, the circuit diagram of the figure 4 is supplemented with a temperature dependent branch. The temperature dependent solution is shown in the Fig.5 [4] .

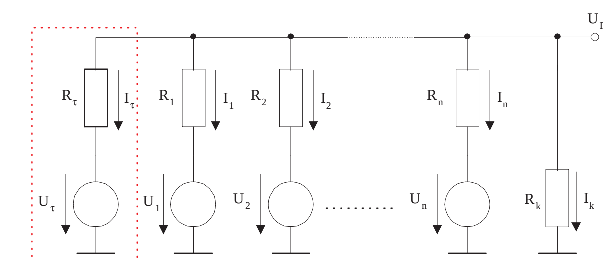

Fig. 5. The temperature dependent solution. Temperature-sensing supplement branch in red dashed box.

Thus, the equation can be supplemented with the equation of the heat sensor branch [9]. So we get equation 7:

$$U_p = R_e \sum_{i=1}^{n} I_n + R_e I_\tau; \tag{7}$$

where τ is the the temperature-sensing current component. From 7 and 6 we get equation 8:

$$U_p = \frac{\sum_{i=1}^{n} \frac{U_i}{R_i} + \frac{U_\tau}{R_\tau}}{\sum_{i=1}^{k} \frac{1}{R_i}}; \tag{8}$$

The element of the branch is the voltage generator and the resistor, each of which can be defined as temperature dependent electronic part [8].

V. Controlled Voltage Generator

By using the equations 4, complete with heuristic results, we can write the voltage generator transfer characteristic equation (9).

$$U_\tau = \mathfrak{f}(\tau(t)dt, \mathfrak{h}); \tag{9}$$

where; $\tau(t)$ time function of semiconductor heating from equation 4, $\mathfrak{h}$ is a heuristical constant from earlier experiments, measures.

The physical content of the proposed solution is thermal coupling of a thermal sensor (U_τ) with the tested semiconductor whose output voltage is temperature dependent (Fig. V).

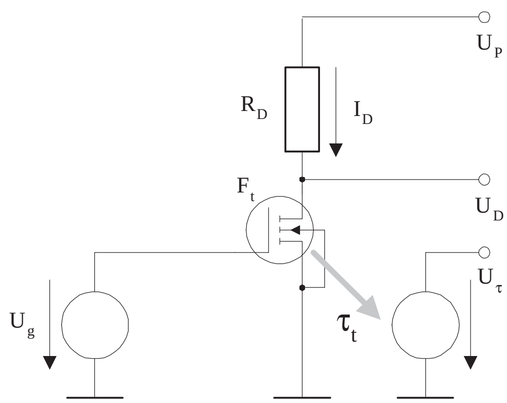

Fig. 6. Thermocouple of a high power transistor (F_t) and a thermos driven voltage generator (U_τ).

Such a temperature sensor voltage generator may be a special thermocouple or a semiconductor circuit designed for this purpose (AD22100, Analog Devices [1]). The latter is an forward-mode current generator drive silicon diode, as described in the equation 10:

$$I_D = I_0(T)((e^{\frac{U_D}{nU_T}} - 1); \tag{10}$$

where; I_0 is the maximal reverse current, T is temperature, n is the emission coefficient; $1 \leq n < 2$, U_T thermic voltage (equation 11):

$$U_T(T) = \frac{kT}{q}; \tag{11}$$

where; q is the elementary charge, k is Boltzmann-constant. The equations 10, 11 gives the practical used result equation 12

$$\frac{\partial U_D}{\partial T}\bigg|_{I_D=constant} = \frac{U_D - U_G - 3U_T}{T}; \tag{12}$$

where; U_G is band gap voltage.
For ΔU_D in practice and from equation 12 is $-1{,}7mV/°C$ largeness change.[12] [13]

As a voltage generator of the Fig. , a current generator driven a forward mode silicon diode is used (Fig.). With its output voltage, connect in serial the U_{GS} voltage of the transistor.

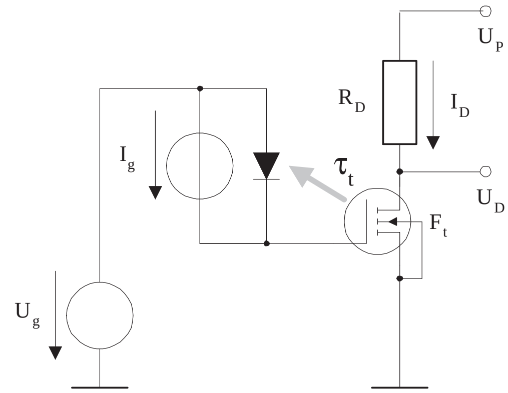

Fig. 7. Thermocouple of a high power transistor (F_t) and a silicon diode.

Thus, we get the dependent output characteristic of semiconductor own heat (Fig.). In the figure, green lines indicate the temperature change.

If we enlarge the important part of the Fig. (8), is seen the different values of the saturation voltage (Fig. 9).

It can be seen that the model works, the output characteristic of the transistor is temperature dependent.

VI. Use of Heat Sensitive Resistor

If a constant-voltage generator is used, we assume that resistor is temperature dependent. In this case, the resistor (R_τ) itself is thermal coupled with the power transistor (Fig. 10).
In the case of thermistors, we are approaching the change of resistance with the usual formulas, equation 13:

$$R(T) = R_\infty e^{\frac{B}{T}}; \tag{13}$$

where B is thermal sensing index in equation 14

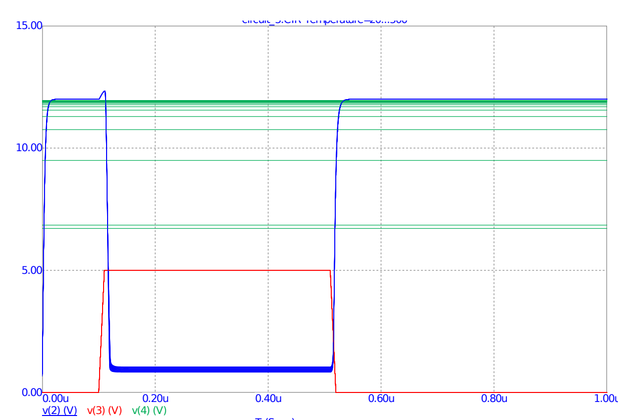

Fig. 8. Output characteristics with modified U_{TH} voltage parameters.

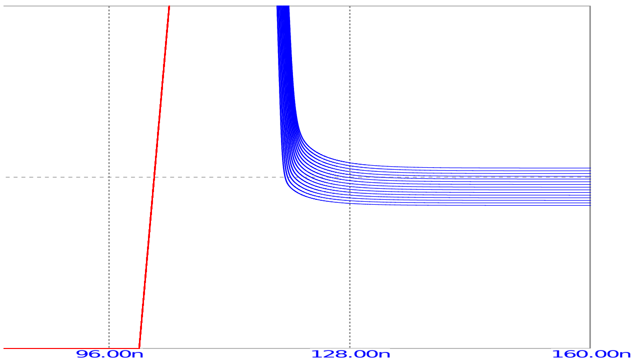

Fig. 9. The relevant enlarged part of turn ON curve of Fig. (8).

$$B = \frac{T_2 T_1}{T_2 - T_1} ln \frac{R_1}{R_2}; \tag{14}$$

where R_∞ is in equation 15

$$R_\infty = R_1 e^{\frac{B}{T_1}}; \tag{15}$$

where $R_1 = R_{T=20°C}$ and $R_2 = R_{T=100°C}$ [10].

We can proceed similarly to the use of thermistor as in Fig. by diode. Of course, we can choose another mode to change the transistor driven by changing the resistance of the thermistor. In this case we need to build different of U_g and U_τ and this driven to transistor's U_{GS} voltage; $U_{GS} = U_g - U_\tau$.

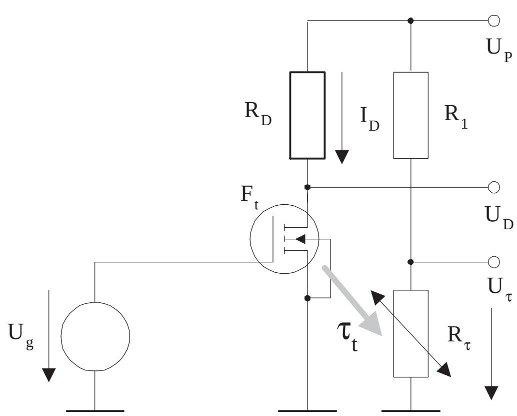

Fig. 10. Thermistor as a heating sensor.

VII. Conclusions

Present article is part of a lengthens future work in which we intend to supervise high-reliability electronic circuits with a microcontroller. To do this, we perform a modeling process in which a circuit simulation method compares the test circuit to some of its voltages, theoretically calculated. To do this, thermal modeling is very useful, and through some simple examples we can prove that the procedure works, it can be used.

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