SPICE-AIDED MODELLING OF THE VOLTAGE REGULATOR L296 WITH SELFHEATING TAKEN INTO ACCOUNT

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Outline

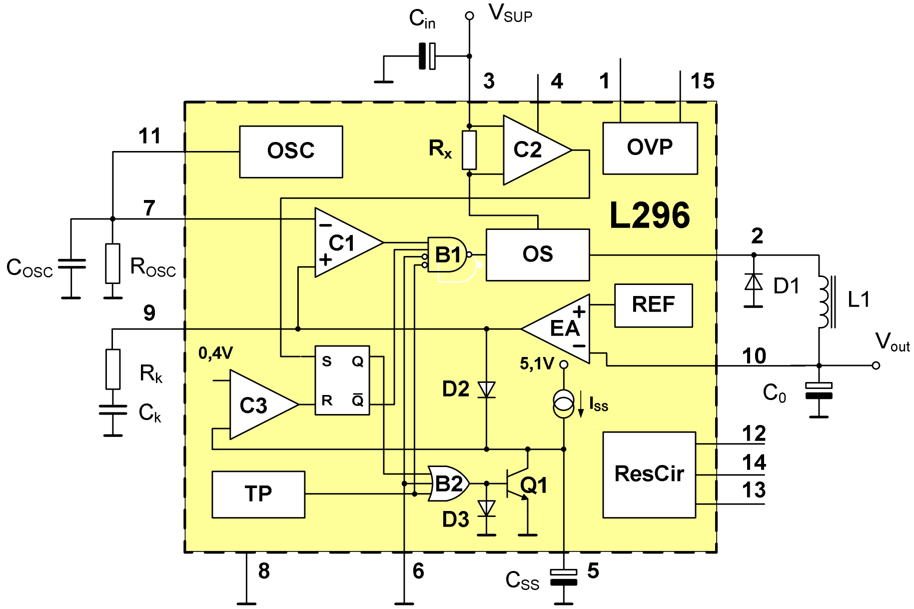
- Introduction
- Structure of the L296 switched voltage regulator
- The electrothermal macromodel of L296 regulator
- The calculations and measurements results
- Conclusions

Introduction

- For the supply of electronic circuits the SMPS are more and more frequently used
- In SMPS commonly are used the switched mode voltage regulators
- One of the most popular voltage regulator is L296
- For a computer-aided design – the proper software and models of electronic devices and ICs are needed
- SPICE - the most popular software to this end
- In electronic devices selfheating phenomenon is observed
- To include selfheating in computer analysis the electrothermal model have to be used
- The aim of the paper - the electrothermal model of L296 regulator

Structure of the L296 switched voltage regulator

- The block structure



- The general description

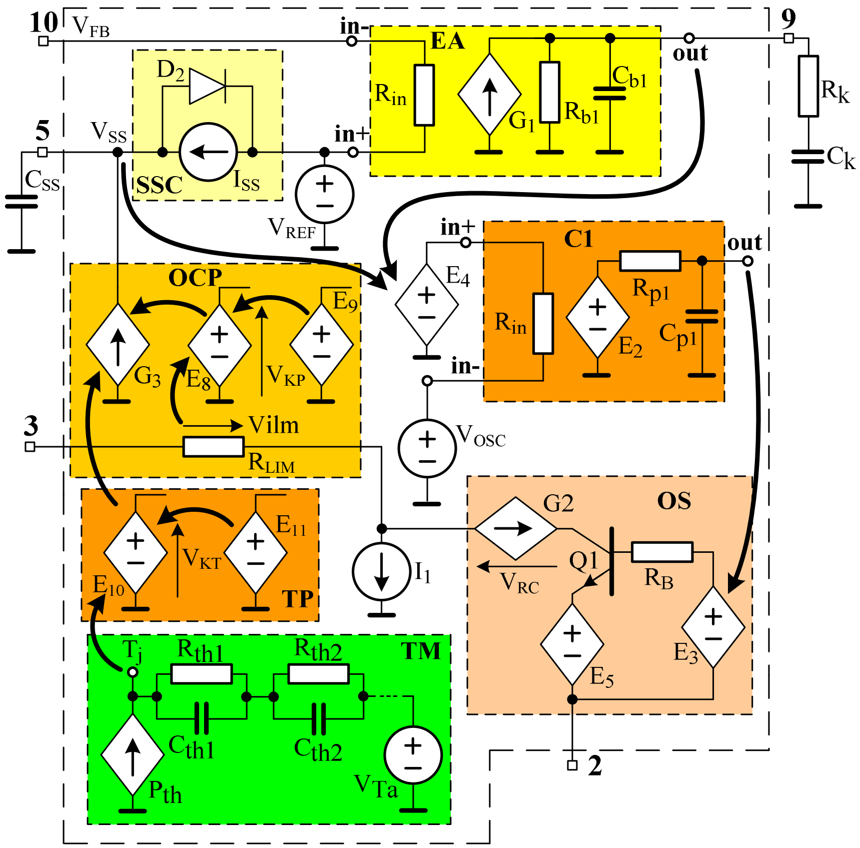
○ The main regulation loop: Error amplifier (EA), Oscillator (OSC), Reference voltage source (REF), Comparator (C1), gate (B1), Output stage (OS)

○ The protection circuits: The over-voltage protection (OVP), the over-current protection ($C2+R_X$), the thermal protection circuit (TP), the soft-start circuit (I_{SS}+Q1+D2+D3)

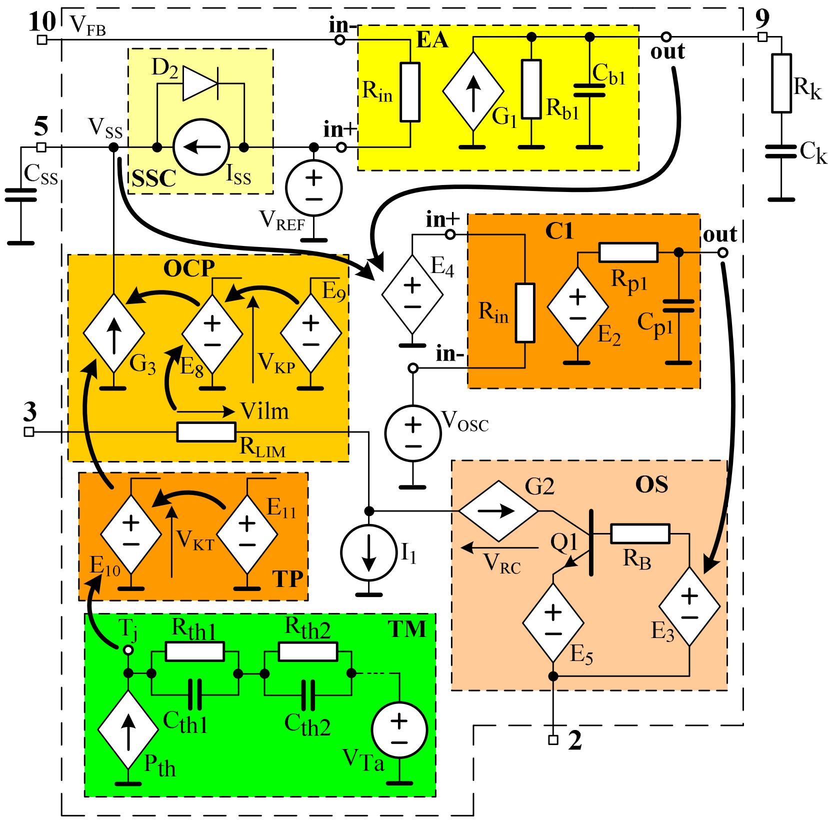
○ External elements: C_{OSC} and R_{OSC} (regulation of oscillator frequency), R_k and C_k (frequency compensation), C_{SS} (soft-start capacitor), C_{in} (input capacitor), D1, L1, C_{wy} (elements of buck converter)

○ The main parameters values: the maximum output current (4A), maximum switching frequency (200 kHz), the supply voltage (from 9 V to 46 V), the output voltage (from 5.1 V to 40 V)

The electrothermal macromodel of L296 regulator



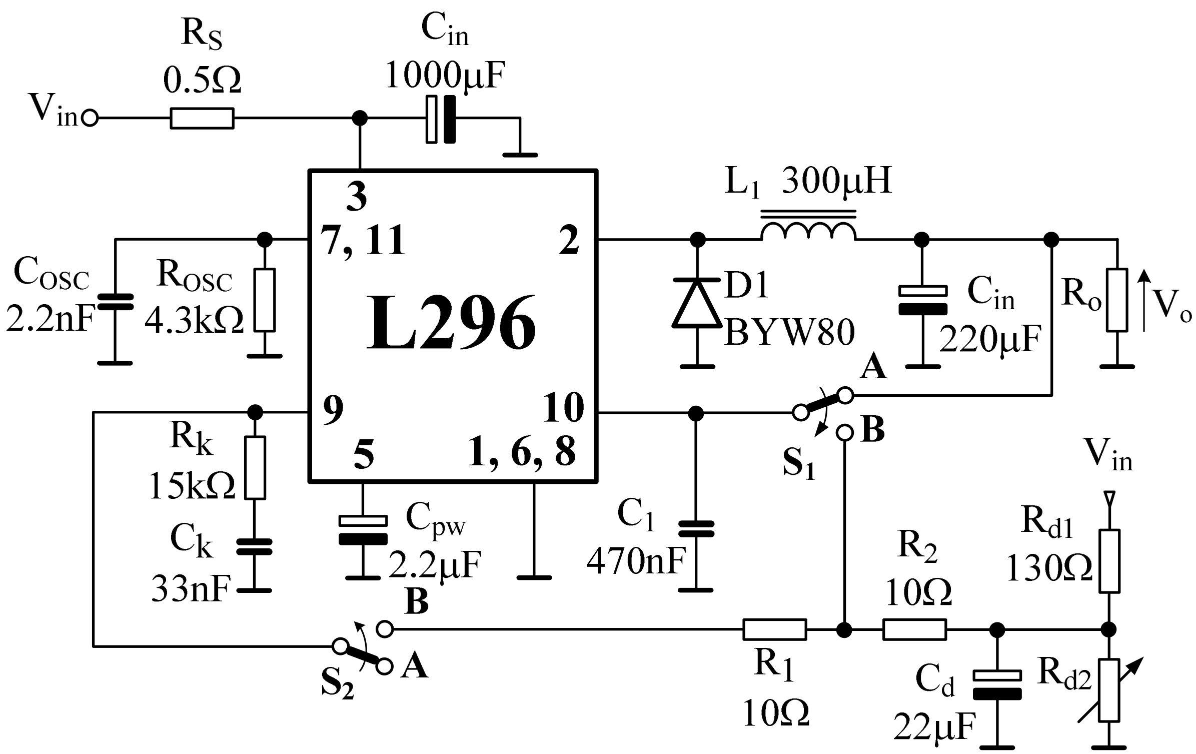
- 9 basic blocks: the error amplifier (EA), the soft-start circuit (SSC), the over-current protection block (OCP), the comparator (C1), the oscillator (V_{OSC}), the reference voltage source (V_{REF}), the output stage (OS), the thermal protection block (TP) and the thermal model (TM)
- The oscillator is modelled as the voltage source V_{OSC} producing the saw-tooth waveform. The pulse fall time t_F and the pulse rise time t_R depend on external elements R_{OSC},$\cdot C_{OSC}$.
- The output voltage of the soft-start circuit (SSC) is the upper boundary of the output actual value of the EA.
- Since the nonlinear dependence of the duration time t_w of the output pulse on the control voltage V_{FB} is observed from experiments, the empirical function of $t_w(V_{FB})$ is proposed



- In order to include selfheating in the isothermal BJT model built-in in SPICE, two additional controlled sources modelling the dependence of the collector resistance on the junction temperature (the current source G_2) and the temperature dependence of the base-emitter voltage (the voltage source E_5), are additionally included in the output stage.
- The current source I_1 models the current consumed from the supply voltage by the inner blocks of the regulator as well as the current controlling the power switch.
- The over-current protection circuit (OCP) is composed of the resistance R_{lim} sampling the regulator input current, two controlled voltage sources E_8 and E_9, as well as the controlled current source G_3
- The thermal model of the L296, consists of the current source P_{th} of the efficiency equal to the electrical real power dissipated in the device, the d.c. voltage source of the efficiency equal to the ambient temperature and Foster RC network.

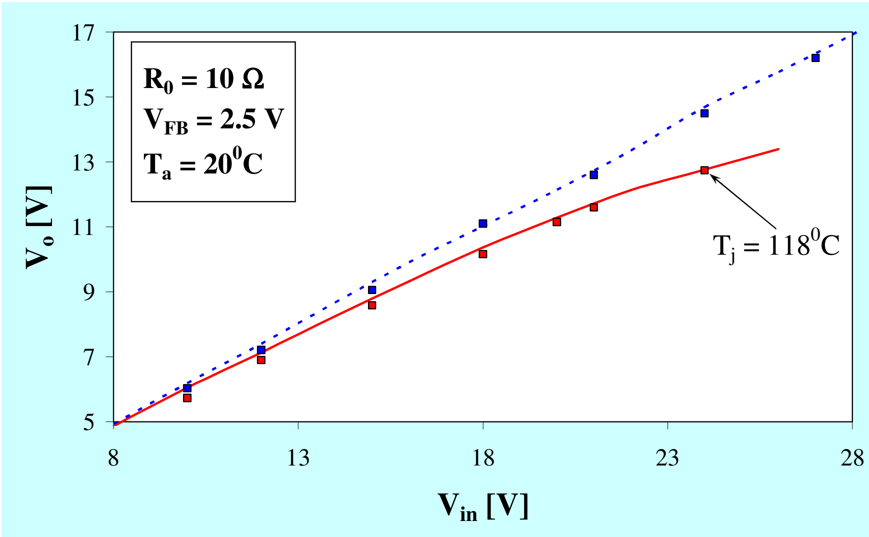
The calculations and measurements results

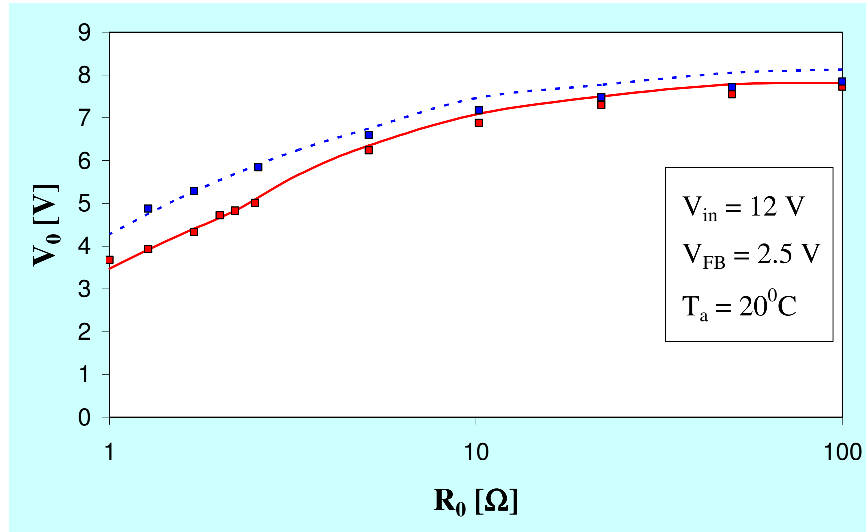
- **The test circuit**



- The converter with the opened (S1 and S2 switches at B position) and closed (both switches at A position) feedback loop was considered.

The calculations and measurements results (cont.)





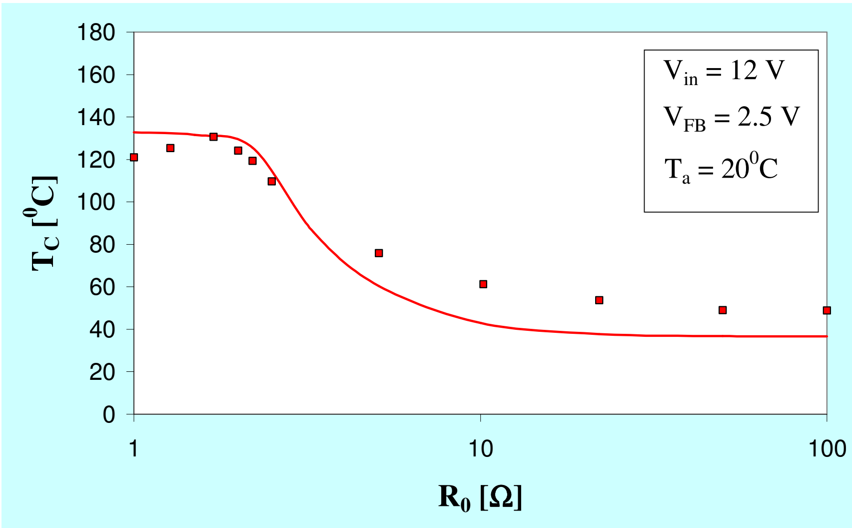
— electrothermal calculations — isothermal calculations

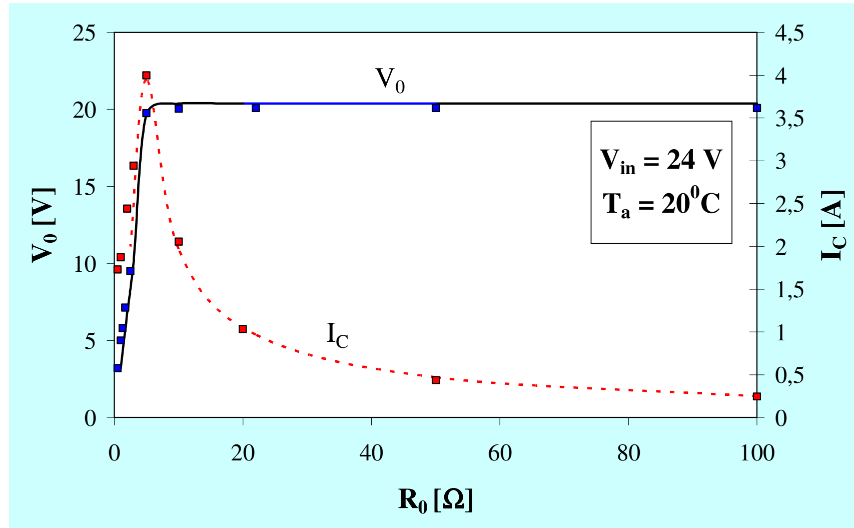
■ ■ ■ electrothermal measurements ■ ■ ■ isothermal measurements

Comments:

- As seen, the results of the simulations and the measurements fit very well.
- Due to selfheating the output voltage of the converter decreases, whereas the differences between the isothermal and nonisothermal characteristics increase according to the increase of the input voltage V_{in}.
- For V_{in} = 24 V the calculated T_j is equal to 118^{0}C.
- The satisfactory agreement between the calculations and the experimental results has been achieved.
- In the considered case the output voltage of the BUCK converter decreases together with a decrease in the load resistance.
- Increasing the junction temperature results in a further decrease of V_{out}.

The calculations and measurements results (cont.)





calculations ■ ■ ■ ■ measurements

Comments:

- In the range of small values of the load resistance R_0 the controlled device inner temperature, at which the thermal protection is activated, is limited to 130^{o}C.
- After activation of the thermal protection the voltage at the output of the regulator is in the form of the rectangular pulses train.
- The measurements fit very well to the simulation results.
- In the range of low values of the load resistance the influence of the operation of the over-current protection block on the shape of the considered dependence is of great importance. As a result, a strong decrease of the current value and a lack of the regulator stability are observed.

Conclusions

- The proposed electrothermal macromodel of the L296 was verified experimentally and the good agreement of the measured and simulated characteristics was observed.
- Selfheating affects the shape of the BUCK characteristics and the differences between the isothermal and nonisothermal characteristics are visible.
- By means of this macromodel the conditions of the safe operation of the considered regulator can be predicted.