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THE INFLUENCE OF COOLING CONDITIONS ON CHARACTERISTICS OF THE LINEAR VOLTAGE REGULATOR

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Key words: Linear voltage regulators, selfheating

Abstract: In the paper the results of experimental investigations showing the influence of the selfheating phenomenon on characteristics of the monolithic voltage regulator 723 are presented. The ideal and real cooling conditions of the voltage regulator mounted in the packages DIL14 and TO-5 operating with a heat-sink and without any heat-sink are considered. The obtained results of measurements show a strong influence of selfheating on the output and transfer characteristics of the application circuits of the considered regulator.

Vpliv hlajenja na karakteristike linearnega napetostnega regulatorja

Kjučne besede: linearni napetostni regulatorji, lastno segrevanje

Izvleček: V članku predstavimo eksperimentalne rezultate vpliva lastnega segrevanja na lastnosti integriranega napetostnega regulatorja 723. Predstavimo vpliv idealnih in realnih pogojev hlajenja napetostnega regulatorja, vgrajenega v ohišja DIL14 in TO-5, prei delovanju z ali brez odvoda tolpote. Rezultati meritev kažejo močan vpliv lastnega segrevanja na izhodne in prenosne lastnosti vezij z regulatorjem.

1. Introduction 1

Linear and switched-mode voltage regulators commonly find application in power supplies /1, 2, 3, 4/. Of course, switched-mode voltage regulators have higher watt-hour efficiency, but on the other hand they are a source of electromagnetic interferences /5/. Therefore, linear voltage regulators are still used due to the short response time for pulse disturbances and a low level of the output ripple voltage /1, 4/.

There are two kinds of monolithic linear voltage regulators. The first are devices of the fixed value of the output voltage, whereas the other are adjustable voltage regulators of the programmable value of the output voltage. One of the most popular devices belonging to the second group of the considered regulators is the voltage regulator 723, manufactured by a lot of producers, e.g. LM723 (National Semiconductor), mA723 (Texas Instruments), MAA723 (Tesla), UL7523 (CEMI). The regulator 723 allows stabilizing the device output voltage in the range from 2 V to 37 V at the output current equal to 150 mA /3, 5, 6/. The use of the considered regulator in the application circuits described, e.g. in /1, 6/ allows broadening considerably broaden the range of stabilized voltages and currents.

The voltage regulator 723 is manufactured with two kinds of packages: the dual-in-line package DIL14 and the metal package TO-5. As it results e.g. from the papers /7, 8, 9/ selfheating affects considerably characteristics of linear voltage regulators. On the other hand, as it is commonly known, the increase of the device internal temperature over the ambient one, is determined by the device thermal resistance R_{th}. The value of R_{th} depends, among other things, on the kind of the device package and the size of the heat-sink included in this package /10/.

In the paper, which is an extended version of the paper /11/, some results of the measurements of the regulator 723 characteristics are presented. Moreover the influence of the device package cooling conditions on these characteristics is discussed in detail.

2. Investigated Circuits

The structure and principle of the considered voltage regulator operation are described e.g. in /2, 6, 7, 11/, whereas the most popular application circuits are shown in /2, 6, 7/.

The circuits shown in Figs. 1, 2 were selected for investigations. The nominal values of the circuit output voltage

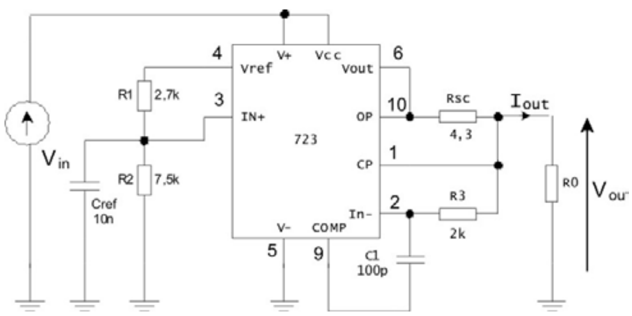

Fig.1. The application circuit of the voltage regulator 723 of the nominal output voltage equal to 5 V

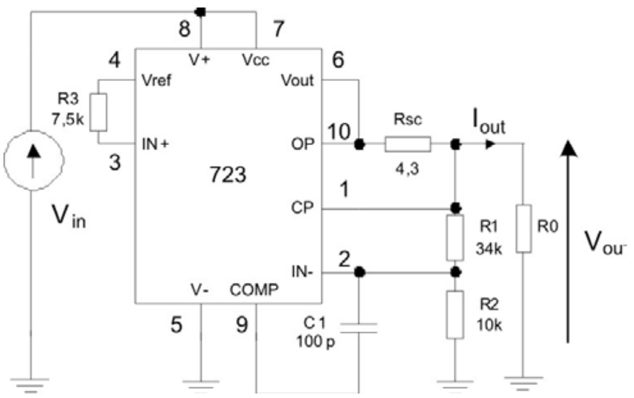

Fig.2. The application circuit of the voltage regulator 723 of the nominal output voltage equal to 30 V

are equal to 5 V and 30 V for the circuits from Fig.1 and Fig.2, respectively.

3. Measurement Results

The characteristics of the considered application circuits operating with different cooling conditions of the voltage regulator 723 were measured by the authors. Two kinds of such characteristics can be distinguished. The first are isothermal characteristics corresponding to the ideal conditions of the device cooling. The others are nonisothermal characteristics, in which the selfheating phenomenon is taken into account.

The isothermal characteristics were performed by the pulse method along with the measuring set described in /12/. On the other hand, the nonisothermal characteristics were obtained by the point-by-point method, which means that each point on the characteristics corresponds to the thermal steady state. Both the regulators were measured without any heat-sink, whereas the device in the package TO-5 was additionally situated on the aluminium heat-sink of the dimensions: 100x90x10 mm.

According to the catalogue data, the thermal resistance of the considered regulator in the package DIL14 and TO-5 is equal to 150 K/W and 165 K/W, respectively.

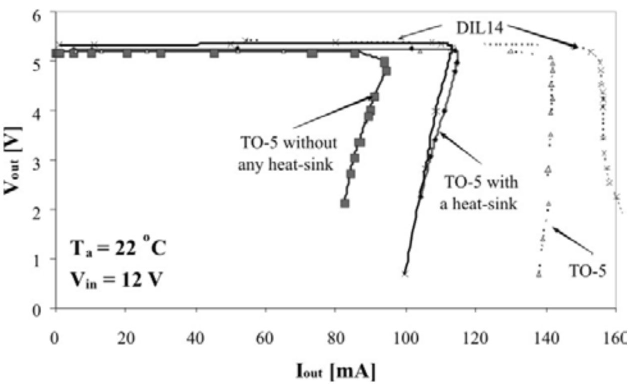

Fig.3. The measured output characteristics of the voltage regulator 723 operating in the application circuit from Fig.1

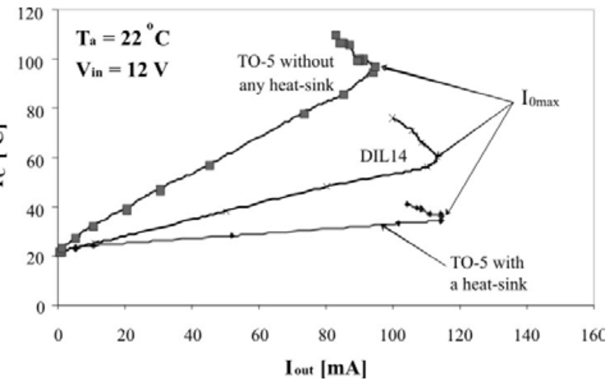

Fig.4. The measured dependences of the case temperature of the voltage regulator 723 operating in the application circuit from Fig.1 on the output current

The measuring results of the circuit from Fig.1 and Fig.2 are shown in Figs.3-7 and Figs. 8 -10, respectively. In these figures the isothermal and nonisothermal characteristics are denoted by the dashed lines and the solid lines, respectively.

Fig.3 and Fig.4 show the output characteristics and the dependence of the case temperature of the regulator from Fig.1 on the circuit output current. The device case temperature was measured with the use of the pyrometer Optex ST-3.

As seen from Fig.3, the maximum value of the circuit output current I_{0max} depends strongly on the device cooling conditions. For example, the value of the current I_{0max} corresponding to the package TO-5 is equal to 140 mA on the isothermal characteristics and less than 90 mA on the nonisothermal ones.

In turn, it is seen in Fig.4 seen, that at the same value of the circuit output current, an increase of the device case temperature (TO-5) is almost twice as high as in the second device (DIL14).

It is worth mentioning that the characteristics from Fig.3 show undercutting resulting from the activation of the overcurrent protection network built-in into the considered regulator.

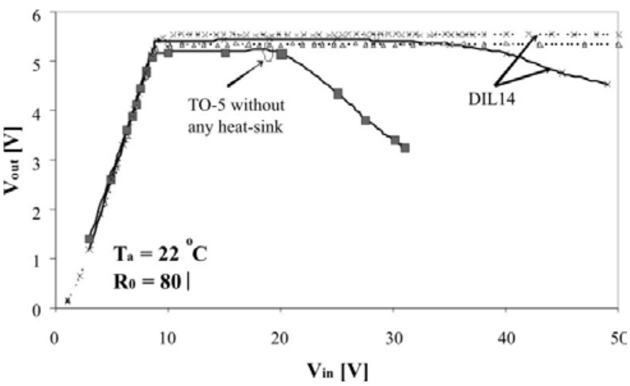

Fig.5. The measured transfer characteristics of the voltage regulator 723 operating in the application circuit from Fig.1 at R_0 = 80 W

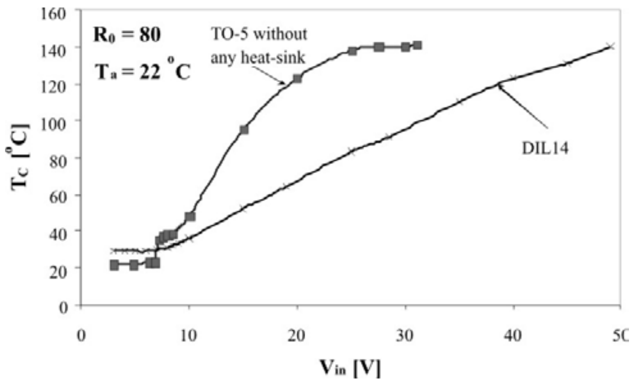

Fig.6. The measured dependences of the case temperature of the voltage regulator 723 operating in the application circuit from Fig.1 on the input voltage

Fig.5 and Fig.6 present the transfer characteristics and the corresponding to them dependences of the case temperature on the input voltage of the application circuit from Fig.1, with the load resistance R_0 = 80 W. As seen from Fig.5, the range of changes of the circuit input voltage corresponding to the fixed value of the circuit output voltage depends on the cooling conditions of the device. For isothermal conditions the stabilization range is limited only "from below" at the input voltage V_{in} = 9 V. Selfheating causes that the circuit stabilized output voltage is additionally limited "from the top" at the input voltage equal to 35 V (DIL 14) and 20 V (TO-5).

We see in Fig.6, that in the range of changes of the input voltage, for which the negative slope of the transfer characteristics is observed, the device case temperature is equal even more than 120°C.

As it was shown in Fig.5, selfheating results in narrowing the circuit stabilized output voltage. Fig.7 shows the transfer characteristics of the application circuit from Fig.1 with R_0 = 39 W. The circuit cannot stabilize the output voltage at all, when selfheating affects the $V_{out}(V_{in})$ characteristics. Note, that in the isothermal characteristics this phenomenon is not observed.

Figs.8 and 9 present the output characteristics and the corresponding to them dependences of the device case

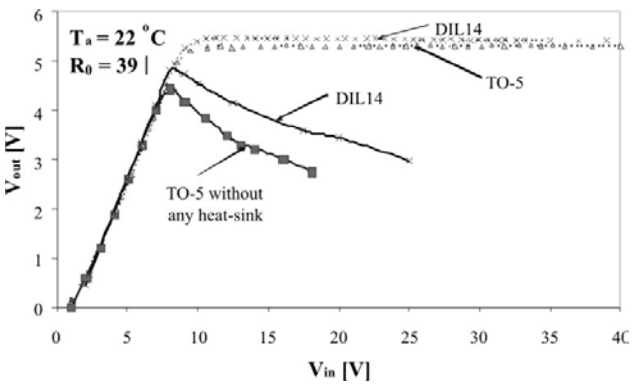

Fig.7. The measured transfer characteristics of the voltage regulator 723 operating in the application circuit from Fig.1 at R_0 = 39 W

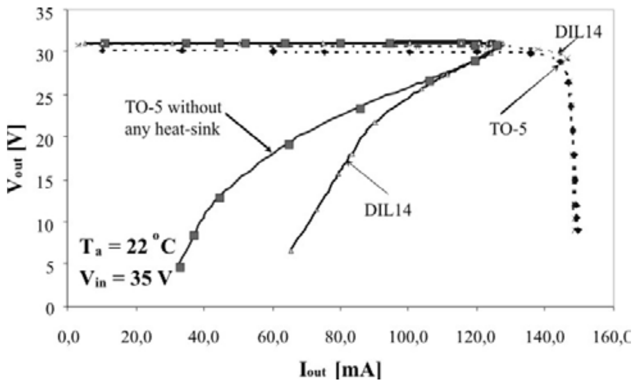

Fig.8. The measured output characteristics of the voltage regulator 723 operating in the application circuit from Fig.2

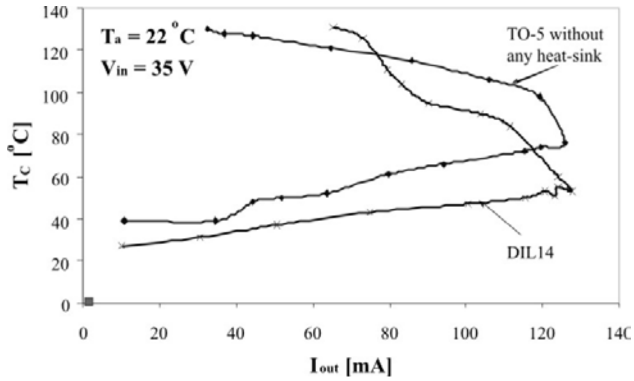

Fig.9. The measured dependences of the case temperature of the voltage regulator 723 operating in the application circuit from Fig.2 on the output current

temperature on the circuit output current. As seen, similarly as it was shown for the circuit from Fig.1, the value of the allowable circuit output current decreases due to selfheating. In the range, in which the overcurrent protection network is activated, the slope of the considered characteristic is much greater than it was in the circuit from Fig.1. In this range of changes of the output current, the strong increase of the device case temperature is observed.

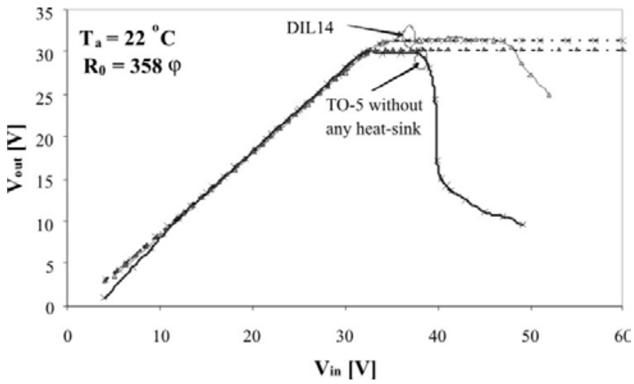

Fig.10. The measured transfer characteristics of the voltage regulator 723 operating in the application circuit from Fig.2

In Fig.10 the transfer characteristics of the application circuit from Fig.2 at the load resistance R_0 = 358 W are presented, whereas Fig.11 shows the dependences of the regulator case temperature on the input voltage, corresponding to these characteristics. As seen, a very narrow range of the stabilized circuit output voltage corresponds to the high value of the voltage V_{out} = 30 V. In particular, for the application circuit with the device package TO-5, a sudden decrease of the output voltage to the value equal to 13 V is observed after the input voltage crosses the value equal to 37 V. A further increase of the circuit input voltage causes a further decrease of the output voltage.

It is visible in Fig.11, that with the rapid increase of the case temperature, the big fall of the voltage regulator output voltage is observed. It is worth to notice, that the case temperature of the regulator is stabilized after achievement of the value 150°C.

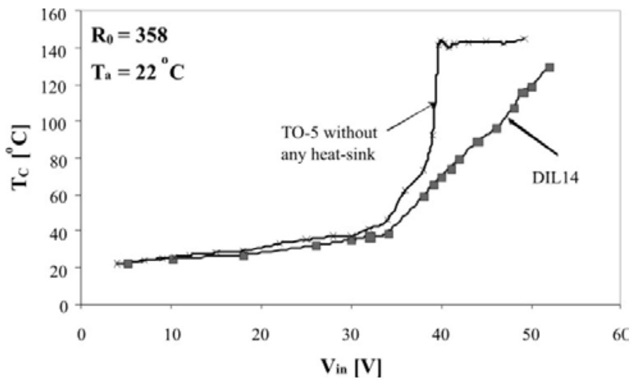

Fig.11. The measured dependences of the case temperature of the voltage regulator 723 operating in the application circuit from Fig.2 on the input voltage

4. Conclusions

In the paper the results of experimental investigations of the influence of cooling conditions of the monolithic voltage regulator 723 on the application circuits of this device are presented. It is seen from the presented results that selfheating causes strong restriction of values of the allowable circuit current and the output voltage. The influence of selfheating on the considered characteristics is more visible in the circuits of a higher nominal value of the output voltage.

Comparing the characteristics obtained from the different device cooling conditions it is seen that using the package TO-5 is less useful than the package DIL14. The characteristics of the device with both the packages are comparable, when the device with TO-5 is situated on the large heat-sink.

When the device case temperature crosses 120°C, the voltage regulator operates in the range of the restricted values of the output current, which results in changes of the shape of its output and transfer characteristics.

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