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Radiation behaviour study of linear voltage regulator

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Abstract. For positive low-dropout linear voltage regulator IS-LS1-3.3V it is established that the output voltage and consumption current change vary slightly in all studied total ionizing dose interval and do not fixed voltage regulator failure. The analytical dependencies of output voltage and consumption current on the total ionizing dose have been obtained.

Keywords: total ionizing dose effects, voltage regulator, X-ray irradiation

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Материалы конференции
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Исследование радиационного поведения линейного стабилизатора напряжения

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Аннотация. Для линейного стабилизатора напряжения положительной полярности с низким падением напряжения IS-LS1-3.3V установлено, что выходное напряжение и потребляемый ток незначительно изменяются во всем исследованном интервале ионизирующей дозы облучения и не зафиксировано отказа стабилизатора напряжения. Получены аналитические зависимости выходного напряжения и потребляемого тока IS-LS1-3.3V от поглощенной дозы.

Ключевые слова: эффекты поглощенной дозы, стабилизатор напряжения, рентгеновское излучение

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Introduction

For development of industries such as cosmonautics, aircraft engineering, nuclear power, it is necessary to achieve reliable functioning of the electronic components such as voltage regulators that used under radiation conditions [1, 2]. Therefore, with taking into account, the main aim of this work is to study the radiation hardness to the effects of the total ionizing dose of the positive low-dropout linear voltage regulator IS-LS1-3.3V produced by JSC "GRUPPA KREMNY EL" (Bryansk) in framework of import substitution program, using the developed hardware and software complex based on the X-ray research complex.

Materials and Methods

As the object of research was the positive low-dropout linear voltage regulator prototype IS-LS1-3.3V produced by JSC "GRUPPA KREMNY EL" (analogue of LT1963 type [3]) with output voltage of 3.3 V and made by epitaxial-planar bipolar technology. Studies of the IS-LS1-3.3V voltage regulator for hardness to ionizing radiation by the effects of total ionizing dose were carried out using the developed hardware and software equipment based on an X-ray research complex XRRC-0401 (JSC "Specialized electronic systems" (SPELS) [4]). The schematic diagram of the developed hardware-software research complex is shown in Fig. 1. The X-ray research complex is an X-ray source RAP-100 with a maximum anode voltage of 80 kV and a maximum anode current of 0.3 mA, which installed in an X-ray protection chamber with a two-coordinate positioning system with a control step of 0.1 mm. The X-ray intensity was monitored using the X-ray comparator DRI-0401. The board of contact equipment is designed to place the sample in the radiation field and ensures its operation.

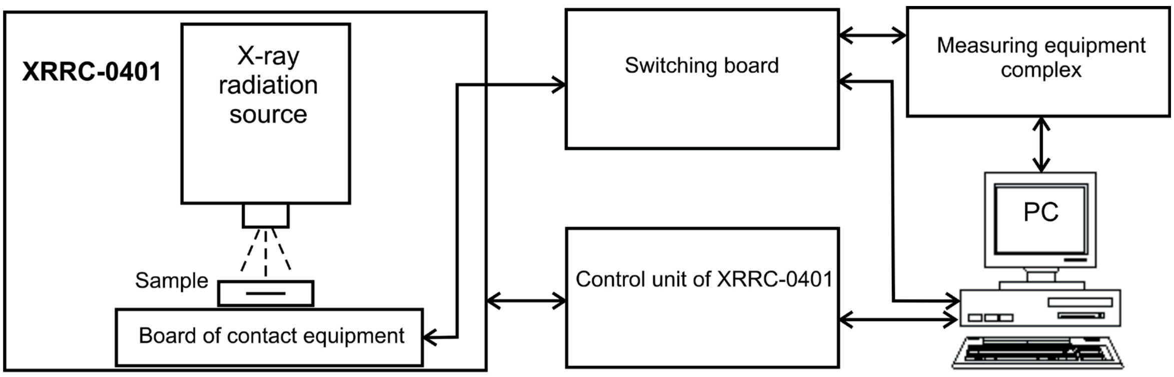

Fig. 1. The scheme of the hardware-software complex: XRRC-0401 – X-ray research complex; source of X-ray radiation; board of contact equipment; switching board; control unit of X-ray hardware-software complex; measuring equipment complex; PC – personal computer

The control unit of contact equipment sets the mode of X-ray source operation and duration of irradiation. The rate of dose of radiation exposure can be controlled by both the change in anode current and the distance from the window of the X-ray source to the sample being irradiated. The switching board specifies the electrical modes of testing sample, as well as the necessary connection of measuring equipment, power sources and loads. The measuring equipment complex includes: RIGOL DP832 power supply, Fluke 8845A multimeter, RIGOL DL3021 programmable electronic load and Keithley 6485 ammeter. The XRRC-0401 was controlled by specialized software developed in the LabView environment, which allows measuring monitored parameters after a given time interval, and also provides the ability to set the electrical mode of operation of the voltage regulator during irradiation. The positive low-dropout linear voltage regulator IS-LS1-3.3V was connected to the board of contact equipment in accordance with typical scheme.

Results and Discussion

During the radiation experimental study of IS-LS1-3.3V positive low-dropout (LDO) linear voltage regulator the following operation mode was used for XRRC-0401: anode voltage of 70 kV, anode current of 150 μA. The distance from the window of the X-ray source equals of 40 mm and rate of radiation dose exposure equals of 35.3 un./s (un. – the units of XRRC-0401). In Fig. 2, *a* are shown experimental results for voltage regulator obtained during radiation experiment. As can be seen, the output voltage V_{OUT} slowly increase with increasing of total ionizing dose D. It is important to note that output voltage not reaches the lower and upper limit of voltage regulator operation mode (3.135–3.465 V). Thus, at value of total ionizing dose equals of 8×10^3 un. (that is equal of ~282 s) output voltage V_{OUT} equals of 3.29 V.

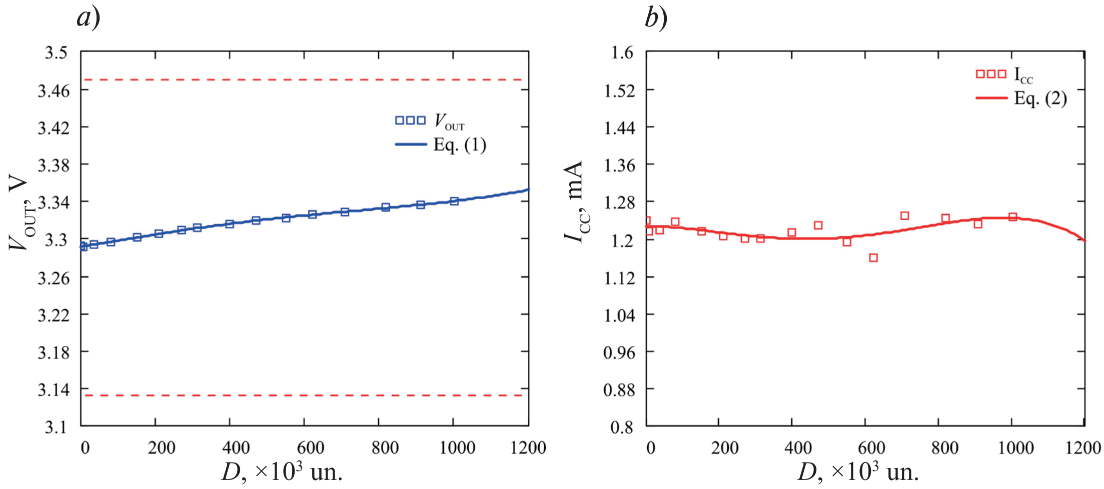

Fig. 2. The experimental (points) and theoretical (lines) data for output voltage dependence V_{OUT} (*a*) and consumption current I_{CC} (*b*) on total ionizing dose D for IS-LS1-3.3V voltage regulator (dashed-line curve – lower and upper limit of voltage regulator operation mode)

Further, during increasing of radiation dose exposure the output voltage V_{OUT} increase nonlinearly and at final value of total ionizing dose equals of 1002×10^3 un. (~35430 s) the output voltage value is 3.33 V ($\Delta V_{OUT} \approx 0.04$ V), i.e. in this case the voltage regulator scheme preserves a functional state without failure.

As follows from Fig. 2, *b* the consumption current I_{CC} varies slightly between 1.59 mA (622×10^3 un.) and 1.25 mA (707×10^3 un.) and reaches 1.246 mA at final value of total ionizing dose equals of 1002×10^3 un. (~35430 s). It should be noted that a similar results were detected in the similar type of positive LDO linear regulator designed specifically for space applications [5]. From a practical viewpoint, for engineering calculations it is important to know for voltage regulator the analytical dependence on the radiation dose. On the basis of above experimental data, analytical dependence of the output voltage V_{OUT} and consumption current I_{CC} on the total ionizing dose D for voltage regulator were calculated using mathematical processing methods of measurement results treatment, especially, the methods of regression analysis. The analytical dependence of the output voltage and consumption current on the total ionizing dose for voltage regulator (in active operating mode at input voltage of 24 V and load current of 5 mA) are following:

$$V_{OUT}=3.204\times10^{-14}D^4-4.435\times10^{-11}D^3-9.187\times10^{-9}D^2+7.041\times10^{-5}D+3.291, \quad (1)$$

$$I_{cc}=-6.276\times10^{-13}D^4+1.183\times10^{-9}D^3-5.368\times10^{-7}D^2-9.1\times10^{-7}D+1.226, \quad (2)$$

where D – the total ionizing dose (10^3 un.), V_{OUT} – the output voltage (V), I_{CC} – the consumption current (mA).

Consequently, the obtained equations can be used by developers-engineers in electronic circuit design for same parameters calculation of linear voltage regulator taking into account of radiation effect, for example, some type of the voltage regulator's that functioning in cosmic space.

Conclusion

The radiation hardness to the effects of the total ionizing dose of the positive low-dropout linear voltage regulator IS-LS1-3.3V produced in framework of import substitution program, has been studied using the developed hardware-software complex based on the X-ray research complex. It is established experimentally that the output voltage varies slightly from 3.29 up to 3.33 V ($\Delta V_{OUT} \approx 1.2\%$) in all total ionizing dose interval and preserves a functional state without failure. It is shown that the consumption current varies slightly between 1.59 mA and 1.25 mA. It is established that total ionizing radiation dose in investigated interval does not lead to the failure of the voltage regulator. For voltage regulator the analytical dependencies for the output voltage and consumption current on the total ionizing dose have been obtained.

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