Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 34, 2022, Sofia

DOI: https://doi.org/10.3897/arb.v34.e09

SIMULATION AND MODELS OF ONBOARD SECONDARY POWER SOURCES FOR AERO AND SPACE DEVICES

Pavlin Gramatikov

Space Research and Technology Institute — Bulgarian Academy of Sciences
e-mail: pgramatikov@space.bas.bg

Keywords: *Secondary power sources, Simulation models, Ltspise, Micro-Cap, NI MultiSim*

Abstract

This article discusses the design and evaluation of secondary power sources using simulation models. In a set of circuit experiments, the models allow various parameters to be measured and visualized and aid in the analysis of the results. The models were developed using "NI MultiSim" (for simulation experiments); "Micro-Cap" (for functional experiments) and "LTspise" (for process control). Simulation helps to understand the basic concepts, analysis and tuning of circuit processes and parameters of secondary power supplies.

1. Introduction

The onboard secondary power sources and systems (SPs and SPS) are designed according to the requirements of the specific loads; regulated technical requirements of the standards for space equipment (SE) and space operating conditions [3]. Incorrectly designed SPS can cause: poor electromagnetic compatibility (EMC); errors in the junior bits when we make analogical-digital conversion; noises in analogue data, etc. Analysing heat processes in SPS helps to increase the reliability and resource of SPS [3, 5]. In order to achieve a long-time use of SPS in advance a thorough analysis of their elements with the shortest resource in space conditions is carried out. That are devices with high operating temperature of the hull (which reduces the time of flawless operation of the SPS): electrolytic capacitors and the switched mode elements (diodes and transistors) operating at the high frequency [5]. The analysis of space SPS can be divided into three groups of consecutive activities: design; creation and final corrections after laboratory testing with space methodology and onboard studies in manned and unmanned spacecraft. Specific activities in the synthesis of a particular cosmic SPS are: choice of the element base according to the working conditions; selection of the structure of the SPS; examination of the thermal regimes and parameters of the SPS according to the SE and the scientific experiment.

In this article we distinguish three types of SPS, according to their application for: manned spacecraft, unmanned spacecraft and unmanned aerial vehicles (UAV):

• For board analysis of the SPS in unmanned spacecraft the means for telemetric control and ground processing of the data, as well as software control from the boarding computers are used. The weight characteristics in the space conditions of use are not in the foreground-in the case of interplanetary flights double and triple reservation [1, 3] shall apply.

• The abilities of the astronaut as operator [11] of the SPS and the scientific apparatus in manual mode (emergency and main) are also used in manned spacecraft. In long term the astronaut performs operation and repair of SPS [3], but the time and means of repair are regulated. SPS for manned spacecraft has a specific construction and specific qualities of materials.

• In case of SPs or SPS for UAV in the development of one product is invested scientific work in order to minimize the weight and volume of the power supply-including cables and achieve satisfactory EMC. The reliability and the resource of the equipment used must be satisfactory for the short flight time, usually within 24 hours. In the UAV is not necessary the reservation of SPS and the multiannual reliability. The SPS technical indicators require the EMC to ensure the functioning of the specific UAV (rather than the functioning of a complex of work and scientific Apparatus as in space SPS) and high energy efficiency.

2. Main types of SPs for aero and space purposes.

In SPS with space application is obligatory to use SPs with galvanic isolation not only in relation to the input/output compounds, but also to the casing, control and telemetry circuits [3]. In The UAV minimizes weight and is usually administered SPs without galvanic isolation, without a choke or a single choke. Depending on the structure of the impulse transducers with galvanic isolation are:

• Mono-phase: forward converter with one or two semiconductor keys and a reverse “flyback” converter with one or two semiconductor keys;

•Two-phase (half bridge and full bridge circuit);

• Multi-phase converters.

Impulse converters according to the mode of switching are: forward and flyback; single-phase and multiphase, resonant, quasi-resonant and etc.

3. Simulation methods for analysis and synthesis of SPs

3.1. Program Product “LTspise”

With this software are possible the following analyses of SPs: “Transient analysis” (Transitional processes after start of supply voltage); “AC small signal” (amplitude and phase frequency analysis in small signal); “DC sweep” (DC regime in dependence of constant voltage or current); “DC transfer function” and “DC_op_pnt” (DC working point).

In Fig. 1 and Fig. 2a are given one model and times diagrams for one driver for MOS transistor, controlled by optical cable. In Fig. 2a are given next parameters in different colors: in the yellow is the voltage Vui at the input to the U3 comparator; the 5 V green is Vc at the input to the U1; the red is Vdr at the input to the FET Driver and the 12 V green is the Vg of the gate of the transistor. Two different resistors R1 and R2 are used for charge and discharge of the gate. After comparing Vdr and the Vg can be seen about 3 times greater delay between open and closing processes the MOS transistor, because R1 is repeatedly bigger than R2. In the positive front of the Vg there is a short sharp peak due to the discharge of the parasitic capacity (between the gate and the drain) and it is specific characteristic of the high voltage MOS transistors in impulse mode.

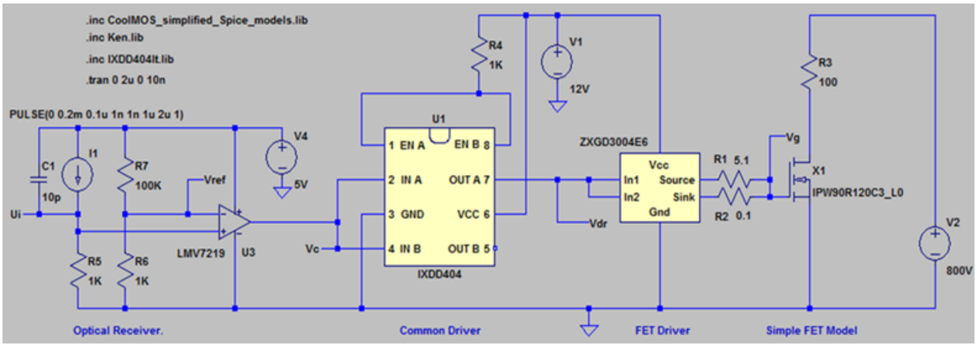

Fig. 1. Model with “LTspise” for one driver for MOS transistor

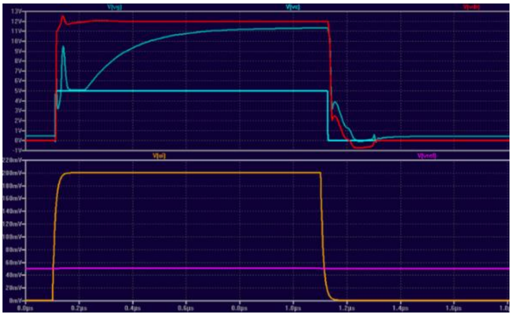

Fig. 2a. Times diagrams with “LTspise” for one driver for MOS transistor

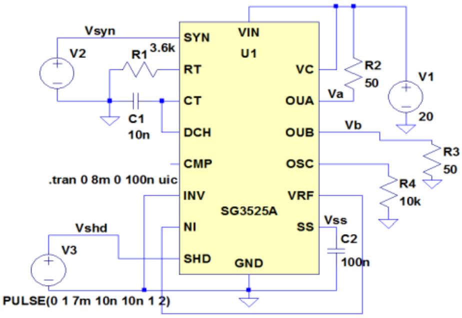

Fig. 2b. Controller with “LTspise”

In Fig. 2b a full functional model of the controller (SG3525A) for SPs is presented. This model can be used to synthesize and optimize the schemes of management of SPs. With time and value controlled generators V_1, V_2 and V_3 are simulated the power, synchronization and authorization of the controller.

Fig. 3 show a model of the flyback converter with controller UC3842 and two feedbacks: from the output voltage V_{out} and from the current of the key transistor I_{SNS}. The following time diagrams are shown in Fig. 4a: with purple color V_{out}; with green color the voltage of the feedback VR6; with blue color, the voltage at the output of the controller V_{mdrv}; with a red color the current of the key transistor I_{SNS}. For the time interval $\Delta t_2 = 0 \div 4$ ms voltage V_{out} is smoothly increased, because with the peak current of the primary winding is limited by comparator S3 to the level $I_{lim} = V_{lim}/R_{sns} = 1\ \text{V}/0.25\ \Omega = 4$ A. This is the way to charge output capacitor $C_{FILT} = 2200$ µF. In Fig. 4b magnifier software was demonstrated, allowing detailed examination of processes from Fig. 4a: in time $\Delta t_3 = 3 \div 3.2$ ms we observed negative and positive halfwave of over-regulation of negative feedback that causes the voltage exceeding the output voltage V_{out} (above the nominal value 12,00 V) — up to 12.3 V. This process is undesirable and should be removed after optimization the feedback for current and voltage on the SPS.

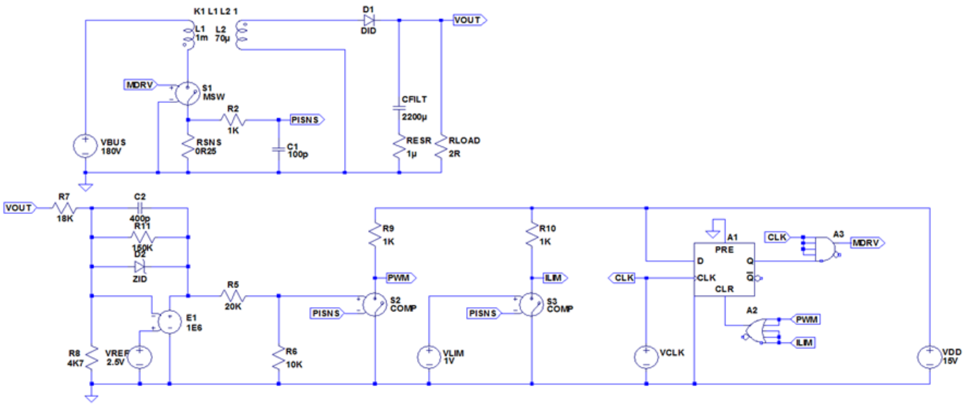

Fig. 3. Simulation of the converter with feedback and controller UC3842

Fig. 5 shows the Flyback model built with the UC3842B controller [2]. It can be seen that the feedback does not regulate the output voltage VR9, and follow the rectified voltage U1 off the secondary winding L2. The startup process from Fig. 8 can be analyzed with the presented simulation data. When U1 = 16 V the controller UC3842B turns on and began the discharge of the starting capacitor C6 to 11 V. At the moment t = 62 ms diode D2 is beginning to conduct and charge the capacitor C6 from 11 V to U1 = 12 V, set by the feedback resistors R2, R3 and U1. Generator V1 simulate work levels for voltage DC supply.

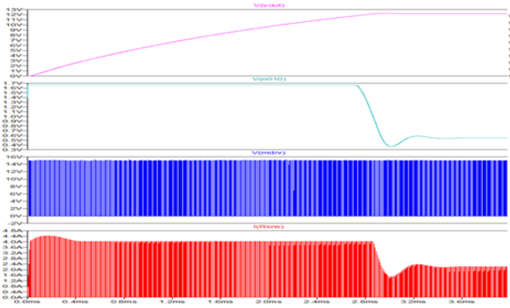

Fig. 4a. Start process at Ts=0÷4 mS

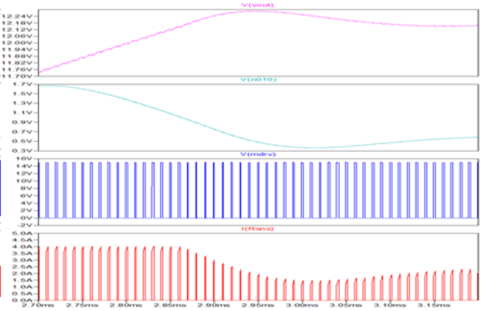

Fig. 4b. Start process at T_s=2,7÷3,2 mS

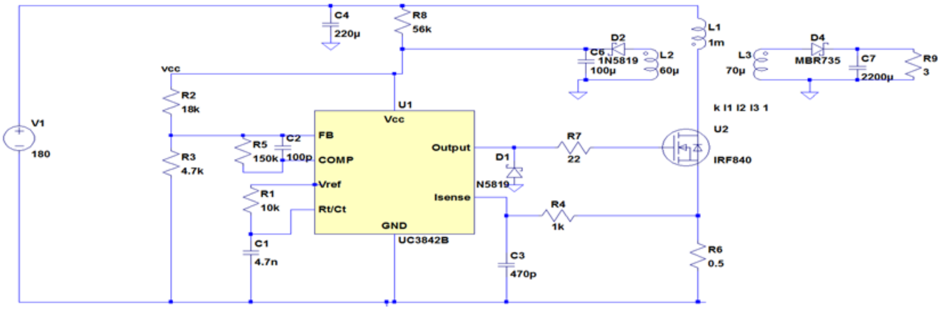

Fig. 5. Flyback model built with the UC3842 controller

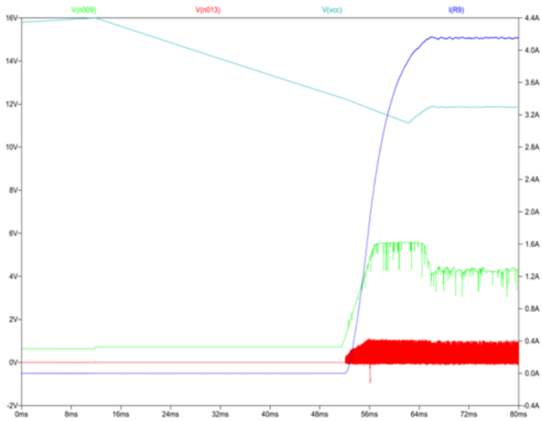

Fig. 6a. Startup process from Fig. 7

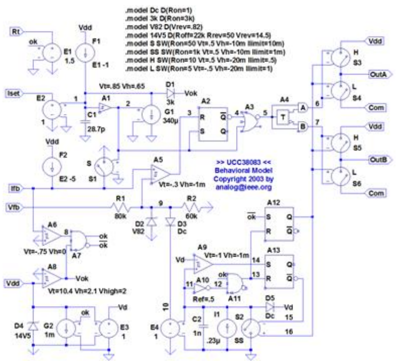

Fig. 6b. Model of the new generation Controller UCC38083

In examining the tension by V_{comp} (in green) from controller U1, Fig. 6a we see five curves: zero level; positive front, horizontal front; the negative zone and horizontal level when feedback is working. In time interval Δt4 = 50÷56 ms Vcomp sets growing smoothly his level which is reflected in the gradual increase of the amplitude of the current of transistor of U2. We see 10 undesirable waves of Vcomp with resonant frequency of 1 KHz in the adjustment zone Δt5 = 66÷80 ms. This undesirable pulsation of the closed system for voltage regulation U1 must be minimize.

In Fig. 6b the structure of the model of the new generation controller UCC38083, simulating its internal structure and all its functions, is shown. This controller is built entirely with MOS technology, has very low consumption in the excluded and active state. It is suitable for use in the synthesis of new management schemes for SPS.

3.2. Program Product "Micro-cap"

With this software, the following analyses are possible: transient processes; small signal frequency analysis: amplitude and phase frequency analysis and Bode's diagram; transmission function on constant voltages and currents: transmission function; V-A characteristic and family static transmission characteristics; dynamic analysis of constant voltages and currents; analysis of the sensitivity of the equivalent scheme for constant voltages and currents to change the parameters of the component.

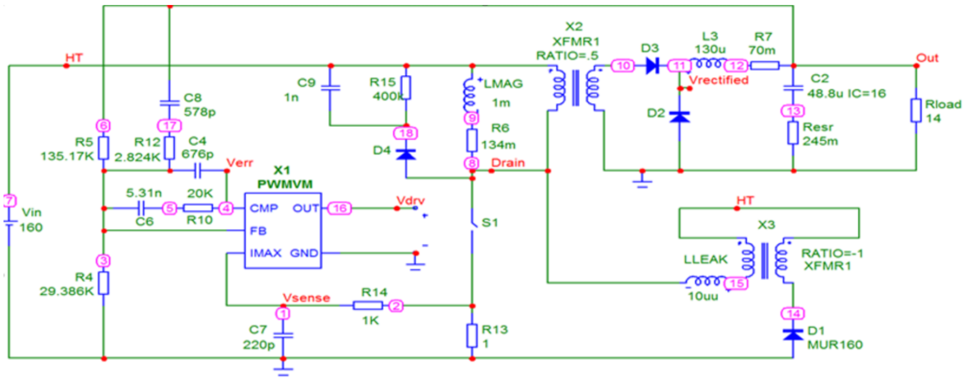

Fig. 7a. Model of Transformer Forward converter

Additional types of analyses are: calculations when modifying one or more parameters; calculation of modification of parameters in a specified tolerance for statistical processing; Fourier analysis; calculation of the graphs of various dependencies and examination of the temperature instability of the model.

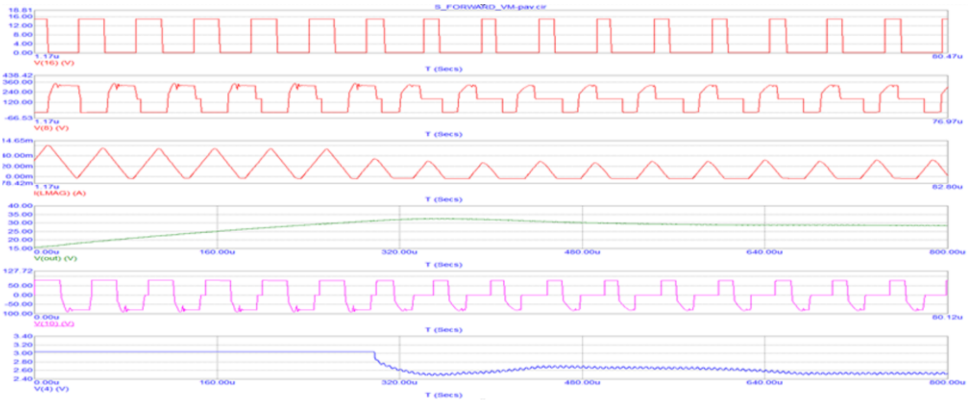

Fig. 7b. Time diagrams of Transformer forward converter

In Fig. 7a it is a model of Transformer Forward converter, in which is used a function equivalent of a X1 controller, operating in a voltage mode of regulation. In Fig. 7b are visualized some of the parameters from Fig. 7a: geit voltage V16 and drain voltage V8 of the function equivalent of MOSFET transistor S1; current I_{Lmag}; output voltage Vout; secondary voltage V10 and output voltage V4 of the error amplifier CMP. The analysis of the Vout graph shows an overshoot to a peak value of 35 V, with a nominal 24 V, which proves an abnormal mode of operation of the voltage feedback and the need for further optimization of its performance. Other wise there is a danger of damage to the user, powered by this SPs.

3.3. Program Product "Multisim".

The library of elements of this program contains more than 2000 "SPICE" pattern. It is possible that through the sub-program "Utiboard" to synthesize and analyze the construction of the PCB, as well as to present in the 2D and 3D appearance of the individual elements.

The resistance of the virtual resistors can have an arbitrary value. Multiple models can be used for a single component. For building blocks, an "SPICE" analysis is usually used. "Multisim" has a rich set of virtual instruments for analyzing the processes [4, 6, 7, 8]. There are two types in the component library, both real and virtual. You can set the time of emulation. In Fig. 8. is a model of SPs for the camera of the multichannel spectrometric system "Spectar-256" [9, 10, 12]. For the visualization of the processes are selected: two virtual oscilloscopes XSC1 (green for source current off Q1transistor and gelb for secondary winding of T1) and XSC2 (blue for gate voltage of Q1 and red for voltage of a soft start of the controller DA1); multimeter XMM2 and wattmeter XWM1. Interactive elements are used: switch S1 (for restart of DA1) and X1 light diode indicator.

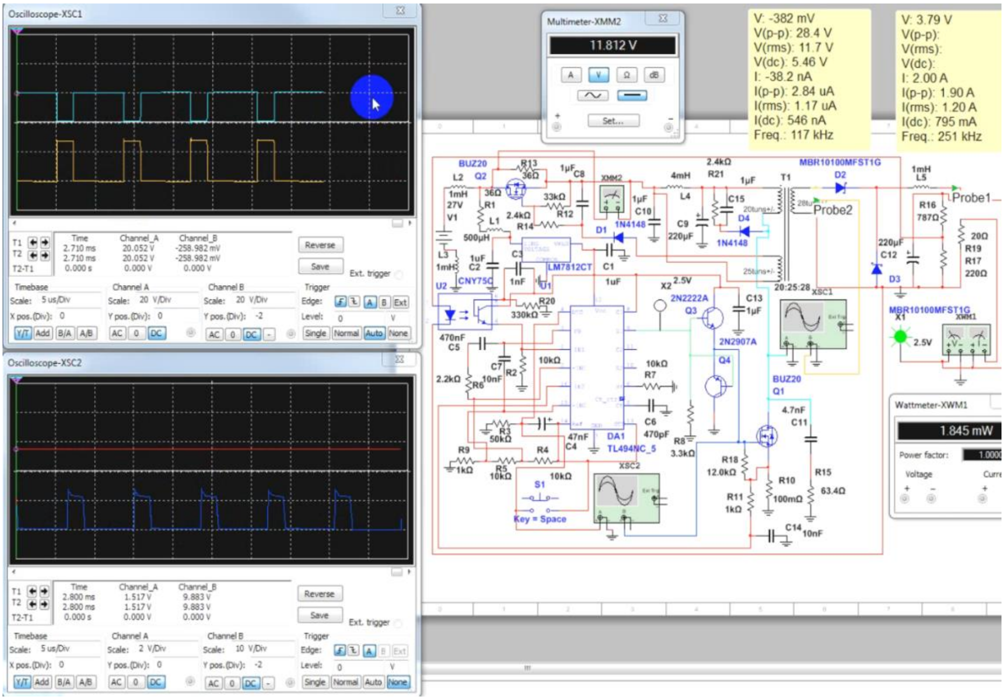

Fig. 8. Model of SPs for the multichannel Spectrometric system “Spectar-256”

Results and Discussions

It was synthesized an author’s model, allowing an interactive simulation of the dynamic processes of SPs for the Spectrometric complex “Spectar-256”. The dynamic regimes were tested in three more models of SPs. It was simulated: basic diagrams of stabilized pulse converters, dynamic parameters; protections and feedbacks; voltage and current pulsation. Modern methods and tools are used for research and design of SPs for board aero and space Equipment – analysis by simulation of complete functional models of power supply sources and their components. The simulation of SPs and SPS allows to reduce the errors in synthesis and by analysis to shorten the time of development.

References

1. Avanesov, G. A., B. I. Bonev, F. Kempe, *et al.* Television observations of Phobos. *Nature*, volume 341, Issue 6243, 1989, 585–587, DOI 10.1038/341585a0
2. Braun, M., Naruchnik po tokozahranvashti ustrojstva, Izdatelstvo “Tehnika”, SofiJa, ISBN 9540304946, 1998, 240 p. (In Russian).

3. Ishodnye tehnicheskie trebovaniJa k apparature i oborudovaniju – ITT2. Kompleks celevyh nagruzok. ITT KCN RS MKS P 34240–515, Raketno-kosmicheskaJa korporacija “Energija” imeni S.P. Koroleva, sentJabry 2000, 111 p. (In Russian).
4. Charles Schuler, Electronics: Principles and Applications w/Multi Sim CD, Book, McGraw-Hill, Inc. New York, NY, USA, m ISBN-10:0073316512, ISBN-13:9780073316512, 2007, 566 p. https://www.semanticscholar.org/paper/Electronics%3A-Principles-and-Applications-w%2FMulti-CD-Schuler/6b81fac2e4885a5605acfa9a515d5d7e6e97fe8e
5. Zjagina, S. S., M. V. Roshtina. Obespechenie teplovyh rezhimov pechatnogo uzla istochnika vtorichnogo elektropitanija, zhurnal “Trudy mezhdunarodnogo simpoziuma nadezhnosty i kachestvo”, tom 2, 2009, pp. 200–201 (In Russian). https://cyberleninka.ru/article/n/obespechenie-teplovyh-rezhimov-pechatnogo-uzla-istochnika-vtorichnogo-elektropitaniya
6. Mahata, S.; A. Maiti ; C. K. Maiti, Cost-effectiveweb-based electronics laboratory using NI MultiSim, LabVIEW and ELVIS II, 2010 International Conference on Technology for Education, IEEE, 2010, 242–243, DOI: 10.1109/T4E.2010.5550110
7. David Báez-López and Félix E. Guerrero-Castro, Circuit Analysis with Multisim, 2011, Copyright © 2011 by Morgan & Claypool, ISBN: 9781608457564 paperbacks, ISBN: 9781608457571 ebook, Print 1932-3166 Electronic 1932-3174, 198 p. DOI 10.2200/S00386ED1V01Y201109DCS035
8. Gramatikov, P., A. Gramatikova, Izpolzvane na programata MULTISIM za poluchavane na volt-amperna harakteristika na diodi, International Conference “Enganging tools for science Education”, Sofia, 31 oktomvri-1 noemvri 2014 g.
9. Mishev, D. N., Kovachev, S. T., Yanev, T. K., & Krezhova, D. D., The multichannel spectrometric system “Spectrum 256”onboard the manned space station ‘MIR’and afterwards. 10 Years from the Space Project Schipka 1998, 104–110.
10. Borisova, D. Izsledvane na spektralnite otrazhatelni harakteristiki na skali, Doktorska disertacija. Sofia, 2015, 105 p. (In Bulgarian)
11. https://ras.nacid.bg/api/reg/FilesStorage?key=afcbb445-7745-4dd0-be63-8b642b8fa764&mimeType=application/pdf&fileName=PhD_text_3(3)(3)_J111_dop_KK.pdf&dbId=1
12. Getzov, P., Z. Hubenova, Reliability Study of Operators Within a Complex Ergatic System, JOURNAL SCIENTIFIC AND APPLIED RESEARCH, Vol. 5, ISSN 1314-6289, 14; ISSN 1314-6289, EBSCO, 2014, 7–14. http://www.rst-tto.com/docs/journal-scientific-and-applied-research-vol-05.pdf
13. Gramatikov, P. SECONDARY POWER SUPPLY SYSTEM FOR MULTICHANNEL SPECTROMETRIC SYSTEM “SPECTRUM-256”. Proceedings SES2018, Space Research Technology Institute — BAS, 2018, ISSN:2603-3313, 217–220. http://www.space.bas.bg/SES/archive/SES%202018%20DOKLADI/2_Aerospace%20Technologies/16_Gramatikov.pdf

СИМУЛАЦИЯ И МОДЕЛИ НА БОРДНИ ВТОРИЧНИ ЕЛЕКТРОЗАХРАНВАЩИ ИЗТОЧНИЦИ ЗА АЕРОКОСМИЧЕСКИ ПРИБОРИ

П. Граматиков

Резюме

В статията се разглежда проектирането и оценката на вторични източници за електрозахранване с помощта на симулационни модели. При набор от схемни експерименти моделите позволяват да се измерят и визуализират различни параметри и спомагат при анализа на резултатите. Моделите са разработени с помощта на "NI MultiSim" (за симулационни експерименти), "Micro-Cap" (за функционални експерименти) и "LTspise" (за контрол на процесите). Симулацията спомага за разбирането на основните концепции, анализа и настройката на схемните процеси и параметри на вторични източници за електрозахранване.