Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 38, 2026, Sofia

DOI: https://doi.org/10.3897/arb.v38.e20

SIMULATION AND MODELS OF SECONDARY POWER SUPPLIES FOR AEROSPACE SYSTEMS

Pavlin Gramatikov

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

Key words: *Secondary power sources, Simulation models, Micro-Cap, TINA-TI, MultiSim, SIMetrix*

Abstract:
The design and evaluation of secondary power sources and systems using simulation and models are discussed. Experiments with electronic circuits are performed. The models allow measurement and visualisation of various parameters as well as analysis of the results. Micro-Cap, TINA-TI, MultiSim, and Symetrix software products are used. The simulation helps to understand the basic characteristics, analyse and tune electronic circuits, and study processes in secondary power sources and systems.

Introduction

The power supply of aerospace equipment (AE) is carried out by two cooperative systems: the primary power supply system (PES) and the secondary power supply system (SES). The purpose of the PES is to convert non-electrical energy into electrical energy. In most cases, the PES, in terms of stability and voltage, is not suitable to power AE, which determines the use of secondary power sources (SPS) and PES designed according to the requirements of specific users and operating conditions. The main energy source of the spacecraft is usually the solar battery, which, together with the batteries, primary pulse converters, power automation, cables and connectors, forms the primary onboard network, which in some Russian spacecraft and aircraft has a constant voltage varying in the range from +24 V to +34 V. Voltages of positive and negative polarity are used in the power supply of AE. In the case of unmanned aerial vehicles, stable voltages with values of +3.3 V, +5 V, etc., are usually applied to digital electronics, and +6 V, +12 V, etc. for actuators.

The developed circuit and design solutions of the SES are tested for compliance with the normative documents and are checked during aerospace flights.

When designing specialised SPS and SES for AE, the following shall be taken into account:

- The characteristic features of the equipment and the specific scientific experiment;
- Operating conditions: outer space; artificial atmosphere in an airtight compartment; mechanical loads at launch; flight; maneuvering and transport; radiation conditions; thermal regimes, etc.;
- The electromagnetic compatibility on board the aerospacecraft.

With qualitatively performed design, research, adjustment, and optimisation of the SES, the main parameters of the SES are improved.

Micro-cap software product

With the Micro-cap software product [1, 5], the following analyses are possible:

- Transient analysis;
- Frequency analysis at a small signal: amplitude-frequency characteristic, phase-frequency characteristic, and Bode diagram (AC analysis);
- Direct voltage and current transmission function: transmission function; volt-amper response and family of static transmission characteristics (DC analysis);
- Dynamic DC analysis;
- Dynamic AC analysis;
- Sensitivity analysis of the equivalent circuit for constant voltages and currents to changes in the parameters of the components (Sensitivity analysis);
- Transfer Function analysis;
- A series of calculations when changing one or more parameters (Stepping);
- Statistical processing (Monte Carlo);
- Fourier analysis;
- Graph calculation of the dependency of certain characteristics (Performance);
- Study of the temperature instability of the model.

The model of a transformer flyback SPS shown in Fig. 1 contains parameters of standard manufactured components, whereby the simulation of their joint operation is as close as possible to the real processes. Shown in a rectangular frame next to the corresponding element are the values of currents calculated by the software (blue colour) and dissipated power (red colour). Some of the parameters from Fig. 1 are observed in Fig. 2 sequentially from top to bottom: gate voltage *Vdrv* on transistor *X13*; current sensor voltage *Vsense*; drain voltage *Vdrain* on transistor *X13*; secondary winding current *Isec*; secondary voltage *Vvsec* and output voltage *Vout.*

Software product TINA-TI

The TINA-TI software [9, 10] is free of charge and has been developed by Texas Instruments. Fig. 3 shows a model of a step-down SES, and Fig. 4 shows its start-up process and analytical dependencies for the capacitor C_{ss} and chokes L_{min}. Fig. 5 shows a model of a transformer flyback SES for three output voltages V_out6, V_(C6), and V_(C8). Due to the high output current at the relatively low output voltage V_out6 = 3.3 V, a synchronous rectifier was implemented with the transistor Q2 and elements D4, D5, and R4 to increase the efficiency of the converter. Fig. 6 shows a model of a transformer flyback SES with a controller UCC2860. The time diagrams from Fig. 7 and Fig. 8 refer to the model in Fig. 6. From the first graph in Fig. 7 for the output voltage, the pulsations from peak to peak can be reported, and from Fig. 8 in green, three half-waves of the start-up readjustment process are visible for the time interval Δ t = 3 ÷ 8 mS.

Multisim software product

The first versions of the software were called Electronics Workbench. The Multisim Education version is designed for educational institutions and contains prepared solutions and manuals. Fig. 9 demonstrates the capabilities of the Multisim program [3–5] for simulation of forward SPS with two key transistors X1 and X2. The Multisim element library contains more than 2000 SPICE models. The Convergence Assistant tool automatically corrects modelling errors. The disadvantage of Multisim is the high load on the processors and memory of Multisim when working with large circuit diagrams.

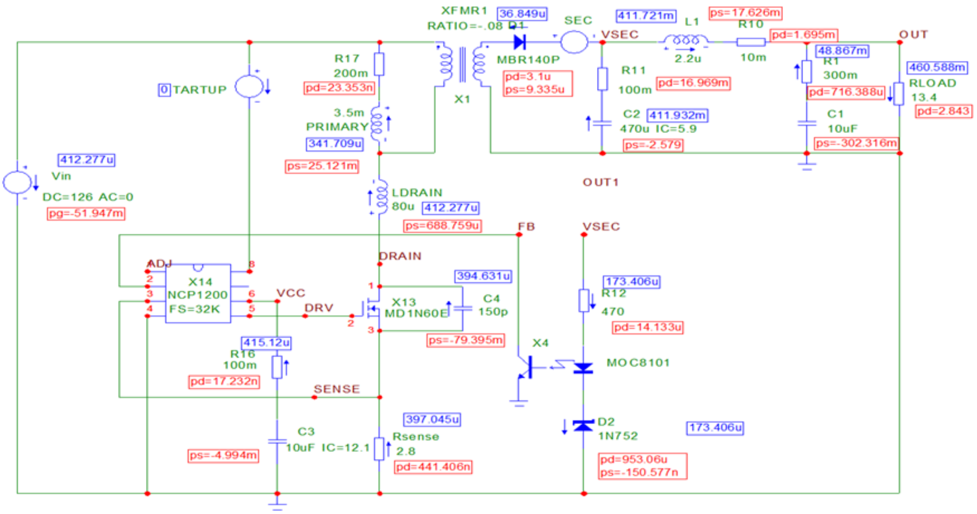


*Fig. 1. Model of transformer flyback SPS with **Micro-cap***

SIMetrix software product

The SIMetrix software product [2, 6–8] uses two publicly available models (SPICE and XSPICE) and is characterised by high performance. There is an efficiency calculator and a Bode probe. In transformer models, not only can the hysteresis curve be set, but also the value of the air slit. Fig. 10 shows the model of the flyback SES, and Fig. 11 shows its starting process. In Fig. 12, the model of the step-up SPS is presented, and in Fig. 13 are its Bode diagrams (amplitude and phase characteristics of feedback).

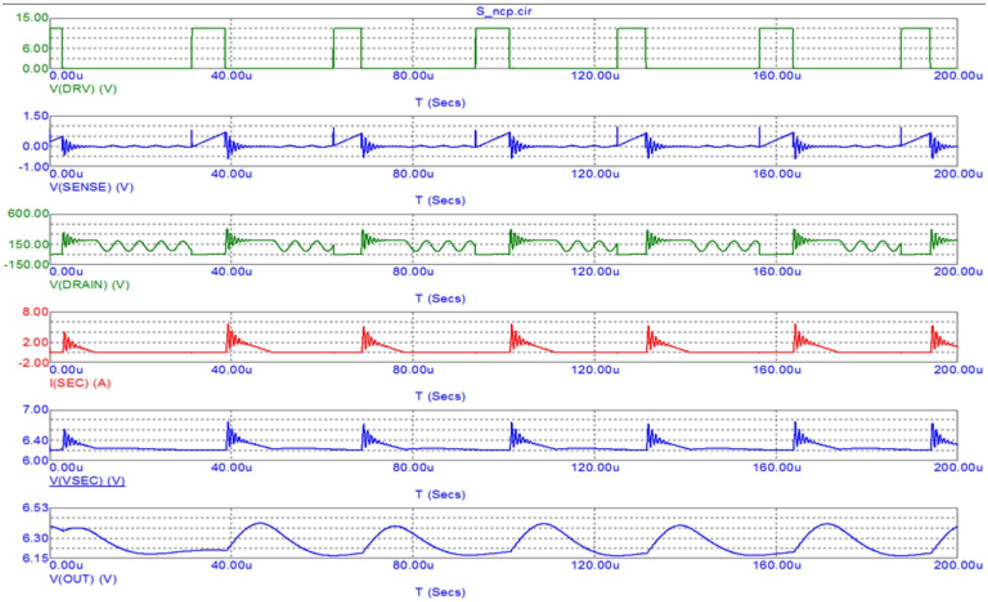


*Fig. 2. Time diagrams with **Micro-cap** of transformer flyback SPS from Fig. 1*

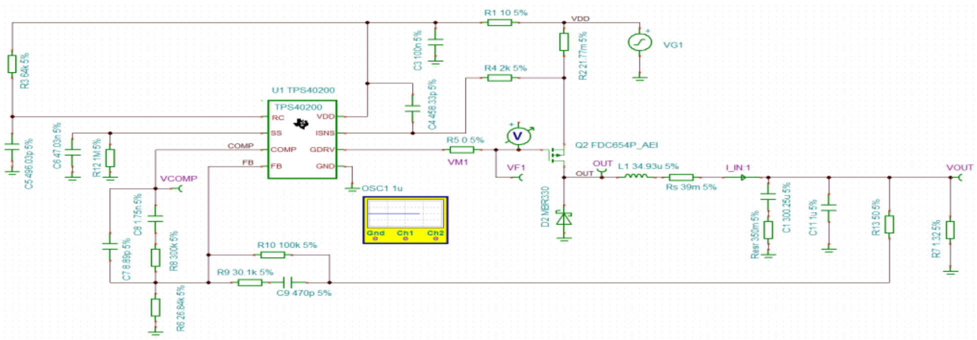
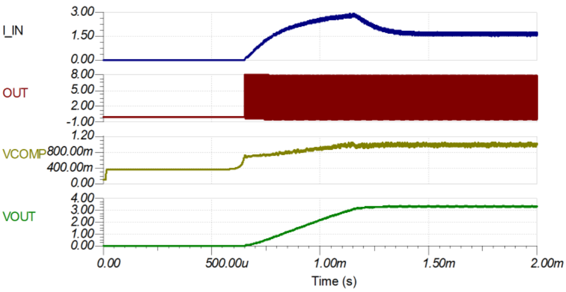


Fig. 3. TINA-TI model of a step-down SPS filled with a TPS40200 controller



$$C_{ss} = \frac{t_{ss}}{R.\,ln(\frac{V_{sst}}{V_{sst-1,4}})}$$

$$L_{min} = \frac{V_{in} - V_{out}}{I_{peak}}.\,t_{on}$$

Fig. 4. ***TINA-TI*** *time diagrams and formulas of SPS from Fig. 3*

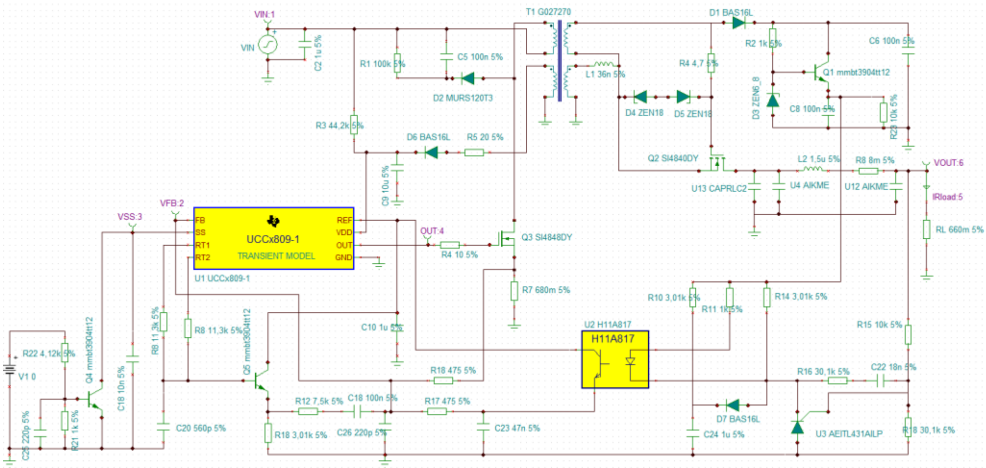


Fig. 5. ***TINA-TI*** *model of a transformer flyback SES completed with a UCC2809-1 controller*

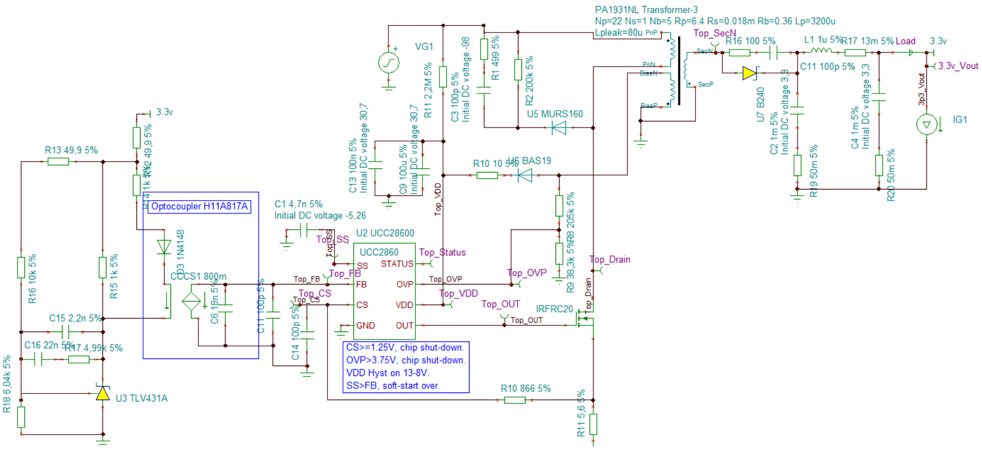


Fig. 6. ***TINA-TI*** *model of a transformer flyback SES completed with a UCC2860 controller*

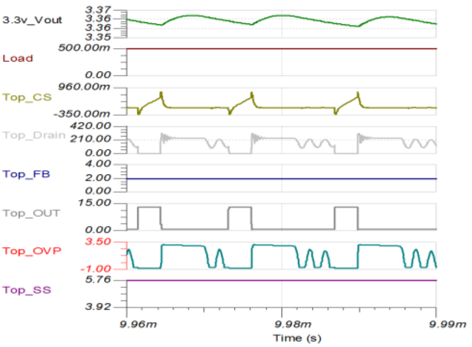


*Fig. 7. **TINA-TI** time charts from Fig. 6*

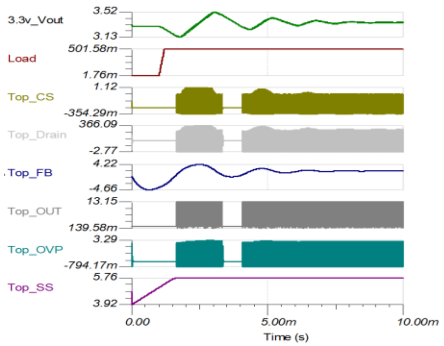


*Fig. 8. **TINA-TI** starting process from Fig. 6*

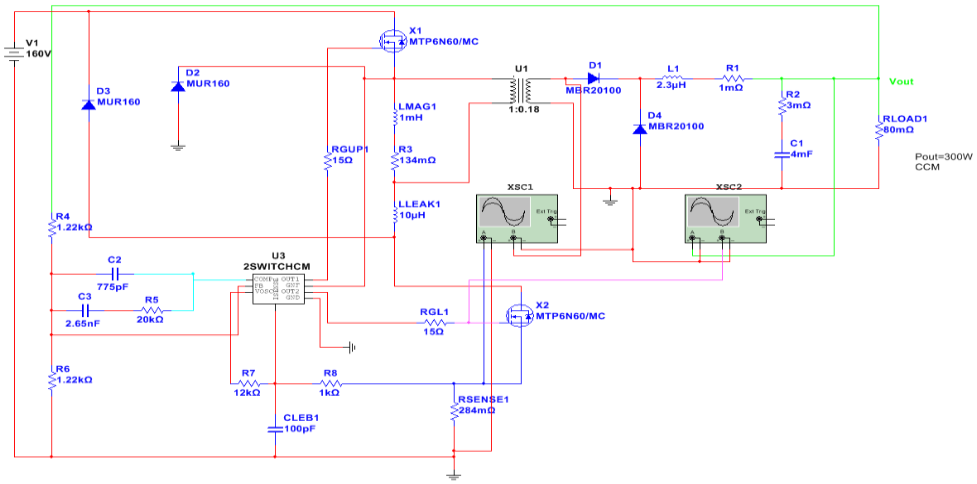


*Fig. 9. **Multisim** model of a forward SPS*

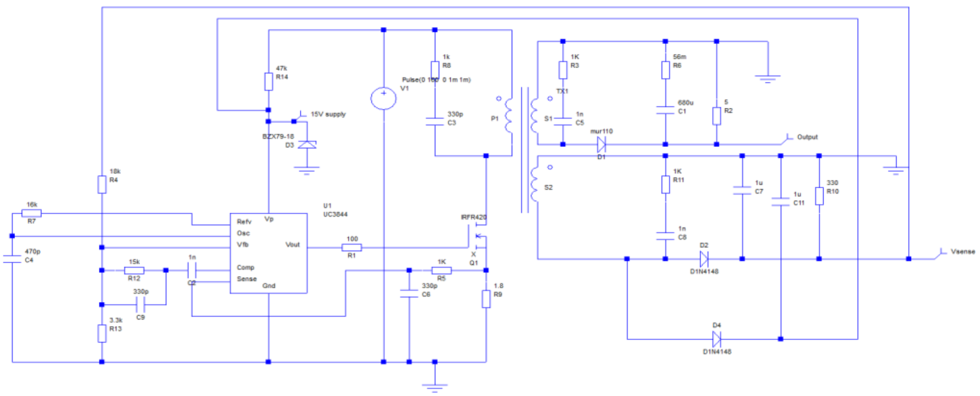


*Fig. 10. **SIMetrix** transformer flyback SES Model (100 KHz Converter)*

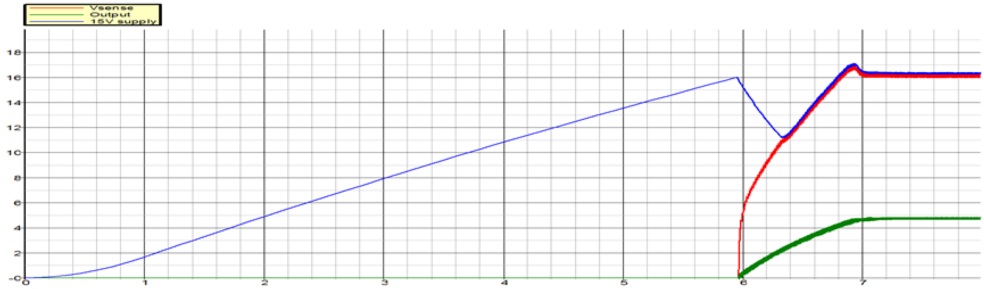
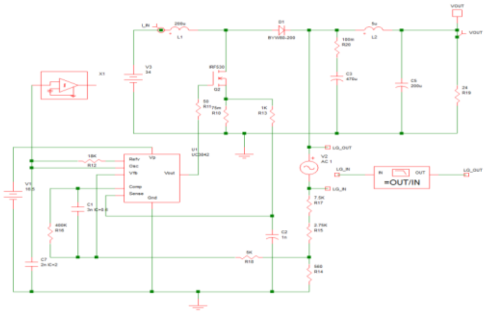


Fig. 11. Starting process of the SES from Fig. 10



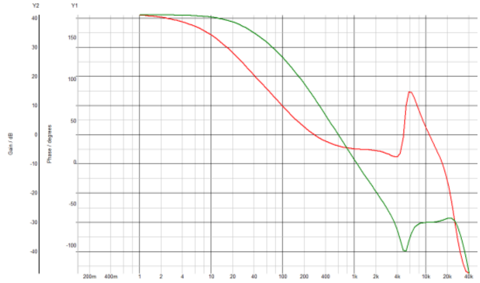


*Fig. 12. **SIMetrix** Model of step-up SPS* *Fig. 13. **SIMetrix** Bode diagrams from Fig. 12*

Conclusion

Simulations and models of secondary power sources and systems have been implemented using four free software products. With the considered instruments, the following are analysed: frequency characteristics; start-up processes; switching pulse powers; virtual meters; transients; and static modes in terms of current, voltage, etc.

References

1. Solovev, Denis B. "Experimental data based current transformer mathematical simulation in micro-cap program", International Review of Electrical Engineering (I.R.E.E.), Vol. 13, N. 2 ISSN 1827-6660 (2018): 149–156.
2. Mao, Hua, et al. "Power Loss Investigation of Si-SiC Hybrid Switches in a Modular Multilevel Converter System", Journal of Physics: Conference Series. Vol. 1754. No. 1. IOP Publishing, 2021. DOI 10.1088/1742-6596/1754/1/012070
3. 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

4. Gramatikov, P., A. Gramatikova, "Using the MULTISIM program to obtain volt-ampere characteristic of diodes", International Conference "Enganging tools for science education", Sofia, 31 October – 1 November 2014.
5. Gramatikov, P., "Simulation and models of onboard secondary power sources for aero and space devices", Aerospace Research in Bulgaria, 34, Space Research and Technology Institute Bulgarian Academy of Sciences, 2022, ISSN:1313-0927, 106–115, DOI: https://doi.org/10.3897/arb.v34.e09
6. Florescu, A. D. R. I. A. N. A., and Sergiu Oprea. "High efficiency LLC resonant converter with digital control" Rev. Roum. Sci. Techn.–Électrotechn. et Énerg 58.2 (2013): 183–192.
7. Ogudo, K. A., & Umenne, P. (2019, August). "Design of a PV based power supply with a NonInverting Buck-Boost Converter". In 2019 IEEE PES/IAS PowerAfrica (pp. 545–549). IEEE. DOI: 10.1109/PowerAfrica.2019.8928656
8. Yang, Peng, et al. "Hybrid data-driven modeling methodology for fast and accurate transient simulation of SiC MOSFET" IEEE Transactions on Power Electronics 37.1 (2021): 440–451. DOI: 10.1109/TPEL.2021.3101713
9. Xue, Tao, et al. "Design and simulation of DC regulated circuit for current source input type based on Tina-TI" Journal of Physics: Conference Series. Vol. 1750. No. 1. IOP Publishing, 2021. DOI 10.1088/1742-6596/1750/1/012011
10. Asadi, Farzin. "Electric and Electronic Circuit Simulation using TINA-TI®". CRC Press, 2022. 1–441.

СИМУЛАЦИЯ И МОДЕЛИ НА ВТОРИЧНИ ТОКОЗАХРАНВАЩИ ИЗТОЧНИЦИ ЗА АЕРОКОСМИЧЕСКИ СИСТЕМИ

Павлин Граматиков

Резюме

Разглеждат се проектирането и оценката на вторични токозахранващи източници и системи с помощта на симулация и модели. Извършени са експерименти с електронни схеми. Моделите позволяват измерване и визуализиране на различни параметри, както и анализ на резултатите. Използват се програмните продукти Micro-Cap, TINA-TI, MultiSim и SIMetrix. Симулацията помага да се разберат основните характеристики, анализът и настройката на електронните схеми, както и процесите във вторичните токозахранващи източници и системи