Ročník 2019 electroscope Číslo II

Power Supply for Space Applications

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Anotace:
Tato práce se zabývá návrhem spínaného zdroje s dodržením návrhových pravidel pro dosažení vysoké spolehlivosti. V práci je rozebrán výčet nutných analýz pro návrh zařízení pro vesmírný průmysl a vybrané komponenty, které jsou použity při realizaci finálního výrobku. Na základě zkušeností a podkladů z ECSS norem jsou zvoleny parametry spínaného zdroje, který by jako modul mohl najít uplatnění při návrhu zařízení pro použití ve vesmíru. Zvolená topologie měniče je sestavena a otestována na vývojovém modelu zdroje s komerčními ekvivalenty součástek použitelných do vesmíru. Jednou z částí práce je i návrh planárního transformátoru a kompenzované tlumivky a jejich realizace.

Annotation:
The following work deals with design of a switched mode power supply. In this essay, there is a basic description of analyzes that are required for space design. Also there is a selection of devices which could be used in final device. The SMPS will be designed to meet ECSS requirements and it will be created as engineering model assembled with commercial components. Part of this work is dedicated to design and fabrication of planar transformer and coupled inductor.

INTRODUCTION

In the last decade, switch-mode power supplies replaced almost every low frequency linear power supply due to its better integration to smaller areas and higher efficiency. Nowadays SMPS are used in almost every electrical device such as mobile phones, laptops etc. where conversion of a higher voltage to lower and vice versa is needed. [5]

ANALYSES

In case of reliable design for space applications it is necessary to perform several analyzes of any circuit solution. The most important is the worst-case analysis, part stress analysis and also failure modes and effect analysis. A great support to designer is a simulation software that allows setting the tolerances of components, their maximum power load and more. The results of simulations are then processed in a next stages of electrical device development and critical points are removed. These potentially dangerous situations are often solved by doubling the passive components. For example, capacitors are most often equipped with a parallel resistor and stacked into ladder to meet the maximum voltage tolerance on individual capacitors.

Worst Case Analysis analyzes behavior of a circuit under extreme conditions. It is performed on electronic circuits and devices to ensure proper operation through the unit lifetime. [3]

Each component in the electrical design must be verified by the so-called parts stress analysis where its thermal stress is monitored. All elements in the circuit have to be designed to count with a derating effect which is a percentage of nominal voltage, current flow and total power. If some of these requirements cannot be met by design, the designer must request an exception or choose another component.

Another important analysis of space design application is the analysis of causes, consequences and their criticality (FMECA - Failure modes, effects and criticality analysis). This analysis is a method to systematically examine the various types and consequences of component failures and listing their severity to a design, assessing the criticality and considering the probability of their occurrence.

DESIGN

This chapter describes a design of the power supply. Engineering design parameters were selected based on a previous experience. First and foremost, it was necessary to determine the minimum and maximum supply voltage according to ECSS-E-ST-20-20C for power sources as required by the ESA. There are two regulated power rails that can be used for power supply input. The first one is a 28V regulated branch with a minimum voltage of 22 V and a maximum of 38 V. [2]

The output voltages 3.3 V, 5 V and -5 V were selected to be applicable for digital circuits and analog circuits. The 3.3 V supply voltage is used for communication between individual instruments on the satellite via LVDS line while 5 V is mainly used to power analog circuits and communication lines (e.g. TTL / CMOS circuits and SBDL).

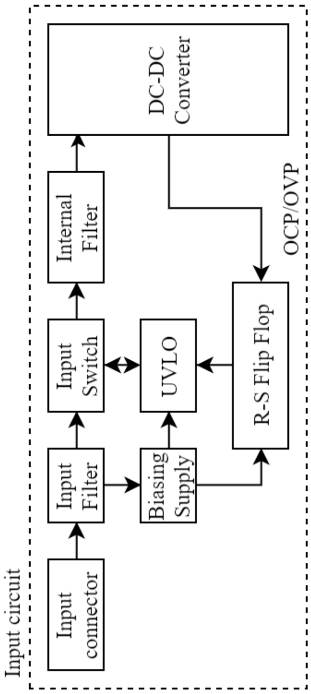

Figure 1: Input circuit block schematic

First part of the power supply consists of the input circuits (Figure 1) ensuring a sufficient noise filtration, input supply voltage monitoring and powering primary control circuits. The primary part also contains a control unit in form of an RS flip-flop that provides the ability to turn off the power supply in case of an error occurring on the primary or secondary side.

Second part of the power supply is the DC-DC converter itself (Figure 2). It is controlled by a PWM controller based on a peak value of sensed primary current and also a voltage feedback obtained from secondary side galvanically separated by an optocoupler. The DC-DC converter is also used in the unit for generating an internal 9 V voltage for powering the primary blocks and PWM controller.

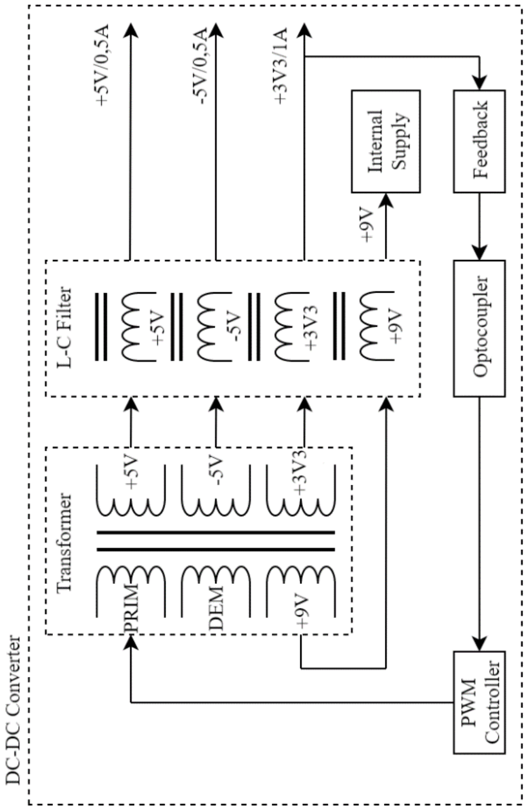

Figure 2: DC-DC converter block schematic

Main transformer design is usually an iterative process. First, a core type and material is selected, next a winding count is being calculated and then verified if the magnetic core meets the required parameters. The E22/6/16 core made of a 3F3 material that consists of two E-type planar cores was selected with respect to the overall power transmission. [4]

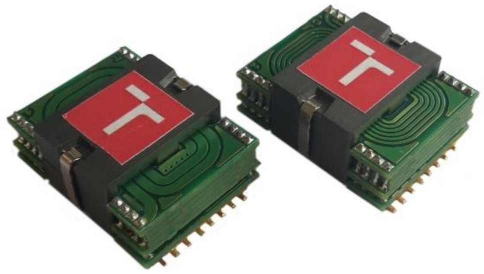

Figure 3: Planar transformer and coupled inductor

During the PCB production for the planar transformers, an unplanned increase in the height of the individual inner layers occurred. Therefore, the manufactured version of the transformer has one PCB less than expected, thus increasing the winding resistance and reducing the magnetic coupling to each other. This adjustment has minimal impact on the resulting function.

MEASUREMENT

The whole power supply unit was subjected to simulations and then tested on a real sample. In the following part, UVLO protection and cross-regulation behavior are described.

The UVLO protection behavior was verified in two steps. The first is to gradually increase and decrease the input voltage to determine the voltage levels of the protection. The second step is to verify the time-delay to stabilize the internal voltages in the control circuit.
When the external power supply, which represents the satellite power bus, is switched on, the power supply voltage reaches the maximum value of 38 V (Figure 4). The first point when the UVLO is deactivated is based on calculations - 25.15 V (measured 25.2 V). The trip-on level should then be 22 V (measured 21.8 V). A slight difference between these values are mainly caused by component tolerances and do not affect the resulting function and reliability of the equipment.

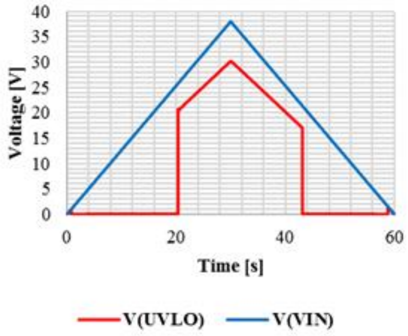

Figure 4: UVLO Simulation

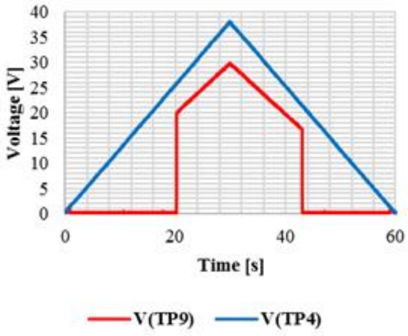

Figure 5: UVLO Measurement

The second part of the measurement deals with influence of coupling choke on the output voltage change at different loads. The individual power rails were connected to nominal loads while the input voltage varied in steps 22.5 V, 28 V and 38 V. The results show voltage reference values for each output power rail which are compared with voltage variations while changing the loads.
The output loads were switched from low to high in different combinations to test the entire power range of the power supply. It is assumed that the +3.3 V power rail, which acts as a reference feedback, will be stable over the entire load range. The aim of the measurement is to prove that the source can control the output voltage of +5 V and -5 V power rail in range of ±10 % even with different values of current drawn.
The results also show that the power supply is able to control the output voltage based on the feedback from only one output rail and a coupling choke with output voltage tolerance of less than ±10 %.

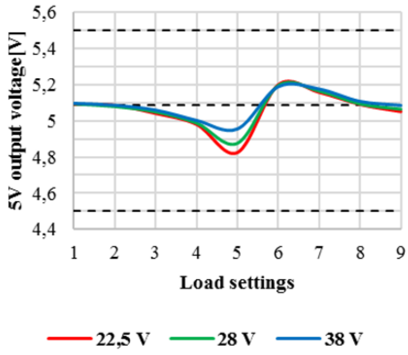

Figure 6: +5 V line cross-coupling

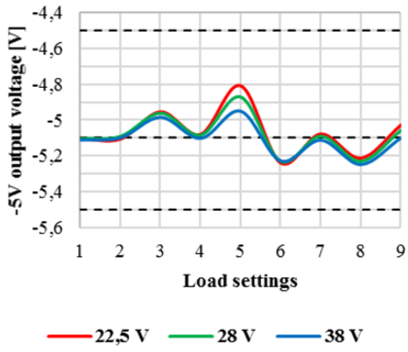

Figure 7: -5 V line cross-coupling

The highest output voltage error (-5.78 % from the nominal value) has the -5 V supply line with the +3.3 V lightened state and the +5 V and -5V power rails fully loaded. From the figure 6 and 7 the output voltage fluctuations of the unregulated supply lines can be seen. These are based on combinations of loads – current drawn from the output lines. This is caused mainly due to voltage drops on the rectifier diodes, compensated choke and the winding of the main transformer. For example, with load combination 5, the current +3.3 V of the branches is the lowest, the regulated resulting output is therefore reduced by less voltage drop on the rectifier diode, and thus the output voltage on the other branches decreases. In the case of a source without a coupling choke, this voltage drop would be much more significant.

CONCLUSION

The whole module is completed with several support blocks. These were designed, simulated and verified based on input parameters. For example, an undervoltage protection that monitors the input voltage and turns on the power supply when the voltage is high enough has the calculated upper limit set to 25.15 V (measured 25.2 V) and the lower limit set to 22 V (measured 21.8 V).

Figure 8: Power supply unit

Using the coupling choke in the design seems to be a good solution for circuits where high efficiency and reliability is required. When using conventional sources with disproportionate current consumption at the output power rails it is expected that their output voltages change. This is usually solved by using the linear controllers or multistage converters which solve the problem, but this solution brings additional components to the design and thus lower reliability and efficiency. When measuring the cross-coupling, i.e. the effect of the compensated choke, it was found that the maximum voltage deviation is 5.78 % from the nominal value. Given the voltage tolerance of ±10 % from the nominal value, the power supply complies with the requirements.

An interesting feature of coupled inductor topologies is the fault-tolerance to an error of the main HF transformer (Single-Failure-Tolerant). During the power-up, a rectifier diode at the +5 V rail was poorly soldered but the output voltage was still within the limits. This is due to the coupling choke concept which acts as a secondary transformer and it transfers power from other power rails to the transformer-open power rail.

It was necessary to create a simplified simulation model. The measurement results and simulations show that the model corresponds with the real power supply unit behavior. [1]

ACKNOWLEDGEMENT

The article was supported by project no. FEKT-S-17-3934, Utilization of novel findings in micro and nanotechnologies for complex electronic circuits and sensor applications.

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