LLC with Flyback DC-DC Converter for the Supply of Low Voltage and High Current in Space Applications

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Abstract— After a systematic review of topologies for the creation of a low voltage- high current DC-DC converters, an architecture was identified as having potential for addressing the growing power requirements of advanced electronic circuits and systems for use in space applications. The LLC with flyback converter was chosen because it provides compact and low mass potential with high performance against the system specification requirements. This choice was made after extensive numerical simulations of the structure, layout and system level performance.

A working prototype of this system has now been fabricated and while there is still work to do, there are very encouraging results from the preliminary analysis. These results are presented in this paper with an explanation of the next steps to be adopted.

I. Introduction

The current and next generation of the highly integrated digital space cores such as FPGA, ASIC, MCU and µP currently being used in many space applications and satellite platforms typically require a well-regulated low voltage, high current power source.A compact, highly efficient power supply is therefore required that can deliver high current low voltage performance from the available power sources on board a modern satellite (e.g. 100 V regulated power bus).

Isolated DC/DC power converters can fulfil this requirement because they can deliver extremely low output voltage and high output current capability (LVHC). The device that fulfils these requirements needs to be a compact and high efficiency isolated DC/DC power converter with low voltage and high current output. The converter also needs to feature a secondary output as an intermediate bus capable of supplying remote Point Of Load (POL) converters. This module will provide all the necessary resources for powering a digital load with high power processing capabilities. The main requirements for this circuit are presented in the next section.

II. Main Requirements

Table 1 Main Requirements

Parameter	Minimum	Typical value	Maximum	Units	Remarks
Vin	90	100	110	V	
Vmain		1.0		V	Adjustable by 10%
I main	0		50	A	
Vbus		8.0		V	For POL Converters
I Bus	0	-	2.5	A	
Efficiency	92.5			%	Peak Efficiency
Losses			8	W	Max Losses

Furthermore, this converter will also feature a soft-start function, external ON/OFF commands, primary under-voltage protection and shall be protected against output short circuit or output over-voltage. Targeted converter dimensions (without mechanical housing) are 75 mm x 45 mm x 13 mm. The total output power rating is 70 W. Considering the allowed max dissipation of 8 W, the efficiency at max load shall not be lower than 90%.

III. Background

There are a large number of possible architectures that could deliver these functions, and they have been surveyed and evaluated from both practical and theoretical as well as conceptual perspectives. These architectures/topologies were reported in conjunction with their advantages and drawbacks at the ESPC conference in 2023. [MAKRIS 1] Based on this information, a choice of topology was made (the LLC converter at resonant frequency with flyback converter used as partial pre-regulator) and reported at the same conference. [DUBUS 2]. Where theoretical predictions of circuit behavior and performance as a function of physical implementations were made based on numerical physics and circuit simulations.

The outcome of these studies on the selected converter topology allows the optimization of the total processed power by using a partial Flyback pre-regulator which only process 20% of the total output power. The converter has two power cells but is sized for a factor of 1.2 times the total output power.

The Flyback, operated in AC/QR modes, runs in soft-switching condition for the whole output power range. The relatively high output voltage (80 V) allows the use of a rectifying diode instead of synchronous rectification which simplifies the necessary control circuits.

The LLC, which operates at its resonant frequency, offers high efficiency performance in a compact size, thanks to the choice of the high switching frequency. The matrix transformer further improves the performance thanks to the high number of legs (8) which minimize the number of turns and reduce the current into each output winding. Voltage regulation is achieved by controlling the Flyback.

The selected non-linear control (constant OFF time) allows to easily switch from AC to QR mode and this improves the dynamic performance by reducing the response time. The control loop operates at its maximum speed because no stability margins which limit the dynamic performance need to be present.

IV. Technical Evaluation of the proposed CIRCUIT

The architecture of the converter is based on a quasi-parallel self-oscillating LLC and flyback topology featuring a full custom matrix power transformer design as shown in Figure 1 and Figure 2.

This converter has been successfully built and tested at the bread board level. The model of the converter has been based on a modular implementation consisting of an LLC power cell board combined with a flyback board, both mounted on a common carrier which hosts the input filter and the TM/TC circuits of the converter. The 3D renderings of the bread-board model are shown in Figures 3 to Figure 5. The next phase of the project involves the development of the engineering model that will represent the target requirements more closely in terms of form factor, volume and size.

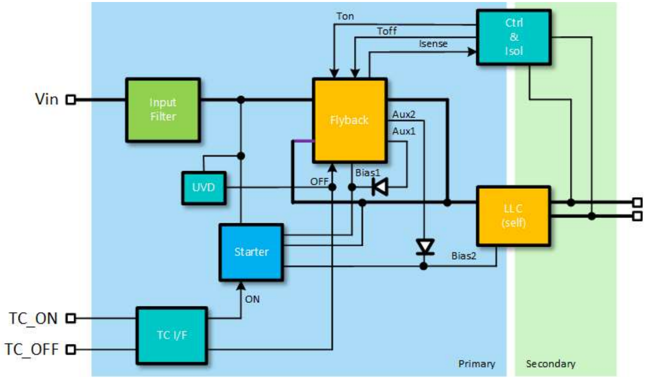

Figure 1 Block Diagram of the LVHC Power Converter

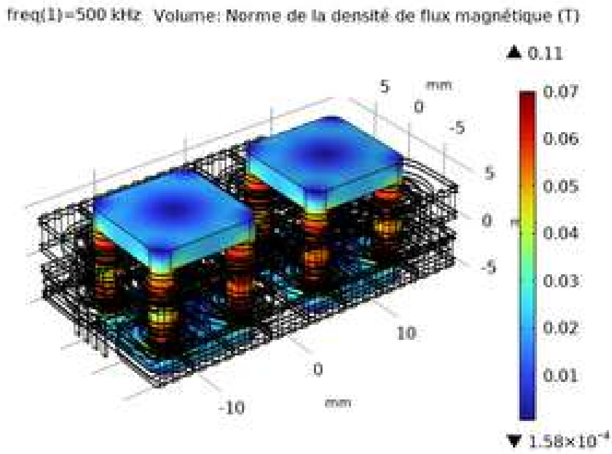

Figure 2 Modelling of the Matrix Transformer

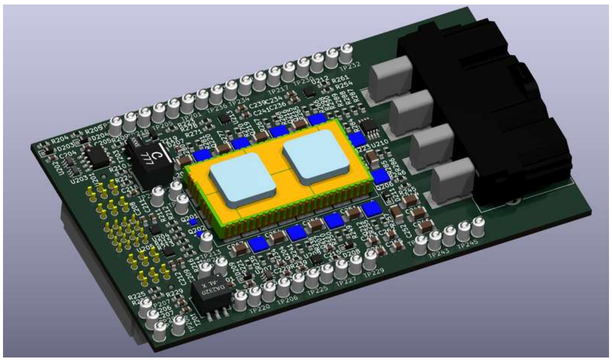

Figure 3 LLC Power Cell of the LVHC Converter

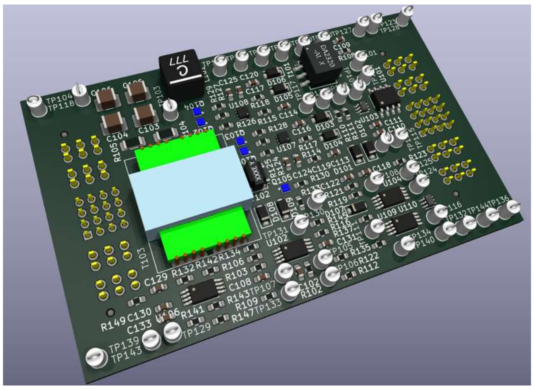

Figure 4 Fly-Back Power Cell of the LVHC Converter

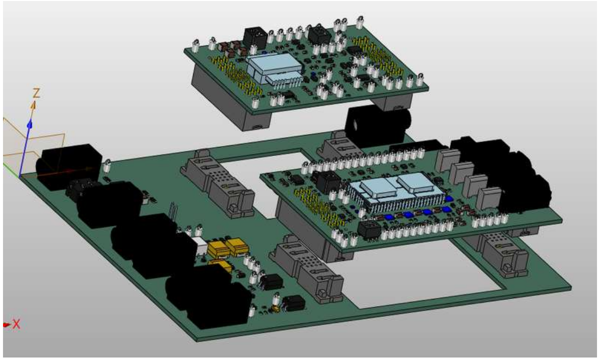

Figure 5 LLC and Flyback Power Cells on the common Carrier board to form the LVHV+C Bread board Model

V. Results

The breadboard test results show a lower efficiency than predicted. After investigation, most of the losses are coming from the Matrix Transformer with higher copper losses than predicted. A lower coupling coefficient is also measured between the secondary windings which add noise at LLC power cell level. As this LLC converter is working at its resonant frequency for best performance and uses a self-oscillating solution, the noise due to the non-optimal coupling disturbs the LLC operation.

This transformer, with its high number of leg (8), introduces also an additional complexity due to the high number of synchronous rectifiers to drive and the high number of secondary windings to put in parallel.

A redesign of the converter is in progress. We have decided to change the matrix transformer configuration from 8 legs to 4 legs for simplification. The new matrix transformer is a bit larger but the reduction of the synchronous rectifiers and their drivers leads to the same final converter dimensions.

The final version of this paper will show the test results with the new converter design with the 4 legs matrix transformer.

VI. References

1] A Comparison of Technologies for the Implementation of Low Voltage, High Current Power Converters for High Power Integrated Circuits. . P. Dubus, K. Makris, M. Mroczkowski, A. Mathewson, J. Oliver N.Van Der Blij, J. Ponin, P. Maynadier, C.Papadas. ESPC 23 European Space Power Conference ELCHE, Span, 2-6 October 2023

2] Low Voltage, High Current Power Converter for High Power Integrated Circuits. P. Dubus, K. Makris, M. Mroczkowski, A. Mathewson, J. Oliver N.Van Der Blij, J. Ponin, P. Maynadier, ESPC 23 European Space Power Conference ELCHE , Span, 2-6 October 2023

VII. Acknowlegements

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