1 MHz Converter with 95 % Peak Efficiency for Aircraft Applications

This design methodology of a 50 W isolated DC/DC converter serving as a power supply for aircraft equipment like a FADEC (Full Authority Digital Electronics Control) has been awarded as Best Paper of PCIM Europe 2016, sponsored by PEE. The particularity of this work is the design of a full converter regarding two antagonistic requirements which are a wide input voltage and high efficiency. **Nicolas Quentin, University of Lyon/Ampere/Safran Group, France.**

All the equipments located inside an aircraft network have to respect several requirements imposed by international standards such as the DO160 or manufacturer customs like the derating/stress on a component. One of the most constraining standard is within the Electromagnetic

Interference (EMI) where the converter does not disturb or is disturbed by other equipment on the electrical network.

To reduce the converter size, the general trend is the switching frequency increase but this implies losses increase. Besides, power supplies are installed in an confined environment. They cannot be cooled down by forced convection in the case of the most extreme applications (operating temperature from ?55°C to +110°C). In this condition, power supply losses impact the converter volume and weight to prevent it from overheating. Therefore, a significant gain in efficiency is the main purposes, since it results in a reduction of weight and volume.

When fed by a DC bus in the 18 to 80 V input voltage range, the power cell provides two 15 V isolated outputs to power all standard electronic devices. As shown in Figure 1, the work is not limited to the power cell and filters which represent only 44.5 % of the components size area, but with the design and implementation of the full converter including all auxiliary functions required for the safety and autonomous operation.

The goal is to use a topology which creates the capacity to increase the switching frequency in order to reduce the value and size of passive elements. Soft-switching is a reasonable technique to increase the switching frequency and limit the power losses at the same time. Figure 2 shows the simplified schematics (power cell only) of the Flyback Active-Clamp circuit. This topology is suitable for wide input voltage applications with a step-down and step-up transfer function depending only on the duty cycle.

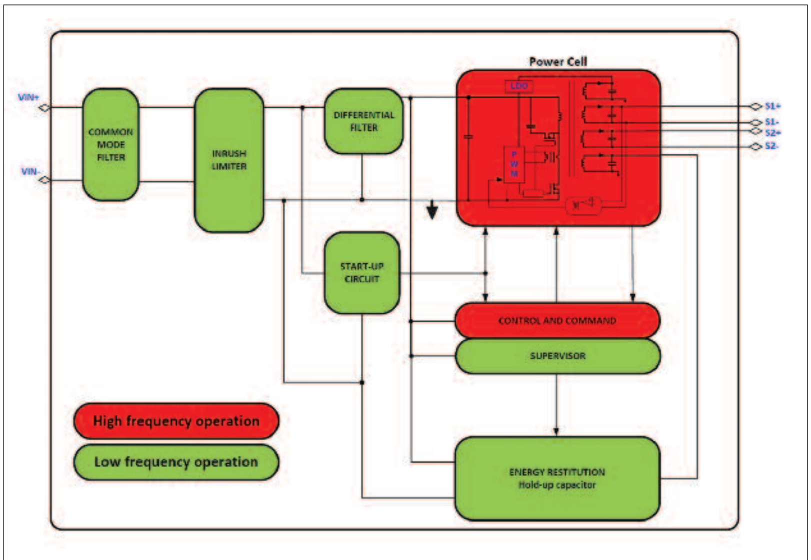

Figure 1. **Synoptic of the overall converter including autonomous and safety functions**

This topology has two additional benefits for a low-power application: a low number of components and a simple control (duty cycle at fixed frequency). Regarding the efficiency this topology can achieve Zero Voltage Switching (ZVS) at the primary side allowing the converter to increase the switching frequency in contrast to a conventional hard-switching converter such as the classical Flyback converter.

High frequency operation prerequisites

This converter includes advanced technologies dedicated to high frequency and high ef ficiency operation with the use of GaN transistors from EPC (EPC2010C; 200 V - 22 A) and planar transformer.

In high frequency applications, it seems clear that using GaN transistor creates a real improvement of the efficiency due to its low output charge (Q_{oss}). In a soft-switching topology the device output charge has an important impact on the energy required to achieve ZVS condition providing a larger power storage and transfer period means naturally a higher efficiency. The other GaN transistor benefits are its low total gate charge (Q_g), and its low drain to source on-state resistance (R_{DSon}), reducing the drive power (losses) and conduction losses respectively. All these features are implemented in a smaller packaging with less parasitic inductances compared to a Si MOSFET with similar power characteristics.

In an isolated converter, the transformer is the key component which has to be designed properly because of its important impact on the efficiency and on

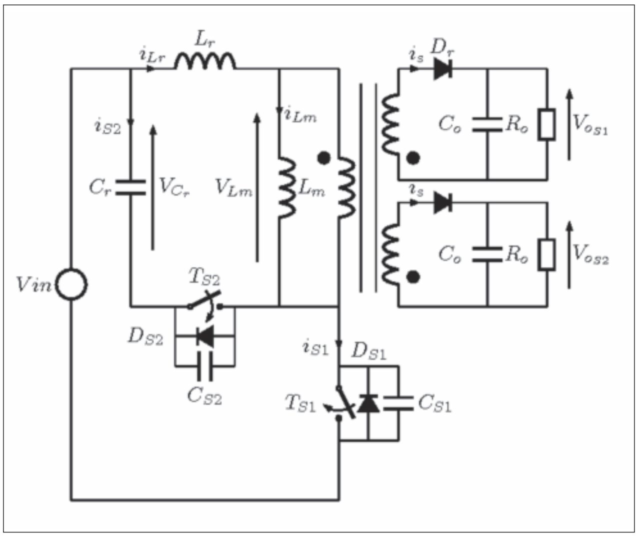

Figure 2. Double output flyback active clamp topology

the global volume of the power cell. For a soft-switching converter, the planar transformer allows to increase the efficiency and the reliability of the converter due to its very low profile, excellent thermal management and the good reproducibility. This last criterion is very important since both magnetizing (L_m) and leakage (L_r) inductances are used to achieve the power transfer and the ZVS conditions.

In a full converter, the transformer has several outputs: two 15 V - 25 W power outputs, one 15 V - 0.75 W to supply the control and command part and one 45 V - 3 W to charge the hold-up capacitor.

Eight layers 70 µm copper PCB have been used to design windings and specific care has been taken on DC resistance in order to limit self-heating. To reduce the leakage inductance, the primary turns are interleaved with the two secondaries. Interleaving windings (primary and secondaries) requires to increase the dielectric layers (so the PCB thickness) to still insure the 1.5 kV insulation requirement. To keep as low as possible parasitic capacitance outside transformer (due to layout considerations), the primary and auxiliary outputs are on one side of the PCB and the two power outputs on the other. Regarding the magnetic part, a 3Ferroxcube F45 ferrite EQ20/PLT-core has been optimized for the application (Figure 3).

PCB size is not directly dependent on the number of components. For example, the supervisor has a lot of small components whereas the filter has less components but larger like the common and differential mode chokes. However in general, the height of the converter is imposed by the highest component (most of the time the hold-up capacitor or the common mode choke). In order to decrease the surface of the converter, the idea is to realize a 3D module on two stages (2 PCB).

The goal is to use the free space around the highest component to implement a part of the converter on a second PCB above the first one. As shown in Figure 4, the separation of the functions on the 2 PCB is done regarding the operating frequency; the low frequency functions (power interruption management system, supervisor, current limiter and soft-start) will be on the motherboard whereas the upper stage is dedicated to the high frequency functions (power cell, driver, control/command) with custom PCB.

This modular strategy allows to adapt the PCB requirements for each part with less connection issues. For instance, the power stage needs thick copper layers (35 – 70 µm) in order to decrease parasitics resistances, whereas the load (digital components) needs high density implementation that imply very thin track (about 5 mils). PCB choice is a trade-off between layer thickness and track width. This approach helps the designer to create a suitable PCB for each function (especially

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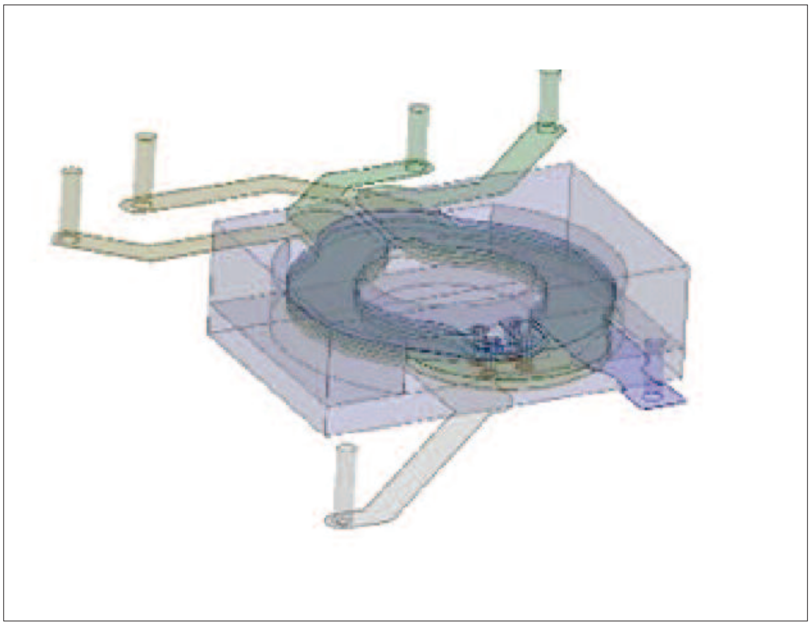

Figure 3. Planar transformer layout design

for the planar transformer).

Another benefit is the layout simplification of the full converter. To summarize, the goal of this modular architecture is to increase the power density. For a 50 W DC/DC converter the frequency limit is imposed by the magnetic components and 1 M Hz seems to be the upper value for ferrite material (at 50 W). Therefore, the easiest way to continue to increase the power density is a better use of the space, especially the height available.

Experimental results

The 1 MHz - 50 W prototype of the proposed full converter is shown in Figure 5 (right), left depicts also the operating waveforms with the primary voltages and currents at 28 V - 30 W.

The efficiency approaches 92 % at the nominal input voltage (28 V) and the peak efficiency is 95.5 % for an input voltage of 18 V.

A thermal analysis has been carried out at the nominal operating point 28 V - 30 W power after half an hour of operation. The thermal behavior is good with a small temperature increase of about 30 K. The hottest component is the main GaN transistor and the temperature increase is due to its important thermal resistance.

Conclusions

The use of the soft-switching topology coupled with suitable technologies such as GaN power FET allows the converter to increase the efficiency and frequency at the same time. At the end, the converter is efficient and compact due to the components and modular architecture. This solution creates a reduction of 60 % of the surface with a better use of the space and an easier layout compared to a single stage converter with the same schematic.

Literature

A Large Input Voltage Range 1 MHz Full Converter with 95% Peak Efficiency for Aircraft Applications, PCIM Europe 2016 Proceedings pp. 1286 – 1293,
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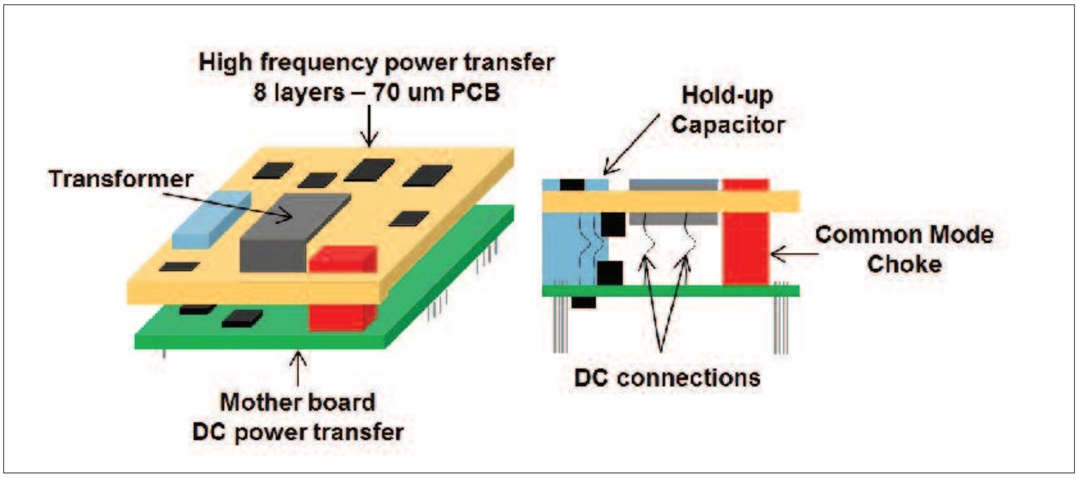

Figure 4. Schematic representation of the modular PCB strategy

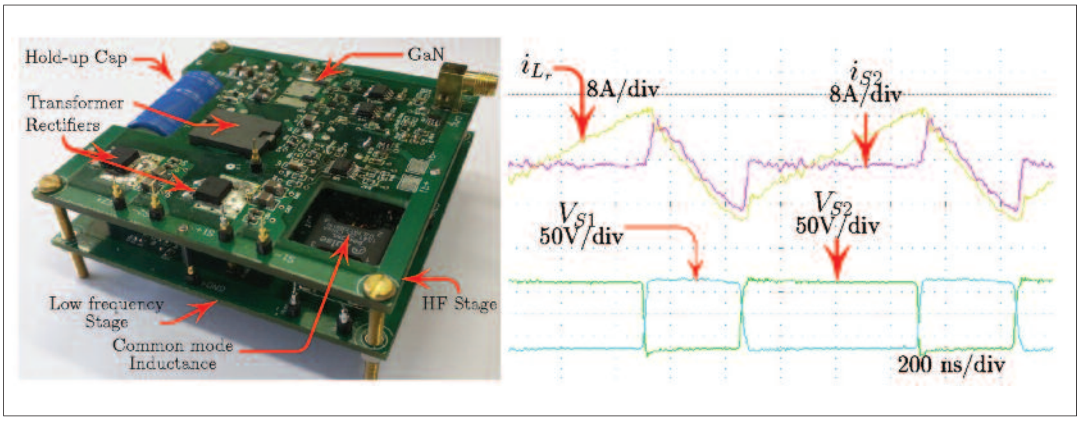

Figure 5. Prototype with GaN transistor EPC2010C and transformer EQ20/PLT 3F45 (right), experimental waveforms V_{S1} and V_{S2} (20 V/div and 200 ns/div)