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Comparative Analysis of Boost DC-DC Converters with Application in Power Electronics Education

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Abstract – **The paper presents a comparative analysis of DC-DC converters that can be successfully utilized in the education of power electronic converters. A comparative analysis is made against four boost converter topologies, which essentially demonstrates the advantages and disadvantages of the practical realization of one and the same DC/DC converter. These are the synchronous and non-synchronous converter and the internal and external switch converters. The hardware realization of the compared evaluation boards is suitable for training of both students and professionals in the field, because they are intended to be simple but in the same time with all the standard features and maximum performance.**

Keywords – **boost converter; DC-DC converter; education;**

I. Introduction

The technological development of society and the ever-increasing energy needs determine the ever-increasing need for efficient conversion of electrical energy. In this aspect, power electronics is a key technology for achieving a green economy and electro mobility in the conditions of shortage and constantly increasing prices of energy distribution systems. Associated with this trend are the ever-increasing number of power electronics specialists with various competencies: trainers, designers, developers, operators of devices and systems, service workers. On the other hand, due to the interdisciplinary nature of the subject area and the difficulties associated with training in power electronics, there is an outflow of those wishing to study in this specialty. The resolution of this contradiction is carried out through the use of modern means of mathematical modeling and computational mathematics and the implementation of modern information and communication technologies in the training of power electronics [1-5, 15-20].

In the present work, a practical study of different implementations of boost DC-DC converters is presented, the idea being to successively go through different circuit variants and, based on the accumulation of knowledge, skills and competences, to make a comparative analysis of the advantages and disadvantages of the considered topologies.

The main applications of DC-DC converters are well known in the conversion of battery operated devices, used in a portable devices such as consumer, telecom and computer devices. Characteristic of them is that the synthesis of control and hardware implementation are also related to these applications [7-14]. This results in the availability on the market of a very wide range of circuits in both integrated and discrete implementations, the aim being to fully cover the entire range of applications and the associated operating frequencies and powers.

On the other hand, the authors have made similar comparisons, which are related to a specific application of DC-DC converters for charging energy storage elements, and the present study is a development and extension of the presented results.

The presented work is a continuation of a previous paper, [6] comparing only the synchronous and non-synchronous solution, with emphasis on other design-specific issues related to the practical realization of the converters. In this manuscript the is extended with additional boards to include more converters, creating a more objective comparison of boost topologies, that can be very useful for trainees, students and other interested parties in the point of view to improve and extend their knowledge of different boost topologies.

A. Brief boost converter theory of operation

The general synchronous boost DC-DC converter power stage is shown on figure 1. For the purposes of the study, it is realized in hardware with different approaches. The synchronous boost converter was used. It consists of the following elements: T_1 and T_2 transistors with their active resistance R_{ON}, which are counter-clocked (anti-phase control pulses are used); inductance L with its active resistance R_L, output capacitor C_0 (its internal resistance is neglected) and load R.

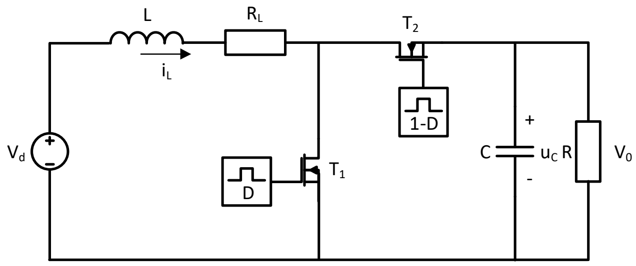

Fig. 1. General synchronous boost DC-DC converter power stage circuit

Usually, the analysis and design of such type of converters are carried out on the basis of the processes in steady-state mode of operation, and thanks to the high efficiency, the losses in all circuit elements are neglected. In this way, the procedure for designing the power circuit is greatly simplified, especially since the tolerances of the circuit elements vary within quite wide limits, and for this reason it is not necessary to use more precise and therefore more complex and with a more difficult physical interpretation methodologies. Accounting for power circuit dynamics can be done at a later stage using model-based design as shown in [24].

The boost converter was designed using following parameters: rated input voltage is in the range V_d = 2.7V to 4.2V; rated output voltage V_0 = 5V, rated output current I_0 = 1A, operating frequency above f = 500 kHz is selected. The design was carried out according to the standard methodology presented in [2, 3, 4], and the following values of the circuit elements were obtained L = 4.7 μH; C = 22μF.

B. Experiment setup

The main goal of the study is to demonstrate in practice the theory behind different boost converter topologies, namely the non-synchronous, synchronous, single phase and multiphase. Also the advantages and disadvantages of the internal and external power stage are demonstrated, in order to be more objective on the study.

In total for the laboratory exercise four converters are studied: A non-synchronous single-phase boost converter with external switch, synchronous single-phase boost converter with external switch, synchronous single-phase boost converter with internal switch and synchronous dual-phase boost converter with internal switch. The synchronous single-phase converter with external switch is based on the integrated solution LTC1700 and dual-MOSFET AP4503AGM, the synchronous single-phase converter with internal switch is based on the integrated solution LTC3122, the synchronous dual-phase converter with internal power stage is based on the integrated solution LTC3124, the non-synchronous is based on the controller LTC1871 with an external MOSFET Si4134DY.

II. Hardware Realization

The hardware realization of the boards is done independently of the producer for each integrated circuit, however the documentation provided is used for the realization, such as test results, reference designs and datasheets [6-13].

The schematic of the evaluation board based upon the LTC1871 is shown on figure 1.

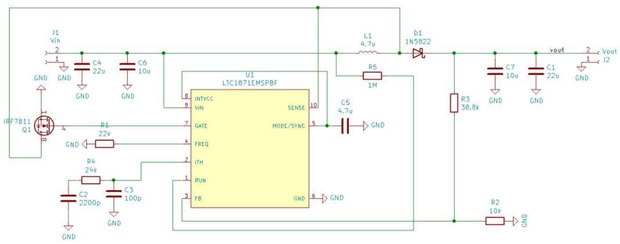

Fig. 2. Evaluation board of LTC1871 DC/DC converter solution

The designed power stage consists of an external switch IRF7811, Schottky diode 1N5822, inductor IHLM2525CZER4R7M06, a total of 20 μF input capacitance and 32 μF output capacitance. It is tuned to operate at 1.2 MHz with an external resistor.

The schematic of the evaluation board based upon the LTC3124 is shown on figure 2.

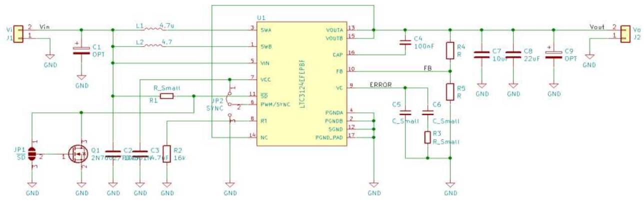

Fig. 3. Evaluation board of LTC3124 synchronous dual-phase DC/DC converter solution

The designed power stage consists of two inductors IHLM2525CZER4R7M06, a total of 480 μF input capacitance, combined from a bulk 470μF electrolytic capacitor and X7R 10 μF ceramic capacitor, the output capacitance is again 32 μF. The necessity for the higher capacitance is driven by the fact that the IC is susceptible to changes in the load and without it the output regulation might fall into a loop that is hard to recover because of the greater transient input currents that are characteristics of the topology. It is tuned to operate at 1.6 MHz with an external resistor.

The schematic of the evaluation board based upon the LTC3122 is shown on figure 3.

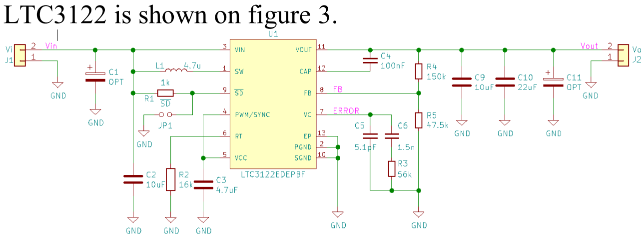

Fig. 4. Evaluation board of LTC3122 synchronous DC/DC converter solution

The designed power stage consists of a single inductor IHLM2525CZER4R7M06, total of 480 μF input capacitance, again with a bulk 470μF electrolytic capacitor at the input and output capacitance of 32 μF. This is driven again by the necessity of the control loop, which is the same for the single-phase version of the chip.

The schematic of the evaluation board based upon the LTC1700 is shown on figure 4.

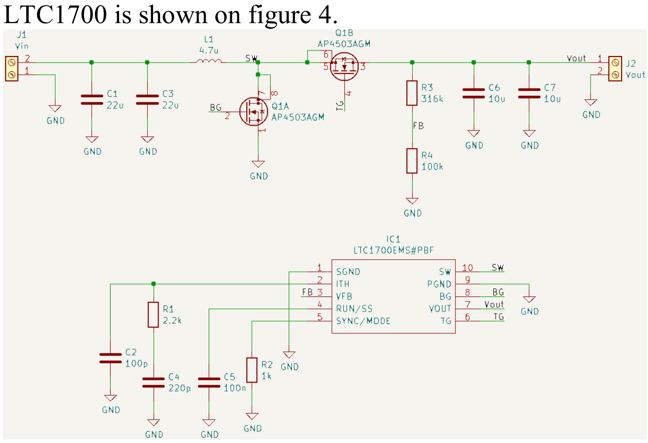

Fig. 5. Evaluation board of LTC1700 synchronous DC/DC converter with external switch solution

The designed power stage consists of a dual external switch AP4503AGM, inductor Würth Elektronik 74437349047, a total of 44 μF input capacitance and 20 μF output capacitance. The operation of the integrated circuit is fixed at oscillating at 560 kHz, set internally without the ability to set it up with an external resistor.

III. EXPERIMENTAL RESULTS

The presented circuit schematics in the previous section are realized in hardware by the authors with layout that is loosely based on the manufacturer recommendations but with optimization on the size footprint of the boards. This gives some disadvantage by reducing the size of copper ground planes that are effectively used as a heatsink of the power stage in this way impacting the overall performance and efficiency of the solutions. However, in real-world hardware and modern design requirements the size of the boards is a serious constraint, that should be accounted in order to realize the devices on the open market competition. That's why the study is conducted with such boards, because it gives a more objective point of view, rather than yet another "ideal conditions" study, meant to extract the maximum performance of the evaluated integrated circuits.

The carried out experiments are made using a power supply unit GwINSTEK PSW30-36 and an electronic-load TENMA 72-13210 bench instruments. The wires used for connecting the instruments with the evaluation boards are thick and short as possible, given the restrictions imposed both by the terminal blocks and the sizes of the boards. The losses are minimized by allowing no more than 50mV voltage drops at maximum load across them, in order the study to be objective.

On figure 6 is shown the efficiency of the boards at the minimum input voltage, which has been chosen 2.7V, reflecting the state-of-charge of depleted Li-ION battery. This study is very importand in the point of durability of the online time of the device.

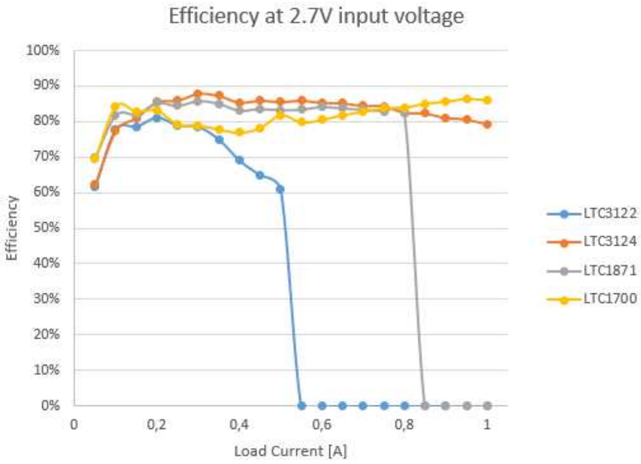

Fig. 6. Efficiency curves at minimum input voltage

As it can be observed, some of the boards fail to regulate the output voltage, just because the efficiency drops drastically and it is unable to support the input power to the output anymore. Here the LTC3124 and LTC1700 solutions can supply the output in the full range of loads just because the efficiency is greater than their counter-parts and the voltage drops in the switching elements is lower, thus allowing the input voltage levels not to drop to ranges, impossible to supply the output stepping of the voltage.

On figure 7 is shown the efficiency of the boards at the nominal input voltage, chosen as 3.7V, once again reflecting the state-of-charge of a charged Li-ION battery.

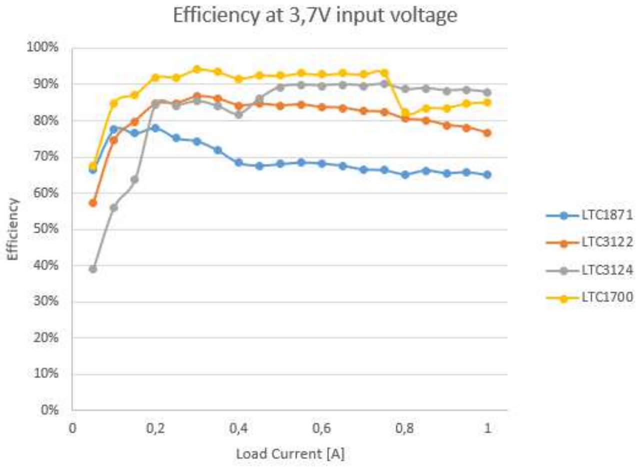

Fig. 7. Efficiency at the nominal input voltage

Here the students can observe well-known facts, such as that the synchronous converters are more energy-efficient that their non-synchronous counter-parts, and that the distributed phases allow room for lower temperature rises, allowing higher efficiency at higher loads.

Of the control system of the LTC1700 solution can be observed a trait, that the efficiency drops at around 0,8 A, but apparently it rises again to acceptable levels, indicating that there is a probable change of the working regime of the IC. Note that light-load optimization is disabled, by forcing the Burst-PWM mode off, achieved in the hardware by grounding the SYNC/MODE pin, so this cannot be accounted by that feature of the control system.

On figure 8 is presented the efficiency at the maximum input voltage, chosen to reflect fully charged cell. This is the lightest operating mode for the DC/DC converters because the difference between the input and output voltages is minimum.

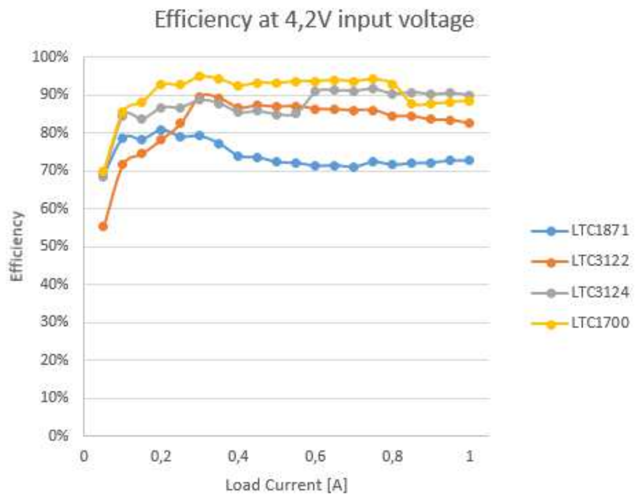

Fig. 8. Efficiency at the maximum input voltage

In the same sense, conclusions can be drawn, that the higher the input voltage is, the better efficiency can be derived from the DC/DC converters. Put in another way, the lower the difference between the input and stepped-up voltage, the higher efficiency is achievable.

Observation of the efficiency curves indicate, that the control systems behave differently when loads pass certain thresholds. On the LTC3124 IC the operation of the IC changes at around 0.6A and at this point the efficiency steps up and naturally slowly declines with the higher load currents. The already observed decline in efficiency of the LTC1700 at around 0.8A is once again noticeable from the figure, reflecting the operating regime change in the control system of the IC.

IV. Conclusion

The manuscript presents the results of practical studies of several types of low-voltage Boost DC-DC converters. Emphasis of the described experiments is the empirical determination of the efficiency of the different converters, thus making a comparison both of the individual topologies and with the catalog data from the manufacturing companies. In this way, a visual and physically adequate description of the processes is achieved and on this basis to improve the success rate and durability of the knowledge of the students and trainees in the field of power electronics.

Different topologies have been studied – synchronous and non-synchronous, single phase against dual-phase and internal versus internal switch. Although the main properties are already well-know, such as the best efficiency achievable, other conclusions, such as load regulation and form of the efficiency curve can be observed and evaluated. This gives another practical point of view about the applicability of the different design solution in terms of suitability for particular design or use case of the real-world hardware realization.

On the other hand, the presented results are also of interest as a comparison of real-world hardware prototypes with the data of manufacturing companies and accordingly to draw conclusions regarding the application of the studied power electronic devices in practice for different applications, ambient working conditions and practical topology realization.

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