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Switched-Capacitor Power Converters for High-Vin Applications

Daniel Lutz, Peter Renz, Bernhard Wicht
Robert Bosch Center for Power Electronics
Reutlingen University, 72762 Reutlingen, Germany
Email: {daniel.lutz, peter.renz, bernhard.wicht}@reutlingen-university.de

***Abstract*—In recent years, significant progress was made on switched-capacitor DCDC converters as they enable fully integrated on chip power management. New converter topologies overcame the fixed input-to-output voltage limitation and achieved high efficiency at high power densities. SC converters are attractive to not only mobile handheld devices with small input and output voltages, but also for power conversion in IoTs, industrial and automotive applications, etc. Such applications need to be capable of handling high input voltages of more than 10 V. This talk highlights the challenges of the required supporting circuits and high voltage techniques, which arise for high Vin SC converters. It includes level shifters, charge pumps and back-to-back switches. High Vin conversion is demonstrated in a 4:1 SC DCDC converter with an input voltage as high as 17 V with a peak efficiency of 45 %, and a buck-boost SC converter with an input voltage range starting from 2 up to 13 V, which utilizes a total of 17 ratios and achieves a peak efficiency of 81.5 %. Furthermore a highly integrated micro power supply approach is introduced, which is connected directly to the 120/230 Vrms mains, with an output power of 3 mW, resulting in a power density >390 μW/mm^2, which exceeds prior art by a factor of 11.**

I. Brief Description and Figures

High input voltages bring up several challenges for fully integrated SC converters. With increasing input voltage, high-voltage devices have to be used, which comprises higher gate charge losses. These losses correlate with the switching frequency fsw. The switching frequency influences the topology, size of the passives (capacitors) and parasitic losses, e.g. the bottom plate losses of the flying capacitors. Therefore, a trade-off in terms of fsw has to be found. To turn on/off the switches a gate overdrive has to be generated by a charge pump CP, and a level shifter LS is also required. However, to achieve a high system efficiency, each supporting circuit has to be designed for low power and optimized for the high-voltage challenges. In this work, an improved

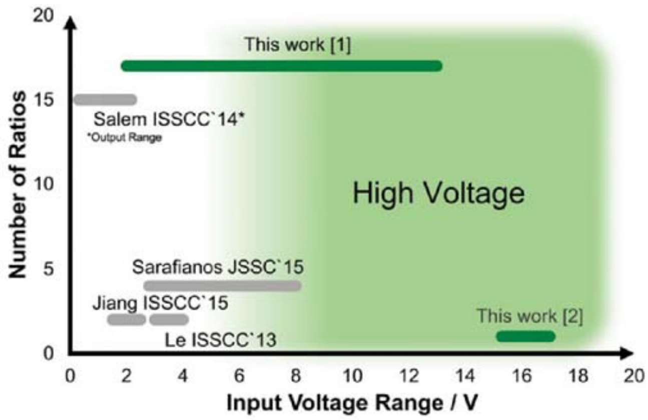

Fig. 1. Figure of Merit

charge pumps is used for the gate overdrive. The gate drive signal will be shifted by a loss optimized pulsed level shifter. With rising input voltage, the losses of the parasitic bottom plate capacitor are becoming significant, a biasing technique is used to reduce these losses. For one of the introduced SC converters, a bidirectional switch is needed. Therefore a loss optimized back-to-back switch topology will be discussed, which reduces the area consumption by a factor of up to 75 % and the gate charge losses by a factor of 70 %. These circuits are implemented in two high Vin SC converters, which will be presented in this talk.

Figure 1 shows a Figure-of-Merit for fully integrated high Vin SC converters, where the number of ratios is drawn over the input voltage range. Both introduced SC converters are working in the high voltage area and facing the impact of high input voltage. In Fig. 2, the efficiency of the buck boost SC converter is depicted over the wide input voltage range from 2 to 13 V. A peak efficiency of 81.5 % and an output power of 10 mW is achieved. Figure 3 shows the efficiency of the 4:1 SC converter over the input voltage. Despite of the

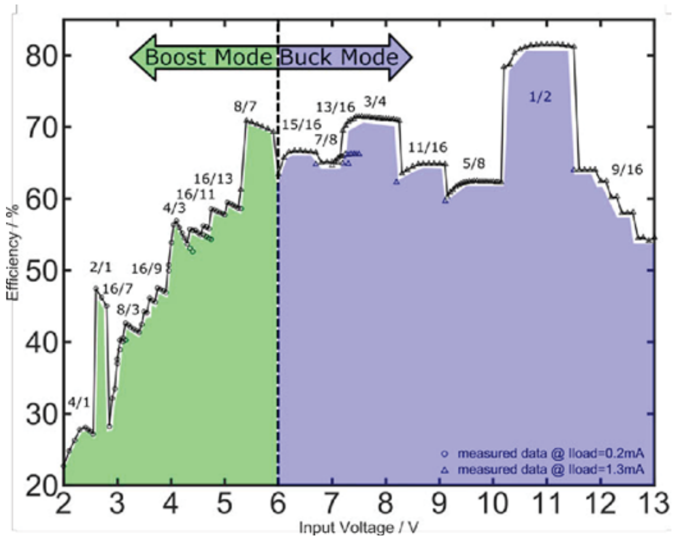

Fig. 2. Efficiency of the buck-boost SC converter [1]

high input voltage, the efficiency is still twice as high compared to a linear regulator (LDO). It still achieves a peak efficiency of up to 45 %.

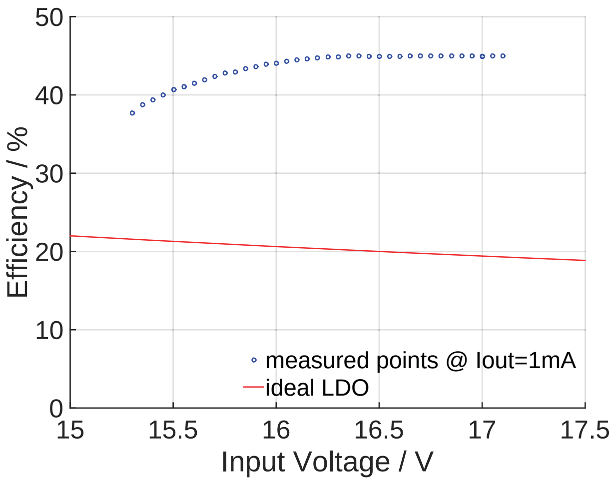

Fig. 3. Efficiency of the 4:1 SC Converter [2]

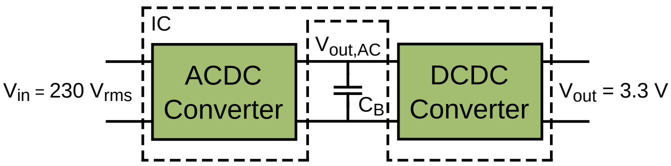

Fig. 4. System Architecture of the micro power supply

The 4:1 SC converter is also used as a second stage in a micro power supply, Fig. 4. It comprises a fully integrated ACDC converter, which rectifies the mains input voltage of 120/230 Vrms. The generated DC voltage is buffered by a small external SMD capacitor and connected to the 4:1 SC converter, which converts the voltage down to a DC output voltage of 3.3 V. The power density of the micro power supply improves prior art by a factor of 11 and achieves a total output power of 3 mW at a compact form factor. The prototype of the introduced micro power supply is depicted in Fig. 5.

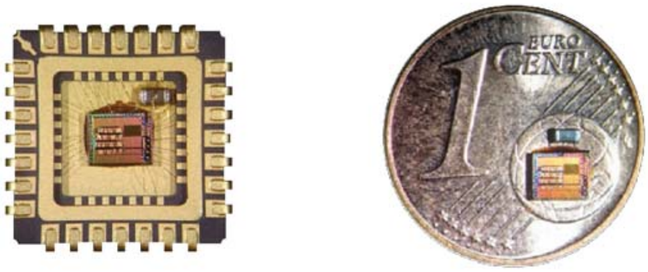

Fig. 5. Prototype of the Micro Power Supply

II. Conclusion

High-voltage challenges for switched capacitor power converters are discussed. Supporting circuits comprise level shifter, charge pumps, driver, back-to-back switch, all optimized for minimum losses at high-voltage operation. The circuits are implemented in two fully integrated SC converters, fabricated in 0.35 μm HV CMOS technology. Also an IC-level mains ACDC converter is presented. All converters allow for fully integrated power supplies for high-Vin applications. They improve prior art in parameters like input voltage, efficiency and output power.

Acknowledgment

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