

Preface

Technological progress in the semiconductor industry has led to a revolution towards new advanced, miniaturized, intelligent, battery-operated and wireless electronic applications. The base of this still ongoing revolution, commonly known as Moore's law, is the ability to manufacture ever decreasing transistor sizes onto a CMOS chip. In other words, the transistor density increases, leading to larger quantity of transistors which can be integrated onto the same single chip die area. As a consequence, more functionality can be integrated onto a single chip die, leading to Systems-on-Chip (SoC) and reducing the total system cost. Indeed, the cost of electronic applications depends in an inverse-proportional fashion on the degree of on-chip integration, which is the main drive for CMOS scaling.

A SoC requires both analog and digital circuitry to be combined in order for it to be able to interact with the analog world. Nevertheless, it is usually processed in a native digital CMOS technology. These CMOS technologies are optimized for the integration of large-scale digital circuits, using very small transistors and low power supply voltages to reduce the power consumption. Beside for the purpose of decreasing the (dynamic) power consumption, the power supply voltage of deep-submicron CMOS technologies is also limited due to the physically very thin gate-oxide of the transistors. This thin gate-oxide, of which the thickness may merely be a few atom layers, would otherwise suffer electrical breakdown. However, the analog circuitry generally needs higher power supply voltages, compared to the digital circuitry. For instance, a power amplifier needs a higher supply voltage to deliver sufficient power into the communication medium. Also, analog signal processing blocks require a higher supply voltage to achieve the desired Signal-to-Noise-Ratio (SNR).

Due to the trend towards electronic applications of portable and wireless nature, (rechargeable) batteries are mandatory to provide the required energy. Although also prone to innovation and improvement, the battery voltage does not scale with the CMOS technology power supply voltages. Obviously, this is due to their physical and chemical constraints. Moreover, their energy density remains limited, limiting the available power and/or the autonomy of the application. Therefore, it is clear that power-management on a SoC-scale is mandatory for ensuring the ongoing feasibility of these applications.

Matching the battery voltage to the required power supply voltage(s) of the SoC can essentially be done in two ways. The first method, which can only be used when the battery voltage is higher than the required power supply voltage(s), is the use of linear voltage converters. This method is very often applied in current state-of-the-art applications, due to the simplicity to integrate it onto the SoC and its low associated cost. However, the excess energy from the battery voltage is dissipated in the form of waste heat, negatively influencing the autonomy and/or physical size of the application. The second method, putting no constraints to the battery voltage, is the use of switched-mode Direct-Current to Direct-Current (DC-DC) voltage converters. These converters are able to increase or decrease the battery voltage in a power-efficient fashion, leading to potentially higher battery autonomies. As a drawback, these switched-mode DC-DC converters are more complex and difficult to integrate onto the SoC, which is why they still require off-chip electronic components, such as inductors and capacitors.

The focus of the presented work is to integrate the switched-mode DC-DC converters onto the SoC, thus reducing both the number of external components and the Printed Circuit Board (PCB) footprint area. However, the poor electrical properties (low Q-factors) of on-chip inductors and capacitors and their low associated values (nH, nF) poses many difficulties, potentially compromising the power conversion efficiency advantage. Combining both the concepts of monolithic SoC integration and achieving a maximal (overall) power conversion efficiency, is the key to success. Moreover, to minimize the costs, the power density of the fully-integrated DC-DC converter is to be maximized.

To achieve these goals a firm theoretical base on the matter of DC-DC conversion is provided, leading to the optimal inductive DC-DC converter topology choices. An extensive mathematical steady-state model is deduced, in order to accurately predict both the trade-offs and performance limits of the inductive DC-DC converters. A further increase the performance of DC-DC converters is achieved through the design of novel control techniques, which are particularly optimized for high-frequency monolithic inductive DC-DC converters. Finally, the theory and simulations are verified and validated through the realization of seven monolithic inductive CMOS DC-DC converters. As such, the highest power density and Efficiency Enhancement Factor (EEF) over a linear voltage converter are obtained, in addition to the feasibility proofing of various novel concepts.

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