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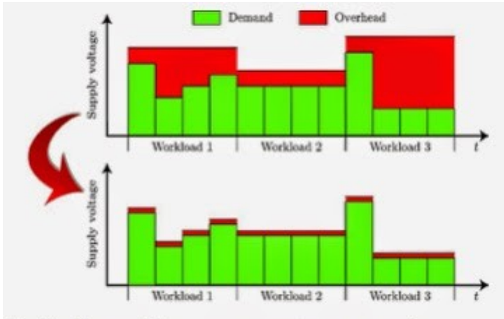
Record 10 Watt On-Chip Power Converter

Written by Toke Andersen, a recent Pre-doc at IBM Research

Research by the Power Electronics Systems Laboratory (PES) at ETH Zurich in collaboration with IBM Research – Zurich demonstrated an on-chip (or fully-integrated) power converter that delivers 10 watt of output power – *at the size of a pin head.*

The power converter, which was presented in February 2015 at the International Solid State Circuits Conference (ISSCC) in San Francisco, delivers more than 6 times the output power of any other on-chip power converter of the switched capacitor type, presented to date.

Designed and realized in an advanced 32 nanometer semiconductor technology, the on-chip power converter is intended to be co-integrated with a microprocessor core, potentially saving more than 10 percent of the total power consumption of future high-performance microprocessor systems.



Enabled by on-chip power converters, a granular microprocessor power delivery with per-core regulation has the potential to significantly reduce the supply voltage overhead, and there by the power consumption, of future multi- and many-core microprocessor systems.

Efficient Microprocessor Power Delivery

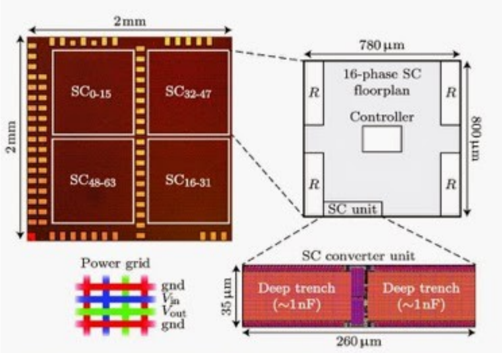
Dynamic Voltage and Frequency Scaling (DVFS) is a popular technique for microprocessor power management. If the supply voltage of the microprocessor core remains high at times of low activity, the additional supply voltage overhead leads the core to consume more power than necessary. In order to reduce the power loss associated with supply voltage overhead, DVFS dynamically changes the supply voltage to match the requirements of the microprocessor core. In that way, the microprocessor core only consumes the power that it requires for a given computational workload. Most of today's microprocessors are multi-core architectures implemented with 2, 4, or even more microprocessor cores. DVFS is applied to all cores simultaneously, thereby introducing power loss due to the voltage overhead present for computational workloads with varying activity among the cores.

By integrating an on-chip power converter onto the microprocessor chip die, a granular microprocessor power management, where each core is independently supply by an on-chip power converter, can be employed. Therefore, the supply voltage is dynamically adjusted to each core's needs. If furthermore the regulation of the on-chip power converters can be made faster than their discretely build counterparts, the ever-present supply voltage overhead, that accounts for supply voltage instability, can be reduced as well.

Microprocessor systems fall under the Information and Communications Technology (ICT) industry, which annually consume several 1,000,000,000 kilowatt-hours of electricity, which equivalents to the electricity consumption of 200,000 typical Swiss households. "Our on-chip power converter solution has the potential to reduce this electricity consumption significantly", says Toke Meyer Andersen, who designed the 10 watt on-chip power converter as part of his PhD study at PES, ETH Zurich.

Integration-Friendly Switched Capacitor Converters

In general, efficient switch-mode power converters are implemented using inductors, capacitors, transistors, and diodes. Inductors and capacitors, which act as energy storage elements, typically take up the majority of the converter volume. To make the passive components, inductors and capacitors, suited for on-chip integration, their volumes can be reduced by increasing the switching frequency of the switch-mode power converter.



Chip photo and layout of the 10 watt on-chip switched capacitor converter implemented in the advanced 32 nanometer semiconductor technology that features the high capacitance density deep trench capacitor.

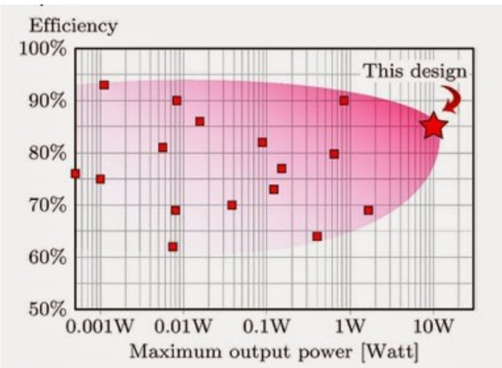
"The switching frequency is increased a 1,000-fold compared to conventional power converters," said Florian Krismer, post-doctoral fellow at PES. "Otherwise, there would have been no way to integrate the passive components on-chip."

Following a thorough analysis of inductors intended for on-chip integration, it turned out that the achievable inductor efficiency using inductors from the available semiconductor technology would be too low for a high-efficiency on-chip power converter design. Instead, the switched capacitor converter, which consists solely of capacitors and transistors, was considered.

"The choice to select the switched capacitor converter was furthermore motivated by the deep trench capacitor available in the 32 nanometer semiconductor technology," said Thomas Toifl, technical manager at IBM Research – Zurich. "The high capacitance density and low losses of the deep trench capacitor, which originally was developed for IBM's embedded memory applications, turned out to be very well suited for on-chip switched capacitor converters."

Record Performance

Due to the ease of integration, switched capacitor converters have increased in popularity for on-chip power converter applications. By operating several converter units simultaneously but out of phase, the input and output decoupling capacitor requirements can be drastically reduced. This converter has been implemented with 64 converter phases, and the converter requires no additional decoupling capacitors. As a result, no external components are required to run the converter.



State-of-the-art overview comparing peak efficiency with maximum output power of published on-chip switched capacitor converters. The 10 watt maximum output power is a factor 6 or more higher output power than previous designs.

Furthermore, using high-frequency digital control specifically developed for this converter, a sub-nanosecond response to a transient event has been achieved. This is 100 to 1,000 times faster than a conventional external voltage regulator module for microprocessor power delivery. Such fast transient responses are an enabler for per-core DVFS to reduce the supply voltage overhead and the power consumption.

The conversion efficiency, when converting from 1.8 volt to 1.1 volt, is as high as 88 percent. Covering a total chip area of 2 millimeters square, the maximum power density is 5 watts per millimeters square. "With this design, we have reached the 10 watt output power mark. This sets a new benchmark for on-chip switched capacitor converters," said Johann W. Kolar, professor at PES at ETH Zurich.

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