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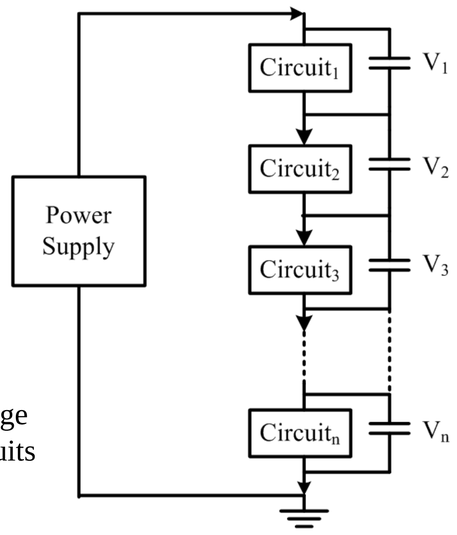
Overcoming the Power Wall: Connecting Voltage Domains in Series

Pradeep S. Shenoy, Sai Zhang, Rami A. Abdallah, Philip T. Krein, and Naresh R. Shanbhag
University of Illinois at Urbana-Champaign

Objective

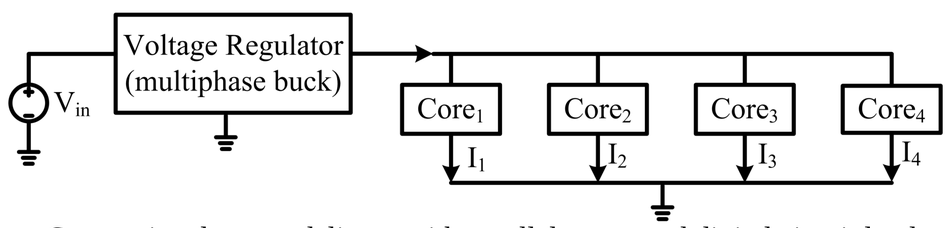
This poster presents a vision to reduce overall system energy consumption by connecting the voltage domains of digital circuits in series.



Series connected voltage domains of digital circuits

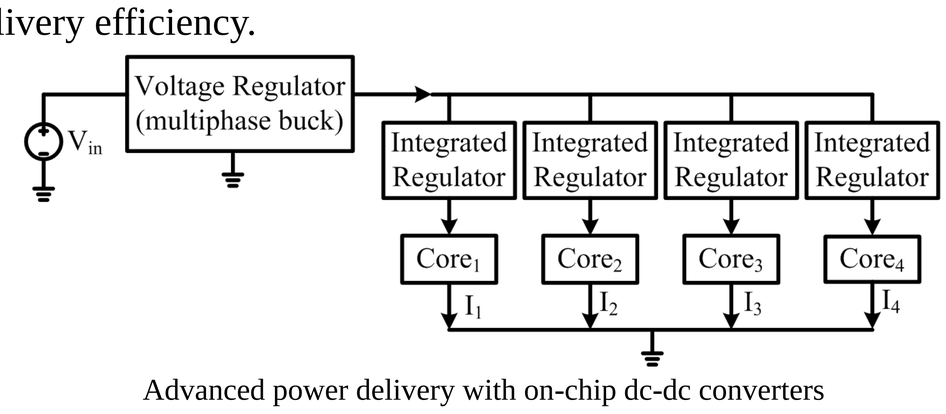
Background

- Reducing energy consumption and heat management overhead are key motivators for rethinking system-level design.
- Microprocessors trend towards computational parallelism (multi/many-core processors) and supply voltage reduction.



Conventional power delivery with parallel connected digital circuit loads

- Advanced designs with on-chip dc-dc converters enable independent voltage domains which may reduce energy consumption in digital circuit loads.
- However, the additional energy conversion stage reduces power delivery efficiency.

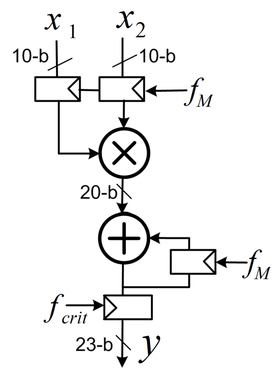


Advanced power delivery with on-chip dc-dc converters

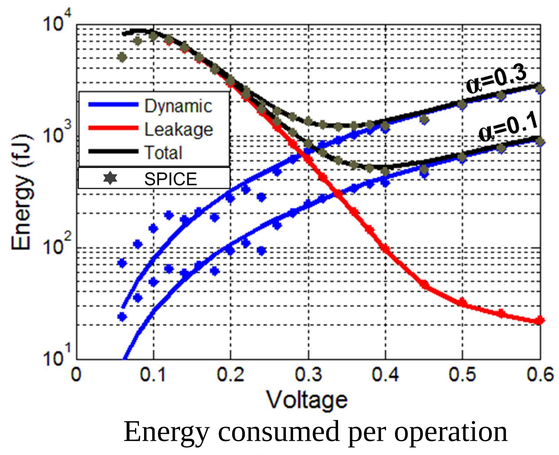
Core Energy Optimal Operating Point

- A minimum energy operating point exists in CMOS circuits (~0.3V).
- The energy consumed is the sum of dynamic and leakage energy.

$$E = E_{dyn} + E_{lkg} = \alpha C V_{dd}^2 + \frac{I_{OFF,V_{dd}} V_{dd}}{f}$$



Ripple-carry based architecture of a 23-bit output MAC unit



Energy consumed per operation in the MAC unit

Power Consumption Analysis

- Power consumption of systems (load and supply) with parallel connected and series connected voltage domains is compared.
- Independent voltage levels are enabled by the series connection.

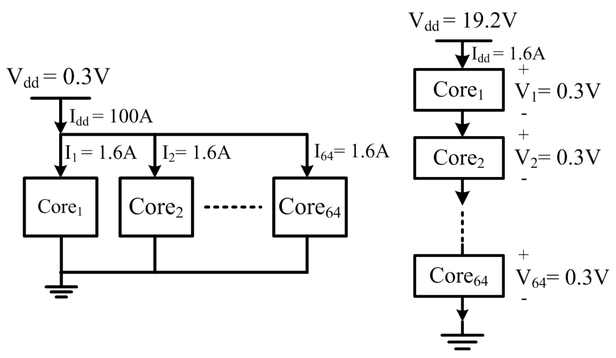
$$P_{out,parallel} = \sum_{i=1}^{N} V_{dd}(I_{load,i}) = \sum_{i=1}^{N} \alpha_i C_{load,i} V_{dd}^2 f_{sw,i} \qquad P_{out,series} = \sum_{i=1}^{N} I_{load,i} V_{dd,i} = \sum_{i=1}^{N} \alpha_i C_{load,i} V_{dd,i}^2 f_{sw,i}$$

- The power supply in a series system is more efficient (less current).

$$P_{cond} = (I_{load}^2 + \frac{\Delta I_{load}^2}{12})(r_L + Dr_1 + (1-D)r_2) \qquad P_{sw} = \frac{1}{2} I_{load} V_{in}(t_{on} + t_{off}) f_{sw} + \frac{1}{2} C_{OSS} V_{in}^2 f_{sw}$$

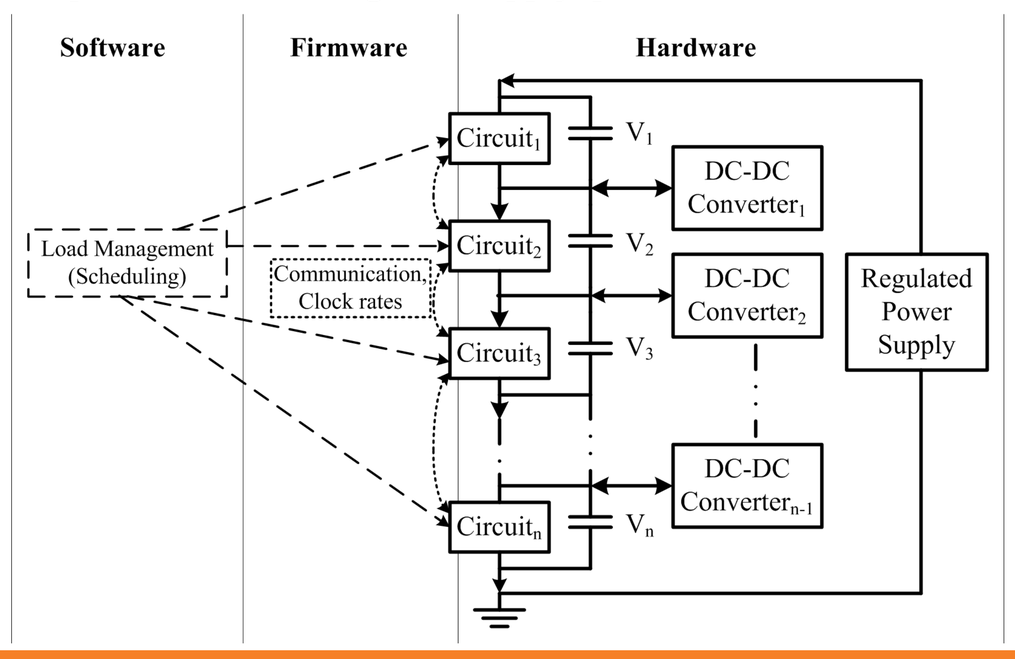
- A series system consumes less power than a parallel system.

Comparison of a 64-core, 30 W processor with cores connected in parallel and series. Effective impedance of series cores is about 4,000 times larger than parallel cores.



Regulation of Series Voltage Domains

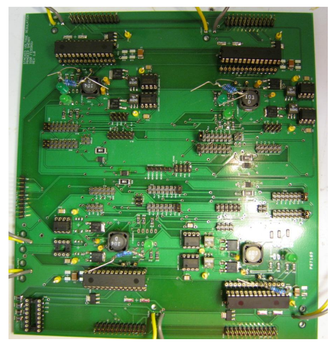
- Balancing the computational load in software (scheduler)
- Adjusting clock rates, swapping tasks, and communication
- Local power electronics, global supply, protection



Conclusions

- Power delivery circuits and digital circuits can operate in their unique region of highest efficiency through series voltage domains.
- Voltage regulation is necessary and achievable using software, firmware, and hardware mechanisms that are efficient and reliable.
- Inter-core communication can be accomplished with capacitively-driven wires, optical interconnects, wireless communication, etc.

Experimental prototype with microcontrollers, data I/Os, and voltage regulation circuits



Selected References

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