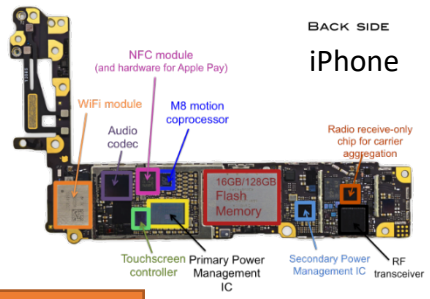
A 94.2%-peak-efficiency 1.53A direct-battery-hook-up hybrid Dickson switched-capacitor DC-DC converter with wide continuous conversion ratio in 65nm CMOS

Berkeley Power and Energy Center

Motivation and Application

Increased power density of advanced CMOS nodes in embedded applications requires the power converters to have:

- Higher efficiency to extend the battery life
- Low loss to ease the thermal management
- Higher power density to match the technology
- Maintain performance at large conversion ratios



Typical Battery voltage 3.2 V to 4.2 V

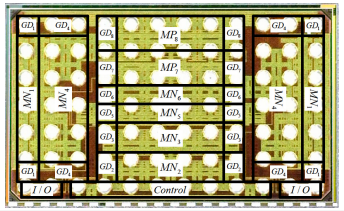
Typical Load voltage 300m V to 1 V

Typical Load current several mA to several A

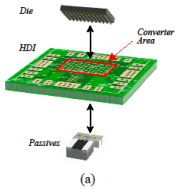
Increasing Gap

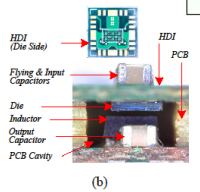
Hardware

- Implemented in CMOS 65nm bulk process
- Flip-Chip packaging for low parasitic
- Voltage borrowing gate drive to eliminate bootstrap capacitors and increase power density
- Active capacitor balancing and output regulation
- External flying capacitors and inductor
- High density interposer for uModule assembly

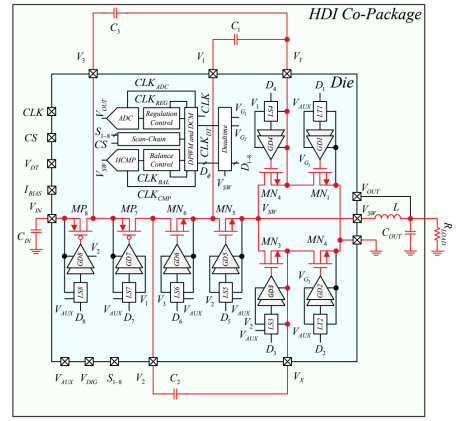


Die
4 mm2





uModule Assembly



System Architecture

Challenges and Solutions

Utilized hybrid switched-capacitor (SC) converters.

Switched-Capacitor stage:

- Higher efficiency at large conversion ratios
- Lower rated devices for advance CMOS integration
- Poor regulation

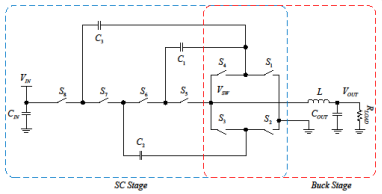
Magnetic Buck stage:

- Achieve tighter regulation
- Lower voltage swing for smaller magnetics

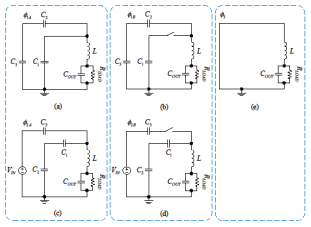
Need higher utilization of passive and active devices:

- Dickson SC has good switch utilization and poor capacitor utilization
- Soft-charging through split-phase control increases capacitor utilization, enhances efficiency and lower switching frequency
- Smaller passives for faster transient response and tighter control

4:1 Hybrid Dickson



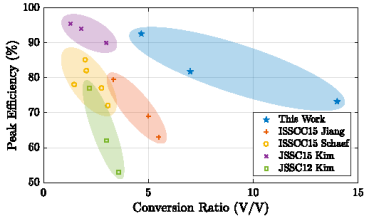
Split-Phase Control

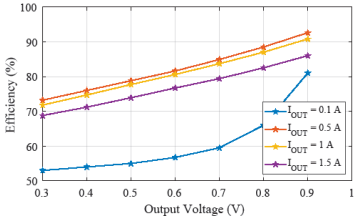


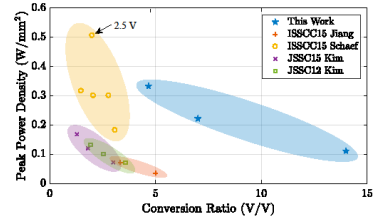
Experimental Verification

Maintained efficiency and power density:

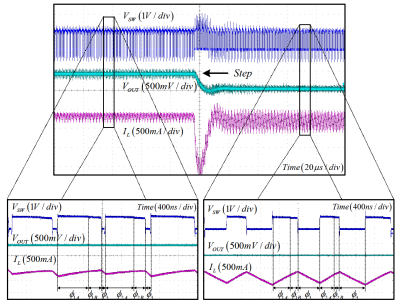
- Across large conversion ratios
- Across large load current range







Output regulation and flying capacitor active balancing



Reference: W. Liu, P. Assem, Y. Lei, P. K. Hanumolu and R. Pilawa-Podgurski, "10.3 A 94.2%-peak-efficiency 1.53A direct-battery-hook-up hybrid Dickson switched-capacitor DC-DC converter with wide continuous conversion ratio in 65nm CMOS," *ISSCC 2017*.

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