A Fully Integrated Switched-Capacitor Voltage Regulator With Dynamic Body Biasing on Power Switches for Energy-Efficient DNN Accelerators

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Abstract

A fully integrated on-chip switched capacitor voltage regulator (SCVR) with a 3:2 conversion ratio and digital capacitance modulation (DCM) is used for efficient power delivery. The proposed dynamic body biasing (DBB) improves power efficiency, achieving a peak of 89% at 30 mA and providing a 2–3% improvement under heavy loads. The regulator demonstrates a 70mV voltage droop and 130ns settling time for a 50ns current step.

Proposed Design

- **The proposed SCVR** uses a 3:2 switched capacitor DC-DC converter with **digital capacitance modulation (DCM)** for dynamic capacitor adjustment based on load variations.
- **Dynamic body biasing (DBB)** is applied to the power switches, improving efficiency by reducing on-resistance under heavy load conditions.
- **On-chip MIM capacitors** are utilized to achieve high power density, while a stack capacitor supports auxiliary power rail generation during startup.

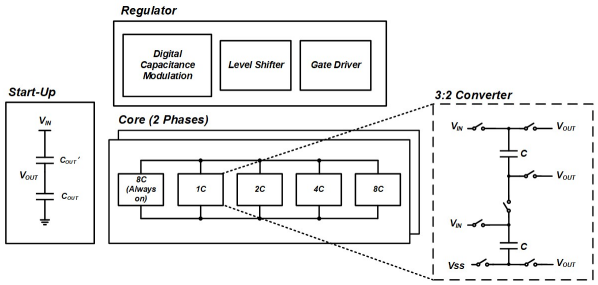

Fig. 1. Overall architecture of proposed SCVR.

Dynamic Body Biasing

- **Dynamic body biasing (DBB)** is implemented to optimize the power efficiency of the SCVR by reducing the on-resistance of power switches under heavy load conditions.
- **DBB applies** forward body bias when the switch is on, minimizing on-resistance, and removes the bias when the switch is off to prevent leakage current.

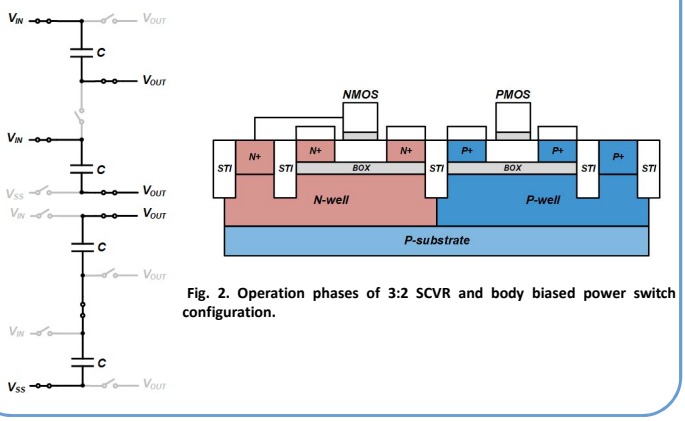

Fig. 2. Operation phases of 3:2 SCVR and body biased power switch configuration.

Digital Capacitance Modulation

- **Digital capacitance modulation (DCM)** dynamically adjusts the number of capacitors in the SCVR based on variations in the load current, optimizing voltage regulation.
- **DCM detects voltage changes** caused by load fluctuations and activates or deactivates capacitors to maintain a stable output voltage.
- This method enables a fixed switching frequency for the SCVR, making it easier to achieve regulation in the following linear regulator and simplifying EMI-related analysis.

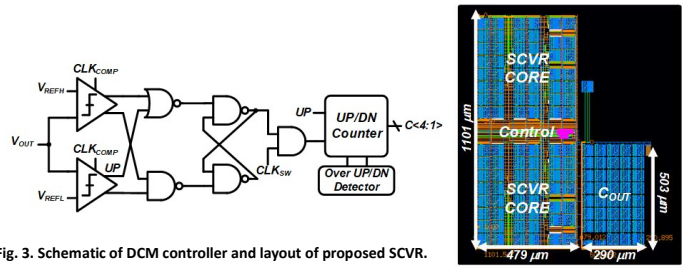

Fig. 3. Schematic of DCM controller and layout of proposed SCVR.

Simulations Results

- The proposed SCVR achieves a peak efficiency of 89% at 30mA, with a 2–3% improvement in power efficiency under heavy load conditions using DBB.
- Transient simulations show a voltage droop of 70mV and a settling time of 130ns for a 50ns current step, demonstrating fast response and stable performance.

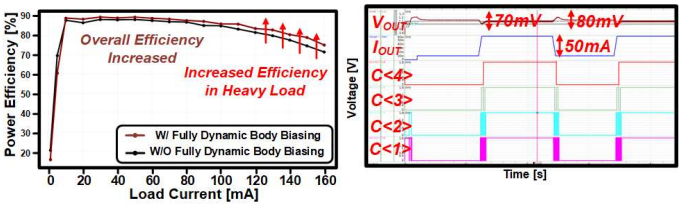

Fig. 4. Simulated power efficiency versus load current, and load transient response of SCVR.

Conclusions

The proposed on-chip SCVR with DCM and FDBB achieves high power efficiency and stable voltage regulation. Simulation results show a peak efficiency of 89% and improved performance under heavy loads. The design demonstrates fast transient response with minimal voltage droop, making it suitable for power-sensitive applications.

Reference

T. Souvignet, B. Allard and S. Trochut, "A Fully Integrated Switched-Capacitor Regulator With Frequency Modulation Control in 28-nm FDSOI," in IEEE Transactions on Power Electronics, vol. 31, no. 7, pp. 4984-4994, July 2016.