Power Management Integration Center

Industry Advisory Board Meeting

July 23 - 24, 2020

Extension: Fast Transient Response and Voltage Balancing for Hybrid SC Converters

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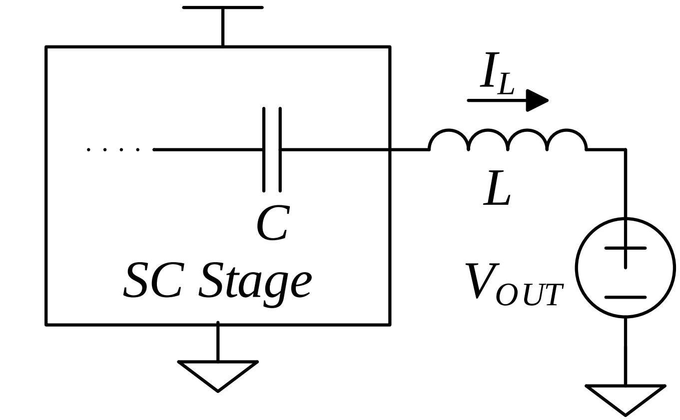
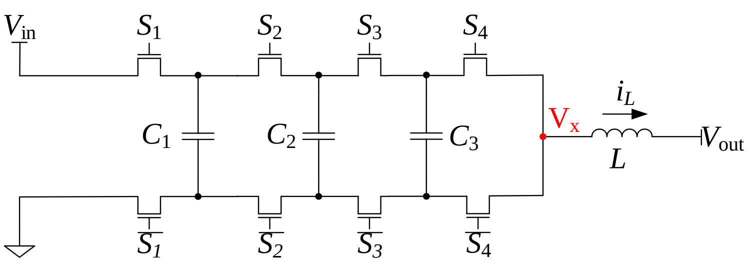
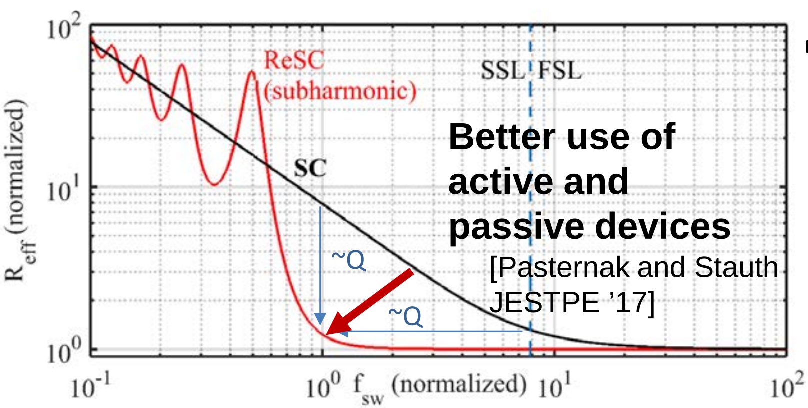
Power Management Integration Center

THAYER SCHOOL OF ENGINEERING AT DARTMOUTH

Hybrid/Resonant Switched Capacitor Converters







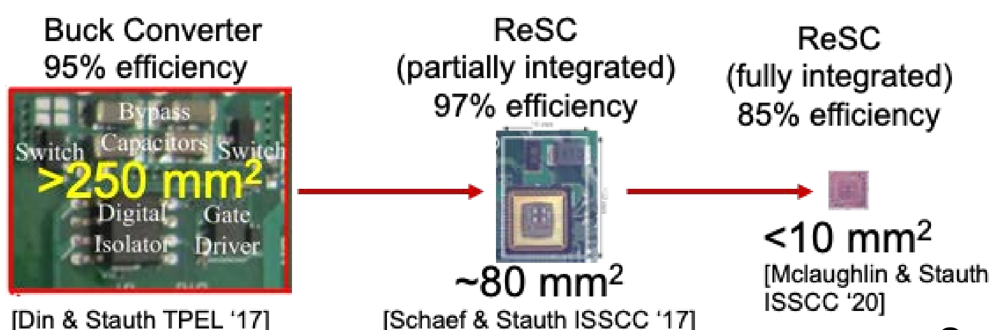
Inductive Impedance
→ Shape the Current Waveform

vs SC:

- Eliminate charge sharing losses
- More voltage swing on caps (better passive component utilization)
- Variable regulation

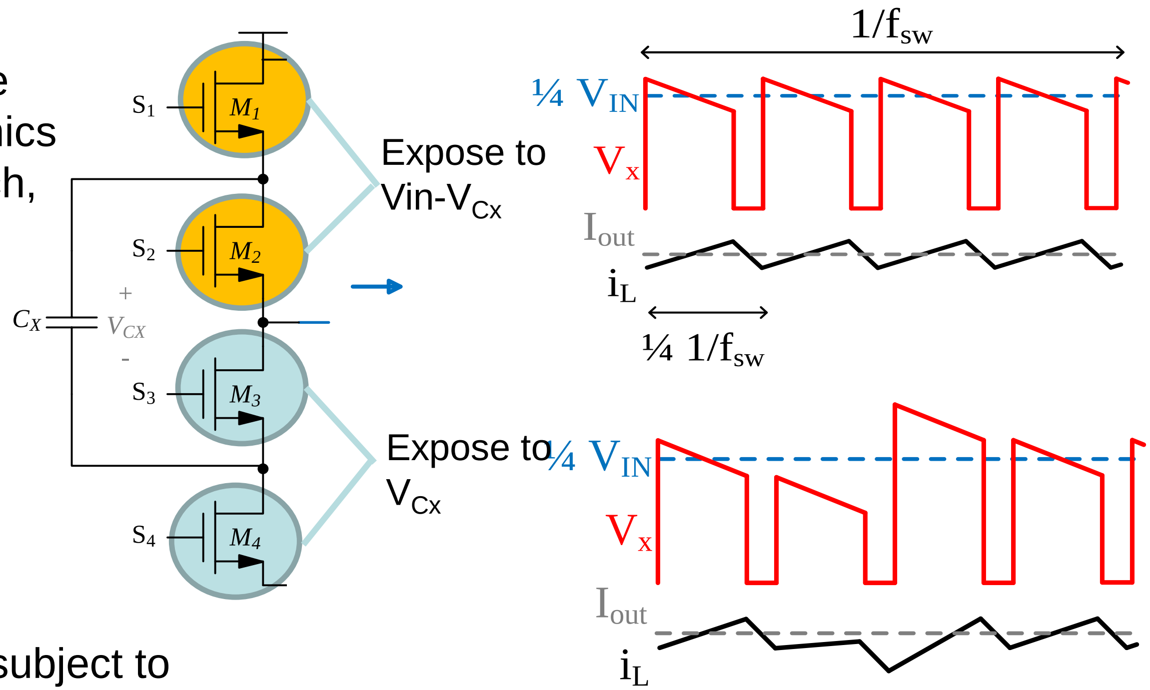
vs Buck:

- Significantly smaller inductor (10-100x) (better passive component utilization)
- Better VA product (active device utilization)

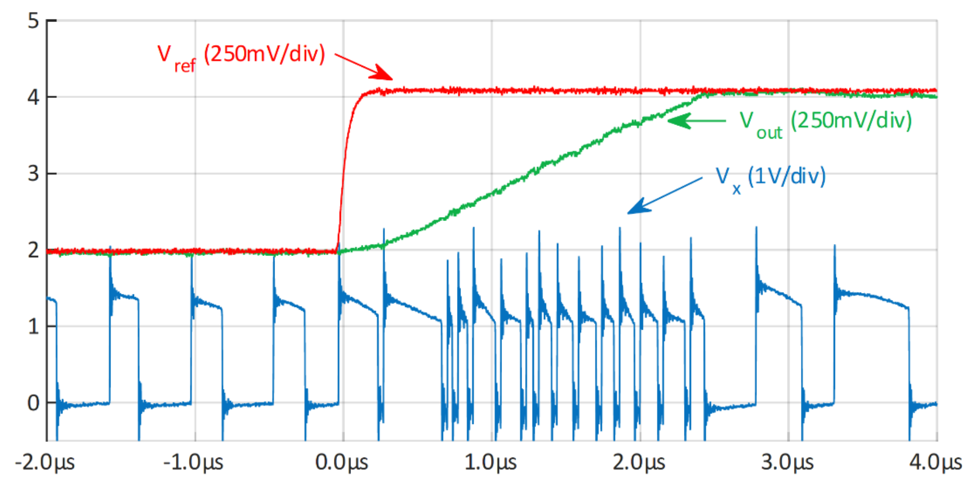


But… Major Challenges for Commercial Adoption

- Flying capacitor voltage balance
  - Effective high-order dynamics
  - Drift due to timing mismatch, parasitics, init. conditions
- Imbalance
  → voltage stress
  →current & voltage ripple
- Challenging during transients
- How to startup?



- Feedback regulation
  - Most common controllers subject to imbalance
  - How to achieve fast regulation and also balance flying capacitors
- Nonlinear control schemes:
  - Manage high-order systems
  - Replicate state feedback with simplified hardware implementation



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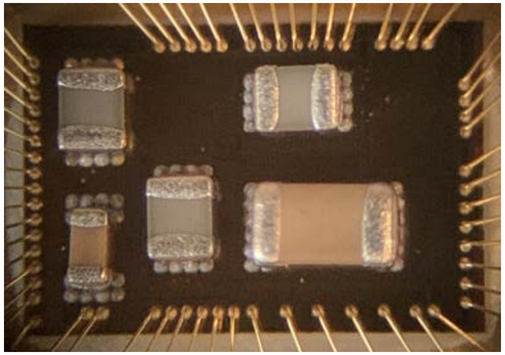
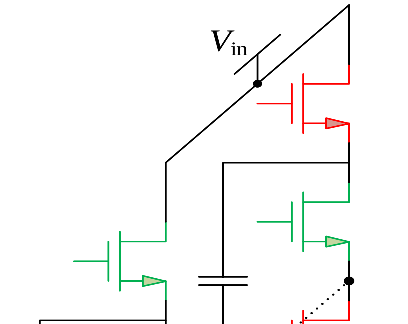
Past Work: Integrated 5V:1V Hybrid-Cascaded SC DC-DC Converter

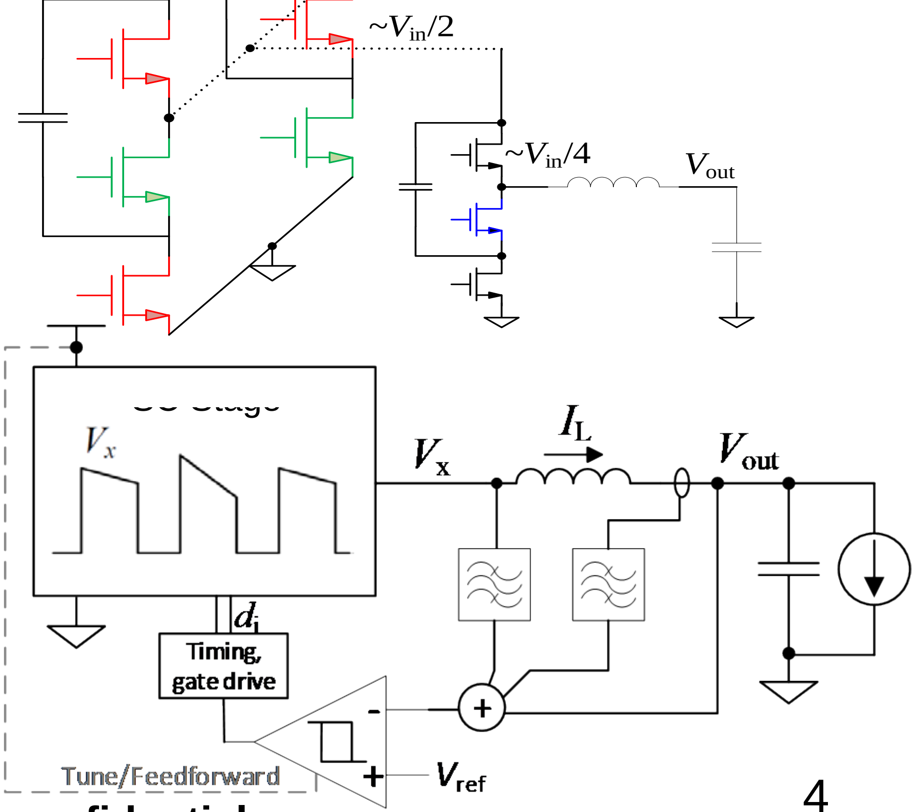
Initial design, fabrication, begin testing

- Target ~5V input, ~1V output
- Up to 1 A load current
- Off-chip passives
- On chip switches, gate drivers, control & instrumentation

Spec	Design	Tested
Supply	4V – 6V	5 V
Output	0.4V – 1.2V	0.4V – 1.2 V
Load Current	10mA - 1.5A	50 mA – 700 mA
Efficiency	~94% @ 300 mA	92.6% 300 mA
Load Transient	± 1A → ~40 mV over/undershoot	TBD
Line Transient	1V/3µs	TBD
Startup		TBD







Past Work: Integrated 5V:1V Hybrid-Cascaded SC DC-DC Converter

Remaining Work

- Finish testing, reporting
- Need to tune & explore efficiency
- Load/Line transient
- Startup performance/behavior

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Supply	4V – 6V	5 V
Output	0.4V – 1.2V	0.4V – 1.2 V
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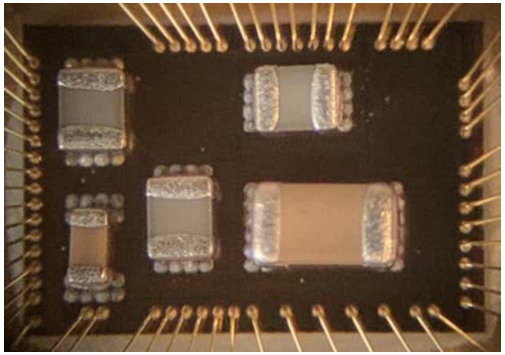
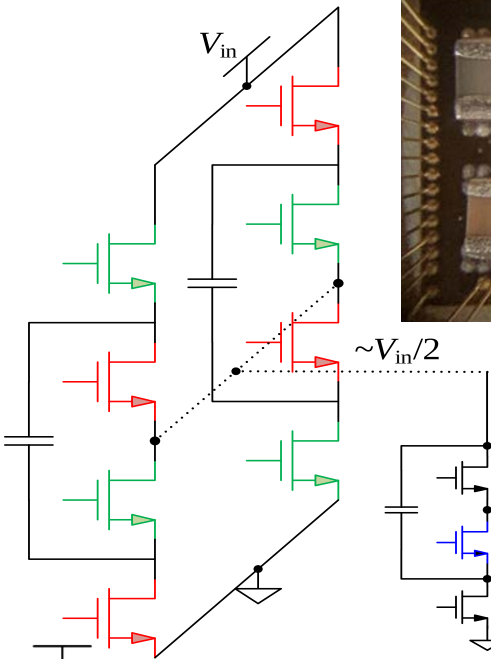
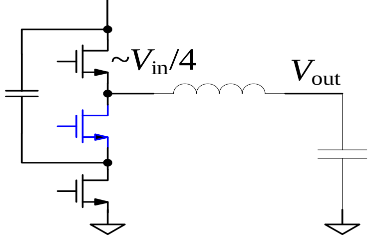
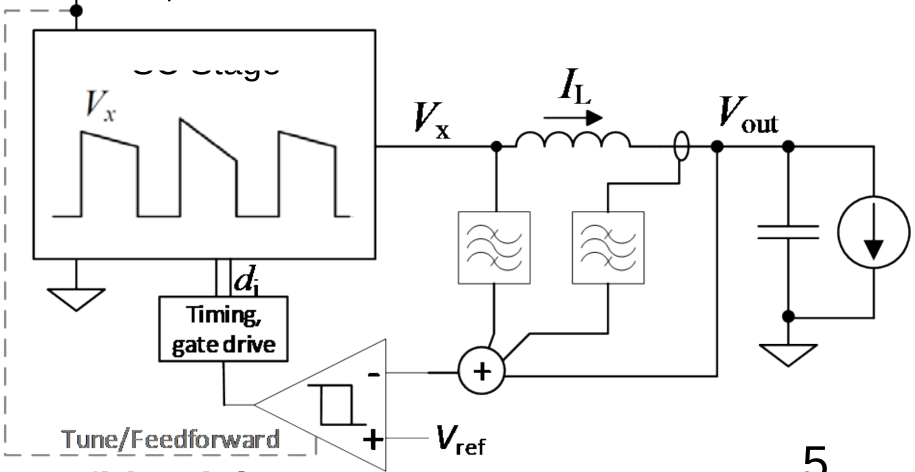




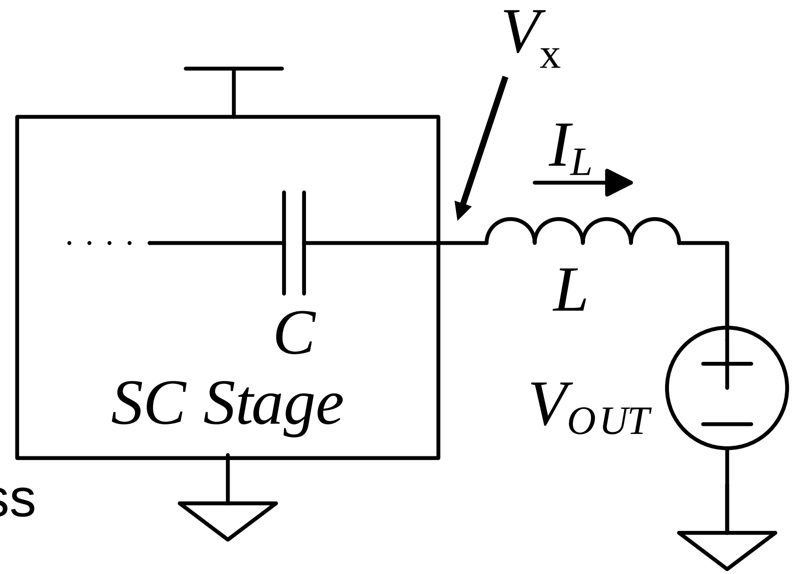


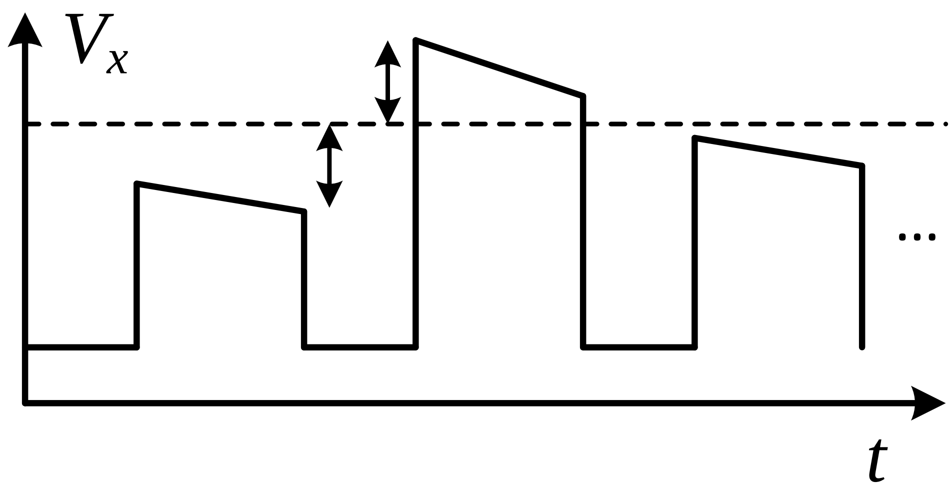


Next Work: New Control Concept

Have Shown:

- For all converters that are ‘controllable’ and ‘observable,’ switching node, Vx, is linked to ‘independent’ flying cap states
- i.e. adjusting/regulating Vx can enforce voltage balance
- Vx level also informs switch voltage stress

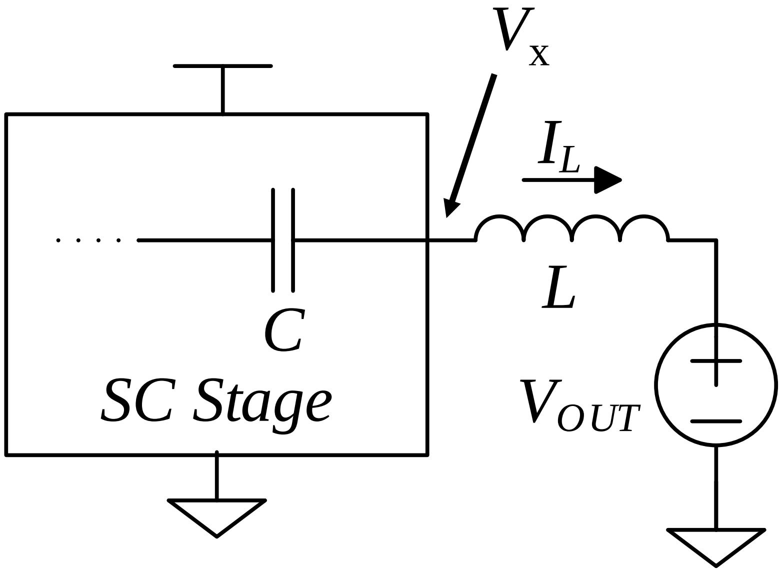


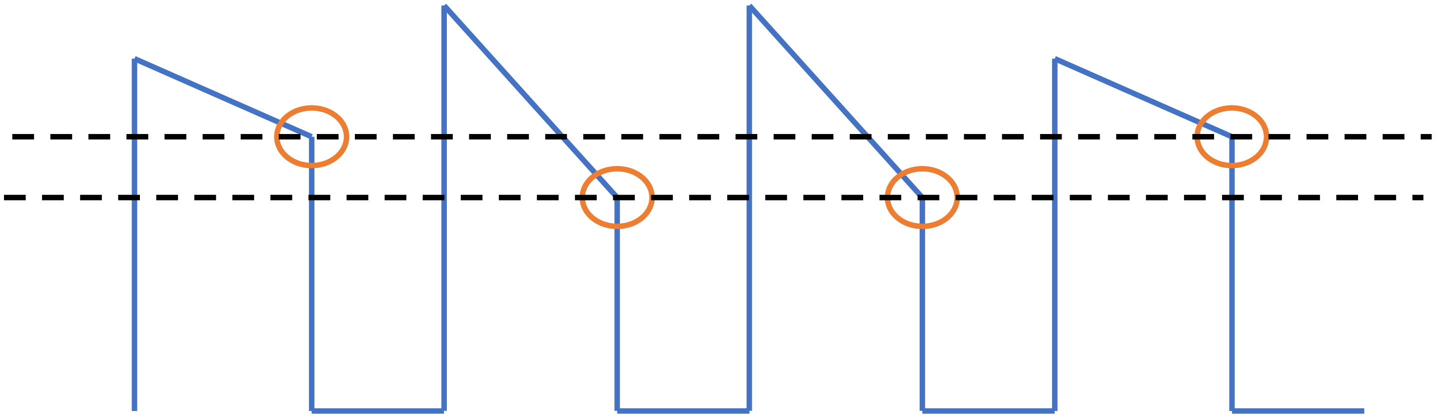


Constant Switch Stress (CSS) Control

Objective

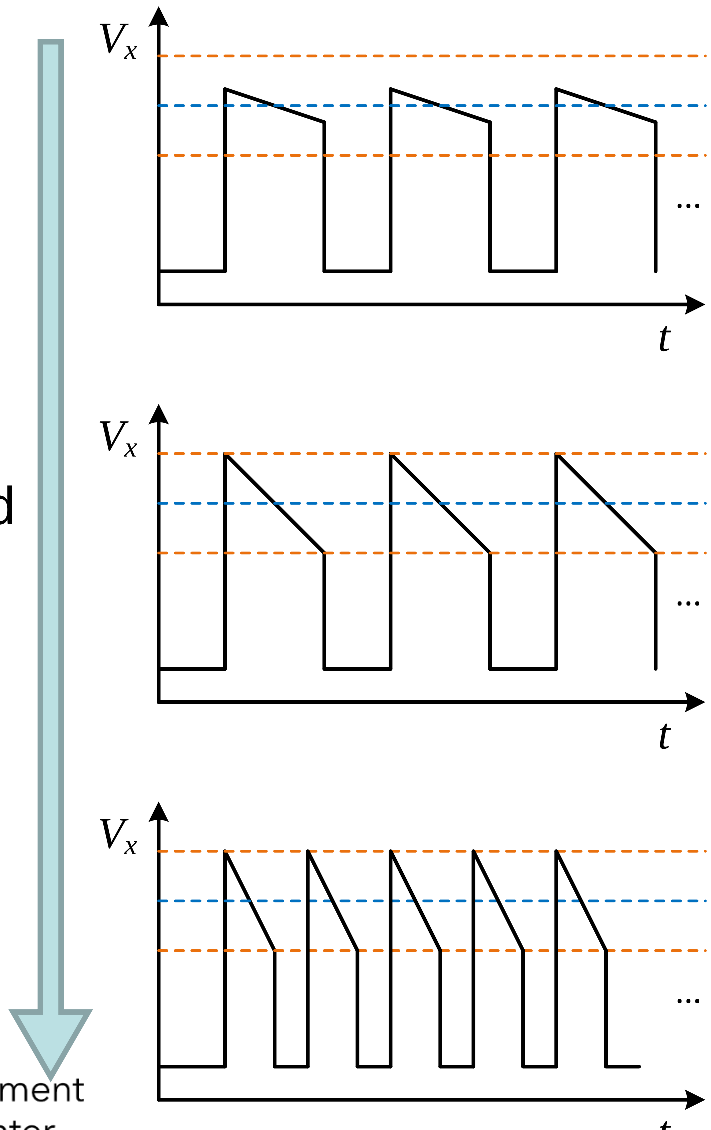
- Regulate the final Vx of 'high' phases.
- 'Low' phases have the same duration.
- Potential to 'adapt' switching threshold depending on cap values, SC network configuration





Constant Switch Stress (CSS) Control

Increase load current



- Constant switching frequency.
- V_C deviation limited for naturally imbalanced topology.
- Fast transient response and start up.

Boundary

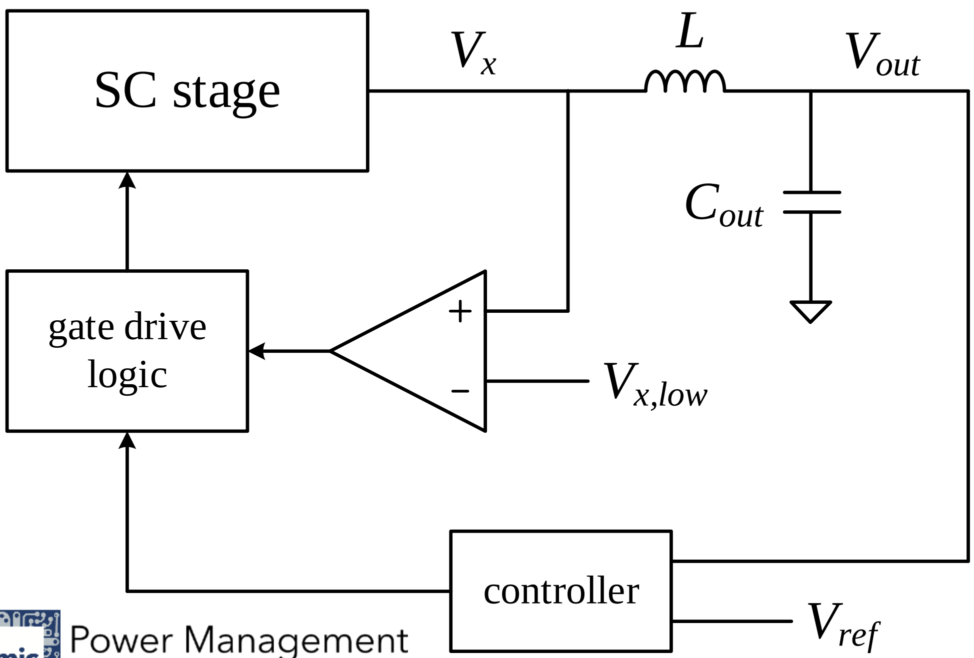
- Constant switch stress.
- Switching frequency automatically adjusted to ensure safe operation.

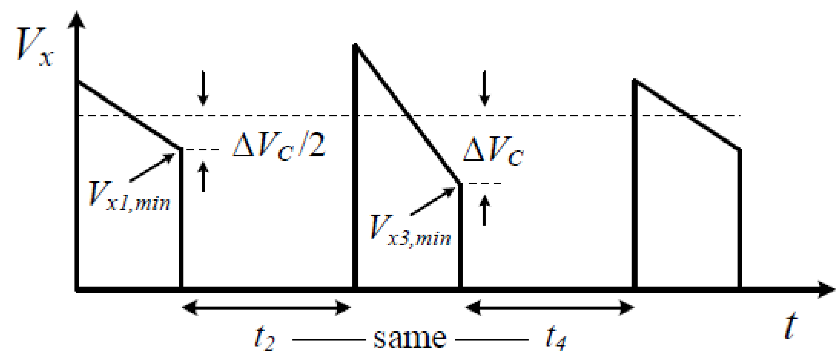
Constant Switch Stress (CSS) Control

Benefit: Simplicity, Scalability/Portability, Robustness

- Vout can be regulated with any control scheme (voltage mode PID, current mode, AOT, hysteretic, etc)
- Only need a secondary loop that triggers ‘high’ to ‘low’ transitions of Vx.

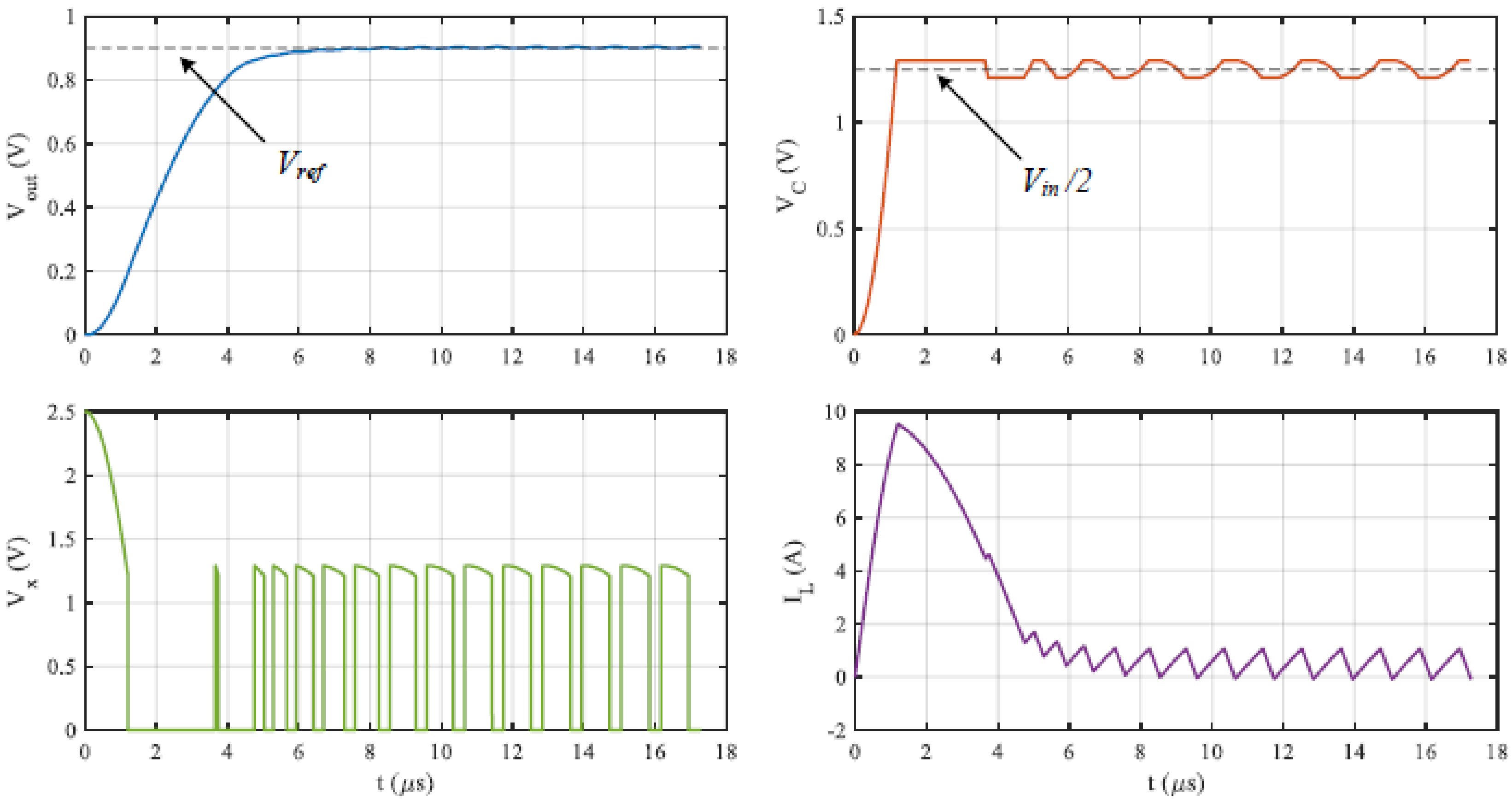
→it is a form of nonlinear control, but only activates when needed; lots of possibilities going forward.





Preliminary Simulation Results

Matlab simulation shows safe startup, fast regulation, balanced operation



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Deliverables and Timeline

- Month 1-2: Finish testing and reporting of previous design
- Month 3-8: Constant Switch Stress (CSS) control
  - Analytical study: stability and balancing requirements
  - Simulation and benchmarking
  - Explore with different control schemes (CM, VM, Nonlinear)
  - Design and simulation of prototype hardware design
- Month 8-10: Hardware design and verification
  - Target discrete (printed circuit board design)
  - Prototype with GaN devices, explore higher power, higher voltage
  - Fabricate and test
- Month 10-12: Reporting, Testing, Prepare for IAB Meeting

Resources and Benefits

Cost and Resources

- Budget $65,000/year
  - 1 student, $61,000
  - Supplies and materials, partial tapeout cost $4000
- Key facilities used:
  - Stauth Research lab
  - Computing and simulation
  - Cadence IC6
- Project leader: PI Stauth

Member Company Benefits

- Explore promising control strategy for future hybrid-SC converters
- Possible IP related to architecture & control scheme
- Early access to research results, students, and investigators