Self-stabilizing, Hysteretic Boost DC-DC Converter for Portable Applications

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Motivation

- Significant dependence of converter frequency response on passive components
- Tolerances in capacitor ESR, ESL values
- Variations in inductor, capacitor values per design

- IC solution for frequency compensation required because
  - Reduction in design time
  - Reduction in part count
  - Reduction in board size, cost
  - Ease of design

- *Need to have IC solution that will give frequency compensation independent of external components*

➢ Various techniques in literature were studied

Comparison of Stabilizing Techniques

	Masking LCR (and/or ESR) Parameters			RHP Zero Elimination		Adaptive control		Boundary control
Characteristic	**Feedforward**	**Modified Hysteretic**	**Constant LCR load**	**Constant capacitor discharge**	**Output peak control**	**Multiple operating point**	**Digital control**	**Voltage hysteretic control**
Complexity	Medium	Low	Highest	Medium	Medium	High	High	**Lowest**
Response	Slowest	Fast	Medium	Medium	Slow	Slow	Slow	**Fastest**
Power losses	**Low**	Medium	**Low**	Highest	**Low**	**Low**	**Low**	**Low**
Output ripple	Low	**Lowest**	Low	Low	High	Low	Low	Low
Stable – LCR variation	Medium	**Highest**	High	Low	Lowest	High	High	High
Versatility	High	Low	Low	Low	Low	High	**Highest**	Medium

Conclusion

Hysteretic control based scheme to be extended to boost converter

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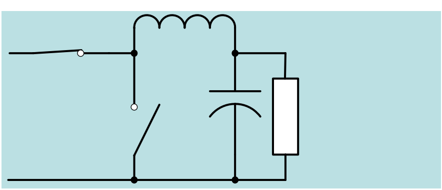
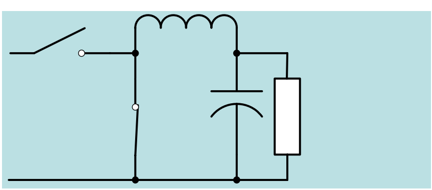
Issues with Hysteretic Control in Boost Converters

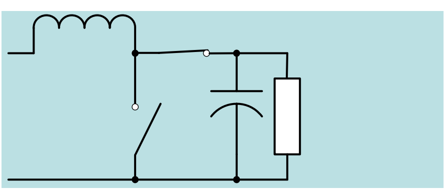
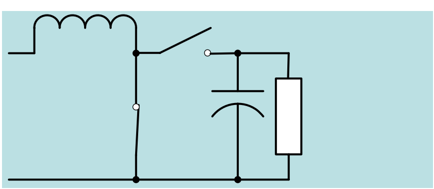
Buck converter	Boost converter
• Inductor current ripple *in phase* with output voltage ripple – <u>Therefore:</u>	• Inductor current ripple *out of phase* with output voltage <u>Therefore:</u>
➢ *Current mode control*	➢ *No current mode control*
➢ *Single pole transfer function*	➢ *Double pole + RHP zero*
➢ *Stable operation*	➢ *Unstable operation*

$V_{IN} > V_{OUT} > 0$

In steady-state, D_1 rises:- V_{OUT} rises

& S_1 on:- V_{OUT} rises

$V_{OUT} > V_{IN} > 0$

In steady-state, D_1 rises:- V_{OUT} rises

but S_1 on:- V_{OUT} falls

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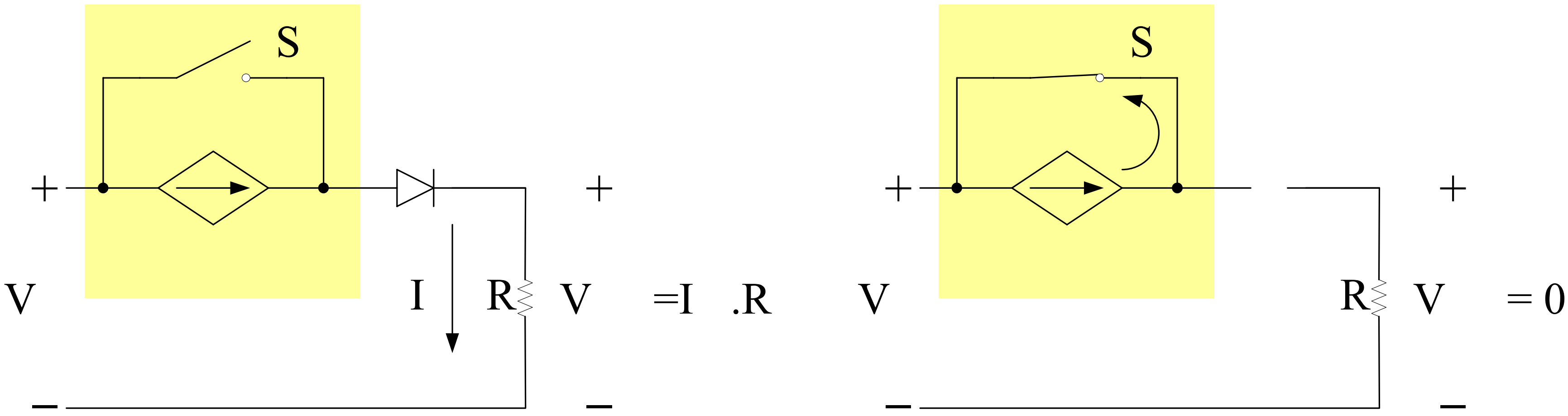
Hysteretic Control in Boost Converters: Proposed Concept



For $I_{CS} > I_{O(desired)}$

- With switch S open, $V_{OUT\ (EQL)} = (I_{CS})(R_{OUT}) > V_{O(desired)}$
- With switch S closed, $V_{OUT\ (EQL)} = 0$

Now, $0 \leq V_{OUT} \leq (I_{CS})(R_{OUT})$

A

➢ **V_{OUT} hysteretically regulated by controlling duty cycle D_A**

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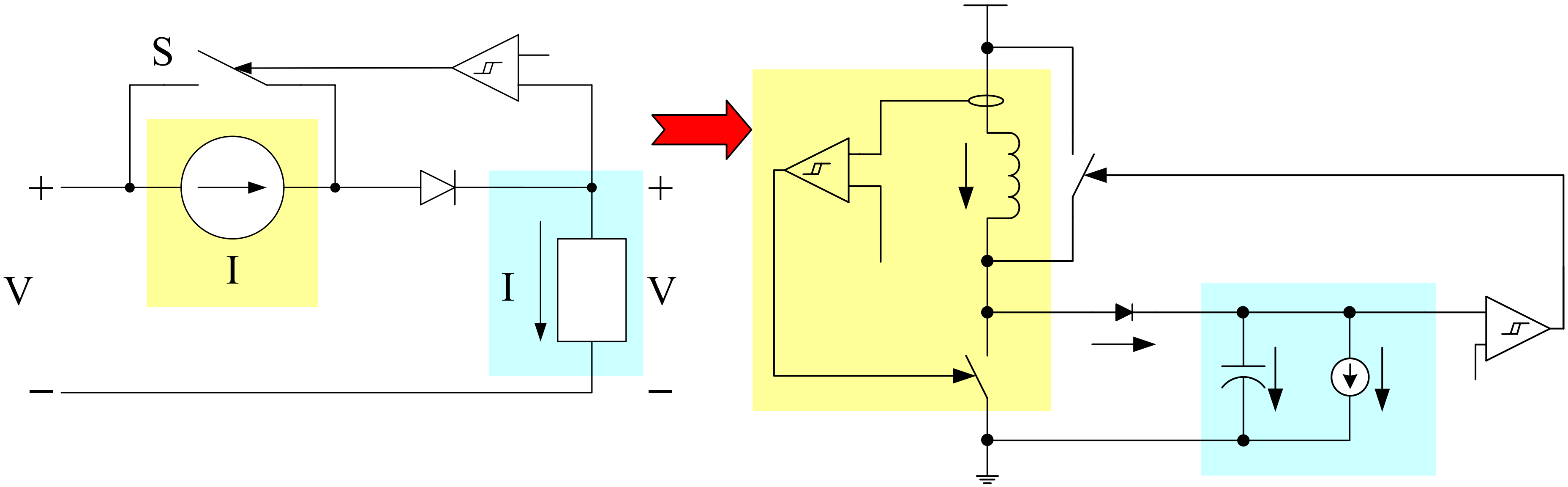
Hysteretic Control in Boost Converters: Implementation 1



- Fixed $I_{REF} \geq I_{LMIN} = I_{OMAX}/(1-D_M)$

✓ Very fast transient response

✓ Stable operation without frequency compensation circuits

× Poor efficiency especially at light loads

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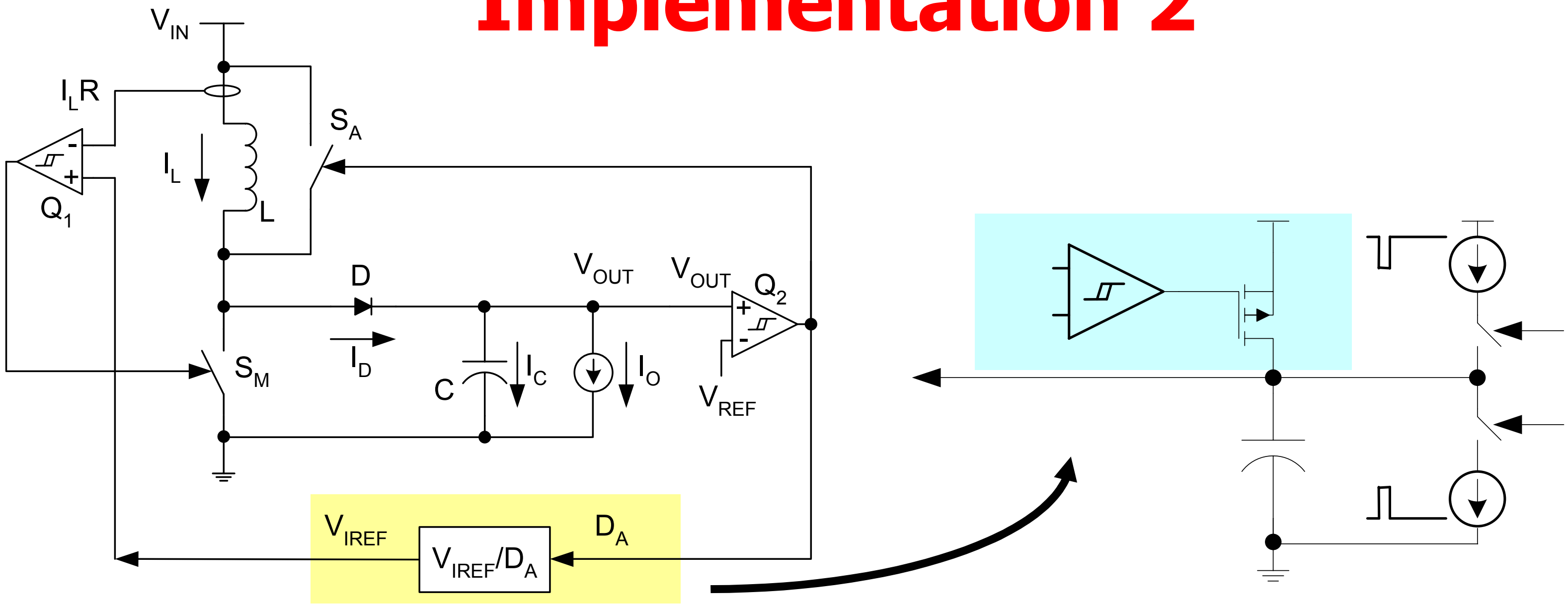
GEDC Industry Advisory Board, April 2004.

Hysteretic Control in Boost Converters: Implementation 2



- Dynamic current reference based on duty cycle D_A
- Use a D_A to V_{IREF} demodulator
- If $D_A \uparrow$ (I_L higher than required), then $V_{IREF} \downarrow$ (I_L decreases)

✓ I_L set only 5% higher than $I_O/(1-D_M)$

✓ Improved power efficiency

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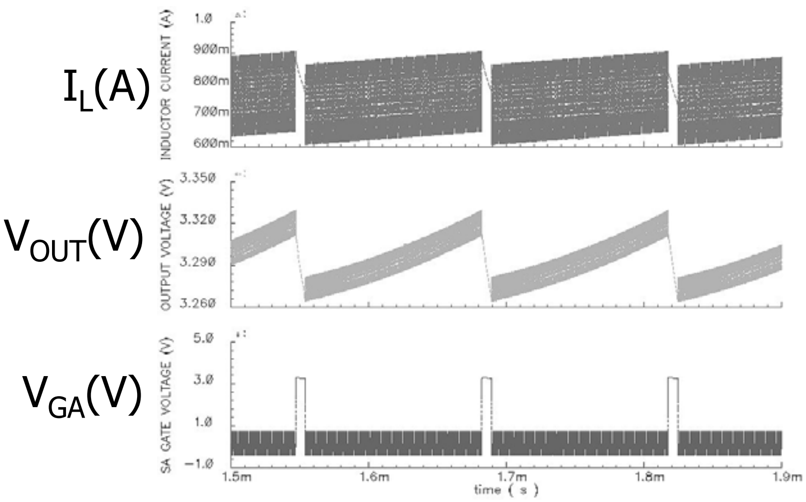
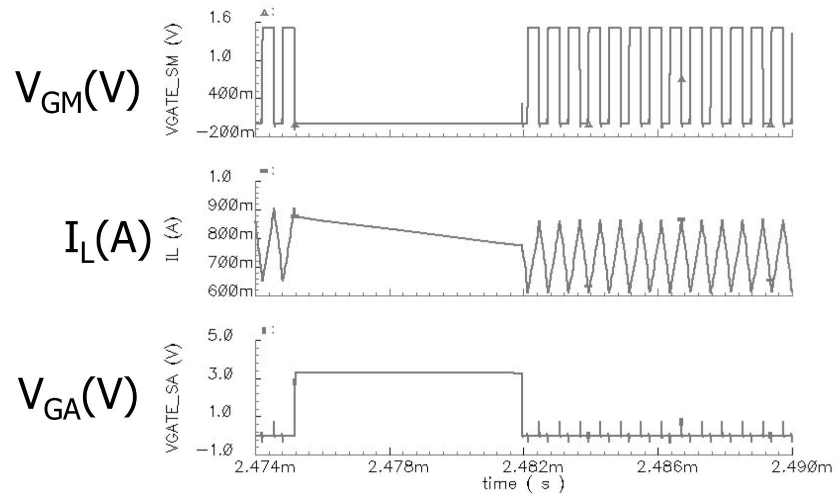
Steady-state Simulations





Specs: V_{IN} = 1.5 V, V_{OUT} = 3.3 V ± 5%, I_{OUT}= 0.1 – 1 A

- I_L free-wheels during on-time of switch S_A
- Switching f_{SW} of S_A << f_{SW} of S_M
- Steady-state duty cycle D_A ~ 5%

✓ V_{OUT} = 3.3 V ± 35mV

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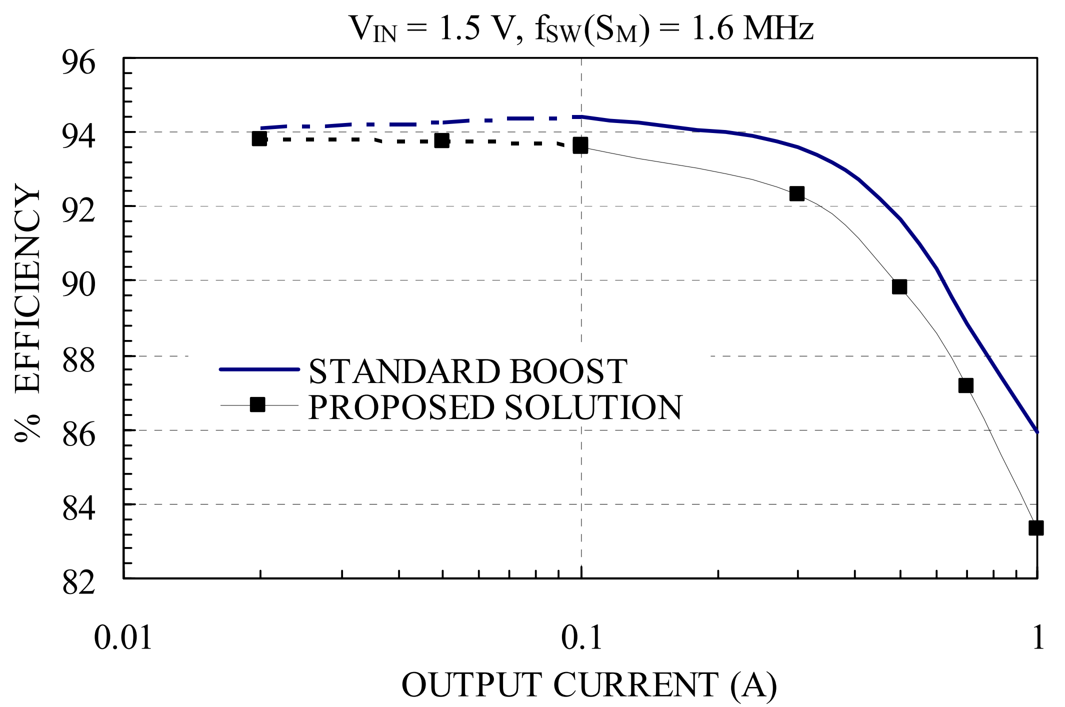
Simulated Power Efficiency



- Proposed solution has slightly lower efficiency (up to 2 % @ 1 A) compared to standard boost converter

✓ At light loads, the efficiencies are comparable

✓ At ~ 20 mA load, the efficiencies equal each other

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Summary

- Techniques to ease stability requirements in DC-DC converters reviewed
- Hysteretic control in buck converters fastest, simple and w/o compensation
- Voltage-mode hysteretic control not been used so far in boost converters
- Novel technique presented to implement hysteretic control in boost converters
- Proposed method can be used with good regulation (3.3 V ± 5%) and fast transient response without using any compensation circuit
- Efficiency degraded up to 2 % @ 1 A, but < 1% at light loads
- Solution can be used towards an increased degree of integration in DC-DC converters – without an external frequency compensation circuit

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