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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Masking LCR (and/or ESR) Parameters</th>
<th>RHP Zero Elimination</th>
<th>Adaptive control</th>
<th>Boundary control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feedforward</td>
<td>Modified Hysteric</td>
<td>Constant capacitor discharge</td>
<td>Output peak control</td>
</tr>
<tr>
<td>Complexity</td>
<td>Medium</td>
<td>Low</td>
<td>Highest</td>
<td>Medium</td>
</tr>
<tr>
<td>Response</td>
<td>Slowest</td>
<td>Fast</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Power losses</td>
<td>Low</td>
<td>Medium</td>
<td><strong>Low</strong></td>
<td>Highest</td>
</tr>
<tr>
<td>Output ripple</td>
<td>Low</td>
<td><strong>Lowest</strong></td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Stable – LCR variation</td>
<td>Medium</td>
<td><strong>Highest</strong></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Versatility</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Conclusion**

Hysteretic control based scheme to be extended to boost converter
# Issues with Hysteretic Control in Boost Converters

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

- **Vin** > **Vout** > 0

  *In steady-state, D1 rises:*  
  **Vout** rises
  & **S1** on:*  
  **Vout** rises

- **Vout** > **Vin** > 0

  *In steady-state, D1 rises:*  
  **Vout** rises
  *but S1 on:*  
  **Vout** falls
Hysteretic Control in Boost Converters: Proposed Concept

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

Now, $0 \leq V_{OUT} \leq (I_{CS})(R_{OUT})$
- $V_{OUT}$ hysteretically regulated by controlling duty cycle $D_A$
Hysteretic Control in Boost Converters: Implementation 1

- Fixed $I_{\text{REF}} \geq I_{\text{LMIN}} = I_{\text{OMAX}}/(1-D_M)$
  - Very fast transient response
  - Stable operation without frequency compensation circuits
  - Poor efficiency especially at light loads
Hysteretic Control in Boost Converters: Implementation 2

- Dynamic current reference based on duty cycle $D_A$
- Use a $D_A$ to $V_{\text{IREF}}$ demodulator
- If $D_A$ (I_L higher than required), then $V_{\text{IREF}}$ (I_L decreases)
  - I_L set only 5% higher than $I_O/(1-D_M)$
  - Improved power efficiency
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 $D_A \sim 5$

✓ $V_{OUT} = 3.3$ V ± 35mV
• 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
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