SHARED INDUCTOR
POWER CONVERTERS

For Use In Mobile Battery Charging and Backlighting

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Power In Mobile Devices

- Do you:
  - Have a smart phone?
  - Care about its size?
  - Care about its price?
  - Expect to charge it from any USB port?
  - Want to use it while it charges?

- Yes? Turns out you are not alone!
  - You and others like you put difficult constraints on mobile device’s power systems.

- The proposed converter aims to reduce the size and cost of mobile devices by combining the battery charging converter and the backlighting converter into a single shared inductor converter.
Typical Mobile Power Architecture

- Mobile devices contain several power converters
  - 1 battery charger followed by several other converters
  - Each with their own inductors
- Inductors are one of the biggest and most expensive passive components
Charger Utilization

- Battery charging circuit is idle the vast majority of the time
- Takes up precious space and cost
- Need internal charger to charge from USB
- Can we share an inductor with another converter during charging?

Percentage Time Spent

- Charging 5%
- Standby 95%
Shared Inductor Introduction

- Simple single input multiple output shared inductor converter
- Switches are operated in a manner such that the current in the inductor is proportional to the sum of the output currents
Even simpler single input multiple output shared inductor converter

Replace inductor with current source

Switches turn on one by one for a time proportional to their output current
Previous Work

- Single Input Multiple Output
- Multiple Input Single Output
- Multiple Input Multiple Output
- Multiple Input Multiple Output w/Battery
Previous Work

- Single Input Multiple Output
- TI Part: TPS65136
Previous Work

- **Multiple Input Single Output**
Previous Work

- **Multiple Input Multiple Output**
Previous Work

- Multiple Input Multiple Output w/Battery
Previous Work

- Single Input Multiple Output
- Multiple Input Single Output
- Multiple Input Multiple Output w/Battery
Previous Work – Shared Inductor Charger

- Common problem in shared inductor converters:
  - Coupling between outputs
  - Changes in one output affect the other

\[ I_{\text{out}1} + I_{\text{out}2} = \text{Inductor Current} \]
Previous Work – Shared Inductor Charger

- Discontinuous Current Mode (DCM) solves this
  - Inductor current starts at zero every time the converter switches outputs
  - Inductor current at any one point in time is only related to a single output
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Proposed Converter

• Combine battery charger and backlight converter
  • Battery only concerned with slow time average charging current
  • Insensitive to fast transients caused by the backlight
• Coupling Tradeoff
  • Reduce coupling from battery to backlight
  • Increase coupling from backlight to battery
• Backlight voltage spec is not as tight as others (e.g. CPU)
Proposed Converter

- \( V_{\text{in}} = 5V \) USB
- \( V_{\text{batt}} = 3.4V \) LiPo
- \( V_{\text{out}} = 24V \) LED Backlighting
Operational Modes

• Four modes of operation
  • **Input has excess of power**
    • Regulate output voltage and battery charging current
  • **Input cannot support desired charging current**
    • Regulate input voltage to max power point (MPP), regulate output voltage, and give battery leftover energy
  • **Input cannot support output load**
    • Regulated input voltage to MPP, regulate output voltage, and use battery for portion of input
  • **Input absent**
    • Regulate output voltage, traditional boost from battery
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Operational Modes

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Work Items

1. Design and implement control of switches in each of four modes of operation
2. Design and implement smooth transitions between different modes of operation
3. Minimize cross-regulation between backlight output and battery charging
Potential Problems

• Very high battery charging current at the same time as very low backlight current
  • Can’t give backlight current every cycle
  • Skip cycles that don’t require current

• Switches are sized for battery charging current
  • Bigger with more capacitance
    • Degrades efficiency when not charging
  • Use only a portion of the switches during these times
Performance Goals

Short Term (MEng)
- Working operation in all four operational modes
- Cross-regulation minimized between backlight and battery
  - Less than 10%

Long Term (Commercial Product)
- Efficiency comparable to traditional topology (Pout/Pin)
  - Within 5%
- Physical size of power system reduced
  - Δ > 225 mm²
- Cost of passive components (inductors) reduced
  - Δ > $0.25
## Proposed Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Project Name</th>
<th>Days</th>
<th>Start</th>
<th>End</th>
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<tbody>
<tr>
<td>1.0</td>
<td><strong>Shared Inductor Converter</strong></td>
<td>156</td>
<td>1-Jul</td>
<td>4-Dec</td>
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</tbody>
</table>

### 1.1 Design Phase

| 1.1.1 | Design control loop for mode 1 | 10   | 1-Jul | 11-Jul |
| 1.1.2 | Test control loop for mode 1   | 3    | 11-Jul| 14-Jul |
| 1.1.3 | Design control loop for mode 2 | 10   | 14-Jul| 24-Jul |
| 1.1.4 | Test control loop for mode 2   | 3    | 24-Jul| 27-Jul |
| 1.1.5 | Design control loop for mode 3 | 10   | 27-Jul| 6-Aug  |
| 1.1.6 | Test control loop for mode 3   | 3    | 6-Aug | 9-Aug  |
| 1.1.7 | Design control loop for mode 4 | 10   | 9-Aug | 19-Aug |
| 1.1.8 | Test control loop for mode 4   | 3    | 19-Aug| 22-Aug |
| 1.1.9 | Design smooth operational mode transitions | 10   | 22-Aug| 1-Sep  |
| 1.1.10| Test mode transitions          | 3    | 1-Sep | 4-Sep  |

### 1.2 Iteration Phase

| 1.2.1 | Optimize Vout loop compensation | 5    | 4-Sep | 9-Sep  |
| 1.2.2 | Optimize batt loop compensation | 5    | 9-Sep | 14-Sep |
| 1.2.3 | Optimize Vin loop compensation | 5    | 14-Sep| 19-Sep |
| 1.2.4 | Test optimized system           | 10   | 19-Sep| 29-Sep |

### 1.3 Implementation Phase

| 1.3.1 | Implement control scheme in realizable schematic | 14   | 29-Sep| 13-Oct |
| 1.3.2 | Test realizable schematic                 | 5    | 13-Oct| 18-Oct |
| 1.3.3 | Layout circuit in silicon                | 17   | 18-Oct| 4-Nov  |
| 1.3.4 | Test circuit including layout parasitics  | 5    | 4-Nov | 9-Nov  |
| 1.3.5 | Design test PCB                         | 4    | 9-Nov | 13-Nov |
| 1.3.6 | Test 1st silicon                        | 21   | 13-Nov| 4-Dec  |
Recap

Battery Charger
Rarely Used

Backlighting

Vin

Load

$\$$
Recap

Battery Charger
Rarely Used

Backlighting

Combine Into Shared
Inductor Converter

|$\\$

Vin

Load

Vout

Vin

Load

Vout

$