Nuances in Ultra-Low Power Designs for Wearable Products

Steven Schnier and Chris Glaser
March 2016
Why is Low Power Needed?

- Wearables consist of many functions
  - Small Battery with Charger
  - Display (AMOLED, PMOLED, LCD, eInk, etc.)
  - Radio (BLE, WLAN, LTEM, etc.)
  - MCU (microcontroller to mobile chipset)
  - Sensors (6-axis sensor, temperature, humidity, light, heart rate, etc)
  - Vibration Motor
- How long the battery lasts depends on carefully managing each function
Why is Low Power Needed?

• Wearable Device Power
  – Requires Small Size to be Worn on the Body
  BUT
  – More Functionality = Greater Power Usage
  – Greater Power Usage = Larger Battery Capacity
  – Larger Battery Capacity = Larger Physical Size

• A better approach:
  – Create separate power domains for each key function
  – Determine the best power approach and maximize the solution based on
    • Function
    • Size
    • Cost
Optimizing Power Domains

• Complex Wearable Systems = Multiple Power Domains

• Some domains focus on lowest leakage when off
  – Good candidates are radio’s and highly duty cycled functions that are not time dependant

• Some domains focus on lowest power when in standby
  – Good candidates are processors and sensors that are low power in standby, but need to be able to respond quickly

• Some domains focus on highest efficiency when in use
  – Good candidates are the highest power consumption devices

• Additionally, for the best “Out of the box experience” you need to ensure that the battery does not die while the product is on the shelf ready for sale!
Low Off Current – Ship Mode

• Choose an architecture that can disconnect the battery from the rest of the system for the lowest leakage when the device is being shipped or on the shelf

• Power Path chargers have a BAT FET that enables this function to ~2nA at room temp!

Example: bq25120
Low Off Current – True Disconnect Switch

• When a sub-system is ‘off’ → you want 0 current consumption
  – This is not physically possible – some nA always remain
• All systems have leakage currents
  – This is the current consumed when it is ‘off’
• Different DC/DC topologies have different leakage paths

Leakage is mainly in high-side FET

Leakage is in low-side FET and to output!
Removing boost converter leakage

TPS61046 contains an internal isolation switch to separate Vin from Vout.
Low Off Current – Load Switch

• For devices that don’t have load disconnect switches, a load switch can provide the same function

• Standalone load switches can be used, or they can be integrated into a larger battery management IC

• The bq25120 has a load switch that can be configured as a regulated LDO output if needed

• The input can be run from the battery, or from the DC/DC converter to optimize efficiency

Example: bq25120
Low Quiescent Current ($I_Q$)

• What is $I_Q$?
  – “Current drawn by the IC in a no-load and non-switching but enabled condition”
  – Current required to operate the IC (and nothing else)
  – Does not include: load/leakage on output, FB (feedback) resistor current, switching required to keep Vout in regulation, etc.
  – Not no-load input current!
  – Useful for comparing the low-power performance of different ICs
  – Not useful for estimating power drawn in your system’s standby state

See $I_Q$: What it is, what it isn’t, and how to use it for a thorough explanation
Buck $I_Q$

- Almost always drawn from $V_{in}$
- TPS62743 $I_Q$ specification:

<table>
<thead>
<tr>
<th>$I_Q$</th>
<th>Operating quiescent current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$EN = V_{IN}, V_{OUT} = 0\mu A, V_{OUT} = 1.8V$, device not switching</td>
</tr>
<tr>
<td></td>
<td>$EN = V_{IN}, V_{OUT} = 0mA, V_{OUT} = 1.8V$, device switching</td>
</tr>
</tbody>
</table>

IC enabled

No-load input current (IC switching)

- For a buck, no-load input current is usually slightly greater than $I_Q$
- Do you have no load or just a very light load (some $\mu A$ or 100s of nA)?
The power of an ultra-low $I_Q$ buck

**TPS62125**: $13 \mu A$ $I_Q$

**TPS62743**: $360 \text{nA } I_Q$

50% efficiency at 30 $\mu A$ load

91% efficiency at 30 $\mu A$ load

50% efficiency at $< 1 \mu A$ load!
Boost $I_Q$

- Some drawn from $V_{in}$ but usually some drawn from $V_{out}$ as well
  - $V_{out}$’s $I_Q$ ultimately comes from $V_{in}$ → creates higher no-load input current
- TPS61220 $I_Q$ specification:

<table>
<thead>
<tr>
<th>$I_Q$ (µA)</th>
<th>$V_{IN}$</th>
<th>$I_Q = 0$ mA</th>
<th>$V_{EN} = V_{IN} = 1.2$ V, $V_{OUT} = 3.3$ V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>5</td>
<td>0.9</td>
</tr>
<tr>
<td>7.5</td>
<td></td>
<td>7.5</td>
<td></td>
</tr>
</tbody>
</table>

- Resulting no-load input current:

Most current is drawn from $V_{out}$!

No-load input current = 20 µA!!
High Efficiency at Full Load

- Light load efficiency is dependent on $I_q$ and switching losses.
- Full load efficiency is dependent on:
  - The ratio of input and output voltages.
  - The resistance of the FET from drain to source ($R_{DSON}$) when conducting.
  - The DCR of the inductor.

Example: bq25120 using inductor with 240mΩ DCR.
Wearables Solutions Coverage

**Audio Devices**
- **bq2510x**
  Smallest Linear Charger
- **TPS62743**
  Smallest Low Iq DC/DC Converter

Smallest Solution IF power path and I2C configurability is not needed

**Activity Monitor**
- **bq25120**
  Meets all basic functional requirements
  Smallest Solution Size and Lowest Power Consumption

**Activity Monitor With Display**
- **bq25120**
  Add **TPS61046** boost for display
  Add **TPS62743** buck if needed
  Most Flexible Solution

**Activity Monitor With Display and Additional Features**
- **bq25120**
  Add **TPS62770** for boost and buck and current sink

Smallest Solution for Full Featured Applications

**Sports Watch With Display and Full Featured**
- **bq25120**
  Add TPS62770 for boost and buck and current sink

Smallest Solution for Full Featured Applications
**bq25120: Battery Management for Wearables**

**Low Iq Linear Charger with Power Path Management, PWM Output, Load Switch, Voltage Based Battery Monitor, and Push-Button Reset**

### Features

1. **Low battery current draw (Iq)**
   
   < 750nA (typ) BAT Iq with 1.8V Output Enabled
   < 50nA (typ) BAT Iq in Shipmode
   
   Low Iq allows wearables to be always-on without draining the battery. Shipmode allows shipping the device with the longest battery shelf life.

2. **Small size**
   
   2.5mm x 2.5mm WCSP Package
   15 mm² solution size (components)

3. **Integration**
   
   **Linear Charger:** 300mA, 3.4V-5.5V input, 20V max
   **LDO:** 100mA
   **Buck Converter:** 300mA, 2.2V- 6.6V input
   **Power path (switcher)**
   **Load switch**
   **pushbutton control**
   **battery voltage monitor:** Accurate 2% VBATREG

   I2C programmable flexibility to set all key parameters including ICHG, VBATREG, ITERM

### Applications

- Fitness Accessories
- Smart Watches and other Wearable Devices
- Health Monitoring Medical Accessories
- Rechargeable Toys
bq25120 – Application Schematic

HOST can control CD, ILIM, TERM, ISET, Hi-Z, LS/LDO, SYS VBATREG, TIMER, RESET, VINDPM, SHIPMODE and see STATUS and FAULTS.

HOST

SDA
SCL
INT
SW
BAT
MR
BQ25120
MCU / SYSTEM+
NTCTS
LS / LDO
<100mA
Load
IN
SYS
RESET
LSCTRL
VINLS
Unregulated Load
PMID
PG

For temp sensing - OPTIONAL

For Radio, Sensor, Motor or other infrequently used functions

Load Switch / LDO input

For default and non-HOST Operation - OPTIONAL
Solution with bq25120 (PMP11311)

For Activity Monitor With Display and Additional Features

- bq25120
- bq51003 for Wireless Charging
- TPS61046 boost for OLED display
- TPS61240 boost for Heart Rate Monitor or LCD display
- TPS62743 buck

Most Flexible Solution
**TPS62770**
Tiny single-chip dual solution with 360nA Iq Buck and up to 15V Boost in WCSP

**FEATURES**
- VIN range 2.5V to 5.5V
- 1x 360nA Iq buck converter (300mA)
  - VOUT selectable with VSEL1-3
  - 1.0V, 1.05V, 1.1V, 1.2V, 1.8V, 1.9V, 2.0V, 3.0V
- 1 x Slew rate controlled load switch
- Discharge on VO1 / Load
- 1 x Dual mode boost converter
  - Mode selection with BM pin
  - LED current driver with PWM to current conversion (max $V_{FB}$ voltage 200mV @ D = 100%)
  - Adjustable constant output voltage up to 15V ($V_{FB}$ 0.8V)
- Tiny CSP16 package, 1.65mm x 1.65mm x 0.5mm, Pitch 0.4mm

**BENEFITS**
- RF Friendly DCS-Control™
- Discharge VOUT
- On board LOAD Switch to disconnect sub-system to extend battery run time
- Minimum external components to optimize board space
- Cover wide range of applications with single device
- Total solution-size: only 21mm². 12% smaller solution compared with TPS62743+TPS61046.

**APPLICATIONS**
- MCU, BLE and Sensor Supply
- Wearable Electronics( HRM, PMOLED, Backlight display)
- Medical Healthcare
- Home Automation (IoT)
TPS62770 Solution 1: Powering PMOLED with BQ25100

Two chip power solution without
power path management:

BQ25100
(1.6 mm x 0.9 mm WCSP)

+ 

TPS62770
(1.65mm x 1.65mm WCSP)
Or use as standalone!
TPS62770 Solution 2: Driving LED in Series for Backlight Display
TPS62770 Solution 3: Driving Green LED for HRM