SimpleLink™ Ultra low power Wireless MCU

Jarle Boe
Texas Instruments
CC26xx/CC13xx Ultra Low Power Wireless MCUs
Multiprotocol Platform

Improving the three key challenges:

<table>
<thead>
<tr>
<th>Easiest to design with</th>
<th>Lowest Power</th>
<th>Most Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Software Development Kits</td>
<td>• ~ 6mA Radio peaks and 1uA Sleep</td>
<td>• 4x4 QFN</td>
</tr>
<tr>
<td>• Get-Started Documentation &amp; Wiki</td>
<td>• ~ 61μA/MHz ARM Cortex M3</td>
<td>• On-Chip Flash</td>
</tr>
<tr>
<td>• Dynamic Design Kits</td>
<td>• &lt;10 uA avg. Current @ 1s BLE</td>
<td>• Single Ended Output</td>
</tr>
<tr>
<td>• Low-cost Tools</td>
<td>• Sensor Controller Engine (SCE)</td>
<td>• Integrated DCDC</td>
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Comprehensive Design Support
Multi-year operation on a coin cell
Complete Bluetooth Smart system on a finger-tip size
SimpleLink CC26xx/CC13xx Architecture

Quick Facts

Ultra-low Power Consumption
- 61 µA/MHz ARM Cortex M3
- 8.2 µA/MHz Sensor Controller
- 1 µA sleep with retention and RTC
- 5.9 mA RX (single-ended)
- 6.1 mA TX (single-ended)
- <3µA while running 10 ADC samples/s

SoCKey Features
- Autonomous sensor controller engine
- 4x4, 5x5, and 7x7 mm QFN
- 1.7 - 1.95 V or 1.8 – 3.8 V supply range
- 128 KB Flash + 8 KB Cache
- 20 KB RAM

RF Key Features
- +5/+15 dBm output power (2.4GHz/Sub1GHz)
- -97/-120 dBm sensitivity (2.4GHz/Sub1GHz)
- Supports 2.4GHz and 915/868/433 MHz
- Pin compatible and SW compatible across protocols and frequency bands
The lowest power: Go battery-less

Designed for low-power operation

- Multi-year on a coin cell
- Faster processing
- Optimized radio
- Ultra low sleep current
- Less than 0.15 µA in shutdown
- Unique integrated Sensor Controller

### Ultra-low power

<table>
<thead>
<tr>
<th>When</th>
<th>Parameter @ 3V</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>While processing</td>
<td>µA/MHz on ARM® Cortex®-M3</td>
<td>61 µA/MHz</td>
</tr>
<tr>
<td></td>
<td>Coremark/mA</td>
<td>48.5</td>
</tr>
<tr>
<td></td>
<td>Coremark @ 48MHz CPU</td>
<td>142</td>
</tr>
<tr>
<td>While communicating</td>
<td>Peak current RX</td>
<td>5.9 mA</td>
</tr>
<tr>
<td></td>
<td>Peak current TX</td>
<td>6.1 mA</td>
</tr>
<tr>
<td>While sleeping</td>
<td>µA/MHz on Sensor Controller</td>
<td>8.2 µA/MHz</td>
</tr>
<tr>
<td></td>
<td>Sleep mode with RTC and full memory retention</td>
<td>1 µA</td>
</tr>
</tbody>
</table>

Best-in-class ULPBench score of 143
MULTI-STANDARD: Five technologies, one architecture

**Application MCU**
- Application
- Profiles / services
- TI RTOS
- Peripheral drivers and libraries
- Royalty free protocol stacks

**Peripherals / modules**
- DC/DC converter
- Temp/battery monitor
- AES
- GPIO
- Timers
- UART / SPI
- I2C / I2S
- DMA

**Radio**
- Sensitivity -97dBm BLE
- Power output:
  - +5dBm @ 2.4 GHz
  - +15dBm @ Sub-1 GHz
- Integrated firmware
- LinkLayer in ROM

**Sensor controller engine**
- ADC and comparators
- Digital sensor readings
- Capacitive sensing

**Memory**
- 128 KB Flash
- 8 KB cache
- 20 KB SRAM

**QFN package options:**
4x4mm, 5x5mm, 7x7mm

ARM® Cortex®-M3

SCE

Memory

Peripherals / modules
Low-power operation

1. When processing with MCU
   - Fast processing using less than 3 mA @48MHz
   - Less time used for stack and application processing and BLE connection events

2. When in sleep
   - Sleep Current:
     - 1 µA Sleep with RTC and full retention
     - Less than 0.15 µA in Shutdown

3. When peripheral is polled for data
   - Sensor controller and its peripherals can be powered while rest of system is power off.
   - Run Sensor Reading with < 5 µA current consumption

4. When radio is in Receive or Transmit
   - ~6mA RX / TX current
Create – develop - prototype – 3D print

Intuitive cloud interface

3D printable

Expandable

Small size

Open design files

Low cost

Intuitive cloud interface

3D printable

Expandable

Low cost
Power Solutions for Smart Wireless Sensor Applications

Extending application run time: an example

Thomas Hoffmann
Marketing
Low Power DC-DC Solutions
Internet of Things and Smart Controls
Examples of Wireless Sensors

Wireless Sensors like:
• Water-Meter
• Gas-Meter
• Heat-Cost-Allocator
• Smoke-Detector
• Climate Control
• Connected Home
• ....

What other applications could you think of?
Internet of Things and Smart Controls
Examples of Wireless Sensors

Wireless Sensors like:
• Water-Meter
• Gas-Meter
• Heat-Cost-Allocator
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• ....

Common challenge:
Achieve a long application life for a satisfying user experience

How do you reduce battery current?
Internet of Things and Smart Controls
Examples of Wireless Sensors

Wireless Sensors like:
• Water-Meter
• Gas-Meter
• Heat-Cost-Allocator
• Smoke-Detector
• Climate Control
• Connected Home
• ....

Typical goals for these Systems:
1. Application should run for many years
2. Application only operates in full mode for a fraction of its life time
3. During standby the system should consume now power but instead during communication requires peak currents
Increasing application run-time with DC-DC conversion

Comparing CR2032 discharge with DC-DC versus no DC-DC

- VBAT open circuit no DC/DC
- VBAT open circuit with DC/DC
- VBAT under load no DC/DC
- VBAT under load with DC/DC

Pulse Load: 15mA for 3ms, 17ms Pause
no Buffer Capacitor,
Step down DC/DC = TPS6223x -2.0V VOUT

e⇒ Runtime up by ~20% using DC/DC
Low-Power Microcontroller + Power concept

Implementation today:
System powered directly from battery

Batteries in smart controls:
• Li–Manganese dioxide (Li-MnO₂) 3V; Primary (Coincell)
• Li-Ion 4.35V – 2.3V - Rechargable
Low-Power Microcontroller + Power concept

Implementation today:
System powered directly from battery

New Power Concept:
Optimized with DC/DC conversion

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Low-Power Microcontroller + Power concept

Implementation today:
System powered directly from battery

- Low Power Controller (MSP430)
- Low Power Wireless (CCXXXX)
- Sensors

Batteries in smart controls:
- Li–Manganese dioxide (Li-MnO₂) 3V; Primary (Coincell)
- Li-Ion 4.35V – 2.3V - Rechargable

New Power Concept:
Optimized with DC/DC conversion

- Ultra Low Power Buck converter – ALWAYS ON
- Load switch

- Ultra low Iq enables an ALWAYS ON buck converter
- Load switch to disconnect leaky subsystems
- Increase battery life time

Texas Instruments
TPS62730
30nA step down converter with bypass

Features

- VIN range 1.9V to 3.8V
- 100mA output current
- 30nA Bypass operation
- 3MHz switching frequency
- Efficiency optimized for 10mA-30mA output current, Fsw ~ 2MHz
- Quiescent current typ. DC/DC (20uA)
- 2W typ. bypass switch between $V_{IN}$ & $V_{OUT}$
- 1x1.5mm SON Package

Applications

- CC2540 Bluetooth Low Energy
- Low power RF metering
- RF4CE
Extending application run time
TPS62730 and CC2540 Bluetooth® low energy system
Why RF friendly DC/DC converter?

Spurious noise comparison with CC2540 2.4GHz 0dBm Constant Waveform

CC2540 directly powered from 3V

CC2540 powered with TPS62730 with VOUT 2.1V, VIN 3V

CC2540 powered with Non-RF friendly DC/DC (ultra low power, low switch frequency) VOUT 2.5V, VIN 3V

!Slow switching DC/DC converter with high output ripple voltage (50mVpp) generates significant side bands near the transmission frequency and impacts peak output power!
## Low Power DC/DC Solutions for IoT Examples

<table>
<thead>
<tr>
<th>Boost with LDO &amp; Load Switch TPS61098</th>
<th>Boost w/ bypass TPS61291</th>
</tr>
</thead>
<tbody>
<tr>
<td>o 300 nA Ultra-Low IQ in Low Power mode</td>
<td>o 200mA/3.3V output from 1.8 VIN</td>
</tr>
<tr>
<td>o Selectable Output Voltage Up to 4.3 V</td>
<td>o Bypass mode with 15nA $I_Q$, Boost mode with &lt;6μA $I_Q$</td>
</tr>
<tr>
<td>o Integrated LDO/Load Switch</td>
<td>o Selectable fixed output voltages: 3.3V, 3.0V, 2.5V</td>
</tr>
<tr>
<td>o Automatic pass-through</td>
<td>o Internal feedback divider disconnect</td>
</tr>
<tr>
<td>o Active Mode: Dual Outputs from Boost and LDO/Load Switch; Low Power Mode: LDO/Load Switch Shut Down, Boost On</td>
<td>o Minimum operating input voltage 0.9V</td>
</tr>
<tr>
<td></td>
<td>o 2x2mm2 SON 6 pin package</td>
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</tbody>
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<table>
<thead>
<tr>
<th>400-nA quiescent current Buck TPS62745</th>
</tr>
</thead>
<tbody>
<tr>
<td>o 10V supply; 4-pin output voltage select in 100mV increments</td>
</tr>
<tr>
<td>o Integrated $V_{IN}$ switch to connect ADC voltage test</td>
</tr>
<tr>
<td>o DCS-Control™ architecture maintains stable output voltage through fast line and load transient response</td>
</tr>
<tr>
<td>o TPS62740 for 5Vin and TPS82740 module solution (L&amp;C integrated) with &lt;7mm² total footprint</td>
</tr>
</tbody>
</table>

**2MHz, 0.3A output Buck TPS62125**

- DCS-Control™ topology
- Adjustable ENABLE threshold and hysteresis
- High efficiency over entire load and supply voltage range
- Wide input voltage range: 3V - 17V
- 100% Duty Cycle for Lowest Dropout

**Boost w/ bypass TPS61291**

- 200mA/3.3V output from 1.8 VIN
- Bypass mode with 15nA $I_Q$, Boost mode with <6μA $I_Q$
- Selectable fixed output voltages: 3.3V, 3.0V, 2.5V
- Internal feedback divider disconnect
- Minimum operating input voltage 0.9V
- 2x2mm² SON 6 pin package
Additional information
Power solutions for smart sensors

When batteries don’t like peak currents:
Energy Buffering for Long-Life Battery Applications
➤ Check design PMP9753
  www.ti.com/tool/pmp9763

Current Savings in CC254x Using the TPS62730
➤ Check Application Note swra365
  www.ti.com/lit/pdf/swra365
The science lab that fits in your pocket and enables hands-on learning
$$\omega = \frac{v}{r}$$

$$\theta = \frac{S}{r}$$

**Axis of rotation**

$$\omega = 2\pi f$$

*f = frequency in revolutions/s*
X Rotation Velocity: -6.5 °/sec
Y Rotation Velocity: -9.0 °/sec
Z Rotation Velocity: -6.9 °/sec
How PocketLab Works

Built-in Sensors
- Barometer
- Accelerometer
- Temperature
- Gyroscope
- Magnetometer

Wireless Data Streaming

Data Storage
- Free Forever
- Subscription

Cloud Software

Advanced Analysis

User Community

PocketLab Data

INSTRUMENTS
PocketLab Design Process
PocketLab Inspiration: I needed a tool to quickly and easily make experimental measurements.
Alpha Prototyping: is our fundamental idea useful to teachers and students?

- 2-3 months of brainstorming, prototyping, and interviewing potential customers
- Wired analog sensors
- Development kits: TI SensorTag, Electric Imp
- Non-functional mechanical mockups
Beta Prototyping: how do we design the PocketLab system to meet customer needs?

- The lab is an ideal testing environment, the real world has many more challenges
- Feedback on: functionality, compatibility with device platforms, ease-of-use, pricing, robustness, interface, colors, and more
Design Iteration: how do we incorporate the user feedback into the production design?

• Prioritize customers needs
• Translate customer needs into engineering tasks and metrics
• Balance the needs of the customer and the resources and capabilities of our team
Production design: how do we build it and how many do we build?

- 6 months finalizing design and preparing for manufacturing
- Pre-orders before production via Kickstarter
- Production runs of 20, 100, 2500 units
Ongoing design: how do we improve the PocketLab experience for existing customers?

• Supporting users
• Developing experiments and lessons
• App and cloud software features that leverage the hardware