Ultra-low-power integrated radios for wireless body area networks

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Outline

- **WBAN requirements**

- **Three cases of ultra-low-power 1V SoC and MEMS-based radios**
  - icyHeart - A 1V RF & DSP SoC in 0.18um
  - WiserBAN – A 1.2V MEMS-based radio microsystem
  - icyTRX - A 1.0V BLE-compliant transceiver

- **Conclusions**
Context of Wireless Body Area Networks

WBAN and requirements for radio ICs
What is WBAN?

- Wireless Body Area Networks (WBAN) is about autonomous wireless sensors distributed in-, on-, or around a person.

- WBAN will support solutions and applications that will help people to live better, at home, at work, in hospitals and on the move.
About autonomy

- «Tomorrow»: Virtually zero-energy circuits and Energy Harvesting

- «Today»: Industry uses batteries
  - Tiny batteries: well-known, widely used, fairly reliable, more or less low-cost
  - Supply range $\sim 3V..2V$: Lithium MnO2 coin-cell
e.g. CR2032 used in many lifestyle applications, rechargeable Li cells, etc
  - Supply range $\sim 1.5V..1V$: Zn-Air, Silver-O2 button-cell
e.g. ZA13 for hearing aids, wristwatches

Source: Renata
About miniaturization

More Than Moore

Digital
Analog/RF
MEMS
Sensors
Energy Harv.

180nm
130nm
90nm
65nm
45nm
...

MEMS+RF IC

ULP RF SoC’s

More Moore

Digital radios

Source: Intel

Zero-energy RF SiP

Source: Cymbet

Source: Intel

Digital radios

Source: Cymbet

Digital radios

Source: Cymbet

Digital radios

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About flexibility

- From **simple** applications...
  - e.g. peer-to-peer sports monitors, wristbands, etc

- ...to more **complex** cases:
  - e.g. hearing aids, bio-medical applications, etc
Three representative cases
Three ULP cases for WBAN

(1) icyHeart  (2) WiserBAN  (3) icyTRX

- Low voltage
  (1V .. 1.2V)

- Low active power
  (few mW’s)

- Narrow-band radios
  (900MHz – 2.4GHz)
Three ULP cases for WBAN

<table>
<thead>
<tr>
<th></th>
<th>(1) icyHeart</th>
<th>(2) WiserBAN</th>
<th>(3) icyTRX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Complete RF SoC</strong></td>
<td>Complete RF SoC</td>
<td>Very tiny SiP</td>
<td>Tiny RF IC</td>
</tr>
<tr>
<td><strong>High link budget</strong></td>
<td>High link budget</td>
<td>Lower</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>( 110 dB )</td>
<td>( 85 dB )</td>
<td>( 95 dB )</td>
</tr>
<tr>
<td><strong>Proprietary</strong></td>
<td>Proprietary</td>
<td>Proprietary</td>
<td><strong>Standard BT LE</strong></td>
</tr>
<tr>
<td></td>
<td>( 900MHz )</td>
<td>( 2.4 GHz )</td>
<td>( 2.4GHz )</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>Average</td>
<td><strong>Good Energy/bit + Fast wake-up</strong></td>
<td><strong>Good</strong></td>
</tr>
</tbody>
</table>

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A power-efficient radio SoC for wireless ECG

Case 1 - icyHeart
Concept

- A power-efficient radio SoC for wireless ECG
  - Home patient health monitoring w. handheld device
  - Health monitoring in medical environment
  - Health monitoring in extreme environments

ECG sensors

Handheld monitor

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System-on-chip (SoC) approach

- RF, w. ADC for sensors, DSP and PMU
- PMU: Low-voltage 1.0-1.8V and 2.0-3.6V
- Real-time ECG A/D signal proc. on-chip

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Die photography

- 0.18μm, plain digital CMOS process, 5mm x 5.3mm

- RF transceiver 8%
- Digital 28%
- Oscillators & LED drivers 4%
- Sensor Interface & ADC 6%
- Power Management 6%
- Padrning 12%
- ROM 2%
- RAM 34%
Key performance

First 1V RF + DSP + ECG sensor A/D proc. on-chip

Sensor interface
- 100uW / channel (x3) - 12b ENOB acq.
- ChainFFT-256 in 2.6k clk cycles - 120µA/MHz @ 1V

Radio section
- True 1V radio
- Rx: 3.5mA (1V) with -100dBm sensitivity (FSK 200kb/s)
- Tx: -5dBm with 4.5mA (1V). 10dBm option.

Industrial grade, ready for production
Smart miniature low-power wireless microsystem for Body Area Networks

Case 2 - WiserBAN
Concept

- Miniature WBAN node integration driven by implanted and body-worn **healthcare** and **lifestyle** scenarios
A 2.4GHz RF Microsystem

- Heterogeneous microsystem – **4mm x 4mm x 1mm³** SiP
  - Miniature antennas

  SiRes MEMS
  - 2.4GHz RF & DSP SoC
  - Propagation study
  - 2.4GHz RF & DSP SoC

  WiserBAN SiP
  - BAW & SAW RF devices
  - WBAN protocol

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:: csem
SoC architecture – Rx section

- Sub-sampling RX
- RF+IF SAW/BAW filters
- Dig BB with SAR ADCs
SoC architecture – Tx section

- Direct mod TX
- BAW 2.048 GHz ref
- LF SiRes for RTC
Transmitter

- TX spectrum compliant with BT Smart and Zigbee masks
- 0dBm output power at 9.2mW, up to 4Mbps (2.3nJ/bit)
Current breakdown

- TX start-up consumption equivalent to 3us TX operation
- \(~1/36\) compared to XTAL start (1ms x 1mW = 1\(\mu\)J)
- 620nJ for 32 bytes packet at 4Mbps; 5% startup overhead

**27.5 nJ for Tx startup**

- DBB: 4%
- Bias: 5%
- (P)PA: 21%
- BAW: 30%
- LO: 30%
- Tx Synth.: 40%

**9.2 mW in Tx mode**

- DBB: 3%
- Bias: 3%
- BAW: 30%
- LO: 9%
- Tx Synth.: 23%
- (P)PA: 62%
Die photography

- 65nm CMOS
- Flip-chip within SIP module
- Tiny 4.6mm²
SiP approach (I)

- Ultimate miniaturization
- Standalone 4x4x1mm³ TRX module
- Lamination within FR4
  - MEMS
  - ASIC
  - Passives
- Cost effective mass production
SiP approach (II)

- Modular 3D stacking of 2D modules
  - 2D module with WiserBAN SoC
  - 2D module with passives, MEMS, ...
  - 2D module with miniature 2.4GHz antenna
A Low Power 2mm$^2$ 2.4GHz Transceiver for Bluetooth Smart, IEEE 802.15.4 and Proprietary Applications

Case 3 - icyTRX
Concept

- 2.4GHz transceiver (e.g. BT LE) as standalone companion chip or IP block
  - Battery powered
  - Easily plugged onto existing systems w/o system revolution
  - Tiny (<2 mm²)
  - ULP (<10 mW)
  - Easy to use & reduced BOM

icyTRX RF IC
2.4GHz IC/IP (BLE RF transceiver)

BLE Controller (protocol engine)

Applicative IC (sensor interfaces, power management, signal processing, application)

Source: RivieraWaves

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Architecture

- High degree of integration
  - RF-interface: single port, integrated matching
  - 48MHz Crystal
  - SPI / I2C interface to external controller

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Die photography

- **65nm CMOS, 2mm²**
Rx measurements

- **Sensitivity vs Temp and Supply** – 65nm version

![Graph showing sensitivity vs input power for different temperatures and supplies.]

- At 27°C, 1.1V:
  - -97 dBm @ 1Mb/s
  - -95 dBm @ 2Mb/s
  - -90 dBm @ 4Mb/s

- At 70°C, 1.32V:
  - -99 dBm @ 1.3V

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Rx measurements

Operation at 0.9V

-97 dBm @ 0.9V @ 0°C
-93 dBm @ 0.9V @ 50°C
Tx Measurements

- Output spectrum & resulting eye diagram

**Frequency = 2448 MHz**
**Power = 0 dBm**

- BLE mask
- Carrier only
- GMSK 1 Mbit/s
- MSK 1 Mbits/s

**GMSK - 1 Mb/s**

**4FSK - 4 Mb/s**
Overview – icyTRX 65nm

- Supply voltage: 1V nom.
- 250kb/s ... 4Mb/s (4-FSK)
- BTLE mode, **Receiver**
  - 1.0V: -97dBm w. 4.6mA
- BTLE mode, **Transmitter**
  - 1.1V: 0dBm w. 8.1mA
  - 1.0V: -1.5dBm w. 7.0mA
  - 0.9V: -3.6dBm w. 5.9mA
- **Fast PLL**
  - 5us settling
- **High degree of integration**
  - No external RF passives, on-chip 50ohm matching
Conclusion
In summary...

- **WBAN is a challenging category of WSN**
  - Low-energy operation: e.g. few mW active power
  - Using tiny low-voltage batteries: e.g. as low as 1V

- **Miniaturization is a must**
  - ULP RF SoC is mature for combining analog + mixed-signal + DSP + RF
  - MEMS+IC approaches bring novel perspectives in terms of miniaturization

- **Need to build on standard and/or proprietary protocols**
  - BT LE is a promising candidate but calls for innovative ultra-low-power chips

- **Three cases were shown to illustrate those challenges**
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Thanks!

- More insight on low-power microelectronics for WBAN?
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