Optimization of IoT Sensing Systems Based on Bluetooth Smart SiP Modules

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Sophia Antipolis France October 15th 2015

Agenda

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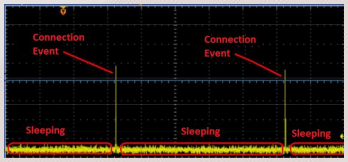
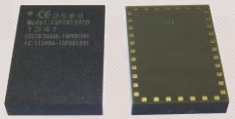
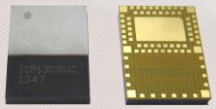
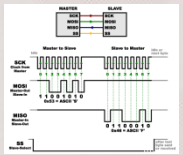
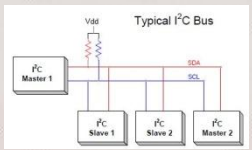
- Introduction
- Bluetooth Smart
  - Principles
  - Timing
  - Modules
- Sensors
  - Interfaces
  - Data requirements
- Optimization
- Examples
- Conclusions

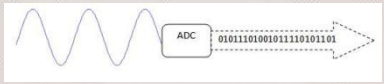




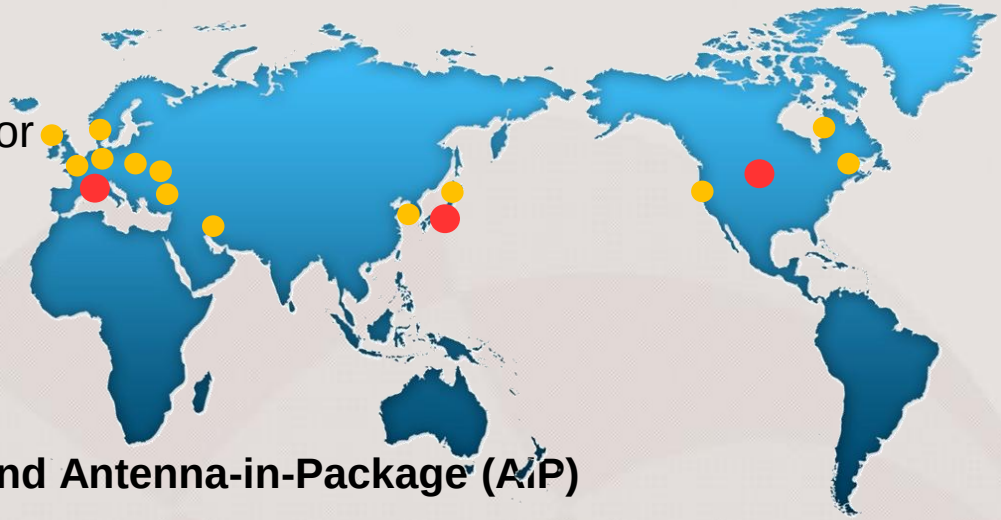






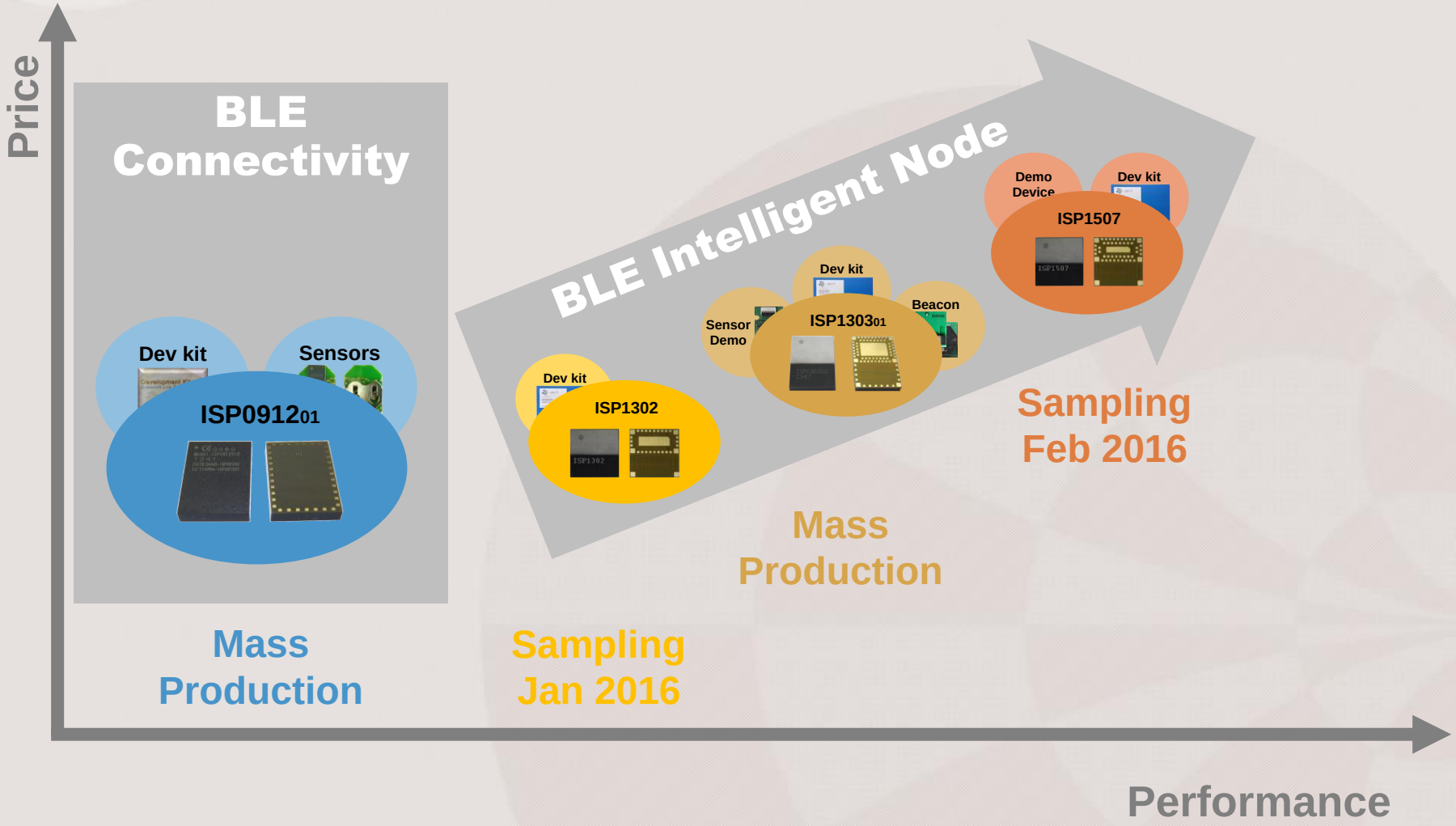


Insight SiP Profile



- **Established in 2005**
  - ✓ Founded by actual CEO and CTO
  - ✓ Core team from National Semiconductor
- **Product Lines**
  - ✓ Turn-key design services and creative packaging solutions
  - ✓ Standard modules for wireless electronic industry
- **Experts in RF System-in-Package (SiP) and Antenna-in-Package (AiP)**
  - ✓ Fabless company
  - ✓ Design & industrialization expertise
  - ✓ Design team : 9 PhD – 6 MSc
  - ✓ 12 to 15 new projects per year
- **Locations**
  - ✓ Europe – HQ and Technical team in Sophia-Antipolis (France) ●
  - ✓ North America – Subsidiary in Denver (USA) since 2008 ●
  - ✓ Asia – Sales office in Tokyo (Japan) since 2008 ●
  - ✓ Global network of distributors ●

Insight SiP SMART Bluetooth



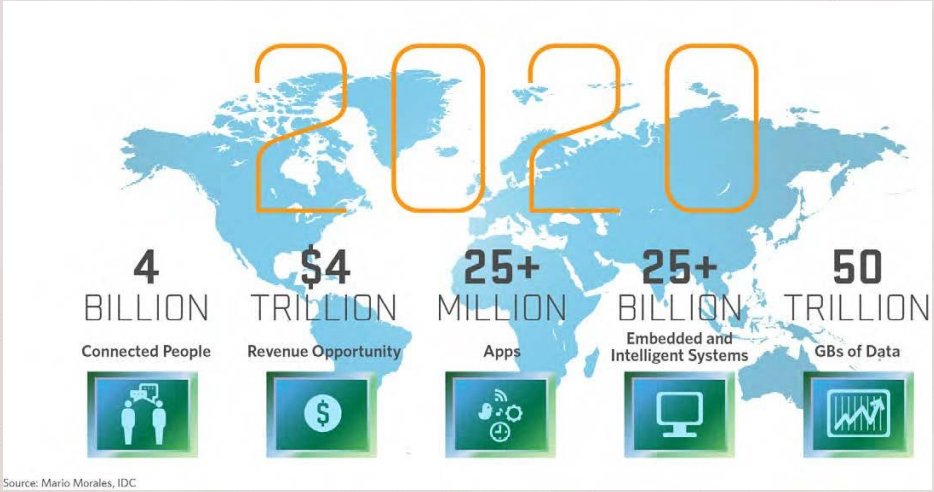
Feature Comparison

	ISP1507	ISP130301	ISP1302	ISP091201
BLE Radio	2.4 GHz + Balun + Antenna	2.4 GHz + Balun + Antenna	2.4 GHz + Balun + Antenna	2.4 GHz + Balun + Antenna
NFC	Type 2 NFC-A Tag	None	None	None
Supply Voltage	1.7 / 3.6 V + LDO + Fully Integrated DCDC	1.8 / 3.6 V + LDO + Fully Integrated DCDC	1.8 / 3.6 V + LDO External Possible DCDC	1.9 / 3.6 V + LDO + Fully Integrated DCDC
Peak current Tx	5.5 mA @ 0 dBm	10.5 mA @ 0 dBm	10.5 mA @ 0 dBm	12.7 mA @ 0 dBm
Peak current Rx	5.5 mA	12.6 mA	12.6 mA	14.6 mA
Deep sleep	0.4 µA	0.5 µA	0.5 µA	2 µA
Output Power	-20 to +4 dBm	-20 to +4 dBm	-20 to +4 dBm	-18 to 0 dBm
Rx sensitivity	-96 dBm	-93 dBm	-93 dBm	-87 dBm
CPU	32-bit ARM Cortex M4	32-bit ARM Cortex M0	32-bit ARM Cortex M0	None
Memory	512 kB flash / 64 kB RAM	256 kB flash / 32 kB RAM	128 kB flash / 16 kB RAM	None
Stack	V4.2	V4.1 + IPv6	V4.1 + IPv6	V4.0
Crystal	32 MHz and 32 kHz	16 MHz and 32 kHz	16 MHz	16 MHz
GPIOs	32 configurable GPIOs	31 configurable GPIOs	16 configurable GPIOs	None
Main Interfaces	3xSPI, 2xI2C, UART, ADC	SPI, I2C, UART, ADC	SPI, I2C, UART, ADC	SPI, UART
Other Interfaces	Comp, T° Sens, PWM, PDM	QDEC, T° Sens, Comp	QDEC, T° Sens, Comp	T° sensor
Size	8 x 8 x 1 mm	11 x 8 x 1.25 mm	8 x 8 x 1 mm	12 x 8 x 1.5 mm

Introduction IoT

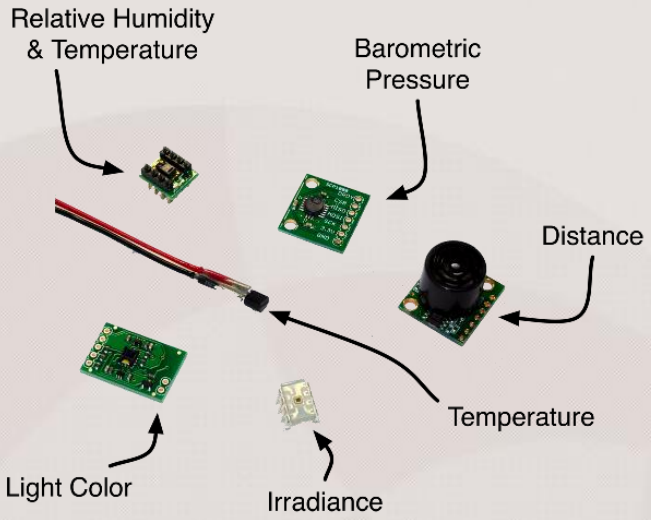
- Internet of Things “IoT”
  - Connecting any object
  - To the Internet

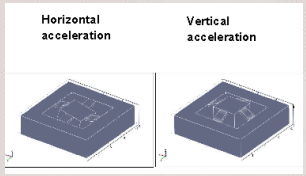
- Potential Business
  - Hardware
  - Apps
  - Users
  - Data
  - €€€



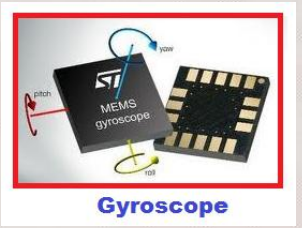
Introduction - Sensors

- Huge choice
  - Temp, Humidity, Atmospheric Pressure/altitude,Lux, UVA, Accelerometer, Gyroscope, Gas sensors (CO, NHx, OX, RED,…),…..
- Often only small quantities of data per day (low data volume)



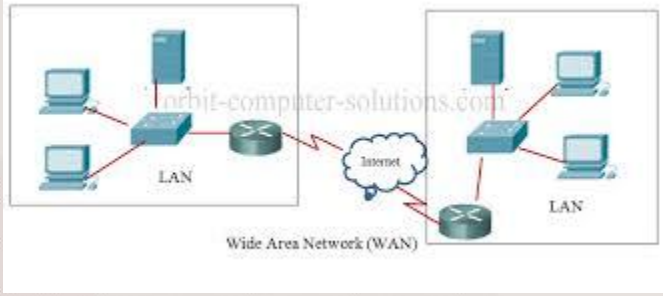


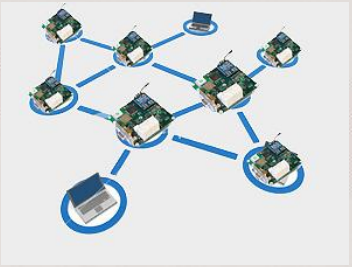
Accelerometer/Attitude

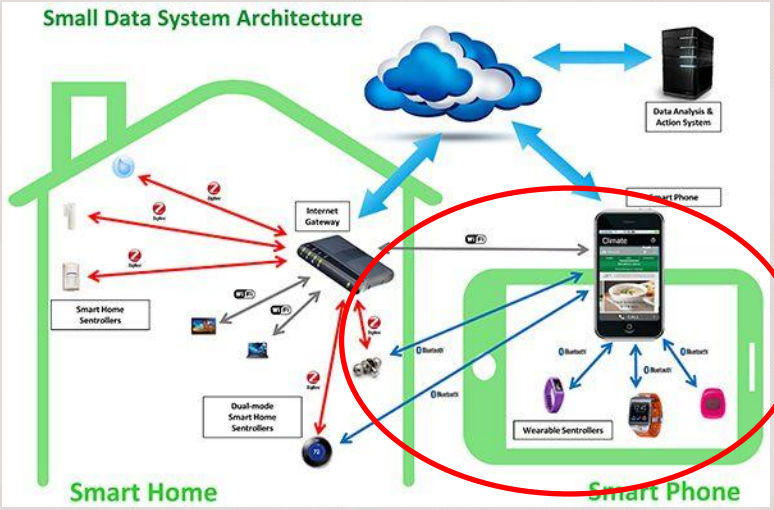


Introduction
Sensor to Internet

- Many Connection types
  - WAN 3G, LTE, 5G
  - LAN/home WiFi
  - Zigbee mesh network
  - Smart Bluetooth to Smart Phone or hub
- This Talk
  - Bluetooth Smart (BLE)
  - Ubiquitous solution
  - Suitable for low data rates
  - Suitable for autonomous solutions (low energy needs)
  - No need to connect to 220V

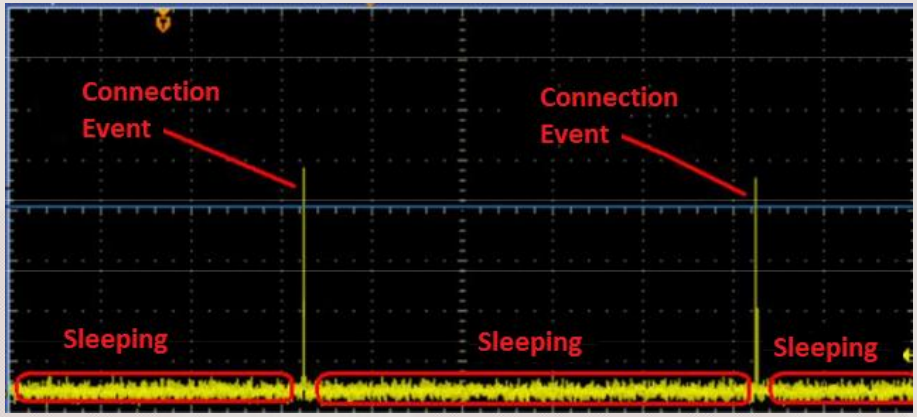


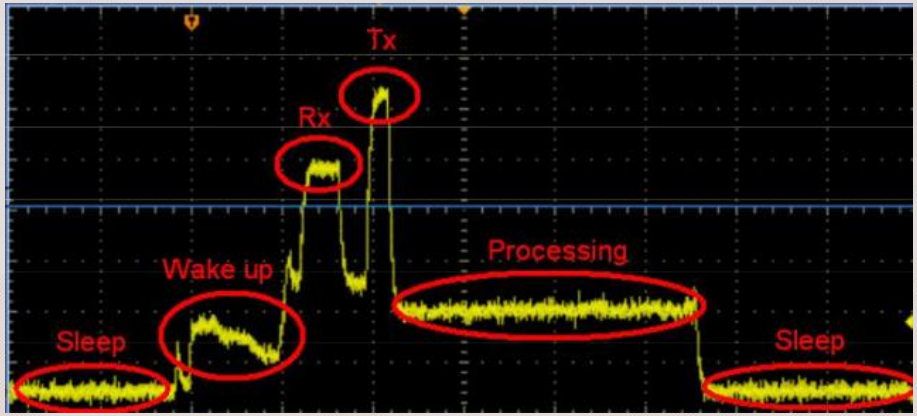




Bluetooth Smart

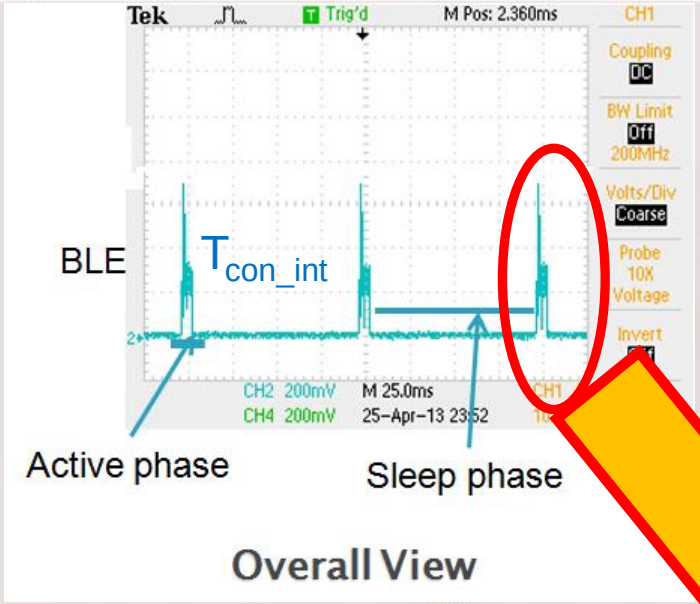
- Low power consumption
  - Tx Rx Current low (ca 10mA)
  - Device sleeps most of the time (10uA max)
  - Average current ➔
    - Sleep/On ratio
    - Quantity of data per connection
- Standard
  - Easy connection to Smart Phone
  - Most Smart Phones have Bluetooth Smart
  - Many existing GATT profiles

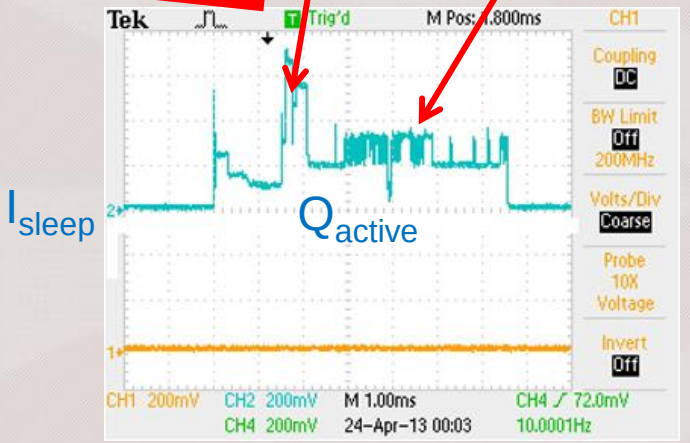




Bluetooth Smart Timing

- I_{avg} (uA)
- Q_{active} (C)
- T_{con_int} (mS)
- I_{sleep} (uA)
- $I_{avg} = I_{sleep} + Q_{active} / T_{con\_int}$

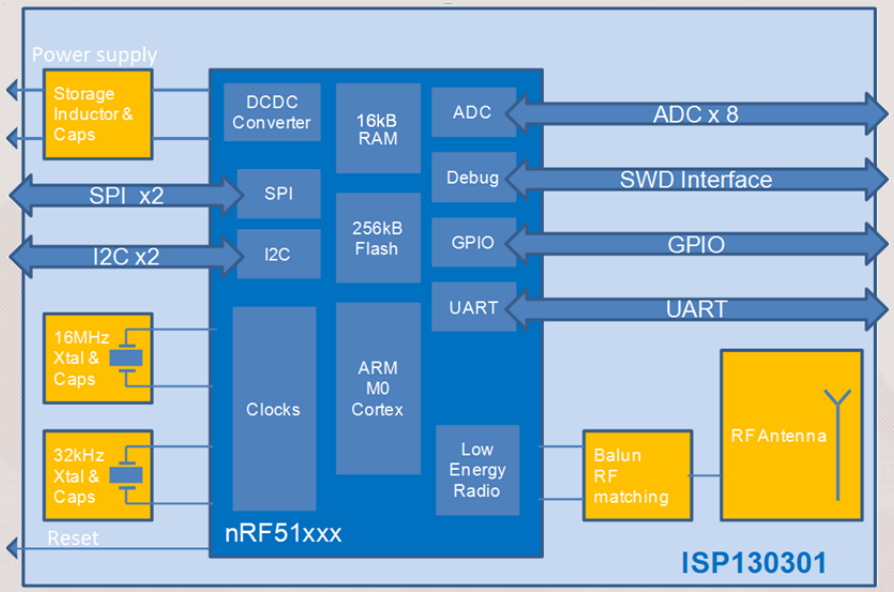


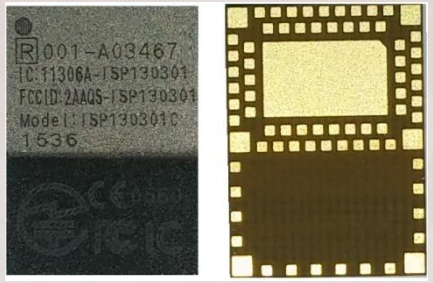


Low power mode dominates !

Bluetooth Smart Modules

- Miniature Smart Bluetooth Modules
- ISP091201
  - Smart Bluetooth Connectivity
- ISP130301
  - Smart Bluetooth with integrated Cortex M0
- Small, certified (FCC, IC,Telec, CE,..)
- Ready to use





11 x 8 x 1.2mm

Sensors

- Huge range of sensors
- Largely Driven by MeMs revolution
- Small size – average 3 x 3 x 1 mm
- Interfaces
  - SPI highest speed
  - I2C lower speed - addressable bus for multi sensors
  - Analog requires ADC ➔ prefer digital options
- Typically low power consumption

Sensor Examples

- Ambient Light
- UVA/UVB
- Temp/Humidity
- Barometric Pressure
- Accelerometer/Magneto-meter/Gyro
- Strain Gauge
- Gas Sensors (CO, NHx, RED, OX,..)

Avago APDS9309

Capella CM3512

TI HDC1008YPAT

Freescale MPL3115A2

Freescale FXOS8700CQ

Requires Analog I/P + Volts

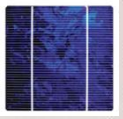
Requires Analog I/P + Current

Sensor Tradeoffs

- Low quiescent current in sleep mode
- Low operating current and short measurement time
- Digital interface (I2C or SPI) possible
- Small quantities of data

Optimization Embedded Sensor Save

- Power supply choice
  - Primary Battery - Coin Cell or Pencil Cell
  - Rechargeable Battery LiPo or NiMh
  - Energy Harvesting



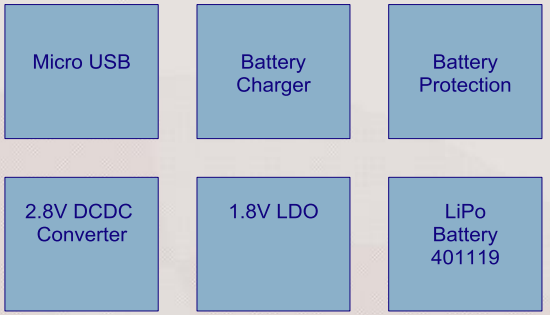
- CR1632 typ 125 mAh
- AA LR6 Alk. 2000mAh
- LiPo 55mAh 4x12x22 mm
- Solar cell, …

- Sensor Choice
  - I2C/SPI/Analog
  - Size
  - Current consumption

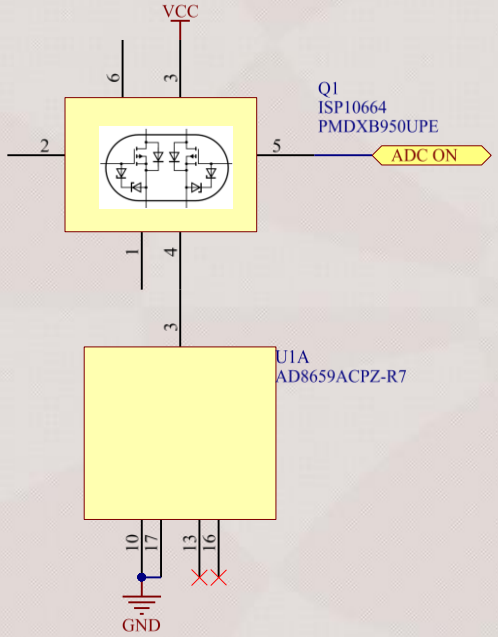
Depending your app

Optimization
Power Supply Design

- Choose Battery Type
- Optimize supply voltage(s)
- Use DCDC step down(s) to maximize battery life
- Choose low $I_{quiescent}$ options
- Add FET switches to switch off devices with high $I_{quiescent}$



Typical LiPo Battery Block Diagram



Optimization Firmware Level

- Choose Connection Interval (Bluetooth Smart)
- Choose Sensor Read Interval (can be independent of connection interval)
- Ensure that system is in Sleep Except for
  - Bluetooth Smart Connections
  - Sensor Reads
- Create GAP/GATT services to put sensor and control data into Bluetooth pipes and send/receive them to/from host

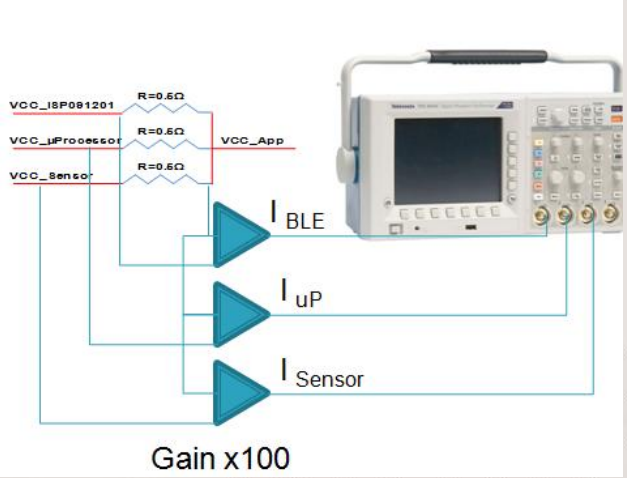
Bluetooth Services

- Choose Standard Service if possible
- Makes Development of App and F/W simpler
- Otherwise create custom services
- Often necessary to adapt services to sensors
- App and F/W must be written together

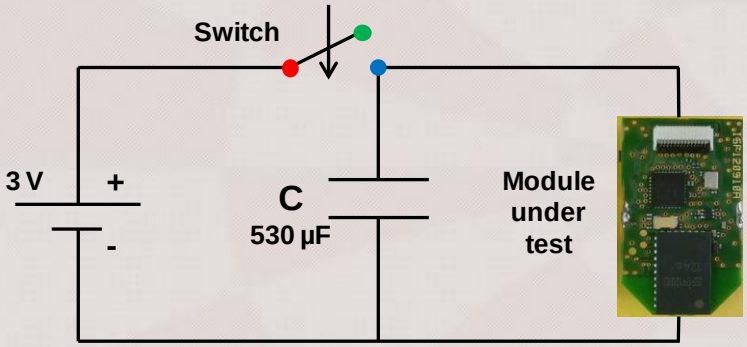
Alert Notification Service Client
Battery Service
Blood Pressure Service
Cycling Speed and Cadence Service
Device Information Service
Glucose Service
Health Thermometer Service
Heart Rate Service
Human Interface Device Service
Human Immediate Alert Service
Human Immediate Alert Service Client
Link Loss Service
Running Speed and Cadence Service
TX Power Service

Optimization Testing

- Measure Current vs time during activity
  - Bluetooth Smart Module
  - Sensors
- Measure Charge loss
  - Drive system from large Capacitor
  - Measure voltage decay
  - Estimate average current
- Compare with Simulations



$$I = \frac{Q}{\Delta t} \text{ où } Q = C \times \Delta V$$



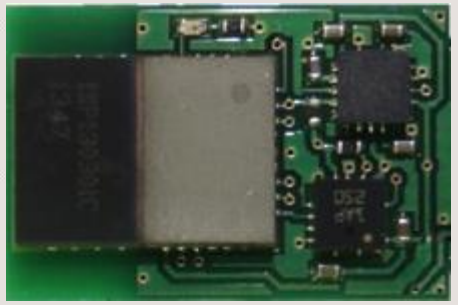
Optimization Test Results

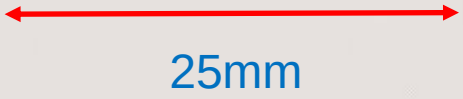
- Excellent Correlation Model vs Measurement
- Autonomy up to 10 months with 4s connection interval CR1632

Sensor node	Connec Interval (ms)	Cons Model (µC)	Cons Meas (µC)	Auton Model (year)	Auton Meas (year)
Temp	1000	52.30	55.12	0.31	0.29
	2000	62.30	63.6	0.51	0.50
	3000	72.30	72.08	0.66	0.67
	4000	82.30	80.56	0.78	0.79
Light	1000	65.72	67.84	0.24	0.24
	2000	76.92	80.56	0.42	0.40
	3000	88.12	93.28	0.54	0.51
	4000	99.32	106	0.64	0.60
Orientation Motion	1000	62.72	63.6	0.25	0.25
	2000	72.72	72.08	0.44	0.44
	3000	82.72	80.56	0.58	0.60
	4000	92.72	89.04	0.69	0.72

Examples

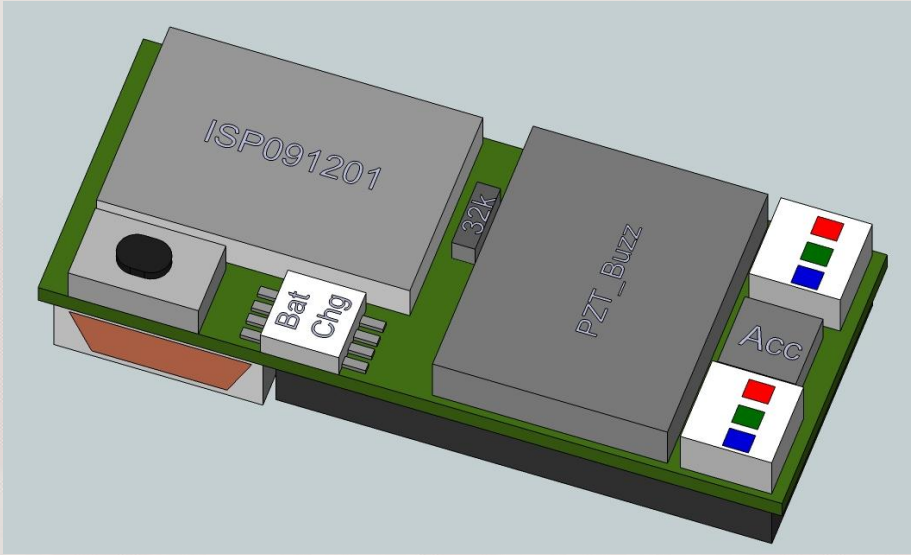
- Multi-sensor
  Acceleration/Magnetometer/Atmospheric Pressure/Temperature





Examples

- Attitude movement bracelet module
- Accelerometer
- uP Bluetooth Smart
- LEDs
- Buzzer
- LiPo battery + charger



Examples

- Multi-sensor Bracelet
- Battery + Charger
- microUSB interface
- 10 sensors including
  - Sun light exposure
  - Temp/humidity
  - Pressure
  - Attitude/movement
  - Diesel fumes

Conclusions

- Bluetooth Smart is ideal last link in IoT chain
- Smart Phone is ubiquitous to make connection
- Careful optimization allows autonomous operation with infrequent changes of battery
- Long connection intervals and very low data rates can allow use of energy harvesting

Conclusions