PROJECT FINAL REPORT

Grant Agreement number: 605264

Project acronym: BLIM4SME

Project title: Bluetooth® Low-energy Integrated Module for SME's

Funding Scheme: FP7-BSG-SME

Period covered: from 1/11/2013 to 31/10/2015

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Bluetooth Low-energy Integrated Module for SME's (BLIM4SME)

Call: FP7-SME-2013, Research for the Benefit of SMEs

Grant Agreement Number: 605264

Project start date: 01/11/2013

Duration: 24 months

Project coordinator:

RTD Talos, Cyprus

Partners:

RivieraWaves SAS (RW), France

Prisma Electronics ABEE (PRISMA), Greece

Nordic Components OY (NORDIC), Finland

Teknologian Tutkimuskeskus VTT (VTT), Finland

CSEM Centre Suisse D'electronique Et De Microtechnique SA - Recherche Et Developpement (CSEM), Switzerland

Executive summary

The demand for **wireless sensors** in the medical, wellness and sport & fitness applications is experiencing ultra-rapid growth right now. One can regularly see the release of exciting and innovative devices such as heart rate monitors, blood pressure monitors, pedometers, body thermometers, blood oxygen level measurement systems, that are typically connected wirelessly to laptop computer, tablet or smartphone for easy **portable control and monitoring**, and getting in this way a **gateway to Internet**.

For such applications the **standardized connectivity** approach is a must for enabling massive market adoption, in particular for enabling seamless interaction with external wireless-enabled devices and ultimately towards the cloud or the Internet of Things (IOT). Bluetooth® Low Energy and Standard Bluetooth® combo functions have emerged to most new tablets and smartphones (about 1000 Million already). **Bluetooth® Low Energy (Bluetooth® Smart)**, developed by Bluetooth® SIG (Bluetooth® Standardization Committee) is then the leading technology to offers wireless connectivity from miniature long-autonomy sensors to everybody's cellular handset and to the Internet.

In such applications, **miniaturization** is a key requirement that calls for integrated circuit (IC) approaches for reducing the size of the RF transceiver and wireless connectivity module. Furthermore, **ultra-low-power** is needed to use tiny coin-cell batteries to satisfy the portability requirements, which puts significant pressure on usually power hungry peripherals such as the wireless link. Last but not least, **cost minimization** is important in a very competitive market.

The **BLIM4SME** project addresses these challenges by developing an ultra-low-power Bluetooth® Low Energy (BLE) module focussing on healthcare and lifestyle. BLE is currently addressed by large semiconductor industries, in the form of complex systems-on-chip (SoC) which aim at covering many applicative areas, but their excessive versatility makes them non-optimal for those applications where ultra-portability and ultra-low-power are mandatory. Therefore, BLIM4SME aims at developing an optimized solution targeting the rapidly increasing landscape of EU SME's and industries that require beyond state-of-the-art, highly integrated and ultra-low-power BLE radios.

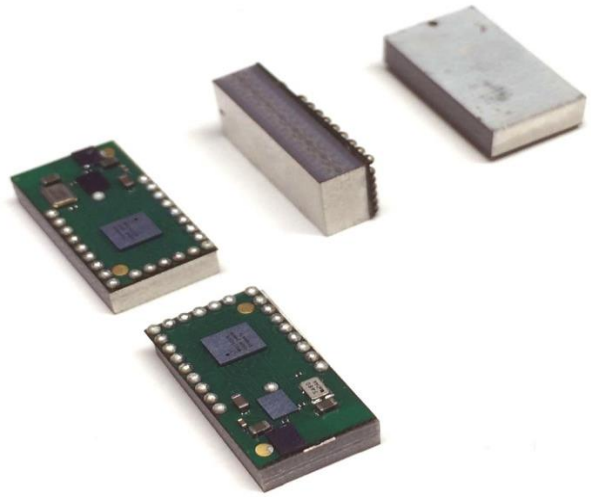


Figure 4.1.0: Ultra-Low-Power antenna-and-radio <0.5 cm^3 Bluetooth® Low Energy module.

1. Project objective and context

Concretely, the project target is integration of RF IP blocks into a **BLIM Testchip** which is embedded with a microcontroller into a single "antenna-and-radio" miniaturized chip-sized **BLIM Module**. This module leverages an innovative "integrated passive devices" (IPD) technology platform. The outcome is a BLE module yielding a factor of at least 5 times better "power-size" figure of merit compared to today's leading industrial solutions. A benchmark **COTS module** is also developed for comparison with challenging solution based on circuit available on the market. A dedicated **Generic Module** is developed as example of exploitation platform for the developed components.

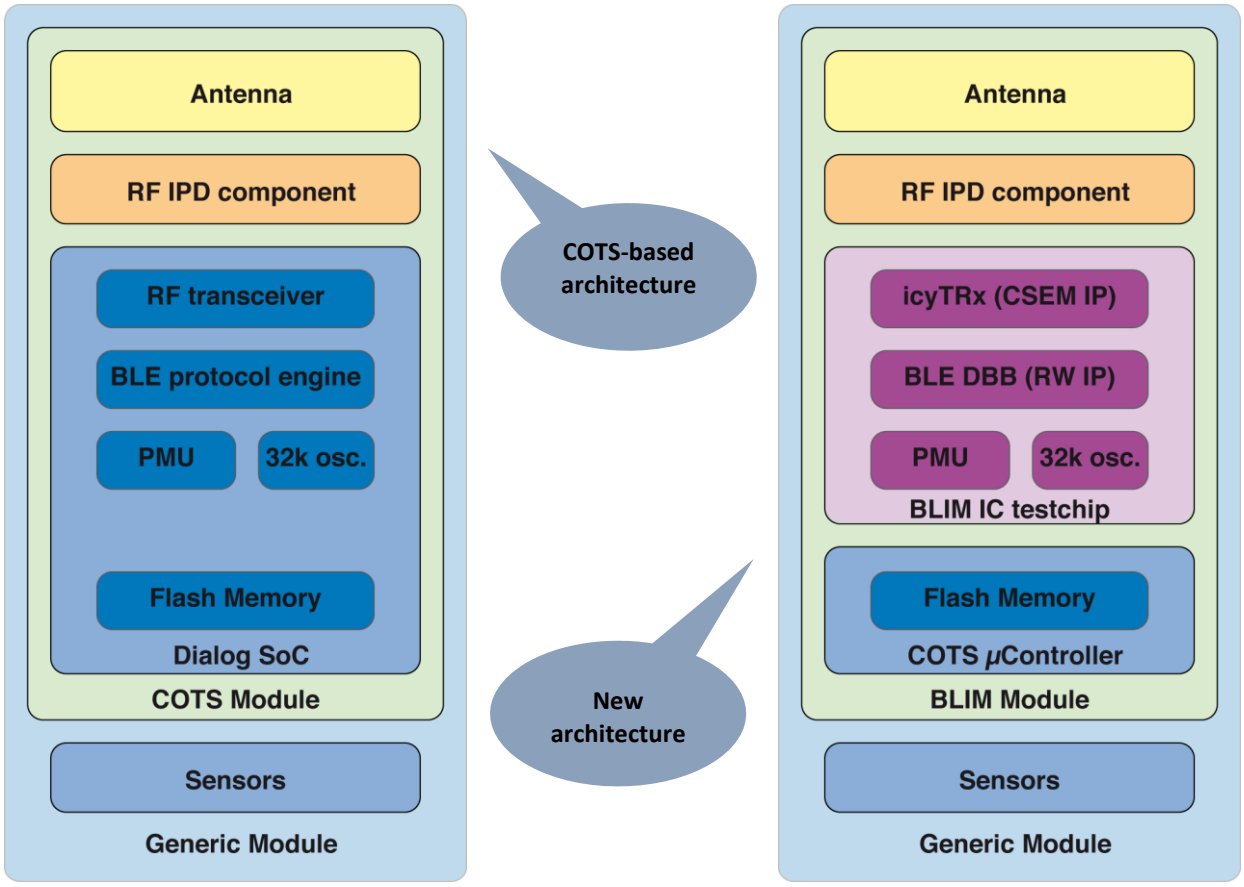


Figure 4.1.1: overview of COTS module (left) and BLIM module (right)

The BLIM Testchip integrates the hardware part of an RF transceiver compliant with Bluetooth® 4.2. The software part is intended to be implemented into a companion microcontroller communicating with the IC via SPI and IRQ. The choice has been made to not integrate the companion microcontroller in order to provide maximum flexibility and evolution of controller choice with minimum silicon footprint (e.g. sizing memory to the application) for cost minimization.

The BLIM RF IC IP is the assembly in TSMC 65 nm of two pre-existing IPs:

- CSEM's icyTRX-65 Bluetooth® Low Energy RF transceiver implementing the Physical Layer, Bit Stream Processing and Air interface Packet assembly and disassembly (i.e. Packet Data Unit insertion / extraction with Access Address

recognition and CRC check). It also addresses IEEE802.15.4 and proprietary standards from 62.5 kbps to 4 Mbps.

- RW' Bluetooth® Low Energy 4.2 protocol engine implementing the Bit Processing, Advertising / Data / Control Packets type support, Encryption, Frequency Hopping management, Time Division Multiple Access events formatting and synchronization, Broadcast / Central / Observer / Peripheral classes support and Real-Time-Clock management. A simple and optimized hardware interface is implanted for the software-implemented protocol part. The BLE software stack, running in "full-embedded mode" where the lower, upper, profile and protocol stacks run on the same microcontroller, is divided into the following components:
  - LL: Link Layer
  - L2CAP: Logical Link Controller and Adaptation Protocol
  - SMP & ATT: Security Manager Protocol and Attribute Protocol
  - GATT / GAP: Generic Profiles
  - LE Profiles: BLE specific profiles

The resultant IC also implements dedicated power management and ultra-low-power time keeping functionalities:

- A capacitive DC-DC voltage converter supplies the IC core from the 2.4-3.6 V supply voltage for minimum peak current and component size and cost.
- A fully-integrated 32 kHz oscillator to eliminate the need for a quart crystal component for minimum size and cost.

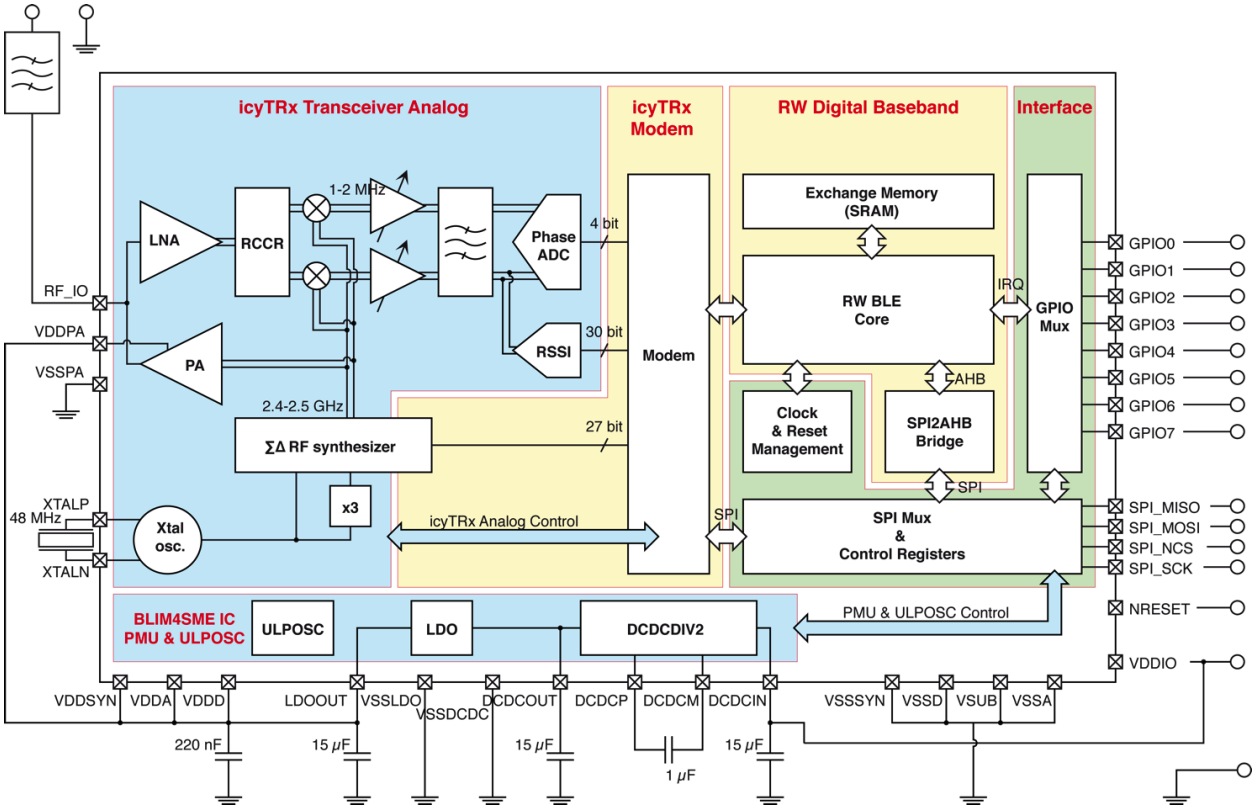


Figure 4.1.2: BLIM testchip block diagram.

The total assembly targets state-of the art performances with minimized power consumption in active and standby modes thanks to optimized architecture, clock gating, power domains, etc.

Two different module implementations are then considered in the project:

- The **COTS module**, which uses off-the-shelf radio components. Besides being a direct outcome, it also serves for benchmark purposes for the BLIM module.
- The **BLIM Module**, which uses the BLIM RF IC, and an off-the-shelf ARM Cortex M0+ with 128 kB of Flash memory running the RW BLE SW Stack and very limited component count.

The goal is to make these modules compatible, in terms of functionality, interface, as well as mechanically (dimensions). Both are integrating the same antenna and Integrated Passive Device (IPD) component, designed by VTT, that implements filtering and antenna impedance matching. The IPD component has been miniaturized for cost optimization.

The application challenges are standardized connectivity for plug-and-play interconnection with other devices, ultra-portability with tiny modules for maximal comfort for the wearer, ultra-low-power consumption for long autonomy and flexibility for simple integration with a heterogeneous set of other components like sensors, signal processors, energy harvesters. The BLIM4SME project addresses those challenges by developing this ultra-low-power Bluetooth® Low Energy (BLE or Bluetooth® Smart) module focusing on healthcare and wellness applications as a stand-alone module.

Furthermore when implemented on a Generic module board with various sensors and extra memory it will also serve well in industrial applications. Indeed, PRISMA is active in remote monitoring and predictive maintenance and intends to expand the capabilities of its wireless sensor nodes, introducing a new series of devices where the retro-compatible BLE module will replace the existing wireless module. This will provide to end users the ability for in-situ machinery inspection with the use of their own mobile device (smartphone or tablet).

Different outcomes can then be considered:

- Result 1: **RF IC IP**: This is related to the RF IC developed specifically in the project, and which is referred to as the **BLIM Testchip**. This outcome is in the form of a silicon IP which will be integrated in the project as a chip.
  The principal exploiter of this Result 1 is **RW**.
- Result 2: **RF IPD** Module: This concerns the radio modules that embeds IPD technology and which will be provided in two forms in the project:
  - The **COTS Module** that uses off-the-shelf radio components. Besides being a direct outcome of Result 2, it also serves for benchmark purposes for the BLIM module described below.
  - The **BLIM Module** that uses the BLIM4SME radio technology of Result 1.

  The principal exploiter of this Result 2 is **NORDIC**.
- Result 3: BLE **Generic Module**: This concerns the BLE Generic Module in the form of a PCB that will embed the outcome of Result 2 with additional features (e.g. sensors, etc.).
  The principal exploiter of this Result 3 is **PRISMA**.

The BLIM4SME consortium consists of SMEs and leading research organizations:

- RivieraWaves SAS (**RW**, France), SME, expert in BLE protocol,

- Nordic Components OY (**NORDIC**, Finland), SME, expert in IPD modules,
- Prisma Electronics SA (**PRISMA**, Greece), SME, expert in modules,
- RTD Talos Limited (**TALOS**, Cyprus), Coordinator of the project,
- Centre Suisse d'Electronique et Microtechnique SA (Swiss Center for Electronics and Microtechnology - **CSEM**, Switzerland), Scientific Leader in the project, RTD performer, expert in low power integrated radios,
- Valtion Teknillinen Tutkimuskeskus (Technical Research Centre of Finland - **VTT**, Finland), RTD performer, expert in IPD technology.

2. Main S&T results/foregrounds

All results are detailed in D5.2 Final datasheet for RF IC, RF IPD Module and Generic BLE module with quantified specifications.

1st integration of **BLIM testchip** is fully functional and used for demonstration. The second integration has been used for minor corrections/improvement and update of BLE protocol from version 4.0 to 4.2. The resulting 1.81 x 1.45 mm 36-bumps Wafer-Level-Chip-Scale-Package is integrated in standard TSMC 65 nm CMOS.

IC system design, RF & analog part design and characterization, digital for PHY layer and PMU control, assembly and integration have been realized by CSEM. RW realized the protocol engine, supported CSEM for its integration and realized validations including demonstration.

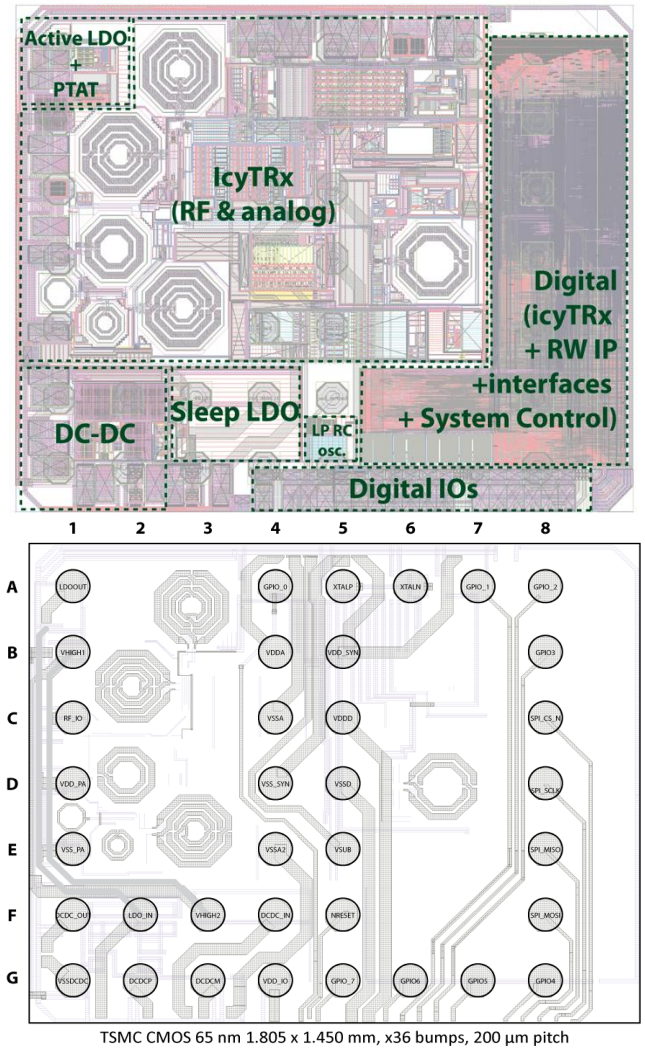


Figure 4.1.3: BLIM testchip floorplan.

Supply conversion, regulation and power domains have been optimized for the application, especially concerning the minimization of current in sleep mode.

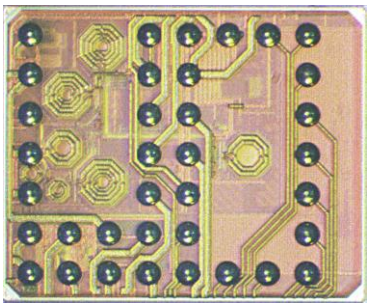
Operation frequency	2.36-2.5 GHz	
Voltage supply	2.4-3.6 V	
Interface	RF: single 50 Ω interface, Digital: SPI & GPIO	
External components	A 48 MHz quartz and 7 ceramic capacitors	
Transmission	0 dBm, 4.5 mA	after 0.5 ms crystal oscillator startup
Reception	-97 dBm, 3.0 mA	
Standby current	600 nA Including RTC based on 32 kHz osc.	

Figure 4.1.3: BLIM testchip specification summary.

All important specifications have been validated by characterization (e.g. all typical currents and times/frequencies, standards compliance, etc.). The limited number of others, because too time-consuming, asking for subcontracting (ESD stress) or integration (corner lot) have been based on simulations results or prior integrations characterization (typ. preceding icytrx testchips).

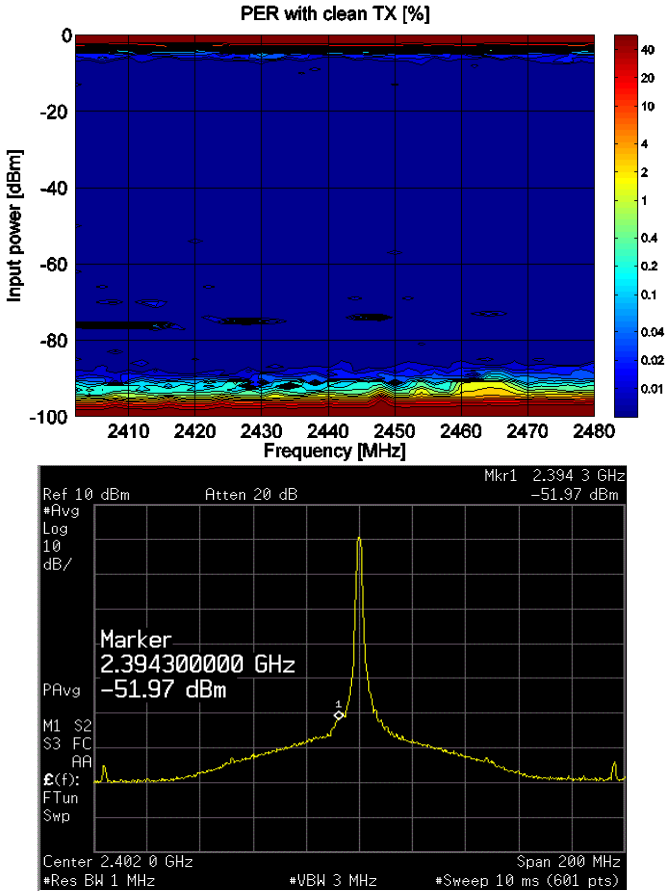


Figure 4.1.4: Example of characterization results for Reception (top) and transmission (bottom).

The integrated Bluetooth® 4.2 protocol engine has been extensively validated on FPGA platform. It has then been validated, for the integrated part, by digital simulation in BLIM Teschip context (i.e. in co-operation with digital part of icyTRx and specific power modes manager). Finally, it has been validated by demonstration with protocol software embedded into the BLIM Module processor, i.e. the Freescale Cortex M0+.

The **miniature antenna and the RF IPD component** containing the antenna matching and filter circuits were designed at VTT. The IPD chip was manufactured at VTT production line. The 1.5 x 1.2 x 0.3 mm size RF IPD component is based on thin film technologies over silicon wafer. IPD technology has in this case provided means for realizing antenna matching and filtering component values that would not be possible to realize with surface mount components or conventional microstrip technology due to the needed extremely tight tolerances, low paracitics and size limitations.

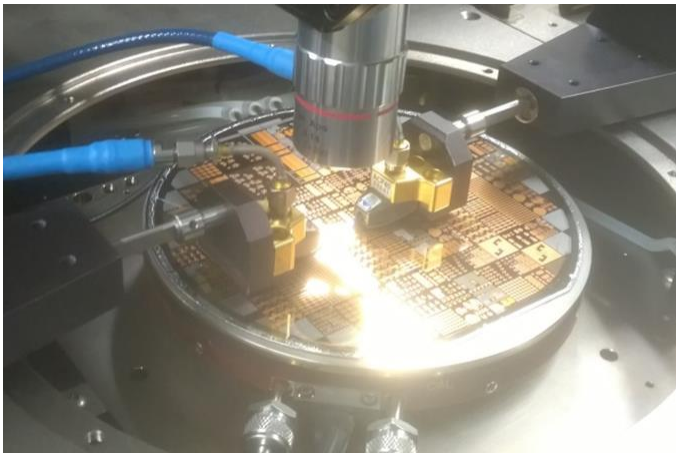


Figure 4.1.5: IPD components on wafer.

The design target for the module and the antenna was to be as independent as possible to particular PCB mounting platform and operation environment. Indeed, current chip or in-package antenna solutions in the market ask for considerably large ground plane with ground plane openings in the mounting PCB to function properly. Characterization result demonstrates PCB platform and environment independent operation of the BLIM radio module.

	free space (dB)	100x300mm metal (dB)	on body (dB)
27x55mm application board	-6.5	-2.5	-4.5
25x25mm application board	-9.5	-2.5	-7.5
EMBC01 fixed 30mm diameter disc incl. plastic casing	-4.5	-4.5	-10.5

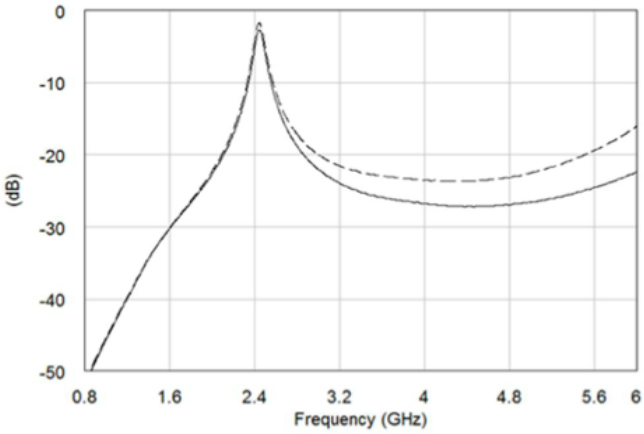


Figure 4.1.6: Module total gain measured in different scenarios (left) and antenna matching loss in free-space (solid) and on 30 x 30 mm metal (dashed) (right).

Both COTS module and BLIM modules are embedding the RF IPD component and associated miniature antenna.

The 13.5 x 7.5 ⁄ 4 mm **COTS Module** has been designed and managed by NORDIC for its manufacturing. Special care has been attached to manufacturability for cost minimization. This module has been used for radiation measurement of RF IPD component and associated miniature antenna.

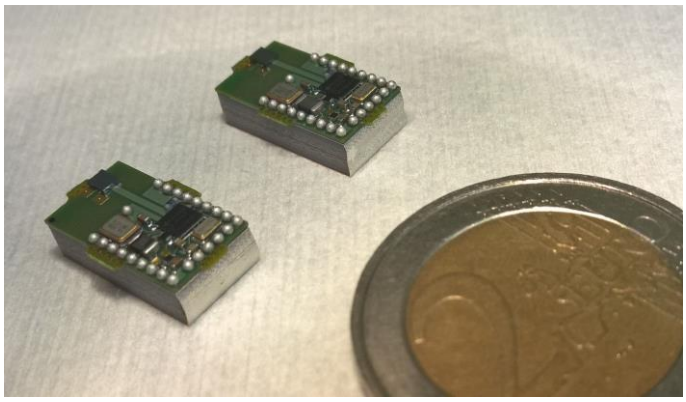


Figure 4.1.7: 4 x 7.5 x 13.5 COTS modules.

The **BLIM module** is compatible with the COTS module for the size, footprint and functionality. However, it embeds the BLIM teschip with a Freescale Cortex M0+ instead of DA14580 COTS BLE SoC. It has been designed and managed by CSEM for its manufacturing.

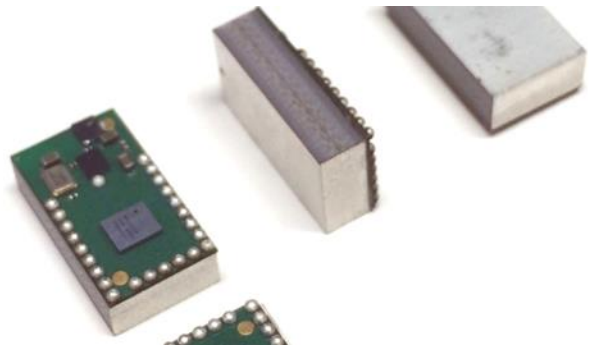


Figure 4.1.8: 4 x 7.5 x 13.5 BLIM modules.

The **Generic Module** has been designed and managed by PRISMA for its manufacturing. It embeds one of the COTS or BLIM module with several sensors (temperature, humidity, barometer, 3D accelerometer and compass, ultrasonic microphone) and a microSD socket (typ. for flash card memory). This Generic Module is pin-to-pin compatible with a Zigbee module presently used in PRISMA products.

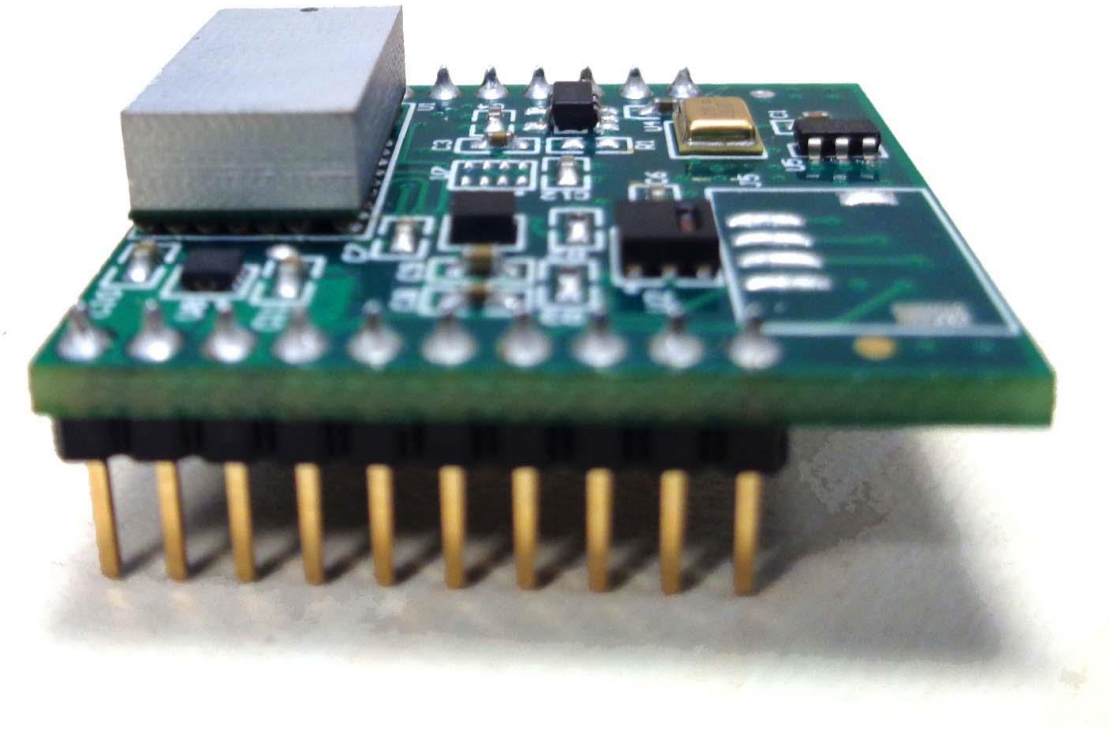


Figure 4.1.9: 27 x 25 mm Generic Module (module footprint on bottom-left).

3. Potential impact, main dissemination activities and exploitation of results

Potential Impact

For Bluetooth low energy, there are several important application areas like automotive, consumer electronics, sport and fitness, consumer health monitoring, building automation and home automation, the major part being driven by the mobile phones. The BLIM4SME end-user SME's will generate strong competitive commercial impact principally in the novel panel of healthcare, bio-medical, lifestyle and sports applications that are emerging, and where unobtrusive, miniature and autonomous wireless technologies are needed, such as for smart watches, smart bandages, smart textiles, body sensor networks, worn and implanted healthcare devices, etc.

The BLIM4SME project objectives contribute directly or indirectly to enable the following EC policies:

- eHealth: by contributing to enable unobtrusive and remote monitoring of patients, the project will contribute to enable better healthcare for Europe, while reducing costs of care.
- AAL Policy: the Ambient Assistant Living Policy provides recommendations for ICT for "Aging well at work", "Aging well in the community" and "Aging well at home". These are clear fields where BLIM4SME technology may be considered as enabling technology.

- i2010: unobtrusive and easy to use man-to-internet interfaces will be instrumental to allow disabled and ill people to interact with ICT-based healthcare services. BLIM4SME will contribute to enable one of i2010's major pillars, which is to foster inclusion, better public services & quality of life through ICTs.
- EU Health and Safety at work: The directive 89/391/EEC requires the introduction of measures to encourage improvements in the safety and health of workers at work, which can be indirectly enabled using miniature unobtrusive wireless technologies like developed by BLIM4SME.
- eLearning: the ultra-low-power wireless technology developed in BLIM4SME will also lend itself in other fields, such as man-to-computer interfaces for eHealth (e.g. electronic prescription services, computerized physician entry), hence speeding up changes in the related education/training systems.
- Energy efficiency directive: The European Union has committed to reduce the energy consumption by 20% until 2020. BLIM4SME targets to contribute directly to this topic, since the main goal of the project is to develop a truly energy efficient wireless module.

BLIM4SME project aims to impact positively the following societal challenges:

- Economy and employment: The SMEs form the backbone of European economy with some 20.7 million firms accounting for more than 98 per cent of all enterprises and employing more than 87 million people. However, the continuing European economic crises pose a severe challenge to SMEs and clearly new products and innovations are crucial to SMEs existence. In BLIM4SME project, three high- tech SMEs are involved from three different countries, Greece, France and Finland. All the countries, especially Greece, have faced the growing unemployment rates during 2008-2012. BLIM4SME aims to contribute to the innovation potential and employment possibilities of the European SMEs.
- Health and wellness: BLE technology has many applications in health and wellness for example in remote sensing of the patients, rehabilitation, portable wellness sensors, assisted living of aging and disabled people. Unobtrusive, easy-to-use tele-healthcare devices and services enabled by BLE will improve their comfort and daily life, bringing them dignity and continuous support, and reduce the number of hospitalization days thanks to preventive monitoring
- Safety of professionals: like firefighters, rescue or marine professionals, for increasing their own safety, in situations where the wireless monitoring of their physiological parameters, or communication from sensor nodes to hand-held devices, is vital to anticipate critical accidental situations.
- Sustainable development: One main goal of the BLIM4SME project is to create a wireless module with ultra-low-energy consumption. RFIC, antenna and the matching circuit development will target for optimal energy efficiency.

The technology base of BLIM4SME, in particular with the 2.4GHz RF IC and the 2.4GHz miniature antenna, will lend itself to further developments of other short-range connectivity standardized solutions. Although they seem a priori to offer a reduced market potential compared with BLE, it could be that applications such as Smart Grid initiatives could be calling for standards such as IEEE802.15.4, Zigbee, WirelessHart, Thread, which operate also on the 2.4GHz band using similar specifications and modulation schemes, thereby allowing to leverage some of the circuit and antenna techniques developed with BLIM4SME.

Dissemination activities

The dissemination activities were realised through various communication channels that were in alignment with the BLIM4SME project progress both over the development and the demonstration phases.

The main instruments and media, which were used for dissemination purposes, fall within the following areas:

A. Events

Events refer to both collaboration and dissemination and include participation in, or organisation of:

- Presentation at conferences
- Workshop for the key stakeholders
- Exhibitions, trade fairs
- Training events
- Networking sessions
- Specialised events

B. Publications

Publications refer to both electronic and printed media, including:

- Press releases
- Short articles published on the internet or in journals and relevant magazines
- Newsletters and other information material produced by the partners
- Academic-level papers published in renowned scientific journals
- Papers published and presented in conferences

C. Electronic media

Electronic media is primarily concerned with the project's website and the services made available there:

- Content published on the BLIM4SME website
- Content published on the partners' company website about the BLIM4SME project

The partners have agreed on the principle that during the initial development phase, dissemination will mainly focus on identification of and reaching the target groups and providing efforts to successfully raise awareness of the project among all stakeholders. Whereas, as soon as the demonstration phase started, the project dissemination actions concentrated more on the promotion of the project results, and on supporting exploitation and sustainability of the project results. The rationale behind this approach is to maximize the project impact by ensuring a balance between efficient dissemination and appropriate protection of the project results.

D. Website

The official project Website (http://www.blim4sme.eu) was launched publically in January 2014.

E. Project logo

The project logo has been designed to be used in all dissemination material.

Figure 1: BLIM4SME project logo

F. Press release

A Press Release was issued for the launch of the project with the title "**New technology consortium formed to develop innovative integrated Bluetooth© Low Energy modules for SMEs",** on December 1st, 2013. This Press Release was relayed by all partners on their websites and by many electronic media, such as EDN Europe, EE-Times, Free library, HighBeam, etc. The press release proved to be a very successful dissemination tool, as it has created a high visibility to the project.

The following table list the dissemination activities performed throughout the project duration:

Table 1: List of Dissemination activities

LIST OF DISSEMINATION ACTIVITIES PERFORMED THE PROJECT (01 NOVEMBER 2013 – 30 OCTOBER 2015)								
No.	**Type of activities**	**Main leader**	**Title**	**Date**	**Place**	**Type of audience**	**Size of audience**	**Countries addressed**
1	Publication of Website	TALOS	BLIM4SME Website	January, 2014	BLIM4SME project website	Scientific community, Public audience, Industry, Media	N/A	World Wide
2	Visit for main customers	NORDIC	Preliminary info for main customers	08/04/2014	Seoul, Hong Kong	Industry	6…10	South Korea, China
3	Press release	CSEM	New technology consortium formed to develop innovative integrated Bluetooth© Low Energy modules for SMEs	12/12/2013	CSEM website	Scientific community	N/A	Europe
4	Press release	RW	New technology consortium formed to develop innovative integrated Bluetooth© Low Energy modules for SMEs	01/12/2013	RW website	Industry, Public audience	N/A	World Wide
5	Conference	PRISMA	Prognostic Health Management Europe Conference (PHM 2014)	July 2014	France	Public audience, Scientific community	N/A	World Wide

No.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
7	Press release	PRISMA	New technology consortium formed to develop innovative integrated Bluetooth© Low Energy modules for SMEs	02/12/2013	PRISMA website	Public audience	N/A	World Wide
8	Conference	CSEM	Electronica 2014	11/11/2014	Munich, Germany	Public audience	N/A	World Wide
9	Symposium	RW	CEVA-RW Technology Symposium	28/10/2015	Shenzen, Shangai, Hsinchu	RW Customers and prospects	50-80	China,
10	Conference	NORDIC	IMAPS Nordic Conference	8/6/2015	Helsingör, Denmark	Public audience	100+	Europe
11	Conference, Exhibition	NORDIC	Bluetooth Europe 2015	16/09/2015	Netherlands	Public audience	100+	Europe
12	Exhibition	PRISMA	Marine Teck Korea 2014	29/09/2014	Seoul, Korea	Public audience	100+	World Wide
13	Exhibition	PRISMA	SMM 2014	9/9/2014	Hamburg, Germany	Public audience	100+	Europe
14	Exhibition	PRISMA	PHME 2014	8/7/2014	Nantes, France	Public audience	100+	Europe
15	Exhibition	PRISMA	Fathom, Ship efficiency	8/9/2015	London, UK	Public audience	100+	Europe
16	Conference	PRISMA	11th Optimising Vessel Maintenance Conference	26/6/2015	London, UK	Public audience	100+	Europe
17	Press Release	NORDIC	BLIM4SME Module availability	6/10/2015	Electronics Components News (ECN), Electronics Sourcing Online, Electronics I Norden.	Public audience	N/A	worldwide
18	Press Release	RW	availability of BLIMIC IP	30/11/ 2015	CEVA website	Public audience	N/A	Worldwide
19	Press Release	VTT NORDIC	News about project results	9/10/2015	VTT's web page	Public audience	N/A	Worldwide

G. Demonstrations

The project has proven the performance of the developed BLIM4SME technologies, through the demonstration of a prototype setup.

The principle of this demo is to use the BLIM4SME module connected to a sensor and interact with a Bluetooth 4.1 enabled smart phone or tablet. In our below example, a temperature sensor is used to send information. An iOS application (for Apple devices) is developed to manage the link, obtain and store the information, display it in a meaningful way, and finally proceed to exchanges with a Cloud database for further processing.

The picture 5.1 shows the set-up instantiated for the Demo:

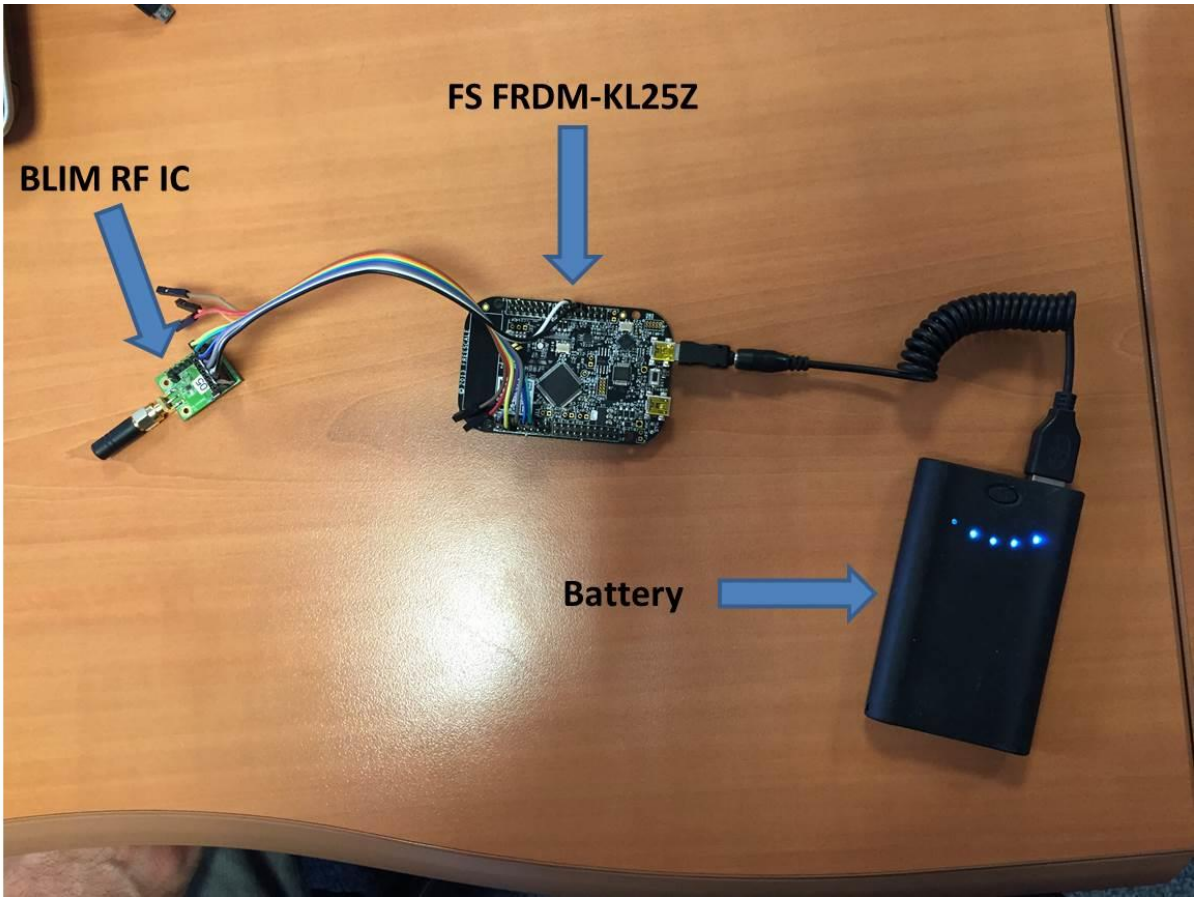


Figure 5.1: BLIM Demo set-up.

An Android Phone was used to test the BLE Link, using an application from Nordic. Despite its non-user friendly interface, it allows to debug and get all BLE indications necessary to control and exchange data for the Demo. Here below is depicted the screen shot showing Health Thermometer interface.

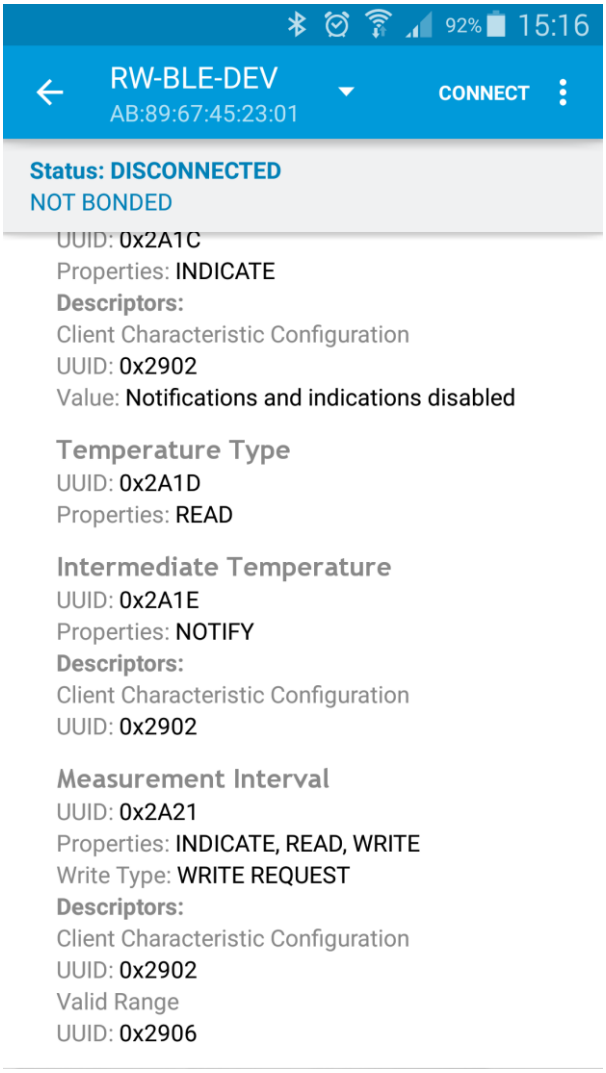


Figure 5.2 : HT screen interface

In addition to the demonstration of BLIM Testchip operated with protocol software embedded into Cortex M0+ microcontroller, the performances of IPD component with associated miniature antenna is illustrated in a small video available in BLIM4SME website:

http://www.blim4sme.eu/en/public-documents/public-deliverables92