



Autonomous self-powered miniaturized intelligent sensor for environmental sensing and asset tracking in smart IoT environments

> Application Note AN1 - Architecture and Components in **AMANDA's Autonomous Smart Sensing Card**

This document describes the architecture and components integrated in the Autonomous Smart Sensing Card (ASSC) developed in the AMANDA project by H2020 partners

THE CONSORTIUM

Explore the world of possibilities of the AMANDA **Autonomous Smart Sensing Card!**

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Application Note AN1, version 1 This document is subject to change without notice.

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AMANDA Project

Amanda Project

Project Concept

- Design and develop a miniaturized and adaptable ASSC. Indoor, outdoor and wearable versions
- Apply miniaturization-oriented design to achieve up to 3 mm thickness
- Ensure maintenance-free and energy autonomy functionalities exploring energy harvesting and storage
- Apply multi-layer optimization strategies for ultra-low-power processing / management
- Integrate advanced miniaturized multi-sensing technology for distributed environmental sensing, asset and people tracking and monitoring
- Enrich wireless connectivity capabilities in support of cyber-secure mesh communication as well as ultra-low power localization and tracking
- ◆ Incorporate built-in ASSC processing capabilities for sensor/data fusion and low power edge intelligence in support of IoT-related services
- ◆ Validate the proposed ASSC in laboratory conditions under variable application scenarios

Use Case

Use Case	Incorporated Scenario 1	Incorporated Scenario 2
UC1 Environment monitoring and reporting	SC01 Environment and thermal comfort monitoring	SC02 Fire detection
UC2 Assets tracking and occupancy monitoring	SC03 Continuous occupancy monitoring in a parking lot	SC04 Asset and people locali- sation with access control
UC3 Mitigating the effects of the current pandemic	SC05 Monitor transportation conditions of medicines / vaccines	SC06 Crowd counting for social distancing

UC1

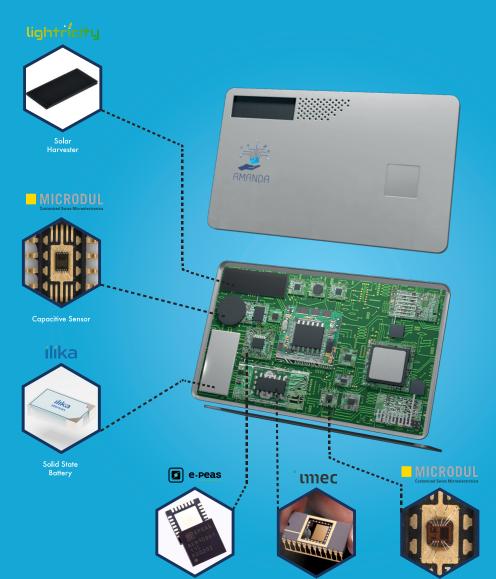
Environmental room sensing for automated room control and safety targets the indoor version of the AMANDA card. It specifically integrates all the use cases specified related to environmental room monitoring

UC2

Assets and goods tracking and monitoring, which targets both the indoor and outdoor versions of the AMANDA card. This use case covers all applications related to monitoring and tracking of different assets

UC3

Mitigating the effects of the current pandemic, which targets both the indoor, outdoor and wearable versions of the AMANDA card: hospital monitoring, patient tracking, transportation conditions of medicines/vaccine



Power Management IC, Imaging Sensor CO₂ Sensor

Low-Power Temperature Sensor



Wireless and Localisation Technologies, Low-Power Design, Simulation and Verification



nd User



System Integration, Edge Intelligence Data Fusion, Cyber Security

End User





Penta is an IT company that develops and implements its solutions in the area of public transportation and the field of smart cities. Penta develops its hardware and software solutions. Within the AMANDA project, Penta is the end-user. In the AMANDA project, Penta contributes with its knowledge and experience in the field of user applications and signal transmission. The rapidly growing market for IoT technologies and the need for energy-autonomous devices has allowed Penta to improve its hardware and software solutions significantly. SmartPark Integrated Solutions - the parking reservation system and BusCARD e-ticketing system, are outstanding platforms for implementing AMANDA's ASSC.

Penta's areas of application are:

- Parking slot occupancy detection
- · Weather station with noise and vibration measurement
- Air quality control
- Tracking and monitoring vehicles
- Long-distance data transmission

Architecture Fundamentals

AMANDA's Autonomous Smart Sensing Card was designed with following stakeholders in mind:

- End-users: May use the AMANDA system covering different use cases. For example, as an automated HVAC room controller or an automated fire detection device
- SMEs: May use the AMANDA ASSC for monitoring and automation purposes such as asset tracking, employee positioning or medical equipment tracking in hospitals
- Research: Will have interest in the technical aspects of the ASSC and the individual components, as well as its mechanical and electrical properties





Conceptual Architecture

PV harvester: A photovoltaic solar cell that gathers solar energy

Energy storage unit: Stores the energy harvested by the PV harvester and provided by the NFC component and can subsequently provide it to power the system

PMIC: The power management unit of the system which provides the system with different power domains

MCU: The main system controller that includes system logic and component communication and involves the processing for data gathered via the system sensors

BLE radio: Implements short-range wireless communication capabilities

LoRa/LoRaWAN radio: Implements long-range wireless communication interface for the ASSC

NFC component: Responsible for secure pairing, fast transfer of large amounts of data and for fast charging the energy storage unit when there is no light

Capacitive sensor: Provides human-computer interaction via a touch-detection element. It is used to wake-up the ASSC from the lowest power sleep state

RTC timer: Provides a periodic interrupt and is used to wake-up the system from the various power sleep states



LoRaWAN and BLE protocols support networks of multiple ASSCs, offer secure over-the-air connections with low power consumption and can cover all the needs of the ASSC.

Bluetooth°



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MCU

Capacitive

sensor

Wireless and security

Temperature sensor & protocols

Sensors and edge intelligence

(processing capabilities)

Imaging sensor

CO2 sensor

Other sensors

design mechanisms

Security by

Interface electronics

Energy management

Harvesting energy (PV)

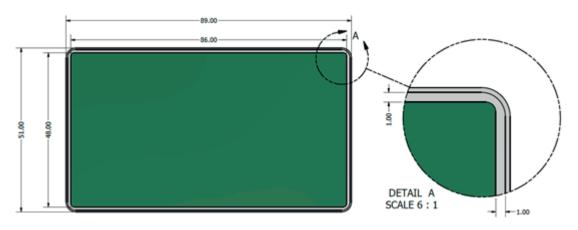
Power management

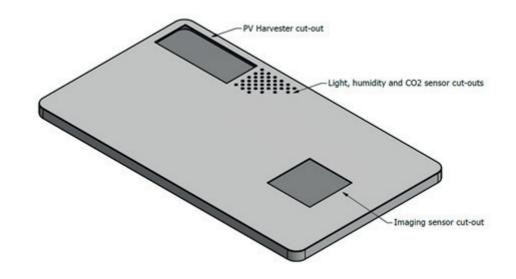
Rechargable storage

• The device enclosure is based on the US Business Card standard with dimensions of 89×51 mm.

The thickness will be a maximum of 3 mm.

- Resistance to solid objects and dust: IP4X Protected against solid objects
- > 1mm in diameter
- Resistance to water: IPX3 Protected against water spray at 60 degree angle





Component Developers

(Sensors and Energy Autonomy Booster)

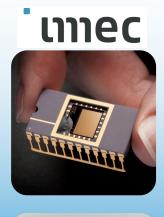
The AMANDA Consortium develops novel, low-power miniaturised sensors.



The capacitive sensor, together with the RTC, is the main wake-up source from the system power-off state of AMANDA. It also serves as a human interface device when the ASSC is in an active mode. To extend battery life further, only a single oscillator is permanently running. This reduces the power consumption of the capacitive touch & RTC combination to less than 100 nA while actively sensing at 2 scans per second.

The ${\rm CO}_2$ sensor consists of an electrochemical transducer (responds to changes in ${\rm CO}_2$ concentration) and an electronic readout (measures the change of electrical properties of the transducer).

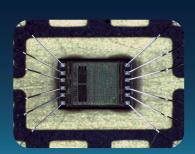
The CO_2 transducer is made of a substrate of ~10 x 10 mm with a thickness of <1 mm, a set of interdigitated electrodes and a thin layer of electrolyte deposited on top. This assembly is much thinner compared to commercially available devices. CO_2 interacts with the electrolyte, changing the electrical properties of the transducer (impedance). The measurements are performed by an integrated circuit, embedded in the ADUCM355 microcontroller's analogue interface. Uniquely, the IMEC sensor uses a technique of measurement that does not require light sources and optical channels, nor elevated temperatures, making this technique more power efficient. IMEC's approach uses room-temperature liquid salts, so-called ionic liquids, as electrolytes.

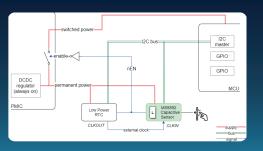




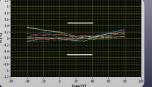
The MS8892 sensor is a derivative of Microdul's existing MS8891 with added:

- \bullet Self-calibration feature to compensate manufacturing tolerances
- Functionality to serve as a system wake-up/power-up controller
- \bullet Functionality to work together with an off the shelf RTC to save further power
- Availability in a chip-scale package with reflow-capable solder bump technology





Customized Swiss Microelectronics



The MS1089 temperature sensor is a further development of Microdul's existing MS1088, which includes a bidirectional handshake line and adds:

- Supply current reduction (zero power in idle mode, reduced power consumption during measurement)
- Reduction of the lower supply voltage limit from 2.4 V to 1.8 V for easy integration in the AMANDA architecture and other 1.8V applications
- Three selectable temperature sensing resolutions (0.1°C (11-bit), 0.05°C (12-bit) and 0.025°C (13-bit), selectable with $\rm I^2C$)

The integrated circuit MS1089 is a fully integrated calibrated digital low power temperature sensor with a typical temperature measurement accuracy of ±0.3°C. It will be provided in a chip-scale package (CSP).





EPEAS is developing a new generation, ultra-low power, time-based image sensor for the AMANDA project.

These image sensors convert the light information into a pulse whose length depends on the intensity.

The pulses are subsequently converted to a digital value via counters.

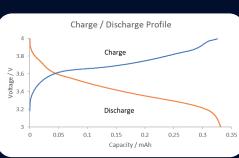
- High dynamic range
- Auto exposure
- Edge map
- Region of interest
- Higher maximum frame rate
- Flip
- Dead pixel correction
- · Aggregation and decimation of pixels
- Interruptions



The ILIKA solid state battery aims to provide an energy storage element that will allow the AMANDA ASSC to operate when there is not sufficient power from the Energy Harvesting component (Lightricity PV panel) to fulfil the required operation. The energy storage component is part of the energy block of the AMANDA card along with the Lightricity PV panel and the EPEAS PMIC.

ILIKA is developing a new micro-fabricated thin-film lithium-ion battery, which is thinner and has a higher footprint utilisation than previous models. The model developed is the Stereax M300, a 6-cell stack, with 300 uAh capacity and target specs shown in the table. Up to 7 M300 batteries will be used in each ASSC.

Energy Storage	Target
Rated Capacity	2mAh
Voltage	3-4V
Standard continuous discharge current	2mA
Peak current (<0.5ms pulse)	40mA
Active Footprint	88%
Quiescent/leakage current	<10nA
Continuous current	20mA
Coulombic Efficiency	>99.95%
Footprint	24x14mm





The purpose of Lightricity's photovoltaic Energy Harvester is to provide continuous power to the AMANDA ASSC when exposed to ambient light but also during periods of darkness, by generating excess energy when light is available. The harvester, based on Lightricity III–V technology, targets a 30–35% module efficiency under white LED and fluorescent spectrum.

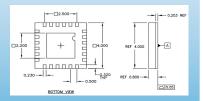
Parameter/Performance	Target	
Module EXL-1V50-SM	200 lux white LED spectrum	
	•	
Size / Thickness	23.8x10.2mm/<1mm	
Active area	2.15cm²	
Number of cell(s)	1	
Open circuit voltage	1.15	
Short circuit voltage	49.8µA	
Operating voltage	1.0V	
Operating current	47.6µA	
Operating power	47.6րW	
Power density (active area)	>20₁W/cm²	
Cell efficiency	>30%	











The power management integrated circuit developed by e-peas powers AMANDA ASSC components, including the sensors, the microcontrollers and the wireless communication circuits when the instantaneous power consumed by the card is higher than the power provided by the photovoltaic cell.

Thanks to its MPP tracking system, the PMIC harvests the maximum available input current up to 110 mA. It integrates an ultra-low power boost converter to charge the AMANDA storage device. The boost converter operates with input voltages in a range from 50 mV to 5 V. With its unique cold-start circuit, it can start harvesting with an input voltage as low as 300mV and an input power of just 2 μW .

The PMIC delivers power to three outputs:

- The always-on output (AOOUT) is regulated around 2.2 V and drives a small current to supply the touch sensor and the RTC
- \bullet The low-voltage output (LVOUT) is connected to the microcontroller and part of the card's sensors that can be supplied at 2.2 V
- \bullet The high-voltage output (HVOUT) drives at 3.3 V the sensors and the radio transmitter that need a higher supply voltage.

AI, Data fusion, Cybersecurity





А

The low-power algorithms that have been developed using machine learning techniques, provide predictive and reactive intelligence at the ASSC. Supervised, unsupervised and semi-supervised learning methods are used to identify patterns, extract and select features, make predictions and decisions with minimal human involvement. The main concept is based on models that are used to make useful predictions and decisions for processing the input data acquired by the sensors while also respecting the low-power and low-memory requirements of the ASSC.

Data fusion.

The ASSC supports a number of data fusion techniques for the self-powered AMANDA's device/gateway, capitalizing on recent advances for data computing at fog/edge nodes such as collection, cleaning, pruning, indexing, encryption and others. There is special attention on providing novel denaturing techniques keeping an optimal balance between privacy & value of the multipurpose data collected inherently by the ASSC. The main focus is the performance of the data fusion techniques in respect to energy consumption and CPU overload. Moreover, auto-calibration algorithms for ASSC sensors are used for the various sensors incorporated by the system. Depending on the envisaged application, the operation of single cards or networks/ swarms of ASSCs automates the inference of the algorithms that were developed and optimized.

Cybersecurity.

The cybersecurity module of the ASSC is focused on low-power implementations that aim to build a complete protection against malicious users or devices. Both hardware and software security is taken into consideration. Machine learning algorithms are used to protect the device against network attacks, while encryption algorithms that combine low-power consumption with high efficiency are deployed to protect not only data in transit, but also data stored in the card. Another security aspect that is handled in this module, is access control. In order to ensure that the card is being used from a legitimate user, an access method that identifies different biometric features of the users has been developed.

Wireless Communications and Localisation

Requirements:

- Low power In line with energy available from energy harvester and the needs of the application
- Size To meet space available on the card
- \bullet Peak current High current draws should be minimised to lessen the pressure on the storage
- Reliability of communication Failure to reliably deliver data means that the application does not work or that more energy is required for retransmissions
- Data rate Depends on the application. Hundreds of bits per second to hundreds of kilobits per second is sufficient
- Range Some applications require short range communications, whilst others call for a high link budget, allowing long range data transfer or communication in a difficult environment.
- Interaction with users Information displayed on a personal device such as a tablet or smartphone and/or further processed on application devices/servers
- Security wireless systems must have been vetted for security flaws to meet security and privacy issues
- \bullet Localisation Possibility to localise the card indoor and outdoor with minimal energy







Proximity Communications		Long Range
NFC	Bluetooth Low Energy	LoRa
 - <10cm Range - Operates in the same frequency band as HF-RFID devices of 13.56 MHz and provides a date rate of up to 424 kbit/s - Used to improve security and facilitate pairing 	 Integrated on RSL10 micro controller Version 5.0 2.4GHz ISM band Higher data rate (up to 2 Mbps) AoA techniques used for indoor localisation 	- SX1261 from Semtech - Low power long range _ Transmit with a power of up to +14 dBm - Supports the EU868MHz LoRa band -TDoA techniques used for outdoor localisation