The Framework Programme for Research & Innovation
Innovation actions (IA)

Project Title:

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

AMANDA

Grant Agreement No: 825464

[H2020-ICT-2018-2020] Autonomous self powered miniaturized intelligent sensor for environmental sensing and asset tracking in smart IoT environments

Deliverable

D1.6 Full System Specification and BOM delivered

Deliverable No.		**D1.6**	
Workpackage No.	**WP1**	Workpackage Title and task type	**System Specifications, Requirements and Use Cases**
Task No.	**T1.5**	Task Title	**Task 1.5: System specifications, Overall Architecture and Design**
Lead beneficiary		**CERTH**	
Dissemination level		**PU**	
Nature of Deliverable		**R**	
Delivery date		**31 August 2019**	
Status		**Final**	
File Name:		**AMANDA_D1.6_Full_System_Specification_&_BOM-v1.1**	
Project start date, duration		**02 January 2019, 36 Months**	

This project has received funding from the European Union's Horizon 2020 Research and innovation programme under Grant Agreement n°825464

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Document history			
Version	Date	Status	Modifications made by
V0.1	01/06/2019	ToC	CERTH
V0.3	10/07/2019	Incorporated contributions from Partners	Penta, ZHAW, IMEC, Lightricity
V0.4	09/07/2019	Content and layout improvements	CERTH
V0.6	20/07/2019	Additional contributions	Ilika, Microdul
V0.7	31/07/2019	Final draft, submitted for internal review	CERTH
V0.8	15/08/2019	Comments from Reviewers received	IMEC, ZHAW
V1.0	26/08/2019	Final version. Reviews addressed, ready for submission	CERTH
V1.1	08/11/2019	Updated based on comments from the 1st Review Meeting	CERTH

List of definitions & abbreviations

Abbreviation	**Definition**
ASSC	Autonomous Smart Sensing Card
BLE	Bluetooth Low Energy (now known as Bluetooth Smart)
BOM	Bill of Materials
DPS	Digital Pixel Sensor
EH	Energy Harvesting
EoL	End of Life
ESS	Electronic Smart Systems
FRAM	Ferroelectric Random-Access Memory
I^2C	Inter-Integrated Circuit
IP	International Protection
LDO	Low-dropout regulator
LPWAN	Low-Power Wide-Area Network
PCM	Pulse-Code Modulation
PMIC	Power Management Integrated Circuit
RTC	Real-Time Clock
SIP	System In Package
SoA	State-of-the-Art
SoC	System on Chip
SPI	Serial Peripheral Interface
UART	Universal Asynchronous Receiver Transmitter
WPAN	Wireless Personal Area Network

Executive Summary

This document is part of **WP1 – System Specifications, Requirements and Use Cases of the AMANDA project**. The aim of WP1 is to provide an overall framework for the project, to ensure a common reference point regarding the system requirements that arise from use analysis and to provide overall consideration and guidelines with respect to the solution introduced. This report is the first version of the **Deliverable D1.6 Full System Specification and BOM delivered** as part of **Task 1.5: System specifications, Overall architecture and Design** and will be updated at **M18** and **M34**. The current document includes the system specifications of the AMANDA ASSC along with the current list of commercialy available modules that will be integrated in the final card. The results of this document will give further directions to clarify the capabilities of the AMANDA platform, based on the selected modules that form the system.

The first part of this document presents a brief overview of the core system and the system versions. The AMANDA project will produce three separate versions of the ASSC (Indoor, Outdoor and Wearable) for different user needs, built on top of a common core system.

The specifications of selected components are given in three different Sections of the Deliverable. First, a choice of core system specifications is defined; then the sensor functional specifications as well as the mechanical specifications of card components are detailed.

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1 Introduction

The purpose of Deliverable D1.6 is to assemble the full system specifications related to the AMANDA ASSC. This document also gives a list of recommendations to provide further directions for the AMANDA work as part of **Task 1.5 System Specifications, Overall Architecture and Design**. Task T1.5 focuses on collecting all the materials and components included in the BOM and the main parts that will be integrated in the final ASSC.

1.1 Scope of this Deliverable

The goal of the project is to extend the limits of the autonomy of ESSs in the domain of intelligent decision making, to ensure an extended, maintenance-free ASSC lifetime and to apply compact design and development techniques for the miniaturization of the system. The AMANDA project will generate an intelligent and fully autonomous environment that will serve multi-sensorial IoT applications for smart living and working environments. The end device will be a next generation Autonomous Smart Sensing Card that will include multiple sensors, such as CO_2, imaging, capacitive and temperature sensors in conjunction with off-the-shelf commercial sensors. In addition, to ascertain that the final design will be protected from external conditions, the ASSC will integrate encapsulation and custom packaging in such a way as to allow the sensors to gather data from the environment.

The main characteristics of the ASSC are that it is autonomous and self-powered via the PV energy harvester, while it has miniaturized dimensions with a maximum thickness of 3mm. Moreover, the device is designed with advanced security aspects in mind to protect gathered and computed data from cyberattacks and common IoT vulnerability vectors. The ASSC will follow the main tasks listed below depending on the use case scenario:

- Collect information
- Process and secure data
- Provide feedback to the end user/communicate data

The scope of this Deliverable is to report the mechanical and electrical specifications for each layer of the system and the full ASSC device, including the core system specifications and the specifications for each version of the ASSC and to collect the list of materials that will be used for the development and integration of the final system as part of **WP5 – Smart Interconnect PCB Development and System Integration**.

1.2 Outline

This document is created based on information from Deliverables **D1.2 - Initial System Requirements Specified** and **D1.3 – Voice-of-the Customer completed.** Additional contributions are derived via research with regards to SoA information from the AMANDA Consortium.

This document is organized in six Sections:

- Section 2 presents a general overview of the ASSC system. It introduces a general description of the core system and the different versions of the ASSC. Additionally, it defines potential applications of the AMANDA platform
- Section 3 describes the functionality of the core system and its components. These include the power management, the processing unit, the RF communication subsystem as well as the sensors and different peripherals
- Section 4 illustrates the system specifications for all sensors of the ASSC
- Section 5 details mechanical requirements and specifications for all three versions (Indoor, Outdoor and Wearable) and the encapsulation of the ASSC that provides the case of the system with protection from particles and liquids (IP protection)
- Finally, Section 6 draws the conclusions of this Deliverable and discusses further work

2 Specifications methodology and ASSC overview

This Section describes the methodology followed for the description of the system specification of the AMANDA ASSC, as detailed in the following Sections of this Deliverable. Moreover, an overview of the individual versions of the card are also given.

2.1 Definition and development process

The overall methodology to derive the AMANDA system architecture, applying the ISO/IEC/IEEE 42010:2011 standard, is presented in detail in Deliverable **D1.7 - Architecture design of the AMANDA system delivered (for both breadboard and integrated/miniaturized system)**. Based on the findings of Tasks **T1.1 – SoA Analysis, feasibility study & benchmarking of best practices** as well as of **T1.2 – System Requirements and Needs**, this document reports on the detailed system specifications of the AMANDA ASSC.

To create the detailed specifications of the ASSC, the three phases of system design and definition were as follows:

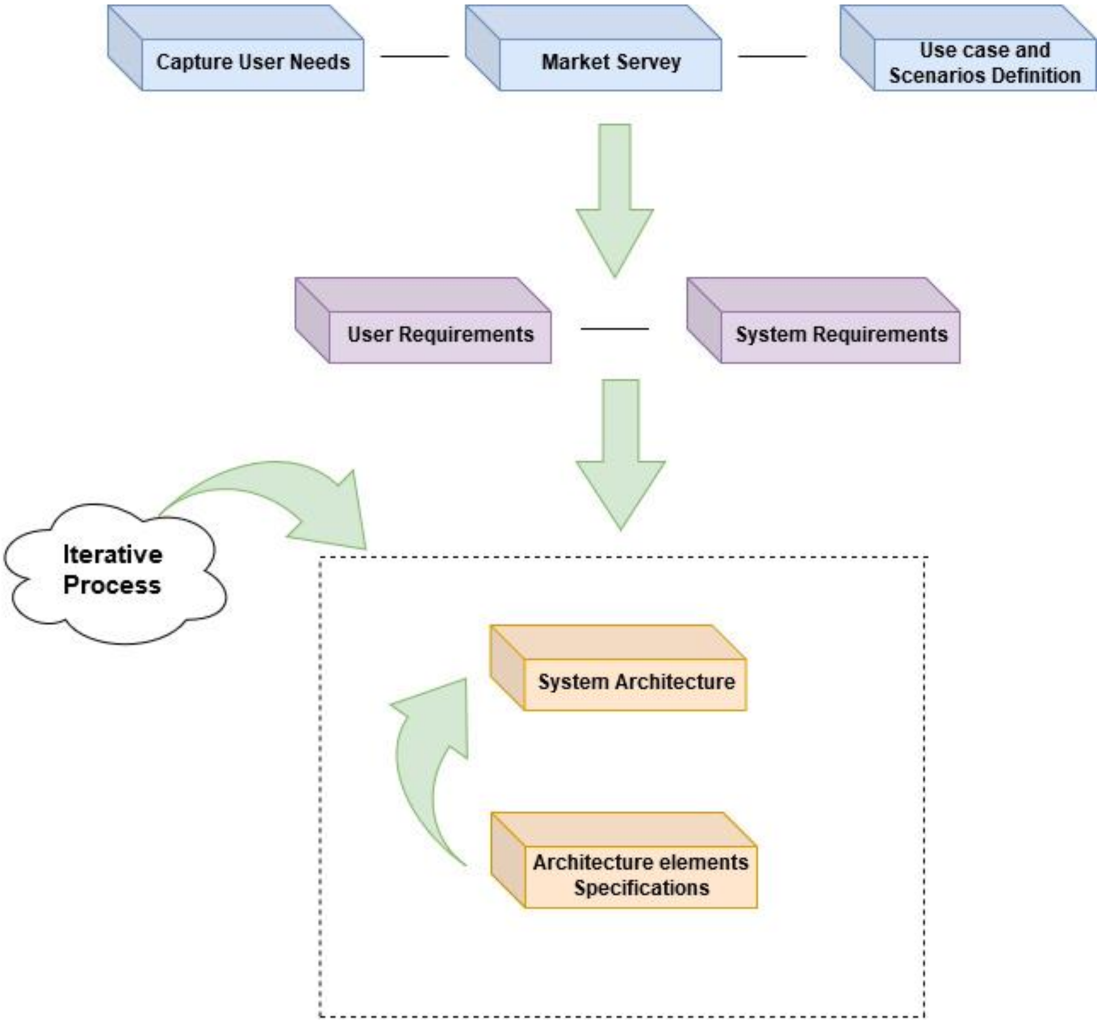


Figure 1 Definition and design process

2.1.1 Phase 1: System definition

The first step in the design and development of the AMANDA system, included the definition of scenarios and use cases that the system should address. These were gathered by questionnaires, case studies and interviews with key stakeholders who provided important feedback for the project. The results of this phase were reported in Deliverable **D1.3 - Voice-of-the Customer completed** under Task T1.2. At the same time, a review of the SoA, a Gap analysis and a thorough market survey were conducted to determine user and business requirements and analyse commercial trends. Findings of this effort were reported in Deliverable **D1.1 - SoA and Gap analysis/recommendations on ESS features report** under Task T1.1.

2.1.2 Phase 2: System requirements specification

Based on key stakeholder needs and concerns recorded in Phase 1, the initial requirements and specifications for technologies related to the AMANDA ASSC were drafted and presented in **Deliverable D1.2 - Initial system requirements specified**. These technologies include the power components (PV Energy Harvesters, batteries, PMIC), main and complementary sensors, MCU and RF components, and peripherals.

2.1.3 Phase 3: Detailed system specifications

In this final step of the definition process, and based on the stakeholder needs, user and business requirements and SoA review derived from Phase 1 and the system requirements specified in Phase 2 of the definition and development process, the architecture of the AMANDA system is defined, taking into account the seven core viewpoints presented in [1], namely the context, functional, information, concurrency, development, deployment and operational viewpoints. Moreover, the mechanical and electrical specifications of the architecture elements of AMANDA are derived, as presented in Figure 1.

2.2 ASSC overview

Depending on the use case scenario, as collected by Deliverable **D1.3 – Voice-of-the Customer completed**, the ASSC can be integrated as one of three different versions; an Indoor version, an Outdoor and a Wearable. Each version has different energy characteristics, components and packaging but at the same time, all are integrated with a common device layer, the core system, as shown in Figure 2.

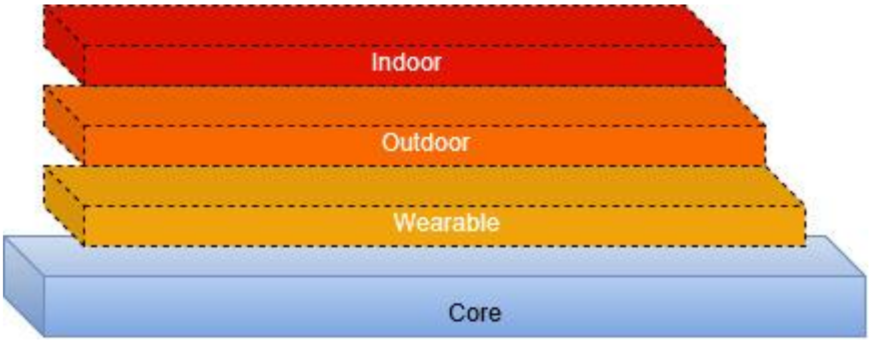


Figure 2 ASSC platform overview

2.3 Core system

The role of the core system is to contain certain fundamental functionalities that all versions require. It includes different electrical components, as presented below:

- **Energy 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 and Zigbee radio.** Implements short-range wireless communication capabilities

- **LoRa/LoRaWAN radio**. Implements long-range wireless communication interface for the ASSC
- **NFC component**. Responsible for fast transfer of large amounts of data and for charging the energy storage unit
- **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

2.4 System versions

Three versions will be created as part of the project; an Indoor, an Outdoor and a Wearable version, based on stakeholder needs and the specific use cases. Each version includes different sensors, has different energy characteristics and uses different packaging to ensure protection from the environment where needed. The different versions are presented in detail in Deliverable D1.7 – Architecture design of the AMANDA system delivered (for both breadboard and integrated/miniaturized system). To summarize, the three different versions of the ASSC will include:

- **Indoor.** It will be limited to interior places and areas. It will include, on top of the core system components, light, audio and magnetic sensors, a pressure, ambient temperature, humidity and gas sensor as well as imaging, temperature, CO_2 and capacitance sensors
- **Outdoor.** It will be installed at outdoor locations, like the surrounding area of a house or a building, or on various outdoor assets, such as a car or other vehicles. Depending on the use case, an energy harvester cell with smaller dimensions can be used comparing to the indoor version, due to the, on average, increased luminosity in outdoor spaces. Since the ASSC will be exposed to external hazards such as rain, dust and others, it is necessary to have IP protection for the platform. This version will include light, audio and magnetic sensors, a pressure, ambient temperature, humidity and gas sensor as well as imaging, temperature, CO_2 and capacitance sensors and an accelerometer
- **The Wearable version** is an on-the-move solution for the end user. It provides various information with regards to the highly diverse environment of the user, like the environmental temperature and the surrounding noise level. It will also require an IP protection for environmental hazards. It will include audio, imaging, temperature, CO_2 and capacitance sensors as well as an accelerometer.

Some of the above versions will use either a BLE and Zigbee radio for short-range wireless communications, a LoRa/LoRaWAN radio for long-range wireless communications or both, depending on the use case.

2.5 Possible applications

The ASSC has the capability of four out of the five human senses. Those are: sight (image sensor), smell (CO_2 sensor), hearing (microphone) and touch (fingerprint sensor). During the first months of the project implementation, the end user needs were researched and the different versions of the platform were designed in a way that they could encapsulate them. All the collected data are published in Deliverable **D1.3 – Voice-of-the Customer completed**. The advantages of the ASSC over other products on the market are its autonomy, unique combination of sensors and its small dimensions. It can be applicable in the field of building automation, smart cities, smart agriculture, wearables, industrial IoT, health and human body condition monitoring, aircraft cabin interior monitoring and others.

A separate module for the application is the data history overview. The obtained and transferred data is stored in a database. The database is sited on the cloud.

The application is a public service accessible to anyone and its administration and maintenance is performed by authorized public administration services.
It also contains the modules needed to alert the responsible public services. One option is the detection of firearms shots. It is performed by the noise sensor and different software algorithms that can detect firearms shots. The detection of an unexpected, immediate increase in CO_2 concentration can be an indication of a possible fire and the system can help to prevent it from spreading at an early stage.

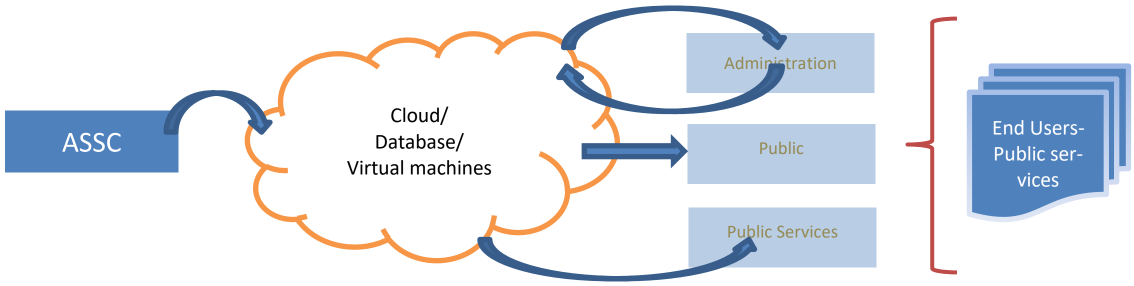


Figure 3 Data flow of possible applications

The example above describes only one possible application of the ASSC. The AMANDA consortium has the ability to develop web services that will allow individual partners to access gathered data from their own platforms and to implement the measurement data into their own applications.

3 Core system specifications

This Section details the overall functional description of the core system of the AMANDA ASSC. It focuses on the specifications of the core AMANDA system and the individual configurations of the power management, the processing, the RF and the sensor communications of the platform that are depicted in Figure 4.

These are the components used in the initial implementation of the AMANDA ASSC and will cover the various use case scenarios detailed in **Deliverable D1.7 - Architecture design of the AMANDA system**. That way, the functionality detailed in the Grant Agreement and in previously published Deliverables will be thoroughly covered. The specifications presented in this document will be updated on M18 and M34.

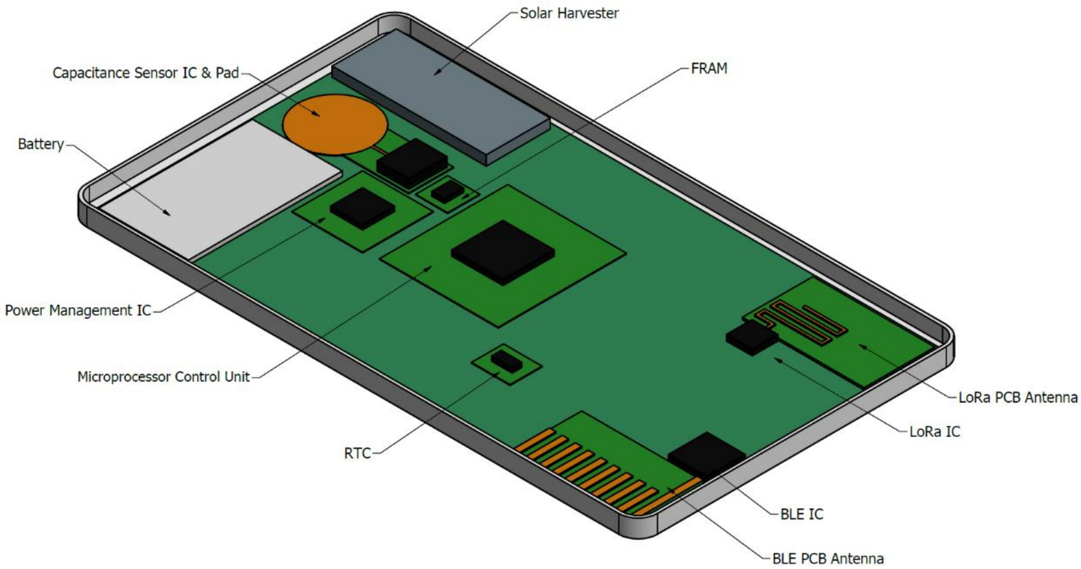


Figure 4 ASSC conceptual core system

3.1 RF communication

3.1.1 LPWPAN RF

Semtech SX1261 Long Range, Low Power, sub-GHz RF Transceiver. The SX1261 can transmit up to +14dBm. Using settings, it can reach up to +15dBm, albeit +14dBm is the maximum for Europe.

The radio is suitable for systems targeting compliance with radio regulations including but not limited to ETSI EN 300 220, FCC CFR 47 Part 15, China regulatory requirements and the Japanese ARIB T-108. Continuous frequency coverage from 150MHz to 960MHz allows the support of all major sub-GHz ISM bands around the world. [2]

The SX1261 supports a wide range of LoRa modulation options:

- Bandwidth: 7.8 - 500 kHz
- Spreading factors SF5 to SF12
- Bit rate: 0.018 - 62.5 kb/s

While using an RF splitter to split the Rx and Tx path, the following receiving sensitivities are possible:

Bandwidth	Spreading Factor	Sensitivity (Typ)
10.4kHz	7	-134dBm
10.4kHz	12	-148dBm
125kHz	7	-124dBm

125kHz	12	-137dBm
250kHz	7	-121dBm
250kHz	12	-134dBm
500kHz	7	-117dBm
500kHz	12	-129dBm

Table 1 LPWPAN RF sensitivity

LoRaWAN uses the LoRa protocol on the physical layer. The higher layers are implemented in the microcontroller's firmware, such as in the RSL10 Bluetooth Smart microcontroller.
The AMANDA project will use the spreading factors SF7 – SF12 in order to be compatible with LoRaWAN.

3.1.2 WPAN RF (Bluetooth Smart)

ON Semiconductor RSL10 multi–protocol 2.4 GHz radio SoC. The RSL10 includes a 2.4 GHz based RF transceiver which implements the physical layer of the Bluetooth Smart technology standard and other proprietary or custom protocols.
The protocol baseband hardware is Bluetooth 5.0 certified and includes support for a 2 Mbps RF link and custom protocol options.
The RSL10 supports:

- Data Rate : 62.5 to 2000 kbps
- Transmitting Power : −17 to +6dBm in 2dBm steps (BLE or 802.15.4 OQPSK)

The following sensitivities are possible depending on the data rate (Bluetooth Smart mode):

Data rate	BER	Sensitivity (Typ)
0.25 Mbps	0.1%	-97dBm
0.5 Mbps	0.1%	-96dBm
1 Mbps	0.1%	-94dBm
2 Mbps	0.1%	-92dBm

Table 2 WPAN RF sensitivity

The RSL10 already includes the Bluetooth Smart stack that runs on the integrated Cortex M3 CPU. The device can be used in Advertising mode (as a beacon) or in Connected mode. The chosen method will depend on the application.

3.2 Sensor Communications

3.2.1 UART

3.2.1.1 Protocol

UART consists of an asynchronous serial communication with a configurable data format and transfer speed. It is a low-cost protocol as only two lines are required, one for each transfer direction. This communication is full-duplex, meaning that it allows to simultaneously transmit data in both directions. Each UART side contains a shift register which is used to ensure the conversion between serial and parallel data.
When transmitting, data are shifted serially and sent out to the target device. Data are transmitted by selecting each byte from the least significant down to the most significant bit. A typical 8-bit transfer sequence is given in Figure 5. A start bit (logic 0) is first required before transmitting 5 to 8 data bits. The sequence ends with a stop bit (logic 1).

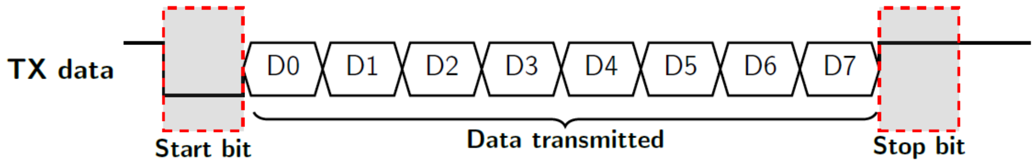


Figure 5 UART TX frame

At the receiver side, the line is continuously monitored at a speed which is much higher than the data rate. Once a start bit has been detected, the line is sampled at a known rate into a shift register. When the expected number of bits has been acquired, the data is made available. A typical 8-bit reception sequence is shown in Figure 6. As the transmitter and the receiver does not share any timing information through a clock line, it is primordial that both sides operate at an identical data rate.

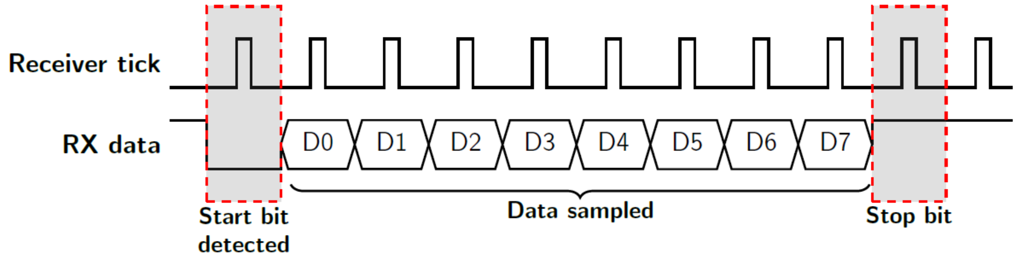


Figure 6 UART RX frame

3.2.2 SPI

3.2.2.1 Protocol

A Serial Peripheral Interface (SPI) offers 8-bit, full-duplex, synchronous, serial communication in a master-slave way. A SPI communication required four different lines: Master Out Slave In (MOSI), Master In Slave Out (MISO), Serial Clock (SCLK) and Slave Select In or Out (SSIN/SSOUT) depending If the device operates in master or slave mode.

When in master, the device initiates and controls all data transactions. The SPI controls data transfers to and from any slaves that are connected to it. The transaction starts with the master putting the SSOUT line low to address one or multiples slave devices. Then, the master sends out a clock signal which will be used to time the whole frame. At each clock cycle, the master shifts out a bit through the MOSI pin while the slave immediately responds through the MISO pin. After eight clock cycles, a new data both at the master and the slave sides is ready and made available. A typical SPI transaction is shown in Figure 7.

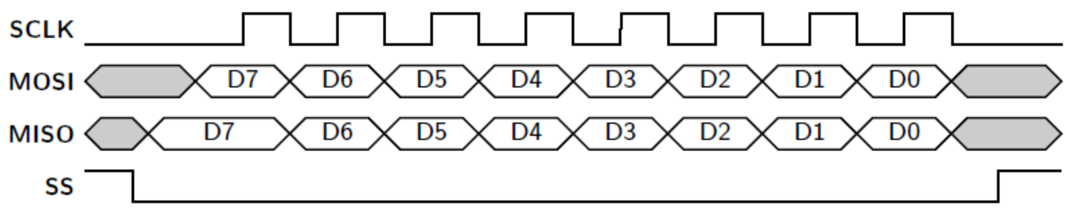


Figure 7 SPI frame

To fit the slave requirements, the master should configure the clock phase (CPHA) and polarity (CPOL). These parameters impact the moment at which data are changed during the transfer as well as the inactive state of the serial clock. In Figure 7, CPHA is set to 0 so that data are changed on the falling edges of the clock and are sampled on the rising edges. As CPOL has been fixed to 0, the serial clock is inactive low.

3.2.3 I²C

3.2.3.1 Protocol

The I²C protocol offers 8-bit, half-duplex, synchronous, serial communication between master and slave. It supports multiple masters and slaves on the communication bus and can operate in different transfer modes: Standard mode (100kbit/s), Fast-mode (400kbit/s), Fast mode Plus (1Mbit/s) and High-speed mode (3.2Mbit/s). An I²C communication requires two different lines: Serial Data (SDA) and Serial Clock (SCL).

When in master, the device initiates and controls all data transactions. A data transfer starts with a start condition being sent by the master peripheral. The slave address (7- or 10-bit depending of the configuration) is then shifted out with a direction bit (write or read operation). The addressed slave responds with an acknowledgment (ACK) and the data transfer begins. Each packet is composed of 8 data bits followed by a validity bit. An acknowledgment (ACK) attests the success of the transfer while a not acknowledgment (NACK) is sent in the opposite case. Once the transaction has completed, the master can either initiate a new transfer or send a stop condition.

Depending of the direction bit, the master can either become a master transmitter or a master receiver. In both cases, the master controls the SCL line. In master transmitter, the device transmits data once an address match occurred and wait for the slave to acknowledge before sending the next byte. The master ends the transaction by sending a stop condition on the bus, as shown in Figure 8. In master receiver, the device only transmits the clock signal once an address match occurred. The slave responds with data bytes and wait for the master to acknowledge before sending the next byte. Once the master considers that the transaction has completed, its sends a NACK followed by a stop condition to release the bus, as depicted in Figure 9.

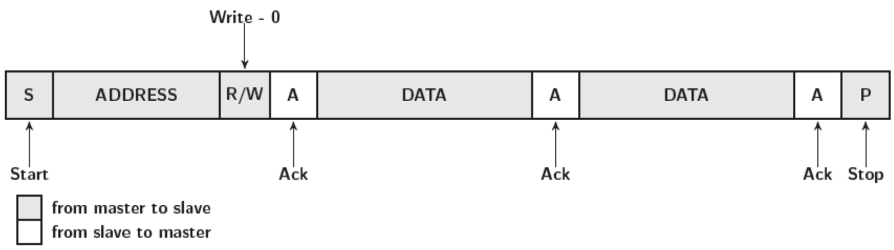


Figure 8 Master transmitter

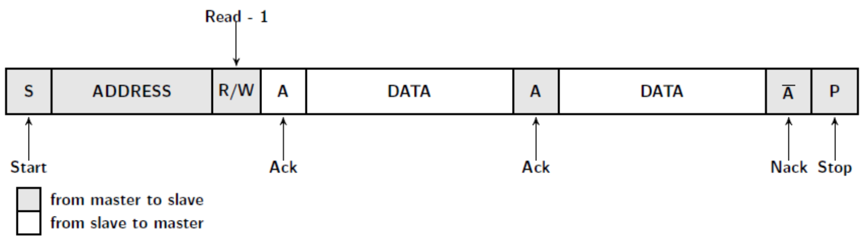


Figure 9 Master receiver

4 Sensor functional specifications

AMANDA is an energy autonomous multisensory device. It combines autonomous operation with a series of measurements executed in ultra-low power manner. In this Section, the sensorial part of the device is specified, unfolding the sensing capabilities of the AMANDA ASSC. Moreover, it contains details with regards to the individual functionality of each component and their characteristics which will enhance the modularity, low power and miniaturization prearranged requirements for the ASSC.

4.1 FRAM

FRAM are non-volatile memory elements that require very low energy. They can be written/read billions of times, making them ideal for applications powered by Energy harvesting. They are thus to be preferred to Flash in this project.
FRAM has several variations with different memory sizes and serial interfaces (SPI or I^2C) exist. Consequently, the appropriate version can be chosen, depending on the user case. The MB85RS64TU used in AMANDA has the following important characteristics:

- Bit configuration: 8192 words x 8bits
- Serial Peripheral Interface: SPI
- Operating frequency: 10MHz (Max)
- High endurance: 10^{13} times / byte
- Data retention: 10 years (+ 85°C)
- Operation temperature range: -55°C to +85°C

4.2 Volatile organic compounds/relative humidity sensor

The BME680 is a digital 4-in-1 sensor and integrates high-linearity and high-accuracy gas, pressure, humidity and temperature sensors. It consists of an 8-pin compact metal-lid 3.0 x 3.0 x 0.93mm³ LGA package which is designed for optimized power consumption. The sensor within the BME680 can detect a broad range of gases, including Volatile Organic Compounds (VOC) from paints (such as formaldehyde), lacquers, paint strippers, cleaning supplies, furnishings, office equipment, glues, adhesives and alcohol. Its small dimensions and its low power consumption enable the integration in battery-powered or frequency-coupled devices, such as handsets or wearables. The gas detection is not specific.

4.3 Accelerometer

The LIS3DH is an ultra-low-power high performance three-axis linear accelerometer. The device features ultra-low-power operational modes that allow advanced power saving and smart embedded functions. The LIS3DH has dynamically user-selectable full scales of ±2g/±4g/±8g/±16g and is capable of measuring accelerations with output data rates from 1Hz to 5.3kHz. The device may be configured to generate interrupt signals using two independent inertial wake-up/free-fall events as well as by the position of the device itself. Thresholds and timing of interrupt generators are programmable by the end user on the fly. The LIS3DH is available in a small thin plastic land grid array package (LGA) and is guaranteed to operate over an extended temperature range from -40°C to +85°C.

4.4 Light sensor

The OPT3001 is an ultra-low power lux meter with a measurement range capability from 0.01 lux to 83k lux that can work either in continuous measurement mode or in single shot mode. It communicates in digital to the microcontroller unit through an I^2C protocol.
The OPT3001 has an interrupt line which can be set to alert the main MCU when specific user-defined lighting conditions are met. This feature is useful for example to alert the MCU of a low-light condition. The MCU can then use that information in parallel of others such as the

battery state of charge to take action by switching the system into a lower power mode to save energy.
The OPT3001 can also be used to extrapolate the power generated by the Lightricity PV energy harvester from the Lux value received by the main MCU. Coupled with other monitored parameters such as the battery voltage, the MCU can perform some self-diagnostic operations to detect potential faults by comparing values from a theoretical model to the experimental ones.

4.5 Acoustic sensor

The SPH0645LM4H-B is a miniature, low power microphone with an I^2S digital output. The solution consists of a proven high performance SiSonic™ acoustic sensor, a serial analog to digital converter, and an interface to condition the signal into an industry standard 24-bit I2S format. The I^2S interface simplifies the integration in the system and allows direct interconnect to digital processors, application processors and microcontrollers. Saving the need of an external audio codec, the SPH0645LM4H-B is perfectly suitable for portable applications where size and power consumption are a constraint. The main features of the acoustic sensor are as following:

- High SNR of 65dB
- Flat frequency response
- Direct attach to microprocessor

4.6 Magnetic sensor

The LIS3MDL is an ultra-low power high-performance three-axis magnetic sensor. The LIS3MDL is available in a small thin plastic land grid array package (LGA) and is guaranteed to operate over an extended temperature range of -40°C to +85°C. These are the main features of the device:

- ±4/±8/±12/±16 gauss selectable magnetic full scales
- Continuous and single-conversion modes
- 16-bit data output in the selected scale
- Interrupt generator for autonomous operation

4.7 Light indicators

Low power SMD LEDs with 0603 footprint (1.55 x 0.85mm) or smaller and a maximum forward current of 2mA will be included as event or energy state indicators. A typical candidate is the SML-P11x from ROHM Semiconductors with 1.0 x 0.6mm footprint (0402 imperial footprint) and a typical current consumption of only 1mA. LEDs will probably indicate in a pulse manner with a low duty cycle scheme (a few hundred milliseconds flash every few seconds) in order to minimize their power consumption. As LEDs are not a critical part of the ASSC and have not been yet been fully specified, this Section will be updated in future versions of the Deliverable.

4.8 Ultra-low power displays

E-Ink segmented displays have been considered but since they usually require 5V for ink transitions they will require a voltage boost circuit to operate. Considering the size constrains of the card, a display will be considered if it can fit. This Section will be updated or removed in future versions of the deliverable.

4.9 Buzzer

A buzzer has been considered in order to be used a sound indicator. Since buzzers are not typically low power and require a lot of space, a device like this will be included in case there is space left and other means of low power indication are not included in the system. This Section will be updated or removed in future versions of the deliverable.

4.10 Fingerprint sensor

A fingerprint sensor can potentially be integrated to the AMANDA ASSC in order to implement biometric security features and to support authentication-related use case scenarios. For these reasons, a complete integrated circuit solution from ZEITEC Semiconductors has been considered. The ZFS1970 is a glass covered capacitance fingerprint sensor IC with a footprint of 8.55 x 6.45mm. An area of 12 x 12mm around the sensor is proposed for optimal device operation. The device requires a minimum of 2.65V for normal operation. It will probably be powered from the high voltage domain that will be used to power the CO_2 sensor as well. The device will be only considered if there is enough space to include it. Therefore, this Section will be updated with specifications or be completely removed in future versions of the Deliverable.

5 Mechanical specifications

In this Section, the mechanical specifications of the device are described. They include the current dimensions of the PCB and of every electronic component, the materials used for the enclosure as well as the design addressing waterproof and dustproof requirements.

5.1 Component dimensions

5.1.1 ASSC PCB and device enclosure

The device enclosure is based on the US Business Card Standard with dimensions of 89 x 51mm. Due to the enclosure material thickness and the corner radius, the internal PCB board is limited to a slightly smaller form factor of 86 x 48mm. A detailed view of the whole structure is given in Figure 10 below, where the 1mm margin between the enclosure and the PCB can be seen.

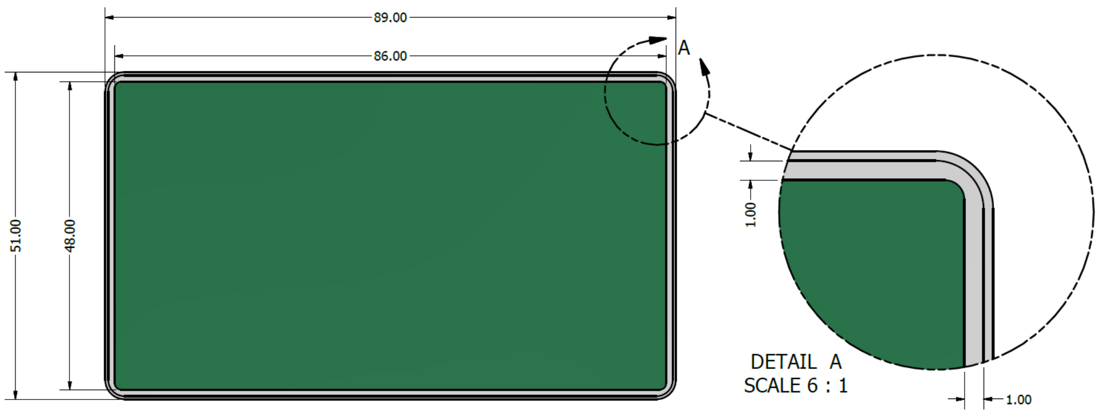


Figure 10 PCB and device enclosure dimensions

Currently, the wall thickness of the enclosure is chosen to 0.5mm. This thickness is not a common value among plastic enclosures. However, it is sufficient, given that there are not mechanical stresses expected and the ASSC will be a completely custom design, both in terms of electronics and of hardware/enclosure.

5.2 Enclosure specifications

In this Section, the enclosure specifications of the ASSC are presented, focusing on the environmental requirements where the device will operate in. In particular, the requirement to operate in such humid environments as internal industrial areas or outdoor exposed locations is critical. Moreover, the enclosure should be able to withstand the UV radiation of the sun.

5.2.1 Water and dust resistance

It is important to ensure that the ASSC will be able to operate without malfunction in a variety of environments, including installations with exposure to high humidity or dust levels, such as industrial production/storage rooms or common exterior places. Apart from physical damage and corrosion of electronic components that can occur due to water and dust, there is an additional implication of dust; it can gradually build up on top of the solar harvester's surface. That way, it can cover the PV surface, resulting in a decrease in the amount of illumination that reaches the solar cell therefore affecting its total performance. As dust concentration on the cell surface depends mainly on the installation environment and not on the operation and materials of the ASSC, there is not an easy solution to implement; however the AMANDA consortium will investigate the use of hydrophobic and dirt repelling surface coatings in order to reduce the implications of this problem.

To address the first requirement, of physical damage, the device enclosure must be able to act as a water and dust cover for the internal components, providing some level of protection. A simple solution would be to design an airtight and waterproof enclosure that would keep both humidity and dust away from the electronics, but there is an additional requirement for openings in the enclosure. In particular, few of the utilized sensors such as the CO_2 concentration or light and imaging sensors, require specific cut-outs on the enclosure, in order to be exposed to the environment; directly for the imaging and light sensor or indirectly for the CO_2 concentration sensor for instance. A visual representation, as designed in this early stage of development, is given in Figure 11 below.

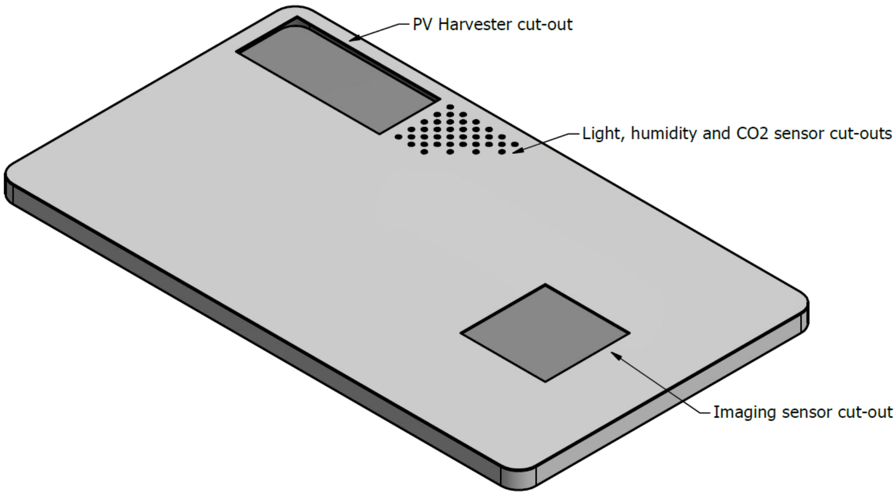


Figure 11 Enclosure openings for sensors

The chosen protection method is a combination of basic water and dust resistance from the enclosure and higher level of humidity and micro-particle protection from PCB encapsulation. Details on this subject are given below. The enclosure openings are designed to leave a minimal gap of approximately 0.2mm between it and the individual parts that protrude. Additionally, an appropriate diameter of 0.7mm is chosen for the circle cut-outs to allow light, humidity and gas measurements to be carried out by the internal on-board sensors.
Due to the above characteristics, the enclosure needs to achieve a resistance against dust particles and some water proofing protection, therefore a suitable overall rating could potentially be IP43, as specified by the IEC 60529 [3] international standard and described in Table 3 below. As the project evolves, the AMANDA consortium might need to alter the rating to a lower or higher level, depending on updated component specifications.

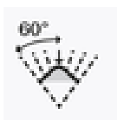
Representation [4]	**Rating Definition**
	Resistance to solid objects and dust: IP4X. Protected against solid objects > 1mm in diameter
	Resistance to water: IPX3. Protected against water spray at 60 degree angle

Table 3 IP Rating of the enclosure

5.2.2 UV resistance

The material of the device's enclosure needs to meet an additional ultraviolet radiation (UV) resistance criteria in order to ensure a proper operation of the card in outdoor application. This type of radiation can heavily impact a common plastic enclosure and cause wear and damages such as discoloration, stress crack formation or development of brittleness.
To address these potential threats, there are two different design approaches:

- Utilise an additional external cover/mount that will protect the device from direct UV radiation. In this case, the enclosure does not need any special care in terms of material selection
- Utilize a UV resistant plastic material for the manufacturing of the enclosure, such as PTFE and PVDF which demonstrate very good UV stability in their natural state. An investigation will be also carried out concerning the ecological impact of the device's materials, such as utilizing biodegradable or eco-friendly solutions, if feasible for the majority of use cases

5.2.3 Dielectric properties and layer stackup for touch sensing

An additional challenge of the AMANDA hardware design is the capacitive sensing circuitry and mechanical setup, in such a form factor. There are two areas of investigation, one considering the materials of the electrode's layer stackup and the second one about the mechanical mount of the electrodes. More details are given for both subjects in the following paragraphs.

5.2.3.1 Capacitive sensor layer stackup

A key factor when designing capacitive sensors is the selection of the suitable materials, as different materials present completely different dielectric and capacitive behaviour. Concerning the sensor electrode itself, the most common design approach is to implement it directly on the PCB board, with the copper traces and an appropriate pad geometry. To achieve the minimum height, the specific choice of flexible PCB is even more important.
To better present the physical aspect of the capacitive sensor assembly, an example design is given in Figure 12 below. However, the amount of components and complexity of the PCB board will probably lead to the use of a multi-layered design, in which the placement of the electrodes would preferably be on the bottom layer. In this configuration, it is easier to obtain a larger capacitance change and achieve better performance of the capacitive sensor.

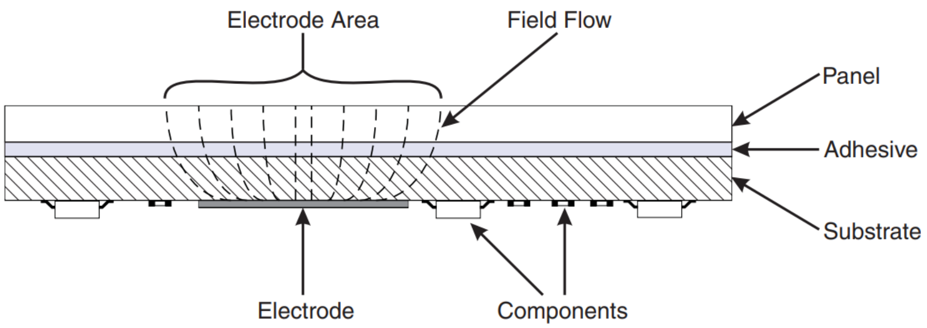


Figure 12 Example „Back-firing“ capacitive sensor layer stackup [5]

The question of material choice arises for the intermediate layer between the user's finger and the actual electrode traces; the role of this dielectric layer will play the device enclosure. More specific, the enclosure's thickness and dielectric constant will highly effect the strength of the electric field at the surface of the control panel, meaning the external surface of the enclosure. Additionally, in case of the "back-firing" sensor design, with a single side PCB and the electrodes on the side away from the user's finger (as presented in Figure 12 above), the extra board thickness and material have to be also taken into account. Therefore, it is important to investigate both of these properties: chosen material and thickness as well as to widely test the final assembly for design validation, after manufacturing. For an initial electrode design, a suitable capacitance simulation software should be employed. The circuit sensitivity will probably need to be adjusted during this step in order to compensate for the specific enclosure thickness, dielectric constant and electrode's size and geometry.

5.2.3.2 Mechanical mount of touch electrode

While not very common, in some design cases it is not feasible to directly mount the PCB onto the panel surface, which in AMANDA ASSC's case is the enclosure. As illustrated in the example below, in some designs the sensor electrode is formed in a secondary PCB, flex or similar substrate.

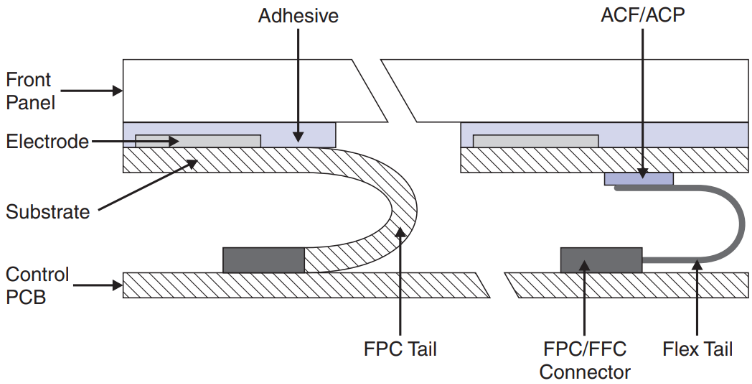


Figure 13 Secondary substrate method of the capacitive sensor [5]

In this way, the potential issues occurring due to height differences of electrode PCB side and the panel are eliminated. Concerning the AMANDA ASSC design, a similar solution is preferable, as the PCB components will likely be populated only on one side, for height restriction; the same side as the sensor electrode. A "back-firing" design approach, with components on the bottom layer, might not work in this case, due to the need to have multiple component ICs facing up too, such as a light sensor. This will give a height difference between the PCB trace forming the electrode and the top of the ICs, making the secondary substrate method ideal.

5.3 PCB Encapsulation

Due to the constrain of the device's enclosure to completely seal and insulate the interior parts from water and dust, the enclosure is targeted to have a rating of IP43, as mentioned in Section 5.2.1. The whole PCB assembly should then be encapsulated, with all electronic components already soldered, in order to ensure its protection from the elements.
There are two common methods of encapsulating electronics, with different characteristics and advantages/disadvantages, potting and conformal coating. Additional details regarding both methods are given below.

5.3.1 Potting

Potting and encapsulation resins usually offer the highest level of PCB protection, both electrically and mechanically. Due to the encapsulation of the entire board as well as the bulk of added material surrounding it, an increased protection and insulation is achieved. The most significant characteristics of this method are given below.
Advantages:

- Superior mechanical protection and rigidity

- High level of electrical insulation

Disadvantages:

- Bulk material is added to the PCB assembly, resulting in increased volume and weight
- No access to the encapsulated board in case of failure/malfunction

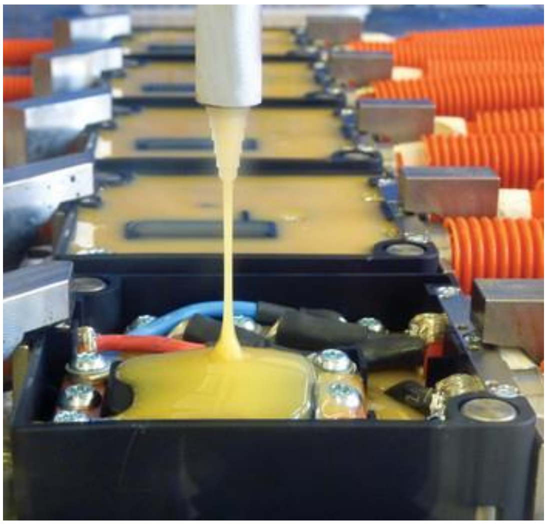


Figure 14 Potting encapsulation method [6]

5.3.2 Conformal coating

Conformal coatings are polymers that can be applied in thin layers to PCB in order to insulate them from environmental stresses such as humidity, corrosion and contaminants. They can be sprayed, brushed, flow coated or dispensed by robots and achieve a minimal added weight and height, a characteristic very suitable for miniaturized assemblies such as AMANDA ASSC. Additionally, they are able to provide some mechanical protection, mostly improving the fatigue life of solder joints [7]. Their most significant characteristics are given below.

Advantages:

- Corrosion protection of solder joints
- Electrical insulation of the exposed conductive areas such as IC's pins and PCB's traces and vias
- Capability of coated PCB to be reworked with chemical coating removal

Disadvantages:

- Due to the thin film of the material, only a basic mechanical protection is achieved
- It can be difficult to protect some of the sensors on the PCB, such as humidity or CO_2. Covering with an often silicone-based coating can even permanently damage some sensors

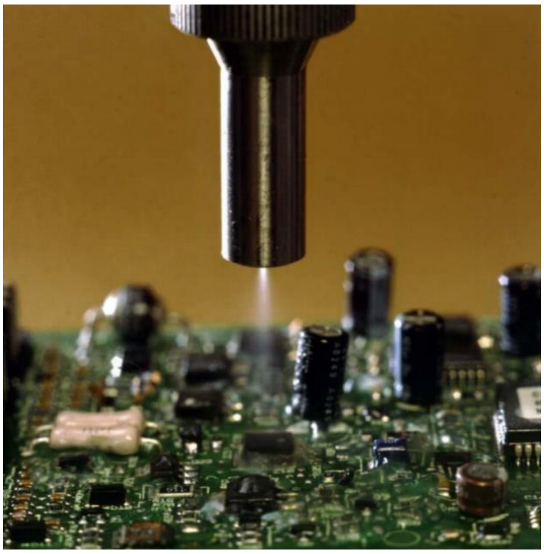


Figure 15 Conformal coating encapsulation method [7]

Based on the characteristics of both methods, the most suitable solution for AMANDA appears to be conformal coating, mainly due to the constraint of the card's size. Furthermore, although mechanical protection is always important in electronic designs, no significant mechanical stresses are expected in the project's use cases, meaning the high priority remains on the size factor.

6 Conclusions and future work

The **Deliverable D1.6 - Full System Specification and BOM completed** report is part of **Task 1.5 System Specification Overall Architecture and Design**. This Deliverable provides the full system specification which includes the functionality of the sensors, mechanical and electrical specifications for the AMANDA ASSC platform as integrated system and for its three separate versions (Indoor, Outdoor, and Wearable) as well.

Future work will be focused on updating the functionality and the specification of the system, especially on functionality of the sensors, mechanical specifications, electrical specifications and also changes of some components with their newest version which will have lower power consumption and thinner dimensions. This modification depends on the use case scenarios and applications as well as to provide the final version of the AMANDA ASSC with more flexibility and autonomous capabilities. The Deliverable will be updated on **M18** and **M34** of the project.

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