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AMANDA

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Deliverable

D2.2 Initial Report on commercial AMANDA Sensors

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List of definitions & abbreviations

Abbreviation	Definition
ADC	Analogue to Digital Converter
AMR	Anisotropic Magneto Resistance (used in some spintronics devices)
ASSC	Autonomous Smart Sensing Card
BOM	Bill of Materials
CMOS	Complementary Metal–Oxide–Semiconductor
FRAM	Ferroelectric Random Access Memory
GMR	Giant Magneto Resistance effect (used in some spintronics devices)
I/O	Input/Output
I^2C	Inter-Integrated Circuit Bus
IoT	Internet Of Things
LED	Light Emitting Diode
LGA	Land Grid Array
LoRa	Long Range (for the Wireless Communication System)
LSB	Least Significant Bit
MEMS	Microelectromechanical Systems
MRAM	Magnetoresistive Random Access Memory
ODR	Output Data Rate
PCB	Printed Circuit Board
PMC	Power Management Controller
PMIC	Power Management Integrated Circuit
PMU	Power Management Unit
PV	Photo Voltaic
PWM	Pulse-Width Modulation
RH	Relative Humidity
RTC	Real Time Clock
SNR	Signal to Noise Ratio
SPI	Serial Peripheral Interface
SPL	Sound Pressure Level
SRAM	Static Random-Access Memory
TMR	Tunnelling Magneto Resistance
UC	Use Case
VOC	Volatile Organic Compounds

Executive Summary

Deliverable D2.2 is part of **WP2 - Sensor development and multisensorial optimisation** of the AMANDA project. The objectives of WP2 are to:

- Research and provide the sensors with the required form factors, sensitivity, reliability
- Evaluate off-the-shelf sensor technologies
- Develop firmware for the optimized energy consumption of the overall sensing functionality

The report is the outcome of works executed within **Task 2.2: Evaluation and Adaptation of off-the-shelf sensors**. It focuses on off-the-shelf sensors, which are necessary to fulfil requirements indicated in the use cases of the project. This report consists of the following Sections:

- Introduction. This Section provides general information about the project and relevant references to submitted reports. The fragment contains clear indication of considered off-the-shelf components and refers them to indicated use cases. Moreover, the end-user point of view towards the sensor evaluation is discussed
- Evaluation of off-the shelf sensors and input/output devices. The main Section of the document. It describes different sensors and discusses their usage in the AMANDA system. Additionally, it evaluates the technical parameters of the components and provides a hands-on advice and suggestions for their integration to the ASSC
- Summary**.** It presents a summary and the conclusions of this Deliverable.

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1 Introduction

1.1 Overall technical objectives

The AMANDA project aims to develop a unique ASSC with the size, feel and look of a credit card. The card can be ideal for easy deployment in buildings (smart living environments) or to be uses as a wearable, including bikes, valuable assets or people. This project covers the triangle of experimentation, development and standardization. AMANDA's vision is to overcome the existing technological challenges and achieve the development of a user-friendly miniaturised platform not only for indoor & outdoor environmental sensing, but also for asset or even people tracking. A combination of developed and existing off-the-shelf technologies is to be selected and integrated into the ASSC. Innovative sensors from IMEC and Microdul, PVs from Lightricity, a PMIC from EPEAS and batteries from Ilika, as well as necessary off-the-shelf components all packed in under 3mm thickness. One of the project objectives is to overcome technical challenges that are coming from low power requirements and extensive miniaturization. The project outcomes will offer a smart card technology with integrated sensors, a small footprint and an ultra-low power consumption.

1.2 Purpose, context and scope

AMANDA incorporates research activity which is able to provide outstanding electronic technology. Detailed description of the research activities will be provided in **Deliverable D2.1 - Report on AMANDA Sensors Development** on M20. In order to emphasise the benefits of the unique features for the provided components, several use cases are selected. However, the efficient usage of AMANDA card requires more functionality than the partner-developed components can provide. That is why off-the-shelf sensors and input/output devices need to be considered in the project. Choice of the commercial components must be made based on the selected application needs. The technical focus of the AMANDA project is the development of a low-power and low-profile electronic system. Thus, the chosen commercial components need to support these requirements. Earlier in the project, the architecture was proposed in the first version of **Deliverable D1.7 - Architecture design of the AMANDA system delivered (for both breadboard and integrated/miniaturised system)** and will be subsequently revised on M18**.** This report is the next step in the system's development, listing chosen components, describing their features, referring them to defined use cases and finally providing advice about methods of component usage. The information is to be utilized in upcoming project tasks, including T2.3, T5.1, T5.2, T5.3 and T6.1, where software and hardware will be developed.

1.3 Use cases and their impact on the AMANDA off-the-shelf sensors and input/output components

During the works in WP1, requirements and operational scenarios were defined. The relevant information is available in Deliverables D.1.2, D1.3, D1.4, D1.6, D1.7, where detail discussion about users need was presented. Based on that information the use cases were narrowed down to the most crucial:

Use case	Description	Component of the system
UC1	Environmental room sensing for automated room control	Core System, Temperature, Humidity, Pressure, VOC, Light Sensor, CO_2, LED
UC2	Multisensory indoor parking slot occupancy monitoring	Core System, Temperature, Humidity, VOC, Light Sensor, Accelerometer, Imaging, Magnetic Sensor
UC3	Infrastructure, noise, weather and air quality monitoring sta-	Core System, Temperature, Humidity, Pressure, Light Sensor, Accelerometer, Magnetic Sensor

	tion	
UC4	Identification and health of people in a working environment	Core System, Temperature, Humidity, Pressure, Light Sensor, Accelerometer, Acoustic Sensor, Magnetic Sensor, LED
UC5	Assets and goods tracking and monitoring	Core System, Temperature, Humidity, Pressure, VOC, Light Sensor, Accelerometer

Table 1 The list of the AMANDA project‘s use cases and required components[1]

Table 1 contains the foreseen functional components which should be utilised for a particular use case. The list contains components developed as part of the project, including the temperature, CO_2 and imaging sensors as well as power management, and also off-the-shelf components. In this Deliverable, only off-the-shelf sensors and input/output components will be discussed.
The project aims for a reduced size and low-power application. Thus, less active components on-board reduce dimensions and power consumption. That is why, each off-the-shelf component is carefully evaluated not only from a technical point of view, but also its presence needs to be justified from a functional point of view. A detailed discussion on each component can be found in Section 2.

1.4 System Architecture - required sensors and input/output components

The use cases allowed to identify technical needs for each system, leading to unique architecture designs of the systems. The architecture and its components are described in D1.6 and D1.7. In the project proposal document some solutions were already suggested, but in the architecture the off-the-shelf components were truly selected. Based on functionality (use case), different combination of components must be used. Table 2 provides a list of sensors while Table 3 presents a list of input/output devices mentioned in the suggested BOM of the AMANDA system (D1.6).

Off-the-shelf sensors	Motivation	Chosen component
Low-power accelerometer	Support for positioning, activity monitoring, event capturing	LIS3DH
Spintronics sensor/Magnetometer	Support for positioning	LIS3MDL
RH & Temperature, VOC sensor	Environment monitoring	BME680
Fingerprint sensor	Human identification	ZFS1970
Light sensor	Light condition monitoring for power failure prediction	OPT3001
Acoustic sensor	Environment monitoring, Event capturing	SPH0645LM4H-B

Table 2 Off-the-shelf sensors proposed in the architecture of the AMANDA card

[1] In the Table, the description of “Core system” is taken from Deliverable D1.6 and represents components which will be used across all applications. It contains a microcontroller, memory, a power management unit as well as radio connectivity components. Those elements of the system will not be discussed in this report

Off-the-shelf input/output	Motivation	Chosen component
Memory	Non-volatile storing of the parameters and temporary data	MB85RS64TU
Display	To give immediate feedback to user	Not identified
Real time clock	Low power interrupt source	RV-3028-C7
LED	Basic feedback to user	SML-LX0404

Table 3 Off-the-shelf input/output components proposed for the AMANDA card

In Section 2, components from Table 2 and Table 3 are discussed both from their usage and technical points of view.

1.5 End-user guidelines towards the evaluation of off-the-shelf components

The aim of the evaluation is to confirm the selection of sensors to be integrated into the end product. The evaluation should present that the sensors selected will meet the project objectives with their characteristics. An end-user-based evaluation methodology is based on four necessary parts:

- Evaluation of sensors according to prerequisites
- Evaluation according to technical aspects
- Critical conditions of individual sensors
- Critical conditions of the sensors group

Evaluation, according to the prerequisites, is based on the Grant Agreement of the AMANDA project and the requirements that an autonomous multi sensitive card must satisfy. The default prerequisites also set the conditions for selecting sensors. The prerequisites are card size, card thickness, autonomy, multi-sensor card, and off-the-shelf sensors. The size of the card is defined by the size of a credit card, while the maximum thickness of the card is 3mm. Such a prerequisite sets the conditions for the size of the sensors, which must satisfy the size and stated requirements. The proposal declared the card's autonomy for ten years of smooth operation. The prerequisite assumes such PV modules and batteries that, even in low light conditions, will provide enough power for the smooth operation of the card. Sensors on the market should be easily accessible, with the prices that will guarantee a final competitive product. Correlates with the promise that the card will be multi-sensing, the card will have at least seven off-the-shelf sensors. Evaluation, according to technical criteria, is based on the need to satisfy the ASSC autonomy requirements. It is crucial to select sensors with low power consumption. For this purpose, it was necessary to obtain the technical characteristics of the sensor in the idle state, the wake-up state, and the continuous operation state. Sensor selection is based on the choice of sensors with the lowest energy consumption, assuming that the tolerance of measurement accuracy is met. The sensor evaluation under critical conditions is reflected in the identification of the weakest link in the sensor chain. The weakest link is the sensor that consumes the most energy in its operation. The critical conditions of the group are reflected in the operation of multiple sensors simultaneously. The simultaneous operation of the sensor group certainly places significant requirements on the amount of energy harvesting.
Previous documents, such as **Deliverable D1.3 - Voice-of-the Customer completed** and **D1.4 - AMANDA Operational Scenarios Definition**, have defined the end-user needs, scenarios and the possible uses of the ASSC. Appreciate the expectations of the end-user and declared

use cases, sensors evaluation should show that the selected sensors meet the stated objectives.

Table 1 shows detailed information on the five selected use cases:

- UC1 encounters the need to collect energy under artificial lighting conditions. Also, in this use case, the possibility of detecting smoke or fire is expected. Managing sufficient energy power is a fundamental prerequisite for ensuring the smooth operation of the ASSC. Another precondition is the accuracy of the measurement. Particular attention is given to working in low light condition
- UC2 defines the presence of vehicles in a parking slot. The accepted, satisfactory standard for parking vehicle presence readings is a 96% reading accuracy. The great advantage of an ASSC card is that it can simultaneously detect the presence of vehicles with multiple sensors. The magnetic sensor should be able to detect the change of earth magnetic flux at distances of 10cm to 80cm from the sensor. Indoor parking spaces are frequently dimly lit, which places significant technical requirements for the autonomy of the operation of the AMANDA ASSC
- UC3 integrates all sensors into its operation. Although the measurement of temperature, pressure and humidity can be defined at regular intervals, the measurement of noise and vibration should be continuous or at least at intervals that provide relevant information. Ensuring card autonomy under constant measurement conditions is an essential prerequisite. UC3 defines the use of ASSC in an outdoor space. Therefore, the amount of energy from the environment is sufficient for the smooth operation of all sensors. Accuracy of measurement data and the frequency of data presentation are critical conditions in UC3
- US4 covers the identification and health of people in a working environment. The system should alarm the appearance of gases in the work environment as well as sudden changes in temperature. The intensive work of the sensory group places critical conditions on ASSC autonomy. Position detection requires wireless communication with the central system, which requires additional energy requirements
- For UC5, the AMANDA ASSC detects changes in the position of assets and goods. The monitoring of the environment is continuous. The selected magnetic sensor and accelerometer are low-energy consumption sensors. In low-light conditions, such low-power sensors will satisfy the autonomy requirements over a given asset and goods tracking period

The evolution of the sensors and their connection to the use case shows that two basic prerequisites have to be met: low-power consumption and measurement accuracy. Sensor evaluation will continue throughout the project, with particular emphasis on the application of sensors to actual operating conditions.

2 Evaluation of off-the shelf sensors and input/output devices

Presence of a commercial component in the system must be justified by its added value to the system application. In this Section, the selected commercial components are presented. In the discussion, the features of each component properties are analysed, as well as their relationship to the use cases. An advice, for most important development steps, is given. The knowledge will be used in upcoming tasks T2.3, T5.1, T5.2, T5.3, T6.1 for implementation of the components in the system.

2.1 Relative humidity, Temperature, pressure, VOC sensor

The BME680 (Figure 1) is a digital 4-in-1 sensor with gas (VOC), humidity, pressure and temperature measurement. The sensing module is housed in a compact metal-lid LGA package. The footprint is only 3 x 3 x 1mm. Its dimensions and low-power consumption enables the application in handsets, wearables, home appliances, navigation systems and IOT devices.

Figure 1 The BME680 sensor

2.1.1 Relationship with the use cases

2.1.1.1 Temperature and humidity

Temperature and humidity of the air are basic parameters for air environment monitoring. Next to carbon dioxide, the dust and nitrogen oxide concentration levels are the most important parameters for human perception and health in indoor and outdoor environments. For this reason, these basic parameters are involved in all use cases. Additionally, many sensors and electronic components can express cross-sensitivity to temperature and in some cases humidity can influence electrochemical sensors. The calibration algorithms can mitigate the cross-sensitivity effect. However, the artefacts in the signals can be eliminated only when the values of the temperature and humidity are known. The architecture already involves a temperature sensor designed proprietarily for the project by Microdul. The BEM680 is an efficient, integrated solution for environmental measurement. Its main contribution to the card functionality is coming from humidity, pressure and VOC. The additional temperature signal source can be used sporadically for long term drift calibration

2.1.1.2 Atmospheric pressure

Some people are more susceptible to changes in the atmospheric pressure. Often, symptoms of air pressure changes include headaches or other minor aches. Thus, atmospheric pressure can be treated as supportive parameter for human well-being monitoring. The data of the sensor will be used in use cases UC1, UC3, UC4, as listed in Table 1.
The total atmospheric pressure is a parameter which can be used in altitude approximation since there is a clear relationship between altitude and atmospheric pressure. That feature might be a supportive parameter for localisation. Altitude information obtained via atmospheric pressure can be applied in use case UC5.

2.1.1.3 Volatile Organic Compounds

VOCs are substances that easily become vapours or gases. The VOCs are released from burning fuel such as gasoline, wood, coal, or natural gas. They are also released from many consumer products: cigarettes, solvents, paints and thinners, adhesives, hobby and craft supplies, dry cleaning fluids, glues, wood preservatives, cleaners and disinfectants, air fresheners, building materials and furnishings, copy machines and printers, pesticides and others. A listed wide variety of compounds indicates that the VOC sensor can give positive response after contact with many substances. Some of these compounds triggering the VOC sensor are a direct indication of hazard like smoke (starting fire) but others are just standard harmless events like increase CO_2 levels coming from breathing or the release of other substances such as perfume. It is a challenge to draw a conclusion about the event just based on VOC sensor output. However, the data from the sensor can have supportive functions. The information can increase the probability of success for event identification as part of decision making algorithms. The VOC sensor will be applied in use cases UC1-UC4.

2.1.2 Technical evaluation

The operating range of the sensor is defined in Table 4. The ranges are able to cover the needs of the targeted applications.

Parameter	**Value**
Temperature	-40°C - +85°C
Relative Humidity	0% - 100%
Pressure	300hPa - 1100hPa

Table 4 Operating parameter range of BME680

The manufacturer claims that with optimum settings and operating conditions, the average current consumption is relatively low:

- 2.1µA at 1Hz humidity and temperature
- 3.1µA at 1Hz pressure and temperature
- 3.7µA at 1Hz humidity, pressure and temperature
- 0.1mA for VOC measurement in ultra-low power mode[2]
- 0.09mA - 12mA for pressure, RH, temperature, VOC depending on operation mode
- 0.15µA in sleep mode [1].

Nevertheless, power consumption can change due to less optimal conditions. Less optimistic version of the most important electrical parameters of BME680 (from implementation point of view) are listed in Table 5. It is clearly visible that measurements of temperature, humidity and pressure are relatively less power demanding than measurements of VOC.

Parameter	**Value**	**Comments**
Supply voltage	1.71V - 3.60V	Ripple max. 50mVpp[3]
Sleep current	0.15µA (max 1µA)	
Standby current (inactive period of normal mode)	0.29µA (max 0.8µA)	

[2] Whilst this is the current consumption during the measurement phase, a large current 12mA is required for the heating stage, which is required to the measurement to take place.

[3] The sensor is optimised for 1.8V

Current during humidity measurement	340µA (max 450µA)	Max value at 85°C
Current during pressure measurement	714µA (max 849µA)	Max value at -40°C
Current during temperature measurement	350µA	
Start-up time	2ms	Time to first communication after both VDD > 1.58V and VDDIO > 0.65V
Peak supply current during VOC measurement	17mA	
Average supply current during VOC measurement	0.09mA	In ultra-low power mode
Response time for VOC	92s	In ultra-low power mode

Table 5 The most important electrical parameter of the BME680 [1]

2.1.3 Adaptation guidelines

2.1.3.1 Component placement

The component dimensions of 3 x 3 x 0.93mm and low-power consumption are suitable for the AMANDA card profile. A capability of measurement temperature, humidity, pressure and VOC by such a small component gives a great advantage for pervasive environmental monitoring. The values can be used for removing artefacts in the other sensors which come from cross-sensitivity. For integration purpose, the advice on footprint dimension is provided in Figure 2. It is also advised to place the sensor on the AMANDA card in the area where low-power components are located, in order to reduce heat transfer from other electric components to the sensor.

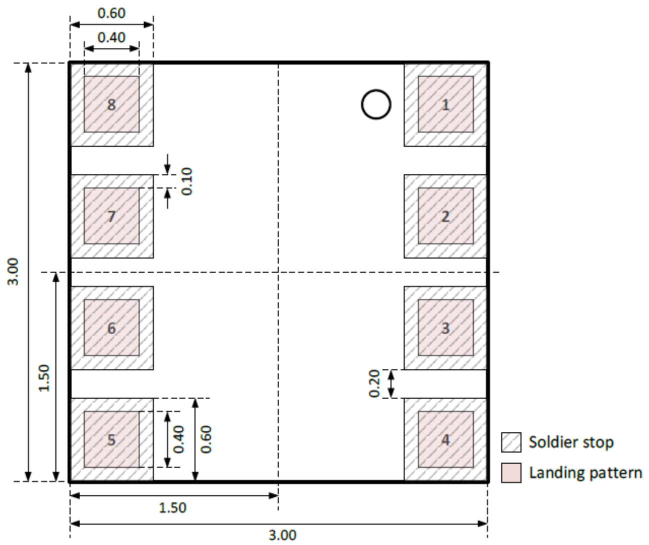


Figure 2 The BME680 sensor footprint (dimensions in mm) [1]

Additionally, it is advised that the application routine minimizes the amount of VOC measurements due to the relatively high-power consumption.

2.1.3.2 Digital interface

For the I²C connection, it is recommended to use 100nF. Moreover, the value for the pull-up resistors should be based on the interface timing and the bus load; a normal value is 4.7kΩ. Finally, a direct connection between CSB and VDDIO is required. A digital interface selection for the sensor is done based on the CSB pin status. If CSB is connected to power supply voltage, the I²C interface is active. If CSB is pulled down, the SPI interface is activated. Using the I²C interface is advised by manufacturer.

The SDA and SCL pins are not pure open-drain. Both pads contain ESD protection diodes to VDDIO and GND. As the devices does not perform clock stretching, the SCL structure is a high-Z input without drain capability.

The 7-bit device address is 111011x. The 6 MSB bits are fixed. The last bit is changeable by an SDO value and can be changed during operation. Connecting SDO to GND results in slave address 1110110 (0x76). Connection it to VDDIO results in slave address 1110111 (0x77). The SDO pin cannot be left floating. If left floating, the I²C address will be undefined [1].

2.1.3.3 External library

The component might be protected by an enclosure. In order to get the most accurate estimation about parameters outside the enclosure the manufacturer provides a library which allows for:

- Calculation of ambient air temperature outside of the device
- Calculation of ambient relative humidity outside of the device
- Calculation of index for air quality (IAQ) level outside of the device

This service might be considered for data-processing purposes.

2.2 Low-power accelerometer

LIS3DH is an ultra-low-power three-axis MEMs accelerometer. The accelerometer is enclosed in a very small LGA-16 package with a footprint of 3 x 3 x 1mm. It also features event based interrupts such as free fall, click and double-click recognition as well as motion detection. It is a widely used product that is utilized in many applications such as vibration monitoring, orientation monitoring, intelligent power saving in electronic devices, gaming, virtual reality input devices and more.

2.2.1 Relationship with the use cases

Acceleration measured in 3-axis is a metric used in most of the project’s use cases. Accelerations can be used as standalone measurements to extract conclusions or as part of sensor fusion technics.

- In UC2, the AMANDA ASSC will be installed in parking slots; it will measure vibrations from incoming cars and will determine whether the parking slot is occupied or not by intelligently utilising measurements from the other on-board sensors
- For UC3, accelerations will be used to estimate strain in infrastructure over time caused by vibrations from the environment
- For UC4, acceleration measurements will be used for monitoring the body movement of employees and identify events such as falls or their status (active movement or immobility)
- For UC5, accelerations can provide information for movement of assets/goods and their orientation. Furthermore, the sensor can monitor the strain from impact various sensitive assets/goods receive from the environment or from misapplication and notify in case of excess strain or a fall event.

2.2.2 Technical evaluation

Table 6 displays the operating range of the basic characteristics of LIS3DH. Available resolutions are 8, 10 and 12bit. It has to be pointed out that the low-power mode works only with an 8bit resolution. The sensitivity of the sensor varies, depending on the measurement range mode. For example, in ±2g range in low-power mode, the sensitivity is $\frac{4}{256}$g while in ±16g range is $\frac{32}{256}$g. Trade-offs should be made according to each use case between bandwidth, low power, resolution, range of measurements and sensitivity.

Parameter	**Value**
Temperature	-40°C - +85°C
Supply Voltage	1.71V - 3.6V
Range of supported modes	±2g / ±4g / ±8g / ±16g
Available Output Data Rates (ODR)	1Hz - 5376Hz
Resolution	8bit - 12bit

Table 6 Operating parameter range of LIS3DH [2]

The AMANDA ASSC aims for ultra-low-power operation without the need for charging. For that reason, low power is the most important among the tradeoffs. Current consumption according to operating modes is summarized in Table 7.

Operating mode/ODR	**Low-power mode (8-bit resolution)**	**Normal mode (10-bit resolution)**	**High resolution (12-bit resolution)**
1Hz	2µA	2µA	2µA
10Hz	3µA	4µA	4µA
25Hz	4µA	6µA	6µA
50Hz	6µA	11µA	11µA
100Hz	10µA	20µA	20µA
200Hz	18µA	38µA	38µA
400Hz	36µA	73µA	73µA
1344Hz	-	185µA	185µA
1620Hz	100µA	-	-
5376Hz	185µA	-	-

Table 7 Current consumption vs operating modes of LIS3DH [2]

Since sensors will be shut down when they do not operate, another important parameter to take into account is the turn-on time of the sensor. Resolution mode impacts turn-on time but also the cut-off frequency of incoming measurements (bandwidth). Table 8 summarizes the relation between resolution, turn-on time and bandwidth.

Operating mode	**Bandwidth**	**Turn-on time**
Low-power mode (8-bit data output)	(ODR/2)Hz	1ms
Normal mode (10-bit data output)	(ODR/2)Hz	1.6ms
High-resolution mode (12-bit data output)	(ODR/9)Hz	(7/ODR)ms

Table 8 Resolution vs bandwidth vs turn-on time of LIS3DH [2]

For evaluation purposes, the current consumption of the LIS3DH sensor was measured experimentally using a RIGOL DS1074 oscilloscope. The test set up involved the connection of LIS3DH via an SPI bus to an ESP32[4]. The measurements were taken on a 10kΩ resistor in series with the sensor and connected to the ground. The program running in ESP32 configured the sensor in 10Hz, 50Hz and 100Hz subsequently and measured ten samples. Voltage on the measurement resistor was observed and using ohm's law the current consumption was estimated.

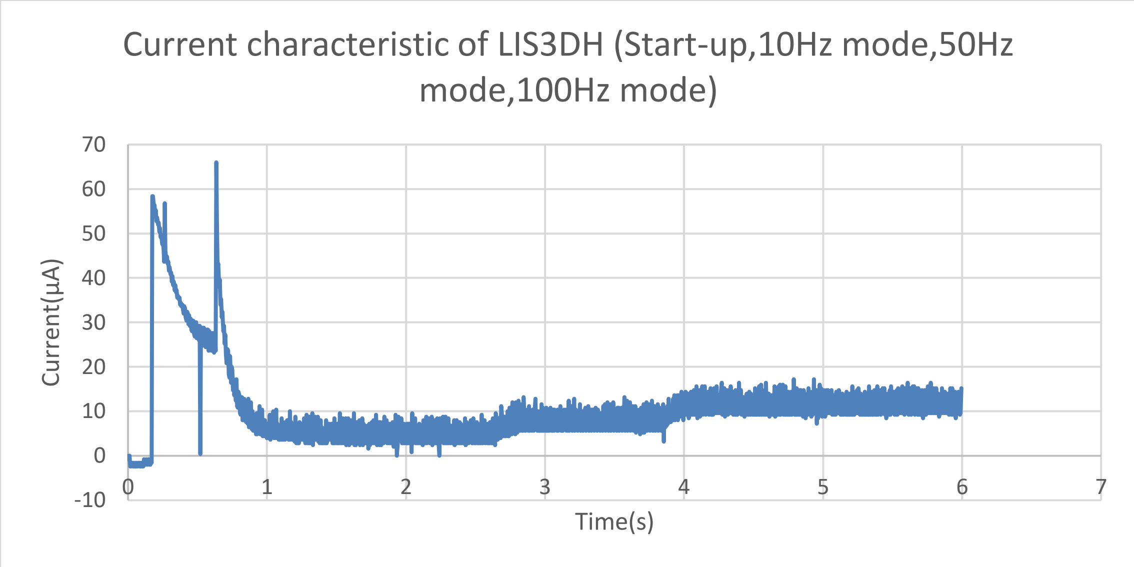


Figure 3 Characteristic of start-up time and 3 modes

In Figure 3, the four stages of operation are visible. From left to right, they include the start-up, 10Hz operation, 50Hz operation and 100Hz operation. During the start-up time (0.19-0.75ms), the average current was measured at 34µA. During the 10Hz operation, the average current was measured at 3.69µA. For 50Hz operation, the average current consumption was approximately 6.89µA and for 100Hz operation was 10.8µA. It has to be pointed out that during sampling, the SPI transactions for reading values create spikes of power consumption, so transactions should be kept at a minimum to ensure low power operation. We have to point out that due to available hardware test setup which is on SPI we did not test I^2C. It is expected that the magnitude of spikes will not differ in any impactful way. However, as I^2C is slower, spike duration can be as high as 40 times longer for I^2C, depending on SPI speed. For example a one-byte read transaction at 400kHz I^2C can last 80µs while a 5MHz SPI read transaction lasts approximately 3.2µs. It is estimated that that difference would contribute approximately an additional of 3-10nA of average current on the above experiments. That is a negligible difference for the purpose of this experiment but it can definitely make a bigger impact for multiple reads over longer time.

2.2.3 Adaptation guidelines

2.2.3.1 Component placement

LIS3DH comes in an LGA 16pin package with a dimension of 3 x 3 x 1mm. It satisfies the height specifications of the AMANDA ASSC while occupying a minimal space on the PCB. MEMS sensors such as LIS3DH have markings according to their orientation so it is advised

[4] ESP32 is a series of low-cost, low-power system on a chip microcontrollers with integrated Wi-Fi and dual-mode Bluetooth

that the sensor's x and y axis to be parallel to the AMANDA card's sides for easier reference to card's orientation. Figure 4 displays the bottom view of the sensor.

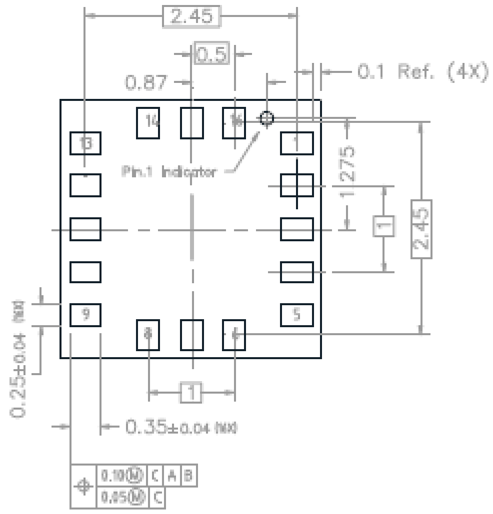


Figure 4 LIS3DH bottom view of package (dimensions in mm) [2]

2.2.3.2 Digital interface

LIS3DH provides an SPI or I²C interface. In order for the sensor to operate in I²C mode, two external pull-ups must be added on the SDA and SCL pins. Furthermore, the CS pin must be held high. The SA0/SDO pin can be used to toggle externally the least significant bit of the I²C address. When CS pin is low, the SPI mode is selected. Modes can be changed dynamically without resetting the sensor by toggling the CS pin. The SPI speed goes up to 10MHz while for I²C up to 400kHz. There are also three ADC outputs for each axis that are directly connected with the analogue output of the MEMs elements before getting digitized. However, ADCs are susceptible to noise and would require techniques that are employed anyway in the sensor's digital interface. Finally, there are two interrupt pins that can output a signal for two separate events, for example free fall and movement detection.

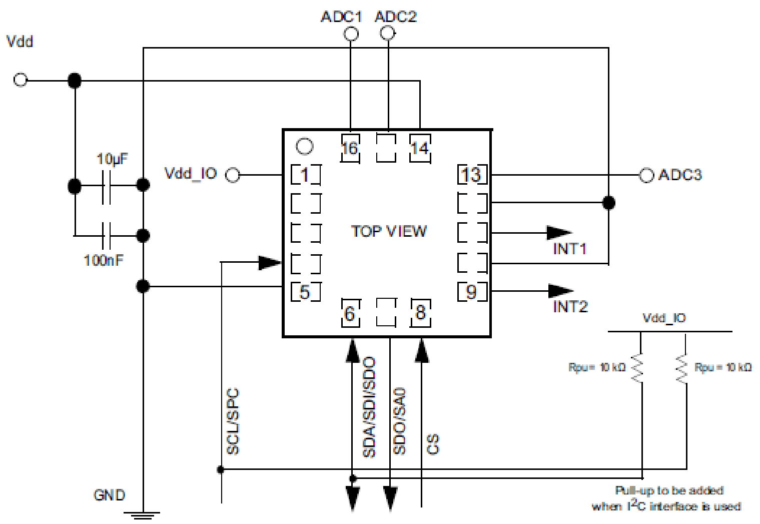


Figure 5 Pinout of LIS3DH [2]

2.3 Spintronics sensor/Magnetometer

The LIS3MDL sensor is a low-power 3-axis sensor that can be used to measure the magnetic fields. Its low-energy requirements, small size and sensitivity make it appropriate for applications requiring measurements related to the earth magnetic field or the presence of other magnetic fields.

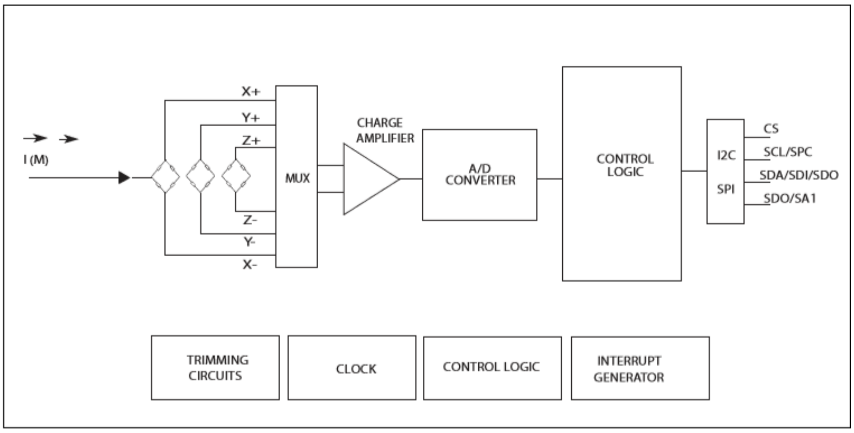


Figure 6 Block diagram of magnetometer [3]. Magnetoresistive elements are arranged to form Wheatstone bridges, allowing measurements in each of the 3 axes.

2.3.1 Relationship with the use cases

The LIS3MDL sensor is foreseen in all use cases where measurement of the magnetic field is important for the application.

- In UC2, the sensor will be used to detect the presence and movement of cars. The "disturbance" of the magnetic field in that case can be related to magnetic metal (or presence of magnets), giving information about the occupancy of the parking slot. The proper level should be estimated in order to discriminate between large and small objects and to filter out false positives. The measured fields can also be associated with other sensors to refine the results (e.g. accelerometer, light sensor, camera). The use of the 3-axis magnetometer can also be helpful in determining other parameters
- For UC3 and UC4, the sensor can help in determining the presence of objects that affect the magnetic field. The presence (near the card) of wires carrying strong currents can also be detected. Those currents induce a magnetic field that can be measured by the sensor. In these use cases it is even possible to use the card to estimate the current flowing in devices near the card [4], [5], [6]

2.3.2 Technical evaluation

Table 9 shows the operating range of the basic parameters of the device.

Parameter	Value
Temperature	-40°C - +85°C
Supply Voltage	1.9V - 3.6V
Magnetic full scales ranges	±4/±8/±12/±16 gauss (user selectable)
Size of output result	16bit

Table 9 Operating range of basic parameters of the LIS3MDL

The important parameters of the sensors during the applications are their accuracy, sensitivity and power consumption. It is also important to optimise HW/SW interfacing in order to reduce the energy requirements. In AMANDA, we are often interested in measuring disturbances to the earth magnetic field. The magnitude of that field at the surface varies between

25 and 65 microteslas (that is 0.25 to 0.65 gauss) [3]. The LIS3MDL sensor allows for 16-bit measurements in 4 selectable magnetic full scale ranges: ±4gauss (6842 LSB/gauss), ±8gauss (3421 LSB/gauss), ±12gauss (2281 LSB/gauss), ±16gauss (1711 LSB/gauss).
Measurements can be made in single shots or continuously. Between those measurements, the device goes in idle mode for a time that depends on the sampling rate.
There are four operating modes that allow the user to trade resolution and power consumption as shown in Table 10. The turn-on time is the time needed to start and finish a measurement, from idle mode to data ready. The RMS noise (in mgauss) is strictly related to the operating mode. The noise level sets the minimum detectable field.

	Low-power mode (LP)	**Medium performance mode (MP)**	**High performance mode (HP)**	**Ultra-high performance mode (UHP)**
Turn on time	1.2ms	1.91ms	3.48ms	6.65ms
RMS Noise per axis	5.3mgauss	4.6mgauss	4.0mgauss	3.5mgauss
Current in idle mode	1µA	1µA	1µA	1µA

Table 10 The most relevant parameters of the LIS3MDL sensor Dependence of some of the characteristics of the sensor [3]

Operating mode/ODR	**Current consumption.**			
	LP	**MP**	**HP**	**UHP**
0.625Hz	6µA	7µA	10µA	15µA
1.25Hz	7µA	10µA	15µA	25µA
2.5Hz	10µA	15µA	25µA	40µA
5Hz	15µA	25µA	40µA	75µA
10Hz	25µA	40µA	75µA	145µA
20Hz	40µA	75µA	145µA	270µA
40Hz	80µA	145µA	285µA	565µA
80Hz	150µA	290µA	565µA	1125µA
155Hz	-	-	-	1950µA
300Hz	-	-	187µA	-
560Hz	-	1720µA	-	-
1000Hz	1500µA	-	-	-

Table 11 Dependence of some of the current consumption characteristics of the LIS3MDL sensor [3]

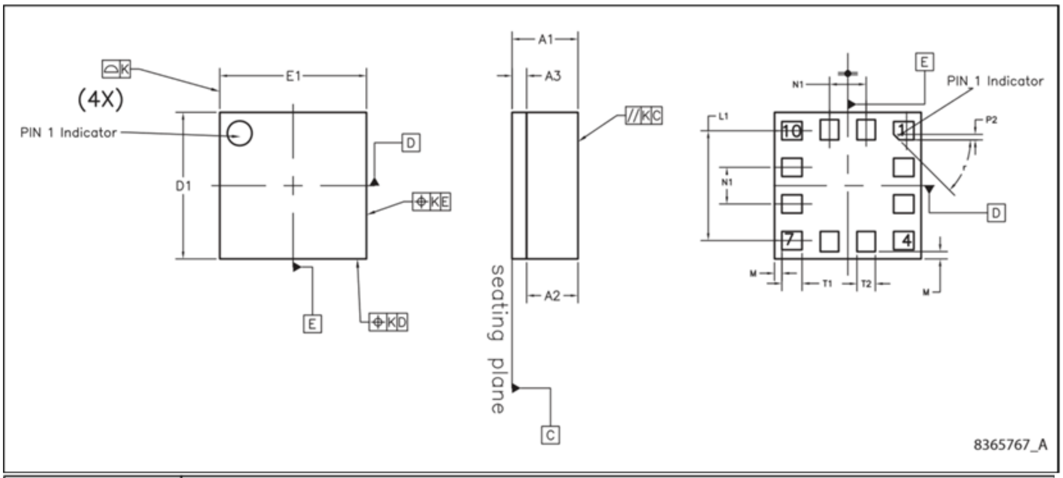
The LIS3MDL is a sensor that uses the TMR effect. A thorough evaluation of the performance of this sensor (and other magnetometers) can be found in [7]. The following information (2019) from ST customer service should be taken into consideration in any use in this project: “LIS3MDL is a TMR sensor where only set pulses mechanism is present, that's why you cannot compensate thermal offset drift. New products like LSM303AGR are AMR technology sensors where a set/reset mechanism is available which is able to remove offset thermal drift. This means that the difference is that in AMR we are able to drive current pulses in two opposite directions alternatively (which is used to cancel offset), while in TMR the current pulses can be driven just in one direction.” [8]

2.3.3 Adaptation guidelines

2.3.3.1 Component placement

The part has a small size and weight. It is packaged in a small, thin, plastic grid array package (LGA-12 2.0 x 2.0 x 1.0mm). It is appropriate for portable applications and where weight should be minimised. The compensation features give some freedom in placing it on a board. For the AMANDA board, it is suggested to place the magnetometer near one of the sides of the card and align its axis in the same way as those of the accelerometer sensor in order to facilitate correlations.

Effect of currents. The presence of PCB traces of wires that carry high currents during the measurements can have an adverse effect on the results. It is therefore recommended to keep such traces a few mm away from the chip, when they draw more than 10mA. One can also write the firmware of the device in such a way as to perform measurements when the rest of the components are not drawing high currents.



Dim.	mm		
	Min.	Typ.	Max.
A1			1
A2		0.785	
A3		0.200	
D1	1.850	2.000	2.150
E1	1.850	2.000	2.150
L1		1.500	
N1		0.500	
T1		0.275	
T2		0.250	
P2		0.075	
r		45°	
M		0.100	
K		0.050	

Figure 7 VFLGA-12 package information [3]

2.3.3.2 Digital interface

The sensor communicates with the microcontroller through an SPI or I^{2}C interface. The user can choose the most appropriate method. There are other pins that can be used in order to facilitate the control firmware or reduce the energy consumption. It is recommended to interface the interrupt pin and react on interrupts. The device can have an own VDD for the I/O pins (serial interface), facilitating the use of different power domains, especially if it is preferred to keep the magnetometer powered while the microcontroller is off.

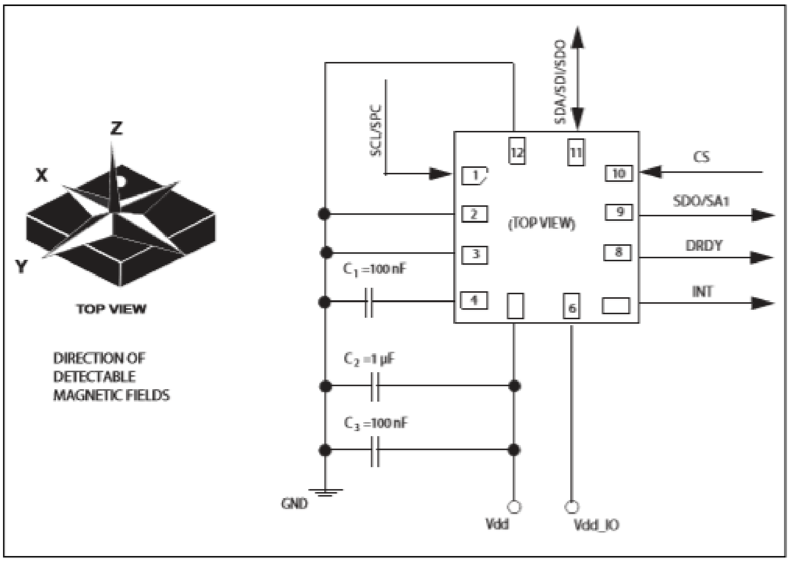


Figure 8 Pinout with interfacing signals [9]

2.3.3.3 Other important guidelines

Other important guidelines for the sensor include:

- Low-power usage through use of interrupt features. It is recommended to use the interrupt pin if it is sufficient to know when the magnetic field in one or more axis has exceeded pre-defined values. This reduces the number of accesses made by the microcontroller and improves the energy consumption. In that case, the interrupt pin of the sensor should be connected to an interrupt input of the microcontroller
- Temperature sensitivity. The sensitivity of the sensor varies with temperature. An on-chip temperature is provided, which can be used for compensation. However, since the AMANDA board already has other sensors, it will be important to evaluate the benefits of using one of those external temperature sensors (e.g. the one of Microdul) in order to save energy
- Compensation of offset. The device provides means to compensate for offsets (e.g. hard-iron effects). The value written in the offset registers are automatically subtracted from the measurements
- Self-test. The device includes a self-test mode that can be used to check the functionality after production or at any other time
- Library and support. The manufacturer provides a firmware library to support the use of the sensor
- Handling. The device is sensitive to magnetic and electrostatic fields. Improper handling can cause permanent damage to the part. It should not be exposed to magnetic fields above 1000gauss [3] (absolute maximum ratings table).

2.4 Light sensor

OPT3001 is a low-power ambient light sensor that accurately measures the intensity of light visible to the human eye. Its strong IR rejection enables high accuracy even when the sensor is installed behind dark glass unlike other alternatives. The sensor is used in a wide range of control systems that require an accurate measurement of light as an input such as lighting control systems, backlight display controls, cameras, home automation systems and more.

2.4.1 Relationship with the use cases

As mentioned earlier, OPT3001 can be used as input in control systems.

- UC1 features such a scenario of automated lighting control of a room
- In UC3, OPT3001 can be used to report the amount of sunlight over a period of time
- For UC4, a lux sensor can be one of the many sensor fusion components that can help locating an employee by excluding or including dark or illuminated places within the premises of a company
- In UC5, the light sensor can provide information on the exposure of sensitive goods to sunlight prior to their consumption or use. Furthermore, it can provide information on the location of assets or goods in dark places or outdoors, with the help of edge intelligence algorithms and sensor fusion

2.4.2 Technical evaluation

OPT3001 features a very wide range of measurements from 0.01 to 83000lux which makes it viable for outdoor uses. The output data rate can be configured to either one measurement per 100ms or one measurement per 800ms, however it must be noted that the 800ms measurement is more accurate. The device starts up in shutdown state so it has to be woken up by setting the configuration register or using the INT pin. Consequently, the start-up time of the sensor equals the sum of the wake-up procedure and 100 or 800 milliseconds depending on the mode selected. The sensor current consumption depends on the lighting conditions and ranges from 1.8μA in dark conditions (when Vdd = 3.6V) to 3.7μA for lighting close to the maximum measurable value.Table 12 summarizes the operating ranges of the sensor.

Parameter	Value
Temperature	-40°C - +85°C
Supply Voltage	1.6V - 3.6V
Range	0.01lux - 83000lux

Table 12 Operating ranges of OPT3001 [10]

OPT3001 stores the result in a 16bit register using 15:12 bits as an exponent(E[3:0]) and bits 11:0 as a 12-bit mantissa (R[11:0]) in order to provide precision at a fraction over a wide range. The formula to translate the register into lux is given below:

$$\text{lux} = 0.01 \times (2^{E[3:0]}) \times R[11:0]$$

Table 13 summarizes values of exponent and LSB size values, which also reveals that there is high sensitivity towards zero lux and lower towards the max lux value:

E3	E2	E1	E0	Full-scale range	LSB size
0	0	0	0	40.95lux	0.01lux/LSB
0	0	0	1	81.90lux	0.02lux/LSB
0	0	1	0	163.80lux	0.04lux/LSB
0	0	1	1	327.60lux	0.08lux/LSB
0	1	0	0	655.20lux	0.16lux/LSB
0	1	0	1	1310.40lux	0.32lux/LSB

0	1	1	0	2620.80lux	0.64lux/LSB
0	0	1	1	5241.60lux	1.28lux/LSB
1	0	0	0	10483.20lux	2.56lux/LSB
1	0	0	1	20966.40lux	5.12lux/LSB
1	0	1	0	41.932.80lux	10.24lux/LSB
1	0	1	1	83865.60lux	20.48lux/LSB

Table 13 Full-scale range and LSB size as a function of the exponent Level [10]

For evaluation purposes, the current consumption of the OPT3001 sensor was measured using a RIGOL DS1074 oscilloscope. The test set up was the OPT3001 sensor connected via the I^{2}C bus to an ESP32. The measurements were taken on a 10kΩ resistor in series with sensor and connected to ground. The program running in ESP32 configured the sensor in 100ms operation mode as 800ms was too power hungry for the AMANDA system. The sensor was sampled at 200ms intervals; 10 samples were taken in continuous mode and 10 samples in a single measurement mode. Voltage on the measurement resistor was observed and using ohm's law the current consumption was estimated.

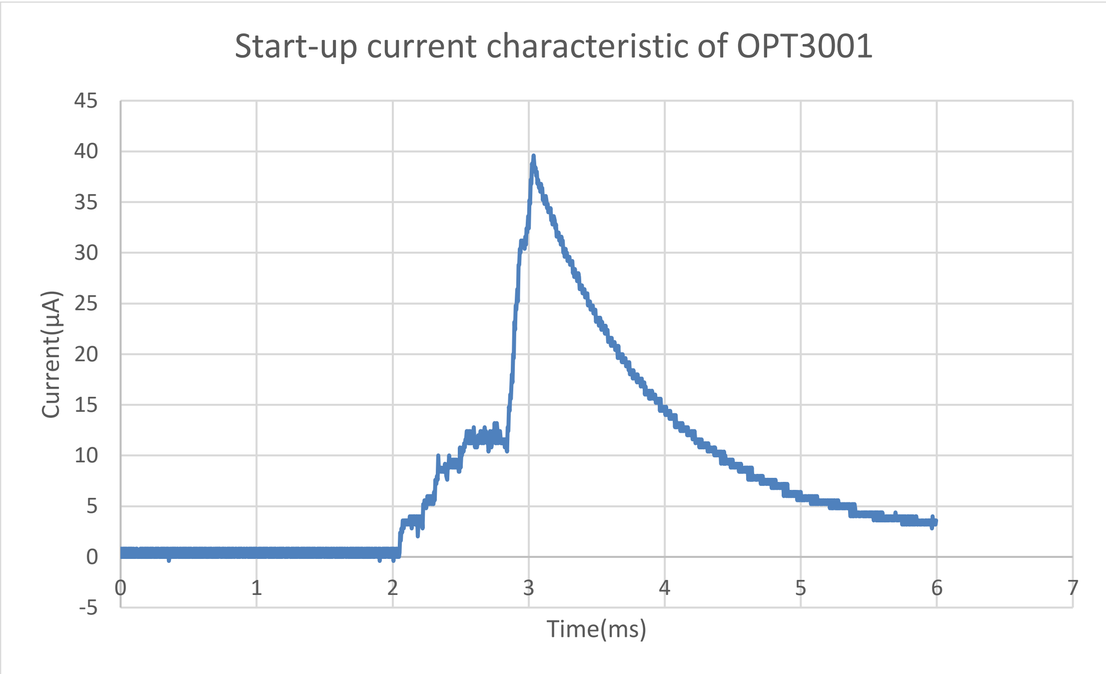


Figure 9 Characteristic of start-up current consumption of OPT3001

Figure 9 depicts the start-up procedure of the OPT3001 sensor. The startup time (without waiting for first measurement) was less than 3ms. The average current consumption from 2 to 6ms is 12.5µA.

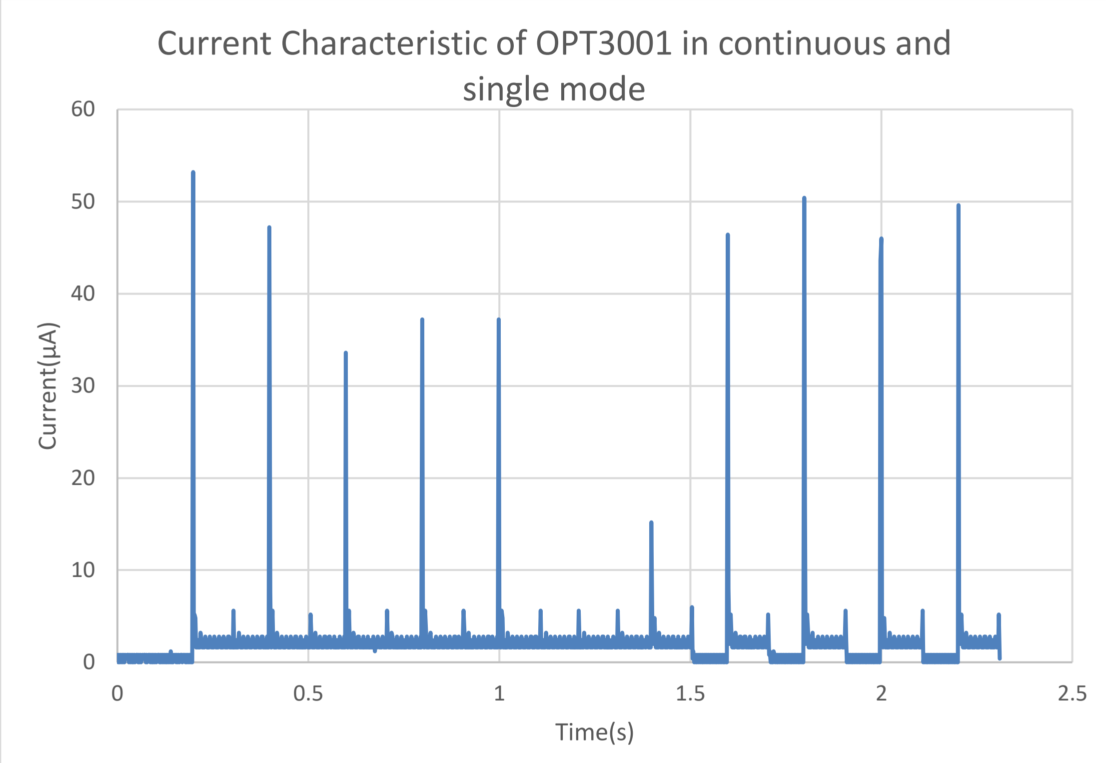


Figure 10 Continuous and single measurement power consumption profile

Figure 10 shows the consumption profile of both continuous and single measurement modes at a 100ms output data rate. The average current consumption for continuous mode was measured at 2.21μA and for single measurement mode at 2.06μA. It can be seen from the Figure that I^{2}C transactions create spikes so they should be kept at minimum. In single measurement mode, the current is dropping after every read transaction as the sensor enters sleep mode, however the average current is not significantly lower, as an extra transaction is required per sample in order to wake up the sensor. The sensor could be woken up from the INT pin to avoid the extra transaction and decrease current consumption further.

2.4.3 Adaptation guidelines

2.4.3.1 Component placement

OPT3001 ships enclosed in an S-PDSO-N6 6pin package, with max dimensions of 2.1 x 2.1 x 0.65mm. Due to the optical nature of the sensor, special care must be taken so that other components on the PCB do not obstruct its vision. Moreover, the sensor should be optically isolated from on-board LEDs or the LEDs should not be active during lux measurements. The AMANDA ASSC enclosure needs to have a transparent opening that allows a ±35°- ±45° field of view to the sensor for best accuracy. The filtering characteristics of the glass in the spectrum of visible light must also be taken into account.

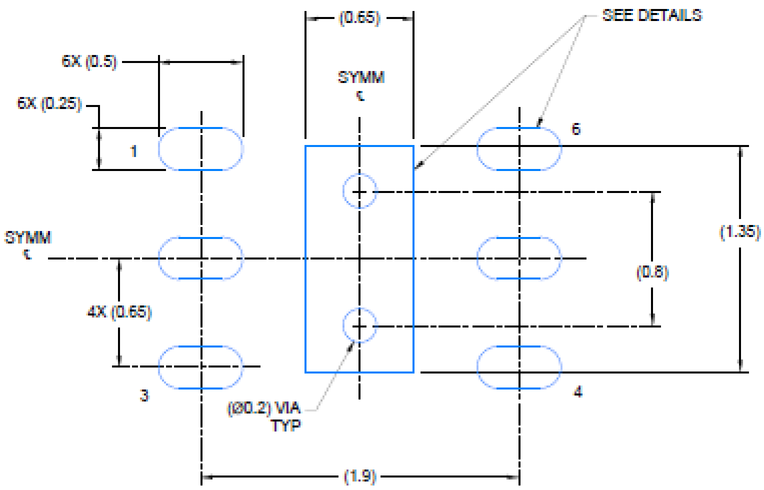


Figure 11 Example PCB footprint for OPT3001 [10]

2.4.3.2 Digital interface

The digital interface of OPT 3001 is simple, as illustrated in Figure 12. The communication between the sensor and the microcontroller is performed through the SDA and SCL pins using the I^{2}C protocol. OPT3001 also has an interrupt pin (INT) that has the following uses depending on the configuration:

- As an input to wake up the sensor from sleep mode
- As an output to notify that a measurement is ready for read
- As an interrupt output when a measurement exceeds a threshold or is measured outside a window

SDA, SCL and INT pins require pull up resistors. The typical value is 10kΩ but other options can be explored according to the characteristics of the designed PCB.

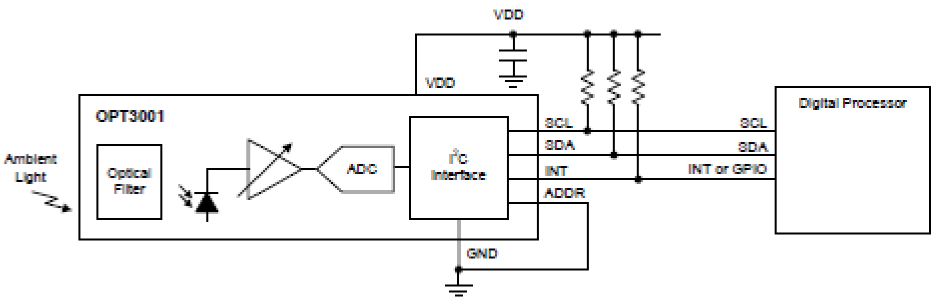


Figure 12 Proposed schematic for OPT3001 integration [10]

2.5 Acoustic sensor

SPH0645LM4H-B is a miniature, low-power SMD microphone with an I^{2}S interface for easy integration. Its small footprint (3.50 x 2.65 x 0.98mm) and low-power consumption make it an ideal addition to the AMANDA ASSC system as an acoustic sensor. A widely used product in the market has been integrated in wearables, TVs, gaming equipment, remote controllers and in various IoT devices.

2.5.1 Relationship with use cases

Various use cases of the project utilise acoustic inputs as a sensor fusion component in order to extract conclusions by combining acoustic signals and measurements from other type of sensors.

- In UC1, acoustic signals can be used as an indication of building occupancy density and contribute to the set-up of AC and lighting controls of a room
- In UC2, car noise can provide additional information to parking slot occupancy
- In UC4, the levels of noise recorded in a workplace are an important variable that participates to the estimation of the healthiness of a working environment

2.5.2 Technical evaluation

The SPH microphone is omnidirectional, has a flat frequency response and is RF shielded, guaranteeing the integrity of the signal regardless of direction, pitch and RF interference. Furthermore, it has a high SNR of 65dB(A) at 94dB SPL input at 1kHz, that provides a clear signal well above the noise floor. The sensitivity is at -23dBFS while the harmonic distortion ranges between 0.2-1%. Typical supply current is at maximum 600µA and by adjusting the clock at <1kHz, it enters sleep mode with a current consumption between 3-10µA. The power-up time is at a maximum of 50ms. Table 14 summarizes the range of additional sensor characteristics.

Parameter	Value
Temperature	-40°C - +100°C (Lower performance) 0°C - 45°C (Specifications guaranteed)
Supply Voltage	1.62V - 3.6V
Acoustic over-load point	120dB SPL

Table 14 SPH0645LM4H-B operational characteristics [11]

For evaluation purposes, the current consumption of the SPH microphone was measured experimentally with a RIGOL DS1074 oscilloscope. The test set up had an SPH microphone connected via the I^2S bus to an ESP32. The measurements were taken on a 1kΩ resistor in series with the sensor and connected to ground. Via ESP32, the sampling rate of I^2S was set at 16kHz and 64kHz in two separate sessions. The microphone after start-up time consumes a rather stable current independent of input and tied to sampling rate. The current consumption at 16kHz was measured at an average of 367µA and at 64kHz was measured at an average of 382µA. Figure 13 illustrates the current profile of microphone at 64kHz during wake-up. Sleep-current was measured at an average of 6µA.

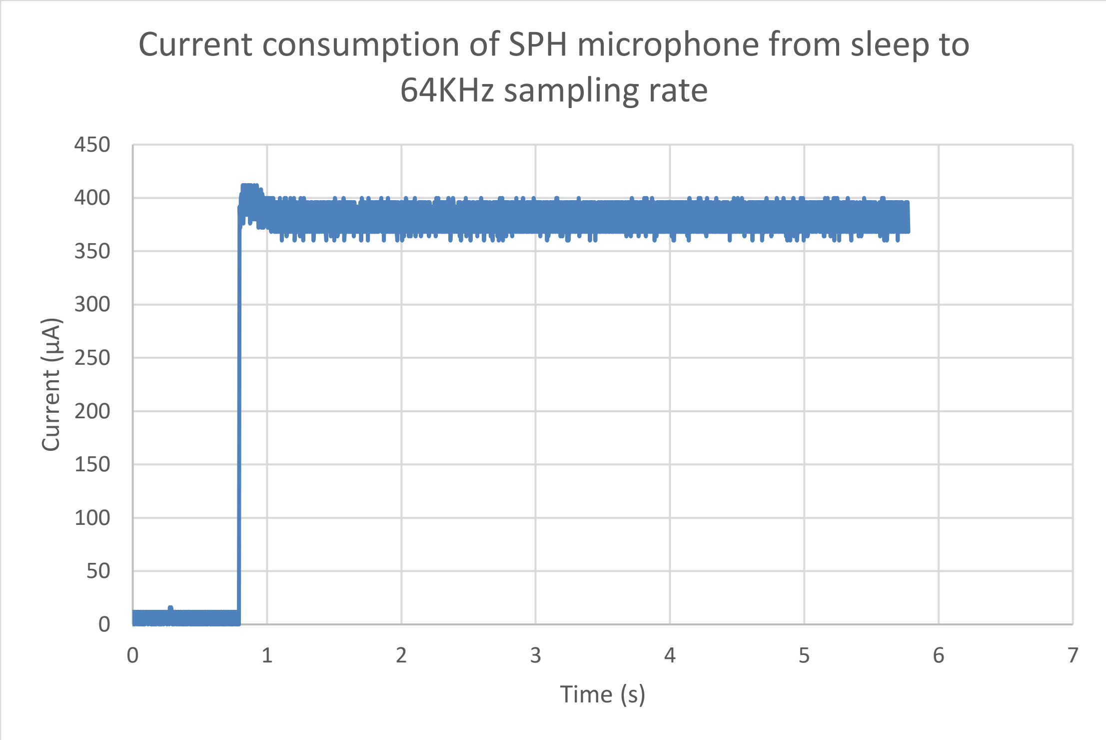


Figure 13 Current characteristic of SPH0645LM4H-B at 64kHz

2.5.3 Adaptation guidelines

2.5.3.1 Component placement

The SPH microphone features a very small footprint of 3.50 x 2.65 x 0.98mm in an SPH Package, which is compatible with the AMANDA thickness specifications and takes up minimal space on the PCB. In Figure 14, pad 3 needs a hole in the centre through the PCB to allow the MEM element of the microphone to capture sound without obstacles. The opening in the centre of pad 3 should have a diameter of at least 0.325mm with a tolerance of ±0.05mm, which is the diameter of the acoustic port of the sensor. Attention should be given towards the enclosure, which should have some openings in order to allow for sound to be captured by the microphone without obstacles and distortion while protecting the sensor and the PCB. Those enclosure openings should be above or as close as possible to the PCB hole. Figure 14 below illustrates the proposed footprint by the manufacturer.

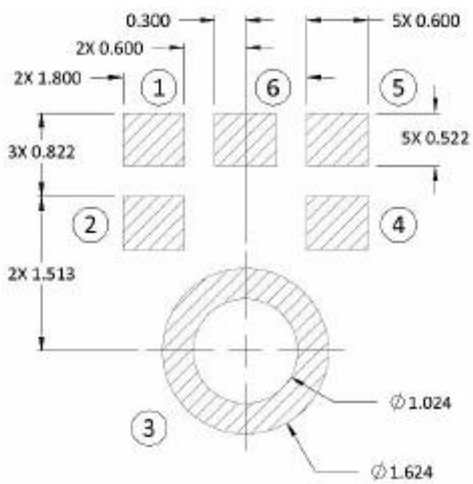


Figure 14 Proposed footprint SPH0645LM4H microphone (dimensions in mm) [11]

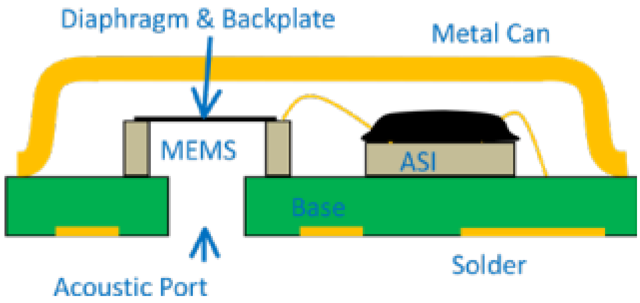


Figure 15 Side-view cross-section of SPH0645LM4H microphone

2.5.3.2 Digital interface

The SPH microphone works as a standard I^2S slave with a maximum clock frequency of 4096kHz and a minimum of 1024kHz. The I^2S protocol is simple and prevalent in most modern microcontrollers. EPEAS will provide an I^2S peripheral in the AMANDA microcontroller that is expected to satisfy the SPH specifications.

2.6 Memory

The MB85RS64TU is a FRAM chip in a configuration of 8,192 words × 8 bits, using the ferroelectric process and silicon gate CMOS process technologies for forming the non-volatile memory cells. The MB85RS64TU is able to retain data without using a back-up battery, as is needed for SRAM.

2.6.1 Relationship with the use cases

An FRAM memory is specially needed, if there is important data which need to be saved non-volatile, so it can be used across system reboots. It will be used in all use cases where LoRa is involved. Therefore, some connection parameters, like keys and counter variables will be saved on the FRAM. It can of course also be used for other scenarios where maintaining non-volatile data could be useful.

2.6.2 Technical evaluation

The MB85RS64TU is a very low power FRAM memory [12]. The memory cells used in the MB85RS64TU can be used for 10^{13} read/write operations, which is a significant improvement over the number of read and write operations supported by Flash memory and E2PROM. The MB85RS64TU does not take as long time to write data like Flash memories or E2PROM usually do and requires no wait time. It also requires less energy (than Flash or EEPROM) at write time. The device can be switched off between important data transfers in order to save energy. It features an extended operating temperature range and a supply voltage range which are suitable for the AMANDA card. Table 15 shows all the important characteristics of the MB85RS64TU.

There is an equivalent I^2C version that transfer data at a slower speed. There are also devices with less/more memory.

Parameter	Value
Bit configuration	8,192 words x 8 bits
Operating frequency	10MHz (Max)
Endurance	10^{13} times / byte
Data retention	10 years (+ 85°C)

Operating power supply voltage	1.8V to 3.6V
Power consumption	Operating power supply current 0.8mA (Max@10 MHz) Standby current 9µA (Typ)
Operation ambient temperature range	– 55°C - +85°C

Table 15 MB85RS64TU operational characteristics [12]

2.6.3 Adaptation guidelines

2.6.3.1 Component placement

The MB85RS64TU features a small 8-pin plastic Small-Outline No-lead (SON) package (LCC-8P-M04) with a size of 2.0 x 3.0mm and a maximum thickness of 0.75mm which is compatible with the AMANDA card thickness restriction. It also takes a minimal space on the PCB while it can be placed anywhere on the card because it has no special requirements regarding the placement. Figure 16 depicts the package dimensions of the MB85RS64TU.

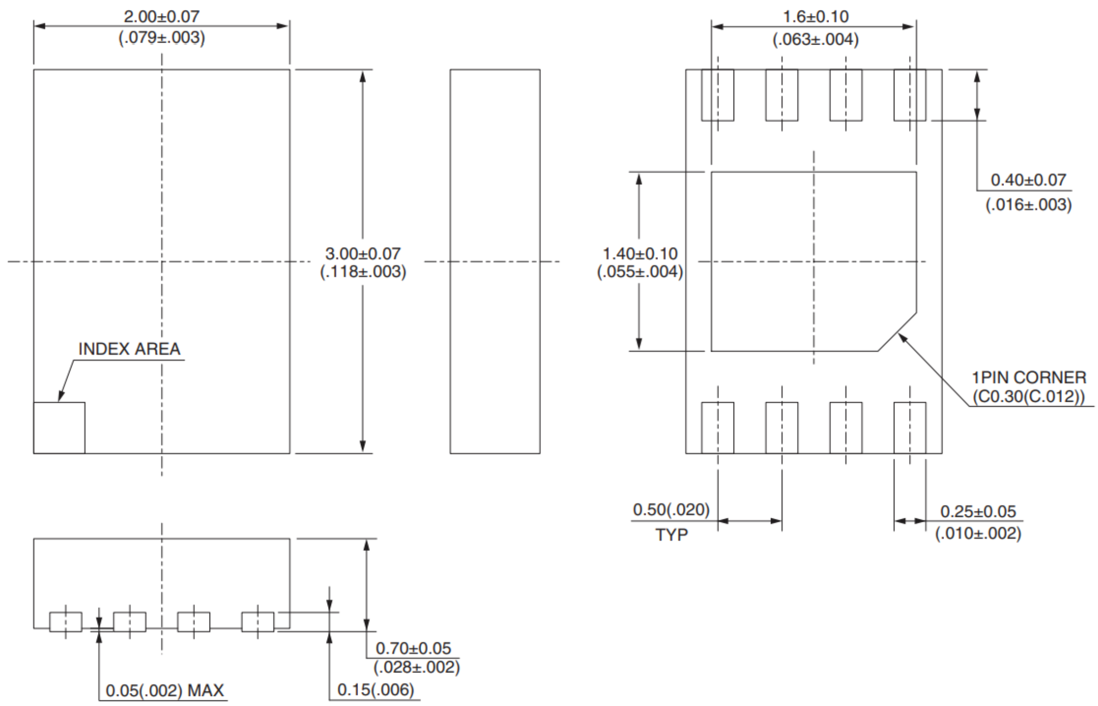


Figure 16 Package dimensions of the MB85RS64TU. Dimensions in mm (inches).
Note: The values in parentheses are reference values. [12]

2.6.3.2 Digital interface

The MB85RS64TU features a serial peripheral interface (SPI) which can operate in mode 0 and mode 3 and at a maximum SPI clock frequency of 10MHz. It contains an 8-bit status register and is being driven via nine 8-bit op-codes.

2.7 Real time clock

The RV-3028-C7 is an ultra-low power real time clock module. It features an embedded 32.768kHz crystal oscillator, counters for seconds, minutes, hours, dates, months, years and weekdays. It offers several programmable interrupt output functionalities like countdown timer interrupt, periodic time update interrupt and alarm interrupts. An external event and time stamp function is also included. The I^{2}C interface ensures easy system integration.

2.7.1 Relationship with the use cases

The real time clock is not specifically linked to any of the use cases, but it will be needed in all of them. With its extreme low energy consumption and capability to time system wakeup's from power off mode (interrupt output of RTC used to enable DCDC-converter) independently from the MCU, the RTC will help meeting low power requirements of the whole system.

2.7.2 Technical evaluation

The RV-3028-C7 has a wide operating voltage range of 1.1V to 5.5V (1.2V if serial communication is used) which is well within the specification of the AMANDA card. It has an extreme low current consumption of typically 45nA at 3V and is therefore ideal for use in a low-power system like the AMANDA ASSC. It offers time accuracy of +/- 1ppm at 25°C. Table 16 provides additional characteristics of the RV-3028-C7.

Parameter	Value
Clock-out frequency (programmable)	32.768kHz, 8192Hz, 1024Hz, 64Hz, 32Hz, 1Hz
Frequency accuracy	+/- 3Ppm
Storage temperature range	-55°C - +125°C
TA Operating temperature range	-40°C - +85°C

Table 16 RV-3028-C7 operational characteristics [13]

For evaluation purposes, the current consumption of the RV-3028-C7 and the current consumption of a sensor node using the RV-3028-C7 to enable its power supply was measured. The measurements were made with a power analyser from Agilent model N6705. The measured current consumption of the RTC was 49nA which is well within the specification of the datasheet. When the RTC was used to control the enable pin of a DCDC-converter of an IoT sensor node, its current consumption during deep sleep periods could significantly be reduced (from 1.1uA down to 219nA in the case of that particular converter).

2.7.3 Adaptation guidelines

2.7.3.1 Component placement

The RV-3028-C7 RTC features a very small footprint of 3.20 x 1.50 x 0.8mm, which is compatible with the AMANDA thickness specifications and takes up minimal space on the PCB. The RTC does not have any special requirements like openings to environment and can therefore be fully embedded in the AMANDA ASSC. Figure 17 shows the package dimensions in a bottom view and the recommended solder pad layout of the RTC.

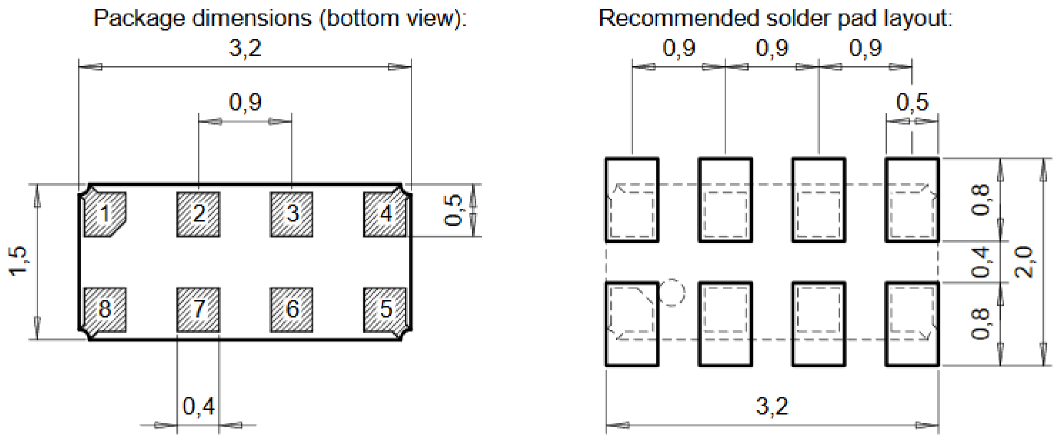


Figure 17 Package dimension and recommended solder pad layout of the RV-3028-C7
Dimensions in mm

2.7.3.2 Digital interface

The RV-3028-C7 features a two-line interface I^2C that supports fast mode up to 400kHz. It is accessed at the read/write addresses 0x52. In addition, the RTC offers an interrupt out pin, an external event pin and a clock out pin.

2.8 Optical indicator LED

SML-LX0404 is a miniature SMD RGB LED that will be used as a simple human-machine interface. It features a red, a blue and a green LED with a common anode and very low recommended minimum forward current of 2mA/per colour, which gives a luminosity of 35mcd for red, 50mcd for green and 20mcd for blue. It ships in a very small package with 1 x 1 x 0.25mm dimensions which takes up minimal space on the AMANDA card.

2.8.1 Relationship with the use cases

The RGB LED is a very simple yet sufficient means of feedback for a user. There are two major types of feedback that can be indicated. The first is informing the user about the status of the card and the second is informing the user about critical events related to the use cases. The status of the card can include among others an indication about correct setup and operation of the card after start up, an indication about successful network connection and warnings about possible malfunction of the card. The RGB LED is also used in UC1 and UC4 in order to notify users for environmental conditions that are hazardous for their health. For UC3 and UC5 the LED can display a code that informs the user that infrastructure or assets and goods have been exposed in extreme conditions that exceeded tolerances and specifications. Indications and warnings can be encoded by colour and number of led blinks.

2.8.2 Technical evaluation

LEDs are intrinsically power hungry devices and the most power efficient ones draw 1-2mA forward currents to provide satisfactory luminance. The only way to moderate the dissipated current is to power them with PWM pulses and trade-off between power dissipation and luminance. Table 17 below summarizes the most important operational parameters of SML-LX0404.

Parameter	Minimum value	Typical value	Max value	Test condition
Peak wavelength	-	Red:632nm Green:518nm Blue:468nm	-	If=2mA
Dominant wave-length	-	Red:627nm Green:531nm Blue:470nm	-	If=2mA
Forward voltage	-	Red:1.95V Green:2.75V Blue:2.70V	Red:2.15V Green:2.95V Blue:2.85V	If=2mA
Reverse voltage	-	-	Red:5V Green:5V Blue:5V	Red: Ir=10µA Green: Ir=50µA Blue: Ir=50µA
Luminous intensi-ty	-	Red:35mcd Green:50mcd Blue:20mcd	-	If=2mA
Forward current	-	-	Red:25mA Green:25mA Blue:10mA	-
Viewing angle	-	120^o	-	-
Operating tem-perature	-40^{o}C	-	85^{o}C	-

Table 17 ML-LX0404 operational parameters [14]

2.8.3 Adaptation guidelines

2.8.3.1 Component placement

Figure 18 below is the recommended footprint from the vendor. The dimensions of the package are 1 x 1 x 0.25mm, so it takes minimal space on the PCB surface. The case should be modified accordingly with an appropriate transparent cover that enables LED visibility to the end user. Special attention should be given to the relative placement of the led and the light sensor to avoid optical interference. Application code should ensure a gap between light measurement and LED indications or else optical isolation should be implemented be-tween the two peripherals.

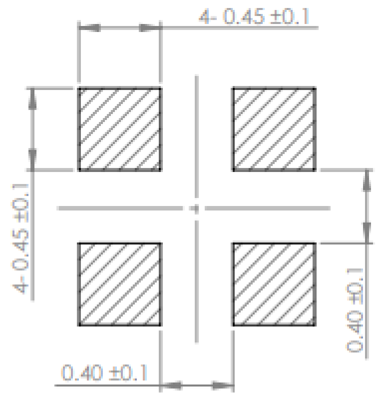


Figure 18 SML-LX0404 recommended footprint [14]

2.8.3.2 Digital interface

Figure 19 displays the schematic of the RGB LED. The common anode (pin 1) can be connected straight to the power supply while the cathodes (pins 4,3,2) can be connected straight to digital pins of microcontroller in PWM mode in series with one protective resistor. Switching transistors should be used if individual or total current dissipation from pins exceeds the specifications of the microcontroller.

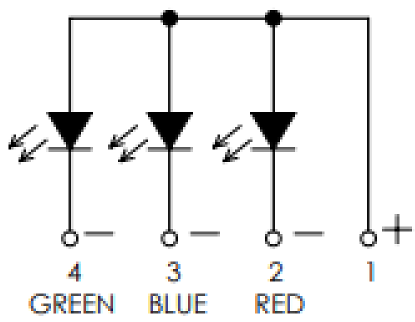


Figure 19 SML-LX0404 schematic [14]

2.9 Display

2.9.1 Relationship with the use cases

The analysis of the use cases indicated that sophisticated direct graphical interface with the user is not required. Indirect communication with the device via radio-communication is sufficient. A simple LED indicator will be implemented for basic feedback to the user. The display will not be implemented in the miniature device, allowing for a more efficient use of area and power. For this reason, the display model is not named and not evaluated further.

2.10 Fingerprint sensor

2.10.1 Relationship with the use cases

User authentication is important for the AMANDA system as it allows it to be used as an access control device. The use of the imaging sensor developed by EPEAS for the project is already considered as an authentication device by using face recognition techniques. A fingerprint sensor was considered as an alternative way of providing user authentication to the system. The only standalone fingerprint sensors that could be included to an embedded system like AMANDA were advertised by ZEITEC Semiconductor, a Taiwan based company with an expertise at touch controller ICs. ZEITEC Semiconductor did not respond to our inquiries about their products. Furthermore, it seems that the fingerprint sensor products are deprecated, considering that they are not listed anymore on their website. As a result, due to lack of availability and support from the manufacturing company along with space availability considerations a decision was made to remove the fingerprint sensor from AMANDA.

3 Summary

This Deliverable presents detailed information about off-the-shelf sensors that are considered for use in the AMANDA system. The report starts with the list of chosen use cases. Based on this, the off-the shelf sensors and I/O devices are critically evaluated. Current consumption and mechanical size are the most important features of the system. Introduction of redundant components to the system might put at risk the achievement of the key system features. In this report all functional components mentioned in the initial phase of the project were carefully considered. Some components like display and fingerprint sensor were discarded from usage, as they are not required in the use cases. The other components, listed in Table 2 and Table 3, were carefully evaluated.

The evaluation suggested the type of information that can be obtained from the sensor and the use cases that can benefit from it. All the sensor information combined in the AMANDA card can perform better than individual components.

Furthermore, the technical parameters were checked with respect to the applications for each evaluated component. Finally, hands-on advice about components usage and performance were expressed. The advice contains topics like hardware layout implementation, component placement and software implementations. Comments originating not from datasheet descriptions but from user experience are included and are crucial for smooth device development.

Unfortunately, it is impossible to summarise required area for all evaluated components, on this stage of system development. It will heavily depend on component placement and electric path routing. The required area will be calculated during works of **WP5 – Smart Interconnect PCB Development and System Integration**. However, it was indicated that the individual components dimensions are not with obvious conflict with wanted final AMANDA card size.

The architecture of the system proposed different voltage domains, as reported in **Deliverable D1.7 - Architecture design of the AMANDA system delivered (for both breadboard and integrated/miniaturised system).** The requirements of analysed components indicated that they all can be placed in a single proposed voltage domain.

All components can work in temperature ranges from -40°C to +85°C. That temperature limitation is sufficient for the proposed applications.

Most of the components use the I^2C protocol for digital communication. The advantage of I^2C is that may components can be operated from a single digital bus. The MB85RS64TU component can be also operated through the SPI interface. The I^2S protocol is required for sound capturing by component SPH0645LM4H-B. Simple digital output will be required to drive the LED.

The information in this Deliverable can be considered as validation of BOM of commercial components used in the architecture design. The description will be used in future during system integration activities of **WP5 – Smart Interconnect PCB Development and System Integration** and firmware development activities of **Task T2.3 – Sensor firmware development and optimisation**.

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