Project Acronym:	PhasmaFOOD
Grant Agreement number:	732541 (H2020-ICT-2016-1 - RIA)
Project Full Title:	Portable photonic miniaturised smart system for on-the-spot food quality sensing

DELIVERABLE

Deliverable Number	**D2.3**
Deliverable Name	**First version of smart system design**
Dissemination level	PUBLIC
Type of Document	REPORT
Contractual date of delivery	M11
Deliverable Leader	WINGS
Status & version	V1.1
WP / Task responsible	WP2 / T2.1, T2.2, T2.3 and T2.4
Keywords:	PhasmaFOOD system architecture; sensing subsystem hardware design; sensing subsystem optic design; main electronic board hardware design; sensing device mechanical design; embedded software; mobile application; cloud platform; cloud database; communication APIs
Abstract:	This deliverable describes the design of every part that the PhasmaFOOD system architecture comprises. Regarding the sensing subsystem, a brief analysis of the optic design, the main features of all sensing components and hardware details for driving them are included. The hardware design of the main electronic subsystem is thoroughly presented. The concept of the mechanical design for the overall sensing device is presented as well. Descriptions of the embedded software, mobile application and cloud platform are also provided in this deliverable along with definitions for the communication among all parts of the PhasmaFOOD system architecture.

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Executive Summary

During the course of the PhasmaFOOD project, a smart food analysis system will be developed. The architecture of this system comprises many different parts, each of which performs a distinct and thoroughly defined functionality. The actual purpose of the PhasmaFOOD food scanning system is to provide a fast and safe feedback to the end-users regarding food samples that they want to analyze. The use cases, which will be used in order to test the PhasmaFOOD system architecture, are defined in Deliverable Report D1.1 [1]. The PhasmaFOOD sensing device incorporates the sensing components and illumination sources, which conduct the measurements on the food samples, as well as an electronic subsystem in order to control, collect and partially process the aforementioned sensory measurements. A mechanical enclosure for the sensing device, particularly designed with emphasis and attention to achieving the highest possible compactness, ensures that the PhasmaFOOD sensing device will be user-friendly and easy to use. A mobile device stands as the main interaction point with the end-user and receives all the sensory data from the sensing device in order to partially process them and send them to the cloud platform of the system architecture for the final processing and verdict on the food sample quality. The specifications of the PhasmaFOOD system parts are defined in Deliverable Report D1.2 [2].

The sensing subsystem of the PhasmaFOOD sensing device integrates the main sensing components and lighting sources for scanning of various food samples. The optics design of the sensing subsystem, as well as the main features and functionalities of all the sensing and lighting components included, were thoroughly described and analyzed in Deliverable Report D2.2 [3]. On top of a brief presentation of these details, in the current Deliverable Report, information on driving all the sensing components are provided adding insight to the control of these components and their communication with the main electronic subsystem. Regarding the main electronic board incorporated in the sensing device, extensive and detailed analysis of its hardware design confirms matching with the requirements of the Deliverable Report D1.2 [2] and explains both the sensory data processing functionalities and the communication with the other parts of the PhasmaFOOD system architecture. The embedded software, which will run on the main electronic board, was described in Deliverable Report D2.1 [4] and is also presented here in order to be in align with the hardware components of the main electronic subsystem.

The mechanical design of the PhasmaFOOD sensing device is also presented in the current Deliverable Report. Information on the positioning and mounting of the sensing components and their driving boards, as well as on the integration of the illumination units, are provided. Also, the current Deliverable Report includes a preliminary design for the mechanical enclosure of the main electronic subsystem, which is under development since the final layout design for the main electronic board of the sensing device has not been finalized yet and, thus, some mechanical parameters still need to be fixed. The same applies to the sample interface. Here, several design proposals are made but the choice of the sample interface(s) can only be

finalized with real-world feedback and suggestions from a new round of WP3 trials, which are currently in progress up to month 12.

The PhasmaFOOD system architecture includes a mobile application, which will be installed on the end-user's mobile device, and a cloud platform. The mobile application is the main interface of the end-user to the PhasmaFOOD system architecture and provides to the end-user the ability of selecting a specific use case analysis and, thus, configuring and controlling the sensing device. The mobile application may partially process the sensory data sent from the sensing device and operates as an intermediate mean for the data flowing from the sensing point to the cloud platform. Guidelines and notifications to the end-user will be also provided through the system's mobile application. The cloud platform receives all the raw or partially processed sensory data, executes some specified data analysis and machine learning algorithms based on the selected use case and makes the final decision on the safety and quality of the scanned food sample. The architecture, design and development of the mobile application and the cloud platform were described and analyzed in Deliverable Report D2.1 [4]. The current Deliverable Report summarizes their functionalities and illustrates the APIs for the communication between them and with the sensing device in order to allow for a complete presentation of the PhasmaFOOD system architecture and for verifying the seamless flow of the sensory data from the point of their collection to their analysis on the cloud platform.

The main achievement of the current Deliverable Report is to provide information and details on the design of each of the parts that the PhasmaFOOD system architecture comprises. The communication, which is established between any two parts of the system architecture and ensures the proper data flow from the sensing edge of the system to the decision making cloud platform, is properly segmented yet analyzed in overall for the PhasmaFOOD system architecture providing feedback for Task 4.1. The complete design of the overall PhasmaFOOD sensing device is presented as the main source for the layout design and subsequent manufacturing of the main electronic board (Task 5.1) and as a supplementary source for the integration of the sensing and lighting components of the sensing subsystem (Task 5.2) since Deliverable Report 2.2 [3] has already provided thorough information towards this goal. Also, the mechanical enclosure of the overall sensing device (Tasks 2.4 and 6.1) is initiated at the current Deliverable Report. The alignment of the embedded hardware and software aspects can support Task 5.3, while the software details regarding the mobile application and cloud platform can add valuable insight to Task 4.2 with reference to the Deliverable Report 2.1 [4], which remains the main source of the system's software development.

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Document History			
Version	**Date**	**Contributor(s)**	**Description**
V0.1	20/10/2017	WINGS	ToC
V1.1	24/11/2017	WINGS, VLF	First version for internal review
V1.2	27/11/2017	WINGS, VLF, IPMS	Final version for internal review
V1.3	30/11/2017	WINGS, VLF, IPMS, FUB, CNR	Final version for submitting to EC

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Definitions, Acronyms and Abbreviations

Acronym	Title
ADC	Analog – to – Digital Converter
API	Application Programming Interface
APN	Apple Push Notification
App	Application
BLE	Bluetooth Low Energy
BR	Basic Rate
CMOS	Complementary Metal-Oxide Semiconductor
DA	Data Analysis
DC	Direct Current
DDR	Double Data Rate
Dx	Deliverable (where x defines the deliverable identification number)
EDR	Enhanced Data Rate
EEPROM	Electrically Erasable Programmable Read-Only Memory
eMMC	Embedded Multi-Media Card
ESD	Electro-Static Discharge
GCM	Google Cloud Messaging
GPIO	General Purpose Input Output
GUI	Graphical User Interface
HW	HardWare
IC	Integrated Circuit
I2C	Inter-Integrated Circuit
IMU	Inertial Measurement Unit
JSON	JavaScript Object Notation
LDO	Low Drop-Out
LE	Low Energy
LED	Light Emitting Diode
MAC	Media Access Control
microSD	micro Secure Digital
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MSPS	Million Samples Per Second
MSx	project Milestone (where x defines a project milestone)
Mx	Month (where x defines a project month)
NIR	Near Infra-Red
PCB	Printed Circuit Board
PHY	PHYsical
PMIC	Power Management Integrated Circuit

PRU-ICSS	Programmable Real-time Unit - Industrial Communication Sub-System
RAM	Random Access Memory
REST	REpresentational State Transfer
RISC	Reduced Instruction Set Computing
ROM	Read-Only Memory
RTC	Real-Time Clock
SAR	Successive Approximation Register
SDRAM	Synchronous Dynamic Random-Access Memory
SIMD	Single-Instruction Multiple-Data
SMD	Surface Mount Device
SMT	Surface Mount Technology
SoC	System-on-Chip
SPI	Serial Peripheral Interface
SRAM	Static Random Access Memory
UML	Unified Modeling Language
USB	Universal Serial Bus
UV	Ultra Violet
UV-VIS	Ultra Violet - Visible
UX	User eXperience
WP	Work Package

1 Overview of the PhasmaFOOD system architecture

The architecture of the PhasmaFOOD system is depicted in Figure 1. It comprises three main parts: (a) the PhasmaFOOD sensing device, (b) the PhasmaFOOD mobile application on an end-user mobile device, and (c) the PhasmaFOOD cloud platform. The PhasmaFOOD sensing device consists of the sensing subsystem and the main electronic subsystem.

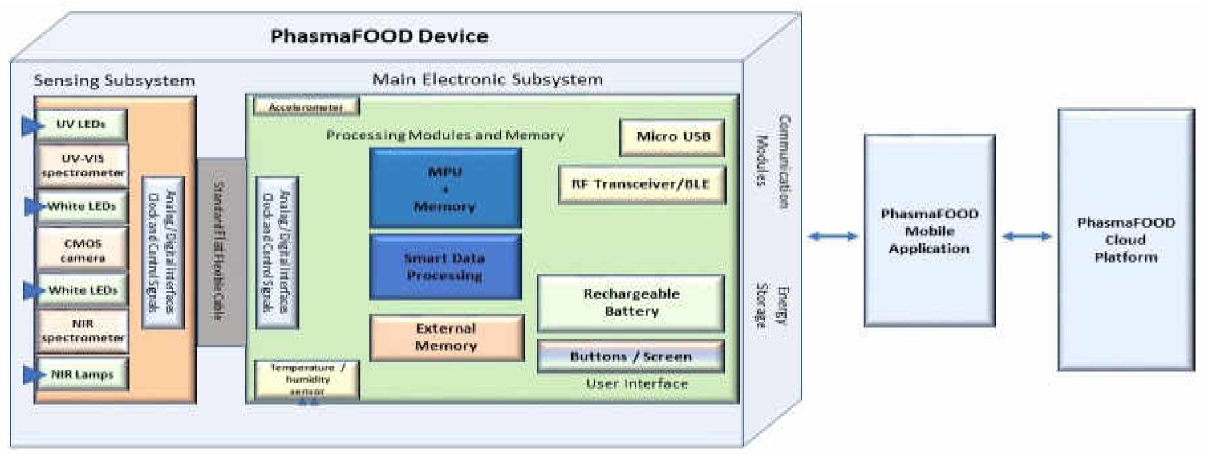

Figure 1 - The architecture of the PhasmaFOOD system.

1.1 PhasmaFOOD Sensing device

1.1.1 Sensing subsystem

Based on a selected use case (i.e., food sample and selection between mycotoxins, adulteration or fraud detection) [1], the sensing subsystem is configured to perform measurements and sends the sensory data to the main electronic subsystem. The configuration of the sensing subsystem is achieved through its communication with the main electronic subsystem, which receives the configuration setup from the end-user's mobile device after they have selected a specific use case to be analyzed.

The sensing subsystem was thoroughly analyzed in Deliverable Report D2.2 [3]. It incorporates an Ultra Violet – Visible (UV-VIS) spectrometer [5], a Near Infra-Red (NIR) spectrometer, which is designed and produced by Fraunhofer Institute for Photonic Microsystems (IPMS), a Complementary Metal-Oxide Semiconductor (CMOS) camera [6] and all the illumination units, which are needed for the right operation of the aforementioned sensing components. These units include Ultra Violet (UV) Light Emitting Diodes (LEDs), white LEDs and NIR micro-lamps. Moreover, the sensing subsystem integrates all the appropriate connectors in order that the driving boards of the sensing and illumination units exchange data and control information with the main electronic subsystem. The sensing subsystem is also described in Section 2.1 of the current deliverable report.

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Contract No. 732541
Project Coordinator: INTRASOFT International S.A.

1.1.2 Main electronic subsystem

The essential requirements for the development and operation of the main electronic subsystem were defined in Deliverable Report D1.2 [2].

The main electronic subsystem mainly incorporates all the necessary processing and memory components for driving the sensing subsystem and performing different measurement scenarios based on the selected use cases (Requirement ELECTR-L-3 [2]). It collects and stores the sensory data, and may perform some pre-processing functionalities on them, e.g., image compression, noise filtering, data compression, data normalization, feature extraction (Requirement ELECTR-L-5 [2], [4]). A microprocessor environment with on-chip memory and external memory components (e.g., Double Data Rate (DDR) Synchronous Dynamic Random-Access Memory (SDRAM), micro Secure Digital (microSD) connector, Embedded Multi-Media Card (eMMC)) are integrated on the main electronic subsystem for both the operation of the processing component and data storage (Requirement MEM-1 [2]).

The pre-processed sensory data are sent to the PhasmaFOOD cloud platform either directly or via the end-user mobile device using the PhasmaFOOD mobile application installed on it. For these communication purposes, the main electronic subsystem integrates a Wi-Fi / Bluetooth / Bluetooth Low Energy (BLE) component (Requirement POWER-4 [2]) and a microUSB connection. Also, all the appropriate connectors targeted for data and control information exchange with the sensing subsystem are integrated on the main electronic subsystem.

The main electronic board interfaces with the end-user with some buttons and a screen installed on it (Requirement ELECTR-L-4 [2]). The screen is used for showing any notifications and messages to the end-user in order to inform them about the current state of the sensing device (Requirement ELECTR-L-7 [2]).

The mechanical design of the PhasmaFOOD sensing device must ensure a stable environment for both the sensing subunit and the main electronics board. For this purpose, auxiliary sensors (i.e., accelerometer, temperature sensor) are integrated at the main electronics subsystem and must be allocated as close to the sensing subunit as possible (Requirements ELECTR-L-6, ELECTR-L-8, ELETR-L-9 [2]).

A rechargeable battery integrated on the main electronic subsystem provides the energy required for the operation of the PhasmaFOOD sensing device. The overall power consumption of the PhasmaFOOD sensing device must be kept at low levels (Requirements POWER-1, POWER-2, POWER-3, POWER-4 [2]).

The main electronic subsystem is thoroughly described and analyzed in Section 2.2 of the current deliverable report, which also includes the complete schematic design for the main electronic board. The respective layout design for the main electronic board is going to be delivered as part of the Deliverable Report D5.2 “Hardware Processing Platform, Storage and Communication units’ integration”.

1.2 Mobile device and application

The PhasmaFOOD system architecture includes an end-user's mobile device with the PhasmaFOOD mobile application installed on it. The PhasmaFOOD mobile application provides interface between the sensing device, which is the primary source of the sensory data, and the cloud platform, which is the primary sink for all data streams. Also, the mobile application interfaces with the end-user allowing them to configure the food analysis measurements or see the analysis results. Both Android and iOS versions of the mobile application will be developed.

The PhasmaFOOD mobile application was thoroughly described in Deliverable Report D2.1 [4] and is also analyzed in Section 4 of the current deliverable report.

1.3 Cloud platform

The PhasmaFOOD cloud platform is the focal point of all sensory and contextual data coming from the PhasmaFOOD sensing device, the mobile application and, if necessary, 3rd party data sources. The cloud platform hosts a data warehouse for all sensory and contextual data sets necessary for performing food analysis and producing results. Data marts derived from this data warehouse train different Machine Learning (ML) / Data Analysis (DA) models for the realization of the project use cases. Reactive (based on end-user measurements) and proactive (strategic and based on data collected over time) decision making algorithms (based on the trained ML models) are implemented on the cloud platform as well in order to make decisions based on the results of data analysis.

The PhasmaFOOD cloud platform was thoroughly described in Deliverable Report D2.1 [4] and is also analyzed in Section 5 of the current deliverable report.

2 PhasmaFOOD Sensing device

2.1 Sensing subsystem (IPMS)

As previously described in Deliverable Report D2.2 [3], the sensing sub-system of the PhasmaFOOD system is going to integrate three different sensors and their corresponding light sources:

1. UV-VIS spectrometer
2. VIS camera
3. NIR spectrometer

The integration concerns all optical aspects, electronic boards and mechanical housing in order to provide the hardware basis for a unified data acquisition and data fusion.

In the following, we give a short summary of the components, their optical characteristics and the level of electronic integration that is going to be implemented in the PhasmaFOOD sensing system. A dedicated small driver board will be used to connect the spectrometer to the main electronics board.

The actual mechanical integration of the UV-VIS spectrometer and its driving board is described in a section further below.

2.1.1 UV-VIS spectrometer

2.1.1.1 Description and optical characteristics

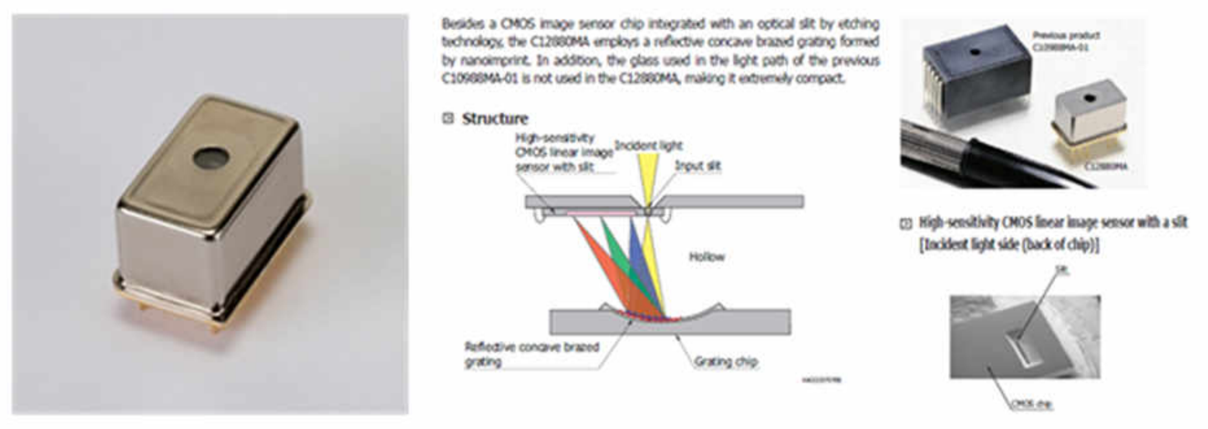


Figure 2 - Hamamatsu miniature UV-Vis spectrometer. Taken from https://www.hamamatsu.com/eu/en/C12880MA.html. [Online] November 2017.

As the UV-VIS spectrometer, the consortium chose the Hamamatsu C12880 MA spectrometer [5] for integration into our sensing system. This spectrometer is the latest item in a series of microspectrometers developed at Hamamatsu, the world's leading diode sensor supplier. It was chosen on account of its superior optical sensitivity, as tested by partner CNR. For testing within WPs 2, 3, 5 and 6 it was purchased together with an evaluation kit as well as the CAD construction files and opto-mechanical information needed for the integration design.

This device has a volume of 20.1 × 12.5 × 10.1 mm and weighs 5g only. It covers a wavelength range of 340 to 850 nm across 288 pixels. For the PhasmaFOOD sensing system, this range will be restricted to ca. 400 to 850 nm by use of a fluorescence cut-off filter, to aid detection requirements in Use case 1. For optical integration, the most important spectrometer parameters are the size of its entrance slit (500 x 50 microns) and its entrance NA of 0.22. Optical configuration: An assembly of achromatic lenses will be used to image a 2:1 magnified area of the sample onto its entrance slit, see also Deliverable Report D2.2 (Annex) [3].

This spectrometer requires a 6V / 20 mA power supply, which will be provided via the driving board described in the next section.

2.1.1.2 Design of driving board

Table 1 summarizes the components, which will be integrated on the driving board of the UV-VIS spectrometer. The UV-VIS spectrometer will be connected on the 115-47-314-41-003000 socket [7]. The digital clock and control signals of the spectrometer will be driven to and from it through a digital buffer [8] following the driving recommendations of the Hamamatsu company [9]. Also, an operational amplifier [10] for the analog video output of the spectrometer will be integrated on the electronic board for the same reason.

A header of 10 pins [11] will be included on the UV-VIS driving board. Two of the header's pins will be dedicated to provide voltage and ground supply to the electronic board from the main one. Four of the pins will be dedicated for driving the clock and control signals (digital signals) to and from the spectrometer. The Serial Peripheral Interface (SPI) for the communication with the main electronic board is dedicated to the sensor data and is a 4-wire interface integrated at the on-board Analog-to-Digital Converter (ADC). Thus, the four remaining pins of the header will be dedicated to it.

The ADC [12] will initially process the analog output of the spectrometer before any further processing will take place on the main electronic board. The output of the operational amplifier will be driven to the input of the ADC, which will handle its conversion to an equivalent digital signal. The sampling frequency of the ADC is 2 Million Samples Per Second (MSPS) and its precision is 16 bits. Also, the ADC will integrate a SPI in order that the microprocessor of the main electronic board can control its operation and its digital output can be transferred to the main electronic board.

An additional low noise Low Drop-Out (LDO) linear regulator [13] will be incorporated on the UV-VIS driving board in order to provide the 1.8 V power supply needed for the operation of the on-board ADC.

Table 1 - Components for the UV-VIS driving board.

Component Name (Component Version)	Reference Designator[1]	Description
ADP7118 [13] (ADP7118ACPZN1.8-R7)	U1	Low Noise, CMOS LDO Linear Regulator – Produces a 1.8 V power supply with 200 mA current
115-XX-XXX-41-003000 [7] (115-47-314-41-003000)	U2	Socket, Through Hole, Vertical, 14 Positions, 2 Rows, 2.54 mm Pitch – Socket for connecting the UV-VIS spectrometer
ADA4805-1 [10] (ADA4805-1AKSZ-Rx)	U3	Low Power, Low Noise, Rail-to-Rail Operational Amplifier – Operational amplifier for the analog video output of the UV-VIS spectrometer

1 The reference designator refers to the part name of the component in the schematic of the UV-VIS driving board.

CD74HCT125 [8] (CD74HCT125MT / CD74HCT125M96)	U4	High Speed CMOS Logic Quad Buffers with 3-State Outputs – Buffer for the digital signals of the UV-VIS spectrometer
AD4000 [12] (AD4000BRMZ)	U5	16-Bit, 2 MSPS Precision Pseudo Differential Successive Approximation Register (SAR) ADC – Converts the analog video output of the UV-VIS spectrometer to digital and communicates via SPI with the main electronic subsystem
5-103330-5 [11]	J1	Header, Right Angle, 10 Positions, 2 Rows, Through Hole, 2.54 mm Pitch – Used for the communication between the UV-VIS driving board and the main electronic subsystem
3x Resistors, 10x Capacitors		Passive Components

The schematic design for the driving board of the UV-VIS spectrometer was developed using the Autodesk Eagle Printed Circuit Board (PCB) design tool [14]. In order for the reader to access a detailed view of the aforementioned schematic design, please refer to the Annex 8.1 of the current Deliverable Report.

For the mechanical integration of this driving board, we note its mechanical parameters:

- size: X = 30 mm / Y = 40 mm
- mounting: 4 x M2 holes on the four edges of the driving board
- The board will be mounted onto the pin connectors of the spectrometer.

2.1.2 NIR spectrometer

2.1.2.1 Description and optical characteristics

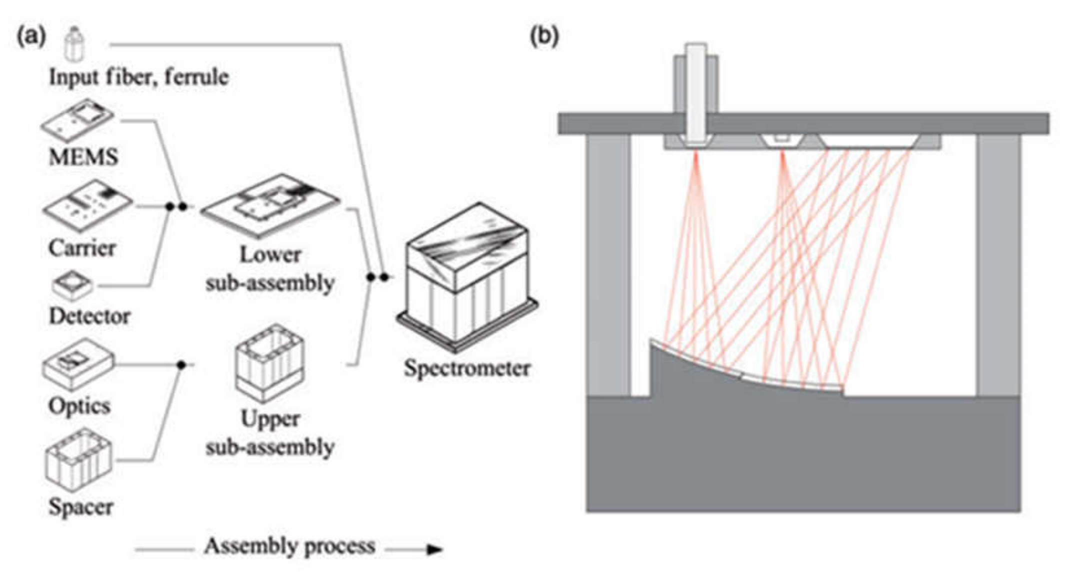


Figure 3 Setup (left) and optical configuration of the IPMS MEMS-based NIR spectrometer.

As the NIR spectrometer, the PhasmaFOOD consortium chose the MEMS-based microspectrometer that has been invented and manufactured by partner IPMS.

The small size (2.1 cm^3) and low weight make this spectrometer ideal for integration in combinatorial system approaches such as PhasmaFOOD. The NIR microspectrometer features an aperture of NA 0.14 and an optical slit size of 50 µm x 250 µm. This information together with the slit position and orientation on the spectrometer body was used to calculate the optical geometry for light coupling from a sample into the NIR spectrometer, see D2.2 (Annex) [3]. The expected signal will be diffuse scattered light, which exhibits Lambertian emission profiles at the sample, out of which a section will be detected. Optical configuration: An assembly of achromatic lenses will be used to image a 2:1 magnified area of the sample onto its entrance slit, see also Deliverable Report D2.2 (Annex) [3].

2.1.2.2 Design of driving board

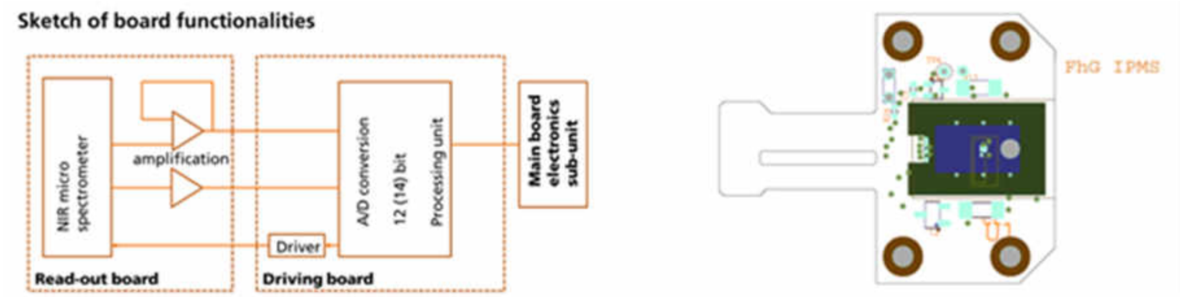


Figure 4-Left: Driving and reading board functionalities. Right: Sketch of NIR microspectrometer mounted on the read-out board.

Figure 5-Left: the sugar-cube sized NIR spectrometer. Right: Design drawing of the spectrometer on its read-out board.

Fraunhofer IPMS adapted the read-out and driving electronics of their NIR spectrometer electronics in order to better fulfil the mechanical requirements of integration into the compact mechanical design of the sensing subsystem (see Annex II). Therefore, instead of using a single board, which might block mounting space for the other sensing and lighting components, the electronics were split into a read-out and driving part connected via a short flexible cable. This board design was already successfully fabricated, assembled and tested in WP5. The power and connector requirements as well as the data protocol are communicated to partner WINGS. For this interface protocol (USB preferred, SPI also possible), please see D2.2 [3].

2.1.3 CMOS camera

2.1.3.1 Description and electrical characteristics

Figure 6-Left: coin-sized Ximea subminiature camera, taken from https://www.ximea.com/en/products/application-specific-cameras/subminiature-cameras/ Right: Edmund optics microvideo lenses, taken from https://www.edmundoptics.de/imaging-lenses/micro-video-lenses/

The camera selected for the PhasmaFOOD system is the Ximea MU9PC-MH subminiature camera [6]. This device is the smallest available Gen TL camera at the moment, weighing 5 g and measuring 15x15x9 mm^3 complete with electronics and mountable robust housing. This camera is S-mount compatible. High-quality S-mount microvideo lenses are readily available from standard manufacturers such as Edmund optics. Here, lenses with a low entrance aperture are preferred as they increase the focal depth and, thereby, the robustness of the imaging process on food surfaces, which are expected to be rough. As was tested at IPMS within WP3, a focal length of 8 mm results in an appropriate lens-detector geometry, resolution and field-of-view for a lens-sample distance of 30 mm.

The 5 Mpix RGB camera consumes less than 1 W and operates at 5 V driving voltage.

2.1.3.2 Design of driving board

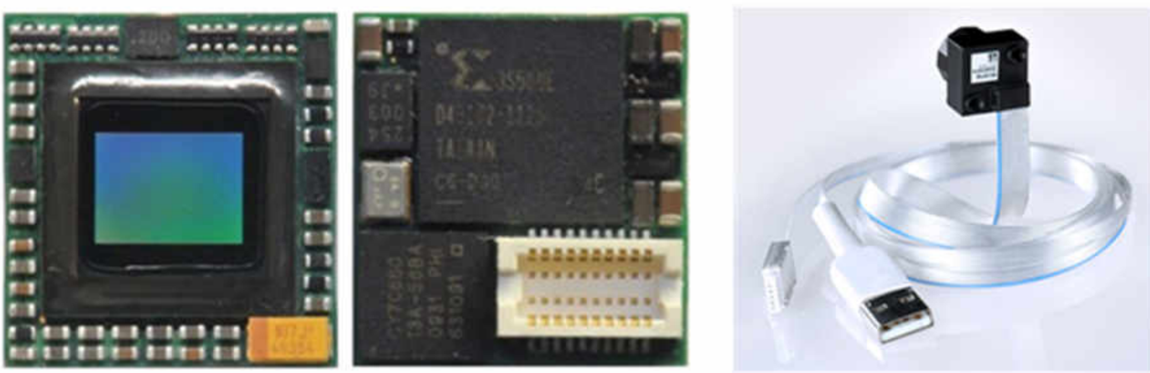


Figure 7-Left: Camera electronics front and back. Right: Ximea camera with commercial USB cable with trigger facility.

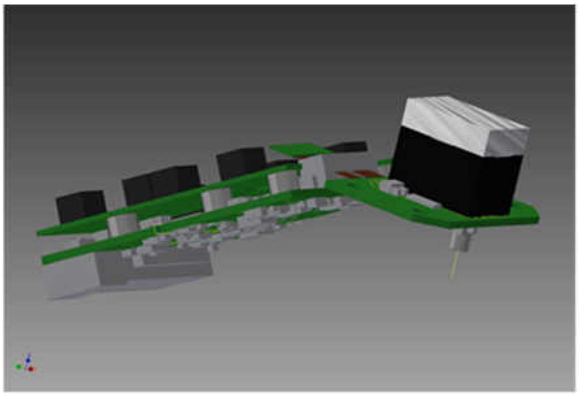
The Ximea MU9PC-MH subminiature camera comes complete with a very small electronic board integrated into the housing. The APTINA sensor chip is mounted directly onto the board and a Ximea custom USB connector is mounted at the back. Powerful software to operate the camera in different modi with pre-processing is available from the manufacturer. This software will be used for testing the device and data options in WPs 3, 4 and 5.

2.1.4 Illumination concept

2.1.4.1 Description

The illumination concept consisting of focused NIR microlamps, focused UV LEDs and white LEDS has been described in detail in Deliverable Report D2.2 [3]. The Annex II of D2.3 also provides a short visual summary. The main goal for this concept is to use light as efficiently as possible, bearing in mind that the power resources of the PhasmaFOOD detection system (battery) are limited, space for light sources is limited and detection limits for the Use Cases are challenging. The second main priority was to create and maintain a stable overlap of all illumination and sensing spots during and between measurements in order to obtain stable calibrations of fused data.

2.1.4.2 Illumination units and optical characteristics



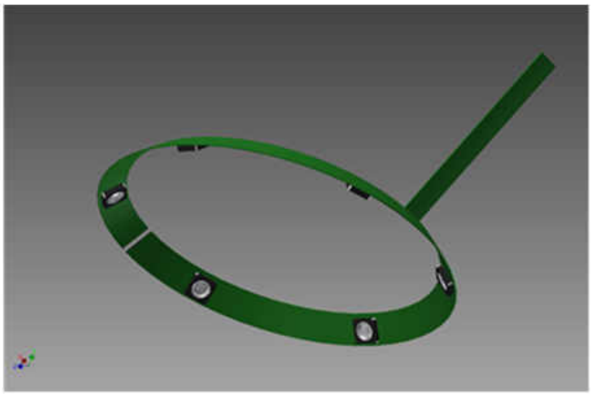


Figure 8-Design images of the illumination control boards. Left: For test purposes in WP5, an NIR lighting control board was stacked on top of the NIR spectrometer control board by IPMS. Right: Ring-shaped lighting board.

Lighting will be controlled and powered via the main electronics board described in the sections below. In order to test the appropriate infrastructure required for NIR lighting, an NIR lighting control board was stacked on top of the NIR spectrometer control board by IPMS, as part of WP5. The useful features of this board were then communicated to WINGS to be integrated into the main control board design.

Additional unfocused lighting (white LEDs) will be mounted directly on a circular board at the front of the sensing sub-unit. The LED drivers will be directly integrated here and power will be connected via a small feed-through extension of the board, see Figure 8. A maximum of six LEDs of two types may be mounted inside the ring board at the front of the sensing sub-unit. During the first manufacturing cycle, only three of these slots will be used, for three identical standard brightness white LEDs. A further three mono- or bichromatic LEDs may be mounted here during the second manufacturing iteration in year 2. In collaboration with the efforts of WP3, it will be tested whether such additional lighting is beneficial and meaningful in the context of the Use cases, in particular Use Case 2.

Light sources will consume the largest part of the power used by the PhasmaFOOD sensing sub-unit. The UV LEDs must be high-power for the demanding fluorescence measurements of Use Case 1. Each of these LEDs (OSA Optolight OCU-440 UE365-X-T) consumes more than 300 mA at ca. 4 V. The NIR microlamps will consume 115 mA at 5 V each. The white LEDs are standard brightness, averaging around 15 mA each.

In this context, the thermal load on the detection system originates mainly from the UV LEDs. In order to prevent heat build-up inside the sensing subsystem and corresponding low signal-to-noise ratios of the detectors, several measures can be taken: Pulsed operation of the light sources to reduce ON-time, and heat management via heat conducting materials or a forced ventilation. While the former two options are implemented in the system design, the third option is under discussion and might result in a miniature ventilator being installed inside the detection unit.

2.2 Main electronic subsystem

2.2.1 Overview of the architecture of the main electronic subsystem

Figure 9 depicts an abstract description of the main electronic subsystem. At the main electronic subsystem, a microprocessor System-on-Chip (SoC) is integrated including a processing unit and a graphics processing machine. The later accelerates the implementation and execution of the complex and computation-intensive algorithms at the field of image / video processing. Two real-time co-processing units and on-chip Random Access Memory (RAM) complement the design of the SoC.

Except from the memories, which are integrated inside the SoC, a number of external memories are also integrated at the main electronic subsystem. A DDR SDRAM component stores incoming sensory data or intermediate results when algorithmic functionalities are processed. An Electrically Erasable Programmable Read-Only Memory (EEPROM) contains identification information for the main electronic board. An eMMC is used for storing the operating system. A microSD connector is integrated in order for any SD card to be connected and supplement the available storage or stand as a boot device.

The communication of the main electronic subsystem with the mobile device and the cloud platform is achieved wirelessly. There are two options of connection between the main electronic subsystem and the cloud platform: a) the main electronic subsystem communicates wirelessly with the mobile device using the BLE protocol implemented at the Wi-Fi / Bluetooth / BLE module and, then, the mobile device is connected to the cloud platform using it's Wi-Fi or 3G / 4G component, or b) the main electronic subsystem is directly connected to the cloud platform via Wi-Fi using its Wi-Fi / Bluetooth / BLE module. Also, a microUSB port offers an alternative way of connection to the mobile device.

Regarding the communication of the main electronic subsystem with the sensing one, it is achieved using wired protocols. Both the NIR and camera driving boards require a USB connection, so, a hub is integrated at the main electronic subsystem providing two USB 2.0 high-speed host ports. An expansion socket provides all the necessary wired connections with the UV-VIS driving board: a) clock and control signals for the UV-VIS spectrometer, and b) SPI signals for the ADC of the driving board. Also, a LEDs driving Integrated Circuit (IC) is integrated at the main electronic subsystem for the proper operation of the illumination units of the sensing subsystem. The lighting units are directly connected to the main electronic subsystem using a number of proper connectors.

An Inertial Measurement Unit (IMU) and a temperature sensor are integrated at the main electronic subsystem ensuring the right operation of the sensing components inside the sensing subsystem. A number of LEDs and buttons are used as an interface to the end-user. Using an expansion socket of the main electronic subsystem with either the SPI or the Inter-Integrated Circuit (I2C) protocol, a small character screen can be connected and the end-user can receive messages and notifications regarding the current status of the sensing device.

A Power Management Integrated Circuit (PMIC), Direct Current (DC)-to-DC converters and LDO regulators form the power management circuit of the main electronic subsystem. They provide all the necessary and different voltage supplies with the appropriate amounts of current in order that all the components of the subsystem work properly. A battery provides all the energy, which is requested for the operation of the PhasmaFOOD sensing device. The microUSB port offers the potential of charging the battery from a host device.

The schematic design for the main electronic board of the sensing device was developed using the Autodesk Eagle PCB design tool [14]. In order for the reader to access a detailed view of the aforementioned schematic design, please refer to the Annex 8.1 of the current Deliverable Report. The schematic design for the main electronic board, which is essential for the operation and control of the sensing device, comprises ten sheets with the first one as a guideline to the following sheets (sheet 1). The aforementioned schematic design includes all the components and connections for power management (sheet 2, see Section 2.2.5), processing and memory storage (sheets 3, 4, 5 and 6, see Section 2.2.2), wireless communication (sheet 7, see Section 2.2.3.1), wired communication and expansion (sheets 8 and 10, see Section 2.2.3.2), and user interface and oscillations / temperature control (sheet 9, see Section 2.2.4) on the main electronic board.

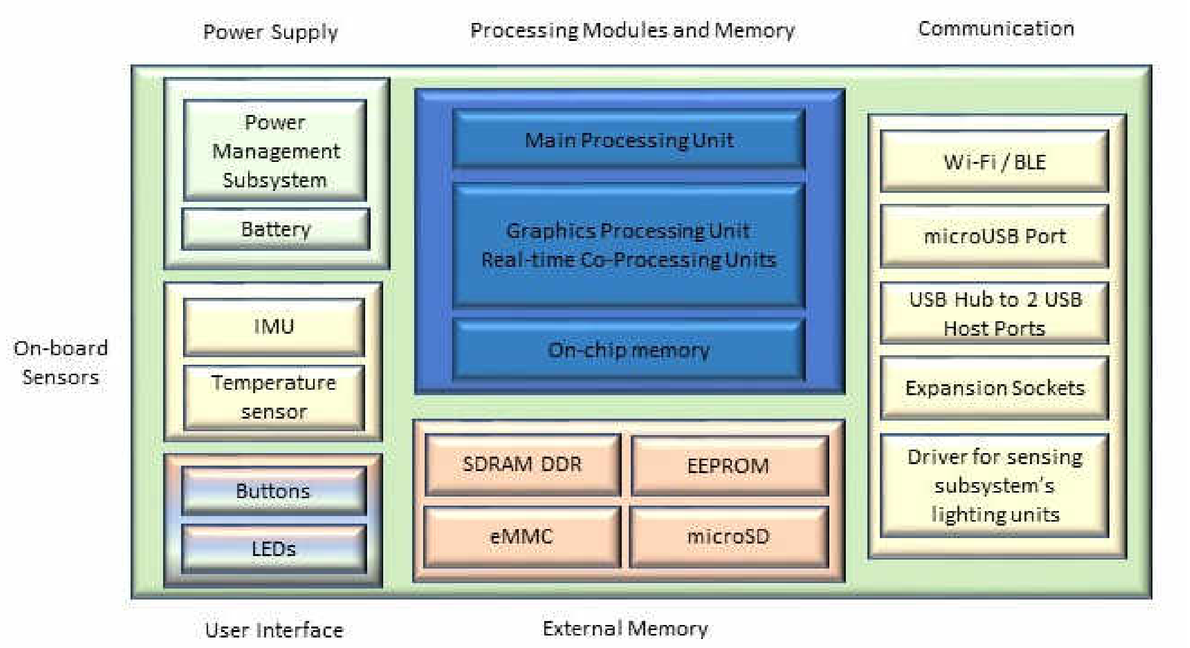


Figure 9 - An abstract description of the main electronic subsystem.

2.2.2 Processing and memory components

Table 2 summarizes the processing and memory components of the main electronic subsystem. The main processing unit is the AM3358 [15] microprocessor. It integrates a Sitara™ ARM® Cortex®-A8 32-bit Reduced Instruction Set Computing (RISC) processor with up to 1 GHz performance frequency. The processor includes a NEON™ Single-Instruction Multiple-Data (SIMD) co-processing unit, which accelerates the implementation and execution of computation-intensive algorithms (e.g., data analysis algorithms such as data normalization, data compression, and feature extraction). 176 KB of on-chip boot Read-Only Memory (ROM) and 64 KB of dedicated RAM are also included in the processor. In addition, the microprocessor offers 64 KB of general purpose on-chip RAM and the possibility of connecting external memory components, e.g., SDRAM DDR, Static Random Access Memory (SRAM), NAND flash memories etc. Also, the microprocessor integrates the PowerVR SGX™ graphics accelerator subsystem, which provides advanced graphics acceleration and could be used for accelerating the image processing functionalities for the raw images of the CMOS camera of the sensing subsystem. Finally, there are two real-time co-processing units, separate from the ARM core, which allow for greater efficiency and flexibility. These units are part of the programmable real-time subsystem of the microprocessor (i.e., Programmable Real-time Unit - Industrial Communication Sub-System (PRU-ICSS)).

Two crystal oscillators are needed for the right operation of the microprocessor: a) one with 24 MHz frequency [16], which is connected as the main oscillating component of the microprocessor, and b) one with 32.768 kHz frequency [17], which stands as the real-time oscillating component for the microprocessor.

Four external memory components are integrated at the main electronic subsystem. The SDRAM DDR2 AS4C128M16D2A [18] memory component runs at 400 MHz and offers 2 GB of storage. Any incoming sensory data (either raw or partially processed on the driving boards of the sensing components inside the sensing subsystem) or any intermediate results during the execution of various functionalities on the board can be stored at the SDRAM DDR2 component. The SDINBDG4 [19] eMMC memory component is based on the NAND flash technology and stands as a storing point for the operating system. A microSD connector [20] is also included in order to connect an external SD card and increase the storage of the main electronic subsystem. The 24LC32A [21] EEPROM is used for storing identification information for the board. However, we should mention that the EEPROM is connected to the microprocessor using the I2C protocol.

Table 2 - Processing and memory components of the main electronic subsystem.

Component Name (Component Version)	Reference Designator[2]	Description
AM3358 [15] (AM3358BZCZA100)	U7	Sitara Processor: ARM Cortex-A8, 3D Graphics, PRU-ICSS – Main processing unit
7A [16] (7A-24.000MAAJ-T)	Y1	Crystal, 24 MHz, 30 ppm Tolerance, 18 pF Load Capacitance – 24 MHz crystal as the main oscillator of the main processing unit
FX135 [17] (FX135A-327 or FK135EIHM0.032768)	Y2	Crystal, 32.768 kHz, 20 ppm Tolerance, 12.5 pF Load Capacitance – 32.768 kHz crystal as the real-time oscillator of the main processing unit
SN74LVC1G07 [22] (SN74LVC1G07DBVx)	U8	Single Buffer/Driver With Open-Drain Output
AS4C128M16D2A [18] (AS4C128M16D2A-25BIN)	U9	SDRAM DDR2, 2 GB (128Mbit x 16 or 8 banks x 16Mbit x 16), 1.8 V, 400 MHz – External DDR2 SDRAM for data storage

[2] The reference designator refers to the part name of the component in the schematic of the main electronic board.

24LC32A [21] (24LC32AT-I/OT)	U11	I2C Serial Compatible EEPROM, 32kbit (4kbit x 8), 2.5 V – 5.5 V, 400 kHz – External EEPROM, which keeps identification information for the electronic board
SDINBDG4 [19] (SDINBDG4-8G-I1)	U10	eMMC Memory, 8 GB, eMMC 5.1 HS400 interface – External eMMC memory for storage of the operating system, potential boot device
DM3 [20] (DM3BT-DSF-PEJS)	X1	microSD Card Connector, Reverse on-Board, Surface Mount Technology (SMT) – Connector for external microSD memory card for storage of the operating system and / or data storage, potential boot device
101x Resistors, 97x Capacitors, 3x Ferrite Beads		Passive Components

The processing and memory components of Table 2 and their connections are depicted in sheets 3, 4, 5 and 6 of the main electronic board's schematic design. In order for the reader to access a detailed view of the aforementioned sheets of the main electronic board's schematic design, please refer to the Annex 8.1 of the current Deliverable Report.

2.2.3 Communication

2.2.3.1 Communication with mobile device and cloud platform (Wireless communication)

Table 3 summarizes the components, which are integrated at the main electronic subsystem and implement the wireless communication with the mobile device and the cloud platform. The WL 1835MOD [23] 2.4-GHz component offers high throughput and extended range along with Wi-Fi and Bluetooth coexistence in a power-optimized design. Since two antennas can be connected to this module, two antenna connectors [24] are integrated. Also, two voltage level shifters [25] and a digital buffer [26] are incorporated for the proper communication of the microprocessor and the Wi-Fi / Bluetooth / BLE module.

Table 3 - Components for the wireless communication of the main electronic subsystem with the mobile device and the cloud platform.

Component Name (Component Version)	Reference Designator[3]	Description
WL1835MOD [23] (WL1835MODGBMOCx)	U15	WiLink™ 8 single band combo 2x2 Multiple-Input Multiple-Output (MIMO) Wi-Fi®, Bluetooth® & Bluetooth Smart module
IQXO-986 [27] (LFSPXO071976Cutt)	OSC1	Standard Clock Oscillator, 32.768 kHz, 30 ppm Frequency Stability, 15 pF Load Capacitance – 32.768 kHz crystal oscillator of the Wi-Fi / Bluetooth / BLE module
2x U.FL [24] (U.FL-R-SMT-1(10))	ANT1, ANT2	Antenna Connector
2x TXS0108E [25] (TXS0108ERGYR)	U12, U13	8-Bit Bidirectional Voltage-Level Shifter For Open-Drain And Push-Pull Application – Voltage level shifter for the connection between the processing unit and the Wi-Fi / Bluetooth / BLE module
SN74LV1T126 [26] (SN74LV1T126DBVR)	U14	Single Power Supply, Single BUFFER GATE w/ 3-State Output (active high enable)
27x Resistors, 12x Capacitors		Passive Components

The components of Table 3 for the wireless communication with the mobile device and the cloud platform, as well as the connections around all these components, are depicted in sheet 7 of the main electronic board's schematic design. In order for the reader to access a detailed view of the aforementioned sheet of the main electronic board's schematic design, please refer to the Annex 8.1 of the current Deliverable Report.

[3] The reference designator refers to the part name of the component in the schematic of the main electronic board.

2.2.3.2 Communication with sensing subsystem and expansion sockets (Wired communication)

Table 4 summarizes the components of the main electronic subsystem, which implement the wired communication with the sensing subsystem and offer potential for expansion. Since the driving boards of both the NIR spectrometer and the CMOS camera request the USB 2.0 interface for communication with the main electronic subsystem, a two-port high-speed 480 Mbps USB 2.0 hub [28] is incorporated at the latter in order to provide two distinct USB 2.0 host ports [29]. The incorporation of the USB 2.0 hub is imposed by the fact that the microprocessor [15] of the main electronic subsystem provides only two USB 2.0 connections and the one of them is dedicated to a microUSB connector [30], which is used for powering and battery charging purposes or as an alternative way of communication with the end-user's mobile device.

The single channel TPS2051B [31] and dual channel TPS2561 [32] components are used to limit at 500 mA the current provided to the VBUS lines of the hub device and the two USB 2.0 host ports respectively. Also, the TPD4S012 [33] components provide Electro-Static Discharge (ESD) protection at all three USB 2.0 ports.

A LEDs driving component [34] is integrated at the main electronic subsystem in order for proper operation of the UV, white LEDs and NIR micro-lamps inside the sensing subsystem. Since there is a voltage drop at the LEDs driver, which may reduce the power of the NIR micro-lamps, N-channel Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) [35] are used in order to pull-down this potential.

Finally, extensive expansion sockets are integrated at the main electronic subsystem in order for connection with the UV-VIS driving board (SPI digital signals for the ADC, control and clock digital signals for the UV-VIS spectrometer), expansion through SPI, I2C or UART protocols or direct communication with the real-time subsystem of the microprocessor [15] with the appropriate voltage lever shifters [25] wherever they are needed.

Table 4 - Components for the wired communication of the main electronic subsystem with the sensing subsystem and for potential expansion.

Component Name (Component Version)	Reference Designator[4]	Description
TUSB4020BI [28] (TUSB4020BIPHPR)	U20	Two-Port High-Speed 480 Mbps USB 2.0 Hub – Provides two high-speed 480 Mbps host connections
7A [16] (7A-24.000MAAJ-T)	Y3	Crystal, 24 MHz, 30 ppm Tolerance, 18 pF Load Capacitance – 24 MHz crystal for the

[4] The reference designator refers to the part name of the component in the schematic of the main electronic board.

		TUSB4020BI USB 2.0 hub
TPS2051B [31] (TPS2051BDGNR)	U17	Single, Current-Limited, Power-Distribution Switch – Provides 5 V voltage and limited 500 mA current for the VBUS line of the USB 2.0 hub
TPS2561 [32] (TPS2561DRCx)	U16	Dual Channel Precision Adjustable Current-Limited Power Switches – Provides 5 V voltage and limited 500 mA current for the VBUS lines of the USB 2.0 host ports
2x UE27 [29] (UE27AC5410H)	X2, X3	USB Connector Type A Receptacle, Right Angle, Through Hole
10118192 [30] (10118192-0001LF)	X4	USB Connector microUSB Type B Receptacle, Surface Mount Device (SMD) / SMT
3x TPD4S012 [33] (TPD4S012DRYR)	U18, U19, U21	4-Channel USB ESD Solution with Power Clamp – ESD protection for USB host and microUSB ports
TLC5922 [34] (TLC5922DAP / TLC5922DAPR)	U25	16-Channel LED Driver w/ DOT Correction – Driver for the illumination units (UV LEDs, NIR micro-lamps, white LEDs) of the sensing subsystem
7x 53047 [36] (53047-0210)	J6, J7, J8, J9, J10, J11, J12	1.25 mm Pitch PicoBlade Wire-to-Board Header, Vertical, with Friction Lock, 2 Circuits, Through Hole – Header for connecting to the illumination units (UV LEDs, NIR micro-lamps, white LEDs) of the sensing subsystem
FDG8850NZ [35] (FDG8850NZ) 3x 803-PP-NNN-10-001101 [37] (803-87-010-10-001101)	U26 J3, J4, J5	30V Dual N-Channel PowerTrench® MOSFET PCB Socket Connector, 10 Positions, 2 Rows, Vertical, Through Hole, 2.54 mm Pitch

803-PP-NNN-10-001101 [37] (803-87-014-10-001101)	J2	PCB Socket Connector, 14 Positions, 2 Rows, Vertical, Through Hole, 2.54 mm Pitch
2x TXS0108E [25] (TXS0108ERGYR)	U24, U27	8-Bit Bidirectional Voltage-Level Shifter For Open-Drain And Push-Pull Application – Voltage level shifter for the connection between the processing unit’s 3.3 V pins and external 5 V signals
20x Resistors, 36x Capacitors, 4x Ferrite Beads		Passive Components

The components of Table 4 for the wired communication of the main electronic subsystem with the sensing subsystem and for potential expansion, as well as the connections around all these components, are depicted in sheets 8 and 10 of the main electronic board’s schematic design. In order for the reader to access a detailed view of the aforementioned sheets of the main electronic board’s schematic design, please refer to the Annex 8.1 of the current Deliverable Report.

2.2.4 On-board sensors, LEDs and buttons

Table 5 summarizes the sensors, which are incorporated at the main electronic subsystem and targeted for the right operation of the sensing device, and the buttons and LEDs, which are offered as an interface with the user of the sensing device. The MPU-9250 [38] integrates an accelerometer and a gyroscope, which can be used in order to detect any oscillations that can damage the sensing device or result to incorrect measurements. The TMP116 [39] monitors the temperature of the sensing device.

Finally, four tactile switches [40] can be used to control the operation of the sensing device and some LEDs [41] can inform about some events at the main electronic subsystem (e.g., enabling the Wi-Fi / Bluetooth / BLE module, battery state etc.).

Table 5 - Sensors, LEDs and buttons of the main electronic subsystem.

Component Name (Component Version)	Reference Designator[5]	Description
MPU-9250 [38]	U22	IMU, Nine-Axis (Gyro + Accelerometer + Compass) MEMS MotionTracking™ Device

[5] The reference designator refers to the part name of the component in the schematic of the main electronic board.

TMP116 [39] (TMP116AIDRVx)	U23	High-Accuracy, Low-Power Digital Temperature Sensor
4x SKQM [40] (SKQMASE010)	S1, S2, S3, S4	Tactile Switch
5x LTST-C191KGKT [41]	LED2, LED5, LED6, LED11, LED12	SMD Chip LED, 0603, Green
2x LTST-C191KRKT [41]	LED7, LED8	SMD Chip LED, 0603, Red
4x LTST-C191KSKT [41]	LED3, LED4, LED9, LED10	SMD Chip LED, 0603, Yellow
12x Resistors, 4x Capacitors		Passive Components

The components of Table 5 and their connections are depicted in sheet 9 of the main electronic board's schematic design. In order for the reader to access a detailed view of the aforementioned sheet of the main electronic board's schematic design, please refer to the Annex 8.1 of the current Deliverable Report.

2.2.5 Power management

Table 6 summarizes the components related to the power management of the main electronic subsystem. The main IC used for the power management purpose is the TPS65217B [42], which provides all the voltage supplies needed for the operation of the microprocessor and some components of the subsystem. This IC is powered by a battery or via the microUSB connection, which can also be used for battery charging. More specifically, the TPS65217B PMIC produces the following supply voltages: a) VDDS_DDR (1.8 V) for the DDR2 memory component, which is the same as the VDD_1V8 (1.8 V) used at the microprocessor, b) the VDD_MPU (1.1 V) for the MPU core domain of the microprocessor, c) the VDD_CORE (1.1 V) for the core domain of the microprocessor, d) the VRTC (1.8 V) for the Real-Time Clock (RTC) domain of the microprocessor, e) the VDD_3V3A (3.3 V), and f) VDD_3V3B (3.3 V). The VDD_3V3A is used for the USBPHY and dual voltage IO domain of the microprocessor, for the pull-up resistances, and for supplying the eMMC memory component and the microSD card. Since VDD_3V3A is produced and outputted before VDD_3V3B, we used at some crucial points of the design due to boot reasons. The VDD_3V3B supplies all the remaining components of the main electronic subsystem, which need a 3.3 V voltage supply.

The only exception regarding the 3.3 V voltage supply is the Wi-Fi / Bluetooth / BLE component of the main electronic subsystem, which is powered from a distinct DC-to-DC converter [43] due to the fact that it may need large amount of current for its operation [23]. The DC-to-DC converter is powered from the battery. Based on the same reason, we integrated a DC-to-DC converter [44], which provides the 1.8 V voltage supply that the Wi-Fi / Bluetooth / BLE component needs. Some voltage level shifters and buffers, which are needed for the proper

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Contract No. 732541
Project Coordinator: INTRASOFT International S.A.

communication of the Wi-Fi / Bluetooth / BLE component with the microprocessor (see Table 3), are also powered by the aforementioned converters.

Moreover, a DC-to-DC converter [45] is installed at the main electronic subsystem in order to produce 5 V, which is essential for the USB-related components and connections and for the proper operation of the UV-VIS spectrometer and its driving board in the sensing subsystem (see Table 4).

Finally, a LDO regulator [46] produces the 1.1 V voltage supply needed for the USB 2.0 hub device [28].

Table 6 - Components of the power management of the main electronic subsystem.

Component Name (Component Version)	Reference Designator[6]	Description
TPS65217 [42] (TPS65217BRSLx)	U1	Power Management IC (PMIC) w/ 3 DC/DCs, 4 LDOs, Linear Battery Charger & White LED Driver – Produces most power supplies requested for the components of the main electronic subsystem
TPS63020 [45] (TPS63020DSJx)	U2	High Efficiency Single Inductor Buck-Boost Converter with 4A Switch – Produces a 5V power supply with 1.5 A
TPS63001 [43] (TPS63001DRCx)	U5	96% Buck-Boost Converter with 1.7A Current Switches, 3.3V Fixed Output voltage – Produces an extra 3V3 power supply with 1 A
TPS63000 [44] (TPS63000DRCx)	U4	96% Buck-Boost Converter with 1.8A Current Switches – Produces an extra 1V8 power supply with 1 A
LP5912 [46] (LP5912-1.1DRVx)	U6	500mA Low-Noise Low-IQ LDO Regulator– Produces a 1V1 power supply with up to 500 mA
JST-PH Connector [47] (S2B-PH-K-S (LF)(SN))	J1	Wire-To-Board Connector, Right Angle, 2 mm Pitch, 2

[6] The reference designator refers to the part name of the component in the schematic of the main electronic board.

		Contacts, 1 Row, Through Hole – Battery connector
SN74LVC2G00 [48] (SN74LVC2G00DCUx)	U3	Dual 2-Input Positive-NAND Gate
LTST-C191KGKT [41]	LED1	SMD Chip LED, 0603, Green – Power LED
18x Resistors, 26x Capacitors, 6x Inductors		Passive Components

The power management components of Table 6 and their connections are depicted in sheet 2 of the main electronic board's schematic design. In order for the reader to access a detailed view of the aforementioned sheet of the main electronic board's schematic design, please refer to the Annex 8.1 of the current Deliverable Report.

2.3 Embedded software architecture

The microprocessor environment of the main electronic subsystem will host an embedded software, which will perform all the essential functionalities that ensure the correct and defined operation of the PhasmaFOOD sensing device. Such functionalities include:

- Control of all communications with the sensing subsystem and the mobile device of the end-user with the PhasmaFOOD mobile application installed on it.
- Configuration of the sensing subsystem based on the configuration values received from the mobile application and collection of all sensory data.
- Preprocessing of the sensory data (e.g., image compression, noise filtering, data compression, data normalization, feature extraction).
- Ensuring accepted levels of temperature and oscillations inside the sensing device for the correct operation of the sensing components.

2.3.1 Operational states and triggered events

2.3.1.1 Operational states

The main electronic board will be able to operate at different states, each defined as a distinct mode of operation and running an explicit service. Figure 10 illustrates a diagram containing all the different states of operation for the main electronic board.

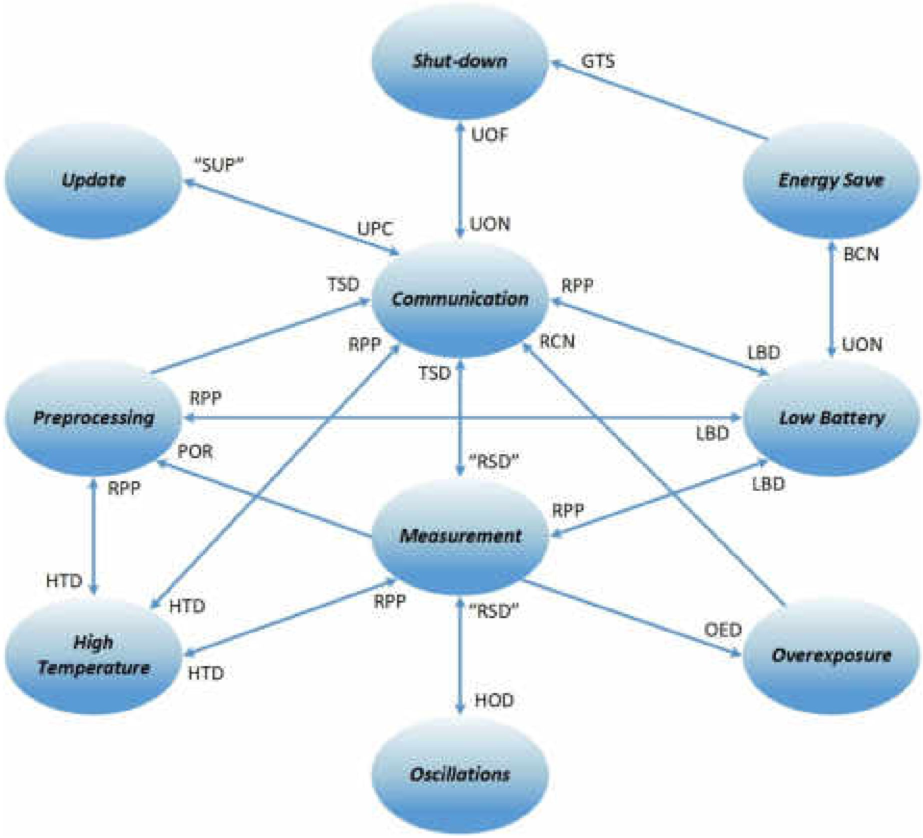

Figure 10 - Diagram of operational states for the embedded software.

The operational states of the main electronic board are described as following:

i) Shut-down

During the Shut-down state of operation, the sensing device is shut down. No communications can be established between the main electronic board and the sensing subsystem or the mobile device. The sensing device remains at the Shut-down state of operation until the end-user presses its start button.

ii) Communication

When the main electronic board starts operating, it goes into the Communication state of operation. There are various cases when the main electronic board goes into the Communication state of operation.

In case the end-user has selected a specific measurement mode to be followed using the PhasmaFOOD mobile application, the process related to the Communication state receives information regarding the selected measurement mode and the configuration of the sensing and lighting components to be used in the following measurements. All sensing components are considered to be used at all three use cases, but there are some special measurement modes for capturing the dark and white references of the UV-VIS and NIR spectrometers and for the calibration of the sensing components as well. All sensing and lighting units of the sensing subunit must be configured and operate according to the information provided by the mobile application. The Application Programming Interface (API) to the Bluetooth / BLE hardware module is used to establish a wireless connection to the mobile device and the PhasmaFOOD application therein. All communication between the embedded device and the mobile application, as well as the transfer of measured data is handled in the Communication state.

In case the data Preprocessing state of operation has finished, the main electronic board goes into the Communication state and the preprocessed data, properly formatted, are sent to the PhasmaFOOD mobile application after establishing a Bluetooth / BLE connection.

In case the main electronic board has just started operating, the process running at the Communication state of operation may receive information about potential software updates. After the end-user has been informed on the existence of new updates, and has agreed to do a software update, the embedded board goes into the Update operational state.

iii) Update

During the Update state of operation, the embedded electronic board integrates the available software updates.

iv) Measurement

While the main electronic board operates at the Measurement state, the running process handles the collection of the sensory measurements and gathers all the output data of the sensing components. All the data are stored at the available on-board memory. Then, they are processed at the Preprocessing operational state or sent directly to the PhasmaFOOD mobile application depending on measurement mode and final configuration of the measurement process.

v) Preprocessing

The process, which handles the data preprocessing at this operational state, applies all the selected preprocessing algorithms to the data collected from the sensing components (e.g., image compression, noise filtering, data compression, data normalization, feature extraction). The resulting data are stored at the available on-board memory, the embedded board goes into the Communication state of operation and the related process handles the transmission of the preprocessed data to the PhasmaFOOD mobile application.

vi) Oscillations

The main electronic board can go into the Oscillations state of operation while the Measurements state is processed. During this state of operation, the sensing device is not stable enough and, thus, the acquisition of the sensory measurements cannot be processed. The level of mechanical and physical oscillations is considered too high. The end-user is notified that the collected sensory measurements cannot be considered as correct and are advised to reduce the level of oscillations and conduct a new measurement. The notification is pushed towards the mobile application and presented to the end-user as a pop up notification.

The sensing device must integrate a small character display in order that the end-user is notified in special cases regarding the battery level, the temperature conditions, or the mechanical and physical oscillations level. This display may be used for providing guidelines to the end-user of the sensing device, or for displaying some intermediate and / or final results as well.

A process, which is measuring the level of mechanical and physical oscillations, is constantly running.

vii) High Temperature

The main electronic board can go into the High Temperature state of operation from any of the Communication, Measurement, or Preprocessing states. The temperature of the sensing device is considered too high and the end-user gets a notification about high temperature.

A process, which is measuring the temperature of the sensing device, is constantly running. When the temperature returns to acceptable operational levels, the main electronic board returns to the previous state of operation.

viii) Overexposure

The main electronic board can go to the Overexposure state of operation while the Measurement state is in operation. The data from the sensing subsystem show that the light level is too high for one or more of the currently active sensing components. The end-user is notified that the collected sensory measurements cannot be considered as correct, specifying the sensing components related to the high lighting levels. The notification is pushed towards the mobile application and presented to the end-user as a pop-up notification. The notification is not sent when the lighting is configured automatically.

ix) Low Battery

The embedded board can go to the Low Battery state of operation from any of the Communication, Measurement, or Preprocessing states. During this operational state, the end-user is notified that the sensing device will soon run out of energy and the battery needs to be charged. If the end-user connects the sensing device to a power source in time, the battery charging starts and the main electronic board returns to the previous state of operation. Otherwise, the previous operational state is stored on a non-volatile mean of storage and the main electronic board goes into the Energy Save operational state.

x) Energy Save

The embedded board enters the Energy Save state in order to wait for battery charging. In case that no battery charging has been established and the sensing device is close to run out of energy, the information regarding interrupted Communication, Measurement, or Preprocessing state is deleted and the main electronic board goes into the Shut-down operational state. In case the battery has been charged to a specified and safe level of energy and the end-user presses the ON / OFF button of the sensing device, then the main electronic board returns to the Low Battery state of operation and resumes the interrupted Communication, Measurement, or Preprocessing state.

2.3.1.2 Triggered Events (Triggers)

A number of events can be triggered during the operation of the main electronic board. These events can be triggered by the end-user of the sensing device, or internally at the main electronic board when some specified thresholds are exceeded. Thus, we can define two major categories of triggered events (triggers). We have to note that there are two events that are triggered internally at the main electronic board, but only after a related command has been sent from the mobile device. However, we will include these two events at the internally triggered ones. The two categories of triggers are described in detail as following:

i) User triggered events

- UON (User pressed button to turn ON)
  This trigger is true when the end-user presses the ON / OFF button in order to turn the sensing device on, when it is in the Shut-down state, or to leave the Energy Save state and return to the Low Battery one in order to resume the interrupted Communication, Measurement, or Preprocessing state.

- UOF (User pressed button to turn OFF)
  This trigger is true when the end-user presses the ON / OFF button in order to turn the sensing device off, when it is in the Communication state.

ii) Internally triggered events

- SUP (Start UPdate)
  This trigger is true when there are software updates available for the main electronic board and the end-user has chosen to integrate them through their mobile application device. We have to note that this event is triggered after a related command is sent from the mobile device.

- UPC (UPdate Completed)

This trigger is true when the embedded board has completed the integration of software updates.

- RSD (Read Sensors Data)
  This trigger becomes true when the mobile device transmits configuration information for the sensing subunit based on the selected measurement mode. After the related command is received from the mobile device, the main electronic board initializes the sensing and lighting components and starts collecting the output sensory data. Moreover, this event can be triggered also when the main electronic subsystem operates at the Oscillations state and the level of oscillations has reached an acceptable value. Thus, this trigger can be considered as an internally triggered event as well.

- POR (Preprocessing Operations Required)
  This trigger is true when the collected sensory data needs to be preprocessed before the sensing device sends them to the mobile application.

- TSD (Transmit Sensory Data)
  This trigger is true when the sensory measurements are ready to be sent to the mobile device either with or without any preprocessing.

- LBD (Low Battery Detected)
  When the battery energy reaches a level that is considered to be low, this event is triggered.

- BCN (Battery Charging Needed)
  This trigger becomes true when the main electronic board is at the Low Battery state and, after a specified amount of time, the end-user has not connected a cable to start charging the battery of the sensing device.

- HTD (High Temperature Detected)
  This event is triggered when the temperature inside the enclosure of the sensing device reaches a level that is considered potentially dangerous for the sensing components. The temperature sensor is placed as close to the sensing subunit as possible.

- HOD (High level of Oscillations Detected)
  This trigger is true when the level of oscillations has reached an upper limit and, thus, the measurements from the sensing components cannot be safely considered as correct.

- OED (OverExposure Detected)

This trigger is true when the levels of one or more lighting sources have exceeded some specified upper limits and, thus, the measurements from the sensing components cannot be taken into consideration.

- GTS (Go To Shut-down)
  This trigger is true when the main electronic board goes from the Energy Save state to the Shut-down one because no battery charging has been established and the sensing device is close to run out of energy.

- RPP (Restore Previous Process)
  This trigger becomes true when the operation of the main electronic board returns to the process that was interrupted due to low battery or high temperature detection.

- RCN (ReConfiguration Needed)
  This event is triggered when higher than acceptable levels of lighting are detected during the measurements of the sensing components. In this case, the embedded board returns to the Communication state of operation and informs the end-user about the issue. Then, the PhasmaFOOD mobile application can suggest counter-measures.

2.3.2 Communication with sensing subsystem

2.3.2.1 Communication with CMOS camera and NIR spectrometer

The main electronic subsystem communicates with the CMOS camera and the NIR spectrometer using the USB protocol. The USB [49] is a cable bus that supports data exchange between a host and a wide range of simultaneously accessible peripherals. The attached peripherals share USB bandwidth through a host scheduled, token-based protocol. The bus allows peripherals to be attached, configured, used, and detached, while the host and other peripherals are in operation.

The USB connects USB devices with the USB host. The USB physical interconnect is a tiered star topology. A hub is at the center of each star. Each wire segment is a point-to-point connection between the host and a hub or function, or a hub connected to another hub or function. Due to timing constraints allowed for hub and cable propagation times, the maximum number of tiers allowed is seven (including the root tier) and, also, five non-root hubs maximum can be supported in a communication path between the host and any device. There is only one host in any USB system. The USB interface to the host computer system is referred to as the host controller. USB devices are either hubs, which provide additional attachment points to the USB, or functions, which provide capabilities to the system.

The main electronic board will act as the USB host and the USB hub component [28] integrated at it will act as a USB device. The USB hub device offers the capability of mounting two distinct USB host connectors on the main electronic board, each used for a connection to a USB device.

The driving boards of the CMOS camera and the NIR spectrometer will act as USB devices since they will integrate the appropriate USB device interfaces and connectors.

The mechanism of transferring data involves the host reading and writing to a set of memory locations located on the USB device. These memory locations are called endpoints. Endpoints are essentially in and out "baskets". The size of an endpoint (i.e., amount of data in an endpoint) can vary significantly between different devices. Device endpoints are found in numbered pairs. Each endpoint number has an IN and an OUT endpoint. OUT endpoints carry data coming out of the host, while IN endpoints contain data being sent to the host.

When the host wants to send a message to a device, the message is placed in an OUT endpoint on the device through the use of a WRITE transaction. The device's application code monitors the OUT endpoints to determine if any messages have been received from the host. After detecting the presence of a message from the host, the device will copy the message from the OUT endpoint. If a device's application wants to communicate with the host, a message is placed in an IN endpoint. The message will remain in the IN endpoint until the host issues a READ transaction. A READ transaction causes the contents of an IN endpoint to be sent to the host [50].

2.3.2.2 Communication with the UV-VIS spectrometer

The main electronic board will control the operation of both the UV-VIS spectrometer and the ADC component on the UV-VIS driving board inside the sensing subunit. The digital clock and control signals of the UV-VIS spectrometer will be handled through General Purpose Input Output (GPIO) pins of the microprocessor and the ADC will communicate with the main electronic board using the SPI protocol [51].

The SPI bus is a synchronous serial communication interface. The SPI modules communicate in full duplex mode based on a master-slave architecture, which supports the existence of a single master. The SPI module of the ADC will operate as slave, while the SPI module on the embedded board will operate as master.

The SPI bus specifies four logic signals as following:

- SCLK (Serial CLocK)
  The SCLK signal is the clock signal with respect to which the data are transferred on the SPI bus. It is an output of the master module and each slave module receives the SCLK signal as its clock input.

- MOSI (Master Output Slave Input)
  The MOSI signal is used for data transmission out of an SPI master module and data reception at a slave one.

- MISO (Master Input Slave Output)

The MISO signal is used for data transmission out of an SPI slave module and data reception at a master one.

- SS (Slave Select)
  When an SPI module operates as a master, in the independent slave configuration, one SS output signal from the master module drives a corresponding input signal at each slave module with which a data transfer may take place. When a specific slave module is selected to communicate with the master one, then the corresponding SS signal is driven low or high in order to establish a connection with the selected slave module. The SS signal is often driven low when the corresponding slave module is selected.

Four communication modes are available (MODE 0, 1, 2, 3) that define the SCLK edge on which the MOSI line toggles, the SCLK edge on which the master samples the MISO line and the SCLK signal steady level. Each mode is formally defined with a pair of parameters called clock polarity and clock phase. A master / slave pair must use the same set of parameters (SCLK frequency, clock polarity, and clock phase) for a communication to be possible. If multiple slaves are used that are fixed in different configurations, the master will have to reconfigure itself each time it needs to communicate with a different slave.

2.3.3 Communication with mobile device

The main electronic board will be able to establish a wireless communication with the mobile device. The Bluetooth protocol will be used for the communication between these two parts of the PhasmaFOOD system architecture. The Bluetooth wireless technology is a short-range communications system. Its key features are robustness, low power consumption, and low cost. There are two forms of Bluetooth wireless technology systems: Basic Rate (BR) and Low Energy (LE). Both systems include device discovery, connection establishment and connection mechanisms. The BR system includes optional Enhanced Data Rate (EDR), Alternate Media Access Control (MAC) and Physical (PHY) layer extensions. The BR system offers synchronous and asynchronous connections with data rates of 721.2 kbps for BR, 2.1 Mbps for EDR and high speed operation up to 54 Mbps with the 802.11 AMP. The LE system includes features designed to enable products that require lower current consumption, lower complexity and lower cost than BR / EDR [52], [53], [54].

The communication between the embedded and mobile devices should be achieved based on the BLE specification. The WL1835MOD [23] module is integrated at the main electronic subsystem for this purpose. More details on the Bluetooth / BLE communication between the main electronic board and the mobile device can be found in the Deliverable Report D2.1 [4] and Section 4.2 of the current Deliverable Report.

The main electronic board may be also able to communicate with the mobile device using the USB protocol. In this case, the embedded board will have the peripheral role called USB device that is attached to a USB host, the mobile (see Section 2.3.2.1).

2.3.4 Communication with cloud platform

The direct communication between the embedded sensing device and the PhasmaFOOD cloud platform is optional. It eliminates the PhasmaFOOD mobile application. More details on this communication between the main electronic board and the cloud platform can be found in Section 5.2 of the current Deliverable Report.

3 Mechanical design of sensing device (IPMS)

Fraunhofer IPMS develops the mechanical design of the mounting and housing aspects for the PhasmaFOOD detection system, taking as an input the sensing, lighting and electronical components detailed above. The mechanical design of the sensing sub-unit is directly based on the optics design presented in D2.2 [3]. The mechanical design of the sample interface is and will be based on tests carried out within WP3 and WP6, which is also where we see potential for continuing development later in the project. The mechanical design of the electronics housing is developed along with the layout of the main electronics board, the required external connectors and any other electronical features that partner WINGS plan to implement.

Please note that the actual mechanical design of the PhasmaFOOD detection system remains confidential and can be found in the Annex II of the current Deliverable Report D2.3.

3.1 Preliminary Design Considerations

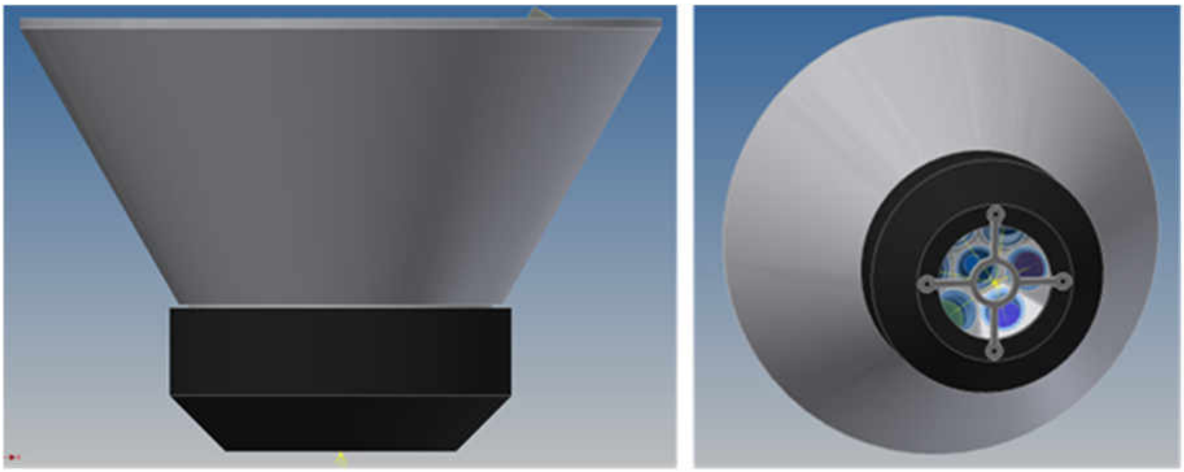

Figure 11-First design study of the PhasmaFOOD sensing sub-unit. Left: Side view. Right: view from below.

Figure 11 shows an impression of the first mechanical design study of the PhasmaFOOD sensing sub-unit. The design has now evolved to a manufacturable state, as shown in the Annex II of the current Deliverable Report. The above study, however, already illustrates the most important features of the mechanical design. In discussion with the entire consortium, priority was given to fulfilling the following criteria:

1) implementation of the optical design of D2.2 [3]
2) implementation of the electrical concept of D2.2 [3]
3) stable mounting of individual components
4) stable mounting of components relative to each other
5) inclusion of one or more sample interfaces
6) robustness

All of these aspects are considered in the detailed description of the actual mechanical design, which is provided in the Annex II of the current Deliverable Report. One further aspect that is always considered in mechanical design, in particular where optical components are involved, is manufacturability. In our case, this concerns both, the actual manufacture of the mechanical elements, methods and materials, as well as the process of assembling and aligning the system out of the multitude of components. In that respect, there exists a difference between the above study and the final first design. The geometrical shape of the study is comparably simple and can be manufactured on a CNC machine. The final design has a more complex interior shape for the benefit of an easier assembly but is limited to 3D print techniques such as selective laser sintering (SLS). Tests will be run in the subsequent work packages in order to verify the actual achievable tolerances and the suitability of this manufacturing method for the PhasmaFOOD system. In worst case, the study geometry can serve as a fall-back option. For the details of the mechanical design, please see the Annex II of the current Deliverable Report.

4 PhasmaFOOD mobile device and application

The PhasmaFOOD mobile application is the communication interface between the PhasmaFOOD device, which runs embedded software, and the PhasmaFOOD cloud platform, as well as the main interface for the end-users of the system. The PhasmaFOOD mobile application enables communication with the PhasmaFOOD sensing device and the end-user's smartphone/tablet over low energy Bluetooth interface. Through this interface, the mobile application transfers configuration parameters for the measurement process and receives preprocessed measurement data to be transferred to the cloud platform for further analysis. On the other side, the mobile application utilizes the Wi-Fi or 3G / 4G interface of the mobile device to connect with the cloud platform. This communication interface is used for transferring preprocessed measurement data to the cloud platform and receiving analysis results derived by the food analysis algorithms residing at the cloud platform level.

In addition to being the communication interface for transferring data, configuration parameters and analysis results, the PhasmaFOOD mobile application is the main interface towards the end-users of the PhasmaFOOD system. The mobile application provides a Graphical User Interface (GUI), which guides the end-users through the measurement process and helps them understand the obtained food analysis results. The PhasmaFOOD smart food analysis system will provide open and well documented APIs and mobile application development guides, which will enable 3rd party developers and system integrators to develop mobile applications specifically tailored for their needs and usage scenarios.

The PhasmaFOOD mobile application may perform additional processing on measurement data obtained from the PhasmaFOOD sensing device. This additional processing can provide further compression of the measurement data, feature selection or direct decision making based on the trained classification models. These machine learning models would be trained on the cloud platform and then downloaded to the mobile application for decision making on end-user measurement data. By performing data preprocessing via embedded software and, possibly, on the mobile application, we improve the communication efficiency by not transferring all measurements to the cloud platform, but only preprocessed and filtered data that are relevant for decision making. This also improves the performance and reactivity of the system. The level of potential performance and reactivity improvement will be assessed for the case that the mobile application hosts ML trained models for decision making based on the current measurement.

The PhasmaFOOD project will produce mobile applications for Android and iOS platforms. For the first software platform prototype, we will prepare only the Android version of the mobile application because of faster prototyping and easy distribution within the consortium. After the Android version of the application is validated, it will serve as the specification for the iOS version.

4.1 Mobile application architecture

The PhasmaFOOD mobile application has five main modules that perform specific tasks and enable the mobile application to be in the middle of the PhasmaFOOD data delivery and analysis chain. These modules include (see Figure 12):

a) Interface and API with the PhasmaFOOD smart scanning device. This module includes an API handler (data formatter and request builder) for the mobile application – embedded software communication channel and classes for working with the BLE interface of the mobile device. This module is responsible for performing scanning function, which will enable the mobile application to discover nearby smart scanners. Next, the mobile application is paired with the scanning device through the BLE interface and data can be exchanged.

b) Interface and API with the PhasmaFOOD cloud platform. This module includes an API handler for the mobile application – cloud platform communication channel and classes for working with the Wi-Fi and mobile network interfaces for accessing Internet and the cloud platform. This module utilizes a REpresentational State Transfer (REST) API for communication with the cloud platform.

c) Mobile agent. This module acts as internal bridge between the two APIs served by the mobile application. It provides a data buffer for enabling uninterrupted data stream and handles any notification services for the end-user and in-app processes (push notification services from the cloud platform based on the Google Cloud Messaging and ApplePush Notification services). Finally, this module enables the mobile application to properly utilize system resources of the mobile device (built in sensors, location services and clock).

d) Mobile application data analysis and preprocessing. This module is a collection of algorithms and trained ML models for performing preprocessing of measurement data (normalization, compression, feature selection) and classifying measurement data based on the trained model.

e) Graphical interface towards the end-user. The interface connects the end-user's actions with the main processes of the PhasmaFOOD system as a whole (from registration, over measurement configuration to result presentation).

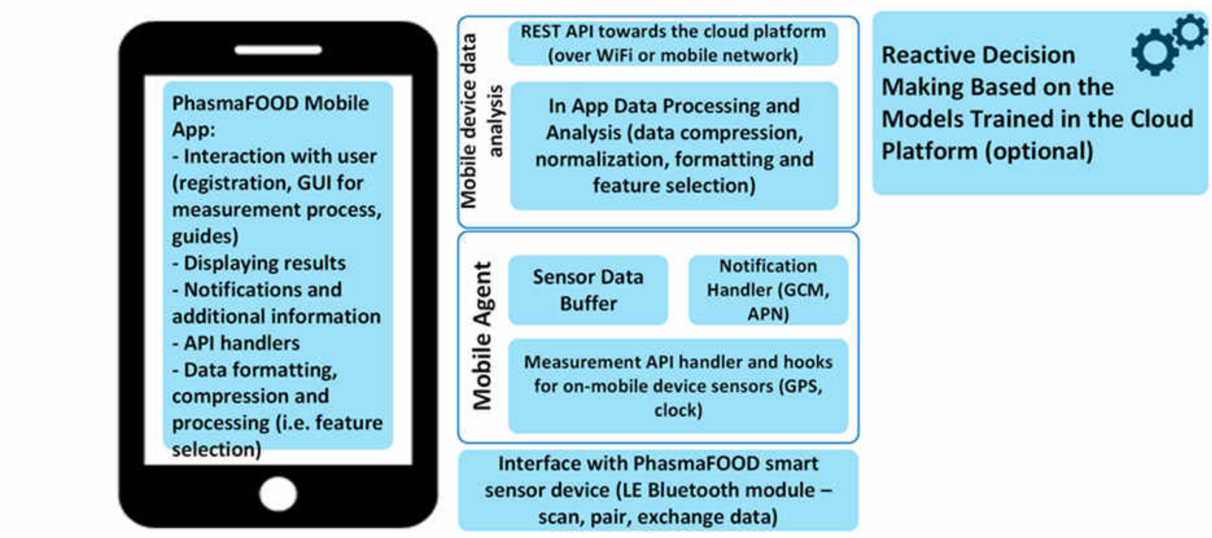

Figure 12 - High level block diagram of the PhasmaFOOD mobile application.

Figure 13 illustrates the Unified Modeling Language (UML) usage diagram for the PhasmaFOOD mobile application. Additionally, Figure 14 and Figure 15 present example mockups for the GUI and User eXperience (UX) provided by the PhasmaFOOD mobile application. Final mockups design is still in development within WP4.

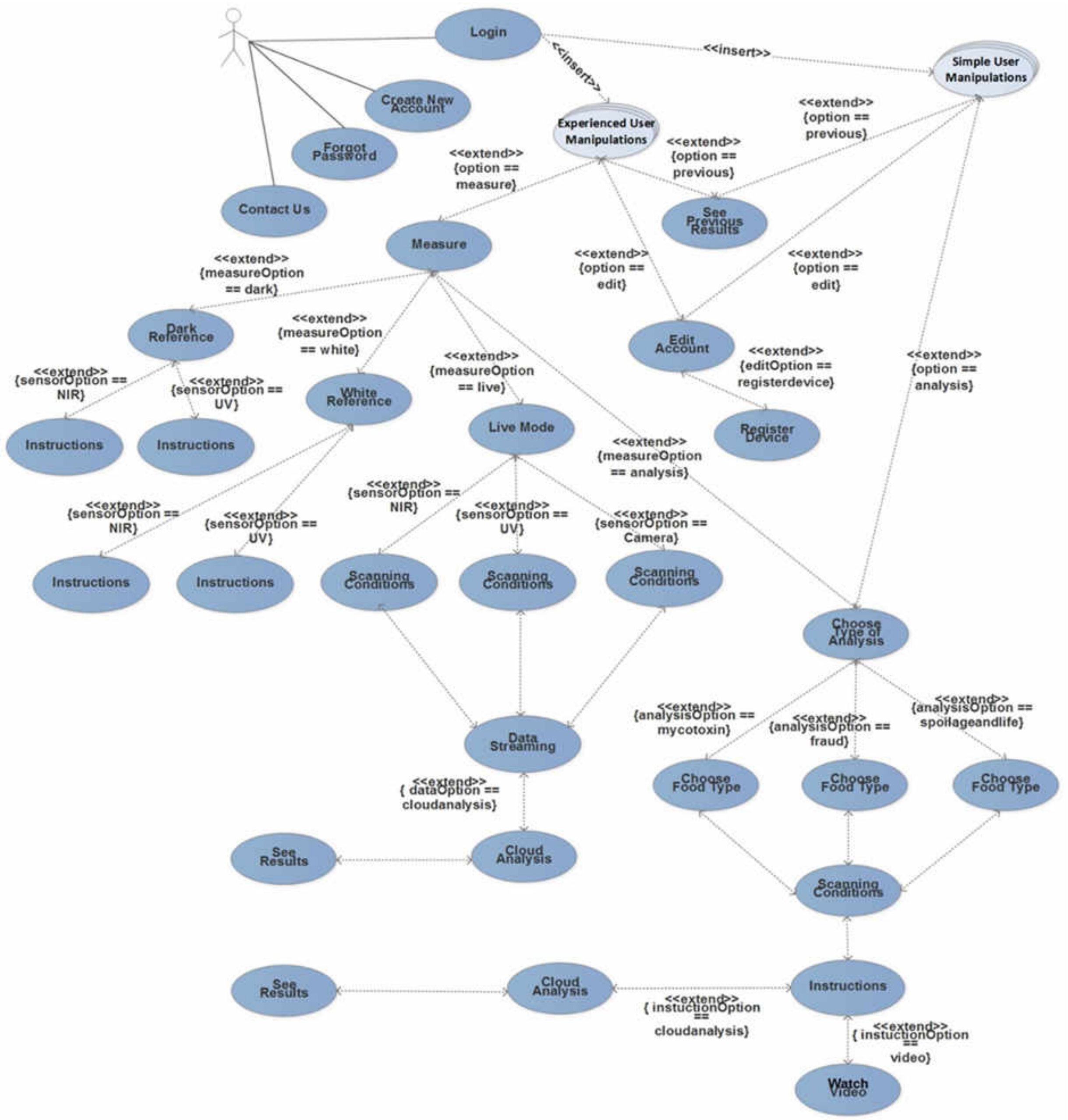

Figure 13 - UML state diagram of the mobile application software design.

When the user opens the mobile application, they may choose to login or create a new account / register to the service. If the user chooses to log in and provides correct credentials, a new screen appears depending on whether the user is identified as a standard user or an experienced one.

All users are presented with three options after successful login. They can edit the details of their account, see the results of previous analysis, or proceed with a new analysis and choose the measurement use case. The level of configurability of the measurement process differs between the two user types. Standard users will be guided through the measurement process based on standard measurement procedures and the measurements collected by standard users will not be included into the PhasmaFOOD training data sets at the cloud platform.

Under account management, the end-user can choose to register a new PhasmaFOOD sensing device to their account. If the user wants to open a new analysis case, a new screen appears on their mobile device and provides three different options based on the project use cases. Then, they must specify the type of food they are going to inspect from the provided list of food and beverages, which the PhasmaFOOD project has obtained data sets and trained decision making models for. Next, the user provides information specifying the scanning conditions. Finally, the user can choose to watch a guide on how to properly conduct measurements, or, if they are already familiar with the measurement process, they can start the process. After the cloud analysis has finished, the results appear on the mobile screen.

An experienced / professional end-user can choose to capture a new dark or white reference measurement for the sample at hand. They will also need to specify the spectrometer, which to include the reference for. When the experienced user chooses the live measurement mode (troubleshooting, alignment and test mode), they select one sensing component and set the configuration parameters (e.g., light level, exposure time). Data acquisition starts, and the sensor data are transferred as a stream to the mobile display. The user can choose whether to send the measurement data to the cloud platform for further analysis and see the results of the analysis on their screen or stay at the screen with the streaming data. All these additional configuration steps ensure that the collected measurements are of sufficient quality, so that the measurement data can be included into the PhasmaFOOD training sets. System administrator appoints experienced users (i.e., project members) or responds to requests to become experienced / professional user.

Figure 14 - Mobile application GUI and UX – Registration, login, profile editing and device pairing processes.

Figure 15 - Mobile application GUI and UX – Example of the measurement process.

More details on the PhasmaFOOD mobile application building blocks and their roles can be found in the Deliverable Report D2.1 [4].

4.2 API handlers for communication with sensing device

The communication channel between the embedded software running on the PhasmaFOOD sensing device and the PhasmaFOOD mobile application running on the end-user's mobile device is established over Bluetooth interfaces. Details about physical and logical connection establishment can be found in Section 2 of the Deliverable Report [4]. Figure 16 shows the sequences in data and command exchange between the mobile application and the embedded software on the PhasmaFOOD scanner. After the connection is established and endpoints are authorized, the food analysis sequence can start. It comprises directives for transferring measurement configuration commands compiled based on the end-user's selections through the mobile application interface for a specific use case and food type. After the configured measurement process is finished on the embedded device, the collected data are preprocessed and sent to the mobile application. Over the established communication channel, the embedded software reports status of the embedded system and triggers alarms when a certain operational condition is met and requires corrective action (i.e., low battery, high oscillation, or high temperature). After the mobile application receives the analysis results and decisions, it transfers the data to the embedded software to be presented on the built-in display. Another stage in information exchange through this API is the embedded software update, which is transferred from the cloud platform to the sensing device through the mobile application.

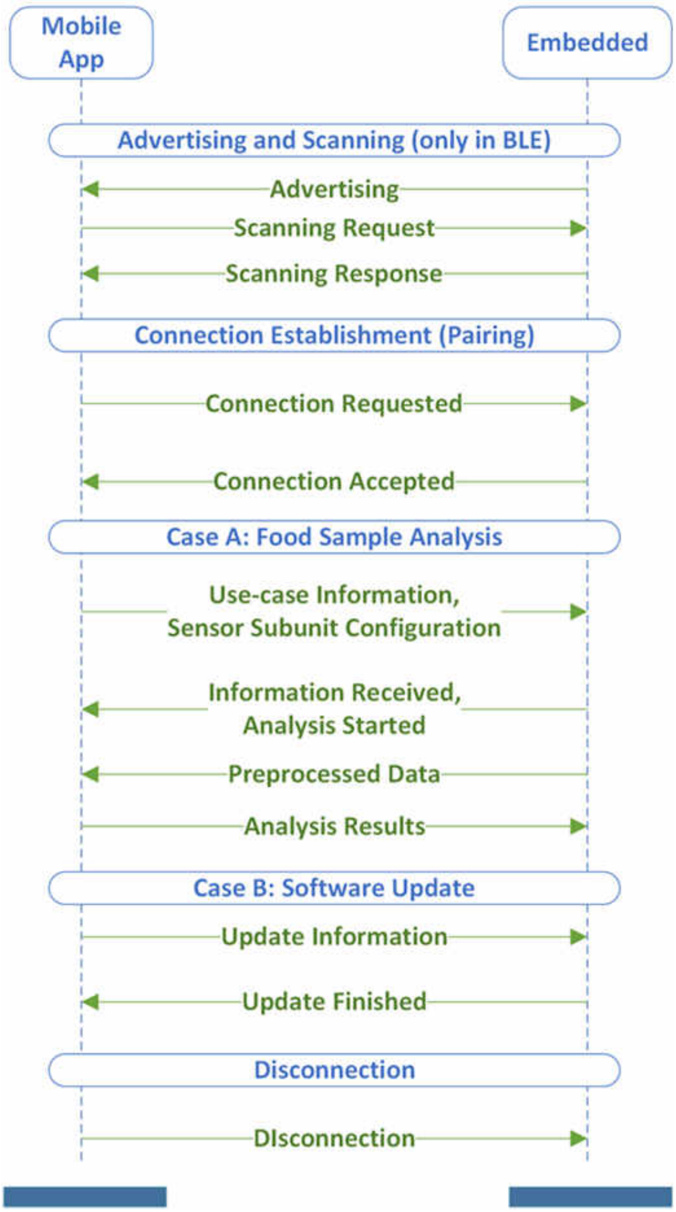

Figure 16 - UML sequence diagram for API between the embedded software and the PhasmaFOOD mobile app.

Sensory data will be transferred in batches once the embedded system has collected the required spectral data and camera image (depending on use case and scenario) for the sample. Figure 17 presents a general data model for storing at the cloud database and exchanging measurement data between the PhasmaFOOD software platform layers.

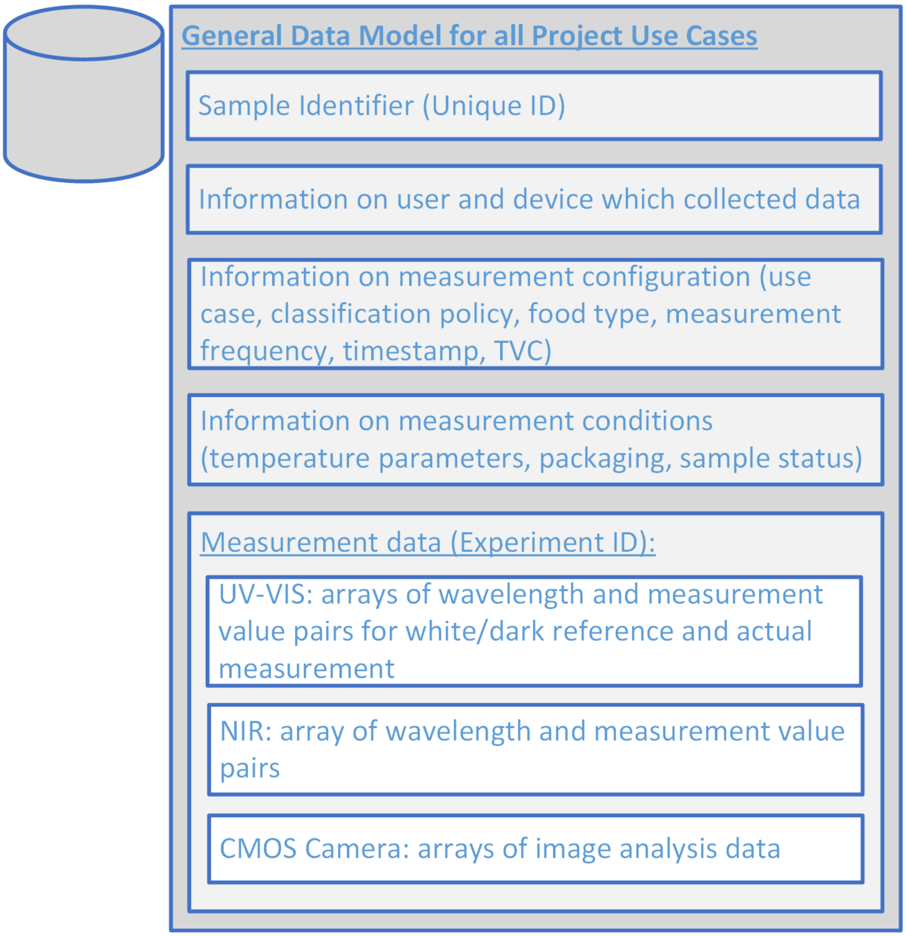

Figure 17 - General data model for the PhasmaFOOD measurements.

In addition to this measurement data model, the following information is exchanged through the mobile application - embedded software API:

- Result reporting:
  - Transferring analysis result code used for displaying result on the built-in display
- Device status data (to be displayed on status page of registered devices, or for triggering notifications for end-users):
  - Device battery status
  - Device temperature
  - High oscillations
  - Memory and processing resource usage during calculations
  - Firmware version

4.3 API handlers for communication with cloud platform

A REST-full API between the PhasmaFOOD mobile application and the cloud platform is designed by the project. Figure 18 provides the sequence diagram for this API. The API provides directives for user registration and authorization. Also, it provides directives, which enable users to add and authorize PhasmaFOOD devices associated with the mobile application instance / user profile. The profile management stage provides messages to be exchanged regarding user profile information, analysis history and notification about available firmware updates for sensing devices. The food sample analysis stage integrates messages and commands for measurement configuration, transfers preprocessed measurement data (processed on embedded software and, optionally, on the mobile application), adds location data to processed measurements. In the opposite direction, the cloud platform provides the mobile application with analysis results, and notifications on analysis status. This API also enables downloading of a trained ML model for decision making from the cloud platform onto the PhasmaFOOD mobile application instance.

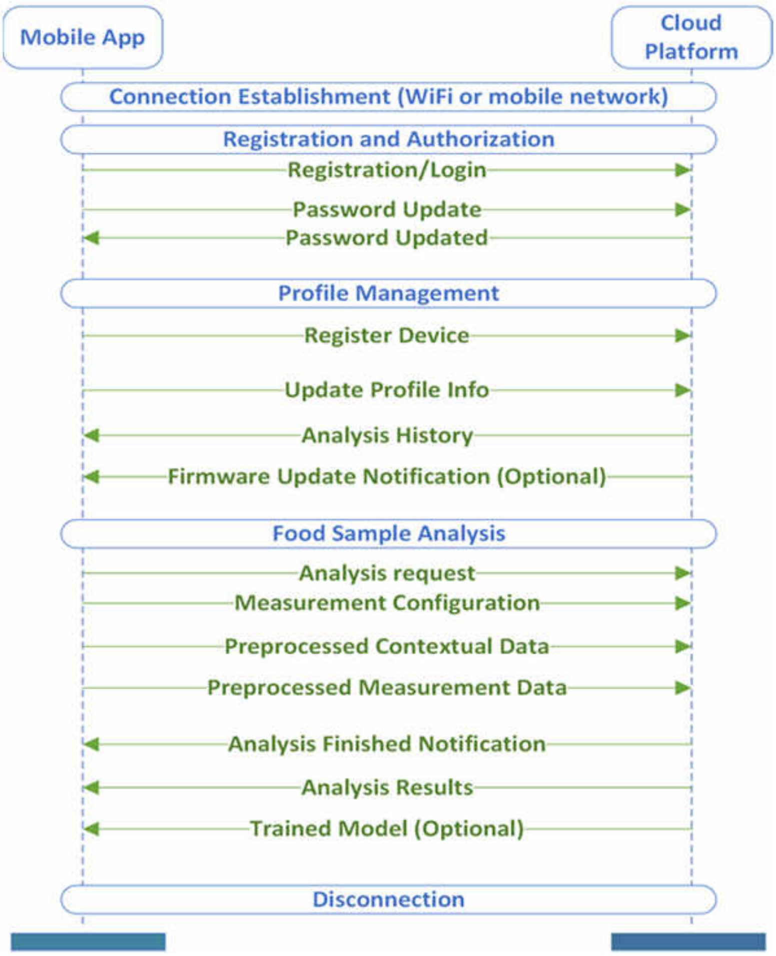

Figure 18 - UML sequence diagram of the mobile app - cloud platform API.

The REST API will employ JavaScript Object Notation (JSON) data model for exchanging information between the mobile application and the cloud platform. The data model for exchanging measurement data is the same as the one depicted in Figure 17. Next to that, the mobile application – cloud platform API will enable exchange of the following information:

- User registration:
    - Email and password
    - Authorization level
    - Authentication token
- Profile management:
    - Profile information
    - History of previous analysis results
    - Password updates
    - Latest firmware version available on the cloud
- Push notification indicating that the analysis has started and finished:
    - Push notifications from the cloud towards the mobile application will be performed with Google Cloud Messaging (GCM) and Apple Push Notification (APN) services.
- Analysis result:
    - Result of the decision
    - Displaying preference
    - Regulatory information to be displayed to the end-user

5 PhasmaFOOD cloud platform

The PhasmaFOOD cloud platform is the focal point of all sensory and contextual data coming from the portable sensing device, the mobile app and, if necessary, 3rd party data sources. The cloud platform is where in-depth analysis of the collected data is performed. The scalability and resource abundancy of a cloud platform ensure that all measurements will be processed in timely manner providing the end-users with near real-time food analysis results.

The platform hosts a data warehouse for all sensory and contextual data sets necessary for performing food analysis and deriving results. From this data warehouse, data marts are derived for training different ML / DA models for realization of project use cases. Decision making algorithms (based on the trained ML models) are hosted on the cloud platform as well. Reactive (based on end-user measurements) and proactive (strategic and based on data collected over time) decision making is performed based on the results of data analysis. The cloud platform layer provides scalability and resource abundance necessary for data warehousing, in-depth analysis of collected data and ML model training.

The cloud platform also provides the best opportunity for building administration and system management dashboards during the project development and for a future deployed system.

5.1 Cloud platform architecture

The PhasmaFOOD cloud platform hosts all decision making procedures, data analysis algorithms and the database containing datasets for all project use cases and their scenarios. The platform contains six main building blocks (see Figure 19):

a) API handler modules. These API handlers enable communication with the PhasmaFOOD mobile application and the scanning device. They also enable integration with 3rd party sources of relevant information (i.e., regulatory services) and enable 3rd party developers to develop their own applications based on the PhasmaFOOD system.

b) Cloud database module. This is the focal point for all measurements and contextual data collected by the PhasmaFOOD scanning device and mobile application.

c) Cloud based data analysis framework. This is a collection of data analysis and processing algorithms with the mechanism for chaining proper algorithms based on the use case and scenario configured for the measurement process. Data analysis includes procedures for data formatting and preprocessing (normalization and feature selection) as well as procedure for training ML models to be used for classification. Trained ML models are used for reactive decision making – classification of the measurement data provided by the end-user performing the measurement with the PhasmaFOOD sensing device.

d) Proactive decision making framework. This module includes ML algorithms and models for in-depth analysis of collected sensory and contextual data across many PhasmaFOOD sensing devices / users. The goal is to provide end-users with recommendations on how to proceed with the obtained results and information on patterns in analyzed data.

e) System authentication and authorization processes. These modules are responsible for registering users and managing their accounts, differentiating between standard and professional usage and registering scanning devices.

f) Web dashboard. This module provides similar functionalities as the mobile application, but with more information and configuration options. It will provide more detailed insight into collected measurement data and analysis results. It will also enable service administrators to manage the data sets, authorized devices and end-users.

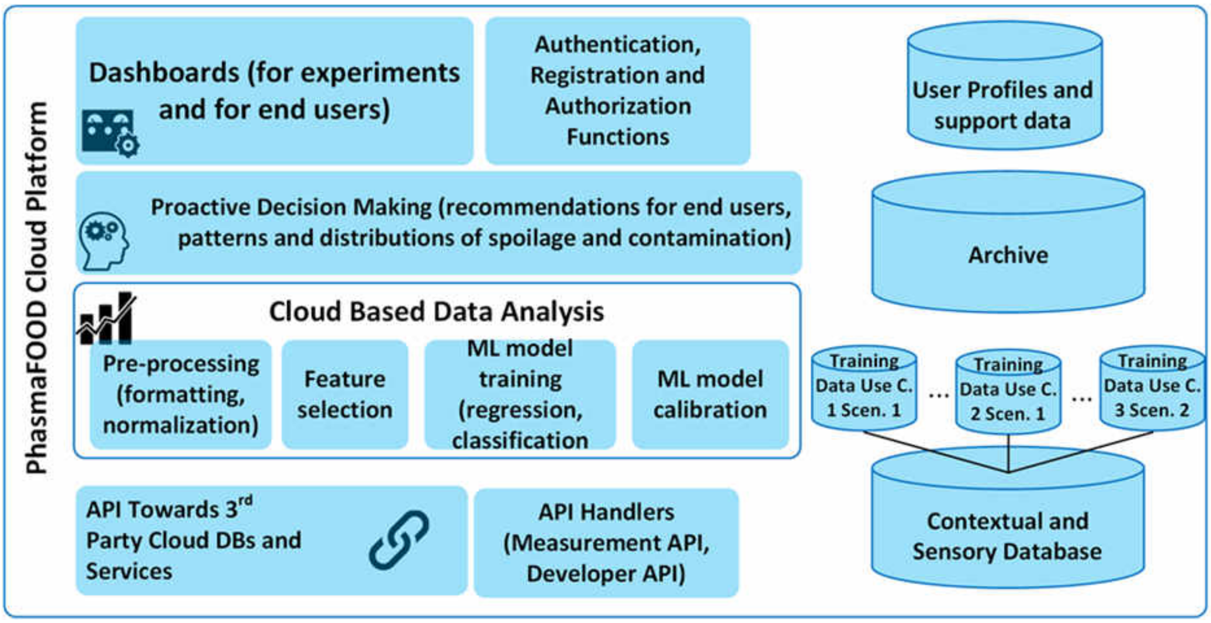

Figure 19 - High level block diagram of the PhasmaFOOD cloud platform.

The PhasmaFOOD cloud platform hosts the PhasmaFOOD data warehouse, which stores all collected sensory measurements and contextual data coming from sensing devices, mobile application and 3rd party services such as regulatory databases. From this main database, the PhasmaFOOD cloud platform procedures derive data sets used for training ML models for decision making required by each project use case and scenario.

Figure 20 shows the high-level structure of the PhasmaFOOD cloud database. The database comprises the following entities:

- Data warehouse. This is the focal point for all measurement and contextual data. It stores all collected measurements and analysis results. From here the cloud platform procedures build use case specific training data sets, identify data fusion opportunities and provide data for offline analysis guiding proactive decision making.

- Data archive. It stores analysis results and history of conducted measurements. It is used for offline data analysis and safe keeping the data warehouse state in case of data corruption.

- Training data sets. These have derived from the data warehouse for each use case and scenario that require specific data fusion and ML model training procedure. It is the working database for training ML models and making reactive decisions based on the current measurement provided by the end-user.

- Trained ML models. This database stores trained ML models in their vector form so that they can be easily employed by software behind decision making processes.

- Proactive analysis results. These are stored derived patterns and distributions based on offline data analysis and strategic, policy oriented decision making.

- Regulatory data set. It contains information from regulatory bodies guiding decision making processes and measurement classification.

- Users' database. It stores user related data.

- Device database. It stores data related to PhasmaFOOD devices.

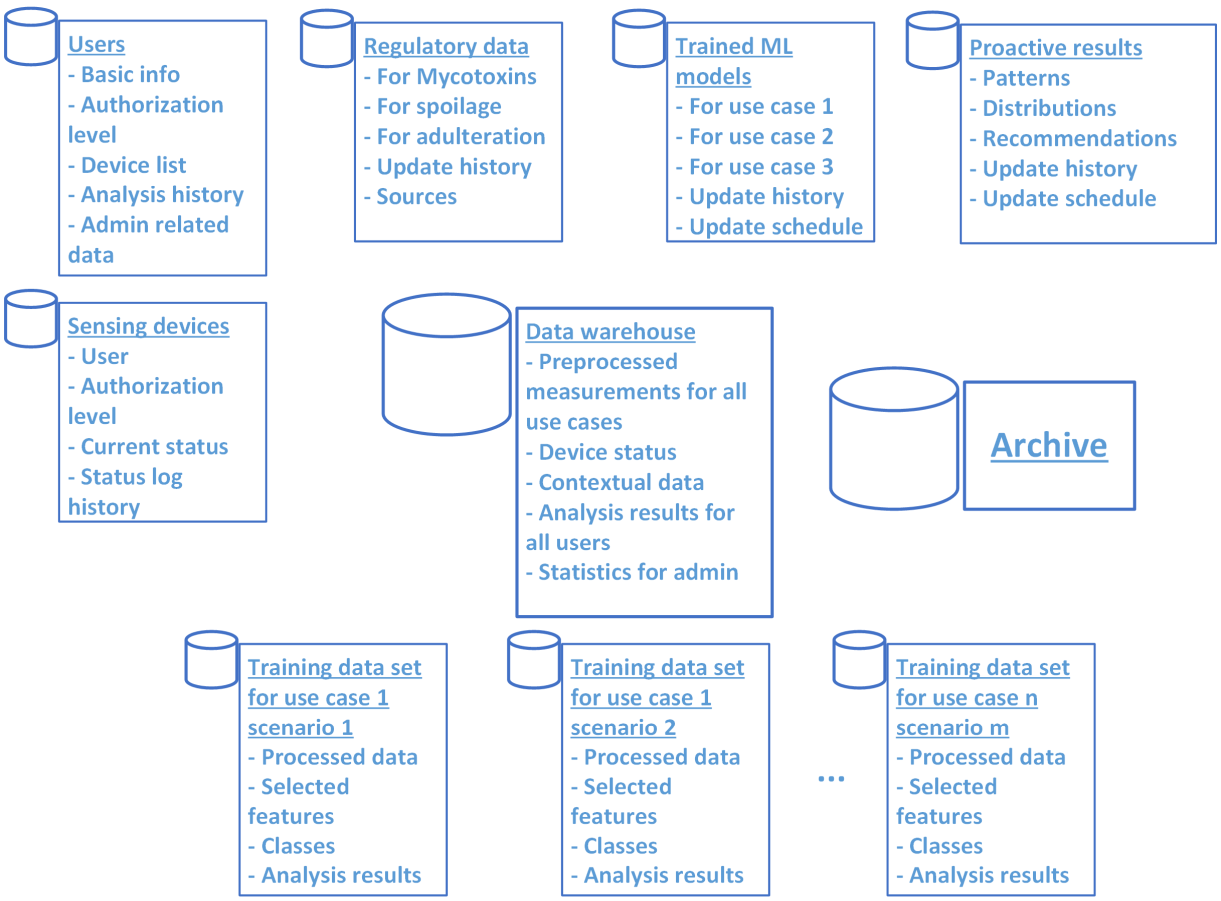

Figure 20 - PhasmaFOOD cloud database.

The PhasmaFOOD cloud platform provides reactive and proactive decision making based on collected data sets, provided measurements from end-users and system defined triggers. These algorithms are the basis for realization of project use cases, system management and strategic planning of monitored supply and production chains. Decision making mechanisms will be implemented as collections of software procedures and algorithms that take as inputs trained ML models, the current measurement/trigger, which to conduct analysis on, and employ rule engine to execute all the steps leading to the final decision whether it is reactive decision or strategic/proactive decision. Specification of the proactive and reactive decision making and accompanying block diagrams can be found in the Deliverable Report D2.1 [4].

The PhasmaFOOD cloud platform will enable integration of 3rd party APIs, which may provide complementary data and information to the data sets collected for execution of project use cases. During the course of the project, we will integrate relevant regulatory data sets for project use cases. This will put conducted analysis and measurements into regulatory context (i.e., allowed mycotoxin level in certain food types). Identified 3rd party sources of information are presented in the Deliverable Report D2.1 [4].

Another role of the PhasmaFOOD cloud platform is to ease integration of the PhasmaFOOD solution with 3rd party services that will be built on top of the basis provided by the project. The PhasmaFOOD data sets, data analysis and decision making procedures will be accessible through REST APIs (which will be either open or based on partner agreement and special permissions) with interactive documentation featured on the project website and wiki page. The interactive REST API documentation will allow 3rd party developers to test APIs and query data sets without the need for implementation of API handlers on their software or downloading data sets. This will help them to quickly reach a conclusion on whether the services provided by the PhasmaFOOD platform are suitable for their applications.

More details on the PhasmaFOOD cloud platform building blocks and their roles can be found in the Deliverable Report D2.1 [4].

5.2 API handlers for communication with sensing device

This is an optional API that will be considered for implementation during the course of the project. This API enables direct communication between the embedded sensing device and the PhasmaFOOD cloud platform. It eliminates the PhasmaFOOD mobile application as intermediary in data analysis chain and data / result transfer. Figure 21 provides the sequence diagram for this API. The communication technology that will be considered for implementation of this API, is REST over Wi-Fi. The main interface towards the end-user would be realized through a web dashboard (configuration of a measurement, displaying results and providing notifications).

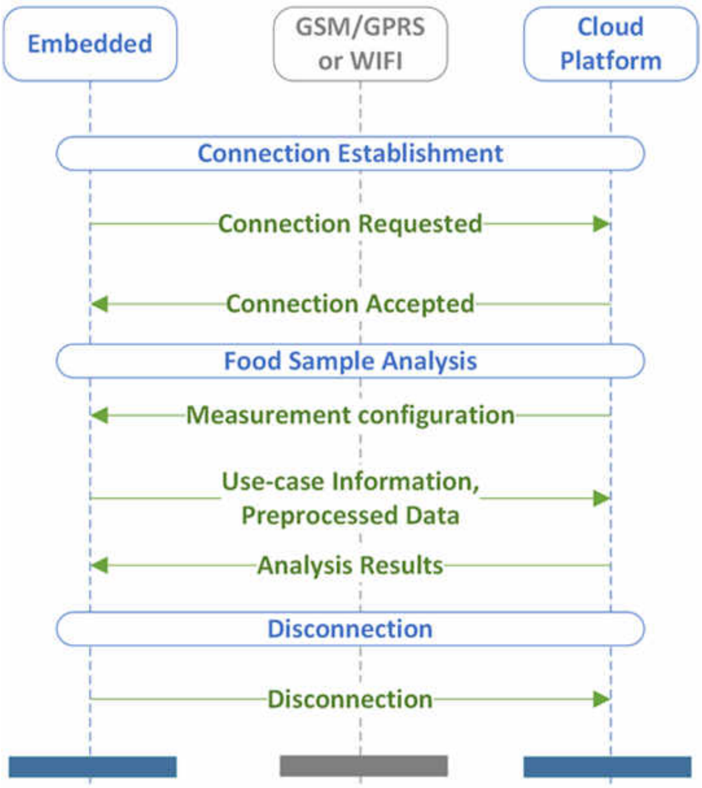

Figure 21 - UML sequence diagram for API between embedded software and the cloud platform.

5.3 API handlers for communication with mobile device

The API specification is provided in Section 4.3. On the cloud side of the API channel, the API handlers will be implemented in the software framework selected for realization of the cloud platform. On this side of the API, the API handler receives data analysis queries containing measurement data and configuration parameters necessary for invoking a suitable data analysis mechanism. It also pushes notifications (through GCM and APN services) containing analysis results and other messages for the end-users (i.e., firmware update ready, calibrated decision making model ready, proactive recommendations).

Figure 22 shows the complete API communication chain enabling exchange of commands and data between the embedded software, the PhasmaFOOD mobile application and the cloud platform.

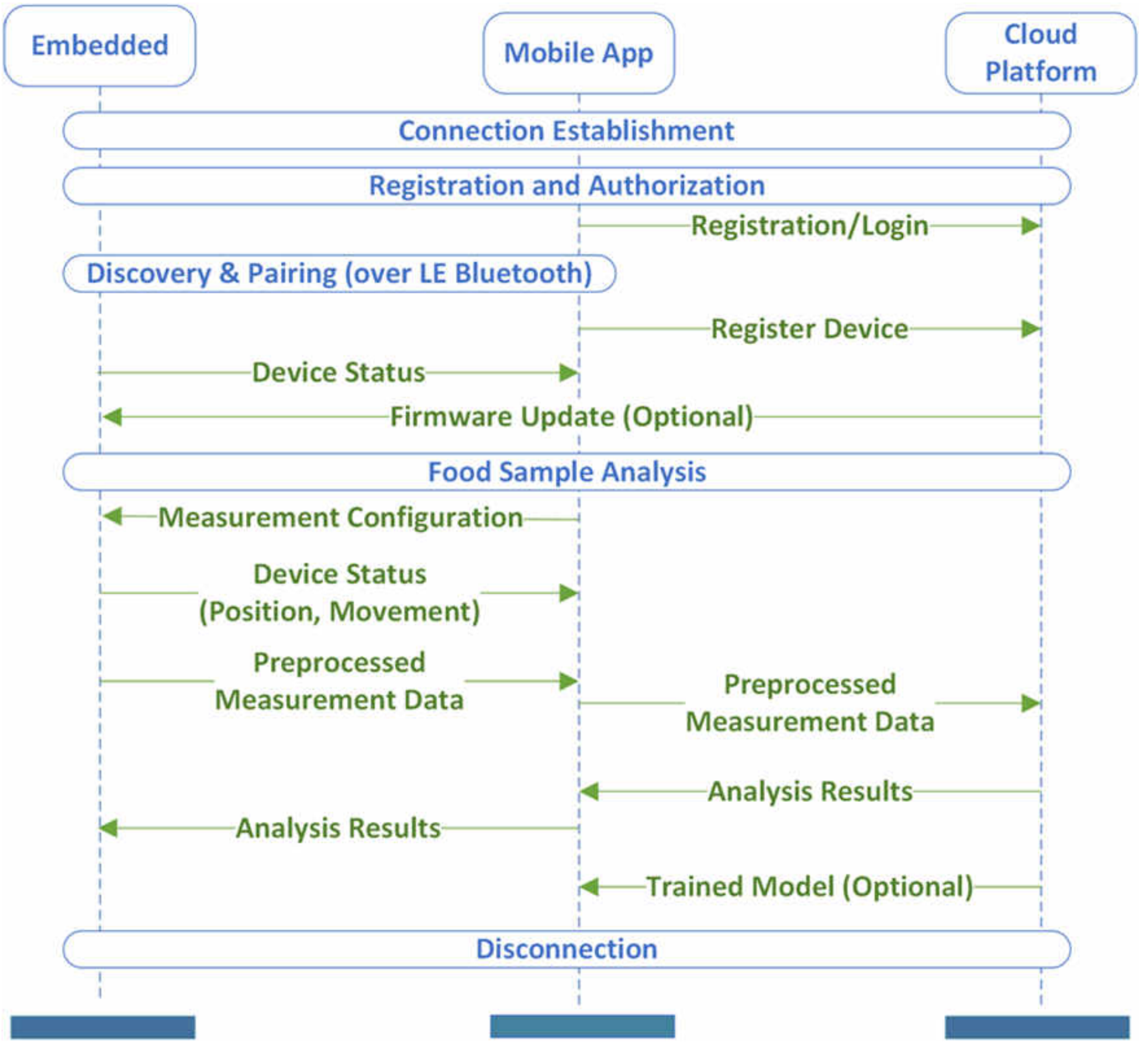

Figure 22 - UML sequence diagram for the complete API chain from the embedded software through the mobile app to the cloud platform.

6 Conclusion and next steps

The current Deliverable Report presents the design of each of the parts that the PhasmaFOOD system architecture comprises. The design of the PhasmaFOOD sensing device, both from the hardware and the software aspects, is presented, integrating information from the Deliverable Reports 2.1 [4] and 2.2 [3]. The concept of the mechanical enclosure for the sensing device is described as well. Communication details between any two hardware and / or software parts in the PhasmaFOOD system architecture can be found in the current Deliverable Report in order to show the seamless data flow from the sensing components to the cloud platform. All the necessary APIs for the connection between the sensing device, the mobile one and the cloud platform are illustrated, while the details for the design and development of the mobile and cloud software complement the description of the PhasmaFOOD smart system design.

Regarding the next steps in the PhasmaFOOD project, the design of the overall PhasmaFOOD sensing device should be the main source for the layout design and subsequent manufacturing of the main electronic board (Task 5.1) and complement the Deliverable Report 2.2 [3] for the integration of the sensing and lighting components of the sensing subsystem (Task 5.2). Task 5.3 should consider the embedded software specifications of the current Deliverable Report in order to develop the embedded software that will be hosted by the manufactured main electronic board. Tasks 4.1 and 4.2 can be supported by the insight provided in the current Deliverable Report for the mobile application and the cloud platform using the more enhanced information provided in the Deliverable Report 2.1 [4] in parallel. Finally, the manufacture of the mechanical components will be carried out within WP6. Here, manufacturing and assembly tests will be run prior to the final manufacture and assembly of the PhasmaFOOD sensing system and its launch in month 18.

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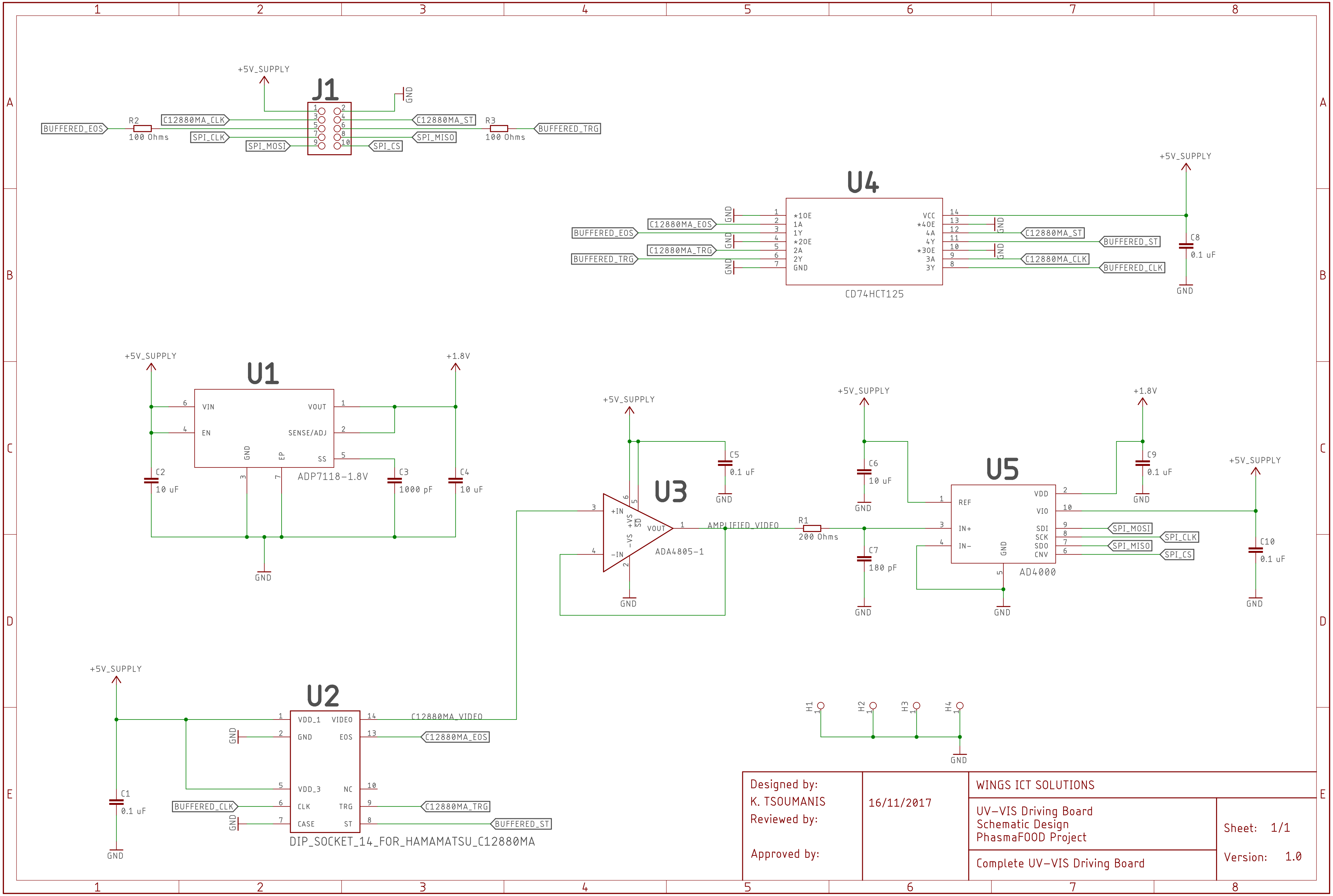
8 Annex I

8.1 Schematic designs – UV-VIS driving board and main electronic board

In this annex, we provide in full detail the schematic designs, which describe the driving board of the UV-VIS spectrometer inside the sensing subunit and the main electronic board of the PhasmaFOOD sensing device. All these schematic designs were developed using the Autodesk Eagle PCB design tool [14]. More specifically, this annex includes the schematic design of the board, which drives the UV-VIS spectrometer that resides inside the sensing subunit of the PhasmaFOOD sensing device (one sheet, see Section 2.1.1.2), and the complete schematic design for the main electronic board, which is essential for the operation and control of the sensing device (ten sheets, see Section 2.2). The latter includes a first sheet (sheet 1 of the main electronic board's schematic design), which guides the readers through the following sheets, and all the components and connections for processing and memory storage (sheets 3, 4, 5 and 6 of the main electronic board's schematic design, see Section 2.2.2), wireless communication (sheet 7 of the main electronic board's schematic design, see Section 2.2.3.1), wired communication and expansion (sheets 8 and 10 of the main electronic board's schematic design, see Section 2.2.3.2), user interface and oscillations / temperature control (sheet 9 of the main electronic board's schematic design, see Section 2.2.4), and power management (sheet 2 of the main electronic board's schematic design, see Section 2.2.5) that take place on the main electronic board.


J1
+5V_SUPPLY
GND
BUFFERED_EOS
R2
100 Ohms
C12880MA_CLK
SPI_CLK
SPI_MOSI
C12880MA_ST
SPI_MISO
SPI_CS
R3
100 Ohms
BUFFERED_TRG
U4
CD74HCT125
*1OE
1A
1Y
*2OE
2A
2Y
GND
VCC
*4OE
4A
4Y
*3OE
3A
3Y
C12880MA_EOS
C12880MA_TRG
BUFFERED_ST
C12880MA_CLK
BUFFERED_CLK
C8
0.1 uF
U1
ADP7118-1.8V
VIN
EN
VOUT
SENSE/ADJ
SS
EP
+1.8V
C2
10 uF
C3
1000 pF
C4
10 uF
U3
ADA4805-1
+IN
-IN
+VS
-VS
SD
VOUT
C5
0.1 uF
AMPLIFIED_VIDEO
R1
200 Ohms
C6
10 uF
C7
180 pF
U5
AD4000
REF
IN+
IN-
VDD
VIO
SDI
SCK
SDO
CNV
C9
0.1 uF
C10
0.1 uF
U2
DIP_SOCKET_14_FOR_HAMAMATSU_C12880MA
VDD_1
GND
VDD_3
CLK
CASE
VIDEO
EOS
NC
TRG
ST
C12880MA_VIDEO
C1
0.1 uF
H1
H2
H3
H4
Designed by:
K. TSOUMANIS
Reviewed by:
Approved by:
16/11/2017
WINGS ICT SOLUTIONS
UV-VIS Driving Board
Schematic Design
PhasmaFOOD Project
Complete UV-VIS Driving Board
Sheet: 1/1
Version: 1.0

Sheet No. 1 : Guide for the schematic

Sheet No. 2 : Power Management
PMIC, 5V Buck–Boost Converter, 3V3 Buck–Boost Converter, 1V8 Buck–Boost Converter, 1V1 LDO

Sheet No. 3 : Processor 1 of 3, Boot Configuration

Sheet No. 4 : Processor 2 of 3

Sheet No. 5 : Processor 3 of 3, Voltages and Grounds of the Processor

Sheet No. 6 : Memory Components (DDR2, EEPROM, microSD and eMMC)

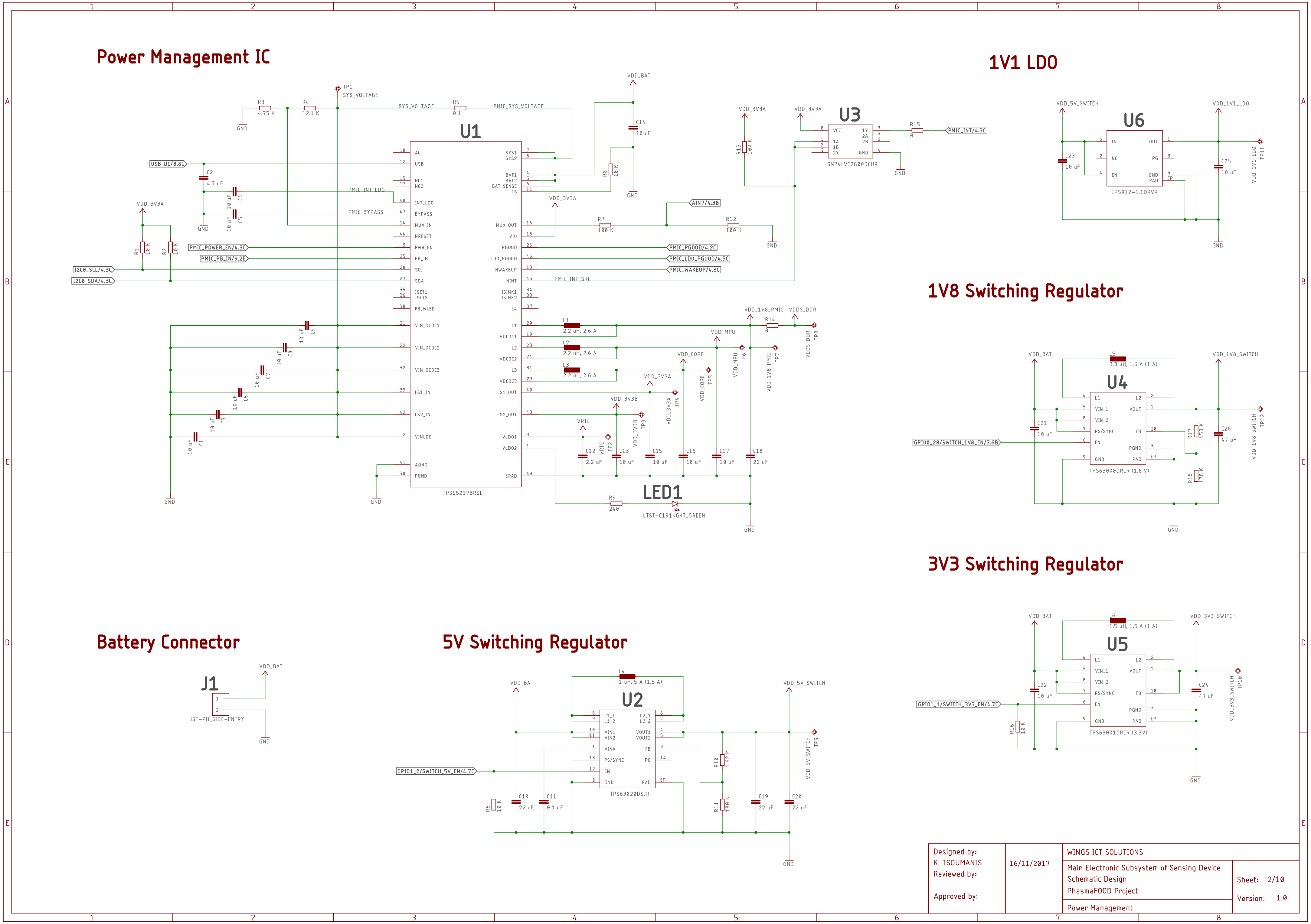
Sheet No. 7 : Wireless Communication (WiFi / BLE and Voltage level shifters)

Sheet No. 8 : USB Subsystem
Hub to 2 Host connectors with ESD protection and current limitation, MicroUSB connector

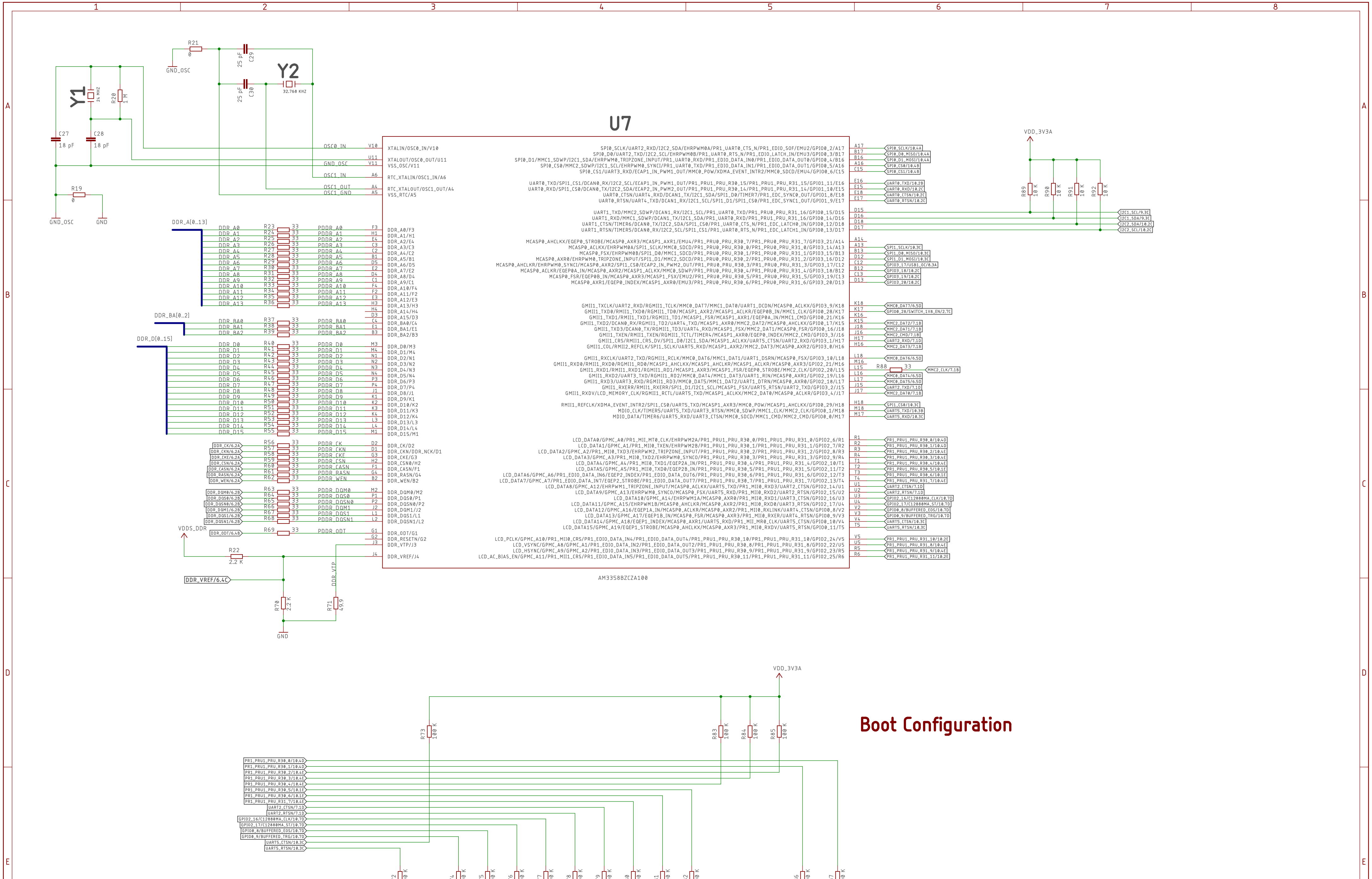
Sheet No. 9 : Sensors, On–board LEDs and Buttons

Sheet No. 10 : Expansion sockets, External LEDs driver

Designed by: K. TSOUMANIS	16/11/2017	WINGS ICT SOLUTIONS	
Reviewed by:		Main Electronic Subsystem of Sensing Device Schematic Design PhasmaFOOD Project	Sheet: 1/10
Approved by:		Guide for the schematic	Version: 1.0



Designed by: K. TSOUMANIS Reviewed by: Approved by:	16/11/2017	WINGS ICT SOLUTIONS	
		Main Electronic Subsystem of Sensing Device Schematic Design PhasmaFOOD Project	Sheet: 2/10
		Power Management	Version: 1.0



Designed by:
K. TSOUMANIS
Reviewed by:

Approved by:

16/11/2017

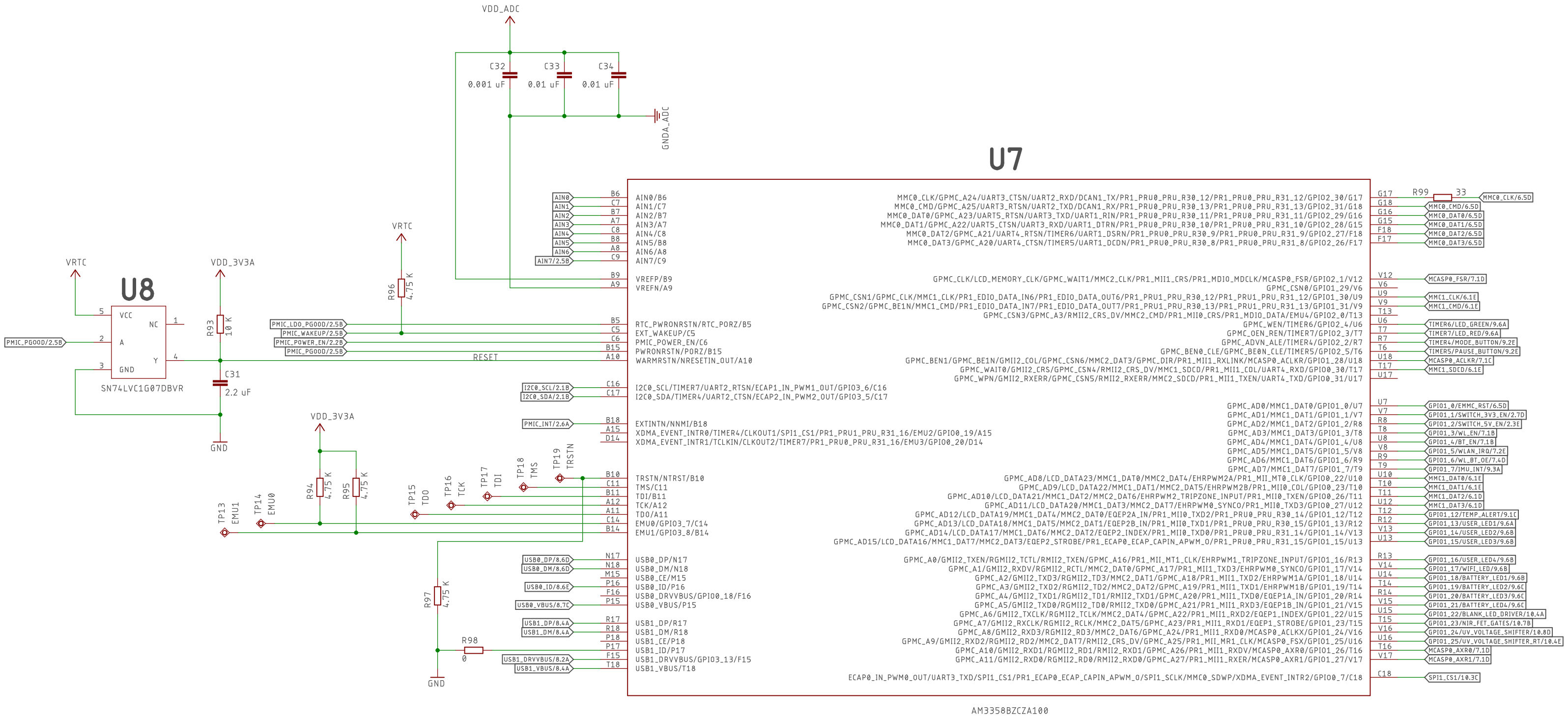
WINGS ICT SOLUTIONS

Main Electronic Subsystem of Sensing Device
Schematic Design
PhasmaFOOD Project

Processor Part 1 of 3, Boot

Sheet: 3/10

Version: 1.0



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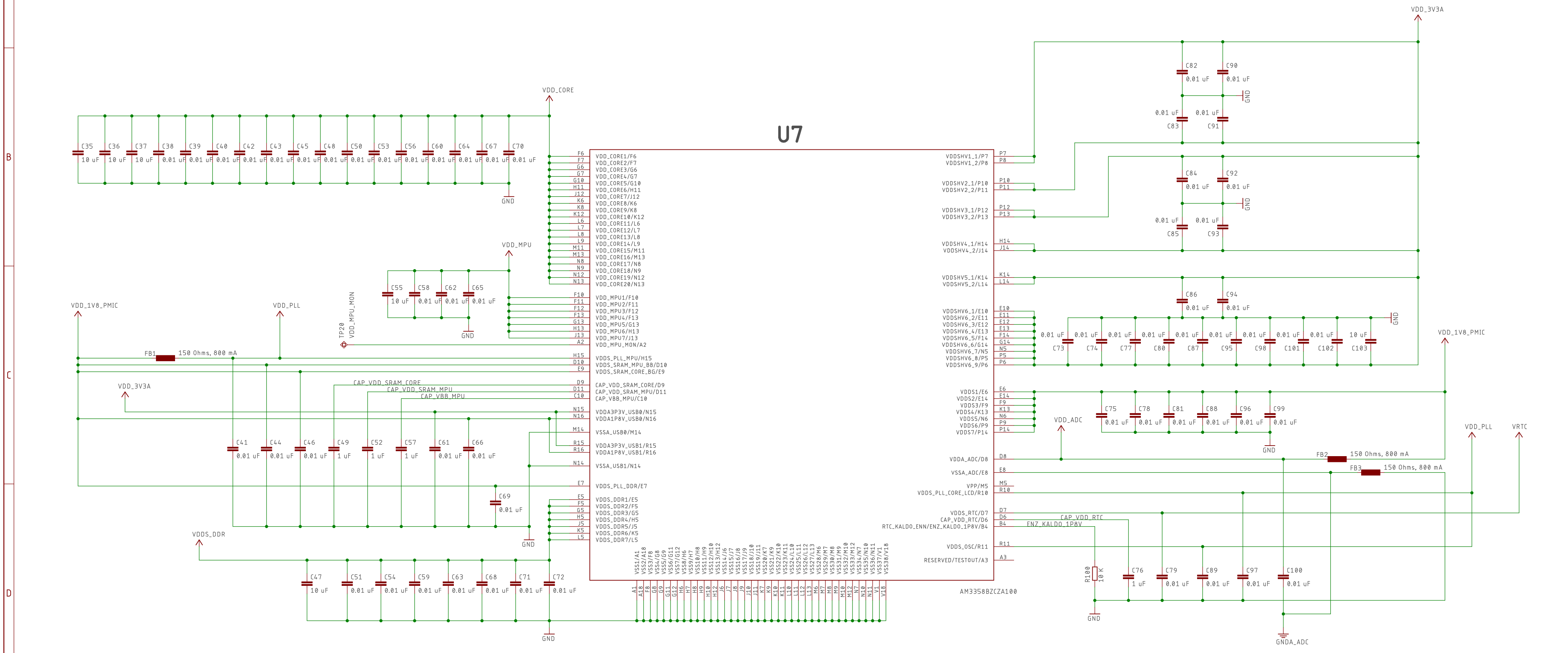
Approved by:		Processor Part 2 of 3	Version: 1.0



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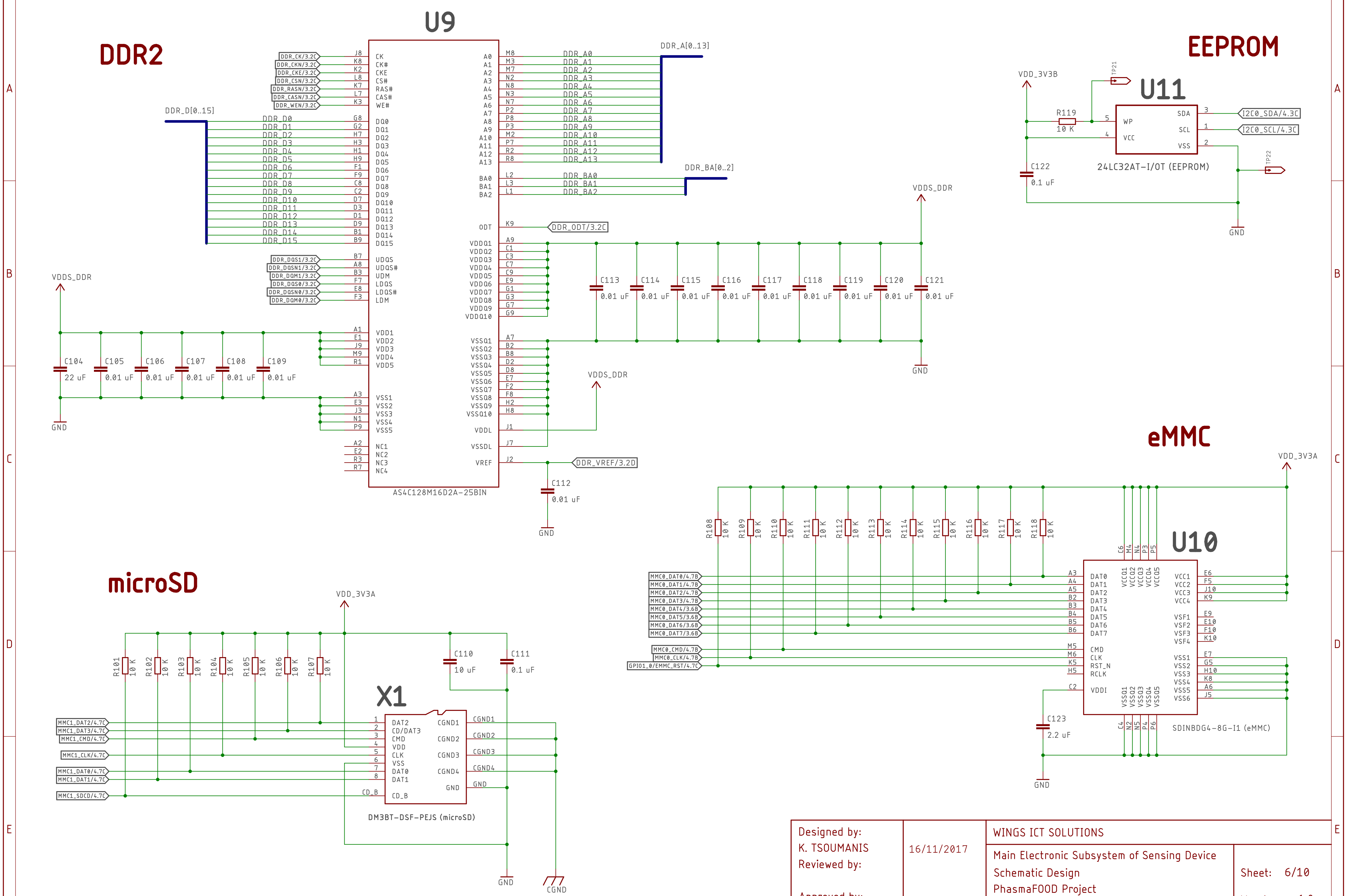
Approved by:		Processor Part 3 of 3 – Voltages, Grounds	Version: 1.0



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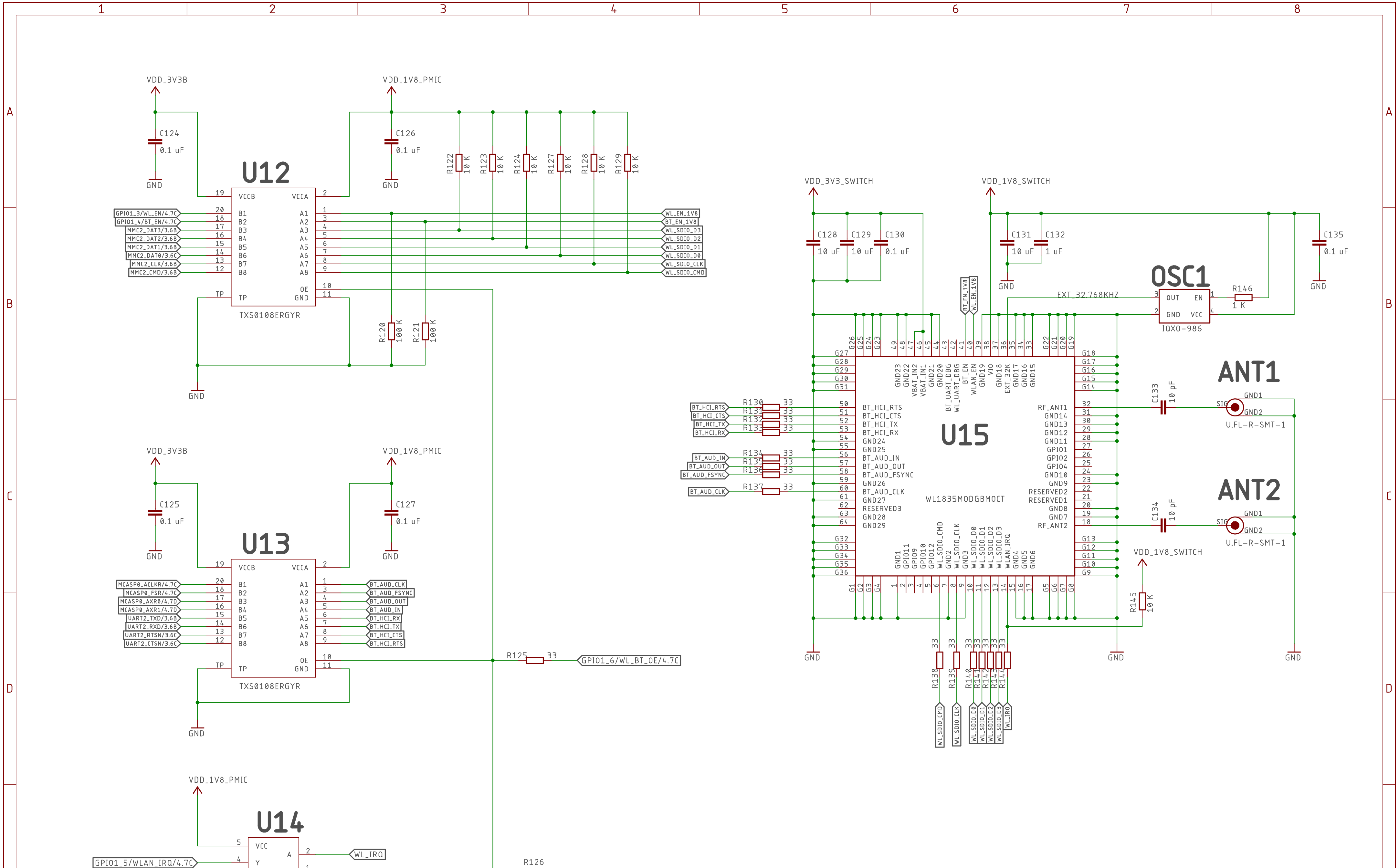
Reviewed by:		Main Electronic Subsystem of Sensing Device Schematic Design PhasmaFOOD Project	Sheet: 6/10
Approved by:		DDR2, EEPROM, microSD, eMMC	Version: 1.0



Designed by:
K. TSOUMANIS
Reviewed by:
Approved by:

16/11/2017

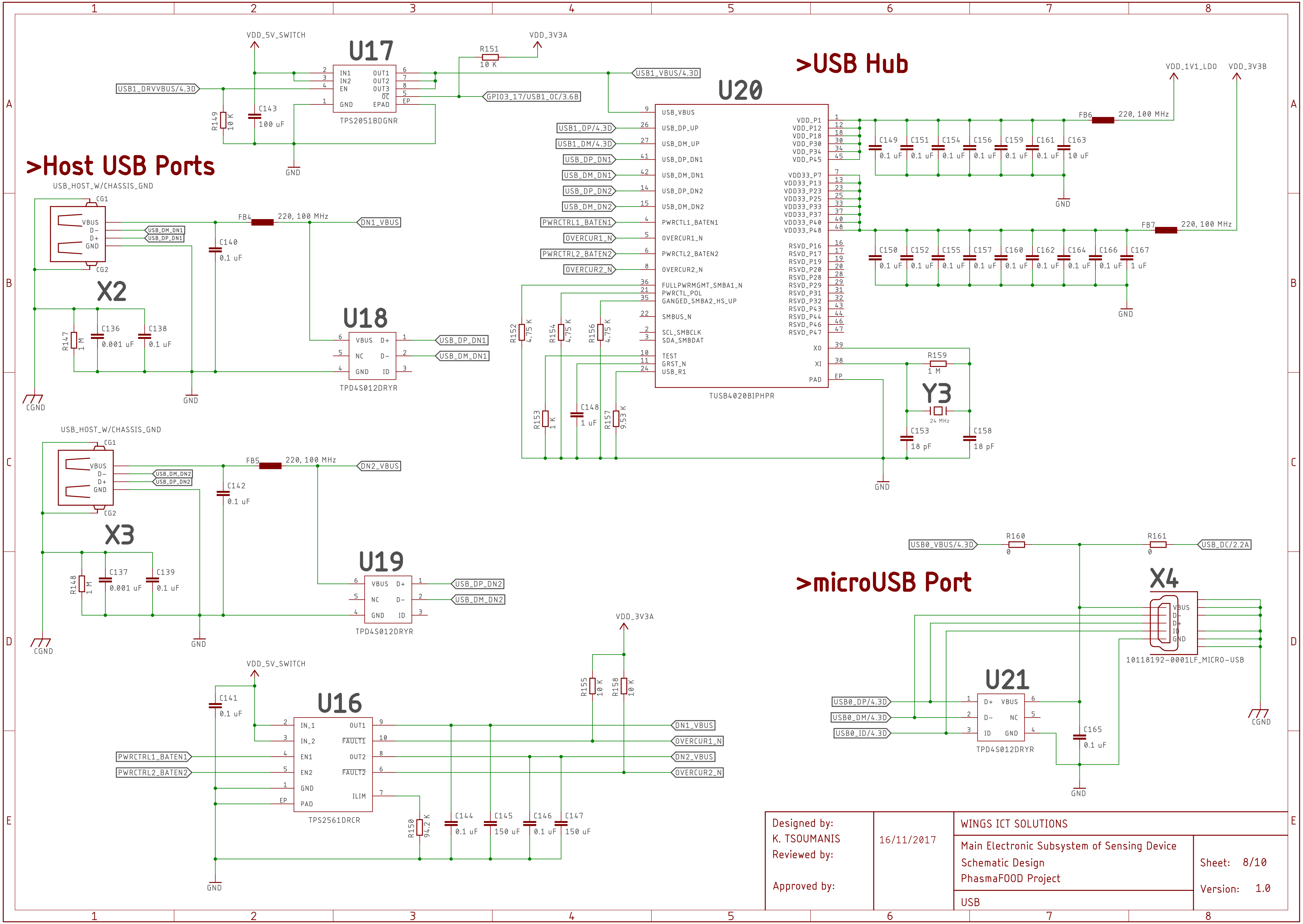
WINGS ICT SOLUTIONS

Main Electronic Subsystem of Sensing Device
Schematic Design
PhasmaFOOD Project

WiFi / BLE

Sheet: 7/10

Version: 1.0



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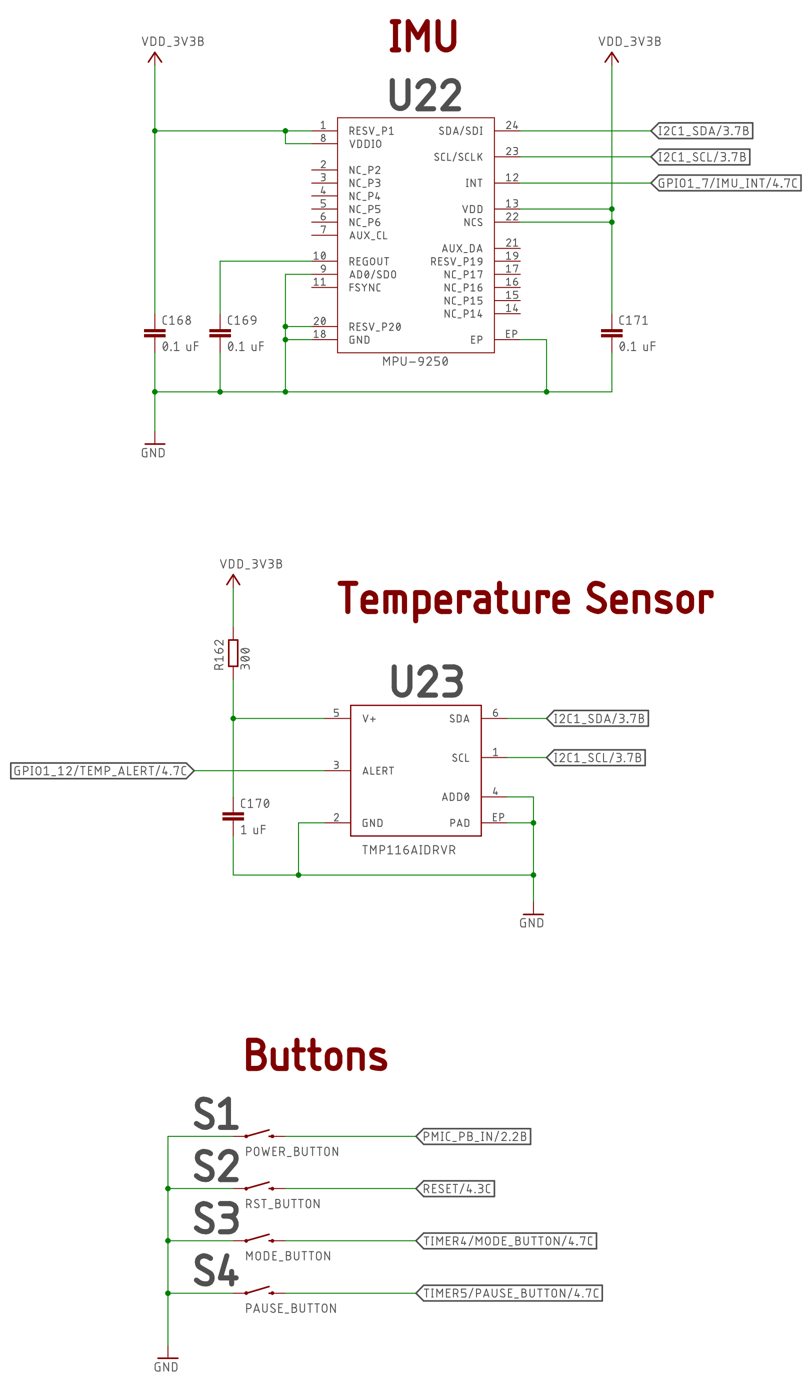
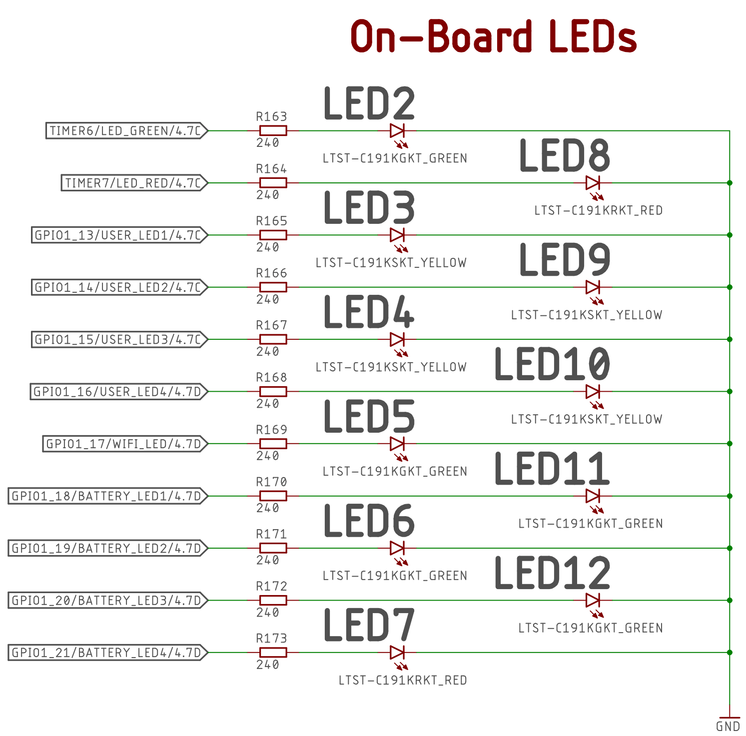
Approved by:		USB

Sheet: 8/10

Version: 1.0





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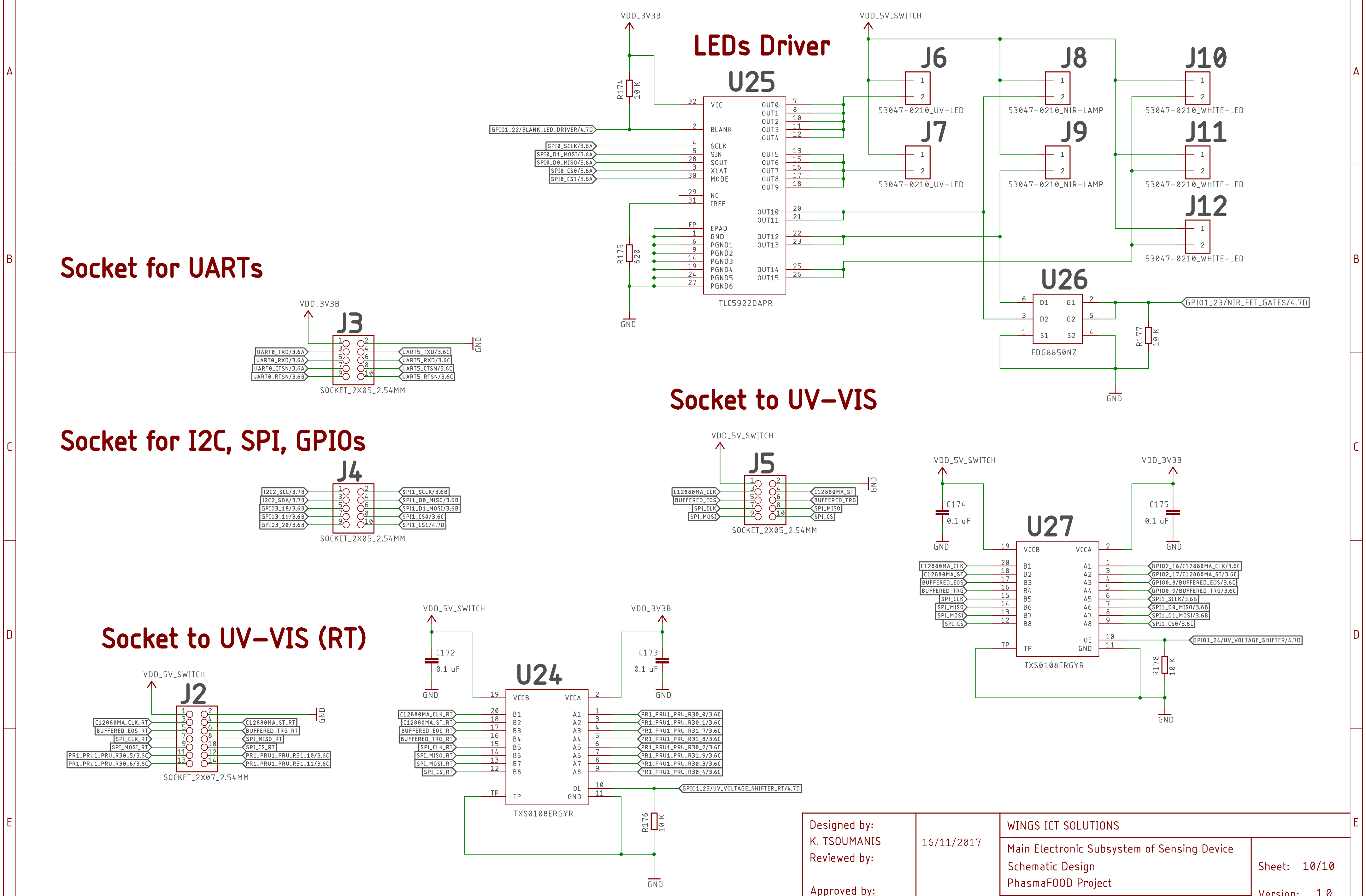
		Sheet: 9/10 Version: 1.0



Designed by: K. TSOUMANIS	16/11/2017	WINGS ICT SOLUTIONS	
Reviewed by:		Main Electronic Subsystem of Sensing Device Schematic Design PhasmaFOOD Project	Sheet: 10/10
Approved by:		Expansion sockets	Version: 1.0