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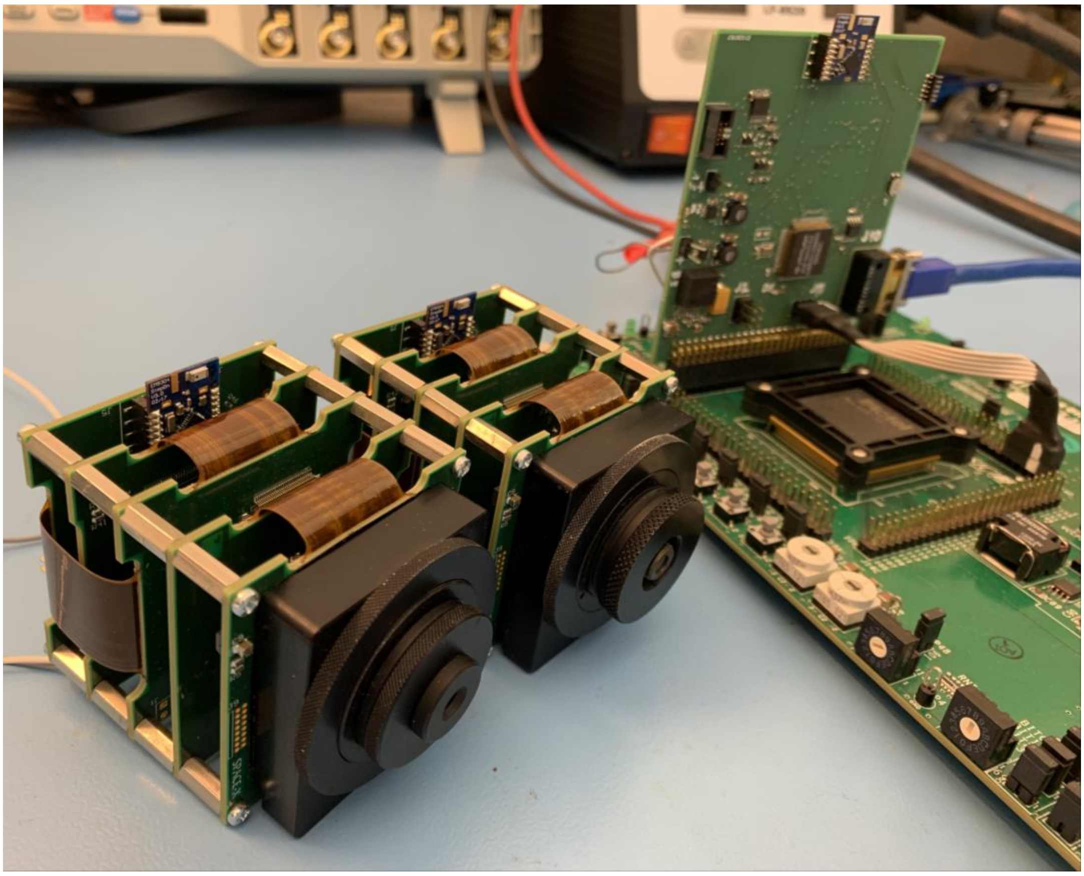
Low Energy Wireless Imaging System



Executive Summary

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Table of Contents

1. Introduction

This document constitutes the Executive Summary for the LEWIS project (ESA RFQ 3-14444/16/NL/LF) in the frame of the ESA Technology Research Programme.

The project milestones were reached as follows:

- Phase 1 of the LEWIS Project started on June 15th, 2016
- A System Requirements Review (SRR) was held on October 21st, 2016
- The Preliminary Design Review (PDR) was held on December 20th, 2016
- The critical design review (CDR) was held on 9th of June 2017
- A delta-CDR was held on 17th of July 2017
- A CDR approval was received on 25th of September 2017
- A test readiness review (TRR) was held on 8th of May 2019
- Tests on the complete system were performed, starting 4th of July 2019
- The Acceptance Review (AR) is foreseen for 30th of October 2019

The present executive summary report provides the following points:

- Context of the LEWIS project
- Programme of work
- Activities performed & Main results achieved

2. List of Acronyms and Abbreviations

AD	Applicable Document
API	Application Programming Interface
AR	Acceptance Review
CDR	Critical Design Review
COTS	Commercial Off-The-Shelf
EBB	Elegant BreadBoard
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
FPGA	Field Programmable Gate Array
FS	File System
IC	Integrated Circuit
IP	Intellectual Property
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
KO	Kick-Off
LEO	Low Earth Orbit
LEWIS	Low Energy Wireless Imaging System
MCU	Microcontroller (Unit)
OBC	OnBoard Computer
PCB	Printed Circuit Board
PDR	Preliminary Design Review
RAM	Random Access Memory
RF	Radio Frequency
RMAP	Remote Memory Access Protocol
S/C	Spacecraft
S/W	Software
SoW	Statement of Work
SRR	System Requirements Review
TID	Total Ionizing Dose
TP	Technology Plan
TRR	Test Readiness Review
UART	Universal Asynchronous Receiver/Transmitter
WAP	Wireless Access Point
WBS	Work Breakdown Structure
WiCa	Wireless Camera
WIM	Wireless Interface Module
WIS	Wireless Imaging System
WP	Work Package

3. Context of the LEWIS project

3.1. Rationale

With the development of micro cameras performed for various space exploration missions such as Rosetta, SMART-1 or ExoMars, the size and mass of such devices have been drastically reduced. However, the electrical interfaces of these micro cameras remain quite heavy with long and heavy cables: it is not uncommon to have the camera harness heavier that the micro camera itself. The micro camera harness is sometimes so constraining that it limits the application and the accommodation of such imaging systems.

Wireless cameras are widely used on Earth. From cameras to household appliances, anything can be remote controlled using various wireless technologies and protocols: IR links, Bluetooth, IEEE 802.11, etc. Connected to a power source or relying only on battery, they are easier to install and allow a very modular use. Earth-based applications of wireless cameras are plentiful:

- Monitoring: Baby-Cam, Wireless alarm system cameras, Pet-Monitoring camera, Dashcam, Personnal Helmet camera, Body-worn cameras
- Communication: WebCam
- Photography/Filming: Camera drones, Action-camera, PhotoCamera

For space applications, wireless communication is mainly used to communicate with the spacecraft from earth, relying on powerful transmitters and receivers capable of long-range communication. While some studies have been performed to develop short range RF communication links between various parts of the spacecraft, such technologies are only emerging. However, such a wireless solution presents three advantages:

- Implementation of cameras where cables are not possible
- Multiple cameras with only one interface (access point)
- Possible mass saving in the camera harness

Hence, the use of wireless cameras for a science imaging instrument can significantly increase the science return of the instrument and of the mission.

From the various possible space applications for wireless camera, the suitability and usefulness of different solutions was weighted against various parameters and a specific use-case was defined for the LEWIS project.

3.2. Use-Case: LEO Camera for Spacecraft Release Monitoring

Rocket payload delivery use-case was selected for further analysis, as it appeared the most suited for a first development of a wireless technology.

3.2.1. Description

The case study for the LEWIS application consists in one or several cameras set on the rocket when the spacecraft payload it carries is released. Here we consider a Low Earth Orbit (LEO) satellite only, e.g. this does not apply for instance for geostationary satellites.

The term LEO encompasses distances between 160 and 2000 km above the surface of the Earth. Typically, the International Space Station (ISS), the former Russian space station MIR, and the Hubble Space Telescope orbit at 400 km, 360 km, and 540 km respectively, while Sun-synchronous satellites orbit between 600 and 800 km and polar orbiting satellite have an altitude between 700 and 1700 km.

The rocket's stages separations and the altitude at which the payload satellite is released depend on the type of the rocket (e.g., Ariane 5, Proton M, Atlas V), but they all fall roughly within the same order of magnitude, as described in Figure 3-2. This figure shows the launch stages for a standard mission with the Ariane 5 launcher.

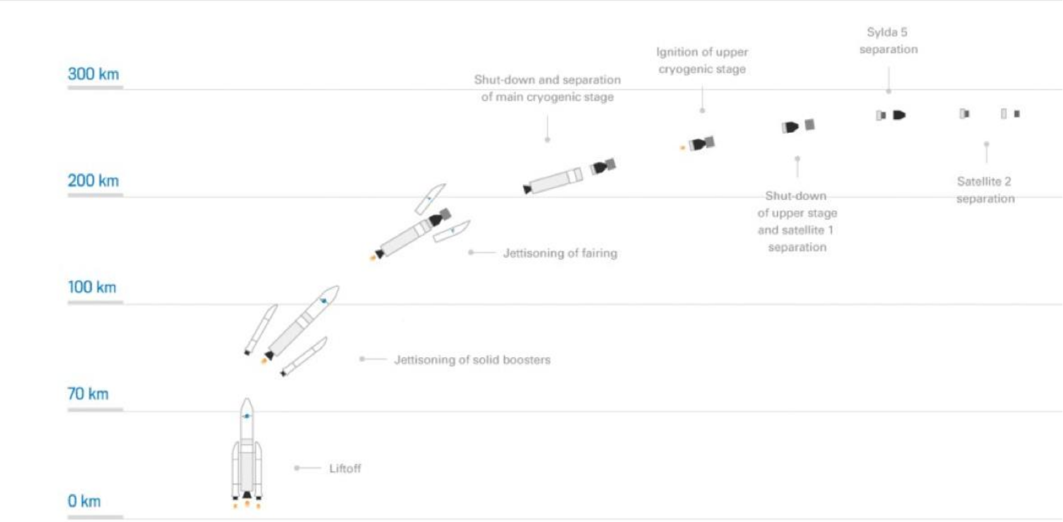

Figure 3-1: stages of a typical Ariane 5 mission (©Arianespace)

This case study focuses on one or several wireless monitoring cameras accommodated outside the main cryogenic stage and within the payload fairing, which will monitor in real time the payload satellite release and deployment, typically at an altitude of 200 to 300 km. The images can be sent to the Wireless Access Point (WAP) and then to the launcher onboard computer (OBC), together located ~5 m from the imaging system, and back to Earth. Having a wireless system in this configuration allows acquiring images from where the payload satellite is released, while keeping the inside of the payload fairing isolated from the lower rocket stage (no hole due to wiring). This is illustrated in Figure 3-2.

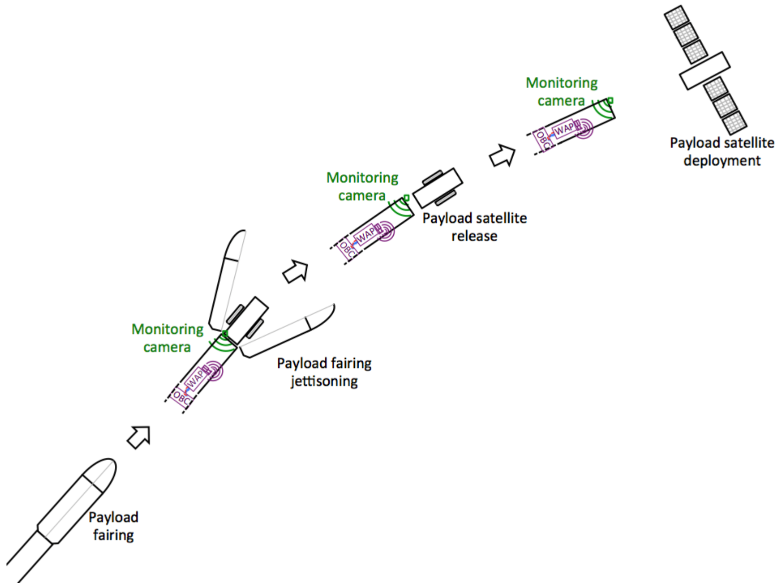

Figure 3-2: Payload satellite monitoring LEWIS use-case

This application can be of great help in case trouble arises during this phase, as for Roscosmos' Phobos-Grunt mission in 2011, or JAXA's Hitomi (also called Astro-H) mission in 2016.

4. Executive Summary

The objective of the LEWIS project is to demonstrate the concept of a wireless imaging system suitable for exploration missions and generic spacecraft monitoring. A compact and elegant demonstrator was designed and implemented with an emphasis on low mass, low energy and low integration complexity.

Several use cases were initially defined following the statement of work and one of them, LEO Camera for Spacecraft Release Monitoring, was retained to serve as a reference objective for the project.

A survey of existing space cameras was performed which provides relevant information about their electrical and data interfaces, power, mass, data rates, imaging sensor, and other available information. It was concluded that the choice of cameras that fall in the category of cameras suitable for the LEWIS project is very limited.

Technology trade-offs and analyses were also performed for all the relevant aspects of the LEWIS system. Trade-offs on the level of components was performed as well as trade-off on the level of hardware architecture and integration.

Tight integration was decided where a new low power camera was to be designed and developed. The options were thoroughly analysed and discussed with the ESA representative. Following the decision for tight integration and the development of new camera a more detailed components trade-off was performed based on the inputs from the discussions and the decisions. The list of requirements was also reviewed.

The choice of wireless module being a key component was analysed thoroughly. The final decision was to use an updated version of the bluetooth module by EM Microelectronics which was also suggested in the statement of work.

Through the contacts with the companies producing RF ICs and also with IMEC which own the IP of some of the RF IC designs it was concluded that those companies have practically no interest in having radiation tolerant, or latch-up immune versions of their circuits. There was also no interest in disclosing the owner of the IP in their circuits. Thus, it was concluded that in the budget and scope of a project such as LEWIS the use of COTS RF IC was inevitable.

For the other key components such as the image sensor and the MCU, a collaboration was established with the manufacturers which provided a privileged access to their technology.

The fact that an MCU is included in the design of the camera has its advantages and disadvantages. The advantages are that a complex communication links such as the configuration of the image sensor, communication with the RF module and the high-level communication protocol would be very resource heavy if implemented in pure FPGA. Using the MCU renders this task much more manageable while still keeping full flexibility with regards to implementing any arbitrary high-level communication protocol thus enabling compatibility with virtually any mission as long as the corresponding hardware communication interface is implemented. The MCU is also radiation hardened for TID >300K rad (Si) and latch-up immune while still being low power. It also provides for implementation of simple compression algorithms by software. The only disadvantage of the MCU in the camera is its speed and number of pins which limits the number of images per second. This can be mitigated by including an FPGA in the proximity of the sensor together with a RAM memory. That solution will increase the speed of image acquisition but also the power needs during image acquisition.

The designed wireless cameras and the wireless access point were developed through several iterations of prototyping. The embedded software for the different functionalities was also developed in parallel and iteratively. Namely as a part of the LEWIS project, in terms of software, the following components were developed:

- Driver for the image sensor configuration triggering and readout
- Driver for the FIFO image frame buffer
- Driver for the NAND Flash memory
- Customized simplified filesystem for the NAND Flash memory
- Driver for the Bluetooth HCI interface with the RF module; establishing and maintaining connections
- High level communication protocol

The LEWIS breadboard wireless cameras and WAP PCB were finally manufactured and assembled.

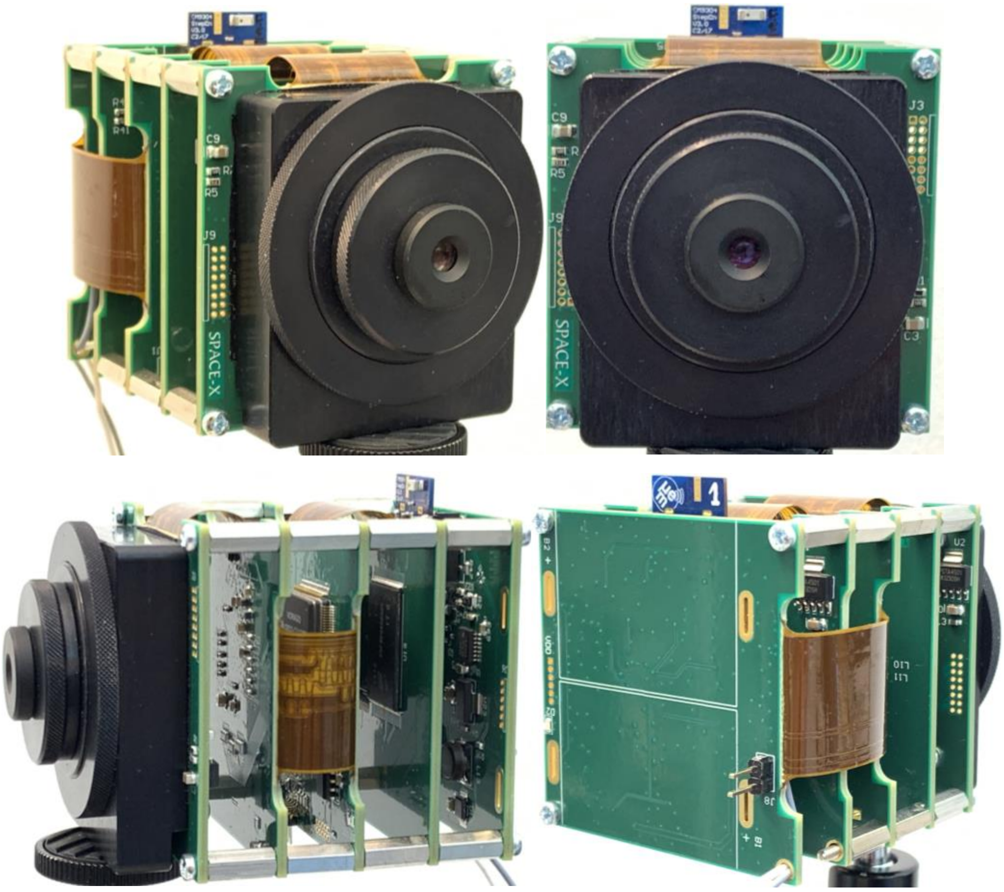

Figure 4-1: Views on the assembled wireless camera with c-mount optics.
Size: 10cm x 5cm x 5cm including optics and batteries

The wireless cameras' PCBs are manufactured in flex rigid technology avoiding the use of connectors between the different PCBs.

The WAP contains the same MCU as the wireless cameras as well as an FPGA that implements a communication bridge between the SpaceWire spacecraft interface and the SPI interface of the MCU.

Additionally, an EGSE console software was designed and developed in order to emulate an OBC connected through SpaceWire RMAP to the WAP.

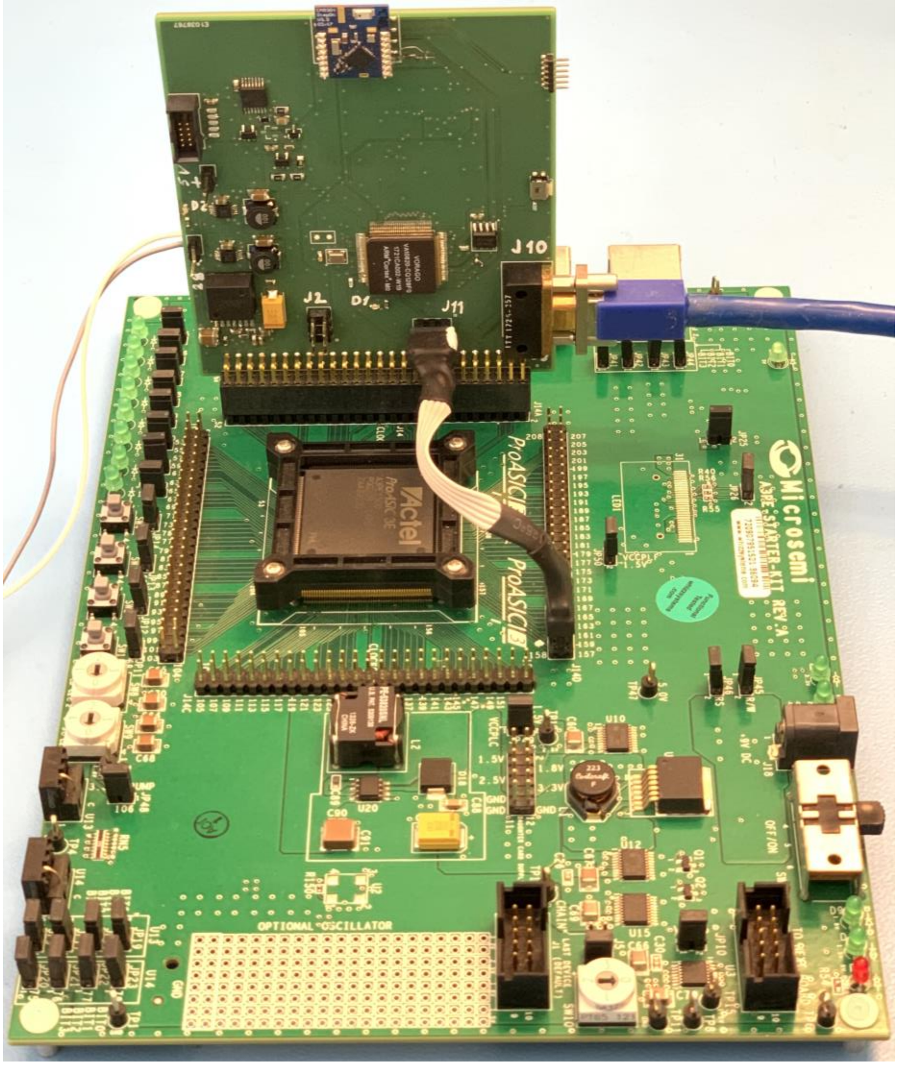

Figure 4-2: The WAP MCU PCB connected to the FPGA board

Tests and verifications on the LEWIS system (2 wireless cameras and 1 wireless access point) were successfully performed. Road mapping towards a flight model was also provided.

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