ECE^{3}SAT

PFE1531 – PFE1533 Presentation

Meet the team

PFE 1533

Arthur Schmitt

Project leader
Electrodynamic Tether
Energy & Environment

Eva Lourau

Electrodynamic Tether
Energy & Environment

Alexandre Hippert

Mechanical Engineering
Energy & Environment

Chabha Abbar

On-Board Computer
Embedded Systems

Arthur Mauvezin

User Interface
Information Systems

Meet the team

PFE 1531

Vincent Renaudat

Project Leader
Electrical Power System
Energy & Environment

Nadir Hafsaoui

Power Conditioning
Circuitry
Embedded Systems

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Electrical Power System
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Network &
Telecommunication

Julien Rodrigues Alves

Telecommunication System
Network &
Telecommunication

Alexandre Massiot

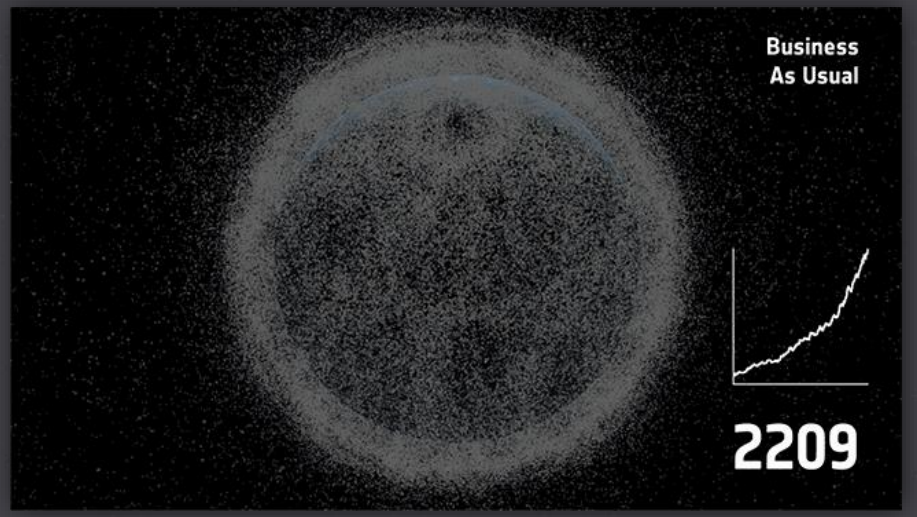
On-Board Computer
Embedded Systems

Contents

01. Introduction

Introduction

Space Debris

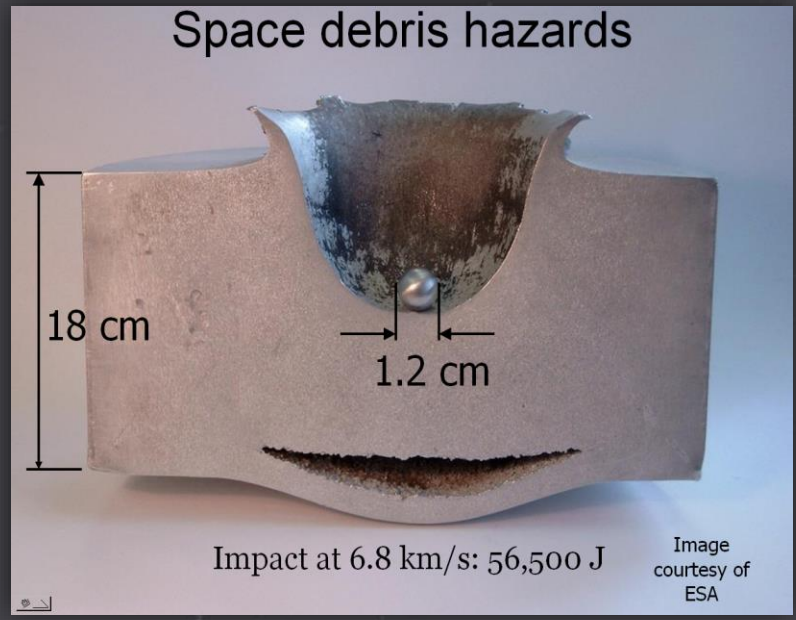


- Increasing debris in orbit
- Situation is getting worse
- Space debris mitigation implementation has started (supported by ESA Clean Space)

Introduction

Space Debris

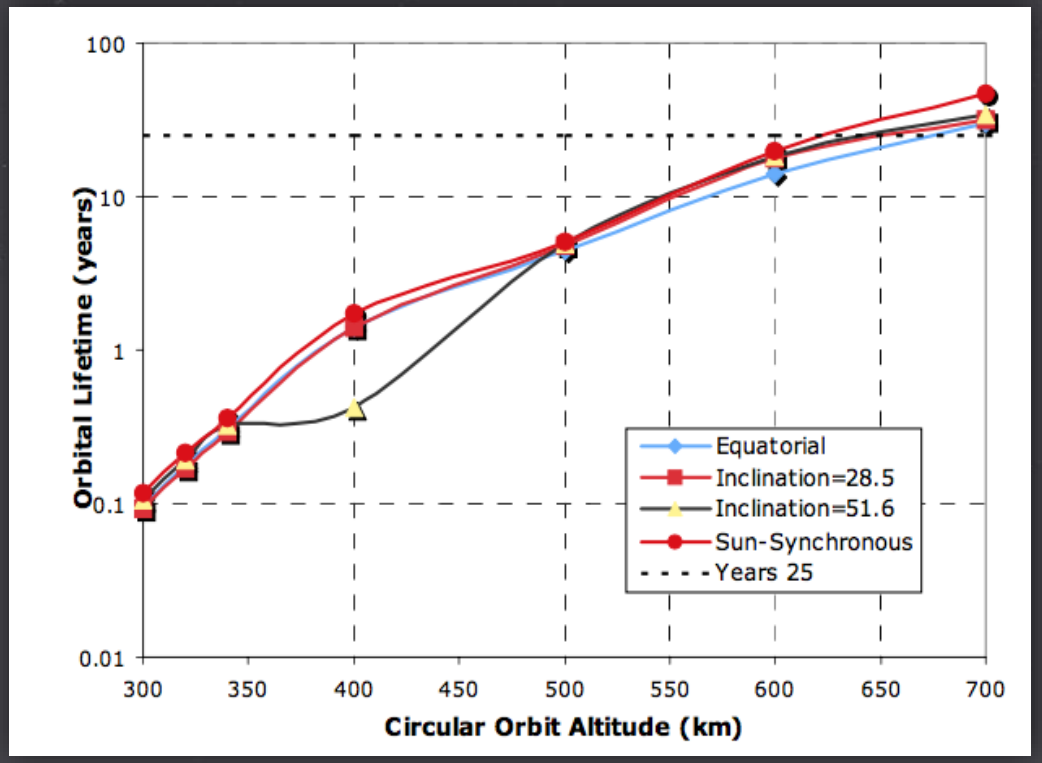
- More than 500 000 trackable units
  - 20 000 are bigger than a tennis ball
- Million of pieces too small to be tracked
- Most of the debris in LEO
- Multiple origins



- **Creation of new debris is forbidden by laws and regulations**
- **25 year disposal space law**

Introduction

CubeSats



Natural orbital lifetime of CubeSats in function of altitude

STANDARDISED MODEL

1dm³ , <1,33kg - design for students

POPULARITY

Forecast: in 2020, more than 2000 CubeSats in orbit

➔ Increase of space debris

COMMERCIALISATION

Due to its low cost, the CubeSat population in Lower Earth Orbit above 700km will keep on increasing.

PRIMARY OBJECTIVE

Develop a cost- efficient, room efficient and light deorbiting system.

Introduction

Project presentation

There is a need for deorbiting systems for CubeSats !

This project will provide, through a technology demonstrator mission, a deorbiting system using Earth magnetic field. This system is required to be cost-efficient, room-efficient and light in order to be easily implemented on other CubeSats missions.

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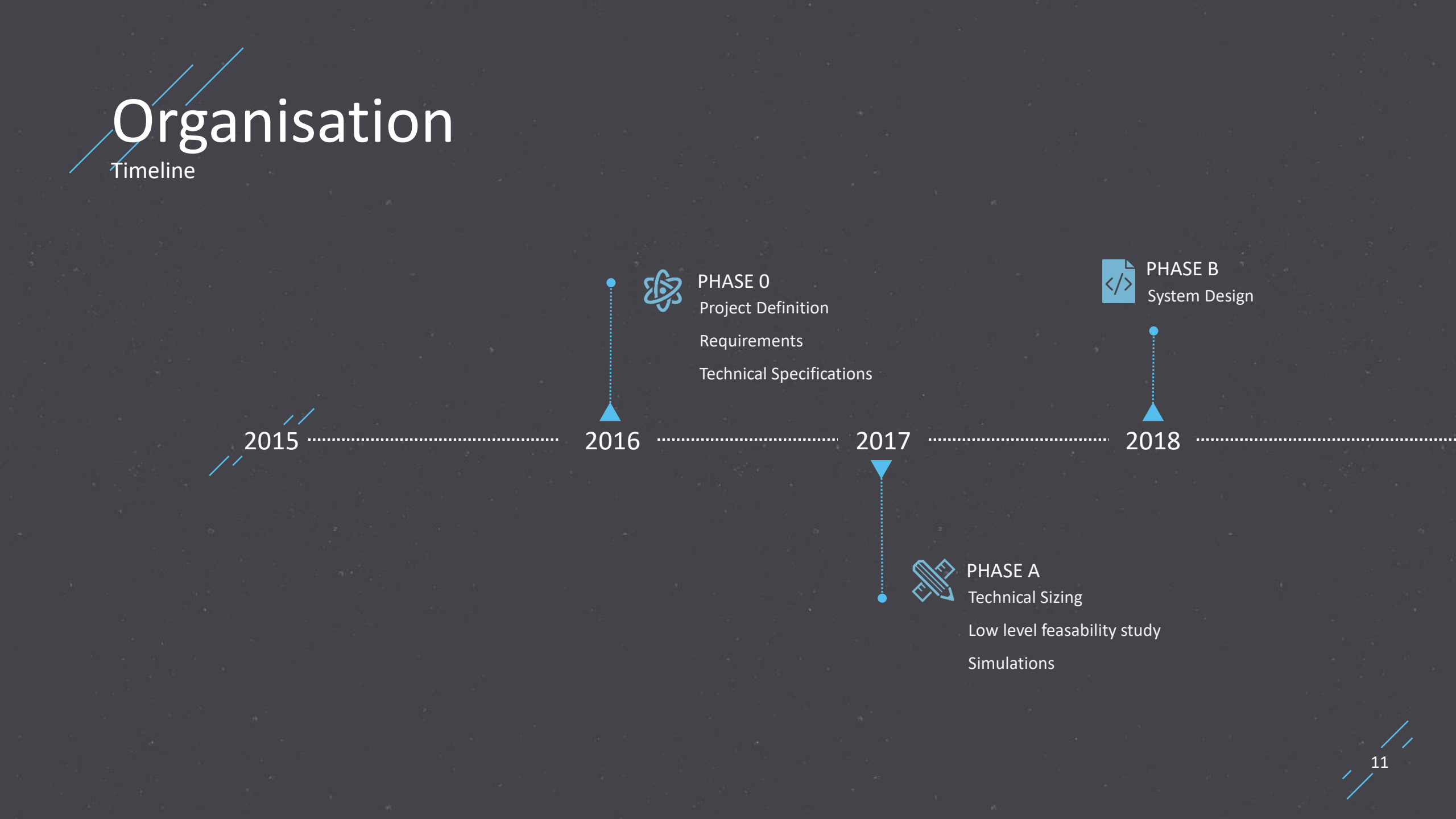
ÉCOLE D'INGÉNIEURS

02. Organisation

Organisation

Timeline



Organisation

Timeline

2019

PHASE C/D

System Development

Unit Testing

2020

PHASE C/D

QM test and Validation

FM development, test and validation

launch

2021

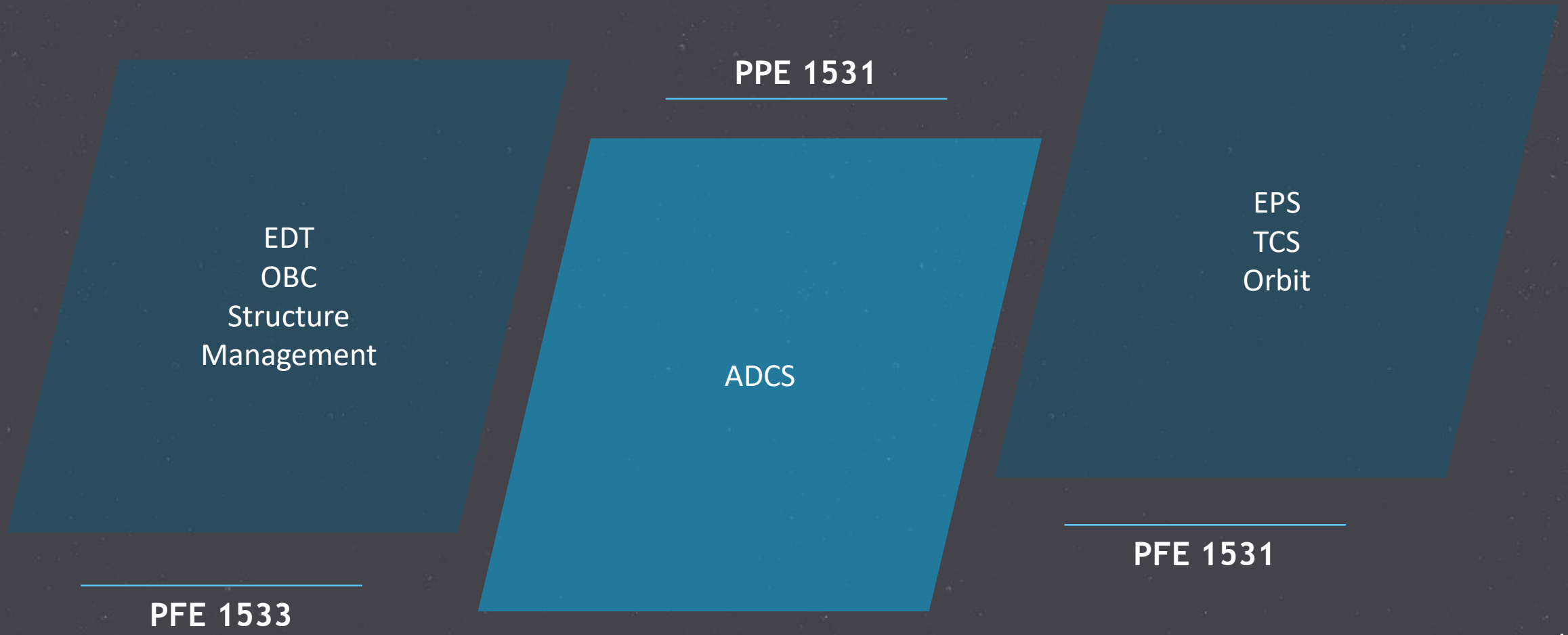
PHASE E/F

Operation

2022

Organisation

Group division



Organisation

Objectives

PHASE 0 Technical Objectives

- A clear project definition
- Validated Requirements Document
- Validated Technical Specification Document

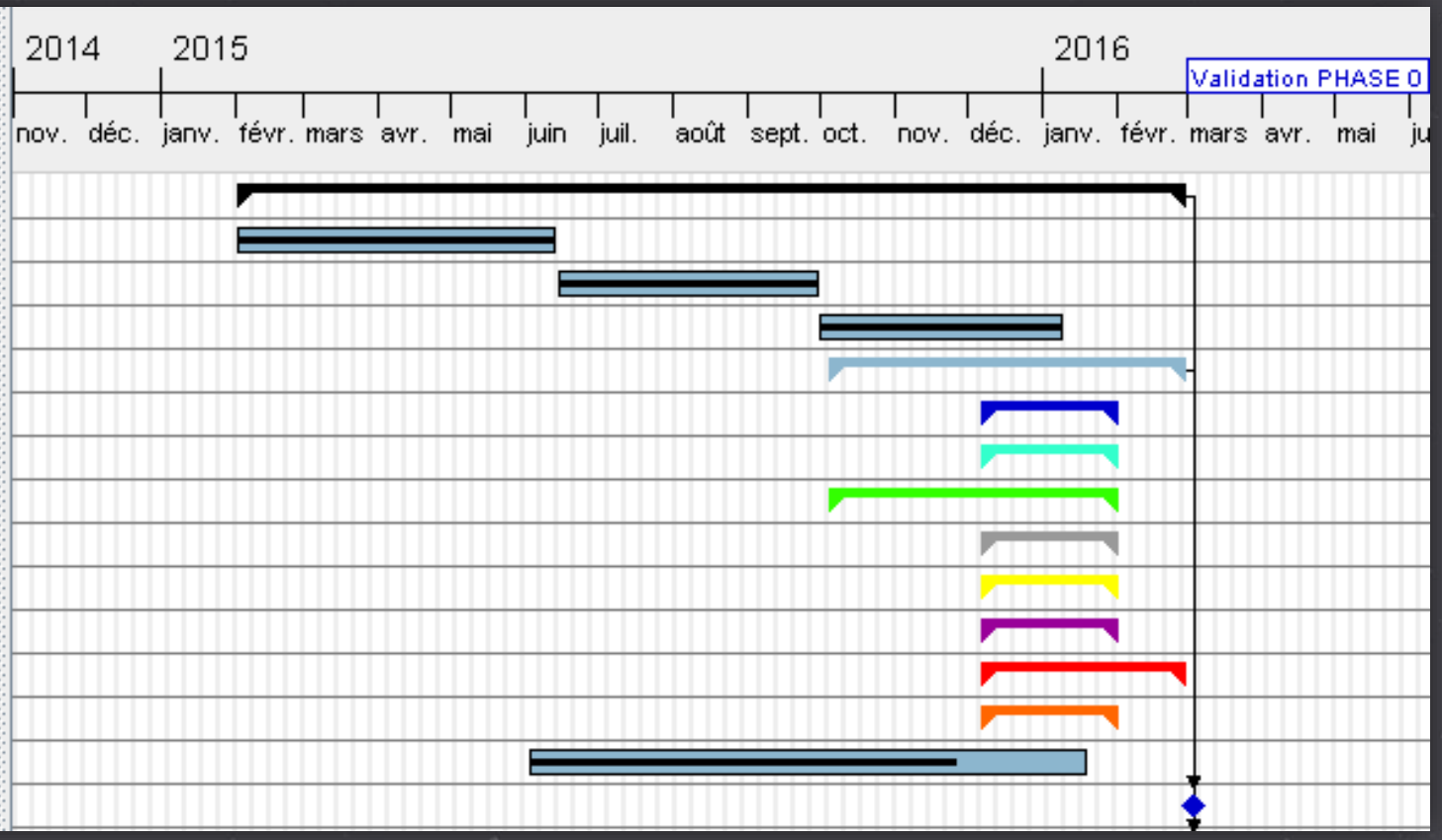
PHASE 0 Management Objectives

- Initiate partnerships
- Project strategy over 5 years
- Set up a fixed project environment

Organisation

Current year task division

Nom	Dat...	Date de fin
PHASE 0	02/0...	29/02/16
Project definition	02/0...	12/06/15
State of the Art	15/0...	29/09/15
Requirements	01/1...	08/01/16
technical specifications	05/1...	29/02/16
Overall Satellite System	07/1...	01/02/16
OBC	07/1...	01/02/16
EDT	05/1...	01/02/16
Structure	07/1...	01/02/16
EPS	07/1...	01/02/16
TCS	07/1...	01/02/16
ADCS	07/1...	29/02/16
GS-UI	07/1...	01/02/16
ECEPACE lab implementation	03/0...	18/01/16
Validation PHASE 0	01/0...	01/03/16



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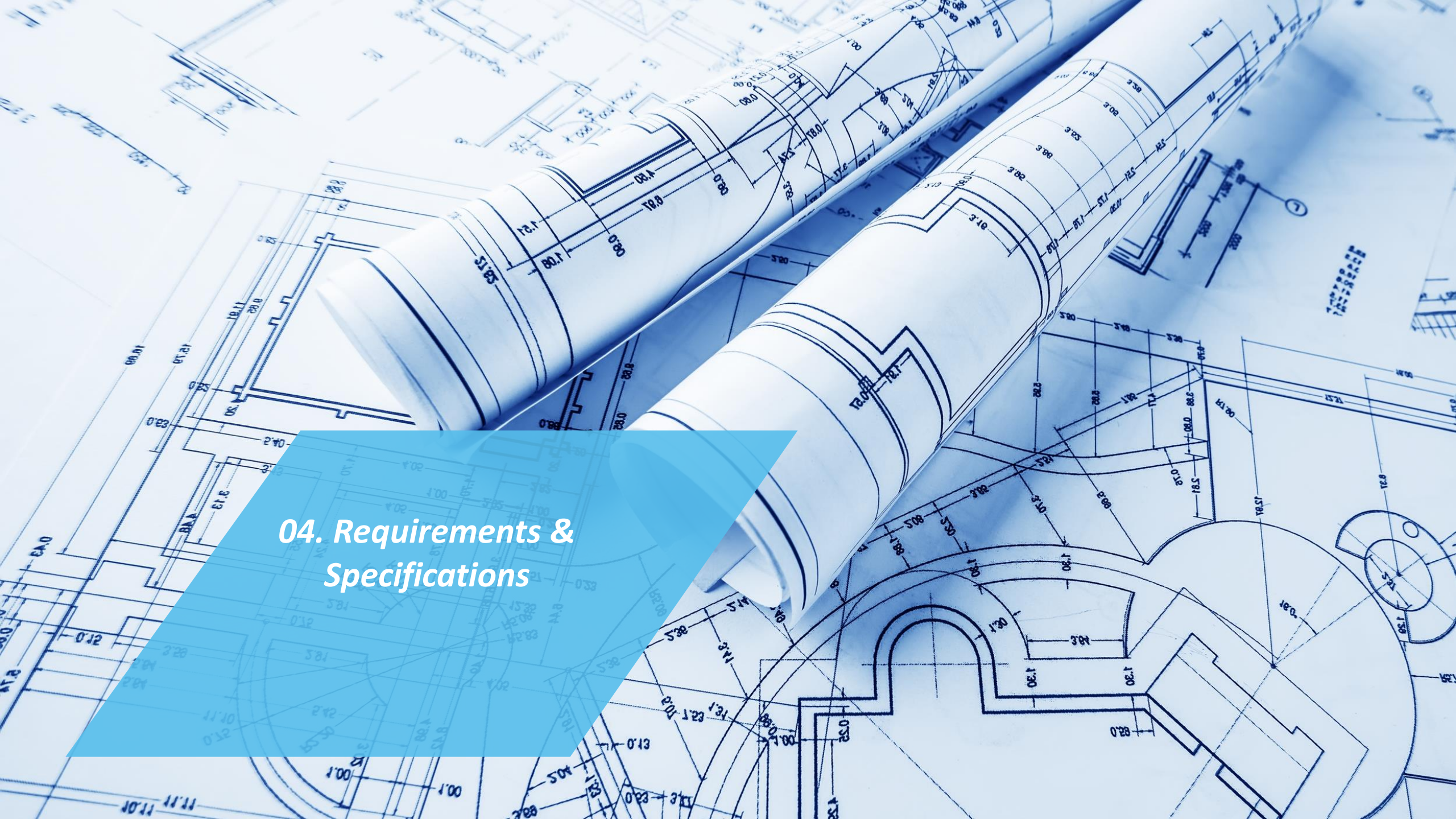
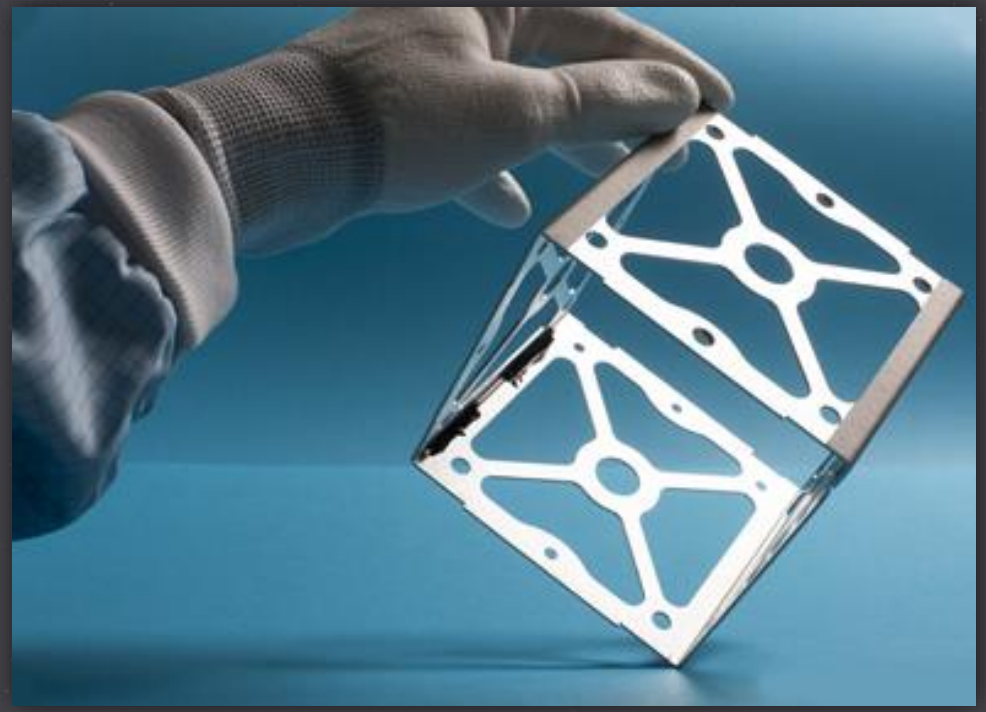
03. Partners



04. Requirements & Specifications

Requirements & Specifications

What is a CubeSat?

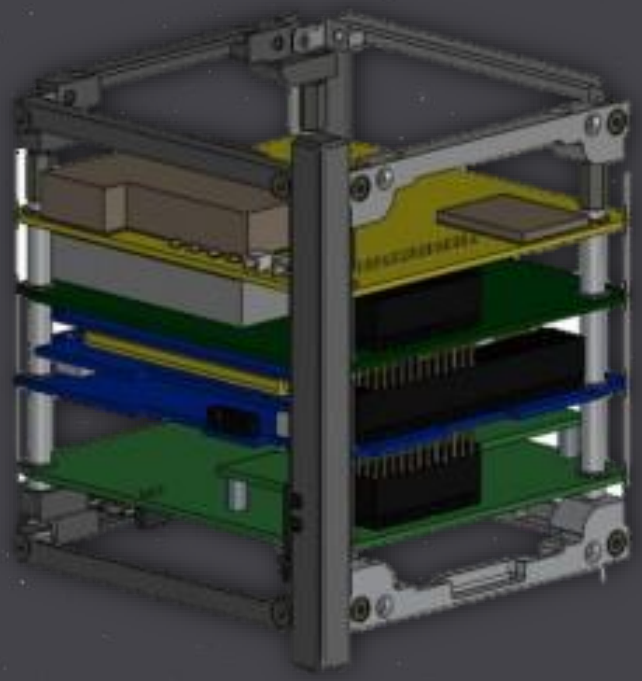


1U CubeSat

- 100 x 100 x 100 mm^3
- Up to 1.33 kg
- Aluminum structure

Requirements & Specifications

What is it made of ?

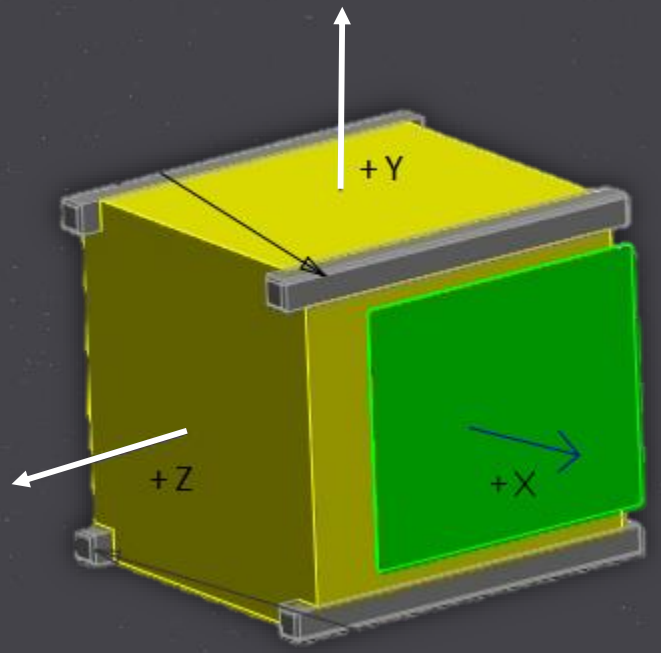


CubeSat composition

- Structure with rails
- On-Board Computer
- Electrical Power System
- Telecommunication System
- Attitude Determination and Control System
- Electrodynamic tether
- Solar panels
- Antennas

Requirements & Specifications

Reference coordinate system



Coordinate system

The +Z face

- Front face
- Tether deployment face
- Always facing the Earth

Requirements & Specifications

What are the different phases of the mission ?

Mission phases

Insertion phase

Launch phase

Cruise phase

Operation phase

De-orbiting phase

Requirements & Specifications

What is the chosen orbit ?

Orbit parameters

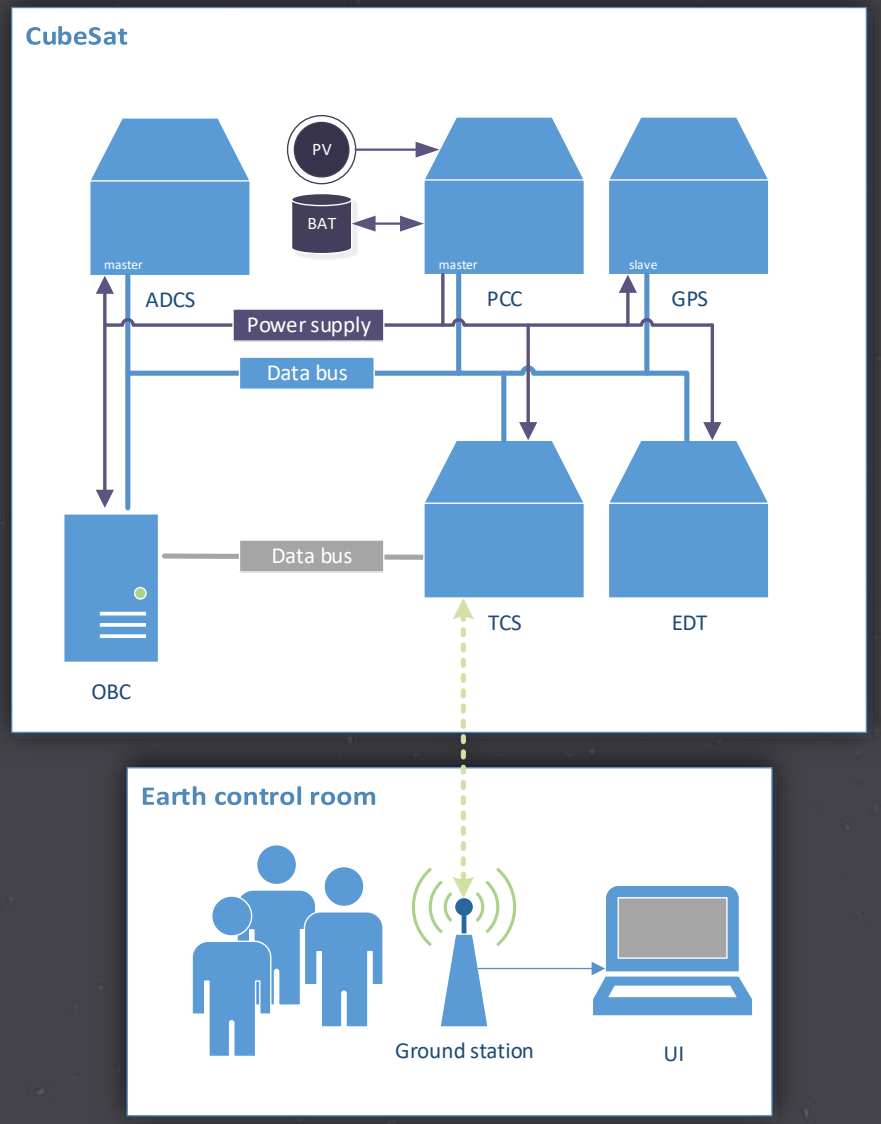
- Circular
- Inclination between equatorial and 51.6°
- Altitude between 400 and 650 km

Earth coverage

Footprint area : 89 000 km²

Requirements & Specifications

Global schema



Specifications

Environment

Natural environment

Transport, Manipulation, Launch pad

Temperature, humidity, mechanical chock, pressure..

In the launcher

Vibration, chocks, stiffness

Vacuum

Loss of pressure, outgassing

In service environment

Thermal

Resistance, Thermal Balance

Atmosphere

Composition changes with altitude

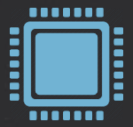
Mechanical

Debris and micrometeorite impacts

EMC

The earth is assimilated to a dipole of a 8.10 exp22 A/m2 momentum

Requirements & Specifications



OBC

The On-Board Computer makes all the calculations and takes all decisions.

GPS

The GPS retrieves the position of the CubeSat.

EPS

The Electrical Power System generates, stores and distributes energy.

EDT

The Electrodynamic Tether deorbits the CubeSat.

TCS

The Telecommunication System links the Earth and the CubeSat.

GS

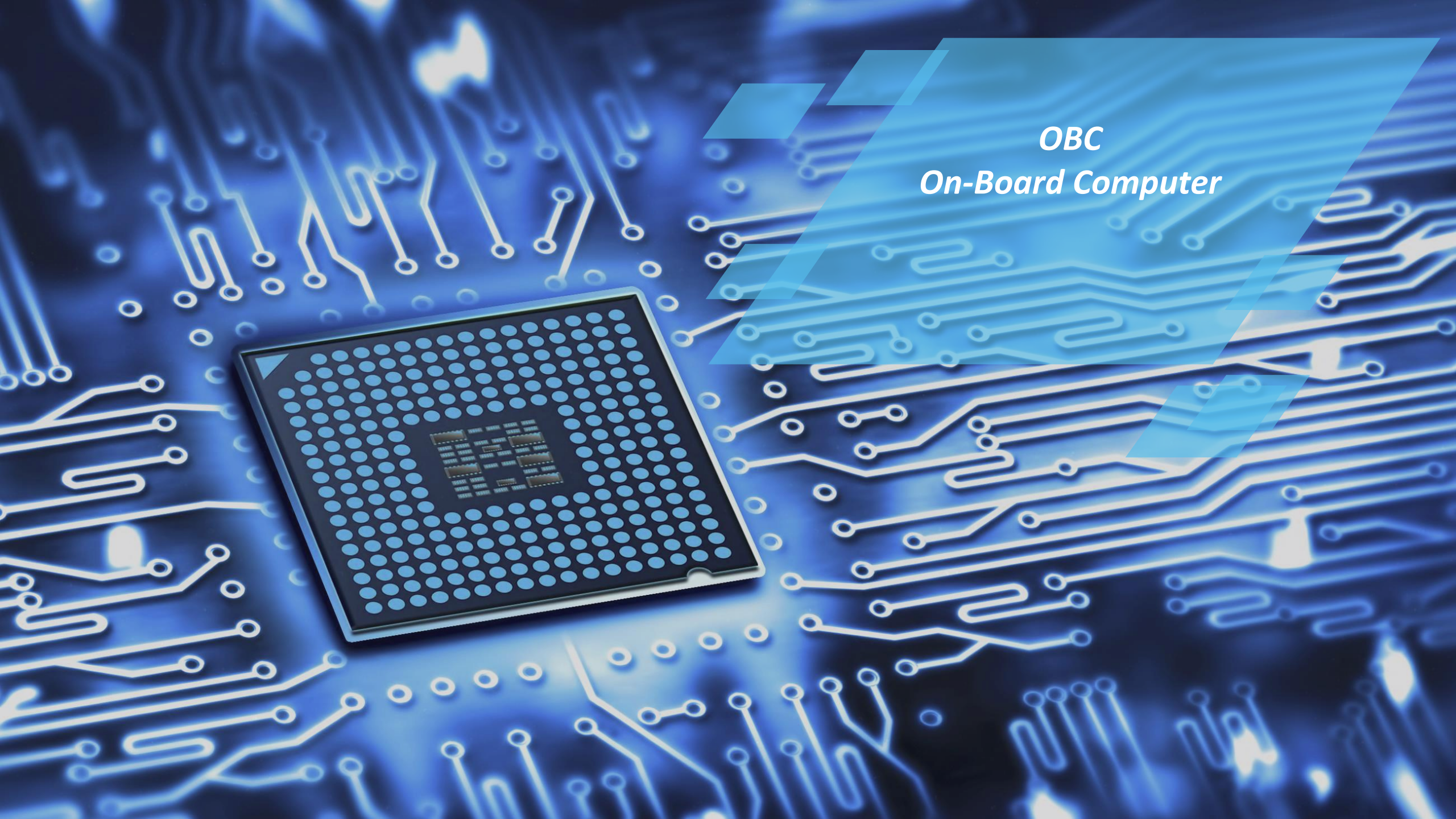
The Ground Station is the Earth station tracking the CubeSat.

ADCS

The Attitude Determination and Control System manages the orientation.

UI

The User Interface gathers and handles the received data.


OBC
On-Board Computer

On-Board Computer

Functions

Handling telemetry

Send it to the TCS.

Execute

Execute Earth orders.

Storage

Store all informations.

Manage

Manage all the CubeSat subsystems.

On-Board Computer

Communication protocols

I2C

Simple / Multi master

Half-duplex

Bi-directional

SPI

Unique master

Full-duplex

Bi-directional

Space wire

High speed

Full-duplex

Bi-directional

CAN

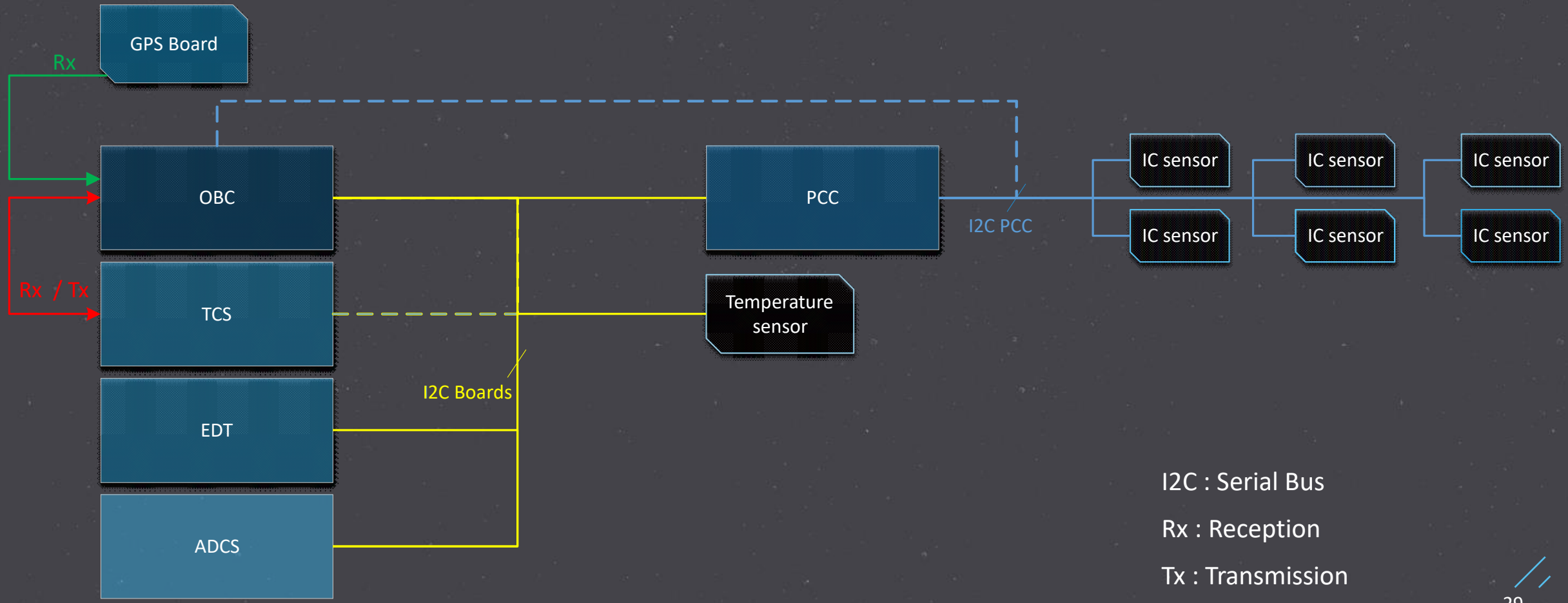
Speed / Distance

Simple / Multi master

Half-duplex

On-Board Computer

Communication inside the CubeSat



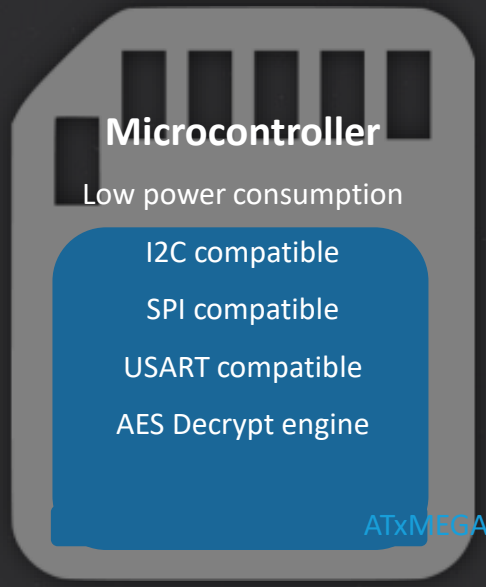
I2C : Serial Bus

Rx : Reception

Tx : Transmission

On-Board Computer

Hardware



ATxMEGA128A1

4Mb available (2 x 2Mb)

592 bits of data

We can store

- 4Mb / 592 frames = 6757 frames

We store data every 30 seconds

- 6757 x 30 / 3600 = 56 hours

Memory

2x2Mbits EEPROM

Low power consumption

SPI compatible

AT25M02

Temperature sensors

I2C compatible

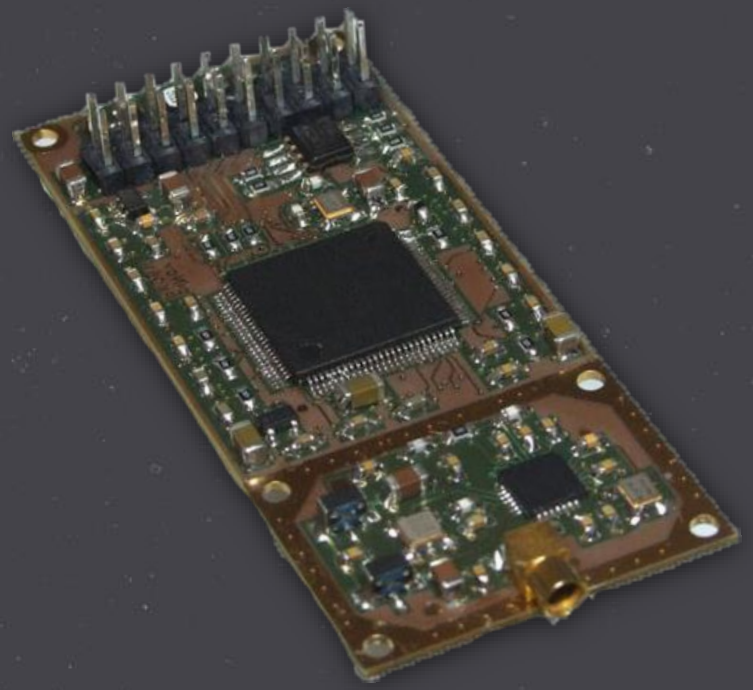
Low power consumption

1°C precision

MCP9808

GPS

Existing products



piNAV-L1/BM

www.skyfoxlabs.com

- Space-Friendly™ Ultra Low Power (120mW)
- Low mass (17g)
- Miniature (70×30×9 mm)
- GPS L1 Receiver
- Navigation receiver for high altitude flights

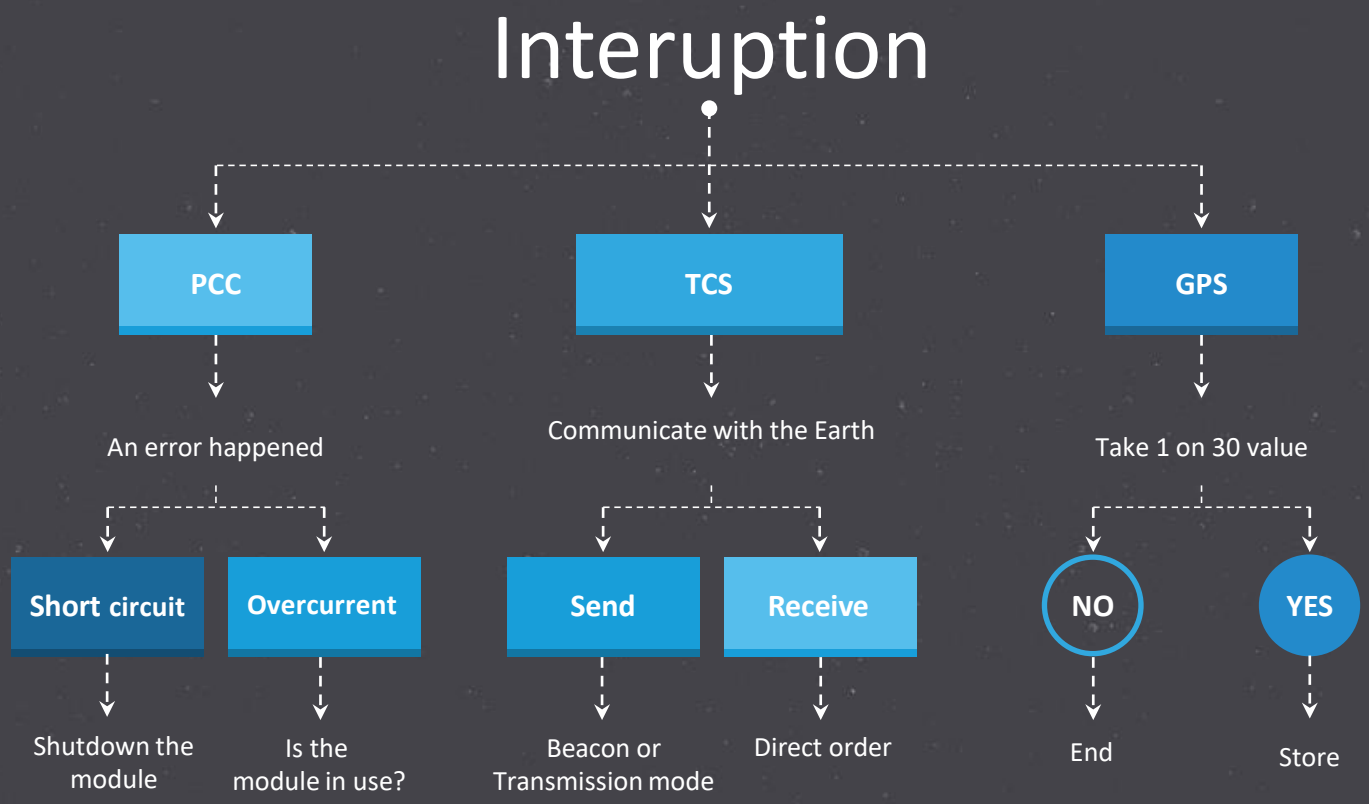
On-Board Computer

Operation modes

	Modes	Description
Startup	Startup mode, used only once at the start of the CubeSat.	**Startup mode** • Start the ADCS for de-tumbling • Deploy the antenna
Survival	Survival mode, used to save power.	**Survival mode** • Save power • Ask the EPS to shut down the OBC
Beacon	Beacon mode, used to gather data and send a simple packet (beacon)	**Beacon mode** • Gather data every 30 seconds • Send packets
Transmission	Transmission mode, used to send all the stored data to the Earth	**Transmission mode** • Receive requests from Earth • Send all the stored data and delete it

On-Board Computer

Algorithm



OBC Schematics

I2C interface
To interconnect all subsystems together

SPI interface
To connect the EEPROM

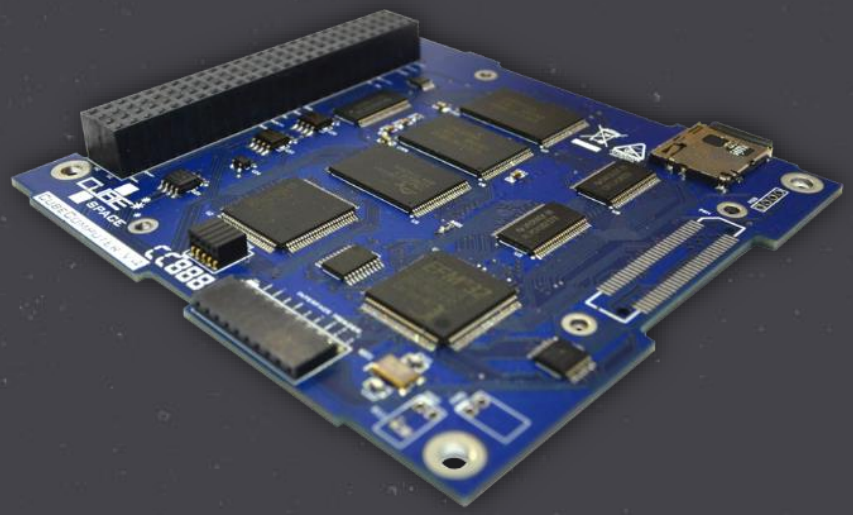
USART
To connect the GPS & TCS modules

Decrypt module
AES 128

Please have a look at the figure 1

On-Board Computer

Existing products

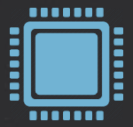


Cube Computer

www.cubesatshop.com

CubeComputer is a general purpose on-board computer for nanosatellites. The OBC is built around an ARM Cortex-M3 MCU which delivers high performance at very low power. CubeComputer is fully compatible with the CubeSat standard and can thus be integrated with a wide variety of other CubeSat components. The module is radiation tolerant and is protected against SEUs and SEL's through sophisticated error detection and correction techniques.

Specifications



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ADCS

The Atitude Determination and Control System, manage the movement.

UI

The User Interface, gather all the data's received.

EPS
Electrical Power System

Electrical Power System

Functions

Energy generation

Using solar energy.

Energy storage

Using rechargeable batteries.

Energy distribution

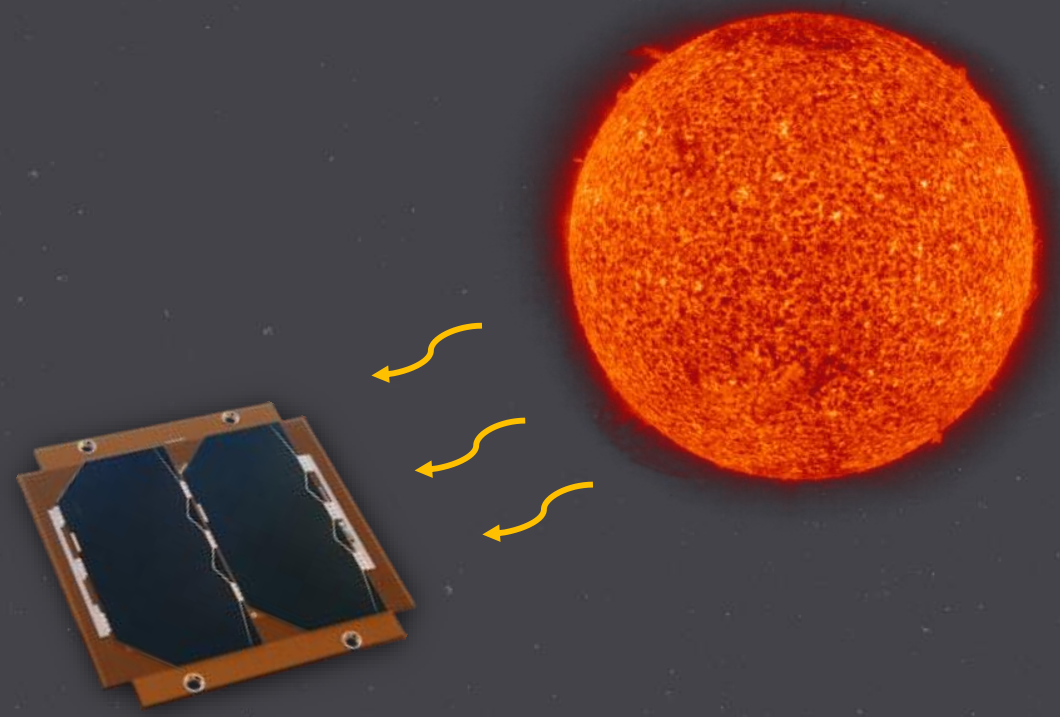
Using different buses.

Security

Short circuits and overcurrent.

Electrical Power System

Energy generation



Triple junction

InGaP/(In)GaAs/Ge

Indium gallium phosphide

Indium gallium arsenide

Germanium

Photovoltaic solar panels

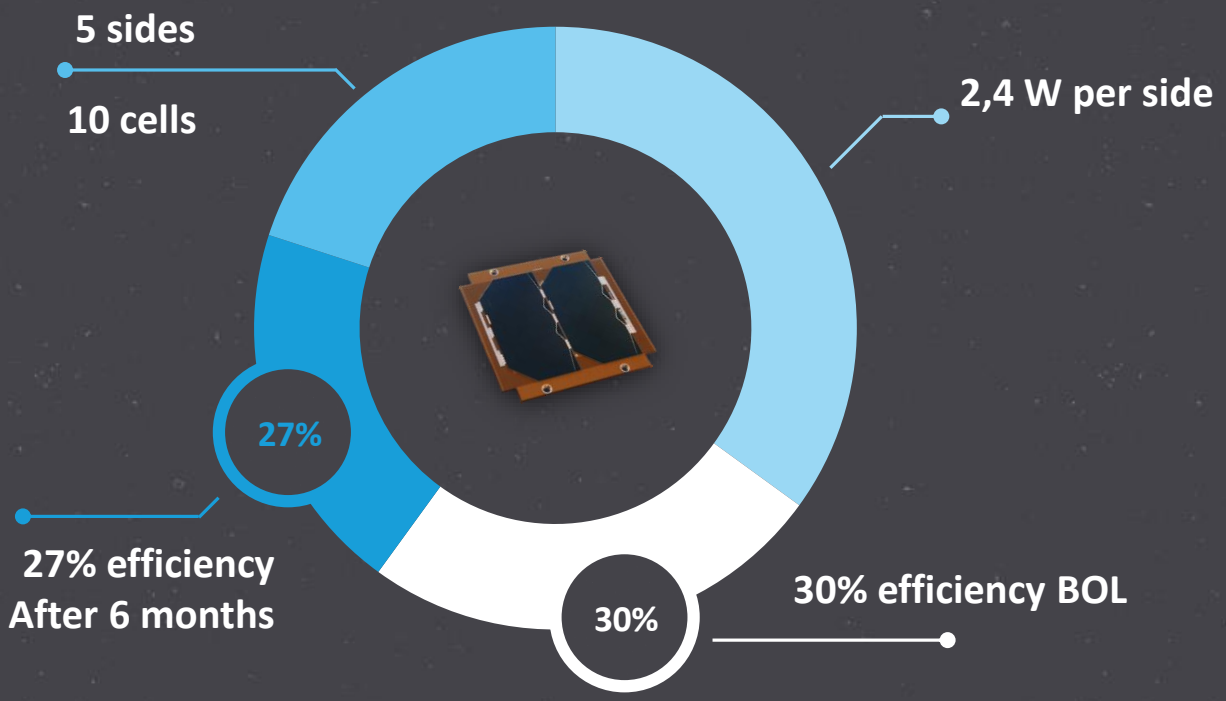
- Convert the solar energy into electrical power
- Light
- Limited energy supply while in eclipse

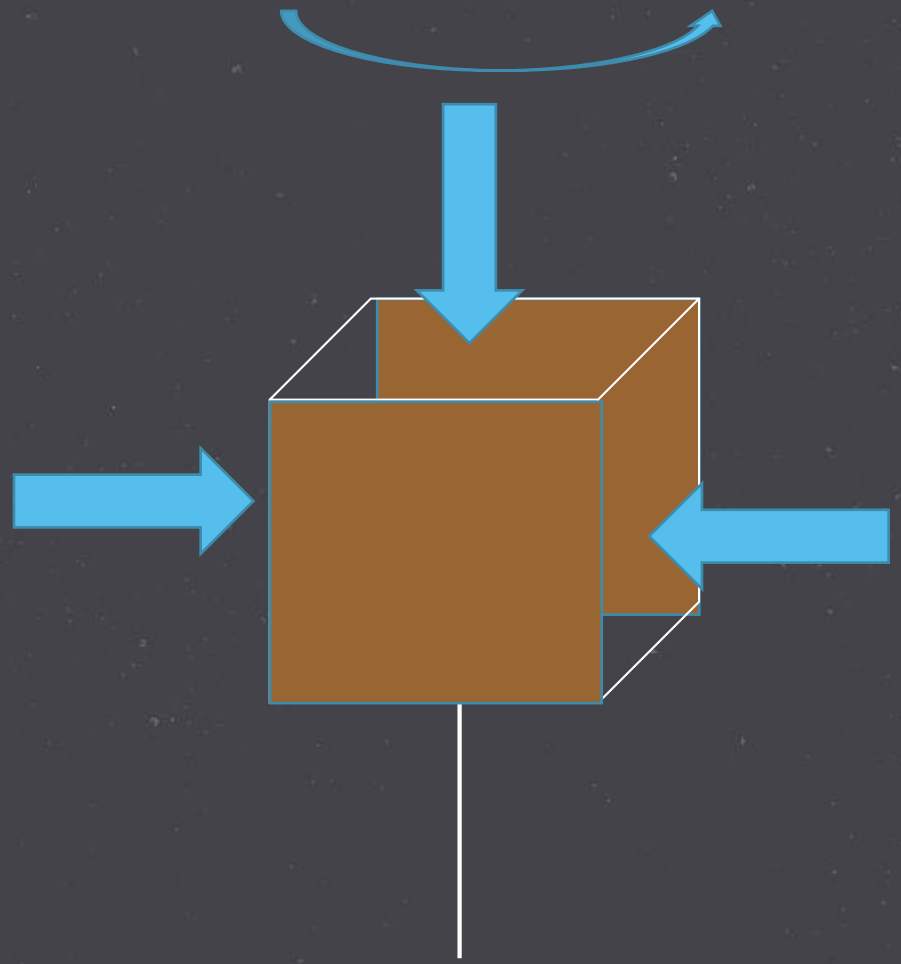
Triple junction solar cells

- Multiple band gaps
- Responds to multiple light wavelengths

Electrical Power System

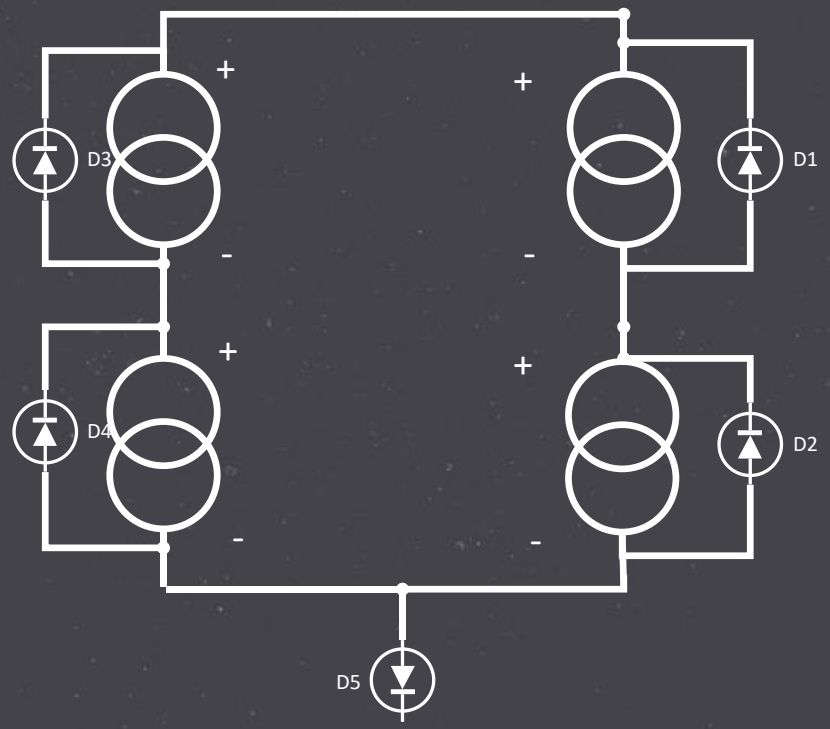
Solar panels





Electrical Power System

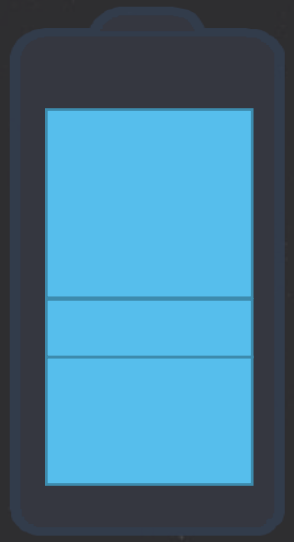
Solar panels



- 2 cells on one side connected in serial
- 2 faces connected in parallel
- By-pass diodes (avoid unnecessary load)
- Diodes to block current from flowing to non-illuminated panels

Electrical Power System

Storage



7,2 Wh

Modules' consumption: 3 Wh during one orbit

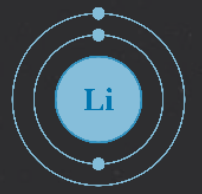
3,6 Wh

At the End Of Life – 20%

3 Wh

Necessary capacity with margin: **7.2 Wh**

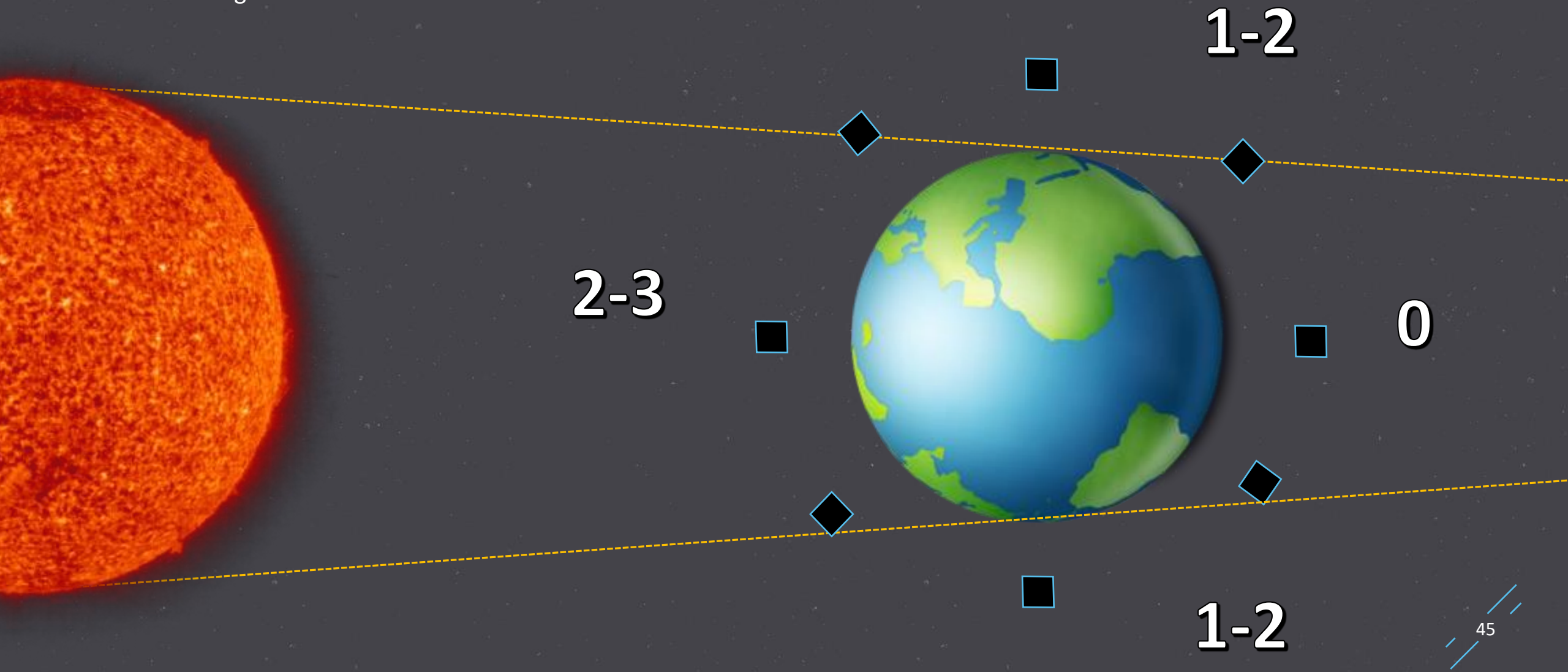
Li-Ion battery



- High energy density
- Must be kept above 0° C

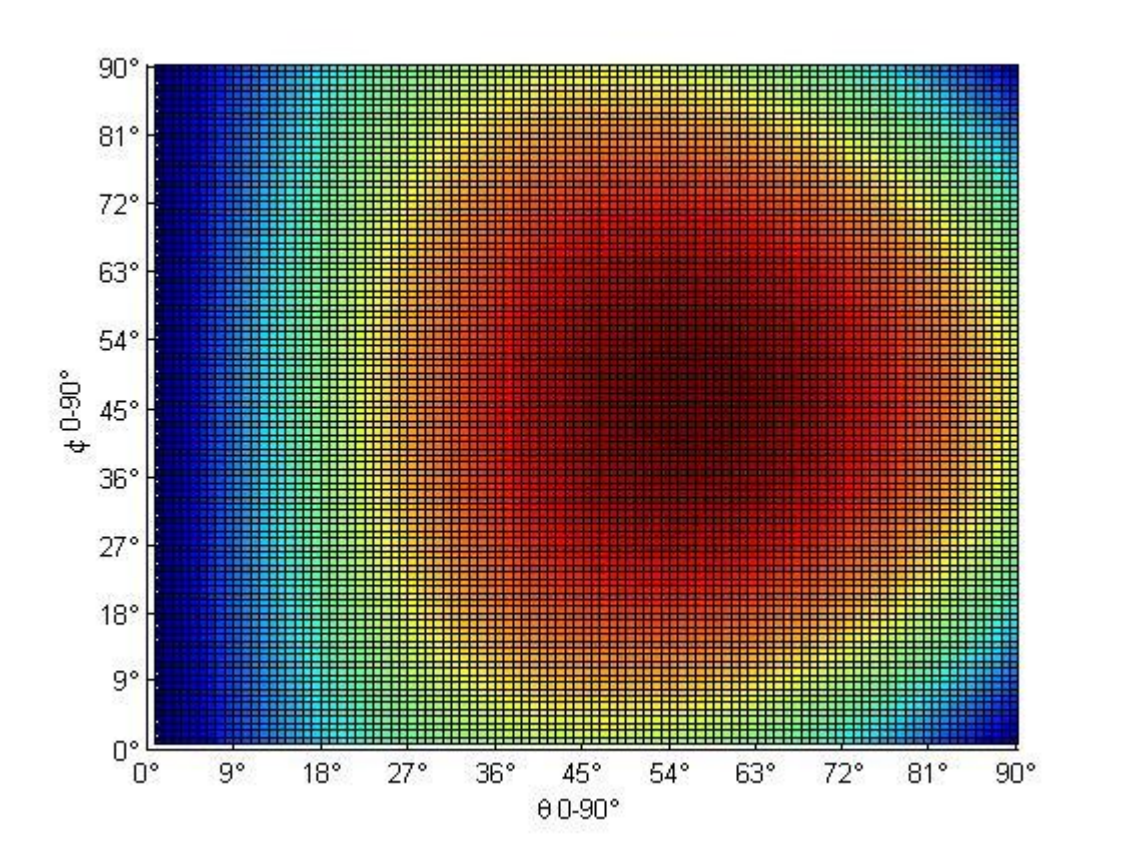
Electrical Power System

Power budget



Electrical Power System

Power budget



Incoming power parameters

- Solar constant ~ 1353 W/m²
- Inclination angles
- Cell surface
- Cell efficiency
- Maximum power point tracking
- EPS efficiency

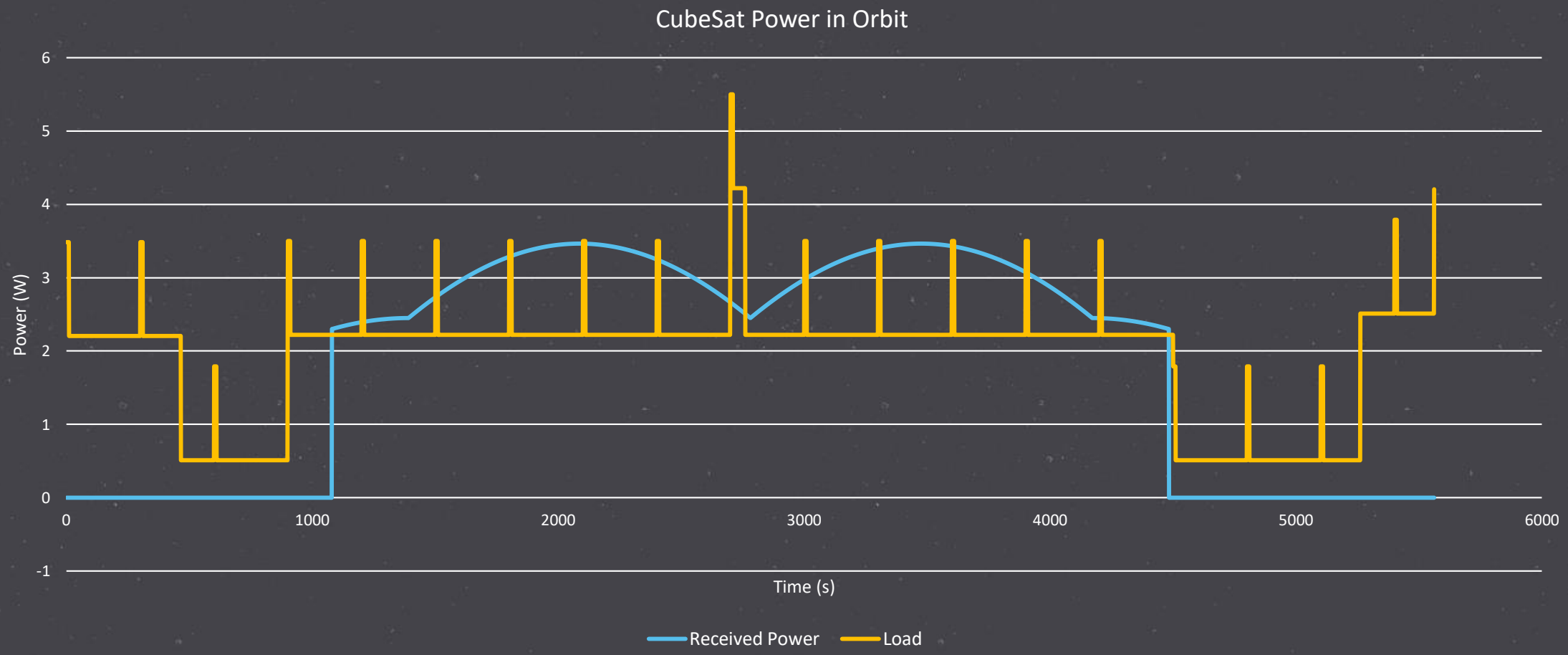
Electrical Power System

Power budget

Subsystem	Active power (mW)	Idle power (mW)	Active time (min)	Idle time (min)
OBC	105	30	12	85
TCS	1698	-	12	85
ADCS	1710	430	10	87
EDT	500	-	1	96
GPS	120	-	6	91
Heater	250	-	~36	~61

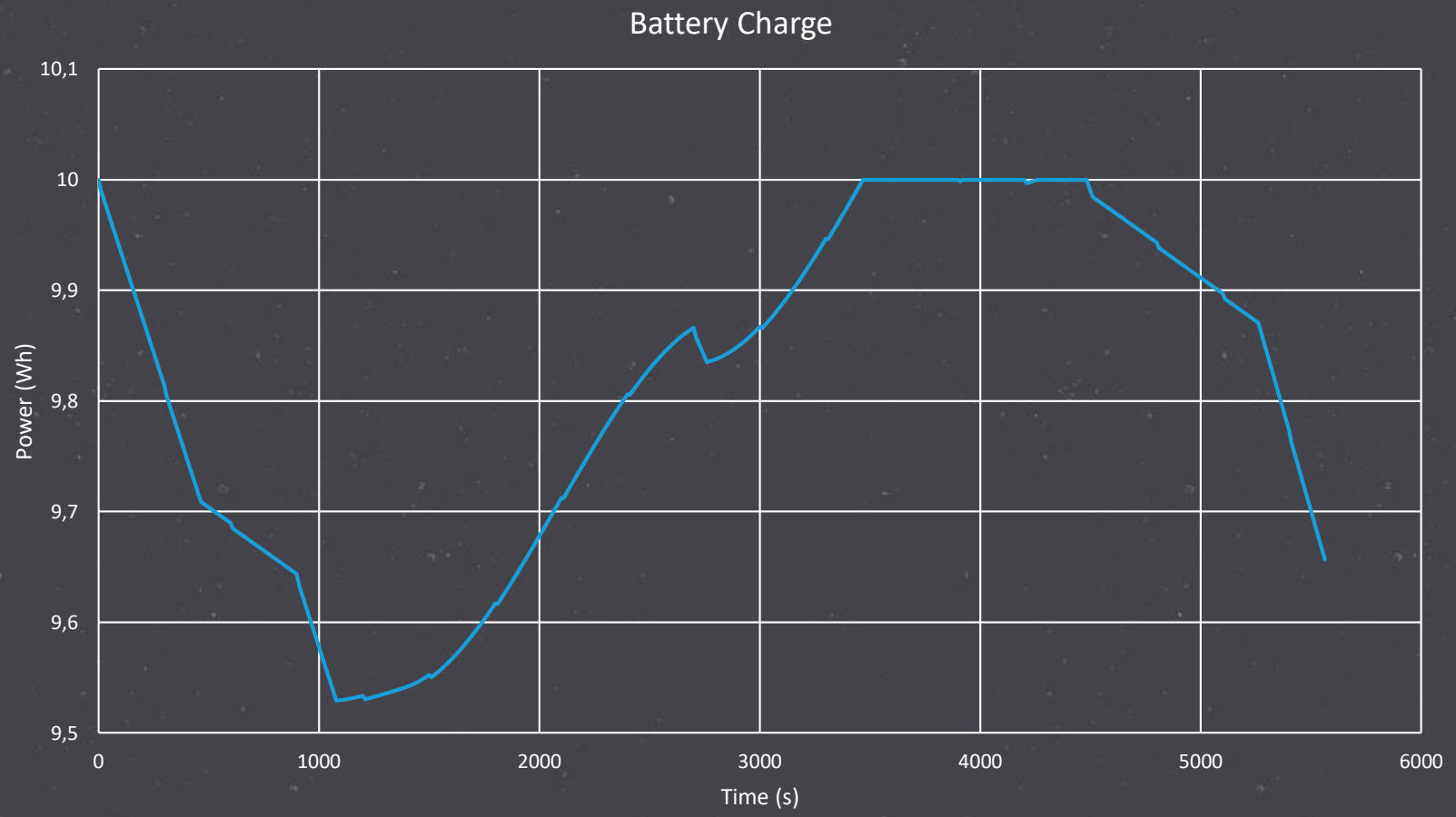
Electrical Power System

Power budget



Electrical Power System

Power budget



Battery requirements

- Fully charged before eclipse
- Consider high power consumption from modules
- Consider PV and battery EOL

Electrical Power System

Hardware

Microcontroller

Low power consumption

I2C compatible

High resolution ADC

ATxMEGA32A4

Current sensors

Low power consumption

I2C compatible

Short cirtcuit detection

Overcurrent detection

INA219B

Electrical Power System

Hardware

MPPT

DC/DC Converter

Step up voltage from 0-4.84 V to 5V using MPPT algorithm

SPV1040

DC/DC Converter

Step down voltage from 5V to 3.3V

LTC3614

DC/DC Converter

Step down voltage from 8.2V to 5V and 3.3V

PicoTLynxTM 4A

DC/DC Converter

Step up voltage from 5V to 10V

PT5546

EPS Schematics

- I2C interface
  To interconnect all subsystems together

- I2C interface
  To connect the sensors

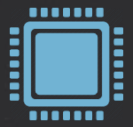
Please have a look at the figure 2

Electrical Power System

Operation modes

	Modes	Description
Startup	Startup mode, used only once at the 1st start of the CubeSat.	**Startup mode** • Start the OBC and other modules when needed
Survival	Survival mode, used to save power.	**Survival mode** • Save power • Start an internal timer to wake up OBC
Normal	Normal mode, used to power modules normally.	**Normal mode** • Check for overcurrent and short circuits and warn the OBC • Calculate the power level of the battery and solar panels • Calculate the power consumption and warn the OBC

Specifications



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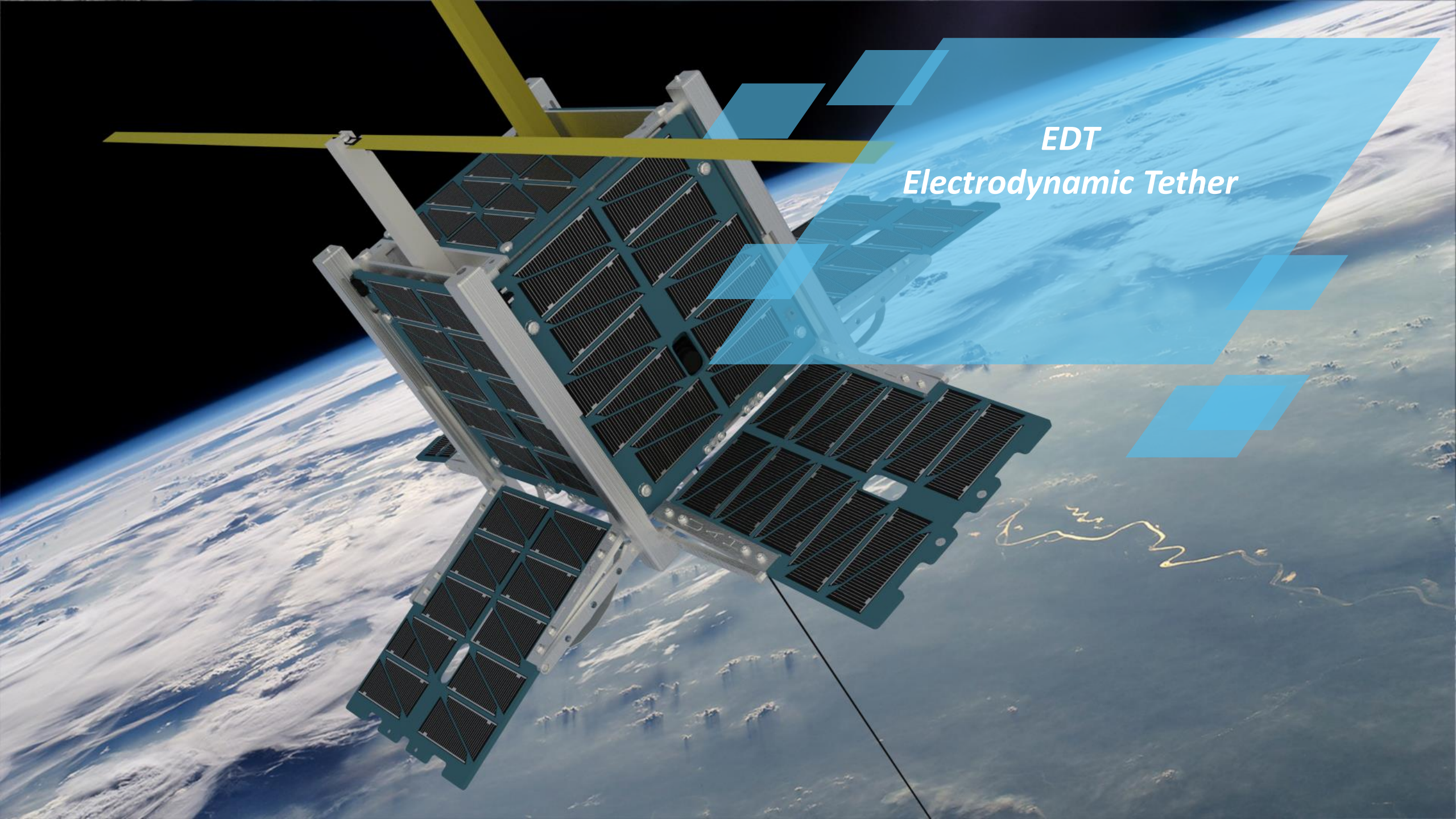

EDT
Electrodynamic Tether

Electrodynamic Tether

Functions

Deorbitation

Through electromagnetic interaction

Technology demonstrator

Electrodynamic tether

Science

Impacts of electromagnetics interactions

Security

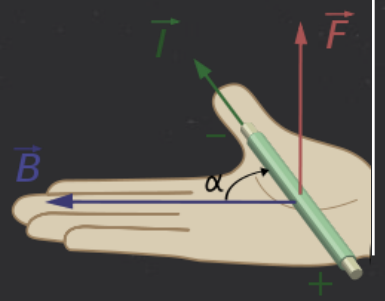
Protection of the other systems from the payload

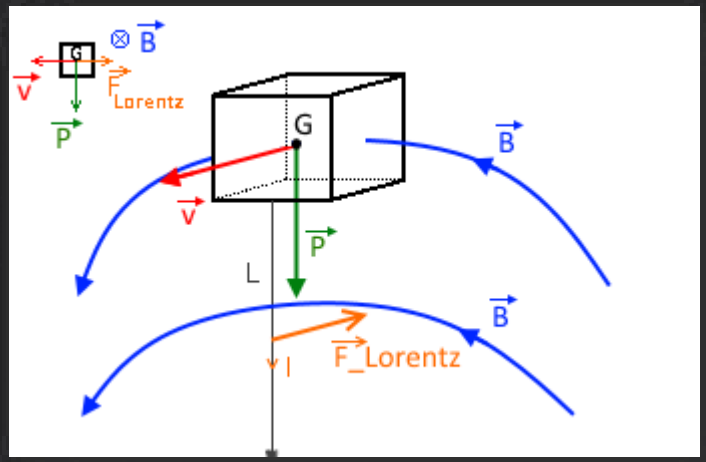
Electrodynamic Tether

Presentation

- Deorbitation through electromagnetic drag

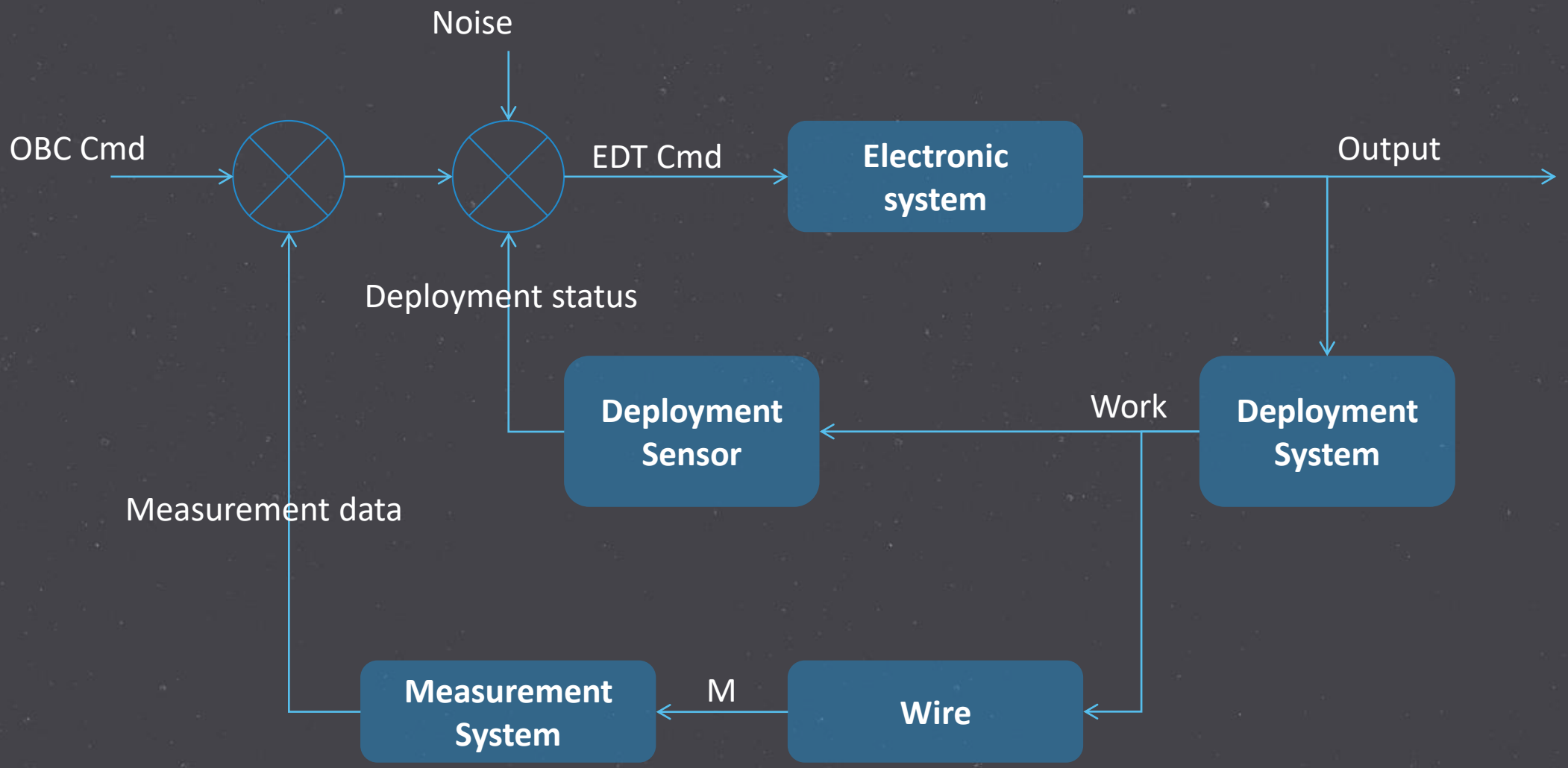
$$\overrightarrow{F_{Lorentz}} = \vec{I} \int \overrightarrow{dl} \wedge \vec{B}$$





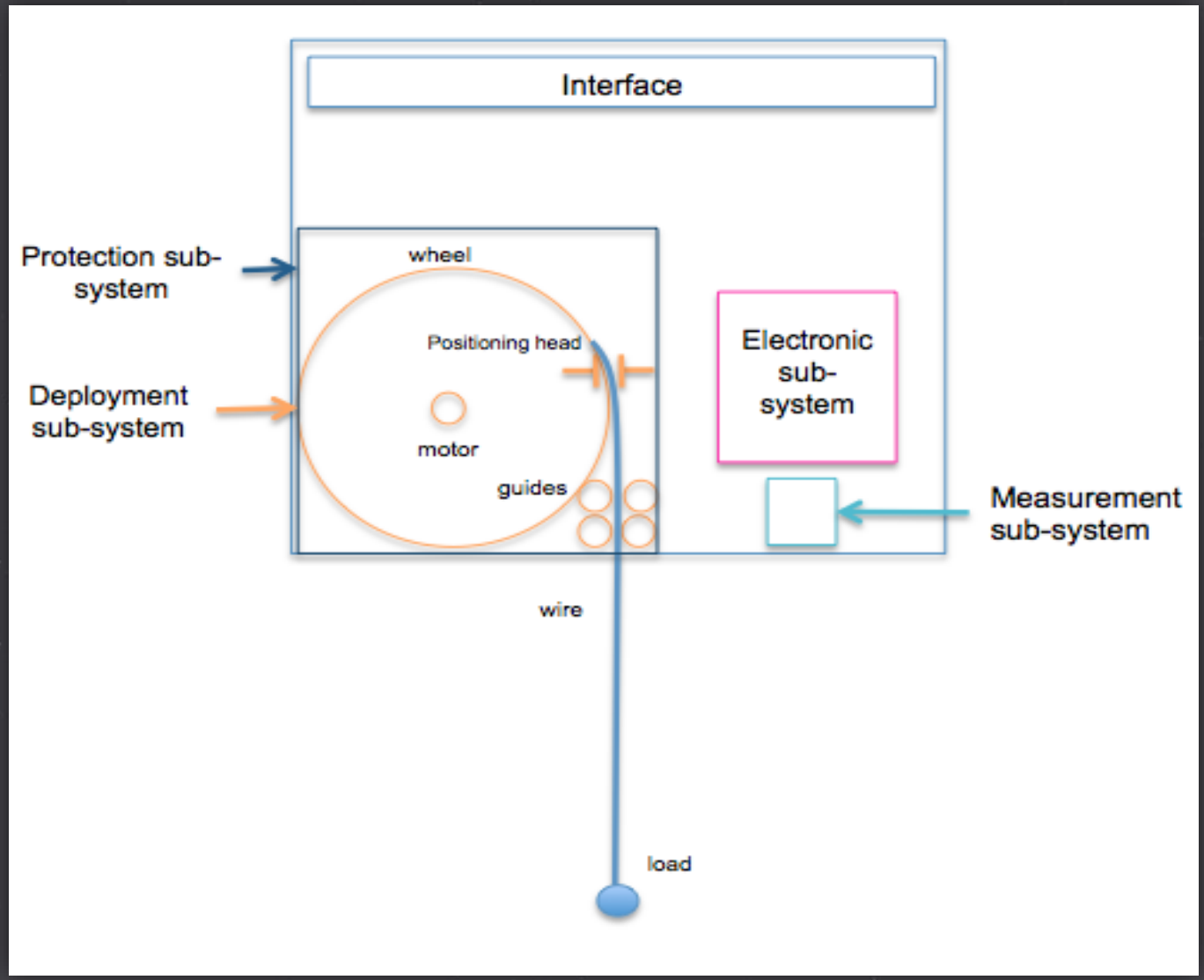
Electrodynamic Tether

Functionning chain



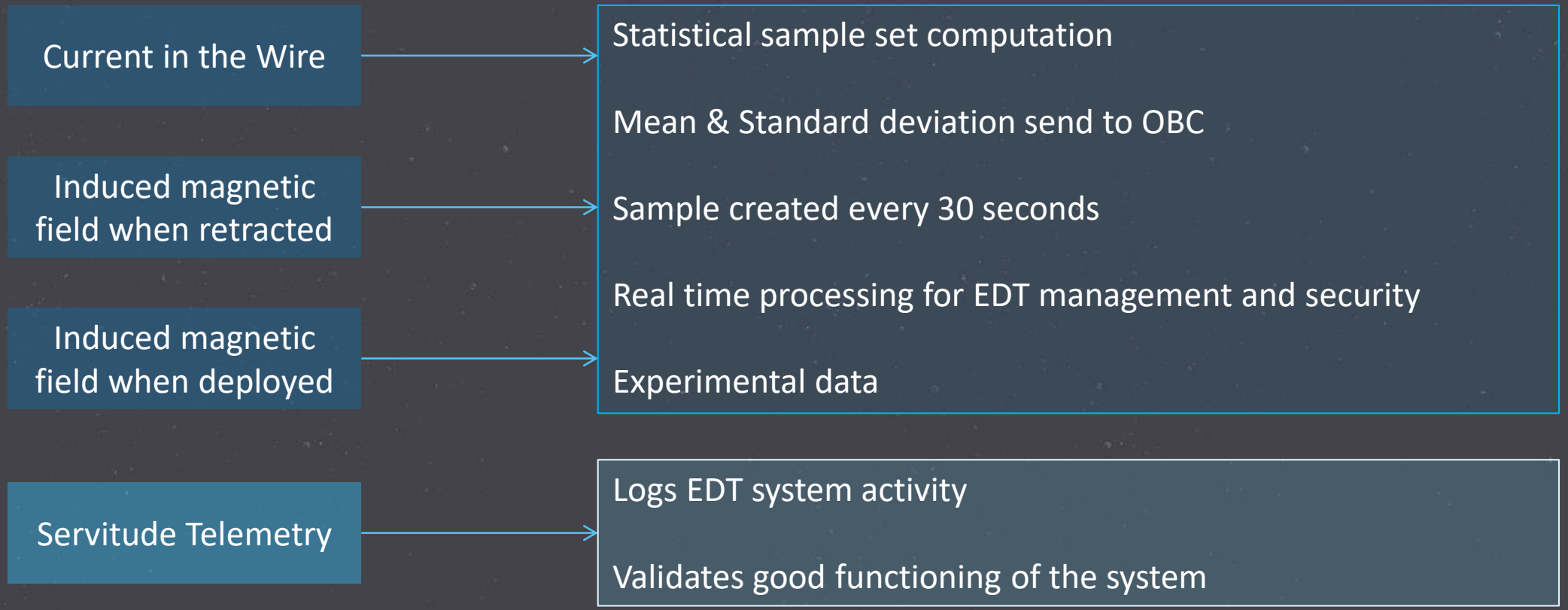
Electrodynamic Tether

Preliminary Design



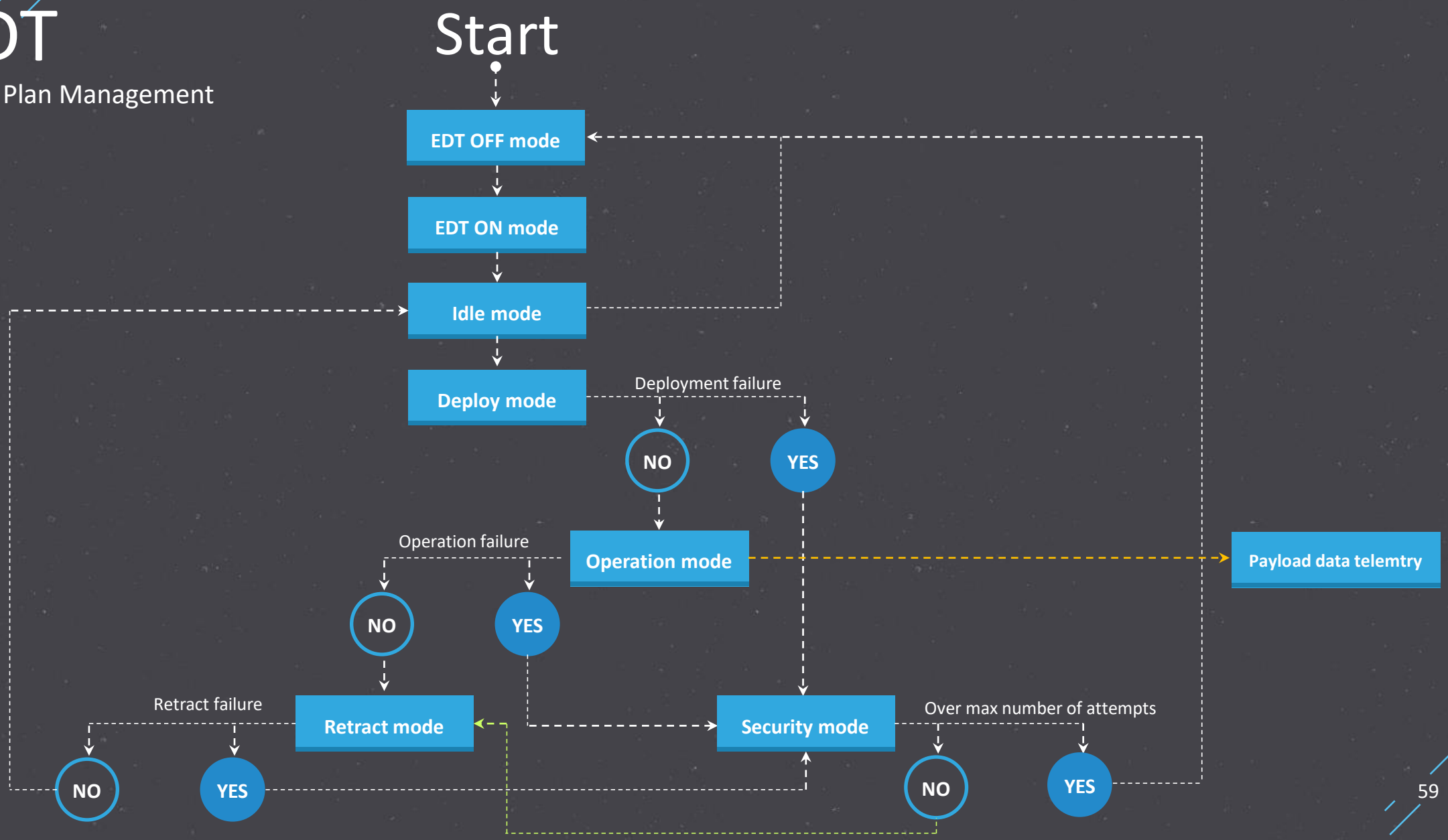
Electrodynamic Tether

Telemetry

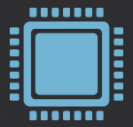


EDT

Work Plan Management



Specifications



OBC

The On Board Computer, make all the calculations and take all decisions.

GPS

Retrieve the position of the CubeSat.

EPS

The Electrical Power System generate, store and distribute energy.

EDT

Electro Dynamic Tether realize the deorbite.

TCS

The Telecommunication System, link the Earth and the CubeSat.

GS

Ground Station, is the Earth station, tracking the CubeSat.

ADCS

The Atitude Determination and Control System, manage the movement.

UI

The User Interface, gather all the data's received.

TCS & GS
Telecommunication System
Ground Station

Telecommunication System

Functions

Communication handling

With the Earth.

Package handling

Build frames.

Link with the OBC

Send data to the OBC.

Ground Station

Functions

Track the CubeSat

Steer the antenna to the CubeSat thanks to a rotor.

Send orders

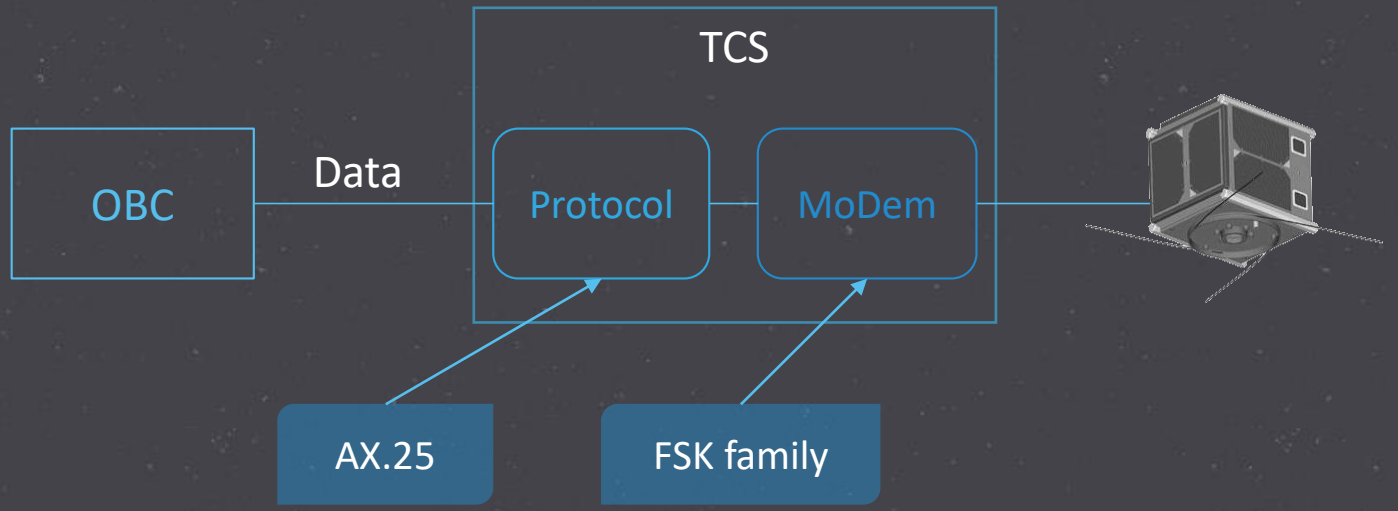
To the CubeSat.

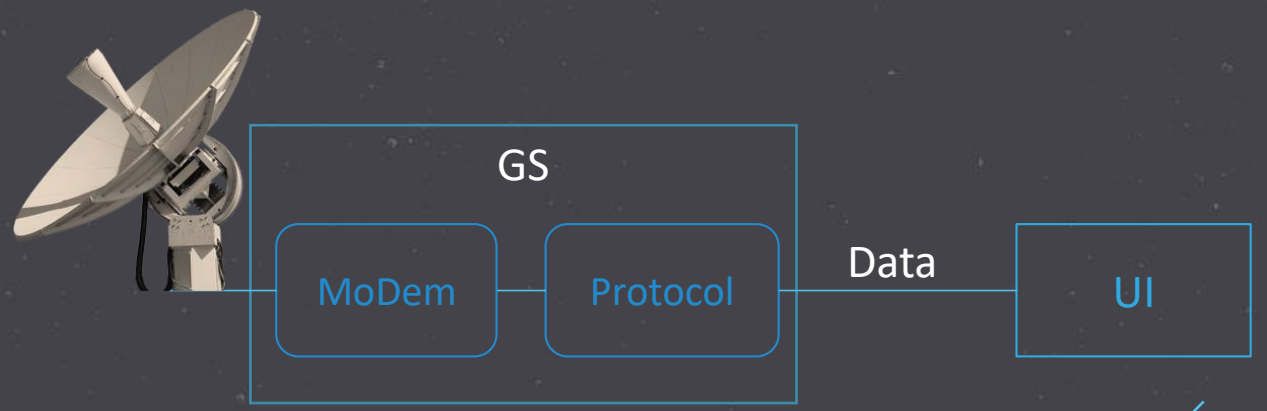
Link with the UI

Share data with the UI.

TCS - GS

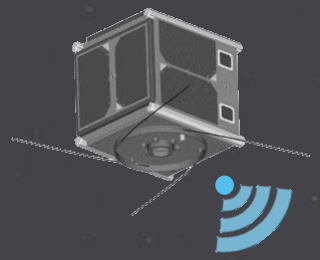
Communication handling





TCS - GS

Communication details



Downlink: 435-438 MHz (UHF)

UHF & VHF

Satelites Radio Amateur Frequencies

- No licence required (free to use)
- IARU coordination highly recommended
- Most common frequencies used with CubeSat

Uplink: 144-146 MHz (VHF)

TCS

Antenna

	Reception (144-146 MHz)	Emission (435-438 MHz)
Type	Dipole lambda/4 minimum	
Length (monopole)	25 cm for lambda/4 50 cm for lambda/2	8,75 cm for lambda/4 17,5 cm for lambda/2
Gain	~ 0 dB	
Directivity	Almost omnidirectional	
Power	~ 1W (<1,5W)	

GS
Antenna

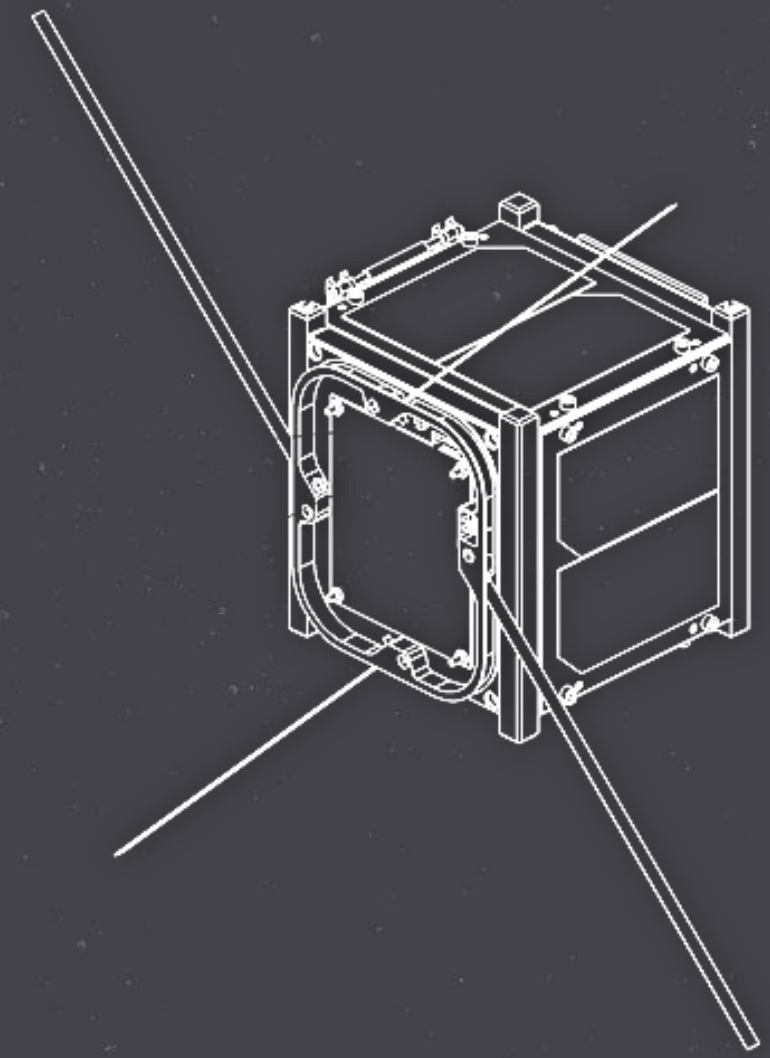
	Reception (435-438 MHz)	Emission (144-146 MHz)
Type	Yagi circular polarization	
Length	2,8 m	3,5 m
Gain	16 dBi	13 dBi
Directivity	Directional (26° at 3dB)	
Power	~ 75W	
Material	Aluminium + plastic	

Telecommunication System

Antennas deployment system

Working principle

- Antennas with shape memory
- Antennas wrap around a sub-chassis and blocked with a wire
- An electrical wire burning deployment system



Telecommunication System

Hardware

Microcontroller

Low power consumption

I2C compatible

Full duplex transiver

Filtering capacities

ADF7021-N

TCS Schematics

USART interface
To connect with the OBC

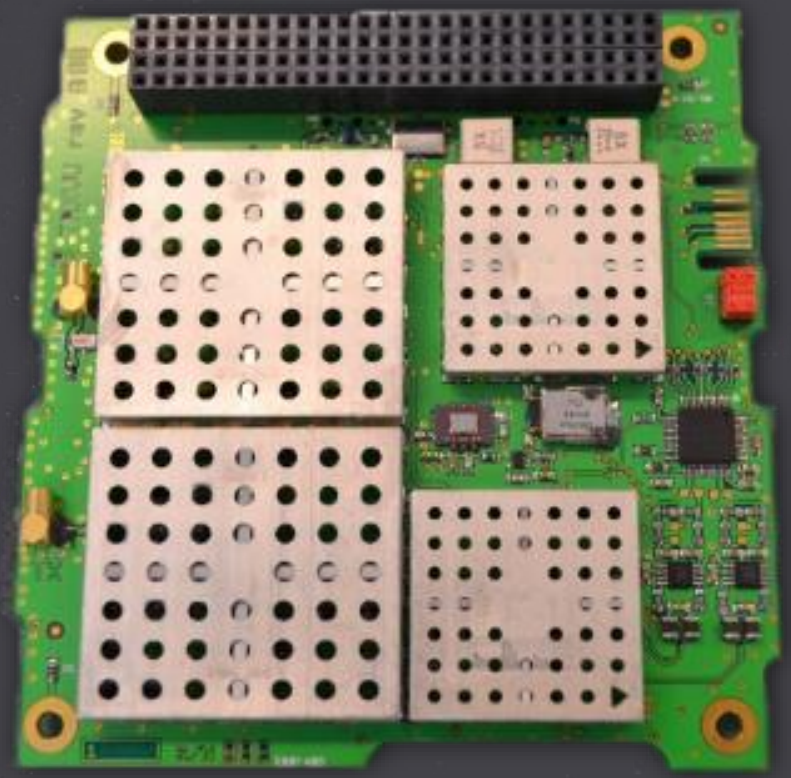
I2C interface
To connect sensors

Modulation 436MHz - Demodulation 144MHz
Standard to communicate with the Earth

Please have a look at the figure 3

Telecommunication System

Existing products



ISIS UHF downlink / VHF uplink Full Duplex Transceiver

www.cubesatshop.com

CubeSat / small satellite UHF downlink, VHF uplink full-duplex transceiver, adds telemetry and telecommand capability to your mission in a single board. Available in 1200 bps to 9600 bps downlink datarate, and AFSK uplink.

Telecommunication System

Operation modes

	Modes	Description
Startup	Startup mode, used only once at the real 1st start of the CubeSat.	**Startup mode** • Deploy the antenna burning the paste
Sleep	Sleep mode, used to save power.	**Sleep mode** • Save power
Normal	Normal mode, used to send packets to the Earth	**Normal mode** • Receive packets from the Earth and transmit it to the OBC • Receive data from the OBC, frame it and send it to Earth • Calculate the CRC of the packet sent to the Earth

Beacon mode:

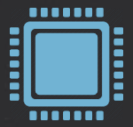
- High priority information
- Less prone to disturbances
- Amateur community

Transmission mode:

- Higher data rate
- More prone to disturbances
- Visibility required

Transmission mode Beacon mode

Specifications



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The User Interface, gather all the data's received.

UI
User Interface

User Interface

Functions

Print CubeSat sensor information

Receives, stores and prints all data from the CubeSat

Send orders

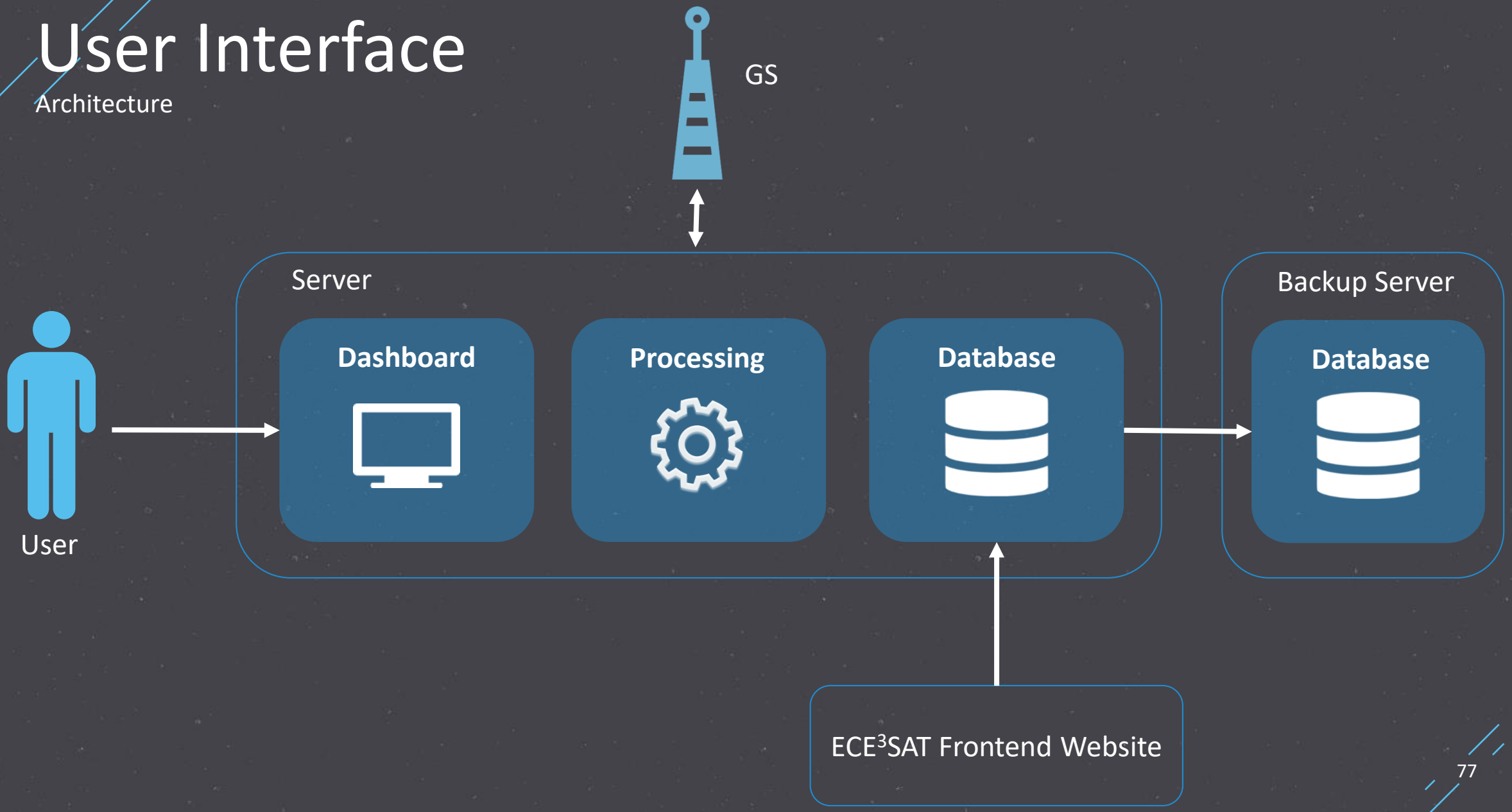
To the CubeSat

Store and analyse received data

Publish logbook of the mission

User Interface

Architecture



User Interface

Dashboard

Print data from the CubeSat

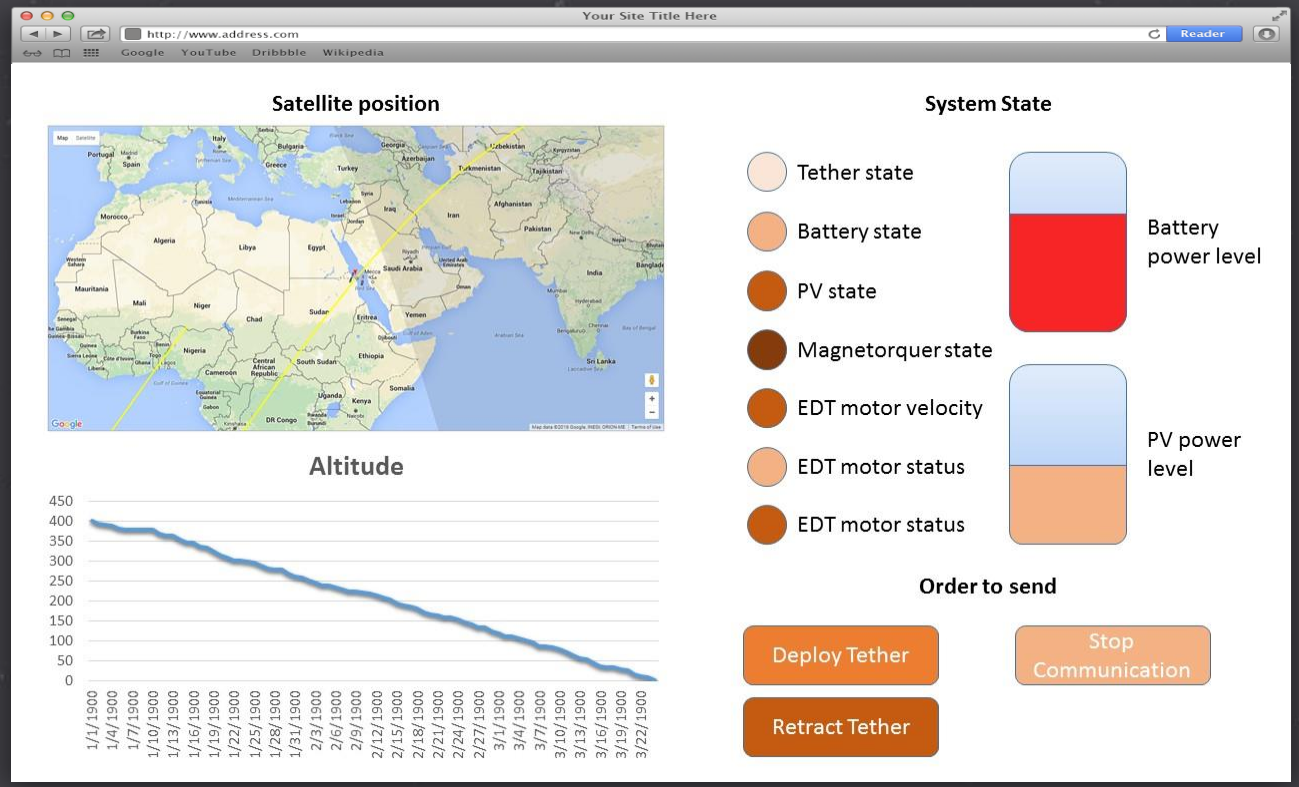
- CubeSat altitude and position
- Status of each sensor onboard

Send order to the CubeSat

- Deploy or retract the tether
- Stop communication temporarily

Store and analyse data

- Stores acquired data
- Analyse data and create report on different indicators
- Create mission logbook




05. Retrospectives

Retrospectives

Achievements

PHASE 0 Technical Objectives

- A clear project definition
- Validated Requirement document (reviewed)
- Validated Technical specification document (in review)

PHASE 0 Management Objectives

- Initiate partnerships
- Project strategy over 5 years
- Set up a fixed project environment

06. Project Strategy

Project Strategy

Overview

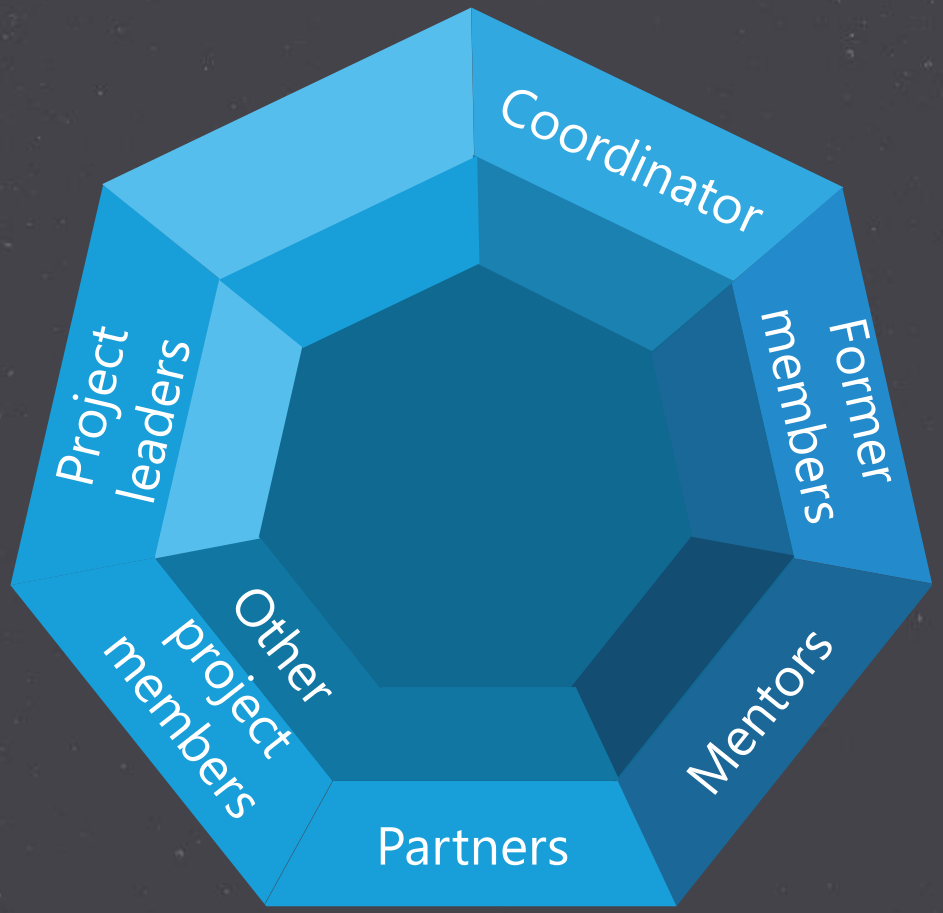
- Coordination Board
- Planning and project division
- Project environment
- Phase transitions
- Evolution perspectives

Project Strategy

Coordination Board

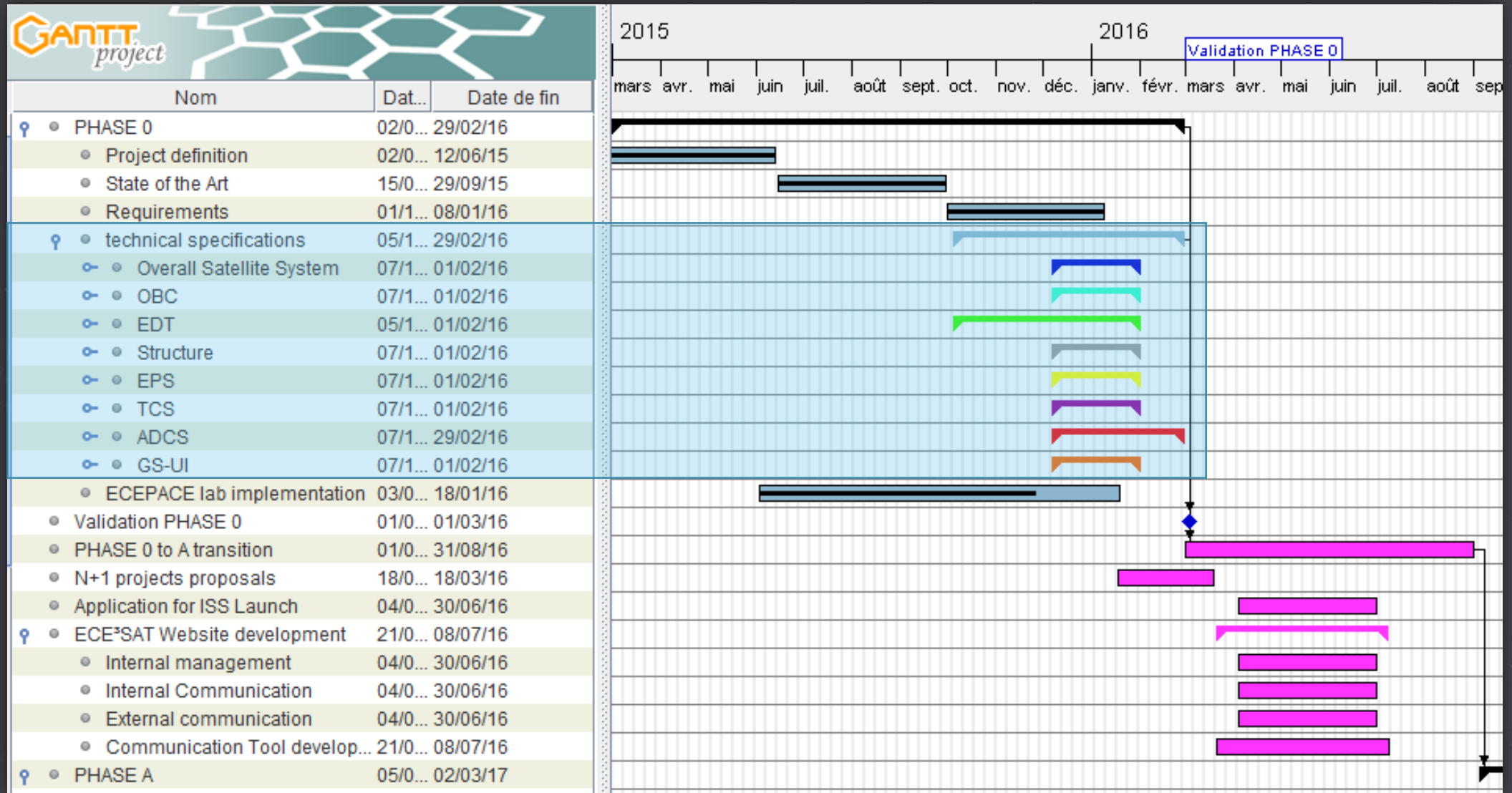
Objectives

- Ensure all the projects are working with each other
- Ensure the integration of the different projects
- Optimize communication between the groups
- Interface with partners and administrations



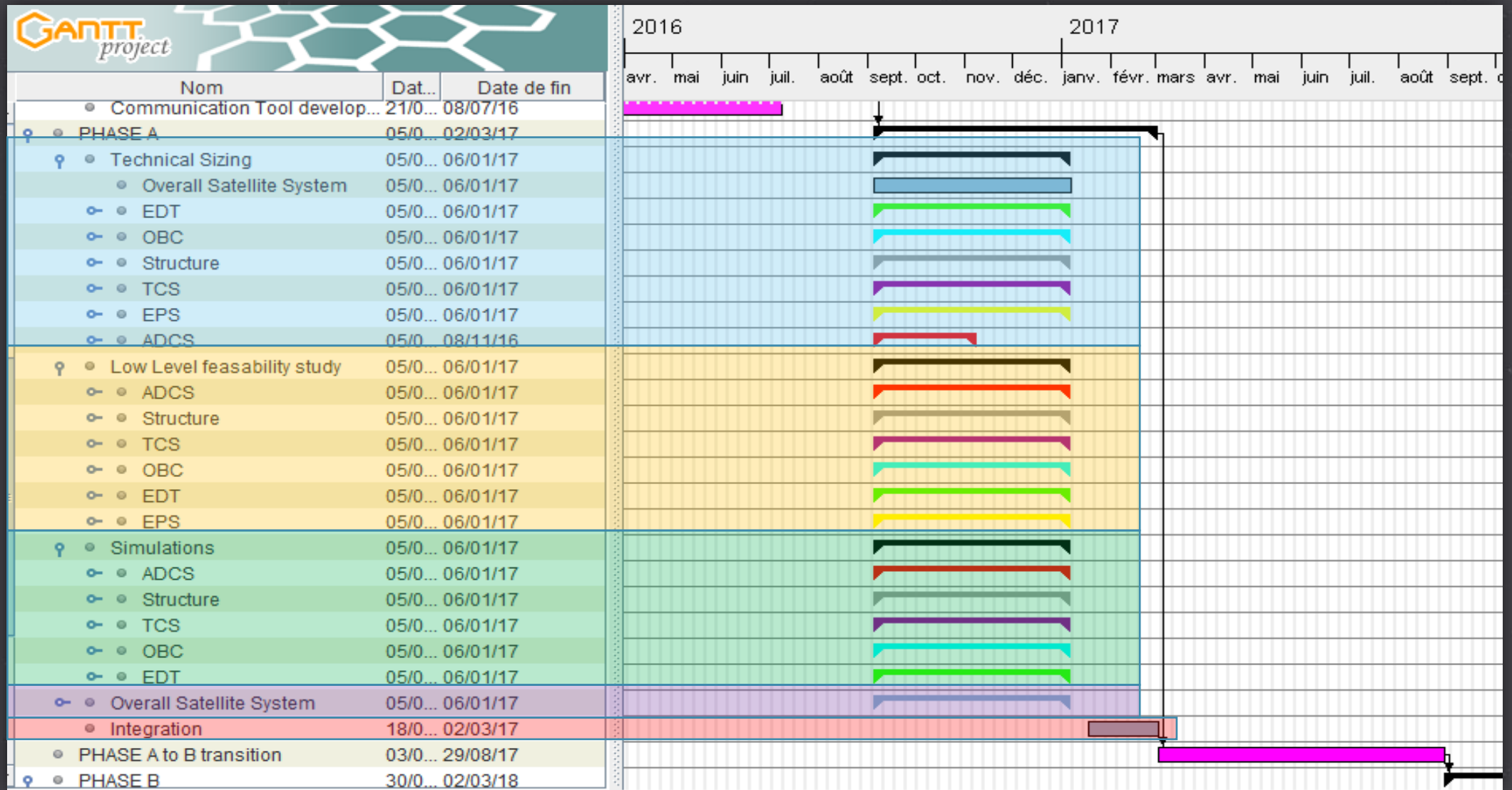
Project Strategy

Planning and project division



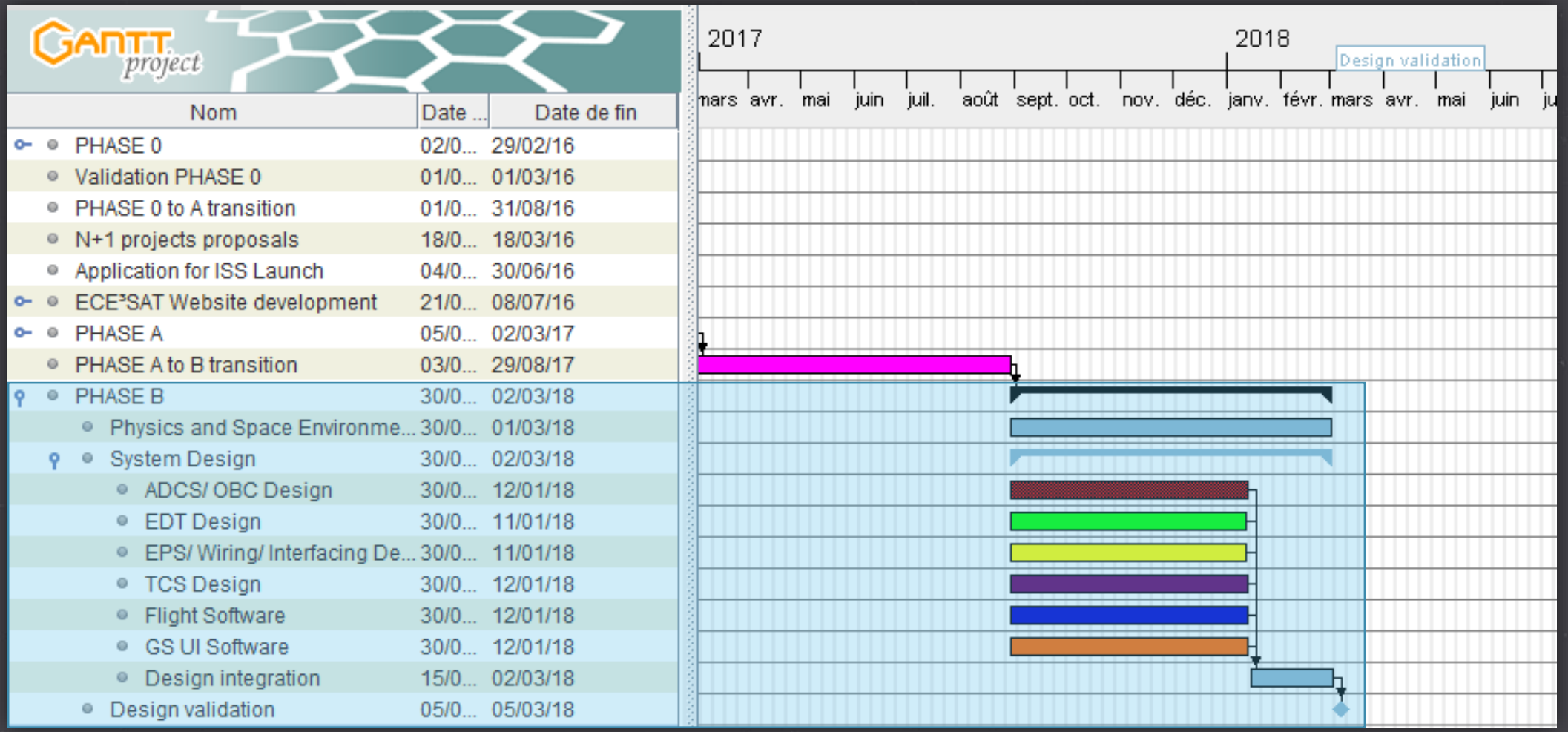
Project Strategy

Planning and project division



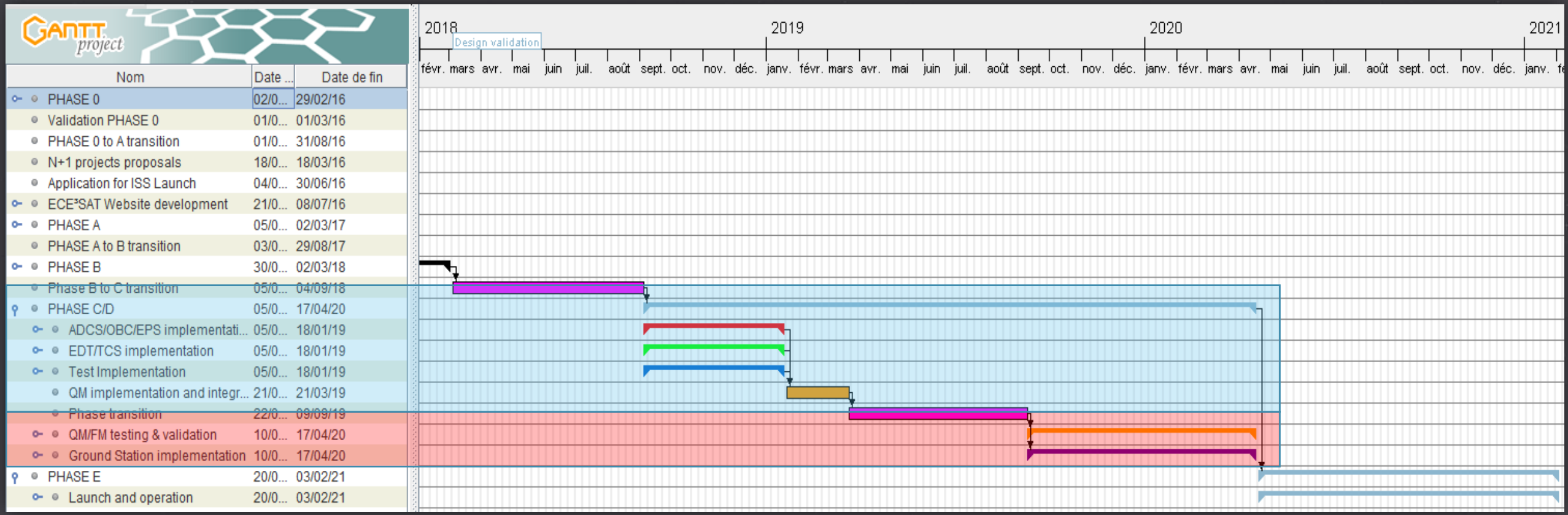
Project Strategy

Planning and project division



Project Strategy

Planning and project division



Project Strategy

Ressources

- Coordination Board
- ECEPACE Lab
- Creation of a new cluster within ECE

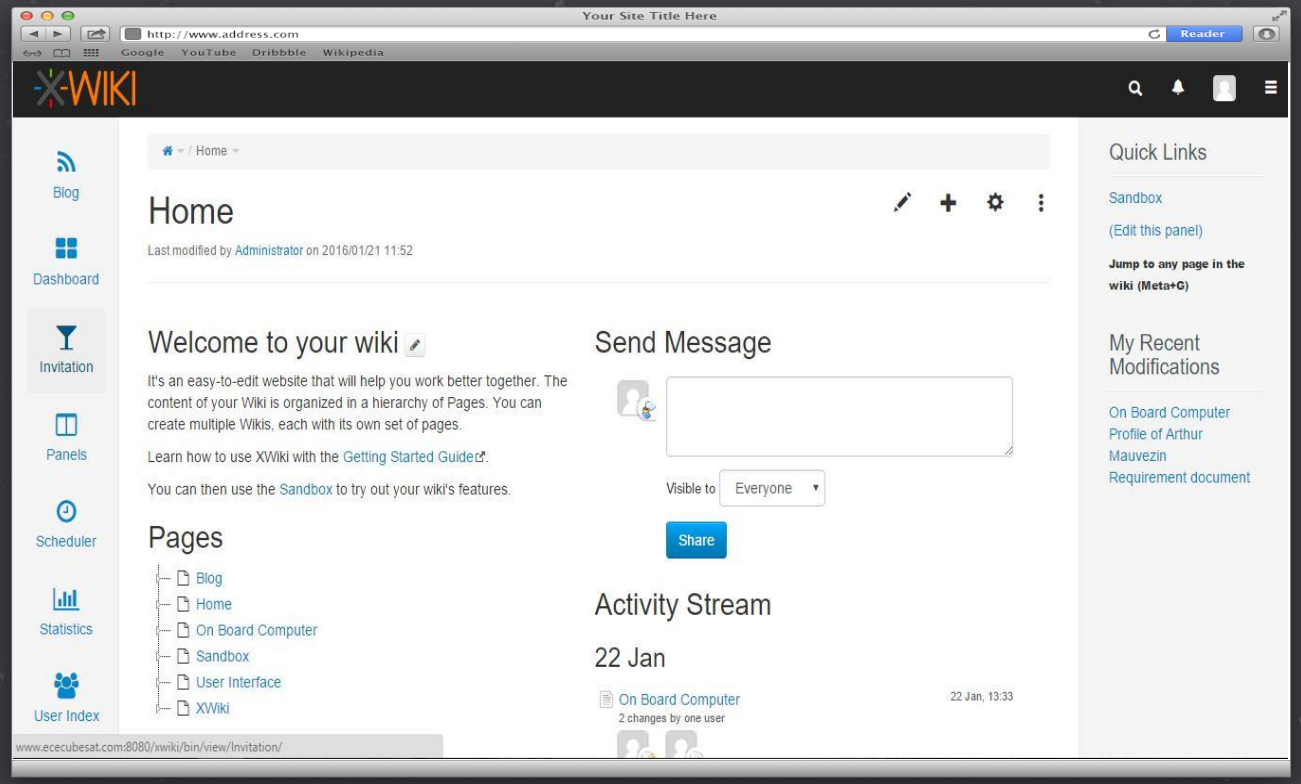
Project Strategy

Communication

- Xwiki Platform

Communication tools

- Task management
- External website
- Internal communication



Project Strategy

Phase transition

How to ensure continuity during summer break ?

- Internships
- PhD
- Apprentice
- Start-up from PHASE B

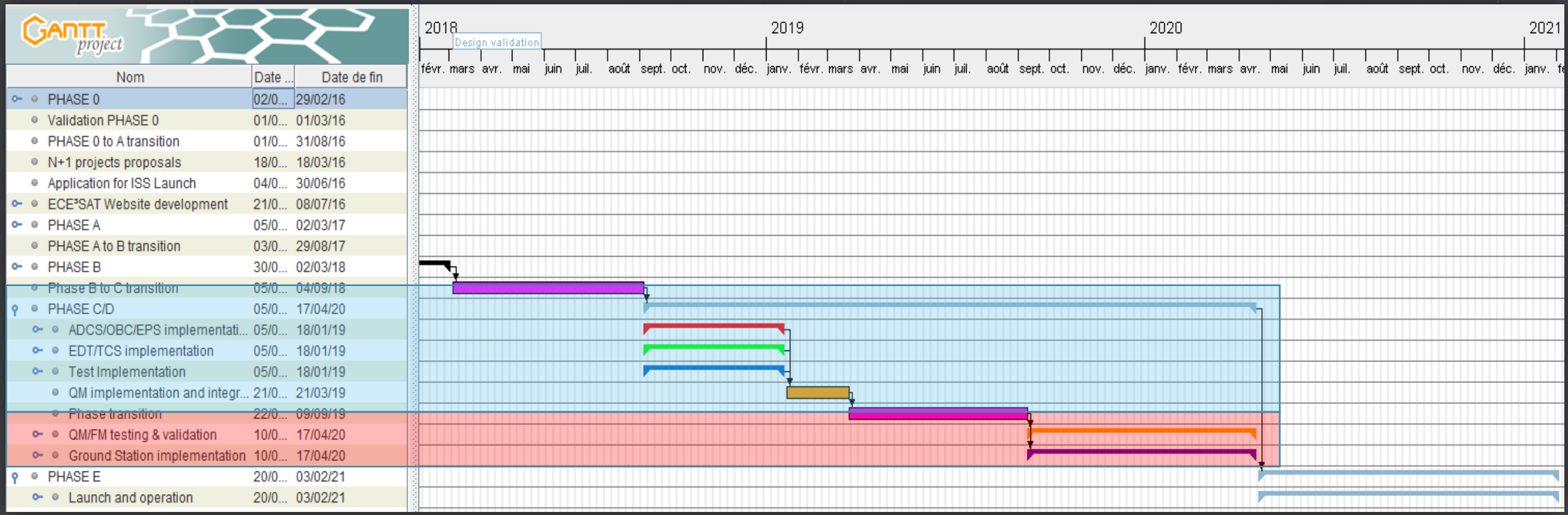
Project Strategy

Evolution perspectives

- Start-up creation from PHASE B
- Patent on EDT
- Open-source satellite
- Integration of a “Campus Spatial”

Project Strategy

Planning and project division



Project Strategy

Futur partners

Thank you for your time

Questions?