AFDEVSAT.ICD.001.01

Interface Control Document

Sunday, February 26, 2023

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Document Versions

Version	Description
1.1	Initial version

1. Introduction

The main scope of the project is to develop hyperspectral-imaging satellite using collaborative capabilities of 6 African countries.

1.1. Scope

This document describes the hardware and the software interfaces of AFDEVSAT 6U CubeSat in conjunction with the specifications of the satellite platform and its payloads.

The project aims to achieve the following objectives:

1. To build and launch a satellite (0.1m X 0.2 m X 0.3 m) for enhanced imaging capabilities (hyperspectral) with 24 months lifetime.
2. To demonstrate the operation of satellite subsystems developed in Africa.

The operation of the satellite will be based on ground control station at participating African countries.

PART 1: SATELLITE ARCHITECTURE

Satellite Architecture Overview

The spacecraft system is divided into two principal elements: the payload and the satellite bus or its platform. The satellite bus provides the payload with the required resources for its functionality. Thus, the breakdown of the main satellite subsystems is shown in the next figure;

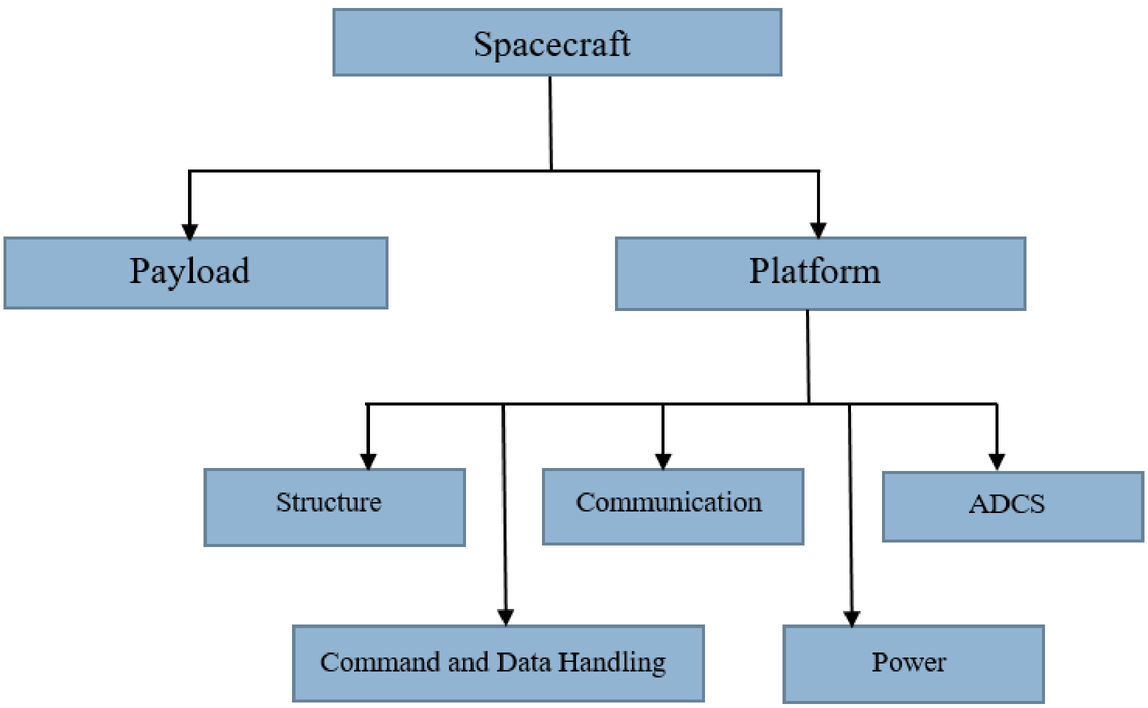


Figure 1: SPACECRAFT SUBSYSTEMS

The architecture of AFDEVSAT is shown in the next figure, it is divided into two main sections:

- Payload section
- Satellite Platform section

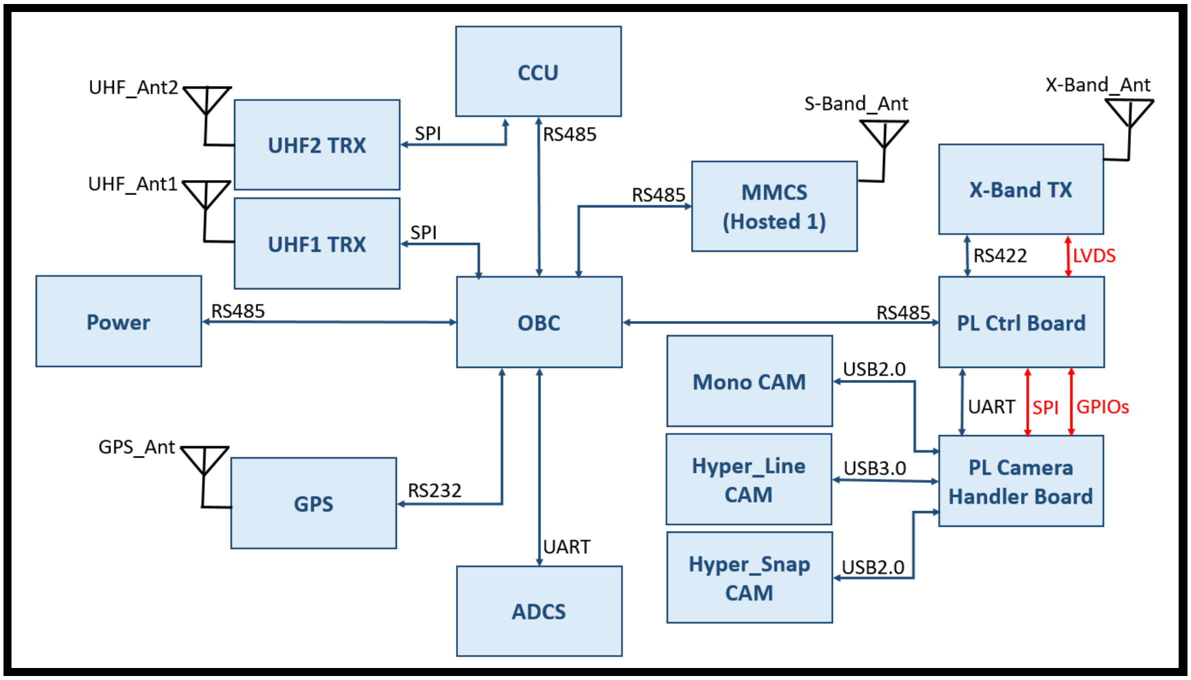


Figure 2: AFDEVSAT Architecture

1.1. Payload Section Components

AFDEVSAT satellite has multi-payloads as it has three remote sensing cameras. This can be listed as follows:

1. Primary Payload: Remote sensing Cameras
   a. Monochromatic Camera.
   b. Hyper Snapshot Camera.
   c. Hyper Line Scan Camera.

1.2. Satellite Platform Section

The platform of AFDEVSAT consists of the following components:

1. Mechanical structure
2. Solar panels
3. Electrical Power Supply (EPS)
4. On-Board Controller (OBC)
5. Attitude determination and control system (ADCS)
6. Centralized Control Unit (CCU)
7. Main UHF module

8. Secondary UHF module
9. X-band Transmitter and its filter
10. GPS
11. Deployment boards
12. Antenna modules
    a. X-Band antenna
    b. UHF antenna
    c. GPS antenna

2. Satellite Bus Specification

The satellite subsystems use the satellite bus to exchange data, telemetry and commands. AFDEVSAT will use stack-through topology for the electrical interface between satellite subsystems with 52 pins distributed in two rows as described in the next subsections.

2.1. Subsystems Boards Specifications

All satellite subsystem boards (OBC, CCU, EPS and PL) that will be connected to the satellite stack must follow the board dimensions as shown in the next figure.

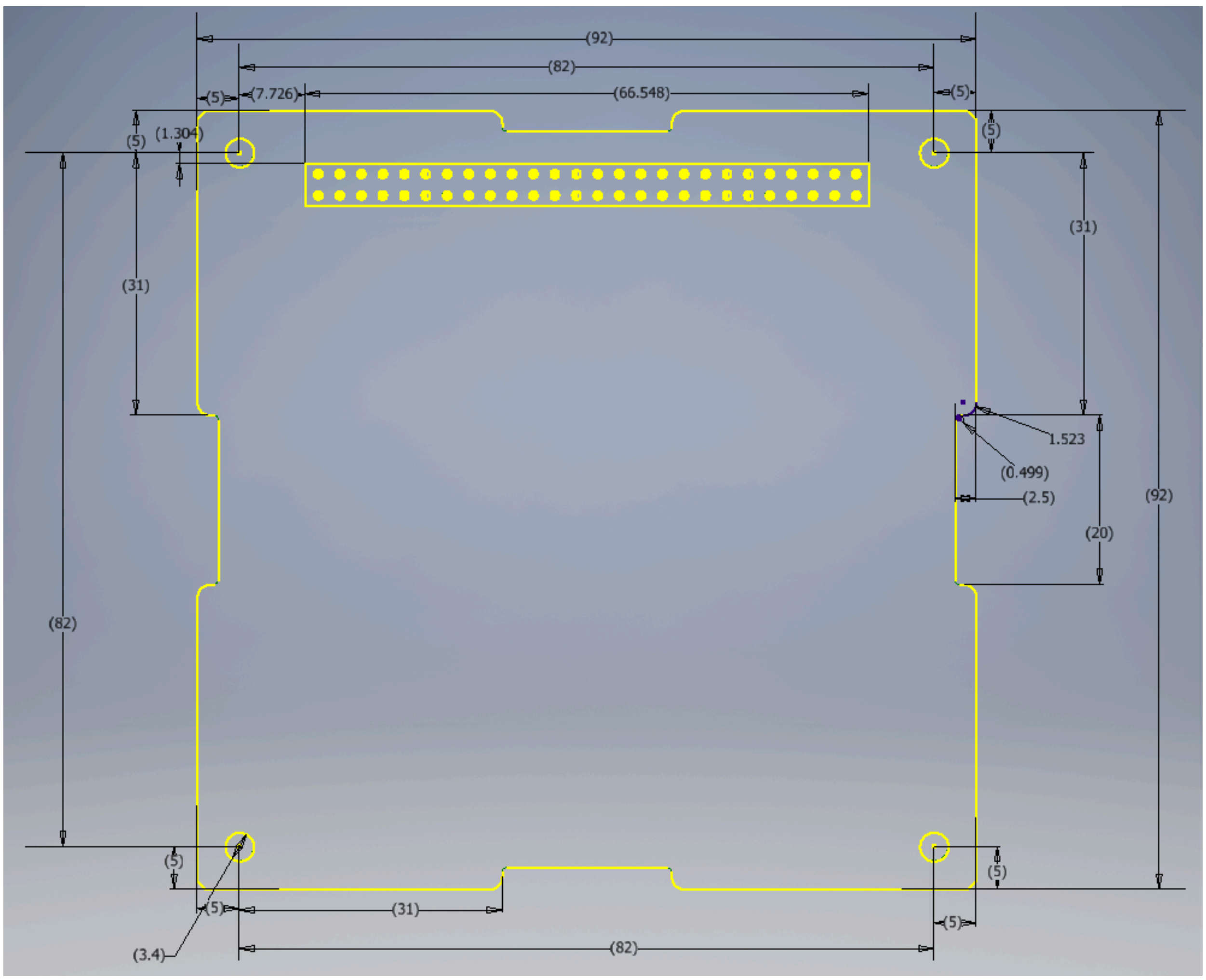


Figure 3: Board Mechanical Layout

2.2. Main Connector Specifications

The main connector between subsystems boards is a 52 Position Elevated Socket Connector 0.100" (2.54mm) Through Hole Gold as shown in the next figure. It has (part NO. ESQ-126-38-G-D) in Samtec Inc. and will be used as satellite stack connector.

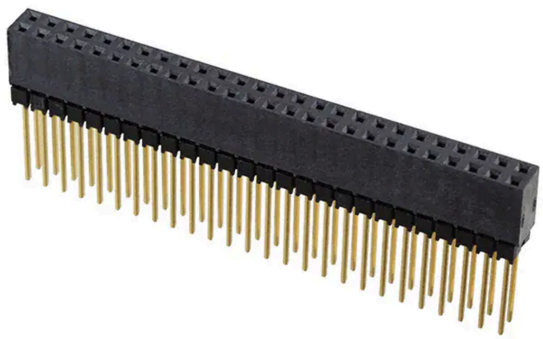


Figure 4: STACK-Through 52 Pin

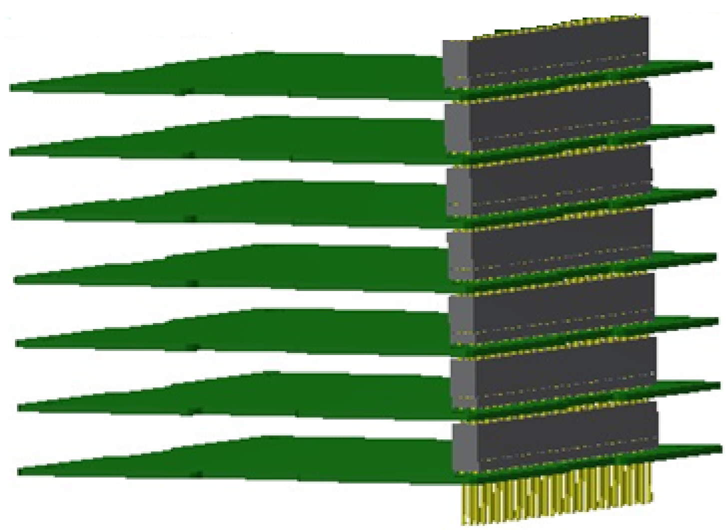


Figure 5: Subsystems Boards in the Stack

2.3. Electrical Specifications

The next table lists the pinout of the 52 stack-through which represents the mechanical interface of the satellite bus.

Table 1: Satellite Bus Electrical Interface

PIN Name	PIN NO.	PIN NO.	PIN Name
PWRL0 (3V3 OBC)	1	2	PWRL15 (3V3 UHF)
GND	3	4	**GND**
PWRL1(5V GPS)	5	6	SPI_2_MISO
PWRL2(12V)	7	8	SPI_2_MOSI
PWRL3(3V3 ADCS)	9	10	SPI_2_CLK
PWRL4(5V ADCS)	11	12	SPI_2_SS
PWRL5(VBAT ADCS)	13	14	Sync_Pulse
PWRL6(3V3 PL)	15	16	**GND**
PWRL7(5V PL)	17	18	RS485_1+
PWRL8(12V PL X-Band)	19	20	RS485_1-
PWRL9(5V Reserved)	21	22	VBAT+
PWRL10(3V3 Reserved)	23	24	VBAT+
PWRL11(5V Reserved)	25	26	VBAT-
PWRL12 (NC)	27	28	VBAT-
RS485+_2	29	30	SPI_2_CS0_PWR(Reserved)
RS485-_2	31	32	SPI_2_CS1_COM(Reserved)
I2C_D	33	34	SPI_2_CS2_ADCS(Reserved)
I2C_C	35	36	SPI_2_CS3_PL(Reserved)
GND	37	38	SPI_2_CS4_CCU(Reserved)
PWR_RST	39	40	SPI_2_CS5(Reserved)

SPI_1_MISO(Reserved)	**41**	**42**	Heart Beat (from OBC)
SPI_1_MOSI(Reserved)	**43**	**44**	Heart Beat (from CCU)
SPI_1_CLK(Reserved)	**45**	**46**	E-RST0 (from CCU)
SPI_1_SS(Reserved)	**47**	**48**	E-RST1 (from OBC)
GND	**49**	**50**	**GND**
PWRL13 (5V CCU Deployment)	**51**	**52**	PWRL14 (3.3V CCU)

- The bus provides thirteen switchable power lines (PWRL_1, PWRL_2 … PWRL_12, PWRL_15) pins (pins: 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27 and 2) to supply the required electrical power for satellite subsystems.
- The bus provides three non-switchable power lines (PWRL_0, PWRL_13 and PWRL_14) at pins (1, 51, and 52) consecutively to supply the required electrical power for OBC and CCU subsystems.
- The ON/OFF control signal for any power line is controlled by the power subsystem upon receiving a command from the On-Board Computer (OBC) or the Ground Control Station (GCS).
- Each power line will supply 3.3V or 5 V or 12 V with maximum current as listed in the following table:

Power Line Name	Subsystem	Voltage	Description	Type	Maximum Current (mA)
PWRL0	OBC	3V3	Main OBC Supply	Non-Switchable	200
PWRL1	GPS – GS50	5	GPS – GS50 Supply	Switchable	600 (3 W)
PWRL2	---	12	---	Switchable	3000
PWRL3	ADCS	3V3	Main ADCS Supply Line	Switchable	200
PWRL4	ADCS	5	Sun sensors, Magnetometer, Gyro and Magnetorquer Supply	Switchable	1000

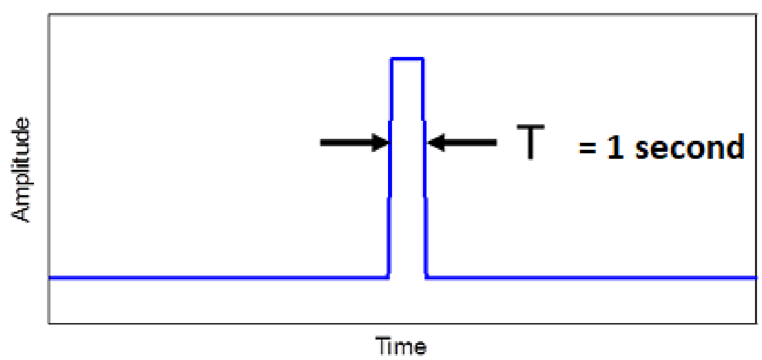
PWRL5	ADCS	VBAT	Reaction wheels Supply	Switchable	600
PWRL6	PL	3V3	To PL Control Board	Switchable	150
PWRL7	PL	5	Payload Supply Line	Switchable	1000
PWRL8	PL	12	X-Band TX Supply	Switchable	1000
PWRL9	-----	5	Reserved	Switchable	-----
PWRL10	-----	3V3	Reserved	Switchable	-----
PWRL11	-----	5	Reserved	Switchable	-----
PWRL12	-----	NC	-----	Not Connected	-----
PWRL13	CCU	5	Deployment Supply	Non-Switchable	2000
PWRL14	CCU	3V3	Main CCU Supply + UHF_2	Non-Switchable	2000
PWRL15	Main UHF (OBC)	3V3	UHF_1 Supply	Switchable	1500

- In addition to these power lines, EPS uses internally some power lines as listed below in the next table:

Power Line Name	Voltage	Description	Type	Maximum current (mA)
EPS board	5	Main EPS Supply	Non-Switchable	100
EPS board	3V3	Main EPS Supply	Non-Switchable	100
Heater	12	Heater Supply	Switchable	1000

- The bus has two half duplex RS485 serial interfaces connected to all satellite subsystems, the OBC uses these interfaces to send commands and receive responses from other subsystems. Those interfaces are hot redundant which implies that if the satellite subsystem receives a command on any port of them, it should reply on the same port.
  - The first serial port RS485_1 uses (pins 18, 20).

    - The second serial port RS485_2 uses (pins 29, 31).
- An emergency hard reset (ERST-0) at (pin 46) from CCU is used to provide power reset to the OBC subsystem. This is an active high signal for 1 second duration from CCU to EPS that is used to cut the power supply of the power lines (switchable and non-switchable) that feed the OBC subsystem.
- Another emergency hard reset (ERST-1) at (pin 48) from OBC is used to provide power reset to the CCU subsystem. This is an active high signal for 1 second duration from OBC to EPS that is used to cut the power supply of the power lines (switchable and non-switchable) that feed the CCU subsystem.
- Also, the PWR-RST at (pin 39) is used to reset the controller of the EPS subsystem and consequently the satellite subsystems will be reset. This is an active high signal for 1 second duration from OBC to EPS that is used to cut the power supply of the power lines (switchable and non-switchable) from the satellite systems for 1 second.



- Four direct battery feeding voltage (pins: 22, 24, 26, and 28) are used to provide unregulated battery voltage (Power system use only).
- The bus provides SPI_1 bus Pins (41, 43, 45 and 47) dedicated to transfer data and images between payload subsystem and the OBC (master on SPI). These pins are not used in AFDEVSAT satellite.
- Pins 6, 8, 10, 12 are used for SPI_2 global bus, to connect the OBC as master to other subsystems. The Main Input Slave Output (MISO) of the global SPI bus must have a tri-state buffer, this buffer is activated with subsystem chip select (CS). The bus provide active low five line (CS0, CS1, CS2, CS3 and CS4) from OBC to other subsystems, (pins: 30, 32, 34, 36 and 38). These pins are not used in AFDEVSAT satellite. This SPI global bus is not used in AFDEVSAT satellite.
- A synchronization pulse (Sync_pulse) from OBC is provided to synchronize the operation (sequence counter) of all satellite subsystems (Pin 16).

- All GPIO signals on the bus use 3.3 V for level ‘1’ and 0V for level ‘0’.
- All serial interfaces, SPI and I2C use 3.3V.

2.4. RS485 Bus Specification

RS-485 is a serial data transmission standard that defines the electrical interface and physical layer for communication protocol between different electrical devices (satellite subsystems).

The RS-485 interface of the satellite bus provides half-duplex transmission, which will be used in communication protocol between satellite subsystems.

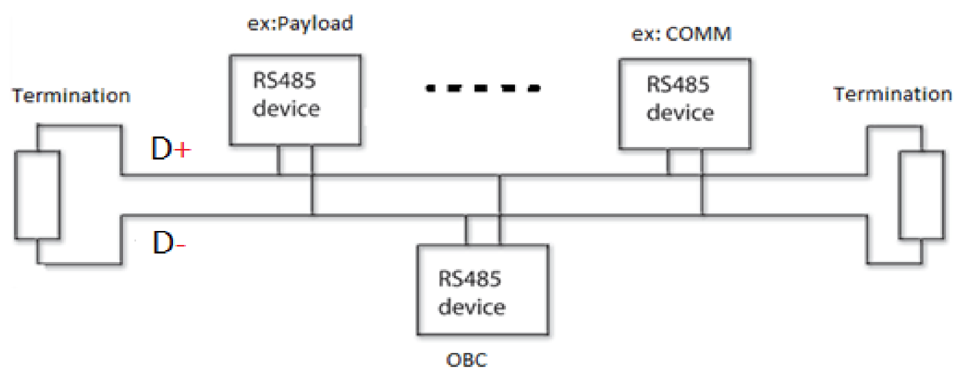


Figure 6: Half-Duplex RS485 BUS Block Diagram

The baud rate of RS-485 bus is 115200 bps, 8 bits, 1 start bit and 1 stop bit. An example for transmitting a byte on the serial bus is shown in the next figure:

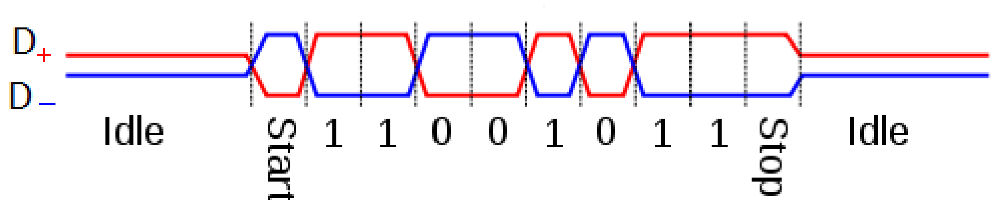


Figure 7: RS485 Half-Duplex Timing Diagram

Thus, the time required to transfer the basic communication protocol frame (No. of bytes ≈ 300) must not exceed (1/115200) * 10 * 300 = 27 msec

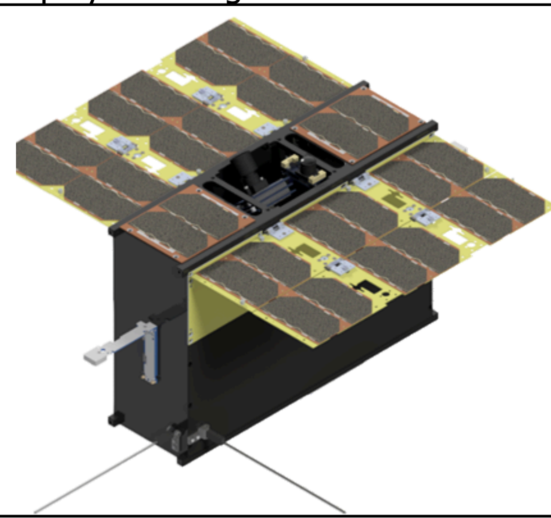
The time required to prepare the reply to any command must not exceed 10 msec

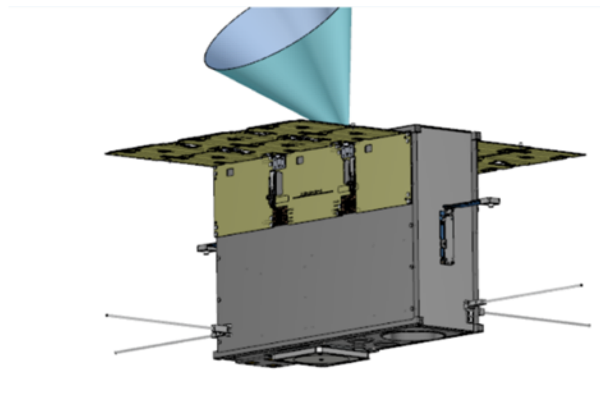
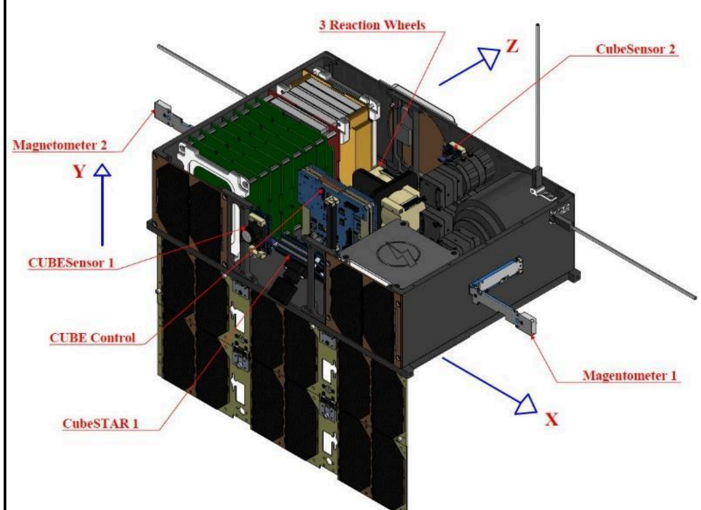
Consequently, the maximum total time for the command and its response must not exceed 27 + 10 + 27 = 64 ≈ 70 msec

Then, maximum number of commands that can be handled per second on serial bus = 1000/64 = 15 commands/sec

2.5. ADCS Requirement Specifications

Satellite Size	Mass: 6U (7.326 kg- to be updated after consolidation ADCS fixation parts) Total area of the satellite (2257850.435 mm^2) Volume (2475887.239 mm^3) Density (2.959 g/cm^3)
Payload Type:	payload: (Hyperspectral and monochromatic camera) preferred pointing directions are: nadir pointing, sun pointing- standby- and ground object tracking(stereo imaging and x-band download of the image)
orbit altitude and inclination	sun-synchronous orbit-SSO 550 km altitude , 98 deg. inclination
Expected launch date	Q2 - 2024
Estimated Moment of inertia	Center of Gravity: X: -0.873 mm Y: 2.737 mm Z: -6.201 mm Mass Moments of Inertia with respect to Center of Gravity: Ixx = 52615.946 kg mm^2 Iyy = 111025.532 kg mm^2 Izz = 94009.707 kg mm^2 Ixy = -391.302 kg mm^2 Ixz = -366.791 kg mm^2 Iyz = 111.440 kg mm^2 Mass Moments of Inertia with respect to Global: Ixx = 52952.600 kg mm^2 Iyy = 111312.880 kg mm^2

	Izz = 94070.185 kg mm^2 Ixy = - 373.791 kg mm^2 Ixz = - 406.464 kg mm^2 Iyz = 235.805 kg mm^2 <u>Principal Moments of Inertia with respect to Center of Gravity</u> I1: 52610.089 kg mm^2 I2: 111028.915 kg mm^2 I3: 94012.181 kg mm^2 <u>Rotation from Global to Principal</u> Rx: -0.39 deg Ry: 0.50 deg Rz: -0.39 deg
Deployments	• UHF antenna rods, length: (200 mm) • 2X Deployable solar panels : o Deployed: (162 mm x 325 mm) o stewed : (81 x 325) mm • 2 X deployable magnetometer
Satellite preliminary configuration	

	 
Pointing modes:	1. De- tumbling (time of detumbling shall be negotiated based on the satellite ADCS capabilities) 2. Sun pointing (in standby) 3. 3-axis Ground target tracking 4. 3-axis Nadir pointing

Pointing accuracy in sunlit-part for various modes	1. Pointing accuracy • 0.5 degree for nadir and ground tracking • 5 degrees for sun-pointing 2. Pointing stability “jitter” : • 0.005-degree/ sec- 3 sigma during nadir and ground tracking • 0.01-degree/sec- 3 sigma during sun tracking
Max Roll/Pitch/Yaw angles during relevant maneuvers	In both x and y axes ADCS shall maneuvers with up to +/-80 degrees(maximum) during this mode angle to be adjusted by command
Maximum slew rate required, and in which maneuvers	Maximum slew rate required during ground tracking: 0.8 deg/ sec
Interface	• 2 UART (1 main, 1 reserved)- hot backup • Power supplies (3.3V, 5V, 12V)

PART 2: SATELLITE BUDGETS

1. Power Budget

The power consumption for the satellite subsystems/modules in different operation modes is shown in the following table:

Table 2: Normal Satellite Mode Power Consumption

Subsystem/ Module	Modes	Voltage (V)	Current (A)	Total Power Consumption (W)
CCU	Active (Stand-by)	3.3	0.05	**0.2**
	Active (Beacon)	3.3	1.5	**5.0**
	UHF (Comm.)	3.3	2	**6.6**
Deployment fuse	Active (only for 6 sec)	5	1	**5.0**
OBC	Active (Stand-by)	3.3	0.1	**0.3**
	Active (Beacon)	3.3	1.5	**5.0**
	UHF (Comm.)	3.3	2	**6.6**

Subsystem/ Module	Modes	Voltage (V)	Current (A)	Total Power Consumption (W)
Power	Active	5	0.1	**0.5**
	Active	3.3	0.1	**0.3**
Heaters	Active	12	0.8	**9.6**
ADCS	Detumbling	3.3 5 12	0.21	**1.8**
	Stand-by (Sun pointing)		0.29	**2.9**
	Imaging (Nadir)		0.29	**2.9**
	Imaging (Ground tracking)		0.29	**2.9**
	Download Mode		0.29	**2.9**
GPS	Active	5	0.6	**3.0**

Subsystem/ Module	Modes	Voltage (V)	Current (A)	Total Power Consumption (W)
Payload	Active (3 Cameras)	5	0.94	**4.7**
	Active (PL Control Board)	5	0.6	**3.0**
	Active (Camera Handler Board)	5	0.6	**3.0**
	X-band (Downloading)	12	0.92	**11.0**
Additional Payload if any		12	2	**24.0**

The power consumption of AFDEVSAT in different satellite operation modes will be illustrated in the following subsections.

1.1. Initialization and Detumbling Modes Power Consumption

The power consumption of the Initialization and the Detumbling satellite operation modes is shown in the following table:

Table 3: Initialization and Detumbling Satellite Modes Power Consumption

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
Initialization	6 x 60	OBC	3.3	0.1	0.33	6.73
		CCU (Deployment: 2x Solar Panel, 2x UHF Antenna, 2x Magnetometer)	5	1	5	
		Power	3.3	0.1	0.83	
			5	0.1		
Detumbling	270 x 60	OBC_Beacon	3.3	1.5	5	

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		CCU_Beacon	3.3	1.5	5	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_ Detumbling (Cubecomputer, Sunsensor, Gyro, Magnetometer, 3x Magnetorquer)	3.3	0.21	1.8	
			5			
			12			

1.2. Normal Mode Power Consumption

The power consumption of the Normal satellite operation mode is shown in the following table:

Table 4: Normal Satellite Mode Power Consumption

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
Normal	91.5 x 60	OBC_Beacon	3.3	1.5	5	5.15
		CCU_Beacon	3.3	1.5	5	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Sun_Pointing (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer,	3.3	0.29	2.9	
			5			

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		3x RW-Average)	12			

1.3. Communication Mode Power Consumption

The power consumption of the Communication satellite operation mode is shown in the following table:

Table 5: Communication Satellite Mode Power Consumption

Satellite Mode of Operation	**Duration (sec)**	**Active Subsystems/ Modules/ Devices**	**Volt (V)**	**Current (A)**	**Power Consumption (W)**	**Average Power Consumption per Orbit (W)**
Communication	7 x 60	OBC_UHF	3.3	2	6.6	5.8
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_SunPointing (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average)	3.3	0.29	2.9	
			5			
			12			

1.4. Payload Mode Power Consumption

The power consumption of the Payload satellite operation mode when the imaging is performed with ADCS Ground Tracking is shown in the following table:

Table 6: Imaging with Ground Tracking in Payload Satellite Mode Power Consumption

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
Payload	15 x 60 (Pre-Image Download)	OBC	3.3	0.1	0.33	5.7
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Ground_Tracking (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer,	3.3	0.29	2.9	
			5			

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		3x RW-Average, Star Tracker)	12			
	2 x60 (Imaging with Ground Tracking)	OBC	3.3	0.1	0.33	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Ground_Tracking (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	3.3	0.29	2.9	
			5			
			12			

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		PL Control Board	5	0.6	3	
		PL Camera Handler Board	5	0.6	3	
		3 Cameras	5	0.94	4.7	
	15 x 60 (Discharge)	OBC	3.3	0.1	0.33	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Ground_Tracking	3.3	0.29	2.9	

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		(Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	5 12			

The power consumption of the Payload satellite operation mode when the imaging is performed with ADCS Nadir mode is shown in the following table:

Table 7: Imaging with Nadir in Payload Satellite Mode Power Consumption

<table>
<tr><th>Satellite Mode of Operation</th><th>Duration (sec)</th><th>Active Subsystems/ Modules/ Devices</th><th>Volt (V)</th><th>Current (A)</th><th>Power Consumption (W)</th><th>Average Power Consumption per Orbit (W)</th></tr>
<tr><td rowspan="9">Payload</td><td rowspan="9">15 x 60 (PreImage Download)</td><td>OBC</td><td>3.3</td><td>0.1</td><td>0.33</td><td rowspan="9">5.4</td></tr>
<tr><td>CCU</td><td>3.3</td><td>0.05</td><td>0.17</td></tr>
<tr><td rowspan="2">Power</td><td>3.3</td><td>0.1</td><td rowspan="2">0.83</td></tr>
<tr><td>5</td><td>0.1</td></tr>
<tr><td>GPS</td><td>5</td><td>0.6</td><td>3</td></tr>
<tr><td rowspan="3">ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)</td><td>3.3</td><td rowspan="3">0.29</td><td rowspan="3">2.9</td></tr>
<tr><td>5</td></tr>
<tr><td>12</td></tr>
</table>

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
	25 (Imaging with Nadir)	OBC	3.3	0.1	0.33	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	3.3	0.29	2.9	
			5			
			12			
		PL Control Board	5	0.6	3	

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		PL Camera Handler Board	5	0.6	3	
		3 Cameras	5	0.94	4.7	
	15 x 60 (Discharge)	OBC	3.3	0.1	0.33	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer,	3.3	0.29	2.9	
			5			

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		3x RW-Average, Star Tracker)	12			

The power consumption of the Payload Imaging during the satellite UHF Communication session when the imaging is performed with ADCS Nadir mode is shown in the following table:

TABLE 8: POWER CONSUMPTION FOR IMAGING DURING COMMUNICATION SESSION WITH ADCS NADIR

<table>
<tr><th>Satellite Mode of Operation</th><th>Duration (sec)</th><th>Active Subsystems/ Modules/ Devices</th><th>Volt (V)</th><th>Current (A)</th><th>Power Consumption (W)</th><th>Average Power Consumption per Orbit (W)</th></tr>
<tr><td rowspan="9">Payload</td><td rowspan="9">15 x 60 (PreImage Download)</td><td>OBC</td><td>3.3</td><td>2</td><td>6</td><td rowspan="9">5.5</td></tr>
<tr><td>CCU</td><td>3.3</td><td>0.05</td><td>0.17</td></tr>
<tr><td rowspan="2">Power</td><td>3.3</td><td>0.1</td><td rowspan="2">0.83</td></tr>
<tr><td>5</td><td>0.1</td></tr>
<tr><td>GPS</td><td>5</td><td>0.6</td><td>3</td></tr>
<tr><td rowspan="3">ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)</td><td>3.3</td><td rowspan="3">0.29</td><td rowspan="3">2.9</td></tr>
<tr><td>5</td></tr>
<tr><td>12</td></tr>
</table>

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
	10 (Imaging with Nadir)	OBC	3.3	2	6	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	3.3	0.29	2.9	
			5			
			12			
		PL Control Board	5	0.6	3	

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		PL Camera Handler Board	5	0.6	3	
		3 Cameras	5	0.94	4.7	
	15 x 60 (Discharge)	OBC	3.3	2	6	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Nadir (Cubecomputer, Sunsensor, Gyro,	3.3	0.29	2.9	
			5			

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	12			

1.5. Image Download Mode Power Consumption

The power consumption of the Image Download satellite operation mode is shown in the following table:

Table 9: Image Download Satellite Mode Power Consumption

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
Image Download	15 x 60 (PreImage Download)	OBC	3.3	0.1	0.33	6.11
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Ground_Tracking (Cubecomputer, Sunsensor, Gyro,	3.3	0.29	2.9	
			5			

<table>
<tr><th>Satellite Mode of Operation</th><th>Duration (sec)</th><th>Active Subsystems/ Modules/ Devices</th><th>Volt (V)</th><th>Current (A)</th><th>Power Consumption (W)</th><th>Average Power Consumption per Orbit (W)</th></tr>
<tr><td rowspan="10"></td><td></td><td>Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)</td><td>12</td><td></td><td></td><td rowspan="10"></td></tr>
<tr><td rowspan="9">4 x 60 (Image Download)</td><td>OBC</td><td>3.3</td><td>0.1</td><td>0.33</td></tr>
<tr><td>CCU</td><td>3.3</td><td>0.05</td><td>0.17</td></tr>
<tr><td rowspan="2">Power</td><td>3.3</td><td>0.1</td><td rowspan="2">0.83</td></tr>
<tr><td>5</td><td>0.1</td></tr>
<tr><td>GPS</td><td>5</td><td>0.6</td><td>3</td></tr>
<tr><td rowspan="3">ADCS_Ground_Tracking (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer,</td><td>3.3</td><td rowspan="3">0.29</td><td rowspan="3">2.9</td></tr>
<tr><td>5</td></tr>
<tr><td>12</td></tr>
</table>

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		3x RW-Average, Star Tracker)				
		PL Control Board	5	0.6	3	
		X-Band	12	0.9	11	
	15 x 60 (Discharge)	OBC	3.3	0.1	0.33	
		CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Ground_Tracking	3.3	0.29	2.9	

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		(Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	5			
			12			

1.6. Emergency Mode Power Consumption

The power consumption of the Emergency satellite operation mode is shown in the following table:

Table 10: Emergency Satellite Mode Power Consumption

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
Emergency	15 x 60	CCU	3.3	0.05	0.17	7.6

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
	(PreImage Download)	Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	
		ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	3.3	0.29	2.9	
			5			
			12			
		CCU	3.3	1.5	6.6	
		Power	3.3	0.1	0.83	
			5	0.1		

Satellite Mode of Operation	Duration (sec)	Active Subsystems/ Modules/ Devices	Volt (V)	Current (A)	Power Consumption (W)	Average Power Consumption per Orbit (W)
		GPS	5	0.6	3	
		ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)	3.3	0.29	2.9	
			5			
			12			
	15 x 60 (Discharge)	CCU	3.3	0.05	0.17	
		Power	3.3	0.1	0.83	
			5	0.1		
		GPS	5	0.6	3	

<table>
<tr><th>Satellite Mode of Operation</th><th>Duration (sec)</th><th>Active Subsystems/ Modules/ Devices</th><th>Volt (V)</th><th>Current (A)</th><th>Power Consumption (W)</th><th>Average Power Consumption per Orbit (W)</th></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3">ADCS_Nadir (Cubecomputer, Sunsensor, Gyro, Magnetometer, Magnetorquer, 3x RW-Average, Star Tracker)</td><td>3.3</td><td rowspan="3">0.29</td><td rowspan="3">2.9</td><td rowspan="3"></td></tr>
<tr><td>5</td></tr>
<tr><td>12</td></tr>
</table>

1.7. Safe Mode Power Consumption

TBD

2. Mass Budget

The mass budget of AFDEVSAT satellite can be illustrated in the following table:

Table 11: Satellite Mass Budget

No.	Satellite Part Name	Quantity	Mass (gm)
1	Power 1 PCB	1	110
2	Power 2 PCB	1	110
3	On Board Computer Subsystem PCB	1	110
4	CCU PCB	1	110
5	PCB backup	1	110
6	PCB backup	1	110
7	(Payload Control board) Back Up PCB	1	110
8	GS 50 (GPS) Antenna	1	0
9	X-Band Transmitter	1	250
10	X-Band Filter	1	60
11	ADCS Subsystem	1	550
12	Battery Box	1	750
13	Antenna ANT2150-ISL Type A	1	95
14	X-Band Antenna	1	50
15	Payload Module	1	0

16	Solar Panel GomSpace	2	800
17	Solar Panel DHV	1	150
18	Structure Subsystem	1	2200
19	UHF Antenna	2	25
Total			6525

3. UHF Link Budget

The satellite AFDEVSAT will use UHF modules to communicate with the GCS. There are two UHF modules onboard the satellite. The main one is the UHF module that is connected to the OBC subsystem while the secondary one is connected to the CCU. The budget of the UHF link will be illustrated in the following subsection.

3.1. UHF Uplink Budget

The UHF uplink budget is illustrated in the following table:

Table 12: UHF Uplink Budget

Ground Station:		
Ground Station Transmitter Power Output:	20.0	watts
In dBW:	13.0	dBW
In dBm:	43.0	dBm
Ground Stn. Total Transmission Line Losses:	4.1	dB
Antenna Gain:	3.2	dBi
Ground Station EIRP:	12.2	dBW
Uplink Path:		
Ground Station Antenna Pointing Loss:	1.5	dB
Gnd-to-S/C Antenna Polarization Losses:	3.0	dB
Path Loss:	143.6	dB
Atmospheric Losses:	0.4	dB
Ionospheric Losses:	0.4	dB
Rain Losses:	0.0	dB

Isotropic Signal Level at Spacecraft:	-136.8	dBW
Spacecraft:		
Spacecraft Antenna Pointing Loss:	1.5	dB
Spacecraft Antenna Gain:	0.0	dBi
Spacecraft Total Transmission Line Losses:	2.7	dB
Spacecraft Effective Noise Temperature:	340	K
Spacecraft Figure of Merrit (G/T):	-28.0	dB/K
S/C Signal-to-Noise Power Density (S/No):	62.3	dBHz
System Desired Data Rate:	4800	bps
In dBHz:	36.8	dBHz
Command System Eb/No:	25.5	dB
Demodulation Method Seleted:	Non-Coherent FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1.0	dB
Telemetry System Required Eb/No:	13.8	dB
Eb/No Threshold:	14.8	dB
System Link Margin:	**10.7**	dB

3.2. UHF Downlink Budget

The UHF downlink budget is illustrated in the following table:

TABLE 13: UHF DOWNLINK BUDGET

Spacecraft:		
Spacecraft Transmitter Power Output:	0.8	watts
In dBW:	-1.2	dBW
In dBm:	28.8	dBm
Spacecraft Total Transmission Line Losses:	0.2	dB
Spacecraft Antenna Gain:	0.0	dBi
Spacecraft EIRP:	-1.5	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	1.5	dB
S/C-to-Ground Antenna Polarization Loss:	3.0	dB
Path Loss:	143.6	dB
Atmospheric Loss:	0.4	dB
Ionospheric Loss:	2.0	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-152.0	dBW
Ground Station:		
Ground Station Antenna Pointing Loss:	1.5	dB
Ground Station Antenna Gain:	3.2	dBi
Ground Station Total Transmission Line Losses:	2.9	dB

Ground Station Effective Noise Temperature:	227	K
Ground Station Figure of Merrit (G/T):	-23.3	dB/K
G.S. Signal-to-Noise Power Density (S/No):	51.8	dBHz
System Desired Data Rate:	4800	bps
In dBHz:	36.8	dBHz
Telemetry System Eb/No for the Downlink:	15.0	dB
Demodulation Method Seleted:	Non-Coherent FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	1	dB
Telemetry System Required Eb/No:	13.8	dB
Eb/No Threshold:	14.8	dB
System Link Margin:	**0.2**	dB

4. X-Band TX Link Budget

The satellite AFDEVSAT will use an X-Band TX to download it's taken images through communication with the Ground Data Reception (**to be allocated in each country**).

4.1. X-Band TX Downlink Budget

The downlink budget of the X-Band TX subsystem is illustrated in the following table:

Table 14: X-Band TX Downlink Budget

Spacecraft:		
Spacecraft Transmitter Power Output:	1.3	watts
In dBW:	1.0	dBW
In dBm:	31.0	dBm
Spacecraft Total Transmission Line Losses:	1.0	dB
Spacecraft Antenna Gain:	13.0	dBi
Spacecraft EIRP:	13.0	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	0.4	dB
S/C-to-Ground Antenna Polarization Loss:	0.5	dB
Path Loss:	174.4	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	1.0	dB
Rain Loss:	3.0	dB
Isotropic Signal Level at Ground Station:	-167.4	dBW

Ground Station:		
Ground Station Antenna Pointing Loss:	0.0	dB
Ground Station Antenna Gain:	51.4	dBi
Ground Station Total Transmission Line Losses:	1.0	dB
Ground Station Effective Noise Temperature:	343	K
Ground Station Figure of Merrit (G/T):	25.0	dB/K
G.S. Signal-to-Noise Power Density (S/No):	86.2	dBHz
System Desired Data Rate:	50000000	bps
In dBHz:	77.2	dBHz
Telemetry System Eb/No for the Downlink:	9.0	dB
Demodulation Method Seleted:	QPSK	
Forward Error Correction Coding Used:	Convolutional R=1/2, K=7	
System Allowed or Specified Bit-Error-Rate:	1.0E-06	
Demodulator Implementation Loss:	2	dB
Telemetry System Required Eb/No:	4.8	dB
Eb/No Threshold:	4.8	dB
System Link Margin:	4.2	dB

5. Data Budget

The satellite AFDEVSAT has three Remote sensing Cameras. They are as follows:

a. Monochromatic Camera.
b. Hyper Snapshot Camera.
c. Hyper Line Scan Camera.

The data budget of each camera is described in the following subsections.

5.1. Monochromatic Camera Data Budget

The data budget of the monochromatic camera is illustrated in the following table:

Table 15: Monochromatic Camera Data Budget

Parameter	Value			Unit
Spatial Resolution	10			m
Spectral Resolution	1			Band
Radiometric Resolution	10			Bits
Bit Depth	16			Bits
Number of Rows	2048			Row
Number of Columns	2048			Column
Seen Size	100	X	20	Km
Swath Width	20480	≈	20000	m
Seen Rows	10000			Row
Seen Colums	2000			Column
Seen Shots	4.8828125	≈	5	Shots
Data Budget Before Stitching	**335544320**	≈	**335**	**MBits**
Data Budget After Stitching	**320000000**	≈	**320**	**MBits**

5.2. Hyper Snapshot Camera Data Budget

The data budget of the hyper snapshot camera is illustrated in the following table:

Table 16: Hyper Snapshot Camera Data Budget

Parameter	Value			Unit
Filter	5	X	5	Pixels
Pixel Spatial Resolution	40			m
Filter Spatial Resolution	200			m
Filter Spectral Resolution	24			Band
Radiometric Resolution	10			Bits
Bit Depth	16			Bits
Number of Rows	1080			Row
Number of Columns	2048			Column
Note	Filter will be treated as pixel			----
Seen Size	100	X	80	Km
Swath Width	81920	≈	80000	m
Seen Rows	500			Row
Seen Colums	400			Column
Seen Shots	2.31481481	≈	3	Shots
Data Budget Before Stitching	**106168320**	≈	**107**	**MBits**
Data Budget After Stitching	**76800000**	≈	**77**	**MBits**

5.3. Hyper Line Scan Camera Data Budget

The data budget of the hyper line scan camera is illustrated in the following table:

Table 17: Hyper Line Scan Camera Data Budget

Parameter	Value			Unit
Spatial Resolution	100			m
Spectral Resolution	192			Band
Radiometric Resolution	10			Bits
Bit Depth	16			Bits
Number of Rows	1080			Row
Number of Columns	2048			Column
Number of Rows per Band	5			Row
Number of Bands in First Area	64			Band
Number of Rows in Guard Band	120			Row
Number of Bands in Second Area	128			Band
Seen Size	200	X	200	Km
Swath Width	204800	≈	200000	m
Seen Rows	2000			Row
Seen Colums	2000			Column
Seen Shots	832			Shots
Data Budget Before Stitching	**29444014080**	≈	**30**	**GBits**
Data Budget After Stitching	**12288000000**	≈	**13**	**GBits**

PART 3: COMMUNICATION PROTOCOLS

This part illustrates the communication protocols between different subsystems connected on satellite bus and the communication protocol between GCS and satellite on the UHF link, in addition to X-band communication protocol from satellite to GCS.

Consequently, this part can be divided into the following sections:

- Bus Communication Protocol.
- UHF Communication Protocol.
- X-Band Communication Protocol.

6. BUS COMMUNICATION PROTOCOL

AFDEVSAT Cube satellite uses the Simple Serial Protocol (SSP) as a basic communication protocol between different satellite subsystems through the satellite internal bus. The next table presents the main fields of AFDEVSAT communication protocol.

TABLE 18: SSP FRAME FIELDS

	1	2	3	4	5	6	7	8	9
Field	Flag	DEST.	SRC.	CM D ID	D_Len	Data	CRC_0	CRC_1	Flag
# Bytes	1	1	1	1	1	Variable size	1	1	1

The description of the SSP protocol fields are as follows:

TABLE 19: SSP FRAME FIELDS DESCRIPTION

Field	Description
Flag	This flag identify the start and the end of a frame and always is one byte equal (0xC0) hexadecimal
DEST.	Destination address (receiver subsystem address)
SRC.	Source address (transmitter subsystem address)
CMD ID	Command identifier
D_Len	data length without header length (data field length in bytes)
Data	Actual data from subsystem
CRC_0	Cyclic Redundant check least significant byte
CRC_1	Cyclic Redundant check most significant byte

- Max frame size in bytes = 256 bytes.
- Max data size in bytes = 256 – 8 = 248 bytes.

Cyclic Redundant Check (CRC)

The Basic communication protocol uses CRC-16-CCITT polynomial ($X^{16} + X^{12} + X^{5} + 1$), The CRC is a 16 bits number calculated by both the sender and the receiver of a frame to ensure that the frame was not corrupted by the transmission medium. CRC_0 is the least-significant byte of CRC number and CRC_1 is the most-significant byte of CRC number.

6.1. Types of Commands

The SSP frame could be a command or a reply for a command, the most significant two bits of CMD_ID are used to identify the type of command (direct or time tagged) and the type of frame (reply or command) as listed in the next table.

Table 20: Command and Frame Types Identifier

Bit number	value
Bit 7	0 = direct command
	1= time tagged command
Bit 6	0 = command frame
	1 = reply frame

The satellite commands can be divided according to execution time into two types as follows:

6.1.1. Direct Commands

This type of commands will be executed immediately after successful reception from destination, and the direct command can be transmitted to any subsystem (any destination).

6.1.2. Time Tagged Commands

This type will be executed at a specific time that defined in the received command frame, the time tagged command transmitted only from GCS to OBC, the OBC stores these commands and retransmit it in the planned time.

The data field of time tagged commands is divided into two sections as listed in the next table;

Section #1		Section #2
Secondary header		
Destination Address	**Execution Time**	**Data**
1 byte	8 bytes	N bytes

The next figure illustrates the time tagged SSP frame fields

Field	1	2	3	4	5	6	7	8	9
	Flag	DEST.	SRC.	CMD_ID	D_Len	Data	CRC_0	CRC_1	Flag
# Bytes	1	1	1	1	1	Variable size	1	1	1

OBC

Section#1		Section #2
Secondary Header		
Destination address	Execution Time	Data
1 byte	8 bytes	N bytes

Consequently, the GCS will command any subsystem by its address and the communication system will decode the received command frame, if the command type is a direct command, the command will be forwarded to the required subsystem on the RS485 internal bus to be executed by the destination subsystem, else if the command is a time tagged command, it will be automatically received by the OBC for later execution.

6.2. Satellite Identification Addresses

6.2.1. Subsystems Addresses

Each electronic subsystem or module must have a unique address which will be used in communication with other subsystems or modules. AFDEVSAT satellite mainly have five subsystems addresses in addition to GCS address

1. On-board controller (OBC)
2. Electrical Power supply subsystem (EPS)
3. Centralized Control Unit (CCU)
4. Attitude Determination and Control System (ADCS)
5. Payload subsystem (PL)
6. Ground Control Station (GCS)

In addition to these addresses, there are some addresses that can be used for other purpose as indicated in the next table where each category has certain range of IDs:

Table 21: Subsystem Addresses

Satellite Subsystem	Address
Subsystems IDs Section (0x01 to 0x1F)	
OBC	0x01
EPS	0x02
CCU	0x03
ADCS	0x04
PL	0x05
Modules Section (0x20 to 0x3F)	
Satellite Module (UHF_1)	0x20
Satellite Module (UHF_2)	0x21
Monochromatic Camera	0x22

Hyperspectral Line Scanning Camera	0x23
Hyperspectral Snap Shot Camera	0x24
X-Band TX	0x25
PL Camera Handler Board	0x26
Hosted Modules Section (0x40 to 0x4F)	
Backup	0x42
GCSs Section (0x50 to 0x5F)	
GCS	0x50
Multicast Section (0xF0 to 0xFE)	
Multicast	0xF0
Broadcast	0xFF

The source Address (SRC.) and the destination Address (DEST.) of the SSP frame should be one of the previous addresses.

6.2.2. Satellite Modes of Operation Identifier

AFDEVSAT satellite has the following modes of operation:

1. Initialization mode
2. De-tumbling mode
3. Normal mode
4. Communication mode
5. Payload mode
6. Download mode
7. Safe mode
8. Emergency mode
9. Backup mode

Their Mode_IDs are illustrated in the following table:

Table 22: Satellite Modes of Operation Identifiers

Satellite Mode Name	Mode ID
Initialization	0x01
Detumbling	0x02
Normal	0x03
Communication	0x04
Payload	0x05
Download	0x06
Safe	0x07
Emergency	0x08
Backup	0x09

6.2.3. Power Line Identifiers

The satellite bus has sixteen power line, each power line has a unique PWRL_ID as listed in the next table:

Table 23: Power Lines ID List

Power Line Name	PWRL ID
PWRL0	0x00
PWRL1	0x01
PWRL2	0x02
PWRL3	0x03

PWRL4	0x04
PWRL5	0x05
PWRL6	0x06
PWRL7	0x07
PWRL8	0x08
PWRL9	0x09
PWRL10	0x0A
PWRL11	0x0B
PWRL12	0x0C
PWRL13	0x0D
PWRL14	0x0E
PWRL15	0x0F

6.2.4. Functions Identifiers

Each subsystem may have configurable target or function like beacon repeating time, system RESET time, GPS reading, … etc. instead of assign a unique CMD_ID for each function, each configurable function will have a unique ID which will be used to exchange (read and write) its parameters (configurable data).

Each target or function must have a unique ID, this ID consists of two bytes, the first one is the subsystem address and the second is the target function address as listed below:

TABLE 24: FUNCTION ID LIST

Function Name	Function ID

OBC_F1 **OBC_F2** **…** **OBC_F255**	0x0101 0x0102 … 0x01FF
EPS_F1 **EPS_F2** **…** **EPS_F255**	0x0201 0x0202 … 0x02FF
CCU_F1 **CCU_F2** **…** **CCU_F255**	0x0301 0x0302 … 0x03FF
PL_F1 **PL_F2** **…** **PL_F255**	0x0401 0x0402 … 0x04FF

❖ MSB of ID is the Subsystem address

6.3. SSP Commands List

The satellite commands can be divided into the following sub-groups as follows:

- Generic Commands and Replies
- Master Commands
- EPS Commands
- PL Commands
- Hosted Subsystems Commands

6.3.1. Generic Commands

The following commands are generic for all satellite subsystems and must be handled in each satellite subsystem. The following table lists the generic commands.

TABLE 25: GENERIC COMMANDS

CMD_ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x00	Ping	To check the subsystem status	Master	ALL
0x04	GD	Get Data	Master	ALL
0x05	PD	Put Data	Master	ALL
0x06	RD	Read Data	Master	ALL
0x07	WD	Write Data	Master	ALL
0x15	SM	Set subsystem Mode of operation	Master	ALL
0x16	GM	Get subsystem Mode of operation	Master	ALL
0x17	GSC	Get Synch Counter value	Master	ALL
0x18	SSC	Set Synch Counter value	Master	ALL
0x1A	GFP	Get Function Parameter	Master	ALL
0x1B	SFP	Set Function Parameter	Master	ALL
0x1C	FON	Function switch ON	Master	ALL
0x1D	FOF	Function switch OFF	Master	ALL
0x25	GOSTM	Get Online Subsystem TeleMetry	Master	ALL

There are also generic replies for a number of commands as will be described in the next sections. The next table lists the generic replies:

TABLE 26: GENERIC REPLY

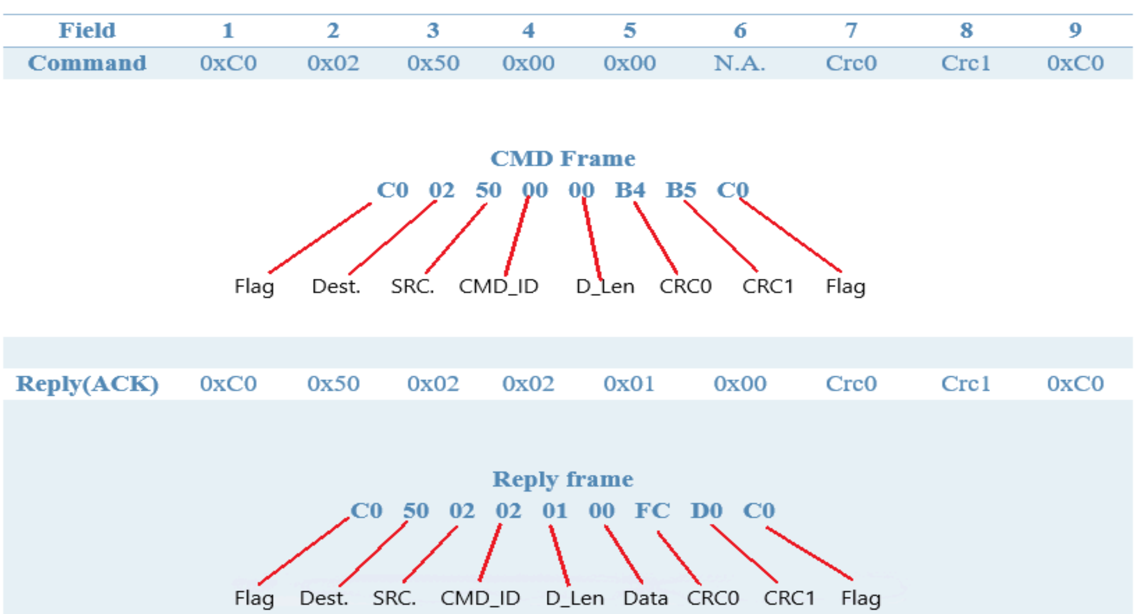
CMD_ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x02	ACK	ACKnowledge reply	ALL	Master
0x03	NACK	No ACKnowledge reply	ALL	Master

- Master = master subsystems (GCS or OBC or CCU)
- ALL = all satellite subsystems
- Each command that do not reply by data, must reply by ACK or NACK
- The satellite subsystem can reply to any command by NACK, in case of receiving unexpected frame as will be described below.

6.3.1.1. ACK (0x02) FRAME

The ACK frame is a reply frame, this ACK frame acts as a response for some commands as will be described in the next subsections. The data field of the ACK frame consists of one byte, which is the CMD_ID of the issued command.

An Example for ACK reply is shown below;



6.3.1.2. NACK (0x03) Frame

The NACK frame is a reply frame, the data field of NACK Frame consists of two bytes, the first byte is the CMD_ID of the issued command and the second is the Error_ID as listed in the next table:

Table 27: NACK Error Type

Type of Error	Error_ID
CRC Error	0x01
Parameters Error	0x02
Command not defined	0x03
Others	0x04

An Example for NACK reply is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x01	0x00	0x00	N.A.	Crc0	Crc1	0xC0
Reply(NACK)	0xC0	0x01	0x02	0x03	0x02	0x0001	Crc0	Crc1	0xC0

- N.A. = Not applicable
- Crc0 & Crc1 are least significant byte & the most significant byte in cyclic redundant check calculation.

6.3.1.3. Ping Command (0x00) Frame

This Command is used to check the status or the connectivity between the source and the destination, the reply to this Command is ACK or NACK. An Example for the Ping Command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x00	0x01	0x03	Crc0	Crc1	0xC0
Reply(NACK)	0xC0	0x50	0x01	0x03	0x02	0x0002	Crc0	Crc1	0xC0

6.3.1.4. GD Command (0x04) Frame

This command allows the source to get certain data from the module memory. The data field of this command has two parameters, the first one is the subsystem module address in one byte and the second one is the sequence number of the data block in two bytes. The reply for this command has three parameters in its data field, the first one is the subsystem module address in one byte, the second one is the sequence number of the data block in two bytes, and the third one is the block of data. An Example for GD frame is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x05	0x01	0x04	0x03	0X22 0X0001	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x44	0x03+n	0X22 0X0001 B1...Bn	Crc0	Crc1	0xC0

- B1 = the data byte number 1, and Bn = the data byte number n

6.3.1.5. PD Command (0x05) Frame

This command allows the source to transfer block of data to certain subsystem module to be written in its memory. If the data size that is required to be transferred to the memory of the subsystem module is greater than the available size of the data field, such data will be divided into blocks and each block is transferred in a separate PD command. The data field of this command has three parameters, the first one is the subsystem module address in one byte, the second one is the sequence number of the data block in two bytes, and the third one is the block of data. The reply for this command is ACK or NACK. An Example for PD frame is shown below;

Field	1	2	3	4	5	6	7	8	9

Command	0xC0	0x05	0x01	0x05	0x03+n	0X22 0X0001 B1...Bn	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x02	0x01	0x05	Crc0	Crc1	0xC0

- n is the size of Data Block that is required to be written to the module's memory
- B1 = the data byte number 1, and Bn = the data byte number n

6.3.1.6. RD Command (0x06) Frame

This Command allows the source to read the parameters or block of data from a specified location in the destination memory. The data field of this command is three bytes which are the memory destination address located in the first two bytes and the third byte is the number of bytes that desired to be read from destination, and the reply data field contains the memory destination address in the first two bytes followed by the memory data. An Example for RD frame is shown below;

Field	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Command	0xC0	0x01	0x50	0x06	0x03	0x000102	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x46	0x04	0x0001AA56	Crc0	Crc1	0xC0

6.3.1.7. WD Command (0x07) Frame

This Command allows the source to write the parameters or the data on a specified location in the destination memory. The data field of this command contains the memory destination address in the first two bytes followed by the memory data, and the reply for this command is ACK or NACK. An Example for WD frame is shown below;

Field	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Command	0xC0	0x01	0x50	0x07	0x04	0x0201000 0	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x07	Crc0	Crc1	0xC0

6.3.1.8. SM Command (0x15) Frame

This Command forces the destination subsystem to transfer itself to the requested satellite mode from the source subsystem, the data field of this command is one byte which is the Mode_ID and the reply of this Command is ACK or NACK. An Example for SM command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x03	0x01	0x15	0x01	B1	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x03	0x02	0x01	0x15	Crc0	Crc1	0xC0

- B1 = MOD_ID

6.3.1.9. GM Command (0x16) Frame

This command allows the source to read the current mode of the destination subsystem. There is no data field for this command (D_len = zero), the reply frame data field is one byte which is the destination current mode. An Example for GM command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x01	0x16	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x02	0x56	0x01	B1	Crc0	Crc1	0xC0

- N.A. = not applicable
- B1 = MOD_ID

6.3.1.10. GSC Command (0x17) Frame

Each subsystem has a synchronization counter of 64 bit size, the destination increment this counter based on receiving a pulse signal on a dedicated satellite bus port (synch_pulse), the OBC asserts this signal every second on the dedicated pin for this on the satellite bus stack (Pin_14).

This command allows the source to read such synchronization counter. There is no data field for this command (D_len = zero), and the data field of the reply has eight bytes which are the current synch (Counter value). An Example for GSC command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x05	0x01	0x17	0x00	NA	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x57	0x08	B1...B8	Crc0	Crc1	0xC0

6.3.1.11. SSC Command (0x18) Frame

Each subsystem has a synchronization counter of 64 bit size, the destination increment this counter based on receiving a pulse signal on a dedicated satellite bus port (synch_pulse), the OBC asserts this signal every second on the dedicated pin for this on the satellite bus stack (Pin_14).

This command force the destination subsystem to change its counter value to the new value that is received from the source subsystem. The data field has eight bytes which are the new synch (Counter value), the reply is ACK or NACK. An Example for SSC command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x05	0x01	0x18	0x08	B1...B8	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x02	0x01	0x18	Crc0	Crc1	0xC0

6.3.1.12. GFP Command (0x1A) Frame

This command allows the source to read the parameters of a specified destination function (Function ID). The data field of this command contains the function ID, and the data field of the reply frame contains the function ID in first two bytes then followed by function parameters. An Example for GFP frame is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x50	0x1A	0x02	0x0201	Crc0	Crc1	0xC0

Reply	0xC0	0x50	0x02	05A	n	B1…B8	Crc0	Crc1	0xC0

- ❖ n is the size of Data field in the SSP reply frame
- ❖ B1 = byte number 1, and Bn = the byte number n
- ❖ Crc0 & Crc1 are the least significant byte & the most significant byte in cyclic redundant check calculation respectively.

6.3.1.13. SFP Command (0x1B) Frame

This command allows the source to write the parameters of a specified destination function (Function ID). The data field of this command contains the function ID in the first two bytes followed by the function parameters. The reply for this command is ACK or NACK. An Example for SFP frame is shown below;

Field	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Command	0xC0	0x01	0x50	0x1B	0x04	0x02010000	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x1B	Crc0	Crc1	0xC0

6.3.1.14. FON Command (0x1C) Frame

This command allows the source to switch ON a specific function (function ID) that is running on the destination subsystem. The data field of this command has two bytes which are the function ID, the reply is ACK or NACK. An Example for FON frame is shown below;

Field	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Command	0xC0	0x02	0x50	0x1C	0x02	0x0201	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x02	0x02	0x01	0x1C	Crc0	Crc1	0xC0

6.3.1.15. FOF Command (0x1D) Frame

This command allows the source to switch OFF a specific function (function ID) that is running on the destination subsystem. The data field of this command has two bytes which are the function ID, the reply is ACK or NACK. An Example for FOF frame is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x50	0x1D	0x02	0x0201	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x02	0x02	0x01	0x1D	Crc0	Crc1	0xC0

6.3.1.16. GOSTM (0x25) Frame

This command used to collect the online subsystem telemetry from the destination subsystem, the data field of this command is null, the destination replies with its telemetry which has a predefined size. The first section of the data field in the reply frame is the secondary header that has two parameters (the subsystem address in one byte, and the timestamp that is the subsystem synch counter in 8 bytes), then the subsystem telemetry parameters are packed in the reply data field. An Example for GOSTM command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x01	0x25	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x02	0x65	n	B1…Bn	Crc0	Crc1	0xC0

<table>
<tr><th colspan="3">Data field</th></tr>
<tr><th colspan="2">Secondary Header</th><th>Subsystem Telemetry Parameters</th></tr>
<tr><td>Subsystem Address
1 Byte</td><td>Timestamp
8 Byte</td><td>B10 … Bn</td></tr>
</table>

- n is the size of Data field

6.3.2. Master Commands

TABLE 28: GCS COMMANDS

CMD ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x01	INIT	Start UHF Communication	GCS	OBC/CCU
0x0E	END	End UHF Communication	GCS	OBC/CCU
0x0F	HRST	Hard ReSeT	GCS	OBC/CCU
0x11	STIME	Set satellite TIME	GCS	OBC
0x12	GTIME	Get satellite TIME	GCS	OBC
0x21	GOTLM	Get Online TeLeMetry	GCS	OBC
0x22	GSTLM	Get Stored TeLeMetry	GCS	OBC/CCU
0x31	KEN	Kill ENable	GCS	OBC/CCU

The description and the details of the data field and the reply for each Master commands is described in the next sub-sections

6.3.2.1. INIT COMMAND (0X01) FRAME

This command used to initiate the UHF communication session between the Ground Control Station (GCS) and the satellite where the source of this command is always the GCS, there is no data field for this command, and the reply is ACK or NACK. An Example for Init command is shown below;

Field	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Command	0xC0	0x01	0x50	0x01	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x01	Crc0	Crc1	0xC0

6.3.2.2. END Command (0x0E) Frame

This command is used to terminate the communication session between the Ground Control Station (GCS) and the satellite where the source of this command is always the GCS, there is no data field for this command, and the reply is ACK or NACK. An Example for END command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x09	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x01	Crc0	Crc1	0xC0

6.3.2.3. HRST Command (0x0F) Frame

This command is issued from GCS to OBC/CCU to reset CCU/OBC consecutively.

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x0F	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x0F	Crc0	Crc1	0xC0

6.3.2.4. STIME Command (0x11) Frame

This command is used to adjust the OBC time from the GCS. The data field has eight bytes (new Timer value), the reply is ACK or NACK. When the OBC received this command, it will issue SSC command to the satellite subsystems (Broadcasting) to adjust their internal synch counters. An Example for STIME command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x11	0x08	B1...B8	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x11	Crc0	Crc1	0xC0

6.3.2.5. GTIME Command (0x12) Frame

This command is issued from the GCS to get the current OBC time to check its value. There is no data field for this command (D_len = zero), and the data field of the reply has eight bytes (current Timer value). An Example for GTIME command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x12	0x00	NA	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x52	0x08	B1...B8	Crc0	Crc1	0xC0

6.3.2.6. GOTLM Command (0x21) Frame

This command is issued from the GCS to the OBC thus the OBC will collect the current online telemetry from the active subsystems in the current satellite operation mode. There is no data field for this command (D_len = zero).

In order to prepare the reply to this command, the OBC will issue a GOSTM command to each active subsystem in the current satellite operation mode. Also, the OBC will construct its own telemetry frame as a reply to the GCS GOTLM command. Then, the OBC will forward the collected set of subsystems telemetry frames to the GCS after collecting the whole online telemetry and the OBC will end this set of frames by an ACK frame that is issued from the OBC to the GCS. An Example for GOTLM command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x21	0x00	NA	Crc0	Crc1	0xC0
Reply (6 frames)	0xC0	0x50	0x01	0x61	n1	B1 ... Bn1	Crc0	Crc1	0xC0
	0xC0	0x01	0x02	0x65	n2	B1 ... Bn2	Crc0	Crc1	0xC0
	0xC0	0x01	0x03	0x65	n3	B1 ... Bn3	Crc0	Crc1	0xC0
	0xC0	0x01	0x04	0x65	n4	B1 ... B1n4	Crc0	Crc1	0xC0

	0xC0	0x01	0x05	0x65	n5	B1 ... Bn5	Crc0	Crc1	0xC0
	0xC0	0x50	0x01	0x02	0x01	0x21	Crc0	Crc1	0xC0

- n1 is the size of Data field in the telemetry frame of the OBC subsystem
- n2 is the size of Data field in the telemetry frame of the EPS subsystem
- n3 is the size of Data field in the telemetry frame of the CCU subsystem
- n4 is the size of Data field in the telemetry frame of the ADCS subsystem
- n5 is the size of Data field in the telemetry frame of the PL subsystem

6.3.2.7. GSTLM Command (0x22) Frame

This command is issued from the GCS to the OBC to download the stored satellite telemetry. The reply to this command is a window of 8 frames.

There are two parameters in the data field of this command. The first parameter is Subsystem_Addr in one byte to indicate the address of the subsystem that it is required to download its stored telemetry. And the second parameter is the Tlm_Frame_Seq_No in two bytes to indicate the required sequence number of the telemetry frame in the OBC memory section that is dedicated to store the telemetry of the identified subsystem.

It is worth noting that the OBC telemetry memory is divided into sections where each section is dedicated to store the telemetry frames for certain subsystem with cyclic overwrite concept and the OBC telemetry frame should indicate the number of stored telemetry frames for each subsystem.

The OBC will reply to GSTLM with a window of 8 frames starting from the indicated Tlm_Frame_Seq_No. where the OBC will concatenate the data fields of the subsystem telemetry frames that are required to be downloaded to construct the data field of the reply frames. Note that the concatenated data fields should belong to complete subsystem telemetry frames which means that the OBC should not divide the data field of the subsystem telemetry frame into different data fields of the reply frames.

Also, it should be noted that the stored subsystems telemetry are collected by the OBC as a reply for the GOSTM command.

Besides, if the requested subsystem address of the GSTLM command is broadcasting (0xFF), then the OBC will reply with 5 telemetry frames which represent the telemetry of the OBC, CCU, Power, ADCS, and PL subsystems.

An Example for GSTLM command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x01	0x50	0x22	0x03	0x02 0x0001	Crc0	Crc1	0xC0
Reply (8 frames)	0xC0	0x50	0x01	0x62	n	B1 ... Bn	Crc0	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n2	B1 ... Bn	Crc0	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n	B1 ... Bn	Crc0	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n	B1 ... Bn	Crc0	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n	B1 ... Bn	Crc0	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n	B1 ... Bn	0x01	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n	B1 ... Bn	0x01	Crc1	0xC0
	0xC0	0x50	0x01	0x62	n	B1 ... Bn	0x01	Crc1	0xC0

6.3.2.8. KEN Command (0x31) Frame

This command is issued from GCS to OBC/CCU to enable the termination of the satellite mission. This command is used at the end of life of the satellite to disconnect the batteries from the solar panels and they are not charged any more. After issuing this command, the satellite will work only until the full discharge of the batteries. As this command is critical, the OBC/CCU will have a function that is called "Mission Termination" and this function must be enabled by the GCS before issuing this command. Thus, when the OBC/CCU received the KEN command, it will check the status of its "Mission Termination" function, if it is enabled, the OBC/CCU will forward KEN command to the EPS subsystem to be executed. There is no data field in this command (D_len = Zero), the reply is ACK or NACK. An Example for KEN command is shown below;

Field	1	2	3	4	5	6	7	8	9

Command	0xC0	0x01	0x50	0x31	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x01	0x02	0x01	0x31	Crc0	Crc1	0xC0

6.3.3. EPS Commands

The EPS commands are SSP commands that are used only for the EPS subsystem. The next table lists the EPS commands.

TABLE 29: EPS COMMANDS

CMD ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x0B	SON	Switch ON subsystem	Master	EPS
0x0C	SOF	Switch OFF subsystem	Master	EPS
0x31	KEN	Kill ENable	OBC/CCU	EPS
0x32	KDIS	Kill DISable	GCS	EPS

The details of the data field and the reply for each EPS commands is described in the next sub-sections.

6.3.3.1. SON COMMAND (0x0B) FRAME

This command is used by master subsystems to switch ON a specific switchable power line from satellite bus, the data field of this command consists of one byte which is the PWRL_ID, the reply is ACK or NACK. An Example for SON command is shown below;

Field	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Command	0xC0	0x02	0x50	0x0B	0x01	0x09	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x02	0x02	0x01	0x0B	Crc0	Crc1	0xC0

6.3.3.2. SOF COMMAND (0x0C) FRAME

This command is used by master subsystems to switch OFF a specific switchable power line from satellite bus, the data field of this command consists of one byte which is the PWRL_ID, the reply is ACK or NACK. An Example for SOF command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x50	0x0C	0x01	0x08	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x02	0x02	0x01	0x0C	Crc0	Crc1	0xC0

6.3.3.3. KEN Command (0x31) Frame

This command is issued from GCS to OBC/CCU to enable the termination of the satellite mission. This command is used at the end of life of the satellite to disconnect the batteries from the solar panels and they are not charged any more. After issuing this command, the satellite will work only until the full discharge of the batteries. As this command is critical, the OBC/CCU will have a function that is called "Mission Termination" and this function must be enabled by the GCS before issuing this command. Thus, when the OBC/CCU received the KEN command, it will check the status of its "Mission Termination" function, if it is enabled, the OBC/CCU will forward KEN command to the EPS subsystem to be executed. There is no data field in this command (D_len = Zero), the reply is ACK or NACK. An Example for KEN command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x01	0x31	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x02	0x02	0x01	0x31	Crc0	Crc1	0xC0

6.3.3.4. KDIS Command (0x32) Frame

This command is used by GCS to resume the satellite working to achieve its mission. This command is used to connect the batteries to the solar panels such that they can be charged, the reply is ACK or NACK. An Example for KDIS command is shown below;

Field	1	2	3	4	5	6	7	8	9
Command	0xC0	0x02	0x50	0x32	0x00	N.A.	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x02	0x02	0x01	0x32	Crc0	Crc1	0xC0

6.3.4. Payload Commands

The payload subsystem commands can be listed as follows:

TABLE 30: PAYLOAD COMMANDS

CMD ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x23	RCS	Run Camera Scenario	Master	PL
0x29	GIMG	Get IMaGe	GCS	OBC/CCU
0x28	TIMG	Transfer IMaGe	Master	PL
0x27	DIMG	Delete IMaGe	Master	PL
0x26	CXT	Command X-band Transmitter	Master	PL

The commands of the payload are used to control the behavior of the PL-submodules. Such addresses are defined in the subsystems addresses section of this document, they are as follows:

TABLE 31: PL-SUBMODULES ADDRESSES

Payload Submodule	Submodule Address
Monochromatic Camera	**0x22**
Hyperspectral Line Scanning Camera	**0x23**
Hyperspectral Snap Shot Camera	**0x24**
X-Band Transmitter	**0x25**
PL Camera Handler Board	**0x26**

The details of the data field and the reply for each PL command will be described in the next sub-sections.

6.3.4.1. RCS Command (0x23) Frame

This command is used to run the imaging scenario by the selected camera. It is issued from the master to the PL.

It should be noted that some commands are required to be executed on board the satellite before issuing this command. They are as follows:

1- The OBC will issue Switch ON the PL subsystem thus the PL Control Board is switched on. Then the PL Control Board will switch on the PL Camera Handler Board.
2- The OBC will issue PING PL subsystem to make sure that the PL Control Board is active.
3- The OBC will issue PING "PL Camera Handler Board" Module to make sure that the PL Camera Handler Board is active.
4- The OBC will issue SET_TIME to synch the PL Control Board timer with the OBC timer. Then the PL Control Board will issue SET_TIME to the PL Camera Handler Board.

After that the RCS command may be issued. The reply to the RCS is ACK or NACK. An Example for RCS command is shown below;

Field	1	2	3	4	5	6	7	8	9
Cmd	0xC0	0x26	0x50	0x23	0x1F	Data Field	Crc0	Crc1	0xC0
Reply	0xC0	0x50	0x26	0x02	0x01	0x23	Crc0	Crc1	0xC0

Field	Data Field				
	CAM_ID	TIME_ON	TIME_SNAP	TIME_OFF	CONFIG
Length (Bytes)	1	8	1	1	20

Field	CONFIG				
	FPS	EXPOSURE_TIME	GAIN	COMPRESSION	RESERVED
Length (Bytes)	4	2	2	2	10

There are five parameters in the data field of the RCS command in thirty-one bytes. They are as follows:

1. The first parameter is the CAM_ID in one byte. It is used to indicate which payload camera is required to run this command and take the image. The CAM_ID is defined in the PL submodules addresses table.
2. The second parameter is the TIME_ON field in eight bytes. This time indicates the time required to turn on the selected camera in it.
3. The third parameter is the TIME_SNAP field in one byte. This item indicates the time shift (in sec) after turning on the selected camera to start snapping the image.
   - ❖ It is worth noting that the TIME_SNAP should accommodate for the time required to configure the selected camera.
4. The fourth parameter is the TIME_OFF field in one byte. This item indicates the time shift (in sec) after turning on the selected camera at which it is required to turn off that camera.
   - ❖ It is worth noting that the TIME_OFF should accommodate for the time required to run the whole imaging scenario of the selected camera.
5. The fifth parameter is the CONFIG field in twenty bytes. This field is used to indicate the configuration parameters that are required to be used in this imaging scenario with the selected camera. The CONFIG field has five consecutive configuration parameters. They are as follows:
   a. The first configuration parameter is the required "Frames Per Second (FPS)" in four bytes.
   b. The second configuration parameter is the required "exposure time" in two bytes.
   c. The third configuration parameter is the required "gain" in two bytes.
   d. The fourth configuration parameter is the required "compression" in two bytes.
   e. The last 10 bytes in the CONFIG field are reserved.

Thus, in each imaging scenario, the payload subsystem is going to perform the imaging scenario using the selected camera following the next steps:

1- Switch ON the selected camera at the time indicated in the TIME_ON field.
2- Configure the selected camera with the parameters indicated in the CONFIG field.
3- Take image after TIME_SNAP (sec) from TIME_ON.
4- Process the taken image (Compression, adding image meta data, etc.)
5- Store the processed image in PL Camera Handler Board memory.
6- Switch OFF the selected camera after TIME_OFF (sec) from TIME_ON.

It must be noted that the PL telemetry should report whether this scenario is successfully performed or it is not completed. Also, the telemetry must indicate which step of the six steps of the imaging scenario is not completed.

In addition, the OBC will assign a Record_ID (in two bytes) for each image. Such Record_ID acts as an image id that starts with one and is ascendingly incremented along the satellite mission. Besides, the OBC will gather the meta data of the image during the imaging process. Then, the OBC will sent the image's Record_ID followed by the image's meta data to the payload subsystem (PL Control Board) using the Put Data (PD) command. Consequently, the PL Control Board will store the received Record_ID and meta data from the OBC just after their corresponding image in the payload memory.

Moreover, the PL memory on both the PL Camera Handler Board and the PL Control Board should be divided into three sections where each section is dedicated to store the images of certain camera.

6.3.4.2. GIMG Command (0x29) Frame

This command is used to transfer certain image from the selected camera memory on the PL control board to the X-Band subsystem to be downloaded to the Ground Reception Station. It is issued from the master to the PL. There are three parameters in the data field of this command. The first parameter is the CAM_ID in one byte to identify the camera that it is required to download one of its images. Whereas, the second parameter is the IMG_ID in one byte to identify which image of the selected camera is required to be downloaded. The third parameter is the IMG_Frame_No in two bytes to identify which frame number of the image is required to be downloaded and this parameter is not used in AFDEVSAT and it is set to 0x0000.

It should be noted that some synchronization bytes will be sent from the PL to the X-Band before starting the transmission of the selected image (this will be clarified upon the reception of the X-Band Transmitter ICD).

It is worth noting that the telemetry of the payload subsystem should indicate the number of stored images per each camera of the payload's cameras.

The reply to GIMG command is an ACK or NACK. An Example for TIMG command is shown below;

Field	1	2	3	4	5	6	7	8	9
Cmd	0xC0	0x05	0x01	0x29	0x02	CAM_ID IMG_ID IMG_Frame_No	Crc 0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x02	0x01	0x29	Crc 0	Crc1	0xC0

6.3.4.3. TIMG Command (0x28) Frame

This command is used to transfer certain image from PL Camera Handler Board to the memory of the PL Control Board. It is issued from the master to the PL. Thus, it will be received by the PL Control Board that will forward it to the PL Camera Handler Board to be executed. There are two parameters in the data field of this command. The first parameter is the CAM_ID to identify the camera that it is required to transfer one of its images. Whereas, the second parameter is the IMG_ID to identify which image of the selected camera is required to be transferred from to the PL Camera Handler Board to the memory of the PL Control Board.

The reply to TIMG command is an ACK or NACK. An Example for TIMG command is shown below;

Field	1	2	3	4	5	6	7	8	9
Cmd	0xC0	0x26	0x01	0x28	0x02	CAM_ID IMG_ID	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x26	0x02	0x01	0x28	Crc0	Crc1	0xC0

6.3.4.4. DIMG Command (0x27) Frame

This command is used to delete certain image from the selected camera storage area. It is issued from the master to the PL. There are two parameters in the data field of this command. The first parameter is the CAM_ID to identify the camera that it is required to delete one of its images. Whereas, the second parameter is the IMG_ID to identify which image of the selected camera is required to be deleted.

The reply to DIMG command is an ACK or NACK. An Example for DIMG command is shown below;

Field	1	2	3	4	5	6	7	8	9
Cmd	0xC0	0x05	0x01	0x27	0x02	CAM_ID IMG_ID	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x02	0x01	0x27	Crc0	Crc1	0xC0

6.3.4.5. CXT Command (0x26) Frame

This command is used to Command the X-Band Transmitter where it is considered as a PL-Submodule. The data field of this command has two parameters consecutively. They are as follows:

1- The address of the X-Band Transmitter in one byte. Such address is defined in the subsystems addresses section of this document.
2- The command of the X-Band that it is required to be executed in ten bytes.

When the PL subsystem receives this command, it distinguishes that it contains an X-Band command from its data field. Consequently, it forwards this X-Band command to the X-Band transmitter through the dedicated RS422 control interface between the PL Control Board and the X-Band Transmitter.

The reply to CXT command will be clarified upon the reception of the X-Band TX ICD to identify the expected reply for each X-Band command.

It should be noted that the PL Control Board will forward the X-Band reply to the OBC such that the OBC is able to monitor the performance of the X-Band.

An Example for CXT command is shown below;

Field	1	2	3	4	5	6	7	8	9
Cmd	0xC0	0x05	0x01	0x26	0x0B	X-Band_ID X-Band_Cmd	Crc0	Crc1	0xC0
Reply	0xC0	0x01	0x05	0x66	TBD	X-Band_ID X-Band_Reply	Crc0	Crc1	0xC0

7. UHF Communication Protocol

The AX.25 protocol is used to ensure link connectivity between the communicating stations. It will be used in half-duplex system configuration.

7.1. AX.25 Frame Structure

There are three general types of AX.25 frames:

a) Information (I) frame.
b) Supervisory (S) frame.
c) Unnumbered (U) frame.

The fields of those frames are illustrated in this section.

Table 32: AX.25 Frame Construction

Flag	Address	Control	Info (opt.)	Padding (opt.)	FCS	Flag
0111 1110	112 bits	8 bits	N*8 bits	n*8 bits	16 bits	0111 1110

❖ For our satellites

- The total frame size = 256 bytes
- (N + n = 256 – headers) = 256 - 19 = 237

7.1.1. The Flag Field

- The Flag (0x7E) delimits the frame.

7.1.2. The Address Field

- The address field identifies the source and the destination of the frame.
- It identifies whether the frame is a command or a response.
- It consists of two subfields; the destination address subfield and the source address subfield as shown in the next table.

Table 33: Address Field Encoding.

Address Field of The Frame

Destination Address Subfield	Source Address Subfield
A1 A2 A3 A4 A5 A6 A7	A8 A9 A10 A11 A12 A13 A14

- Each subfield consists of a call-sign (6 Octets) and a one Octet Secondary Station Identifier (SSID). The call-sign is made of alpha and numeric characters (upper case only, six characters maximum). The call-sign for the GCS is "EGYGCS". The encoding of the destination and source subfields is illustrated in the following table:

TABLE 34: DESTINATION AND SOURCE SUBFIELDS ENCODING.

Destination Address Subfield	Source Address Subfield	Subfield Element
Octet	Octet	
A1 A2 A3 A4 A5 A6	A8 A9 A10 A11 A12 A13	Call-sign
A7	A14	CRRSSIDX

- The elements of the SSID octets (A7 and A14) are:
  - The "C" bit is set to "0".
  - The "R" bits are reserved bits and set to "0".
  - The SSID is four bits integer that is used to identify multiple stations using the same call-sign and it is set to "1" for our satellite in both the source and the destination addresses.
  - The "X" bit is the extension bit. It is set to "0" in the destination address subfield and to "1" in the source address subfield.

- AFDEVSAT satellite has two UHF transceivers, each transceiver has a unique call-sign

So, the address field for AFDEVSAT will be as follows,

UHF	Source/Dest.	AFDEVSAT	
		Call-sign	SSID Octet
Main	Source	AFDEVM	0x03
	Destination		0x02
Secondary	Source	AFDEVS	0x03
	Destination		0x02

7.1.3. The Control Field

- The control field identifies the type of frame being sent. It is modeled as shown in the following table:

TABLE 35: CONTROL FIELD FORMAT.

Frame Type	Control Field Bits				Our satellites' applicability
	7 6 5	4	3 2 1	0	
I Frame	N(R)	P	N(S)	0	applicable
S Frame	N(R)	P/F	S S	0	applicable
U Frame	M M M	P/F	M M	1	Not applicable

- The "S" bits are the supervisory function bits. They are encoded as listed in the following table where:

TABLE 36: S FRAME CONTROL FIELD FORMAT.

Control Field Type	Control Field Bits					
	7 6 5	4	3	2	1	0
Receiver Ready (RR)	N(R)	P/F	0	0	0	1
Receiver Not Ready (RNR)	N(R)	P/F	0	1	0	1
Reject (REJ)	N(R)	P/F	1	0	0	1
Selective Reject (SREJ)	N(R)	P/F	1	1	0	1

- The Receiver Ready "RR" frame is used to:
  - Indicate that the sender of the RR is now able to receive more "I" frames.
  - Acknowledge the proper reception of "I" frames up to "N(R)-1".
  - Clear a previously busy condition.
- The Receiver Not Ready "RNR" frame is used to indicate that the station is temporarily busy and cannot accept more "I" frames. Frames up to "N(R)-1" are acknowledged. Frames N(R) and above that may have been transmitted are discarded and must be retransmitted again.
- The Reject "REJ" frame is used to request the retransmission of "I" frames starting with N(R) and any frames sent with a sequence number "N(R)-1" are acknowledged.
- The Selective Reject "SREJ" frame is used to request the retransmission of a single "I" frame numbered N(R).

- The "M" bits are the unnumbered frame modifier bits. They are encoded as listed in the following table where:

TABLE 37: U FRAME CONTROL FIELD FORMAT.

Control Field Type	Type	Control Field Bits							
		7	6	5	4	3	2	1	0
Set Asynchronous Balanced Mode Extended (SABME)	Command	0	1	1	P	1 1		1	1
Disconnect (DISC)	Command	0	1	0	P	0 0		1	1
Disconnect Mode (DM)	Response	0	0	0	F	0 1		1	1
Unnumbered Acknowledge (UA)	Response	0	1	1	F	0 0		1	1
Unnumbered Information (UI)	Either	0	0	0	P/F	0 0		1	1
Test (TEST)	Either	1	1	1	P/F	0 0		1	1

- The SABME frame is used to set the two stations in a balanced mode of operation where the two communicating nodes will be treated as peers.
- The DISC frame is used to terminate a link session between the two stations.
- The DM frame is used to indicate that the station cannot accept a connection at the moment.
- The UA frame is used to acknowledge the reception and the acceptance of a SABME or a DISC frame.
- The UI frame is used to exchange information along the link outside the normal information control (i.e. bypassing flow control). As these frames are not acknowledged, if a frame is lost, it cannot be recovered.
- The TEST frame is used to perform a basic test of the data-link control between the two communicating stations where a TEST command caused the addressed station to respond with a TEST response. The station that initiates the test condition considers the data-link layer test is terminated by the reception of the TEST response or by the expiration of a timeout period.

- The frame variables and sequence numbers can be listed as follows:
  - The Send State Variable "V(S)" which contains the next sequential number that will be assigned to the next "I" frame to be sent.
  - The Send Sequence Number "N(S)" which contains the sequence number of the "I" frame being sent.
  - The Receive State Variable "V(R)" which contains the sequence number of the next expected "I" frame to be received.
  - The Received Sequence Number "N(R)" which exists in both "I" and "S" frames. Prior to sending an "I" or "S" frame. N(R) is updated to equal V(R) [to acknowledge the proper reception of frames up to "N(R)-1"].
- The Poll/Final "P/F" bit is used in a command mode to request an immediate reply to a frame (poll mode). In the response to the poll, the final bit is set.

7.1.4. The Information Field

The Information field carries user data from one end to the other. It contains an integral number of octets. In our mission, each AX.25 frame encapsulates one SSP frame. The length of the AX.25 frame is fixed and equals 256 bytes. Consequently the data field of the AX.25 is padded as necessary with 0xAA to get constant AX.25 packet length.

7.1.5. The Frame Check Sequence (FCS) Field

The FCS is a 16 bits number calculated by both the sender and the receiver of a frame to ensure that the frame was not corrupted by the transmission medium. In our mission, this field will not be checked, instead, the CRC field of the encapsulated SSP will be checked.

7.2. Communication Sequence With GCS

The GCS and satellite shall use the readiness/rejection control fields as the acknowledgment mechanism as follows:

Control Field Type	Description	TRx modes	Our Satellites' Applicability
Receiver Ready (RR)	The receiving side is ready to receive more frames.	After TX, it shall switch to RX mode	applicable

Receiver Not Ready (RNR)	• The received frame is ACKed from UHF module • The receiving side is not ready to receive more frames. (it has some data need to be sent)	After TX, it shall stay at TX mode	applicable
Reject (REJ)	The received frames are NACKed and a retransmission is required starting from the last ACKed frame	After TX, it shall switch to RX mode	Not applicable
Selective Reject (SREJ)	The received frame is NACKed and a retransmission is required for that frame only	After TX it shall switch to RX mode	Not applicable

- If the communication system is in the receiving mode - after sending the beacon - and it receives the INIT SSP command, then the communication session starts with the GCS. Note that it is not allowed to interrupt the beacon transmission by any uplink commands. So, the INIT SSP command is to be sent from the GCS to the satellite every one second, before it enters and during the visibility zone; once an acknowledgement is received, the communication session starts. Thus, the GCS starts the communication session with the satellite by sending the communication Initialization command to the satellite and the satellite shall reply by one of the supervisory frames.
- In the communication session mode, the UHF communication system is operated in FM mode with a data rate of 4800 bps.
- The satellite shall only use RNR as response to "get telemetry" and "download image" commands, to inform the GCS that it received the command and ready to send the required data.

- Each AX25 frame has fixed length (AX frame's length is 256 byte) while the SSP frame is not with fixed length and its maximum size is 237 byte, the difference between the two frames is padded with 0xAA.
- The stored telemetry shall be sent in windows (8 continuous frames at a time), then, the GCS acknowledges them. After that the satellite can send the next 8 frames. All the SSP frames should be 237 bytes length.
- The get online telemetry consists of 8 frames and all the online telemetry SSP frames may be less than maximum length.
- Each command is sent three times from the GCS. The communication subsystem shall receive the first copy of each AX.25 frames and calculates the CRC of the encapsulated SSP, if the CRC is correct it shall hold one second to switch to transmission mode and sends the reply to the GCS. If the CRC wasn't correct the communication subsystem shall try to receive the next copy of the command or the third one. If it couldn't receive any of the commands correctly, it shall respond to the GCS with a negative response where in this case the UHF COMM will reply to the GCS by the AX.25 RR S-frame with N(R) equals to the value of the ground station sent sequence number of the received corrupted frame.
- It should be noted that the OBC will listen to the activities on the RS485 internal satellite bus and records the performed actions in a log file to be downloaded to the GCS upon its request.
- Timeout of GCS is 4 seconds for the commands that have single I-frame in their reply. It is calculated from the time of sending the last bye of the last frame till the time of receiving a valid frame from the satellite. After this time the GCS can start transmitting. The timeout shall be 8 seconds in case of receiving a window of frames.
- The communication subsystem shall not accept the reception of any command with sequence number other than the next sequence number.

- The End SSP command will be sent from the GCS at the end of the UHF communication session to force the satellite to switch to Normal mode and sends beacon. The UHF communication subsystem should complete processing the current command and reply to it before executing any mode change.

8. X-Band Communication Protocol

The X-Band TX is communicating with the Ground data Reception station, using the AOS CCSDS Standard.

More data is available at X-band datasheet: X-band High Data Rate Transmitter

EWC27 - Syrlinks

The Ground reception station will be based in country(ies) that can receive from this X-band device.

For each country, please specify – if available – the X-band ground station here:

1-Aswan, Egypt- Datron

2- Nairobi, Kenya

ANNEX 1: COMMANDS LIST SUMMARY

TABLE 38: LIST OF COMMANDS

CMD ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x00	Ping	To check the subsystem status	Master	ALL
0x01	INIT	Start UHF Communication	GCS	OBC/CCU
0x02	ACK	Acknowledge reply	ALL	Master
0x03	NACK	No ACKnowledge reply	ALL	Master
0x04	GD	Get parameter Data from the device	Master	ALL
0x05	PD	Put parameter Data to the device	Master	ALL
0x06	RD	Read Data	Master	ALL
0x07	WD	Write Data	Master	ALL
0x08				
0x09				
0x0A				
0x0B	SON	Switch ON subsystem	Master	EPS
0x0C	SOF	Switch OFF subsystem	Master	EPS
0x0D				
0x0E	END	End UHF Communication	GCS	OBC/CCU
0x0F	HRST	Hard ReSeT	GCS	OBC/CCU

CMD ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x10				
0x11	STIME	Set satellite TIME	GCS	OBC/CCU
0x12	GTIME	Get satellite TIME	GCS	OBC/CCU
0x13				
0x14				
0x15	SM	Set subsystem Mode of operation	Master	ALL
0x16	GM	Get subsystem Mode of operation	Master	ALL
0x17	GSC	Get Synch Counter value	Master	ALL
0x18	SSC	Set Synch Counter value	Master	ALL
0x19				
0x1A	GFP	Get Function Parameter	Master	ALL
0x1B	SFP	Set Function Parameter	Master	ALL
0x1C	FON	Function switch ON	Master	ALL
0x1D	FOF	Function switch OFF	Master	ALL
0x1F				
0x21	GOTLM	Get Online TeLeMetry	GCS	OBC/CCU
0x22	GSTLM	Get Stored TeLeMetry	GCS	OBC/CCU

CMD ID (hexadecimal)	CMD Name	Description	SRC.	DEST.
0x23	RCS	Run Camera Scenario	Master	PL
0x24				
0x25	GOSTM	Get On line Subsystem TeleMetry	Master	ALL
0x26	CXT	Command X-band Transmitter	Master	PL
0x27	DIMG	Delete IMaGe	Master	PL
0x28	TIMG	Transfer IMaGe	Master	PL
0x29	GIMG	Get IMaGe	GCS	OBC/CCU
0x2A				
0x2B				
0x2C				
0x2D				
0x2E				
0x2F				
0x30	THS	Testing Hosted Subsystem	Master	Hosted Subsystem
0x31	KEN	Kill ENable	GCS	EPS
0x32	KDIS	Kill DISable	GCS	EPS