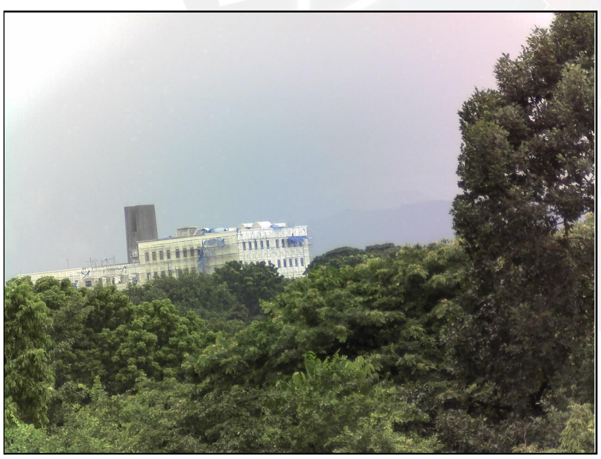
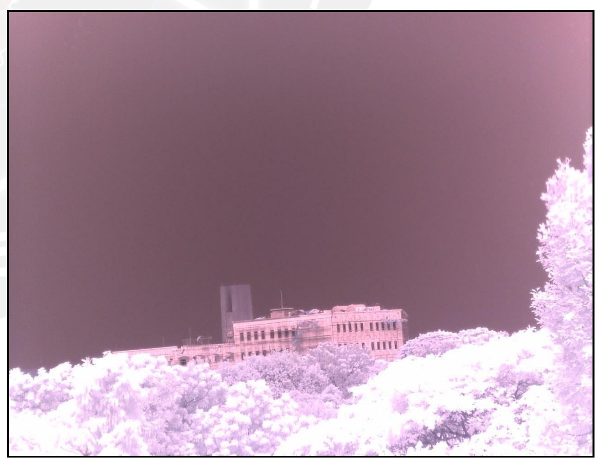
Maya-3 and Maya-4 Cube Satellites

HIGH-LEVEL SPECIFICATIONS

Maya-3 and Maya-4 are the first Philippine university-built satellites designed and developed by the first batch of scholars under the Space Technology and Applications Mastery, Innovation, and Advancement (STAMINA4Space) Program: Project 3 - Space Science and Technology Proliferation through University Partnerships (STeP-UP), funded and supported by the Department of Science and Technology (DOST) with scholarship grants from its Science Education Institute (SEI). The STeP-UP Project is implemented by the University of the Philippines-Diliman in collaboration with the Kyushu Institute of Technology in Japan.





Sample image using the RGB [Left] and Near-Infrared (NIR) [Right] Camera modules.

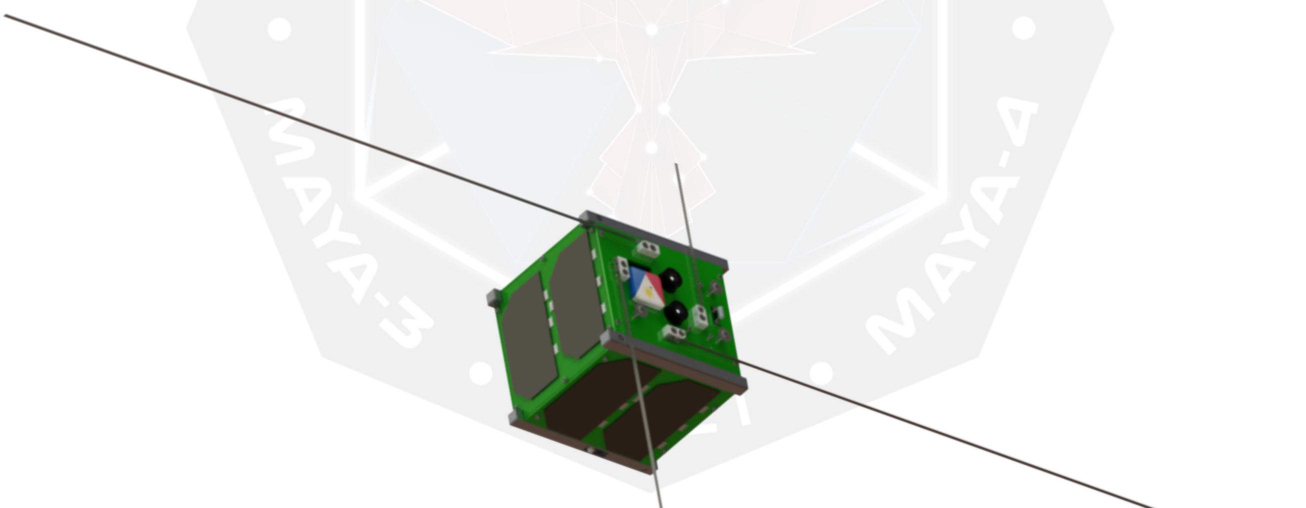
I. Technical Overview

Class	Cube Satellite (Cubesat)
Mass	1.15kg
Type	Technology Demonstration
Dimensions	10cm × 10cm × 11.35cm (Stowed State)
Orbit	Low Earth
Payloads	Maya-3: RGB Camera, Automatic Packet Reporting System Message Digipeater (APRS-DP) Payload, Global Positioning System (GPS) Chip, Anisotropic Magnetoresistance Sensor Maya-4: RGB Camera, Near-Infrared (NIR) Camera, Automatic Packet Reporting System Message Digipeater (APRS-DP) Payload, Global Positioning System (GPS) Chip, Anisotropic Magnetoresistance Sensor
Release	To be determined
Mission/s	● Demonstration of Ground Data Acquisition using Store and Forward (S&F mission) ● Commercial off-the-shelf (COTS) APRS-Digipeater Payload Demonstration on Cubesat (APRS-DP mission) ● Image and Video Capture (RGB CAM mission) ● Demonstration of Near-Infrared camera (NIR CAM mission), for Maya-4 only ● GPS Chip Demonstration (GPS mission) ● Detection of and protection from Single Event Latch-up due to space radiation (SEL mission) ● Magnetic Field Measurement in Space using an Anisotropic Magnetoresistance Sensor (AMR-MM mission)

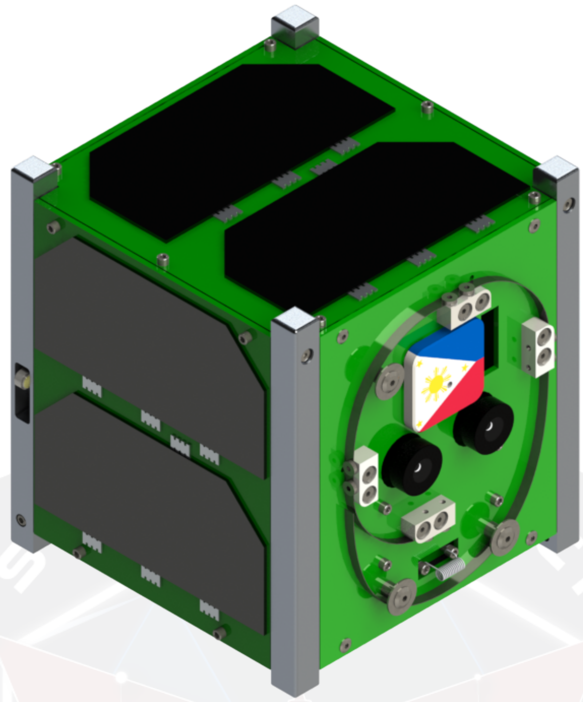
II. Cube Satellite Bus System

A. Structures

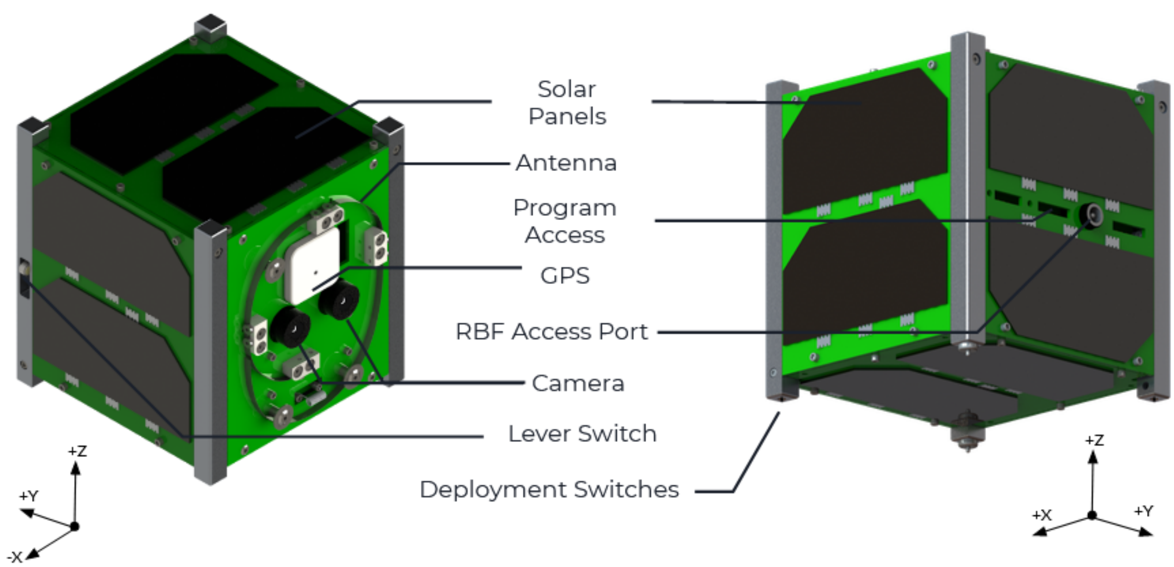
The Maya-3 and Maya-4 CubeSats measure 10 x 10 x 11.35 cm with an estimated mass of 1.1 kg. Both satellites feature two (2) deployable UHF and VHF antennas, solar array panels, GPS patch antenna, and a lever switch. The Cubesats carry two 5MP visual cameras mainly to capture images of the home country and for general visual assessment of landmass and bodies of water. One of the cameras of the Maya-4 CubeSats is a near-infrared camera for technology demonstration. The satellites' attitudes are passively stabilized by permanent magnets and hysteresis dampers.



Maya-3 and Maya-4 structural design with deployed dipole antennas



Maya-3 and Maya-4 CubeSats stowed antenna

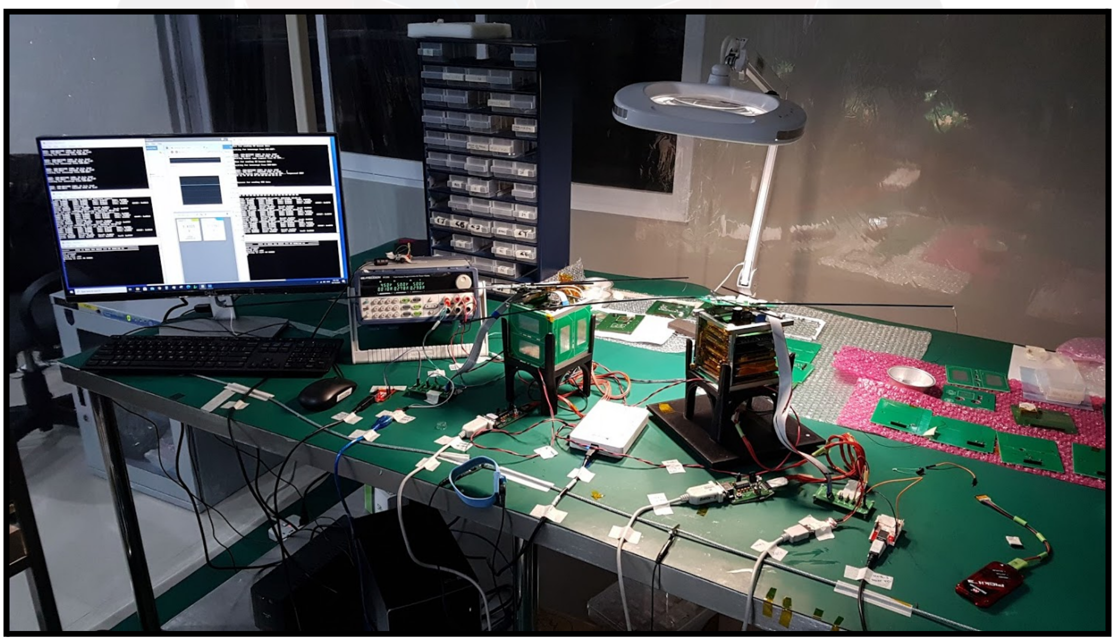


Maya-3 and Maya-4 CubeSats external components

B. Onboard Computer (OBC)

The On-Board Computer (OBC) is basically the brain of the CubeSat. It consists of three (3) microcontrollers, which are responsible of the following satellite functions:

a. Manages (collect, process, and store) housekeeping and mission data;
b. Collects data from equally significant satellite's subsystems and generates morse coded beacons grouped in three (3) containing the satellite's health status (or telemetry), and sensor data;
c. Executes the validated uplink command;
d. Executes reserve commands if the satellite fails to receive a valid command from the Ground Station (GS) in a given limited duration; and
e. Monitors the satellite health parameters.



Maya-3 and Maya-4 CubeSats Integration and Functionality Test

C. Communication

The Maya-3 and Maya-4 CubeSats operate in the amateur frequency band. Using a dipole antenna, the following functions are executed by the communication subsystem:

a. Receives uplink command from Ground Station (GS), validates, and sends to the On-Board Computer (OBC) for execution.
b. Transmits telemetry data to GS through CW beacon.
c. Encode using the AX25 transfer format and transmits mission data to GS.

Outdoor communication test of Maya-3 EM

Maya-3 Antenna Deployment Test

Link Budget

Mission Downlink		
Center Frequency	437.375 MHz	
Mean Orbital Altitude	400 km	
Parameters	***Elevation Angle***	
	10 deg	***80 deg***
SC RF Transmit Power (W)	0.8	0.8
SC RF Transmit Power (dBm)	29.03	29.03
SC Antenna gain (dBi)	1.1	1.1
SC EIRP (dBm)	30.13	30.13
GS pointing loss (dB)	3	3
Polarization Loss (dB)	3	3
Atmospheric + Ionospheric Loss (dB)	1.4	1.4
Free Space Path Loss (dB)	148.42	137.42
Isotropic received signal level (dBm)	-125.69	-114.69
GS Antenna Gain (dB)	13	13
GS Transmission Line Loss (dB)	1.7	1.7
GS Antenna Noise Temperature (K)	270	270
GS Receiver Noise Temperature (K)	300	300
GS Transmission Line Temperature (K)	290	290
GS Effective System Noise Temperature (K)	784.37	784.37
GS Receiver Sensitivity (dBm)	-113	-113
GS Signal to Noise Ratio (S/N)(dB)	11.33	22.08
Link Margin (SNR Method)	**1.08**	**12.08**

Command Uplink		
UL Frequency	435 - 437 MHz	
Mean Orbital Altitude	400 km	
Parameters	***Elevation Angle***	
	10 deg	***80 deg***
GS RF Transmit Power (W)	75	75
GS RF Transmit Power (dBm)	48.75	48.75
GS Antenna gain (dBi)	13	13
GS EIRP (dBm)	60	60
GS pointing loss (dB)	3	3
Polarization Loss (dB)	3	3
Atmospheric + Ionospheric Loss (dB)	1.4	1.4
Free Space Path Loss (dB)	148.4	137.38
Isotropic received signal level (dBm)	-95.8	-86.70
SC Antenna Gain (dB)	1.1	1.1
SC Transmission Line Loss (dB)	0.13	0.13
SC Antenna Noise Temperature (K)	290	290
SC Receiver Noise Temperature (K)	870	870
SC Effective System Noise Temperature (K)	1160	1160
SC Figure of Merit G/T (dB/K)	-29.54	-29.54
SC Receiver Sensitivity (dBm)	-105	-105
SC Signal to Noise Ratio (S/N)(dB)	28.73	39.87
Link Margin (SNR Method)	**18.9**	**29.87**

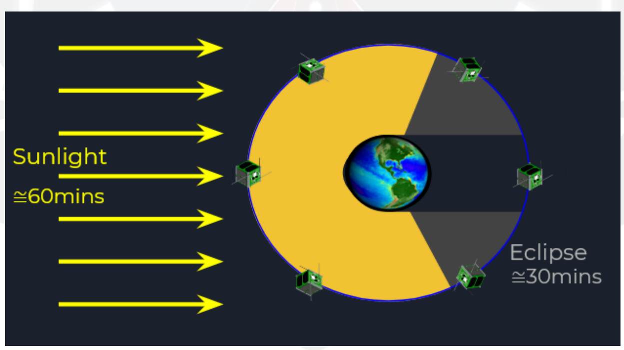
D. Electrical Power System (EPS)

This system is composed of solar array panels, a battery pack, a microcontroller, voltage regulators, buck-boost converters, and Over-current / Over-voltage Protection (OCPs/OVPs) circuits in order to provide regulated power to different subsystems of the satellite.

The primary functions of the EPS are to collect and transform solar energy into DC electrical energy, store and distribute this power to the CubeSat's subsystems. Secondarily, the EPS provides unregulated power for the antenna deployment, monitors and protects the subsystems from over-current and/or over-voltage, and protects the CubeSat from Single-Event Latchup (SEL).

Power Generation Estimation

Maya-3 and Maya-4 each have five solar array panels connected in parallel with 2 solar cells in series. As the CubeSat freely tumbles in its orbit, it collects solar energy through the solar panels and transforms it into electrical energy. The power generated is then stored in the satellite's battery during sunlight (battery charging) while simultaneously supplying power to the cubesats subsystems. During the eclipse period, the battery supplies the power (battery discharging) to the cubesats subsystems in order to provide continuous electrical power to the satellite even during the absence of sunlight.



Using the five (5) solar panels with 2 solar cells each, the satellite's estimated average power generated in one orbit is about 1.3 W-h. This power generated is capable of restoring the battery charge that was consumed during the eclipse period and during satellite missions.

Power Generation Estimation

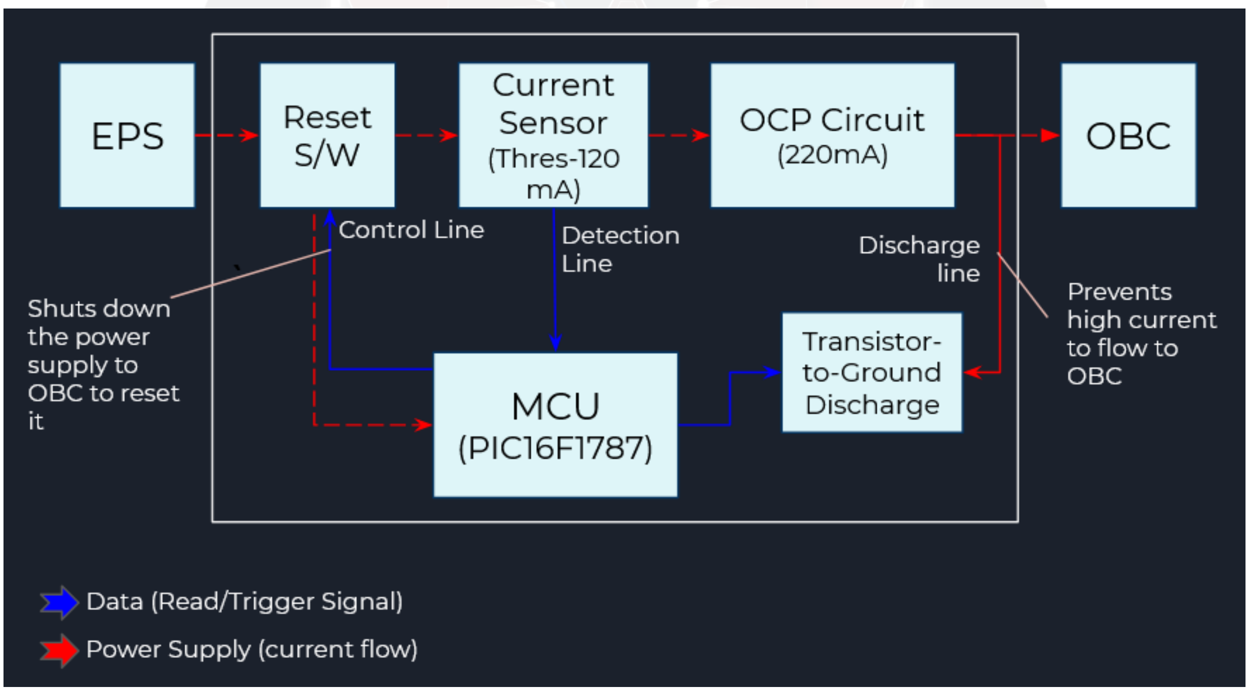
Configuration of Solar Panels	2S5P
Total voltage per panel, [V]	4.818
Total current per panel, [A]	0.5029
Solar Cell efficiency	0.3
Total Solar Cell Area per panel, A_{Tsc} [m^2]	0.006036
Solar Constant, SC [W/m^2]	1367
Total Power Generated per panel, [W] $P = SC_{eff} * SC * A_{Tsc}$	1.65
Total generated power during sunlight per orbit, [W-h] (based on simulation from BIRDS-2 for 10 solar cells)	1.59
Efficiency of DC/DC Converters	0.8
Estimated average available power per orbit, [W-h]	**1.27**

Single-Event Latchup (SEL) Protection

Single Event-Latchup is one of the hard errors of Single Event Effects (SEE) that occur in space due to the presence of heavy ions or protons from cosmic rays or solar flares. SEL occurs when there is a sudden increase of the supply current led by the activation of parasitic bipolar structures. This effect, if not prevented or mitigated, may lead to serious damage or permanent destruction to the MOS devices, particularly the On-Board Computer (OBC) of the Cubesat.

To protect the CubeSats from Single-Event Latch-ups, they are designed to have a current monitoring system at the supply line to the OBC that is connected to the EPS microcontroller. When the microcontroller detects any sudden current increase or surge at the said supply line, it then activates the transistor placed in between the distribution line to the OBC to drain the current to the ground, switching off the OBC and restarts the Cubesat in a few seconds.

SEL Functional Diagram



Power Budget

Subsystems	Power Reqt (W)	Duration (h)	Energy Consumption per Orbit (W-Hr)	MISSION MODES									
				Antenna Deploy & Beacon	CMD U/L & Beacon	Capture Image (Continuous mode)	Capture image (Normal mode)	Capture Image (Target mode)	Capture Video	GPS ON	Image/ Video/SF Data Download	Digi-peat & Store sensor data	SAFE MODE
Camera (capture)	1.0	0.017	0.017			0.017	0.017	0.017					
Camera (video)	1.0	0.05	0.050						0.050				
UHF Tx (CW/Beacon-OFF/STANDBY)	0.045	0.857	0.039	0.026	0.048	0.048	0.048	0.048	0.048	0.048	0.047	0.048	0.048
UHF Tx (CW/Beacon-ON)	0.59	0.643	0.379	0.128	0.141	0.141	0.141	0.141	0.141	0.141	0.138	0.141	0.141
UHF Tx (Image/Sensor Data DLink)	5.365	0.133	0.715								0.568		
UHF Rx (Uplink)	0.17	0.857	0.146	0.156	0.189	0.189	0.189	0.189	0.189	0.189		0.189	0.189
VHF Rx	0.15	1.5	0.225								0.225		
VHF Tx (Amateur Packeted Data)	2.05	0.250	0.513									0.513	
VHF Rx (Sensor Data & Amateur Packeted Data)	0.43	0.250	0.108									0.108	
ADCS	0.03	1.5	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
GPS	0.198	0.25	0.050					0.050		0.050			
OBC/EPS	0.22	1.5	0.330	0.330	0.330	0.330	0.330	0.330	0.330		0.330	0.330	0.330
Antenna	8.96	0.013	0.107	0.11									
Energy-Consumed per Orbit, W-h				**0.79**	**0.75**	**0.84**	**0.84**	**0.89**	**0.87**	**0.80**	**1.35**	**1.37**	**0.75**
Average Energy Consumed per Orbit, W-h				**0.91**									
Average power generated from solar panels per orbit, W-h				**≅1.27**									

E. Attitude Determination Control System (ADCS)

The Maya-3 and Maya-4 CubeSats implement magnetic passive stabilization of their attitude through permanent magnets and hysteresis dampers. Sensors for attitude determination include a MEMS magnetometer, which measures the earth's magnetic field, and gyroscope, which measures the rate of rotation of the satellite. Along with these sensors are the solar cells which function as coarse sun sensors. The attitude is estimated using the TRIAD algorithm. Position is determined with a commercial off-the-shelf GPS receiver.

III. Maya-3 and Maya-4 CubeSats Telemetry

CW Telemetry Format

Format	Satellite Callsign	-	Satellite Name	-	Type**	Telemetry Data (Hex)									
						B0	B1	B2	B3	B4	B5	B6	B7	B8	B9
Example	*DX3MYA*	-	*Maya3*	-	*a*	*c4*	*7a*	*3b*	*82*	*7a*	*ab*	*71*	*ed*	*1c*	*12*

Beacon Frequency: 437.375 MHz

**CW Beacon type identifier

a - Type 1
d - Type 2
e - Type 3

Important Instruction: All raw data MUST be converted into **decimal format.**

CW Beacon Type 1		
Format & No. of Characters		**Description**
DX3MYA	Alphanumeric, 6	Satellite Callsign
_	Alphanumeric, 1	Spacer
Maya3	Alphanumeric, 6	Name of Satellite
_	Alphanumeric, 1	Spacer
a	Alphanumeric, 1	Beacon Type Specifier [*a*: Type 1, *d*: Type 2, *e*: Type 3]
B0	Hex, 2	Battery Voltage [mV] (2.5*Decimal_value*16/4096)*2000 mV
B1	Hex, 2	Battery Current [mA] (Decimal_value*16*0.78)-1620)/0.264 mA
B2	Hex, 2	Battery Temperature *a. For (Decimal_value * 16) greater than 4448* Batt_tmp = (Decimal_value * 16 - 4100)/11 Note: Add negative symbol *b. For (Decimal_value * 16) greater than 4338 and lesser than or equal to 4448* Batt_tmp = (Decimal_value * 16 - 3800)/21 Note: Add negative symbol *c. For (Decimal_value * 16) greater than 4079 and lesser than or equal to 4338* Batt_tmp = (Decimal_value * 16 - 3600)/31 Note: Add negative symbol *d. For (Decimal_value * 16) greater than 3532 and lesser than or equal to 4079* Batt_tmp = (Decimal_value * 16 - 3553)/41 Note: Add negative symbol *e. For (Decimal_value * 16) greater than 1169 and lesser than or equal to 3532* Batt_tmp = (3539 - Decimal_value * 16)/47 *f. For (Decimal_value * 16) greater than 493 and lesser than or equal to 1169* Batt_tmp = (2344 - Decimal_value * 16)/23 *g. For (Decimal_value * 16) greater than 351 and lesser than or equal to 493*

		Batt_tmp = (1920 - Decimal_value * 16)/17 *h. For (Decimal_value * 16) greater than 306 and lesser than or equal to 351* Batt_tmp = (1670 - Decimal_value * 16)/14 *i. For (Decimal_value * 16) greater than 253 and lesser than or equal to 306* Batt_tmp = (1610 - Decimal_value * 16)/13 *j. For (Decimal_value * 16) greater than 216 and lesser than or equal to 253* Batt_tmp = (1540 - Decimal_value * 16)/12 *k. For (Decimal_value * 16) greater than 189 and lesser than or equal to 216* Batt_tmp = (1450 - Decimal_value * 16)/11 *l. For (Decimal_value * 16) greater than 163 and lesser than or equal to 189* Batt_tmp = (1375 - Decimal_value * 16)/10 *m. For (Decimal_value * 16) greater than 143 and lesser than or equal to 163* Batt_tmp = (1275 - Decimal_value * 16)/9 *n. For (Decimal_value * 16) greater than 121 and lesser than or equal to 143* Batt_tmp = (1180 - Decimal_value * 16)/8 *o. For (Decimal_value * 16) greater than 105 and lesser than or equal to 121* Batt_tmp = (1070 - Decimal_value * 16)/7 *p. For (Decimal_value * 16) greater than 89 and lesser than or equal to 105* Batt_tmp = (955 - Decimal_value * 16)/7 *q. For (Decimal_value * 16) greater than 78 and lesser than or equal to 89* Batt_tmp = (840 - Decimal_value * 16)/5 *r. For (Decimal_value * 16) greater than 67 and lesser than or equal to 78* Batt_tmp = (700 - Decimal_value * 16)/4 *s. For (Decimal_value * 16) greater than 58 and lesser than or equal to 67* Batt_tmp = (553 - Decimal_value * 16)/3 *t. For (Decimal_value * 16) greater than 49 and lesser than or equal to 58* Batt_tmp = (395 - Decimal_value * 16)/2 *u. For (Decimal_value * 16) greater than 35 and lesser than or equal to 49* Batt_tmp = (225 - Decimal_value * 16)

		*v. For other (Decimal_value * 16) less than 35* Batt_tmp = (228 - Decimal_value * 16)
B3	Hex, 2	OBC Temperature *For Decimal_value less than 163* Decimal_value/2 *For Decimal_value greater than 163* (Decimal_value - 255)/2
B4	Hex, 2	Backplane Temperature *If ref_temp within -50~50 celsius, inclusive* *For Decimal_value less than 128* Decimal_value/2 *For Decimal_value greater than or equal to 128* (Decimal_value - 256)/2 *Else, if ref_temp is greater than 50 celsius* Decimal_value/2 *Else, (if ref_temp is less than -50 celsius)* (Decimal_value - 256)/2 *ref_temp = median(battery_temperature, OBC_temperature, UHF_temperature, VHF_temperature, missionboard_temperature)*
B5	Hex, 2	UHF Transmitter Temperature ((Decimal_value*16*2500/4095)-1366)/5
B6	Hex, 2	VHF Transmitter Temperature ((Decimal_value*16*2500/4095)-500)/10
B7	Hex, 2	Mission Board Temperature *For Decimal_value less than 128* -0.9048243*Decimal_value + 40.7604467 *For Decimal_value greater than 128* -0.9048243*(Decimal_value - 256) + 40.7604467 *Round to the nearest integer*
B8	Binary, Bit 7	Heater Flag indicator [B8: _ x x x x x x x] 1: Enabled, 0: Disabled
B8	Binary, Bit 6	Mission Queue indicator [B8:x _ x x x x x x] 1: 1, 0: 0

B8	Binary, Bit 5	Operation Mode indicator [B8:x x _x x x x x] 1: Mission, 0: Nominal
B8	Binary, Bit 4	Main Kill indicator [B8:x x x_ x x x x] 1: OFF, 0: ON
B8	Binary, Bit 3	Com Kill indicator [B8:x x x x_ x x x] 1: OFF, 0:ON
B8	Binary, Bit 2	First Uplink Command indicator [B8:x x x x x_ x x] 1:Received, 0: Not Received
B8	Binary, Bit 1	Solarcell +X indicator [B8:x x x x x x _ x] 1: Sunshine, 0: Shadow
B8	Binary, Bit 0	Solarcell -X indicator [B8:x x x x x x x _] 1: Sunshine, 0: Shadow
B9	Binary, Bit 7	Solarcell +Y indicator [B9: _ x x x x x x x] 1: Sunshine, 0: Shadow
B9	Binary, Bit 6	Solarcell -Z indicator [B9: x_ x x x x x x] 1: Sunshine, 0: Shadow
B9	Binary, Bit 5	Solarcell +Z indicator [B9: x x_ x x x x x] 1: Sunshine, 0: Shadow
B9	Binary, Bit 4	ANT Deployment Success Indicator [B9: x x x_ x x x x] 1: Success, 0: Failed
B9	Binary, Bits 3~0	Reset Time Indicators [B9: x x x x _ _ _ _] Convert the given binary raw data into decimal. Example: 0 0 1 1 = 3 hours from the last reset

CW Beacon Type 2		
Format & No. of Characters		**Description**
DX3MYA	Alphanumeric, 6	Satellite Callsign
_	Alphanumeric, 1	Spacer
Maya3	Alphanumeric, 6	Name of Satellite
_	Alphanumeric, 1	Spacer
d	Alphanumeric, 1	Beacon Type Specifier [*a*: Type 1, *d*: Type 2, *e*: Type 3]
B0	Hex, 2	Battery Voltage (2.5*Decimal_value*16/4096)*2000 mV
B1	Hex, 2	Battery Current (Decimal_value*16*0.78)-1620)/0.264 mA
B2	Hex, 2	OBC Temperature *For Decimal_value less than 163* Decimal_value/2 *For Decimal_value greater than 163* (Decimal_value - 255)/2
B3	Hex, 2	Gyroscope X [degrees per second] If numerical value is greater than 127: − (256-value) × 0.56 If numerical value is less than or equal to 127: value × 0.56
B4	Hex, 2	Gyroscope Y [degrees per second] If numerical value is greater than 127: − (256-value) × 0.56 If numerical value is less than or equal to 127: value × 0.56
B5	Hex, 2	Gyroscope Z [degrees per second]

		If numerical value is greater than 127: – (256-value) × 0.56 If numerical value is less than or equal to 127: value × 0.56
B6	Hex, 2	Magnetometer X Magnetic Field [milligauss] If numerical value is greater than 127: – (256-value) × 40.96 If numerical value is less than or equal to 127: value × 40.96
B7	Hex, 2	Magnetometer Y Magnetic Field [milligauss] If numerical value is greater than 127: – (256-value) × 40.96 If numerical value is less than or equal to 127: value × 40.96
B8	Hex, 2	Magnetometer Z Magnetic Field [milligauss] If numerical value is greater than 127: – (256-value) × 40.96 If numerical value is less than or equal to 127: value × 40.96
B9 - 1	Hex, 1	Solar Panel +Z Voltage [mV] (16 levels) Numerical value × 390.6
B9 - 2	Hex, 1	Solar Panel +Z Current [mA] (16 levels) Numerical value × 31.25

CW Beacon Type 3		
Format & No. of Characters		**Description**
DX3MYA	Alphanumeric, 6	Satellite Callsign
_	Alphanumeric, 1	Spacer
Maya3	Alphanumeric, 6	Name of Satellite
_	Alphanumeric, 1	Spacer
e	Alphanumeric, 1	Beacon Type Specifier [*a*: Type 1, *d*: Type 2, *e*: Type 3]
B0 - 1	Hex, 1	Solar Panel -Z Voltage [mV] (16 levels) Numerical value × 390.6
B0 - 2	Hex, 1	Solar Panel -Z Current [mA] (16 levels) Numerical value × 31.25
B1 - 1	Hex, 1	Solar Panel +Y Voltage [mV] (16 levels) Numerical value × 390.6
B1 - 2	Hex, 1	Solar Panel +Y Current [mA] (16 levels) Numerical value × 31.25

B2 - 1	Hex, 1	Solar Panel -X Voltage [mV] (16 levels) Numerical value × 390.6
B2 - 2	Hex, 1	Solar Panel -X Current [mA] (16 levels) Numerical value × 31.25
B3 - 1	Hex, 1	Solar Panel +X Voltage [mV] (16 levels) Numerical value × 390.6
B3 - 2	Hex, 1	Solar Panel +X Current [mA] (16 levels) Numerical value × 31.25
B4	Binary, Bit 7	GPS lock indicator [B4: _ x x x x x x x] 0: No fix, 1: Valid fix
B4	Binary, Bits 6~3	UTC month [B4: x _ _ _ _ x x x] 1~12: January ~ December
B4 ~ B5	Binary B4: Bits 2~0 B5: Bits 7~6	UTC date [B4: x x x x x _ _ _ , B5: _ _ x x x x x x] 1~31: Day of the month
B5	Binary, Bits 5~1	UTC hour [B5: x x _ _ _ _ _ x] 0~23: 24-hour format
B5 ~ B6	Binary B5: Bit 0 B6: Bits 7~3	UTC minutes [B5: x x x x x x x _ , B6: _ _ _ _ _ x x x] 0~59: Minutes
B6 ~ B7	Binary B6: Bits 2~0 B7: Bits 7~5	UTC seconds[B6: x x x x x _ _ _ , B7: _ _ _ x x x x x] 0~59: Seconds
B7	Binary, Bit 4	East/West indicator [B7: x x x _ x x x x] 0: East, 1: West
B7 ~ B8	Binary B7: Bits 3~0 B8: Bits 7~4	Longitude [B7: x x x x _ _ _ _ , B8: _ _ _ _ x x x x] 0~179: Longitude in degrees
B8	Binary, Bit 3	North/South indicator [B8: x x x x _ x x x] 0: North, 1: South
B8 ~ B9	Binary B8: Bits 2~0 B9: Bits 7~4	Latitude [B8: x x x x x _ _ _ , B9: _ _ _ _ x x x x] 0~89: Latitude in degrees
B9	Binary, Bits 3~0	Unimplemented [B9: x x x x _ _ _ _]