Formation Flying Mission

Title: ERFM: Europa Reconnaissance Formation Mission

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1. Mission Objective

Introduction:

Since 300BCE our species has been wondering are we alone in the Universe or not? The discovery of signs of extant life is critical if we are to understand biology as a universal process. We turned towards the sky in search for answers and found some hints. Jupiter's moon Europa is a prime target in our exploration of potentially habitable worlds beyond Earth. This fascinating world contains a massive saltwater ocean hidden under 10 to 20 kilometers of ice which could host life. To investigate whether extraterrestrial life exists on Europa we need an in-situ exploration of the environment but before sending any landers, we must have a survey of Europa to define a suitable landing zone. Our mission intends to orbit Europa and gain as much science as possible.

Scientific impact: The most promising instrument of all is our GPR (Ground penetrating Radar). It would be able to penetrate deep into the ice shell revealing the underground topology of Europa. As Europa is tidally locked, we would be passing the same sites over and over which gives us an advantage to study the surface changes and geology of Europa as it orbits Jupiter. The LIDAR and mass spectrometer can test the basic elemental requirements for carbon-based life forms to exist. Finding a new form of life opens endless research possibilities for all fields like biology and chemistry.

Technological impact: This mission acts as a technology demonstration as well as a scientific explorer as no CubeSats have ever been sent to the outer solar system let alone, orbit a moon of Jupiter. These satellites divide a big satellite into smaller CubeSats, saving mission cost. The data from our mission would help in laying the foundation for further in situ Europa explorations like Europa Lander.

Social impact: The discovery of life on Europa would imply our universe is much more alive than we ever imagined. It would change the fundamental context in which all of humanity understands itself. Today, the Earth is faced with global challenges that can only be met by increased international cooperation. At such a time, the growth of a unifying cosmic perspective is potentially of enormous importance.

2. How to realize the mission objectives

The formation flying is an **in-track formation** (Fig 1) [1] in which the satellites occupy slightly different orbital planes separated by right ascension of the ascending node, which accounts for the rotation of the Earth. The CAMSAT and SCISAT are released to the left side at an inclination of 45 degrees from a vertical reference line (Fig 2). The RADARSAT is released 45 degrees to the right of the reference line. The Relay is released along the vertical line. The CAMSAT, RADARSAT and Relay are released at the same time. As there is no necessity of

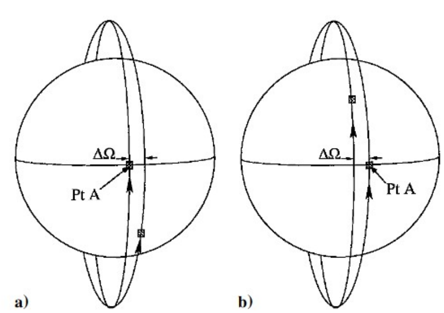

Fig. 1 In-track formation.

position change after decoupling, we do not require any individual propulsion on the satellites. CAMSAT, RADARSAT and SCISAT (called recon sats together) will have a two-way data link to the Relay. The recon sats to relay transmission occurs at 8.2GHz and vice versa at 8.3GHz (Fig.3). The relay communicates the recon sat data to Earth at 8.4GHz that will be received by the Deep Space Network (DSN). The recon sats require their main payloads to be facing the Nadir (towards Europa's surface) at time of observation. In case of Earth signal loss, a special Earth finding maneuver named "EFM1" (Earth Finding Maneuver1) is to be performed. EFM1 involves the use of Received Signal Strength Indicator. The satellite measures the received signal strength for 8GHz along one plane by rotating using the ADCS and points the antenna along the maximum signal strength and locks movement in that direction. It would then rotate in the plane perpendicular to the initial plane and lock the antenna in the direction with maximum signal strength. Thus, Earth (DSN signal at 8GHz) would be found.

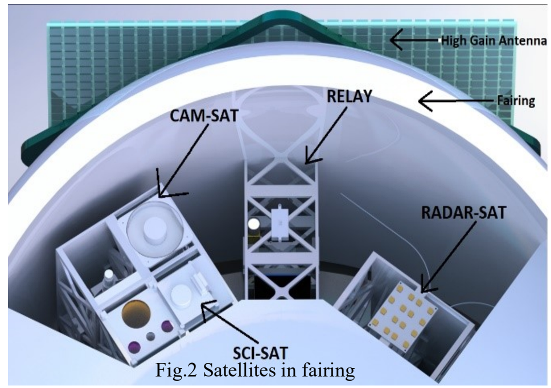

Fig.2 Satellites in fairing

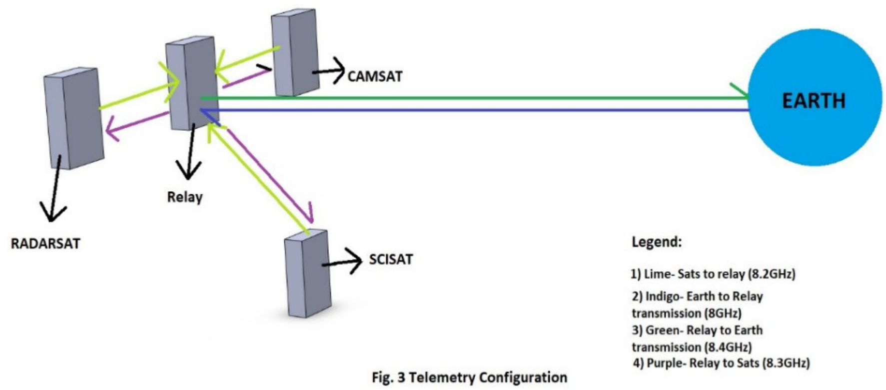

Fig. 3 Telemetry Configuration

3. Technological aspects

Orbital Design: The CubeSats are inside a thick fairing (micrometeorite protection) on a carrier stage (4,250Kg: 2,231 kg of oxidizer (Dinitrogen Tetroxide) and 2,019 kg of fuel (Monomethyl Hydrazine) with a fuel to oxidizer ratio of 1.81:2). The carrier stage is powered by a 1.5 kN hypergolic engine we designed with max delta V=7,753m/s. It is used for final heliocentric orbital (HCO2) insertion, deep space maneuvers, JOI (Jupiter Orbital Insertion), Europa intercept and EOI (Europa Orbital Insertion).

Launch: The Mission starts on 27th January, 2027 with launch from Space Launch Complex 41 at Cape Canaveral Space Force Station in Florida using the Falcon 9 Full Thrust variant. The Falcon 9 puts the payload to a 200km Low Earth Orbit and perform a burn putting the payload into an HCO with excess velocity of 3,150m/s. **Heliocentric transfer & Deep Space Maneuvers:** After that our carrier stage performs a burn providing a delta V of 1,850m/s for final HCO2 with excess velocity=5,000m/s (C3=25 $km^2/s^{2)}$. The HCO trajectory is like Juno probe launched by NASA. After a 1.01 year transfer, a 511m/s burn is done at the aphelion (320,797,178 kilometers) on February 5, 2028 to encounter an earth flyby on December 15, 2028 which will speed up the payload from a heliocentric velocity of 34,785m/s to 38,584 m/s at the perihelion (149.599x10^{6}km) increasing the aphelion to 778.479x10^{6}km , the semi-major axis of Jupiter's orbit around the Sun. Post flyby, the payload will have a 2.93 years transfer till Jupiter encounter on November 22, 2031. V excess at arrival is 5,642m/s and the pericenter velocity of the Jovian hyperbola is 20,236m/s. **JOI:** At the hyperbola pericenter, a retrograde burn with delta V of 1,236m/s is done to put the vehicle into a Jovian orbit with 670,900km, 190,000m/s and 14,546,182km and 876.3m/s as the perijove and apojove altitude and velocity respectively with a period of 4.455 months (3,254 hours) and 0 inclination relative to Europa. **Europa Intercept and EOI:** It would then fly to its apojove with a Europa intercept while approaching perijove on April 9, 2032 at 14:40 UTC when Europa has a phase angle of 178.8° relative to Jupiter at an altitude of 675,500km. A 4 m/s burn is done to raise the perijove to 675,600km and a broken plane maneuver is done such that the vehicle approaches Europa at a slightly inclined orbit. The vehicle approaches Europa with an excess velocity of 5,191m/s and pericenter velocity at 100km altitude from the surface (distance from center: 1,660.8km) of the approach is 5,550m/s. A retrograde burn of delta V=3,745m/s is done. Thus, 1,660km and 9,000km are final apoapsis and periapsis with a 12hrs period. Overall mission delta V is 7,526m/s. **Post EOI:** After the satellites are placed in a nearly polar orbit, the 4 CubeSats are released (fig. 2) via spring mechanism so that the max separation between two sats is 10km.

Table 1 Battery life span (Time in hrs)

	Relay	CAMSAT	SCISAT	RADARSAT
Full Operation	23.2	14	13.2	23.2
Sleep Mode	55	55	55	55

Payload Description: Every CubeSat has: Computer, Reaction Wheels, Solar Sensors, Star tracker, IMU, Battery, Solar Panels, X-band transmitter and receiver. All these satellites will have a small radiation chamber housing the essential electronics like computer, battery, transmitter and receiver protecting them from Jupiter's intense radiation (5.4 Sv around Europa). The Lithium polymer TITAN-1 350Whr Power Bank Module (84000mAh) provides the performance as shown in Table 1. The on-board computer (OBC) has a 32-bit microchip with 16MB RAM, 8GB Flash NAND Memory. All scientific data collected is stored in the OBC and x band transmitter till transmitted. Due to the Jupiter's extreme distance from the sun, the amount of power generated by solar panels at Jupiter is 1/25th generated at LEO requiring large and efficient solar panels. Concentrated PV Cell based solar panels provide an efficiency of 40-42% generating 65W at direct sunlight and 62W at ±15° of incident angle. The solar array would be made of 40 units, 22cm*36cm each which would fold to symmetrically fit with the CubeSat body. The X-band transmitter provided by endurosat has a transmission power of 18W at 33 dBm and 32GB storage. EnduroSat's X-Band 4x4 Patch Antenna Array provide >16dBi gain. Satellites in depth:

i)CAMSAT: It consists of a narrow and a wide field camera. Both the images can be combined to make a high-quality image of the surface of Europa like never before. This can enhance the study of geological and surface phenomena on Europa's surface.

Table 2 Camera parameters

	Wide Field	Narrow field
Spatial res	39m	3m
SWATH	80km	12km

ii)SCISAT: It consists of three instruments: <u>a) Mass Spectrometer</u>: A Low Energy Ion Neutral Mass Spectrometer (0.1eV to 20eV) can make high-resolution, in-situ measurements of [H], [He], [O], [N2], [O2] & [H+], [He+], [O+], [N2+], [O2+] with a Ram facing FOV of 10º x 10º, mass resolution M/dM~10-12, mass range 1-40 amu, Ion densities: 1e3 to 1e8 /cm3 and a sampling time of 0.1-10s. [2] <u>b) LIDAR</u>: Long-range CubeSat lidar configurations can support 1,000 km of range and can be used for Europa's topology mapping (identification of ancient lakes, rivers, fissures, and overall Europa Geodesy), altimetry, measure surface properties of solid ices (Spectral identification of minerals, water, methane, CO2, and others in the 1-4 um bands), tell the difference between liquid and solid phase and dynamic studies of plumes. The lidar is capable of 3D imaging for 10-degree cone angles at long range and 60-degree cone angles at short range [3]. This

LIDAR will have a 2051 nm wavelength for CO2 lidar and the laser can efficiently operate between 1.9 nm and 2.1 um. c) Magnetometer: The theory is that time-variations of Jupiter's magnetic field induce Europa to produce its magnetic field, probably via electric currents flowing in a salty ocean beneath Europa's ice thus allowing scientists to confirm whether an ocean exists on Europa, and measure its salinity and depth.[4] We are using NSS Magnetometer provided by New Space Systems with a range of ±60 000 nT ±2% and a measurement sensitivity of ≤ 8 nT.

iii) RADARSAT: It searches for an ice-ocean interface and characterizes the ice shell's global structure, investigates the processes governing material exchange among the ocean, ice shell, surface, and atmosphere, characterizes scientifically compelling sites, and hazards, for a potential future landing missions, determines whether the ice shell is thermally conductive or unstable due to convection, searches for water signatures, compositional, thermal variations, buried deposits and confirms the presence of a global subsurface ocean. It operates by sending pulses of 9MHz ranging between 20-100 microseconds towards the ground which penetrate deep into icy surface and are reflected. The reflected waves are then received, processed and sent to the relay. The radio will be a Frontier Radio Multi Lingual (Transceiver), having a transmission power of 20W and sounding capability from 4 to 10km vertically to measure the thickness of Europa's ice shell [5].

iv)RELAY: It consists of a Frontier Radio: 7.9 to 8.5 GHz both uplink and downlink having 2,625 Mbps uplink and downlink speed (8PSK modulation). It has a transmission power of 30W. The frontier radio will be used for: recon sat data reception, data forwarding to Earth and relaying commands from Earth to recon sats. The high gain antenna (HGA) on the relay requires ±5° of accuracy to point towards Earth. It is made up of circularly polarized unit cells. The entire antenna is an array of these unit cells, 32 on a side. The antenna is 32.5 by 32.5 inches and can achieve a downlink rate to Earth of 33 kilobits per second at 80 percent efficiency [6]. An accuracy of ±0.1° which is enough to point to Earth.

4. How to realize the required relative attitude and position control of satellites.

The attitude of the satellites is controlled by the ADCS (Attitude Determination and Control Subsystems). Our ADCS consists of 3 reaction wheels, 6 solar sensors on each face of the CubeSat, an IMU (Inertial Measurement Unit) and a star tracker (The MAI-SS Star Tracker). All these combines to provide an accuracy of 365.9 arcseconds or 0.1°. The sun sensors can find the attitude of satellite relative to the sun in 2 axes. The star tracker helps in determining the location and attitude of a satellite by analyzing the placement of the surrounding stars relative to the satellite. IMU measures specific gravity and angular rate of the satellite. The reaction wheels then work together to change the attitude. The reaction wheels each provide ±0.5 mNm torque at 0.04 Nms (5V power supply) sold by Rocket Lab. The sun sensor sold by CubeSat shop has ± 60 º FOV, accuracy of 0.3°. The star tracker sold by Adcole Maryland Aerospace has Cross Axis- 5.7 arcsec, Boresight-27 arcsec accuracy.

5. Rough images of satellites

RADAR-SAT	Mass(kg)	Dimensions(cm)	Power Usage(W)
ADCS			
Computer	0.038	9 x 9 x 1	0.3
Reaction Wheels	0.555	5 x 5 x 4	5.4
Solar sensor	0.035	5 x 3 x 1.2	1.89
Heater	0.05		10
IMU	0.055	4.4 x 3.8 x 2.1	2
The MAI-SS Star Tracker	0.305	5.5 x 6.5 x 7.0	1.5
Telemetry			
X band transmitter	0.27	9.59 x 9.02 x 2.25	18
X band receiver	0.1	5 x 5 x 2	5
Power Systems			
Battery	2.4	8.9 x 9.5 x 9.8	
Solar Panels	8.5	(140 x 110)*2	65(Generation)
Payload			
Ground Penetrating Radar - Electronics	1	10 x 10 x 10	20
Ground Penetrating Radar - Dipole Antenna	0.11	1500 x 0.1	
Structure weight	2		
Total	**15.418**		**64.09**

CAM-SAT	Mass(Kg)	Dimensions(cm)	Power usage(W)
ADCS			
Computer	0.038	9 x 9 x 1	0.3
Reaction wheels	0.555	5 x 5 x 4	5.4
Solar Sensor	0.213	5 x 3 x 1.2	1.89
Heater			10
IMU	0.055	4.4 x 3.8 x 2.1	2
The MAI-SS Star Tracker	0.305	5.5 x 6.5 x 7.0	1.5
Telemetry			
X band Transmitter	0.275	9.59 x 9.02 x 2.25	18
X band receiver	0.1	5 x 5 x 2	5
Power Systems			
Battery	2.4	8.9 x 9.5 x 9.8	
Solar Panels	8.5	140 x 110	65(Generation)
Payload			
Wide Field Camera	0.4	10 x 10 x 6.5	4.5
Narrow Field Camera	1.8	10 x 10 x 24.5	10
Structure weight	2	36 x 22 x 10	
Total :	**16.641**		**58.59**

RELAY	Mass(Kg)	Dimensions(cm)	Power usage(W)
ADCS			
Computer	0.038	9 x 9 x 1	0.3
Reaction wheels	0.555	5 x 5 x 4	5.4
Solar Sensor	0.213	5 x 3 x 1.2	1.89
Heater	0.05		10
IMU	0.055	4.4 x 3.8 x 2.1	2
The MAI-SS Star Tracker	0.305	5.5 x 6.5 x 7.0	1.5
Telemetry			
Frontier Radio	1	10 x 10 x 10	30
Power Systems			
Battery	2.4	8.9 x 9.5 x 9.8	
Solar Panels	8.5	(140 x 110)*2	65(Generation)
Structure weight	2	36 x 22 x 10	
Total :	**15.116**		**51.09**

SCI-SAT	Mass(Kg)	Dimensions(cm)	Power (W)
ADCS			
Computer	0.038	9 x 9 x 1	0.3
Reaction wheels	0.555	5 x 5 x 4	5.4
Solar Sensor	0.213	5 x 3 x 1.2	1.89
Heater	0.05		10
IMU	0.055	4.4 x 3.8 x 2.1	2
The MAI-SS Star Tracker	0.305	5.5 x 6.5 x 7	1.5
Telemetry			
X band Transmitter	0.275	9.59 x 9.02 x 2.25	18
X band receiver	0.1	5 x 5 x 2	5
Power Systems			
Battery	2.4	8.9 x 9.5 x 9.8	
Solar Panels	8.5	(140 x 110)*2	65(Generation)
Payload			
Mass Spectrometer	0.56	9 x 10 x 13	1.8
LIDAR	2	10 x 10 x 20	14.3
Magenetometer	0.082	9.914 x 4.3 x 1.7	0.735
Structure weight	2	36 x 22 x 10	
Total	**17.133**		**60.925**

Details	Cost in USD ($)
Components	3,191,336
Launch	67,000,000
Testing	1,500,000
Operation Cost	1,100,000
Total Mission Cost	72,791,336

Communication Speed			
Uplink(Relay→Earth)	270Kbps	Downlink (Earth→Relay)	2Kbps
Uplink (Relay→Sat)	124Mbps	Downlink (Sat →Relay)	124Mbps

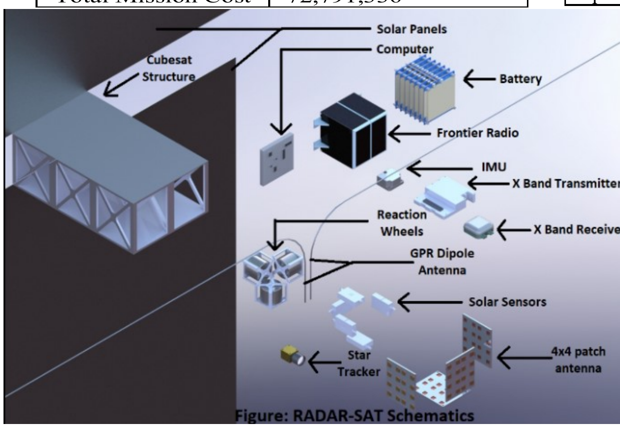

Figure: RADAR-SAT Schematics

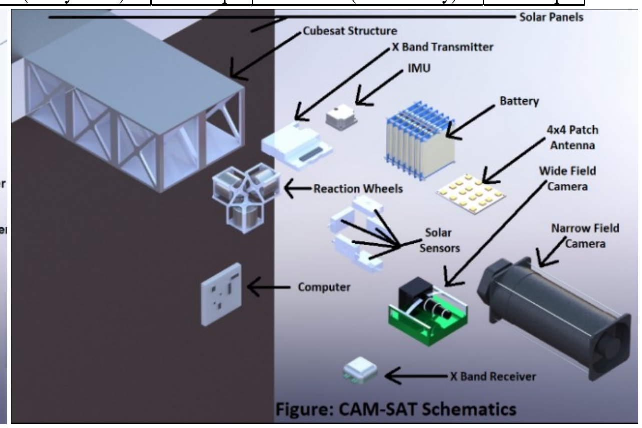

Figure: CAM-SAT Schematics

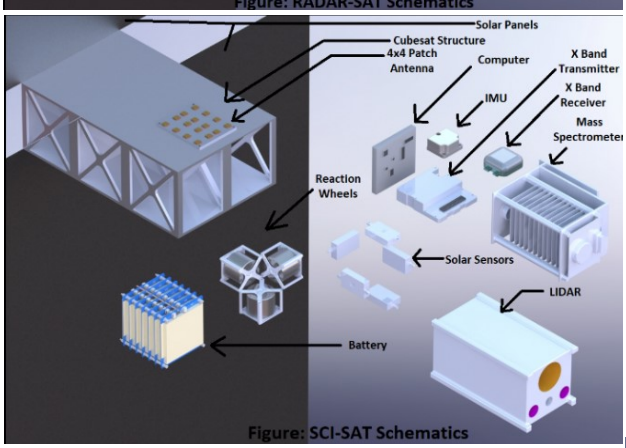

Figure: SCI-SAT Schematics

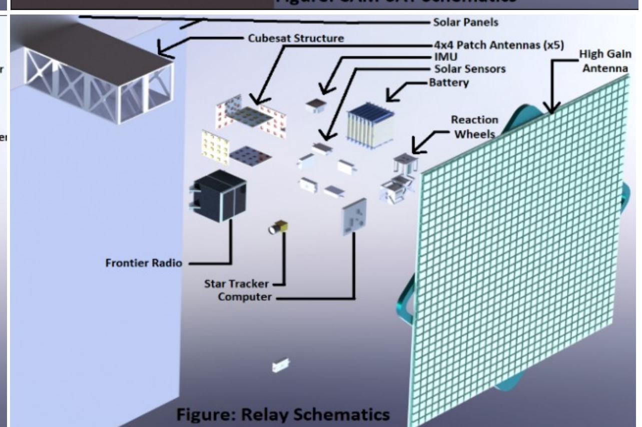

Figure: Relay Schematics

References

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[2] Nikolaos P. Paschalidis, "[Mass Spectrometers for Cubesats]".

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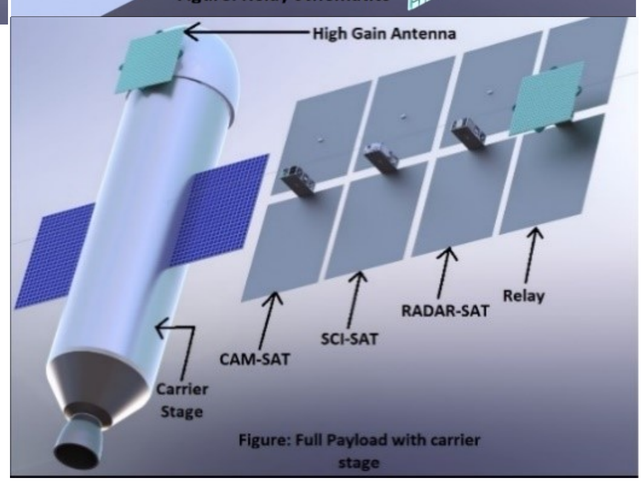

Figure: Full Payload with carrier stage

sample capture, surface, and atmospheric science," 2017

[4] Nico Schilling et al, "Time-varying interaction of Europa with the jovian magnetosphere.

[5] REASON instrument NASA.

[6] HGA for direct Earth telemetry.