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Preliminary design of a CubeSat for plume sampling and imaging at Europa

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Abstract

Europa is the closest and probably the most promising target to perform a comprehensive characterization of habitability and search for extant life. A proposal to ESA's Cosmic Vision programme has recently been submitted in order to propose that NASA and ESA join forces to design an ambitious planetary mission (JEM, for Joint Europa Mission) to reach this objective. JEM will be assigned the following overarching goal: Understand Europa as a complex system responding to Jupiter system forcing, characterize the habitability of its potential biosphere, and search for life in its surface, sub-surface and exosphere. The proposed JEM mission will consist of two space platforms: a carrier/relay/orbiter platform (hereafter referred to as orbiter), and a soft lander platform.

Possible CubeSat additions to JEM can complement the science objectives in a unique way, in order to study phenomena of great interest not achievable by the orbiter. The recent observations by the Hubble Space Telescope of plumes rising hundreds of kilometres above Europa's surface rises the interest for directly sampling the material from these plumes, when occurring, as part of our life search strategy.

In this paper, we will present a preliminary design of a 12U CubeSat designed to be deployed by the Joint Europa Mission in order to study in detail potential Europa plumes through in situ measurements of their charged particles and magnetic field environments as well as imaging of their surface sources. Flying a CubeSat in the Jupiter/Europa environment constitutes a significant challenge and we will address in particular issues related to propulsion, power as well as radiation mitigation.

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Increasing Small Satellite Reliability for Planetary Science Missions

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Abstract

Planetary Science is expected to benefit greatly from the advent of CubeSats and/or SmallSats and the science community is embracing this. Three deep space planetary CubeSats have been built at JPL but at present, CubeSat components and buses are generally not appropriate for planetary missions where significant risk of failure, or the inability to quantify risk or confidence is unacceptable. However, in the future we anticipate that CubeSats will be used for missions routinely for Planetary missions. In addition, SmallSats using CubeSat components and subsystems but not having the CubeSat form factor will likely be developed for many Planetary applications. Both CubeSats and SmallSats could then be used where their attributes enable or enhance mission objectives or provide other meaningful benefits—e.g. lower cost, increased coverage (spatial, temporal, spectral), agility, resiliency, etc. This paper will discuss the genesis of and drivers for a Small Satellite Reliability Initiative, how a public-private collaboration is being executed, findings and recommendations derived to date, and next steps towards broadening small satellite mission potential. It will also discuss some available and upcoming technologies that will enable planetary missions

1. Introduction

Planetary Science is expected to benefit greatly from the advent of CubeSats and/or SmallSats and the science community is embracing this as evidenced by the 102 submissions to a recent NASA PSD call for Planetary Science Deep Space SmallSat Studies. Three planetary CubeSats have been built at JPL but at present, CubeSat components and buses are generally not appropriate for missions where significant risk of failure, or the inability to quantify risk or confidence is unacceptable. However, in the future we anticipate that CubeSats will be used for missions requiring reliability of 1-3 years for Earth missions and even longer for Planetary missions. In addition, SmallSats could be developed using CubeSat components and subsystems but will not have the CubeSat form factor, which will be likely for most Planetary applications. Both CubeSats and SmallSats could then be used where their attributes enable or enhance mission objectives or provide other meaningful benefits—e.g. lower cost, increased coverage (spatial, temporal, spectral), agility, resiliency, etc. Historically, it was understood and accepted that "high risk" and "CubeSat" were largely synonymous; expectations were set accordingly. But their growing potential utility is driving an interagency effort to improve and quantify CubeSat reliability, and more generally, small satellite mission risk.

2. Small Satellite Reliability Initiative (SSRI)

The Small Satellite Reliability Initiative (SSRI)—an ongoing activity with broad collaborative participation from civil, DoD, and commercial space systems providers and stakeholders—targets this challenge. The Initiative seeks to define implementable and broadly accepted approaches to achieve reliability and acceptable risk postures associated with several SmallSat mission risk classes—from "do no harm" missions, to those associated with missions whose failure would result in loss or delay of key national objectives. These approaches will maintain, to the extent practical, cost efficiencies associated with small satellite missions and consider constraints associated with supply chain elements, as appropriate. The SSRI addresses this challenge from two architectural scopes—the mission- and system-level, and the component- and subsystem-level. The mission- and system-level scope targets assessment approaches that are efficient and effective, and mitigation strategies that facilitate resiliency to mission or system anomalies while the component- and subsystem-level scope addresses the challenge at lower architectural levels. The initiative is not limiting recommended strategies and approaches to proven and traditional methodologies, but is focused on fomenting thought on novel and innovative solutions.

This paper will discuss the genesis of and drivers for this initiative, how the public-private collaboration is being executed, findings and recommendations derived to date, and next steps towards broadening small satellite mission potential. It will also discuss some available and upcoming technologies that will enable planetary missions.

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Planetary exploration with nanosatellites: a space campus for future technology development

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Abstract

Planetary exploration is at the eve of a revolution through nanosatellites accompanying larger missions, or freely cruising in the solar system, providing a man-made cosmic web for in situ or remote sensing exploration of the Solar System. A first step is to build a specific place dedicated to nanosatellite development. The context of the CCERES[1] PSL space campus presents an environment for nanosatellite testing and integration, a concurrent engineering facility room for project analysis and science environment dedicated to this task.

1. Introduction

The development of nanosatellites has reached a formidable increase during the last decade. It is sometimes described as a democratization of access to space for experiments in the context of universities and institutes. The specificity of the domain, and the interaction with university projects have raised the need for new approach in satellite developments, qualification and integration. Supported by space laboratories in France, the space campus CCERES intends to coordinate these efforts in relationship with institutional and entrepreneurial actors to develop a new domain of expertise.

1.1 Description of the scientific context

Three types of nanosatellites have been developed: educational, technological, and scientific. CCERES is working in the field of scientific and technological nanosatellites, in order to provide an answer to dedicated science questions, as well as paving the way for future missions through technological development of new instruments, by increasing their TRL. The CCERES campus joins science and education guides:

- ESEP: the “laboratoire d’excellence” ESEP[2] coordinates science activities and research and developmenet in the domain of technology for instruments of space mission. As a coordination of space laboratories in space research, it decides of the scientific selection of projects for the space campus

- The master degree OSAE[3] the educational frame for space projects, and surveys the development of projects

1.2 Facilities for nanosatellite development

The integration of nanosatellites projects is made within the facilities available in Paris Observatory for CCERES :

- Room for concurrent engineering: under the coordination of a system engineer, a project team is supported to design a pertinent mission profile and to size its key systems within a concurrent engineering process.
- Clean integration rooms and access to specialized facilities : different qualification and tests can be performed under controlled environment (bake out, thermal vacuum, plasma, etc.)

[1] Campus et Centre de Recherche pour l’Exploration Spatiale ; https://cceres.univ-psl.fr/
[2] Exploration Spatiale des Environnements Planétaires ; http://www.esep.pro
[3] Astronomical and space based systems engineering ; http://osae.obspm.fr

2. Current nanosatellite projects under study

A list of the projects considered for a support in the CCERES facilities is given in Table 1.

Table 1: list of nanosatellite projects supported within CCERES/ESEP

Name	Laboratory	Principal Investigtor
BIRDY-T	IMCCE	D. Hestroffer
CIRCUS	LESIA	K. Issautier
PICSAT	LESIA	S. Lacour
OGMS-SA	LISA	N. Grand
METEOR	IMCCE	N. Rambaux
GPU4SPACE	LESIA	D. Gratadour
SERB	LATMOS	M. Meftah

A selection of three projects is described in more details here, among these projects:

a) PICSAT

PICSAT is a nanosatellite project in final phase of construction [1]. It is aimed to detect a potential transit of the exoplanet beta-Pictoris b, predicted to occur in 2017 [2]. This 3-unit cubesat has been developed with a fine pointing optical fiber system to reach the sensitivity for transit photometry

b) CIRCUS

CIRCUS is a nanosatellite devoted to in-situ plasma measurements. It is developing a new technology of numerical radioreceptors, for space qualification. CIRCUS is also a prototype of a network of nanosatellites in the NOIRE projects [3], intended to study the heliosphere through space radio low frequency interferometry.

c) BIRDY-T

BIRDY-T is a nano-/micro-satellite technology for quasi-autonomous navigation in deep space with a pulsed plasma thruster (PPT) propulsion that could unlock new scientific and commercial applications [4, 5]. The first science case is a CubeSat for planetary geodesy that is released by a mothercraft in the vicinity of an asteroid. Then the autonomy of the CubeSat allows multiple flybys at very close range to perform radio-science measurements that probes the very local gravitational field. The precise orbit reconstruction will constrain the mass densities of the explored asteroid and yield major assumptions in the theories of planetary system formations.

3. Summary and Conclusions

The activities of CCERES space campus are growing toward a federation of different space campus in the area of Paris region Ile de France. By providing a panel of space integration and facilities, it participates to the construction of a network of supporting structure, with a unique environment of expertise to develop new projects.

Acknowledgements

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SMALL INNOVATIVE MISSIONS FOR PLANETARY EXPLORATION

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Abstract

When we think of space satellites that assist with communications, weather monitoring and GPS here on Earth, we likely picture them as being quite large—many are as big as a school bus and weigh several tons. Yet there's a class of smaller satellites that's growing in popularity. These miniaturized satellites, known as nanosatellites or CubeSats, can fit in the palm of your hand and are providing new opportunities for space science.

CubeSats are small satellites built from a set of standardized subunits that each measure 10x10x10 cm and weight 1.33 kg (designated '1U'). Common configurations include 1U, 2U, 3U, and 6U (2Ux3U) satellites, deployers for all of which are commercially available. Due to their standardized form and low-cost disposable nature, these satellites are suitable platforms on which to train students and early career researchers. Indeed, while CubeSats have historically been used as teaching tools and technology demonstrations, today's CubeSats have the potential to conduct important space science investigations as well.

The NASA Planetary Science Division (PSD) Small Innovative Missions for Planetary Exploration (SIMPLEx) supports the formulation and development of science investigations that require a spaceflight mission that can be accomplished using small spacecraft.

This program encourages the submission of CubeSat investigations that operate in interplanetary space and would, therefore, meet more demanding engineering and environmental requirements than has been experienced by previous CubeSats. While it is expected that proposed investigations would involve some advanced engineering development of instruments and/or spacecraft systems technology, all proposals must include a science investigation that will return and publicly archive usable scientific data and result in the publication of results in refereed scientific journals.

This presentation will discuss the NASA Planetary Science Divisions SIMPLEx initiative and provide a status update on the first cadre of selected investigations.

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Asteroid touring nanosat fleet with single-tether E-sails

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Abstract

The electric solar wind sail (E-sail) is a method for generating efficient low-thrust propulsion outside Earth's magnetosphere. In its simplest form the E-sail is a single spinning ~ 20 km long tether biased at ~ 10 kV positive voltage by an onboard electron emitter and high-voltage source. Here we consider a fleet of ~ 5 kg spacecraft, propelled by the E-sail tether and making quasi-elliptic passes through the asteroid main belt. Each spacecraft also uses its tether to make a ~ 1000 km flyby of 6-7 asteroids. Data are stored in memory and downloaded at a final Earth flyby at the end of the mission using conventional non-directional radio subsystem. Using this mission architecture, the cost per imaged asteroid is only ~ 200 k€ which is a reduction by about 3 orders of magnitude with respect to the state of the art.

1. Introduction

The electric solar wind sail (E-sail) uses the natural solar wind for generating efficient propellantless propulsion [1]. The E-sail is very well suited for asteroid missions because they typically have high low-thrust delta-v requirements and many applications have been proposed and analysed [3, 4, 5, 6]. Here we consider a fleet of nanosatellites propelled by a simple single-tether E-sail [2] (Figs. 1, 2). Using only a single tether increases reliability and makes it possible (by attaching the tether at the spacecraft's centre of mass) to point the spacecraft to a target without moving parts other than internal momentum wheels.

2. Single-tether E-sail nanosat

With 10 kV tether voltage, the tether generates 250 nN/m thrust per unit length at 1 au in average solar wind. Hence, if a 5 kg spacecraft has a 20 km tether, characteristic acceleration of 1 mm/s^2 is obtained at 1 au. Orbital calculations show that this level of E-sail acceleration is enough to make the spacecraft fly through the asteroid main belt in a quasi-elliptic orbit taking ~ 3.2 years (Fig. 3). The E-sail uses full thrust after leaving Earth and before entering the main belt, and then enters reduced thrust science mode where the available E-sail propulsion is used for active manoeuvring to maximise the number of asteroids flown by at close range. The number of well-known (numbered) asteroids reached by the spacecraft is then typically 6-7. Data are stored in flash memory chips during the mission and downloaded at a final Earth flyby so that only ~ 3 hours of deep-space network time is required to download the ~ 10 GB of data. The surface resolution of the flyby images is 100 m pixel size or better (with 4 cm telescope at 1000 km distance the diffraction limit would be even ~ 20 m) and a separate NIR spectrometer can be used to identify surface minerals.

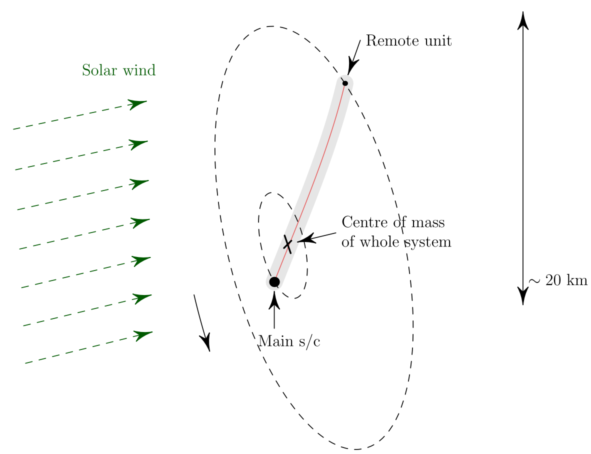

Figure 1: The single-tether E-sail spacecraft.

The main science instrument is a 4 cm telescope which is used to image the asteroids at ~ 1000 km flyby range. Between the asteroid encounters, the telescope is also used for autonomous optical navigation based on known nearby asteroids. Typically, more than 5 asteroids are observable within 10 million km

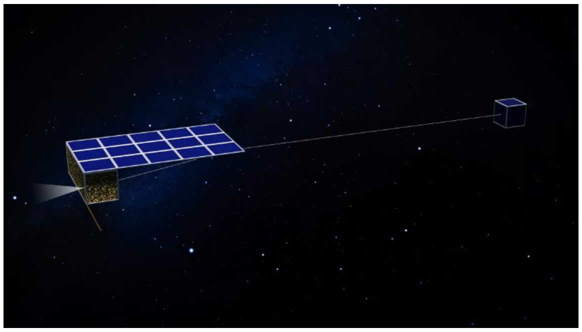

Figure 2: Artist's concept of the spacecraft.

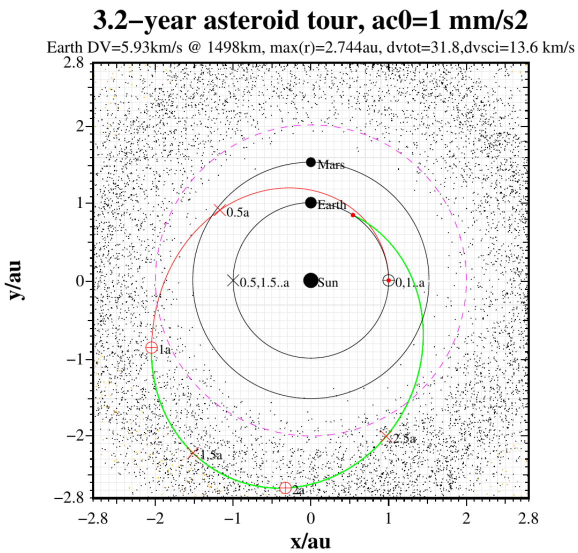

Figure 3: Mission trajectory.

range, and with 10^{-4} angular accuracy (a conservative estimate because 7 times less than diffraction limit for a 4 cm telescope), 1000 km or better orbital accuracy is obtained. Pointing the telescope towards the asteroids is possible because the spinning tether is attached at the centre of mass of the spacecraft: the spacecraft can turn in two axes by using its internal momentum wheels.

3. Fleet mission

Any number of the nanosats can be launched and the escape or high elliptic orbit launch mass is $\sim 10\,\mathrm{kg}$ per spacecraft including the launch pod. For example, the PSLV can lift $\sim 500\,\mathrm{kg}$ to such orbit and thus could launch a cluster of 50 asteroid touring nanosats. Because of satellite makes a flyby of 6-7 asteroids, the total number of asteroids imaged is over 300. The mission total cost is ~ 60 M€ including R&D, launch and operations, so that the cost per asteroid is ~ 0.2M€.

4. Rationale

- Asteroids are very diverse target, hence a large number of them should be studied *in situ*. The only cost-effective way to do it is to use small spacecraft.
- Lightweight optical+NIR instrumentation yields lot of information: size, shape, collision history, presence of moons if any, mineral composition, amount of regolith...
- Low cost: few hundred thousand per asteroid.
- Flexible launch: single or small groups of spacecraft can be piggybacked with any planetary, lunar or Lagrange point missions, or the whole fleet can be launched at once e.g. by PSLV. The requirement is to reach high elliptic or escape orbit, but otherwise the launch orbit's parameters do not matter. The E-sail only needs to get outside Earth's magnetosphere to have access to the solar wind.
- Low telemetry cost since Earth flyby is used to download data. The nanosatellites do not need high-gain antennas.

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Feasibility of asteroid exploration using CubeSats — ASPECT case study

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Introduction

Operation of a small CubeSat in the deep-space microgravity environment brings additional challenging factors as the increased radiation environment, significant contribution of non-gravitational forces on satellite orbit, or the limited communication opportunities. These factors need to be taken into account in the form of modifications to classic CubeSat architecture. Additionally to increased radiation resistance, the semi-autonomous operation, navigation, and the active orbit correction are required. Such modified CubeSat platform can potentially deliver high performance / mass and cost ratio. The Asteroid Spectral Imaging Mission (ASPECT) is a three unit (3U) CubeSat mission build on these principles. ASPECT is equipped with a visible – near-infrared hyperspectral imager and will deliver both technological knowledge as well as scientific data about the origin and evolution of the small Solar System bodies.

Asteroid CubeSat mission analysis

The deep space environment bring several additional challenges compared to CubeSat operations at low earth orbit (LEO). Following major factors were identified to be addressed for successful CubeSat deep space operations:

- F1 Low-gravity environment
- F2 Reduced set of objects for navigation reference
- F3 Presence of significant perturbation forces as solar /radiation wind pressure, planetary perturbations, own heat radiation force relative to the gravity of the orbiting object
- F4 Increased radiation background (operation outside Earth magnetosphere)
- F5 Limited direct communication opportunities

In order to successfully cope with the abovementioned factors characteristic for deep-space environment following modifications to the classic CubeSat configuration have to be implemented:

- M1 Active propulsion system
- M2 Multi-reference advanced navigation
- M3 Reliable, semi-autonomous mission operation, navigation, and trajectory correction
- M4 Enhanced radiation shielding/tolerance
- M5 Foldable dish antenna or communication utilizing relay spacecraft

ASPECT concept

ASPECT is a 3U CubeSat technological demonstration mission developed for the ESA-NASA AIDA (Asteroid Impact & Deflection Assessment) project. In 2016 it underwent preliminary design study and was down selected as the only CubeSat payload for European AIDA component AIM-D[2] (Asteroid Impact Mission – Deflection Demonstration).

The payload, avionics, and cold gas propulsion units occupy each 1U space. The CubeSat platform provides required subsystems for operating the payload and communication. The operation infrastructure is centered on the S-band radio link, which provides the satellite attitude control location data from the mothercraft, as well as access directly to all the other subsystems of the satellite, negating the need for a traditional failure-prone hub, e.g. an Onboard Computer, to access the subsystems. The system architecture, space-qualified subsystem modules, structural components and the platform software are currently used in the Reaktor Space Lab's Hello World in-orbit demonstration satellite. The ASPECT platform avionics, including the S-band radio equipment, batteries, attitude and orbit control, and the electrical power system, are integrated in a 1U module to minimize external connections and to simplify the system. Also included in the platform section are solar panel connections and all required harnessing. The CubeSat platform will be a radiation-hardened and single-event effect (SEE) resistant to guarantee reliable operation for at least 3 month mission period. The satellite system block diagram is depicted in Fig. 1. All subsystems are monitored and switchable during operations from the electrical power system.

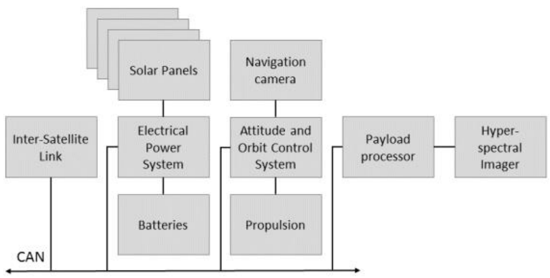

Figure 1. ASPECT high-level systemblock diagram.

Spectral imager payload

The payload is a miniaturized spectral imager extending from the visible up to the shortwave infrared wavelengths. In contrast to more traditional spatial-scanning imaging spectrometers, the Asteroid Spectral Imager utilizes tunable Fabry-Perot Interferometers (FPI) to select the imaged wavelengths. When multiple snapshots are combined, a spectral datacube is formed, where the wavelength bands are separated in the time domain. The instrument is based on the space-qualified designs of the Aalto-1 Spectral Imager and Picasso VISION.

The instrument envelope is 97 mm x 97 mm x 100 mm (roughly 1U), which is split into three measurement channels, one in the visible (VIS), and two in the infrared (NIR and SWIR). The VIS and NIR channels are imaging spectrometers, while the SWIR channel only measures a single point. The target wavelength range is 500 - 900 nm for the VIS channel, 900 - 1600 nm for the NIR channel and 1600 - 2500 nm for the SWIR channel. The spectral separation is done by a tunable Fabry-Perot Interferometer (FPI). All three channels have dedicated FPIs optimized for the desired wavelength range. The imaged wavelengths are freely selectable within these ranges, and the targeted spectral resolution is ca. 10 - 50 nm. All three channels can be operated simultaneously and are independent of each other. Even if a single image sensor or FPI is lost, the mission can still carry on with limited capabilities. The main instrument parameters are listed in Table 1.

Table 1. The main Asteroid Spectral Imager parameters.

Parameter	VIS channel	NIR channel	SWIR channel	notes
Field of View [deg]	6° x 6°	5.3° x 5.3°	5° circular	
Spectral range [nm]	500 – 900	900 – 1600	1600 - 2500	
Image size [pixels]	614 x 614	256 x 256	1 pixel	
No. spectral bands	Ca. 14	Ca. 24	Ca. 30	Tunable in flight
Spectral resolution [nm]	< 20 nm	< 50 nm	< 25 nm	

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SmallSat Spinning Lander with a Raman Spectrometer Payload for Future Ocean Worlds Exploration Missions

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Abstract

We describe an Evolved Expendable Launch Vehicle Secondary Payload Adapter (ESPA)-class SmallSat spinning lander concept for the exploration of Europa or other Ocean World surfaces to ascertain the potential for life. The spinning lander will be ejected from an ESPA ring from an orbiting or flyby spacecraft and will carry on-board a standoff remote Spatial Heterodyne Raman spectrometer (SHRS) and a time resolved laser induced fluorescence spectrograph (TR-LIFS), and once landed and stationary the instruments will make surface chemical measurements. The SHRS and TR-LIFS have no moving parts have minimal mass and power requirements and will be able to characterize the surface and near-surface chemistry, including complex organic chemistry to constrain the ocean composition.

1. Introduction

The spinning lander concept is a novel adaption of a classic dual-spin spacecraft architecture. A spinning module provides robust gyroscopic attitude stability, a relatively benign thermal environment (by evenly distributing heat loads) and centripetal acceleration (for effective propellant settling and flow control); it is connected to a despun module *via* a rotor/bearing assembly, and this despun module also accommodates a landing leg system. Most subsystems for a spinning lander—power, telemetry and command, RF telecommunications, attitude control, despun rotor control, propulsion, etc.—are nearly identical functionally to those included on over a hundred successful dual-spin spacecraft missions in the past [1-3]. What converts this proven, robust, scalable spacecraft architecture into an effective small lander [4, 5] is the addition of landing legs to the despun section, a landing radar and dedicated science instrument payloads that are commensurate with CubeSat volumes, *e.g.*, spatial heterodyne Raman spectrometer [6, 7]. It is envisaged that a constellation of spinning landers (each spinning lander carrying a dedicated payload) would be ejected and deployed from an ESPA. Fig. 1 shows an ESPA-class spinning lander concept with a 1U CubeSat avionics enclosure volume.

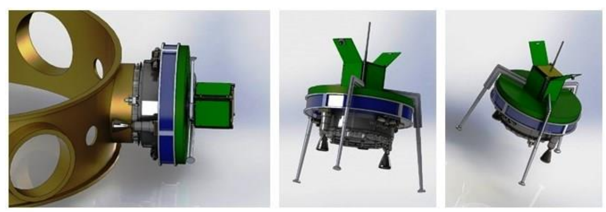

Figure 1: ESPA-class spinning lander concept (only one spinning lander shown). There is an 8" Lightband interface with the ESPA ring port and ~1U CubeSat-sized avionics electronics enclosure on the despun side.

Fig. 2 shows a notional spinning lander mission concept. Control of spacecraft velocity, spin rate and attitude is accomplished *via* relatively simple and independent sets of thrusters: axial (parallel to spin axis), radial (normal to spin axis) and tangential (to spinning section rim). In free space, bulk spin rate of the spacecraft is controlled with the tangential thrusters, while relative spin rate and azimuth phase control between the despun and spun sections is accomplished with the rotor/bearing assembly, which also passes power and signals across the interface *via* a series of slip rings. Telecom antennas, scaled to meet mission objectives, can be mounted to both sections, though the higher gain antenna(s) are almost always on the despun section.

During the terminal landing phase, with despun section and legs set at zero spin, the spinning portion of the lander continues to spin until touchdown, providing significant gyroscopic stability to the entire landed system. Importantly, this system essentially can't tip over during landing, but will rather 'bounce' or 'stick' depending on the leg system design. Depending on mission goals, once on the surface the spacecraft's spinning section can either be stopped or left to spin at any desired rate *via* rotor/bearing control. In the spinning mode, the entire lander becomes an excellent hopper as well, providing extended range/coverage options, onboard propellant permitting. Selected instruments on the despun section can be controlled independently in azimuth and elevation during all mission phases using typical pan-tilt assemblies. Instruments and components on the spun side can be positioned in azimuth by rotation of the entire spun module.

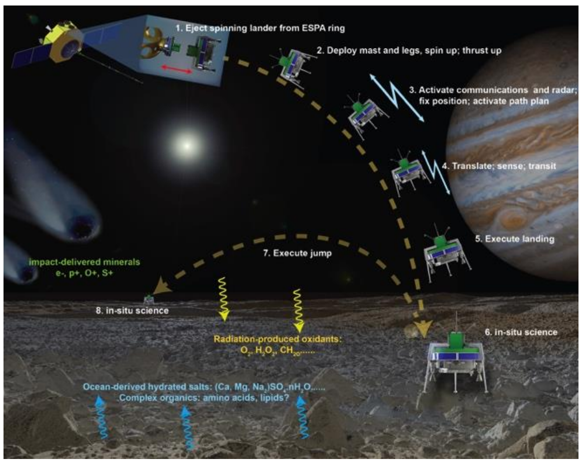

Figure 2: Cartoon of stowed spinning lander in an ESPA ring and subsequent ejection and concept of operations. For example a dedicated Raman spectrometer science payload on a Europa Mission will provide surface and near-surface spectroscopy while the lander is stationary or hovering. Europa's surface composition is derived from a mixture of processes, which must be unraveled to understand the ocean below.

The mass-efficient, cost-effective spinning lander system designs can, for relatively low total mission costs, address mission objectives for planetary exploration, resource utilization and commercialization at various solar system destinations. Solar system mission capability is enabled primarily by how much onboard Δv capability is incorporated (*via* some combination of liquid monopropellant and/or bipropellant and/or solid kick motor systems) and available power (*via* spun- and despun-mounted solar arrays, batteries).

2. Future Work

Apart from issues of landing leg design, spun-despun bearing design, lander dynamics and control system design and analyses, propulsion subsystem design, *etc.*, adapting the small spinning lander concept to Ocean World exploration missions brings into play some additional challenges not yet addressed [8]:

- Lander Δv requirements will be different for specific missions. These differences will likely drive propulsion subsystem sizing and technologies in significant ways, and perhaps other subsystems.
- Communication relay operations will be much more challenging.
- Landing targeting will inherently come with significant uncertainties.
- Miniaturized RTG's and primary batteries are anticipated to be far superior for longer mission duration. However focused science objectives must be accomplished in hours to days.
- Outer planet and moon surface environments are extremely cold, and subject to extreme radiation so temperature-control and radiation hard subsystem designs need to be addressed.
- Two-way light times from Earth to target and back combined with a short mission duration will likely lead to the requirement that all lander operations be conducted in a fully autonomous mode.

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CUVE - Cubesat UV Experiment: Unveil Venus' UV Absorber with Cubesat UV Mapping Spectrometer

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Abstract

Our Venus mission concept Cubesat UV Experiment (CUVE) is one of ten proposals selected for funding by the NASA PSDS3 Program - Planetary Science Deep Space SmallSat Studies. CUVE concept is to insert a CubeSat spacecraft into a Venusian orbit and perform remote sensing (Fig. 1) of the UV spectral region using a high spectral resolution point spectrometer to resolve UV molecular bands, observe nightglow, and characterize the unidentified main UV absorber. The UV spectrometer is complemented by an imaging UV camera with multiple bands in the UV absorber main band range for contextual imaging. CUVE would complement past, current and future Venus missions with conventional spacecraft, and address critical science questions cost effectively.

1. Figures

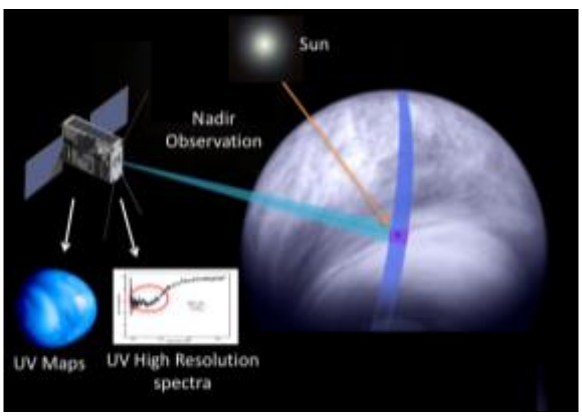

Figure 1: CUVE – Cubesat UV Experiment – in orbit around Venus will observe dayside and night side.

2. Introduction

The Venusian upper cloud deck, situated at an altitude range 60-70 km, is formed of small droplets comprising a mix of ~80% sulfuric acid (H_2SO_4) and water. These clouds are the reason for Venus' high albedo in the visible, where 70-80% of the incoming solar radiation is backscattered to space. For this reason, despite Venus being closer to the Sun than Earth, it absorbs a similar quantity of energy to that absorbed on our home planet. The maximum absorption of solar energy by Venus occurs in the UV where we observe spectral contrast features that originate from the non-uniform distribution of unknown absorbers within its clouds. This opacity source affects the energy balance in the Venusian atmosphere. The efficient absorbing power of the unknown UV absorbers in the clouds controls Venus' atmospheric engine. Determining the nature, concentration and distribution of these absorbers will increase the understanding of the overall radiative and thermal balance of the planet, in particular the atmospheric dynamics and the chemistry of the upper clouds. Sulfur dioxide SO_2 and the later discovered sulfur monoxide SO are strong UV absorbers present in Venus' spectrum between 200 and 340 nm; however, these species do not explain the strong absorption at longer wavelengths, around 365 nm which signifies a different substance (in gas or aerosol form) distributed non-uniformly in the cloud top and absorbing in the UV (for overview see [1]). Some candidate species have been proposed to explain the spectral contrast features in the UV: SO_2, $FeCl_3$, Cl_2, Sn, SCl_2, S_2O (e.g., [2], [3], [4], [5], [6]), elemental sulfur (S_8 o S_x) ([7]) and the recently hypothesized S_2O_2 (OSSO) ([8]). Spectroscopic measurements that reveal spatial and temporal variability will constrain contributions from these species.

The dayside nadir view UV spectrum of Venus is composed of solar light back-scattered by the cloud particles in the atmosphere. This solar radiation interacts with Venus' atmosphere and experience extinction in in its path to the clouds top and back and therefore contains spectroscopic signatures of the atmospheric gases and scattering particulates. Venus' top-of-the-atmosphere UV spectrum contains diagnostic signatures: a component of Rayleigh scattering; pure absorption of CO_2 below 200 nm; two strong bands of SO_2 at 215-225 nm and 270-310 nm; absorption of SO around 200-220 nm, blended in one of the SO_2 bands; other possible species absorbing in that range and continuum absorption believed to be due to the UV unknown absorber responsible for the contrast features observed in the UV at 365 nm. On the nightside, we can also observe nightglow emissions by NO, CO, O_2.

Previous missions and studies did not successfully detect the origin of the absorber. Venus Express instruments didn't have sufficient resolution, spectral range and UV sensitivity to study the relation between the unknown absorber and sulphur bearing species. VMC on Venus Express and Akatsuki are UV cameras with filters and not spectrometers. Pioneer Venus resolution was 1.3 nm and spectra were very noisy (*e.g.,* [9]). It is hard to investigate the UV absorber from Earth's surface due to strong UV absorption in Earth's atmosphere; it is challenging to investigate the UV absorber with the Hubble Space Telescope due to Sun-avoidance requirements. Venus was observed by HST ([10]), but there will be unlikely other future observations.

3. CUVE concept

CUVE is a targeted mission, with a dedicated science payload and a compact spacecraft bus capable of interplanetary flight independently or as a ride-share with another mission to Venus or to a different target.

CUVE Science Objectives are: 1) Nature of the "Unknown" UV-absorber; 2) Abundances and distributions of SO_2 and SO at and above Venus's cloud tops and their correlation with the UV absorber; 3) Atmospheric dynamics at the cloud tops, structure of upper clouds and wind measurements from cloud-tracking; 4) Nightglow emissions: NO, CO, O_2.

CUVE has a high spectral resolution spectrometer capable of resolving SO and SO_2 lines. The payload measures a broad spectral range spanning all relevant UV absorbers, and also includes a UV imager.

4. Summary and Conclusions

CUVE will produce high spectral resolution UV spectra of Venus and broad spectral range imaging maps. These maps will characterize the nature of the components in its atmosphere that absorb in the UV. This mission will be an excellent platform to study Venus' cloud top atmospheric properties where the UV absorption drives the planet's energy balance.

Acknowledgements

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BIRDY-T – Interplanetary CubeSat to small body of the Solar System

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Abstract

We are developing the Birdy concept of a scientific interplanetary Cubesat, for interplanetary cruise, or proximity operations around a Small body of the Solar System (asteroid, comet, satellite). The scientific aim is to characterise the celestial body's shape, gravity field, and internal structure through imaging and radio-science techniques. Radio-science is now of common use in planetary science (flybys or orbiters) to derive the mass of the scientific target and possibly higher order terms of its gravity field. Its application to a nano-satellite brings the advantage of enabling low orbits that can get closer to the body's surface, hence increasing the SNR for precise orbit determination, or possibly two nano-satellites on a leading-trailing trajectory, to improve the gravity field determination. However application of the technique to Cubesat and inter-satellite link has to be proven.

Interplanetary Cubesats however need to overcome a few challenges to go successfully to deep-space: link to ground-segment, energy supply, protection against radiation, etc. Besides, the Birdy Cubesat — as a basis concept — is accompanying a mothercraft and relies on the main space probe and mission for reaching the target, as well as data-link with the Earth. However, all constraints to the mothercraft needs to be reduced, by having the Cubesat as autonomous as possible. In this respect, propulsion and auto-navigation are key aspects, that we are studying in a Birdy-T engineering model.

Acknowledgements

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CubeSAT X-ray Telescope (CubeX) for Elemental Abundance Mapping of Airless Bodies and X-ray Pulsar Navigation (XNAV)

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Abstract

The CubeSAT X-ray Telescope (*CubeX*) is a concept for a 12U planetary X-ray telescope, which utilizes Miniature Wolter-I X-ray optics (MiXO) and a combination of X-ray CMOS and SDD sensors for the focal plane. *CubeX* will map the surface elemental composition of diverse airless bodies using X-ray Fluorescence (XRF), which can help us to understand the formation and evolutionary history of the individual bodies and the workings of the Solar system as a whole. *CubeX* will also conduct a feasibility and performance test of X-ray pulsar timing based deep space navigation (XNAV), which can lower operation costs of space navigation and enable autonomous deep space navigation. The first *CubeX* concept is designed to rideshare to the Moon as a secondary spacecraft on a primary mission that will be inserted into a high-altitude lunar orbit (4000 x 6000 km). High resolution imaging enabled by MiXO in *CubeX* allows flexible observing conditions from relatively stable elliptical polar lunar orbits. *CubeX* will study >8 key regions (~35-140 km) of geological interest on the Moon for a year to produce a high resolution (~0.6-2.3 km) elemental abundance map of each region. The novel focal plane design of *CubeX* also allows us to conduct delta-correction using the Crab pulsar and PSR B1937+21, and evaluate the performance of absolute navigation by sequential observations of several millisecond pulsars during the dark side of the orbits.

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ESTCube-2 integrated platform for interplanetary missions

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Abstract

This paper presents mission analysis, mission requirements and system architecture of a 3-unit CubeSat satellite ESTCube-2. Satellite subsystems are integrated in one compact satellite bus to allocate maximal volume for payloads in the satellite. The bus of ESTCube-2 is developed as technology demonstration unit for ESTCube-3 mission.

Plasma brake is a propellantless propulsion device concept based on coulomb drag interaction between ionospheric plasma and a negatively charged thin tether.

Upon succession of ESTCube-2 mission, ESTCube-3 will be launched to Moon orbit in order to test electric solar wind sail (E-sail) in interplanetary environment

1. Introduction

One of the main technical drivers to influence mission launch cost, design lifetime and mission objectives is spacecraft propulsion. By using conventional space propulsion systems, like rockets, tanks with propellant can take up large volume of satellite. One way of achieving thrust without gas propellant is to use propellantless propulsion systems. One of the most popular is solar sail, which rely on photon pressure.

Another way of tapping solar wind momentum is by using an electric solar wind sail (E-sail) [1]. E-sail uses coulomb drag force to propel spacecraft by positively charging E-sail tether [2]. Exploiting same E-sail tether, plasma brake concept can be tested in Low Earth Orbit (LEO). Plasma brake is a propellantless propulsion device concept based on coulomb drag interaction between ionospheric plasma and a negatively charged thin tether [3]

To validate tether system and deployment of it in Low Earth Orbit (LEO), ESTCube-1 satellite hosted E-sail module with 10 m tether. On ESTCube-1 main mission objectives were to demonstrate the deployment of E-sail tether and to measure the electrostatic force, however deployment test was unsuccessful [4]. This experience lead to a complete redesign of system architecture for ESTCube-2 satellite.

2. ESTCube-2 nanosatellite

Successor to ESTCube-1 satellite [5], ESTCube-2 is a 3-unit CubeSat satellite developed as technology demonstration unit for ESTCube-3 mission in Moon orbit. The bus of the satellite is developed as an integrated system, consisting of electrical power, communications, onboard computer and star-tracker systems, sensors, reaction wheels and prismatic type batteries (Figure 1).

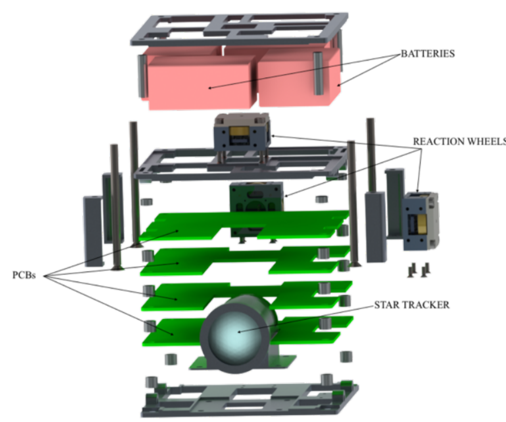

Figure 1: Exploded view of ESTCube-2 integrated bus. Credit: I. Iakubivskyi

In-orbit demonstration of the plasma brake device contains three experiments. 1. 300 m long tether deployment, will be done by centrifugal force spinning up satellite to 360 deg s^{-1}, achieved with ESTCube-1 [6]. 2. The change of angular velocity will be measured when deploying satellite or charging the tether. 3. Satellite deorbiting experiment will be carried out using plasma braking force which will reduce orbital speed in order to decrease orbital altitude.

In addition to plasma brake payload, ESTCube-2 will host two Earth observation cameras for red (650-680 nm) and NIR (855-875 nm) imaging, C-band spectrally efficient communications payload, which is compatible with

Deep Space Network standards [7] and cold gas propulsion system for angular velocity spin-up in order to deploy tether and unload reaction wheels (Figure 2).

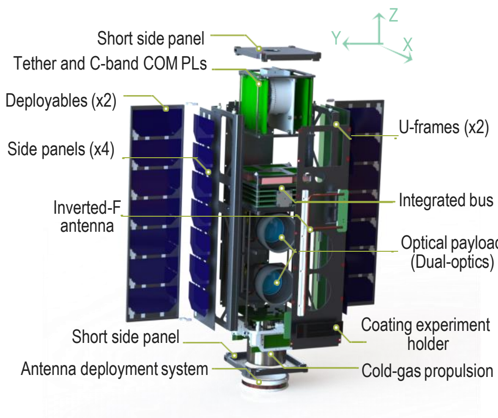

Figure 2: Exploded view of ESTCube-2 model. Credit: I. Iakubivskyi

3. Interplanetary mission platform

Geological and geophysical properties, including spectral information, are only known for a handful of large Main Belt asteroids such as (1) Ceres, (4) Vesta, (21) Lutetia, and (253) Mathilde, and a similar number of relatively small Near Earth Objects (NEO) such as (433) Eros and (25143) Itokawa. In addition to targeting asteroids belonging to different size regimes in the Main Belt and the near-Earth population, close-range studies by space missions have shown that all asteroids visited so far are virtually unique.

To attain more information about Main belt and NEO objects, self-propelled missions with E-sail (Figure 3) is very well suited to visit multiple asteroids in one mission. By launching fleet of satellites average cost per visited asteroid could be as low as 200 kEUR [8].

Acknowledgements

I would like to extend my sincerest and appreciation to all ESTCube team members. I would first like to recognize Dr. Andris Slavinskis, my supervisor, for his guidance and advises. In addition author would like thank ESTCube foundation, Tartu Observatory and SpaceTEM project for financial and development support.

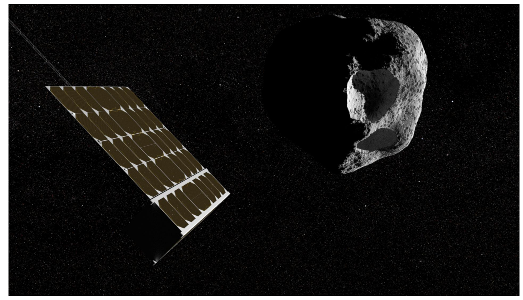

Figure 3: Artist's concept of asteroid touring nanosatellite. Credit: M. Pajusalu

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Development of 5.8 GHz circular polarized 2x2 patch array antenna for CubeSat

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Abstract

Meeting the limited power budget requirements of CubeSats while increasing the radio link data rate is a challenging task. It is necessary to develop a compact and reliable RF subsystem which must include an antenna with excellent directivity and efficiency characteristics. This paper focuses on 5.8 GHz planar technology antenna design for a CubeSat. Antenna was designed as 2x2 patch array with corner truncations to achieve circular polarization. Planar type antenna was chosen by their low cost and volume, lightweight and need for mechanically robust construction as well as ease of installation and aerodynamic profile.

1. Introduction

Over the recent years there has been an increasing trend in count of launched nanosatellites, especially the CubeSats. With the most popular commercial application being earth observation, the demand for increased communication downlink data rate has sharply risen. Based on it there is necessity for communication systems with high data rates. The goal of this work is to develop planar technology antenna prototype for C-band transceiver payload of ESTCube-2 nanosatellite [1]. The transceiver in this case is an experimental reconfigurable communication subsystem [2].

2. Antenna design

Antenna is designed and simulated with CST electromagnetic solver to achieve specification requirements which determines the need of circular polarization, 6 dB as minima antenna gain, 3 dB beamwidth of 60 degrees or less and 50 ohm impedance. It is necessary for communication channel link budget to use large diameter antenna for satellite radio signal reception, like RT-16 radiotelescope (Latvia, Irbene). Also antenna must be able work effectively in two bands: uplink from 5.65 – 5.67 GHz and downlink 5.83 to 5.85 GHz. Hence, theoretically there is minimum of 200 MHz impedance bandwidth, where input impedance of antenna has to be 50 ohms, in order to avoiding from undesirable reflections. Form factor restrictions of substrate along its length L is 100 mm and along width W 82.80 mm (see fig. 1).

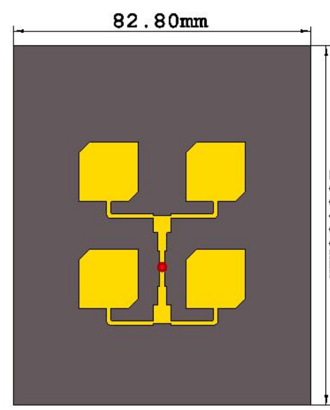

Figure 1: Antenna design and dimensions (red point is the RF signal feed point).

To reach set conditions, 2x2 patch array with corporate feed network using Rogers RT 5880 laminate as substrate (h = 1.6 mm, ε_r = 2.2) was used in design process to achieve high directivity and efficiency, therefore to meet demand of high gain antenna. Square patch elements with corner truncations were chosen to achieve circular polarization.

Simulation results show, that achievable gain is approximately 12 dB and 3 dB beamwidth ~ 45 degrees either for uplink and downlink frequency bands. Return loss at 5.66 GHz (downlink band middle frequency) is -23.5 dB and at 5.84 GHz (uplink band middle frequency) -18.8 dB. The total efficiency over band is above 90% and VSWR is below 1.5.

Antenna radiation pattern in 3D space is shown in fig. 2. Patterns for principal E and H planes for 5.66 GHz as example are shown in fig. 3 and fig.4, respectively.

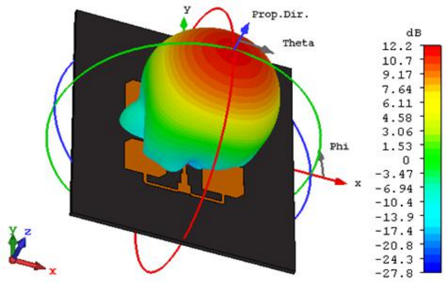

Figure 2: Simulated antenna radiation pattern (3D, log scale).

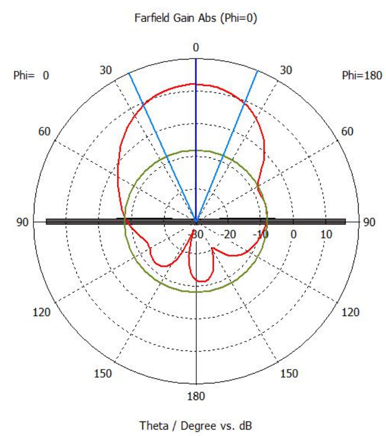

Figure 3: Simulated H plane pattern at 5.66 GHz (log scale).

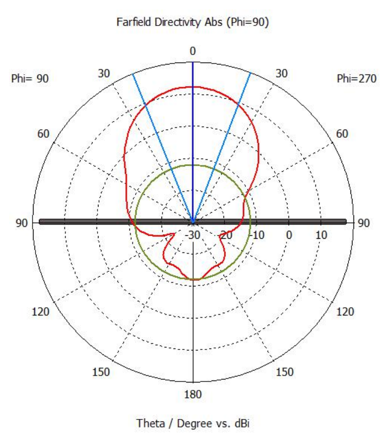

Figure 4: Simulated E plane pattern at 5.66 GHz (log scale).

3. Summary and Conclusions

This paper presents the simulation results of a 2x2 patch array antenna. The results are shown and discussed, such as principal E and H plane patterns for uplink band middle frequency, 3 dB beamwidth, return loss, efficiency and VSWR. All characteristics of antenna comply with initial requirements.

This antenna design will be used to manufacture a prototype that will be measured in order to compare it's characteristics with the simulated model. If successful the antenna design will be used in ESTCube-2 mission as a part of the high speed communication subsystem payload.

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On feasibility of Moon remnant magnetic field measurements with a CubeSat mission

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Abstract

In this paper, we propose a CubeSat mission for mapping Moon remnant magnetic field and discuss various technical aspects and difficulties, such as instrumentation for weak magnetic field measurement, magnetic cleanliness of the CubeSat platform, orbit and orbital maneuvers. The mission would give information about the history of the Moon and possibly help to better plan lunar bases and manned missions.

1. Introduction

According to current knowledge, the Moon has no inner dynamo which could generate magnetic field. However,the lunar crust still has weakly magnetic regions, magnetic anomalies, which tell us about the evolutionary history of the Moon. The lunar magnetic anomalies range in intensity from tens of nano-Tesla up to a micro-Tesla at the lunar surface, some possibly able to stand off the impinging solar wind and create miniature magnetospheres. Recently, Arkani-Hamed and Boutin [1] published a study stating that the *Lunar Prospector* magnetometry data points both to a lunar dynamo and pole wander and magnetic reversals. The anomalies are also curiously antipodal to impact basins, pointing to a mechanism of formation related to the massive impacts. The plasma environment of lunar magnetic anomalies also provides for a unique plasma laboratory at ion and electron kinetic scales, and may have consequences for the electric and charged dust environment at the lunar surface at these sites. This may be of importance to planning of lunar bases.

2. Mission goals and orbit

The mission goal is to provide accurate measurements of the magnetic field produced by the lunar magnetic anomalies, at low altitudes (down to < 10 km) and at a high spatial and temporal resolution, to provide for more accurate general description of the crustal magnetic fields and plasma processes at and around the magnetic anomalies. In order to achieve a low enough orbit, the orbital altitude should be decreased gradually and therefore an elliptical orbit is proposed. To lower the orbit, e-sail technology in solar wind [2] can be used. A polar Moon orbit would allow to scan slowly the surface and form a map of magnetic field. The e-sail technology, required for orbital maneuvers, is currently being tested on board of many CubeSat missions, including Aalto-1 mission, operated by the authors.

3. Scientific instrumentation

The main instruments of the mission will be (1) a fluxgate magnetometer and (2) MF/HF radio instruments, both developed at Aalto University, and (3) a Langmuir probe. Due to the nature of the measurable phenomenon and the accuracy requirements, a boom mount will be designed to accommodate the magnetometer. Though somewhat uncommon in CubeSat platforms, several boom designs have been proposed by the community. The measurement requires also additional cleaning from spacecraft platform induced magnetic noise an several more magnetometers inside the spacecraft and boom. The Langmuir probe (made by university of Oslo) is already used on board of Aalto-2 satellite, however, longer probes are needed to measure the electron density in the tenuous Lunar plasma magnetic anomaly region. The HF/HF frequency range radio wave instrument, which is onboard Suomi 100-satellite, enables to measure possible electromagnetic disturbances caused by the magnetic anomaly.

4. Satellite platform and magnetic cleanliness

In order to have better estimates on magnetic disturbances inside the Aalto-series CubeSat platform, Aalto-1 and Aalto-2 satellite magnetometer readings are used [3]. In Aalto-1 satellite, we expect for the spacecraft to have a total residual magnetic moment of 58.5e-3 Am^3. For Aalto-1 configuration, this residual magnetic moment translates into an offset of 2000-5000 nT in the magnetometer reading. Depending on the sensitivity of the magnetometer, its noise level, and the configuration of the satellite bus used in the scientific mission, the magnetometer for Lunar magnetic mapping might require a deployed boom system to minimize the influence of the spacecraft remnant magnetic field. Detailed magnetic environment simulations based upon previous CubeSat missions will be undertaken to further strengthen the calibration of the magnetometer [4]. Also, in order to achieve required signal cleanliness, the spacecraft influence should be removed from the signal as well as possible.

5. Satellite Platform

The CubeSat platform has strong size limitations which poses challenges for communication, as large antennas are difficult to implement. Additionally, attitude control cannot rely on magnet torquers and therefore a propulsion system is needed to load off the reaction wheels. To some extent solar wind sail can be used to also orient the satellite, however, to achieve full control of the attitude, also a more versatile gas propulsion system is needed. To fit all required instruments to the satellite, we propose that a 6U 8 kg CubeSat with deployable solar panels can be used. The platform wold provide enough power for communication, around 10 W, to be operable already with relatively small ground station.

6. Summary

In this paper we proposed a CubeSat mission to map Moon remnant magnetic field and discussed various technical aspects of the mission. The biggest challenge is to acquire good signal level in a very tiny satellite. Therefore a very sensitive sensor should be used and various signal cleaning algorithms are proposed. The mission features also plasma temperature measurement instrument and radio noise measurement instrument. The consortium behind this proposal has some experience on all proposed instruments on board CubeSat platform.

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The Role of the Space Industry in Latvia

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Abstract

Here I present the value of the Space Industry for Latvia.