Developing a distributed and fractionated system of 10 grams satellites for planetary observation

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Abstract

The miniaturization of electronic components enables major reduction of spacecraft size and mass, as is the case of CubeSats, PocketQubes, and Femtosats, which offer shorter development time and costs, in comparison with traditionally larger satellites. However, these miniaturized satellites still require a considerable effort in terms of time and investment (several years of development, and costs around 10^5-10^6 EUR for CubeSats). More recently, an even smaller class of spacecraft, the Chipsats has been introduced. Chipsats are microchip-shaped spacecraft with masses ranging from a few grams to 10s of grams. At the lower end of the mass range (1-10 grams), they belong to the class of Attosats. Due to their small size, Attosats enable unprecedented low costs, agile development and potential for swarm missions of distributed and fractioned systems for applications such as planetary observation. However, despite their benefits there have not been many initiatives to develop Attosat systems. In this article, the development of a satellite system of three 10-grams satellites is presented. The three satellites work together to achieve the common goal of studying Earth's atmospheric environment, conforming a distributed system. Moreover, as the different satellites are designed to perform different functions, they conform a fractionated system as well: one satellite acts as a communication node transmitting data to ground stations, while the two other satellites have environment sampling capabilities. Visual intersatellite communication capabilities ensure data transmission among the satellites. The presented system is meant as a technology demonstration project for future distributed and fragmented satellite swarm systems for atmospheric planetary exploration. The Attosats are scheduled for launch on October 2023 on board of a Momentus spacecraft.

Keywords: Chipsat, attosat, distributed, fractionated systems

Acronyms/Abbreviations

- Commercial of the shelf (COTS)
- Space Systems Engineering (SpaSys)
- University of Luxembourg (UL)
- Interdisciplinary Centre of Security, Reliability and Trust (SnT)
- Initiative for interstellar studies (i4is)

1. Introduction

The miniaturization of electronic components enables major reduction of spacecraft size and mass.

Some examples are Cubesats (10x10x10cm unit(s)), PocketQubes (5x5x5 cm unit(s)) and Femtosats (100 gram-class spacecraft). These spacecraft offer shorter development time and time to science, decreased risk of obsolescence, and decreased overhead costs, in comparison with traditional, larger (on the order of tons) satellites [1]. More recently, an even smaller class of spacecraft, the Chipsats has been introduced. Chipsats are microchip-shaped spacecraft where all spacecraft components are integrated on a single PCB board with masses ranging from a few grams to 10s of grams. At the lower end of the mass range, they belong to the class of Attosats (1 -10 gram-class spacecraft) [2].

One of the many applications [1] of these miniaturized satellites is in swarm missions of distributed systems. In this type of missions, swarms of 10 →1000 spacecraft are distributed across a celestial body, or cruising through space, gathering data from different locations. Such distributed systems can also be fractioned, in which different spacecraft carry different components (or modules) and perform different functions, which could enable more flexibility and robustness than traditional, monolithic satellite designs [3].

Due to their small size, Attosats enable low costs, agile development [4, 5], rapid iterations, and massive swarm redundancy.

1.1 2. Chipsat initiatives for planetary exploration

Table 1. Summary of Chipsat missions

Chipsat	Size (cm)	Mass (g)	Owner	Orbital launch year	Comments
Sprite [4]	3.5x3.5	5	Cornell University	2014, 2017, 2019	Deployed in swarm of 105 units in 2019 (300km)
SpinorSat [6]	3.5x4.0	<10	US Berkeley	2019	Design based on Sprite. Manoeuvrable (torque coils)
Drexel PinPoint [9]	2.5x2.5	-	I4is/Drexel University	Not launched	Designed to carry a laser sail.
WaferSat [10]	20 (diam.)	<100	MIT	Not launched	Under development
Monarch [5]	5.0x5.0	2.5	Cornell University		Intersatellite communication capabilities

* i4is Initiative for interstellar studies

Chipsat missions have been of interest for research institutions over the last decade. In Table 1, a summary of Chipsat missions already deployed in space or under development is presented. These missions were or are to be deployed on Earth's atmosphere to increase the technology readiness of Chipsat systems, such as their intersatellite communication capabilities [5], or manoeuvrability [6]. Other authors [7, 8] have proposed the use of Femtosats and Chipsats as distributed and fractionated systems for planetary exploration, as they could collect vast amounts of data on different locations of a celestial object.

Some of the major disadvantages of the small size of Attosats are their low survivability due to space conditions (e.g. radiation), and their lack of available power for instruments and communication, which are the advantages of traditional, larger satellites. However, Chipsats missions compensate the lack of individual satellite capabilities by deploying swarms of thousands of satellites from which only hundreds might survive, but their high number will still provide relevant and competitive data [5].

As presented by authors such as Manchester et. al. [4], most of the power produced by the Chipsats, around 132mW in this case, is consumed by the radio frequency (RF) transceiver CC1101 UHF (about 50%) for satellite communication.

To reduce the power consumption of the communication modules, an alternative is the implementation of optical communication systems [9, 10], as in nanosatellites, such as cubesats, optical communication systems have been demonstrated to have a higher data rate than RF transceivers while using less power [11, 13, 14, 15].

A large portion of research about optical intersatellite communication focuses on laser-based systems [13, 14, 15], and its benefits such as large bandwidth, license free spectrum, high data rate, and low mass requirements [12]. A complete survey of optical communication for space applications can be found in the work by Kaushal and Kaddoum [12], and Khaligui and Uysal [16]. However, the development of laser communication links for attosats remains a challenge due to the difficulty in integrating telescope optics and other mechanisms in such a limited volume.

A more affordable alternative for attosats are diode (LED)-based optical communication systems, due to their reduced volume (microchip-sized) and the further power consumption reduction capabilities [11, 17, 18]. However, the main drawback of diode-based communication is the divergent nature of the light emission which causes a reduction of the communication range. At the same time, light divergence can also be an asset, as it relaxes the pointing requirements of lasers [11].

Up to this date, LED-based communication systems have not yet been deployed in space for attosats applications.

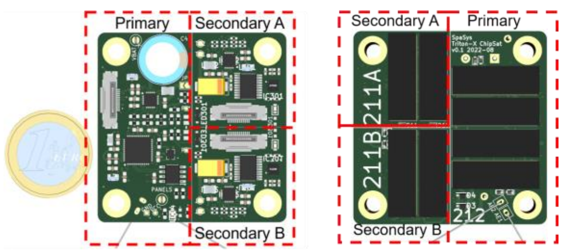
This article introduces the preliminary design of a distributed and fractionated attosats system with LED-based intersatellite communication capabilities, designed and developed by the Space Systems Engineering (SpaSys) research group at the Interdisciplinary Centre of Security, Reliability and Trust (SnT) at University of Luxembourg (UL), scheduled to be launched and operated in space in 2023.

2. Distributed and fractionated Chipsat swarms with optical communication capabilities

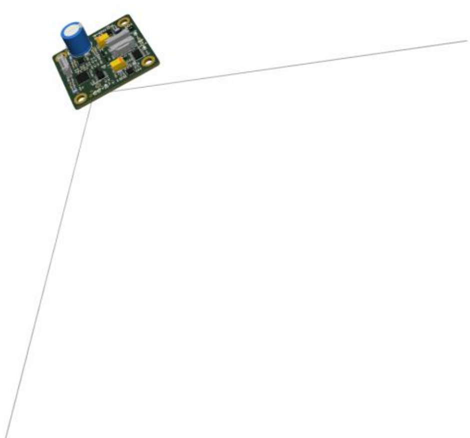
To demonstrate the implementation of LED-based communication systems for attosats, a network of three attosats was developed. The satellites, one denominated "primary" and the other two "secondary" (Secondary A and Secondary B), are meant to collect atmospheric information, that is then collected in the primary, from where is transmitted to a ground station. Currently, both secondaries have temperature sensors included in their microcontrollers, moreover, Secondary B is equipped with a TSL25853PM ambient light sensor, and Secondary A with an IAM-20680HP gyroscope and accelerometer. The primary transfers data to the ground station using an RF transmitter set for the radio amateur frequency of 438MHz. The primary is able to transmit up to 20dBm, with no reception capabilities. Primary and secondaries communicate with LED-based terminals.

As the objective of this mission is to demonstrate LED-based communication capabilities for attosats, in this first mission the satellites are going to be launched attached to a payload from LuxSpace [19], on board of a Momentus [20] spacecraft.

The three satellites, albeit independent from each other and electrically separated, are contained in a (50x50) mm PCB, as presented in Fig. 1.a.



a)



b)

Fig. 1. a) Attosats network preliminary design compared to a 1EUR coin, b) Attosat network with RF antennas from the primary satellite.

The components of the network are COTS and detailed in Table 2 and Table 3. As secondaries and primary have different components and functionalities, the network is a distributed and fractionated system [3]. The primary has a 17cm long RF antenna (see Fig.1.b.). UHF communication uses BPSK encoding with spread spectrum and Forward Error Correction. The primary is based on an STM32 wireless system-on-chip, while the secondaries use low-power STM32 microcontrollers. The energy is acquired from miniaturised monocrystalline solar cells, covering a total area of 14.72 cm² of the back side of the network. Solar energy passes through an MPPT energy harvester and is stored in high-density capacitors.

The total mass of the network is 18,3g, with a power consumption of 462mW for the primary and 70mW for secondaries. Mass and power budget are presented in Table 2 and Table 3, respectively.

The whole network is attached to the payload by four M4 screws and rests on top of a 30g aluminium bracket, with the solar cells facing out.

Table 2. Attosats network preliminary mass budget.

Element	Mass (g)
PCB	9.8
Solar cells (primary)	0.7
Solar cells (secondary)	0.7
Capacitors (primary)	3.1
Capacitors (secondary)	2.0
Electronic components (both)	1.0
Antenna	0.5
Total system mass	**18.3**

Table 3. Attosats network preliminary power budget.

Component	**Full Power (mW)**	**Sleep Mode (mW)**
Microcontroller	3.30	3.30
Transceiver	364.65	0.00
I2C network	0.00	0.00
Memory	1.32	1.32
Photodiode	0.00	0.00
Microcontroller	0.73	0.73
LED	50.00	0.00
Attitude sensor	4.95	0.02
Ambient light sensor	0.96	0.02
Converter efficiency	80%	

The satellite network software has been developed and tested for functionality at the CubeSat laboratory at SnT (UL). Additional simulations and tests were performed for the communication terminals and the design of the RF antenna configuration specifically. Different antenna arrangements were tested in an open field (keeping more than 2m from buildings and metallic structures)

using a VNA calibrated for the test equipment (cables, connectors, etc..), equipment configuration, and spiders.
The antenna configuration with the best results in terms of the trade-off between signal transmission/reflection and antenna size, was an arrangement of two 17cm long straight antennas with a 90 degrees separation, as seen in Figure 1.b.
The next steps for the network are to undergo qualification tests for, vibration, at the end of 2022, and then being delivered to LuxSpace for lunch in 2023 on board of a Momentus spacecraft launched from U.S. California (Falcon 9). The whole network was developed in less than six months with a total development and manufacturing cost of less than 1000EUR.

5. Discussion

The miniaturization of electronic components enabled a reduction of spacecraft size and mass, offering shorter development times and costs. This article presents the preliminary design of a 30g network of three attosats, developed by the SpaSys research group from SnT(UN), in less than six months and with a cost of less than 1000EUR. These efforts are several orders of magnitude smaller than those required for the development of CubeSats (2-5 years for development and costs around 10^5-10^6 EUR).
The short development time and low costs incurred during this project confirm statements by authors such as Manchester et al. [4], or Adams [5] regarding AttoSats enabling unprecedented low costs and agile development.
The design presented in this article builds up from the lessons learned and documentation from previous projects by Manchester [4], Adams [5], and Umansky-Castro et al. [8]. However, the proposed network will be a pioneer in the field of attosats due to its distributed and fractionated nature and unprecedented optical communication capabilities. Moreover, the secondaries could be considered the smallest satellites ever launched and operated in space, with an estimated weight of less than 10g and a power consumption of 70mW.
The low power consumption of this type of network make it a competitive alternative for planetary exploration, especially for planets far from a star where power is severely limited.
After launching this attosats network in 2023 on the next steps are to further develop the network capabilities for planetary observation and data transmission. Currently, both secondaries have temperature sensors for sampling atmospheric temperatures at different locations. Future network designs will include a larger number of satellites, increasing the robustness and reliability on the network, the implementation of different atmospheric sensors, a larger number of satellite-ground transmission nodes, and improvement on the optical intersatellite communication system. Moreover, launch and operation of the satellite network in a not-attached configuration is envisioned.

6. Conclusions

This article resents the preliminary design of a 30g network of three attosats, developed by the SpaSys research group from SnT(UN), to be launched in 2023 attached to a payload from LuxSpace on board of a Momentus spacecraft. The development efforts consisted of less than six months of system design, development and manufacturing, incurring in a cost of less than 1000EUR.
The proposed network will be a pioneer in the field of attosats due to its distributed and fractionated nature and unprecedented LED-based optical intersatellite communication terminals. Moreover, the smallest satellites in this network will be the smallest satellites ever launched and operated in space, weighting less than 10g.
The low power consumption of this type of network, and the robustness and reliability associated to swarm satellite systems, make it a competitive alternative for planetary exploration.
After launching this attosats network in 2023 on the next steps are to further develop the network capabilities for planetary observation and data transmission, including a larger number of satellites with different atmospheric sensors, a larger number of satellite-ground transmission nodes and improvements on the optical intersatellite communication system.

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