THE NEMO BUS: A THIRD GENERATION HIGH-PERFORMANCE NANOSATELLITE FOR EARTH MONITORING AND OBSERVATION

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ABSTRACT

The NEMO (Nanosatellite for Earth Monitoring and Observation) bus is the next evolution to the Generic Nanosatellite Bus (GNB) technology and provides a foundation for future high-performance nanosatellites from the Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies (UTIAS). The bus has a primary structure measuring 20 cm by 20 cm by 40 cm. It is capable of peak power generation up to 80W. A minimum of 30W is available to the payload, which enables the bus to support a dedicated state-of-the-art high speed transmitter. The bus is designed with a total mass of 15 kg, 9 kg of which is dedicated to the payload. It can be configured for full three-axis control with up to 1 arcmin pointing stability. The first spacecraft to use this new bus technology is the NEMO-AM (Aerosol Monitoring) spacecraft, which is designed to perform multi-spectral observations in the visual band. The satellite will detect aerosol content in the atmosphere with a nominal equivalent ground resolution of 200 m. NEMO-AM is being built under a collaborative agreement between SFL and the Indian Space Research Organization (ISRO). This paper summarizes the innovative aspects of the NEMO bus and the NEMO-AM mission.

INTRODUCTION

Space Flight Laboratory at the University of Toronto Institute for Aerospace Studies (UTIAS/SFL) currently has three operational spacecraft in orbit and maintains end-to-end expertise in mission and component design, spacecraft manufacturing, cost-effective launches, spacecraft operation and instrument design. UTIAS/SFL has been developing several missions based on a multi-mission or “generic” nanosatellite bus (GNB). Of the GNB spacecraft currently under construction at UTIAS/SFL, one is awaiting launch as a “pre-operational” mission intended fast track the readiness of a new ship monitoring technology, three are intended for space astronomy, and two are for technology demonstration. These spacecraft build upon a set of common components and technologies that are shared across multiple missions and implement an architecture that is directly expandable to larger, operational missions.

These GNB missions target a performance level that defines the current nanosatellite state-of-the-art. The experience obtained during the development of these GNB spacecraft opens the door toward realizing an even higher-performing nanosatellite.

THE GENERIC NANOSATELLITE BUS

A GNB spacecraft weighs up to 7.5 kg, measures 20 cm by 20 cm by 20 cm (excluding appendages), and can accommodate a payload with mass of up to 2 kg and 17 cm by 13 cm by 8 cm [1]. The GNB spacecraft implements an architecture that is incorporates a number of redundancies. All sensors and actuators have dual connections to mitigate against failures. The spacecraft are able to recover from a failure in one of multiple on-board computers or in one of multiple sets of battery electronics. The electrical components used on the spacecraft are selected after rigorous radiation tests. Due to exterior surface limitation for antennas, the spacecraft implements a single-string communication system.

The on-board computers on the GNB spacecraft are based on the ARM7TDMI processor, along with 2 MB SRAM with triple voting EDAC and up to 512 MB of Flash storage. Typically, a GNB spacecraft will have two on board computers, one Housekeeping Computer (HKC) and one Attitude Control Computer (ACC). A third computer can also be added to handle any payload-specific functions.

The power system on the GNB spacecraft implements a peak power tracking topology. Triple junction solar cells (>26% efficiency) are used to generate power of up to an average of 9 W. A battery charge and discharge regulator (BCDR) controls the charging and discharging of the Lithium ion battery. Two prismatic-type Lithium ion batteries can be accommodated. The power system also implements current limiting functions on each of the 3.6 V power lines.

Communication from the ground to the spacecraft uses the UHF band, operating at 4 kbps, while downlink is achieved on S-band at a minimum rate of 32 kbps. The attitude determination and control system on the GNB spacecraft can be customized to meet specific mission requirements, from passive magnetic stabilization using permanent magnets and hysteresis rods, to a three-axes stabilized platform with circa one arcminute pointing accuracy. Available sensors include a miniature three-axis magnetometer, three-axis rate sensors, coarse sun sensors, and fine sun sensors. Available actuators include magnetorquers and reaction wheels.

Current GNB missions [2] include AISSat-1 (ship tracking, 2010), UniBRITE/CanX-3A (bright-star astronomy, 2010), BRITE-Austria/CanX-3B (bright-star astronomy, 2010), CanX-4 and CanX-5 (formation flying, 2011), BRITE-Poland (bright-star astronomy, 2011).

THE NEMO BUS

The experience obtained during the development of the GNB missions helped shape the development of the next generation bus. A survey of past, present, future mission requirement was performed to understand the requirements for advanced missions and payloads. The survey suggests a requirement of higher power for high data throughput (use of high power transmitter in higher bands); larger payload volume; larger instrument aperture (exterior surface); additional system resources overall (three-axes stabilization, larger reaction wheels, etc.). The new bus shall also improve the overall system efficiency, including payload mass fraction and power density ratio.

This results in the evolution of the SFL GNB technology into the NEMO (Nanosatellite for Earth Monitoring and Observation) bus. The new bus builds upon existing GNB components and subsystems to maintain heritage as well as to shorten the development cycle. The NEMO bus implements these existing components and subsystems in an innovative architecture to further enhance the capability and performance of a nanosatellite.

The NEMO bus has a primary structure measuring 20 cm by 20 cm by 40 cm and is capable of peak power generation up to 80W. Higher peak generation is possible with higher efficiency solar cell. A minimum of 45 W is available to the payload. The NEMO bus is designed with a total mass of 15 kg. Up to 9 kg maybe dedicated to the payload and mission-specific components.

The payload is accommodated in two areas within the bus: a primary volume measuring 20 cm by 20 cm by 22 cm for up to 7 kg of mass and a secondary volume measuring 17 cm by 13 cm by 8 cm for up to 2 kg of mass. The maximum internal payload length is 39 cm. Up to 20 cm by 20 cm of exterior aperture is available. The high peak power generation and the increased payload capacity enable the NEMO bus to support various payloads. The payload can also include a dedicated state-of-the-art high speed transmitter for state-of-the-art downlink data rate.

The NEMO bus can be configured for full three-axes control with up to 1 arc-min pointing stability. NEMO spacecraft will interface to the launch vehicle using the XPOD Duo separation system, which was originally developed for the CanX-4 and 5 dual spacecraft mission.

With the new level of performance, the NEMO bus provides a foundation for future high-performance nanosatellites from SFL. The development of NEMO missions will continue to follow the microspace approach for managing risks and ensuring rapid development, which maintains cost-effectiveness and responsiveness for new missions.

The NEMO bus will include a number of subsystem and components that are currently in use in the GNB spacecraft, namely:

- ARM7TDMI computers with up to 512 MB storage and 2 MB of EDAC RAM.
- Battery charge discharge regulators.
- Current limiting power supply.
- 100 Wh Lithium ion battery.
- 4 kbps UHF receiver.
- 32 to 2048 kbps S-band transmitter.
- Three-axes magnetometer and fine sun sensors
- Magnetic torquers and nano reaction wheels
- Attitude control computer with Extended Kalman Filter.
- Primarily passive thermal design.
- XPOD Duo separation system

In addition, the NEMO bus will include a new power system. The NEMO power system will be able to handle the higher peak generated power as well as will be capable of providing up to 65 W to the instrument. For improved mass efficiency and structural performance, the structure will use a combination of Aluminum, Magnesium, and carbon-fibre reinforced panel.

Table 1 below compares the various SFL nanosatellite bus. CanX-2 and NTS uses the same electronics; NTS implements CanX-2 electronics in a GNB structure. NEMO has twice the mass of GNB while realizing an improvement factor of four in the payload mass and ten in the power generation.

Table 1: Bus Comparison

	CanX-2	NTS	GNB	NEMO
Spacecraft Mass	3.5 kg	6.5 kg	7.5 kg	15 kg
Spacecraft Volume	10 x 10 x 34 cm	20 x 20 x 20 cm	20 x 20 x 20 cm	20 x 20 x 40 cm
Peak Power 25ºC,BOL	2-7 W	4-7 W	7-9 W	80 W
Payload Mass	1 kg	2 kg	2 kg	9 kg [4]
Payload Volume	1000 cm^3	1700 cm^3	1700 cm^3	8000 cm^3
Payload Power @duty cycle	1-2 W @100%	2 W @20-30%	3-4 W @100% 6 W max	45 W @40% min 65 W max
ACS stability	~ 2 º [1]	Passive	~ 2 º [2] ~ 60 " [3]	~ 2 º [2] ~ 60 " [3]
Downlink	32 k – 1 Mbps	32 k – 1 Mbps	32 k – 2 Mbps	32 k – 2 Mbps [5]
Service	2008 Active	2008 Active	2010 (AISSat-1) 2011 (BRITE, CanX-4&5)	2011

1. Nadir pointing with magnetometer, sun sensor and one reaction wheel
2. With magnetometer, fine sun sensor and three reaction wheels
3. With star-tracker
4. Including payload-specific equipment
5. Using existing SFL transmitter; NEMO has sufficient power for a 30 Mbps X-band transmitter at 20% duty cycle

UPCOMING NEMO MISSION

The first spacecraft to use this new bus technology is the NEMO-AM (Aerosol Monitoring) spacecraft. NEMO-AM is designed to perform observations in the visual band for detecting aerosol content in the atmosphere. It will carry an optical instrument capable of observing in the blue, green, and red visible bands in two polarizations and from multiple angles. The instrument also has optional observation capability in the short-wave infrared band. The SFL-designed optical instrument is capable of a ground sampled distance that is scalable from 40 m to 200 m and a ground swath of 129 km from an orbital altitude of 650 km. The mission is designed to cover an area of up to 80,000 square km daily [3].

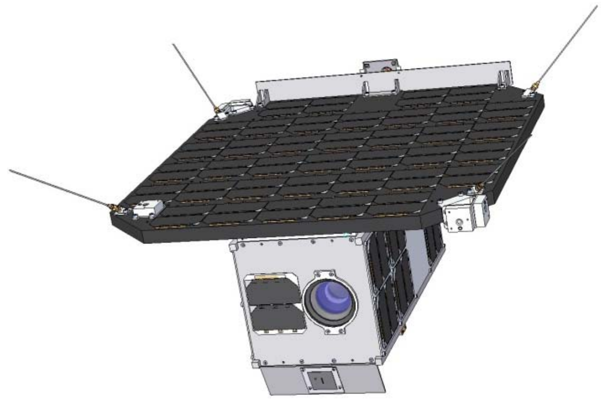

Figure 1: NEMO-AM Spacecraft

NEMO-AM is being built under a collaborative agreement between SFL and the Indian Space Research Organization (ISRO). ISRO will provide the scientific expertise and the science algorithm. The spacecraft will be controllable from both SFL in Toronto and ISRO ISTRAC facility, using SFL distributed ground station network technology.

In addition to the standard NEMO bus components, NEMO-AM will add an instrument computer that will be capable of up to 400 Mbps data transfer. Titanium is being considered for instrument support structure due to its thermal and mechanical properties.

At the time of this writing the spacecraft design is entering its PDR preparation. A number of subsystems have been analyzed and have undergone successful prototyping work. Tests of the instrument breadboard successfully confirm instrument concept. The power system has been tested to provide 44 W of continuous power into a simulated instrument electronic. Analysis of the attitude determination and control system predicts a pointing accuracy of 2.3 degrees with the fine sun sensors. Preliminary thermal and structural analysis has also been completed. Structural and instrument qualification is currently scheduled for summer 2010.

In parallel, SFL is also developing a very-high resolution optical instrument that is compatible with the NEMO bus.

CONCLUSION

The latest bus technology from the UTIAS/SFL has been presented. The NEMO bus is a third generation nanosatellite bus that has been specifically designed toward a level of performance that will redefine the state-of-the-art for nanosatellites. With up to 80 W peak power generation, the bus is capable of providing a minimum of 45 W to the payload. The larger payload capacity of up to 9 kg opens numerous payload possibilities, and the bus can be configured with state-of-the-art downlink and three-axes stabilization with up to one arcminute of pointing accuracy. The 15 kg NEMO bus builds upon the heritage of the GNB hardware. The first mission based on the NEMO bus, the aerosol monitoring NEMO-AM, is currently under development with a target delivery of early 2011.

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