The Antarctic Broadband Demonstration Nanosatellite: Fast Internet for the Bottom of the Earth

Grant Bonin, Robert E. Zee
UTIAS Space Flight Laboratory
4925 Dufferin St., Toronto, ON. Canada, M3H 5T6; +1 (416) 667-7973
gbonin@utias-sfl.net; rzee@utias-sfl.net

www.utias-sfl.net

Michael Brett, Jan King
Aerospace Concepts Pty Ltd
PO Box 371, Fyshwick, ACT 2609,
michael.brett@concepts.aero; jan.king@concepts.aero

www.concepts.aero

www.antarcticbroadband.com

ABSTRACT

High bandwidth communications is the largest sector of the commercial satellite industry. While micro- and nanosatellites have yet to service this market on a commercial basis, it is expected that such spacecraft will play an increasing role in the communications industry, with initial applications likely to be in niches that cannot be readily or easily addressed by traditional service providers. Antarctica is one such niche.

Communication needs in the Antarctic are increasing rapidly, with high growth rates in operational and scientific activities across the continent. Traditional space and terrestrial communication solutions will not be able to meet these needs in the near-future, due to the inherent orbital limitations of geostationary communication satellites and the remoteness and harsh environment of the Antarctic.

The Antarctic Broadband program is intended to establish a high-quality communications service for the international research community in Antarctica. The initial project phase, supported under the Australian Government's Australian Space Research Program, is intended to define a satellite communications service optimized to meet the current and future data transfer needs of the entire Antarctic community, and to test a number of important technologies which will support the flight of a nanosatellite demonstrator mission and lead to a fully operational system. This paper presents the proposed Antarctic Broadband system, and focuses on the current state of the nanosatellite demonstration mission.

INTRODUCTION

The Antarctic Broadband program intends to establish a high-bandwidth, high-quality communications service for the international research community in Antarctica [1]. Using small satellites tailored to the specific task of Antarctic communications, the program will provide dedicated, reliable, and high-availability links to one of the most remote locations on Earth, and one of the last locations to enjoy reliable broadband access.

Funded under the Australian Space Research Program (ASRP)--a competitive merit-based grants program aimed at supporting space-related research and development [1]--the Antarctic Broadband project, once complete, will have deployed a set of small satellites to enable broadband communications beyond what is currently available, in terms of both coverage and speed. This service is intended to directly support research activities and expanded human presence in the Antarctic [1].

The Antarctic Broadband program is being undertaken by a consortium of international partners, offering a broad spectrum of capabilities. These partners include:

- Aerospace Concepts Pty Ltd (overall project management and systems engineering);

- UTIAS Space Flight Laboratory (demonstrator nanosatellite bus provider);
- EM Solutions Pty Ltd (payload provider)
- Australian National University (Ground station and integration host);
- Environmental Systems and Services (Ka-Band ground terminal development)
- Josephmark Pty Ltd (public relations, branding)
- Tauri Group (North America customer relations)

Project Overview

The Antarctic Broadband program broadly consists of two primary phases:

- Development of a nanosatellite demonstration mission; and
- Development of an operational satellite constellation.

The end-to-end operational mission (Figure 1) represents the end-goal of Antarctic Broadband: a mature, complete communications constellation providing broadband services at or near 100% availability across the Antarctic circle.

The demonstration mission is intended to be the near-term precursor, which will reduce risk by validating key payload performance parameters and eventually demonstrating a quasi-operational capability. The Antarctic Broadband demonstrator satellite has been designed by the UTIAS Space Flight Laboratory, based on their Generic Nanosatellite Bus (GNB) platform, most recently been used in the highly successful AISSat-1 mission (launched July 2010). The demonstrator could be launched as early as Q1 2013.

The demonstrator Ka-Band transponder payload has been developed in Australia by EM Solutions. The spacecraft requires four Ka-Band horn antennas, one pair of which will be actuated.

MOTIVATION

The need for high-availability, high-bandwidth communications services in the Antarctic is becoming increasingly evident. Figure 2 illustrates the exponential trend in South Pole data requirements projected through 2012—clearly there is growing need for data services in the Antarctic. At present, the majority of data services to Antarctic stations are provided either by intermittent, low-quality links using "stray" GEO communications satellites —which are already operating beyond their design lifetime—or by using the Iridium constellation, which is expensive and relatively low-speed. Alternative solutions are also problematic: fiber optics would be prohibitively expensive and prone to damage caused by moving ice and snow, and Antarctic bases are far too remote for line-of-sight terrestrial microwave links [3]. A dedicated satellite solution is ostensibly the best way to solve the data transfer bottleneck of concern to current and future researchers in the Antarctic.

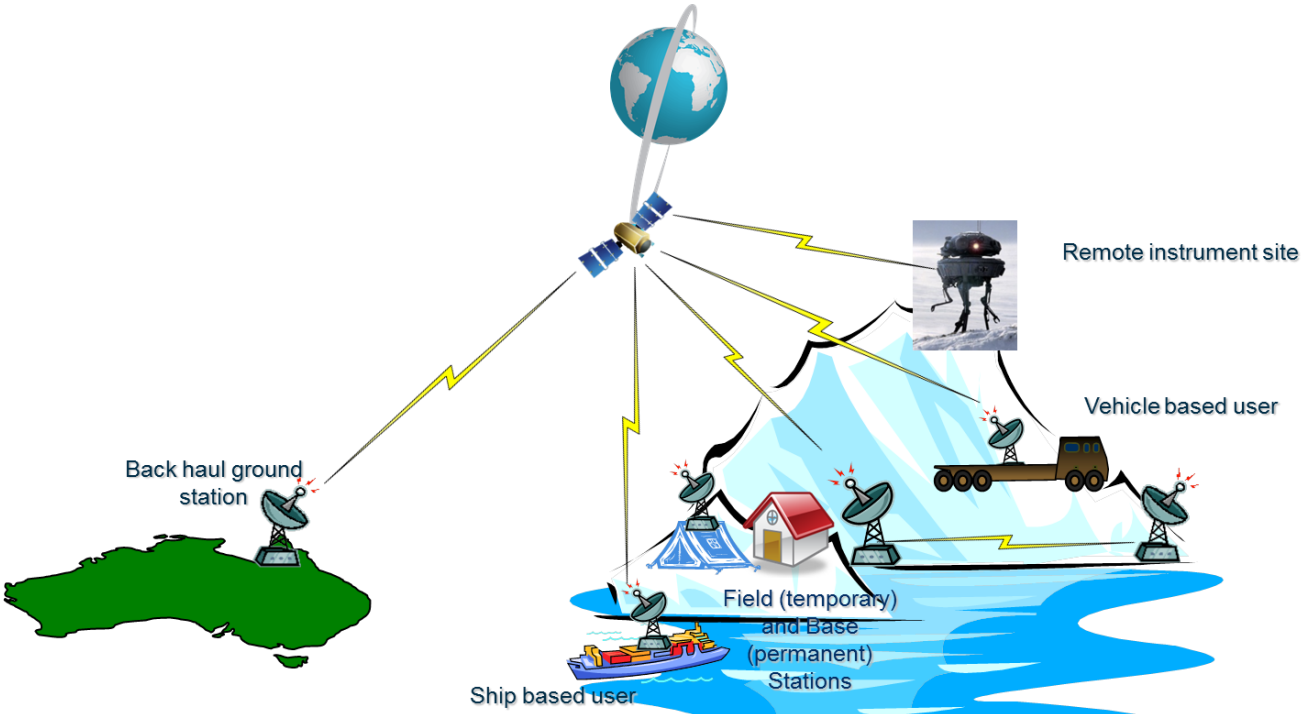

Figure 1: Antarctic Broadband Operational Concept

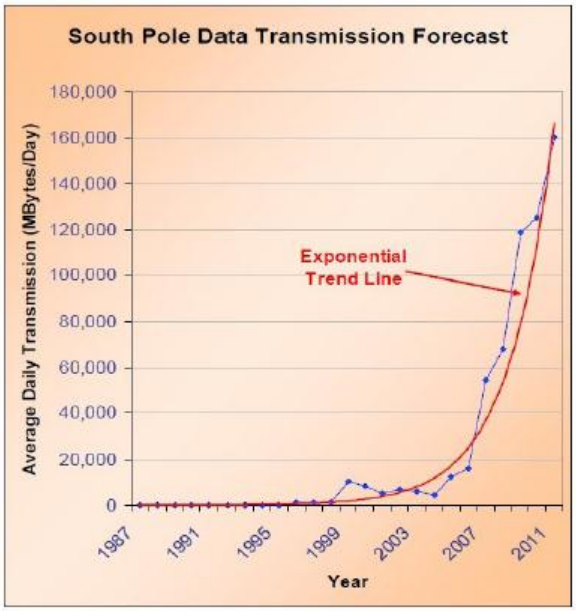

Figure 2: South Pole Station data transmission forecast, (Source: US National Science Foundation, Antarctic support contract Pre-solicitation Conference, 2008)

DESIGN DRIVERS

Ground Terminals

There are several unique system requirements for a satellite communication serviced in Antarctica. First and foremost, the Antarctic is an extreme environment for all ground equipment. Temperatures on the Antarctic plateau in winter can reach as low as -90C, while summer temperatures rise above freezing in many locations. Wind loads on ground terminals present significant challenges: in particular, the Antarctic coastline is the windiest place on Earth, and violent storms are commonplace. Conversely, inland locations are comparatively dry and have little wind at all. Blown snow and ice tend to fill cavities and build up into drifts, which can destroy mechanisms and gears, and the relatively low pressures on the Antarctic plateau can cause materials and devices to exhibit unexpected behavior [1].

Compounding these difficulties, equipment transport and repair is difficult to execute in a timely manner, if at all. Thus, critical high-reliability systems must be designed to rigorous reliability requirements due to the cost and risk associated with failures. Install costs for equipment are typically many times the purchase price of said equipment as a result of difficulty of access. Power is extremely expensive, as diesel fuel and batteries must often be delivered to the continent by air.

These factors and others drive the need for any ground terminal installations to be as simple, robust, and cost-effective as possible. This combined with high bandwidth requirements drives the need for small, mobile dishes for communications, which in turn must be kept small to be portable and raydomed for protection from the environment.

Satellite System

The design of a satellite system for Antarctic communications is similarly challenging. Satellites in geostationary orbits see only a small fraction of the Antarctic continent, and then only at very low elevation angles. Long distances to gateway stations effectively preclude bent pipe LEO systems, driving prospective service providers either to higher orbits with greater radiation exposure, or to a larger number of LEO satellites with complex intersatellite links.

These challenges, combined with the (relatively) low number of users in the Antarctic, make closing an immediate business and technical solution challenging. But it is such niche applications that are ideally suited for dedicated small satellite solutions, which the Antarctic Broadband program aims to provide.

OPERATIONAL SYSTEM OVERVIEW

The operational Antarctic Broadband mission will consist of two or more satellites providing continuous high-bandwidth coverage over the Antarctic continent, as well as to several gateway stations on other continents.

The design of the operational system for Antarctic Broadband is driven by a set of challenging requirements, which either drive the number of satellites or their cost, complexity, and uniqueness of orbit.

Highly Eccentric Orbit Implementation

In the operational mission study [4], four synchronous "inverted Molniya" elliptical orbits were considered, with inclinations equal to 63.4 degrees to keep perturbations to the argument of perigee near zero. Highly eccentric orbits permit long dwell times over the Antarctic for each satellite, and our studies indicate that that 100% coverage can be achieved with only two satellites.

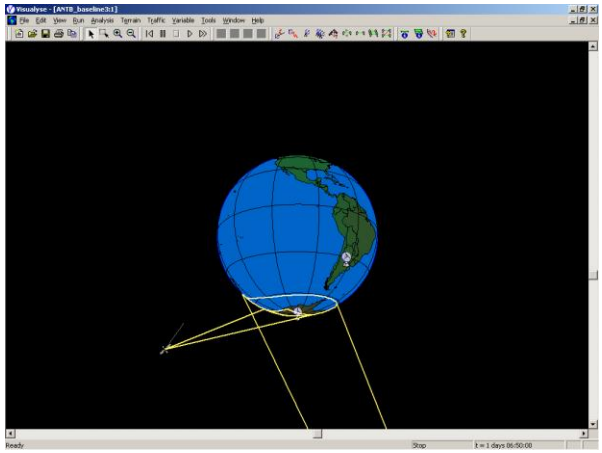

Figure 3: Operational Mission using Highly Elliptical Earth Orbits (HEEOs)

String of Pearls Implementation

Alternatively, a mini-constellation of eight LEO satellites, referred to as a "string of pearls" configuration, has also been considered. This configuration allows data to be relayed from the Earth's surface up to whichever satellite in the string is visible, which in turn forwards the message via satellite-to-satellite relay until the receiving ground station is in view of the constellation, at which point the data can be downlinked. The string of pearls configuration requires a larger number of spacecraft, but has a more benign radiation environment and less exotic orbits. As well, the string of pearls approach has a linear cost growth model--the constellation can be built up incrementally, and can be quasi-operational at lower cost than the elliptical orbit implementation, the latter of which will require a dedicated launch. However, with the string of pearls configuration there are additional service area coverage and satellite antenna design issues that must be resolved.

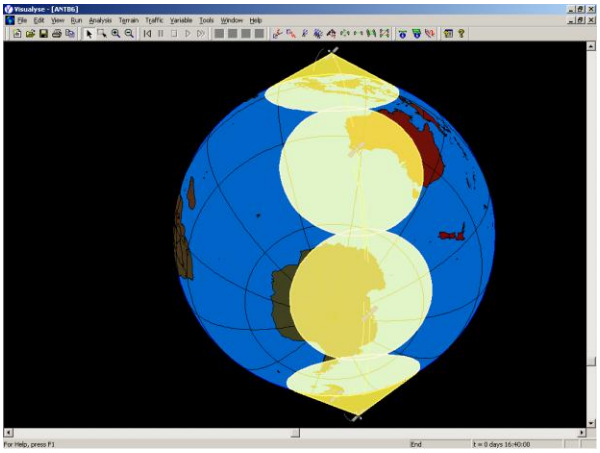

Figure 4: Operational Mission using String of Pearls Configuration

Trade studies are ongoing as of this writing, and neither type of implementation option has been discarded at present.

DEMONSTRATOR MISSION

The Antarctic Broadband demonstrator is intended to be designed and manufactured by the UTIAS Space Flight Laboratory based on their Generic Nanosatellite Bus (GNB) platform. The GNB platform was originally developed for the CanX-3 (BRITE) constellation and CanX-4/-5 formation flight demonstrators, and has most recently been used in the highly successful AISSat-1 mission (launched July 2010). The demonstrator Ka-Band transponder payload will be developed in Australia by EM Solutions. The spacecraft requires four Ka-Band horn antennas, one pair of which will be actuated.

Key objectives of the demonstration mission include:

- Measurement of Ka-Band uplink and downlink excess path losses due to meteorological effects;
- Demonstration of transponder performance (i.e. Eb/No, BER)
- Performance demonstration using adaptive modems;
- Measurement of radiated interference at Ka-Band received on the satellite uplink; and
- Quasi-operational demonstration.

Perhaps the most compelling objective from the standpoint of the end user is quasi-operational demonstration. If successful, the demonstration nanosatellite may be used to transfer user data between two facilities in the Antarctic circle, or even beyond the continental coverage zone to gateway stations located on ships or other continents.

Demonstrator Operations

The demonstrator is intended to operate in a circular low-Earth orbit (LEO), with a design altitude between 750km and 1000km. Operation over the southern Antarctic continent necessitates a polar or near-polar inclination. The satellite system will be controlled in attitude so that it may direct one transmit and one receive antenna in the direction of corresponding ground stations. The system will have a dual analog transponder capable of either relaying high speed data between two Earth stations or transmitting a CW carrier for measuring propagation effects on the uplink and/or the downlink paths, in both directions (forward and return). The transmitter power of the payload will be between 0.6 and 1 Watt in the forward direction and 20 to 30 mW in the return direction. The satellite's DC power produc-

tion capability will be less than 10 Watts orbit average. The four payload antennas will be horn antennas each with approximately 20 dBi gain.

. The primary Earth station terminals for both link directions are expected to be located within the Antarctic Circle. It is possible for brief periods of time to relay data via the satellite to ground terminals located further north, outside the coverage area defined above. The Earth station terminals will use small Ka-Band dish antennas which will be required to track the satellite as it moves across the sky during each pass. For all stations within the coverage area the satellite will be visible for some period of time during every orbit.

Table 1 summarizes key ground terminal characteristics for Antarctic Broadband.

The Generic Nanosatellite Bus (GNB)

The Antarctic Broadband demonstrator will be based on the UTIAS/SFL GNB satellite platform, configured to comply with mission and system level requirements found in [AD1]-[AD3]. A short description of the basic GNB is provided in this section.

The SFL Generic Nanosatellite Bus (GNB, Figure 5) is a 20cm cubical spacecraft design massing less than 10 kg, with an approximately 17 x 13 x 8 cm internal payload volume. This central payload volume sits between two trays which house the majority of spacecraft electronics and actuators. These trays connect together via payload mounting brackets and external panels, which also serve as mounting surfaces for solar cells and antennas.

Table 1: Ground Terminal Characteristics

Uplink Station:		**Downlink Station:**	
High Speed Data:	R=15Mbps	SNR = 3.72 dB	(typical at max. range)
Transmitter Power:	40 W	Receiver Noise Temp.:	120 K
Transmit Antenna:	1.0 meter parabola	Receiver Antenna:	1.0 meter parabola
Medium Speed Data:	R = 2.5 Mbps	SNR = 8.50 dB	(typical at max. range)
Transmitter Power:	5 W	Receiver Noise Temp.:	120 K
Transmit Antenna:	0.5 meter parabola	Receiver Antenna:	1.0 meter parabola
Low Speed Data/CW:	R = 100 kbps or CW	SNR = 15.00 dB	(typical at max. range)
Transmitter Power:	1.0 W	Receiver Noise Temp.:	120 K
Transmit Antenna:	1.0 meter parabola	Receiver Antenna:	1.0 meter parabola

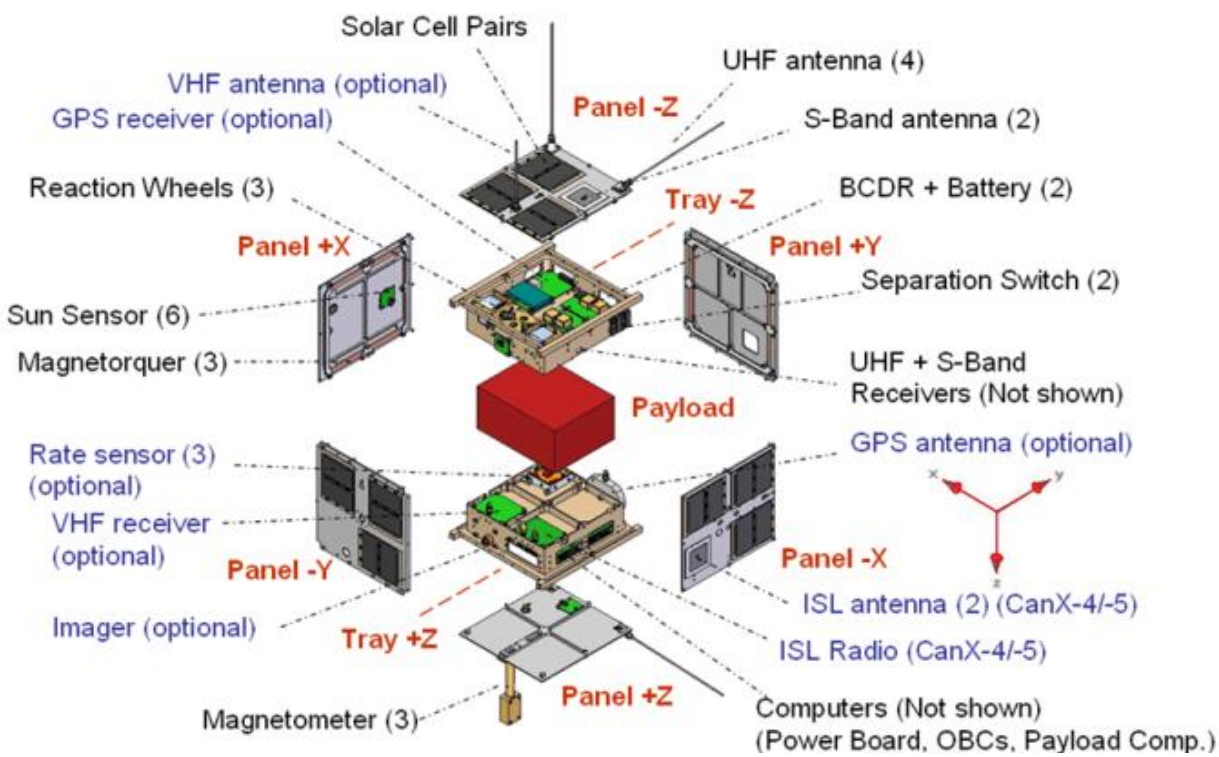

Figure 5: The SFL Generic Nanosatellite Bus (GNB) [5]

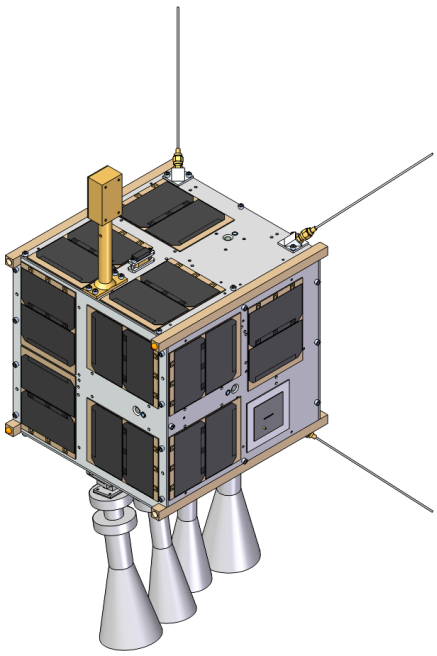

Figure 6: The Antarctic Broadband Demonstration Nanosatellite

All GNB spacecraft contain two identical on-board computers (OBCs). A Housekeeping Computer (HKC) enables communications with the ground, as well as telemetry collection and mass data storage, while an Attitude Determination and Control Computer (ADCC) controls a suite of sensors and actuators. Both computers are identical in design, and only one computer is theoretically required for both housekeeping and ADCS functions. A UHF receiver provides a 4 kbps command uplink, while an S-band transmitter provides primary downlink at 32 kbps minimum.

Each GNB spacecraft is three-axis stabilized, using three reaction wheels for precision attitude control and three magnetorquers for coarse control and momentum dumping. Degree-level attitude determination is enabled by a suite of six sun sensors, magnetometer, and rate sensors. An optional star tracker improves attitude determination to the sub-arcminute level. Timing and position estimates can also be refined through the inclusion of aGPS receiver.

The Generic Nanosatellite Bus has solar arrays on all panels, each of which nominally generates approximately 5.7W under worst-case-hot end-of-life (WCH/EOL) conditions. The GNB power system is additionally capable of regulating the system operating voltage such that maximum power can be extracted from solar panels as required. A distributed power system allows various loads to be switched on and off and also provides voltage and current telemetry for all power switches. Power is generated by multiple body-mounted strings of triple-junction solar cells, and energy is stored in two independent 5.3Ahr lithium-ion batteries, each of which is integrated to the bus via integral Battery Charge/Discharge Regulators (BCDRs). The spacecraft power system uses a high-efficiency direct-energy transfer (DET) topology with peak-power tracking (PPT) capability.

GNB is highly reconfigurable. Any of the equipment described above can be omitted (or in some cases, additional units included) as required. The operational orbit for GNB missions is nominally 500 to 1000 km sun-synchronous, and as part of the GNB philosophy, the thermo-optical properties of all GNB spacecraft can be tailored to achieve passive thermal control for any Local Time of Ascending Node (LTAN).

GNB spacecraft are designed to use the UTIAS/SFL XPOD separation system. Different XPOD designs can accommodate one or more spacecraft of size up to 200 x 200 x 440 mm and 15 kg. The XPOD releases its spacecraft when signaled to do so by the launch vehicle at the appropriate time in the launch sequence. The XPOD-GNB, designed to release a single GNB-sized spacecraft, has been used to successfully deploy two spacecraft in the past three years (NTS and AISSat-1).

Table 2: Demonstrator Specifications

Specification	Value
Spacecraft Volume	20x20x20 cm
Mass	6.82 kg
Attitude Solution	±1.0°
Attitude Control	±2.0°
Attitude Pointing Mode	Target Tracking
Power Generation	5.7-14 W
Battery Capacity	5.3 Ah (x2)
Bus Voltage	3.5-5.5 Vdc
Data Downlink	Up to 256 kbps
Data Storage	Up to 256 MB
Launch Interface	XPOD Ejection System
Payload Volume	8x13x17 cm
Payload Mass	2.0 kg
Payload Energy / Orbit	3.33 Wh
Payload Voltage	Bus Voltage
Data Production	5MB/day maximum
Survival Temperature	-40 to +80°C
Operational Temperature	-20 to +60°C
Uplink Margin	7.19 dB
Downlink Margin	6.05 dB

Current GNB missions include:

- AISSat-1 (maritime monitoring using automatic identification system signals);
- AISSat-2 (a follow-on to the highly successful AISSat-1);
- BRITE Constellation (six spacecraft, two each from Austria, Poland and Canada); and
- CanX-4&5 (Formation flight demonstration)

The first BRITE spacecraft and CanX-4&5 are slated for launch in 2012.

Ka-Band Transponder Payload

The demonstrator mission employs an advanced Ka-band transponder payload, tailored for integration with the GNB platform. The payload consists of two pairs of Ka-band horn antennas, one pair of which is actuated. During payload operations, the satellite ADCS is used to track a ground station of interest, while the actuated pair of antennas is commanded to track a second ground target in order to link the two stations.

The payload consists of two separate transponders, and is assembled in two halves, with one half containing the forward transponder and the other the return. All payload electronics are powered from a set of synchronized high-efficiency switch-mode power supplies.

Table 3: Transponder Payload Specifications

Specification	Value
Transponder Frequency	Ka Band
Payload Maximum Data Rate	15.84 Mbps
Payload Power Consumption	10W
Transponder Efficiency	10%
Coverage Area	Antarctic Continent
Max ground terminal separation	≈ 6000 km

CONCLUSIONS

The Antarctic Broadband program is currently working towards establishing a high-bandwidth, high-quality communications service for the international community in Antarctica [1]. Using small satellites tailored to the specific task of Antarctic communications, the Antarctic Broadband program is intended to provide low-cost, reliable communications to some of the most remote, hard-to-reach locations on Earth—places where the flow of information is of increasing importance.

As of June 2011, the consortium has completed critical design review of the nanosatellite bus, developed and tested a protoflight version of the Ka-band payload, commissioned a telemetry and command ground station at the Australian National University Mt Stromlo Observatory outside Canberra, Australia and fostered a strong working relationship between the program partners. Further development is contingent on additional funding however the consortium will continue efforts to address this niche opportunity and support the important research work in the Antarctic regardless.

Once complete, Antarctic Broadband will have deployed a constellation of satellites which will collectively offer superior communications capabilities to the Antarctic in terms of coverage, uptime and speed. In general, robust, cost-effective and high-bandwidth data services are critical for establishing increased activities in the Antarctic; and the Antarctic Broadband program intends to enable more efficient and effective work in one of the most remote, inhospitable locations on Earth by providing such services.

The nanosatellite precursor mission represents a strategic investment in understanding and supplying the emerging market of Antarctic data services. If successful, the demonstrator mission will establish confidence and lower the barrier to entry for implementing the operational system, both in space and on the ground.

ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Brett, D. Faber, C. Boyd, J. King, I. Vuletich, and S. Wilson, "Antarctic Broadband - A Micro-Satellite Niche", IAC-10.B4.3.6, 2010.
[2] Bonin, D. Sinclair, and R. E. Zee, “Peak Power Tracking on a Nanosatellite Scale: The Design and Implementation of Digital Power Electronics on the SFL Generic Nanosatellite Bus (GNB)”, SSC09-XI-9, Proc. of the 23rd Annual AIAA/USU Conference on Small Satellites, Logan, UT., August 2009.
[3] Antarctic Broadband Satellite Project Team Celebrates Grant, Available: http://www.spacedaily.com/reports/Antarctic_Broadband_Satellite_Project_Team_Celebrates_Grant_999.html
[4] J. King, A. Dando, M. Brett, W. Williams, and S. Kearney, “Antarctic Broadband Operational System Trade Study and Preliminary Design”, ANTB-REPORT-0051, Version 0.19, Issued 14 May 2011.
[5] G. de Carufel, *Assembly, Integration and Thermal Acceptance Testing of the Generic Nanosatellite Bus*, Master’s Thesis, 2009.