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ANTARCTIC BROADBAND: FAST INTERNET FOR THE BOTTOM OF THE EARTH

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High-bandwidth communications is the largest sector of the commercial satellite industry. While micro- and nanosatellites have yet to service this market, it is expected that such spacecraft will play an increasing role in the communications industry, with likely initial applications in niches that cannot be readily or easily addressed by traditional service providers. Polar communications are one such niche. Communication needs at the poles are increasing rapidly, and traditional space and terrestrial communication solutions will not be able to meet these needs in the near-future. Inherent orbital limitations exist for geostationary communication satellites, while environmental issues limit what can practically be accomplished with terrestrial infrastructure.

The Antarctic Broadband program has developed miniaturized communications technology specifically designed to meet the data transfer requirements of users in the Antarctic. Funded under the Australia Space Research Program, the project consortium, comprised of industry and research organizations, has developed a number of innovative solutions to meet the challenge of transferring data from polar regions to anywhere on Earth at very high speed. The first spacecraft expected to be launched by this program—a nanosatellite demonstrator—will be able to provide end-to-end data links at speeds in excess of 15 Mbps between small Earth stations, which may be fixed or mobile. Alternatively, if configured as a telemetry transmitter, the nanosatellite payload can achieve downlink speeds between 60 and 120 Mbps at 1 Watt RF output power.

This paper discusses the Antarctic Broadband program, including the key technologies which have been developed to facilitate high-speed polar communications; an initial risk-reduction nanosatellite demonstration mission; and the envisioned operational broadband system.

INTRODUCTION

The need for high-availability, high-bandwidth communications services in the Antarctic is becoming increasingly evident. The problem is fundamentally one of supply and demand—at present, the need for broadband data services in polar regions is increasing exponentially, while available services are insufficient and expected to decrease in the near-future. At present, the majority of data services for Antarctic stations are provided either by intermittent, low-quality links to GEO communications satellites, TDRS satellites or GOES-3 (which are either close to or beyond their operational lifetimes); or by the Iridium constellation, which is expensive and relatively low-speed. The supply and demand problem is illustrated by Figure 1, which shows a projection of the evolving data demands of South Pole Station (SPS) versus the expected number of healthy TDRS satellites able to service the station. The trends are diverging.

While data services provided by satellites are clearly limited, alternative Earth-bound solutions are challenging as well, to the point of being un-workable. Fiber-optic cabling would be prohibitively expensive and prone to damage caused by moving ice and snow, and Antarctic bases are too remote for any terrestrial line-of-sight microwave link [1], [2].

ANTARCTIC BROADBAND

A dedicated satellite solution is ostensibly the best way to solve the data transfer bottleneck of concern to current and future Antarctic researchers. The Antarctic Broadband program intends to provide this solution. Antarctic Broadband aims to establish a high-bandwidth, high-quality communications service for the international research community in Antarctica [3]. Using small satellites tailored to the specific task of Antarctic communications, the program will provide

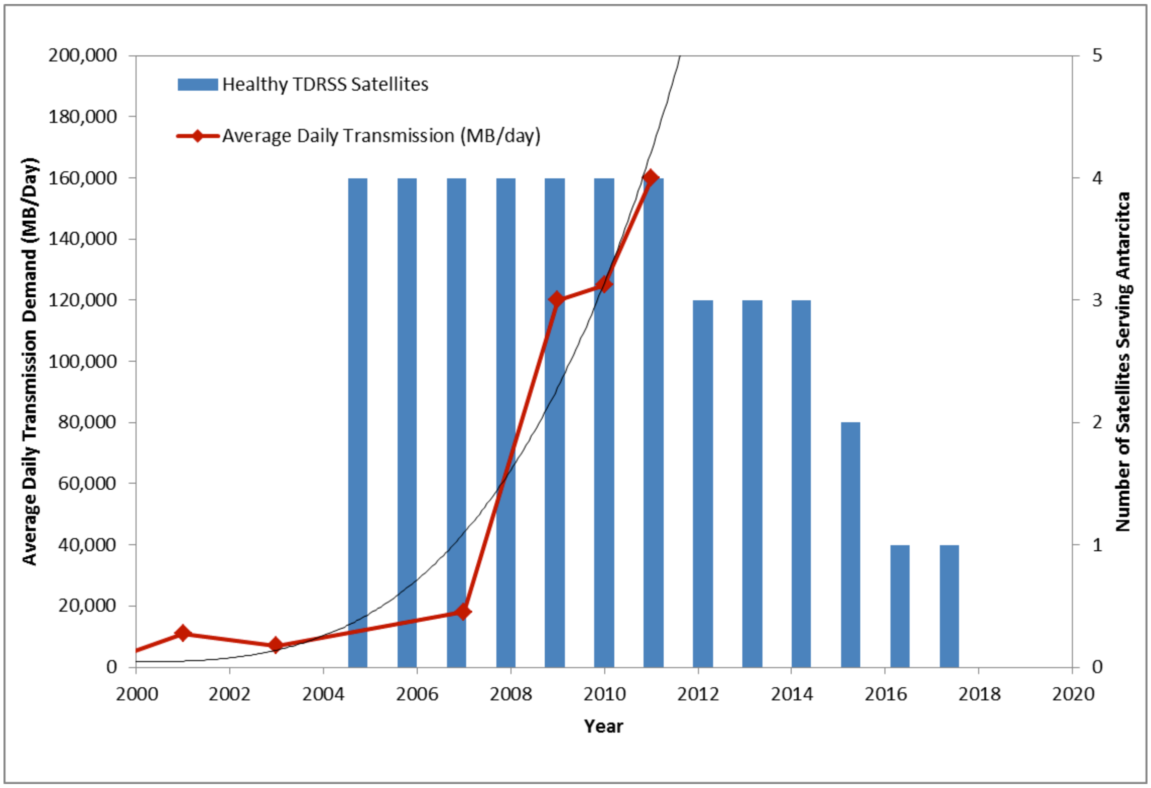


Figure 1: South Pole Station Data Forecast and TDRS Satellite Availability Forecast

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

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 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, brand-ing)
- Tauri Group (North America customer relations)

development [3]—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 broadly consists of two primary phases: to develop a nanosatellite demonstration mission; and to develop an operational satellite constellation.

The end-to-end operational mission (

) 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 its Generic Nanosatellite Bus (GNB) platform, most recently used in the highly successful AISSat-1 mission (launched July 2010), and the basis for BRITE

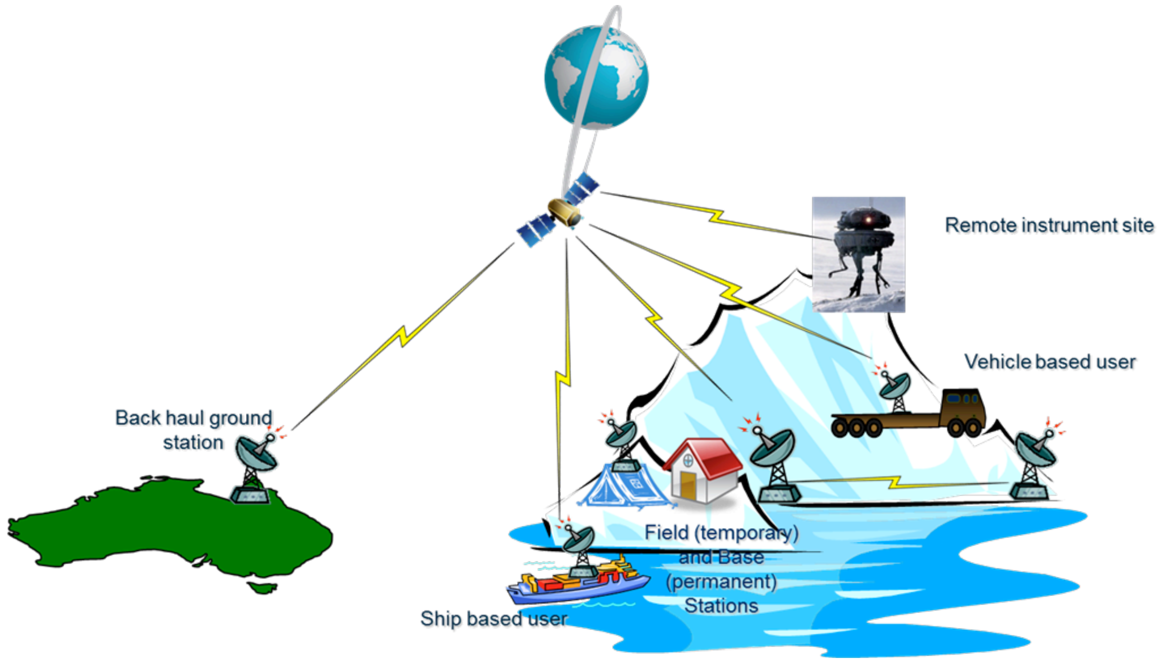


Figure 2: Antarctic Broadband Operational Concept

Constellation (launch Q4 2012), the CanX-4&5 formation flying missions (launch 2014), and AISSat-2 (launch 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 and is is depicted in Figure 3.

At present, the Antarctic Broadband demonstrator has completed Phase C (detailed design) and is ready for manufacture. The demonstrator mission could be launched as early as late 2013.

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 [5].

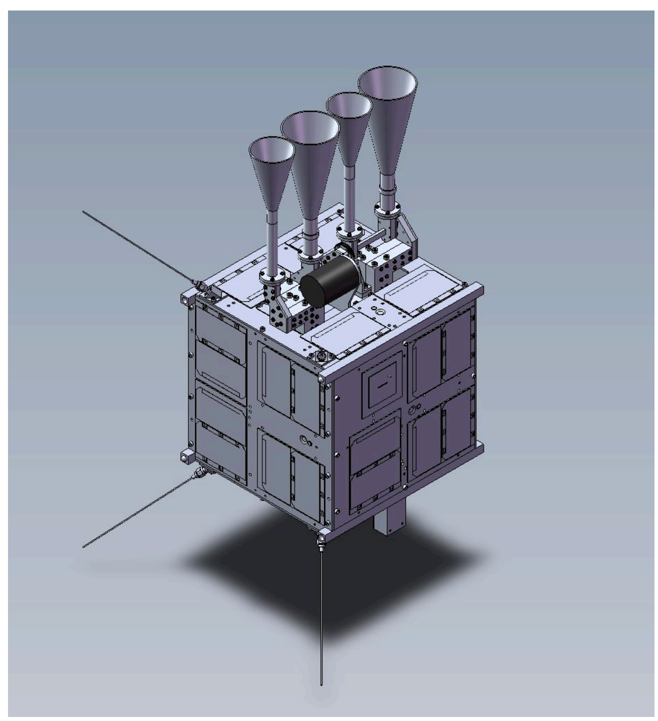


Figure 3: The Antarctic Broadband Demonstrator Nanosatellite [4]

OPERATIONAL SYSTEM

Highly Eccentric Orbit Implementation

In the operational mission study [5], 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 100% coverage can be achieved with only two satellites. Thus, a dual HEEO (Highly Elliptical Earth Orbits) satellite approach is the current baseline for the operational mission [1].

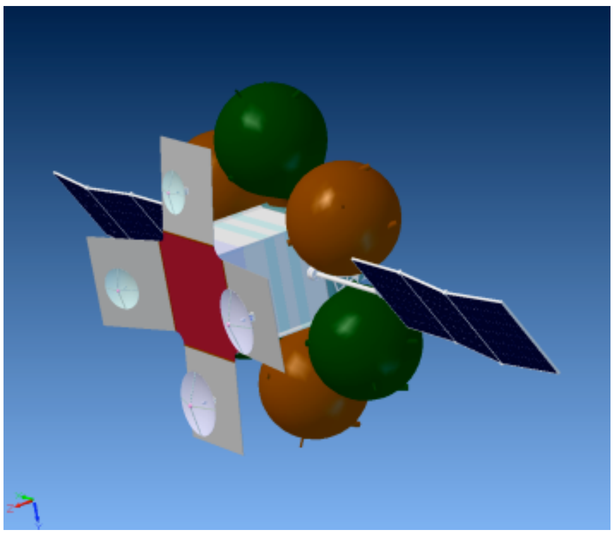


Figure 4: Concept Operational Spacecraft for HEEO Orbit

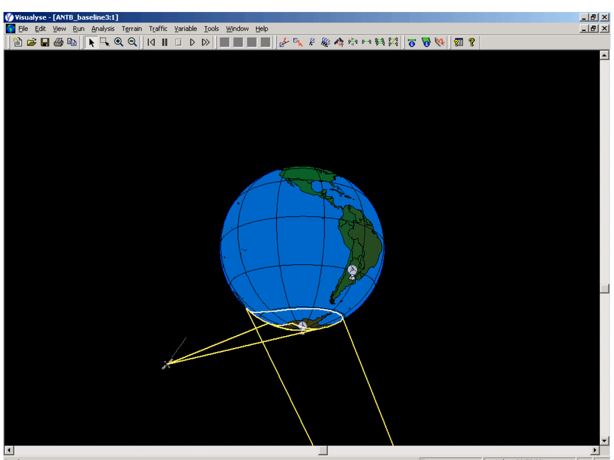


Figure 5: Operational Mission using Highly Elliptical Earth Orbits (HEEOs)

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 more complex spacecraft (due to the need for inter-satellite communications), 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 [1], especially for reduced-size (i.e. incomplete) constellations.

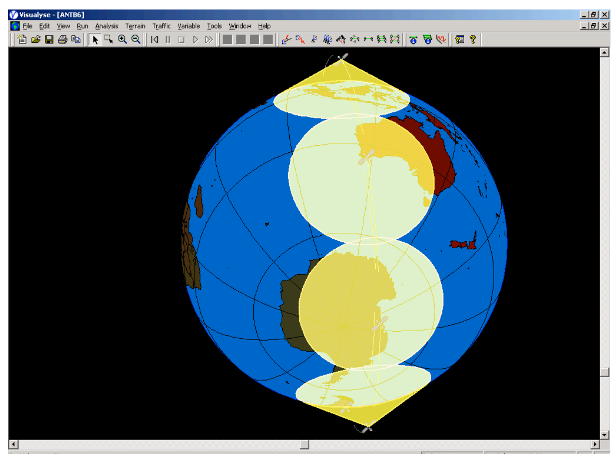


Figure 6: Operational Mission using String of Pearls Configuration

DEMONSTRATION MISSION

In order to verify the performance of a Ka-Band system in a non-GEO orbit, and to verify link characteristics and modem performance in polar conditions, a LEO demonstration mission design was also undertaken for Antarctic Broadband. This demonstrator nanosatellite was taken to the Critical Design Review (CDR) stage in

2011, and deliverables included both a protoflight "flatsat", ready for flight testing, as well as a fit/form/function Ka-Band transponder system designed for the nanosatellite scale [4]. This represents the first attempt at developing a nanosatellite-scale Ka-band system to the knowledge of the authors. Testing of the Ka-band payload occurred at Australian National University (ANU) in July 2011, with the payload tested both at the unit level and integrated with the nanosatellite flatsat. The integration milestone was achieved on schedule and within budget—this was not simply a paperwork exercise.

The demonstrator is intended to be designed and manufactured by the UTIAS Space Flight Laboratory based on its Generic Nanosatellite Bus (GNB) platform. The GNB platform was originally developed for the CanX-3 (BRITE) constellation and CanX-4/-5 formation flight demonstrators.

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 [1].

Generic Nanosatellite Bus (GNB)

The SFL Generic Nanosatellite Bus (GNB, **Figure 7**) 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.

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 a GPS 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.

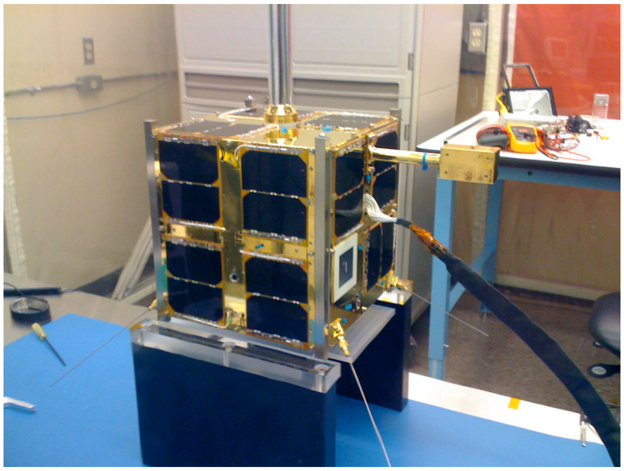


Figure 7: GNB (AISSat-1 Implementation)

Table 1: 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
Telemetry Downlink Rate	Up to 1 Mbps
Data Storage	Up to 1 GB
Launch Interface	XPOD Ejection System
Payload Volume	8x13x17 cm
Payload Mass	1.7 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
Command Uplink Margin	7.19 dB
Telemetry Downlink Margin	6.05 dB

Ka-Band Transponder

The general characteristics of the linear transponder developed by the Antarctic Broadband program are summarized in Table 2.

Table 2: Demonstrator Ka-Band Linear Transponder Characteristics

Property	**Performance / Value**
Mass	1.7 kg
Forward Link	> 100 dB gain > 28 dBm output power 16 MHz bandwidth
Return Link	> 100 dB gain > 10 dBm output power 500 kHz bandwidth
Receive Frequency	29.975 GHz
Transmit Frequency	19.725 GHz
Forward Frequency Drift	< 10 kHz from startup < 1 kHz after 15 sec
Return Frequency Drift	< 11 kHz from startup < 1 kHz after 15 seconds
DC Input Power	< 10 W
Forward Intermodulation Level	-20 dBc

Figure 8 shows the exposed central tray of the nanosatellite Ka-Band transponder, and **Error! Reference source not found.** presents a block diagram of the overall payload. The transponder is actually a dual transponder, with the forward and return link transponders contained within one envelope. Because full duplex communications are essential for internet applications, the transponder is configured to operate with wideband performance in the forward direction while providing a more narrowband link in the return direction [4]. In the case of the demonstrator mission, the return link serves primarily to provide acknowledgement of receipt of packets sent in the forward direction.

With reference to Figure 3 and **Error! Reference source not found.**, the payload has a total of four high-gain horn antennas, with a pair for each link (forward and return). Of these antennas, two are fixed directly to the payload and, perforce, the satellite, while the other pair are actuated together using a single DOF positioner.

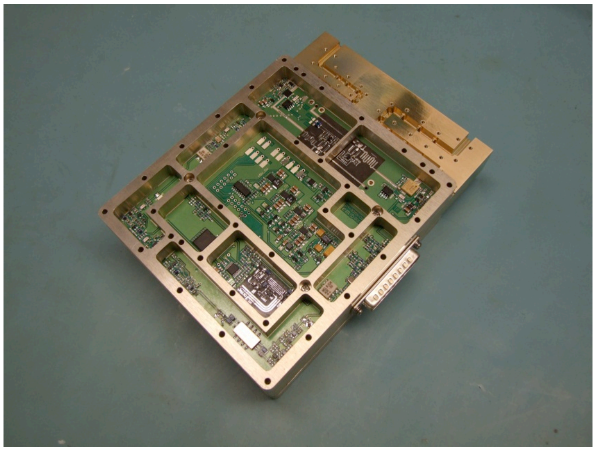


Figure 8: Antarctic Broadband Ka-Band Transponder (Central Tray)

This arrangement allows the demonstrator spacecraft to be in mutual communication with two visible ground stations desiring to communicate with each other. To achieve the link between two ground terminals, the spacecraft attitude control system points its two fixed antennas at one ground station; rolls about the fixed antenna pair to place the second ground station in the plane of the second antenna pair positioner; and then actuates the second pair to point at the second ground station. The attitude of the spacecraft and rotation of the positioner are continuously updated to track the two ground stations. For two stations located at typical bases in Antarctica, from a 1000 km circular SSO, pointing angle rates of change can be as high as 5 degrees/second for short periods, but are rarely above 2 degrees/second [4].

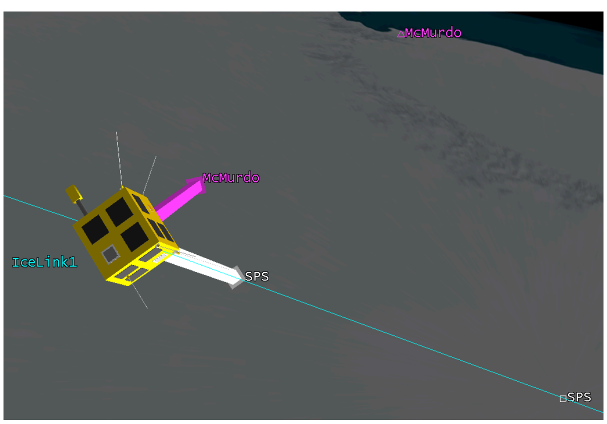


Figure 9: Depiction of Demonstrator Nanosatellite Tracking Two Ground Stations (McMurdo and SPS)

The Antarctic Broadband transponder prototype and flatsat were designed and tested to support at least 30 minute ON times, as verified by bench tests.

ALTERNATIVE APPLICATIONS

The dual station tracking and communications solution described above can also be used to enable other types of mission at that nanosatellite level [4]. The GNB-derived Antarctic Broadband nanosatellite is able to continuously track and point at two positions on the Earth continuously, which is a general solution to a far more general problem. In particular, if the fixed pair of Ka-band horns were replaced with an optical instrument or generally exchanged for a remote sensing instrument, the remaining two antennas could be used as a high-speed downlink and uplink channel to/from the instrument. In this sort of application, the return antenna pair would be eliminated, and the forward antenna pair would be used as a telemetry transmitter and command receiver. The high-speed, high efficiency telemetry transmitter thus derived is shown in Figure 10. The achieved high-efficiency Ka-Band payload, combined with the SFL GNB's high-performance attitude control system, together enable a new class of high-performance EO missions at the nanosatellite scale. This is further explored by these authors in reference [4].

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 August 2012, the consortium has completed the following major milestones:

- Phase B preliminary design of an operational mission;
- Phase C detailed design of a demonstrator mission;
- Delivery of a flight-worthy core flatsat, consisting of on-board computers and power system;
- Development and testing of a prototype Ka-band transponder; and
- Installation and commissioning of a telemetry and command ground station at Mt. Stromlo, ANU

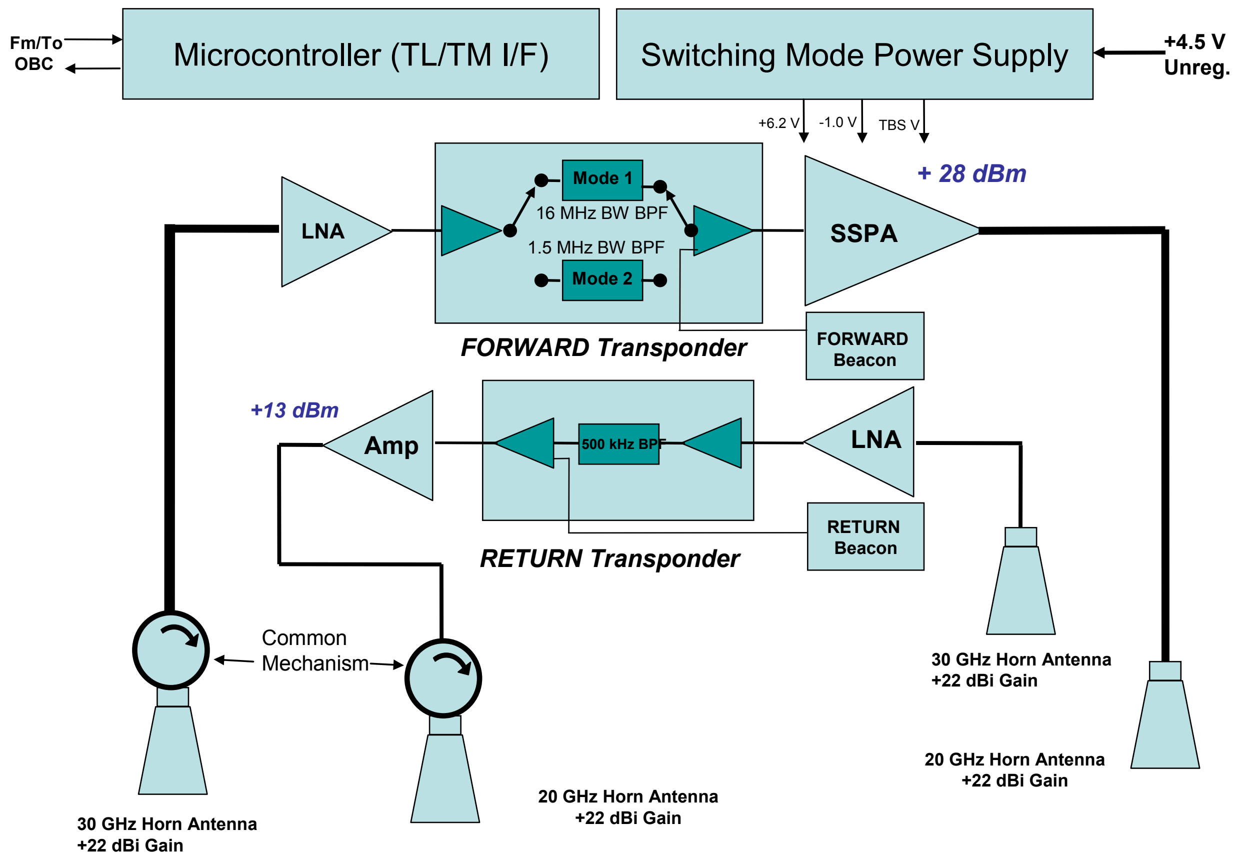


Figure 11: Ka-Band Transponder Block Diagram

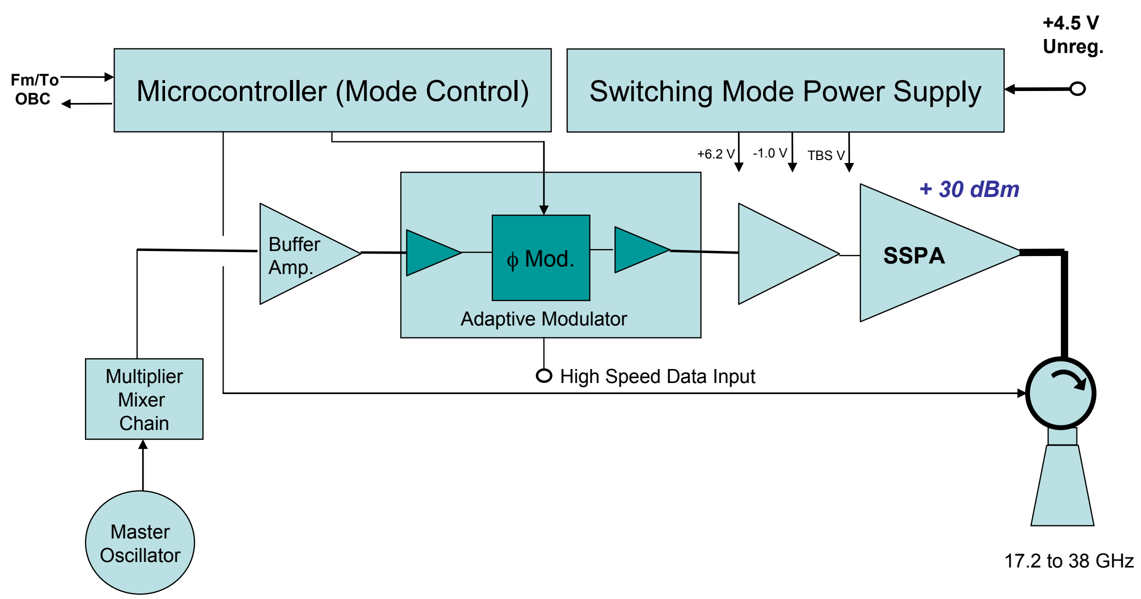
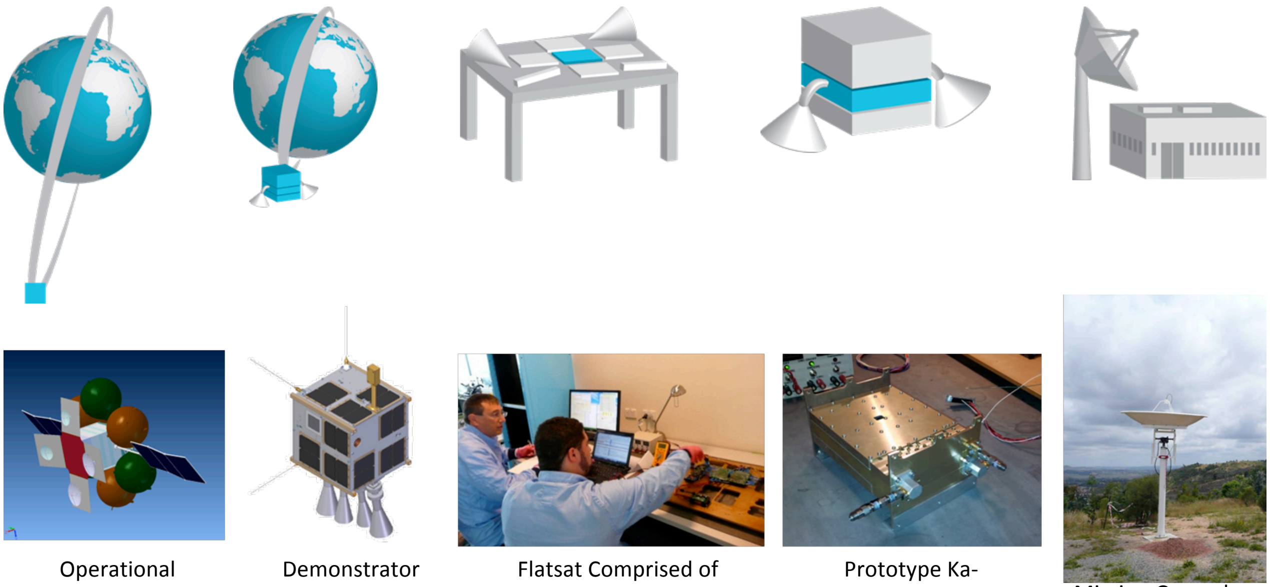


Figure 10: High-Speed Ka-Band Telemetry Transmitter Derived from Antarctic Broadband Transponder



Operational Mission Preliminary Design | Demonstrator Mission Detailed Design | Flatsat Comprised of Flight Avionics | Prototype Ka-Band Transponder | Mission Ground Station

Figure 12: Antarctic Broadband Program: Committed (top) and Achieved (bottom) Milestones

Further development of Antarctic Broadband is contingent on additional funding, though the consortium will continue efforts to address this niche opportunity. To the extent that the systems developed are able to de-risk and address the increasingly important issue of polar communications, as well as enable a new class of nanosatellite remote sensing mission, the consortium considers the team and technology to be worth continuing.

ACKNOWLEDGEMENTS

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