SSC10-X-4

Real-time, near global, low earth orbit communications using geostationary Inmarsat BGAN system as a relay

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ABSTRACT

This paper describes a new service and related communications hardware that provides continuous, near global access to and from Leo Spacecraft utilizing the existing geostationary INMARSAT BGAN Satellite System as a data relay. This new communications link for LEO platforms will provide full duplex data rates from as low as 100kbps up to 475kbps with near-real time latencies and near global coverage. A team of Broad Reach Engineering (US), COM DEV Europe (UK), and INMARSAT (UK) is developing the terminal and service for use on LEO Spacecraft.

The paper highlights some of the key features and advantages compared to traditional communications architectures and presents missions and applications, some previously impossible, that are enabled by the system. The development progress is described along with some of the challenges and solutions related to implementing the 3G based BGAN technologies on a space flight capable platform. The business case and decisions leading up to the development are discussed and the timeline for completing the development is shown.

INTRODUCTION

Current Low Earth Orbiting (LEO) Satellites rely on dedicated Ground Stations to receive download data (both Payload and TT&C). This necessitates the use of ground facilities or the implementation of a specific dedicated ground station or ground station network, all of which are significant cost and program factors in the operation of a satellite mission. Any space-to-ground communications architecture needs to consider territorial regulations, frequency allocations, line-of-sight, orbit design, data backhaul, ground operations, duty cycles, and many other factors. Traditional architectures that rely on earth stations alone have limitations such as limited access duration, long access gaps, and difficulties related to placement in hard-to-reach locations. To address some of these issues a team consisting of INMARSAT, COM DEV Europe and Broad Reach Engineering are developing a communications terminal and service for LEO missions that will allow constant, real-time communications from LEO to the ground using the geostationary Inmarsat I4 constellation as a communications relay. While similar service has been available via NASA's TDRS system for years, this new data service will be available globally and commercially, will lessen the need for earth stations, enable new missions, improve mission efficiencies, and dramatically reduce data latency in retrieving payload and TT&C data from LEO spacecraft.

THE INMARSAT BGAN SYSTEM AND LEO OPERATIONS

Architecture and Components

The SB-SAT system consists of three key elements: the Inmarsat I-4 constellation of GEO satellites; the BGAN network and service infrastructure; and the SB-SAT terminal hardware and software that is deployed on the LEO asset. The Inmarsat I-4 constellation consists of 3 satellites spaced at 120 degrees from each other at GEO. These satellites provide communications services to user equipment at L-Band frequencies using a combination of global, regional, and spot beams. Originally designed to service ground, maritime, and aeronautical users, the BGAN system and ground infrastructure is now being extended to cover space based terminals at LEO.

In the SB-SAT architecture the LEO asset hosts an SB-SAT terminal which communicates with the I-4 satellite. The SB-SAT terminal installed on the LEO utilizes the existing Inmarsat I-4 constellation and BGAN ground network capabilities similar to how a ground terminal would. The SB-SAT system relies on the terminal to adjust its transmit and receive characteristics to fit seamlessly into the existing and operating BGAN system in order to minimize the impacts and changes required at the Inmarsat ground network.

There are many BGAN terminal types in use on the ground from a number of manufacturers. For the SB-SAT transceiver unit those technologies are being evolved and adapted for the LEO application through custom development and licensing of existing core BGAN terminal technology by a team led by Broad Reach Engineering and COM DEV Europe.

Service Coverage, as Provided by the Inmarsat-4 Constellation

The Inmarsat I-4 constellation is composed of 3 state of the art telecommunications GEO satellites, located at 98ºW, 25ºE and 143.5ºE. Each of the Inmarsat I-4 satellites supports 192 narrow spot beams for traffic channels, plus 19 wide spot beams and a global beam for system and signalling channels. The satellite generates 67 dBW of transmission power, and supports 600 channels of 200 kHz in the forward and return direction. By 2013 Inmarsat plan to have the Alphasat satellite that will be added to the Inmarsat I-4 constellation and will provide a significant enhancement in terms of added capacity, service coverage and availability.

The SB-SAT system takes advantage of the coverage provided by the Inmarsat I-4 constellation, which is not limited to covering the surface of the earth, but extends significantly into space. SB-SAT terminals will be able to take advantage of their high altitudes, and benefit from this extended coverage. Figure 2 provides a polar view of the Inmarsat-4 constellation and illustrates the extended coverage provided by the Inmarsat-4 outer ring of spot beams. The coverage offered to the SB-SAT terminal depends on the LEO satellite altitude and inclination and therefore the actual service coverage for each LEO mission will be defined on a case by case basis.

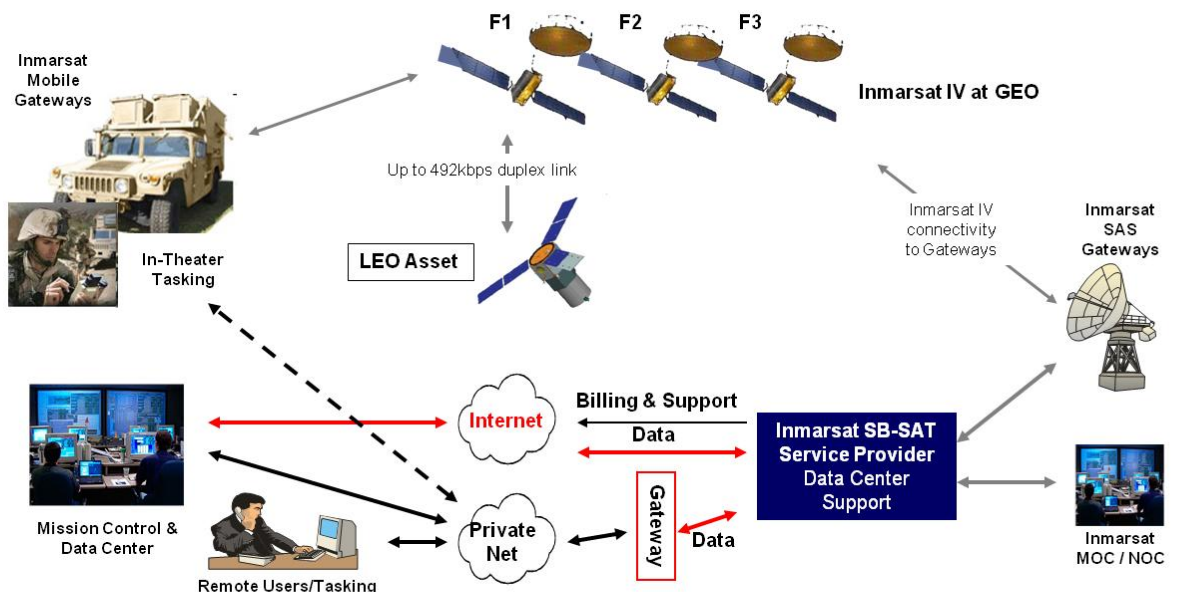


Figure 1. SB-SAT Network Architecture

For a BGAN class 6 based SB-SAT terminal it will be possible to extend the coverage by an additional 2dB from the nominal contour of the BGAN service coverage area and still have BGAN service at a reduced throughput. A BGAN class 7 based SB-SAT terminal will be more limited in its RF capability and therefore will not be capable of BGAN service beyond the nominal contour of the BGAN service coverage area.

Error! Reference source not found. Figure 3 provides an illustration of the extended service coverage at LEO orbital altitudes of 300 km and 900 km.

Table 1: Service coverage variations with orbital altitude and inclination

Altitude	Coverage	Orbit Inclination			
		30 º	45 º	60 º	90º
300 km	Nominal	100%	100%	96%	87%
300 km	Extended	100%	100%	100%	100%
500 km	Nominal	100%	98%	95%	81%
500 km	Extended	100%	100%	99%	93%
700 km	Nominal	95%	91%	77%	57%
700 km	Extended	100%	99%	93%	71%
900 km	Nominal	92%	84%	66%	52%
900 km	Extended	99%	95%	82%	61%

Note: the figures in Table 1 were obtained under the following assumptions:

- Interruptions in service due to satellite-to-satellite handover are not accounted for (between 2 and 3 handovers per orbit, and estimated as less than 40 seconds of interruption per handover).
- The effect of congested (“hot”) spots on service continuity is not considered (i.e. the highest level of priority is assumed with service always available within the service coverage)

SB-SAT TERMINAL DESCRIPTION

A nominal SB-SAT terminal system consists of the transceiver, L-Band antennas, GPS subsystem, and antenna pointing mechanism. Fundamentally SB-SAT can be operated in different configurations, ranging from a transceiver only option with fixed low gain antenna to a system that includes a mechanically steered antenna, the related control electronics, and an internal GPS unit. At the core of all options is the BGAN Core Module which comprises the RF front-end, physical layer implementation (modem) and radio software (protocols, terminal control, and I/O). Since SB-SAT requires position and velocity information, an internal GPS unit is to be included unless a reliable external GPS source can be tightly coupled into the Core module, using the same interface definition of the internal GPS. The SB-SAT terminal design accommodates this configuration through a modular architecture that can be easily extended and modified to accommodate specific mission requirements while maintaining the integrity of the Core Module.

The SB-SAT terminal includes the following elements:

BGAN Modem Board

This module consists of the BGAN physical layer (modem) and the processing complex that manages the modem operation, hosts the BGAN protocol stacks, and provides SB-SAT system specific functionality and user interfaces. The physical layer is based on the design of an existing aeronautical based BGAN terminal and BGAN physical layer test systems designs ported to fully radiation hard technology. The implementation makes use of a combination of space flight proven DSPs and FPGAs with core logic and software derived from existing terminal implementations which are modified to accommodate the specific hardware constraints and SB-SAT terminal environmental requirements. The radio software is based on a mature BGAN protocol stack design, updated for SB-SAT terminal functionality, and ported onto a rad-hard Broad Reach Engineering BRE 440 System-On-A-Chip (SOC) PowerPC. This 200+MIPS CPU is required to host the BGAN protocol stack, drive the physical layer, and operate the SB-SAT application layer. The modem baseband functions are handled by a TI 320C6727 DSP that is being radiation hardened by a collaboration of AFRL and TI through a process called “hardened by isolation.” Both the TI device and BRE PowerPC 440 are available now.

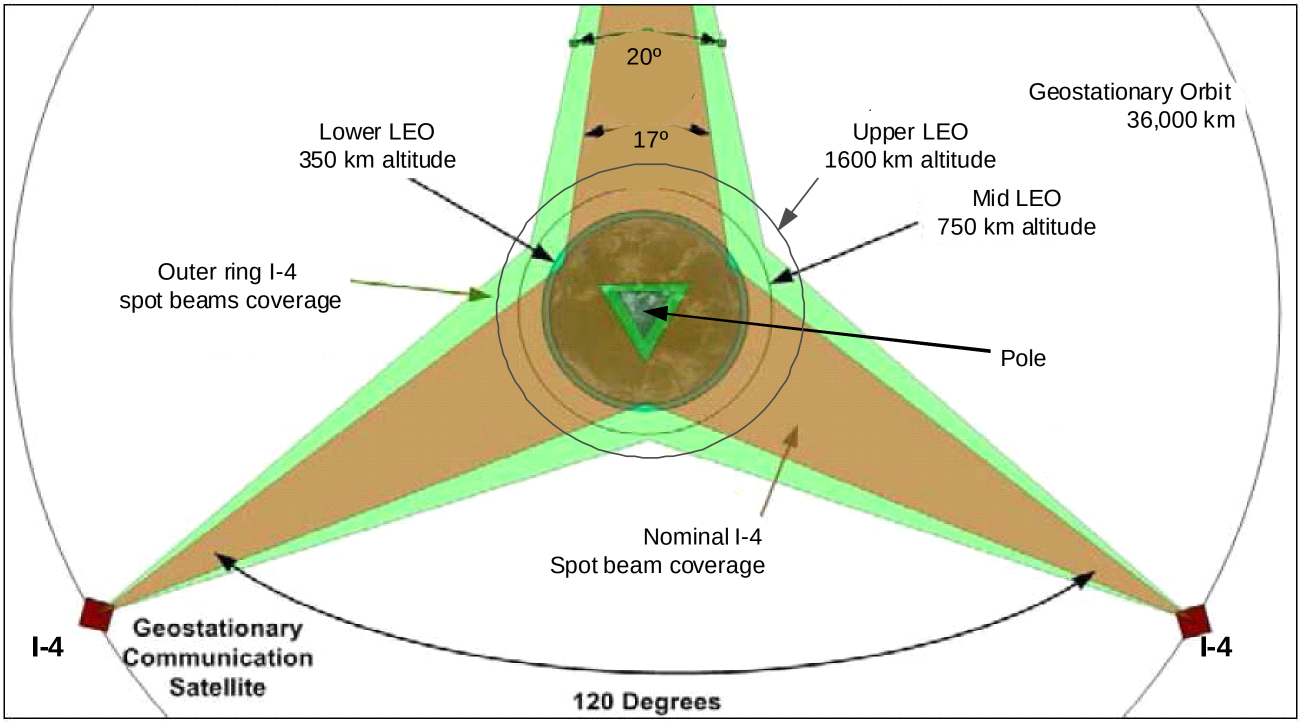


Figure 3: Service Coverage and Constellation Coverage

RF Front End

The RF front end consists of the RF up/down-conversion hardware, Low Noise Amplifier (LNA), High Power Amplifier, Diplexer, and linearizer hardware developed by COM DEV Europe specifically for space flight and BGAN applications. A unique feature of the COM DEV Europe solution is the proven linearizer/amplifier and diplexer/LNA (DLNA) which are adapted specifically for the BGAN system. COM DEV already supplies over 80 DLNAs per month for the ARINC class BGAN terminal.

Figure 4 shows the top level functional diagram of the Class 6 equivalent SB-SAT RF Subsystem.

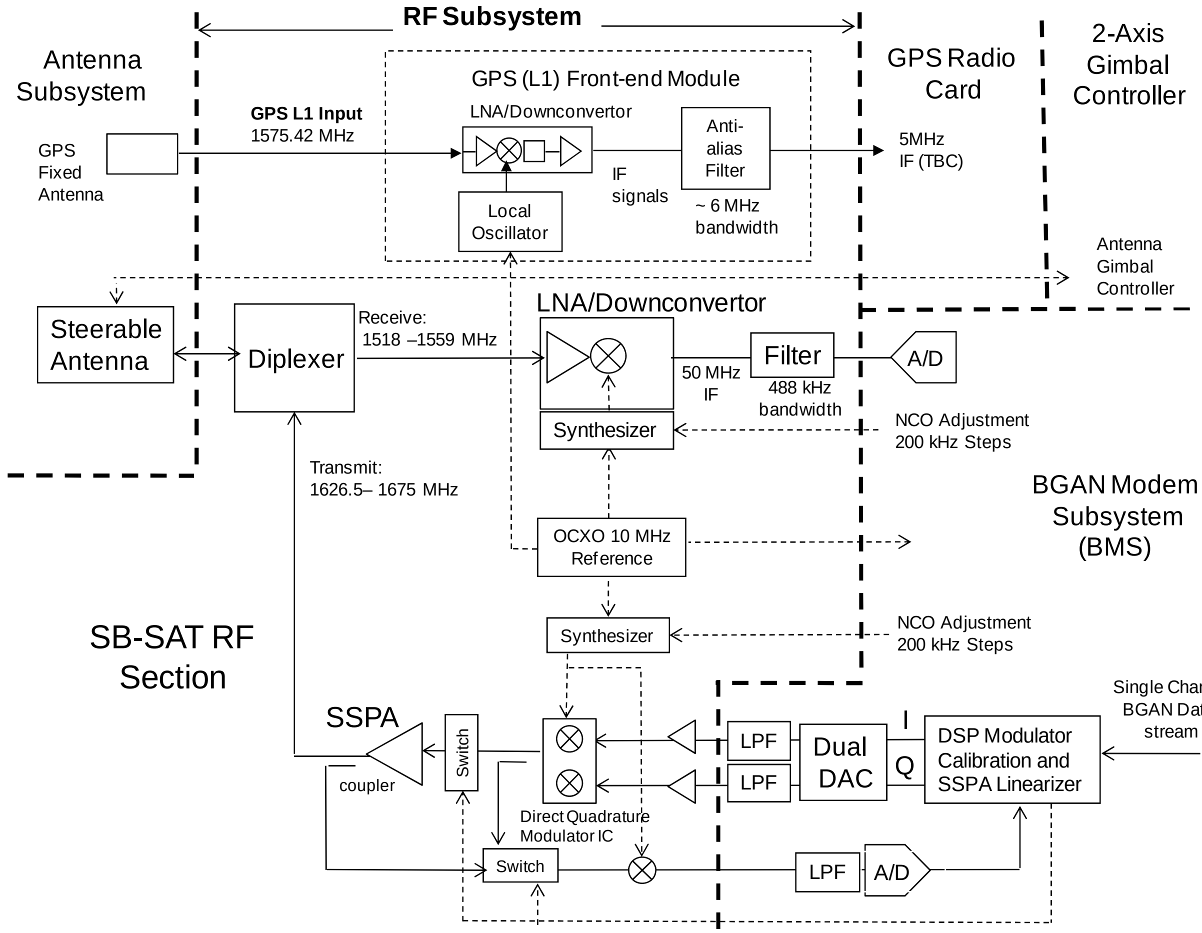


Figure 4. Functional Block Diagram of RF Subsystem

The RF Subsystem consists of the following major components:

- Transmit/Receive Diplexer
- SB-SAT LNA/synthesizer-downconvertor with Anti-aliasing Filter
- Analogue section of Self-calibrating Direct Modulator/Linearizer (SDML)/Synthesizer
- High Efficiency Gallium Nitride (GaN) based SSPA
- GPS LNA/Downconvertor/Anti-aliasing Filter

The SB-SAT RF subsystem is divided into the Forward and Return sections.

The Forward RF section receives the L-band signals from an Inmarsat IV/Alphasat satellite anywhere within the frequency range 1518.0 to 1559.0 MHz. The received signal is then input to the diplexer filter which limits the receive noise bandwidth and suppresses any out-of-band signals or interference. The signal then passes to the L-band receiver which provides low noise amplification and frequency down conversion. A numerically controlled synthesizer down converts the wanted signal located anywhere in the 41 MHz receive passband in 200 kHz steps to a fixed intermediate frequency (IF) of about 50 MHz. The signal then passes through a narrowband anti-aliasing bandpass filter prior to digitizing.

The signal is bandpass sampled (under sampled) in the ADC providing the frequency conversion to low IF before digital frequency translation to complex baseband and filtering is used to isolate a single desired digitized version of the signal. This digital down conversion is part of the BGAN Modem Subsystem (BMS) which also provides Doppler frequency compensation. A highly stable reference signal from the crystal oscillator (OCXO) is provided to the synthesizer.

In the Return direction, there are a number of possible approaches to the implementation of the RF subsystem. In order to minimize the D.C. power consumption of the SB-SAT UT, the baseline design will include a digital linearizer such that the SSPA can be operated efficiently while meeting the stringent linearity and spectral regrowth requirements of the BGAN system.

The linearizer design utilizes a DSP approach consisting of a feedback loop to sample the signal waveform distortion at the output of the SSPA. A downconverted and filtered version of the waveform is then digitized before being analyzed using proprietary DSP algorithms. The DSP then provides correction coefficients to the input I and Q data streams from the BGAN Modem Subsystem that reduce intermodulation and modulation regrowth levels so the amplifier can be operated closer to saturation and thus with better Power Added Efficiency (PAE). In addition to providing feedback to aid linearization, the feedback loop can be switched to sample the waveform at the output of the vector modulator prior to the SSPA input. Similar algorithms can be applied to this signal to determine imperfections in the I and Q paths to the direct modulator and provide corrections in amplitude, phase and DC offsets so that the carrier and lower sideband at the modulator output are suppressed sufficiently to comply with relevant BGAN requirements.

A frequency synthesizer under the control of the BMS provides tuning capability in 200 kHz steps so that the output signal can be transmitted anywhere within the transmit bands; 1626.5 to 1660.5 MHz or 1668.0 to 1675 MHz. Doppler frequency offsets to the transmitted signals are determined by the Doppler Compensation Processor (part of the BRE FPGA) and applied to the baseband I and Q signals. Any burst-by-burst re-tuning inside the assigned 200 kHz channel band is performed in the baseband BMS section.

In order to achieve high efficiency, the SSPA will utilize Gallium Nitride power devices in place of conventional Gallium Arsenide (GaAs) devices. This takes advantage of the extensive improvements to these devices that have occurred over the past few years.

GPS Receiver

The GPS receiver module is an embedded single frequency 12-Channel GPS receiver that is derived from the NASA/GSFC developed Navigator GPS which Broad Reach Engineering is porting to Broad Reach developed hardware for a US mission. Broad Reach has licensed the intellectual property rights to commercially market this receiver design. The receiver module is a single antenna implementation of the Navigator GPS with the existing RF front-end design being built into the BGAN L-Band front-end by COM DEV to maximize the level of integration. A GPS input is required by the SB-SAT terminal for managing Inmarsat I-4 satellite spot beam handovers, and for correcting for Doppler and delay variations by integrating the GPS based range and range rate information into the BGAN signal acquisition and tracking functions. This tightly coupled system provides the required information and robustness to allow reliable BGAN signal compensation and tracking.

Motor Driver System

This optional module provides the capability to drive stepper motors as commonly used on antenna gimbals on missions that require the higher data rate. The motor

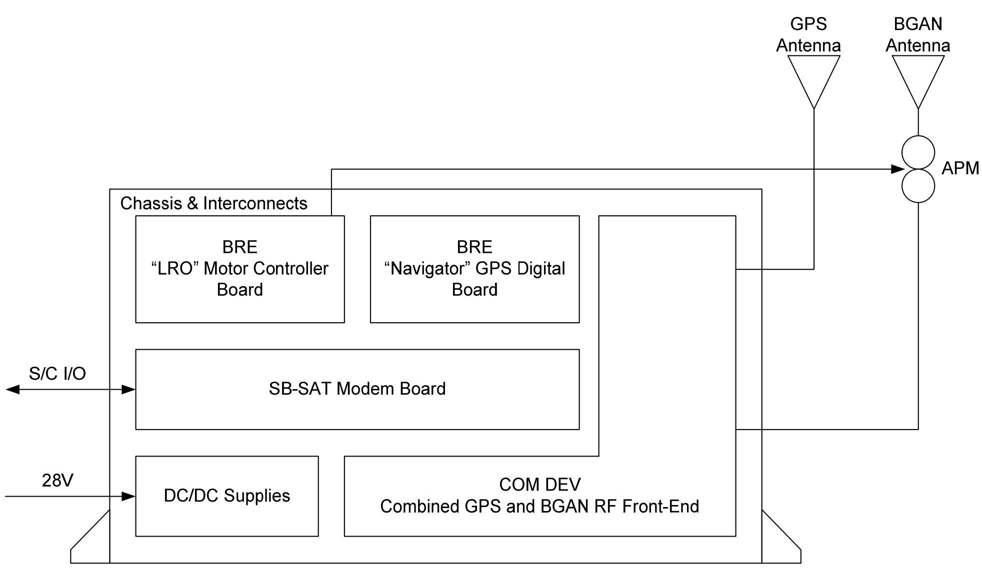


Figure 5. Baseline terminal block diagram showing major sub-components

driver is implemented as a single 3U add-on card that is based on a BRE developed system successfully flown on the NASA Lunar Reconnaissance Orbiter. The motor driver is setup to support two 2-phase and 3-phase stepper motors that are commonly used to drive gimbal systems.

Chassis & Power Supplies

The chassis, DC/DC converters, and interconnects provide the housing for the various boards and RF front end. The design of this element builds on many similar chassis versions that BRE has developed and successfully deployed for various missions

Terminal Size, Mass, Power

The target mass for the SB-SAT terminal, not including antennas, is 5 kg including GPS receiver. The design operating power for the basic terminal including GPS is 45W during transmit and less than 15W in standby mode (ready to transmit). The current physical envelope for the terminal is 18cm x 26cm x 11cm (not including antennas or gimbals).

GPS & BGAN Antennas

The GPS Antenna is an L-Band patch antenna with 3dBic gain and approximately hemispherical 3dB gain pattern. BRE has previously used and flown this antenna in conjunction with its IGOR GPS receiver. The BGAN combined transmit and receive antenna is typically a 3x3 array of L-Band patches using similar technology as the GPS antenna. This 3x3 antenna provides approximately 14dBic gain. For systems requiring higher data rates various Antenna Pointing Mechanism from a variety of supplier can be used. A typical Antenna Pointing Mechanism mass is less than 4kg.

BGAN Modem (Waveform) Implementation

The BGAN Modem is based on technology by Square Peg Communications Inc (SPCI), suppliers of a number of previous Inmarsat physical layers and physical layer test equipment. The SPCI IP is ported to Broad Reach Engineering developed hardware consisting of CPU, DSP, FPGA, and ADC and DAC hardware.

The main changes to the BGAN modem for SB-SAT relates to the Doppler effects that will require the modem to handle much larger frequency offsets and dynamic delay variation requiring much better signal acquisition and tracking performance in the modem.

The following modifications are required in an SB-SAT terminal as an extension to standard BGAN-X terminals.

- Fast and Optimized Handovers

Due to the velocity of the terminal in its LEO orbit, spot-beam handovers will occur on a frequent basis and the timing of each handover must be optimized to achieve the best possible success rate. The approach to spot-beam handovers will need to be proactive as opposed to the reactive approach applied currently.

- Improved Return Link Timing

Due to the rate of change of velocity of the terminal in its LEO orbit compared to the earth station, the timing calculations for when to transmit on the return link must be changed for SB-SAT in order to achieve exact timing of bursts at the earth station.

- Beam Access

Beam access functionality has the purpose to control in which spot-beams the SB-SAT terminal exchanges data with the ground networks. This is done to be able to use beams which are less loaded with traffic and/or which can be used at less cost than other beams. The resulting list of preferred beams is expected to be dynamic and to change over time.

SB-SAT TERMINAL PERFORMANCE

Tables 2 and 3 shows the typical data rate capability and data throughput capability for the SB-SAT Terminal (using a pointed 14dBi antenna), although the exact figures will depend upon orbital height and inclination for a specific mission.

Table 2. Typical Data rate

Coverage	Case	RTN	FWD
Nominal	Best case (center of beam)	475 kb/s	464 kb/s
	Worst case (edge of beam)	332 kb/s	300 kb/s
Extended	Worst case (edge of extended beam)	258 kb/s	200 kb/s

Table 3. Best and worst case throughput supported by an SB-SAT terminal

Orbital Inclination	45º		90º (polar)	
Link direction	RTN	FWD	RTN	FWD
Sustainable average throughput (kb/s)	330.5	298	322	287
Sustainable volume per orbit (MB)	229	206	208	185

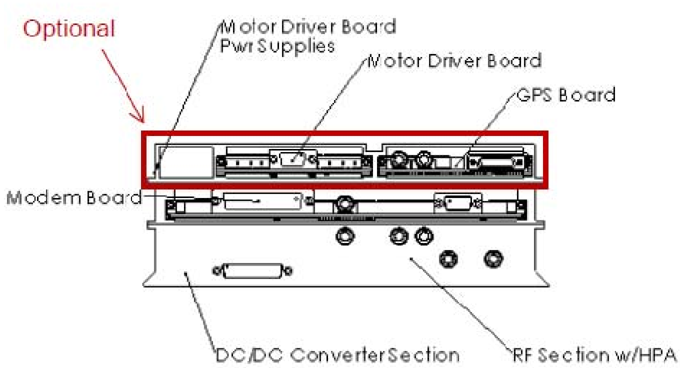
It can be seen that significant capability is provided by the terminal and certainly more than is required for conventional TT&C.

Figure 6 shows a computer model of the unit and its construction.

Table 4 provides a summary of the specifications of the unit:

Table 4 Summary Specification

Mass	<4kg
Temperature non Operational	-40 °C to +85°C
Temperature Operational	-25°C to +60°C
Power consumption (including GPS) when transmitting	40W



- Single String Design
- Built-In GPS
- Standard Interfaces
- Single Channel BGAN
- Designed for 5-7 Year life
- Rad-hard technologies
- Modular construction
- Optional Gimbal Control

	Single Ch w/GPS & Motor Ctrl
Total Mass	<5.0kg
Temp. Non-Op	-40C to +85C
Temp. Op	-25C to +60C
Power consumption	<45W (Tx) / <15W Idle
Conduction interface via baseplate (cooling/heating)	
Radiation hardened / tolerant "designed for space"	

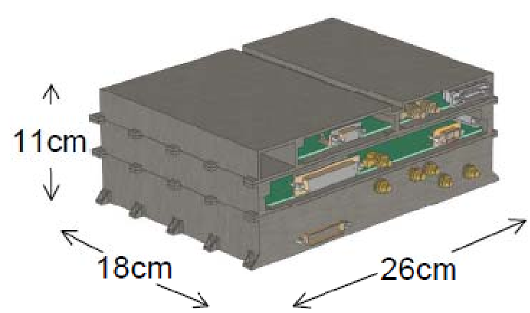


Figure 6. Terminal Configuration

Quality of Service

SB-SAT will support the following types of IP services:

- Standard (background) IP service is expected to satisfy the service requirements of the majority of LEO satellite applications of SB-SAT, and therefore it is considered the normal mode of SB-SAT operation.
- Streaming IP service may be required in exceptional cases by a SB-SAT customer with unique requirements such as constant bit-rate, real-time video, or voice over IP (VoIP).

The BGAN service supports multiple PDP contexts capability for delivering multiple parallel IP-sessions, subject to available throughput.

All IP services are delivered at modem frame error rate of better than 10e-3. Background IP frame errors are identified and eliminated using a retransmission mechanism built into the BGAN air interface.

End-to-End Transmission Latency

End to end transmission latencies differ between different IP service types:

- Background (standard) IP: Due to the dynamic nature of resource allocation for this IP service, latency will vary for different traffic profiles. Assuming an active data transfer is in progress, latency could vary between 500msec and 1500msec.
- Streaming IP: typically less than 500msec

SB-SAT: ENABLING TECHNOLOGY

Key Advantages

SB-SAT provides a number of features that are unique compared to traditional commercially available communications architectures as follows:

- Real-time communication from LEO-to-Ground
- Global coverage
- Fairly high data rate, full-duplex communications link
- Existing network infrastructure
- No need for frequency allocations
- On-Demand service, zero call-up delay
- Commercially available hardware & service
- Flexible service plans
- Competitive solution (terminal plus service) when compared with space to ground data relay alternatives

Application in Telemetry, Tracking and Control

Current LEO spacecraft predominantly use the congested S band spectrum for TT&C functions and every new spacecraft requires ground segment access and back haul to a control centre that can be costly and difficult to source. In addition, the satellite can only exchange TT&C data during its pass over a ground station (limited to up to perhaps 10% of the orbit, depending on orbital inclination and ground station location). The SB-SAT system will allow near 100% access to the satellite with very low latency, and without needing new ground infrastructure thus potentially making it easier to close the business case for new LEO Spacecraft.

Application to Mission Data Collection

Through the INMARSAT system, analysis has shown that data rates of up to 475 kbps are possible. This opens up several new applications summarised below that can effectively change how LEO spacecraft can be used.

- <u>Snapshot imaging</u> - to determine value of more detailed observations. Of particular interest to EO data providers is the possibility to dramatically increase the efficiency of data production. In discussions with a major EO data provider up to 40% of daily images are ‘wasted’ due to the presence of cloud cover. There is a strong interest in being able to see low resolution images in real time and being able to task in real time to avoid wasted data capture (and the cost of transmitting the data to ground and around the associated ground network). They estimate that data capture could be increased to nearly 100% with no increase in cost.
- Real-Time Tasking of on-orbit assets from anywhere on the planet. The connectivity via Inmarsat will allow users in the field to task assets directly. Applications include military, NGO, relief agencies, and logistics activities.
- Instant access to ship Automatic Identification System (AIS). AIS signals are transmitted by every ship over 300 tonnes and there is a growing space based capability to receive those signals and provide government bodies with information

regarding ship movements on a global basis. The possibility to receive that data in real time and use that data to deploy coastguard or Special Forces to investigate suspicious vessels has major benefits.

- Rapid access to time critical data (such as Space Weather events) will allow the monitoring of critical events in real-time and will allow "now-casting" (vs forecasting) of potentially harmful events.
- Radically improved anomaly investigation possibilities with simpler mechanisms for tracking events during orbit. In this application any anomaly that has been notified via the TT&C link can be monitored on a constant basis rather than waiting till the signal is retrieved from a ground station.
- Launch Vehicle TT&C to eliminate or reduce reliance on down-range tracking stations and to increase launch geometry options.
- Long term shuttle replacement and space tourism applications such as Virgin Galactic where a link to ground for video or VOIP will provide publicity and marketing advantage.
- Operationally Responsive Space (ORS) systems that require near-zero call-up delay and instant on telecommunications service.
- TDRS augmentation – SB-SAT can act as a backup or augmentation system to TDRS for missions or mission modes that don't warrant access to the heavily used TDRS system.
- Terminal installation on the International Space Station (ISS). Given the extended life of the ISS and the limited availability of data links, SB-SAT is being considered as a complementary communications link for the European Space Agency Columbus Module, to provide independent data links for crew.

SERVICE OPTIONS

Several Types of Service offerings are being considered, including:

- Low Data volume, high latency LEOs: This class may be TT&C only and/or provide limited mission data collection. Affordability is the driving constraint. Latency is not considered to be a driving issue.
- High Data volume, low latency LEOs: This class is dominated by time critical TT&C and/or mission data, Latency, of course, is important.
- TT&C only, low latency LEOs: This class is a subset of the High DATA, low latency class, with same assumptions on their drivers and cost base, however mission data is not latency critical and delivered via commercial ground based data relay (at s-band). SB-SAT is used to achieve real-time, always-on, on-demand, low latency TT&C.

The service options and corresponding typical monthly traffic volumes are summarized in Table 5

In assessing the attractiveness of the SB-SAT service, and the appropriate price range for the service, the overall annualized cost base was evaluated for the terrestrial service for each of the customer classes, and was compared with the SB-SAT service.

Table 5. Summary Service options

Customer Type	Traffic description	Typical Traffic Volumes (monthly)
Low Data Volume LEO	Quiet beams only	4,000 MBs
High Data Volume LEO	All beams	15,000 MBs
TT&C only LEO	All beams	600 MBs

The analysis concluded that SB-SAT is:

- Competitive for high latency, single satellite TT&C when the alternative is considering multiple contacts per day (e.g. via USN).
- Very competitive for low latency, or real-time, TT&C.
- Competitive for low latency, mission data applications

PROJECT TIMESCALES

Significant risk retirement work has already been performed under internal company funding and at the time of writing of this document two proposals that would provide further funding support for the development and for the first LEO satellite flight are close to being secured. Overall the schedule leads to first flight unit being available in **mid 2012**. In parallel to this the various upgrades required for the INMARSAT Ground segment will also be undertaken.

CHALLENGES

Both technical and commercial challenges have to be addressed during the course of this development, in large part due to the nature of the Inmarsat BGAN system and the BGAN waveforms. The BGAN system is based on a 3GPP protocol implementation and uses both time and frequency division multiplexing. While data rates are less than 500kbps per channel, the BGAN system was designed for maximum spectrum efficiency resulting in higher processing requirements at the terminal. Additionally, this BGAN technology needs to be implemented in a high dynamics environment under harsh environmental conditions. Specific challenges and enabling technologies are described below:

The 3GPP based protocol is CPU intensive requiring a minimum of 200MIPS to execute the protocols at the maximum data rates. The BRE440 Rad Hard PowerPC running at 133MHz/266MIPS is employed to provide the required processing at the protocol layer. Running at less than 5W full speed, there is no comparable processor designed for space available at this time. To further reduce the implementation complexity, the SB-SAT terminal builds on a proven BGAN protocol stack from GateHouse (Denmark) which has been successfully deployed on many existing mobile BGAN terminals. Minor modifications are made to accommodate the orbit dynamics.

The BGAN waveform is complex & processing intensive. As with the protocol stacks, SB-SAT incorporates existing modem IP from SquarePeg Communications (Canada), which develops the "BGAN Gold Standard" test equipment as well as a DSP based modem implementation for BGAN. This IP will be ported and modified to execute on BRE digital hardware designed around a TI/AFRL DSP running at 200+MHz.

BGAN Requires GPS for spot beam management and to aid in signal acquisition. SB-SAT nominally includes a BRE developed single frequency (L1) rad-hard GPS receiver. As a by-product, SB-SAT delivers "free" GPS PVT data to the host spacecraft.

BGAN has demanding RF filtering requirements to avoid inter channel interference and to avoid interference with neighbouring systems, such as GPS and Iridium. SB-SAT employs a combination of flight proven and specifically designed linearizer, PA, and filter technology to generate a clean and highly power efficient waveform.

Finally, SB-SAT is targeted to be available as primary communications device on-board spacecraft. As such, high reliability and radiation hardness is considered a requirement, especially for high value assets or mission lifetimes greater than 3 years. The SB-SAT terminal employs proven, world-leading BGAN IP deployed on 'designed-for-space' flight hardware.

SUMMARY AND CONCLUSIONS

This paper has described the design, application and development timeframe for the introduction of a novel service that can revolutionise the way in which LEO spacecraft are operated as well as enable novel new applications that become possible from having "24/7" access to spacecraft data and telemetry.