AN INTRODUCTION TO THE PROPOSED BOLAS MISSION FOR IONOSPHERIC RESEARCH

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INTRODUCTION

GPS is becoming an important part of space positioning and navigation for the same reasons of cost, flexibility, efficiency, and accuracy that it has become the prime technology in world-wide earth surface and near surface positioning and navigation. Many space agencies and other organisations are pursuing or beginning to pursue research in applications of spaceborne GPS (SGPS). Figure 1 illustrates this growing use of GPS in space by showing the cumulative number of missions carrying SGPS receivers since the first, Landsat 4, which was launched in 1982. This survey does not include undisclosed military missions, sub-orbital rocket flights, nor all launches of space shuttles equipped with SGPS receivers. In pursuing the goal of GPS application development, the Geodetic Research Laboratory (GRL) of the University of New Brunswick has become a member of the BOLAS spacecraft mission team.

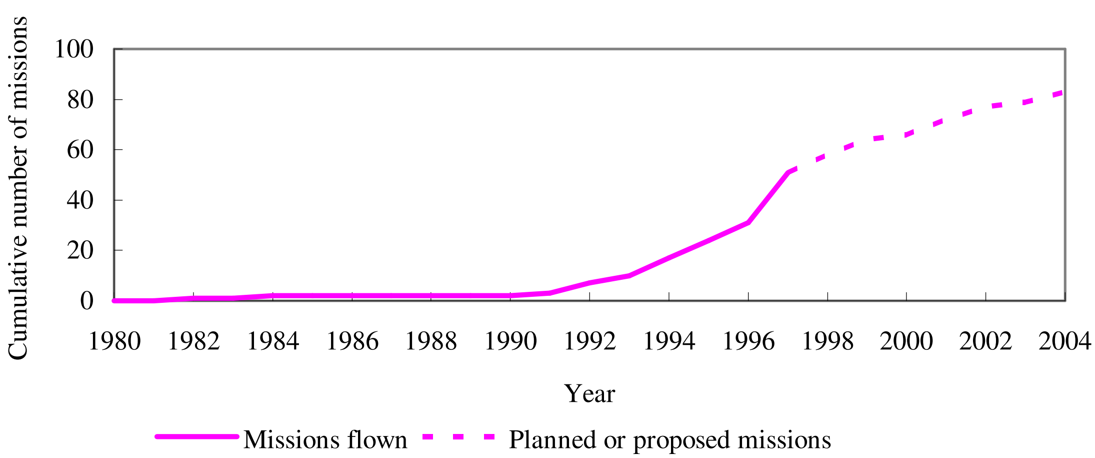

Figure 1. Cumulative number of missions carrying SGPS receivers (compiled from Bisnath [1997]).

BOLAS, which stands for Bistatic Observations with Low Altitude Satellites is a proposed mission designed to exploit unique developments in Canada and the United States in tether and micro-satellite technology, as well as to perform novel scientific research in investigating the global ionosphere in general and in studying space plasmas over the auroral region of North America in particular. Much of this research hinges on the use of SGPS receivers. It is intended that the spacecraft, comprising two payload packages separated by a one hundred metre tether and in a bolas (or cartwheel) rotation in low earth orbit, be launched in the fourth quarter of 2001.

BOLAS SPACE SCIENCE AND TECHNOLOGY TEAMS

The mission has been proposed by the Communications Research Centre (a division of Industry Canada), with participation of Bristol Aerospace Ltd., a number of Canadian universities, the Canadian Space Agency (CSA) Space Technology Branch, the Defence Research Establishment Ottawa (a section of the Canadian Department of National Defence), NASA Marshall Space Flight Center, NASA Goddard Space Flight Center, Routes Inc. (a private firm specialising in space instrument development), and Southwest Research Institute (a non-profit, research laboratory specialising in the creation and transfer of technology in engineering and the physical sciences), in response to a small-payloads solicitation by the Space Science Program of the CSA.

SCIENTIFIC SCOPE OF MISSION

The scientific scope of the BOLAS mission has been divided into three objectives [James, 1997]. The first is to investigate ionospheric density irregularities that affect radio wave transmission using a spaceborne, two-element, direction finding, sensor array coordinated with ground transmissions from the Super Dual Auroral Radar Network (SuperDARN - a global network of coherent high frequency (HF) backscatter radar facilities) and Canadian Advanced Digital Ionosonde (CADI) ground sites. Figure 2 illustrates this objective of the mission. The interpretation of HF scatter is based on hypotheses of ray-optics propagation to and from regions of irregularity. By observing the amplitude, delay and direction of arrival (DOA) of such HF waves in space, these scattering hypotheses can be tested. Onboard HF receivers will measure the amplitude of the incoming signals and SGPS receivers would provide the timing and frequency control for the HF receivers operating in interferometric mode, to allow the determination of the latter two parameters.

The second objective is to investigate kinetic instabilities of the auroral plasma involving low-energy ions and electrons using field and particle probes separated by about 100 metres – the tether length. This would lead to improved models of localised plasma instability. And in turn, the observation of a broad spectrum of particle energies would improve our understanding of both the sources and consequences of low to mid-altitude plasma waves. The electrostatic emission parameters to be measured are the amplitude, wave number and propagation direction.

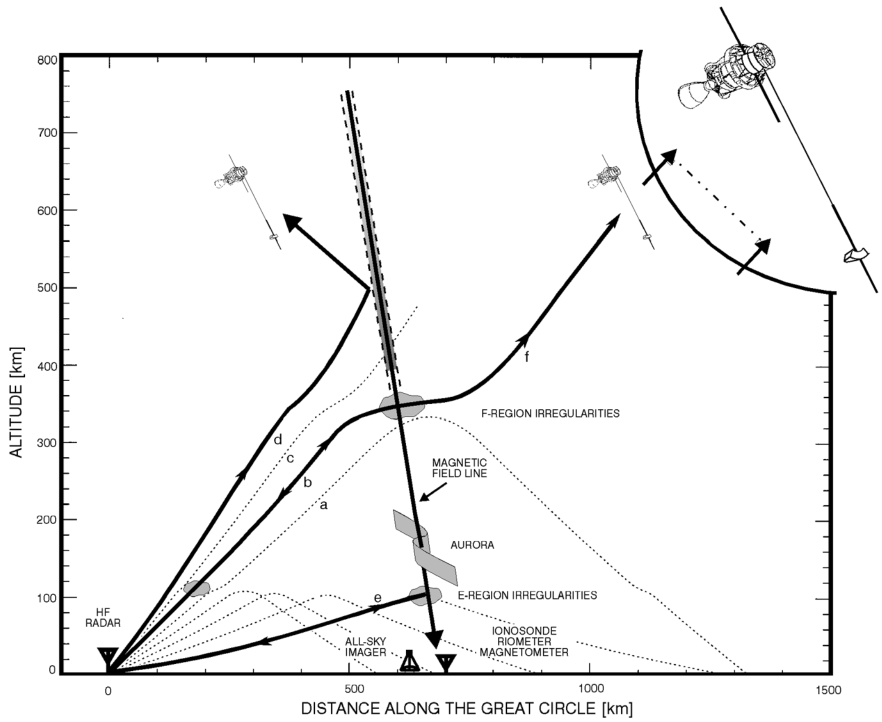

Figure 2. The BOLAS interferometer coordination with ground radars and ionosondes to provide new perspectives on F-region and topside irregularities (from James [1997]). Symbols *a* through *f* identify various paths of the SuperDARN HF transmitted pulses.

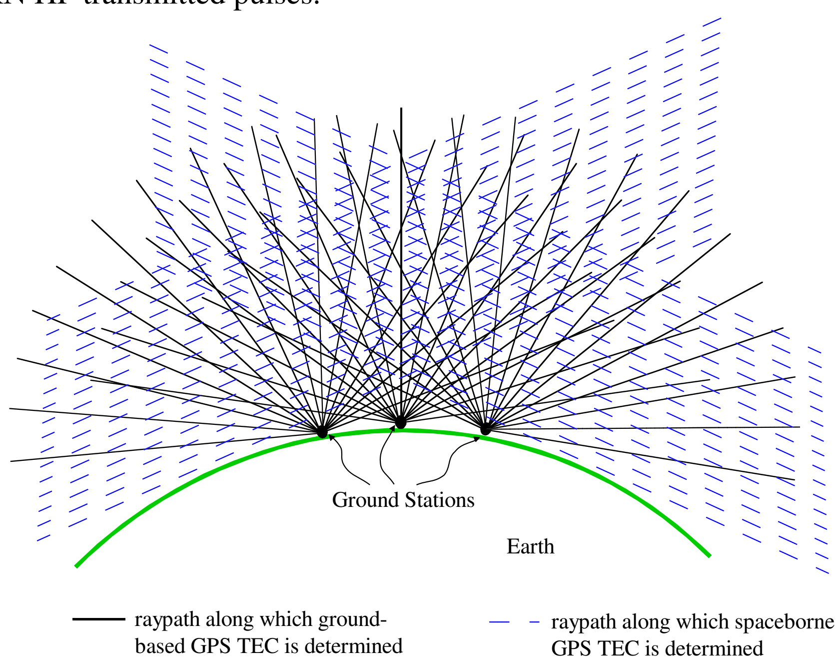

Figure 3. High resolution two- and three-dimensional ionospheric tomography based on combined ground and spaceborne GPS receiver measurements.

The third objective is to measure electron density profiles with a GPS signal occultation technique, and to use the results to develop three-dimensional total electron content (TEC) models using digital tomography. GPS-derived TEC at ground stations is currently being used to derive two-dimensional global zenith TEC maps through interpolation with empirical models [see *e.g.* Komjathy *et al.*, 1996]. These determinations are limited by both the absence of information on vertical electron density distribution and the resolution of the maps. By having SGPS receiver(s) tracking GPS satellites rising or setting relative to BOLAS, vertical profiles of electron density could be determined where the line of sight cuts through the ionosphere. The combination of such spaceborne data and terrestrial data will allow for high resolution two- and three-dimensional tomography over the study region and if resources permit, over the entire globe. The resulting superior geometry is depicted in Figure 3.

SPACECRAFT AND MISSION SPECIFICATIONS

BOLAS will consist of two payload packages of approximately 70 kg each, separated by a 100 metre tether. This assembly would be in a bolas (or cartwheel) rotation in low earth orbit (see Figure 4), with a mission life of approximately six months. Each subsatellite would carry, along with a standard satellite payload, an HF receiver to detect ionospheric density irregularities, an SGPS receiver, and two instruments, the Thermal Electron Capped Hemisphere Spectrometer (TECHS) and the Suprathermal Ion Instrument (SII), to measure drift energy, direction, temperature and density of the electrons and ions, respectively, in the ambient plasma (see Figure 5). These instruments will be described in more detail below. It is proposed that the spacecraft be a secondary payload accompanying RADARSAT II on a Delta-II vehicle to be launched in 2001.

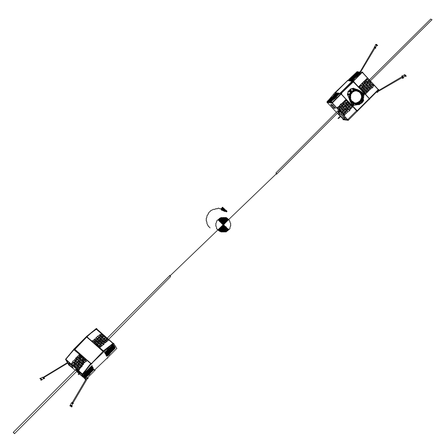

Figure 4. BOLAS spacecraft in final deployment configuration (from James [1997]).

Following the RADARSAT II deployment, BOLAS would be deployed in a sun-synchronous (therefore near-polar), dawn-dusk orbit, with an orbital period of approximately one hundred minutes. The orbital perigee and apogee would be 350 km and 600 km respectively, with perigee over the North American auroral region. A drift of the orbit's right ascension of the ascending node of 120 degrees over the course of the mission will accommodate both daylight and night-time passes over the study area. The tethered subsatellites would rotate in a cartwheel fashion, ten to thirty times per orbit, approximately in the orbital plane, to provide for scanning of the ionosphere by the dipole (HF) antennas and the particle instruments.

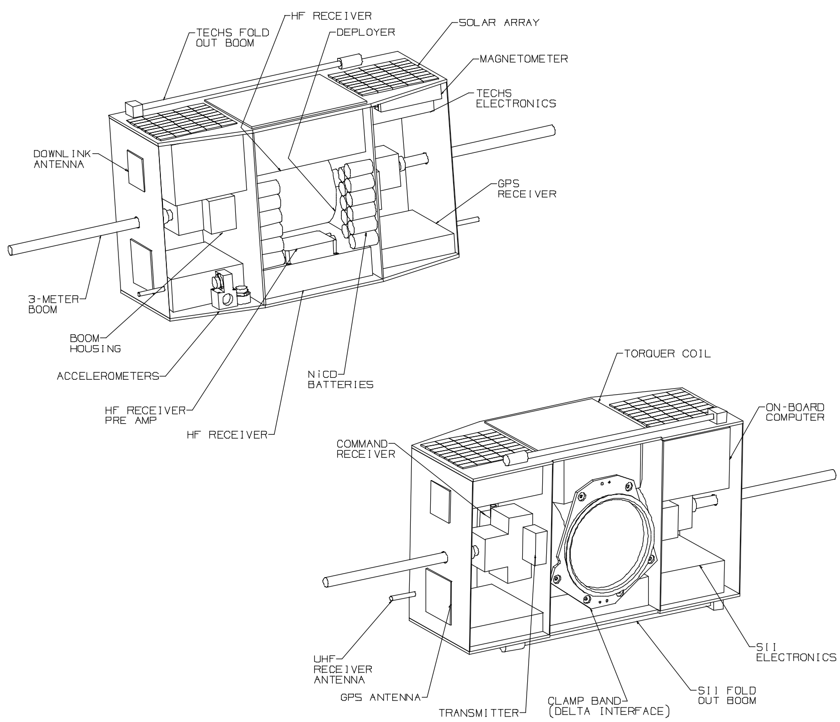

Figure 5. BOLAS subsatellite layout (from James [1997]).

SCIENTIFIC INSTRUMENTATION

The HF receiver is a broadband receiver designed to measure wave fields from both artificial and natural sources. The receiver has considerable heritage from the OEDIPUS-C sounding rocket REX receiver. The SII images the two dimensional ion distribution from 0-50 eV, and provides an integral measure of ion flux at rates sufficient to resolve localised ion heating structures on spatial scales of tens of metres. The TECHS is an azimuthal imaging tophat electrostatic analyser. By sweeping the analyser voltage, TECHS measures a count rate that can be directly related to the distribution function of low energy and thermal electrons [James, 1997].

DESCRIPTION AND REQUIREMENTS OF THE SGPS RECEIVERS

An SGPS receiver operating on each of the subsatellites would be required in order to collect much of the data needed to meet the first two scientific objectives, as well as all of the data for the third objective. A specific receiver model has not yet been chosen, but the baseline receiver used in the proposal is the TurboStar from Allen Osborne Associates, Inc. (AOA). The TurboStar is an eight channel, dual frequency receiver and has its heritage in the TurboRogue terrestrial, geodetic receiver. The current unit is 23 cm square by 5 cm, weights 2.3 kg, and requires 6 W of power. Although the receiver is not fully space-qualified, it has performed beyond expectations for the GPS/MET mission on the MicroLab-1 satellite, it will be used on a number of upcoming space missions, software has already been developed for occultation measurements from this receiver, and the GRL has experience with data from the GPS/MET mission [Bisnath and Langley, 1996].

The novel role of GPS in this mission would be its multipurpose use. The receivers would be used for reference frequency generation, spacecraft instrument time synchronisation, and orbit determination (OD) - both real-time and post-processed. The OD of each receiver would also allow for tether attitude determination. Aside from these applications, the occulted GPS signals would of course also be measured for electron density determination.

The GPS receivers must provide 5 MHz reference signals to the two HF receivers with an accuracy of no less than 4×10^{-7} over an integration period of 300 μs. Timing synchronisation of the HF receivers must be provided at the ±10 ns level. This would allow for the two HF receivers to act as an interferometer, given that the separation vector between them would be known and the incoming artificial waves from the earth are assumed to be planar. The tether length of 100 m would be a number of times larger than the incoming SuperDARN and CADI HF signal wavelengths of the order of 30 m. This would minimise the ambiguity associated with the interferometric fringes. Thus an accurate DOA of incoming signals would be achieved from the HF phase measurements.

The other major requirement for the receivers would be to provide approximately decimetre position determination of each subsatellite. This would entail precise orbit determination (POD) in a post-processing mode. This information would be needed to determine the excess Doppler shift in the carrier phase measurements of the SGPS receivers on occulted GPS satellites for ionospheric occultation determinations in support of three dimensional ionospheric tomography. The POD would involve relative positioning, through the use of the double difference methodology, between the spaceborne receivers and International GPS Service for Geodynamics (IGS) ground stations. Orbit determination to the metre level would be required to compute the instantaneous tether direction to ±1° in inertial coordinates. Finally, real-time orbit determination, derived from the SGPS receiver navigation solution, would be required for the scheduling of occultation events. Table 1 summarises these requirements of the receivers.

Measurement type	Estimated accuracy requirement
5 MHz reference frequency	$\pm 4\text{x}10^{-7\,*}$
time sychronisation	±10 ns
precise orbit determination (POD)	±20 cm
attitude determination	±1°
real-time orbit determination	±100 m

*integration period of 300μs.

Table 1. Requirements of the SGPS receivers.

THE GRL'S COMMITMENTS TO THE MISSION

The participation of the GRL would consist of three principal segments. In the first, a decision has to made as to the choice of SGPS receivers to be used and if backup receivers are required. The GRL would be involved with receiver software augmentation and testing to satisfy the mission requirements, specifically the frequency control and time synchronisation of the HF receivers. The second segment would pertain to the GPS data processing. This would include the POD computations and attitude determinations. The final segment would involve the ionospheric occultation experiments over the North American auroral region. The vertical electron density profiles would be produced and integrated with the GRL's two dimensional TEC maps derived from terrestrial GPS data in a three dimensional computer tomographic imaging technique.

SUMMARY AND CONCLUDING REMARKS

The proposed BOLAS mission has been designed to study the large-scale density irregularities and microscale plasma instabilities in the F region of the ionosphere. Although other multiple-satellite missions are being operated or proposed for these purposes, BOLAS would occupy a special niche by virtue of its small payload separation and its relatively low altitude at and just above the ionosphere-magnetosphere interface [James, 1997]. There would also be a novel role for GPS in this mission, given the multipurpose application of SGPS receivers for reference frequency generation, time sychronisation, real-time and precise OD, and attitude determination, and for the associated radio occultation and tomographic processing techniques for the above stated scientific goals. The mission is seen as a future contributor to and user of the IGS IONEX data format. Finally, we believe that the future of ionospheric sensing, in terms of TEC maps, is in the integration of terrestrial and spaceborne data gathering techniques.

There are however a number of challenges to be met, including coping with the high costs of the SGPS receivers; receiver weight and power constraints; customising the receivers; optimising the location of the receiver antennas on the spacecrafts; integrating the receiver outputs with the scientific experiments; optimising the number of occultations given the dynamics of the subsatellites, and coping with the subsatellite dynamics in the orbit determination process.

This mission will present an opportunity to evaluate all of the abilities of spaceborne GPS. For example, the POD results would be intercompared, the real-time orbit determination would be compared with the POD, and the attitude determination of a non-rigid body in space with GPS could be compared with the onboard magnetometer determinations.

The inclusion of SGPS receivers in scientific mission payloads is becoming more common. Therefore the demand for GPS to provide such information as POD, attitude determination, clock synchronisation, and relative positioning will continue to grow, resulting in increased requests for high quality, high rate, and timely IGS reference station data. These special requirements have been acknowledged by the IGS [Melbourne *et al.*, 1997].

REFERENCES

Bisnath, S.B. (1997). "GPS Mission Directory." *Spaceborne GPS Information Site*, http://gauss.gge.unb.ca/grads/sunil/sgps.htm, 30 March.

Bisnath, S.B. and R.B. Langley (1996). "Assessment of the GPS/MET TurboStar GPS receiver for orbit determination of a future CSA micro/small-satellite mission." Final report by the Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, N.B. for the Directorate of Space Mechanics, Space Technology Branch of the Canadian Space Agency, St-Hubert, Qué., Canada under Public Works and Government Services Canada Contract No. 9F011-5-0651/0651/001/XSD, July, 188 pp.

James, H.G. (1997). "BOLAS: Bistatic Observations with Low Altitude Satellites". A proposal for space research in response to the small-payloads solicitation of July 1996 by the Canadian Space Agency, 10 January.

Komjathy, A., R.B. Langley, and D. Bilitza (1996). "Updating the International Reference Ionosphere using a global network of GPS stations: Preliminary results." Presented at the *Workshop for Ionospheric Delay Correction for Single-frequency Radar Altimetry*, Colorado Center for Astrodynamics Research of the University of Colorado, Boulder, Col., U.S.A., 24-25 September. "Recent Proceedings Papers, Presentations and Research Reports for On-line Viewing and/or Downloading." *Attila Komjathy's Homepage*, http://gauss.gge.unb.ca/grads/attila/papers/papers.htm#boulder, 30 March.

Melbourne, W.G., J. LaBrecque, M. Watkins, J. Dow and C. Reigber (1997). "IGS White Paper on Low Earth Orbiting GPS." Presented at the *IGS Analysis Center Workshop*, Jet Propulsion Laboratory, Pasadena, Calif., U.S.A., 12 - 14 March, in press.