CASSIOPE: A CANADIAN SMALLSAT-BASED SPACE SCIENCE AND ADVANCED SATCOM DEMONSTRATION MISSION

Gregory B. Giffin, Waqar-Un-Nissa (Vicky) Ressl
MacDonald Dettwiler and Associates, Ltd.
13800 Commerce Parkway
Richmond, BC, Canada. V6V 2J3
+1-604-231-2004 ggiffin@mda.ca

Andrew W. Yau, E. Peter King
University of Calgary, Department of Physics and Astronomy, Institute for Space Research
2500 University Dr NW
Calgary, AB, CANADA T2N 1N4
+1-403-220-8825 yau@phys.ucalgary.ca

ABSTRACT

Cassiope, which stands for 'CASCADE Smallsat and Ionospheric Polar Explorer', is a recently announced and challenging smallsat mission. Primed by MacDonald Dettwiler (MDA), and enabled by contributions from the Canadian Space Agency (CSA) and Technology Partnerships Canada (TPC), Cassiope will support two distinct payloads and objectives. A general mission overview followed by a focus on the technical and scientific aspects of both payloads is presented.

The first payload is a suite of space science instruments that in sum are referred to as e-POP, the Enhanced Polar Outflow Probe. Developed by a scientific team led by the University of Calgary, e-POP will be Canada's first space environment sensor suite, providing Canadian scientists with the opportunity to understand the impact the variability of the Sun has on the space environment.

The second payload is an experimental Cascade payload. It will be used to demonstrate key aspects of what will be the world's first commercial space-based digital courier service. Analogous to a "FedEx™-in-the-Sky", the operational Cascade system is envisioned to deliver extremely large digital data files, nominally ranging in size from 50 to 500 Gbytes, to and from anywhere on Earth typically within a day. The experimental Cascade payload on Cassiope will develop and demonstrate the key enabling Cascade technologies and demonstrate the feasibility of this very large file end-to-end transfer method.

Introduction

CASSIOPE is a small satellite mission built in Canada to advance Canadian technology, provide valuable scientific data and demonstrate future commercial technologies. The mission will be achieved through the development of a single advanced small satellite comprising two payloads – the Enhanced Polar Outflow Probe (e-POP) instrumentation set and the Cascade CX communications payload. These payloads will be carried on a Canadian built small satellite bus that will be designed to allow adaptation for future Canadian space programs. Ground infrastructure will also be developed during the project to allow control of the satellite and its payload and the receipt of data. Primed by MacDonald Dettwiler (MDA), and enabled by contributions from the Canadian Space Agency (CSA) and Technology Partnerships Canada (TPC), Cassiope is scheduled for launch in 2007 with a two-year lifetime.

The e-POP payload is a suite of eight (8) space science instruments comprising of imaging plasma and neutral particle sensors, magnetometers, radio wave receivers, dual-frequency GPS receivers, CCD cameras, and a beacon transmitter. The mission objective of e-POP is to investigate atmospheric and plasma flows and related wave-particle interaction and radio wave propagation in the topside ionosphere. Its specific scientific objectives are to quantify the micro-scale characteristics of plasma outflow and related micro- and meso-scale plasma processes in the polar ionosphere, explore the occurrence morphology of neutral escape in the upper atmosphere, and study the effects of auroral currents on plasma outflow and those of plasma microstructures on radio propagation. The e-POP payload is a collaborative effort by scientists and engineers from Canadian universities and International research organizations with the University of Calgary as the lead institute.

The second payload is an advanced satellite communications demonstration payload called Cascade CX where the 'X' stands for experimental. The mission objectives of Cascade CX are two-fold. First, it must develop and demonstrate the key enabling Cascade technologies. Second, it must demonstrate the feasibility of the unique very large file end-to-end transfer method proposed by MacDonald Dettwiler to support the future Cascade business. If successful, Cascade CX will reduce technical risk to a degree sufficient to enable the follow-up commercial Cascade system to be deployed, forming the world's first commercial space-based digital courier service. Key enabling Cascade technologies that will be demonstrated on Cassiope include Ka-band RF transmit and receive chains, 350 Mbps digital space qualified modulators and demodulators, and high capacity, low power, low mass on-board bulk data storage.

Both Cassiope payloads will be supported by the first Canadian SmallSAT Bus. The Canadian SmallSAT Bus is a CSA-sponsored initiative to develop a bus which will be applicable to a wide variety of future CSA missions. This paper does not discuss this initiative in detail as it is expected that it will be addressed by future submissions by the CSA and Bristol Aerospace, the provider selected by CSA to develop this bus capability.

Both payloads were initially envisioned as stand-alone missions. The e-POP payload was proposed as a micro-satellite while the Cascade payload was expected to be a technology demonstrator to remove technical risk and allow for the development of a fleet of Cascade satellites. The combined mission is expected to maximize the return to Canada since it satisfies both parties' objectives without the need for flying two dedicated spacecraft.

This paper will present the following:

- High level Cassiope system overview
- High level spacecraft characteristics
- An e-POP overview
- A Cascade CX overview
- Unique considerations of the combined mission

Cassiope System Overview

The Cassiope System is composed of a single small satellite space segment and the associated ground segment. The system elements, their high level interactions and the associated external entities are shown in Figure 1. Each element is discussed in turn as follows:

CX Users: The CX Users are responsible for proof of key CASCADE technologies and demonstration of the Cascade end-to-end data transfer method feasibility.

The CX Users request data delivery service via the CX Ground Terminal. They provide User Data over a high speed connection to the CX Ground Terminal for uplinking to the Spacecraft and receive User Data downlinked from the Spacecraft over the same high speed data interface. The CX Users receive data transfer Performance Reports from the CX Service Control Centre.

E-POP Science Operations Centre: The e-POP Science Operations Centre will be operated by University of Calgary scientists who represent the interests of all e-POP mission stakeholders. The e-POP Science Operations Centre schedules the e-POP instrument data collection using predicted Spacecraft position and spacecraft constraint information provided by Mission Control. The e-POP Science Operations Centre will coordinate Science Data collection involving the simultaneous data recording by the e-POP Payload Radio Receiver Instrument and RF emissions by Ground Transmitters. The e-POP Science Operations Centre will also coordinate ground data recordings using a network of ground Reception Stations and RF transmission from the Coherent Electromagnetic Radio Tomography Instrument (CERTO) of the e-POP Payload. The e-POP Science Operations Centre receives Science Data downlinked over S-band via Mission Control and over Ka-band via the CX Ground Terminal.

CSA SmallSAT Bus Team: The CSA SmallSAT Bus Team receives Spacecraft Bus performance reports from Mission Control in order to assess Spacecraft Bus performance.

Ground Transmitters: The Ground Transmitters consist of the Super Dual Auroral Radar Network (SuperDARN), the Canadian Advanced Digital Ionosondes (CADI) and other radio facilities in Canada and elsewhere. The Ground Transmitters emit in the ULF to HF frequency range.

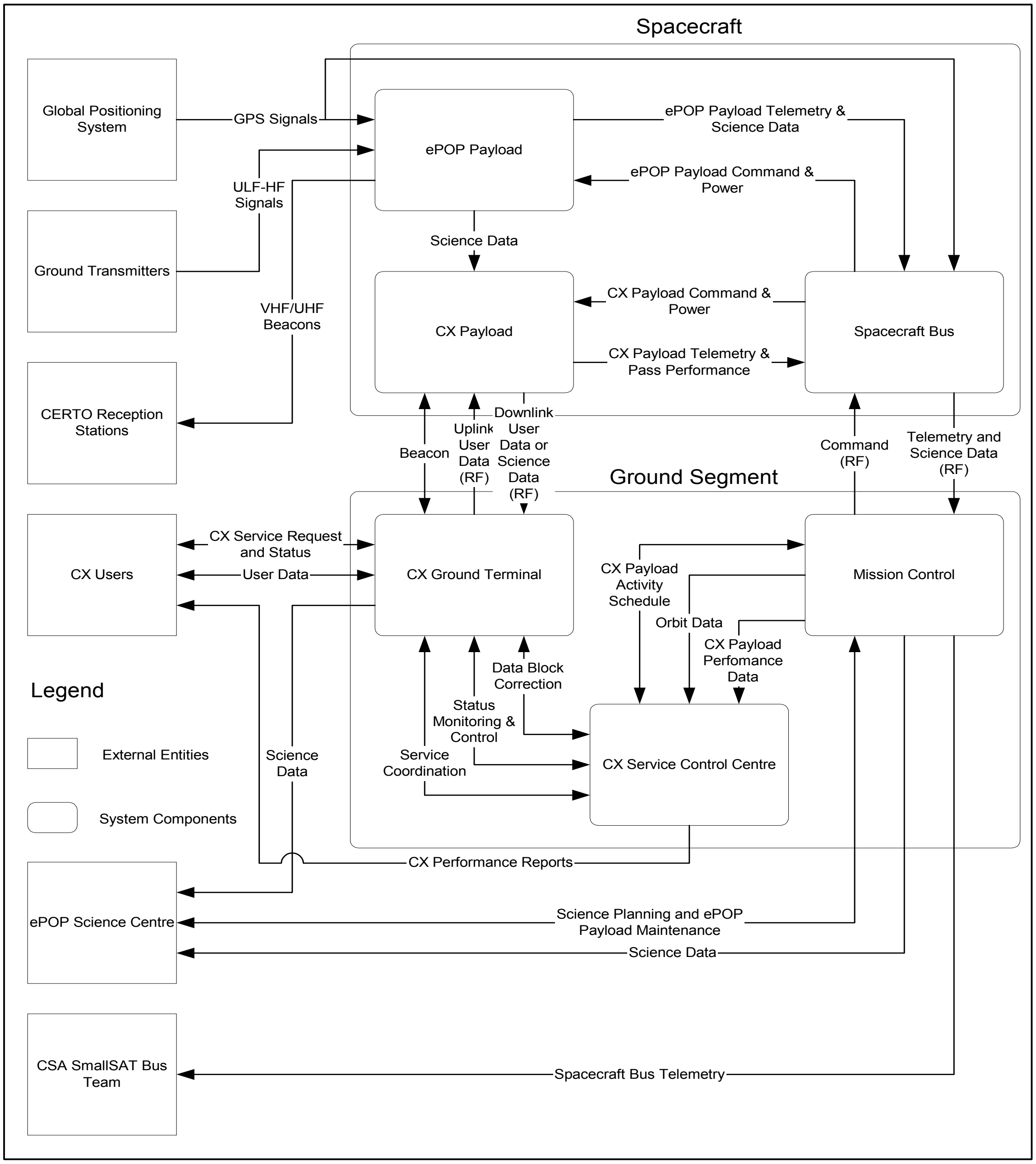

Figure 1: The Cassiope System

CERTO Reception Stations: The CERTO Reception Stations consist of a chain of globally dispersed ground receivers. The CERTO Reception Stations receive and record beacon signals transmitted by the e-POP Payload's CERTO instrument in 3 different VHF and UHF frequencies on board the CASSIOPE Spacecraft.

A future spacecraft named Computerized Ionospheric Tomography Radio Instrument in Space (CITRIS) may also receive these beacon signals.

Space Segment: The Space Segment consists of the Spacecraft and Launch Services. The Spacecraft consists of the Bus (including solar arrays and batteries, payload support equipment and deployment structures), the CX Payload and the e-POP Payload.

The Spacecraft communicates with the ground using both S-band and Ka-band frequencies. The Spacecraft communicates with Mission Control over the S-band uplink and downlink channels. The S-band uplink carries spacecraft commands while the downlink carries the e-POP Science Data as well as the spacecraft housekeeping data. The Spacecraft supports half-duplex transmission and reception of User Data (large data packages) to and from the CX Ground Terminal over Ka-band frequencies.

The payloads within this segment are addressed in more detail later in this paper.

Ground Segment: The Ground Segment consists of Mission Control, the CX Ground Terminal, the CX Service Control Centre and Ground Support Equipment (GSE). During mission Operations phase, the Ground Segment controls and monitors the health of the Spacecraft and its payload instruments. It tracks the position and orientation of the Spacecraft and generates definitive orbit and attitude data in support of e-POP science data analysis. It also generates predicted orbit data to enable the scheduling of ground reception and spacecraft payload activities. The Ground Segment receives planning information from the e-POP Science Operations Centre and tasks the CASSIOPE Spacecraft to collect e-POP Science Data. The Ground Segment receives e-POP Science Data and e-POP Payload housekeeping data from the Spacecraft and sends them to the e-POP Science Operations Centre. The Ground Segment supports the CX end-to-end data transfer demonstration by accepting User Data from the CX Users, uplinking it to the Spacecraft, storing it on-board the Spacecraft, receiving the stored data via the downlink and finally, delivering it to the CX Users.

Mission Control and the CX Service Control are expected to be located at the CSA St. Hubert facility while the CX ground terminal is expected to be located in Halifax.

High Level Spacecraft Characteristics

The high level characteristics of the Cassiope spacecraft, as of the recently completed System Requirements Review, are included in Table 1.

Table 1: Key System and Spacecraft Parameters

Parameter	Value
Orbit	300 x 1500 km, polar inclination (but not sun synch), orbit maintenance not needed but may be demonstrated
Launch	Will be compatible with multiple vehicles
Lifetime	Sized for 2 years on orbit
Spacecraft Mass	~400 kg
Spacecraft Size	Hexagonal 1.8 m hex corner to corner 1.2 m in height
Spacecraft Power	Payloads each take approximately 60 W OAP, CX payload peak of almost 400 W during communication passes
S-band TT&C	Nominally 125 kbps uplink, at least 1.6 Mbps downlink, near-omni coverage
Spacecraft Attitude	3-axis zero momentum Ram-Nadir fixed for typical e-POP operations Lat/long point tracking to within 0.8 degrees for Cascade CX communications events to keep horn antenna pointed at Halifax

The spacecraft size and power subsystem are currently dominated by the bus due to the generic development approach. This approach adds functionality not specifically needed to service e-POP or Cascade CX but which CSA wants developed to support future missions. The Cassiope spacecraft is shown here in Figure 2.

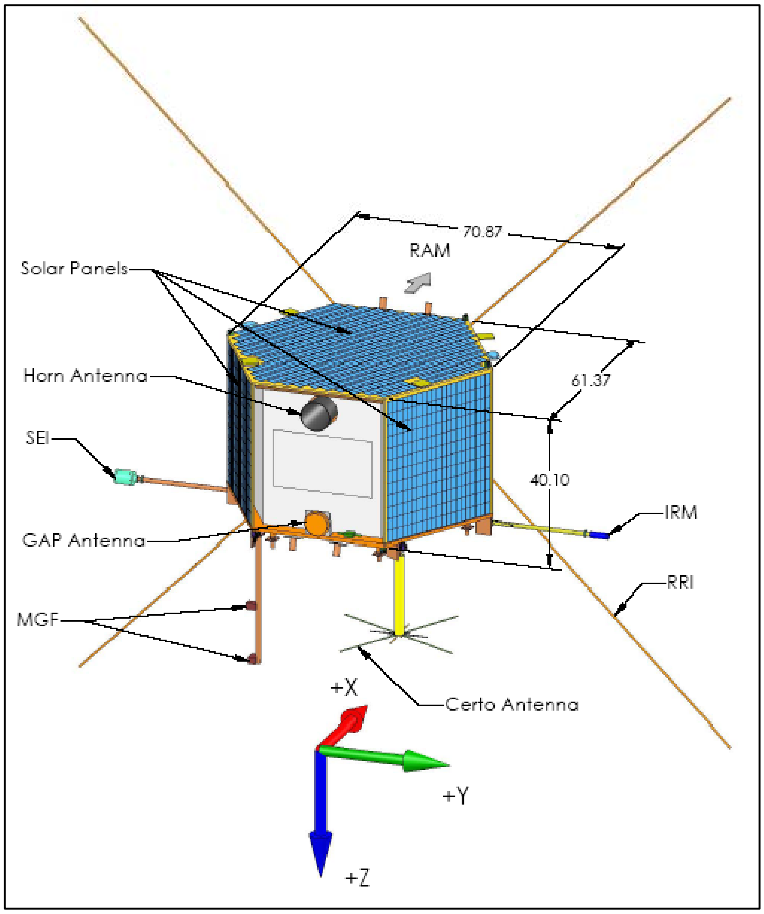

Figure 2: The Cassiope Spacecraft
Preliminary diagram from the recent System Requirements Review, dimensions in inches

e-POP Overview

The e-POP payload will be Canada's first mission contribution to the International Living with a Star (ILWS) initiative. It will make plasma, wave, and field observations at ultra-high and in some cases unprecedented temporal-spatial resolutions, and utilize the advanced data storage and downlink capability of the companion CASCADE payload on CASSIOPE.

The mission objective of e-POP is to investigate atmospheric and plasma flows and related wave-particle interaction and radio wave propagation in the topside ionosphere, illustrated in Figure 3. Its specific scientific objectives are to quantify the micro-scale characteristics of plasma outflow and related micro- and meso-scale plasma processes in the polar ionosphere, explore the occurrence morphology of neutral escape in the upper atmosphere, and study the effects of auroral currents on plasma outflow and those of plasma microstructures on radio propagation.

The e-POP payload consists of a suite of 8 scientific instruments, including imaging plasma and neutral particle sensors, magnetometers, radio wave receivers, dual-frequency GPS receivers, CCD cameras, and a beacon transmitter. The imaging plasma sensors and magnetometers will measure particle distributions and field-aligned currents, respectively, on the time scale of 10-ms and spatial scale of ~100 m. The CCD cameras will perform auroral imaging on the time scale of 100-ms. The radio wave and GPS receivers will perform near real-time tomographic studies of the ionosphere in conjunction with ground-based radars, and the beacon transmitter will send signals to ground receiving stations for generating comprehensive 2-D ionospheric density maps.

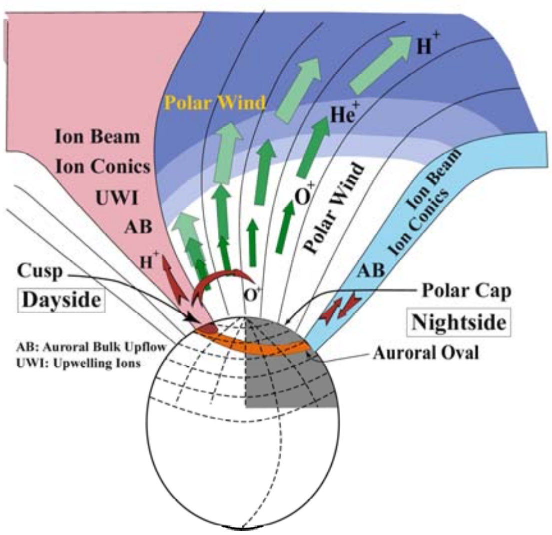

Figure 3: Atmospheric and plasma flows and related wave-particle interaction and radio wave propagation in the topside ionosphere

To meet the mission science objectives, the e-POP Payload would fly in an elliptical orbit with a maximum 300km perigee and a minimum 1500km apogee. This orbit must also have orbit plane drift (i.e. not sun-synchronous) and at least one rotation of its argument of perigee in a year.

The mission will be directed to specifically investigate:

• The detailed quantitative relationship between the solar electromagnetic (extreme ultraviolet) energy input, the photoionization of the polar region of the atmosphere, and the acceleration and outflow of the polar wind plasma and accompanying neutrals to the magnetosphere.

• The relationship between solar electrodynamics (solar wind) energy input via magnetospheric electron precipitation and convection electric field, the resulting electron impact ionization and wave particle interactions, and the plasma energization and outflow in the dayside cleft and nightside auroral ionosphere.

• Plasma density inhomogeneities over a wide range of scale sizes and microscale plasma instabilities, their effects on radio wave propagation, and their role in the energy and mass flow in the collisionless topside polar ionosphere.

This project is part of ongoing Canadian research to understand how our space environment is affected by the short and long term variability of the Sun. The e-POP team is comprised of scientists and engineers from seven Canadian universities and three research organizations: the University of Calgary, York University, the Universities of Alberta, Athabasca, Saskatchewan, Western Ontario, and New Brunswick. The Communications Research Centre, located in Ottawa, as well as the Institute of Space and Astronautical Science of Japan and the U.S. Naval Research Laboratory are also partners in the project.

e-POP Instruments

The e-POP instruments, the participating organisations and the specific measurement capabilities are summarized in Table 2. The following provides more detail on each e-POP instrument.

IRM

The Imaging and Rapid-Scanning Ion Mass Spectrometer (IRM) measures the-mass composition and 3-dimensional velocity (energy and angular) distributions of 0.5-100 eV ions. It is an improved version of the Thermal Suprathermal Analyzer (TSA) on the SS520-2 sounding rocket and the Thermal Plasma Analyzer (TPA) on the ACTIVE sounding rocket and the Nozomi spacecraft.

The IRM sensor contains several circuit boards that implement a semi-autonomous ion detection and imaging system. It consists of a semi-toroidal electrostatic deflection system, a pair of fast-switching time-of-flight electrodes, a hemispherical electrostatic analyser, a micro-channel plate detector, and a 64-pixel anode. Its output data rate is driven by the incident ion flux and varies from 0 to 300 kwords/second.

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Table 2: Summary of e-POP instruments

IRM	Imaging rapid-scanning mass spectrometer	Calgary Amerl	Composition, density, velocity, temperature (1-40 amu, 0.1-70 eV)
SEI	Suprathermal electron imager	Calgary Knudsen	Suprathermal electron and photoelectron energy and pitch-angle spectra (<200 V)
NMS	Neutral mass and velocity spectrometer	ISAS Hayakawa	Neutral composition, density, velocity, temperature (1-40 amu, 0.1-2 km/s)
FAI	Fast auroral imager	Calgary Murphree	Fast broadband visible (10 per sec) and slower monochromatic images (630 nm)
RRI	Radio receiver instrument	CRC James	HF and VLF wave electric field polarization and propagation: E(ω), k(ω)
MGF	Magnetic field instrument	Mag'trics Wallis	Magnetic field perturbation and field-aligned currents $\Delta B \Rightarrow$ FAC
GAP	GPS attitude, position, occultation experiment	UNB Langley	Ionospheric Irregularities (differential GPS); spacecraft attitude (GPS interferometry)
CER	Coherent EM radiation tomography experiment	NRL Bernhardt	Ionospheric Irregularities (differential line-of-sight plasma wave propagation delays)

SEI

The Suprathermal Electron Imager (SEI) measures the 2-dimensional energy and angular distributions of thermal electrons and soft electrons in the 1-200 eV/q range; it can also measure ions over the same energy range. It is a derivative of a design developed at the University of Calgary and flown on the GEODESCIC sounding rocket. This device is implemented as a hemispherical electron analyzer with micro-channel plate electron amplification producing images on a phosphor screen. The phosphor screen images are optically coupled to a frame-transfer CCD located in the electronics module.

The SEI sensor will be situated at the end of a 0.5 m to 1 m boom, and a design goal is to keep it out of direct sunlight as much as possible, as sunlight will contaminate the electron measurements. The sensor must not be deployed in the motional "wake" of the spacecraft.

FAI

The Fast Auroral Imager images the aurora in the near infrared and the visible. It is a dual-head CCD digital camera, with detectors for near infrared and narrow-band visible (630nm). It will operate only over the polar regions. It will have, at a minimum, two image resolutions: 128 × 128 pixels in high-resolution mode, and 64 × 64 pixels in low-resolution mode. Additionally, FAI will include the capability of imaging at the full resolution of the detectors, or 256 × 256 pixels. Typically, FAI will take images at the rate of approximately 60 0.1-second exposures per minute with the NIR camera, and one 1/2-second exposure per minute with the 630 nm camera.

NMS

The neutral-particle mass spectrometer (NMS) measures the density and velocity of neutral atmospheric species. It will operate only in the perigee and the near-perigee phase of the orbit (300-400 km), where the atmospheric density is highest.

In orbit, neutral particles are rammed into the entrance slit. Internally, NMS employs a high-voltage electron gun to ionize the neutral particles, and an electric-field deflection and focusing system to image the ions onto a micro-channel plate (MCP), which amplifies the ion signals image them onto a 256 × 256 element CCD detector. The CCD data is binned and compressed within the instrument to reduce data bandwidth.

RRI

The Radio Receiving Instrument measures radio waves in the VLF and HF frequency range (up to 18 MHz). It is a four-channel VLF/HF digital radio receiver, and will operate in burst mode when it is in the beams of cooperating HF ground radars such as CADI and SUPERDARN. The burst mode operation will be up to several minutes, depending on the spacecraft position relative to the radars.

GAP

The Ground Positioning System (GPS) Attitude, Position, and Profiling Experiment (GAP) consists of two components:

GAP-A: 3 single-frequency (L1) GPS receivers and 4 patch antennas. The GAP-A complement will be used to provide an accurate absolute time reference, spacecraft 3-axis attitude, and post-processed spacecraft position and velocity.

GAP-O: The GAP-O complement will be used for ionospheric tomography. It consists of a dual-frequency (L1/L2) GPS receiver with >10-Hz GPS phase data sample rate, i.e. sufficient for tomographic analysis.

The four GAP-A patch antennas are mounted in opposing corners of the spacecraft, on the side away from the Earth, in order to minimize multi-path reflections from the SC structure and maximize the baseline between antennas and thus the accuracy of the 3-axis attitude solutions.

For GAP-O, the helical antenna will be placed on the –X side of the spacecraft, and phase measurements are acquired for several minutes (5 minutes typical, 7 minutes maximum) per occultation from a GPS satellite in occultation using a single dual-frequency (L1/L2) receiver.

GAP will distribute GPS time ticks and time-of-day data to certain e-POP instruments for precision time stamping of science data, via the e-POP Data Handling Unit (DHU).

MGF

The Magnetic Field Instrument (MGF) measures the Earth's magnetic field and its perturbation by field-aligned currents.

MGF will provide vector magnetic field data (in 3 digital output channels) with a precision of 21 bits and resolution of 0.06 nT. It will sample at 160 Hz, and have a total instrument dynamic range of ±65,536 nT.

CERTO

The Coherent Electromagnetic Radio Tomography Experiment (CERTO) or (CER) generates beacon signals used for ionospheric tomography. CERTO transmits three beacon signals at frequencies near 150, 400, and 1066 MHz, for reception by a network of receiving stations all over the World. Data are collected from these receiving stations and analyzed, producing 2-D ionospheric density maps.

Cascade CX Overview

CASCADE will be a digital courier service in the sky. A constellation of Low-Earth-Orbiting (LEO) Ka-band satellites will circle the earth, picking up very large digital data packages or "GigaPackages" that can be tens to hundreds of GigaBytes in size from remote locations on land or over any ocean and deliver the data directly into a user-specified data archive or processing center.

The CASCADE digital courier service will deliver virtually error-free, secure GigaPackages to and from anywhere on Earth. Since CASCADE is focused on this high data volume, store-and-forward market niche, its design is optimized to meet the unique needs of the market for very large and timely data file transfers.

The CASCADE system will provide:

- daily accessibility to any point on the globe (excluding the polar areas);
- high bandwidth data links;
- large capacity storage on-board the spacecraft; and
- service on a regular and reliable basis.

The process of getting to commercial Cascade service consists of two major phases, the Cascade CX phase and the commercial phase, oftentimes referred to as Cascade CP. The payload deployed as part of Cassiope will be a reduced version of what will be deployed in the CP phase but will be sufficient to significantly reduce CP technical risk. The CX payload will essentially be the commercial payload but with 2 channels instead of 4 (5 if redundancy is considered). The remainder of this section will deal with the CX payload. The block diagram for the CX payload is shown in Figure 4 while it's preliminary layout on the payload panel is given in **Error! Reference source not found.**.

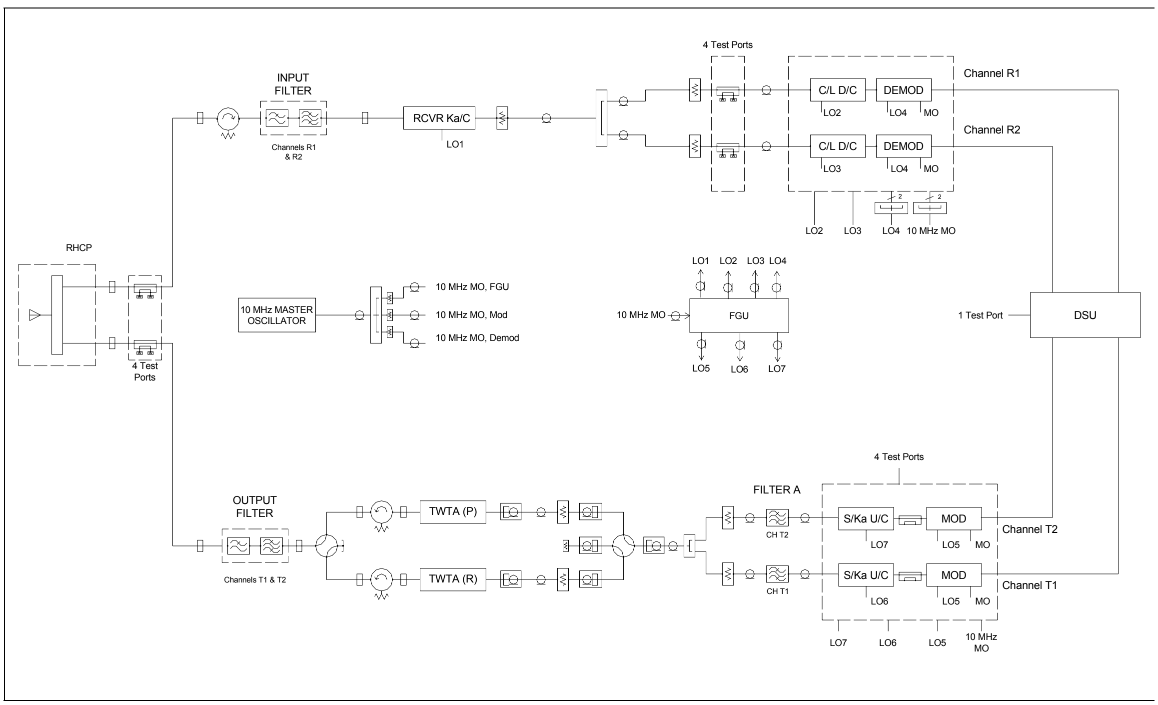

Figure 4: Cascade CX Payload Block Diagram – Preliminary

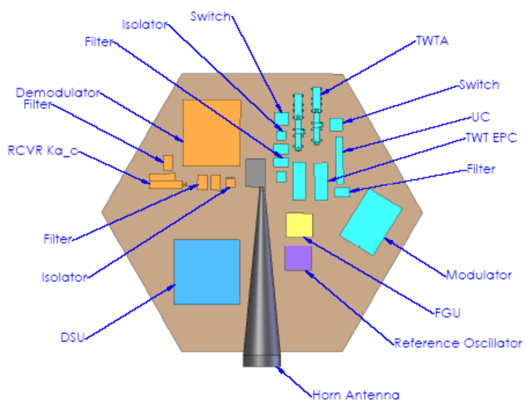

Figure 5: Cascade CX Payload Layout – Preliminary

The CX payload provides two-way data communications capability to the ground terminal. The payload consists of two major parts, the RF/Digital Subsystem and the Data Storage Unit. The payload will be operated in a half-duplex mode, that is, it will be either transmitting or it will be receiving, but not both simultaneously. Generally during a single contact with a ground station the payload will transmit or it will receive, however, nothing should preclude the payload from switching between transmit and receive during a contact.

The RF/Digital Subsystem consists of a fixed body mounted horn antenna, the RF chains, and a set of high-speed modems. The demonstration payload will have two RHCP channels separated in frequency. Each channel operates at 350 Mbps. The future commercial payload will have two more channels that will be LHCP in order to stay within the allocated 500 MHz of Ka-band spectrum.

At Ka band rain fade of the RF signal can be significant. To minimize the chances of sending data during high fade conditions the receiving end of the satellite/ground station link transmits a beacon signal. The transmitting end of the link monitors the strength of the beacon signal, and transmits dummy fill data when the beacon signal strength is below the operational threshold. To provide error-free transmission of data Cascade uses a combination of methods. The primary method is the use of an interleaved Reed Solomon forward error correction method to correct the majority of transmission bit errors. The Reed Solomon code used is the CCSDS recommended (255,223) code. The second method is the use of a low speed backhaul link (a dial-up telephone link at 9600 bps or better) between the receiving and transmitting ground terminals to retrieve random data blocks with uncorrectable errors. The third method is to retransmit bad segments of data from the originating ground terminal.

A high capacity Data Storage Unit is key to the store and forward mode of operation for Cascade. Besides high capacity the Data Storage Unit needs to have a relatively random access, a low power consumption, and a reasonable size and mass. Ideally the Data Storage Unit would have a single Data Storage Unit for all four data channels, however, up to one Data Storage Unit per data channel would be acceptable. The data storage unit is the subject of another paper being given at this conference "A Novel Approach to a High Speed, Large Memory Spacecraft Data Storage Unit" (SSC04-V-6) so the reader is invited to refer to that paper for a description of this low power, low mass, high capacity data storage unit, one of the key enabling technologies for the future Cascade System.

Associated with the payload is obviously the CX ground terminal. The CX ground terminal provides the terrestrial end of the high rate Ka-band link and allows data to be moved onto or off of the system. The terminal will be both transmit and receive capable on a half duplex basis. Future commercial terminals may also be transmit only or receive only and will range in size from 1.2 m (Tx only variant) to 2.4 m (Rx and also Rx/Tx variants). These terminals are significantly more advanced in capability than 'traditional' T1 class broadband Ka-band terminals and are more aptly regarded as scaled down versions of EO data reception facilities that MacDonald Dettwiler has been implementing since the 1970s.

The ground terminal interfaces with three other system elements: the users, the SCC and the satellite fleet. It accepts user data to be transmitted and transfers data received back to the user. The terminals also responds to user queries with status and update messages. With the SCC, it receives service co-ordination information, responds to SCC initiated status queries & control messages and performs data block back-haul correction activities. With the satellite fleet it, via the Ka-band link, transmits or receives GigaPackages.

The high level architecture of the ground terminals is provided in Figure 6.

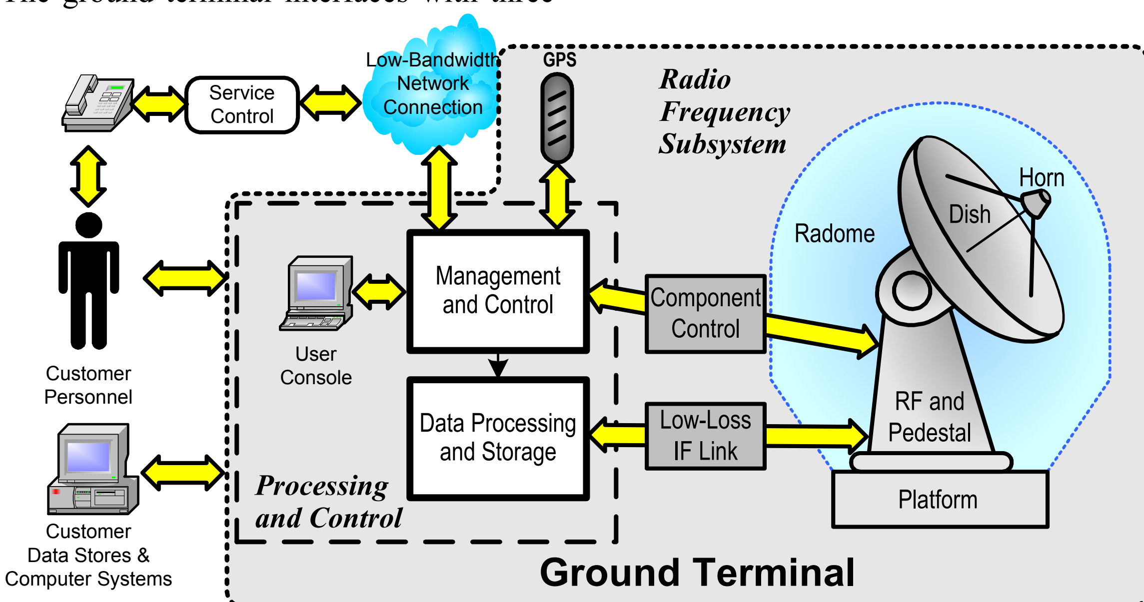

Figure 6: Cascade CX Ground Terminal

The terminal has two subsystems: the radio frequency subsystem and the processing and control subsystem. The radio frequency subsystem consists mainly of the needed outdoors equipment and includes the radome (marine option), antenna, antenna pointing and stabilization mechanisms, waveguides, the high power amplifier, the low noise amplifier, up and down frequency converters and the processing and control subsystem interfaces. The processing and control subsystem consists mainly of the needed indoors equipment and includes the data processing (including data encoding/decoding, signal conditioning, modulation/demodulation), terminal control and monitoring, storage of user data, the user interface, the SCC interface and lastly the GPS interface.

The Combined Mission

Use of CX Payload and Ground Terminal to Enhance e-POP Science Data Return

The e-POP mission is expected to generate more data than it can downlink via the modest few Mbit/sec downlink rate that it is limited to with just the S-band. This forced e-POP to design for use of at least 2:1 compression and to have an on-board prioritization of data. Consequently, only the higher priority data would be downlinked and the remainder would have be lost.

Use of the Cascade CX payload offers a link over two orders of magnitudes higher in capability as well as about 100 times more data storage capacity, up to 1 Tbit, than e-POP would have had without it. This allows e-POP to avoid the need for compression of data using the Ka-band link and also means data amounts of up to about 15 Gbytes/day can be downlinked, significantly improving the overall scientific return. The feasibility of connection between the Cascade CX payload and e-POP and the associated operational concept for e-POP data dumping to the CX payload has been considered and shown to be quite simple. Once on the ground at the CX Ground Terminal the e-POP data can be routed to the University of Calgary via either Internet or periodic courier of significant numbers of CDs.

The benefit to Cascade of having e-POP use the Cascade payload is that e-POP essentially becomes the ‘first’ Cascade service customer.

It should be noted that while the CX payload is a significant enhancement of e-POP data flow since CX is highly developmental in nature the S-band capability originally needed by e-POP will still be implemented to ensure multiple options to move e-POP to the ground exist.

Sharing of the Spacecraft Resources Between CX and e-POP

The approach to sharing the satellite resource is to do so on a time division basis. First, it is important to note that Cascade CX satisfies most of it’s technical demonstration objectives as part of commissioning. The maximum number of orbits used by CX during commissioning will be four since that is the maximum number of passes over the single Cassiope Ka-band ground terminal per day.

Once commissioning is complete however Cascade CX needs additional use of the satellite on a periodic basis to gather data on life effects and to demonstrate the service to potential users. It has been agreed with e-POP that for up to 2 weeks out of every 8, CX can return to commissioning levels of activity. During these two week periods e-POP can use up to the other 10 out of 14 daily orbits to make measurements.

For the other 6 out of every 8 weeks, the spacecraft is dedicated to e-POP. If e-POP elects to use the CX payload to downlink data then an orbit must be reserved for the downlink. During reserved orbits e-POP science operations are constrained by power since operation of the CX payload requires significant power.

It should be noted that the power now available to support e-POP, as a natural consequence of sizing the bus power sub-system to support the demanding Cascade CX orbits, is significantly above what was available to e-POP when it was envisaged as a stand-alone micro-satellite. So while there is a sharing of the satellite on an orbit-by-orbit basis the duty cycle of e-POP instruments is expected to be enhanced.

The time-share approach avoided driving the bus power subsystem to accommodate simultaneous operation which would have been relatively rare in any event. This choice also minimized EMI/EMC concerns and also took advantage of the obvious fact that when a CX event is taking place the spacecraft must track the ground terminal lat/long position, meaning that the attitude would not be suitable for most e-POP instruments anyway.

e-POP Orbit Effect on CX

It is clear a compromise had to be made on orbit when combination of Cascade CX and e-POP was considered. The use of the elliptical orbit was driven by the e-POP science objectives and the question was whether Cascade CX could still achieve it's objectives given this orbit.

Prior to combination with e-POP, the CX orbit was nominally going to be a circular ~800 km orbit of reasonably high inclination to permit significant coverage of Canada. The e-POP elliptical orbit had several impacts which were considered, as follows:

1) The apsidal rotation of the elliptical orbit of e-POP will result in long periods (i.e. months) where the satellite will be at or near perigee when in the higher northern latitudes. During those times the daily amount of access by a given northern (i.e. Canadian) point will be limited. This will limit the periods during which CX demonstrations can be performed. This is acceptable for CX since the trials to be performed with the payload can be scheduled around the times when the access to the spacecraft is limited. Note however that it would be necessary for the mission to be launched such that the apogee is rotating into the northern latitudes so that several months of good access to the satellite will be possible to support commissioning and initial technical trials.

2) In order to operate CX at the lower than previously anticipated altitude, additional power control dynamic range would be needed. This represents a minor delta.

3) There will likewise also be periods when the satellite will typically be near apogee in the higher northern latitudes. The CX links have power/gain to operate at the target availability at only 800 km. However, since this is a demonstration mission it is acceptable to have slightly reduced availability for the higher altitudes and/or accept higher operating elevation angles.

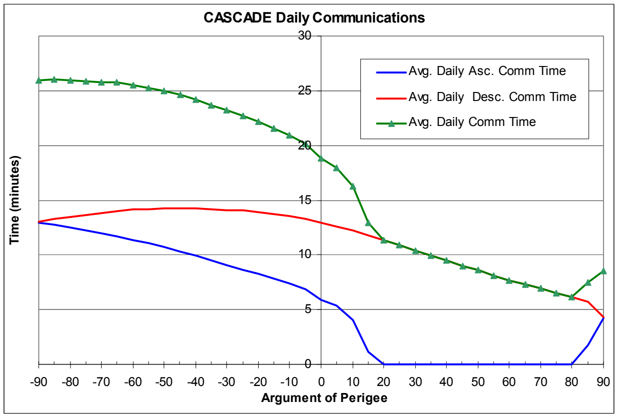

Figure 7: Access time in minutes per day between the CX payload and the CX ground terminal given the e-POP orbit.

The drop in communication time near perigee is due to an operation restriction from the bus. It can not track the lat/long point below about 400 km due to aero-torques.

Points 1-3 were boiled down to an access analysis whose example results are shown in Figure 7. This level of access is judged more than sufficient to allow CX to meet it's technology demonstration objectives and to allow very large amounts of e-POP data to be downlinked.

4) Lastly, Doppler at the lower heights will be significant. However, the payload has already been designed with a programmable offset in the receiver and to calculate the needed Doppler offset. Therefore the additional Doppler should not be an issue.

Overall, based on this consideration, it was judged feasible for the Cascade CX payload to operate in and achieve the objectives using the e-POP orbit.

Conclusion

Presentation of the combined Cascade CX and e-POP mission in significant detail was found difficult to achieve within the confines of a single paper. However, a high level overview of each and unique features of the combined mission was provided. Future papers will be submitted to allow specific aspects of this mission to be addressed in more detail. The author hopes the Smallsat community at large now has a greater appreciation of this new, exciting and quite unique mission.

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