Canadian Space Agency | Agence spatiale canadienne

Generic Earth Station Architecture for CubeSats (GESAC)

Reference Ground Station Requirements

Revision P2

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REVISION HISTORY

Revision	Revision Date	Author	Review by	Revision Description
P1	2019/07/11	P. Kazakoff, C. Berggren	T. Pellerin	Draft Revision
P2	2019/07/22	P. Kazakoff, C. Berggren		Second Draft

1.0 APPLICABLE AND REFERENCE DOCUMENTS

1.1 Applicable documents

The requirements contained in the applicable documents listed below shall be complied with. If requirements contained in the applicable documents are conflicting with those present in this document, the latter shall take precedence.

[AD1] RBR-4 — Standards for the Operation of Radio Stations in the Amateur Radio Service

[AD2] ITU Radio Regulations, Edition of 2016

[AD3] Radio Amateurs of Canada – 2m band plan

[AD4] Radio Amateurs of Canada – 70cm band plan

1.2 Reference documents

[RD1] “Computed Maximum Wind Gust Speeds,” National Research Council, February 1958

2.0 INTRODUCTION

2.1 Background

The Generic Earth Station Architecture for CubeSats (GESAC) will be a single, universal reference ground station architecture. It will provide support for a superset of up/down frequencies, modulations, and protocols to support Canadian academic CubeSat communications systems. Key features include:

- A novel software defined radio approach which leverages OS containerization to provide a modular, low-impact method to deploy and host all the ground segment software for a particular mission.
- A comprehensive set of documentation and software allowing academia team to build and operate their own GESAC ground station with minimal effort.
- Clearly defined RF figures-of-merit (G/T, EIRP) to support the development of link budgets by satellite operators.
- Developed using interchangeable hardware modules wherever it is reasonably possible to do so, enabling customized variants of the GESAC architectures to utilize existing infrastructure.

2.2 Requirements Nomenclature

Requirements are organized by their respective sections and numbered in sequential order. They will follow the nomenclature [GS-XXX-YYY] where XXX indicates the section (ie. GS-GEN-YYY for general requirements, GS-ANT-YYY for antenna requirements, etc.) and YYY indicates the requirement number.

The term “shall” is used to indicate a mandatory requirement,

The term “should” indicates a goal or preferred alternative. Such goals or alternatives must be treated as requirements on a best efforts basis, and verified as for other requirements. The actual performance achieved must be included in the appropriate verification report, whether or not the goal performance is achieved.

The term “may” indicates an option.

The term “will” indicates a statement of fact or intention.

The term “(TBD)”, which means “to be determined”, designates that insufficient information currently exists to allocate a value or subject.

The term “(TBC)”, which means “to be confirmed”, designates that information exists regarding a requirement but further confirmation or study is necessary.

Below some of the requirement criteria in italics is a brief note for the requirement. The note provides further details to clarify the intent of the requirement.

2.3 Requirement ID

Requirements in this document are organized by the following identification:

- GS Applicable Ground Station requirement

3.0 Ground Station Requirements

3.1 General

[GS-GEN-010] The ground station, to the extent reasonably practicable, should be able to communicate with Canadian academic satellites using amateur radio frequencies.

[GS-GEN-020] The Ground Station shall be located at the John H. Chapman Space Centre.

3.2 Antenna Requirements

[GS-ANT-010] The VHF antenna system shall meet all requirements while operating in the frequency ranges of 144.300 – 144.500 MHz and 145.800 – 146.000 MHz.

These are the internationally coordinated frequency ranges for the 2m band amateur satellite service.

[GS-ANT-020] The UHF antenna system shall meet all requirements while operating in the frequency range 435.000 – 438.000 MHz.

This is the internationally coordinated frequency range for the 70m band amateur satellite service.

[GS-ANT-030] The VHF antenna system shall have a minimum G/T of -15 $dB \cdot K^{-1}$ while pointed at all elevation angles greater than or equal to 5 degrees from the horizon.

Based on reference link budget considering a low-power (-3.5 dBW EIRP) satellite using 19200 bps uncoded non-coherent FSK downlink, plus 5 dB of design margin.

[GS-ANT-040] The UHF antenna system shall have a minimum G/T of -10 $dB \cdot K^{-1}$ while pointed at all elevation angles greater than or equal to 5 degrees from the horizon.

Based on reference link budget considering a low-power (-3.5 dBW EIRP) satellite using 19200 bps uncoded non-coherent FSK downlink, with no design margin.

Ideally, 3-5 dB of design margin would be added to this requirement, however, this is not achievable for the GESAC prototype without replacing the existing UHF antenna for a higher-gain model, which is out of scope. -10 $dB \cdot K^{-1}$ still provides a healthy margin for modern error-

corrected modulation schemes – for example, the same reference link budget using convolutional coded GMSK instead of uncoded non-coherent GSMK has approximately 8 dB of margin.

[GS-ANT-050] Both the VHF and UHF antenna systems shall be circular polarized.

[GS-ANT-060] Both the VHF and UHF antenna systems shall have a means to allow the antenna polarization to be electronically selected between right-hand circular and left-hand circular polarization.

Right hand and left hand circular polarization is needed to be able to communicate with multiple cube satellites.

[GS-ANT-070] Both the VHF and UHF antenna systems shall be steerable to all azimuth and elevations using steps of 3.0 degrees or less.

[GS-ANT-071] Elevation shall have a minimum threshold of 5 degrees above the horizon.

[GS-ANT-080] Both the VHF and UHF antenna pointing systems shall have a minimum slew rate of 1.5 degrees per second.

Based on the approximate angular speed observed from the ground of a satellite in a 300 km orbit tracking across the sky.

[GS-ANT-090] The VHF and UHF antenna pointing systems may be one system common to both antennas.

For example, both antennas may be mounted on a single boom and rotated collectively by one positioning system.

[GS-ANT-100] The VHF and UHF antennas shall not have a -3dB beamwidth narrower than 10.0 degrees *plus* the pointing accuracy of the chosen pointing system.

4.0 degrees is the approximate expected angular position error of a satellite at 300 km after one week of TLE propagation drift of 3 km/day, so 10.0 degrees provides significant margin.

3.3 RF Requirements

[GS-RF-010] The Ground Station shall be capable of reception and transmission in the frequency ranges of 144.300 – 144.500 MHz, 145.800 – 146.000 MHz, and 435.000 – 438.000 MHz.

This covers the 2m and 70cm amateur satellite bands.

[GS-RF-020] The Ground Station shall be capable of half-duplex operation in the 435.000 – 438.000 MHz frequency range with a turnaround time of less than or equal to 2.0 milliseconds. Turnaround time is defined as the time required to switch from transmitting to receiving and vice-versa.

*Minimum uplink (TX-to-RX) turnaround time limited by time-of-flight time to satellite and back. At 300 km while directly overhead, the minimum time of flight is (2*300 km)/c = 2.0 msec. For symmetry, the maximum downlink (RX-to-TX) turnaround time is chosen to be the same.*

[GS-RF-030] The Ground Station should be capable of half-duplex operation in the 144.300 – 144.500 MHz and 145.800 – 146.000 MHz frequency ranges with a turnaround time of less than or equal to 2.0 milliseconds. Turnaround time is defined as the time required to switch from transmitting to receiving and vice-versa.

*Minimum uplink (TX-to-RX) turnaround time limited by time-of-flight time to satellite and back. At 300 km while directly overhead, the minimum time of flight is (2*300 km)/c = 2.0 msec. For symmetry, the maximum downlink (RX-to-TX) turnaround time is chosen to be the same.*

[GS-RF-040] The Ground Station shall be capable of full-duplex operation with the 144.300 – 144.500 MHz or 145.800 – 146.000 MHz frequency ranges used as uplink and the 435.000 – 438.000 MHz frequency range used as downlink.

[GS-RF-050] Third harmonic suppression to -137 dBm for full duplex operation in (GS-RF-040) shall be provided to avoid interference with the downlink signal. This third harmonic shall be measured with the following procedure:

1. Apply a tone to the VHF transmit chain at a power level sufficient to produce the minimum EIRP stated in GS-RF-100.
2. Measure the third harmonic power at 435 MHz on the UHF receive antenna immediately before the first LNA.
3. Subtract the nominal UHF antenna gain from the power level measured in (2).

The above procedure shall be performed for two unmodulated carrier tones of 145.000 MHz and 146.000 MHz to verify compliance with this requirement.

The 70cm satellite band is an exact third harmonic of the 2m satellite band. Suppression of third harmonic content from the transmit chain is required to ensure that the transmitter does not self-interfere with the receiver.

[GS-RF-060] The Ground Station shall be capable of full-duplex operation with the 435.000 – 438.000 MHz frequency range used as uplink and the 144.300 – 144.500 MHz or 145.800 – 146.000 MHz frequency ranges used as downlink.

[GS-RF-070] The ground station VHF low noise amplifier shall have an input-referenced 1 dB compression point (P1dB) of at least 0 dBm. Input-referenced P1dB shall be defined as taking the output P1dB of the amplifier and subtracting the gain.

Assumed "worst-case" interferer is a vehicle-mounted VHF land mobile radio user parked on Boulevard Clairevue, 200 m away from the ground station site and radiating at 20 W EIRP. With these assumptions, received power into an isotropic antenna is about -18 dBm on the CSA roof. Assuming around 13 dBi of antenna gain, a 0 dBm cutoff gives 6 dB of headroom.

[GS-RF-080] The ground station UHF low noise amplifier shall have an input-referenced 1 dB compression point (P1dB) of at least -7 dBm. Input-referenced P1dB shall be defined as taking the output P1dB of the amplifier and subtracting the gain.

Assumed "worst-case" interferer is a vehicle-mounted UHF land mobile radio user parked on Boulevard Clairevue, 200 m away from the ground station site and radiating at 20 W EIRP. With these assumptions, received power into an isotropic antenna is about -28 dBm on the CSA roof. Assuming around 16 dBi of antenna gain, a -7 dBm cutoff gives 5 dB of headroom.

[GS-RF-090] The ground station transceiver shall have a frequency tolerance of +/- 2.2 ppm or better in the temperature range specified in GS-ENV-070.

This frequency tolerance assures a maximum carrier frequency error of 1kHz at 438 MHz (1 kHz / 438 MHz = 2.28 ppm).

[GS-RF-100] When connected to the VHF antenna system, the transmit signal chain shall support a minimum EIRP from the antenna of 39 dBm.

Based on a notional "worst-case" uplink calculation assuming 1200-baud AFSK with no forward error correction and a 3.5 dB satellite noise figure, plus 5 dB of design margin.

[GS-RF-110] When connected to the UHF antenna system, the transmit signal chain shall support a minimum EIRP from the antenna of 48 dBm.

Based on a notional "worst-case" uplink calculation assuming 1200-baud AFSK with no forward error correction and a poor satellite noise figure of 4.5 dB, plus 5 dB of design margin.

[GS-RF-120] The 1 dB compression point (P1dB) of the VHF amplifier shall be at least 3 dB above the amplifier output level while transmitting at the EIRP stated in GS-RF-100.

[GS-RF-130] The 1 dB compression point (P1dB) of the UHF amplifier shall be at least 3 dB above the amplifier output level while transmitting at the EIRP stated in GS-RF-110.

3.4 Baseband Requirements

[GS-BB-010] The ground station transceiver shall digitize the received baseband signal into a complex baseband format suitable for real-time streaming to GNURadio.

Likely implies an I-Q UDP stream.

[GS-BB-020] The ground station transceiver accept a digitized baseband transmit signal in a complex baseband format suitable for real-time streaming from GNURadio.

Likely implies an I-Q UDP stream.

[GS-BB-030] The maximum supported quadrature bandwidth of the transceiver shall be 50 kHz or greater in both receive and transmit directions.

[GS-BB-040] The minimum dynamic range of the transceiver shall be 8 bits in both receive and transmit directions.

[GS-BB-050] The ground station shall have an auxiliary transceiver with narrowband FM voice support.

3.5 Software System Requirements

[GS-SS-010] The Ground Station software system shall allow for customized deployments of various baseband processing softwares.

[GS-SS-020] The Ground Station software system shall allow for pre-programmed, autonomous contacts with spacecraft.

[GS-SS-030] Prior to a contact, the software system shall automatically configure the appropriate antenna polarization.

[GS-SS-031] Prior to a contact, the software system shall automatically configure the correct uplink and downlink centre frequencies.

[GS-SS-032] Prior to a contact, the software system shall automatically configure any RF switches for the appropriate signal path for uplink and downlink.

[GS-SS-033] Prior to a contact, the software system shall rotate the antenna(s) to the position where the contacted satellite is predicted to cross the horizon as per the satellite's TLE.

[GS-SS-040] Prior to a contact, the software system shall automatically instantiate the appropriate baseband processing software.

[GS-SS-050] During a contact, the software system shall pass control of the antenna rotator(s) to the baseband processing software.

[GS-SS-060] During a contact, the software system shall provide a mechanism for the baseband processing software to read from the received quadrature stream, in a format compatible with GNURadio.

[GS-SS-070] During a contact, the software system shall provide a mechanism for the baseband processing software to write to the transmitted quadrature stream, in a format compatible with GNURadio.

[GS-SS-080] The software system may provide a mechanism for the baseband processing software to change the direction of a half-duplex link.

[GS-SS-090] The software system shall allow multiple baseband processing softwares from different users to be present on the same host.

[GS-SS-100] Deployment of new baseband processing softwares should be straightforward, requiring minimal configuration.

3.6 Operational

[GS-OP-010] The ground station shall obtain reservations for satellite contacts from a remote server.

[GS-OP-020] The ground station server shall be accessible to authorized users from the public internet.

[GS-OP-030] Baseband processing softwares shall be allowed access to the public internet.

3.7 Digital Interfaces

[GS-DG-010] The ground station server's internet connection shall support a minimum transfer rate of at least 20 Mbit/sec for both upload and download.

3.8 Hardware

[GS-HW-010] The ground station components should be reused from previous CSA projects wherever practicable.

3.9 Power

[GS-PWR-010] The ground station shall be connected to circuit(s) with auxiliary power at John H. Chapman Space Centre.

John H. Chapman Space Centre has auxiliary generators to ride through power outages.

[GS-PWR-020] The ground station shall be able to operate through a power outage of 30 minutes duration.

This allows the ground station to bridge to auxiliary power while the generators are starting up, and allows a large safety margin if there are issues with transferring to generators.

3.10 Environmental

[GS-ENV-010] Ground station equipment mounted outside shall withstand maximum wind gusts of 145 km/h.

Maximum expected 30-year wind gust for Montreal as per "Computed Maximum Wind Gust Speeds," National Research Council, February 1958 [RD1].

[GS-ENV-020] Ground station equipment mounted outside shall survive temperatures in the range of -40 to +40 °C.

Historical temperature extremes in Montreal range from approximately -38 to +38 °C, based on data collected at YUL since 1941.

[GS-ENV-030] Ground station equipment mounted outside shall continue to operate in temperatures in the range of -30 to +40 °C.

Most amateur radio equipment does not operate below -30 °C, and days below -30 °C are rare in Montreal.

[GS-ENV-040] Ground station equipment mounted outside shall continue to operate in 95% relative humidity, non-condensing.

[GS-ENV-050] Ground station equipment mounted outside shall survive 100% relative humidity.

Days with 100% RH do occur in Montreal during the summer.

[GS-ENV-060] Ground station equipment mounted outside shall survive 130 mm ice accumulation from freezing rain.

Historical worst-case freezing rain ice accumulation for Montreal (1998 ice storm).

[GS-ENV-070] Ground station equipment mounted inside shall continue to operate in temperatures in the range of +10 to +30 °C.

John H. Chapman Space Centre is climate-controlled year round.

[GS-ENV-080] Ground station equipment mounted inside shall continue to operate in 60% relative humidity, non-condensing.

John H. Chapman Space Centre is climate-controlled year round.

3.11 Personnel

[GS-PSL-010] The ground station development process shall support HQP training of junior CSA personnel, including early-career engineers and students.

3.12 Regulatory

[GS-REG-010] The ground station shall comply with RBR-4 — Standards for the Operation of Radio Stations in the Amateur Radio Service [AD1].

[GS-REG-020] The ground station shall comply with the ITU Radio Regulations [AD2].

[GS-REG-030] Ground station operations shall comply with the RAC 2m band plan [AD3].

[GS-REG-040] Ground station operations shall comply with the RAC 70cm band plan [AD4].

4.0 LIST OF ACRONYMS

AD	*Applicable Document*
AFSK	*Audio Frequency-Shift Keying*
CDR	*Critical Design Review*
CSA	*Canadian Space Agency*
G/T	*Antenna Gain-to-Noise Temperature*
GESAC	*Generic Earth Station Architecture for CubeSats*
HQP	*Highly Qualified Personnel*
ISED	*Innovation, Science, and Economic Development Canada*
ITU	*International Telecommunications Union*
MRD	*Mission Requirements Document*
RAC	*Radio Amateurs of Canada*
RF	*Radio Frequency*
TDMA	*Time Division Multiple Access*
TLE	*Two-line Element Set*
UDP	*User Datagram Protocol*
UHF	*Ultra High Frequency*
VHF	*Very High Frequency*