30th June 2013

Garada

SAR Formation Flying

Annex 10. Ground Segment Definition

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Executive Summary

This Ground Segment Definition Report summarises the work performed by BAE Systems in undertaking Work Package 10: Ground Segment Definition for the Garada SAR mission. This work was undertaken in conjunction with work package 9: Garada Industrialisation Analysis. During the course of WP10: Ground Segment Definition, five reports were delivered:

i. TK10.1 Operational Concept Document

ii. TK10.2 Functional Performance Specification

iii. TK10.3 Preliminary Ground Segment Architecture

iv. TK10.4 Ground Segment ROM Cost Estimate

v. TK10.5 Ground Segment Definition Report.

Together, these reports establish the user needs and provide a definition, analysis, requirements, preliminary architecture, candidate solutions and ROM costing for the ground segment to support Garada.

For the Garada mission the ground segment provides monitoring and control of the spacecraft, processing and archiving of the SAR data, and interfacing to end users who request and consume the SAR data and its derived products. The architectural design decomposed the ground segment to the following systems:

- Mission Control System (MCS)
- Mission Management and Data Processing System (MMDPS)
- Ground Station System (GSS)
- Ground Communications System (CS)
- Support System (SS)

The Mission Control System is responsible for the control of the SAR payload, the monitoring and control of the spacecraft, and the monitoring and control of the ground station. It is based on an array of COTS hardware computing platforms running COTS based software solutions for the satellite command, control and monitoring. Bespoke software is required to be developed to interface the COTS software products to the Garada system and for the mission specific functionality of ground station control, SAR management, application specific databases and the MCS simulator.

The Mission Management and Data Processing System provides the SAR operations and data processing and archiving to generate and exploit the SAR products. It provides the interface to the end users, receives data requests and delivers end products. Its implementation is based on COTS computing platforms running mainly bespoke software. Development activities are required for the software for processing the SAR echo data, which is matched specifically to the Garada SAR, into imagery. The SAR products require further processing to produce the end products of soil moisture contours, and flood, forest, and oil slick outlines required by the end users. These processes require further software to be developed to implement the complex algorithms required.

The Ground Station System provides the communications link to the spacecraft in orbit. The system is located remotely from the MCS at a geographical location that optimises the contact time with the spacecraft. The station is remotely operated and controlled and in normal use, operates unmanned. Considerable analysis and trade studies were undertaken to determine the optimum location of the ground stations. The National Earth Observations from Space Infrastructure Plan (NEOS-IP) discussion papers proposes the upgrade of Australia's three high data rate receiving stations to six with the addition of three new sites in North Eastern Australia, Western Australia and Antarctica. The assessment of the coverage of Garada from these sites, existing Australian receiving sites and other locations was undertaken.

It was concluded that a combination of a new ground station at Mawson in the Antarctic and the existing TERSS station at Hobart offers the best coverage for the Garada mission. The combination of Hobart with Mawson, due to their southerly locations and east-west spacing,

offer access to 80% of the orbits of the polar orbiting spacecraft. The Hobart station will require upgrading to handle the higher data rates of Garada and S-band telemetry and telecommands. A new ground station will need to be established at Mawson station in the Antarctic, consistent with NEOS-IP discussion paper intent. The two ground stations at different geographical locations provide redundancy and diversity as well as increased orbital coverage.

The return of the data from the Antarctic station to Australia is planned to be implemented through the proposed Antarctic Broadband system which has been initially funded by an Australian Space Research Program (ASRP) grant. The existing TDRSS satellite system and the forthcoming Inmarsat Global Xpress series of broadband satellites are also possibilities for the Antarctic link.

The Kongsberg Satellite Services (KSAT) operated ground station in the Svalbard archipelago in the Arctic was the best location examined, with nearly complete orbital coverage. Whilst outsourcing the ground station to KSAT is an option for Garada, the Mawson / Hobart combination is baselined due to its reuse of existing assets and consistency with the discussion papers for the National Earth Observations from Space Infrastructure Plan.

Detailed analysis and trade studies were also undertaken on the spacecraft to ground link design to handle the high data rate of the SAR instrument. These are provided in the Preliminary Ground Segment Architecture report and are updated in section 18 of this document with the results of the spacecraft communications trade studies. It is concluded that a dual wide band data link using the full bandwidth of the X band allocation will provide the data rate required and provide compatibility with existing ground stations in other countries to maximise the opportunities for export sales of the SAR data.

The Communications System provides the interconnections between the systems. It handles all voice and data communications between the ground systems and between the ground segment to the outside world. The National Broadband Network provides the main high speed data link to transport the data between ground systems geographically separated within Australia and from the MMDPS to customers.

The Support System provides hardware and software maintenance and upgrades to the ground segment. It also undertakes spacecraft flight software updates to be uploaded to the Garada spacecraft. It is built around the use of existing COTS hardware and software tools and requires little development activities.

The ground segment also includes an operations segment which is comprised of the trained staff who operate the ground segment and the plans and procedures required to undertake the mission preparation and operations. For Garada these teams will typically involve the following types of people:

- Operations managers
- Spacecraft operators
- SAR operators
- Mission planners
- Flight dynamics engineers
- Ground system operators
- SAR payload exploitation personnel; eg scientific and algorithm experts, end user liaison staff, product generation support staff, and calibration experts.
- Ground system maintenance engineers.

Details of the skills and training required to support Garada operations in Australia are discussed in TK9.5: Garada Industrialisation Plan, where a roadmap is also provided. It is concluded that Australia is well capable of priming the ground segment and undertaking the ongoing operation and maintenance of the Garada system.

A decomposition of the ground segment work was undertaken and a Work Breakdown Structure (WBS) generated. From this, parametric estimating techniques were used to provide a Rough Order of Magnitude (ROM) costing for a ground segment that meets the Ground Segment Functional Performance Specification based on the architectural solution described in the Preliminary Ground Segment Architecture document. The costing is provided in the Garada Ground Segment ROM Cost Estimate report and the reader is referred to that document for full details of the costing and scope. From the WBS an indicative schedule for the ground segment was also derived. A total duration of 69 months is required, comprising the following major activities:

- Phase A, Mission and operational analysis, conceptual design:- 9 months
- Phase B, Preliminary design: 12 months
- Phase C, Detailed design: 12 months
- Phase D, Production, AIT and Verification: 36 months

1. Scope

This is the Ground Segment Definition Report for the ground segment of the Garada formation flying satellite based Synthetic Aperture Radar (SAR) system. This document is a deliverable under Garada Work Package 10- Ground Segment Definition, deliverable TK 10.5 Ground Segment Definition Report.

1.1. Work Package Context

The context of this document within WP 10- Ground Segment Study, is illustrated in Figure 1: Work Package 10.5 Context.

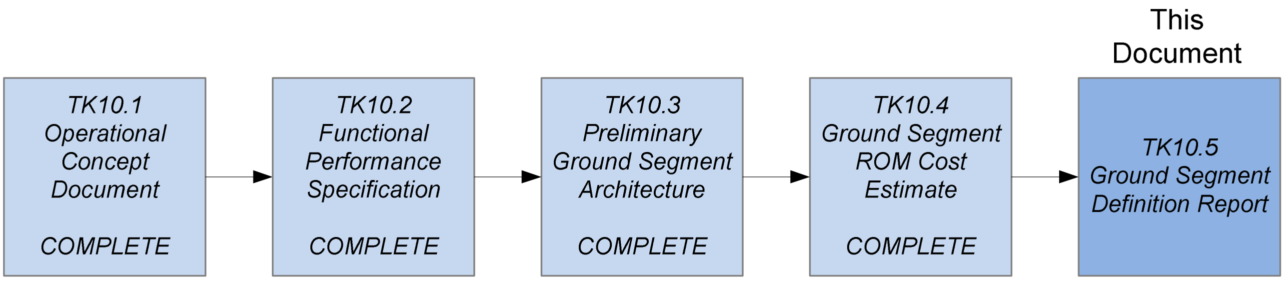

Figure 1: Work Package 10.5 Context

1.2. Document Purpose

The purpose of this document is to inform stakeholders of the role, requirements, functionality, architectural design and ROM costing of the ground segment of Garada. It summarises the detailed analysis that has been performed and captured in the reports TK10.1, 10.2, 10.3, and 10.4.

2. Referenced Documents and Acronyms

2.1. Referenced Documents

Ref	Document Identifier	Title	Rev.	Date
1	2344DT00009	TK 10.2 Functional Performance Specification for the Ground Segment of the Garada Formation Flying Synthetic Aperture Radar System	1	29 Jun 12
2	2344DT00010	TK 10.3 Preliminary Ground Segment Architecture for the Garada Formation Flying Synthetic Aperture Radar System	1	21 Dec 12
3	2344DT00008	TK 10.1 Operational Concept Document for the Garada Formation Flying Synthetic Aperture Radar System	1	31 Mar 12
4	2344DT00007	TK 9.5 Project Industrialisation Plan for the Garada Formation Flying Synthetic Aperture Radar System	2	30 Jun 13
5		TK1.4 Thermal Requirements and Baseline Model, Spacecraft Communications System Report, Antenna Trade-off Report	V01_00	31 Mar 13

Ref	Document Identifier	Title	Rev.	Date
6	GAR-TA-ASU-SY-001	Garada – SAR Payload Preliminary Thermal Analysis.	1.1	15 Jan 13
7	2344DT00006	TK 9.2 Australian Industry Capability Report for the Garada Formation Flying Synthetic Aperture Radar System	1	21 Dec 12
8	DIISRTE, 12/257	Australia's Satellite Utilisation Policy		9 Apr 13
9	2344DT00011	TK 10.4 Garada Ground Segment ROM Cost Estimate	1	28 Mar 13
10	ISBN 978-1-921954-40-5	"*Continuity of Earth Observation Data for Australia" , 2011.* Geoscience Australia, Commonwealth of Australia.		2011
11		Garada Mission Baseline	V01_00	1 Aug 2012
12		Garada Objective System Requirements Baseline	V01_00	30 Aug 2012.

2.2. List of Acronyms

Abbreviation	Expansion
ACM	Adaptive Coding and Modulation
AIT	Assembly Integration and Test
AOCS	Attitude and Orbital Control System
AR	Acceptance Review
ASRP	Australian Space Research Program
BoM	Bureau of Meteorology
CDR	Critical Design Review
CoC	Certificate of Conformance
COTS	Commercial Off The Shelf
CRR	Customer Requirements Review
CS	Communications System
CSCI	Computer Software Configuration Item
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Department of Climate Change and Energy Efficiency
DIDS	Data Item Description Sheets
DSTO	Defence Science and Technology Organisation

Abbreviation	Expansion
EO	Earth Observation
EOL	End Of Life
ESA	European Space Agency
FPS	Functional Performance Specification
GA	Geoscience Australia
GNSS	Global Navigation Satellite System
GSS	Ground Station System
GST	Goods and Services Tax
HWCI	Hardware Configuration Item
ICD	Interface Control Document
IF	Intermediate Frequency
IFCI	International Forest Carbon Initiative
IRD	Interface Requirements Document
IT	Information Technology
KSAT	Kongsberg Satellite Services AS
LCM	Life Cycle Management
LEOP	Launch and Early Orbit Phase
LNA	Low Noise Amplifier
LTAN	Local Time Ascending Node
MCS	Mission Control System
MDB	Murray Darling Basin
MDR	Mission Definition Review
MMDPS	Mission Management and Data Processing System
NBN	National Broadband Network
NEOS-IP	National Earth Observations from Space Infrastructure Plan
NEST	Next ESA SAR Toolbox
OCD	Operational Concept Document
OEM	Original Equipment Manufacturer
OQR	Operations Qualification Review
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PHAR	Preliminary Hazard Analysis Report
PHS&T	Packaging, Handling, Transportation and Storage

Abbreviation	Expansion
PRF	Pulse Repetition Frequency
QPSK	Quadrature Phase Shift Keying
QR	Qualification Review
R&D	Research and Development
RF	Radio Frequency
RFI	Radio Frequency Interference
ROM	Rough Order of Magnitude
RPS	Radiation Protection Standard
SAR	Synthetic Aperture Radar
SLOC	Source Lines of Code
SME	Subject Matter Expert
SRR	System Requirements Review
SS	Support System
TDRS	Tracking and Data Relay Satellite
TERSS	Tasmanian Earth Resources Satellite Station
TOPS	Terrain Observation by Progressive Scan
TT&C	Telemetry, Tracking and Command
UNSW	University of New South Wales
V&V	Verification and Validation
WBS	Work Breakdown Structure
WP	Work Package

3. Garada Overview

Garada is a proposed Australian led Formation Flying L-Band Synthetic Aperture Radar (SAR) satellite system that provides SAR imagery and interpreted data to primarily Australian end users for the purposes of soil moisture mapping, forest change detection, flood and disaster monitoring and bistatic research. It is aimed primarily at civilian applications but may also support defence.

The system comprises two identical satellites flying half an orbit apart in a sun synchronous orbit of 630km altitude. The orbit repeat cycle of 6 days results in the whole of Australia being overflown every three days. The main payload is a high resolution L band Synthetic Aperture Radar that has a resolution of 4-11m in range and 7m in azimuth. A secondary payload is a Global Navigation Satellite System (GNSS) receiver designed to receive positioning and timing signals from multiple satellite navigation systems. The Garada spacecraft are designed to be launched from the SpaceX Falcon 9 launch vehicle. The satellites are based on Astrium's Snapdragon configuration and TerraSAR-L experience. The primary ground station for receiving the satellite data is located in Antarctica and uses the proposed Antarctic broadband link to return the data to Australia or an equivalent capability. A secondary ground station in Tasmania provides additional orbit coverage and redundancy.

The mission and payload operations and payload data processing are carried out in Australia by Australian personnel.

4. Project Life Cycle Context

This document provides the Ground Segment Definition for the Garada mission. In the context of the typical life cycle of space projects, this covers phases 0 to E where the phases are as described below.

- Phase 0 - Mission analysis/needs identification
- Phase A - Feasibility
- Phase B - Preliminary Definition
- Phase C - Detailed Definition
- Phase D - Qualification and Production
- Phase E - Utilisation
- Phase F - Disposal

Phases 0, A, and B are focused mainly on the elaboration of system functional and technical requirements and identification of system concepts to comply with the mission statement.

Phases C and D comprise all activities to be performed in order to develop and qualify the space and ground segments and their products.

Phase E comprises all activities to be performed in order to launch, commission, utilise, and maintain the orbital elements of the space segment and utilize and maintain the associated ground segment.

Phase F comprises all activities to be performed in order to safely dispose of all products launched into space as well as the ground segment.

Currently, Garada activities are being undertaken that are associated with the project Phase 0 and Phase A scope. This is being carried out under the Australian Space Research Program Funding Agreement ASRP5. These activities comprise the following work packages:

WP1	Space Systems Engineering and Radar Applications
WP2	SAR Solution
WP3	SAR System Analysis
WP4	Bistatic Radar
WP5	Prototype Receiver
WP6	Formation Flying Algorithms
WP7	Orbit Models
WP8	Orbit Control Analysis
WP9	Industrialisation Analysis
WP10	Ground Segment Definition.

This Ground Segment Definition Report under WP10 covers the ground segment work that would be undertaken in phases A, B, C, and D as described in this document.

5. Mission Objectives

The primary aim of the Garada mission is to utilise a space-borne L band Synthetic Aperture Radar instrument to provide benefits to Australian agricultural, land management, and emergency management communities. In particular, the Garada mission covers the following applications:

- Frequent soil moisture measurements of the Murray Darling Basin in Australia by analysing the returns from the SAR.
- Forestry change in Australian and regional forests.
- Flood monitoring along the east coast of Australia.
- Land use classification and mapping by the provision of SAR imagery to the Australian land management and geospatial communities.
- Provision of SAR imagery to foreign countries on an opportunity basis.

These aims are achieved by utilising two spacecraft equipped with a high resolution L band SAR in a sun synchronous orbit. A single spacecraft gives a 6 day repeat cycle, decreasing to 3 days for a dual spacecraft solution. Data is downloaded via a high bandwidth link to a primary ground station located in Australian Antarctic Territory and sent to Australia via a wideband satellite data link. Processing of the data is performed in an Australian data processing and distribution centre. An additional ground station located in south eastern Australia provides backup to the main ground station and access to a small number of additional orbits.

6. Operational Concept

6.1. Justification for Capability

Satellite based SAR data is currently used in Australia for a wide range of applications including modelling climate, mapping of forests, responding to disasters, biomass monitoring, locating mining and energy resources, topographic data mapping, weather and climate, ocean wave height assessment, flood assessment and monitoring, ocean oil slick monitoring, research and monitoring international agreements. To support these applications, Australia is reliant on data from foreign satellites made available through intergovernmental agreements and commercial contracts with overseas jurisdictions.

The satellites Australia currently relies on are approaching end of life and although future missions are planned by foreign countries, there are currently no formal arrangements in place for Australia to receive the data from the sensors that will be carried on missions planned during the next decade. (Ref 10)

Reliance on foreign data sources for SAR data has inherently several limitations and risks:

a. Incomplete spatial coverage and resolution for Australian areas of interests.

b. Non optimised system design that does not meet Australia's needs.

c. Cessation of the service, access rights or increased cost.

d. Low priority in requesting operating modes and surveillance of areas of interest to Australia.

As an increasing number of land, water and disaster management solutions become dependent on SAR data, these risks increase. An Australian owned and operated satellite SAR system will considerably mitigate or eliminate these risks and provide Australian programs, both civil and defence, with priority access to high quality SAR data into the future.

6.2. Garada Users

The Garada System will be owned and operated by the Australian Government and will service a wide variety of end users. End users of Garada products will be:

a. Australian Government, non-Government and commercial organisations.

b. Foreign governments and commercial organisations, subject to appropriate inter government agreements.

c. Australian Department of Defence, subject to appropriate security requirements.

The organisations that are expected users of the end products of the Garada System are listed in Table 1: Garada End Users. (Ref 2)

Table 1: Garada End Users

Customer	Customer Application
Department of Climate Change and Energy Efficiency	Forestry Change
Department of Agriculture, Fisheries and Forestry	Soil moisture mapping in Murray Darling region
Murray Darling Basin Authority	Flood mapping to determine extent of water in the Murray Darling Basin
Border Protection Command	Strategic surveillance of Australia's surrounds
Bureau of Meteorology	Flood mapping
Emergency Management Australia	Flood & Disaster Monitoring
State emergency management and state emergency services	Flood & Disaster Monitoring
Marine Environment Division of Australian Maritime Safety Authority	Disaster Monitoring
University of New South Wales	Bistatic research

The Garada products will be made accessible to users via the Australian National Broadband Network (NBN).

6.3. Integration with Australia's Existing Earth Observation System

The Garada system is an adjunct to the current system within Australia of acquiring earth observation data. It is designed to supplement the earth observation data products acquired from overseas systems with data specifically targeted to Australia's needs. It is important that Garada integrate virtually seamlessly with the current earth observation system to minimise the costs through additional staffing, training, facilities and infrastructure.

The existing system for accessing satellite based earth observation data both optical and SAR relies on the sharing of data from foreign owned earth observation satellites through intergovernmental agreements or commercial contracts with overseas agencies.

Satellite missions inherently have a finite life and new agreements and contracts have to be negotiated to ensure continued access to data. Whilst new earth observation missions are planned there is no guarantee they will provide the data coverage Australia requires or that acquisition agreements will be ratified. The reliance on foreign sources of SAR data has several risks as detailed in section 6.1:

The Garada system will mitigate or eliminate these risks as follows:

a. The system will be optimised specifically for coverage of Australian areas of interest.

b. The system will be designed so that key performance parameters, such as waveband, resolution, revisit time and latency, are optimised to meet the needs of Australia's end users.

c. As owner and operator of the system, Australia will not be subject to access rights negotiated with foreign owners and will have a known end of life that is determined by the life of the system not intergovernmental agreements.

d. As the owner of the system, Australia will set the priorities for use of the system and will not be subject to the requirements of other countries taking precedence.

The Satellite Utilisation Policy (ref 8) nominates the Australian government agencies responsible for earth observations from space as Geoscience Australia (GA), Bureau of Meteorology (BoM) and CSIRO. GA provides geoscientific advice and information to government, industry and the community; BoM utilises space observations for weather forecasting and CSIRO uses space observations to support space science research. The application of existing SAR data to the end uses targeted by Garada are primarily managed through GA. SAR data from foreign owned and operated EO systems is provided to GA through intergovernmental agreements or on a commercial basis. GA processes and interprets the data and applies it to the end use to support government objectives. GA also provides the data, at various levels of processing, to commercial EO service providers on a commercial basis.

The Garada system is designed to have minimal impact on Australia's current EO customers' processes and systems. Garada data will be provided to customers in standard formats allowing many aspects of the customer's current EO SAR processing, analysis, archiving and distribution systems to be reused. Figure 2 illustrates how the Garada system will integrate into the existing Earth Observation (EO) supply and processing system. In effect, Garada becomes another source of SAR data in the existing system, though one of high quality and high availability, that can be targeted specifically to Australia's end users' needs. As a government owned system Garada will provide its data to GA free of charge and to non-government bodies on a commercial basis.

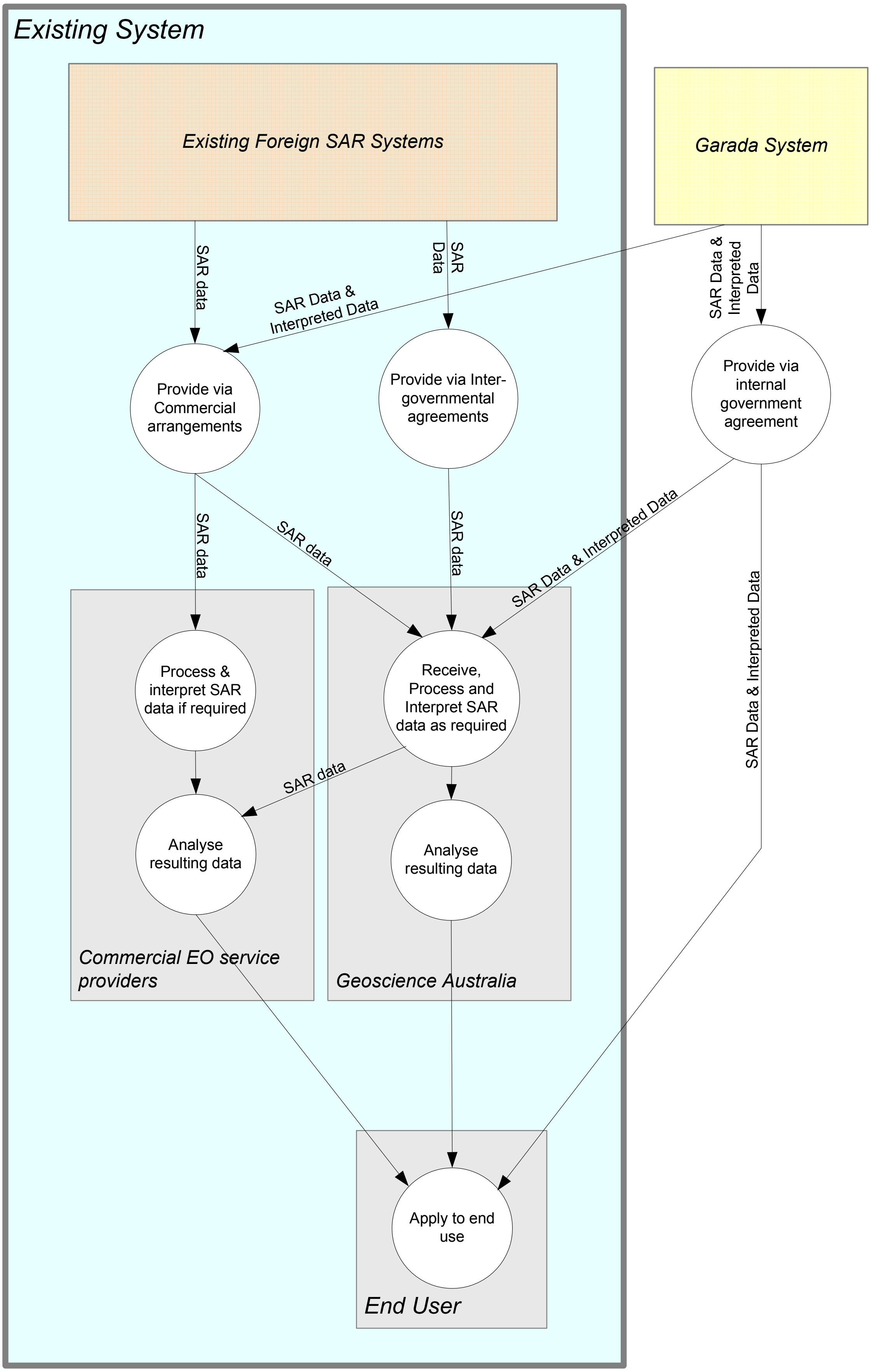

Figure 2: Garada Integration into Existing System

7. Usage Scenarios

The primary usage scenario of the Garada system is the request from, and the supply of data to, an end user. This may be for new data or a request to access archive data. It may be an ongoing request to provide SAR data from an area over a period of time, or a specific request for limited temporal and spatial data. In all cases the scenario is triggered by a request from an end user for specific data and follows the abbreviated description below:

1. A request is received from a customer for new or archived data.
2. All requests are logged and assessed for validity.
3. The requests are prioritised and details provided for actioning. Prioritisation of requests is performed in accordance with an acquisition priority. Examples of priority are: flood and disaster management requests take priority over research requests etc.
4. For archived data, the data is recovered from the SAR archive, and processed to the level specified by the customer.
5. For new data, the SAR on board the satellite is commanded to scan the required area at the necessary time using the appropriate modes.
6. The acquired raw data is stored on board until the satellite is within range of a ground station. The data is then transmitted to the ground station whilst the spacecraft is in access range.
7. The raw data is processed to the level specified by the customer, packaged in the requisite format and the resulting product delivered to the customer.
8. The customer is invoiced if payment is required.
9. All acquired raw data and all processed products are archived.

Further less frequently used usage scenarios are explored in ref 3. From these usage scenarios and the end user applications described in Table 1, key end user common scenario parameters were identified as described in Table 2. These parameters form a key input to the requirements of the ground segment.

Table 2: Common Scenario Parameters

Parameters	Details
Update Frequency	The time between imaging of the same scene. This may vary from hours, days, weeks or months.
Latency	The time between the scene being imaged and the data being made available to the customer.
Resolution	The ability of the sensor to distinguish two closely spaced objects as two rather than one object.
Data type	Different degrees of processing can be conducted on the acquired SAR data to create different products in accordance with customer needs. These products can include: Raw data. The unprocessed matrix of echos as received from the sensor. The customer will require SAR processing capabilities to use this product. Path image. A processed image that is aligned parallel to the satellites orbit path. Lat and Long positional information is added to the data. Single Look Complex: is stored in slant range. It is also corrected

Parameters	Details
	for satellite reception errors and includes latitude and longitude information. It retains the original phase and amplitude information. It cannot be directly viewed as an image. Map Image: An image oriented with north up and corrected to a map projection. Multi look image: An image where independent images of the same area are averaged to reduce speckle.
Data format	The format and containers for the deliverable data. In most cases these will be in accordance with standard industry requirements.
Interpreted data	In most cases the SAR map image is not directly usable by the customer and requires further interpretation to deduce the information required. This interpretation may be undertaken by the customer but in many cases the customer requires the interpretation to be performed by the Garada system so they can act on it directly. The Garada system should interpret the data to provide the identification of soil moisture content, flood boundaries, and clear cut forestry areas.
Area	The area to be scanned.
Location	The location in the world.

8. Constraints and Requirements

High level constraints or limitations in how the mission system satisfies the operational requirements were derived in the Operational Concept Document (ref 3) from the described operational concept and mission objectives as follows:

a. Development of hardware and software shall be kept to a minimum and maximum use made of existing proven hardware and software.

b. Existing regulatory requirements shall be met.

c. To minimise development and operating costs, existing infrastructure shall be used where possible.

d. Standard data formats shall be used to allow maximum use of existing COTS products in the Garada system and minimise the impact on existing customers systems.

e. To accommodate possible future applications the system shall be designed to allow for the separation of data and data processing into classified and unclassified classes.

Detailed requirements were derived, within the above constraints, from the OCD (ref3), the draft Garada Mission Baseline (ref 11) and the draft Garada Objective System Requirements Baseline (ref 12) and published in the Functional Performance Specification for the Ground Segment (ref 1).

9. Mission Segments

The Garada mission is composed of a space segment and a ground segment.

The space segment is comprised of the Garada spacecraft, the ground support equipment for the spacecraft and the launch services. The space segment is not covered in detail in this document.

The Garada ground segment is composed of two main segments:

- The ground segment comprising all ground systems that are used to support the preparation activities leading up to mission operations, the conduct of operations themselves and all post–operational activities.
- The operations segment comprising the organisation of human resources undertaking the mission preparation and mission operations tasks.

The context of the ground segment in the Garada system is shown in Figure 3.

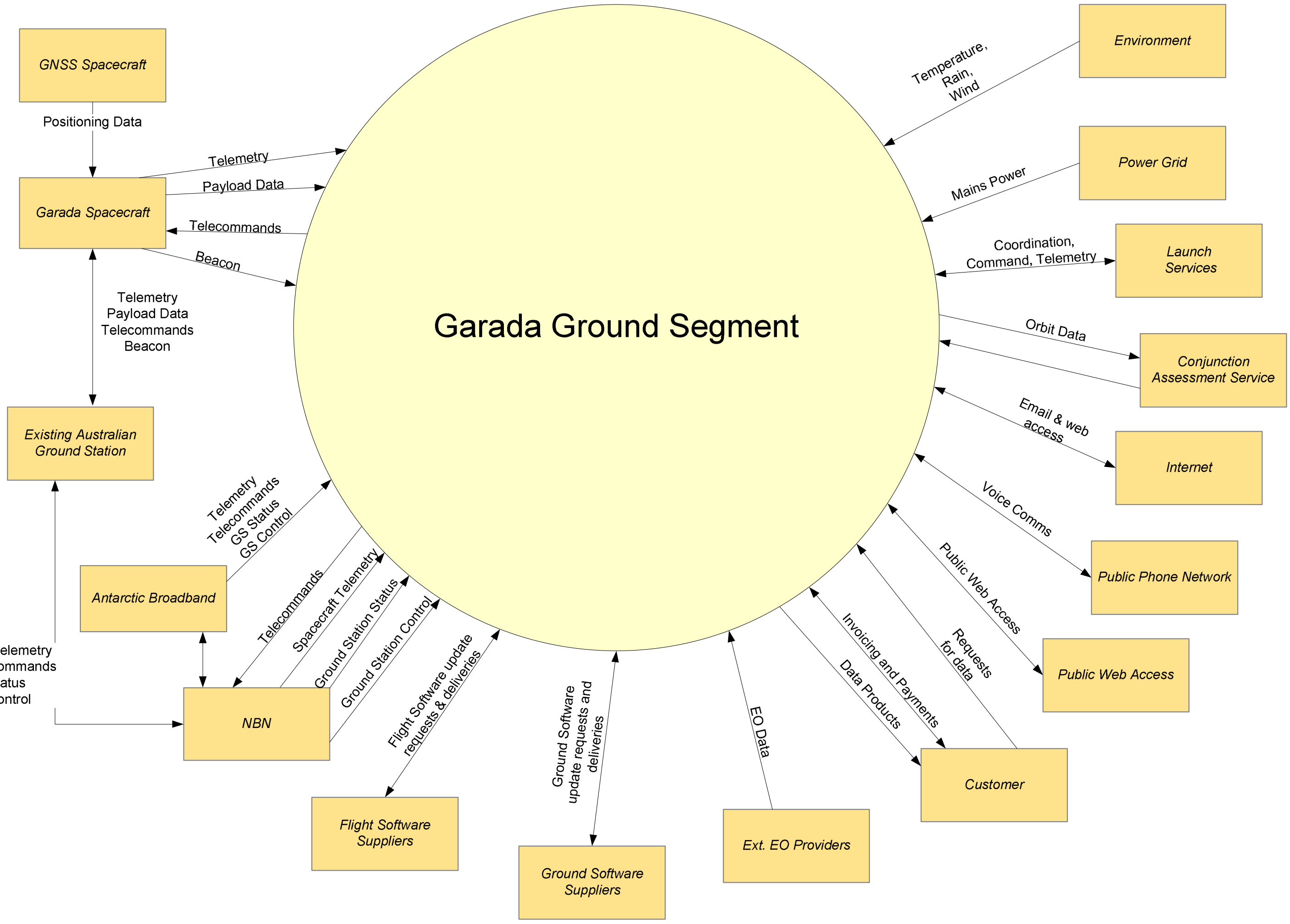

Figure 3: Ground Segment Context Diagram

10. Specification Tree

The high level Garada mission requirements are described in the “Garada Objective System Requirements Baseline” (Ref 12). These requirements are decomposed to requirements for the ground segment described in the “Functional Performance Specification for the Ground Segment of the Garada Formation Flying Synthetic Aperture Radar System” (Ref 1) and are decomposed to requirements for the space segment described in the “Space Segment Functional Performance Specification” delivered as part of the Garada final report.

The specification hierarchy is illustrated in Figure 4. Further decomposition of the requirements from the segment specifications will be undertaken in the next phase of the project. The set of ground segment requirements will be decomposed into system specifications for each of the ground segment systems, which in turn will be decomposed into requirements for individual hardware and software configuration items. The interface between the space and ground segments will be described in the “Space Segment to Ground

Segment Interface Requirement Document (IRD)". The interfaces between the ground segment systems will be described in the "Ground Systems IRD" and the Ground Segment external interfaces will be captured in the "Ground Segment External Interface IRD".

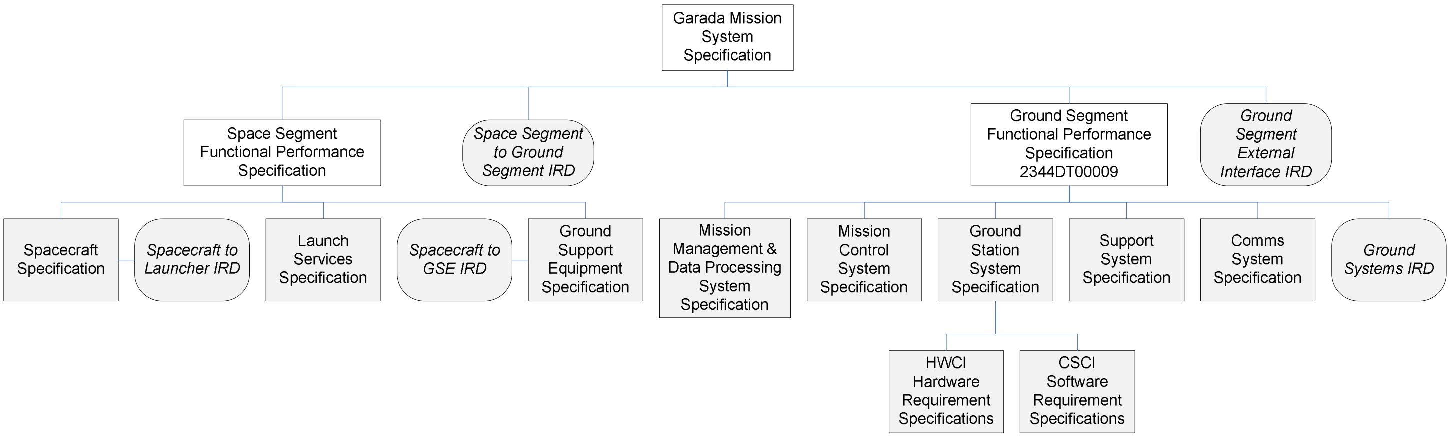

Figure 4: Top Level Specification Tree

11. Space Segment

The Garada spacecraft is comprised of:

- The platform including the attitude and orbital control system, the thermal control system, the electrical power system, the data handling system, the propulsion system and the communication system.
- The payload comprising
  - An L band Synthetic Aperture Radar (SAR), and
  - A high precision Global Navigation Satellite System (GNSS) receiver.

The SAR payload is optimised for soil moisture and deforestation monitoring using measurements in the L band. The SAR is equipped with a large (15.5m x 3.9m) rigid antenna structure using deployable panels and distributed power amplifiers. The large antenna size is the key to defining the performance of the SAR and its ability to suppress ambiguities. High ambiguity suppression is required to obtain the level of radiometric accuracy needed for accurate soil moisture determination and to support the use of quad polarisation measurements. The nominated antenna is the largest that can fit within the fairing of a Falcon 9 launch vehicle. The key SAR performance parameters are listed in Table 4.

The Garada spacecraft reside in a sun synchronous 630km orbit with an 89 orbit, six day repeat cycle. The orbit is designed to enable the spacecraft to observe the earth at 6:00am local time. They receive commands from the ground segment and send telemetry to the ground segment via an S band link. High data rate SAR data is received by the ground segment via a dual X band link. Orbital parameters for the spacecraft are listed in Table 3.

Table 3: Garada Orbit Parameters

Orbit Parameters	
Nominal Height	630 km
Type	Sun-synchronous
Orbits per repeat	89
Repeat period	6 days
LTAN	6 am
Inclination	97.9°
Orbit duty cycle	> 4%

Table 4: SAR Parameters

SAR Parameters	
Radar frequency	1218 – 1297 MHz
Band	L-band
Wave length	0.23 m
PRF	1400 – 2500 Hz
Polarisation	Single, quad, compact
Operating modes	Stripmap, TOPS ScanSAR
Look direction	Left and Right (tbc)
Antenna width	3.9 m
Antenna length	15.5 m
Range resolution	4m - 11m (single look)
Azimuth resolution	7 m (single look, stripmap) 60 m – 100m TOPS ScanSAR

The Garada space segment consists of two spacecraft. In the two spacecraft mission the second spacecraft is identical to the first and offset by half an orbit to provide a three day repeat cycle.

12. Ground Segment

12.1. Ground Segment Systems

The Garada ground segment provides monitoring and control of the spacecraft and the interface between the end users and the Garada system. The Garada ground segment consists of the following top level systems:

- Mission Control System (MCS)
- Mission Management and Data Processing System (MMDPS)
- Ground Station System (GSS)
- Ground Communications System (CS)
- Support System (SS)

Under the main operating scenario, data requests from external users are received by the Mission Management and Data Processing System, converted to requests for SAR surveys or archive data and, in the case of new data, provided to the Mission Control System. Specific satellite and SAR control commands are generated and transmitted to the satellite via the Ground Station System. The SAR on board the satellite scans the designated area in the required mode, stores the data and transmits it to the ground station when in range. The raw SAR data is provided to the Mission Management and Data Processing System where it is processed to create the final product required by the customer.

The ground segment consists of existing and bespoke systems interconnected by high speed data links. An overview of the Garada ground segment architecture is shown in Figure 5.

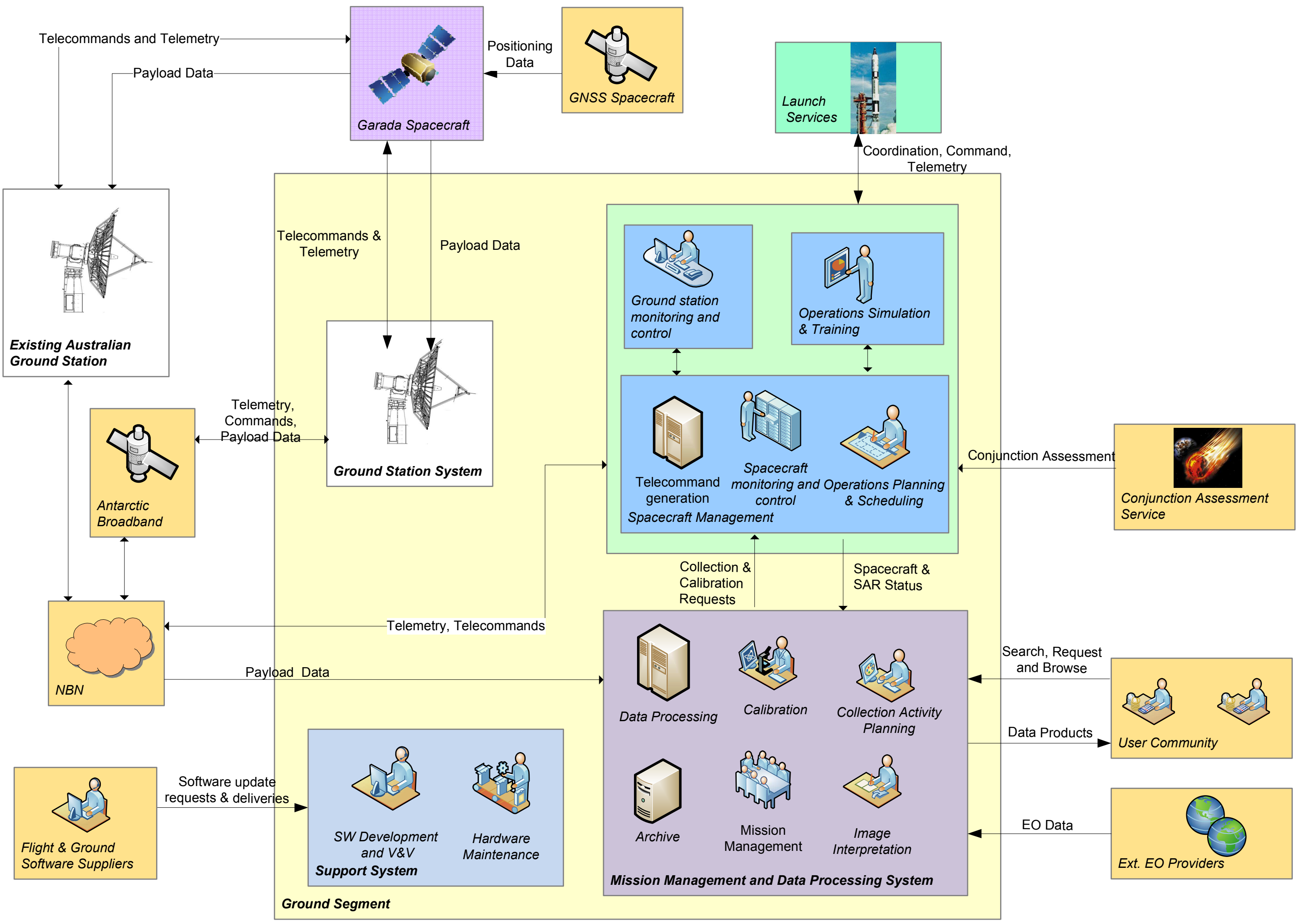

Figure 5: Overview of Garada Ground Segment Architecture

The Garada System is composed of Garada controlled elements as well as external elements.

External Ground Segment Elements include:

i. Providers of earth observation data

Existing providers of geospatial information such as providers of maps and satellite visual and multi spectral imagery. This information is used to incorporate into Garada generated products to improve the usability of the SAR products to the end users.

ii. Conjunction Assessment Service

The conjunction assessment service tracks all objects in orbit around the earth including active and inactive satellites, discarded space debris such as spent rocket stages and debris resulting from satellite collisions and destructive tests. The service performs conjunction assessments and generates warning alerts, supports avoidance manoeuvring planning and RFI mitigation with other spacecraft.

iii. Platform and Payload Prime Contractors

The platform and payload prime contractors provide patches for the spacecraft on board software, provide housekeeping data recorded during spacecraft Assembly, Integration and Test (AIT) activities to support the AIT of the Ground Segment, and assist in the diagnosis of problems during spacecraft commissioning and operation.

iv. National Broadband Network (NBN)

The NBN provides the main high speed data communication links between sites in Australia.

v. Antarctic Broadband

The Antarctic broadband link provides a relatively high speed data link from Antarctica to the Australian mainland to support the transfer of data from the primary ground station located on the Antarctic coast. The link is planned to be implemented through the proposed Antarctic Broadband system which has been initially funded by an Australian Space Research Program (ASRP) grant. The existing TDRS satellite system and the forthcoming Inmarsat Global Xpress series of broadband satellites are also possibilities for the Antarctic link.

vi. Existing Australian Ground Station

The existing Tasmanian Earth Resources Satellite Station (TERSS) located at Hobart, forms part of the Garada ground architecture. It provides a backup facility to the main ground station in Antarctica and, being located considerably further east of Mawson and Casey, can access additional orbital passes. The TERSS will be required to be upgraded with high speed modems and S band capability to support Garada.

12.2. Mission Control System

The Mission Control System is responsible for the control of the SAR instrument, the monitoring and control of the spacecraft, and the monitoring and control of the ground station. The MCS receives spacecraft telemetry from the ground station and provides control commands to the ground station for transmission to the spacecraft. SAR control is undertaken in accordance with operating requests received from the Mission Management and Data Processing System. The MCS manages all housekeeping for the spacecraft (orbital and attitude control, power management etc) and ensures the SAR is operated at the correct times in the appropriate modes to fulfil a customer request. It also plans for and manages the collisions risks of the spacecraft using data provided by an external conjunction assessment service.

The MCS supports the following:

- Mission analysis
- Mission operations preparation
- Mission planning and scheduling
- Spacecraft monitoring and control
- Spacecraft orbit and attitude monitoring and control
- Conjunction management
- On-board software maintenance and management

- Spacecraft Telemetry, Tracking and Command (TT&C) data archiving
- Spacecraft performance analysis and reporting
- SAR command generation
- Time management between the space and ground systems
- GSS monitoring and control
- Simulation and training of spacecraft operators
- Network management and scheduling
- Network reporting

12.3. Mission Management and Data Processing System

The MMDPS provides the SAR operations and data support to generate and exploit the SAR products. It provides the interface to the end users, receives data requests and delivers end products. It provides the high level mission management and sets goals and policies that govern the other systems.

The MMDPS supports the following:

- Mission management
- Configuration management (space segment, ground segment, mission information);
- User services
- Financial management and accounting
- SAR operations analysis
- SAR operations planning and scheduling
- SAR operations control
- SAR data processing
- SAR data archiving
- SAR calibration
- SAR Data product delivery
- SAR Performance analysis and reporting
- SAR algorithm tuning and development, verification and validation
- GNSS monitoring, analysis and calibration

12.4. Ground Station System (GSS)

The GSS provides the communications link to the spacecraft in orbit. It houses the dual feed tracking antenna for payload data downloads and TT&C transmission and reception from the spacecraft. The system is located remotely from the MCS at a geographical location that optimises the contact time with the orbiting spacecraft. It is remotely operated and controlled and in normal use, operates unmanned. Two ground stations at different geographical locations are used to provide redundancy, diversity and increased orbital coverage. All communication between the GSS and the MCS is via the ground Communications System. The Ground Station supports the following:

- Telemetry reception, storage and distribution;
- Telecommand transmission;
- Tracking, ranging, Doppler and meteorological data acquisition;
- Station monitoring and control
- Payload data reception
- Data distribution

12.5. Communications System

The Communications System provides the interconnections between the systems. It handles all voice and data communications between the ground systems and between the ground systems to the outside world. It provides the interfacing to the NBN that is used to transport the data between ground systems geographically separated within Australia. It also provides the interfacing to the Antarctic Broadband communications link that provides a broadband data link between Australia and the ground station located in Antarctica. The Communications System supports the following:

- Inter system voice and data communications
- Voice and data communications with outside world
- Backup communications
- Internet access
- Network monitoring
- Network trend analysis

12.6. Support System

The Support System provides hardware and software maintenance and upgrades to the ground segment. It undertakes spacecraft flight software updates in accordance with software change requests from the MCS and undertakes verification and validation activities on the ground and flight software. It supports the following:

- System maintenance
- Configuration management of ground segment hardware and software
- Spacecraft and ground segment software maintenance, verification and validation

13. Operations Segment

The Operations Segment is comprised of the trained staff who operate the ground segment and the plans and procedures required to undertake the mission preparation and operations. For Garada these teams will typically involve the following types of people:

- Operations managers
- Spacecraft operators
- SAR operators
- Mission planners
- Flight dynamics engineers
- Ground system operators
- SAR payload exploitation personnel; eg scientific and algorithm experts, end user liaison staff, product generation support staff, and calibration experts.
- Ground system maintenance engineers.

Training of the operations personnel and the addressing of skill deltas is addressed in the Project Industrialisation Plan (ref 4).

14. Ground Segment Locations

14.1. Existing Australian Ground Receiving Stations

Australia currently has three earth observation ground receiving stations with antennas greater than 8m and communication link bandwidths greater than 100Mbps. Their location and capabilities are listed in Table 5 and illustrated in Figure 6.

Table 5: Existing EO Ground Receiving Stations, >8m Antenna

Facility	Location	Agencies	Communications Bandwidth	Capabilities (Downlink)
IFCI	Darwin NT	DCCEE	800Mbps	X
Alice Springs	Alice Springs NT	GA	>100Mbps, (currently being upgraded to 800Mbps)	X, L Polar, S, TDRSS
TERSS	Hobart, Tas	CSIRO, GA, BoM, University of Tasmania.	>100Mbps	X

Figure 6: Existing Australian High Bandwidth Earth Observation Receiving Stations

The National Earth Observations from Space Infrastructure Plan (NEOS-IP) discussion papers (ref 5) propose the upgrade of Australia's three high data rate receiving stations to six with the addition of three new sites in North Eastern Australia, Western Australia and

Antarctica. The assessment of the coverage of Garada from these sites is detailed in reference 2 Annex D and reference 2 section 16.3.

Figure 7 shows the number of orbits out of the 89 in the 6 day repeat cycle that are accessible from each location. It is concluded that a combination of a new ground station at Mawson in the Antarctic and the existing station at Hobart offers the best coverage for the Garada mission. The combination of Hobart with Mawson, due to their east-west spacing, offers access to an additional 12 orbits per repeat cycle than that from Mawson alone. The combination of the two locations gives 79% coverage (70/89 orbits). The Hobart station will require upgrading to handle the higher data rates of Garada and S band telemetry and telecommands. A new ground station will need to be established at Mawson station in the Antarctic, consistent with NEOS-IP discussion paper intent.

The Antarctic ground station will require the establishment of a broadband link to provide a high speed data link from Antarctica to the Australian mainland. Existing data links to Antarctica do not have the capacity to handle the volume of data that will be received from Garada. The link is planned to be implemented through the proposed Antarctic Broadband system which has been initially funded by an Australian Space Research Program (ASRP) grant. The existing TDRS satellite system and the forthcoming Inmarsat Global Xpress series of broadband satellites are also possibilities for the Antarctic link.

Australia’s subantarctic station on Macquarie Island in the southern ocean is located east of Tasmania, south of New Zealand and approximately halfway between Australia and Antarctica. Owing to this more southerly and easterly location, in combination with Mawson it gives better access than the Mawson / Hobart combination at 89% coverage (79/89 orbits). However, as Macquarie Island requires a new ground station to be installed, and with the difficulties in returning the data to Australia, the Mawson / Hobart combination is preferred.

The present receiving station at Alice Springs, if updated to S band transmission as well as the existing S band reception, and high data rate reception, can serve as a backup to Hobart and Mawson if there are failures or weather outages at these sites.

The Kongsberg Satellite Services (KSAT) operated ground station in the Svalbard archipelago in the Arctic is the best location examined; 80/89 orbits have accesses greater than 360 seconds and 100% of orbits have access times greater than 300 seconds. Whilst outsourcing the ground station to KSAT is an option for Garada, the Mawson / Hobart combination is baselined due to its reuse of existing assets and consistency with the discussion papers for the National Earth Observations from Space Infrastructure Plan.

The orbits accessible from Svalbard, Mawson and Hobart are illustrated as ground tracks in Figure 8.

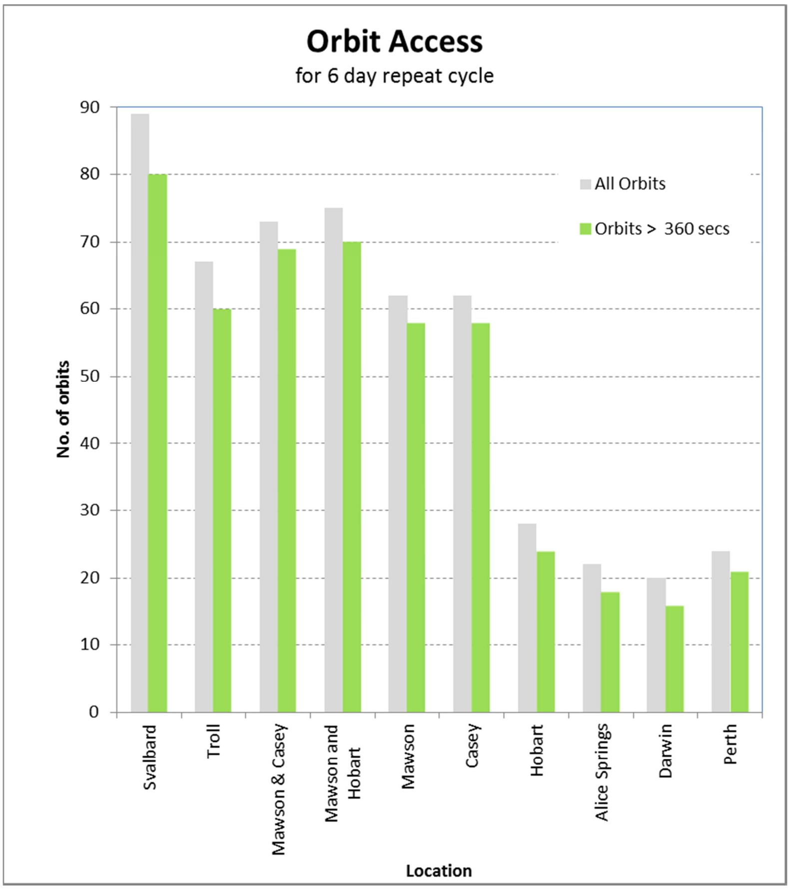

Figure 7: Accessible Orbits

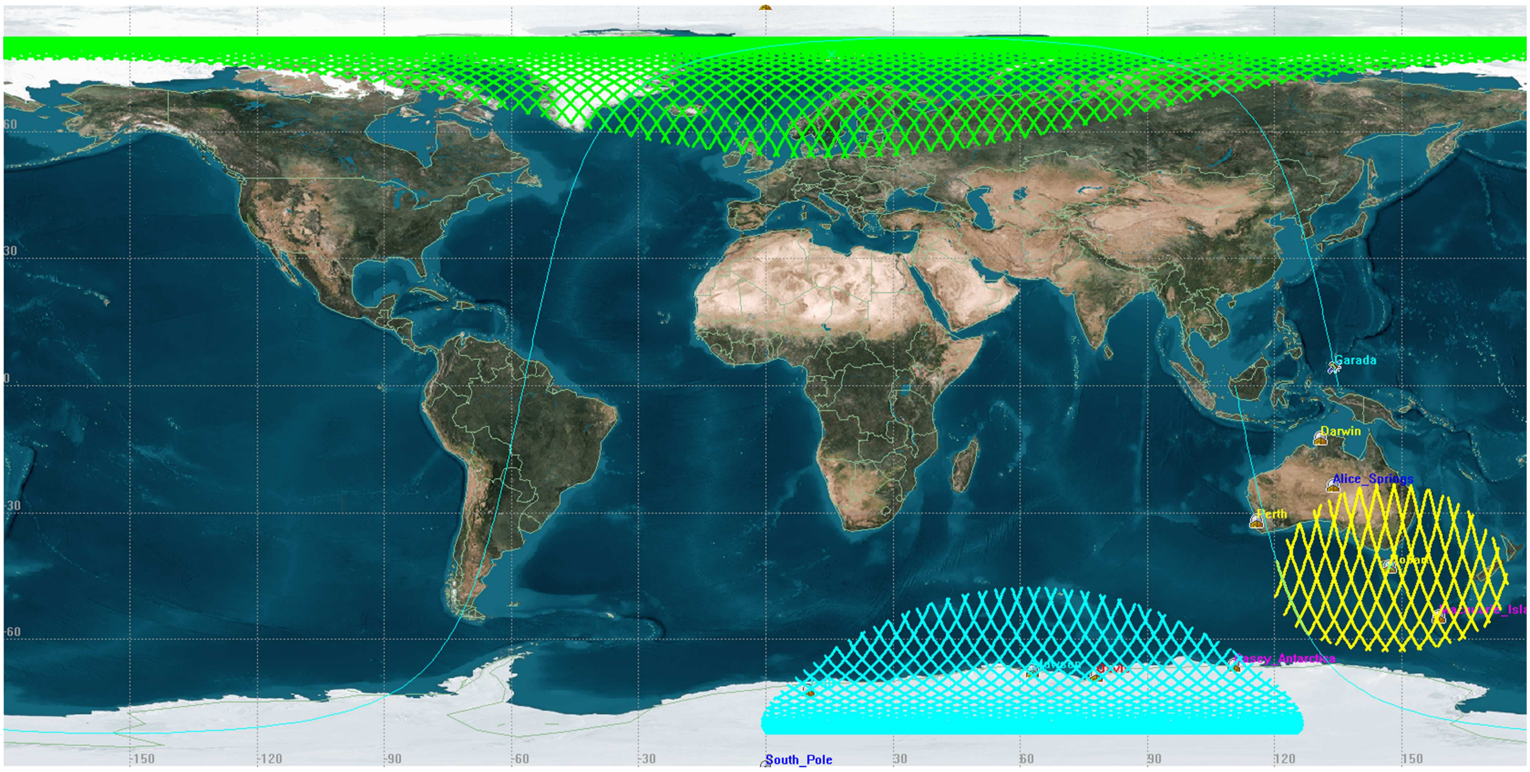

Figure 8: Orbits Accessible from Mawson, Hobart and Svalbard

14.2. Garada Ground Segment Locations

The ground segment will be located at three major sites. The Mission Control System and Mission Management and Data Processing System have close interaction and similar physical needs. They are collocated on the same site, preferably within the one building. This can be located anywhere in Australia that has access to high speed broadband communications and the team of operating personnel. For the purposes of this report, Canberra has nominally been chosen.

The Ground Station System is split over two sites, a south easterly Australian site at the existing TERSS ground receiving station near Hobart, and an Antarctic ground receiving station located at Australia's most westerly Antarctic base, Mawson station. The Communication System uses communication infrastructure external to the Garada project, primarily the proposed Antarctic Broadband satellite network, the NBN, and public accessible voice and data infrastructure. This infrastructure is geographically dispersed across the Garada ground systems.

The main components of the Support System will be located with the MCS and MMDPS, with which much of the software development will be associated. The remaining components will be located at the Mawson base to maintain the ground Station there.

The Ground Segment locations are illustrated in Figure 9.

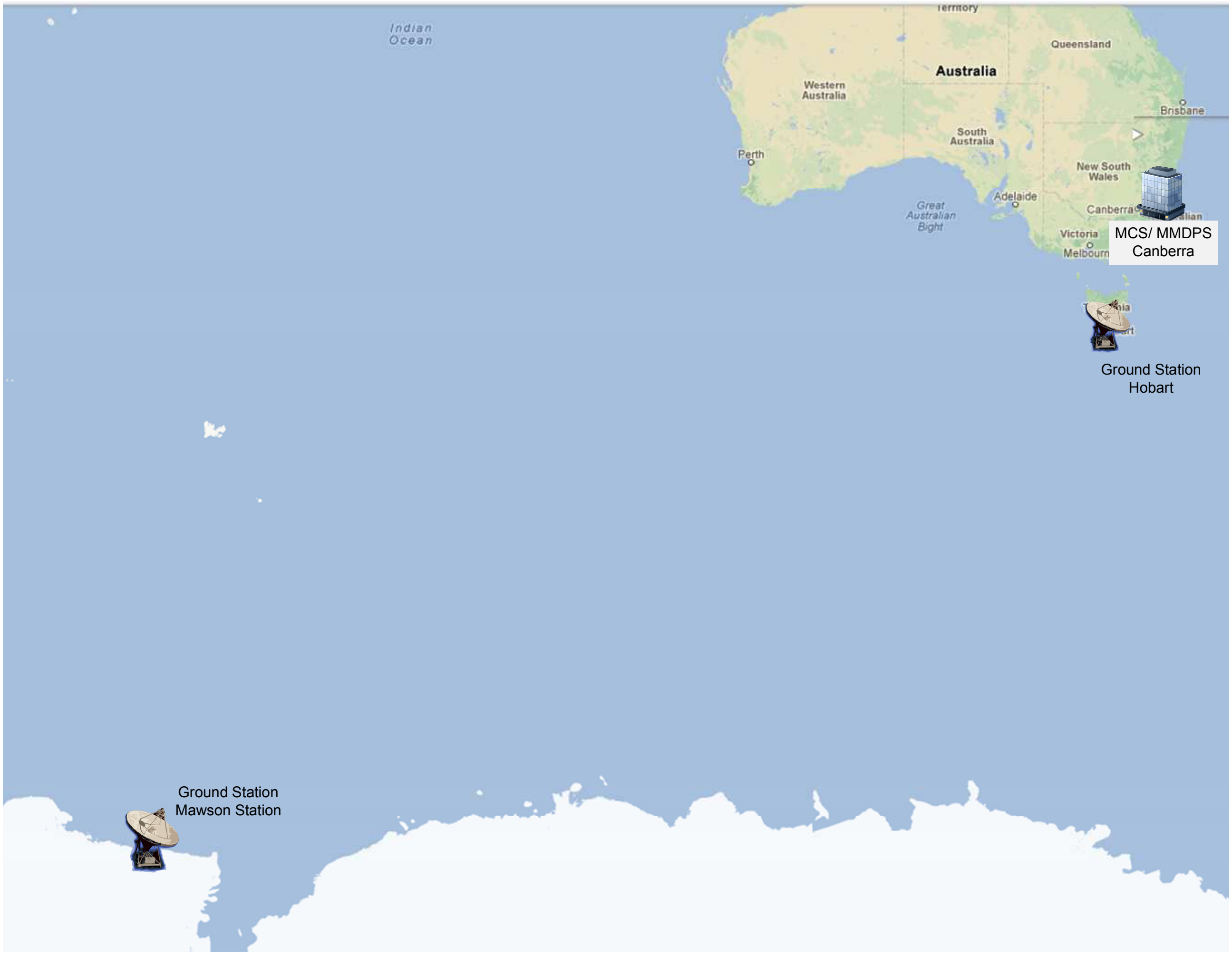

Figure 9: Ground Segment Locations

14.3. Support of Mission Phases

The mission is broken down into the following phases:

Launch and Early Orbit Phase (LEOP): expected duration 2 weeks covering launch, separation, orbit injection, safe pointing mode acquisition, S band link acquisition and initial spacecraft checkout.

Commissioning Phase: expected duration 6 weeks covering spacecraft nominal operations and checkout, verification of the GNSS, activation and checkout of the SAR.

SAR Calibration Phase: expected duration 4 weeks covering calibration of the SAR in all modes.

Operational Phase: expected duration 60 months minimum covering tasking of the SAR and downloading and processing of SAR data.

Decommissioning Phase: covering deorbiting of the spacecraft, decommissioning of the ground segment and archiving of all spacecraft and payload data.

The ground segment is required to support all phases of the mission. The spacecraft will be operated from a single ground station during all mission phases except for LEOP during which other ground stations may support the acquisition of S band data. Another ground station located in Australia, or elsewhere in the world, will provide backup of S band communications in the case of a failure of the main ground station. The ground segment will be compatible with the download of payload data from other ground stations such as existing Australian ground stations and other international ground stations.

15. Mission Planning

15.1. Flight Operations Planning

The planning of spacecraft operations is based on the mission plan which is specified by the mission planning team based on the prioritised data collection schedules, payload calibration requirements and spacecraft maintenance requirements (eg software uploads, orbital manoeuvres).

The flight operations planning covers the following activities:

i. Routine commanding and monitoring of the spacecraft platform and payloads.

ii. Commanding of the SAR to survey the required area in the required modes.

iii. Downloading of SAR data from memory during passes over the ground station.

iv. Planning and execution of manoeuvres for orbit corrections and collision avoidance.

v. Platform and payload calibration and maintenance activities.

vi. Planning of spacecraft operations and configuration during eclipse periods.

Flight operations planning is performed by the personnel in the operations segment using the capabilities of the Mission Control System.

15.2. Data Processing Planning

The processing of the SAR data is primarily data driven; ie the availability of the data triggers the processing. In the Garada system there is no real time broadcast of the SAR data. The data is stored on board the spacecraft and downloaded to the ground station on the next accessible pass. For the majority of orbits the download of the data will take place within 80 minutes of collection. Increased delays will occur for orbits that do not overfly the primary or secondary ground stations and hence require downloading of data on subsequent orbits. Delays will also be incurred where there is a malfunction of the on board or on ground communications systems.

For normal operation, no near real time processing of the data is required. The data products are processed after each pass. Quick look products of lower resolution that require significantly less computational time will be used to confirm the quality of the acquired data.

Planning input to the data processing activity of acquisition, download and calibration schedules, and customer delivery schedules will be provided by the operations team in the MCS and customer services team in the MMDPS.

15.3. Collection Activity Planning

The collection activity planning generates the high level SAR data collection schedules. The bulk of the data collection is performed to the requirements of the long term acquisition plan. These requirements are interleaved with requests to support calibration activities and user community requests. The policies that govern data collection are set by the Garada Management Board and are implemented within the MMDPS. Refer reference 3.

16. Data Processing

16.1. Telemetry Reception

Telemetry data will be downloaded each pass over each ground station via one S band channel. The telemetry data will contain:

i. Real time telemetry data downlinked during the pass

ii. Telemetry data recorded during the entire orbits since last telemetry download

iii. SAR data required to support calibration

16.2. Telemetry and Telecommands Archiving and Retrieval

Received telemetry is both stored at the receiving ground station and transmitted in real time to the MCS. In the case of malfunctioning communications links from the MCS to the ground station the stored data is sent to MCS on request when the link is restored. All telemetry received at the MCS is archived in the spacecraft database. Telemetry data will be stored as raw data and all attributes and calibration data required to interpret the telemetry data will also be stored. The archived data will be available to all ground segment systems that require this data.

Telecommands are archived at the MCS and at each ground station along with their transmission records and acknowledgement. Retrieval of the records can be undertaken by the MCS on specifying which data to retrieve and the time window for data retrieval.

16.3. Payload Data Reception

The RAW SAR and GNSS data will be recorded on board the spacecraft during the orbit and downloaded from memory during the pass over the ground station. Approximately 12 of the orbits can be accessed from both the Hobart and Mawson ground stations. In the case of dual access, the data will be downloaded at the Hobart ground station. This reduces the volume of data to be transferred over the Antarctic broadband link. The data provided during each pass will be the data collected since the previous pass. When there are malfunctions of the spacecraft data link during download resulting in missing data, the MCS will request a deferred download of the missing data.

All payload data is stored at the receiving ground station and sent to the MMDPS on request. Nominally the data received during one orbital pass is sent to the MMDPS prior to the next orbital pass. Time tagged telemetry data describing the spacecraft parameters including orbit and attitude at the time of collection are sent to the MMDPS by the MCS. The MMDPS archives this data along with the raw SAR data.

16.4. SAR Data Processing

The raw SAR data downloaded from the spacecraft will be provided to the MMDPS along with the corresponding spacecraft telemetry data. The following data products will be generated and archived in the MMDPS as required by end users:

Level 0	The RAW SAR data after decryption and before unpacking associated with auxiliary data including satellite data (trajectory, attitude, position, payload status) and calibration data required to produce the other products.
Level 1A	Single look complex slant product consisting of RAW data in the slant range azimuth projection, calibrated and containing in phase and quadrature data.
Level 1B	Detected Ground Multi-look product obtained by detecting, multi looking and projecting the single look complex data onto a rectangular ground grid.
Level 1C	Geocoded product obtained by projecting the 1A product onto a regular grid in a chosen cartographic reference system. The surface is the earth ellipsoid.
Level 1D	As per level 1C, but with a digital elevation model used to approximate the real earth surface.
Level 2	Georeferenced product forming a map image and interpreted data.

Level 0 products are processed within the duration of one orbit before the next download starts. Quicklook products- low resolution level 1 products, are processed within the duration of one orbit to confirm the quality and calibration of the radar data. Level 1 products are generated after the receipt of the Level 0 product in accordance with the end user priorities.

All products and associated data are archived in the MMDPS.

17. Interfaces

17.1. Interface Definitions

The ground segment interfaces are illustrated in Figure 10 and summarised in reference 2. Work on the detailed design of the interfaces has not commenced and will be part of the phase B activities. The transfer of data across the interfaces will mainly be performed by the exchange of computer files via network connections. The main exceptions are:

i. Interfacing to the Garada spacecraft will be performed through RF connections.
ii. Transfer of data from the customer will be via a web interface.
iii. The delivery of final products to the end users will be via the internet or on physical media.
iv. Voice communications will be via the public switched telephone network.

The interfaces will be described in the following documents, refer Figure 4:

a. Interfaces to the space segment are described in the “Space Segment to Ground Segment Interface Requirements Document”
b. Interfaces to external entities ie entities not belonging to the space segment, are described in the “Ground Segment External Interface Requirements Document”.
c. Interfaces internal to the ground segment are described in the “Ground Systems Interface Requirements Document.”

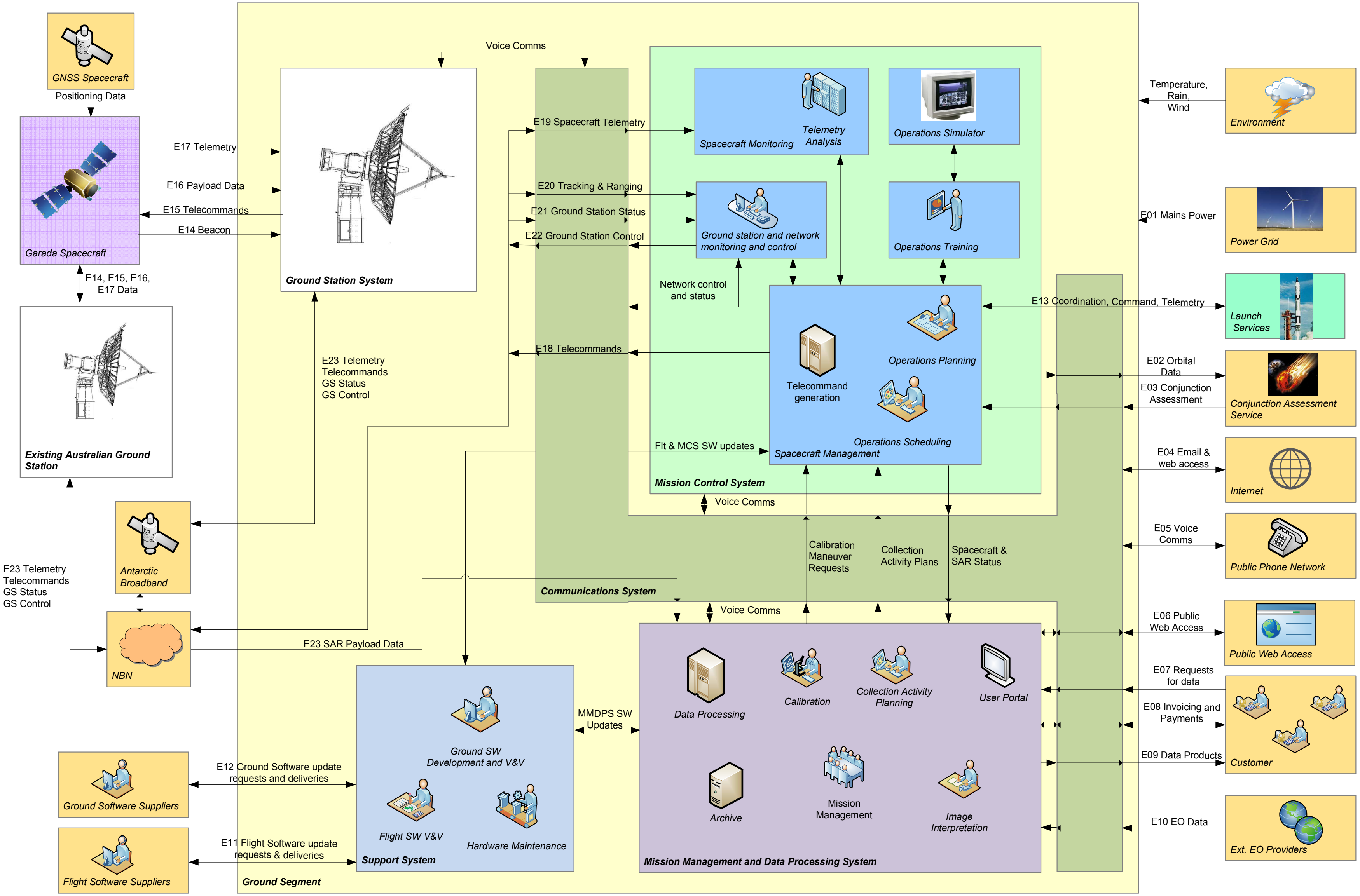

Figure 10: Ground Segment Interfaces

18. Communications System Update

The following paragraphs update the information provided in reference 2 annex C, and reference 2 annex D.

The ground segment communications system design has been iterated based on the design trades undertaken by the spacecraft communication systems designers and described in reference 5. The communications system's bandwidths, bitrates, EIRP, and antenna size trades undertaken for the X, Ku and Ka bands detailed in the Ground Segment Architecture Report (ref 2) have been used as the basis for the design trades of the spacecraft communications system. In reference 5 an additional criterion is taken into account, that of using the spacecraft to image other countries for the public good and commercial imaging. This is considered to be both politically and commercially desirable to strengthen the case for Garada. This criterion drives a derivation of a new requirement for the data communications system, that of compatibility with existing ground station infrastructure in other countries. A further requirement is introduced for the spacecraft communications system to use the maximum bitrate available from commercially available transmitters.

The first of these requirements leads to the conclusion that as X band has been used in every earth observation spacecraft launched to date, there is an existing ground infrastructure supporting X band communications. To ensure compatibility with this infrastructure, X band is nominated for the Garada data communications system.

To support the latter requirement for the selected communications band, reference 2 nominates the use of the Surrey Satellite Technology XTx400 X Band transmitter. A maximum data rate of 500Mbps and 8PSK 5/6 TCM encoding can be supported by this transmitter. Two of these can be operated through separate antennas with opposite polarisations to give a combined data rate of 1,000Mbps. This becomes the new baseline for the communications system data rate.

The maximum time the spacecraft can spend imaging during an orbit is related to the duty cycle that the spacecraft can support (it is also dependent on whether the imaging is toward or away from the sun). The duty cycle is determined by the power and thermal constraints of the spacecraft. Reference 2 examines the power consumption of the spacecraft and concludes that due to the large surface area of the solar panels, the power system will support a duty cycle of 100%; ie continuous operation of the SAR. The thermal modelling performed by Astrium and detailed in TK3.4 "Thermal Analysis" (ref 6), shows that, for a first iteration, 20 mins or 21% duty cycle is possible. This is for the best case of imaging away from the sun. For imaging towards the sun, a SAR operational limit of three orbits is imposed due to the higher temperatures incurred at the equipment shelves. The maximum data that can be downloaded is then set by the lesser of:

i. The total data given by the product of the download data rate, access time and number of accesses per orbit
ii. The data acquired for a 21% duty cycle.

The Garada system is designed for a polar ground station to provide the maximum number of orbits that can be accessed during the full orbital complete cycle. In the baseline design the number of accesses per orbit is one.

The payload data download rate for the Garada spacecraft has been baselined at 1000Mbits/sec. The DVB RCS S2 FEC codec which enables Adaptive Coding and Modulation (ACM) has been chosen as the optimal codec for the payload data link. Refer reference 2 annex A. The minimum required modulation and coding schemes vary from the 8/9 QPSK for 1000Mbps in the K and Ka band to 4/5 QPSK that is required to achieve 500Mbps in the 375MHz bandwidth for each of two transmitters in the X band. Table 6 summarises the bitrates for different modulation and coding schemes for a 640MHz IF bandwidth.

If K or Ka band are used, the first 5% of elevation will be run with the slower ½ QPSK codec with lower Eb/No to allow signal acquisition in the higher atmospheric attenuations that occur at these low elevation angles. The transmission will switch to a 3/4 QPSK or faster codec at the higher elevations where there is less attenuation and more power is available.

Table 6: Achievable Codec Bitrates for a single channel

Name	Bitrate for 640MHz IF bandwidth (max channel capacity) Mbps	Bitrate for X band Mbps (375MHz BW)	Bitrate for K and Ka band Mbps (1.5GHz BW)	Comment
QPSK DVB S2 (LDPC) 1/2	532	312	532	
QPSK DVB S2 (LDPC) 2/3	710	416	710	
QPSK DVB S2 (LDPC) 3/4	801	470	801	
QPSK DVB S2 (LDPC) 4/5	855	**501**	855	Required for 500Mbps in X band
QPSK DVB S2 (LDPC) 5/6	887	520	887	
QPSK DVB S2 (LDPC) 8/9	952	558	952	Required for 1000Mbps in K and Ka band
8PSK DVB S2 (LDPC) 2/3	1,065	624	1,065	
8PSK DVB S2 (LDPC) 3/4	1,199	703	1,199	
8PSK DVB S2 (LDPC) 5/6	1,334	782	1,334	
8PSK DVB S2 (LDPC) 8/9	1,425	835	1,425	

Astrium has provided the bit rate of the SAR for the primary and other operational modes in Ref 6. The SAR bit rate required to support the primary application of monitoring the Murray Darling Basin soil moisture is 290Mbps based on 4I and 4Q sampling for each polarimetric channel and a spatial resolution of 1000m. For high resolution quad polar observations in stripmap mode with 6mx8m resolution, a 730Mbps bit rate is required. Single polar operational modes have much lower bit rates and allow longer swath lengths as detailed below.

Using a minimum access time of 360 seconds (ref 2 Annex A) the data quantities and swath lengths for the SAR primary application and high resolution sampling modes are shown in Table 8 and summarised in Table 7. The quantities are calculated using a 2% data framing overhead.

For quad polar stripmap mode the swath length and surveillance time could be increased to 8,400km and 1,222 seconds by the use of additional ground stations to give multiple accesses per orbit. These ground stations would be required to be located near the earth's poles to maximise the number of orbits that can have multiple accesses. Additional ground stations will not increase the surveillance time for the other SAR operational modes as the system is limited by the spacecraft dwell time rather than the amount of data that can be downloaded in one access period.

Table 7: SAR Operating Modes and Acquired Data

Mode	SAR data rate Mbits/sec	Swath Width	Swath Length Km	Spatial Resolu-tion m	Surveillance Time (secs)	Dwell Time %	Data Acquired Gbytes	Download rate Mbits/sec
Quad polar wide swath (MDB mode)	290	377	8,400	1,000	1,222	21%	45	1,000
Quad polar stripmap	730	50	3,300	6 x 8	485	8%	45	1,000
Single polar wide swath	156	958	8,400	180	1,222	21%	24	540
Single polar strip map	190	50	8,400	6 x 8	1,222	21%	30	540

Table 8: SAR Data and Swath Lengths

MDB mode

Limited by duty cycle

					Quad polar wide swath		Quad polar strip map		Single polar strip map		Single polar wide swath	
Swath Length km	Surveilance Time Sec	Dwell Time %	Surveilance Time Sec	Dwell Time %	Data Acquired Gbytes	Payload bit rate during download Mbits/sec	Data Acquired Gbytes	Payload bit rate during download Mbits/sec	Data Acquired Gbytes	Payload bit rate during download Mbits/sec	Data Acquired Gbytes	Payload bit rate during download Mbits/sec
10	1	0.0%	1	0%	0	1	0	3	0	1	0	1
1,000	146	2.5%	146	3%	5	120	14	301	4	78	3	64
1,500	218	4%	218	4%	8	179	20	451	5	117	4	96
2,000	291	5%	291	5%	11	239	27	602	7	157	6	129
2,500	364	6%	364	6%	13	299	34	752	9	196	7	161
3,000	437	8%	437	8%	16	359	41	903	11	235	9	193
3,330	485	8%	485	8%	18	398	**45**	**1,002**	12	261	10	214
4,000	582	10%	582	10%	22	478	54	1,204	14	313	12	257
5,000	728	13%	728	13%	27	598	68	1,505	18	392	14	322
6,000	873	15%	873	15%	32	717	81	1,806	21	470	17	386
6,300	917	16%	917	16%	34	753	85	1,896	22	493	18	405
7,000	1,019	18%	1019	18%	38	837	95	2,107	25	548	20	450
8,000	1,164	20%	1164	20%	43	956	108	2,408	28	627	23	515
8,400	1,222	21%	1222	21%	**45**	**1,004**	114	2,528	30	658	24	540
9,000	1,310	23%	1310	23%	48	1,076	122	2,709	32	705	26	579
9,600	1,397	24%	1397	24%	52	1,148	130	2,889	34	752	28	617
10,000	1,455	25%	1455	25%	54	1,196	135	3,010	35	783	29	643
11,000	1,601	28%	1601	28%	59	1,315	149	3,311	39	862	32	707
11,700	1,702	29%	1702	29%	63	1,399	158	3,521	41	916	34	752
12,000	1,746	30%	1746	30%	65	1,435	163	3,612	42	940	35	772
13,000	1,892	33%	1892	33%	70	1,554	176	3,912	**46**	**1,018**	38	836
14,000	2,037	35%	2037	35%	75	1,674	190	4,213	49	1,097	41	900
15,000	2,183	38%	2183	38%	81	1,793	203	4,514	53	1,175	43	965
16,000	2,328	40%	2328	40%	86	1,913	217	4,815	56	1,253	**46**	**1,029**
17,000	2,474	43%	2474	43%	91	2,033	230	5,116	60	1,332	49	1,093
18,000	2,619	45%	2619	45%	97	2,152	244	5,417	63	1,410	52	1,158
20,000	2,910	50%	2910	50%	108	2,391	271	6,019	70	1,567	58	1,286

19. Ground Segment Implementation

The solution baselined from this study implements the functionality described in the preliminary architecture document (Ref 2). Key elements of each subsystem implementation are summarised below.

19.1. Ground Station System

19.1.1. New Ground Station

The new ground station is based on an 8m antenna with pedestal and equipment cabin with the following capabilities:

i. X band feed and block down converter

ii. High data rate receiver

iii. Data Encryption

iv. S band feed

v. S band block up / down converter

vi. S band modem

vii. Antenna tracking and control computer

viii. Ground station server

ix. Interface to NBN

All items are Commercial Off The Shelf (COTS) with the exception of the software running on the ground station server which will be a development item.

19.1.2. Updated Existing Ground Station

It is assumed that the upgrade of the existing TERSS X band earth observation ground station in Tasmania will require the replacement of the baseband componentry to meet the higher data rate requirements of Garada.

19.2. Mission Control System (MCS)

The MCS is based on an array of COTS hardware computing platforms running COTS based software solutions for the satellite command control and monitoring. Bespoke software is required to be developed to interface the COTS software products to the Garada system and for the mission specific functionality of ground station control, SAR management, application specific databases and the MCS simulator.

19.3. Mission Management and Data Processing System (MMDPS)

The MMDPS uses COTS computing platforms running mainly bespoke software. This system has the largest amount of software development in the ground segment. The most significant item to be developed is the software for processing the SAR echo data into imagery. Astrium has advised that the detailed format of the raw SAR data, which contains echo data plus orbit and AOCS data, will be specific to the Garada SAR, requiring the development of a custom data interface. The mathematical processing kernel is matched to the SAR data streams and, whilst components of the processing kernel can be purchased, the advice received from DSTO based on their experience with airborne SARs, is that significant coding of complex algorithms is required.

The output side of the SAR data processing system processes the SAR value matrix of complex radar reflectivity with associated metadata to produce the single look complex slant range images, multi look detected slant range images and other products. This is quite specific to the Garada SAR and again, will require significant software development effort.

The ortho-rectification and terrain correction processing which ortho-rectifies the image onto a standard map projection is planned to be undertaken with custom software using available production utilities such as the Next ESA SAR Toolbox (NEST).

The SAR products require further processing to produce the end items of soil moisture contours, and flood, forest, and oil slick outlines specified in the Functional Performance Specification (Ref 1). These processes require software to be developed to implement the complex algorithms required. The development of the algorithms themselves is not included as part of the ROM scope. These R&D tasks are allocated to the University research organisations in the Garada Project Industrialisation Plan (Ref 4).

Other bespoke software is required for the spacecraft and payload command and telemetry simulations, the payload data interface server, and calibration workstation.

19.4. Communications System (CS)

The Communications System solution is based on interfacing to two prime data networks for the transmission of data between systems and between the segment and external agencies.

i. The NBN is used for sending data within Australia. This high speed network based on the use of a high speed terrestrial fibre backbone between the major cities will be fully operational within the timeframe of Garada.

ii. The proposed Antarctic Broadband Network for data communications between Australia and a ground station in Antarctica. This relatively low speed but high availability link is based on the use of small satellites in an inverse Molniya orbit over the Australian Antarctic Territory. This project has completed a definition study and demonstration of significant hardware, but there are presently no plans to fund the implementation. Should an alternative network be used it is expected to use a similar IP protocol and the changes to the ground segment interface will not be a significant cost driver to the ROM estimate.

20. ROM Costing

A Rough Order of Magnitude (ROM) costing was undertaken for the ground segment and reported in TK 10.4 Garada Ground Segment ROM Cost Estimate (ref 9). The ROM cost is for a ground segment that meets the Ground Segment Functional Performance Specification (Ref 1) based on the architectural solution described in the Preliminary Ground Segment Architecture Document (Ref 2).

20.1. Work Scope

The ROM cost covers the design, development, production and verification of the ground segment for Garada including:

i. The delivery, installation and on site verification of the ground systems.

ii. Integrated logistics support including operation and maintenance manuals, and the preparation of training courses for operators and maintainers.

iii. Operations engineering covering the analysis, concept development, data production and data validation for operations.

iv. Project management, engineering management, configuration management, and quality management to support the above.

During the ground segment costing process it was necessary to limit some specific items from the scope of the costing. These were:

i. Design for Antarctic environment & installation of a ground station in Antarctica. The costing is for installation into an Australian location.

i. Building civil infrastructure for the MCS, MMDPS, SS and CS.

ii. Spacecraft hardware for the flight software Verification and Validation (V&V) environment.

iii. Research into processing algorithms.

iv. Spacecraft hardware for ground systems and operational data verification.

v. Operations execution for the spacecraft's operational life including: operations teams build up and training, provision of spares to support ongoing operations, and ongoing engineering support to operations.

The assumptions for the ground segment are described in reference 9.

20.2. Ground Segment ROM Price

A Rough Order of Magnitude (ROM) price for undertaking the Garada ground segment was derived by BAE Systems using parametrics as $87m ex GST. The costing is provided in Ref 9 and the reader is referred to that document for full details of the costing and scope. The ROM price is intended to be used for budgetary purposes only and to inform stakeholders of the approximate cost of implementing a ground segment for the Garada Mission.

21. Ground Segment Schedule

The indicative schedule for the ground segment is shown in Figure 11. This shows a total duration of 69 months, broken down as follows:

- Phase A, Mission and operational analysis, conceptual design:- 9 months

  Requirements from the ground segment and operations customers are analysed to identify and characterise the ground segment in terms of operational feasibility, expected performance, reliability, availability, maintainability and safety. Operational constraints are also evaluated. This phase culminates in the Customer Requirements Review (CRR) where the completeness of the customer requirements, operations concept and ground segment baseline are reviewed.

- Phase B, Preliminary design: 12 months

  This phase refines the ground segment baseline, confirms its ability to meet the ground segment requirements and defines the ground segment baseline. Preliminary Interface Control Documents (ICDs) and system specifications are produced. A System Requirements Review (SRR) is held during this phase and a Preliminary Design Review (PDR) at the end of the phase.

- Phase C, Detailed design: 12 months

  The ground segment design is completed to the level of individual subsystems and production commenced. The operations organisation is defined and the production of mission operations data is commenced. Phase C is concluded by a Critical Design Review (CDR).

- Phase D, Production, AIT and Verification: 36 months

  All ground systems are manufactured or procured and integrated into an operational ground segment. Operations data production is completed and validated. The ground segment AIT concludes with an Acceptance Review (AR) and a Qualification Review (QR). The validation of operations data concludes with an Operations Qualification Review (OQR).

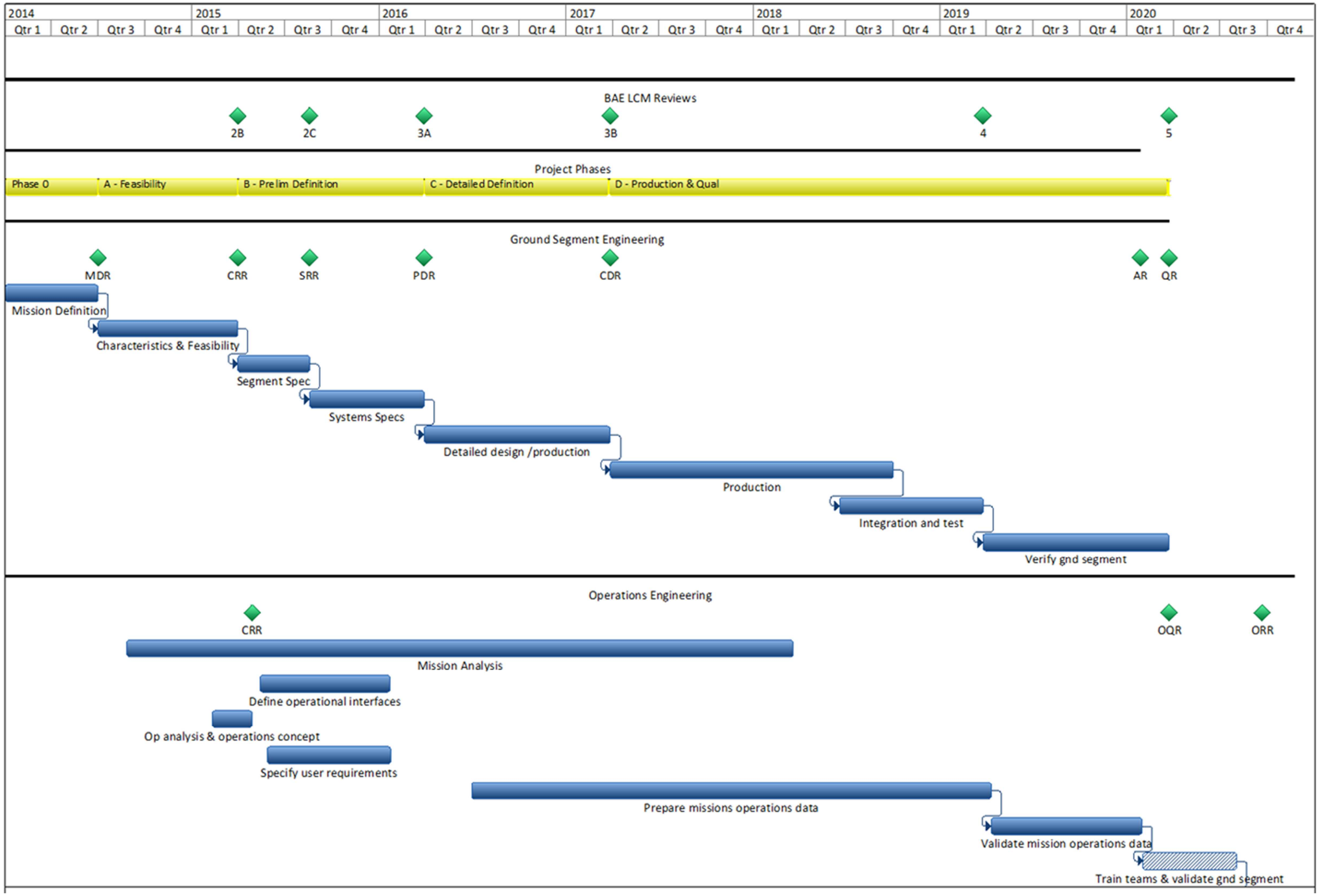

Figure 11: Indicative Ground Segment Schedule

22. Summary Work Breakdown Structure

A detailed Work Breakdown Structure (WBS) for the Garada ground segment was generated to support the capability requirements analysis undertaken as part of the Garada Industrialisation analysis and expanded to support the generation of the ROM pricing. The full WBS is provided at Annex A to ref 9. A summary of the WBS is provided in Annex A. The WBS breaks down the work to the individual ground segment subsystems, integrates these as subsystems and integrates and tests the subsystems to create the segment. The work at the subsystems is supported by segment level systems engineering, integration and test and project management.

23. Conclusion

The Garada Work Package 10 for the ground segment definition has been completed with a thorough analysis and definition that meets all of the objectives of the work package. The next steps include the completion of the phase 0 activities and the undertaking of phase A activities. This includes:

i. Refining the mission analysis, completing the mission description document, and holding a Mission Definition Review.

ii. Deriving the ground segment customer requirements and mission operations concept. Undertaking requirements and design engineering to refine the ground segment requirements. Generating the ground systems requirements along with engineering, AIT and verification plans.

iii. Holding a Customer Requirements Review.

The work undertaken for the Garada ground segment definition has general applicability to other next generation earth observation spacecraft, both SAR and optical. Whether receiving and processing data from foreign owned spacecraft to progress Australia's national interest, or operating a wholly Australian owned spacecraft. The work on the ground station capabilities, locations, high data rate downlinks and data processing is aligned with the intents of the NEOS-IP and applicable to future programs.

Annex A: Summary Ground Segment Work Breakdown

Table 9: Summary Ground Segment Work Breakdown

1	**Garada Space Segment**
2	**Garada Ground Segment**
2.1	**Ground Segment**
2.1.1	**Ground Segment Definition**
2.1.1.1	**Ground Segment engineering planning**
2.1.1.1.1	Ground segment engineering plan
2.1.1.1.2	Ground segment AIT plan
2.1.1.1.3	Ground segment verification plan
2.1.1.2	**Ground Segment requirements engineering**
2.1.1.2.1	Requirement analysis
2.1.1.2.2	Ground segment requirements specification
2.1.1.3	**Ground Segment design engineering**
2.1.1.3.1	Ground segment design analysis
2.1.1.4	**Ground Systems requirements engineering**
2.1.1.4.1	Ground systems specifications
2.1.1.5	**Interface definition**
2.1.1.5.1	Internal interface definition
2.1.1.5.2	External interface definition
2.1.2	**Ground Segment Production**
2.1.2.1	**Ground Station System #1**
2.1.2.1.1	Specify
2.1.2.1.2	Design
2.1.2.1.3	Antenna and payload data receiver
2.1.2.1.4	S Band Transmitter & receiver
2.1.2.1.5	Cryptographic module
2.1.2.1.6	Ground Station Server
2.1.2.1.7	Mounting and interconnection Hardware
2.1.2.1.8	Integrate and test
2.1.2.1.9	Antarctic Design
2.1.2.1.10	Antarctic Installation
2.1.2.2	**Ground Station System #2 (upgrade existing ground station**
2.1.2.3	**Mission Control System**
2.1.2.3.1	Specify
2.1.2.3.2	Design
2.1.2.3.3	MCS Ground Station Monitoring and Control
2.1.2.3.4	MCS Spacecraft Management
2.1.2.3.5	MCS Communication System Monitoring and Control
2.1.2.3.6	MCS Simulator
2.1.2.3.7	Interface software CSCI
2.1.2.3.8	Network
2.1.2.3.9	Office Furniture

2.1.2.3.10	Integrate
2.1.2.3.11	Test
2.1.2.4	**Mission Management and Data Processing System**
2.1.2.4.1	Specify
2.1.2.4.2	Design
2.1.2.4.3	Calibration workstation
2.1.2.4.4	Payload data interface server
2.1.2.4.5	SAR database server
2.1.2.4.6	SAR archive server
2.1.2.4.7	Data processing workstation
2.1.2.4.8	L2 processing workstation
2.1.2.4.9	Interpretation workstation
2.1.2.4.10	Web server
2.1.2.4.11	Customer Management Workstation
2.1.2.4.12	Network
2.1.2.4.13	Office Furniture
2.1.2.4.15	Integrate
2.1.2.4.16	Test
2.1.2.5	**Communications System**
2.1.2.5.1	Specify
2.1.2.5.2	Design
2.1.2.5.3	External interfaces
2.1.2.5.4	NBN interface
2.1.2.5.5	Antarctic broadband interface
2.1.2.5.6	Integrate and Test
2.1.2.6	**Support System**
2.1.2.6.1	Ground software development and V&V
2.1.2.6.2	Flight software V&V environment
2.1.2.6.3	Hardware Maintenance
2.1.3	**Ground Segment AIT**
2.1.3.1	Integration
2.1.3.2	Integration Testing
2.1.3.3	Verification
2.1.4	**Enabling Products**
2.1.4.1	Software development environments
2.1.4.2	**Enabling Products CSCI**
2.1.4.2.1	Satellite telemetry simulator
2.1.4.2.2	SAR data simulator
2.1.4.4	Integration laboratory
2.1.4.5	Special to task test tools
2.1.5	Systems Engineering support
2.1.6	**Integrated Logistics Support**
2.1.6.1	Logistics support planning
2.1.6.2	Logistics support analysis

2.1.6.3	**Support Elements Deployment**
2.1.6.3.1	Training
2.1.6.3.2	Spares provisioning
2.1.6.3.3	Support equipment
2.1.6.3.4	Support facilities
2.1.6.3.5	PHS&T
2.1.6.3.6	Software support provisions
2.1.6.3.7	User Manuals
2.1.6.3.8	Maintenance manuals and procedures
2.1.7	**Safety**
2.2	**Operations Segment**
2.2.1	**Operations engineering planning and support**
2.2.1.1	Operations engineering planning
2.2.1.2	Operations engineering support tools
2.2.2	**Requirements analysis and concept development**
2.2.2.1	Mission analysis
2.2.2.2	Operational analysis and concept development
2.2.2.3	Operational interfaces definition
2.2.2.4	Contribution to ground segment and ground system requirements
2.2.2.5	Operational validation plan
2.2.3	Mission operations data production
2.2.4	Mission operations data validation
2.2.5	Operations team training
2.2.6	Operational validation
2.2.7	Operational configuration management
2.3	**Project Management**
2.3.1	Project planning and implementation
2.3.2	Cost and schedule management
2.3.3	Risk management
2.4	**Quality**
2.4.1	Quality Assurance
2.5	**Configuration Management**
2.5.1	Configuration Management
2.6	**Engineering Management**
2.6.1	Engineering management
2.6.2	Test management
2.6.3	Integration management
2.6.4	Design authority