Goonhilly-6 Antenna Support to the Orion Exploration Mission 1 Flight

Executive Summary

Reference:	GNY-AS-REP-QIQ-00019
Issue:	1
Rev:	0
Date:	24th March 2016

Administration page

Customer Information	
Customer reference number	RFQ/3-14226/14/D/EF
Project title	Goonhilly-6 Antenna Support to the Orion Exploration Mission 1 Flight
Document title	Executive Summary
Customer organisation	ESA/ESOC
Customer contact	Mr P. M. Besso
Contract number	4000114131/15/D/EF
Milestone due	Final Completion

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1 Introduction

1.1 Background and objective of the project

The overall objective of the study was to assess the feasibility of upgrading the 32m Goonhilly-06 (GHY-06) antenna to support NASA's Orion Exploration Mission 1 (EM-1). This US mission, which will involve a circumlunar flight, will constitute the first flight of the US Space Launch System (SLS) and the second unmanned test flight of the Orion Multi-Purpose Crew Vehicle (MPCV). Latest information indicates a launch date in late 2018.

Under a revised plan recently announced by NASA, EM-1 will be a precursor to a NASA robotic mission called the Asteroid Redirect Mission (ARM), with an expected launch date in the early 2020's.The Orion EM-1 flight will demonstrate the crew element of the ARM.

It is anticipated that NASA will require 24 hour communications coverage of the EM-1 flight for all phases of the mission. For the trans-lunar phase, this implies three ground stations positioned at approximately equal intervals around the earth. The baselined ground stations are those at Goldstone (US), Canberra (Australia) and Madrid (Spain). The study aimed to address the technical and programmatic feasibility of upgrading the GHY-06 antenna so that it could act as either a replacement or back-up European ground station for the mission.

The GHY-06 antenna is owned and operated by Goonhilly Earth Station (GES) Ltd and forms part of the UK ground segment infrastructure for space missions and satellite applications. The UK Space Agency (UKSA) were a stakeholder in this study project and it is anticipated that the findings will enable UKSA to consolidate, in preparation for the next Ministerial Council, a potential UK contribution to an upgrade implementation programme.

1.2 Study programme

The project was led by QinetiQ Space UK supported by GES Ltd and BAE Systems Applied Intelligence Ltd (BAES), who were sub-contracted to address the following specific areas:

- GES Ltd - Responsible for providing inputs to the study associated with the antenna element of the upgrade, including its mechanical and structural design, and the auxiliary equipment and on-site infrastructure needed for its support and operation.
- BAES - Responsible for the baseband element of the upgrade which is to be based on the Tracking Telemetry and Command Processor (TTCP). This system was originally developed by BAES as an upgrade of the Intermediate Frequency and Modem System (IFMS) system, as currently installed in the ESA Deep Space Antenna (DSA) ground stations.

2 Assessment of requirements

2.1 Overall mission requirement

Some input was obtained from NASA on the top-level Orion EM-1 mission requirements. Link budgets were established for worst, best and nominal cases.

The nominal frequency baseline for Orion EM-1 is S-band up and down, but the study also considered enhancements for future Orion missions, such as ARM, including X-band (up and down) and K-band (down only) - frequencies which would also see application in a future Deep Space mission context. GES's desire to retain the existing C/Ku capability was also taken into account. The link budgets for the S-band baseline showed a best / worst case of 3.1 / 0.7 Mbps for the downlink against a requirement of 36 kbps – 2 Mbps (range). The uplink showed a worst-case margin of 10.6 dB against the maximum Orion data rate of 250 kbps. Hence, it was concluded that GHY-06 performance would be more than adequate for the Orion mission.

2.2 Existing GHY-06 performance and status

The GHY-06 antenna is a large Cassegrain antenna with a main reflector of 32m diameter. It employs a unique feed system composed of four focused beam reflectors and a corrugated primary horn. The antenna, which operates at C and Ku-band, is still functional and in routine use in support of Telemetry, Tracking and Control (TT&C) operations, however parts of the system are now over 30 years old and some parts are no longer used.

The current antenna system performance was assessed by GES in the first part of the study. This included testing key sub-systems, in particular the azimuth and elevation drive capability. The status of the antenna structure and mechanical equipment was also assessed to establish the scope for re-use or refurbishment of existing equipment rather than complete replacement.

2.3 GHY-06 upgrade requirements

The GHY-06 system upgrade requirements were established by comparing the derived requirement for the Orion ground station with the current GHY-06 antenna performance and status assessment. The principal findings are summarised in Table 1.

2.4 System performance specification

In conjunction with establishing the upgrade requirements, a system performance specification for the ground station was also produced (Table 2). This is considered provisional at the current time and will be firmed up following completion of more detailed design and analysis work to be undertaken as part of the next phase of the project.

Item	Brief description of work	Reason / comment
System schematics and equipment layout	Redesign of system schematics and equipment layout.	Redefinition of antenna purpose and capabilities.
Feed	New feed for S/X/K-bands.	Existing feed limited to C/Ku-band.
Reflector assembly	Surface profile analysis to be carried out and panels to be re-aligned if necessary. Modelling of RF performance.	Surface accuracy / reflector condition not currently known.
Structure	Remedial / refurbishment work urgently needed on structure, plus modelling of structure using finite element analysis.	To address structural defects identified during survey.
Mechanical	Assess whether az/el drive system suitable for upgrade, replace parts if necessary, carry out any maintenance required. (Replacement of key drive components such as motors, gearboxes recommended).	Operational but 30 years old and in need of maintenance. Designed for GEO not LEO tracking rates.
Servo system	Replacement recommended / required.	Operational but the technology and equipment are 30 years old. Designed for GEO not LEO tracking rates.
Auxiliary equipment	Recommission, rearrange or replace as necessary.	To modernise, ensure fit for purpose and / or meet current legislation for example.

Table 1 Summary of the main modifications/ upgrade work required to GHY-06

Parameter	Performance
Availability / lifetime	99.98% / 10 years
Frequency bands	2.2 - 2.3 / 2.025 – 2.12 GHz (S-band Rx / Tx) 8.4 – 8.5 / 7.145 – 7.235 GHz (X-band Rx / Tx) 25.5 – 27 GHz (K-band, Rx only)
Polarisation	RHCP and LHCP (Rx), RHCP or LHCP (Tx)
Cross polarisation	≥ 25 dB (Rx and Tx)
Pointing modes	Open loop (Programme Track), Closed loop (Conical Scan)
Tracking accuracy	6 mdeg
Transmit gain Receive gain	54.0 / 64.6 dBi (S/ X-band) 54.6/ 66.0 / 72.8 dBi (S/ X/ K-band)
G/T	36.8/ 47.8/ 53.3 dB/K (S/ X/ K-band)
EIRP	86.3 / 99.4 dBW (S/ X-band)
Angular travel	Azimuth: 358.4° (CCW) to 1.6°(CW), Elevation: 0° to 92°
Max / min velocity	0.4 / 0.0001° /sec (Azimuth and Elevation)

Table 2 Summary of key antenna performance parameters for the GHY-06 upgrade

3 Preliminary design

3.1 Introduction

The preliminary design proposals developed under this project are based largely on information provided by potential suppliers in response to a Request For Proposals (RFP) issued by GES for “The Upgrade and Refurbishment of the Goonhilly 6 Antenna System”. The RFP invited proposals for aspects of the proposed upgrade including refurbishment of the antenna mechanical structure, the antenna optics and feed design, system and RF tracking design, mechanical and servo design, and auxiliary subsystem and power design.

RFP responses were received from a number of potential supplies. Unfortunately, in most cases the bidders were unable to provide detailed technical proposals due to the need for additional information and data, such as a model of the antenna optics. However, despite the level of detail in the preliminary design proposals being necessarily limited, the information is considered sufficient to demonstrate the essential feasibility of an upgrade programme.

All the companies who visited the Goonhilly site were complimentary about the general condition of the GHY-06 antenna.

3.2 Optical and feed design

The present GHY-06 antenna design is C/Ku-band only and employs a unique feed system composed of four focused beam reflectors and a corrugated primary horn. A new feed arrangement is required to support S-band (Orion baseline), also X and K for future missions. In addition, it is desired to retain C/Ku capability. It is proposed to achieve this with a rotating indexable lower mirror to select multiple feeds. Feeds may be combined in various ways, for example one proposal was for C/Ku and S/X feeds, with a dichroic mirror to provide K-band receive if needed. By this means the capability can gradually be expanded in a step-wise manner as and when funds allow.

3.3 System and RF tracking design

Figure 1 presents a block diagram showing the main elements of the proposed upgraded antenna system, covering both the baseline S-band plus the enhancements needed for X and K-band. It is proposed that all the frequency bands be realised as cryogenic systems to reduce the system noise temperature. To meet the system availability requirement, the cryogenic sub-systems can be implemented in a redundant architecture. This concept is the same as that implemented in the ESA Deep Space Antennas (DSA).

3.3.1 Baseband design - TM/TC processing and ranging

The baseband part of the GHY-06 upgrade will be provided by the TTCP system developed by BAES. This system has an established pedigree having been installed in the ESA DSA ground stations. However some changes will be necessary to support Orion, as this will use the Advanced Orbiting Systems (AOS) space datalink protocol for TM/TC.

For ranging, besides CCSDS 414.1-B-2 PN ranging, Orion also requires a second form of PN ranging which is compatible with the CDMA approach used in

data relay situations (CCSDS 415.1-B-1). This second method is not implemented in the baseline TTCP and will need to be developed as additional functionality in the ranging block.

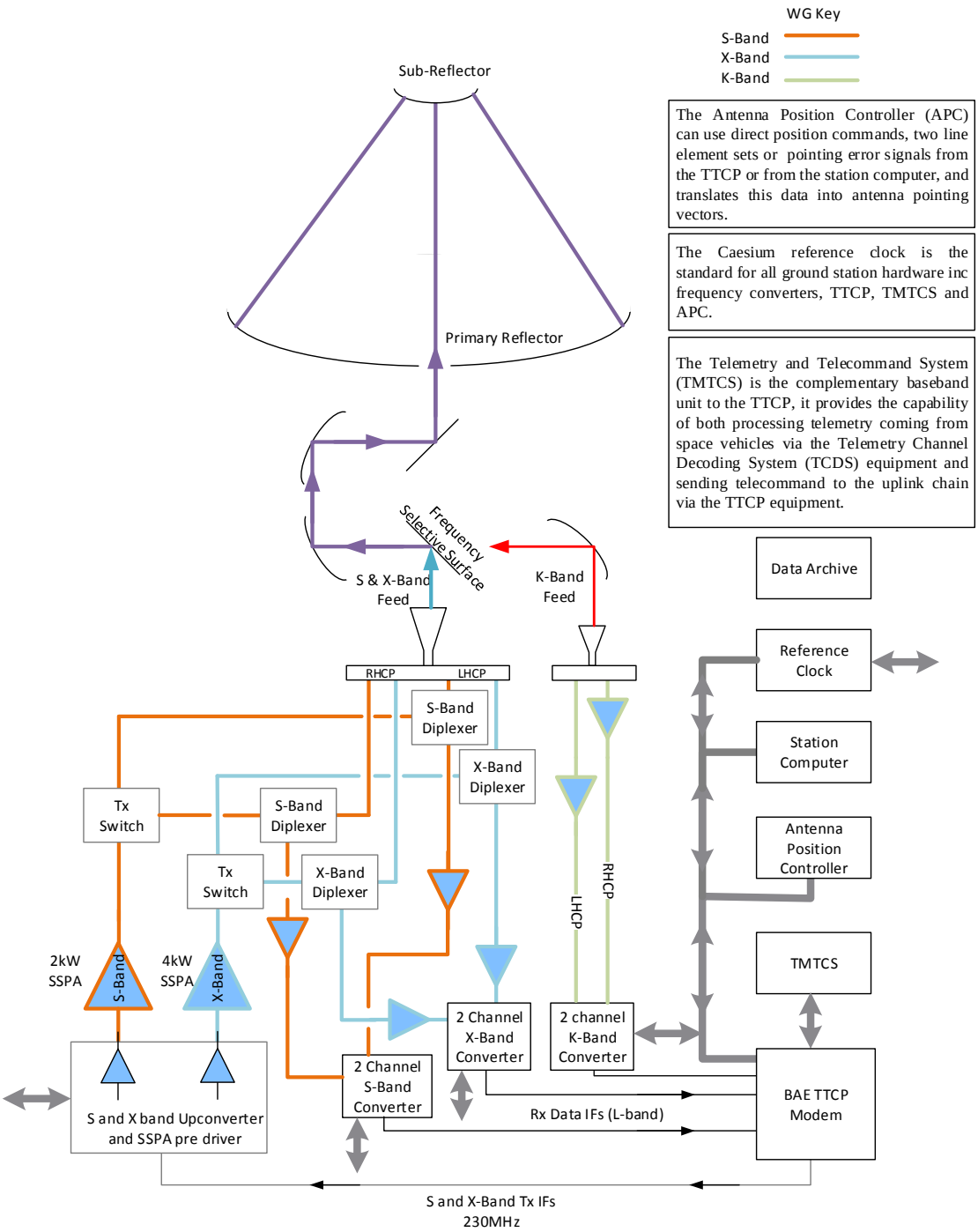

Figure 1 Block diagram of GHY-06 Orion ground station

3.5 Mechanical and servo design

Given the age of the present GHY-06 system, and the fact that the servo system is based on relay logic and that increased tracking / slew rates are required, a new servo and tracking system is proposed. This will include an Antenna Control Unit (ACU) together with new drive systems comprising new motors, brakes and encoders.

The present GHY-06 drive system comprises multiple motors per axis. Retention of this drive concept is considered highly desirable as it provides redundancy and graceful degradation in the event of a failure in any part of the drive system.

The Monitoring and Control (M&C) aspects of the antenna control function will need to be integrated with the overall M&C system, which is to be provided as part of the baseband (TTCP) system.

3.6 Monitoring and control design

The M&C design proposals address both local and remote elements.

Two options have been identified for local M&C at Goonhilly, to ensure the various subsystems are appropriately configured. These are either to implement a bespoke station control system, specific to the Goonhilly station, or alternatively, to implement a station M&C system based on the ESA STC2 (station computer) but with the Front-End Controller (FEC) and Monitoring and Control Module (MCM) components replaced with Goonhilly-specific functions. The former would allow all Goonhilly-specific functions to be incorporated, although the station would not necessarily then be compatible with the ESTRACK network. The latter would allow the station to be compatible with ESTRACK.

In both cases an interface to the NASA Orion Mission Operations Center (MOC) would need to be added to allow remote station operation, which would include high-level configuration of the station and upload and download of data files. In ESA stations the operations network (OPSNET) is an IP-based redundant wide-area network which links the ESTRACK stations. The NASA equivalent for the Near Earth Network of ground stations is IONet. Little information is currently available regarding the protocols for remote M&C in the context of the Orion mission, however it is assumed that Goonhilly would form part of the IONet network.

3.7 Auxiliary subsystem and power design

The study included a preliminary assessment of the auxiliary equipment and infrastructure needed to support and operate the upgraded GHY-06 antenna system. This included consideration of the following, particularly with regard to whether to re-use, refurbish or replace the existing provision - air conditioning (refurbish/renew); power (e.g. UPS: renew; wiring: bring up to consistent standard); pressurisation (inspection/maintenance service); Frequency & Timing (new equipment needed); communication links (fibre, Gigabit links, already planned); fire systems (new equipment required); safety features (i.e. interlocks etc., check and upgrade as necessary); building accommodation (upgrades required); security (upgrades required).

Further work will be required to complete detailed design of the necessary upgrades to auxiliary equipment and infrastructure, taking into account requirements for overall system reliability and availability.

4 Programmatics

Besides addressing the technical feasibility of the upgrade, the study also considered the programmatic aspects needed to bring a GHY-06 upgrade programme to fruition within the timescale of Orion EM-1. Aspects covered included availability/risk analysis, programme definition and scoping (including schedule, work breakdown structure and product tree) and Rough Order of Magnitude (ROM) cost estimation. Due to the proprietary nature of the information, the ROM cost estimates for the upgrade programme have been presented in a Proprietary Annex to the Final Report.

Figure 2 illustrates how the current study activity and the proposed antenna upgrade implementation programme map to the ESA lifecycle phases. The proposed upgrade programme will cover 3 main Phases (B, C & D) providing a potential breakpoint between each Phase.

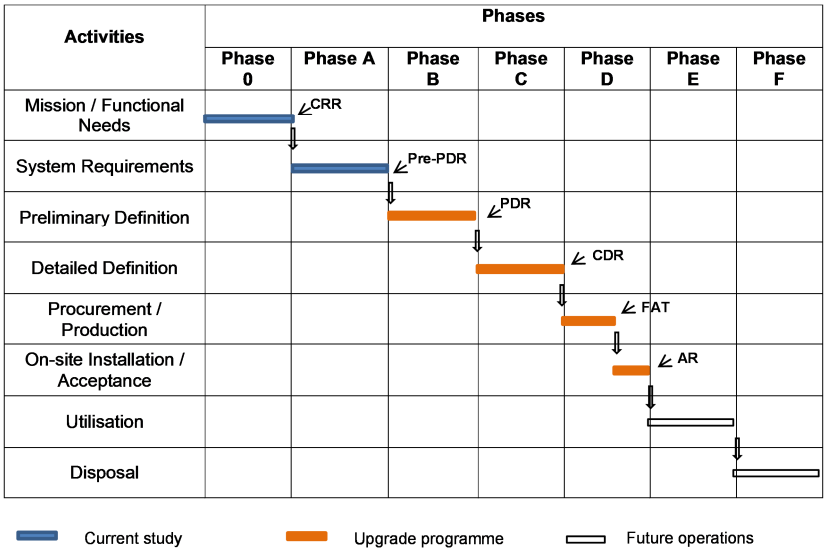

Figure 2 Programme mapping to ESA project phases

Figure 3 illustrates how the proposed upgrade schedule fits with the current expected launch dates of NASA's Orion EM-1 and ARM missions. This is subject to the assumption of a Phase B start in late Summer 2016 and completion of each Phase within ROM estimated phase durations of 4, 6 and 14 months respectively for Phases B, C & D.

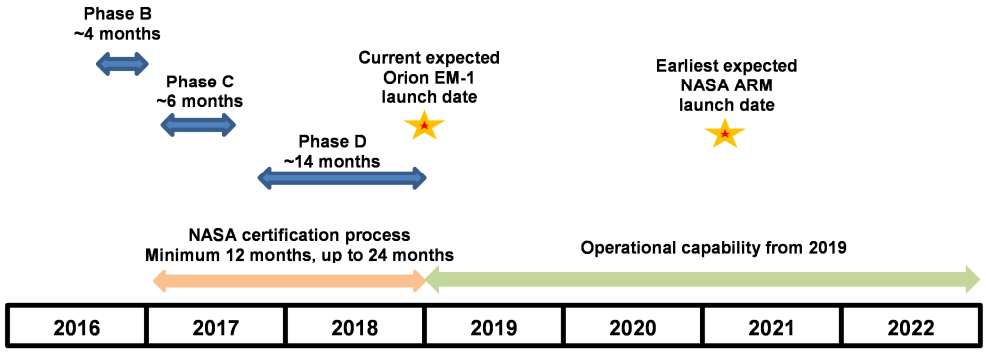

Figure 3 Schedule overview

5 Conclusions

The main conclusion of the study is that a programme of work to upgrade the GHY-06 antenna system to support Orion EM-1 is feasible from both a technical and programmatic perspective. It has been shown that, once upgraded, GHY-06 will be able to provide a useful level of performance consistent with Orion requirements. This applies not only at S-band, but also at the other frequencies of interest for subsequent missions, such as X-band and K-band. A modular approach has been proposed to allow these new frequencies to be accommodated as and when funding becomes available, subject to provision being made for them in planning at the outset. This will allow best value to be gained from the investment, by enabling the broadest range of mission applications to be accessed.

A baseline schedule of 2 years is considered realistic for the proposed GHY-06 antenna upgrade implementation programme. Subject to further detailed planning and consideration of schedule acceleration options, it may be possible to achieve completion within a stretch target of 19 months from Kick Off.

The objective of achieving operational readiness in time to support Orion EM-1 at its launch circa December 2018 is considered achievable, subject to a) an early start on Phase B preliminary definition work by the beginning of September 2016, and b) the assumption that NASA certification can be pursued in parallel with Phase B/C/D engineering work. Subject to the latter assumption (b), it is suggested that Orion EM-1 could serve as a certification test of the GHY-06 system, which would be operated during the mission in a back-up mode for the purpose of demonstrating and confirming its performance.

To enable early decisions on funding for Phases B and C, the overall ROM cost estimate for the upgrade has been split between Phases. This split has been driven by considerations of schedule, cost and risk, the aim being to ensure that early work addresses the key activities needed to de-risk the programme, at a reasonable cost/price, prior to commitment of funds for the full implementation programme under Phase D.

6 Recommendations

The principal recommendation is to progress and implement the GHY-06 upgrade programme as outlined in this study. In summary, this should cover provision of a minimum baseline S-band, as needed for Orion, with consideration given to operation in other frequency bands. In particular it is recommended that the upgrade retain the capability to operate in the standard TT&C bands, as this will provide a regular revenue stream and help ensure GHY-06 remains viable in the longer term, noting that the GES business model is based on this approach.

An early start on Phase B preliminary definition tasks by no later than the beginning of September 2016 is needed in order to achieve operational readiness in time to support Orion EM-1. It is recommended that work start as soon as possible to develop a Statement of Work for the critical early start activities, which as a minimum should include a Site Inspection Review, an optical survey to precisely determine the GHY-06 antenna shape, development of a Finite Element Model (FEM) of the antenna structure and development of an RF model.