450-SRD-KaTP

MISSION SERVICES PROGRAM OFFICE

Ka-Band Transition Product (KaTP) System Requirements Document (SRD)

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Greenbelt, Maryland

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Preface

This document is under the configuration management of the Mission Services Program (MSP) Configuration Control Board (CCB).

Configuration Change Requests (CCRs) to this document shall be submitted to the MSP CCB, along with supportive material justifying the proposed change. Changes to this document shall be made by document change notice (DCN) or by complete revision.

Questions and proposed changes concerning this document shall be addressed to:

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Section 1. Introduction

This section provides an introduction to the Ka-Band Transition Product (KaTP). It is divided into the following sections:

Section 1.1	Purpose.
Section 1.2	Scope.
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1.1 Purpose

The purpose of the KaTP is three-fold:

1. To provide a Ka-band 650-MHz-wide channel intermediate frequency (IF) return service to the Space Network (SN).
2. To provide a S/Ka-band demonstration ground terminal for the Ground Network (GN).
3. To facilitate demonstrations of the Ka-band capabilities of the SN and the GN.

A key feature in the design of the SN and GN Ka-band capabilities is a common IF interface. If a customer's equipment is compatible with the SN IF output signal, it will also be compatible with the GN IF output, and vice versa.

1.2 Scope

The KaTP will upgrade the SN ground stations at the White Sands Complex (WSC) to take advantage of the new Tracking and Data Relay Satellite (TDRS) H, I, J spacecraft's 650-MHz-wide Ka-band space-to-space return link. This effort will result in a new customer service – the wideband Ka-band return IF service. Changes to the SN include modifying the scheduling and control systems that support Ka-band service.

In addition, a demonstration ground station will be built for the GN to support ultra-wideband direct-to-ground communications at Ka-band. The GN station will provide a telemetry IF output port with a 1.2-GHz bandwidth. The station will also support S-band command, telemetry, and tracking.

This document addresses the functional and performance requirements for the SN and GN elements of the KaTP. Only the SN and GN requirements are addressed in this document. Requirements for other KaTP elements, such as high-rate data processing and service simulation, if deemed necessary, will be addressed in a separate document.

1.3 Background

Due to increasing congestion in the S, X, and Ku-band frequencies, as well as the need for higher data rates, the National Aeronautics and Space Administration (NASA) has begun exploring the use of Ka-band frequencies and wider bandwidths for communicating with customer platforms.

In June 2000, NASA launched the first of three new geostationary Tracking and Data Relay Satellites, TDRS H, I, J. TDRS H, I, J will support existing SN customer platforms at S-band and Ku-band while supporting new customer platforms at Ka-band. The Ka-band space-to-space links will operate in bands with co-primary allocations and with bandwidths of either 225 or 650 MHz. In contrast, existing Ku-band SN missions use secondary frequency allocations (subject to operational restrictions in the future) and are limited to 225-MHz bandwidths.

Low-earth orbit (LEO) missions that need even wider bandwidths can use the GN for direct-to-ground support. GN stations have been allocated space-to-ground Ka-band spectrum with a 1.5-GHz bandwidth. This dual allocation provides future NASA missions with the option of using either inter-satellite or direct-to-ground links for science data dumps.

1.4 Overview

Figure 1-1 below is reference architecture that illustrates the four segments of the KaTP and their interfaces. These segments and the capabilities or services they provide are:

- Ground Network Segment.
  - Ka-band telemetry IF and antenna tracking demonstration capabilities.
  - S-band command, telemetry (baseband and IF), and tracking demonstration capabilities.
- Space Network Segment.
  - Ka-band 225-MHz-wide telemetry service.
  - Ka-band command services.
  - Ka-band 650-MHz-wide telemetry IF service.
- Customer/Service Simulation Segment (future implementation/outside the scope of this requirements document).
  - RF simulation services.

  The Customer/Service Simulation Segment will simulate the RF interfaces to the SN and GN Segments for Ka-band telemetry, S-band telemetry, and S-band command customer services.
- Data Processing Segment (future implementation/outside the scope of this requirements document).
  - GN Ka-band telemetry baseband service.
  - SN Ka-band 650-MHz-wide telemetry baseband service.

  The Data Processing Segment will provide high-rate data acquisition (demodulation and bit synchronization).

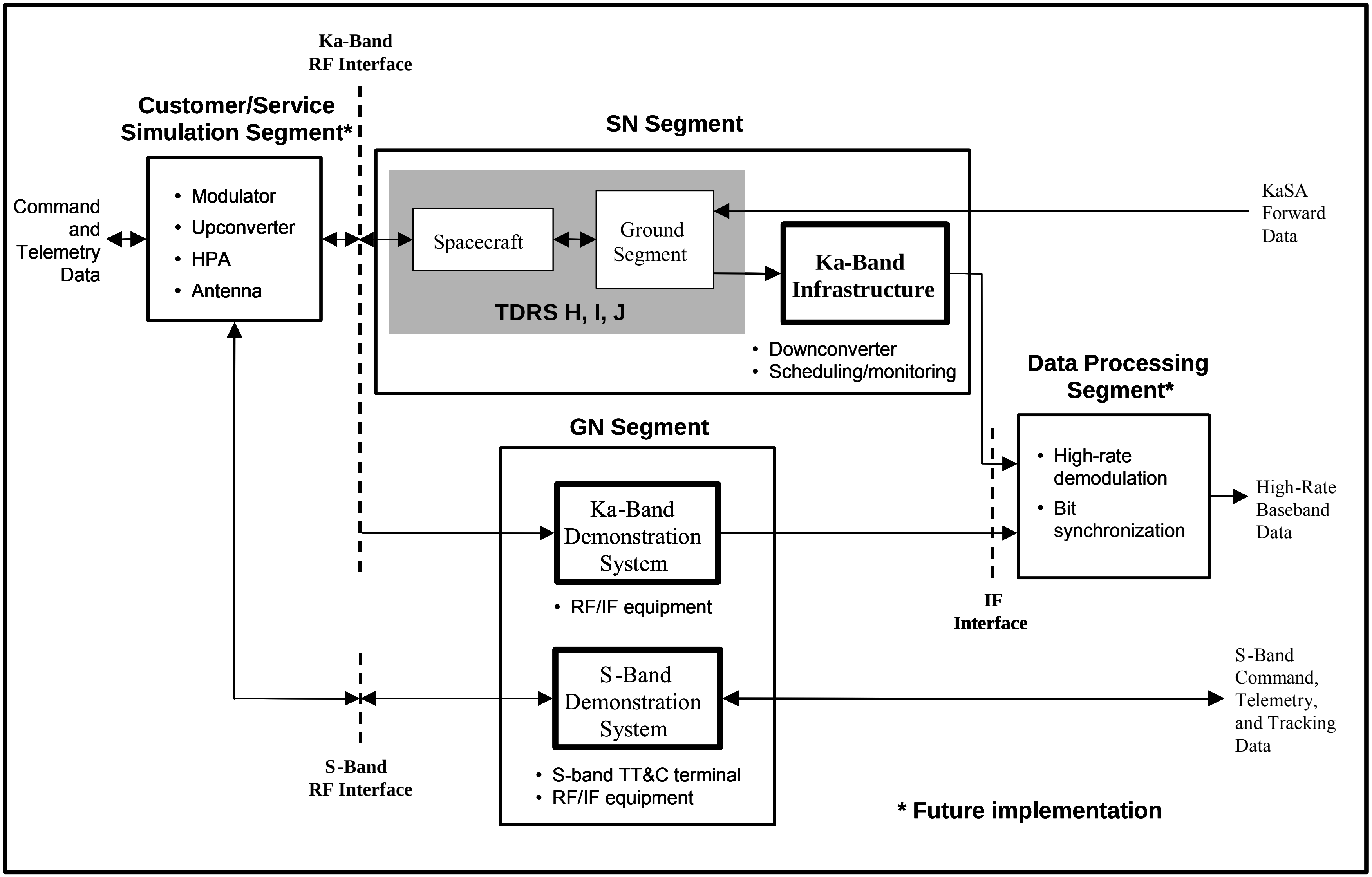

Figure 1-1: System Architecture

1.5 Document Organization

- Section 1. "Introduction," provides an introduction to the KaTP. It describes the purpose, scope, background, and overview of the project, and provides the document organization, nomenclature, and the list of applicable and reference documents.
- Section 2, "System Description," provides a description of the KaTP and its four constituent segments: the Customer/Service Simulation Segment, Ground Network Segment, Space Network Segment, and Data Processing Segment. Only requirements for the SN Segment and the GN Segment are specified in this document.
- Section 3, "Space Network Segment," specifies the requirements on the Space Network Segment of the KaTP.
- Section 4, "Ground Network Segment," specifies the requirements on the Ground Network Segment of the KaTP.
- Appendix A, "UTDF Frames," specifies the requirements for generating Universal Tracking Data Format (UTDF) frames, in order to supplement the requirements in 450-TAH-STDN.
- The "Abbreviations and Acronyms" list follows Appendix A.

1.6 Nomenclature

As used in this document, the following definitions apply:

a. Customer Platform

The platform carrying the customer's receiving and/or transmitting equipment. The platform can be a spacecraft or an aircraft. (The SN can also support sea- or land-based platforms, since the SN antenna is located high above the earth on a satellite.)

b. Mission Operations Center (MOC)

The SN or GN customer's terrestrial *baseband* processing facility.

c. Data Rate

From the sender's perspective, data rate is defined *after* any virtual channelization but *before* any encoding, Attached Sync Marker (ASM) attachment, or data format conversion. (CCSDS pseudo-randomization does not change the data rate.)

From the receiver's perspective, data rate is defined *after* any decoding, data format conversion, and frame synchronization, but *before* virtual channel extraction.

d. Symbol Rate

From the sender's perspective, symbol rate is defined *after* any virtual channelization, encoding, and ASM attachment, but *before* any data format conversion. (CCSDS pseudo-randomization does not change the symbol rate.)

From the receiver's perspective, symbol rate is defined *after* any data format conversion, but *before* any decoding, frame synchronization, and virtual channel extraction.

1.7 Documents List

The documents list is composed of applicable and reference documents. Applicable documents impose requirements on the KaTP. Reference documents are provided only for information.

1.7.1 Applicable Documents

The following documents form part of this specification to the extent specified herein. The most recent version of these documents takes precedence. If there are conflicts between the listed documents and the requirements of this specification, the requirements of this specification take precedence.

1.7.1.1 NASA Documents

a. 405-TDRS-RP-SY-001, TDRS H, I, J Technical Requirements Specification.

b. 405-TDRS-RP-SY-011, White Sands Complex (WSC) Ground Terminal Requirements for the TDRS H, I, J Era.

c. 423-42-05, Interface Control Document (ICD) Between the Earth Observing System (EOS) Operations Center (EOC) and the Wallops Orbital Tracking and Information System (WOTIS).

d. 430-14-01-001-0, Interface Control Document Between Landsat 7 and the Landsat 7 Ground Network (LGN).

e. 450-TAH-STDN (formerly STDN No. 724), Tracking and Acquisition Handbook for the Spaceflight Tracking and Data Network.

f. 530-ICD-NCC-FDF/WSC, Interface Control Document (ICD) between The Network Control Center (NCC)/Flight Dynamics Facility (FDF) and The White Sands Complex (WSC).

g. 450-SNUG, Revision 8, Space Network (SN) Users' Guide.

h. Automated Tracking Station User's Manual.

i. BASD Document 545460, Ground System Interface Control Document, QuikSCAT CDRL: DID Sequence Number 5.

j. NPD 2570.5B (NASA Policy Directive), Radio Frequency Spectrum Management.

k. NPG 2810.1, Security of Information Technology: NASA Procedures and Guidelines.

l. 530-WSC-0024, Information Technology Systems Security Plan for the WSC

m. 530-WSC-0009, WSC Security Manual

1.7.1.2 International, Federal, and Industry Standards

a. 451-PN Code-SNIP, Space Network Interoperable PN Code Libraries.

b. CCSDS 101.0-B-4, Recommendation for Space Data System Standards: Telemetry Channel Coding.

c. CCSDS 102.0-B-5, Recommendation for Space Data System Standards: Packet Telemetry.

d. CCSDS 103.0-B-1, Recommendation for Space Data System Standards: Packet Telemetry Services.

e. CCSDS 201.0-B-3, Recommendation for Space Data System Standards: Telecommand, Part 1 – Channel Service: Architectural Specification.

f. CCSDS 202.0-B-2, Recommendation for Space Data System Standards: Telecommand: Part 2 – Data Routing Service.

g. CCSDS 301.0-B-2, Recommendation for Space Data Systems Standards: Time Code Formats.

h. CCSDS 401.0-B, Recommendation for Space Data System Standards: Radio Frequency and Modulation Systems – Part 1: Earth Stations and Spacecraft.

i. CCSDS 701.0-B-2, Recommendation for Space Data System Standards: Advanced Orbiting Systems, Networks and Data Links: Architectural Specification.

j. ITU-R SA.1273 (ITU Recommendation), Power Flux-Density Levels from the Space Research, Space Operation and Earth Exploration-Satellite Services at the Surface of the Earth Required to Protect the Fixed Service in the Bands 2025-2110 MHz and 2200-2290 MHz.

k. Manual of Regulations & Procedures for Federal Radio Frequency Management (Redbook).

l. Radio Regulations, Volume 1, International Telecommunications Union (ITU).

m. Recommendation 13-3R1, Data Relay Satellite Channel Plans for the 23 and 26 GHz Bands, Space Frequency Coordination Groups (SFCG).

n. Recommendation 14-1, Protection of Deep-Space Earth Stations from Line of Sight Interference in the Bands 2290 – 2300 MHz, 8400 – 8450 MHz, and 31.8 – 32.3 GHz, Space Frequency Coordination Groups (SFCG).

o. Recommendation 17-2R1, Efficient Spectrum Utilization for Space Science Services on Space-to-Earth Links, Space Frequency Coordination Groups (SFCG).

p. Recommendations for International Space Network Ka-Band Interoperability, Space Networks Interoperability Panel (SNIP).

1.7.1.3 Technical Memorandums

a. SES-450-100027, TDRSS Ka-Band User Constraint Specifications, John Wesdock, et al, ITT Industries.

b. SES-450-100029, TDRSS Ka-Band Autotrack Acquisition Verification, John Wesdock, ITT Industries.

c. SES-450-100043, Impact of Noncompliant Ground Segment Phase Nonlinearity on KaSAR-Wide BER Performance, Revision 1, John Wesdock and Ajitha Painumkal, ITT Industries.

d. CSOC-GM55-124, KaSAR-Wide User Gain Flatness and Phase Nonlinearity Specification Examination, Abby Kassa and John Wesdock, ITT Industries.

e. CSOC-GM55-128, Ka-Band Dynamics Study Follow-Up, Revision 1, Mark Burns, ITT Industries.

f. CSOC-GM55-143, Impact of Noncompliant WSC 225 MHz Downconverter LO Phase Noise on TDRSS KuSAR, KaSAR Performance, Revision 1, John Wesdock and Leonardi Tran, ITT Industries.

g. CSOC-GM55-214, Comparison of WSC KSA 225 MHz Downconverter LO Phase Noise Bids, Leonardi Tran and John Wesdock, ITT Industries.

h. CSOC-GM55-257, BER Performance Assessment of TDRSS KaSAR-Wide Service Assuming 8PSK, 8PSK/TCM, and GMSK Modulation, Revision 1, John Wesdock, et al, ITT Industries.

i. CSOC-GM55-457, Comparison of WSC KSA 225 MHz Downconverter LO Phase Noise Bids Based on Revised Miteq LO Phase Noise Data, Leonardi Tran and John Wesdock, ITT Industries.

j. CSOC-GM55-496, Recommended User Constraints for GN S-Band Telemetry, John Wesdock et al, ITT Industries.

k. CSOC-GM55-xxx, Impact of Noncompliant 225 MHz Downconverter LO Phase Noise on TDRSS KuSAR, KaSAR Performance (Magnum-Microwave Data), John Wesdock and Leonardi Tran, ITT Industries.

l. CSOC-SODA55-524, GN P_{rec} Calculations for S-Band Telemetry Portion of KaTP SRD, David Miller, ITT Industries.

m. CSOC-SODA55-525, GN P_{rec} Calculations for Ka-Band Telemetry Portion of KaTP SRD, David Miller, ITT Industries.

1.7.2 Reference Documents

The following documents are provided only for informational purposes; they do not form part of this specification.

a. 405-TDRS-RP-ICD-001, Interface Control Document (ICD) between the Network Control Center (NCC)/Flight Dynamics Facility (FDF) and the White Sands Complex (WSC) for the TDRS HIJ Era.

b. 453-PMP-KaTP, Ka-Band Transition Product Management Plan.

c. 451-WDISC-OCD 98, WSC Transmission Control Protocol (TCP)/Internet Protocol (IP) Data Interface Service Capability (WDISC) Operations Concept.

d. 451-WDISC-SRD 98, WSC Transmission Control Protocol (TCP)/Internet Protocol (IP) Data Interface Service Capability (WDISC) System Requirements: Initial Capability.

e. 451-WDISC-SSD 98, WSC Transmission Control Protocol (TCP)/Internet Protocol (IP) Data Interface Service Capability (WDISC) Service Specification.

f. 452-F&PR1-EPGS, EOS Polar Ground Stations (EPGS) Project Phase I Functional and Performance Requirements.

g. 452-GNUG-GN, Ground Network (GN) Users' Guide.

h. 452-KaGT-GN, Ka-Band Ground Terminal Product Plan.

i. 530-RSD-WSC, Requirements Specification for the White Sands Complex (WSC).
j. 532-FPR-WSC, White Sands Complex Functional and Performance Requirements.
k. CCSDS 203.0-B-1, Recommendation for Space Data System Standards: Telecommand: Part 3 – Data Management Service: Architectural Specification.
l. Channel Coding with Multilevel/Phase Signals, Gottfried Ungerboeck, IEEE Transactions on Information Theory, Volume 28, Number 1.
m. DS80409-H00-001, TDRS H,I,J Spacecraft Design Specification.
n. Error Control Coding Handbook (Final Report), Joseph P. Odenwalder.
o. ETS-450-100012, NASA GSFC Efficient Spectrum Utilization Analysis.
p. ITU-R SA.509-2 (ITU Recommendation), Generalized Space Research Earth Station and Radio Astronomy Antenna Radiation Pattern for Use in Interference Calculations, Including Coordination Procedures.
q. Project Commitment Document (PCD): Data Services: Ka-Band Transition Project.
r. Recommendation 12-5R1, Limitations on Earth – Space Link Power Levels, Space Frequency Coordination Groups (SFCG).
s. Recommendation 15-2R2, Use of the Band 25.25 – 27.5 GHz for Inter-Satellite (Data Relay Satellite and ISS Proximity Links) and Earth Exploration Satellite Service Applications, Space Frequency Coordination Groups (SFCG).
t. RFC 791, Internet Protocol: DARPA Internet Program Protocol Specification.
u. RFC 793, Transmission Control Protocol: DARPA Internet Program Protocol Specification.
v. RFC 959, File Transfer Protocol, J. Postel and J. Reynolds, Information Sciences Institute (ISI).
w. S-805-1, Performance Specification for Services via the Tracking and Data Relay Satellite System.
x. SE-BB-01, [TDRS H,I,J] Spacecraft Design Specification.
y. SE-BD-05, [TDRS H,I,J] Spacecraft Systems Manual.
z. SE-BE-01, TDRS H,I,J Program: Ground Segment Subsystem Specification.
aa. SF17 – 28/D, CCSDS-SFCG Efficient Modulation Methods Study at NASA/JPL: Phase 3: End-to-End System Performance.
bb. STDN No. 108, PN Codes for Use with the Tracking and Data Relay Satellite System (TDRSS) [superseded by 451-PN Code-SNIP].
cc. STDN 220.29, TDRSS Spacecraft/Ground Segment ICD.
dd. STDN 220.30, Interface Control Document (ICD) Between the Second TDRSS Ground Terminal (STGT) and Ground Communications Facilities.
ee. STGT-HE-01/03 (GES-STGT-0001), STGT: System/Subsystem Specification.

ff. STGT-HE-04-06 (GES-STGT-1324), STGT: K-band Single Access (KSA) High Data Rate (HDR) Equipment HWCI Specification (HWCI No. 6).

gg. Transition Plan for the Efficient Use of NASA/GSFC Spectrum.

hh. Programmable Telemetry Processor for Windows NT, User’s Manual.

Section 2. System Description

This section provides a description of the KaTP.

It is divided into the following sections:

2.1 Customer/Service Simulation Segment

The Customer/Service Simulation Segment will provide the RF signal inputs to the SN Segment and the GN Segment. It will transmit a RF signal to the SN and GN Segments for reception and down-conversion to IF. The Customer/Service Simulation Segment will be capable of receiving and processing Ka-band signals transmitted by the SN Segment. It will also be capable of receiving and transmitting S-band signals from and to the GN Segment. Customer/Service Simulation Segment requirements will not be addressed in this document.

2.2 Ground Network Segment

The GN Segment will support the approved NASA S-band command (2025 to 2120 MHz), S-band telemetry (2200 to 2300 MHz), and Ka-band telemetry (25.5 to 27 GHz) frequency ranges. The S-band portion of the GN Segment will provide tracking, telemetry, and command (TT&C) support similar to existing S-band GN stations.

The GN Segment will provide a Ka-band RF interface to the Customer/Service Simulation Segment and an IF interface to the Data Processing Segment. The GN Segment will be capable of program tracking and autotracking the Ka-band and S-band RF signals.

2.3 Space Network Segment

The SN Segment consists of the existing TDRS H, I, J capability and a new Ka-Band Infrastructure to support a Ka-band single access return (KaSAR) wideband IF service. The development of a 650-MHz-wide high-rate IF service within the SN (in addition to the current 225-MHz capability) will require modifications to hardware and software to allow automatic scheduling and configuration of support services via the TDRS H, I, J 650-MHz KaSAR channels. The SN modifications will include the addition of downconverters and an IF switch to support each of the four TDRS H, I, J-compatible Space-Ground Link Terminals (SGLTs) at WSC, as well as modifications to the WSC and the Data Services Management Center (DSMC) (formerly the Network Control Center (NCC)) software to enable scheduling, status monitoring, and real-time control of these services. Although customer platform autotracking will not be implemented for the 650-MHz KaSAR service, it may be added in the future.

2.4 Data Processing Segment

The Data Processing Segment will perform high-rate data acquisition (demodulation and bit synchronization). As Figure 1-1 above shows, the SN and GN Segments will provide a common IF interface that will allow the same high-rate data acquisition equipment to be used in the SN and GN. Data Processing Segment requirements will not be addressed in this document.

Section 3. Space Network Segment

This section specifies requirements on the SN Segment of the KaTP.

Introduction

The SN Segment consists of two parts: the existing TDRS H, I, J capability, and new equipment called the Ka-Band Infrastructure. Figure 3-1 below shows the reference architecture for the Ka-Band Infrastructure at the WSC.

The SN Segment has already been upgraded to support limited customer services with the TDRS H, I, J spacecraft. The new, wide-bandwidth 650-MHz KaSAR capability – supplementing the existing 225-MHz KaSAR capability – requires modifications to hardware and software at WSC and DSMC. These modifications include adding downconverters and an IF switch to support the four TDRS H, I, J-compatible SGLTs at WSC, and modifications to the software at WSC and DSMC to support scheduling and status monitoring. In addition, the existing 225-MHz downconverters at WSC will be modified to support both the Space Network Interoperability Panel (SNIP)/Space Frequency Coordination Group (SFCG) and the TDRS H, I, J frequency plans. Although customer platform autotracking will not be implemented with the initial 650-MHz service, it may be added in the future.

The KaSA forward (KaSAF) service is provided by the existing TDRS H, I, J capability. The KaSAR services are provided by the existing TDRS H, I, J capability supplemented by the Ka-Band Infrastructure.

The Ka-Band Infrastructure is designed to support a new KaSAR IF service with a bandwidth of 650 MHz and an IF frequency of 1.2 GHz. Customers can interface with any of several IF output ports at WSC and perform their own demodulation and baseband processing on the IF signal.

Organization

SN requirements are organized into the following sections:

Section 3.1 General.

Section 3.2 TDRS H, I, J.

Section 3.3 Ka-Band Infrastructure.

3.1 General

The General requirements specified below apply to the entire SN Segment.

General requirements are divided into the following sections:

Section 3.1.1 Simultaneous Support Requirement.

Section 3.1.2 Availability Requirements.

Section 3.1.3 Security Requirements.

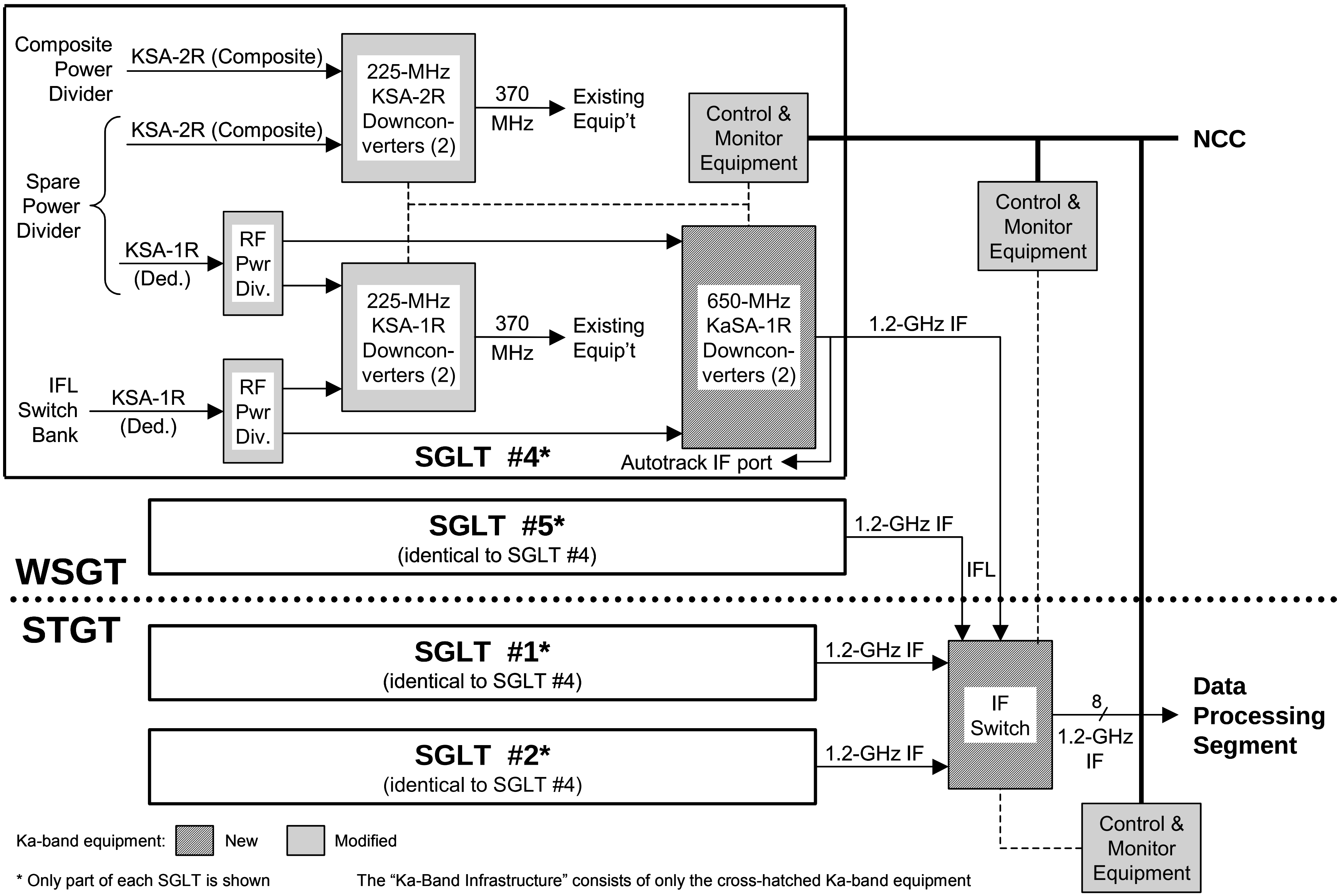

Figure 3-1: Ka-Band Infrastructure Reference Architecture

3.1.1 Simultaneous Support Requirement

The SN Segment shall be capable of simultaneously providing the Ku- and Ka-band forward and return services specified in each row of Table 3-1 below.

Table 3-1: Simultaneous SN Ku- and Ka-Band Services

Require-ment Identifier	Number of Available TDRS H, I, J Satellites	Number of SAF Services[2] (KSAF or KaSAF)[3]	Number of SAR Services[2]	
			225 MHz (KSAR or KaSAR)[3,4]	650 MHz (KaSAR IF)
a.	1	2	1	1
b.	1	2	2	0
c.	2	4	2	2
d.	2	4	3	1
e.	2	4	4	0
f.	3	6	3	3
g.	3	6	4	2
h.	3	6	5	1
i.	3	6	6	0

Notes:

1. In any row, all of the services will be available simultaneously.
2. The SAF and 225-MHz SAR services are baseband services, and the 650-MHz KaSAR service is an IF service. When a TDRS SA antenna simultaneously supports forward and return services, both services must be in the same band (that is, both must be Ku-band or both must be Ka-band).
3. Any SAF or 225-MHz SAR service can be either Ku- or Ka-band.
4. The WSC TCP/IP Data Interface Service Capability (WDISC) can simultaneously support only three SAF channels and three SAR (I or Q) channels at STGT, and the same number at WSGT (see the NOTE in Sections 3.2.1.2.2 and 3.2.2.3.1.b below).

3.1.2 Availability Requirements

This section specifies the availability requirements applicable to the ground station portion of the SN Segment. Redundancy may be used to meet these requirements.

Operational availability, A_o, should be calculated using the formula defined in Section 3.1.2.3 below.

3.1.2.1 225-MHz Ka-Band Telemetry Baseband Service

The A_o of the 225-MHz Ka-band telemetry baseband service (including, but not limited to, the RF, IF, baseband, and control and monitor services but *excluding the WDISC*), measured over a 10,000-hour interval, shall be ≥ 0.9999. (This requirement excludes the availability of the TDRS H, I, J satellites.)

3.1.2.2 650-MHz Ka-Band Telemetry IF Service

The A_o of the 650-MHz Ka-band telemetry IF service (including, but not limited to, the RF, IF, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.9999. (This requirement applies to the existing TDRS H, I, J capability in conjunction with the Ka-Band Infrastructure, but excludes the availability of the TDRS H, I, J satellites.)

3.1.2.3 Operational Availability (A_o) Calculation

A_o should be calculated using the following formula:

$$A_o = \frac{\text{Time Service is Available}}{\text{Time Service is Available} + \text{Time Service is Not Available}}$$

Definitions

Time Service is Available

"Time Service is Available" is measured over a contiguous 10,000-hour interval.

Time Service is Not Available

"Time Service is Not Available" includes all of the times service is not available due to any of the following causes:

a. Corrective maintenance downtime.

b. Preventive maintenance downtime.

c. Administrative downtime.

d. Logistics supply downtime.

Downtime due to any of the following causes is *not* counted:

e. Loss of facility services, such as power or air conditioning.

f. Loss of system capability resulting from unusual weather conditions, such as icing or severe rainstorms.

3.1.2.4 WDISC

The availability of the WDISC shall be ≥ 0.9999. WDISC availability includes both the forward and return service capabilities.

For the WDISC only, availability should be calculated using the following formula:

$$\text{Availability} = \frac{\text{Mean Time Between Failures (MTBF)}}{\text{MTBF} + \text{Time to Restore to Operations}}$$

3.1.3 Security Requirements

The SN Segment shall employ security measures and techniques in accordance with the policies and procedures specified in the following documents:

a. NPG 2810.1, Security of Information Technology: NASA Procedures and Guidelines.

b. 530-WSC-0024, Information Technology Systems Security Plan for the WSC.

c. 530-WSC-0009, WSC Security Manual.

3.2 TDRS H, I, J

This section specifies requirements on the existing TDRS H, I, J space and ground segments to support KaSAF and KaSAR services.

Availability Requirement: Ka-Band Command Baseband Service

The A_o of the Ka-band command baseband service (including, but not limited to, the baseband, IF, RF, and control and monitor services but *excluding the WDISC*), measured over a 10,000-hour interval, shall be ≥ 0.9999.

A_o should be calculated using the formula defined in Section 3.1.2.3 above. Redundancy may be used to meet this requirement.

Organization

The remaining requirements are divided into the following sections:

Section 3.2.1 KaSAF.

Section 3.2.2 KaSAR.

3.2.1 KaSAF

This section specifies requirements on the existing TDRS H, I, J to support the KaSAF service.

3.2.1.1 Simultaneous S- and Ka-Band Services

Each TDRS H, I, J spacecraft, in conjunction with the WSC, shall be capable of simultaneously providing one SSAF and one KaSAF service to up to two customer platforms within the same SA antenna beamwidth.

3.2.1.2 Baseband-to-IF Processing (WSC)

This section specifies the KaSAF baseband-to-IF processing requirements for the TDRS H, I, J ground segment at WSC.

3.2.1.2.1 Baseband Command Reception

The TDRS H, I, J ground segment shall be capable of receiving baseband customer commands with the following characteristics:

a. Data rate: 1 kbps to 7 Mbps.

b. Data format: NRZ-L, NRZ-M, or NRZ-S.

3.2.1.2.2 Baseband Command Processing Standards

This section specifies the following baseband command processing standards recommended by the CCSDS and other organizations.

NOTE

Some of the following requirements apply *only if the customer uses the WDISC*. WDISC KaSAF support is limited to the following:

Data rate: 100 bps to 50 kbps per channel.

Data rates > 50 kbps may be supported at the risk of overloading the WDISC. Analysis and testing will be necessary to ensure reliable operation.

Number of channels: 3 at STGT and 3 at WSGT.

For more information on the WDISC, see the following documents in Section 1.7.2 above:

451-WDISC-OCD 98.

451-WDISC-SRD 98.

451-WDISC-SSD 98.

3.2.1.2.2.1 Delivery Header Stripping

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of stripping the following types of delivery headers from the received command blocks:

a. Internet Protocol Data Unit (IPDU) header, in accordance with 430-14-01-001-0 (Landsat 7 – LGN ICD).

b. Earth Observing System (EOS) Data and Operations System (EDOS)/Ground Transfer Data Unit (GTDU) header, in accordance with BASD Document 545460.

3.2.1.2.2.2 Command Data Unit Protocols

This section specifies the following types of command data unit protocols recommended by the CCSDS.

3.2.1.2.2.2.1 Telecommand Transfer Frame

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of receiving and processing Telecommand (TC) Transfer Frames, in accordance with CCSDS 201.0-B-3 and CCSDS 202.0-B-2. Each TC Transfer Frame is broken into one or more TC codeblocks. The

TC codeblocks for one TC Transfer Frame are encapsulated inside a Command Link Transmission Unit (CLTU).

3.2.1.2.2.2.2 Command Link Transmission Unit (CLTU) Frames

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of receiving and processing CLTU frames, in accordance with CCSDS 201.0-B-3 and CCSDS 701.0-B-2. Each CLTU encapsulates the set of TC codeblocks for exactly one TC Transfer Frame.

3.2.1.2.2.3 Internet Protocols

a. *If the customer uses the WDISC*, the TDRS H, I, J ground segment shall be capable of receiving customer command data that is transferred between the WSC and terrestrial facilities such as MOCs and the DSMC via TCP/IP (Transmission Control Protocol/Internet Protocol).

b. After receiving the command data, which will be encapsulated inside TCP/IP packets, the WDISC shall be capable of extracting and processing the command data into CCSDS frames in accordance with CCSDS 201.0-B-3.

3.2.1.2.3 Command Channel Modulation

This section specifies how the TDRS H, I, J ground segment modulates the command channel.

3.2.1.2.3.1 Inhibiting Modulation

The TDRS H, I, J ground segment shall not modulate the command channel when command data is not received. (PN modulation may still be applied when command data is not received.)

3.2.1.2.3.2 Data Rates ≤ 300 kbps

When the command data rate is ≤ 300 kbps, the TDRS H, I, J ground segment shall be capable of the following:

a. Pseudo-random (PN)-spreading the command channel.

b. Inhibiting PN spreading of the command channel.

3.2.1.2.3.3 Data Rates > 300 kbps

The TDRS H, I, J ground segment shall not PN spread the command channel when the command data rate is > 300 kbps.

3.2.1.2.3.4 Idle Patterns

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of generating and modulating both of the following idle patterns onto the command channel (not simultaneously):

a. Alternating 1’s and 0’s (that is, 101010…).

b. A string of 0’s (that is, 00000…).

3.2.1.2.4 Range Channel Transmission

Although the TDRS H, I, J ground segment does not provide Ka-band ranging service, the range channel requirements below apply.

3.2.1.2.4.1 Command Data Rates ≤ 300 kbps

When the command data rate is ≤ 300 kbps, the TDRS H, I, J ground segment shall be capable of the following:

a. Transmitting the range channel if the command channel is PN spread.

b. Inhibiting transmission of the range channel (that is, transmitting only the command channel) if the command channel is not PN spread.

3.2.1.2.4.2 Command Data Rates > 300 kbps

The TDRS H, I, J ground segment shall not transmit the range channel when the command data rate is > 300 kbps (that is, only the command channel will be transmitted).

3.2.1.2.5 Command Signal Parameters

The TDRS H, I, J ground segment shall be capable of providing the KaSAF signal parameters specified below:

a. For data rates ≤ 300 kbps: The parameters specified in Table 3-2 below.

b. For data rates > 300 kbps: The parameters specified in Table 3-3 below.

3.2.1.2.6 Carrier Frequency Sweep

The TDRS H, I, J ground segment shall be capable of sweeping the Ka-band carrier frequency from 30 kHz below the center frequency to 30 kHz above the center frequency within 120 seconds.

3.2.1.2.7 Doppler Compensation

This section specifies Doppler compensation requirements for the TDRS H, I, J ground segment.

3.2.1.2.7.1 Carrier Frequency Compensation

The TDRS H, I, J ground segment shall be capable of Doppler compensating the carrier frequency as specified below:

a. Range: ≤ ±630 kHz (≤ 7.9 km/s at 23.55 GHz).

b. Rate: ≤ ±900 Hz/sec (≤ 11.4 m/s^2 at 23.55 GHz).

c. Acceleration: ≤ ±1.02 Hz/sec^2 (≤ 0.013 m/s^3 at 23.55 GHz).

Table 3-2: KaSAF Signal Parameters: Data Rates $\leq$ 300 kbps

Parameter	Requirement[1]
a. Ratio of command channel power to range channel power	+10 dB
b. Command channel:	
1. Data modulation	Modulo-2 added asynchronously to PN code
2. Data rate	1 kbps to 300 kbps[3]
3. Data format[4]	NRZ-L, NRZ-M, or NRZ-S
4. Carrier suppression	$\geq$ 30 dB
5. PN modulation	BPSK
6. PN chip rate[5]	$31/(1469 \times 96) \times (F - 8.78 - 0.005\ K)$ Gchips/second
7. PN code length	$2^{10} - 1$ chips
8. PN code family	Gold codes, in accordance with 451-PN Code-SNIP
c. Range channel[2]:	
1. PN modulation	BPSK
2. PN chip rate	Synchronous with command channel PN chip rate
3. Carrier frequency	Command channel carrier frequency delayed 90°
4. Carrier suppression	$\geq$ 30 dB
5. PN code epoch reference	Epoch (all 1's condition) synchronized to command channel PN code
6. PN code family	Truncated 18-stage shift register sequences, in accordance with 451-PN Code-SNIP

Notes:

1. All frequencies, chip rates, and data rates are specified before Doppler compensation, if used.
2. Even though ranging service is not provided, the range channel can be transmitted when the command channel data rate $\leq$ 300 kbps.
3. Data rates are limited to 50 kbps if the customer uses the WDISC. See the NOTE in Section 3.2.1.2.2 above.
4. The TDRS H, I, J ground segment is transparent to the data format, which is established by the MOC. Data format conversion is not required, but is available at the WDISC.
5. "K" is the number of 5-MHz steps from 22.555 GHz, where $0 \leq K \leq 198$.
   "F" is the Ka-band transmit frequency to the customer platform in GHz (specified in Section 3.2.1.4.2 below).

Table 3-3: KaSAF Signal Parameters: Data Rates > 300 kbps

Parameter	Requirement
a. Data modulation	BPSK
b. Data rate[1]	> 300 kbps to 7 Mbps[3]
c. Data format[2]	NRZ-L, NRZ-M, or NRZ-S
d. Carrier suppression	≥ 30 dB

Notes:

1. Data rate is specified before Doppler compensation, if used.
2. The TDRS H, I, J ground segment is transparent to the data format, which is established by the MOC. Data format conversion is not required
3. The current WSC data interface supports up to 7 Mbps; however, upgrades to support up to 25 Mbps are planned.

3.2.1.2.7.2 PN Chip Rate Compensation (As Applicable)

The TDRS H, I, J ground segment shall be capable of Doppler compensating the PN chip rate, when applicable, as specified below:

a. Range: ≤ ±140 chips/sec.

b. Rate: ≤ ±0.20 chips/sec^2.

c. Acceleration: ≤ ±0.00023 chips/sec^3.

3.2.1.2.7.3 Doppler Compensation Frequency Accuracy

The TDRS H, I, J ground segment shall be capable of Doppler compensating the carrier frequency with the following accuracy to customer platforms that meet the constraints specified below:

$F_R = F_0 \pm E$, where:

F_R = Carrier frequency received by the customer platform (in Hz).

F_0 = Receive frequency defined in the customer schedule (in Hz).

E = 550 x $\ddot{R}$, for $\ddot{R} \le 11.4$ m/sec^2.

Customer platform constraints:

Range rate: ≤ 7.90 km/sec.

Range acceleration: ≤ 11.4 m/sec^2.

3.2.1.2.7.4 Doppler Inhibit

The TDRS H, I, J ground segment shall be capable of inhibiting Doppler compensation.

3.2.1.2.7.5 Frequency Continuity

The TDRS H, I, J ground segment shall be capable of maintaining the continuity of the frequency received by the customer platform when Doppler compensation is inhibited.

3.2.1.2.8 Input Port

This section specifies requirements on the KaSAF IF input port in the TDRS H, I, J ground segment.

NOTE

The TDRS H, I, J ground segment is *not* required to Doppler compensate nor sweep the IF input signal.

3.2.1.2.8.1 External Signal Reception

The TDRS H, I, J ground segment shall provide an IF input port capable of receiving an external IF signal (modulated or unmodulated).

3.2.1.2.8.2 Signal Parameters

The TDRS H, I, J ground segment shall provide an IF input port in accordance with the signal parameters specified in Table 3-4 below.

Table 3-4: KaSAF IF Input Port

Parameter	Requirement
a. Center frequency	370 MHz
b. IF 3-dB bandwidth	≥ 50 MHz
c. Input VSWR	≤ 1.3:1 with 50Ω source, ±20 MHz from center frequency
d. Input signal level	-10 dBm ± 3 dB

3.2.1.3 IF-to-Ku-Band Processing (WSC)

This section specifies KaSAF IF-to-Ku-band processing requirements for the TDRS H, I, J ground segment at WSC.

3.2.1.3.1 Upconversion to Ku-Band

The TDRS H, I, J ground segment shall be capable of upconverting the modulated IF command signal to the following Ku-band frequencies:

a. KaSA-1F: 14,625.0 MHz.

b. KaSA-2F: 15,200.0 MHz.

3.2.1.3.2 Power Amplification

The TDRS H, I, J ground segment shall be capable of power amplifying the modulated command signal.

3.2.1.3.3 Command Uplink Transmission

The TDRS H, I, J ground segment shall be capable of transmitting the Ku-band KaSAF command signal to the TDRS H, I, J spacecraft via the SGL antenna at WSC.

3.2.1.3.4 HPA Power Measurement

The TDRS H, I, J ground segment shall be capable of measuring the power at the output of the high-power amplifier (HPA).

3.2.1.3.5 WSC Command Testing

The TDRS H, I, J ground segment shall be capable of testing the WSC KaSAF command equipment (not required during customer support), including:

a. Generating simulated (PN) baseband command data.

b. PN-spreading the simulated command data (when applicable).

c. BPSK-modulating the carrier with the command channel.

d. Generating a simulated range channel (when applicable).

e. QPSK-modulating the carrier with the simulated command and range channels (when applicable).

f. Upconverting the simulated carrier to Ku-band.

g. Sampling the uplink signal at the Ku-band feed of the antenna.

h. Demodulating the carrier (BPSK or QPSK, as applicable).

i. PN-despreading the simulated command data (when applicable).

j. Generating a clock signal and synchronizing it to the simulated command data.

k. Measuring the BER of the simulated (PN) command data.

3.2.1.4 Ku-to-Ka-Band Processing (TDRS)

This section specifies the TDRS H, I, J spacecraft requirements for receiving the Ku-band signal from WSC via the SGL uplink, upconverting it to Ka-band, and relaying it to the customer platform.

3.2.1.4.1 Command Uplink Reception

The TDRS H, I, J spacecraft shall be capable of receiving the KaSAF uplink from the TDRS H, I, J ground segment at the Ku-band frequencies specified in Section 3.2.1.3.1 above.

3.2.1.4.2 Upconversion to Ka-Band

The TDRS H, I, J spacecraft shall be capable of upconverting the Ku-band command signal to any of the Ka-band center frequencies specified below:

a. Minimum: 22.555 GHz[1,2].

b. Maximum: 23.545 GHz[1,2].

c. Tuning step size: ≤ 5.0 MHz[2].

Notes:

1. Frequencies are specified before Doppler compensation, if used.
2. The TDRS H, I, J spacecraft can tune to any center frequency between 22.555 GHz and 23.545 GHz in 5-MHz steps; that is 199 different frequencies.

   Both the SNIP and the SFCG recommend that only the following six center frequencies be used:

   23.205 GHz

   23.265 GHz

   23.325 GHz

   23.385 GHz

   23.445 GHz

   23.505 GHz.

   Each of these SNIP/SFCG frequencies matches a TDRS H, I, J frequency.

3.2.1.4.3 KaSAF Relay to Customer Platform

The TDRS H, I, J spacecraft shall be capable of transmitting the KaSAF signal to the customer platform in accordance with:

a. The distortion constraints specified in Table 3-5 below.

b. The service parameters specified in Table 3-6 below, except that the references to KaSAR autotracking do *not* apply to the 650-MHz KaSAR service.

3.2.2 KaSAR

This section specifies requirements on the existing TDRS H, I, J space and ground segments to support the 225- and 650-MHz KaSAR services.

3.2.2.1 Ka-to-Ku-Band Processing (TDRS)

This section specifies the TDRS H, I, J spacecraft requirements for receiving a KaSAR signal from the customer platform, downconverting it to Ku-band, and relaying it to WSC via the SGL downlink.

Table 3-5: KaSAF Signal Distortion Constraints

Parameter	Requirement
a. BPSK modulator phase imbalance[1]	±3° (peak)
b. Relative phase between command and range channels	90° ±3°
c. Modulator gain imbalance[1]	±0.25 dB (peak)
d. Data asymmetry[1]	±3% (peak)
e. Data transition time (from 90% of initial state to 90% of final state)[1]	≤ 5% of data bit duration but ≥ 4 nsec.
f. Phase nonlinearity (all types)[1]	≤ 0.3 rad. (peak-to-peak) over ±17.5 MHz
g. Gain flatness[1]	≤ 1.6 dB (peak-to-peak) over ±17.5 MHz
h. AM/AM	> 0 dB/dB
i. AM/PM[2]	≤ 7°/dB
j. PN code chip jitter	≤ 1° rms (including effects of Doppler compensation)
k. Data bit jitter[2,3]	≤ 1% (peak)
l. Spurious PM[2]	≤ 1° rms
m. Spurious outputs[2]	≤ -27 dBc
n. Frequency stability[1]	
1. 1 to 100 seconds average time	$< 9 \times 10^{-13}$
2. 24-hour average time	$< 1 \times 10^{-12}$
o. Incidental AM[1]	≤ 2% (peak)
p. Phase noise	
1. 1 Hz to 10 Hz	≤ 2.4° rms
2. 10 Hz to 32 Hz	≤ 2.5° rms
3. 32 Hz to 1 kHz	≤ 5.3° rms
4. 1 kHz to 25 MHz	≤ 2.0° rms
q. PN code chip skew	≤ 0.01 chips (peak)
r. PN code chip asymmetry	≤ 0.01 chips (peak)
s. PN code chip-rate offset	≤ 0.01 chips/sec. (peak; relative to absolute coherence with carrier)

Notes:

1. This parameter is defined in 450-SNUG, Revision 8.
2. This parameter is defined in 450-SNUG, Revision 8.
3. The total bit jitter is the sum of the weighted spurious and random jitter components.
4. For command data rates ≤ 300 kbps, this tolerance specifies the ratio of command channel power to range channel power.

Table 3-6: KaSAF Service Parameters

Parameter	Requirement
a. EIRP	
1. Program track[1]	≥ 56.2 dBWi
2. LEO program track[2]	≥ 59.5 dBWi
3. Autotrack[3]	≥ 63.0 dBWi
b. Transmit antenna	
1. Location	TDRS satellite (H, I, or J)
2. Polarization	RHC and LHC (selectable)
3. Axial ratio	≤ 1.5 dB over 3-dB beamwidth
4. Angular rate (θ-dot)[4]	
(a) Program track[5]	≤ 0.0135°/sec
(b) LEO program track[6]	≤ 0.0122°/sec
(c) Autotrack[5]	≤ 0.0135°/sec
5. Field of view (FOV)	
(a) Program track	
(1) Primary	
[a] Beam shape	Rectangular
[b] North-south[7,8]	±28.0°
[c] East-west[7,8]	±22.0°
(2) Extended	
[a] Beam shape	Elliptical
[b] Elevation[7]	±30.5°
[c] Azimuth[7]	
[1] Inboard	±24.0°
[2] Outboard	±76.8°
(b) LEO program track	
(1) Beam shape	Circular
(2) FOV	±10.5°

Table 3-6: KaSAF Service Parameters (Cont'd)

Parameter	Requirement
(c) Autotrack[9]	
(1) Primary	
[a] Beam shape	Rectangular
[b] North-south[7,8]	±28.0°
[c] East-west[7,8]	±22.0°
(2) Extended	
[a] Beam shape	Elliptical
[b] Elevation[7]	±30.5°
[c] Azimuth[7]	
[1] Inboard	±24.0°
[2] Outboard	±76.8°
c. RF channel 3-dB bandwidth	≥ 50 MHz
d. C/N at output of TDRS H, I, J spacecraft antenna	> 16 dB

Notes:

1. With TDRS open-loop antenna pointing, a customer ephemeris uncertainty of ±2.0 seconds, and a TDRS SA antenna axial ratio of 3 dB.
2. EIRP in the direction of the customer platform with a customer ephemeris uncertainty of ±1.5 seconds, uniformly distributed along the customer platform orbital track, and allowing for an SA antenna axial ratio of 3 dB.
3. EIRP in the direction of the customer platform during KaSAF service in conjunction with KaSAR service autotracking.
4. θ-dot (the time derivative of θ) is the maximum angular rate for which service will be provided.

   θ-dot = RSS (θ_x-dot, θ_y-dot), where:

   θ_x is the north-south component of the angle between the TDRS H, I, J spacecraft/nadir vector and the TDRS H, I, J spacecraft/customer platform vector, and

   θ_y is the east-west component of that angle.
5. With customer ephemeris uncertainty of ±2.0 seconds, uniformly distributed along the customer platform orbital track.
6. With customer ephemeris uncertainty of ±1.5 seconds, uniformly distributed along the customer platform orbital track.
7. Spacecraft orbit normal coordinates, as defined in SE-BB-01.
8. North-south refers to elevation in the spacecraft orbit-normal coordinate system. East-west refers to azimuth in the spacecraft orbit-normal coordinate system.
9. KaSAF service in conjunction with KaSAR service autotracking.

3.2.2.1.1 Ka-Band Frequencies

The TDRS H, I, J spacecraft shall be capable of receiving a KaSAR signal from a customer platform at the Ka-band center frequencies specified below (these frequencies do not include the effects of Doppler shift):

3.2.2.1.1.1 225-MHz Service

The 225-MHz KaSAR service supports two frequency plans: the TDRS H, I, J and the SNIP/SFCG frequencies.

3.2.2.1.1.1.1 TDRS H, I, J Frequencies

The TDRS H, I, J spacecraft shall be capable of tuning to any of the following center frequencies:

a. Minimum: 25.2534 GHz.

b. Maximum: 27.4784 GHz.

c. Step size: ≤ 25-MHz (that is, ≥ 90 different frequencies).

3.2.2.1.1.1.2 SNIP/SFCG Frequencies

The TDRS H, I, J spacecraft shall be capable of supporting all of the following SNIP/SFCG center frequencies (although it cannot tune to these exact frequencies):

a. 25.60 GHz.

b. 25.85 GHz.

c. 26.10 GHz.

d. 26.35 GHz.

e. 26.60 GHz.

f. 26.85 GHz.

g. 27.10 GHz.

h. 27.35 GHz.

3.2.2.1.1.2 650-MHz Service Frequencies

The 650-MHz KaSAR service supports only the SNIP/SFCG frequency plan.

The TDRS H, I, J spacecraft shall be capable of supporting all of the SNIP/SFCG frequencies specified in Section 3.2.2.1.1.1.2 above, *except 27.35 GHz* (although it cannot tune to these exact frequencies).

NOTE

For the 650-MHz service, although the TDRS H, I, J spacecraft can tune to any center frequency between 25.545 GHz and 27.195 GHz in 25-MHz steps (that is, 67 different frequencies), it is not required to support any of these frequencies.

3.2.2.1.2 Service Parameters

The TDRS H, I, J spacecraft shall be capable of providing the KaSAR service in accordance with the parameters specified in Table 3-7 below.

3.2.2.1.3 Channel Characteristics

The TDRS H, I, J spacecraft shall be capable of processing a KaSAR signal with the channel characteristics specified in Table 3-8 below.

3.2.2.1.4 Downconversion from Ka-Band to Ku-Band

The TDRS H, I, J spacecraft shall be capable of downconverting the KaSAR signal from Ka-band to the Ku-band frequency specified in row 1.b in Table 3-8 below.

3.2.2.1.5 Transmission via Ku-Band SGL Downlink

The TDRS H, I, J spacecraft shall be capable of transmitting the KaSAR signal to the TDRS H, I, J ground segment via the Ku-band SGL.

3.2.2.2 Ku-Band Reception: 650-MHz IF Service (WSC)

This section specifies the requirements for receiving the Ku-band 650-MHz KaSAR signal by the existing TDRS H, I, J ground segment at WSC.

3.2.2.2.1 Ku-Band SGL Downlink Reception

The TDRS H, I, J ground segment shall be capable of receiving the 650-MHz KaSAR signal via the Ku-band SGL downlink.

3.2.2.2.2 G/T

The TDRS H, I, J ground segment shall be capable of providing an effective system G/T ≥ 40.3 dB/K.

3.2.2.2.3 Channel Parameters

The TDRS H, I, J ground segment shall be capable of meeting the 650-MHz channel parameter requirements in Table 3-9 below.

3.2.2.3 Ku-Band-to-Baseband Processing: 225-MHz Service (WSC)

This section specifies the Ku-band-to-baseband processing requirements for the 225-MHz KaSAR signal by the existing TDRS H, I, J ground segment at WSC.

General Requirements

The TDRS H, I, J ground segment shall be capable of:

a. Receiving the 225-MHz KaSAR signal via the Ku-band SGL downlink.

b. Providing an effective system G/T ≥ 40.3 dB/K.

Table 3-7: TDRSS H, I, J KaSAR Service Parameters

Parameter	Requirement	
	1. 225-MHz Service	2. 650-MHz Service
a. Receive antenna location	TDRS spacecraft (H, I, or J)	TDRS spacecraft (H, I, or J)
b. Polarization (selectable)	RHC and LHC	RHC and LHC
c. Axial ratio (over 3-dB beamwidth)	≤ 1.0 dB	≤ 1.0 dB
d. FOV		
1. LEO program track		
(a) Beam shape	Circular	Circular
(b) FOV	±10.5°	±10.5°
2. Program track		
(a) Primary		
(1) Beam shape	Rectangular	Rectangular
(2) North-south[1,2]	±28.0°	±28.0°
(3) East-west[1,2]	±22.0°	±22.0°
(b) Extended		
(1) Beam shape	Elliptical	Elliptical
(2) Elevation[1]	±30.5°	±30.5°
(3) Azimuth[1]		
[a] Inboard	±24.0°	±24.0°
[b] Outboard	±76.8°	±76.8°
3. Autotrack		N/A
(a) Primary		
(1) Beam shape	Rectangular	
(2) North-south[1,2]	±28.0°	
(3) East-west[1,2]	±22.0°	

Table 3-7: TDRSS H, I, J KaSAR Service Parameters (Cont'd)

Parameter	Requirement	
	1. 225-MHz Service	2. 650-MHz Service
(b) Extended		
(1) Beam shape	Elliptical	
(2) Elevation[1]	±30.5°	
(3) Azimuth[1]		
[a] Inboard	±24.0°	
[b] Outboard	±76.8°	

Notes:

1. TDRS spacecraft orbit normal coordinates.
2. In the TDRS spacecraft orbit-normal coordinate system, "north-south" refers to elevation and "east-west" refers to azimuth.

Table 3-8: TDRS H, I, J Spacecraft KaSAR Channel Characteristics

Parameter	Requirement[1]	
	A. 225-MHz Service	B. 650-MHz Service
1. Center frequency		
a. Input to TDRS (Ka-band tuning)	As specified in Section 3.2.2.1.1.1 above	As specified in Section 3.2.2.1.1.2 above
b. Output from TDRS (Ku-band)	As specified in row 1, column A of Table 3-15 below	As specified in row 1, column B of Table 3-15 below
2. Gain flatness	≤ 1.2 dB (peak-to-peak) over ±80 MHz about the center frequency[3a]	≤ 1.2 dB (peak-to-peak) over ±230 MHz about the center frequency[3b]
3. Phase nonlinearity (all types)	≤ 12° (peak-to-peak) over ±80 MHz about the center frequency[4a]	≤ 12° (peak-to-peak) over ±230 MHz about the center frequency[4b] peak-to-peak over ±230 MHz.
4. AM/AM	> 0.6 dB/dB	> 0.6 dB/dB
5. AM/PM	≤ 6°/dB	≤ 6°/dB
6. 3-dB RF bandwidth	≥ 225 MHz	≥ 650 MHz
7. Spurious PM	≤ 2.24° rms between 100 Hz and 112.5 MHz from the center frequency	≤ 2.24° rms between 100 Hz and 325 MHz from the center frequency
8. Spurious outputs	≤ -30 dBc (within 3-dB RF bandwidth)	≤ -30 dBc (within 3-dB RF bandwidth)

Table 3-8: TDRS H, I, J Spacecraft KaSAR Channel Characteristics (Cont'd)

Parameter	Requirement[1]	
	A. 225-MHz Service	B. 650-MHz Service
9. Incidental AM	≤ 1% (within 3-dB RF bandwidth)	≤ 1% (within 3-dB RF bandwidth)
10. Phase noise[2]		
a. 1 Hz to 10 Hz	≤ 27.5° rms	≤ 27.5° rms
b. 10 Hz to 100 Hz	≤ 14.3° rms	≤ 14.3° rms
c. 100 Hz to 1 kHz	≤ 4.3° rms	≤ 4.3° rms
d. 1 kHz to 150 MHz	≤ 2.7° rms	N/A
e. 1 kHz to 400 MHz	N/A	≤ 2.7° rms

Notes:

1. Parameters are measured at the Ku-band SGL antenna output of the TDRS H, I, J spacecraft. Contributions from only the TDRS H, I, J spacecraft are included, except for carrier phase noise, which also includes contributions from the customer platform (see note 2 below).
2. Phase noise is specified as the result of contributions from both the customer platform and the TDRS H, I, J spacecraft.

   For the 225-MHz service, the customer platform contribution is:

   a. 1 Hz to 10 Hz: ≤ 27.2° rms.
   b. 10 Hz to 100 Hz: ≤ 13.6° rms.
   c. 100 Hz to 1 kHz: ≤ 3.6° rms.
   d. 1 kHz to 150 MHz: ≤ 2.0° rms.

   For the 650-MHz service, the customer platform contribution is the following:

   e. 1 Hz to 10 Hz: ≤ 27.2° rms.
   f. 10 Hz to 100 Hz: ≤ 13.6° rms.
   g. 100 Hz to 1 kHz: ≤ 3.6° rms.
   h. 1 kHz to 400 MHz: ≤ 2.0° rms.
3. Gain flatness is specified as the residual RF amplitude variation from linearity after subtracting the linear and parabolic components lying within the equalization bounds corresponding to the amplitude equalization bounds specified in the following figure in 405-TDRS-RP-SY-001:

   a. 225-MHz service: Figure 6-12 (KuSAR).

   b. 650-MHz service: Figure E-2.
4. Phase nonlinearity is specified as the residual RF phase variation from linearity after subtracting the cubic and parabolic components lying within the equalization bounds corresponding to the phase equalization bounds specified in the following figure in 405-TDRS-RP-SY-001:

   a. 225-MHz service: Figure 6-9 (KuSAR), or the equivalent group delay equalization bound specified in Figure 6-10 (KuSAR).

   b. 650-MHz service: Figure E-1.

Table 3-9: TDRS H, I, J Ground Segment Channel Parameters: 650-MHz Service

Parameter	Requirement[1]
1. Center frequency (Ku-band)	As specified in row 1, column B in Table 3-15 below
2. Gain flatness	≤ 0.6 dB (peak-to-peak) over ±230 MHz about the center frequency, sinusoidal, ripple period ≥ 20 MHz
3. Gain slope	≤ 0.1 dB/MHz over ±230 MHz about the center frequency
4. Phase nonlinearity	
a. Parabolic[3]	Over ±230 MHz about the center frequency
(1) STGT	
(a) South antenna	$\leq 340 \times Q_p \times (\Delta F)^2$ degrees
(b) Central antenna	$\leq 230 \times Q_p \times (\Delta F)^2$ degrees
(c) North antenna	$\leq 120 \times Q_p \times (\Delta F)^2$ degrees
(2) WSGT	
(a) South antenna	$\leq 316 \times Q_p \times (\Delta F)^2$ degrees
(b) Central antenna	$\leq 216 \times Q_p \times (\Delta F)^2$ degrees
(c) North antenna	$\leq 116 \times Q_p \times (\Delta F)^2$ degrees
b. Non-parabolic	≤ 6° (peak-to-peak) over ±230 MHz about the center frequency
5. AM/AM	> 0.95 dB/dB
6. AM/PM	≤ 0.5°/dB
7. 3-dB bandwidth	≥ 650 MHz
8. Noise figure	≤ 6 dB
9. Phase noise[2]	
a. 1 Hz to 10 Hz	≤ 27.5° rms
b. 10 Hz to 100 Hz	≤ 14.3° rms
c. 100 Hz to 1 kHz	≤ 4.3° rms
d. 1 kHz to 400 MHz	≤ 2.7° rms

Notes:

1. Parameters are measured at the Ku-band interface between the TDRS H, I, J ground segment and the Ka-Band Infrastructure (between the IFL HWCI and KSA High Data Rate Equipment HWCI). Contributions from only the TDRS H, I, J ground segment are included, except for phase noise (see note 2 below).
2. Phase noise is specified as an accumulation of contributions from the customer platform, TDRS H, I, J spacecraft, and TDRS H, I, J ground segment. The total contribution from the customer platform and the TDRS H, I, J spacecraft is specified in row 10, column B of Table 3-8 above.
3. Parabolic phase nonlinearity induced by the WSC Antenna Subsystem.
   ΔF = Deviation from center frequency in MHz, $Q_p = 1.5 \times 10^{-5}$ ±20%.

3.2.2.3.1 Customer Signal Parameters

For the 225-MHz KaSAR service, the TDRS H, I, J ground segment shall be capable of supporting a signal from the customer platform with the parameters defined in Table 3-10 below, with the following exceptions:

a. Reed-Solomon coding is applicable *only if the customer uses the WDISC*.

b. Concatenated coding is applicable *only if the customer uses the WDISC*.

Customer signal distortion constraints for the 225-MHz KaSAR service are defined in Table 8-9 of 450-SNUG, Revision 8.

NOTE

WDISC KaSAR support is limited to the following:

Data rate: 100 bps to 512 kbps per channel.

[Data rates > 512 kbps may be supported at the risk of overloading the WDISC. Analysis and testing will be necessary to ensure reliable operation.

Number of channels*: 3 at STGT and 3 at WSGT.

* "Channel" means an I channel or a Q channel. WDISC cannot simultaneously support two dual-channel QPSK customers at the same site, since a dual-channel customer needs two channels: one I and one Q.

(For further information on the WDISC, see the documents 451-WDISC-OCD 98, 451-WDISC-SRD 98, and 451-WDISC-SSD 98. These references are listed in Section 1.7.2 above.

NOTE

The documents ETS-450-100012 and SF17 - 28/D provide additional information about Staggered Quadrature Phase Shift Keying (SQPSK; synonymous with OQPSK). These references are listed in Section 1.7.2 above.

3.2.2.3.2 Data Formats with Convolutional Coding

This section specifies the data formats that are supported by the TDRS H, I, J ground segment if the customer platform uses convolutional encoding for the 225-MHz KaSAR service.

3.2.2.3.2.1 Input Data Format

For the 225-MHz KaSAR service, the TDRS H, I, J ground segment shall be capable of supporting convolutional decoding if the data format at the input to the customer platform encoder is NRZ.

Table 3-10: 225-MHz KaSAR Customer Signal Parameters (BPSK, QPSK, or SQPSK)

Parameter	Customer Constraint
1. Carrier frequency reference	customer platform oscillator
2. I:Q power ratio (N/A to BPSK)	1:1 or 4:1
3. Data format[1]	NRZ-L, M, or S or Biϕ-L, M, or S
4. Symbol format[2]	NRZ or Biϕ
5. Data rate[3]	
a. NRZ data[1]	
(1) Uncoded	
(a) Total[7]	1 kbps to 300 Mbps
(b) I channel and Q channel	1 kbps to 150 Mbps
(2) R-S coded[6]	
(a) Total	1 kbps to 1.024 Mbps[8]
(b) I channel and Q channel	1 kbps to 512 kbps[9]
(3) Rate-½ coded, without Biϕ conversion[4]	
(a) Total[7]	1 kbps to 150 Mbps
(b) I channel and Q channel	1 kbps to 75 Mbps
(4) Rate-½ coded, then Biϕ-converted[4]	
(a) Total[7]	1 kbps to 10 Mbps
(b) I channel and Q channel	1 kbps to 5 Mbps
(5) Concatenated coded[6] (with or without Biϕ conversion)	
(a) Total	1 kbps to 1.024 Mbps[8]
(b) I channel and Q channel	1 kbps to 512 kbps[9]
b. Biϕ data (uncoded only[5])	
(1) Total[7]	1 kbps to 10 Mbps
(2) I channel and Q channel	1 kbps to 5 Mbps

Notes:

1. Format before symbol conversion to Biϕ, if used.
2. Format after convolutional encoding, if used.
3. Data on I and Q channels may be independent and asynchronous.
4. Data rate is measured at the input to the convolutional encoder.
5. Data rate is measured at the input to the Biϕ converter.
6. Data rate is measured at the input to the R-S encoder.
7. If the data on the I and Q channels are independent, the sum of the I and Q-channel data rates must not exceed the “Total” data rate.
8. Because (a) only the WDISC can process R-S and concatenated data, and (b) the WDISC supports data rates up to only 512 kbps per output port, the Total data rate for single-channel customers is limited to 512 kbps. See Sections 3.2.2.3.1.a and b above and the NOTE immediately thereafter.
9. Because only the WDISC can process R-S and concatenated data, the maximum data rate is limited to 512 kbps per channel. See the NOTE after Section 3.2.2.3.1.b above.

3.2.2.3.2.2 Output Data Format

For the 225-MHz KaSAR service, the TDRS H, I, J ground segment shall be capable of supporting convolutional decoding if the data format at the output of the customer platform encoder is the following:

a. I and Q Data Rates ≤ 5 Mbps

1. NRZ.
2. Biϕ, and both of the following conditions are met.
   (a) Symbol interleaving is not used.
   (b) The G2 output from the convolutional encoder is not inverted.

b. I and Q Data Rates > 5 Mbps

NRZ.

(There is *no* requirement to support convolutional decoding if the output of the customer platform encoder is converted from NRZ to Biϕ format.)

3.2.2.3.3 Customer Configurations

For the 225-MHz KaSAR service, the TDRS H, I, J ground segment shall be capable of supporting all of the customer configurations defined in Table 3-11 below.

3.2.2.3.4 Coding and Interleaving Configurations

This section specifies the customer platform coding and interleaving configurations supported by the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.4.1 Convolutional Codes and Interleaving

The TDRS H, I, J ground segment shall be capable of supporting the customer platform convolutional coding and interleaving configurations specified below.

NOTE

The convolutional code defined below is KSAR Code 1 in Appendix K to SY-011. It is identical to the code recommended in CCSDS 101.0-B-4, except that the CCSDS (1) always inverts the G2 symbols, and (2) makes no recommendations regarding the use of parallel encoders.

a. Rate (R)

R = ½.

b. Constraint Length (K)

K = 7.

Table 3-11: 225-MHz KaSAR Customer Configurations: BPSK, QPSK, and SQPSK

Customer Configuration	A. BPSK	B. QPSK[6]	C. SQPSK
1. Single data channel			
a. Uncoded	X		X[1]
b. Convolutionally coded	X		
(1) Alternating symbols[2]			X[4]
(2) Individually coded[3]			X
c. R-S coded[7]	X		X[5]
d. Concatenated coded[7]	X		X[3,5]
2. Dual independent data channels			
a. Uncoded		X	X[1]
b. Convolutionally coded		X	X
c. R-S coded[7]		X	X
d. Concatenated coded[7]		X	X

Notes:

1. Alternating I/Q data bits.
2. Alternating coded symbols on the I and Q channels.
3. I- and Q-channel data is individually convolutionally encoded.
4. Only for data rates < 10 Mbps.
5. R-S encoding occurs before the data is split into I and Q channels.
6. QPSK is allowed only if the I and Q-channel symbol rates are unequal. (If the symbol rates are equal, the I and Q channels must be offset by half a symbol period relative to one another; i.e., SQPSK must be used.)
7. R-S and concatenated coding are allowed *only if the customer uses the WDISC*.

c. Generator Polynomials

1. G1 = 1111001.
2. G2 = 1011011.

d. G1 and G2 Symbol Timing

Symbols generated from G1 will precede symbols generated from G2 relative to the data bit period.

e. G2 Inversion

Symbols generated from G2 can be either true or complemented.

f. Single-Channel SQPSK > 10 Mbps

For SQPSK single-channel data rates > 10 Mbps:

1. Each encoder will consist of "n" branch encoders in parallel.
2. The composite serial symbol output from the encoder will consist of the branch encoder output symbols interleaved every n^{th} symbol.
3. 450-SNUG, Revision 8, defines the configuration of the parallel encoders.
4. The number of branch encoders is calculated as follows:

   $n = R_d/20$, rounded to the next higher integer if $n \neq$ integer, where:

   n = Number of branch encoders for the I and Q channel.

   R_d = Channel data rate (in Mbps).

g. Dual-Channel SQPSK > 10 Mbps

For dual-channel data rates > 10 Mbps:

1. The data will be encoded by an n-parallel encoder.
2. 450-SNUG, Revision 8, defines the configuration of the parallel encoders.
3. The number of branch encoders is calculated as follows:

   $n = R_d/10$, rounded to the next higher integer if $n \neq$ integer, where:

   n = Number of branch encoders for the I and Q channel.

   R_d = Channel data rate (in Mbps).

3.2.2.3.4.2 Reed-Solomon Codes

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of supporting the customer platform R-S coding configuration specified below:

a. (255,223,16) Code

The R-S (255,223,16) code is defined in CCSDS 101.0-B-4.

b. R-S Modes

1. Detect and correct.
2. Detect only.
3. Bypass.

3.2.2.3.4.3 Concatenated Codes

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of supporting the concatenated code defined in CCSDS 101.0-B-4.

3.2.2.3.5 Baseband Processing

This section specifies those baseband telemetry processing standards recommended by the CCSDS and other organizations that are supported by the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.5.1 Frame Synchronization

The WDISC shall have the capability to provide frame synchronization functions for the following:

a. CCSDS Channel Access Data Unit (CADU) frames that are formatted in accordance with CCSDS 701.0-B-2.

b. Frames with Attached Sync Marker (ASM) in accordance with CCSDS 101.0-B-4.

3.2.2.3.5.2 Data De-Randomization

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of de-randomizing pseudo-randomized data, in accordance with CCSDS 101.0-B-4.

3.2.2.3.5.3 Virtual Channel Data Unit (VCDU) Extraction

The WDISC shall have the capability to provide Virtual Channel Data Unit (VCDU) or Coded VCDU (CVCDU) extraction for the CCSDS CADU frames that are formatted in accordance with CCSDS 701.0-B-2. CADU frames are constructed by adding a synchronization marker to a VCDU or CVCDU.

3.2.2.3.5.4 Header Appending

The WDISC shall have the capability to append headers to processed CADUs prior to sending the processed data to the DSMC or MOC via the NASA Integrated Services Network (NISN) IP Network. The header options are listed in the AVTEC Systems Programmable Telemetry Processor (PTP) for Windows NT User's Manual. New header options can also be added to the WDISC by upgrading the PTP software. Header options can include Low Earth Terminal (LEO-T) header, Standard Formatted Data Unit (SFDU) header, and IPDU header.

3.2.2.3.5.5 CCSDS CADU Frames

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of receiving and processing the CCSDS CADU frames that are formatted in accordance with CCSDS 701.0-B-2.

3.2.2.3.5.6 Internet Protocols

The WDISC shall have the capability to use the Internet protocols specified below to transfer data from the ground stations to terrestrial facilities such as MOCs and the DSMC.

a. TCP/IP

Sending customer telemetry data (processed CADUs) to the MOC or DSMC via the NISN IP Network using TCP/IP.

b. File Transfer Protocol (FTP)

Sending customer telemetry data files to the MOC or DSMC via the NISN IP Network using FTP.

3.2.2.3.5.7 Time Tagging

If the customer uses the WDISC, the TDRS H, I, J ground segment shall be capable of the following:

a. Accuracy

Time-tagging the telemetry data with an accuracy ≤ 10 ms.

b. Format

Formatting the time tag in accordance with the CCSDS Day Segmented Time Code specified in CCSDS 301.0-B-2.

3.2.2.3.6 Data Recording

This section specifies the customer digital data recording performance of the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.6.1 General Requirements

The TDRS H, I, J ground segment shall be capable of the following:

a. Recording at all of the data rates specified in Table 3-10 above.

b. Playing back at data rates from 1.5 to 150 Mbps.

c. Providing rate buffering; i.e., recording at the customer return data rate and playing back at a lower rate.

3.2.2.3.6.2 WDISC Recording Capability

The WDISC shall have the capability to store processed CADU data on its file servers for future playback to the MOC or the DSMC.

3.2.2.3.7 Customer Dynamics

This section specifies the customer platform dynamics supported by the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.7.1 Frequency Dynamics

The TDRS H, I, J ground segment shall be capable of supporting customer platforms with the frequency dynamics defined below:

a. Doppler: ≤ ±730 kHz (≤ 7.9 km/s at 27.48 GHz).

b. Doppler rate: ≤ ±1.1 kHz/s (≤ 11.4 m/s^2 at 27.48 GHz).

c. Doppler acceleration: ≤ ±1.2 Hz/s^2 (≤ 0.013 m/s^3 at 27.48 GHz).

3.2.2.3.7.2 Antenna Tracking

The TDRS H, I, J ground segment shall be capable of tracking customer platforms that meet all of the following constraints:

a. Angular Velocity

"Angular velocity" is defined as the time rate-of-change of the angle of the SA antenna on the TDRS H, I, J spacecraft.

1. Program track: ≤ 0.0135°/sec.
2. LEO program track: ≤ 0.0122°/sec.
3. Autotrack: ≤ 0.0135°/sec.

b. Ephemeris Uncertainty

1. Program track: ≤ ± 2.0 sec.
2. LEO program track: ≤ ± 1.5 sec.
3. Autotrack: ≤ ± 2.0 sec.

The ephemeris uncertainty is assumed to be uniformly distributed along the customer platform orbital track.

3.2.2.3.8 Clock Synchronization (Symbol Transition Density)

For the 225-MHz KaSAR service, the TDRS H, I, J ground segment shall be capable of achieving and maintaining clock synchronization if each channel of the customer platform signal meets both of the following constraints:

a. Number of symbol* transitions: ≥ 128 within any sequence of 512 symbols.

b. Number of consecutive symbols* without a transition: ≤ 64.

* A "symbol" is defined as the data unit *after* any encoding (convolutional, R-S, or concatenated) but *before* any conversion to biphase format. See the definition of "Symbol Rate" in Section 1.6.d above.

3.2.2.3.9 Implementation Loss

This section specifies the implementation loss for the 225-MHz KaSAR service in the TDRS H, I, J ground segment.

NOTE

For the purposes of this Implementation Loss requirement, the "TDRS H, I, J ground segment" does not include the *WDISC*.

"Implementation loss" is defined as the difference between the following two E_b/N_o values:

a. The E_b/N_o needed to achieve a given BER with an *imperfect* customer signal.

b. The E_b/N_o *theoretically* required to achieve the given BER with an ideal, distortion-free customer signal.

The imperfect customer signal and the theoretically required E_b/N_o are defined below in Sections 3.2.2.3.9.2 and 3.2.2.3.9.3, respectively.

3.2.2.3.9.1 Implementation Loss Requirement

The TDRS H, I, J ground segment shall be capable of providing the implementation loss specified in Table 3-12 below, in the presence of additive white Gaussian noise (AWGN), under all of the conditions defined in Section 3.2.2.3.9.2 below.

Table 3-12: Implementation Loss: 225-MHz KaSAR Service

Modulation and Coding	Implementation Loss[1,2]
1. Uncoded	As specified in Table 5-26b of 405-TDRS-RP-SY-011
2. Convolutionally coded	As specified in Table 5-26a of 405-TDRS-RP-SY-011
3. Reed-Solomon coded	Same as for Uncoded[3]
4. Concatenated coded	Same as for Convolutionally coded[4]

Note:

1. Implementation loss is specified for each I and Q channel.
2. Implementation loss does *not* include the WDISC.
3. R-S decoding is performed by the WDISC and is outside the scope of the Implementation Loss requirement.
4. Concatenated decoding requires R-S decoding that is performed by the WDISC, and is therefore outside the scope of the Implementation Loss requirement.

3.2.2.3.9.2 Conditions

This section defines the conditions under which the Implementation Loss Requirement specified in Section 3.2.2.3.9.1 above must be met.

This section does not specify requirements and, therefore, does not contain “shall” statements. Rather, it defines selected conditions of the customer platform and TDRS signal and dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

3.2.2.3.9.2.1 BER

The following BERs are referenced to the output of the TDRS H, I, J ground segment, *not including the WDISC*:

a. 10^{-5}.

b. 10^{-6}.

c. 10^{-7}.

3.2.2.3.9.2.2 Input Signal Characteristics

The following signal characteristics are defined at the input to the TDRS H, I, J ground segment:

a. **Signal Level**

The nominal total isotropic power (customer signal plus customer-to-TDRS AWGN) received at the aperture of the SGL ground antenna is defined below for clear-sky conditions with a noise temperature of 100 K:

1 KSA-1 (Dedicated): -127.63 dBmi.

2. KSA-2 (Composite): -131.28 dBmi.

b. **Bandwidth**

2.5-dB RF signal bandwidth, maximum:225 MHz.

c. **Phase Noise**

The total phase noise due to the customer platform and the TDRS H, I, J spacecraft is defined in Table 3-8 above.

d. **Signal Dynamics**

The frequency dynamics that result from the customer platform's range dynamics are defined in Section 3.2.2.3.7.1 above.

e. **Symbol Transition Density**

The Symbol Transition Density constraints on the customer platform are defined in Section 3.2.2.3.8 above.

f. **Jitter**

The meaning of symbol jitter and jitter rate is explained in 450-SNUG, Revision 8.

The constraints on symbol jitter and jitter rate are defined below:

1. Symbol jitter: $\leq$ 0.1%.
2. Symbol jitter rate: $\leq$ 0.1%.

For uncoded data, symbol jitter should be interpreted as data jitter.

The total symbol jitter is the sum of the weighted spurious and random jitter components. The values apply to rate-½ convolutionally encoded data signals.

3.2.2.3.9.2.3 Other TDRS-Induced Distortions

The following TDRS-induced distortions are defined in Table 3-8 above:

a. Gain Flatness

b. Phase Nonlinearity

c. RF Bandwidth

3.2.2.3.9.2.4 Other Customer Platform-Induced Distortions

The following customer platform-induced distortions:

a. **Gain Flatness**

$\leq$ 0.6 dB (peak-to-peak) over ±80 MHz.

b. **Phase Nonlinearity (All Types)**

$\leq 6°$ (peak-to-peak) over ±80 MHz.

c. **Channel Bandwidth (3-dB)**

$\geq 2 \times$ maximum channel symbol rate (prior to the power amplifier).

(For the Channel Bandwidth constraint, the symbol rate for Biϕ-formatted data is twice the symbol rate prior to the NRZ-to-Biϕ data format conversion.)

3.2.2.3.9.2.5 Customer Signal Parameters

Customer Signal Parameters are defined in Section 3.2.2.3.1 above.

3.2.2.3.9.2.6 Data Formats with Convolutional Coding

Data Formats with Convolutional Coding are defined in Section 3.2.2.3.2 above.

3.2.2.3.9.2.7 Customer Configurations

Customer Configurations are defined in Section 3.2.2.3.3 above.

3.2.2.3.9.2.8 Coding and Interleaving Configurations

Coding and Interleaving Configurations are defined in Section 3.2.2.3.4 above.

3.2.2.3.9.2.9 C/No Levels

The following C/N_o levels are referenced to the output of the TDRS H, I, J ground segment, *not including* the WDISC:

a. Minimum: The C/N_o needed for a BER of 10^{-5}.

b. Maximum: 12 dB greater than the C/N_o needed for a BER of 10^{-5}.

3.2.2.3.9.3 Theoretically Required Eb/No

Table 3-13 below defines the theoretically required E_b/N_o in an AWGN channel for a BER of 10^{-5}, 10^{-6}, and 10^{-7}.

3.2.2.3.10 Interference

The TDRS H, I, J ground segment shall be capable of meeting all of the 225-MHz KaSAR service requirements specified in Section 3 during the following condition: The center of the sun is > 0.5° outside the boresight of the TDRS H, I, J satellite SA antenna that is providing the service.

Table 3-13: Theoretically Required E_b/N_o: 225-MHz KaSAR Service

Configuration	Theoretically Required E_b/N_o (dB)		
	A. 10^{-5} BER[1]	B. 10^{-6} BER[1]	C. 10^{-7} BER[1]
1. Uncoded[2]			
a. NRZ-L and biphase-L data	9.6	10.5	11.3
b. NRZ-M, S and biphase-M, S data[3]	9.9	10.7	11.5
2. Convolutionally coded: R-½, K=7			
a. NRZ-L and biphase-L symbols	4.2[4]	4.8[4]	5.4[4,5]
b. NRZ-M, S and biphase-M, S symbols[3]	4.4	5.0	5.6
3. Reed-Solomon coded: (255,223,16)	Same as for uncoded[6]	Same as for uncoded[6]	Same as for uncoded[6]
4. Concatenated coded: R-½, K=7 convolutional with Reed-Solomon	Same as for convolutionally coded[7]	Same as for convolutionally coded[7]	Same as for convolutionally coded[7]

Notes:

1. BER is referenced to the output of the TDRS H, I, J ground segment, *not including* the WDISC.
2. E_b/N_o's were analytically derived using the complementary error function.
3. E_b/N_o's for differentially formatted data (symbols) (that is, -M and -S) were determined by doubling the BER for NRZ-L and biphase-L data (symbols) and calculating the resultant change in E_b/N_0.
4. Source: Figures 5.11 and 7.2 in "Error Control Coding Handbook (Final Report)," Joseph P. Odenwalder, Linkabit Corp., 15 July 1976. E_b/N_o's for 10^{-9} BER extrapolated from 10^{-8} BER.
5. Source: Figure A-3 in 700.0-G-3, "Advanced Orbiting Systems, Networks and Data Links: Summary of Concept, Rationale, and Performance," Green Book, Issue 3, CCSDS, November 1992.
6. R-S decoding must be performed by the WDISC, and is outside the scope of the Implementation Loss requirement.
7. Concatenated decoding requires R-S decoding that is performed by the WDISC, and is therefore outside the scope of the Implementation Loss requirement.

3.2.2.3.11 Autotracking

This section specifies the TDRS SA antenna autotracking performance of the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.11.1 Customer Dynamics Constraints

The TDRS H, I, J ground segment shall be capable of autotracking any customer platform that meets the Customer Dynamics constraints defined in Section 3.2.2.3.7 above.

3.2.2.3.11.2 Autotrack Acquisition Time

The TDRS H, I, J ground segment shall be capable of acquiring autotrack in ≤ 10 seconds with a probability > 0.99 if the KaSAR customer signal meets the P_{rec} constraints defined in Table 3-14 below.

Definition of Autotrack Acquisition Time

"Autotrack acquisition time" is defined as the interval between the following start and stop times:

Start time: When the KaSAR customer signal is received at the input of the autotrack receiver in the TDRS H, I, J ground segment.

Stop time: When autotrack acquisition occurs.

Definition of Autotrack Acquisition

"Autotrack acquisition" is defined to have occurred when the antenna autotrack error signals maintain the TDRS SA antenna boresight axes in continuous alignment with the customer platform with sufficient accuracy to provide the autotrack-mode EIRP specified for the KaSAF service in Table 3-6 above.

Table 3-14: 225-MHz KaSAR Customer P_{rec} Constraints for SA Antenna Autotrack Acquisition

Parameter	Constraint
1. P_{rec} for Primary Field of View autotrack acquisition	≥ -183.2 dBW or consistent with the P_{rec} for BER, whichever is greater (see 450-SNUG, Rev. 8)
2. P_{rec} for LEO Field of View autotrack acquisition	≥ -188.1 dBW or consistent with the P_{rec} for BER, whichever is greater (see 450-SNUG, Rev. 8)
3. P_{rec} for Extended Elliptical Field of View autotrack acquisition	≥ -184.2 dBW or consistent with the P_{rec} for BER, whichever is greater (see 450-SNUG, Rev. 8)

3.2.2.3.11.3 Failure to Acquire

If antenna autotrack acquisition does not occur within the specified time, the TDRS H, I, J ground segment shall be capable of continuing the acquisition process until one of the following events occurs:

a. Autotrack is acquired. ("Autotrack acquisition" is defined in Section 3.2.2.3.11.2 above.)

b. A reacquisition is requested.

c. The scheduled 225-MHz KaSAR service ends.

3.2.2.3.12 Carrier Acquisition Time

This section specifies requirements on the TDRS H, I, J ground segment for acquiring the 225-MHz KaSAR customer platform carrier.

3.2.2.3.12.1 Acquisition Time Requirement

Under all of the Conditions defined in Section 3.2.2.3.12.2 below, the TDRS H, I, J ground segment shall be capable of acquiring the 225-MHz KaSAR customer platform carrier within the time interval specified below with a probability ≥ 0.9:

a. Normal Frequency Uncertainty

Customer platform transmit frequency uncertainty ≤ ±6 kHz: ≤ 1 second.

b. Extended Frequency Uncertainty (> ±10 kHz)

Customer platform transmit frequency uncertainty ≤ ±21 kHz: ≤ 3 seconds.

Definition of Carrier Acquisition Time

"Carrier acquisition time" is defined as the interval between the following start and stop times:

Start time: When the KaSAR customer signal appears at the input of the demodulator in the TDRS H, I, J ground segment.

Stop time: When the KaSAR customer signal appears at the output of the demodulator in the TDRS H, I, J ground segment.

3.2.2.3.12.2 Conditions

a. C/N_o at SGL Antenna Input

1. BPSK

$C/N_o = 70$ dB-Hz.

2. QPSK or SQPSK

(a) I:Q = 1:1

$$C/N_{o\,\text{I channel}} + C/N_{o\,\text{Q channel}} = 70 \text{ dB-Hz.}$$

(b) I:Q = 4:1

$$C/N_{o\,\text{I channel}} = 70 \text{ dB-Hz.}$$

b. Customer Platform Dynamics

The Frequency Dynamics defined in Section 3.2.2.3.7.1 above.

3.2.2.3.13 Signal Tracking

This section specifies customer platform signal tracking requirements on the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.13.1 Bit Slips

3.2.2.3.13.1.1 Normal Transition Density

For the symbol transition density and C/N_o defined below, the TDRS H, I, J ground segment shall be capable of providing a mean time between bit slips, caused by a cycle slip in the symbol recovery loop, ≥ 90 minutes or ≥ 10^{10} clock cycles, whichever is longer:

a. Symbol Transition Density

1. NRZ symbols: ≥ 40%.
2. Biphase symbols: Any (0% to 100%).

b. C/N_o

The C/N_o required for a BER of 10^{-5} at the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.13.1.2 Low Transition Density

For the symbol transition density and C/N_o defined below, the TDRS H, I, J ground segment shall be capable of providing a mean time between bit slips, caused by a cycle slip in the symbol recovery loop, ≥ 90 minutes or ≥ 10^{10} clock cycles, whichever is longer:

a. Symbol Transition Density

NRZ symbols: ≥ 25% and < 40%.

b. C/N_o

The C/N_o 1 dB greater than that required for a BER of 10^{-5} at the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.13.2 Cycle Slips

The TDRS H, I, J ground segment shall be capable of providing a mean time-to-cycle-slip in carrier tracking ≥ 90 minutes for a C/N_o 3 dB less than that required for a BER of 10^{-5} at the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.13.3 False Carrier Acquisition

During signal acquisition and signal tracking, the TDRS H, I, J ground segment shall be capable of protecting against false carrier acquisition.

3.2.2.3.13.4 Symbol Synchronization

Symbol synchronization is measured by the mean clock cycle slip rate.

3.2.2.3.13.4.1 Normal Transition Density

For the symbol transition density and C/N_o defined below, the TDRS H, I, J ground segment shall be capable of providing a mean clock cycle slip rate ≤ 10^{-6} slips per cycle:

a. Symbol Transition Density

1. NRZ symbols: $\geq 40\%$.
2. Biphase symbols: Any (0% to 100%).

b. C/N_o

The C/N_o 3 dB less than that required for a BER of 10^{-5} at the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.13.4.2 Low Transition Density

For the symbol transition density and C/N_o defined below, the TDRS H, I, J ground segment shall be capable of providing a mean clock cycle slip rate $\leq 10^{-6}$ slips per cycle:

a. Symbol Transition Density

NRZ symbols: $\geq 25\%$ and $< 40\%$.

b. C/N_o

The C/N_o 2 dB less than that required for a BER of 10^{-5} at the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.14 Carrier Reacquisition Time

The TDRS H, I, J ground segment shall be capable of reacquiring a 225-MHz KaSAR customer platform carrier within the time specified in Section 3.2.2.3.12 above.

3.2.2.3.15 Ambiguity Resolution

This section specifies requirements on the TDRS H, I, J ground segment for resolving data polarity ambiguity (“1” vs. “0”) and I-Q channel ambiguity for the 225-MHz KaSAR service.

3.2.2.3.15.1 Data Polarity Ambiguity

Data polarity ambiguity is the uncertainty whether the logical sense of the data is true or complemented (that is, a “1” or a “0”).

The TDRS H, I, J ground segment shall be capable of resolving the data polarity ambiguity for all customer configurations, except the following:

a. NRZ-L data that is not frame synchronized by the WDISC.

b. Uncoded biphase-L data that is not frame synchronized by the WDISC.

3.2.2.3.15.2 I-Q Channel Ambiguity

I-Q channel ambiguity is the uncertainty whether the I-channel data will appear on the Q-channel output interface port, or vice-versa.

The TDRS H, I, J ground segment shall be capable of resolving the I-Q channel ambiguity for all customer configurations, except if *all* of the following conditions apply:

a. The customer configuration is dual-channel QPSK.

b. The I:Q power ratio is 1:1.

c. Both I and Q channels are coded, or both are uncoded.

d. The symbol rates of the I and Q channels differ ≤ 25%.

3.2.2.3.16 Symbol and Decoder Synchronization Time

This section specifies the symbol and decoder synchronization requirements on the TDRS H, I, J ground segment for the 225-MHz KaSAR service.

3.2.2.3.16.1 Uncoded Data

Under all of the Conditions defined in Section 3.2.2.3.16.3 below, the TDRS H, I, J ground segment shall be capable of achieving uncoded symbol synchronization with a probability ≥ 0.9 within the time interval specified below:

a. NRZ symbols: ≤ 3000 / (data rate in bps) seconds.

b. Biphase symbols: ≤ 300 / (data rate in bps) seconds.

Definition of Symbol Synchronization Time for Uncoded *Data*

“Symbol synchronization time” is defined as the interval between the following start and stop times:

Start Time: When carrier acquisition is achieved.

“Carrier acquisition” is defined as the “Stop Time” in Section 3.2.2.3.12.1 above.

Stop Time: When the BER ≤ 10^{-5} for the next 1000 bits.

BER is referenced to the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.16.2 Convolutionally Coded Data

Under all of the Conditions defined in Section 3.2.2.3.16.3 below, the TDRS H, I, J ground segment shall be capable of achieving both symbol and decoder synchronization with a probability ≥ 0.99 within the time interval specified below:

a. NRZ symbols: ≤ 6500 / (data rate in bps) seconds.

b. Biphase symbols: ≤ 1100 / (data rate in bps) seconds.

Definition of Symbol and Decoder Synchronization Time for Convolutionally Coded *Data*

“Symbol and decoder synchronization time” is defined as the interval between the following start and stop times:

Start Time: When carrier acquisition is achieved.

"Carrier acquisition" is defined as the "Stop Time" in Section 3.2.2.3.12.1 above.

Stop Time: When the BER ≤ 10^{-5} for the next 1000 decoded bits.

BER is referenced to the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.2.2.3.16.3 Conditions

This section defines the conditions under which the Symbol and Decoder Synchronization requirements specified in Sections 3.2.2.3.16.1 and 3.2.2.3.16.2 above must be met.

This section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's signal. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

a. Symbol Transition Density

The Symbol Transition Density values defined in Section 3.2.2.3.8 above.

b. C/N_o

The minimum C/N_o required for a BER of 10^{-5} at the output of the TDRS H, I, J ground segment, *not including* the WDISC.

3.3 Ka-Band Infrastructure

This section specifies requirements on the Ka-Band Infrastructure. The Ka-Band Infrastructure supports the 650-MHz KaSAR IF service only.

NOTE

The 650-MHz KaSAR IF service is not required to provide a Doppler-corrected IF output signal.

As shown in Figure 3-1 above, the Ka-Band Infrastructure consists of 650-MHz KSA-1R down-converters and an IF switch.

Organization

The redundancy requirement is specified in the Section 3.3 below.

The remaining requirements are divided into the following sections:

Section 3.3.1 Ku-Band-to-IF Processing (650-MHz IF Service).

Section 3.3.2 Control and Monitor.

Section 3.3.3 Testing and Fault Isolation.

Section 3.3.4 Interfaces.

Redundancy

The Ka-Band Infrastructure in each TDRS H, I, J-compatible SGLT shall contain two identical 650-MHz KaSA-1R downconverters.

3.3.1 Ku-Band-to-IF Processing (650-MHz IF Service)

The Ka-Band Infrastructure shall be capable of:

a. Receiving a 650-MHz KaSAR signal at Ku-band from the TDRS H, I, J ground segment as specified in column B of Table 3-15 below.

b. Downconverting the KaSAR signal from Ku-band to the IF frequency specified in Table 3-16 below.

c. Processing the 650-MHz KaSAR signal with the channel parameters specified in Table 3-17 below.

d. Performing phase and gain equalization of the 650-MHz KaSAR signal, either before or after downconversion, as necessary, to meet the requirements specified in Table 3-17 below.

e. KaSA Autotrack Error Signal Output

This section describes the KaSA autotracking error signals for TDRS H, I, and J; no requirements are specified. See SE-BD-05 for further description.

NOTE

Customer platform autotracking is not supported by the 650-MHz KaSAR service. However, the Ka-Band Infrastructure will be implemented so as to facilitate the addition of autotracking in the future.

1. Two error signals are generated onboard the TDRS, one from each channel of a two-axis monopulse system, to closed-loop track each KaSA antenna.
2. The two error signals, corresponding to the two KaSA antenna gimbal axes, are time-division multiplexed to form a single error signal that switches between error channels every 32 ms.
3. The error signal is BPSK-modulated by a 2048-bit sequence (generated by Manchester [Biϕ-L] encoding a 1024-chip PN code). Since the bit rate is 2 kbps, the sequence repeats every 1.024 seconds.
4. The PN epoch is controlled by the telemetry frame sync clock, which is transmitted in the telemetry data.
5. The BPSK-modulated error signal amplitude modulates the KaSAR signal with a modulation index that varies between 0 (during autotracking) and 0.10 (during autotrack pull-in). This signal can be analytically expressed as follows:

$V_r \cos [\omega_r t + \theta_r(t)] \bullet [1 + M_e(t)] \bullet [1 + N(t)]$, where

V_r = Return signal voltage.

ω_r = Return signal Ka-band carrier frequency (radians/second).

$\theta_r(t)$ = Return signal phase modulation and phase offset.

Table 3-15: KaSAR Interfaces

Parameter	Requirement	
	A. 225-MHz Service	B. 650-MHz Service
1. Center frequency		
a. KaSA-1 (Dedicated)		
(1) SNIP/SFCG	13,525.0 MHz ±2.1 MHz	13,725 MHz ±2.1 MHz
(2) TDRSS H, I, J	13,528.4 MHz ±2.1 MHz	N/A
b. KaSA-2 (Composite)		
(1) SNIP/SFCG	13,925.0 MHz ±2.1 MHz	N/A
(2) TDRSS H, I, J	13,928.4 MHz ±2.1 MHz	N/A
2. 3-dB bandwidth	≥ 225 MHz	≥ 650 MHz
3. Input signal level*		
a. KaSA-1 (Dedicated) (at input to divide-by-four RF Power Divider [in IFL HWCI]; see Figure 3-1 above)		
(1) Minimum	≥ -32 dBm	≥ -32 dBm
(2) Maximum	≤ -11 dBm	≤ -11 dBm
b. KaSA-2 (Composite) (between divide-by-two RF Power Divider [in IFL HWCI] and input to KSA-2R Downconverter; see Figure 3-1 above)		N/A
(1) Minimum	≥ -40 dBm	
(2) Maximum	≤ -16 dBm	
4. RFI		
a. Pulse width	≤ 1 μsec	≤ 1 μsec
b. Pulse amplitude	≤ 10 dB above average received power	≤ 10 dB above average received power
c. Duty cycle	≤ 1%	≤ 1%

* Not including the effects of RF interference (RFI) (see row 4 above).

Table 3-16: Ka-Band Infrastructure IF Output Interface

Parameter	Requirement
1. Center frequency	1.2 GHz ±2.1 MHz
2. Bandwidth	≥ 650 MHz (4-dB)
3. Output level	-15 dBm ±3 dB
4. Number of output ports	≥ 8 (at STGT)
5. Output VSWR	≤ 1.3:1 into 50Ω load, ±230 MHz from center frequency

$M_e(t)$ = Modulation index, $0 \leq |M_e(t)| \leq 0.10$.

N(t) = Incidental AM (defined in 450-SNUG, Revision 8).

6. The modulation index, $M_e(t)$, can be expressed as follows:

$$M_e(t) = \sum_n (\Delta V_n / V_r)\, P_s(t - nT_s) \bullet \sum_m P_c(t - mT_c), \text{ where}$$

ΔV_n = Sample of error voltage on nth channel (n = 1 or 2).

$-M \leq (\Delta V_n / V_r) \leq M$, where

M = 0.10 = Maximum modulation index.

$P_s(t - nT_s) = 1$ for $nT_s \leq t \leq (n + 1)\, T_s$

= 0 elsewhere

= Time sampling of two error channels with 50% duty factor.

T_s = switching time = 32 msec ±0.03% (coherent with telemetry data).

$P_c(t - mT_c) = \pm 1$ for $mT_c \leq t \leq (m + 1)\, T_c$

= Manchester-encoded PN code on error signal.

T_c = chip time = 50 msec ±0.03% (coherent with telemetry data).

7. The amplitude modulated Ka-band signal is downconverted to Ku-band and transmitted to WSC.

f. Routing any 650-MHz KaSAR input signal to any of the IF output ports specified in Table 3-16 above.

g. Providing an IF output signal as specified in Table 3-16 above.

Table 3-17: Ka-Band Infrastructure Performance

Parameter	Requirement[1]
1. IF center frequency	As specified by row 1 in Table 3-16 above
2. Gain flatness	≤ 0.9 dB (peak-to-peak) over ±230 MHz about the center frequency
3. Gain slope	≤ 0.1 dB/MHz over ±230 MHz about the center frequency
4. Phase nonlinearity[2]	≤ 30° (peak-to-peak) over ±230 MHz about the center frequency
5. AM/PM	≤ 0.5°/dB
6. Bandwidth	≥ 650 MHz (4-dB)
7. Spurious outputs	Over ±230 MHz about the center frequency
a. Individual	< –40 dBc
b. Total	< –30 dBc
8. Noise figure	≤ 15 dB
9. Phase noise induced by Ka-Band Infrastructure[3]	Referenced to Ku-band
a. 1 Hz to 10 Hz	≤ 1.3° rms
b. 10 Hz to 100 Hz	≤ 1.3° rms
c. 100 Hz to 1 kHz	≤ 2.5° rms
d. 1 kHz to 400 MHz	≤ 0.9° rms

Notes:

1. Parameters are measured at the IF output port of the IF Switch. Contributions from only the Ka-Band Infrastructure are included, except for phase nonlinearity (see note 2 below).
2. The phase nonlinearity requirement includes contributions from the Ka-Band Infrastructure and *parabolic* contributions from the TDRS H, I, J ground segment. *Non-parabolic* contributions from the TDRS H, I, J ground segment are not included. TDRS H, I, J ground segment contributions are specified in Table 3-9 above.
3. Includes the phase noise specified for the CTFS frequency reference. Does not include spurious outputs.

h. Meeting the performance requirements specified in Table 3-17 above, as measured at the IF output port.

i. Pulsed RFI

1. Operation

Meeting all signal processing requirements in the presence of the pulsed RFI defined in Table 3-15 above.

2. **Degradation**

The pulsed RFI defined in Table 3-15 shall not degrade or damage the Ka-Band Infrastructure.

3. **Prolongation**

Not extending the effect of each RFI pulse:

(a) On the customer data signal by more than 100 nsec. (This excludes the additional extension that naturally occurs with differentially formatted or convolutionally encoded data.)

(b) On the autotrack IF output signal by more than 0.5 msec.

3.3.2 Control and Monitor

This section specifies the requirements for controlling and monitoring the Ka-Band Infrastructure.

3.3.2.1 Control

This section specifies the requirements for controlling the Ka-Band Infrastructure.

3.3.2.1.1 Automatic Equipment Configuration

The Ka-Band Infrastructure shall be capable of being automatically configured for customer support in response to SHOs and OPMs, in accordance with 530-ICD-NCC-FDF/WSC, including but not limited to the following:

a. Configuring the 1.2-GHz IF switch to route the customer IF signal to the appropriate output port.

b. Configuring the 225-MHz KSA-1R downconverters for the appropriate frequency plan: SNIP/SFCG or TDRS H, I, J.

c. Configuring the 225-MHz KSA-2R downconverters for the appropriate frequency plan: SNIP/SFCG or TDRS H, I, J.

3.3.2.1.2 Manual Control

The Ka-Band Infrastructure shall be capable of the following manual control:

a. From the TOCC.

b. Local control.

3.3.2.2 Monitor

This section specifies the requirements for monitoring the Ka-Band Infrastructure.

3.3.2.2.1 Equipment Performance Monitoring

a. The Ka-Band Infrastructure shall be capable of locally and remotely monitoring equipment performance, including:

1. Ku-band signal spectra.
2. IF signal spectra.
3. Key equipment health parameters.
4. Key equipment performance parameters.

b. The Ka-Band Infrastructure shall be capable of sending the parameters and spectra specified in Section 3.3.2.2.1.a above to the control and monitor equipment depicted in Figure 3-1 above.

3.3.2.2.2 Equipment Failure Detection

a. The Ka-Band Infrastructure shall be capable of detecting equipment failures.

b. When the Ka-Band Infrastructure detects equipment failures, it shall be capable of notifying the control and monitor equipment depicted in Figure 3-1 above.

3.3.3 Testing and Fault Isolation

The Ka-Band Infrastructure shall be capable of:

a. Supporting system testing (end-to-end test support is not required).
b. Supporting manual fault isolation.
c. Providing access to test and monitoring points, including:
    1. Ku-band signals.
    2. IF signals.

3.3.4 Interfaces

This section specifies the hardware interfaces of the Ka-Band Infrastructure. These interfaces are shown in Figure 3-1 above.

3.3.4.1 Ku-Band Input Interface

a. Each TDRS H, I, J-compatible SGLT shall provide a 650-MHz KSA-1R (Dedicated) downlink interface at Ku-band to the Ka-Band Infrastructure, as specified in row 1.a, column B in Table 3-15 above.

b. Each TDRS H, I, J-compatible SGLT shall provide the following 225-MHz KSAR downlink interfaces at Ku-band to the Ka-Band Infrastructure:
    1. KSA-1R (Dedicated) interfaces, as specified in row 3.a, column A in Table 3-15 above.
    2. KSA-2R (Composite) interfaces, as specified in row 3.b, column A in Table 3-15 above.

3.3.4.2 IF Output Interfaces

This section specifies the IF output interfaces of the Ka-Band Infrastructure.

3.3.4.2.1 STGT IF Output Interface

The Ka-Band Infrastructure shall provide a 650-MHz KSA-1R IF output interface at the STGT, as specified in Table 3-16 above.

3.3.4.2.2 Autotrack IF Output Port

a. The Ka-Band Infrastructure shall provide at least one additional IF output port in each 650-MHz KSA-1R downconverter. (This port is provided for future use by an autotrack receiver.)

b. Each autotrack IF output port shall be capable of providing a 650-MHz KSA-1R IF signal that meets the following requirements:

   1. **Center frequency**

      As specified in row 1 of Table 3-16 above.

   2. **Output level**

      –10 dBm ±3 dB (excluding cable losses).

   3. **Bandwidth**

      ≥ 650 MHz (1-dB).

   4. **AM/AM**

      > 0.95 dB/dB.

   5. **Output VSWR**

      ≤ 1.3:1 into a 50Ω load, ±230 MHz from center frequency.

3.3.4.3 Control and Monitor Interfaces

This section specifies the control and monitor interfaces of the Ka-Band Infrastructure.

3.3.4.3.1 650-MHz Downconverter Interface

The 650-MHz KaSA-1R Downconverters in the Ka-Band Infrastructure shall provide an interface with the control and monitor equipment in each TDRS H, I, J-compatible SGLT.

3.3.4.3.2 IF Switch Interface

The 650-MHz KaSAR IF Switch in the Ka-Band Infrastructure shall provide an interface with the control and monitor equipment in both the STGT and the WSGT.

Section 4. Ground Network Segment

This section specifies requirements on the GN Segment of the KaTP.

Introduction

The GN segment will be implemented by a new ground station consisting an S-Band Demonstration System and a Ka-Band Demonstration System. The S-Band and Ka-Band Systems share a S/Ka dual-band 5-meter antenna capable of autotracking either band. Figure 4-1 below illustrates the reference architecture for the GN Segment.

The S-Band Demonstration System provides customer TT&C support. The command uplink supports direct carrier modulation – either BPSK, QPSK, or linear PM – at a data rate up to 8 Mbps, in addition to the traditional BPSK-modulated subcarrier format. An EIRP of 52.5 dBWi is specified with a 50-watt HPA.

The S-band telemetry downlink supports BPSK, QPSK, or SQPSK modulation at a data rate up to 8 Mbps, in addition to the traditional residual carrier format. The station will support several kinds of convolutional, Reed-Solomon, and concatenated coding. BERs from 10^{-5} to 10^{-9} are specified. A diversity-combined, Doppler-corrected IF output signal is provided for customers who wish to perform their own demodulation and baseband processing.

The S-band customer platform tracking capability provides the traditional support: one- or two-way Doppler tracking measurements and ground antenna angle positions.

The Ka-Band Demonstration System supports a new Ka-band telemetry IF capability with a 1.2-GHz bandwidth, as well as customer platform tracking. Customers can interface with the IF output port and perform their own demodulation and baseband processing on the telemetry IF signal. Ka-band customer platform tracking supports only ground antenna angle position reports.

Organization

GN requirements are organized into the following sections:

Section 4.1 General.

Section 4.2 S-Band Demonstration System.

Section 4.3 Ka-Band Demonstration System.

Section 4.4 Interfaces.

4.1 General

The General requirements specified below apply to the entire GN Segment.

General requirements are divided into the following sections:

Section 4.1.1 Simultaneous S/Ka-Band Support.

Section 4.1.2 Antenna Pointing.

Section 4.1.3 Time and Frequency Standards.

Section 4.1.4 Security.

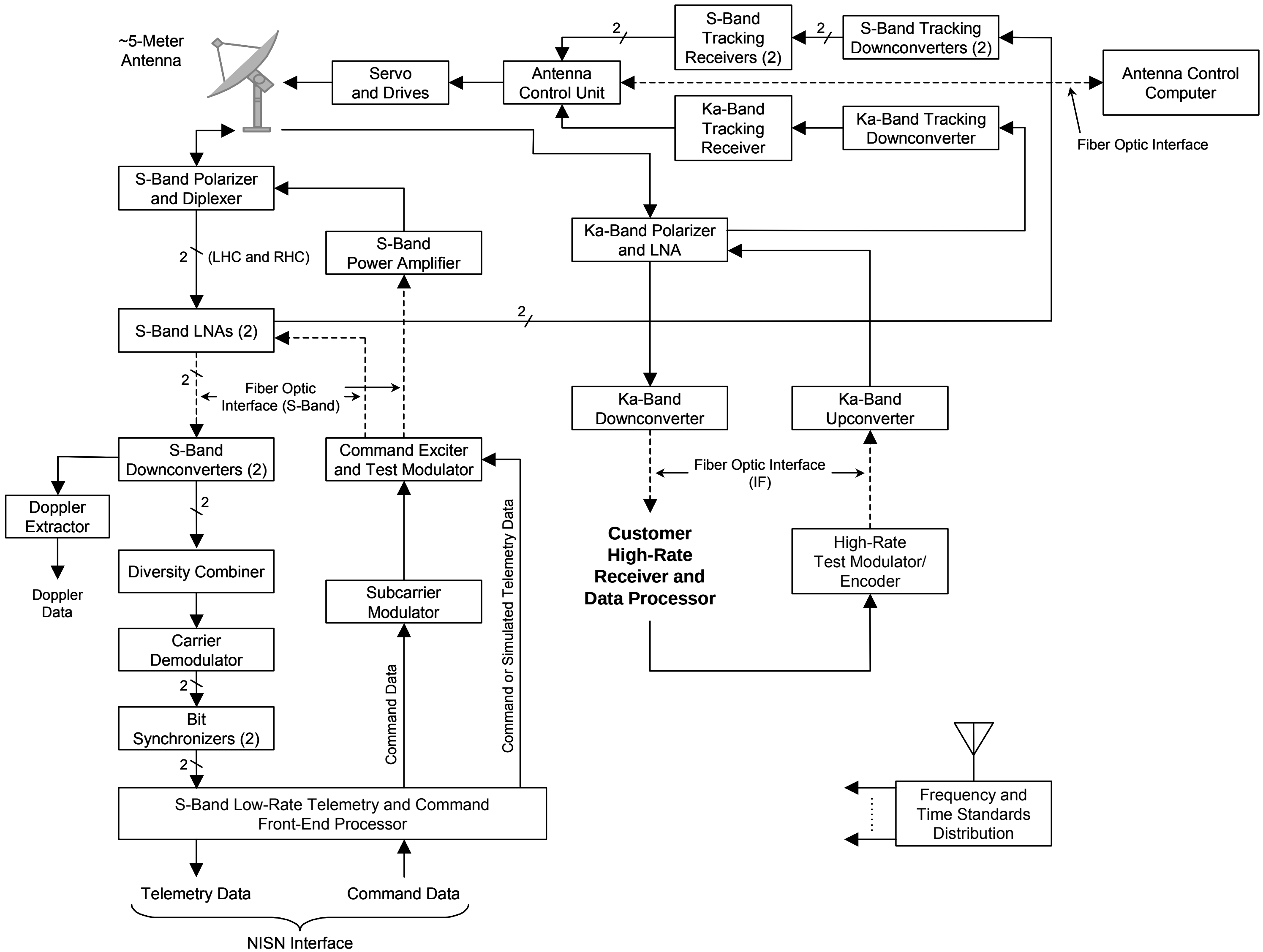

Figure 4-1: GN Segment Reference Architecture

4.1.1 Simultaneous S/Ka-Band Support

The GN Segment shall be capable of simultaneously providing all of the following capabilities to a single customer platform:

a. One S-Band Command Uplink

"Providing an S-band command uplink" is defined as receiving baseband command data, processing it, and transmitting an S-band command signal to the customer platform.

b. One S-Band Telemetry Downlink

The S-band telemetry downlink can provide outputs at either baseband or IF:

1. Baseband Output

"Providing an S-band telemetry downlink with baseband output" is defined as receiving an S-band telemetry signal from the customer platform, simultaneously processing the two channels (carrier and subcarrier, or I and Q channels), extracting the VCs (when applicable), storing the data as files for post-pass FTP transfer, and providing one or more simultaneous baseband telemetry data streams in real-time.

2. IF Output

"Providing an S-band telemetry downlink with IF output" is defined as receiving an S-band telemetry signal from the customer platform, downconverting, diversity combining, and Doppler-correcting it, and providing an IF output signal.

c. One S-Band Tracking Capability

"Providing an S-band tracking capability" is defined as receiving an S-band telemetry signal from the customer platform, extracting the one- or two-way Doppler information, generating angle tracking data derived from the ground antenna pointing angles, and providing UTDF files to the NISN interface.

d. One Ka-Band Telemetry Downlink (IF Output)

"Providing a Ka-band telemetry downlink (with IF output)" is defined as receiving a Ka-band telemetry signal from the customer platform, downconverting it, and providing an IF output signal.

e. One Ka-Band Tracking Capability

"Providing a Ka-band tracking capability" is defined as receiving a Ka-band telemetry signal from the customer platform, generating angle tracking data derived from the ground antenna pointing angles, and providing UTDF files to the NISN interface.

4.1.2 Antenna Pointing

This section specifies the pointing modes of the dual-band antenna: program track, scan, and autotrack. Also specified are the capabilities for automatic switching between and within these modes.

4.1.2.1 Pointing Modes

This section specifies the following four pointing modes of the dual-band antenna: program track, scan, S-band autotrack, and Ka-band autotrack.

4.1.2.1.1 Program Track

The dual-band antenna shall be capable of using ephemeris to calculate the customer platform's position as a function of time, in order to automatically point at and track the customer platform.

(Ephemeris processing requirements are specified in Sections 4.2.5.1.1.b and 4.3.4.1.1.b below for the S-Band and Ka-Band Demonstration Systems, respectively.)

4.1.2.1.2 Scan

a. The dual-band antenna shall be capable of superimposing a spiral scan on the program track (to assist in acquiring Ka-band autotrack).

b. The following scan parameters of the dual-band antenna shall be programmable:

   1. Spiral size.
   2. Scan rate.

4.1.2.1.3 S-Band Autotrack

The dual-band antenna shall be capable of autotracking at S-band using both of the following (not simultaneously):

a. LHC signal.

b. RHC signal.

4.1.2.1.4 Ka-Band Autotrack

The dual-band antenna shall be capable of autotracking at Ka-band using both of the following (not simultaneously):

a. LHC signal.

b. RHC signal.

4.1.2.2 Polarization Switching (S-Band)

4.1.2.2.1 LHC to RHC Switching

The dual-band antenna shall be capable of automatically switching from LHC to RHC S-band autotracking if the signal-to-noise ratio (SNR) of the RHC signal exceeds that of the LHC signal.

4.1.2.2.2 RHC to LHC Switching

The dual-band antenna shall be capable of automatically switching from RHC to LHC S-band autotracking if the SNR of the LHC signal exceeds that of the RHC signal.

4.1.2.3 Mode Switching (Program Track – Autotrack)

4.1.2.3.1 S-Band Mode Switching

a. **Program Track to S-Band Autotrack**

The dual-band antenna shall be capable of automatically switching from program tracking to S-band autotracking if the SNR of the S-band signal exceeds the S-band autotracking threshold.

b. **S-Band Autotrack to Program Track**

The dual-band antenna shall be capable of automatically switching from S-band autotracking to program tracking if the SNR of the S-band signal falls below the S-band autotracking threshold.

4.1.2.3.2 Ka-Band Mode Switching

a. **Program Track to Ka-Band Autotrack**

The dual-band antenna shall be capable of automatically switching from program tracking to Ka-band autotracking if the SNR of the Ka-band signal exceeds the Ka-band autotracking threshold.

b. **Ka-Band Autotrack to Program Track**

The dual-band antenna shall be capable of automatically switching from Ka-band autotracking to program tracking if the SNR of the Ka-band signal falls below the Ka-band autotracking threshold.

4.1.2.3.3 Threshold Programmability

The dual-band antenna shall be capable of manually and independently setting the values of the following autotrack thresholds:

a. **S-Band Mode Switching (S-Band Autotrack – Program Track)**

The SNR needed to automatically switch between S-band autotracking and program tracking (that is, from S-band autotracking to program tracking, and from program tracking to S-band autotracking).

b. **Ka-Band Mode Switching (Ka-Band Autotrack – Program Track)**

The maximum SNR needed to automatically switch between Ka-band autotracking and program tracking (that is, from Ka-band autotracking to program tracking, and from program tracking to Ka-band autotracking).

4.1.2.4 Band Switching

4.1.2.4.1 S-Band to Ka-Band

The dual-band antenna shall be capable of the automatically switching from S-band autotracking to Ka-band autotracking if both of the following conditions occur:

a. The Ka-band telemetry SNR is above the Ka-band autotracking threshold.

b. Automatic switchover from S-band to Ka-band autotracking is enabled.

4.1.2.4.2 Ka-Band to S-Band

The dual-band antenna shall be capable of the automatically switching from Ka-band autotracking to S-band autotracking if all three of the following conditions occur:

a. The Ka-band telemetry SNR is below the Ka-band autotracking threshold.

b. The S-band telemetry SNR is above the S-band autotracking threshold.

c. Automatic switchover from Ka-band to S-band autotracking is enabled.

4.1.2.4.3 Threshold Programmability

The dual-band antenna shall be capable of manually and independently setting the value of the minimum SNR needed to automatically switch between S-band and Ka-band autotracking (that is, from S-band to Ka-band autotracking, and from Ka-band to S-band autotracking).

4.1.2.4.4 Inhibiting Band Switching

The dual-band antenna shall be capable of inhibiting automatic switching between S-band and Ka-band autotracking (that is, from S-band to Ka-band autotracking, and from Ka-band to S-band autotracking).

4.1.3 Time and Frequency Standards

The GN Segment shall be capable of providing the following reference signals:

a. All of the time standards required by the GN Segment (for example: IRIG-B and 1-pulse-per-second (PPS)).

b. All of the frequency standards required by the GN Segment (for example: 10 MHz).

4.1.4 Security

The KaTP shall employ security measures and techniques in accordance with the policies and procedures specified in NPG 2810.1, Security of Information Technology: NASA Procedures and Guidelines.

4.2 S-Band Demonstration System

This section specifies requirements on the S-Band Demonstration System. A functional diagram is shown in Figure 4-2 below.

Organization

General Requirements that apply to the entire S-Band Demonstration System are specified in the following sections:

Section 4.2.a Simultaneous Support.

Section 4.2.b G/T.

Section 4.2.c EIRP.

Section 4.2.d Availability.

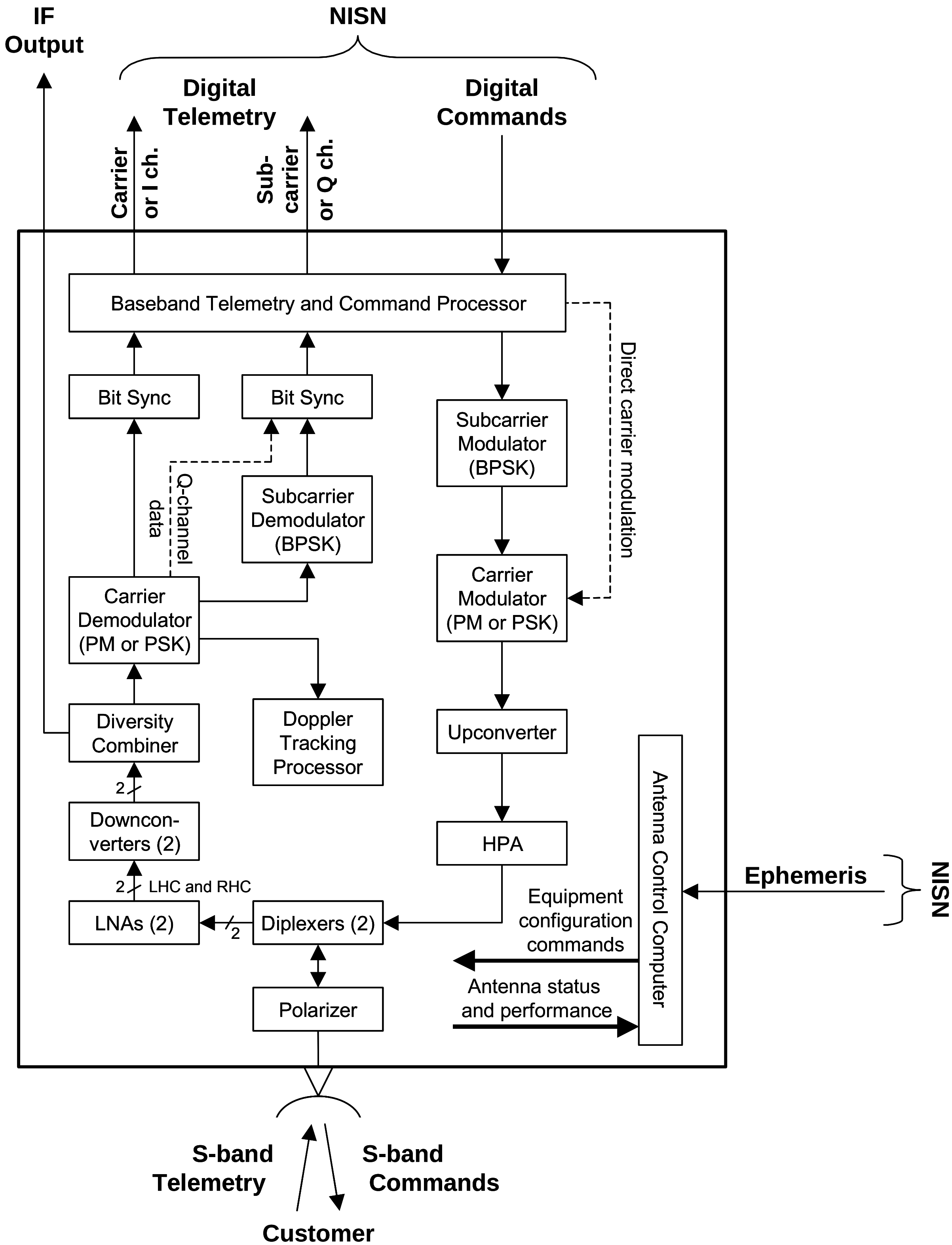

Figure 4-2: S-Band Demonstration System Functional Diagram

The remaining requirements are divided into the following sections:

Section 4.2.1 S-Band Antenna.

Section 4.2.2 S-Band Command.

Section 4.2.3 S-Band Telemetry.

Section 4.2.4 S-Band Tracking.

Section 4.2.5 Control and Monitor.

Section 4.2.6 Testing and Fault Isolation.

General Requirements

The General Requirements specified below apply to the entire S-Band Demonstration System.

a. Simultaneous Support

The S-Band Demonstration System shall be capable of the following:

1. Simultaneously providing the following S-band services:
   (a) One S-band command service.
   (b) One S-band telemetry service (baseband or IF).
   (c) One S-band tracking service.
2. Meeting all of the S-Band Telemetry requirements specified in Section 4.2.3 below while simultaneously transmitting and receiving the following signals:
   (a) Transmitting an S-band uplink signal with the power specified in Section 4.2.2.2.b below, and
   (b) Receiving a Ka-band downlink signal as specified in Section 4.3 below.

b. G/T

The S-Band Demonstration System shall be capable of providing a system G/T ≥ 16.5 dB/K at any elevation angle between 10º and 90º.

c. EIRP

The S-Band Demonstration System shall be capable of providing an EIRP ≥ 52.5 dBWi at the frequencies specified in Section 4.2.1.2.a below.

d. Availability

This section specifies the availability requirements for the S-Band Demonstration System.

Operational availability, A_o, should be calculated using the formula defined in Section 4.2.d.5 below. Redundancy may be used to meet these requirements.

1. S-Band Command

The A_o of the S-band command service (including, but not limited to, the baseband, IF, RF, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.99.

2. S-Band Telemetry: Baseband

The A_o of the S-band telemetry baseband service (including, but not limited to, the RF, IF, baseband, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.99.

3. S-Band Telemetry: IF

The A_o of the S-band telemetry IF service (including, but not limited to, the RF, IF, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.99.

4. S-Band Tracking

The A_o of the S-band tracking service (including, but not limited to, the RF, IF, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.99.

5. A_o Calculation

A_o should be calculated using the following formula:

$$A_o = \frac{\text{Time Service is Available}}{\text{Time Service is Available} + \text{Time Service is Not Available}}$$

Definitions

Time Service is Available

"Time Service is Available" is measured over a contiguous 10,000-hour interval.

Time Service is Not Available

"Time Service is Not Available" includes all of the times service is not available due to any of the following causes:

a. Corrective maintenance downtime.

b. Preventive maintenance downtime.

c. Administrative downtime.

d. Logistics supply downtime.

Downtime due to any of the following causes is *not* counted:

e. Loss of facility services, such as power or air conditioning.

f. Loss of system capability resulting from unusual weather conditions, such as icing or severe rainstorms.

4.2.1 S-Band Antenna

This section specifies requirements on the S-band portion of the dual-band antenna in the S-Band Demonstration System.

4.2.1.1 Receive Signal Characteristics

The dual-band antenna shall be capable of receiving S-band signals with the following characteristics:

a. Center Frequency

1. Minimum: 2200 MHz.
2. Maximum: 2300 MHz.
3. Tuning step size: ≤ 100 kHz.

b. Polarizations (Simultaneous)

1. RHC.
2. LHC.

NOTE

The RHC- and LHC-polarized signals are diversity combined by the ground station.

4.2.1.2 Transmit Signal Characteristics

The dual-band antenna shall be capable of transmitting S-band signals with the following characteristics:

a. Center Frequency

1. Minimum: 2025 MHz.
2. Maximum: 2120 MHz.
3. Tuning step size: ≤ 1.0 Hz.

b. Polarization (Selectable)

1. RHC.
2. LHC.

4.2.1.3 Axial Ratio

The dual-band antenna shall be capable of providing the following axial ratios at S-band:

a. Receive

≤ 2.0 dB over a 3-dB beamwidth.

b. Transmit

≤ 2.0 dB over a 3-dB beamwidth.

4.2.1.4 Feed Isolation

The dual-band antenna shall be capable of providing isolation ≥ 85 dB from the S-band transmit feed port to the S-band receive feed port at any frequency the antenna is required to operate.

4.2.1.5 Receive Gain Flatness

The dual-band antenna shall be capable of providing a gain flatness at the output of the S-band LNA ≤ ±1.5 dB across the entire receive band specified in Section 4.2.1.1.a above.

4.2.1.6 Receive Sidelobes

The dual-band antenna shall be capable of providing S-band receive sidelobe levels ≥ 18 dB below the peak level of the main lobe.

4.2.1.7 Transmit Sidelobes

The dual-band antenna shall be capable of providing S-band transmit sidelobe levels ≥ 18 dB below the peak level of the main lobe.

4.2.1.8 Transmit VSWR

The dual-band antenna shall be capable of providing a S-band transmit VSWR ≤ 1.5:1.

4.2.1.9 Radial Tracking Error

The dual-band antenna shall be capable of providing a 1σ system radial tracking error ≤ 0.05° rms at S-band.

4.2.1.10 Autotrack Boresight Alignment

The dual-band antenna shall be capable of providing the following RF-to-mechanical boresight alignments:

a. S-band to Ka-band coincidence: ≤ 0.05°.

b. Ka-band to S-band coincidence: ≤ 0.05°.

4.2.1.11 Slewing

The dual-band antenna shall be capable of providing the following slewing performance at S-band:

a. Slewing Rate

1. Program Track: ≥ 3°/sec.
2. Autotrack: ≥ 3°/sec.

b. Slewing Acceleration

≥ 0.05°/sec.^{2} (each axis).

4.2.1.12 Transmit Bandwidth

The dual-band antenna shall be capable of providing a RF channel 3-dB transmit bandwidth ≥ 16 MHz at S-band.

4.2.1.13 Autotracking

This section specifies the S-band autotracking performance of the dual-band antenna.

4.2.1.13.1 Customer Dynamics Constraints

The dual-band antenna shall be capable of acquiring and autotracking an S-band customer platform that meets all of the following constraints:

(The following section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.)

a. Range Dynamics

The customer platform Range Dynamics defined in Section 4.2.3.1.1.2.7 below.

b. Antenna Tracking

Both of the following constraints:

1. Angular velocity: $\leq 3°$/sec.

   Angular velocity is defined as the time rate-of-change of the angle of the dual-band antenna.

2. Ephemeris uncertainty: $\leq \pm 2.0$ sec.

   (This assumes that the ephemeris uncertainty is uniformly distributed along the customer platform orbital track.)

4.2.1.13.2 Autotrack Acquisition Time

The dual-band antenna shall be capable of acquiring S-band autotrack in ≤ 2 seconds with a probability > 0.99 for a P_{rec} value of ≥ -170.3 dBWi.

"P_{rec}" is defined in Section 4.2.3.1.1.2.8.1 below.

Definition of Autotrack Acquisition Time

Autotrack acquisition time is defined as the interval between the following start and stop times:

Start time: When a customer signal is received at the aperture of the ground antenna.

Stop time: When the autotrack error signals align the ground antenna boresight axis with the customer platform with sufficient accuracy to provide a system G/T $\geq$ 16.3 dB/K at S-band.

[16.3 dB/K is 0.2 db less than the system G/T specified in Section 4.2.b above: 16.5 dB/K.]

4.2.1.13.3 Failure to Acquire

If S-band autotrack acquisition does not occur within the specified time, the dual-band antenna shall be capable of continuing the acquisition process until one of the following events occurs:

a. Autotrack is acquired. (“Autotrack acquisition” is defined in Section 4.2.1.13.2 above as the “Stop time.”)

b. The scheduled S-band telemetry pass ends.

4.2.1.14 FOV

The dual-band antenna shall be capable of providing a FOV ≥ 5° in elevation.

4.2.1.15 Environment

The S-band portion of the dual-band antenna shall be capable of providing the following environmental performance:

a. Survivable Wind Speed

1. During operations: ≥ 80 mph.
2. While stowed: ≥ 120 mph.

b. Operating Temperature

1. Minimum: -50° F.
2. Maximum: 120° F.

c. Operating Relative Humidity

1. Minimum: 2%.
2. Maximum: 100%.

4.2.2 S-Band Command

This section specifies the command requirements for the S-Band Demonstration System.

4.2.2.1 Baseband-to-IF Processing

This section specifies the requirements for processing commands from baseband to IF for the S-Band Demonstration System.

4.2.2.1.1 Signal Distortion Constraints

The S-Band Demonstration System shall be capable of providing command signals in accordance with the distortion constraints specified in Table 4-1 below.

4.2.2.1.2 Baseband Command Processing Standards

This section specifies the baseband command processing requirements for the S-Band Demonstration System.

Table 4-1: S-Band Command Signal Distortion Constraints

Parameter	Requirement	
	A. PM Carrier with BPSK Subcarrier	B. BPSK or QPSK Carrier
1. BPSK Modulator Phase Imbalance[1]	≤ ±3° (peak)	≤ ±3° (peak)
2. QPSK Modulator Phase Imbalance[1]	N/A	≤ ±3° (peak)
3. PSK Modulator Gain Imbalance[1]	≤ ±0.25 dB (peak)	≤ ±0.25 dB (peak)
4. I:Q Power Ratio Tolerance	N/A	≤ 0.5 dB (QPSK only)
5. Data Asymmetry[1,4]	≤ ±3% (peak)	≤ ±3% (peak)
6. Data Transition Time (90% of Initial State to 90% of Final State)[1,4]	≤ 5% of data bit duration	≤ 5% of data bit duration
7. Phase Nonlinearity[1]	≤ 4.25° (peak, best straight line) over ±5.6 MHz	≤ 4.25° (peak, best straight line) over ±5.6 MHz
8. Gain Flatness[1]	≤ ±0.4 dB (peak) RSS over ±5.6 MHz	≤ ±0.4 dB (peak) RSS over ±5.6 MHz
9. Gain Slope[1]	≤ ±0.1 dB/MHz (peak) over ±5.6 MHz	≤ ±0.1 dB/MHz (peak) over ±5.6 MHz
10. AM/AM[2]	≥ 0.6 dB/dB and ≤ 1.0 dB/dB	≥ 0.6 dB/dB and ≤ 1.0 dB/dB
11. AM/PM[2]	≤ 4°/dB	≤ 4°/dB
12. Data Bit Jitter[2,3,4]	≤ 1% (peak)	≤ 1% (peak)
13. Spurious PM[2]	≤ 0.8° rms over ±8 MHz	≤ 0.8° rms over ±8 MHz
14. Spurious Outputs[2] (from all transmit sources)		
a. Sum of All In-Band Spurs	≥ 30 dB below modulated carrier over ±8 MHz	≥ 30 dB below modulated carrier over ±8 MHz
b. All Discrete In-Band Spurs	≥ 40 dB below modulated carrier over ±8 MHz	≥ 40 dB below modulated carrier over ±8 MHz

Table 4-1: S-Band Command Signal Distortion Constraints (Cont'd)

Parameter	Requirement	
	A. PM Carrier with BPSK Subcarrier	B. BPSK or QPSK Carrier
15. Frequency Stability[1]		
a. Carrier (1 to 100 seconds average time)	$< 5 \times 10^{-11}$	$< 5 \times 10^{-11}$
b. Subcarrier		N/A
1. 1 second	$< \pm 1 \times 10^{-5}$	
2. 24 hours	$< \pm 5 \times 10^{-5}$	
16. Incidental AM[1]	≤ 1.4% (peak) over ±8 MHz	≤ 1.4% (peak) over ±8 MHz
17. Phase Noise		
a. 1 Hz to 10 Hz	≤ 1.4° rms	≤ 1.4° rms
b. 10 Hz to 32 Hz	≤ 1.4° rms	≤ 1.4° rms
c. 32 Hz to 1 kHz	≤ 3.9° rms	≤ 3.9° rms
d. 1 kHz to 8 MHz	≤ 1.0° rms	≤ 1.0° rms

Notes:

1. This parameter is defined in 450-SNUG, Revision 8.
2. This parameter is defined in 450-SNUG, Revision 8.
3. The total bit jitter is the sum of the weighted spurious and random jitter components.
4. Data Asymmetry, Data Transition Time, and Data Bit Jitter include only the S-band command service's contribution, assuming perfect command data at the Ethernet interface.

4.2.2.1.2.1 Delivery Header Stripping

The S-Band Demonstration System shall be capable of stripping the following types of delivery headers from the received command blocks:

a. IPDU header, in accordance with 430-14-01-001-0 (Landsat 7 – LGN ICD).

b. EDOS/GTDU header, in accordance with BASD Document 545460.

4.2.2.1.2.2 Command Data Unit Protocols

This section specifies the types of command data unit protocols recommended by the CCSDS.

4.2.2.1.2.2.1 Telecommand Transfer Frame

The S-Band Demonstration System shall be capable of receiving and processing Telecommand (TC) Transfer Frames, in accordance with CCSDS 201.0-B-3 and CCSDS 202.0-B-2. Each TC Transfer Frame is broken into one or more TC codeblocks. The TC codeblocks for the one TC Transfer Frame are encapsulated inside a Command Link Transmission Unit (CLTU).

4.2.2.1.2.2.2 Command Link Transmission Unit (CLTU) Frames

The S-Band Demonstration System shall be capable of processing CLTU frames, in accordance with CCSDS 201.0-B-3. Each CLTU will encapsulate the set of TC codeblocks for exactly one TC Transfer Frame.

4.2.2.1.2.3 Internet Protocols

The S-Band Demonstration System shall be capable of the following:

a. Using TCP/IP to transfer customer command data between the S-Band Demonstration System and MOCs via NISN.

b. Extracting and processing the command data, which is encapsulated inside TCP/IP packets, into CCSDS frames in accordance with CCSDS 201.0-B-3.

4.2.2.1.2.4 Time Tagging

The S-Band Demonstration System shall be capable of recording the time each CLTU is sent to the modulator with an accuracy ≤ 1 second.

4.2.2.1.2.5 Logging

The S-Band Demonstration System shall be capable of automatically recording each customer's command data to a separate file when the commands are transmitted.

4.2.2.1.3 Command Reception

This section specifies the requirements for receiving digital customer commands by the S-Band Demonstration System.

4.2.2.1.3.1 Data Rate

The S-Band Demonstration System shall be capable of receiving digital customer commands at the following data rates:

a. Subcarrier

1. Minimum: 100 bps.
2. Maximum: 32 kbps.

b. Carrier

1. Minimum: 1 kbps.
2. Maximum: 8 Mbps.

4.2.2.1.3.2 Data Format

The S-Band Demonstration System shall be capable of receiving digital customer commands with any of the following data formats:

a. Subcarrier

1. NRZ-L.
2. NRZ-M.
3. NRZ-S.

b. Carrier

1. NRZ-L.
2. NRZ-M.
3. NRZ-S.

4.2.2.1.4 Data Format Conversion

The S-Band Demonstration System shall be capable of the following:

a. Converting the format of the command data as specified below:
   1. From NRZ-L to NRZ-M.
   2. From NRZ-L to NRZ-S.

b. Bypassing the data format converter.

4.2.2.1.5 Idle Sequence Generation

This section specifies the requirements for generating command idle sequences for the S-Band Demonstration System.

The S-Band Demonstration System shall be capable of the following:

a. Generating an idle sequence with any of the following bit patterns:
   1. Alternating 1’s and 0’s (1010…).
   2. Repeating 1’s (1111…).
   3. Repeating 0’s (0000…).

b. Inserting the idle sequence at the following locations:
    1. Before the first CLTU.
    2. Between blocks of CLTUs.
    3. After the final CLTU.
c. Bypassing the idle sequence generator.
d. Supporting Physical Layer Operations Procedure-2 (PLOP-2) as defined in CCSDS 201.0-B-2.

4.2.2.1.6 Subcarrier Generation

The S-Band Demonstration System shall be capable of generating a command subcarrier as specified below:

a. Subcarrier Frequency

1. Minimum: 1 kHz.
2. Maximum: 2 MHz.
3. Step Size: ≤ 1 Hz.
4. Accuracy: ≤ ±0.001%.
5. Coherency with Data Rate

   Data bit transitions within ±7.2° of the subcarrier frequency zero crossings.

   (Applicable only when the subcarrier frequency is ≤ 32 kHz and an *integral multiple* of the data rate.)

b. Subcarrier Waveform

Sinusoid.

c. Subcarrier Suppression

≥ 30 dB.

4.2.2.1.7 Modulation Schemes

The S-Band Demonstration System shall be capable of providing all of the following command modulation schemes (not simultaneously):

a. PM Carrier with BPSK Subcarrier

Command data BPSK modulates a subcarrier that linearly phase modulates the carrier.

b. PM

Command data linearly phase modulates the carrier.

c. **BPSK**

Command data BPSK modulates the carrier.

d. **QPSK**

Command data QPSK modulates the carrier.

4.2.2.1.8 Subcarrier Modulation onto Carrier

The S-Band Demonstration System shall be capable of modulating the command subcarrier onto the carrier as specified below:

a. **Carrier Modulation**

Linear PM.

b. **Modulation Index**

1. Minimum: 0.2 radians (peak sinusoidal).
2. Maximum: 1.5 radians (peak sinusoidal).
3. Step Size: ≤ 0.1 radians.
4. Accuracy: ≤ ±10%.

4.2.2.1.9 Carrier Modulation

The S-Band Demonstration System shall be capable of modulating the command carrier as specified below:

a. **Data Modulation** (not simultaneously)

1. BPSK.
2. QPSK.
3. Linear PM.

b. **Modulation Index** (linear PM only)

1. Minimum: 0.2 radians (peak sinusoidal).
2. Maximum: 1.5 radians (peak sinusoidal).
3. Step size: ≤ 0.1 radians.
4. Accuracy: ≤ ±10%.

c. **I:Q Power Ratio**

1:1 (QPSK modulation only).

d. **Carrier Suppression**

≥ 30 dB (BPSK and QPSK modulations only).

4.2.2.1.10 Carrier Sweep

This section specifies the command carrier sweep requirements on the S-Band Demonstration System.

4.2.2.1.10.1 Sweep Range

The S-Band Demonstration System shall be capable of sweeping the S-band command carrier over the frequency range specified below:

a. Range: $\geq \pm 160$ kHz centered at f_d.

   f_d = Receive frequency defined in the customer schedule + Doppler compensation.

b. Step size: ≤ 600 Hz.

4.2.2.1.10.2 Sweep Rate

The S-Band Demonstration System shall be capable of sweeping the command carrier at the frequency rates specified below:

a. Minimum: ≤ 500 Hz/sec.

b. Maximum: ≥ 12 kHz/sec.

c. Step size: ≤ 500 Hz/sec.

d. Step rate: ≥ 500 steps/sec.

4.2.2.1.10.3 Inhibiting Modulation

The S-Band Demonstration System shall be capable of the following:

a. Inhibiting the carrier modulation before sweeping the command carrier.

b. When the sweep has completed, re-enabling the carrier modulation that was inhibited before the sweep began.

4.2.2.1.10.4 Sweep Algorithm

The S-Band Demonstration System shall be capable of the following:

a. Sweeping the carrier frequency in a triangular pattern centered at f_d, where

   f_d = Receive frequency defined in the customer schedule + Doppler compensation.

b. Sweeping the carrier frequency until acquisition occurs.

   Acquisition is defined to occur when any of the following events occurs:

   1. Non-Coherent Mode

      The carrier has been sweeping for ≥ 30 seconds since the antenna slews above the horizon mask.

   2. Coherent Mode

      The telemetry downlink signal has been sweeping in unison with the command uplink signal continuously for ≥ 15 seconds.

3. CCSDS CLCW Mode

   The Receiver Lock Status bit = 1 continuously for ≥ 15 seconds. (This bit is part of the Command Link Control Word [CLCW] in the CCSDS Transfer Frame.)

c. When acquisition occurs, continuing to sweep in the triangular pattern until the frequency returns to f_c, where f_c = the center frequency without Doppler compensation.

d. Terminating the sweep when any of the following conditions occur:

   1. The carrier frequency returns to f_c.
   2. ≥ 4 minutes have elapsed while sweeping without acquiring in the Coherent Mode or the CCSDS CLCW Mode.
   3. The antenna slews below the horizon mask at the end of the pass.

4.2.2.2 IF-to-RF Processing

This section specifies the requirements for processing commands from IF to RF for the S-Band Demonstration System.

The S-Band Demonstration System shall be capable of:

a. Generating a command carrier at any of the center frequencies specified in Section 4.2.1.2.a above.

b. Amplifying the modulated command signal to an output power ≥ 50 watts.

c. Automatically reducing the output power to zero upon termination of customer support.

d. Protecting the HPA from damage due to power reflected back from the antenna or other upstream components.

e. Providing a command signal in accordance with the distortion constraints specified in Section 4.2.2.1.1 above.

f. Providing a command signal with the following parameters:

   1. RF channel 3-dB bandwidth: ≥ 16 MHz.
   2. Signal-to-thermal noise ratio: ≥ 43 dB at specified EIRP within RF channel 3-dB bandwidth.
   3. Out-of-band spurs: ≥ 40 dB below unmodulated carrier (up to 30 GHz).

4.2.3 S-Band Telemetry

This section specifies the S-band telemetry requirements for the S-Band Demonstration System.

4.2.3.1 General

General S-band telemetry requirements are divided into the following sections: implementation loss and interference.

4.2.3.1.1 Implementation Loss

This section specifies the implementation loss for telemetry in the S-Band Demonstration System.

"Implementation loss" is defined as the difference between the following two E_b/N_o values:

a. The E_b/N_o needed to achieve a given BER with the customer signal defined in Section 4.2.3.1.1.2 below.

b. The E_b/N_o *theoretically* required to achieve the given BER with an ideal, distortion-free customer signal.

   The theoretically required E_b/N_o is defined in Section 4.2.3.1.1.3 below.

4.2.3.1.1.1 Implementation Loss Requirement

The S-Band Demonstration System shall be capable of providing the implementation losses specified in Table 4-2 below, in the presence of AWGN, under all of the conditions defined in Section 4.2.3.1.1.2 below.

4.2.3.1.1.2 Conditions

This section defines the conditions under which the Implementation Loss Requirement specified in Section 4.2.3.1.1.1 above must be met.

This section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines the customer platform signal and dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

4.2.3.1.1.2.1 BER

The following BERs are referenced to the S-Band Demonstration System's output interface to NISN:

a. 10^{-5}.

b. 10^{-7}.

c. 10^{-9}.

4.2.3.1.1.2.2 Customer Signal Parameters

a. Modulation Schemes

1. PM Carrier with BPSK Subcarrier

A BPSK-modulated subcarrier is added to a second digital data channel, and the sum linearly phase modulates the carrier.

2. PSK

The carrier is either BPSK, QPSK, or SQPSK-modulated.

b. Signal Parameters

Customer signal parameters are defined in Table 4-3 below.

Table 4-2: Implementation Loss: S-Band Telemetry

BER	Data Coding	Implementation Loss[1] A. Carrier[3]	B. Subcarrier[2]	C. BPSK	D. QPSK or SQPSK[3]
1. 10^{-5}	a. Uncoded	≤ 2.2 dB	≤ 0.7 dB	≤ 1.8 dB	≤ 4.3 dB
	b. R-½ convolutionally coded[4]	≤ 2.3 dB	≤ 0.9 dB	≤ 1.9 dB	≤ 2.4 dB
	c. Reed-Solomon coded[5]	≤ 2.2 dB	≤ 0.7 dB	≤ 1.8 dB	≤ 4.3 dB
	d. Concatenated coded[4,6]	≤ 2.3 dB	≤ 0.9 dB	≤ 1.9 dB	≤ 2.4 dB
2. 10^{-7}	a. Uncoded	≤ 2.6 dB	≤ 0.8 dB	≤ 2.2 dB	≤ 5.6 dB
	b. R-½ convolutionally coded[4]	≤ 2.6 dB	≤ 0.9 dB	≤ 2.2 dB	≤ 2.9 dB
	c. Reed-Solomon coded[5]	≤ 2.6 dB	≤ 0.8 dB	≤ 2.2 dB	≤ 5.6 dB
	d. Concatenated coded[4,6]	≤ 2.6 dB	≤ 0.9 dB	≤ 2.2 dB	≤ 2.9 dB
3. 10^{-9}	a. Uncoded	≤ 2.9 dB	≤ 0.9 dB	≤ 2.5 dB	≤ 6.5 dB
	b. R-½ convolutionally coded[4]	≤ 2.7 dB	≤ 0.9 dB	≤ 2.3 dB	≤ 3.4 dB
	c. Reed-Solomon coded[5]	≤ 2.9 dB	≤ 0.9 dB	≤ 2.5 dB	≤ 6.5 dB
	d. Concatenated coded[4,6]	≤ 2.7 dB	≤ 0.9 dB	≤ 2.3 dB	≤ 3.4 dB

Notes:

1. Implementation losses assume the following:
   a. NRZ-L or biphase-L symbol format. If NRZ-M, NRZ-S, biphase-M, or biphase-S is used, implementation losses should be increased by 0.1 dB.
   b. Doppler tracking is not required. If Doppler tracking is required, the customer platform must meet tighter phase noise constraints (see Table 4-5 below) that will result in reduced implementation loss.
   c. Total ground terminal gain flatness ≤ ±1.5 dB.
   d. Total ground terminal phase nonlinearity ≤ 6° peak-to-peak.
2. Implementation losses assume that carrier interference degrades the subcarrier C/(N + I) by 0.4 dB, and subcarrier interference degrades the carrier C/(N + I) by 0.4 dB.
3. Implementation losses are specified for each I and each Q channel.
4. The implementation losses were calculated based on infinite soft-decision bits with Viterbi decoding.
5. Assumes implementation loss with R-S coding is identical to that with uncoded data.
6. Assumes implementation loss with concatenated coding is identical to that with convolutional coding.

Table 4-3: S-Band Telemetry Customer Signal Parameters

Parameter	Customer Constraint A. PM Carrier with BPSK-Modulated Subcarrier	 B. BPSK, QPSK, or SQPSK
1. Carrier frequency reference		
a. Coherent	Received S-band command frequency (Turn-around ratio = 240/221)	Received S-band command frequency (Turn-around ratio = 240/221)
b. Non-coherent	customer platform oscillator	customer platform oscillator
2. I:Q power ratio	N/A	1:1 or 4:1 (N/A to BPSK)
3. Carrier modulation index		N/A
a. Minimum	0 radians	
b. Maximum	1.2 radians[6,7]	
4. Carrier suppression	N/A	≥ 30 dB
5. Subcarrier frequency (sinusoidal)		N/A
a. Minimum	500 Hz	
b. Maximum	4 MHz[7]	
6. Subcarrier modulation (subcarrier onto carrier)	Linear PM	N/A
7. Subcarrier modulation index (subcarrier onto carrier)		N/A
a. Minimum	0 radians	
b. Maximum	0.8 radians	
8. Subcarrier data modulation (data onto subcarrier)	BPSK	N/A

Table 4-3: S-Band Telemetry Customer Signal Parameters (Cont'd)

Parameter	Customer Constraint A. PM Carrier with BPSK-Modulated Subcarrier	Customer Constraint B. BPSK, QPSK, or SQPSK
9. Subcarrier suppression	≥ 30 dB	N/A
10. Data rate[2,7]		
a. NRZ data[1]		
(1) Uncoded		
(a) Carrier	1 kbps to 8 Mbps	N/A
(b) Subcarrier	100 bps to 64 kbps	N/A
(c) Total[8]	N/A	1 kbps to 8 Mbps
(d) I channel and Q channel	N/A	1 kbps to 4 Mbps
(2) R-S coded[5]		
(a) Carrier	1 kbps to $(8 \times r)$ Mbps	N/A
(b) Subcarrier	100 bps to $(64 \times r)$ kbps	N/A
(c) Total[8]	N/A	1 kbps to $(8 \times r)$ Mbps
(d) I channel and Q channel	N/A	1 kbps to $(4 \times r)$ Mbps
(3) R-S coded, then Biϕ-converted[5]		
(a) Carrier	1 kbps to $(4 \times r)$ Mbps	N/A
(b) Subcarrier	100 bps to $(32 \times r)$ kbps	N/A
(c) Total[8]	N/A	1 kbps to $(4 \times r)$ Mbps
(d) I channel and Q channel	N/A	1 kbps to $(2 \times r)$ Mbps

Table 4-3: S-Band Telemetry Customer Signal Parameters (Cont'd)

Parameter	Customer Constraint	
	A. PM Carrier with BPSK-Modulated Subcarrier	B. BPSK, QPSK, or SQPSK
(4) R-½ convolutional coded[3]		
(a) Carrier	1 kbps to 4 Mbps	N/A
(b) Subcarrier	100 bps to 32 kbps	N/A
(c) Total[8]	N/A	1 kbps to 4 Mbps
(d) I channel and Q channel	N/A	1 kbps to 2 Mbps
(5) R-½ convolutional coded, then Biφ-converted[3]		
(a) Carrier	1 kbps to 2 Mbps	N/A
(b) Subcarrier	100 bps to 16 kbps	N/A
(c) Total[8]	N/A	1 kbps to 2 Mbps
(d) I channel and Q channel	N/A	1 kbps to 1 Mbps
(6) Concatenated coded[5]		
(a) Carrier	1 kbps to $(4 \times k)$ Mbps	N/A
(b) Subcarrier	100 bps to $(32 \times k)$ kbps	N/A
(c) Total[8]	N/A	1 kbps to $(4 \times k)$ Mbps
(d) I channel and Q channel	N/A	1 kbps to $(2 \times k)$ Mbps

Table 4-3: S-Band Telemetry Customer Signal Parameters (Cont'd)

Parameter	Customer Constraint	
	A. PM Carrier with BPSK-Modulated Subcarrier	B. BPSK, QPSK, or SQPSK
(7) Concatenated coded, then Biϕ-converted[5]		
(a) Carrier	1 kbps to (2 × k) Mbps	N/A
(b) Subcarrier	100 bps to (16 × k) kbps	N/A
(c) Total[8]	N/A	1 kbps to (2 × k) Mbps
(d) I channel and Q channel	N/A	1 kbps to k Mbps
b. Biϕ data, uncoded[4]		
(1) Carrier	1 kbps to 4 Mbps	N/A
(2) Subcarrier	100 bps to 64 kbps	N/A
(3) Total[8]	N/A	1 kbps to 4 Mbps
(4) I channel and Q channel	N/A	1 kbps to 2 Mbps

Notes:

1. Before symbol conversion from NRZ to biphase, if used.
2. Data on I and Q channels may be independent and asynchronous.
3. Data rate is measured at the input to the convolutional encoder.
   r = convolutional code rate = ½.
4. Data rate is measured at the input to the NRZ-to-biphase converter.
5. Data rate is measured at the input to the R-S encoder.
   k = R-S code rate (for example, k = 223/255).
6. CCSDS recommends that the customer select a modulation index such that carrier suppression ≤ 10 dB. The rationale is two-fold: (1) A high modulation index can make the residual carrier difficult to detect with a conventional phase-locked loop receiver, and (2) the recoverable power in the data channel decreases. (CCSDS 401.0-B-4)
7. When data is modulated onto the subcarrier, the subcarrier frequency and the data rate and modulation index of the main carrier channel must be selected such that the data on the subcarrier and main carrier do not interfere with each other.
8. If the data on the I and Q channels are independent, the sum of the I and Q-channel data rates must not exceed the "Total" data rate.

4.2.3.1.1.2.3 Data Formats

Data formats are defined below.

4.2.3.1.1.2.3.1 Uncoded Data Formats

The following data formats are defined for uncoded data (that is, data that is not convolutionally coded, R-S coded, or concatenated coded):

a. **PM Carrier with BPSK-Modulated Subcarrier**

   NRZ-L, M, or S, or biϕ-L, M, or S.

b. **BPSK, QPSK, or SQPSK**

   NRZ-L, M, or S.

4.2.3.1.1.2.3.2 Coded Data Formats

a. **Input Data Format**

   The following data formats are defined at the input to the customer platform's encoder:

   1. **Convolutional Encoder**
      (a) NRZ-L.
      (b) NRZ-M.
      (c) NRZ-S.
   2. **R-S Encoder**
      NRZ-L.
   3. **Concatenated Encoder**
      (a) At the input to the customer platform's concatenated *R-S* encoder: NRZ-L.
      (b) At the input to the customer platform's concatenated *convolutional* encoder:
         (1) NRZ-L.
         (2) NRZ-M.
         (3) NRZ-S.

b. **Output Data Format**

   The following data formats are defined at the output of the customer platform's encoder:

   1. **Convolutional Encoder**
      (a) NRZ.
      (b) Biphase, and both of the following conditions are met:
         (1) Symbol interleaving is not used.
         (2) The convolutional encoder does not perform G2 inversion.

2. **R-S Encoder**
   (a) NRZ-L.
   (b) NRZ-M.
   (c) NRZ-S.
   (d) Biϕ-L.
   (e) Biϕ-M.
   (f) Biϕ-S.
3. **Concatenated Encoder**
   (a) NRZ.
   (b) Biphase, and both of the following conditions are met:
      (1) Symbol interleaving is not used.
      (2) The convolutional encoder does not perform G2 inversion.

4.2.3.1.1.2.4 Customer Signal Distortions

Customer signal distortions are defined in Table 4-4 below.

4.2.3.1.1.2.5 Customer Configurations

Customer configurations are defined in Table 4-5 below.

4.2.3.1.1.2.6 Coding Configurations

The customer platform coding configurations are defined below.

4.2.3.1.1.2.6.1 Convolutional Code

One convolutional code is defined.

This code is identical to the code recommended in CCSDS 101.0-B-4, except the CCSDS code *always* inverts the G2 symbols.

a. **Rate (R)**

   R = ½.

b. **Constraint Length (K)**

   K = 7.

c. **Generator Polynomials**

   1. G1 = 1111001.
   2. G2 = 1011011.

d. **G1 and G2 Symbol Timing**

   Symbols generated from G1 will precede symbols generated from G2 relative to the data bit period.

e. **G2 Inversion**

   Symbols generated from G2 can be either true or complemented.

Table 4-4: S-Band Telemetry Customer Signal Distortion Constraints

Parameter	Customer Constraint				
	PM Carrier with BPSK Subcarrier			BPSK, QPSK, or SQPSK	
	Carrier				
	A. Uncoded or R-S Coded	B. Convolu-tional or Concat-enated Coded	C. Subcarrier	D. Uncoded or R-S Coded	E. Convolu-tional or Concat-enated Coded
1. I:Q power ratio tolerance (N/A to BPSK)	N/A	N/A	N/A	≤ ±0.4 dB	≤ ±0.4 dB
2. Phase imbalance[1]	≤ ±3°	≤ ±9°	≤ ±9°		
a. BPSK				≤ ±3°	≤ ±9°
b. QPSK and SQPSK				≤ ±3°	≤ ±5°
3. Gain imbalance[1]	≤ ±0.25 dB	≤ ±1.0 dB	≤ ±1.0 dB		
a. BPSK				≤ ±0.25 dB	≤ ±1.0 dB
b. QPSK and SQPSK				≤ ±0.25 dB	≤ ±0.5 dB
4. Symbol asymmetry[1,2]	≤ ±3%	≤ ±3%	≤ ±3%	≤ ±3%	≤ ±3%
5. Symbol transition time (from 90% of initial state to 90% of final state)[1,2]	≤ 5% of symbol duration	≤ 5% of symbol duration	≤ 5% of symbol duration	≤ 5% of symbol duration	≤ 5% of symbol duration
6. Phase nonlinearity (all types)[1] (over ±70% of R_s MHz[5])	≤ ±3°	≤ ±4°	≤ ±4°	≤ ±3°	≤ ±4°
7. Gain flatness[1] (over ±70% of R_s MHz[5])	≤ ±0.3 dB	≤ ±0.4 dB	≤ ±0.4 dB	≤ ±0.3 dB	≤ ±0.4 dB
8. Gain slope[1] (over ±70% of R_s MHz[5])	≤ ±0.1 dB/MHz	N/A	N/A	≤ ±0.1 dB/MHz	N/A
9. AM/PM[1]	≤ 12°/dB	≤ 15°/dB	≤ 15°/dB	≤ 12°/dB	≤ 15°/dB
10. AM/AM[1]	N/A	N/A	N/A	N/A	N/A
11. 3-dB channel bandwidth prior to power amplifier[1,3,5]	≥ 2 × maximum channel R_s	≥ 2 × maximum channel R_s	N/A	≥ 2 × maximum channel R_s	≥ 2 × maximum channel R_s
12. Symbol jitter and jitter rate[1,2,4]	≤ 0.1%	≤ 0.1%	≤ 0.1%	≤ 0.1%	≤ 0.1%

Table 4-4: S-Band Telemetry Customer Signal Distortion Constraints (Cont'd)

Parameter	Customer Constraint				
	PM Carrier with BPSK Subcarrier			BPSK, QPSK, or SQPSK	
	Carrier				
	A. Uncoded or R-S Coded	B. Convolutional or Concatenated Coded	C. Subcarrier	D. Uncoded or R-S Coded	E. Convolutional or Concatenated Coded
13. Untracked Spurious PM[1]	≤ 2° rms	≤ 2° rms	≤ 2° rms		
a. BPSK				≤ 2° rms	≤ 2° rms
b. I:Q = 1:1				≤ 1° rms	≤ 1° rms
c. I:Q = 4:1				≤ 2° rms	≤ 2° rms
14. Spurious outputs			N/A		
a. Within the data bandwidth[6]	≤ -30 dBc	≤ -23 dBc		≤ -30 dBc	≤ -23 dBc
b. Between the data bandwidth[6] and the 3-dB channel bandwidth	≤ -15 dBc	≤ -15 dBc		≤ -15 dBc	≤ -15 dBc
c. Between the 3-dB channel bandwidth and twice that bandwidth	≤ -15 dBc	≤ -15 dBc		≤ -15 dBc	≤ -15 dBc
d. Outside of twice the 3-dB channel bandwidth	≤ -30 dBc	≤ -30 dBc		≤ -30 dBc	≤ -30 dBc
15. Frequency stability (peak)[1]			$\leq \pm 3.7 \times 10^{-9}$		
a. 1-second average time	$\leq \pm 6.5 \times 10^{-9}$	$\leq \pm 6.5 \times 10^{-9}$		$\leq \pm 6.5 \times 10^{-9}$	$\leq \pm 6.5 \times 10^{-9}$
b. 5-hour average time[8]	≤ ±1.4 ppm	≤ ±1.4 ppm		≤ ±1.4 ppm	≤ ±1.4 ppm
c. 48-hour average time[8]	≤ ±4.3 ppm	≤ ±4.3 ppm		≤ ±4.3 ppm	≤ ±4.3 ppm
16. Incidental AM (peak)[1]	≤ 5%	≤ 5%	≤ 5%	≤ 5%	≤ 5%

Table 4-4: S-Band Telemetry Customer Signal Distortion Constraints (Cont'd)

Parameter	Customer Constraint				
	PM Carrier with BPSK Subcarrier			BPSK, QPSK, or SQPSK	
	Carrier				
	A. Uncoded or R-S Coded	B. Convolu-tional or Concat-enated Coded	C. Subcarrier	D. Uncoded or R-S Coded	E. Convolu-tional or Concat-enated Coded
17. Phase noise[7]					
a. 1 Hz to 10 Hz	≤ 0.8° rms	≤ 0.8° rms	≤ 2.0° rms	≤ 0.8° rms	≤ 0.8° rms
b. 10 Hz to 100 Hz	≤ 0.4° rms	≤ 0.4° rms	≤ 1.0° rms	≤ 0.4° rms	≤ 0.4° rms
c. 100 Hz to 1 kHz	≤ 0.4° rms	≤ 0.4° rms	≤ 1.0° rms	≤ 0.4° rms	≤ 0.4° rms
d. 1 kHz to 8 MHz	≤ 0.4° rms	≤ 0.4° rms	≤ 1.0° rms (to 64 kHz)	≤ 0.4° rms	≤ 0.4° rms
18. I/Q symbol skew (relative to the requirements for I/Q data synchronization, where appropriate)[1,2]	N/A	N/A	N/A	≤ ±3%	≤ ±3%
19. Modulation index tolerance	≤ ±10%	≤ ±10%	N/A	N/A	N/A

Notes:

1. This parameter is defined in 450-SNUG, Revision 8.
2. For uncoded data, the symbol parameters should be interpreted as data bit parameters.
3. For the channel bandwidth constraint, the symbol rate for biphase-formatted data is twice the symbol rate prior to the NRZ-to-biphase data format conversion.
4. The total symbol jitter is the sum of the weighted spurious and random jitter components. The values apply to rate-½ convolutionally encoded data signals.
5. R_s, the symbol rate, is defined *after* convolutional and/or R-S encoding but before any NRZ-to-biphase data format conversion (except for the channel bandwidth constraint; see note 3 above). If the I and Q-channel symbol rates are unequal, R_s is the larger of the two.
6. Data bandwidth is the modulation null-to-null bandwidth.
7. Assumes a total Doppler tracking error limit of 0.2 radians and a 1-second averaging time.
8. Based on a customer transmit frequency uncertainty of ±20 kHz (defined in Section 4.2.3.3.1.a). Assumes the customer will estimate the frequency ≤ 48 hours before start-of-service. If the customer does not provide updated estimates, the frequency stability constraint is ≤ ±4.3 ppm for the entire mission duration.

Table 4-5: S-Band Telemetry Customer Configurations

Customer Configuration	Linear PM		C. BPSK	D. QPSK	E. SQPSK
	A. Subcarrier	B. Carrier			
1. Single data channel					
a. Uncoded	X[3]	X[7]	X		X[1]
b. Convolutionally coded	X[3]	X[7]	X	X[2]	X[2]
c. Reed-Solomon coded	X[3]	X[7]	X		X[4]
d. Concatenated coded	X[3]	X[7]	X		X[2,4]
2. Dual independent data channels					
a. Uncoded	X	X			
b. Convolutionally coded	X[5,6]	X[5,6]			
c. Reed-Solomon coded	X[5,6]	X[5,6]			
d. Concatenated coded	X[5]	X[5]			

Notes:

1. Alternating I/Q data bits.
2. Alternating coded symbols on the I and Q channels.
3. The carrier is transmitted but without data modulation.
4. Reed-Solomon encoding occurs before the data is split into I and Q channels.
5. One channel may be coded and the other not.
6. One channel may be convolutionally coded and the other Reed-Solomon coded.
7. The unmodulated subcarrier may or may not be transmitted.

4.2.3.1.1.2.6.2 Reed-Solomon Code

One R-S code is defined: a (255,223,16) code.

a. (255,223,16) Code

The R-S (255,223,16) code is defined in CCSDS 101.0-B-4.

b. R-S Modes

The following R-S decoding modes are defined:

1. Detect and correct.
2. Bypass.

4.2.3.1.1.2.6.3 Concatenated Code

The concatenated code is defined in CCSDS 101.0-B-4.

(A concatenated code is the combination of a R-S outer code with a convolutional inner code.)

4.2.3.1.1.2.7 Signal Dynamics

Frequency dynamics that result from the customer platform range dynamics defined in Table 4-6 below.

Table 4-6: S-Band Telemetry Customer Platform Range Dynamics

Parameter*	Constraint
1. Range rate	≤ 9 km/sec.
2. Range acceleration	≤ 400 m/sec.^{2}
3. Range jerk	≤ 15 m/sec.^{3}

Note:

* Range is defined as the distance between the customer platform and the ground antenna.

4.2.3.1.1.2.8 Signal Levels

4.2.3.1.1.2.8.1 P_{rec}

"P_{rec}," the nominal total isotropic power level (customer platform signal plus AWGN) received at the aperture of the ground antenna, is defined below for clear-sky conditions with a noise temperature of 100 K:

a. Minimum P_{rec}: As defined in Table 4-7.

b. Maximum P_{rec}: –127.0 dBWi.

P_{rec} Definition

P_{rec} is the minimum required signal power received at the ground station for a BER performance of at least 10^{-5}, or for autotrack acquisition in ≤ 2 seconds with a probability of > 0.99. P_{rec} is defined on a per-channel basis – for pure PSK-modulated signals, both the I channel and the Q channel must meet the constraints; for BPSK/PM-modulated signals, both the carrier and the subcarrier must meet the constraints. P_{rec} does not include the gain of the ground antenna nor its pointing loss.

Customers would calculate their P_{rec} by adding their EIRP, customer platform antenna pointing loss, free space loss, atmospheric/rain loss, RFI loss, and polarization loss due to the mismatch between the axial ratios of the customer platform and the ground antenna.

4.2.3.1.1.2.8.2 Additional Dual Data Channel Configurations

Dual data channel configurations are defined under all of the following conditions:

Table 4-7: S-Band Telemetry Customer P_{rec} Constraints with Autotracking

Parameter	Customer Constraint[3]			
	A. PM carrier (10^{-5} P_E)	B. BPSK subcarrier (10^{-5} P_E)	C. BPSK (10^{-5} P_E)	D. QPSK or SQPSK (10^{-5} P_E)
1. P_{rec} for 10^{-5} BER requirements with autotracking[1,6]				
a. Uncoded	≥ –230.4 + 10 $\log_{10} R_b$ dBWi [4]	≥ –231.9 + 10 $\log_{10} R_b$ dBWi [5]	≥ –230.8 + 10 $\log_{10} R_b$ dBWi	≥ –228.3 + 10 $\log_{10} R_b$ dBWi
b. With R-½ convolutional coding	≥ –235.5 + 10 $\log_{10} R_b$ dBWi [4]	≥ –236.8 + 10 $\log_{10} R_b$ dBWi [5]	≥ –235.8 + 10 $\log_{10} R_b$ dBWi	≥ –235.4 + 10 $\log_{10} R_b$ dBWi
c. With R-S (255, 223) coding	≥ –230.4 + 10 $\log_{10} R_b$ dBWi [4]	≥ –231.9 + 10 $\log_{10} R_b$ dBWi [5]	≥ –230.8 + 10 $\log_{10} R_b$ dBWi	≥ –228.3 + 10 $\log_{10} R_b$ dBWi
d. With concatenated coding	≥ –235.5 + 10 $\log_{10} R_b$ dBWi [4]	≥ –236.8 + 10 $\log_{10} R_b$ dBWi [5]	≥ –235.8 + 10 $\log_{10} R_b$ dBWi	≥ –235.4 + 10 $\log_{10} R_b$ dBWi
2. P_{rec} floor for autotrack acquisition[2,7]	–170.3 dBWi in a 3 MHz bandwidth	–170.3 dBWi in a 3 MHz bandwidth	–170.3 dBWi in a 3 MHz bandwidth	–170.3 dBWi in a 3 MHz bandwidth

Notes:

1 P_{rec} is calculated as follows: P_{rec} = Theoretically Required Eb/No for 10^{-5} BER + Implementation and Constraint Loss + Required Link Margin – G/T + Boltzmann's Constant + 10*log (Rb). R_b = Telemetry bit rate (prior to encoding, if applicable).

2. The P_{rec} required with autotracking is equal to the greater of rows 1 and 2 in the table.

3. These constraints apply only to the data rates listed in Table 4-4 below.

4. This P_{rec} for residual carrier modulation applies to the power in the PM data component only. The total P_{rec} will include the power in this data component, the power in the residual CW carrier, and the power in the subcarrier data component if a subcarrier is used simultaneously with the PM data.

5. This P_{rec} for subcarrier data modulation applies to the power in the subcarrier data component only. The total P_{rec} will include the power in this subcarrier data component, the power in the residual CW carrier, and the power in the PM data component if PM data is used simultaneously with the subcarrier data.

6. For program tracking, the required minimum P_{rec} will be 5.2 dB higher than the minimum P_{rec} values in this table.

7. P_{rec} is calculated as follows: P_{rec} = Required Receiver S/N for Autotrack – G/T + Boltzmann's Constant + 10*log (IF Bandwidth).

a. PM Carrier with BPSK Subcarrier

1. The subcarrier is not transmitted and the P_{rec} of the carrier is unaffected.
2. The subcarrier is not data modulated and the P_{rec} of the carrier is unaffected.
3. The carrier is not data modulated and the P_{rec} of the subcarrier is unaffected.

b. QPSK or SQPSK

1. The I channel is not transmitted and the P_{rec} of the Q channel is unaffected.
2. The Q channel is not transmitted and the P_{rec} of the I channel is unaffected.
3. The I channel is not data modulated and the P_{rec} of the Q channel is unaffected.
4. The Q channel is not data modulated and the P_{rec} of the I channel is unaffected.

4.2.3.1.1.2.9 Symbol Transition Density

The symbol transition density defined below:

a. Number of symbol transitions: $\geq$ 125 within any sequence of 1000 consecutive symbols.

b. Number of consecutive symbols without a transition: $\leq$ 64.

4.2.3.1.1.2.10 C/No Levels

The following C/N_o levels:

a. Minimum: The C/N_o needed for a BER of 10^{-5}.

b. Maximum: The C/N_o 12 dB greater than that needed for a BER of 10^{-5}.

4.2.3.1.1.3 Theoretically Required Eb/No

Table 4-8 below defines the theoretically required E_b/N_o in an AWGN channel.

4.2.3.1.2 Interference

The S-Band Demonstration System shall be capable of meeting all of the S-band telemetry requirements specified in Sections 4.2.a, b, d.2, and d.3, 4.2.1, 4.2.3, 4.2.5, and 4.2.6 during both of the following conditions:

a. Sun Intrusion

The center of the sun is $\geq 1°$ outside the boresight of the dual-band antenna.

b. Interference from Other Customer Platforms

The ratio of the power received from the customer platform to the composite interference power contained within the channel bandwidth from other customer platforms is $\geq$ 30 dB.

4.2.3.2 RF-to-IF Processing

The S-Band Demonstration System shall be capable of the following:

a. Receiving customer platform signals with the following parameters:
   1. The center frequency specified in Section 4.2.1.1.a above.
   2. The polarizations specified in Section 4.2.1.1.b above.

b. Simultaneously processing the two polarizations of a single S-band downlink signal.

c. Providing a maximum RF channel 3-dB bandwidth of 20 MHz at the last IF.

Table 4-8: Theoretically Required E_b/N_o: S-Band Telemetry

Configuration	Theoretically Required E_b/N_o (dB)		
	A. 10^{-5} BER[1]	B. 10^{-7} BER[1]	C. 10^{-9} BER[1]
1. Uncoded[2]			
a. NRZ-L and biphase-L data	9.6	11.3	12.5
b. NRZ-M, S and biphase-M, S data[3]	9.9	11.5	12.7
2. Convolutionally coded: R-½, K=7[8]			
a. NRZ-L and biphase-L symbols	4.2[4]	5.4[4,5]	6.3[5]
b. NRZ-M, S and biphase-M, S symbols[3]	4.4	5.6	6.5
3. Reed-Solomon coded:(255,223,16)[5,6]	6.0	6.3	6.5
4. Concatenated coded: R-½, K=7 convolutional with (255,223,16) Reed-Solomon[4,6,7,8]			
a. NRZ-L and biphase-L symbols	~2.6	~2.8	~3.0
b. NRZ-M, S and biphase-M, S symbols[3]	~2.7	~2.8	~3.0

<u>Notes</u>:

1. BER is referenced to the S-Band Demonstration System's output interface to NISN.
2. E_b/N_o's were analytically derived using the complementary error function.
3. E_b/N_o's for differentially formatted data (symbols) (that is, -M and -S) were determined by doubling the BER for NRZ-L and biphase-L data (symbols) and calculating the resultant change in E_b/N_0.
4. Source: Figures 5.11 and 7.2 in "Error Control Coding Handbook (Final Report)," Joseph P. Odenwalder, Linkabit Corp., 15 July 1976. E_b/N_o's for 10^{-9} BER extrapolated from 10^{-8} BER.
5. Source: Figure A-3 in 700.0-G-3, "Advanced Orbiting Systems, Networks and Data Links: Summary of Concept, Rationale, and Performance," Green Book, Issue 3, CCSDS, November 1992.
6. 8 bits per R-S symbol, E=16.
7. Values are estimates, since theoretically required E_b/N_0 varies with R-S interleaving depth "I".
8. E_b/N_o's were based on *infinite* soft-decision bits with Viterbi decoding. (Some sources base their values on only *3* soft-decision bits.)

4.2.3.3 IF-to-Baseband Processing

This section specifies the IF-to-Baseband processing requirements for the S-Band Demonstration System.

4.2.3.3.1 Signal Acquisition Time

Under all of the conditions defined below, the S-Band Demonstration System shall be capable of acquiring the customer platform signal in ≤ 1 second with a probability ≥ 0.9.

The section below does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's signal and dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

a. Customer Platform Transmit Frequency Uncertainty

$\leq \pm 20$ kHz.

b. Customer Platform Dynamics

The customer platform dynamics constraints defined below:

1. Signal Dynamics

The signal dynamics defined in Section 4.2.3.1.1.2.7 above.

2. Antenna Tracking

The ground antenna tracking constraints defined in Section 4.2.1.13.1.b above.

Definition of Signal Acquisition Time

Signal acquisition time includes the time to acquire the carrier, and is defined as the interval between the following start and stop times:

Start time: When a customer signal is received at the aperture of the ground antenna with a power equal to the minimum P_{rec} required for a 10^{-5} BER as defined in Table 4-7 above (see note 6 below the table for antenna program track P_{rec}).

Stop Time: When the customer telemetry signal appears at the output of the carrier demodulator in the ground station.

4.2.3.3.2 Signal Tracking

This section specifies customer platform signal tracking requirements on the S-Band Demonstration System.

4.2.3.3.2.1 Bit Slips

The S-Band Demonstration System shall be capable of providing a mean time-to-bit-slip ≥ 90 minutes or $\geq 10^{10}$ clock cycles, whichever is longer, for the following values of P_{rec}:

a. Autotrack

The minimum P_{rec} for 10^{-5} BER requirements with autotracking defined in row 1 of Table 4-7 above.

b. Program Track

The minimum P_{rec} for 10^{-5} BER requirements with program tracking defined in note 6 of Table 4-7 above.

4.2.3.3.2.2 Cycle Slips

The S-Band Demonstration System shall be capable of providing a mean time-to-cycle-slip in carrier tracking ≥ 90 minutes for a $P_{rec} \geq X - 3$ dB, for the following values of "X":

a. Autotrack

X = The minimum P_{rec} for 10^{-5} BER requirements with autotracking defined in row 1 of Table 4-7 above.

b. Program Track

X = The minimum P_{rec} for 10^{-5} BER requirements with program tracking defined in note 6 of Table 4-7 above.

4.2.3.3.2.3 False Carrier Acquisition

During signal acquisition and signal tracking, the S-Band Demonstration System shall be capable of protecting against false carrier acquisition.

4.2.3.3.2.4 Symbol Synchronization

The S-Band Demonstration System shall be capable of maintaining symbol synchronization for a $P_{rec} \geq X - 3$ dB, for the following values of "X":

a. Autotrack

X = The minimum P_{rec} for 10^{-5} BER requirements with autotracking defined in row 1 of Table 4-7 above.

b. Program Track

X = The minimum P_{rec} for 10^{-5} BER requirements with program tracking defined in note 6 of Table 4-7 above.

4.2.3.3.3 Diversity Combining

The S-Band Demonstration System shall be capable of coherently combining the dual-polarized signals as specified below:

$SNR_{out} \geq 10 \log_{10} (SNR_1 + SNR_2) - 0.5$, where:

SNR_{out} = SNR of the combined signal (in dB).

SNR_1 = SNR of one input signal (absolute; *not* in dB).

SNR_2 = SNR of the other input signal (absolute; *not* in dB).

4.2.3.3.4 Demodulation

The S-Band Demonstration System shall be capable of demodulating a customer platform signal with:

a. Any of the Modulation Schemes defined in Section 4.2.3.1.1.2.2.a above (not simultaneously).

b. Any of the Customer Configurations defined in Section 4.2.3.1.1.2.5 above.

4.2.3.3.5 Customer Signal Parameters

a. The S-Band Demonstration System shall be capable of supporting a customer platform signal with the parameters defined in Section 4.2.3.1.1.2.2.b above.

b. The S-Band Demonstration System shall be capable of supporting a customer platform signal with the Additional Dual Data Channel Configurations defined in Section 4.2.3.1.1.2.8.2 above.

4.2.3.3.6 Carrier and Subcarrier Processing

The S-Band Demonstration System shall be capable of simultaneously processing the telemetry on the carrier and subcarrier channels.

4.2.3.3.7 I and Q-Channel Processing

The S-Band Demonstration System shall be capable of simultaneously processing the telemetry on the I and Q channels.

4.2.3.3.8 Clock Synchronization (Symbol Transition Density)

a. The S-Band Demonstration System shall be capable of achieving and maintaining clock synchronization for the Symbol Transition Density constraints defined in Section 4.2.3.1.1.2.9 above.

b. If only one of two channels meets the Clock Synchronization requirement specified in Section 4.2.3.3.8.a above, the S-Band Demonstration System shall be capable of achieving and maintaining clock synchronization on that channel.

4.2.3.3.9 Baseband Processing

This section specifies the baseband telemetry processing requirements for the S-Band Demonstration System.

4.2.3.3.9.1 Telemetry Standards

This section specifies the baseband telemetry processing standards recommended by the CCSDS and other organizations.

4.2.3.3.9.1.1 Frame Synchronization

The S-Band Demonstration System shall be capable of providing frame synchronization functions for the following:

a. CCSDS Channel Access Data Unit (CADU) frames that are formatted in accordance with CCSDS 701.0-B-2.

b. Frames with Attached Sync Marker (ASM) in accordance with CCSDS 101.0-B-4.

4.2.3.3.9.1.2 Data De-Randomization

The S-Band Demonstration System shall be capable of de-randomizing pseudo-randomized data, in accordance with CCSDS 101.0-B-4.

4.2.3.3.9.1.3 Virtual Channel Data Unit (VCDU) Extraction

The S-Band Demonstration System shall be capable of providing Virtual Channel Data Unit (VCDU) or Coded VCDU (CVCDU) extraction for CCSDS CADU frames that are formatted in accordance with CCSDS 701.0-B-2. CADU frames are constructed by adding a synchronization marker to a VCDU or a CVCDU.

4.2.3.3.9.1.4 Header Appending

The S-Band Demonstration System shall be capable of appending the following types of headers to the processed telemetry frame:

a. IPDU header, in accordance with 430-14-01-001-0 (Landsat 7 – LGN ICD).

b. Small Explorer (SMEX) header, in accordance with http://itos.gsfc.nasa.gov/ITOS/tcif/wrap_smex.html.

4.2.3.3.9.1.5 CCSDS Channel Access Data Unit (CADU)

The S-Band Demonstration System shall be capable of receiving and processing the CCSDS Channel Access Data Unit (CADU) frames that are formatted in accordance with CCSDS 701.0-B-2.

4.2.3.3.9.1.6 Time Tagging

The S-Band Demonstration System shall be capable of time-tagging customer platform telemetry data with an accuracy ≤ 100 µsec.

4.2.3.3.9.2 Internet Protocols

This section specifies the TCP/IP and FTP Internet protocols.

These protocols are used to transfer customer telemetry data from the S-Band Demonstration System to terrestrial facilities (such as MOCs).

4.2.3.3.9.2.1 TCP/IP

The S-Band Demonstration System shall be capable of sending real-time customer telemetry data, including transfer frames from selected VCs, to the NISN interface via TCP/IP.

4.2.3.3.9.2.2 FTP

After a pass has completed, the S-Band Demonstration System shall be capable of automatically sending customer telemetry data files to the NISN interface via FTP, including VC files.

4.2.3.3.10 Decoding

The S-Band Demonstration System shall be capable of decoding telemetry data for all of the following configurations and formats:

a. The Customer Configurations specified Section 4.2.3.1.1.2.4 above.

b. The Customer Coding Configurations specified in Section 4.2.3.1.1.2.6 above.

c. The Customer Data Formats with Coding specified in Section 4.2.3.1.1.2.3 above.

4.2.3.3.11 Reacquisition Time

The requirements on the S-Band Demonstration System for reacquiring the customer platform signal shall be identical to those specified for initial acquisition in Section 4.2.3.3.1 above.

4.2.3.3.12 Ambiguity Resolution

This section specifies requirements on the S-Band Demonstration System for resolving data polarity ambiguity (“1” vs. “0”) and I-Q channel ambiguity.

4.2.3.3.12.1 Data Polarity Ambiguity

Data polarity ambiguity is the uncertainty whether the logical sense of the data is either true or complemented (that is, a “1” or a “0”).

The S-Band Demonstration System shall be capable of resolving the data polarity ambiguity for all customer configurations, except for the following:

a. NRZ-L data that is not frame synchronized.

b. Uncoded biphase-L data that is not frame synchronized.

4.2.3.3.12.2 I-Q Channel Ambiguity

I-Q channel ambiguity is the uncertainty whether the I-channel data will appear on the Q-channel output interface port, or vice-versa.

The S-Band Demonstration System shall be capable of resolving the I-Q channel ambiguity for all customer configurations, except for dual-channel QPSK.

4.2.3.3.13 Symbol and Decoder Synchronization Time

This section specifies the symbol and decoder synchronization requirements for the S-Band Demonstration System.

4.2.3.3.13.1 Uncoded Data

Under all of the Conditions defined in Section 4.2.3.3.13.3 below, the S-Band Demonstration System shall be capable of achieving uncoded symbol synchronization with a probability ≥ 0.9 within the time interval specified below:

a. NRZ symbols: $\leq$ 3000 / (data rate in bps) seconds.

b. Biphase symbols: $\leq$ 300 / (data rate in bps) seconds.

Definition of Symbol Synchronization Time for <u>Uncoded</u> Data

“Symbol synchronization time” is defined as the interval between the following start and stop times:

Start Time: When signal acquisition is achieved.
(“Signal acquisition” is defined as the “Stop Time” in Section 4.2.3.3.1 above).

Stop Time: When the BER $\leq 10^{-5}$ for the next 1000 bits.

4.2.3.3.13.2 Convolutionally Coded Data

Under all of the Conditions defined in Section 4.2.3.3.13.3 below, the S-Band Demonstration System shall be capable of achieving both symbol and decoder synchronization with a probability ≥ 0.9 within the time interval specified below:

a. NRZ symbols: $\leq$ 6500 / (data rate in bps) seconds.

b. Biphase symbols: $\leq$ 1100 / (data rate in bps) seconds.

Definition of Symbol and Decoder Synchronization Time for <u>Convolutionally Coded</u> Data

"Symbol and decoder synchronization time" is defined as the interval between the following start and stop times:

Start Time: When signal acquisition is achieved.

("Signal acquisition" is defined as the "Stop Time" in Section 4.2.3.3.1 above.)

Stop Time: When the BER $\leq 10^{-3}$ for the next 1000 decoded bits.

4.2.3.3.13.3 Conditions

This section defines the conditions for which the Symbol and Decoder Synchronization requirements specified in Sections 4.2.3.3.13.1 and 4.2.3.3.13.2 above must be met.

This section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's signal. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

a. Symbol Transition Density

The Symbol Transition Density values defined in Section 4.2.3.1.1.2.9 above.

b. P_{rec}

The minimum P_{rec} required for a BER of 10^{-5} or the minimum P_{rec} required for autotrack acquisition, whichever is greater, as defined in Table 4-7 above (see note 6 below the table- for program tracking).

4.2.3.3.13.4 One of Two Channels

If only one of two channels meets both of the Conditions defined in Sections 4.2.3.3.13.3.a and b above, the S-Band Demonstration System shall be capable of meeting the Symbol and Decoder Synchronization Time requirement for that channel.

4.2.3.3.14 Data Recording

This section specifies the telemetry data recording requirements for the S-Band Demonstration System.

4.2.3.3.14.1 Telemetry Data Recording

This section specifies the requirements for recording customer platform digital telemetry data.

The S-Band Demonstration System shall be capable of the following:

a. Automatically determining whether sufficient recording space exists ≥ 1 minute before a pass begins, based on the customer schedule.
b. If sufficient recording space does not exist, automatically deleting the oldest files until adequate recording space becomes available.
c. Recording all VCs to the same file.
d. Recording each VC to a separate file.
e. Recording only selected VC frames.
f. Automatically inhibiting recording when no data is present.
g. Managing disk space to prevent overwriting of critical data or system files.
h. Transferring data files to a non-volatile, high-capacity recording medium such as tape (“archiving”).

4.2.3.3.14.2 I and Q Dual-Channel Data Recording

When recording dual-channel telemetry data, the S-Band Demonstration System shall be capable of recording the data from the I and Q channels separately.

4.2.3.3.14.3 Data Rates

The S-Band Demonstration System shall be capable of recording at all of the data rates specified in Table 4-4 above.

4.2.3.3.14.4 Storage Capacity

The S-Band Demonstration System shall be capable of recording ≥ 20 GB of telemetry data.

4.2.3.3.14.5 Playback

The S-Band Demonstration System shall be capable of playing back the recorded data.

4.2.3.4 IF Output

This section specifies the telemetry IF output requirements for the S-Band Demonstration System.

4.2.3.4.1 IF Output Port

a. The S-Band Demonstration System shall include an IF output port that provides access to the customer platform IF signal as follows:
    1. After the customer platform IF signal has been diversity combined.
    2. Prior to demodulation.
b. The S-Band Demonstration System shall provide at least one IF output port.

4.2.3.4.2 Doppler Correction

The S-Band Demonstration System shall be capable of providing an IF output signal that is Doppler-corrected.

4.2.3.4.3 Signal Parameters

This section specifies requirements on the IF output signal parameters of the S-Band Demonstration System.

4.2.3.4.3.1 Requirements

Under all of the Conditions defined in Section 4.2.3.4.3.2 below, the S-Band Demonstration System shall be capable of providing an IF output signal with the parameters specified in Table 4-9 below.

Table 4-9: S-Band Telemetry IF Output Signal Parameters

Parameter	Requirement
1. Center frequency (without Doppler)	20 MHz ± 3 Hz
2. 3-dB bandwidth	≥ 12 MHz
3. Output signal level	-10 dBm ±3 dB
4. Output VSWR	≤ 1.3:1 into 50Ω load, ±7 MHz from center frequency
5. Spurious signals[1]	
a. Individual spurious	≥ 40 dB below desired signal
b. Total spurious within 3-dB bandwidth	≥ 30 dB below desired signal
6. Phase noise[1]	
a. 1 Hz to 10 Hz	≤ 1.0° rms
b. 10 Hz to 100 Hz	≤ 1.0° rms
c. 100 Hz to 1 kHz	≤ 0.77° rms
d. 1 kHz to 6 MHz	≤ 2.41° rms

Note:

1. Spurious signals and phase noise requirements include contributions from the entire ground station.

4.2.3.4.3.2 Conditions

This section defines the conditions under which the Requirements specified in Section 4.2.3.4.3.1 above must be met.

The section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines the customer platform signal and dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

4.2.3.4.3.2.1 Customer Signal Distortions

The following Customer Signal Distortions are defined in Section 4.2.3.1.1.2.4 above:

a. Customer platform axial ratio.

b. Phase nonlinearity.

c. Gain flatness.

d. AM/PM.

e. Spurious PM.

f. Spurious outputs.

g. Frequency stability.

h. Phase noise.

4.2.3.4.3.2.2 Customer Platform Dynamics

The following customer platform dynamics:

a. Range Dynamics

The customer platform Range Dynamics defined in Section 4.2.3.1.1.2.7 above.

b. Antenna Tracking

The ground Antenna Tracking constraints defined in Section 4.2.1.13.1.b above.

4.2.3.4.3.2.3 P_{rec} for Autotrack Acquisition

If the customer platform is being autotracked: The minimum P_{rec} required for autotrack acquisition, equal to the greater of rows 1 and 2 in Table 4-7 above (see note 2 below the table).

4.2.3.4.4 Interference from Other Customer Platforms

The S-Band Demonstration System shall be capable of meeting all of the IF Output requirements specified in Sections 4.2.3.4.1 through 4.2.3.4.3 above, inclusive, if the ratio of the power received from the customer platform to the composite interference power contained within the channel bandwidth from other customer platforms is ≥ 30 dB.

4.2.4 S-Band Tracking

This section specifies the S-band tracking requirements for the S-Band Demonstration System.

4.2.4.1 Time Sampling

This section specifies the low-rate and high-rate sampling requirements for measuring tracking in the S-Band Demonstration System.

4.2.4.1.1 Low-Rate Sampling

4.2.4.1.1.1 Sampling Interval

For the duration of the scheduled pass, the S-Band Demonstration System shall be capable of providing tracking measurements every 10 seconds.

NOTE

In Section 4.2.4.1.2 below, this requirement is expanded to specify "every 1 or 0.1 seconds" in order to facilitate FDF troubleshooting.

4.2.4.1.1.2 Timing Accuracy

The S-Band Demonstration System shall be capable of providing tracking measurements as follows:

a. Doppler samples within ±1 μsec of the 10-PPS time reference in the ground station.

b. Analog samples within ±20 ms of the 10-PPS time reference in the ground station.

4.2.4.1.2 High-Rate Sampling

For the duration of the scheduled pass, the S-Band Demonstration System shall be capable of providing tracking measurements at the following intervals:

a. Every second.

b. Every 0.1 seconds (that is, 10 tracking measurements per second).

NOTE

High-rate sampling is intended to support MMFD troubleshooting.

4.2.4.2 Doppler Tracking

This section specifies the customer Doppler tracking data requirements for the S-Band Demonstration System.

4.2.4.2.1 One-Way Doppler Tracking

The S-Band Demonstration System shall be capable of generating one-way Doppler tracking data based on the difference between the following two frequencies:

a. The received frequency of the customer platform S-band telemetry carrier.

b. The assigned frequency of the customer platform S-band telemetry carrier.

4.2.4.2.2 Two-Way Doppler Tracking

When the S-band telemetry and command signal frequencies are coherent, the S-Band Demonstration System shall be capable of generating two-way Doppler tracking data based on the difference between the following two frequencies:

a. The frequency of the received customer platform S-band telemetry carrier.

b. The frequency of the transmitted S-band command carrier multiplied by the S-band transponder turnaround ratio (240/221).

4.2.4.2.3 Measurement Accuracy

Under all of the Conditions defined in Section 4.2.4.2.4 below, the S-Band Demonstration System shall be capable of providing one-second-average Doppler frequency measurements with an error ≤ 0.033 Hz rms for an SNR ≥ 8 dB.

NOTE

1. Customer platform-generated phase noise is excluded from this requirement.
2. Measurement timing errors are excluded from this requirement. They are specified in the "Timing Accuracy" requirement in Section 4.2.4.1.1.2 above.

4.2.4.2.4 Conditions

This section defines the conditions under which the Doppler Measurement Accuracy requirement specified in Section 4.2.4.2.3 above must be met.

The section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's signal and dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

4.2.4.2.4.1 Customer Platform Dynamics

A customer platform with the following dynamics:

a. **Range Dynamics**

   The customer platform Range Dynamics defined in Section 4.2.3.1.1.2.7 above.

b. **Antenna Tracking**

   The ground Antenna Tracking constraints defined in Section 4.2.1.13.1.b above.

c. **Doppler Frequency**

   The S-band telemetry carrier Doppler frequency of ±230 kHz.

d. **Doppler Rate**

   The S-band telemetry carrier Doppler rate of 1.5 kHz/sec.

4.2.4.2.4.2 Telemetry Signal Parameters

A customer platform telemetry signal with the Customer Signal Parameters defined in Section 4.2.3.1.1.2.2.b above.

4.2.4.2.4.3 Telemetry Signal Distortions

A customer platform telemetry signal with the Customer Signal Distortions defined in Section 4.2.3.1.1.2.4 above.

4.2.4.2.4.4 Telemetry Configurations

The telemetry Customer Configurations defined in Section 4.2.3.1.1.2.5 above.

4.2.4.3 Angle Tracking

This section specifies the ground antenna angle tracking data requirements for the S-Band Demonstration System.

4.2.4.3.1 Data Generation

The S-Band Demonstration System shall be capable of generating angle tracking data that is derived from the ground antenna pointing angles.

4.2.4.3.2 Resolution

The S-Band Demonstration System shall be capable of providing ground antenna angle tracking data with a resolution ≤ 0.001° per axis.

4.2.4.3.3 Accuracy

Under all of the Conditions defined in Section 4.2.4.3.4 below, the S-Band Demonstration System shall be capable of providing ground antenna angle tracking data with an accuracy ≤ 0.1° per axis.

"Accuracy" is defined as the difference between the actual and the reported pointing angle.

4.2.4.3.4 Conditions

This section defines the conditions under which the ground antenna angle Accuracy requirement specified in Section 4.2.4.3.3 above must be met.

This section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's dynamics and telemetry signal. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

4.2.4.3.4.1 Customer Platform Dynamics

A customer platform with the following dynamics:

a. **Range Dynamics**

   The customer platform Range Dynamics defined in Section 4.2.3.1.1.2.7 above.

b. **Antenna Tracking**

   The ground Antenna Tracking constraints defined in Section 4.2.1.13.1.b above.

4.2.4.3.4.2 P_{rec}

A customer platform telemetry signal that meets the minimum P_{rec} required for S-band autotrack acquisition, equal to the greater of rows 1 and 2 in Table 4-7 above (see note 2 below the table).

4.2.4.4 UTDF Frames

This section specifies the UTDF generation requirements for the S-Band Demonstration System.

4.2.4.4.1 UTDF Format

The S-Band Demonstration System shall be capable of generating tracking data frames in the UTDF format as specified in Appendix A, except for "Data Rate," which is specified below.

4.2.4.4.2 Data Rate

This section specifies the requirements for inserting the tracking data rate into each tracking data frame.

4.2.4.4.2.1 Low-Rate Sampling

For the sampling rate of 0.1 frames per second, the S-Band Demonstration System shall be capable of inserting the tracking data rate into each tracking data frame as specified in Appendix A.

4.2.4.4.2.2 High-Rate Sampling

For sampling rates ≥ 1 frame per second, the S-Band Demonstration System shall be capable of inserting the tracking data rate into each tracking data frame as the 2's complement of the number of frames per second.

4.2.4.5 Tracking Data Files

This section specifies the requirements for generating tracking data files for the S-Band Demonstration System.

4.2.4.5.1 File Generation

The S-Band Demonstration System shall be capable of combining all of the UTDF frames from a tracking pass into a single tracking data binary file by concatenating the frames.

4.2.4.5.2 Filename

This section specifies how the S-Band Demonstration System names the tracking data files.

4.2.4.5.2.1 Low-Rate Sampling

For files containing tracking data that was sampled < 1 per second, the S-Band Demonstration System shall be capable of naming tracking data files according to the following case-sensitive convention:

LSUTDF_SSSSVV_PPP_YYYY_DDD_HHMM.trk .

The following definitions apply:

a. LSUTDF

"LSUTDF" is in all upper-case characters.

b. SSSS

SSSS = Customer's SIC.

c. VV

VV = Customer's VIC (usually "01").

d. PPP

PPP = Antenna PADID.

(PADID is a decimal number assigned by MMFD.)

e. YYYY

YYYY = UTC year when end-of-track (EOT) occurred.

f. DDD

DDD = UTC day of the year when EOT occurred.

g. HH

HH = UTC hour of the day when EOT occurred.

h. MM

MM = UTC minutes of the hour when EOT occurred.

i. trk

"trk" is in all lower-case characters.

4.2.4.5.2.2 High-Rate Sampling

For files containing tracking data that was sampled ≥ 1 per second, the S-Band Demonstration System shall be capable of naming tracking data files according to the following case-sensitive convention:

HSUTDF_SSSSVV_PPP_YYYY_DDD_HHMM.trk .

The following definitions apply:

a. HSUTDF

"HSUTDF" is in all upper-case characters.

b. Other Definitions

The definitions in Sections 4.2.4.5.2.1.b through i above apply.

4.2.4.5.3 File Transfer Delay

The S-Band Demonstration System shall be capable of sending the tracking data file to the NISN interface ≤ 10 minutes after the end of the scheduled tracking pass.

4.2.4.6 FTP Protocol

The S-Band Demonstration System shall be capable of sending customer tracking data files to the NISN interface via FTP.

4.2.4.7 Interference

The S-Band Demonstration System shall be capable of meeting all of the S-band tracking requirements specified in Sections 4.2.a, b, and d, 4.2.1, 4.2.4, 4.2.5, and 4.2.6 when the constraints defined in Sections 4.2.3.1.2.a and b above ("Sun Intrusion" and "Interference from Other Customer Platforms," respectively) are both met.

4.2.5 Control and Monitor

This section specifies the requirements for controlling and monitoring the S-Band Demonstration System.

4.2.5.1 Control

This section specifies the requirements for controlling the S-Band Demonstration System.

4.2.5.1.1 Automatic Antenna Configuration

a. The S-Band Demonstration System shall be capable of automatically configuring the antenna for tracking in response to customer platform ephemeris information.

b. The S-Band Demonstration System shall be capable of ingesting and processing ephemeris received in any of the following formats:

   1. **IIRV Messages**

      Improved Interrange Vector (IIRV) messages are defined in 450-TAH-STDN.

   2. **NORAD TLE Messages**

      North American Air Defense Command (NORAD) Two-Line Element (TLE) messages are defined in 450-TAH-STDN.

c. The S-Band Demonstration System shall be capable of ingesting and processing ephemeris received in accordance with the format used by the Wallops Orbital Tracking Information System (WOTIS) in the GN.

4.2.5.1.2 Automatic Test Configuration

The S-Band Demonstration System shall be capable of configuring equipment for the following tests:

a. System G/T measurements.

b. Antenna servo tests.

c. Autotrack error gradient tests.

4.2.5.1.3 Front Panel Control

The S-Band Demonstration System shall be capable of manual control from the front panels of the equipment.

4.2.5.2 Monitor

This section specifies the equipment performance monitoring requirements for the S-Band Demonstration System.

NOTE

There is no requirement to monitor equipment performance remotely; front panel displays are sufficient.

4.2.5.2.1 Spectrum Monitoring

The S-Band Demonstration System shall be capable of monitoring RF and IF signal spectra.

4.2.5.2.2 Equipment Health and Performance Monitoring

This section specifies the equipment health and performance parameters that are monitored by the S-Band Demonstration System.

4.2.5.2.2.1 General

The S-Band Demonstration System shall be capable of monitoring the On/Off status of all equipment.

4.2.5.2.2.2 Antenna Equipment

The S-Band Demonstration System shall be capable of monitoring the following health and performance parameters of the antenna equipment:

a. Pointing angles to a resolution of 0.01° (both axes).
b. Polarization: LHC or RHC.
c. Pointing mode: Autotrack, program track, scan, etc.
d. Autotrack lock status.
e. Autotrack error signals (both axes).
f. Autotrack SNR.

4.2.5.2.2.3 Telemetry Equipment

The S-Band Demonstration System shall be capable of monitoring the following health and performance parameters of the telemetry equipment:

a. Input S-band downlink frequency.
b. Input S-band downlink power.
c. IF output frequency.
d. IF output power.
e. Carrier lock.
f. Subcarrier lock.
g. Acquisition time (carrier, subcarrier, I channel, and Q channel).
h. Modulation mode: Subcarrier, BPSK/PM, BPSK, QPSK, or SQPSK.
i. AGC level (carrier).
j. Data channels: Single or dual.
k. Symbol lock (carrier, subcarrier, I channel, and Q channel).
l. Viterbi decoder lock (carrier, subcarrier, I channel, and Q channel).
m. Frame synchronizer mode: Locked, not locked, flywheel, or checkframes.
n. R-S decoder lock (carrier, subcarrier, I channel, and Q channel).
o. Data presence (carrier, subcarrier, I channel, and Q channel).
p. Clock presence (carrier, subcarrier, I channel, and Q channel.
q. Data rate (carrier, subcarrier, I channel, and Q channel).
r. Virtual channels status (frame counts, cyclic redundancy check [CRC] errors, and R-S errors).
s. Virtual channel data quality statistics.

4.2.5.2.2.4 Command Equipment

The S-Band Demonstration System shall be capable of monitoring the following health and performance parameters of the command equipment:

a. Clock presence.

b. Data presence.

c. Input data rate.

d. Input data format: NRZ-L, M, or S.

e. Idle sequence generator (for example, “active” or “inactive”).

f. Output data format: NRZ-L, M, or S.

g. Modulation mode: subcarrier, BPSK, QPSK, or linear PM.

h. Modulation index (subcarrier onto carrier, and carrier).

i. Command sweep width (or “inactive”).

j. Command sweep rate (or “inactive”).

k. Subcarrier frequency.

l. S-band output frequency.

m. HPA S-band output power.

4.2.5.2.2.5 Tracking Equipment

The S-Band Demonstration System shall be capable of monitoring the Doppler frequency (one-way and two-way) in the tracking equipment.

4.2.6 Testing and Fault Isolation

This section specifies the testing and fault isolation requirements for the S-Band Demonstration System.

4.2.6.1 Command Uplink

The S-Band Demonstration System shall be capable of testing the entire command uplink chain, including:

a. Generating simulated baseband command data.

b. Routing the simulated command data to the command uplink equipment.

c. Sampling the S-band command signal at the output of the HPA.

d. Routing the sampled command signal to the command test equipment.

e. Demodulating the command carrier (BPSK or PM).

f. BPSK demodulating the command subcarrier.

g. Measuring the BER of the command data.

4.2.6.2 Telemetry Downlink

The S-Band Demonstration System shall be capable of testing the entire telemetry downlink chain, including:

a. Generating at least one stream of simulated baseband telemetry data.

b. Recording the simulated baseband data.

c. Playing back the following kinds of baseband telemetry data:

   1. Simulated data.

   2. Actual customer data, including data files.

d. Routing the playback data to the input of the baseband telemetry test equipment.

e. Modulating the test data onto the following (not required simultaneously):

   1. Subcarrier or main carrier.

   2. I channel or Q channel.

f. Simulating customer platform dynamics (Doppler shift and amplitude variations) by automatically changing the frequency and amplitude of the test signals.

g. Upconverting the modulated test telemetry signal to S-band.

h. Injecting the S-band test telemetry signal into the S-band antenna feed before the LNA.

i. Measuring the BER of the telemetry data on the carrier and subcarrier (not required simultaneously).

j. Measuring the BER of the telemetry data on the I channel and Q channel (not required simultaneously).

4.2.6.3 Tracking Equipment

The S-Band Demonstration System shall be capable of testing the tracking equipment, including:

a. Generating 1-way Doppler tracking data derived from the simulated S-band downlink signal.

b. Generating 2-way Doppler tracking data derived from the simulated S-band downlink signal when the simulated downlink frequency is coherent with the simulated uplink signal, with a turn-around ratio of 240/221.

c. Generating simulated tracking data files containing UTDF frames, in accordance with 450-TAH-STDN.

4.2.6.4 Test and Monitoring Points

This section specifies the requirements for providing access to test and monitoring points in the S-Band Demonstration System.

4.2.6.4.1 RF Signals

The S-Band Demonstration System shall be capable of providing access to RF signals for test and monitoring, including access to the following signals:

a. S-band command signals, including access:
   1. Before the HPA.
   2. After the HPA.
b. S-band telemetry signals, including access:
   1. Before the LNA.
   2. After the LNA.

4.2.6.4.2 IF Signals

The S-Band Demonstration System shall be capable of providing access to IF telemetry signals for test and monitoring.

4.3 Ka-Band Demonstration System

This section specifies requirements on the Ka-Band Demonstration System. A reference architecture is shown in Figure 4-3 below.

Organization

General Requirements that apply to the entire Ka-Band Demonstration System are specified in the following sections:

Section 4.3.a	Simultaneous Support.
Section 4.3.b	G/T.
Section 4.3.c	Availability.

The remaining requirements are divided into the following sections:

Section 4.3.1	Ka-Band Antenna.
Section 4.3.2	Ka-Band Telemetry.
Section 4.3.3	Ka-Band Tracking.
Section 4.3.4	Control and Monitor.
Section 4.3.5	Testing and Fault Isolation.

General Requirements

The General Requirements specified below apply to the entire Ka-Band Demonstration System.

a. Simultaneous Support

The Ka-Band Demonstration System shall be capable of the following:

1. Simultaneously providing the following Ka-band support:
   (a) One Ka-band telemetry downlink with IF output.
   (b) One Ka-band tracking capability.

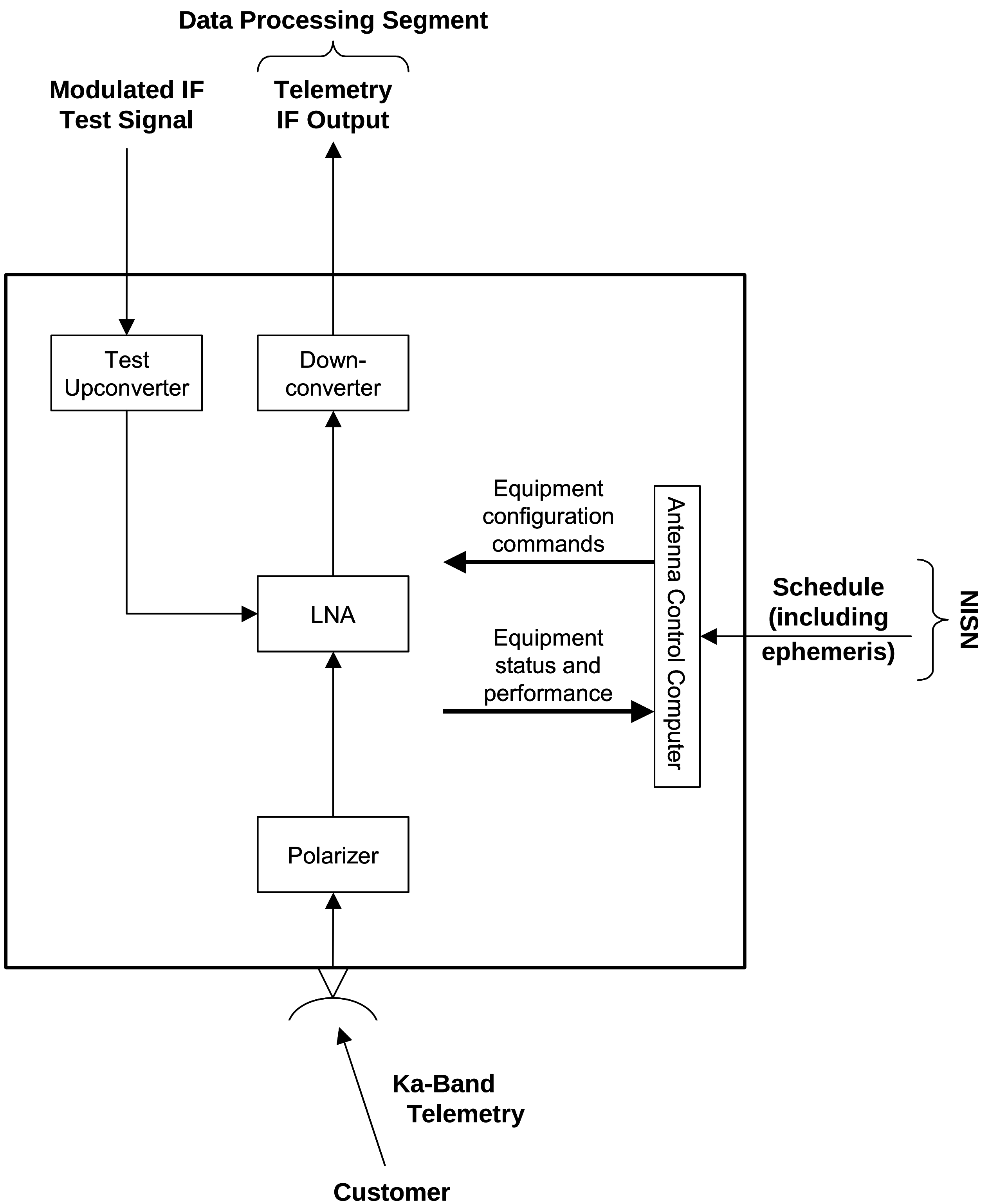

Figure 4-3: Ka-Band Demonstration System Reference Architecture

2. Meeting all of the Ka-Band Telemetry requirements specified in Section 4.3.2 below while simultaneously transmitting and receiving the following signals:
   (a) Transmitting an S-band uplink signal with the power specified in Section 4.2.2.2.b above, and
   (b) Receiving an S-band downlink signal as specified in Section 4.2 above.

b. G/T

The Ka-Band Demonstration System shall be capable of providing a system G/T ≥ 32.5 dB/K at elevation angles between 10° and 90° during clear-sky conditions.

c. Availability

This section specifies the availability requirements for the Ka-Band Demonstration System.

Operational availability, A_o, should be calculated using the formula defined in Section 3.1.2.3 above. Redundancy may be used to meet these requirements.

1. Ka-Band Telemetry IF

The A_o of the Ka-band telemetry IF service (including, but not limited to, the RF, IF, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.99.

2. Ka-Band Tracking

The A_o of the Ka-band tracking service (including, but not limited to, the RF, IF, and control and monitor services), measured over a 10,000-hour interval, shall be ≥ 0.99.

4.3.1 Ka-Band Antenna (Receive Only)

This section specifies requirements on the Ka-band portion of the dual-band antenna in the Ka-Band Demonstration System.

4.3.1.1 Receive Signal Characteristics

The dual-band antenna shall be capable of receiving Ka-band signals with the following characteristics:

a. Frequency Band

1. Minimum: 25.5 GHz.
2. Maximum: 27 GHz.
3. Tuning step size: ≤ 125 kHz.

b. Polarization (Selectable)

1. LHC.
2. RHC.

4.3.1.2 Axial Ratio

The dual-band antenna shall be capable of providing a receive axial ratio ≤ 2.0 dB over a 3-dB beamwidth at Ka-band.

4.3.1.3 Bandwidth

The dual-band antenna shall be capable of providing an RF channel 3-dB receive bandwidth ≥ 1.5 GHz at Ka-band.

4.3.1.4 Sidelobes

The dual-band antenna shall be capable of providing Ka-band receive sidelobe levels ≥ 15 dB below the peak level of the main lobe.

4.3.1.5 FOV

The dual-band antenna shall be capable of providing the FOV specified in Section 4.2.1.14 above.

4.3.1.6 Gain Flatness

The dual-band antenna shall be capable of providing the following gain flatness at the output of the Ka-band LNA:

a. ≤ 1.0 dB across all 800-MHz segments of the receive band specified in Section 4.3.1.1.a above.

b. ≤ ±1.5 dB across the entire receive band specified in Section 4.3.1.1.a above.

4.3.1.7 Radial Tracking Error

The dual-band antenna shall be capable of providing a 1σ system radial tracking error ≤ 0.05° rms at Ka-band.

4.3.1.8 Slewing

The dual-band antenna shall be capable of providing the same slewing performance at Ka-band as specified in Section 4.2.1.11 above for S-band.

4.3.1.9 Autotracking

This section specifies the Ka-band autotracking performance of the dual-band antenna.

4.3.1.9.1 Customer Dynamics Constraints

The dual-band antenna shall be capable of autotracking a Ka-band customer platform that meets all of the following constraints:

The following section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

a. Range Dynamics

The range dynamics for a Ka-band customer platform are identical to those defined for an S-band customer platform in Section 4.2.3.1.1.2.7 above.

b. Antenna Tracking

Both of the following constraints:

1. Angular velocity: ≤ 3°/sec.

   "Angular velocity" is defined as the time rate-of-change of the angle of the ground station antenna.

2. Ephemeris uncertainty: ≤ ±2.0 sec.

   (This assumes that the ephemeris uncertainty is uniformly distributed along the customer platform orbital track.)

4.3.1.9.2 Autotrack Acquisition Time

The dual-band antenna shall be capable of acquiring Ka-band autotrack in ≤ 2 seconds with a probability > 0.99 for a P_{rec} value of ≥ -180.3 dBWi.

"P_{rec}" is defined in Section 4.2.3.1.1.2.8.1.

Definition of Autotrack Acquisition Time

Autotrack acquisition time is defined as the interval between the following start and stop times:

Start time: When a customer signal is received at the aperture of the ground antenna.

Stop time: When the autotrack error signals align the ground antenna boresight axis with the customer platform with sufficient accuracy to provide a system G/T ≥ 32.3 dB/K at Ka-band.

(32.3 dB/K is 0.2 db less than the system G/T specified in Section 4.3.b above: 32.5 dB/K.)

4.3.1.9.3 Failure to Acquire

If Ka-band autotrack acquisition does not occur within the specified time, the dual-band antenna shall be capable of continuing the acquisition process until one of the following events occurs:

a. Autotrack is acquired. ("Autotrack acquisition" is defined in Section 4.3.1.9.2 above as the "Stop time.")

b. The scheduled Ka-band telemetry pass ends.

4.3.1.10 Environment

The Ka-band portion of the dual-band antenna shall be capable of providing the same environmental performance as specified for the S-band portion in Section 4.2.1.15 above.

4.3.2 Ka-Band Telemetry

This section specifies the Ka-band telemetry requirements for the Ka-Band Demonstration System.

NOTE

The Ka-Band Demonstration System supports a Ka-band telemetry downlink with only an IF output. Demodulation and baseband processing is *not* provided.

4.3.2.1 RF-to-IF Processing

4.3.2.1.1 P_{rec}

The Ka-Band Demonstration System shall be capable of receiving customer platform signals with the following power levels (P_{rec}):

a. Minimum: –180.3 dBWi.

b. Maximum: –138 dBWi.

4.3.2.1.2 Downconversion

The Ka-Band Demonstration System shall be capable of downconverting the signal from Ka-band to IF as specified in Table 4-10 below.

Table 4-10: GN Ka-Band Downconverter Performance

Parameter	Requirement[1]
1. IF center frequency	1.2 GHz ±60 Hz (without Doppler)
2. Noise figure	≤ 16 dB
3. Spurious outputs	
a. Signal-related	≤ -45 dBc in-band
b. Not signal-related	≤ -60 dBm
4. Image rejection	≥ 60 dB

Note:

1. Parameters are measured at the output of the downconverter. Contributions from only the downconverter are included.

4.3.2.2 IF Output

This section specifies the telemetry IF output requirements for the Ka-Band Demonstration System.

4.3.2.2.1 IF Output Port

The Ka-Band Demonstration System shall include at least one IF output port that provides access to the customer platform IF signal prior to demodulation.

4.3.2.2.2 Doppler Correction

The Ka-Band Demonstration System is not required to provide a Doppler-corrected IF output signal.

4.3.2.2.3 Signal Parameters

This section specifies requirements on the IF output signal parameters of the Ka-Band Demonstration System.

4.3.2.2.3.1 Requirements

Under all of the conditions defined in Section 4.3.2.2.3.2 below, the Ka-Band Demonstration System shall be capable of providing an IF output signal with the parameters specified in Table 4-11 below.

4.3.2.2.3.2 Conditions

This section defines the conditions under which the Requirements specified in Section 4.3.2.2.3.1 above must be met.

The section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines the customer platform signal and dynamics. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

4.3.2.2.3.2.1 Customer Platform Dynamics

The following customer platform dynamics:

a. **Range Dynamics**

   The customer platform Range Dynamics defined in Section 4.3.1.9.1.a above.

b. **Antenna Tracking**

   The ground Antenna Tracking constraints defined in Section 4.3.1.9.1.b above.

4.3.2.2.3.2.2 P_{rec} for Autotrack Acquisition

If the customer platform is being autotracked: The minimum P_{rec} required for autotrack acquisition as defined in Section 4.3.1.9.2.

Table 4-11: GN Ka-Band Telemetry IF Output Signal Parameters

Parameter	Requirement
1. IF center frequency	As specified in Table 4-11 above
2. 3-dB bandwidth	≥ 1.2 GHz
3. Maximum output signal level	– 6 dBm
4. Output VSWR	≤ 1.3:1 into 50Ω load, ±420 MHz from center frequency
5. Gain flatness[1]	≤ 2.0 dB peak-to-peak over ±420 MHz about the IF frequency
6. Spurious signals	
a. Individual spurious	≥ 40 dB below desired signal
b. Total spurious within 3-dB bandwidth	≥ 30 dB below desired signal
7. Phase nonlinearity[1]	≤ 10° peak-to-peak over ±420 MHz about the IF frequency
8. Phase noise[1,2]	
a. 1 Hz to 10 Hz	≤ 2.5° rms
b. 10 Hz to 100 Hz	≤ 2.5° rms
c. 100 Hz to 1 kHz	≤ 4.8° rms
d. 1 kHz to 1 GHz	≤ 1.8° rms

Notes:

1. The gain flatness, phase nonlinearity, and phase noise requirements include contributions from the entire ground station.
2. Includes the phase noise contributed by the frequency reference, but does not include spurious outputs.

4.3.2.3 Interference

The Ka-Band Demonstration System shall be capable of meeting all of the Ka-band telemetry requirements specified in Sections 4.3, 4.3.1, 4.3.2, 4.3.4, and 4.3.5 during both of the following conditions:

a. Sun Intrusion

The center of the sun is ≥ 1° outside the boresight of the dual-band antenna.

b. Interference from Other Customer Platforms

The ratio of the power received from the customer platform to the composite interference power contained within the channel bandwidth from other customer platforms is ≥ 30 dB.

4.3.3 Ka-Band Tracking

This section specifies the Ka-band tracking requirements for the Ka-Band Demonstration System.

NOTE

The Ka-Band Demonstration System supports only ground antenna angle tracking. Doppler tracking is not required.

4.3.3.1 Time Sampling

This section specifies the low-rate and high-rate sampling requirements for measuring tracking in the Ka-Band Demonstration System.

4.3.3.1.1 Low-Rate Sampling

4.3.3.1.1.1 Sampling Interval

For the duration of the scheduled pass, the Ka-Band Demonstration System shall be capable of providing tracking measurements every 10 seconds.

NOTE

In Section 4.3.3.1.2 below, this requirement is expanded to specify "every 1 or 0.1 seconds" in order to facilitate FDF troubleshooting. These higher sampling rates are not provided to the customer, however.

4.3.3.1.1.2 Timing Accuracy

The Ka-Band Demonstration System shall be capable of providing tracking measurements as follows:

a. Doppler samples within ±1 μs of the 10-PPS time reference in the ground station.

b. Analog samples within ±20 ms of the 10-PPS time reference in the ground station.

4.3.3.1.2 High-Rate Sampling

For the duration of the scheduled pass, the Ka-Band Demonstration System shall be capable of providing tracking measurements at the following intervals:

a. Every second.

b. Every 0.1 seconds (that is, 10 tracking measurements per second).

NOTE

High-rate sampling is intended to support MMFD troubleshooting.

4.3.3.2 Angle Tracking

This section specifies the ground antenna angle tracking data requirements for the Ka-Band Demonstration System.

4.3.3.2.1 Data Generation

The Ka-Band Demonstration System shall be capable of generating angle tracking data that is derived from the ground antenna pointing angles.

4.3.3.2.2 Resolution

The Ka-Band Demonstration System shall be capable of providing ground antenna angle tracking data with a resolution ≤ 0.001° per axis.

4.3.3.2.3 Accuracy

Under all of the Conditions defined in Section 4.3.3.2.4 below, the Ka-Band Demonstration System shall be capable of providing ground antenna angle tracking data with an accuracy ≤ 0.1° per axis.

"Accuracy" is defined as the difference between the actual and the reported pointing angle.

4.3.3.2.4 Conditions

This section defines the conditions under which the ground antenna angle Accuracy requirement specified in Section 4.3.3.2.3 above must be met.

The section does not specify requirements and, therefore, does not contain "shall" statements. Rather, it defines constraints on the customer platform's dynamics and telemetry signal. The paragraphs are given unique identifiers solely to facilitate cross-referencing.

4.3.3.2.4.1 Customer Platform Dynamics

A customer platform with the following dynamics:

a. **Range Dynamics**

   The customer platform Range Dynamics defined in Section 4.3.1.9.1.a above.

b. **Antenna Tracking**

   The ground Antenna Tracking constraints defined in Section 4.3.1.9.1.b above.

4.3.3.2.4.2 Customer Platform Transmit Frequency

The Ka-band telemetry frequencies defined in Section 4.3.1.1.a above.

4.3.3.2.4.3 P_{rec}

A customer platform telemetry signal that meets the minimum P_{rec} required for Ka-band autotrack acquisition as defined in Section 4.3.1.9.2.

4.3.3.3 UTDF Frames

This section specifies the requirements for generating tracking data frames in the UTDF format. These requirements are identical for both the Ka-Band and S-Band Demonstration Systems, with one exception: the Ka-Band Demonstration System is not required to support Doppler tracking.

The Ka-Band Demonstration System shall meet the requirements specified in Section 4.2.4.4 above, with the following exceptions (note that Section 4.2.4.4 cites Appendix A):

a. Section A.1.2, “Doppler Frequency Conversion,” does not apply.

b. Section A.4, “AGC,” does not apply.

c. Section A.5, “Transmit Frequency,” does not apply.

4.3.3.4 Tracking Data Files

This section specifies the requirements for generating customer tracking data files. These requirements are identical for both the Ka-Band and S-Band Demonstration Systems.

The Ka-Band Demonstration System shall meet the requirements specified in Section 4.2.4.5 above.

4.3.3.5 FTP Protocol

The Ka-Band Demonstration System shall be capable of sending customer tracking data files to the NISN interface via FTP.

4.3.3.6 Interference

The Ka-Band Demonstration System shall be capable of meeting all of the Ka-band tracking requirements specified in Sections 4.3 through 4.3.5, inclusive, when the constraints defined in Sections 4.3.2.3.a and b above are both met.

4.3.4 Control and Monitor

This section specifies the requirements for controlling and monitoring the Ka-Band Demonstration System.

4.3.4.1 Control

This section specifies the requirements for controlling the Ka-Band Demonstration System.

4.3.4.1.1 Automatic Antenna Configuration

a. The Ka-Band Demonstration System shall be capable of automatically configuring the antenna for tracking in response to customer platform ephemeris information.

b. The Ka-Band Demonstration System shall be capable of ingesting and processing ephemeris as specified in Sections 4.2.5.1.1.b and c above.

4.3.4.1.2 Automatic Test Configuration

The Ka-Band Demonstration System shall be capable of configuring equipment for the following tests:

a. System G/T measurements.

b. Antenna servo tests.

c. Autotrack error gradient tests.

4.3.4.1.3 Front Panel Control

The Ka-Band Demonstration System shall be capable of manual control from the front panels of the equipment.

4.3.4.2 Monitor

This section specifies the equipment performance monitoring requirements for the Ka-Band Demonstration System.

NOTE

> There is no requirement to monitor equipment performance remotely; front panel displays are sufficient.

4.3.4.2.1 Spectrum Monitoring

The Ka-Band Demonstration System shall be capable of monitoring RF and IF signal spectra.

4.3.4.2.2 Equipment Health and Performance Monitoring

This section specifies the equipment health and performance parameters that are monitored by the Ka-Band Demonstration System.

4.3.4.2.2.1 General

The Ka-Band Demonstration System shall be capable of monitoring the On/Off status of all equipment.

4.3.4.2.2.2 Antenna Equipment

The Ka-Band Demonstration System shall be capable of monitoring the following health and performance parameters of the antenna equipment:

a. Pointing angles to a resolution of 0.01° (both axes).

b. Polarization: LHC or RHC.

c. Pointing mode: Autotrack, program track, scan, etc.

d. Autotrack lock status.

e. Autotrack error signals (both axes).

f. Autotrack SNR.

4.3.4.2.2.3 Telemetry Equipment

The Ka-Band Demonstration System shall be capable of monitoring the following health and performance parameters of the telemetry equipment:

a. Input Ka-band downlink frequency.

b. Input Ka-band downlink power.

c. IF output frequency.

d. IF output power.

4.3.5 Testing and Fault Isolation

This section specifies the testing and fault isolation requirements for the Ka-Band Demonstration System.

4.3.5.1 Telemetry Downlink

The Ka-Band Demonstration System shall be capable of testing the telemetry downlink chain, including:

a. Receiving a high-data-rate modulated test telemetry signal at IF from an external source.

b. Upconverting the IF test telemetry signal to Ka-band.

c. Injecting the Ka-band test telemetry signal into the Ka-band antenna feed before the LNA.

4.3.5.2 Tracking Equipment

The Ka-Band Demonstration System shall be capable of testing the tracking equipment, including generating simulated tracking data files containing UTDF frames, in accordance with 450-TAH-STDN.

4.3.5.3 Test and Monitoring Points

This section specifies the requirements for providing access to test and monitoring points in the Ka-Band Demonstration System.

4.3.5.3.1 RF Signals

The Ka-Band Demonstration System shall be capable of providing access to RF signals for test and monitoring, including access to Ka-band telemetry signals after the LNA.

4.3.5.3.2 IF Signals

The Ka-Band Demonstration System shall be capable of providing access to IF signals for test and monitoring, including access to IF telemetry signals.

4.4 Interfaces

This section specifies the interface requirements for the GN Segment.

Requirements are divided into the following sections:

Section 4.4.1 S-Band Demonstration System Interfaces.

Section 4.4.2 Ka-Band Demonstration System Interfaces.

4.4.1 S-Band Demonstration System Interfaces

This section specifies the interface requirements for the S-Band Demonstration System.

4.4.1.1 Customer Platform Interface

This section specifies the requirements for the interface between the customer platform and the S-Band Demonstration System.

4.4.1.1.1 Receiving from Customer Platform

The S-Band Demonstration System shall be capable of receiving S-band telemetry from the customer platform.

4.4.1.1.2 Transmitting to Customer Platform

The S-Band Demonstration System shall be capable of transmitting S-band commands to the customer platform.

4.4.1.2 NISN Interface

This section specifies the requirements for the interface between NISN and the S-Band Demonstration System.

4.4.1.2.1 Receiving from NISN

The S-Band Demonstration System shall be capable of receiving real-time digital customer command data (including test commands) from NISN via the Ethernet interface.

4.4.1.2.2 Transmitting to NISN

The S-Band Demonstration System shall be capable of providing the following customer telemetry data to NISN:

a. Real-time digital customer telemetry data (including test telemetry), via TCP/IP.

b. Recorded digital customer telemetry data files (including test telemetry files), via FTP.

c. Digital customer telemetry data in NRZ-L format.

4.4.2 Ka-Band Demonstration System Interfaces

This section specifies the interface requirements for the Ka-Band Demonstration System.

4.4.2.1 Customer Platform Interface

This section specifies the requirements for the interface between the customer platform and the Ka-Band Demonstration System.

4.4.2.1.1 Receiving from Customer Platform

The Ka-Band Demonstration System shall be capable of receiving Ka-band telemetry from the customer platform.

4.4.2.1.2 Transmitting to Customer Platform

N/A.

4.4.2.2 Data Processing Segment Interface

This section specifies the requirements for the interface between the Data Processing Segment and the Ka-Band Demonstration System.

4.4.2.2.1 Receiving from Data Processing Segment

The Ka-Band Demonstration System shall be capable of receiving high-data-rate modulated test telemetry signals from the Data Processing Segment, in accordance with the following parameters:

a. Center frequency: 1.2 GHz.

b. Bandwidth: $\geq$ 1.2 GHz.

c. Input power: 5 dBm.

d. Input impedance: 50 Ω.

4.4.2.2.2 Providing to Data Processing Segment

The Ka-Band Demonstration System shall be capable of providing IF telemetry signals (including test telemetry signals) to the Data Processing Segment, in accordance with Table 4-11 above.

Appendix A. UTDF Frames

This appendix specifies the requirements for generating UTDF frames.

The following requirements are provided to supplement and clarify the requirements specified in 450-TAH-STDN.

After the General requirement below, the remaining requirements are organized into the following sections:

Section A.1	Measurement Conversions.
Section A.2	Time Tags.
Section A.3	SIC and VIC.
Section A.4	AGC.
Section A.5	Transmit Frequency.
Section A.6	Data Rate.
Section A.7	"Last Frame of Data" Flag.

General

The S-Band Demonstration System shall be capable of generating 75-byte tracking data frames in the UTDF format, in accordance with Section 4.2.2 in 450-TAH-STDN.

NOTE

Nomenclature: A UTDF "frame" is synonymous with a UTDF "record."

This includes, but is not limited to, the following:

A.1 Measurement Conversions

This section specifies the requirements for converting antenna pointing angles and Doppler frequency measurements.

A.1.1 Antenna Pointing Angle Conversion

The S-Band Demonstration System shall be capable of converting the antenna pointing angles from units of degrees into fraction-of-circle (FOC) units, where:

$$\text{Angle (in FOC)} = \text{Angle (in degrees)} \times 2^{32} / 360.$$

The angle in degrees may range from 0° to 359.9999999162°, and the angle in FOC may range from 00000000_{16} to $FFFFFFFF_{16}$.

A.1.2 Doppler Frequency Conversion

A.1.2.1 Converting Hertz to Doppler Counts

The S-Band Demonstration System shall be capable of converting Doppler frequencies from units of Hertz into units of Doppler count, N, where:

$$N(t) = N(t_0) + \text{round}\left[\int_{t_0}^{t} 1000\, f_D(\tau)\, d\tau + 240{,}000{,}000\,(t - t_0)\right], \text{ where:}$$

$N(t)$ is the Doppler count at any time t.

$N(t_0)$ is the Doppler count at time t_0.

$f_D(\tau)$ is the Doppler frequency, in Hertz, as a function of time.

"round" is the round-to-the-nearest-integer function.

(Since the Doppler frequency can range from –230 kHz to +230 kHz [as defined in Section 4.2.4.2.4.1.c above], the Doppler count will increment from 10 million to 470 million, respectively, every second.)

A.1.2.2 Counter Overflow

The S-Band Demonstration System shall be capable of counting the Doppler modulo-248. (That is, when the Doppler count reaches $k + 2^{48}$, the counter resets to "k".)

A.2 Time Tags

The S-Band Demonstration System shall be capable of inserting the time of the tracking measurement into each tracking data frame in the following time format:

a. Year

The current year, UTC.

b. Seconds

Seconds elapsed in the current year, UTC.

c. Microseconds

Microseconds elapsed in the current second.

(This will be zero if measurements are made exactly on the 10-PPS time tick. See Section 4.2.4.1.1.2 above.)

A.3 SIC and VIC

The S-Band Demonstration System shall be capable of inserting the following identification codes into each tracking data frame:

a. SIC.

b. VIC.

A.4 AGC

The S-Band Demonstration System shall be capable of inserting the receiver's AGC signal level as an integer into each tracking data frame, according to the following formula:

$$\text{AGC} = \text{Round}\,[\,-(\text{SS} + 50) \times 8192 / 150\,], \text{ where:}$$

"Round" is the round-to-the-nearest-integer function.

"SS" is the receiver signal strength in dBm.

A.5 Transmit Frequency

The S-Band Demonstration System shall be capable of inserting the S-band command transmit frequency, in units of 10 Hz, into each tracking data frame.

(For example, a frequency of 2,106.40625 MHz would be inserted as 210.640625×10^6.)

A.6 Data Rate

The S-Band Demonstration System shall be capable of inserting the tracking data rate into each tracking data frame, in units of seconds between frames.

A.7 "Last Frame of Data" Flag

The requirement to set the "Last frame of data" flag (bit 4 in byte 53), as specified in 450-TAH-STDN, need not be implemented.

Abbreviations and Acronyms

AGC	automatic gain control
AM	amplitude modulation
A_o	operational availability
ASM	attached sync marker
AWGN	additive white Gaussian noise
BER	bit error rate
biϕ	biphase
bps	bits per second
BPSK	binary PSK
CADU	Channel Access Data Unit
CCB	Configuration Control Board
CCR	Configuration Change Request
CCSDS	Consultative Committee for Space Data Systems
CLCW	Command Link Control Word
CLTU	Command Link Transmission Unit
Comp.	composite
C/N_o	carrier-to-noise power spectral density ratio
CRC	cyclic redundancy check
CTFS	Common Time and Frequency System
CVCDU	Coded VCDU
dB	decibel
dBc	dB referenced to the carrier
dBi	dB isotropic
dBm	dB referenced to one milliwatt
dBW	dB referenced to one watt
dBWi	dBW isotropic
D/C	downconverter
DCN	Document Change Notice
Ded.	dedicated
DIS	Data Interface System
DQM	data quality monitor
DSMC	Data Service Management Center
DSN	Deep Space Network

E_b/N_o	energy per bit-to-noise power spectral density ratio
EDOS	EOS Data and Operations System
EIRP	effective isotropic radiated power
EOS	Earth Observing System
EOT	end-of-track
FEC	forward error-correction
FOC	fraction-of-circle
FOV	field of view
FTP	File Transfer Protocol
GB	gigabyte
GHz	Gigahertz
GN	Ground Network
GSFC	Goddard Space Flight Center
G/T	gain-to-noise temperature ratio
GTDU	Ground Transfer Data Unit
HPA	high-power amplifier
Hz	Hertz
IF	intermediate frequency
IFL	Inter-Facility Link, or Intra-Facility Link
IIRV	improved interrange vector
IP	Internet Protocol
IPDU	Internet Protocol Data Unit
I:Q	I channel to Q channel power ratio
IRAC	Interdepartment Radio Advisory Committee
ITU	International Telecommunications Union
JPL	Jet Propulsion Laboratory
KaSAF	Ka-band SAF
KaSAR	Ka-band SAR
KaTP	Ka-Band Transition Product
kbps	kilobits per second
kHz	kilohertz
km	kilometer
KSAF	Ku-band SAF
KSAR	Ku-band SAR
LEO	low earth orbit

LEO-T	Low-Earth Orbit Terminal
LHC	left-hand circular
LHCP	LHC polarized
LNA	low-noise amplifier
m	meter
MA	multiple access
MAF	MA forward
MAR	MA return
Mbps	Megabits per second
Mchips	megachips
MHz	megahertz
MMFD	Multimission Flight Dynamics
MOC	Mission Operations Center
MSP	Mission Services Program
MTBF	mean time between failures
N/A	not applicable
NASA	National Aeronautics and Space Administration
NCC	Network Control Center
NISN	NASA Integrated Services Network
NORAD	North American Air Defense Command
NRZ	non-return to zero
NRZ-L	NRZ-level
NRZ-M	NRZ-mark
NRZ-S	NRZ-space
ns	nanosecond
NTIA	National Telecommunications and Information Agency
ODM	operations data message
OOB	out-of-band
OPM	operations message
OQPSK	offset QPSK
P_E	probability of error
PFD	power-flux density
PLOP-2	Physical Layer Operations Procedure-2
PM	phase modulation
PN	pseudo-random

Pol.	Polarization
ppm	parts per million
PPS	pulse per second
P_{rec}	received power
PSK	phase shift keying
PTP	Programmable Telemetry Processor
QPSK	quadrature (or quaternary) PSK
R	rate
R_b	bit rate
RF	radio frequency
RFI	RF interference
RHC	right-hand circular
RHCP	RHC polarized
rms	root-mean-square
R-S	Reed-Solomon
RSS	root-sum-square
s	second
SA	single access
SAF	SA forward
SAR	SA return
sec	second
SFCG	Space Frequency Coordination Group
SFDU	Standard Formatted Data Unit
SGL	space-ground link
SGLT	Space-Ground Link Terminal
SHO	scheduling message
SIC	Support Identification Code
SLR	Service-Level Status Report
SMEX	Small Explorer
SN	Space Network
SNIP	Space Network Interoperability Panel
SNR	signal-to-noise ratio
SQPSK	staggered QPSK
SRC	square root raised-cosine
SSAF	S-band SAF

SSAR	S-band SAR
SSC	subsystem controller
STGT	Second TDRSS Ground Terminal
TC	Telecommand
TCP	Transmission Control Protocol
TDRS	Tracking and Data Relay Satellite
TLE	two-line element
Tlm	telemetry
TT&C	tracking, telemetry, and command
UQPSK	unbalanced QPSK
U.S.	United States
UTC	Universal Time Coordinated
UTDF	Universal Tracking Data Format
VC	virtual channel
VCDU	Virtual Channel Data Unit
VIC	Vehicle Identification Code
VSWR	voltage standing wave ratio
WDISC	WSC TCP/IP Data Interface Service Capability
WOTIS	Wallops Orbital Tracking and Information System
WRC	World Radiocommunication Conference
WSC	White Sands Complex
WSGT	White Sands Ground Terminal

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