TDRSS Space Ground Link Terminal Forestalls Obsolescence with Component Replacement and Upgrades

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The National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite (TDRS) System (TDRSS) is a unique, world-class satellite communications system which relays command, telemetry, and science data between on-orbit customer spacecraft and the ground. The purpose of the User Services Subsystem (USS) Component Replacement (USS CR) Project is to replace and upgrade, as necessary, the S-Band and K-Band (Ku & Ka) Single Access (SA) equipment in the Space Ground Link Terminals (SGLT) at the White Sands Complex (WSC). The replacement of the obsolete SN ground segment S-band and K-band equipment with upgraded new equipment requires modifications to the existing architecture for the two SGLTs. This new equipment includes both the narrowband (NB) and wideband (WB) modems that support advanced modulation and coding techniques such as Low Density Parity Check (LDPC) code, Turbo Product Code (TPC) and 8-PSK in addition to the conventional signal structures, as well as the new frequency converter and the associated control and monitor subsystem with TCP/IP and Simple Network Management Protocol (SNMP) interface protocols. This paper describes the upgraded two SGLTs, the new architecture and interfaces and the new system hardware (NB and WB modems, frequency converter and the new control and monitor subsystem, etc) that supports SA services. The enhanced capability of the USS-CR modems is presented.

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I. Introduction

The National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite (TDRS) System (TDRSS) is a unique, world-class satellite communications system which relays command, telemetry, and science data between on-orbit customer spacecraft and the ground. The global TDRS fleet currently consists of four first-generation and the three second-generation satellites supported by three tracking stations, two at White Sands, New Mexico, and a third on the Pacific island of Guam. The first two third-generation satellites will be deployed in 2013. This combination of seven geosynchronous satellites and the three ground stations comprise NASA's Space Network (SN). TDRSS customers currently include low earth orbiting scientific satellites, the International Space Station (ISS), aircraft, scientific balloons, expendable launch vehicles, and remote terrestrial systems.

II Background

The SN Ground Segment originated in the early 1980's with the building of the White Sands Ground Terminal (WSGT). In 1994, White Sands Complex (WSC) was augmented with a Second TDRSS Ground Terminal (STGT), and then in 1996, WSGT was upgraded using STGT technology. The Guam Remote Ground Terminal (GRGT) closed the Zone of Exclusion over the Indian Ocean for TDRSS customers when it became operational in July 1998. Currently, the WSC ground segment is being modified and upgraded to support the two third-generation satellite TDRS K & L which will be launched in 2013.

Each active TDRS satellite is associated with a Space Ground Link Terminal (SGLT) within one of the three ground terminals in the WSC, with the SGLT at Guam controlled from the WSGT at White Sands as shown in Figure 1.

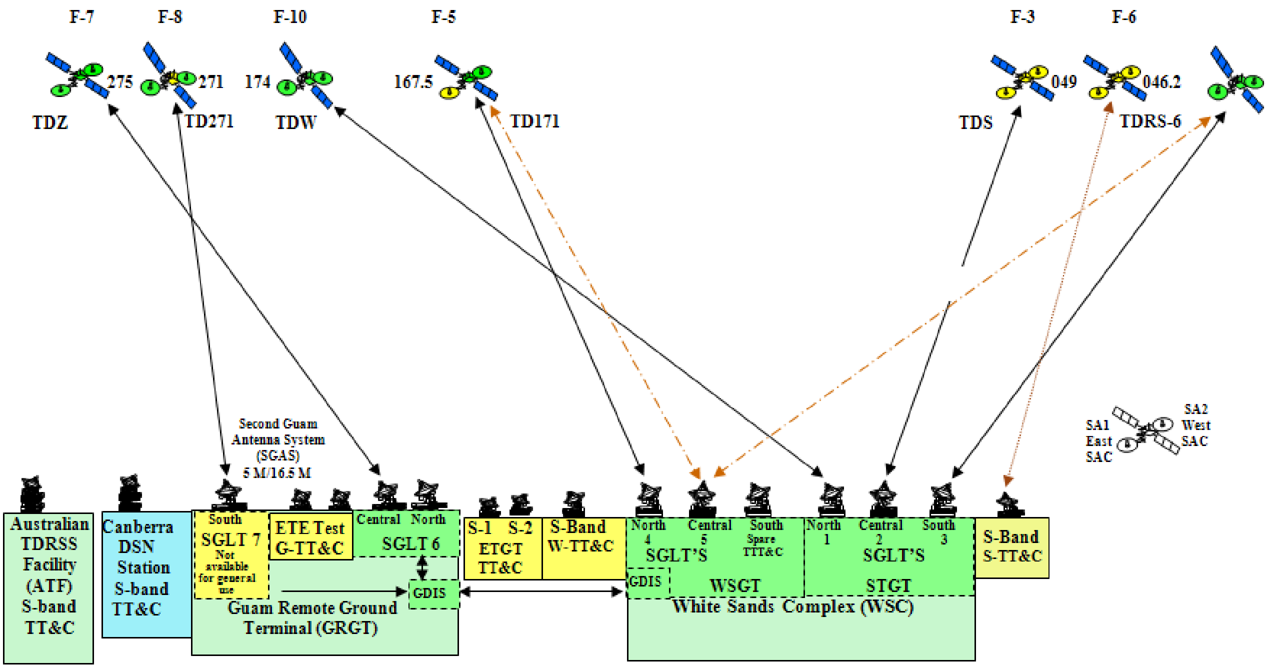

Figure 1. Space Network Elements Showing SGLTs at the STGT, WSGT, and GRGT

User services are provided using the body-mounted Multiple Access (MA) phased array on TDRS at S-band or using the two Single Access (SA) parabolic reflector antennas at S-band and Ku-band on the first generation TDRS or S-band and Ku- or Ka-band on the second generation TDRS and soon-to-be third generation TDRS.

The equipment in the current SN ground segment is nearing obsolescence and difficult to maintain. In order to address the obsolescence issues, NASA established the User Service Subsystem Component Replacement (USS CR) Project. The USS CR requirements are intended to ensure SN compatibility with all current legacy SN Single Access (SA) service modes while still solving the SN obsolescence issues[1]. The scope of the USS CR project only extends to replacement of a subset of

USS equipment in two SGLTs. By replacing critical obsolete equipment in two SGLTs, replaced equipment can then be used as spares in the other SGLTs. Therefore, the SN will have the needed spares to maintain the availability requirements of the SN until at least CY2017. The SN Ground Segment Sustainment (SGSS) Project will replace all SN hardware and software by 2017. NASA's Space Communications and Navigation (SCaN) office established the SGSS Project to sustain the SN operations for a minimum of 25 years additional service.

III. USS CR Objectives

The Space Network ground segment currently relies on 1990's era RF and baseband processing equipment with network interfaces typical of that era. Much of the RF signal processing equipment was fully custom designed to meet the stringent performance requirements of TDRS ground segment. The USS Component Replacement (USS CR) Project was instituted in response to the NASA SN Ground Segment near term sustainment needs to replace and upgrade, as necessary, unsustainable TDRSS SGLT S-Band and K-Band (Ku- and Ka-band) Single Access Service (one user spacecraft communicating via one of the two high gain TDRS antennas) modulators and receivers and other associated USS equipment in two SGLTs at White Sands. The USS CR Project Office is located in Goddard Space Flight Center (GSFC) at Maryland with a geographically diverse group of supporting contractors and suppliers team as shown in Figure 2.

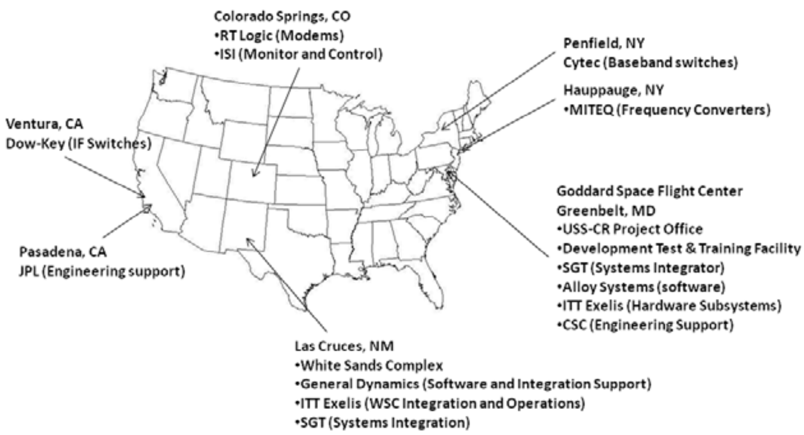

Figure 2. USS CR Project

The overall objective of the USS CR project is to replace key portions of the SA legacy equipment with modified COTS equipment that incorporates high TRL digital signal processing and IP network capability that is now widely commercially available. The technology advancements have allowed much of the customer hardware to be replaced by mostly COTS hardware while still achieving the stringent performance requirements. Specifically, this includes:

- Replacing the legacy ground segment SA S-band and K-band modulator and receiver functions with platforms utilizing software defined waveforms, a GUI based user interface, and commercially available IP network interface. This resulted in compressed footprints for narrowband (NB) and wideband (WB) modems and a more efficient ground terminal design.
- Replace the legacy S and K Band uplink and downlink frequency converter with a new generation of frequency converters utilizing IP interfaces.
- Control all the new equipment via IP interfaces and Simple Network Management Protocols (SNMP) while maintaining the various legacy interfaces and controls for equipment not replaced by USS-CR.
- Providing a minimum disturbance to the satellite controllers and the concept of operations at WSC.
- Minimize new software development and modifications to existing software.

Software and hardware from the various project suppliers are shipped to GSFC for initial integration in the Development, Test and Training Facility (DTTF). After thorough checkout in the DTTF, the equipment is integrated into the WSC operational system.

IV.   USS CR System Architecture

The replacement of the SN ground segment S-band and K-band equipment with upgraded new equipment requires modifications to the existing architecture for the two SGLTs. For the most part, the legacy architecture that exists today will be retained. Figure 3 depicts the organization of the K-Band Single Access Return (KSAR) SGLT service architecture. A similar architecture exists for the S-Band Single Access Return (SSAR) services. Legacy hardware which continues to be controlled by existing Subsystem Controllers (SSC) retains its legacy IEEE-488 and discrete message commands. The SSCs are 486 based machines with old communications protocols (1553, 488, 449, 422, discrete). This approach will ensure reliable operations at WSC until the SN Ground Segment Sustainment (SGSS) Project is implemented in December 2017. USS CR implementation in SGLTs 4 and 5 will be completed by July 2013. The major modifications include:

- Functions of the forward service modulator, Modulator/Doppler Predictor (MDP), and the return service receiver, Integrated Receiver (IR), will be consolidated in the modulator and demodulator of the new NB Modem used in the S-band Single Access (SSA) and the low data rate K-band Single Access (KSA) portions of the USS. The legacy Performance Measuring and Monitoring System Test Equipment (PTE) modems used to emulate the customer for loop testing will be consolidated in the new NB test modem and the WB test modulator.
- The legacy Autotrack Receivers (ATR) will be incorporated into the USS CR modems in both the Narrowband Modem and the Wideband Demodulator. Autotrack is a closed loop tracking function available for K-band user spacecraft pointing at the TDRS Single Access Antennas in the auto tracking mode.
- A new Monitor and Control (MCS) system utilizing standard protocols such as TCP/IP and SNMP to interface and control the new equipment.
- New switching and interface hardware to allow the new modem equipment to closely emulate the legacy KSA and SSA control function.

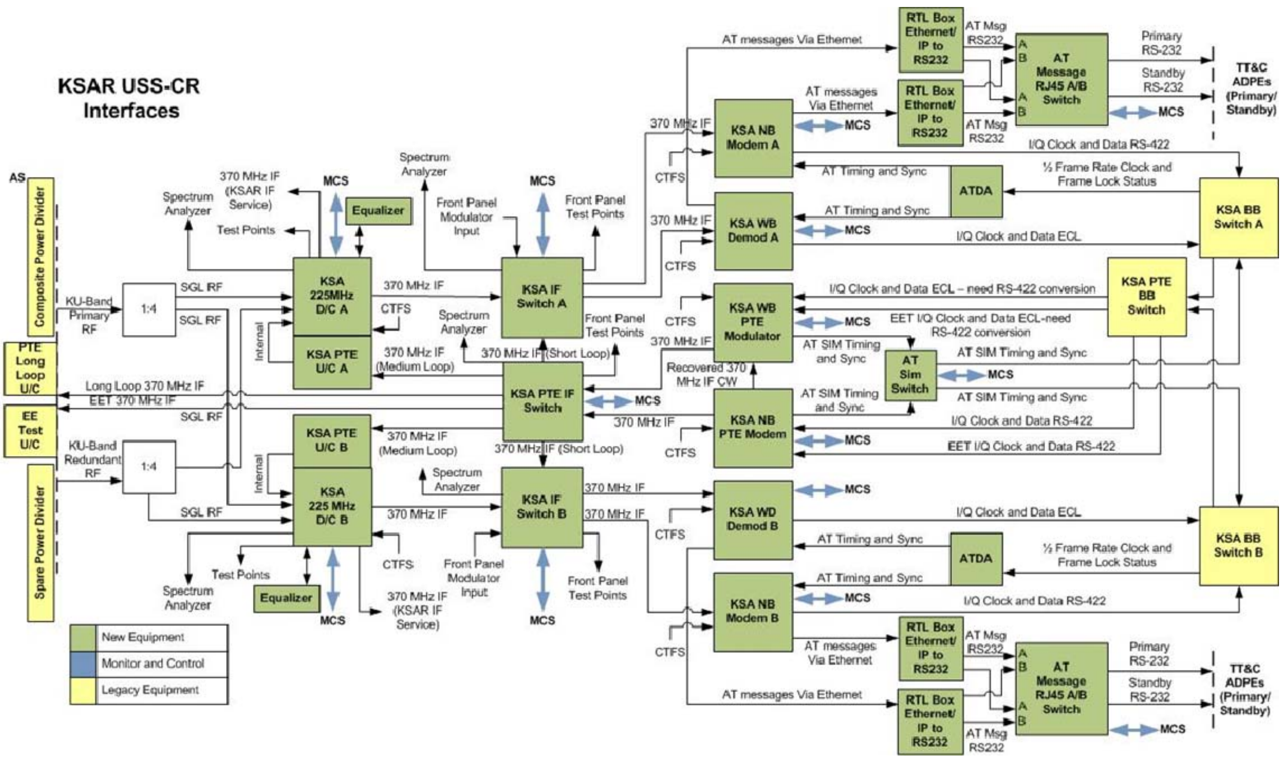

Figure 3. USS CR KSAR SGLT Architecture

V. USS CR New Hardware System Design

A.   USS CR Modem

The USS CR Project selected RT Logic in Colorado, as the vendor for the modems. The major modem configuration items includes:

1. The Narrowband (NB) Modem and the Wideband (WB) demodulator. The NB modem will replace the legacy Integrated Receivers (IR) and Modulator/Doppler Predictors (MDPs) now used in the SSA and KSA portions of the USS. These modems will support all SSA forward and return services and the KSA low rate forward and return services. The WB demodulator will replace the legacy High Data Rate Receiver now used in the KSA return service.
2. Narrowband Test Modem and Wideband Test Modulator. The NB test modem will replace the Low Data Rate Equipment Test Modem and the associated Performance Measuring and Monitoring System (PMMS) Test Equipment (PTE). The NB Test Modem will support test and verification of the forward and low rate return link. The WB test modulator will replace the Loral PTE modulator.
3. The legacy Autotrack Receivers (ATRs) will be incorporated in the USS CR NB and WB modems. The Autotrack Simulator will be provided in the NB test modem and the WB test modulator.

The USS CR modems are a software defined radio device. The NB modem is a single board computer with I/O signal distribution cards. The NB PTE uses the same hardware platform. The WB demodulator includes demodulator, Adaptive Baseband Equalizer (ABBE) and FEC cards providing signal processing with analog frond end cards selected between IF inputs, filters and digitizers. The USS CR modems will be controlled and monitored via SNMP v3 protocol. The modems support advanced modulation and coding techniques such as Low Density Parity Check (LDPC) code, Turbo Product Code (TPC) and 8-PSK modulation in addition to the conventional signal structures currently employed by the SN. The new modems will ensure the legacy SSA and KSA forward and return services requirements are met.

USS CR Project has completed both the NB and WB modem Factory Acceptance Tests (FATs) during the summer and fall in 2011[2]. Selected Bit Error Rate (BER) results are shown in Figure 4. A distortion filter emulating the major TDRSS channel distortion parameters including 3 dB bandwidth, gain flatness and phase nonlinearity is used during the FAT. Based on factory and risk mitigation test results conducted at WSC during the summer of 2011, the new modems outperform the existing IR and Loral high rate receivers including BER and acquisition performance. Issues such as Data Latency Variation (DLV), I/Q skew, coherent signal acquisition, baseband data customer interface and autotrack signal presence and lock were mitigated in accordingly. Additional testing for the non legacy modes, i.e., capabilities beyond the current WSC equipment including LDPC code and 8-PSK modulation, were performed through the TDRSS End-To-End (ETE) test system at WSC during the summer of 2011. Results of the non legacy modes testing have demonstrated the maturity of the new coded modulation schemes as implemented by the USS CR NB modem. For detail of the non legacy modes test, please see a separate paper in SpaceOps 2012, Michael Cheng, Yen Wong, et al, "An Evaluation of New Coding and Modulation Schemes for National Aeronautics and Space Administration (NASA) Space Network". Currently, both the NB and WB modems are used in the Development Test and Training Facility (DTTF) at GSFC to support the hardware and software integration testing.

Results of the modems FAT system allocated performance, with respect to the specification, are shown in the USS CR new hardware performance summary in Table 1.

B. Frequency Converter

Miteq in Long Island was the vendor for the frequency converter. The USS CR frequency converters include:

1. The SSA and KSA up converter/PTE down converter. Convert IF (~370 MHz) to Ku (~14 GHz). PTE converts Ku to IF for testing of the forward link.
2. The SSA return link Ku-Band Down-converter/PTE up converter. Convert Ku (~14 GHz) to IF (~370 MHz). PTE converts IF to Ku for testing of the return link.
3. The Ku-Band return link 225 Down-converter/PTE up converter. Convert Ku (~14 GHz) to IF (~370 MHz). PTE converts IF to Ku for testing of the return link.
4. A Ku-band return link waveguide equalizer to equalize the amplitude and phase for three different antenna runs of rectangular and elliptical waveguide.

All three converters will be controlled and monitored with remote SNMP v1 protocol.

USS CR Project has completed the frequency converter FAT in the spring of 2012. The results indicate that the frequency converters performed at or above the specifications with good RF performance characteristics. Results of the converters FAT, with respect to performance specification, are shown in the USS CR new hardware performance summary in Table 1.

C. SGLT Switching Implementation

The USS CR system functionality is identical to the existing system but the hardware capabilities differ and require additional signal switching.

1. KSA IF Switch
   Replaces legacy IF switches which lacked sufficient I/O to support all required paths. The IF switch will be controlled by the MCS via TCP/IP ptotocol.
2. Autotrack Timing and Distribution Assembly
   Provides KSA Autotrack Timing and Sync signals to both Narrow- and Wide- band equipment
3. Autotrack Switch
   Selects between Narrow and Wide-band equipment as the source of Autotrack Status (gimbal error, etc…) Messages.
4. Autotrack Simulation Switch
   Selects between Narrow and Wide-band PTE as the source of simulated Timing and Synchronization Signals.

Dow-Key in CA is the vendor for the IF switch. Cytec in Penfield, NY is the vendor for the baseband switch and autotrack switch. USS CR has completed the switch FAT in December, 2011. Key switches FAT results, with respect to performance specification, are shown in the USS CR hardware performance summary in Table 1.

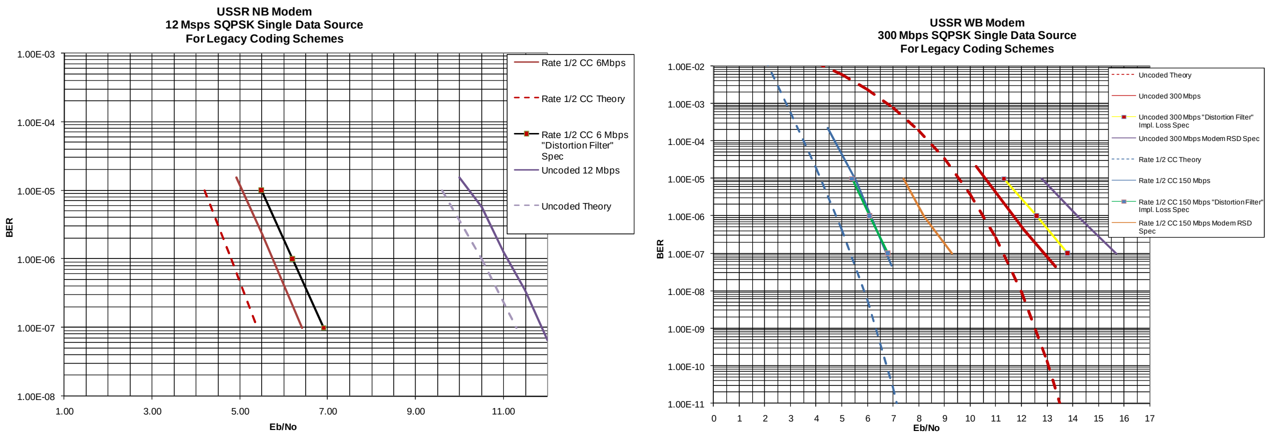

Figure 4. Selected BER Performance for FAT Results

VI. USS CR Control and Monitor System (CMS)

Today at WSC, the control and monitoring of the RF and baseband equipment, interfaces to the various operator workstations and processing of spacecraft telemetry, tracking and control is distributed over a network of legacy systems. USS CR developed a Control and Monitor System (CMS) that integrates the legacy distributed network architecture of HP Alpha servers - referred to as the Automated Data Processing Equipment (ADPE), with PC server driven, local area networks. This design permits the new equipment and existing legacy equipment to coexist. The top level architecture is shown in Figure 5. Legacy equipment at the top of Figure 5 is controlled by Subsystem Controllers (SSC) either over a MIL-STD-1553 bus for the ADPE or IEEE 488 and discrete interface for the hardware. New hardware subsystem (HWS) equipment is controlled by the Monitor and Control Subsystems (MCS) communicates via IP. Table 2 lists the network interfaces used by USS CR. The implementation is completely transparent to users, i.e. users will not know if they are connected to a SGLT modified by USS CR. Also, the entire USS CR system is completely isolated from all outside network connectivity. Control of USS CR equipment is performed by the Control and Monitoring System (CMS).

Table 1. USS CR Hardware Performance Summary: Measurement vs Specification

Parameter	Value													
	Modem								Converter					
	FWD KSA		FWD SSA		RTN KSA		RTN SSA		Upconverter		SSA Downconverter		225 MHz Downconverter	
	Measured	Specification	Measured	Specification	Measured	Specification	Measured	Specification	Measured	Specification	Measured	Specification	Measured	Specification
Gain Imbalance (peak), dB	0.0064	0.25	0.0064	0.25	--	--	--	--	--	--	--	--	--	--
Phase Imbalance (peak), deg	0.05	3	0.05	3	--	--	--	--	--	--	--	--	--	--
3 dB Bandlimiting, MHz	60	50	60	20	240	240	50	17	50	50	25.8	25	370	370
Gain Flatness (peak), dB	0.22	0.4	0.22	0.4	0.02 (NB only)	0.3	0.02	0.3	0.18	0.3	0.08	0.3	0.46	0.8
Gain Slope (peak), dB/MHz	0.024	0.1	0.024	0.1	0.023 (NB only)	0.1	0.023	0.1	0.03	0.05	0.05	0.05	0.06	0.1
Phase Nonlinearity (peak), deg	0.2	4.25	0.2	4.25		3		3	0.4	1.5	1.3	3	3.205	6
Data Asymmetry (peak), %	0.13	3	0.13	3	--	--	--	--	--	--	--	--	--	--
Data Bit Jitter (peak), %	0.097	1	0.097	1	--	--	--	--	--	--	--	--	--	--
Data Transition Time, %	1	5	1	5	--	--	--	--	--	--	--	--	--	--
Incidental AM (peak), %	negligible	1.5	negligible	1.5	--	--	--	--	--	--	--	--		
Spurious Outputs, dBc	-58	-30	-58	-30	--	--	--	--	-74.99	-33	-80	-35	-67	-35
Spurious PM (rms), deg	negligible	0.8	negligible	0.8	--	--	--	--	--	--	--	--	--	--
AM/AM, dB/dB	--	--	--	--	--	--	--	--	0.05	0.25	--	--	0.9	0.95
AM/PM, deg/dB	negligible	5	negligible	5	--	--	--	--	0.5	1	0.3	1	--	--
PN Chip Asymmetry (peak), chip	0.0007	--	0.0007	--	--	--	--	--	--	--	--	--	--	--
PN Chip Jitter (rms), deg	0.51 Peak	1	0.51 Peak	1	--	--	--	--	--	--	--	--	--	--
I/Q PN Chip Skew (peak), chip	0	0.01	0	0.01	--	--	--	--	--	--	--	--	--	--
PN Chip Rate (peak), chip/sec	-bit NCO @ 3Mc	0.01	-bit NCO @ 3Mc	0.01	--	--	--	--	--	--	--	--	--	--
PN Chip Rate (mean), chip/sec	0.000018	--	0.000018	--	--	--	--	--	--	--	--	--	--	--
I/Q Power Ratio Tolerance, dB	0.1	0.5	0.1	0.5	--	--	--	--	--	--	--	--	--	--
Phase Noise (rms) Total, deg														
1 Hz - 10 Hz	0.035	0.1	0.035	0.1	0.035	0.1	0.035	0.1	0.531	1.4	0.386	1.4	0.342	1.4
10 Hz - 32 Hz	0.0169	0.1	0.0169	0.1	0.0169	0.1	0.0169	0.1	0.533	1.4	0.492	1.4	0.367	1.4
32 Hz - 1k Hz	0.028	0.1	0.028	0.1	0.028	0.1	0.028	0.1	0.657	3.9	0.229	3.9	0.191	3.9
1k Hz - 25M Hz	0.0637	0.1	0.0637	0.1	0.0637	0.1	0.0637	0.1	0.445	1	0.505	1	0.372	1
Phase Noise (rms) LO, deg														
1 Hz - 10 Hz	--	--	--	--	--	--	--	--	0.535	0.8	0.184	0.8	0.225	0.8
10 Hz - 32 Hz	--	--	--	--	--	--	--	--	0.282	0.7	0.089	0.7	0.067	0.7
32 Hz - 1k Hz	--	--	--	--	--	--	--	--	0.336	0.8	0.066	0.8	0.061	0.8
1k Hz - 25M Hz	--	--	--	--	--	--	--	--	0.315	0.8	0.141	0.8	0.143	0.8

Note: the KSA IF switch performance: 3 dB band limiting: 450 Mhz (measured) vs 400 Mhz (spec), gain flatness: 0.05 dB (measured) vs 0.1 dB (spec), phase nonlinearity: 1 deg (measured) vs 1 deg (spec).

Table 2. USS-CR Control Interfaces

Interface	Functional	Application	Transport/Network	Link
SA ADPE - MCS	Monitor & Control	ADPE / MCS API	TCP/IP	Ethernet
MCS - NB Modem/PTE	Monitor & Control	SNMPv3	UDP/IP	Ethernet
	Ephemeris	MCS API / EPIC	TCP/IP	Ethernet
MCS - WB Demod/PTE	Monitor & Control	SNMPv3	UDP/IP	Ethernet
	Ephemeris	MCS API / EPIC	TCP/IP	Ethernet
MCS - UC/PTE DC (SSA or KSA)	Monitor & Control	SNMPv1	UDP/IP	Ethernet
MCS - DC/PTE UC (SSA or KSA)	Monitor & Control	SNMPv1	UDP/IP	Ethernet
MCS - 225 MHz DC/PTE UC (KSA)	Monitor & Control	SNMPv1	UDP/IP	Ethernet
MCS - KSA IF Switch	Monitor & Control	MCS API	TCP/IP	Ethernet
MCS - KSA PTE IF Switch	Monitor & Control	MCS API	TCP/IP	Ethernet
MCS - KSA PTE MUX	Monitor & Control	MCS API	TCP/IP	Ethernet
MCS – Autotrack Switch	Monitor & Control	MCS API	TCP/IP	Ethernet
MCS - Autotrack Sim Switch	Monitor & Control	MCS API	TCP/IP	Ethernet
MCS - Network Switch	Monitor	SNMPv3	UDP/IP	Ethernet
MCS - Time & Freq Processor	Time and Frequency	NTP	UDP/IP	Ethernet
MCS - Central Log Server	Logging	Syslog/NFSv4	TCP & UDP/IP	Ethernet

A. CMS Design

The CMS is consists of:

1. Software modifications to the legacy ADPE running on HP Alpha platforms
2. MCS situated on Dell PowerEdge R510 servers

Each of these elements are briefly described below.

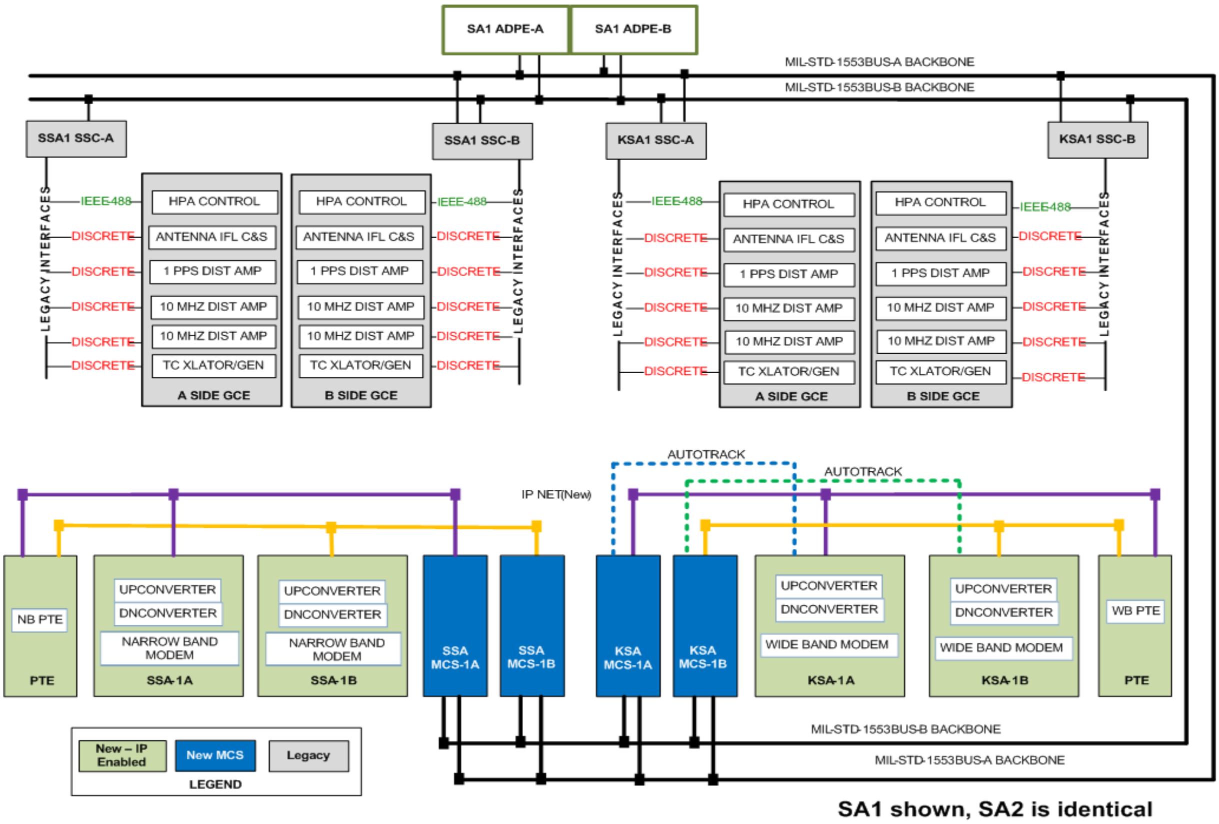

Figure 5. USS-CR CMS Architecture

1. USS-CR Software modifications to the legacy ADPE

The legacy ADPE harbors over 11 million lines of code distributed across multiple platforms and a variety of software languages, including:

- ADA
- Sherill-Lubinski
- G2 Gensym Knowledgebase
- Ingres SQL Database Management System
- Oracle Rdb

Software updates to the legacy ADPE code were performed by the General Dynamics team in Las Cruces, NM. Development and maintenance of the software code base is affected by the ongoing software maintenance occurring at WSC as well as updates being performed simultaneously by multiple projects. USS-CR maintains multiple code baselines of its own code modifications and the existing operational baseline to ensure that no conflicts exist between our code updates and the operational baseline. GD provides the ADPE software updates to the USS-CR development team at GSFC. The USS CR project maintains a software configuration control process utilizing the same tools as the WSC. Although USS-CR software modifications affect less than 1% of the existing code, extensive verification is required to ensure that the operational system will not adversely be affected by the code changes. Code changes were limited to functional areas that were directly affected by USS-CR, e.g. workstation displays, failover management.

2. USS CR Monitor and Control System (MCS)

The MCS provides the middleware between the legacy ADPE and the new hardware systems. One of the major design goals of the USS-CR project is to minimize changes to the ADPE. Legacy USS commands will remain largely unchanged. MCS development followed a low risk development path.

- Build upon a proven commercial monitor and control (M&C) product
- Utilize a model similar to flight M&C systems
- Conduct industry surveys with various vendors of space and ground M&C systems.
- Require simulation and modeling capabilities to facilitate MCS development
- Utilize a database and script-driven approach
  - Database determines mapping and routing of commands
  - Scripting is used for automation

The functional architecture of the MCS is shown in Figure 6. MCS performs the following functions:

- TCP/IP Manager. The TCP/IP manager contains the IP protocol suite and the necessary API for the TCP/IP interface. It handles configuration and error handling of the lower layers of the protocol stack, message and transaction management between the MCS and SA ADPE. It routes commands to Ephemeris Download Manager or Command Process depending on command type.
- Command Process. The Command Process translates ADPE commands into USS-CR HWS SNMP commands.
- Ephemeris Download Manager. The Ephemeris Download manager performs the ephemeris data download functions, receives the ephemeris data from ADPE Interface Manager, interfaces with Command Process to determine when and where the ephemeris data should be sent and interfaces with the GCE Interface Manager to route the ephemeris data to modems or PTE over the TCP/IP interface.
- MCS Database. The MCS Database provides data storage, data access, and data management functions for internal MCS processes.
- Ground Communication Equipment (GCE) Interface Manager. The GCE Interface Manager performs the application layer handling of the interface between the MCS and the GCE.
- SNMP Manager. The SNMP Manager provides the protocol interface to GCE that uses SNMP. It contains a SNMP manager demon, SNMP proxy, a set of SNMP APIs, SNMP MIBs and SNMP protocol error handling software. SNMP v3 is for modems and PTE. SNMP v1 is for up-converters, down-converters, and PTE.
- Status Process. The Status Process translates native status data into legacy SN status reports.
- Logging Manager. The Logging Manager provides time-tagged logging of all MCS events.
- Time Manager. The Time Manager provides a synchronized UTC time standard for the MCS

The MCS runs on the Dell PowerEdge R510 server with:

- Dual Intel Xeon E5630 2.53 GHz, 12M Cache, Quad Core with HT
- Red Hat Enterprise Linux
- Two 250 GB and five 500 GB RAIDs

For efficient network connectivity, the new equipment of USS CR is organized into series of virtual local area networks. USS-CR equipment for each service (SSA A chain, SSA B chain, KSA A chain, KSA B chain, SSA common, KSA common) are connected via routable IP interfaces through network switches. This permits routable access to all permitted combinations of A and B chain, A and common, B and common functionality. All network access activity is recorded via a central log server for the USS-CR equipment.

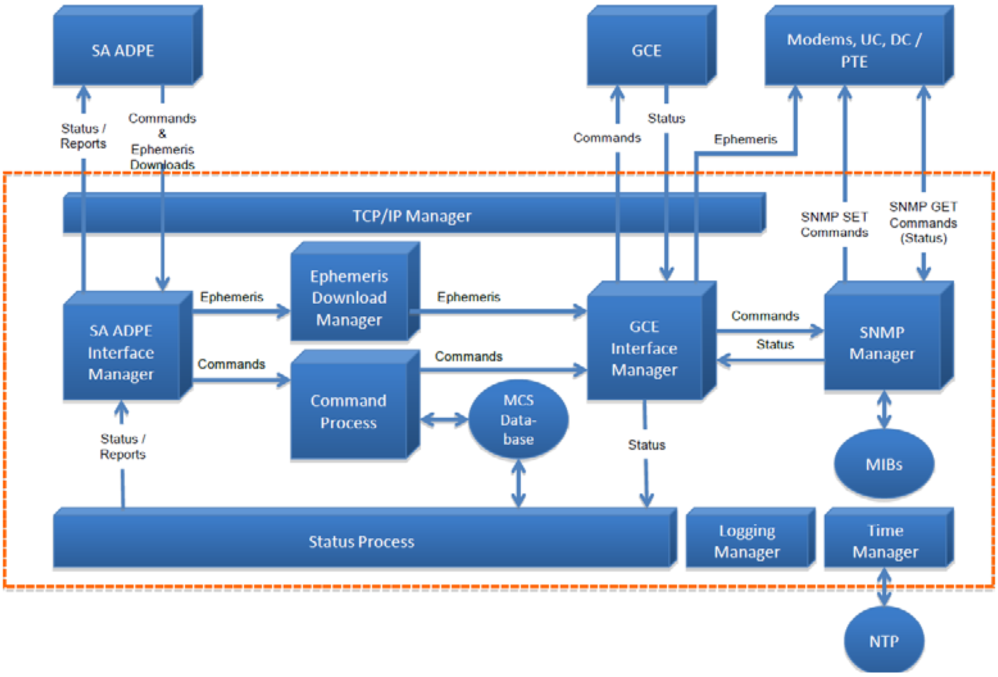

Figure 6. MCS Functional Architecture

VI. Modem Enhanced Capabilities

The USS CR modems were designed to maintain the backward compatibility with traditional S-band and Ku-band customers, it also provides new capabilities beyond the current WSC equipment.

New capabilities highlights include:

1. Enhanced capabilities for traditional S-band/Ku-band and 225 MHz channel Ka-band customers (e.g., much higher return data rates; options for 50 Mbps forward link rate for Ku-band; expanded frequency search acquisition range)
2. Flexibility to add new modes of operations after delivery through software defined radio expandability without requiring hardware modification.
3. Enabling bandwidth and power efficient modulation to increase maximum S-Band data rates and the envisioned ultra-high data rate Ka-band service to Earth science missions made possible by using the 650 MHz channel on the Second and Third Generation TDRS satellites

Table 3 provides an overview of the enhanced capabilities that the USS CR modems will support in addition to the legacy capabilities of the current WSC equipment.

Table 3. Modem Enhanced Capabilities

Modem Enhancement	**Description**
LDPC Code Support for the General Customer	Forward and return service rate ½ and rate 7/8 LDPC code support for the general SN SSA, KuSA, and KaSA customer.
Reed-Solomon (RS) and Concatenated Rate 1/2 Convolutional Code	SSA, KuSA, and KaSA forward and return service concatenated (255,223) RS and rate ½ convolutional code support. KuSA and KaSA forward and return service (255,223) RS code support for the general SN SSA, KuSA, and KaSA customer.
TPC Code Support for the General Customer	Return service rate 7/8 TPC code support for the general SN KuSA and KaSA customer.
CCSDS Randomization	SSA, KuSA, and KaSA forward and return service CCSDS data randomization support.
8PSK Support for the General Customer	SSA, KuSA, and KaSA return service 8PSK support

Expanded Powered-Flight Customer Orbital Dynamics Support for the General Customer	Support of R ≤ 15 km/s, R ≤ 50 m/s2, and R ≤ 70 m/s3 powered flight orbital dynamics. Data Rate >=300 bps.
Return Service Expanded Frequency Search Support	Expanded frequency search range support for SSA and KSA low rates • Includes full ± 40 KHz range supported by legacy IR equipment.
Forward Service QPSK/SQPSK Support	Support unspread forward QPSK/SQPSK for SSA, KuSA, and KaSA.
Increased Forward Service Data Rate Support	Maximum SSAF data rate increased to 14 Mbps (QPSK/SQPSK) Maximum KSAF data rate increased to 50 Mbps (QPSK/SQPSK)
Increased Return Service Data Rate Support	Maximum SSAR DG1 data rate increased to 525 kbps (rate 7/8 LDPC code) Maximum SSAR DG2 data rate increased to 15.75 Mbps (SQPSK rate 7/8 LDPC code) and 23.6 Mbps (8PSK rate 7/8 LDPC code). Maximum Ku/KaSAR-225 MHz DG2 data rate increased to 410 Mbps (SQPSK rate 7/8 LDPC code/TPC code) and 550 Mbps (8PSK rate 7/8 LDPC)
KaSAR-650 MHz Baseband Data Service	Support a KaSAR-650 MHz baseband channel with SQPSK and 8PSK modulation and rate 1/2 LDPC code and rate 7/8 LDPC code/ TPC. Support data rates up to 1.0 Gbps (SQPSK rate 7/8 LDPC code/TPC) and 1.2 Gbps (8PSK rate 7/8 LDPC code/TPC).
Block Interleaving Support	SSA, KuSA, and KaSA forward and return links block interleave support for RS, concatenated, LDPC, and TPC coded link. Maximum interleave depth of eight.
Ka-band One-Way Doppler Tracking Support	Support Ka-band one-way Doppler tracking for all Ka-band service modes.
Soft Decision Port	Support an interface port which provides I and Q channel soft decision digitized data and clock
Expanded Coherent Return Service PN Search without C/No Penalty	Support an S-band coherent return service PN search which allows customer ephemeris uncertainty to be greater than ±9 sec
SNMP over IP Monitor & Control (M&C) Interface	Support an SNMP over IP monitor and control to/from all USS CR active equipment

Note that the USS CR modems will be required to configure to support only the legacy modes as full automated services for the two SGLSs. The enhanced capabilities including new modulation and coding schemes such as LDPC, TPC and 8-PSK modulation which are non-legacy modes will not be implemented by the USS CR Project as full automated services. The use of modems non-legacy modes will be through the IF service.

Using the new modem coding option, more power efficient and bandwidth efficient performance will be available compared to the legacy Rate 1/2 Convolutional Coded QPSK/SQPSK as shown in Table 4. The comparison is based on a normalized 12 Mbps SQPSK BER performance in AWGN channel for the ½ LDPC, 7/8 LDPC, concatenated R-S & ½ convolutional and ½ convolutional coding schemes. Figure 7 is the normalized 12 Msps SQPSK BER curves for these coding schemes.

Table 4. USS CR Modem Coding Performance Compare to Rate ½ Convolutional Code

Service Description	Theoretical Coding Gain, dB		Measured Coding Gain, dB		Bandwidth Efficient
	@1E-5 BER	@1E-7 BER	@1E-5 BER	@1E-7 BER	
QPSK/SQPSK Rate ½ LDPC	2.51	3.4	1.9	2.9	None
QPSK/SQPSK Rate 7/8 LDPC	0.45	1.4	0.85	2.1	44%
QPSK/SQPSK Concatenated (255,223) R-S & Rate ½ Convolutional Code	1.29	2.0	<0.1	1.0	None (An Increase)

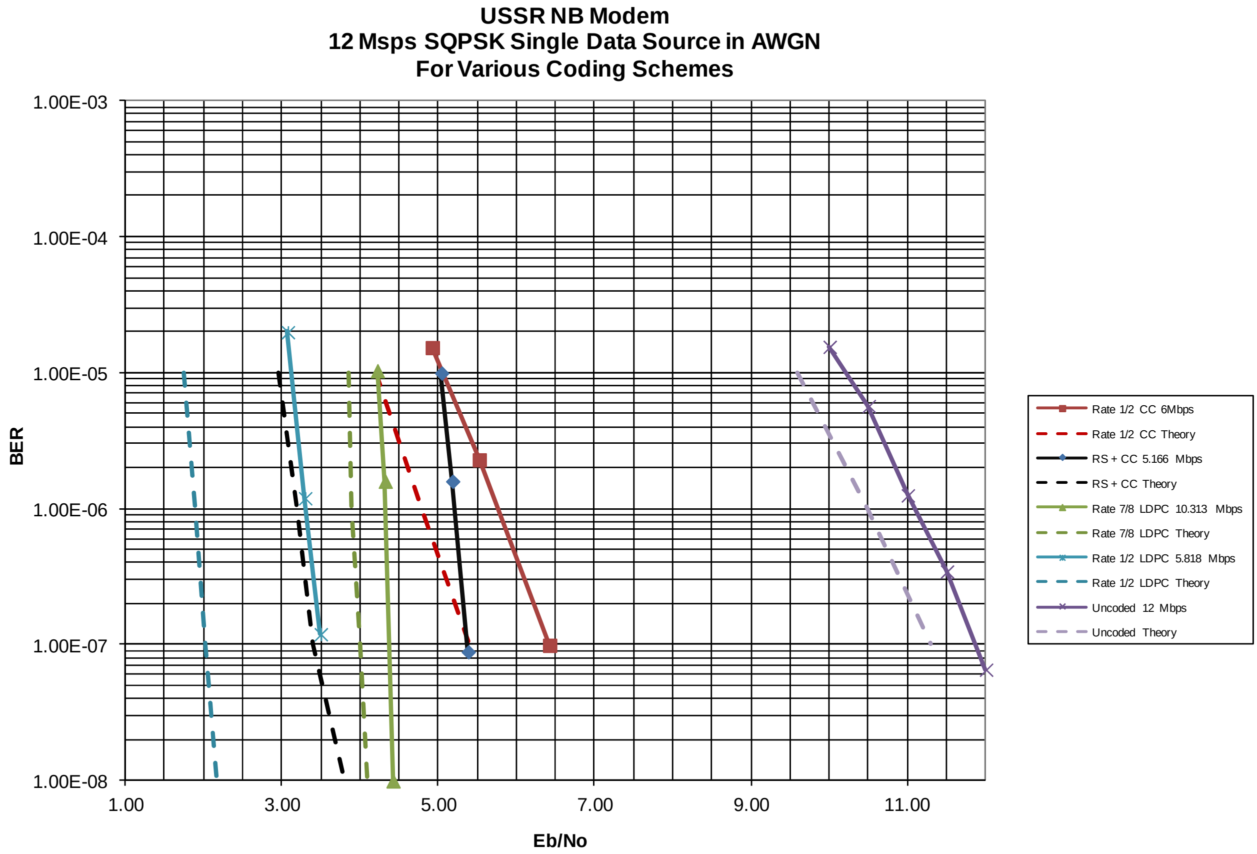

Figure 7. Normalized 12 Msps SQPSK BER performance for various coding schemes

IX. Conclusions

The USS CR project at NASA is in the process of completing a major sustainment effort for the Single Access ground communications services at WSC. This effort will add bandwidth and power efficient modulation and coding options requested by NASA customers under the existing services. This effort will also ensure the continued reliable operation of the SN ground segment until its replacement under the SGSS project.

Acronym List

8-PSK	8-ary Phase Shift Keying
ABBE	Adaptive Baseband Equalizer
ADPE	Automatic Data Processing Equipment
ATR	Auto Track Receiver
CMS	Control & Monitor System
DLV	Data Latency Variation
DSN	Deep Space Network
DTTF	Development Training and Testing Facility
ETE	End-To-End
ETGT	Expanded Tracking Ground Terminal
FAT	Factory Acceptance Test
GDIS	Guam Data Interface System
GRGT	Guam Remote Ground Terminal
IP	Internet Protocol
IR	Integrated Receiver
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSA	K-band Single Access
KSAF	K-band Single Access Forward
KSAR	K-band Single Access Return
LDPC	Low Density Parity Check
MCS	Monitor and Control Subsystem
MDP	Modulator/Doppler Predictor
NASA	National Aeronautics and Space Administration
NB	Narrowband
OQPSK	Offset Quadrature Phase Shift Keying
PMMS	Performance Measuring and Monitoring System
PTE	Performance Test Equipment
QM	Qualification Model
RF	Radio Frequency
SA	Single Access
SCaN	Space Communication and Navigation
SGL	Space-to-Ground Link
SGLT	Space-Ground Link Terminal
SGSS	SN Ground Segment Sustainment
SN	Space Network
SNMP	Simple Network Management Protocol
SQPSK	Staggered Quadrature Phase-Shift Keying
SRR	System Requirements Review
SSA	S-band Single Access
SSAF	S-band Single Access Forward
SSAR	S-band Single Access Return
SSC	Subsystem Controller
STGT	Second TDRSS Ground Terminal
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TPC	Turbo Product Code
USS	User Services Subsystem
USS CR	User Services Subsystem Component Replacement
WB	Wideband

WSC	White Sands Complex
WSGT	White Sands Ground Terminal

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