National Aeronautics and Space Administration's (NASA)Third-Generation Tracking and Data Relay Satellites (TDRS)

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NASA has contracted with Boeing to provide two third-generation Tracking and Data Relay Satellites (TDRS) designated TDRS K and L, with an option to provide two additional satellites designated TDRS M and N. These TDRS will be used to continue and enhance the user support services of the existing first- and second-generation TDRS spacecraft. The existing TDRS, in conjunction with the TDRS Ground Terminals at the White Sands NM Complex (WSC) and Guam, constitute the Tracking and Data Relay Satellite System (TDRSS). The TDRSS, with other supporting elements, is referred to as the Space Network (SN). The launch of the TDRS K is projected for 2012 with TDRS L planned to follow in 2013. The contract also provides for the modifications to the TDRS Ground Terminals at the WSC required for operation of the new TDRS. This paper provides an overview of the customer services provided by the existing and new TDRS. In addition, planned future customer services such as Bandwidth Efficient Modulation (BEM) and new coding schemes are briefly discussed.

I. Introduction

THE National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite System (TDRSS) or Space Network (SN) was established in the early 1980s. The SN consists of a constellation of geosynchronous satellites (TDRS), associated ground systems, and supporting elements designed to provide service to customer platforms in earth orbit. This paper provides an overview of the customer services provided by the existing and third-generation TDRS.

The current TDRS constellation consists of the first-generation TDRS build by TRW and designated F1-F7, and the second-generation built by Boeing and designated F8-F10 or H,I,J. The F1 and F8 TDRS are not available for SN support. The TDRS constellation provides telemetry, command, and tracking services to customer platforms. An example of TDRS constellation plans is shown in Table 1.

The ground systems consist of the White Sands Complex (WSC) and the Guam Remote Ground Terminal (GRGT). The WSC has two ground terminals; the White Sands Ground Terminal (WSGT) and the Second TDRS Ground Terminal (STGT). The STGT has three Space Ground Link Terminals (SGLTs 1, 2 and 3). An SGLT contains all ground equipment for processing customer telemetry, command, and tracking data, from RF to baseband, for a single TDRS. This processing includes telemetry demodulation, bit synchronization, convolutional decoding, deinterleaving, K-band autotrack, customer ranging and Doppler, and command modulation. The WSGT has two SGLTs; 4 and 5. The GRGT has two SGLTs; 6 and 7. SGLT 7 is not available for SN support. The GRGT is operated from the WSC and closes the Zone of Exclusion, i.e., the orbital area not seen by TDRS operated from the WSC. The STGT and WSGT have S-band Tracking, Telemetry, and Command (STTC) terminals providing TDRS support, but not customer services. All SGLTs have associated End-to-End Test (EET) terminals for providing customer platform simulation for testing without the need for a customer platform.

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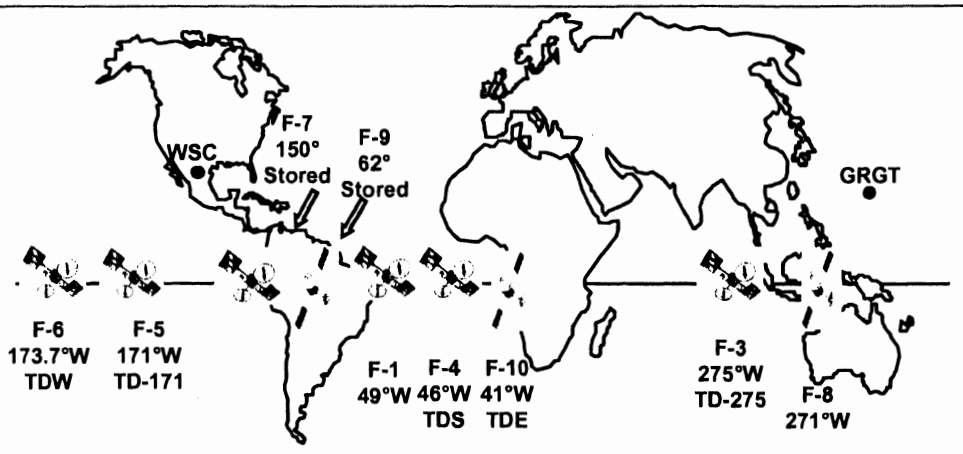
Table 1. Example of TDRS Constellation Plans



Example of TDRS Constellation – Spring 2007

Example Constellation Plan	Geosynchronous Longitudes of First-Generation Satellites (TDRSs F1-F7)	Geosynchronous Longitudes of Second-Generation Satellites (TDRSs F8-F10)
First-Generation TDRSs and 3 Second-Generation TDRSs	46°W (F4) 49°W (F1) 171°W (F5) 275°W (F3) 150°W (F7) (storage) 174°W (F6)	41°W (F10) 62°W (F9) (storage) 271°W (F8)

The SN supporting elements include (1) the Flight Dynamics Facility (FDF) located at the Goddard Space Flight Center (GSFC), providing customer and TDRS orbit prediction information, (2) the Network Control Center Data System (NCCDS) located at GSFC, providing scheduling and operations communications with customer control centers [Payload Operations Control Centers (POCC) and Mission Operations Centers (MOC)], and (3) the NASA Integrated Services Network (NISN), providing communications links between customer facilities and the WSC and GRGT, including baseband data interfaces and operations data interfaces. A diagram showing the WSC, supporting elements and data flows is shown in Fig. 1.

Operation of the SN for customer services is fully automated. The SN typically provides customer service availability greater than 99.9%.

II. Customer Services via TDRS F1-F10

The TDRSS provides forward (command), return (telemetry), and tracking telecommunications services at S-band and Ku-band. TDRS F8-F10 provide, in addition to S- and Ku-band services, forward and return customer services at Ka-band. There are no tracking services at Ka-band. Telecommunications services provided by the SGLTs are summarized in Fig. 2.

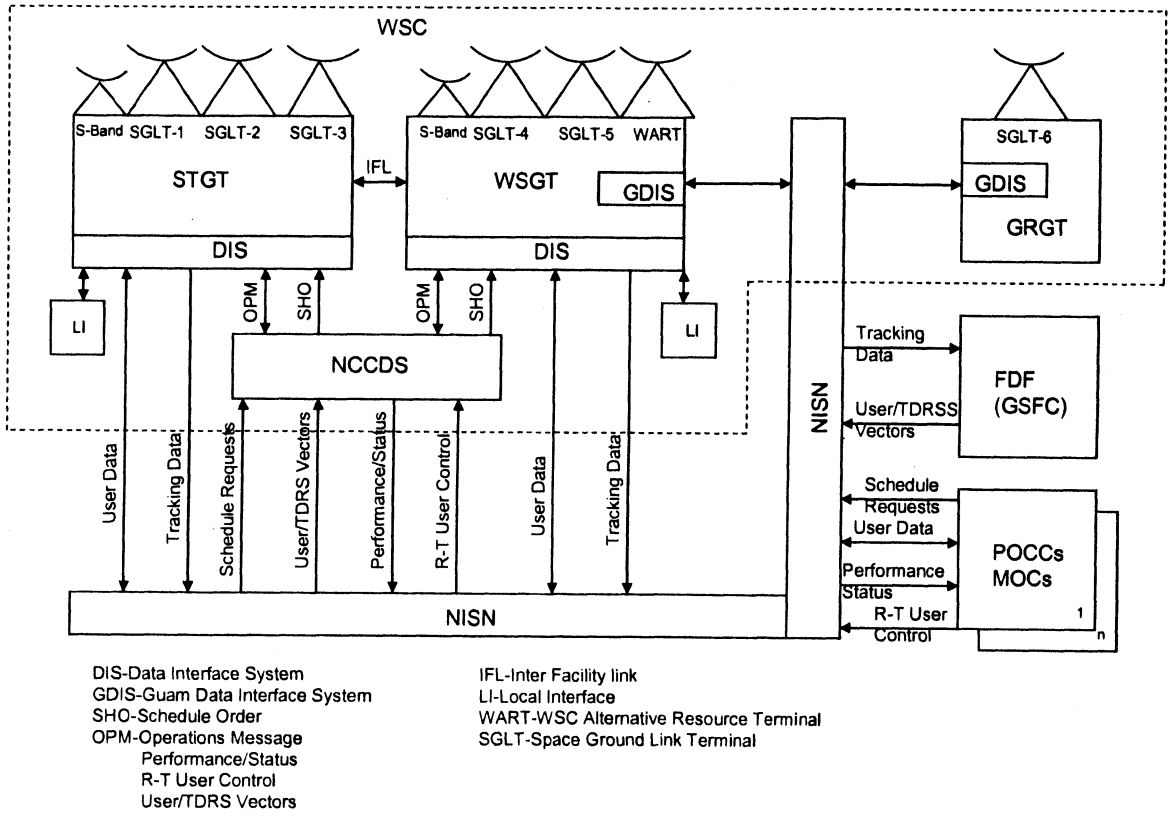
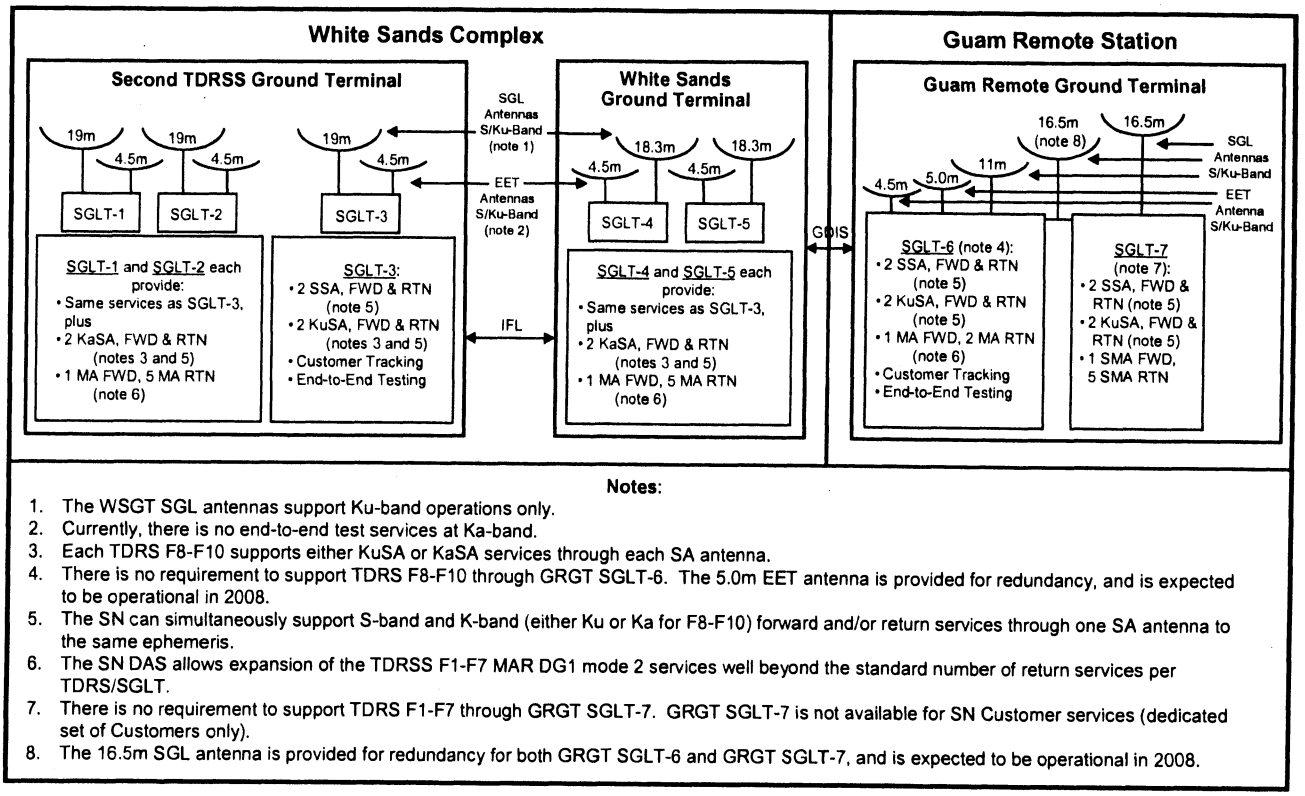


Figure 1. WSC Supporting Elements and Data Flows

S-band Single Access (SSA) services, Ku-band Single Access (KuSA) services, and Ka-band Single Access (KaSA) services are provided by two Single Access (SA) antennas on each TDRS. Simultaneous SA and KuSA, or SSA and KaSA (F8-F10 only) are provided on each SA antenna. Multiple Access (MA) services are provided on the F1-F7 spacecraft via an MA phased array antenna, with return customer beamforming in the ground terminals and forward beamforming on the TDRS. The F8-F10 spacecraft also provide MA services via a phased array, but with forward and return beamforming done on-board the TDRS. Figures 3 and 4 show the first- and second-generation TDRS and services provided. Associated with the F1-F7 MA return signals is a ground-implemented Demand Access System (DAS) with multiple return beamformers and providing near-real-time access to services. For details of the DAS service characteristics and initiating service requests, see the [1]Space Network Users' Guide (SNUG).

Forward service characteristics are summarized in Table 2. Ground terminal forward data rates are currently limited to 7 Mbps. Upgrades to support 25 Mbps are planned. For forward data rates $\leq$ 3 kbps, the I-Channel of the QPSK signal contains the command data modulo-2 added to a short (2^{10}-1 chip) 3 Mbps PN code and the Q-Channel contains a long ([2^{10}-1]*256 chip) 3Mbps PN code used for customer ranging.



Notes:

1. The WSGT SGL antennas support Ku-band operations only.
2. Currently, there is no end-to-end test services at Ka-band.
3. Each TDRS F8-F10 supports either KuSA or KaSA services through each SA antenna.
4. There is no requirement to support TDRS F8-F10 through GRGT SGLT-6. The 5.0m EET antenna is provided for redundancy, and is expected to be operational in 2008.
5. The SN can simultaneously support S-band and K-band (either Ku or Ka for F8-F10) forward and/or return services through one SA antenna to the same ephemeris.
6. The SN DAS allows expansion of the TDRSS F1-F7 MAR DG1 mode 2 services well beyond the standard number of return services per TDRS/SGLT.
7. There is no requirement to support TDRS F1-F7 through GRGT SGLT-7. GRGT SGLT-7 is not available for SN Customer services (dedicated set of Customers only).
8. The 16.5m SGL antenna is provided for redundancy for both GRGT SGLT-6 and GRGT SGLT-7, and is expected to be operational in 2008.

Figure 2. Telecommunications Services for Each SGLT

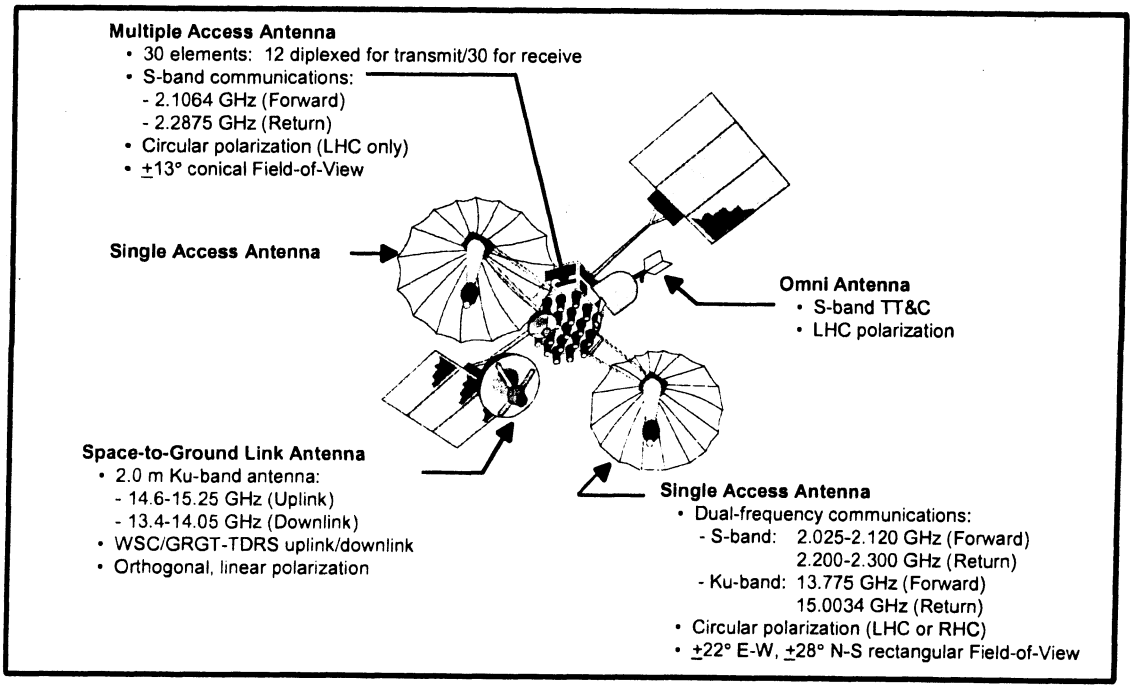


Figure 3. First-Generation Tracking and Data Relay Satellite (F1-F7)

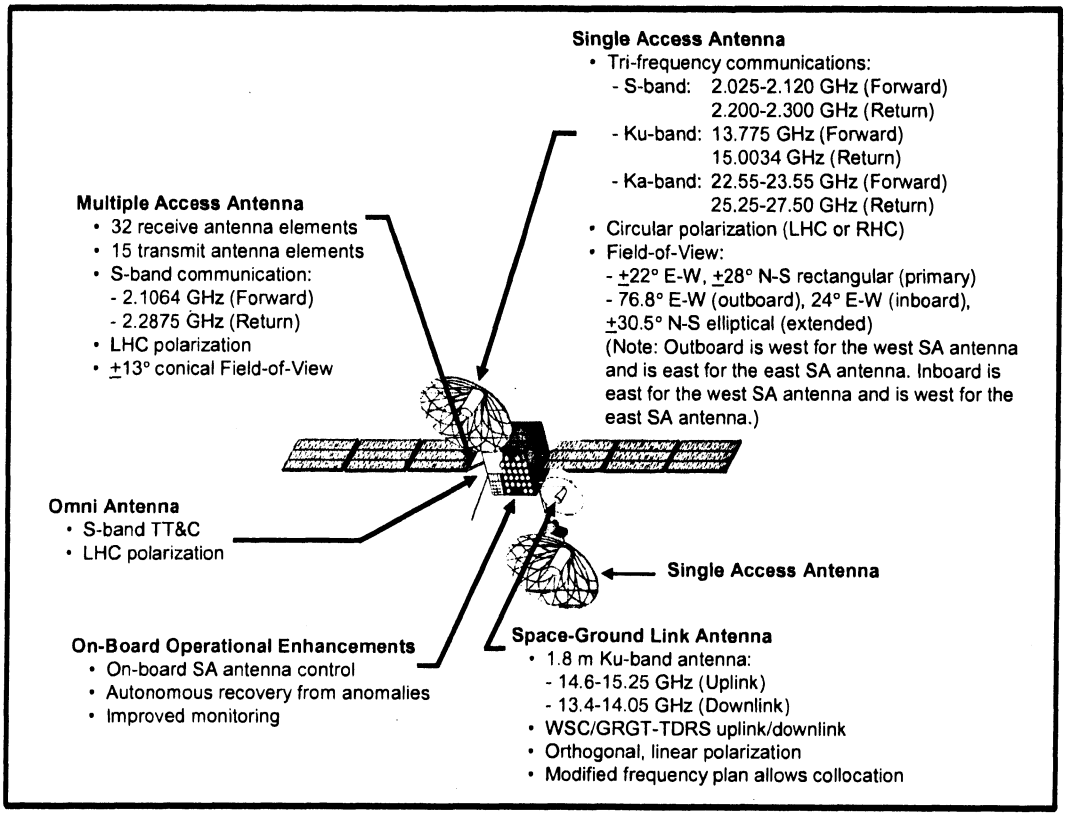


Figure 4. Second-Generation Tracking and Data Relay Satellite (F8-F10 also known as H,I,J)

Return service characteristics are summarized in Table 3. Automated Intermediate Frequency (IF) services, which require customer receive equipment at WSC are also provided. Ka-band data rates higher than in Table 3 are achievable through the 650 MHz bandwidth IF service. Forward and return polarization must be the same for each service band.

User ranging and Doppler are provided. For user ranging, the long PN code on the forward link Q-Channel is turned around at the customer platform transponder and the two-way range between the ground terminal and the customer platform (via the TDRS) is measured. One- or two-way customer Doppler is measured. These data are provided to the FDF for customer orbit determination. Further detail on the telecommunications services provided by the TDRSS may be found in the SNUG.

III. Customer Services via the Third-Generation TDRS

NASA has contracted with Boeing for the third-generation TDRS. The contract is for two spacecraft designated TDRS K and L with an option for two additional TDRS (TDRS M and N). Proposed launch dates for TDRS K and L are 3/2012 and 2/2013. The contract includes modifications to the ground terminals at the WSC required for customer support via the new TDRS. The frequency plan and customer services via the new TDRS are essentially the same as with TDRS F8-F10. New features with the TDRS K, L include:

1) a new COMSEC implementation and associated TDRS command and telemetry system. There are no customer service impacts from this change.
2) a new digitally implemented 5-channel return MA beamformer with a new interface to the DAS system.
3) a Ka-band EET system for use with the new TDRS and F8-F10. Current EET capabilities are at S- and Ku-band only.

In addition, Boeing has proposed enhancements which include increased (higher than NASA specification) EIRPs for the SSA, MA and KuSA forward services. The values of forward EIRPs will be provided in the SNUG after on-orbit verification of the new TDRS.

Table 2. TDRSS Forward Service Characteristics

	MA (TDRS F1-F7 / TDRS F8-F10)	SSA	KuSA	KaSA (TDRS F8-F10)
Customer service links/satellite	1	2	2	2/TDRS up to 8/WSC
Space-to-Space Freq. Bands	2106.4 MHz	2025.8-2117.9 MHz	13.775 GHz	22.55-23.55 GHz
Space-Space Polarization	LHCP only	LHCP and RHCP (selectable)	LHCP and RHCP (selectable)	LHCP and RHCP (selectable)
RF Channel BW (3 dB, minimum)	6 MHz	20 MHz	50 MHz	50 MHz
Max Data Rate	300 kbps	7 Mbps	25 Mbps	25 Mbps
Modulation Scheme	QPSK/SS-BPSK; data rates ≤300 kbps	QPSK/SS-BPSK for data rates ≤ 300 kbps BPSK: 300 kbps < dr < 7 Mbps PCM/PM for data rates ≤ 1 Mbps PCM/PSK/PM for data rate ≤ 8 kbps	QPSK/SS-BPSK for data rates ≤300 kbps BPSK: 300 kbps < dr < 25 Mbps	QPSK/SS-BPSK for data rates ≤300 kbps BPSK: 300 kbps < dr < 25 Mbps
Field of View (max.)	• Primary (PFOV): ± 13° conical • LEOFOV: ± 10.5° conical	• PFOV: (rectangular) ± 22° east-west ± 28° north-south • Extended Elliptical (EEFOV) (F8-F10 only): 76.8° east-west (outboard) 24° east-west (inboard) ± 30.5° north-south	• PFOV: (rectangular) ± 22° east-west ± 28° north-south • LEOFOV: ± 10.5° conical • EEFOV (F8-F10 only): 76.8° east-west (outboard) 24° east-west (inboard) ± 30.5° north-south	• PFOV: (rectangular) ± 22° east-west ± 28° north-south • LEOFOV: ± 10.5° conical
Minimum Forward Link EIRP	• PFOV: F1-F7: 34 dBW F8-F10: 40 dBW • LEOFOV: F1-F7: 34 dBW F8-F10: 42 dBW	• PFOV (F1-F10) and EEFOV (F8-F10 only): Normal: 43.6 dBW High:46.3 dBW (F1-F7)/ 48.5 dBW (F8-F10)	• PFOV (F1-F10) and EEFOV (F8-F10 only): Normal/high autotrack mode: 46.5 dBW/48.5 dBW Normal/high program track mode: 40.5 dBW/42.5 dBW • LEOFOV: Normal/high autotrack mode: 46.5 dBW/48.5 dBW Normal/high program track mode: 44.0 dBW/46 dBW	• PFOV: Autotrack: 63.0 dBW Program track: 56.2 dBW • LEOFOV: Autotrack: 63.0 dBW Program track: 59.5 dBW

Table 3. TDRSS Return Service Characteristics

	MA (TDRS F1-F7 / TDRS F8-F10)	SSA	KuSA	KaSA (TDRS F8-F10)
Customer service links/satellite	5/TDRS up to 20/WSC 2/TDRS through GRGT	2	2	2/TDRS up to 8/WSC
Space-to-Space Freq. Bands	2287.5 MHz	2200-2300 MHz	15.0034 GHz	25.25-27.5 GHz
Space-Space Polarization	LHCP only	LHCP and RHCP (selectable)	LHCP and RHCP (selectable)	LHCP and RHCP (selectable)
RF Channel BW (3 dB, minimum)	6 MHz	10 MHz	225 MHz	225 or 650 MHz
Max Total (I+Q) Data Rate	300 kbps (F1-F7) / 3 Mbps (F8-F10) (rate ½ coded)	6 Mbps (rate ½ coded)	300 Mbps (uncoded)	300 Mbps (uncoded)
Return FEC Scheme	Rate 1/2 convol. (F1-F7) / Rate 1/2 or 1/3 convol. (F8-F10)	Rate 1/2 or 1/3 convol.	Rate 1/2 convol. or uncoded	Rate 1/2 convol. or uncoded
Return Data Group and Mode	DG1 modes 1 and 2 (F1-F7) / DG1 and DG2 (F8-F10)	DG1 and DG2	DG1 and DG2	DG2
Field of View (max.)	• PFOV: ± 13° conical • LEOFOV: ± 10.5° conical	• PFOV: (rectangular) ± 22° east-west ± 28° north-south • EEFOV (F8-F10 only): 76.8° east-west (outboard) 24° east-west (inboard) ± 30.5° north-south	• PFOV: (rectangular) ± 22° east-west ± 28° north-south • LEOFOV: ± 10.5° conical • EEFOV (F8-F10 only): 76.8° east-west (outboard) 24° east-west (inboard) ± 30.5° north-south	• PFOV: (rectangular) ± 22° east-west ± 28° north-south • LEOFOV: ± 10.5° conical • EEFOV: 76.8° east-west (outboard) 24° east-west (inboard) ± 30.5° north-south
TDRS G/T (Nadir, minimum)	Formed Beam: • PFOV: F1-F7: 2.2 dB/K F8 (cold)-F10: 3.2 dB/K F8 (hot): -0.2 dB/K • LEOFOV: F1-F7: 3.1 dB/K F8 (cold), F9-F10: 4.5 dB/K F8 (hot): 1.2 dB/K	• PFOV: 9.5 dB/K • EEFOV (F8-F10 only): 9.5 dB/K	• PFOV (F1-F10) and EEFOV (F8-F10 only): Autotrack: 24.4 dB/K Program track: 18.4 dB/K • LEOFOV: Autotrack: 24.4 dB/K Program Track: 21.9 dB/K	• PFOV and EEFOV: Autotrack: 26.5 dB Program track: 19.1 dB/K (PFOV only) • LEOFOV: Autotrack: 26.5 dB Program Track: 23.0 dB/K

IV. Planned Future Customer Services

As part of a modernization of the ground terminals, enhanced customer service capabilities are planned. Enhancements include replacement of existing High Data Rate and Integrated Receivers which provide all return data processing. The current customer support capabilities of these receivers will be retained. Enhancements being considered include (1) bandwidth-efficient modulation schemes, e.g., 8QPSK, and (2) block-error correction techniques, e.g., R 1/2 and R 7/8 LDPC and TPCs. Combinations of these enhancements are expected to increase achievable data rates to the 1.0 to 1.5 Gbps range and reduce customer EIRP for lower data rates. The operational timeframe for these enhancements is estimated to be 2015.

These improvements will be included in the SNUG when available.

References

[1]"Space Network Users' Guide (SNUG)," NASA 450-SNUG, Rev. 9, August 2007. http://sep.gsfc.nasa.gov/tdrss/guide.html.