TDRSS 2nd Workshop

Sponsored by
NASA Headquarters' Office of Space Communications and Goddard Space Flight Center's Mission Operations and Data Systems Directorate

TDRSS Information Package:

The information in this document was prepared for and provided to individuals invited to attend the 2nd TDRSS Workshop held June 25, 26 1996. This information is being added to the TDRSS User Base Expansion (TUBE) project website to provide current, future and prospective TDRSS customers with additional technical data. Individuals desiring additional information are encouraged to utilize the points of contact as identified on the homepage or the contact as identified below.

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SYNOPSIS OF PRESENT AND FUTURE TDRSS CAPABILITIES

This document contains an overview of the present and planned Tracking and Data Relay Satellite System (TDRSS) and the capabilities of the TDRSS System. This document is also divided into the Space Segment capabilities, SECTION I, the Space Network/Ground Segment capabilities, SECTION II, and the spacecraft TDRS F_{1-7}/TDRS H, I, J Service Support Capabilities Comparison.

Introduction:

The present TDRSS consists of two operational geosynchronous altitude orbital TDR Satellites (TDRSs) located at 41° West Longitude (TDRS-4, designated TDE) and at 174° West Longitude (TDRS-5, designated TDW), and two operational Ground Terminals at the White Sands Complex (called the WSC) near Las Cruces, New Mexico (see Note 1). Additionally, there are TDRSs located at 46° West Longitude (TDRS-6), 49° West Longitude (TDRS-1), and 171° West Longitude (TDRS-7). Also, TDRS-3 is located at 275° West Longitude and is providing Zone of Exclusion (ZOE) support to the Gamma Ray Observatory (GRO) and the Space Shuttle (STS). It should be noted that the ZOE spacecraft has successfully supported the IUS/F-7 Transfer Orbit, during launch, as well. The TDRS is essentially a space based relay platform to provide "bent pipe" RF telecommunications based on the designed frequency plan, discussed later.

Note [1]: For up-to-date information on TDRSS, the satellite constellation and the White Sands Complex visit the GSFC Code 530 homepage at http://www530.gsfc.nasa.gov/tdrss/tdrsshome.html

The current NASA baseline requires three operating TDRS Spacecraft (TDE, TDW, and TDS) and a fourth TDRS over the Indian Ocean providing support through the GRO Remote Ground Terminal (GRTS). Two of the six TDRS Spacecraft are currently being held in "reserve". Similar "reserve" capability will continue following the White Sands Ground Terminal Upgrade return to operations in June 1996. Figure 1 provides an overview of the Space Network (configuration current as of June 1996).

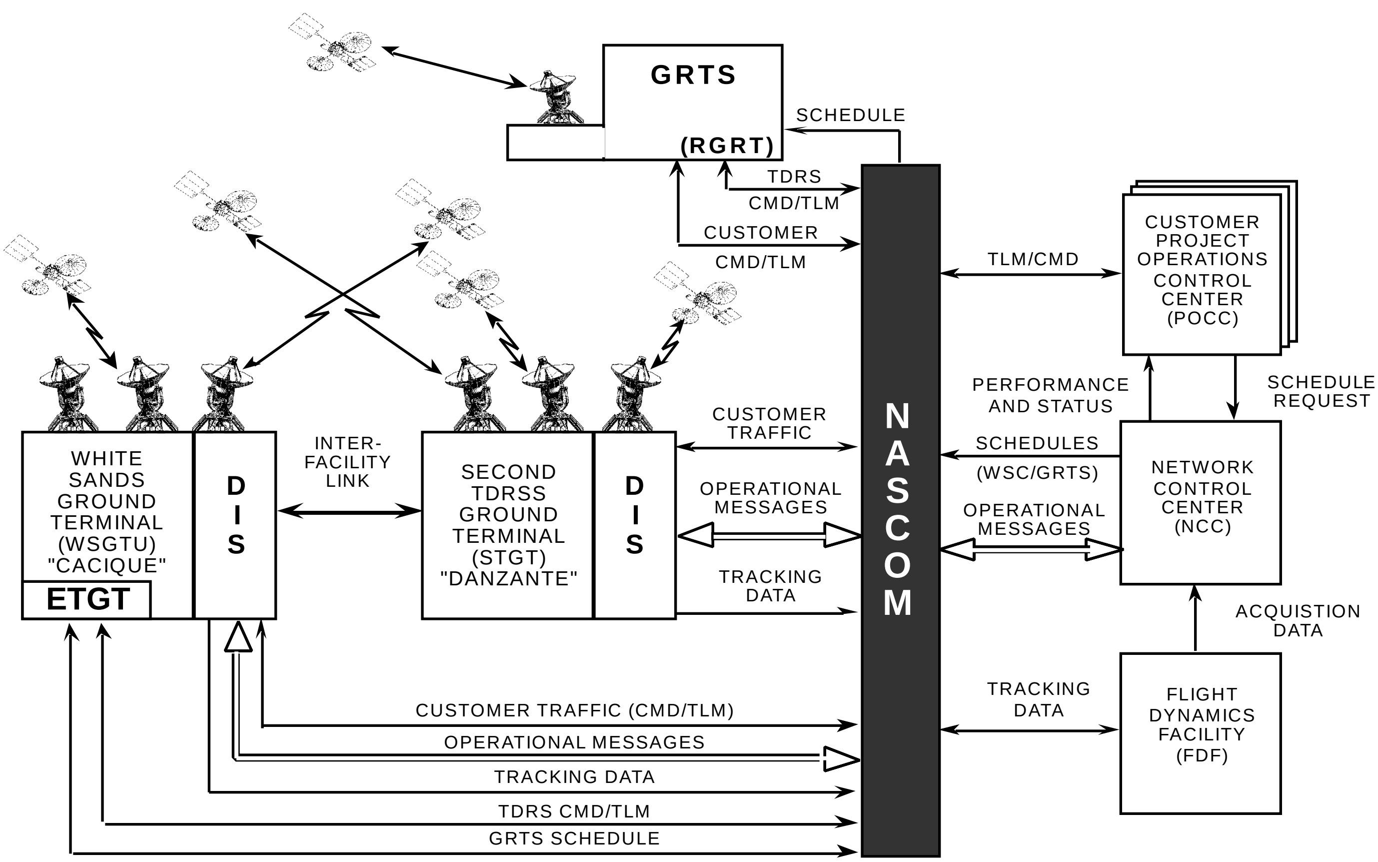


Figure 1 Space Network Overview

The present TDRSS provide the following types of mission support:

1) Provide Forward (to the User spacecraft) and Return (from the User spacecraft telecommunication links and data traffic between the User spacecraft Payload Operations Control Center (POCCs), via NASA Communications (NASCOM) interfaces, and the orbital User spacecraft.

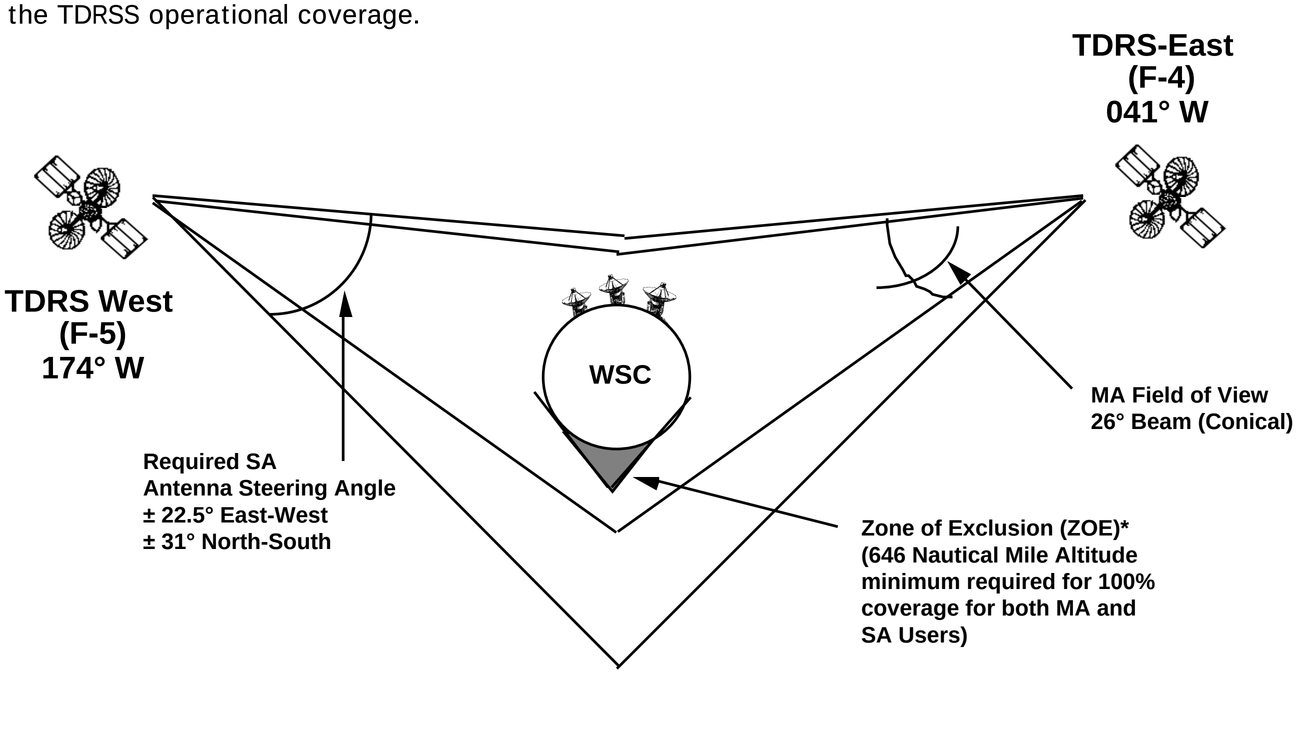
2) The TDRSS will provide three types of User spacecraft telecommunication services;
a) S-Band Single Access (SSA),
b) Ku-Band Single Access (KSA), and
c) Multiple Access (MA).

These services may be various modes and data rates of 100 BPS up to 25 MBPS[2] on the Forward link services and from 100 BPS to 300 MBPS[2] on the Return link services. The services may consist of coherent or non-coherent modes and provide range (tracking) and range rate (Doppler) services in conjunction with the data traffic.

3) Provide User spacecraft simulation and TDRSS system verification services. Ground Terminal generated data are used to simulate User spacecraft for performance verification. User spacecraft dynamics may also be simulated while performing various verification tests on the simulated services.

Note [2]: All data rates provided in this document are present TDRSS system capabilities and are, in most cases, Ground Terminal constraints. Each TDRS spacecraft has the capability to support higher data rates and formats assuming the Ground Terminal(s) are modified to accommodate these increased capacities. The specifics of the "increased" TDRS spacecraft capabilities are discussed and will become apparent in the next section of this document.

The TDRSS is characterized by its unique ability to provide bi-directional high data rates, as well as position information, to moving objects in real-time nearly everywhere around the globe. Figure 2 depicts the TDRSS operational coverage.



**TDZ (275° W) closes the ZOE.*

Figure 2 Operational TDRSS Coverage.

SECTION I:

Tracking and Data Relay Satellite (TDRS) Space Segment Overview:

This portion of the document provides an overview and summary description of major elements of the telecommunications payload of the NASA Tracking and Data Relay Satellite (TDRS), or the space segment of the TDRSS and the NASA Space Network (SN). See figure 3.

SPACE SEGMENT

TRACKING AND DATA RELAY SATELLITE

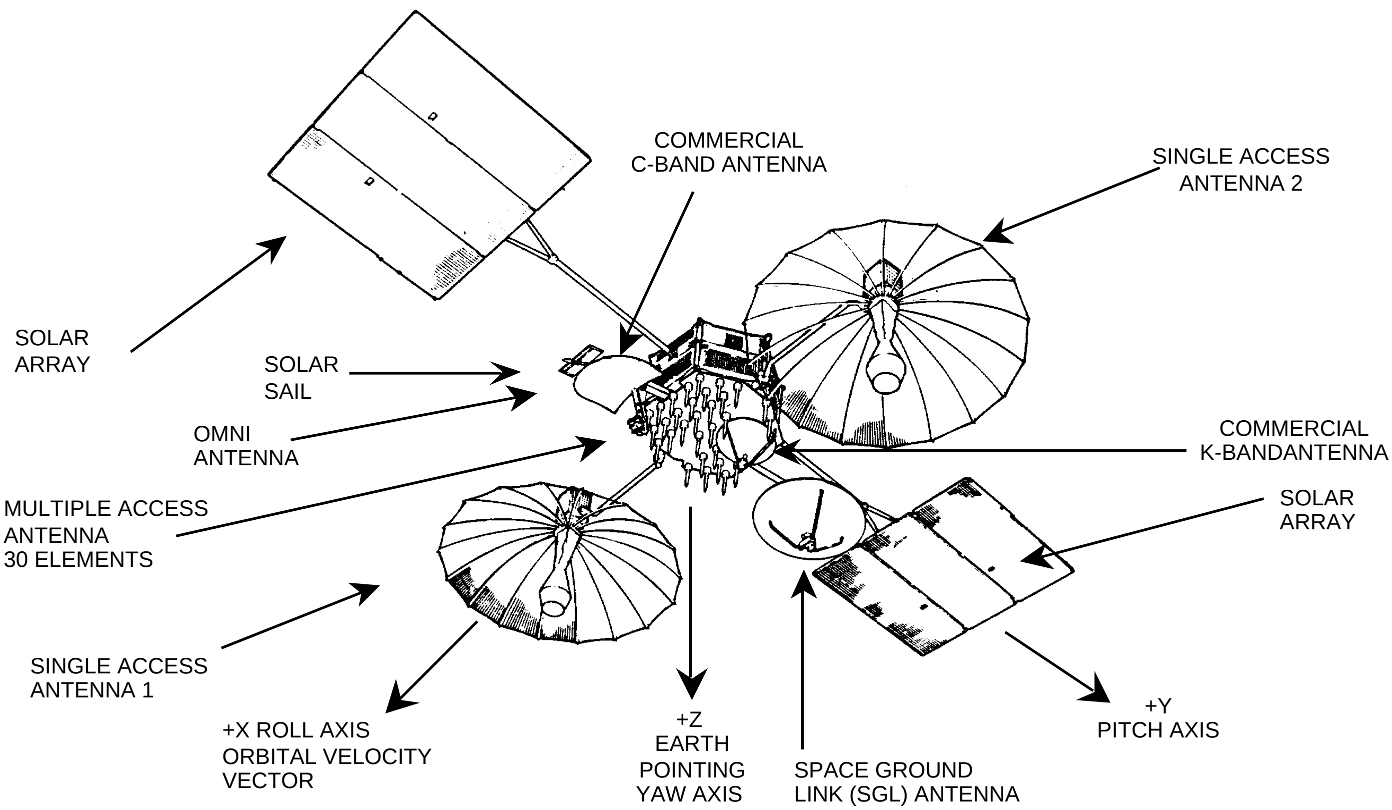


Figure 3 TDRS Satellite

TDRS S-Band and Ku-Band Telecommunications Payload Elements:
The TDRS telecommunications payloads includes three principal functional elements: the S-Band Multiple Access system (MA); the S-Band Single Access system (SSA); and the Ku-Band Single Access system (KSA). Each of these three functional elements may be described as a two-way (or full duplex) repeater system for radio frequency (RF) signals. Each repeater system has the major parameters of:

a. receive and transmit frequency(ies);

b. repeater bandwidth, gain, and operating characteristic;

c. antenna field-of-view (FOV), directivity, and polarization; and

d. repeater system figures-of-merit for receive sensitivity and transmit RF power level(s).

The tandem (two-hop) RF signal path from the NASA White Sands Complex (WSC) through the TDRS and on to a signal destination or customer is referred to as a forward link. The tandem RF signal path from a customer to the TDRS and on back to the WSC is referred to as a return link. That portion of a TDRS forward or return link which connects the WSC with the TDRS is referred to as a space-to-ground link (SGL); that portion of a forward or return link which connects the TDRS and a customer is referred to as a space-to-space link (SSL).

TDRS SGL and SSL frequency plans and major RF parameters are summarized in Tables 1 and 2, using the above definitions. The payload bandwidths listed in Table 1 are nominal as-built values and represent the maximum bandwidth available for signal reception, processing, and retransmission without the introduction significant amplitude and phase distortions.

TDRS Ku-Band Frequency Plan:
The TDRS Ku-Band frequency plan for SGL and SSL functions is shown in Table 1. The plan uses frequency division multiplexing and frequency re-use via orthogonal linear polarizations to accomplish multiple functions. KSA forward and return SSL frequencies are "nested" within the SGL bands.

Table 1: TDRS Payload Frequency Plan (Actual)

Service / Function	RF Link	Frequency, GHz (center or range)	Bandwidth, MHz (nominal)
MA	SSL Forward	2.1064	6
	SSL Return	2.2875	5
SSA	SSL Forward	2.030 to 2.113 [1]	20
	SSL Return	2.219 [2] to 2.290 [2]	12
KSA	SSL Forward	13.775	50
	SSL Return (Dedicated)	15.0034	225
	SSL Return (Composite)	15.0034	212
SGL	SGL Forward	14.6 to 15.23	650 [3]
	SGL Return (Pol 1)	13.51	225 [4]
	SGL Return (Pol 2)	13.4 to 14.05	650 [5]

Notes:

1. SSA forward and return center frequencies are tunable in 0.5 MHz steps.
2. SSA tuning capability extends below 2.219 GHz above 2.290 GHz, but is not normally used in Space Network operations because of the potential for customer interference to the "potential" TDRS S-Band Telemetry (at WSC) and the NASA Deep Space Network, respectively.
3. Uses frequency division multiplex; includes TDRS pilot and command signals; the spectrum region adjacent to either side of the 15.0034 KSA SSL Return frequency band is not used.
4. The SGL TWTA for Pol 1 handles only one signal: the KSA SSL Return Dedicated channel.
5. Pol 2 uses frequency division multiplex with linear polarization re-use; the stated bandwidth is not available as a contiguous signal channel; the KSA SSL Return Composite channel is at the high end of the band; also included are MA Return (30), SSA Return (2), and TDRS spacecraft 1 kbps telemetry.

Table 2: TDRS Payload RF Parameter Summary (Actual)

Service / Function	Polarization	TDRS EOL Specifications [1]		3 dB Contour Diam., Nadir	
		EIRP(dBW), min	G/T (dB/K), min	(deg)	(km)
MA	LHCP (fixed)	≥34.0 [2]	≥+0.5	4	2500
SSA	RHCP / LHCP (selectable)	≥37.5/43.6/46.1 (lin/norm/high)	≥+8.5	1.85	1155
KSA	RHCP / LHCP (selectable)	≥40.5/46.5/48.5 (lin/norm/high)	≥±23.8	0.28	175
SGL [4]	Linear, POL 1	≥50.8	≥+8.5	0.70	437
	Linear, POL 2	≥47.4	(N/A)	(N/A)	(N/A)

Notes:

1. End of Life; all TDRS spacecraft have excess performance capabilities at beginning of life; SSL EIRP values are TDRS F_{1-7} requirements established by NASA specification; SSL G/T values are TDRSS contractor allocations flowed down from NASA specifications.
2. Transmit formed MA beam which is command-steerable over ±13 degree conical FOV.
3. Any one of twenty receive ground-implemented formed beams, each steerable over a ±13 degree conical FOV.
4. SGL EIRP and G/T parameters in the table are allocations established by the TDRSS contractor. TDRS has no SGL POL 2 receive capability.

TDRS Reception of RF Signals:
Forward RF signals transmitted from the WSC to TDRS for retransmission to a customer are received on the TDRS SGL antenna, frequency converted, and routed to a signal processor for filtering (band limiting), amplification, and subsequent retransmission. The TDRS SGL antenna is steerable using mechanical gimbals in two axes. The pointing of the TDRS SGL antenna is continually adjusted using an open-loop control technique under WSC command and control to maintain the peak of the RF beam in the direction of the WSC.

Return RF signals transmitted to TDRS from a customer are received on one of the two single access (SA) antennas or on the MA phased array. Each SA antenna is pointed in the direction of its customer using mechanical gimbals in two axes. S-Band SA antenna pointing uses an open loop control technique with WSC command and control (program track); Ku-Band SA antenna pointing also has the option of using a closed loop pointing technique (autotrack). The S-Band TDRS MA phased array receiving system points an RF beam in the direction of a customer using an open-loop ground-implemented beam forming technique. This enables TDRS to point multiple MA receive beams at multiple customers simultaneously.

As is the case of forward signals, return signals are subject to frequency conversion, filtering, and amplification in preparation for retransmission to the WSC. TDRS processing of forward and return signals is discussed further below.

TDRS ALC Controlled Signal Processors:
Forward and return signals received at the TDRS are band-limited and linearly amplified in forward and return processors (alternatively referred to as repeaters or transponders). The processors act to maintain the processor output signal+noise power in the processor bandwidth at a level which is independent of received input signal level and noise conditions. The processor automatic level control (ALC) function controls its filtered output signal+noise power to a pre-set constant value. The processor ALC function readjusts to a change in steady-state input signal and noise conditions with a nominal time constant of 25 ms.

The input-to-output amplification factor (gain) of the processor is thus dependent on signal and noise conditions at the processor input. In addition to the ALC feature, step attenuation controls at the processor output permit ground operator adjustment of the processor output power to provide operational control of TDRS EIRP parameters and to compensate for payload component aging and unit-to-unit performance of redundant components in a given forward or return signal path. The processor output pin diode attenuator (PDA) control range is in excess of 20 dB.

Strong pulsed signals at the TDRS signal processor input are subjected to clipping (limiting) if their input instantaneous power is 9 dB or more above the steady-state input signal+ noise power which controls the processor ALC. This design feature precludes severe transient overdrive of subsequent components in the signal path (upconverter and TWTA, SSPA, etc.).

TDRS Retransmission of RF Signals:
After processing, forward signals received from the WSC are retransmitted to customers using one of the two single access (SA) antennas or using the MA phased array. Final signal amplification of SA signals is via traveling wave tube amplifiers (TWTA) (on F-7, solid-state power amplifiers (SSPAs) are used) with input power drive controls to adjust transmitter power, The S-Band TDRS MA phased array transmitting system uses eight solid-state power amplifiers to point a single RF beam in the direction of any single MA

customer using an open-loop beam forming technique under WSC command. There is no command adjustable power control for the MA forward transmission from TDRS.

Similarly, return RF signals received from customers are retransmitted to the WSC using the SGL antenna. Final power amplification of SGL return signals is done using wideband TWTAs. As is the case of forward signals, return signals are subject to frequency conversion, filtering, ALC leveling, and amplification in preparation for retransmission to the WSC.

TDRS TWTA Power Amplifiers:

Final power amplification of frequency translated and processed TDRS forward or return signals is done by traveling-wave tube amplifiers (TWTA). The power in vs. power out signatures of the TWTA devices used for the four TDRS transmit functions (SSA, KSA, and SGL POLs 1 and 2) are referred to as gain transfer characteristics or curves. The "power in" units are the PDA counts or settings of the processor output PDA control circuit. The PDA scale is approximately 0.25 dB per count, with zero counts being minimum attenuation. The ordinate "power out" units are calculated spacecraft EIRP.

After several years of on-orbit operations, TWTA cathode degradation and other aging effects will typically require PDA adjustments to shift operating points to the right (lower PDA counts), with some increase in TWTA amplifier amplitude non-linearity (compression). This is not, in general, an operational concern because the constant envelope angle-modulated signals designs used in all SN forward and return links are intrinsically insensitive to simple amplitude compression effects. Although F-7 uses SSPAs on the Ku-Band and S-Band Forward Services, the behavior of these amplifiers are similar to the TWTAs on F_{1-6}.

Payload Amplitude and Phase:
TDRS payload forward and return amplitude and phase requirements are specified in the form of templates with provisions for corrections using external equalization. Within the nominal bandwidths listed in Table 1, amplitude response is typically ≥1 dB peak to peak and phase response is typically ≥12 degrees peak to peak. Group delay (an alternate measure of phase response) is not specified or measured directly in the case of the TDRS payload. For the case of the KSA wideband return services in particular, instrumentation of phase measurements on-orbit poses practical problems; this contributes to a heavy reliance on the TDRS contractor's pre-launch factory data to model channel performance and specification compliance for all forward and return TDRS payload channel signal paths.

AM/PM and AM/AM:
The TDRS SA forward and return services can be operated in a number of modes with varying degrees of amplitude linearity and amplitude-to-phase effects. Table 3 summarizes TDRS payload AM/AM and AM/PM requirements, which are applicable at the TWTA drive conditions specified in Table 2. The TDRS MA forward link EIRP is not adjustable, and the AM/AM specification of ≥0.0 dB/dB is consistent with the as-built design, which uses bipolar transistors operated in saturation. All TDRS spacecraft meet or exceed AM/PM and AM/AM requirements when operated under specification conditions of signal tuning, TWTA drive, etc. As in the case of payload phase response, contractor's pre-launch factory data is the primary basis for specification compliance.

Table 3 TDRS Payload AM/PM and AM/AM Requirements

Service / Function	RF Link and Type	AM/PM (deg/dB, max)	AM/AM (dB/dB, max)
MA	Forward Return (each of 30 channels)	≥10.0 ≥4.0	≥ 0.00 ≥ 0.40
SSA	Forward lin/norm/high Return	≥10.0 ≥5.5	≥ 0.80 ≥ 0.50
KSA	Forward, lin/norm/high Return	≥6.0 ≥6.0	≥ 0.80 ≥ 0.75

Notes:

1. All requirements in this Table are allocations made by the TDRS F_{1-6} contractor as flow-down from requirements established by NASA specification.
2. The TDRSS customer scheduling process enables the customer to specify SA forward service as linear, normal, or high power, and the TDRS payload is reconfigured as necessary to make required adjustments in TDRS forward processor PDA settings to provide the requested forward link EIRP condition.

Incident Signal Strength to Capture TDRS Processor ALC:

A parameter which is frequently used to specify the sensitivity of a signal repeater or transponder in a communications satellite is the incident signal power flux density (PFD) to saturate the repeater output transmitter. The TDRS, as described above, uses linear ALC processors in the forward and return SA signal paths, and does not achieve output signal saturation in response to strong incident signals. A counterpart of the PFD to saturate parameter for TDRS is the isotropically received power (Prec) to fully capture the processor ALC. The TDRS forward or return processor is fully captured by an incident signal if the signal-to-noise ratio in the processor (Prec) noise bandwidth equals or exceeds +16 dB. Table 4 presents typical as-built TDRS processor noise bandwidths and calculated incident signal for ALC capture in the TDRS forward and return links. The MA return Prec parameter is N/A because the TDRS MA return system is code division multiplexed spread spectrum and is not operated in an ALC capture condition. The units of Prec are dBWi, i.e. watts received isotropically at TDRS.

Table 4 TDRS Noise BW and Prec for ALC Capture:

Service / Function	RF Link	Rcv. Freq. (GHz)	Noise BW (MHz)	Prec to Capture ALC (dBWi at TDRS)
MA	Forward	14.8	10	≥-151.1
	Return	2.2875	7	(N/A)
SSA	Forward	14.7	28.5	≥-145.5
	Return	2.250	16	≥-149.1
KSA	Forward	14.6; 15.2	65	≥ -141.9
(Ded)	Return (SGL Pol 1)	15.0034	236	≥ -153.6
(Comp)	Return (SGL Pol 2)	15.0034	217	≥ -153.3

Notes:

1. The center frequencies shown are nominal; the noise bandwidths shown are representative.
2. Ku-Band SGL forward links from the WSC are normally operated continuously and achieve ALC capture except in conditions of severe rain attenuation, gross antenna mispointing, or other anomaly.
3. SN SSA customers with forward error correction coding will typically operate with reduced power and utilize SSL return signals which are 10 dB or more below TDRS return processor ALC capture.
4. SN KSA customers with uncoded data rates ≥100 MBPS will typically operate in or near ALC capture.

Doppler Frequency Effects and Compensation:

As is the case for any geostationary satellite, RF signals transmitted to and from a TDRS are subject to frequency shifts due to the Doppler effect. SSL RF links to SN customers in LEO are subject to tens of kHz Doppler shift at S-Band and hundreds of kHz at Ku-Band. The Doppler effects experienced in S-Band and Ku-Band link from TDRS to the ground are much smaller, and depend on the details of the TDRS orbit, location of the ground site, and time-of-day. SSL RF link Doppler shifts and their rate of change are important as aids in the SN customer support functions of customer satellite orbit determination and update.

In routine SN operations, all frequencies generated on-board the TDRS are phase-lock referenced to a stable signal source at the WSC by the mechanism of the 15.500 GHz CW pilot signal. The pilot signal is received Doppler shifted at TDRS, and is used without frequency correction as the on-board phase-lock reference. Thus, forward signals transmitted from TDRS will be subject to complex Doppler offsets dependent on the details of the SGL uplink frequency used, time of day, etc. For many cases or conditions of SN customer forward link support, this is not viable and the design feature of TDRSS Doppler compensation is employed. In a typical forward service scenario, the customer specifies to TDRSS in his schedule request a corrected (or best-lock) frequency at which he desires the forward SSL signal to arrive at his moving satellite. TDRSS sets up the forward link with a predetermined frequency offset to fully compensate for all Doppler effects in both the Ku-Band SGL link and the Ku-Band or S-Band SSL. Doppler compensation may be removed in controlled fashion after the Customer's receiver has locked up to the TDRS forward SSL signal for the purpose of making range-rate measurements uncontaminated by offsets due to Doppler compensation.

The WSC return service equipment (receivers, demodulators, decoders, bit synchronizers, etc.) used to process Customer return signals are fixed-tuned, and an analog of the forward service Doppler compensation described above is used to position the center frequency of the customer's received signal exactly at the ground receiver's best-lock frequency. The return service equipment chains at STGT take advantage of *apriori* knowledge of Customer signal Doppler frequency offsets to aid ground receiver signal acquisition and processing.

Frequency Stability and Phase Noise:

The frequency reference for the SGL pilot signal is based on a cesium standard at the WSC. It has long-term stability and accuracy specifications of parts in 10^{-12}. Because all frequencies on TDRS are phase-locked to this reference, the operational TDRS has exceptional properties of frequency stability and accuracy. TDRS phase noise non-coherent with the ground standard is specified in terms of spectral regions removed from the carrier and bandwidth for each TDRS forward and return service. These specifications are consistent with high performance digital signal system performance in an environment which is primarily additive white gaussian thermal noise. A typical TDRS phase noise specification is ≥ 2.0 degrees rms over the band 1 kHz to 25 MHz for the KSA forward service. All TDRS F_{1-7} spacecraft meet or exceed applicable phase noise requirements.

Restrictions on Customer Signal Spectral Occupancy:

The SN does not impose major constraints on customer spectral occupancy other than those necessary by applicable bodies such as the ITU, FCC, and NTIA and good engineering practice. With the exception of the MA return service which uses code division multiplex to support multiple Customers simultaneously, TDRS supports Customers on a "one customer at a time per service" basis. Thus, in most instances, Customer signal power radiated at TDRS outside the TDRS receive frequency bands stated in this document is rejected through filtering or will be received at power levels and at frequencies which are of little practical consequence. The SN does have standards on customer RF and data signals which should be met to ensure expected levels of forward and return service performances. These standards were developed and formulated for use by moving satellite platforms, and on a case-by-case basis may not be applicable to stationary or near-stationary Customers.

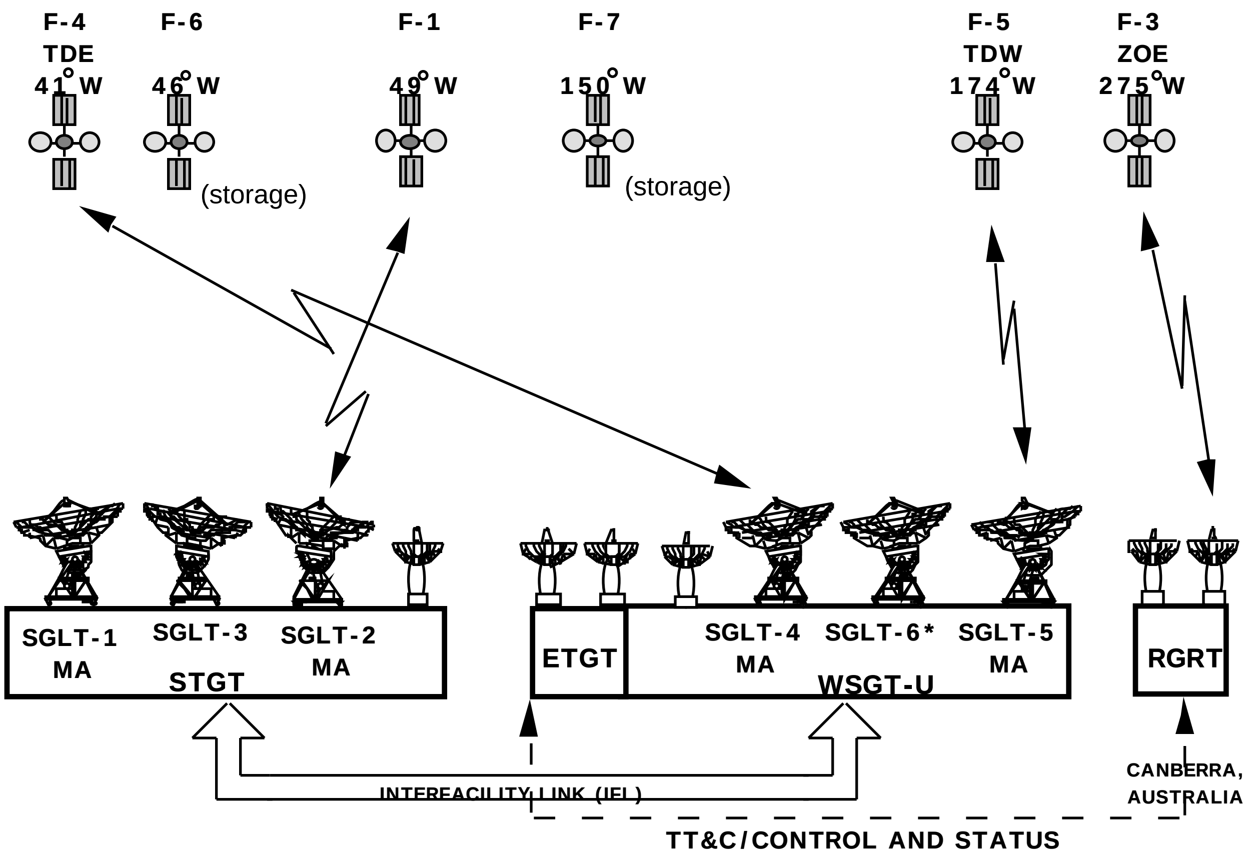
TDRS Constellation Stationkeeping:

All TDRS spacecraft are subject to East-West stationkeeping to ± 0.5 degree about their assigned longitude by ITU regulation. Certain spacecraft are station kept more tightly, including North-South to ± 0.1 degree at certain times and for certain applications. For the most part, NASA does not require stringent North-South stationkeeping to maintain TDRSS Services. Current TDRS operations (specification) allows N/S inclination growth to ± 7 Degrees

SECTION II:

Space Network/Ground Segment Capabilities

The White Sands Complex (WSC) consisting of the Second TDRSS Ground Terminal (STGT) and the White Sands Ground Terminal-Upgrade (WSGT-U), processes and routes, via NASCOM, all User communications and tracking data and provides full redundancy capabilities, within each Space to Ground Link Terminal (SGLT) Thus one SGLT can operate with one TDRS spacecraft and provide very high availability. Additional redundant equipment (including antennas for SGLT-3 and SGLT-6) may be simultaneously utilized by a Spare TDRS, or reserved as a "hot backup" for the primary assigned equipment, should there be a problem with the primary SGLTs equipment in service. NOTE: Presently, there are no Multiple Access capabilities on either SGLT-3 or SGLT-6. See Figure 4 (configuration current as of June 1996).



***** SGLT 6 originally planned for WSGT-U will be relocated to a new Remote Ground Terminal on Guam as an extended WSC SGLT. For up-to-date information on TDRSS, the satellite constellation, orbital locations, White Sands Complex, and the GRO Remote Ground Terminal please visit the NASA GSFC Space Network homepage at http://www530.gsfc.nasa.gov/tdrss/tdrsshome.html

FIGURE 4: WSC SGLT ARCHITECTURE

The current NASA baseline requires three operating TDRS Spacecraft (TDE, TDW, and TDS) and a fourth TDRS (TDZ) over the Indian Ocean supporting the GRO Remote Ground Terminal (RGRT). Two of the TDRS Spacecraft are currently being held in "reserve". Similar "reserve" capability will continue following the WSGT-Upgrade return to operations in June 1996.

TDRS-1 Through TDRS-7 Space to Ground (SGL) Link:

The TDRS Ku-Band Space to Ground link contains a combined Uplink (to a TDRS) and a Frequency Division Multiplexed (FDM) Downlink (from a TDRS) of User Forward and Return signals and the TDRS TT&C. The Downlink signals consist of two orthogonally polarized RF spectra, for isolation.

The Polarization 1 (POL1) Dedicated channel, is vertically polarized and provides:

KSA-1; A User Return dedicated channel with a total bandwidth of >225 MHz, and a center frequency of 13.5284 Ghz.

The Polarization 2 (POL 2) FDM Composite channel, is horizontally polarized and provides all of the remaining Return link services. The Composite Return channel (POL 2) is comprised of:

MA; 30 Return phased array elements with a total bandwidth of >225 MHz, and a center frequency of 13.51375 GHz.

SSA-1; A User Return channel with a total bandwidth of >10 MHz, and a center frequency of 13.6775 GHz.

SSA-2; A User Return channel with a total bandwidth of >10 MHz, and a center frequency of 13.6975 GHz.

Telemetry; The TDRS status is utilized by the WSC for spacecraft state of health monitoring, and a center frequency of 13.731 GHz.
Note: The S-Band Telemetry link (when activated) is transmitted at 2211.0 MHz.

KSA-2; A User Return channel with a total bandwidth of >225 MHz, and a center frequency of 13.928 Ghz.

The vertically polarized (POL1) SGL Uplink is comprised of a 625 MHz bandwidth with carriers at the following center frequencies:

MA; 1 User Forward channel at 14.8264 GHz ±200 kHz.

SSA-1; 1 User Forward channel at 14.6795 GHz ±380 kHz.

SSA-2; 1 User Forward channel at 14.7195 GHz ±380 kHz.

KSA-1; 1 User Forward channel at 14.6250 GHz ±1310 kHz.

KSA-2; 1 User Forward channel at 15.2000 GHz ±1310 kHz.

Command; 1 TDRS (only) channel at 14.7860 GHz ±2 kHz, utilized for TDRS commanding.
Note: The S-Band Command link (when used) is transmitted at 2035.9625 MHz.

Pilot Tone; 1 TDRS (only) channel at 15.1500 GHz ±2 kHz, utilized to control system frequency and phase coherence.

User Spacecraft Forward and Return Links:

NOTE: In the instances where "(H,I,J)" are provided, it is presented for comparison to TDRS $_{1-7}$ only.

- Single Access (SA) User Support Services:

  The TDR Spacecraft contain two dual-feed Single Access (AS) steerable antennas that provide both S-Band and Ku-Band telecommunication services to and from the User spacecraft. The East antenna services are referred to as SSA-1 or KSA-1 services, while the West antenna services are referred to as SSA-2 or KSA-2. The tables below provide all of the Forward and Return RF signal characteristics (Specification parameters) for both S-Band and Ku-Band. Additionally, the supported data rates (bit rates) are provided for each service channel. It should be noted that the Ground Segment data rates limit the capacity of the system and that if modified, could enhance and increase the data rates supportable. As an example, recent testing with hardware installed has successfully provided data rates of 450 MBPS through an existing TDRS, utilizing the 225 MHz Ku-Band Return Channel.

User S-Band (SSA-1 and SSA-2) Forward (Specification)

Transmit Frequency	Polarization	Antenna Gain
2020.0 MHz to 2123.5 MHz tunable in 0.05 MHz steps	LHCP or RHCP Command Selectable	>36 dB
Channel Bandwidth	Output Power	Antenna Beam width
≥20 MHz (2.5 dB)	>26 Watts	Appr. 2.08° (3 dB)
EIRP	Supported Data Rates*	Antenna Pointing
48.5 dBW (Shuttle High Power) 46.4 dBW (End of Life) 46.2 dBW (High Power) 44.3 dBW (Normal Power) 37.7 dBW (Linear IF)	100 BPS to 300 kBPS	Adj. over ±22.5° E/W and ±31° N/S

User S-Band (SSA-1 and SSA-2) Return (Specification)

Return Frequency	Polarization	Antenna Gain
2200 MHz to 2300 MHz tunable in 0.05 MHz steps	LHCP or RHCP Command Selectable	>36.8 dB
Channel Bandwidth	Input Range	Antenna Beam width
>10 MHz (2.5 dB)	-138 to -117 dBmi	Appr. 2.0° (3 dB)
G/T	Supported Data Rates*	Antenna Pointing
>8.9 dB/K	1 kBPS to 12 MBPS	Adj. over ±22.5° E/W and ±31° N/S

* SSA Return data is normally Rate 1/2 encoded or Rate 1/3 encoded and can also be Bi-Phase formatted. Detailed information Detailed information pertaining to modes of operation, convolutional encoding, data

formatting, interleaving, and modulation schemes can be found in the NASA Space Network Users Guide which is available on-line at http://www530.gsfc.nasa.gov/tdrss/guide.html

User Ku-Band (KSA-1 and KSA-2) Forward (Specification)

Transmit Frequency	Polarization	Antenna Gain
13.775 GHz ± MHz	LHCP or RHCP Command Selectable	>52.5
Channel Bandwidth	Output Power	Antenna Beam width
≥50 MHz (2.5 dB)	>1.5 Watts	Appr. 0.27° (3 dB)
EIRP	Supported Data Rates*	Antenna Pointing
49.4 dBW (End of Life) 49.4 dBW (High Power) 47.1 dBW (Normal Power) 41.3 dBW (Linear IF)	1 kBPS to 25 MBPS	Adj. over ±22.5° E/W and ±31° N/S with Autotrack capability

User Ku-Band (KSA-1 and KSA-2) Return (Specification)

Return Frequency	Polarization	Antenna Gain
15.0034 GHz ±3 MHz	LHCP or RHCP Command Selectable	>53.54 dB
Channel Bandwidth	Input Range	Antenna Beam width
>225 MHz (2.5 dB)	-140 to -119 dBmi	Appr. 0.27° (3 dB)
G/T	Supported Data Rates*	Antenna Pointing
>23.8 dB/K (F1-7) Actual >24.4 dB/K (F1-7) Spec >24.4 dB/K (H,I,J)	1 kBPS to 300 MBPS	Adj. over ±22.5° E/W and ±31° N/S with Autotrack capability

* KSA Return data can be uncoded, Rate 1/2 encoded and or Bi-Phase formatted. Detailed information pertaining to modes of operation, convolutional encoding, data formatting, interleaving, and modulation schemes can be found in the NASA Space Network Users Guide which is available on-line at http://www530.gsfc.nasa.gov/tdrss/guide.html

• Multiple Access (MA) User Support Services:

The TDRS MA receive antenna is a 30 element helical array, 12 of which are diplexed for transmit and receiving. The transmit (Forward) beam is formed on-board the TDRS by the utilization of commandable 4 bit phase shifters in the path of 8 of the 12 transmit elements. The tables below provide all of the User Forward and Return RF signal characteristics for the MA services. Additionally, the supported data rates (bit rates) are provided for the Forward and Return service channels. It should be noted that the Ground Segment data rates limit the capacity of the system and that if modified, could enhance and increase the data rates supportable.

User Multiple Access (MA) Forward (Specification)

Transmit Frequency 2106.4 MHz ±230 kHz Total EIRP (End of Life) >34 dBW (F1-7) >42 dBW (H,I,J)	Channel Bandwidth 6 MHz (2.5 dB) Polarization LHCP (only) Formed Beam Pointing 13° Conical (F1-7) 10.5° Conical (H,I,J)	Antenna Element Gain 12.8 dB Supported Data Rates* 100 BPS to 10 kBPS (F1-7) 100 BPS to 300 kBPS (H,I,J)

User Multiple Access (MA) Return

Transmit Frequency 2287.5 MHz ±230 kHz	Channel Bandwidth 6 MHz (3 dB) Polarization LHCP (only)	Formed Beam G/T > -1.5 dB/K (F1-7) > -4.5 dB/K (H,I,J) Supported Data Rates* 100 BPS to 100 kBPS (F1-F7) 100 BPS to 3 MBPS (H,I,J)

***** Ma Return is always Rate 1/2 encoded. * Detailed information pertaining to modes of operation, convolutional encoding, data formats and modulation schemes can be found in the NASA Space Network Users Guide. This document is available on-line at http://www530.gsfc.nasa.gov/tdrss/guide.html

TDRSS Service Summary/System Capacity

	Service Type	Maximum Data Rate[1]	Services per spacecraft[2]	STGT SGLT 1	STGT SGLT 2	STGT SGLT 3	WSGT-U[3] SGLT 4	WSGT-U[3] SGLT 5	WSGT-U[3] SGLT 6	White Sands Complex capability[4]
SSA	Forward	300 Kbps	2	2	2	2	2	2	-	10
SSA	Return	6 Mbps	2	2	2	2	2	2	-	10
KSA	Forward	25 Mbps	2	2	2	2	2	2	-	10
KSA	Return	300 Mbps	2	2	2	2	2	2	-	10
MA	Forward	10 kbps	1	1	1	0	1	1	-	4
MA	Return	100 kbps	5	5	5	0	5	5	-	20

Notes:

1- Detailed information pertaining to the various modes of operation, data formats, convolutional encoding options, and modulation schemes is available on-line at the TDRSS Online Information Center at http://www530.gsfc.nasa.gov/tdrss or at the NASA GSFC Space Network Users Guide site located at http://www530.gsfc.nasa.gov/tdrss/guide.html

2- Fully operational TDRS 1-7 series spacecraft

3- Current planning calls for the relocation of SGLT-6 from the WSGT-U to a new Remote Ground Terminal on Guam as an extended WSC SGLT. This node is planned to be operational in 1998.

4- This chart does not include support capability from the Extended TDRSS Ground Terminal and the Remote Ground Relay Terminal (RGRT). The ETGT is used to command and control the TDRS spacecraft designated as TDZ. The TDZ spacecraft in conjunction with the RGRT supports real-time operations for GRO and other customers requiring service in what is known as the TDRS Zone of Exclusion (ZOE). For additional information on the ZOE visit the TDRSS Online Information center. The ETGT also provides S-Band TT&C contingency backup to the STGT and WSGT-U ground terminals.

* Customer Tracking is available on all TDRSS services. Tracking services available are; one-way doppler and frequency determination and two-way doppler and range determination using Data Group 1 PN codes.

TDRS 1-7/TDRS H, I, J Service Support Capabilities Comparison

The following chart provides a comparison of the service capabilities available with the current TDRS 1-7 series of satellites and the TDRS H, I, J series of satellites. The TDRS-H, I, J enhanced MA and KaKSA capabilities will require hardware and software enhancements to the WSC Ground Terminals.

TDRS 1-7 /TDRS-H, I, J Baseline Service Comparison

SERVICE			TDRS 1-7	TDRS-H, I, J	NOTES
SINGLE ACCESS	S-BAND	FWD	300 kbps	300 kbps	NO CHANGE See Note 1
		RTN	6 Mbps	6 Mbps	
	Ku-BAND	FWD	25 Mbps	25 Mbps	NO CHANGE See Notes 1, 2
		RTN	300 Mbps	300 Mbps	
	Ka-BAND	FWD	N/A	50 Mbps	23/25-27 GHz frequency band See Notes 1, 2 and 3
		RTN	N/A	300 Mbps	
	NUMBER OF LINKS PER SPACECRAFT		2 SSA 2 KuSA	2 SSA 2 KuSA 2 KaSA	For TDRS-H, I, J, simultaneous operation of S & Ku and S & Ka services via a single SA antenna are required
NUMBER OF MULTIPLE ACCESS LINKS PER SPACECRAFT	FWD		1 @ 10 kbps	2 @ 300 kbps	See Note 4 For TDRS-H, I, J, beamforming will be performed on the spacecraft Anticipated SSA users <3 Mbps offloaded to TDRS-H, I, J MA See Notes 1 and 5
	RTN		5 @ 100 kbps	5 @ 1.5 Mbps	
CUSTOMER TRACKING			150 meters 3 sigma	150 meters 3 sigma	NO CHANGE

Notes:

1- The return data rates in this table are maximum I + Q total values. Detailed information pertaining to modes of operation, data formats, convolutional encoding options and modulation schemes is available on-line at the TDRSS Online Information Center http://www530.gsfc.nasa.gov/tdrss and at the Space Network Users Guide http://www530.gsfc.nasa.gov/tdrss/guide.html

2- The TDRS- H, I, J spacecraft will have the capability to support higher data rates, up to 800 Mbps, utilizing the full SGL bandwidth of 650 Mhz.

3- The TDRS-H, I, J Ka-Band service is time shared with the Ku-Band service.

4- The MA Forward EIRP is adjustable in 1 dB steps from 34 to 42 dBW.

5- TDRS 1-7 series spacecraft can support up to 20 MA Return links. The WSC Ground Terminals can only support 5 MA Return links per TDRS. (Each ground terminal can support multiple TDRS spacecraft)

Other TDRS H,I, J enhancements:

- TDRS H, I, J have the ability of collocating with themselves or one of the TDRS 1-7 spacecraft which allows for taking advantage of TDRS spacecraft with partially operating services.

- Dual TT&C frequency enables handling of the collocated spaceraft.

- The Single Access Antennas can point out to 70 degrees out board.

- The Ka-Band is tunable over the 2.5 Ghz range, while the Ku-Band is set at 15.0034 Ghz.