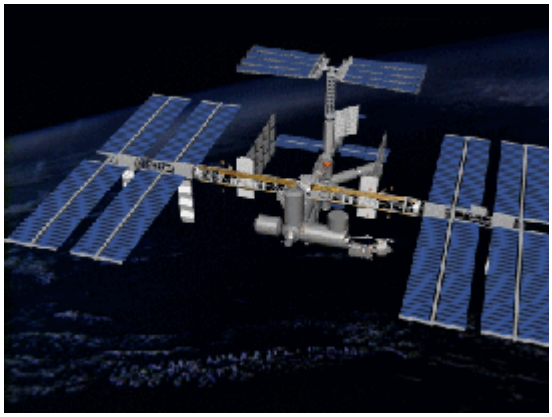
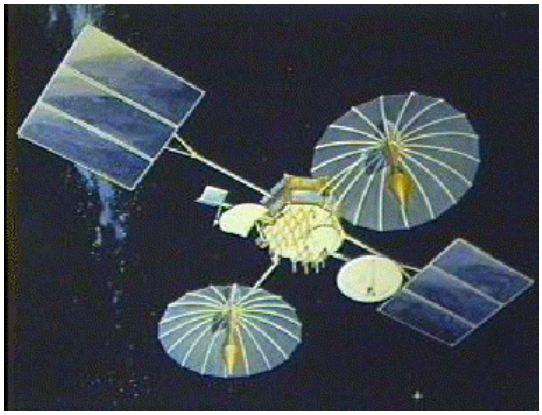
# INTERNATIONAL SPACE STATION

## COMMUNICATIONS, TRACKING, AND DATA ACQUISITION REQUIREMENTS AND OPERATIONS CONCEPTS





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## ABSTRACT

The main goal of the Space Network (SN) is to provide multiple crewed and robotic flight programs with high-quality, very reliable, global Communications, Tracking, and Data Acquisition (CT&DA) services. The most ambitious and complex of these programs is the International Space Station (ISS).

The ISS and associated re-supply missions referred to as Visiting Vehicles, require multiple space-to-ground Radio Frequency (RF) links as well as a global network of ground communication paths to join vehicle and payload operations with terrestrial-based controllers and scientists.

To understand the requirements the ISS and Visiting Vehicles have placed on the SN, it is convenient to organize them into three primary components: the Core Vehicle, Science, and Visiting Vehicle CT&DA services. These requirements are in some cases reasonably firm and complete, while others are evolutionary. Coordination of these services is on-going and involves several ISS teams and International Partner (IP) forums.

This paper provides a brief discussion of the requirements, both firm and evolving, and the SN planning and technical approaches to meeting the ISS's future service needs. Information on ground systems communication and data transport configurations are not addressed herein; however, this information can be provided upon request.


## SECTION 1. INTRODUCTION

The current SN architecture has progressed from a basic single satellite, main-frame based ground station to a multiple satellite, dual ground station system in response to expanded customer service support requirements, while taking full advantage of the evolution of computer and electronic technology. The ISS era is stimulating the application of continually improving technologies coupled with innovative SN operations techniques to ensure continued, high-quality customer support. To address the progression of enhanced and expanded SN capabilities, this paper is organized to first outline the ISS and Visiting Vehicle requirements, followed by information on the SN's evolution to today's configuration and operations concepts, and then concluding with the Tracking and Data Relay Satellite System (TDRSS) service characteristics and capabilities planned to be in place to meet all of the SN customer's needs during the ISS era.

## SECTION 2. ISS CT&DA REQUIREMENTS

Clear, unambiguous agreements between SN customers and service providers represent one of the key planning tools essential to enabling the manager’s ability to seek and obtain reconciliation between flight program CT&DA needs and support system capabilities. For the ISS, these agreements (or requirements) are quite complex and long-term, involving large expenditures and representing several years of coordination and cost-benefit trades.

ISS requirements are presented in two tables. Table 1A contains documented (firm) requirements, divided into Core Vehicle, Telescience, and Visiting Vehicle CT&DA services. Table 1B is similarly structured and includes evolving requirements designed to accommodate the enhanced video and science needs of the ISS customers and visiting re-supply vehicles in the operations and utilization phase. Also included, in Table 1C and Figure A, are the known and anticipated radio systems operating as part of the overall ISS clustered in the S-band frequency spectrum.

**Table 1A. Documented ISS/TDRSS Requirements**

| Date | FLT | Event | Requirement |
|---|---|---|---|
| **International Space Station Communication** | | | |
| July 1998 | 2A | Node 1/Early Communications (ECOMM) | S-band U/L: 6/128 kbps<br>D/L: 20.48/128 kbps |
| March 1999 | 4A | S-band Low Data Rate (LDR) Activation | S-band U/L: 6 kbps<br>D/L: 12 kbps |
| May 1999 | 5A | S-band High Data Rate (HDR) Activation | S-band U/L: 72 kbps<br>D/L: 192 kbps |
| June 1999 | 6A | Ku-band Activation | Ku-band D/L: 50 Mbps |
| January 2000 | UF-1 | Communications Outage Recorder | – |
| **Telescience Communication** | | | |
| June 1999 | 6A | Lab Racks Space to Space<br>– No FWD Link Supported<br>– Video Baseband Signal Processor (VBSP) up to 4 channels of video | Ku-band D/L: 50 Mbps |
| June 2002 | UF-5 | Ku-band Upgrade<br>– Ku-band FWD (RCVR & DEMUX)<br>– Multi-Channel FWD Compressed Video & sync Audio<br>– Multi-Channel Compressed Video FWD and RTN sync Audio | Ku-band D/L: 75 Mbps<br>Ku-band U/L: 3-10 Mbps |
| October 2003 | UF-7 | Ku-band Upgrade | Ku-band D/L: 150 Mbps |
| **Visiting Vehicle Communication** | | | |
| – | – | Space Shuttle | S-band U/L: 72 kbps<br>D/L: 192 kbps<br>Ku-band U/L: 216 kbps<br>D/L: 50 Mbps or Video |

**Table 1B. Evolving ISS/TDRSS Requirements**

| Date | FLT | Event | Requirement |
|---|---|---|---|
| **International Space Station Communication** | | | |
| July 1998 | LV | Russian Service Module (SM) | S-band & Ku-band |
| December 1998 | 2A.1 | Interim Control Module (ICM) | S-band U/L: 1 kbps<br>D/L: 1-8 kbps |
| June 1999 | 6A | Ku-band Activation | Ku-band U/L: 3 Mbps |
| **Telescience Communication** | | | |
| Future (?) | TBD | Wideband Ka-band (Enhanced K-band Plan Phase III)<br>– Expanded Bandwidth<br>– Increased Coverage<br>– High Speed Data Router FWD/RTN<br>– Support High Definition TV (HDTV) | Ka-band D/L: 300 Mbps<br>U/L: 25 Mbps |
| **Visiting Vehicle Communication** | | | |
| January 2001 | LV | Inspector | S-band D/L: 1 kbps |
| March 2002 | LV | Automated Transfer Vehicle (ATV) | S-band U/L: 2 kbps<br>D/L: 8 kbps |
| October 2002 | LV | H-II Transfer Vehicle (HTV) | S-band U/L: 250-500 kbps<br>D/L: 2-4 kbps |
| March 2003 | 18A | Crew Return Vehicle (CRV) | S-band D/L: 512 kbps |
| Future | TBD | Spartan-400 | S-band U/L: 2 kbps<br>D/L: 2 Mbps |
| Future (2010) | – | Reusable Launch Vehicle (RLV) | S-band |
| Future | LV | Soyuz | S-band |

**Table 1C. S-band Frequencies**

| 2287.5/2106.4 MHz (MA/SSA) | 2217.5/2041.9 MHz (SSA) | To Be Determined |
|---|---|---|
| ECOMM | Assembly Contingency Subsystem (ACS) | Spartan-400 |
| ATV | Space Shuttle | Inspector |
| HTV | CRV | RLV |
| Space Shuttle | | SM |
| | | ICM |
| | | Soyuz |

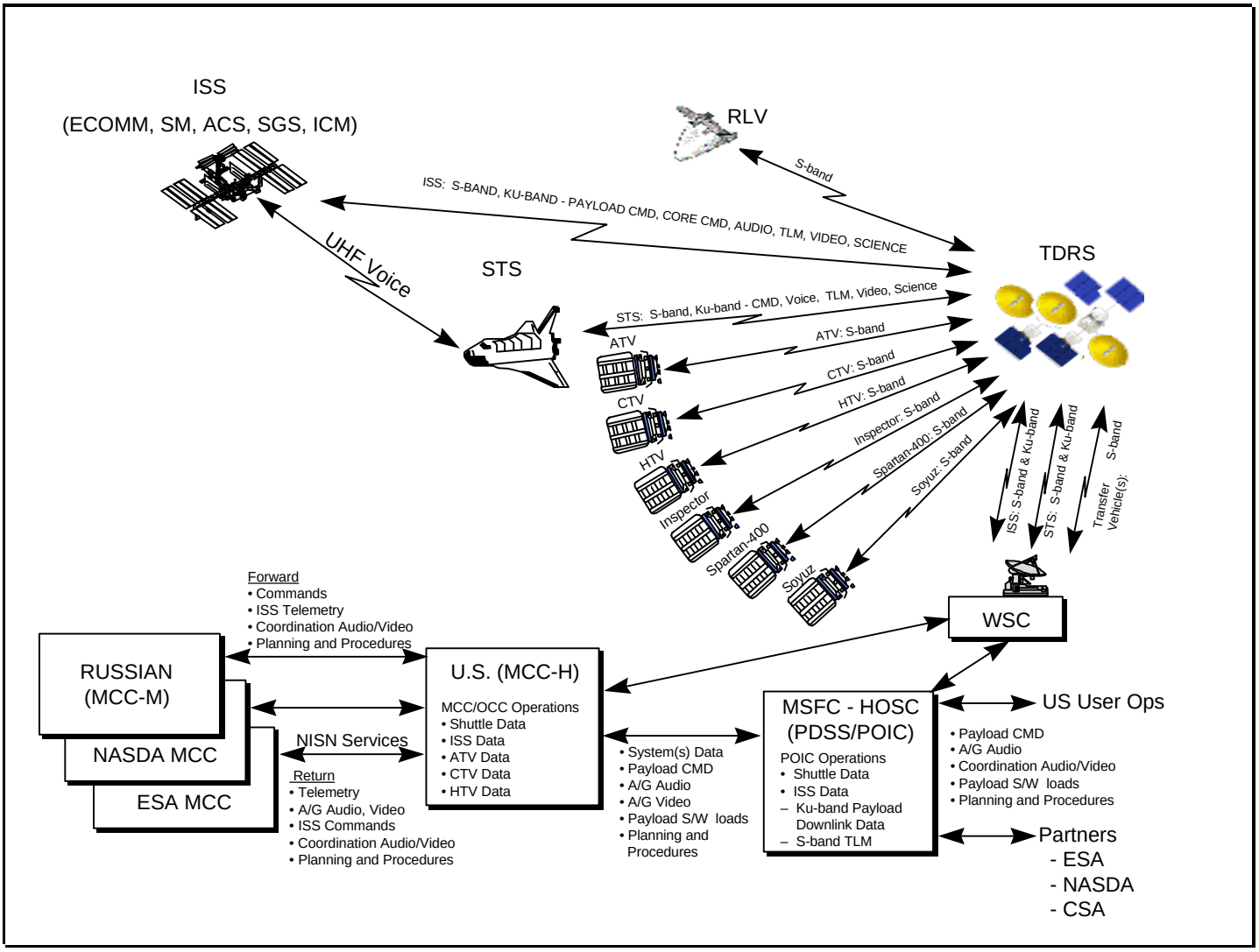


**Figure A. ISS/TDRSS Links**

## SECTION 3. SN CONFIGURATION AND OPERATIONS CONCEPTS

The evolution of the SN from a single satellite, single ground station configuration to today's multiple satellite and ground stations configuration (Figure B) was accomplished because the anticipated customer utilization model supported the need for significant increases in supportable services. Another upgrade objective was to implement an architecture consistent with technological advances in Radio Frequency devices and data handling/management systems. The services provided by the early configuration are no different in the current system; however, there will be improved support capabilities included in the follow-on Tracking and Data Relay Satellites (TDRSs) H, I, and J implementation as discussed in Section 4.

The SN operations concept is driven by electronically-conveyed customer requests for specific services for determined times, using pre-established configurations and Radio Frequency (RF) parameters. The services provided include forward and return links with tracking if requested.

Forward data relay services are provided for S-band Single Access (SSA), S-band Multiple Access (SMA) or Ku-band Single Access (KSA) scheduled supports and are only handled as real-time activities via the telecommunications path between the flight project control center and the user spacecraft.

Return data relay services are also provided using the SSA, SMA, or KSA scheduled supports handled in real-time, or with data recorded and played-back for either rate buffering, line outage protection, or to meet unique data needs of the receiving control center. No provisions are available for processing customer data except for time tagging and blocking into a format suitable for commercial data transport systems.

The SN provides one- or two-way tracking data for customer spacecraft orbit determination in the form of range and range rate measurements. Range measurements require the return service to have a Psuedo-random Noise (PN) range code which is coherent with the forward service range channel PN code. Two-way Doppler measurements require carrier frequency coherency between the forward and return services. PN ranging and Doppler measurements can be provided in conjunction with SSA, SMA, or KSA services.

Detailed information concerning the functions and operational use of the SN are available in the *Space Network User's Guide*, 530-SNUG, and other technical documents available via the Internet/World Wide Web (WWW) at Uniform Resource Locator (URL) http://tip.gsfc.nasa.gov/project/530other.htm.

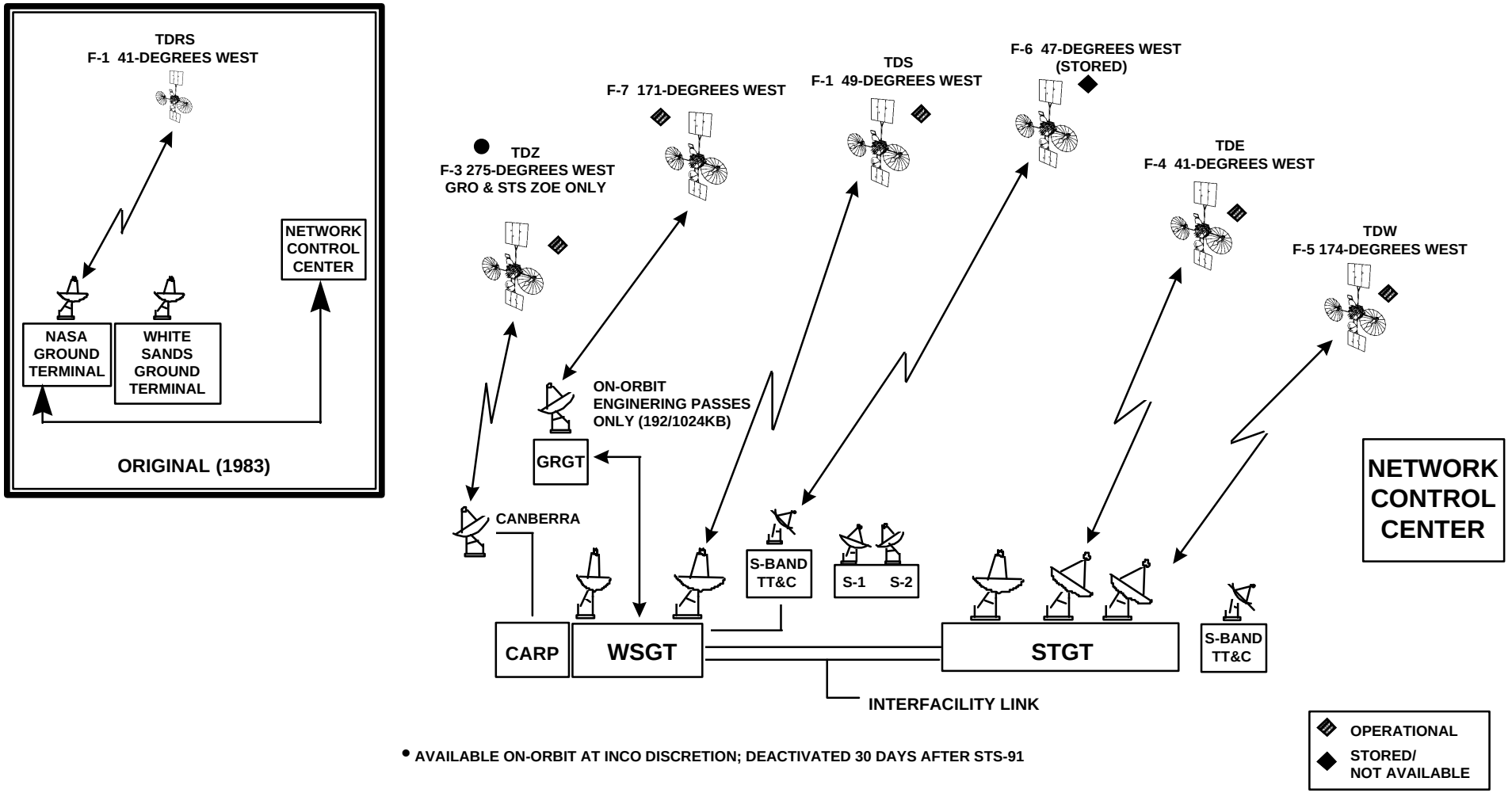


**Figure B. Space Network Configuration - Original (1983) and Present (1998)**

## SECTION 4. TDRSS SERVICES

Future Capabilities: The next generation of Tracking and Data Relay Satellites (TDRSs), termed H, I, and J, and their associated changes to NASA's White Sands Complex (WSC) are being developed for NASA by the Hughes Space and Communications Group (HSC) to provide SN customer support into the 21st century. Six of the current fleet of TDRSs, termed A through G, are on-orbit and providing scheduled services almost continuously as either prime or spare resources. This section describes the user support services provided by the SN and contrasts the new H, I, and J capabilities with those of the A through G spacecraft. Table 4A summarizes these services as provided by the SN.

**Table 4A. WSC Capabilities Comparison [4]**

| Service | | | WSC TDRS A-G Capabilities | WSC TDRS H, I, J Capabilities |
|---|---|---|---|---|
| Single Access | S-band | Forward | 300 kbps | 300 kbps |
| | | Return | 6 Mbps | 6 Mbps |
| | Ku-band | Forward | 25 Mbps | 25 Mbps |
| | | Return | 300 Mbps | 300 Mbps |
| | Ka-band | Forward | ———— | 25 Mbps |
| | | Return | ———— | 300 Mbps/800 Mbps[1] |
| | Number of Links | | 2 SSA/TDRS; 12 SSA/WSC<br>2 KuSA/TDRS; 12 KuSA/WSC | 2 SSA/TDRS; 12 SSA/WSC<br>2 KuSA/TDRS; 12 KuSA/WSC<br>2 KaSA/TDRS; 8 KaSA/WSC[2] |
| Multiple Access | | Forward | 1/TDRS @ 10 kbps<br>4/WSC | 2/TDRS[3] @ 300 kbps<br>4/WSC |
| | | Return | 5/TDRS @ 100 kbps<br>20/WSC | 5/TDRS @ 3 Mbps<br>20/WSC |
| User Tracking | | | Range, 1- & 2-way Doppler | Range, 1- & 2-way Doppler (No Ka-band Tracking) |

(1) Spacecraft Only; (2) Ku or Ka; (3) 1/TDRS at WSC; (4) For User Data Configurations, refer to the *Space Network User's Guide* (530-SNUG)

Support: The TDRSs support the SN missions with a real-time, bent-pipe telecommunications concept in which the TDRS acts as a relay between the user spacecraft and WSC. The WSC provides RF to base-band signal processing, data distribution, and user tracking data processing. TDRS services across the fleet include S-band Multiple Access (MA) and S-/Ku-band Single Access (SA) using 4.9-meter steerable antennae. For the H, I, and J spacecraft, Ka-band services are also available. Data rates for the services described in the following paragraphs are shown in Table 4A. Effective Isotropic Radiated Power (EIRP) and Gain/Temperature (G/T) values applicable to ISS and Visiting Vehicles as well as other near-earth orbiters are provided in Table 4B. The frequency bands described in the following paragraphs are for the TDRS to/from user links.

S-band: S-band SA Forward (SSAF) service frequencies are 2030 MHz to 2113.5 MHz. Return (SSAR) service frequencies are 2200 MHz to 2300 MHz. SSAR BPSK, QPSK, SQPSK, and SQPN modulation with Rate 1/2 encoding is supported by the SN with right- or left-hand circular polarization.

**Table 4B. TDRS H,I,J Forward and Return Link Capabilities**

| TDRS | Forward Link EIRP (dBw) | | | |
|---|---|---|---|---|
| H, I, J (Specification Values) | SSA | KuSA | MA | KaSA |
| | 36.3 to 48.5 in 1.0 dB steps | 39.0 to 49.0 in 1.0 dB steps | 34.0 to 42.0 in 1.0 dB steps | 59.5 Prog. Track 63.0 Autotrack |
| A-G (Current Operating Values) | 43.6 Normal 46.1 High | 46.5 Normal 48.5 High | 34.0 Minimum | – |
| **TDRS** | **Return Link G/T (dB/K)** | | | |
| H, I, J (Specification Values) | SSA | KuSA | MA | KaSA |
| | 8.5 | 18.4 Prog. Track 24.4 Autotrack | 4.5 | 23.0 Prog. Track 26.5 Autotrack |
| A-G | 8.5 | 23.0 | -14.7 per Element Max. 30 Elements | – |

Ku-band: The Ku-band Forward (KSAF) service frequency is 13775 MHz. The return frequency is 15003.4 MHz. Modulation schemes and polarization options are the same as the SSAR services with or without Rate 1/2 encoding.

Ka-band: User services supported via the TDRS H, I, and J spacecraft may make use of a new TDRSS service in the Ka-band frequency spectrum. Forward frequencies are tunable in 5-MHz steps, from 22555 MHz to 23545 MHz. Return frequencies are tunable in 25-MHz steps, from 25253.4 MHz to 27478.4 MHz. Polarization is selectable left- or right-hand circular, and modulation schemes are identical to the current TDRS A-G spacecraft for Ku-band.

**Note**

Simultaneous SA S-band and either Ku-band or Ka-band can be provided via each spacecraft SA antenna concurrent with MA services.

Multiple Access Services: MA services using the TDRS A-G spacecraft are provided through phased array antennas at S-band with a forward frequency of 2106.4 MHz and a return frequency of 2287.5 MHz. Beamforming for up to five simultaneous return services is performed at the WSC. Return service modulation is SQPN with Rate 1/2 encoding. Beamforming for forward services is performed on the TDRS spacecraft. Left-hand circular polarization is required.

MA services on the TDRS H, I, and J spacecraft use separate forward and return phased array antennae with on-board beamforming to provide up to five return and two forward services. Currently the WSC can only provide one forward service per TDRS spacecraft. As delineated in Table 4A, data rates available for MA user services are considerably higher than current TDRS spacecraft. Modulation schemes are identical to the SSAR services. Frequencies and polarization are the same as MA services on TDRS A-G.

Data Interleaving: Periodic convolutional deinterleaving and decoding is provided in the WSC for S-band services with data rates greater than 300 kbps.

Tracking Services: PN code ranging and Doppler tracking services are available for all TDRSS support except Ka-band. TDRSS auto-tracking of user spacecraft is offered when operating at both Ku-band and Ka-band.

# ACRONYMS AND ABBREVIATIONS

| ***Term*** | ***Definition*** |
|---|---|
| A-G | Air to Ground |
| ACS | Assemble Contingency Subsystem |
| ATV | Automated Transfer Vehicle |
| BPSK | Biphase (or Binary Phase) Shift Keyed (or Keying) |
| CRV | Crew Return Vehicle |
| CT&DA | Communications, Tracking, and Data Acquisition |
| dB | Decibel |
| dBW | Decibel Referred to 1 Watts |
| DEMUX | Demultiplexer |
| D/L | Downlink |
| ECOMM | Early Communications |
| EIRP | Effective Isotropic Radiated Power |
| FLT | Flight |
| FWD | Forward |
| G/T | Gain/Temperature |
| HDR | High Data Rate |
| HDTV | High Definition Television |
| HSC | Hughes Space and Communications Group |
| HTV | H-II Transfer Vehicle |
| ICM | Interim Control Module |
| IP | International Partner |
| ISS | International Space Station . |
| KaSA | Ka-band Single Access |
| kbps | Kilobits per Second |
| KSA | Ku-band Single Access |
| KSAF | Ku-band Forward |
| KuSA | Ku-band Single Access |
| LDR | Low Data Rate |
| LV | Launch Vehicle |
| MA | Multiple Access |
| Mbps | Megabits per Second |
| PN | Psuedo-random Noise |
| QPSK | Quadriphase Shift Keyed (or Keying) |
| RCVR | Receiver |
| RF | Radio Frequency |
| RLV | Reusable Launch Vehicle |
| SA | Single Access |
| SM | Service Module |
| SMA | S-band Multiple Access |
| SN | Space Network |
| SQPN | Staggered Quadriphase Pseudorandom Noise |
| SQPSK | Staggered QPSK |
| SSA | S-band Single Access |
| SSAF | S-band SA Forward |
| SSAR | S-band SA Return |
| TBD | To Be Determined |
| TDRS | Tracking and Data Relay Satellite |
| TDRSS | Tracking and Data Relay Satellite System |
| UF | Utility Flight |
| U/L | Uplink |
| URL | Uniform Resource Locator |
| VBSP | Video Baseband Signal Processor |
| WSC | White Sands Complex |
| WWW | World Wide Web |