PDS\_VERSION\_ID = PDS3

LABEL\_REVISION\_NOTE = "

 2006-12-27 SOC:Carcich Initial version;

 2007-06-30 SOC:Carcich Copied DSN info from dataset

 CO-SS-RSS-1-SCC2-V1.0

 on PDS Atmospheres Sub-node for NH archive

 2007-06-30 SOC:Carcich Misc fixes

 2014-07-03 SOC:Carcich Modified more recent DSN text

 2014-07-03 SOC:Carcich Re-wrote many sections.

 2014-08-08 PDS:Simpson Streamlined and updated for REX.

 "

RECORD\_TYPE = STREAM

OBJECT = INSTRUMENT

 INSTRUMENT\_HOST\_ID = "NH"

 INSTRUMENT\_ID = "REX"

 OBJECT = INSTRUMENT\_INFORMATION

 INSTRUMENT\_NAME = "RADIO SCIENCE EXPERIMENT"

 INSTRUMENT\_TYPE = "RADIO SCIENCE"

 INSTRUMENT\_DESC = "

########################################################################

########################################################################

REQUIRED READING:

- Tyler et al. (2008) [TYLERETAL2008]

########################################################################

########################################################################

 The REX & DSN descriptions were adapted from [DEBOLTETAL2005],

 from [DEBOYETAL2004], from [TYLERETAL2008], from PDS dataset

 CO-SS-RSS-1-SCC2-V1.0 at the PDS Atmospheres sub-node, and from

 the New Horizons website.

INSTRUMENT OVERVIEW

===================

REX requires the coordinated use of Earth-based transmitters and the New

Horizons receiver. The Earth-based 'Ground Element' is made up of the DSN

hardware and operations facilities that support the NH mission. The 'Flight

Element' includes the 2.1 m spacecraft high-gain antenna (HGA) and the NH

radio receiver that has a REX-specific signal processing board, which sends

its output to spacecraft data storage.

Scientific Objectives - REX

========

The primary purpose of the REX system is to investigate open questions

regarding atmospheric and ionospheric structure, surface conditions, and

planetary radii of both Pluto and Charon.

The REX encounter with the Pluto system is focused on occultations, by Pluto

and Charon, of an Earth-based, uplink radio signal. The New Horizons HGA will

remain pointed toward Earth for the duration of the occultation events,

beginning and ending with the line-of-sight to Earth well above any

anticipated sensible atmosphere or ionosphere. This arrangement

sets up three investigations at each occultation, plus a fourth gravity

investigation:

Investigation 1: Atmosphere characterization or detection

--------

As the Earth-spacecraft line-of-sight passes through the atmosphere of Pluto,

there will be a detectable shift in phase of the 7.2 GHz uplink signal as measured via the heterodyne-, downconversion- and sampling-circuitry that

composes REX. These occultation phase shifts provide opportunities for

characterization of Pluto's atmosphere and of a possibly sensible ionosphere;

a similar encounter allows a search for a sensible atmosphere and ionosphere

of Charon.

Investigation 2: Diameter measurement

--------

As the path of the signal approaches the limb, there will be predicable,

detectable changes in signal strength due to diffraction, allowing precise

measurement of entry and exit events. The time difference between the entry

and exit events, plus knowledge of Pluto-Charon, Earth, and spacecraft

ephemerides, will provide the length of the occultation chords.

Investigation 3: Dark side thermal emission

--------

During each occultation (when the uplink signal from Earth has been blocked),

REX can make measurements of radiothermal emissions at 4.2 cm (7.2 GHz).

The motion of the spacecraft causes the antenna beam to sweep across the

night side of Pluto and Charon while the pointing of the HGA remains fixed in

the Earth direction.

Investigation 4: Individual body masses

--------

Away from the limbs and above any atmosphere, perturbations in the measured

uplink signal, caused by the gravitational attractions of Pluto and Charon

on the spacecraft, may be used to infer their individual masses.

Those four investigation descriptions are greatly simplified; see

[TYLERETAL2008] for more detail.

INSTRUMENT OVERVIEW – FLIGHT ELEMENT

====================================

On-board the NH spacecraft, the REX instrument includes a low-power digital

receiver, a card-based transceiver implemented within an integrated

electronics module, and an ultrastable oscillator (USO) that provides the

precision frequency reference necessary for the uplink radio science

experiment. Other spacecraft hardware used by REX includes the

telecommunications system electronics and the 2.1 meter high gain antenna

(HGA). Refer to [TYLERETAL2008] for details.

Signals captured by the HGA are downconverted and passed through a 4.5 MHz

filter before entering the REX signal conditioning unit. Outputs from this

unit are: (1) in-phase (I) and quadrature (Q) 16-bit integer samples at

1250 sample pairs (complex) per 1.024 seconds -- i.e., approximately 1220.7

I samples per second and 1220.7 Q samples per second; and (2) the

radiometer output, consisting of 40-bit accumulating samples at a rate of

10 samples every 1.024 seconds.

SPECIFICATIONS

--------------

NAME: REX (Radio Science Experiment)

DESCRIPTION: Local oscillator vs. uplink signal phase comparator

PRINCIPAL INVESTIGATOR: Len Tyler, Stanford University

WAVELENGTH RANGE: 4.2 cm

FIELD OF VIEW: 20 mRad

ANGULAR RESOLUTION: 20 mRad

FREQUENCY RESOLUTION: 3 x 10^-13 (delta-f/f)

POWER CONSUMPTION: 0.33 W (1) / 1.6 W (2)

MASS: 3.5 g (1) / 160 g (2)

VOLUME: 1.25 cm^3 / 520 cm^3

(1) REX Hardware implementation

(2) REX on-board resource usage

Instrument Calibration - REX

========

HGA Beam Pattern Calibration

--------

The REX commissioning test on July 20, 2006 was dedicated to mapping the beam

pattern of the NH spacecraft high gain antenna. The REX science team obtained

the beam pattern by tuning the frequency of an unmodulated uplink signal of

constant power from the DSN to arrive at the NH spacecraft with a constant

frequency; the signal served as a calibration source. At the same time, the

team varied the spacecraft attitude with respect to the direction to Earth,

thus implementing a scan of the HGA beam over a small range of angles about

the Earth direction, centered approximately on the beam maximum. The initial

offset of the scan was set at the upper left corner of a 2007 x 2007 angular

box. The beam direction then was made to 'nod and step' parallel to the box

edges so as to perform a raster scan about the Earth direction. During the

scan the transceiver captured the uplink signal in REX mode, with the REX

output recorded and time-tagged on-board. At the same time the spacecraft body

vectors were logged and time-tagged. The combination of these two time

sequences allowed the team to map estimates of the uplink signal power to the

spacecraft pointing direction.

Sample Calibration

------------------

Raw 16-bit I and Q sample values are scaled to standard voltages using a

calibrated reference voltage and an Automatic Gain Control (AGC) setting.

The 40-bit radiometer samples are scaled to temperature values in Kelvin,

using a reference temperature calibrated from the noise figure of the New

Horizons radio receiver.

Radiometer Calibration

----------------------

On June 29, 2006, while in REX mode, the team obtained a series of five

crossed scans of radio astronomy sources together with dwells on cold sky.

The spacecraft HGA was initially commanded to point at an offset from the

source direction of -1 degree along the NH body coordinate x, and then scanned

across the source at 1E-4 rad/s to X = +1 degree, a maneuver that required

approximately 350s. Similar scans were performed for the vertical, or Z

coordinate, but with a dwell of 300 s at the origin x = z = 0.

One-second samples of power in a 4.5 MHz bandwidth were smoothed using a 10-s

sliding window; the standard deviation of the 10-s averages indicates that

the NH transceiver is radiometrically stable at a level of approximately

5 parts in 10,000, and thus adequate for measuring radiometric temperature

to a precision of 0.1K, or about 1 part in 1000.

Two additional radiometer calibrations were performed during the Jupiter

encounter at ~100Rj, on 24 February (inbound) and 05 March (outbound) 2007,

when the angular size of Jupiter closely matched the HGA beam.

See section 6 of [TYLERETAL2008] for further details.

Operational Considerations - REX

========

Controls

--------

The primary controls for REX are its power, the allocation of memory to store

REX data on the Solid State Recorder (SSR) via Command and Data Handling

(C&DH), and the automatic gain control (AGC) setting. REX generates In-phase,

Quadrature-phase and Radiometry values whenever it is on, although the memory

allocation determines when and whether those values are stored in the SSR.

Configuration of the spacecraft telecommuncations subsystem for use by REX

([HASKINS&MILLARD2004]; [TYLERETAL2008]; [DEBOYETAL2004]), allocation of

memory on the Solid State Recorder to store REX data, and telemetering stored

data to Earth are all necessary but outside the scope of this document.

The intersection of the periods when REX was on (time) and data allocations

(data volume) can be inferred from the existence of time-contiguous files of

REX data in the archived data set.

The AGC settings are provided as state tables, REX\_ACGGAINA.\* and

REX\_AGCGAINB.\* in the DOCUMENT/ section of the REX data sets.

REX data compression

--------------------

REX writes data to the SSR constantly, from before the first 1PPS (One Pulse

Per Second; spacecraft timekeeping signal) encountered after instrument

power-on until either the instrument is powered off, or the SSR allocation is

filled. For this reason, it is possible for the first frame (due to the wait

until the first 1PPS) and last frame (due to a power off asynchronous with

frame boundaries) to be incomplete.

When REX data are stored using compression, C&DH processing logic assumes

complete frames. Thus, when C&DH tries to compress REX data with incomplete

frames, it logs an error. Once this behavior was recognized (after 05 March

2007) REX data were always downlinked in packetized formats (Application

Process Identifiers. ApIDs - 0x7b1 or 0x7b3) rather than compressed formats

(ApIDs 0x7b0 or 0x7b2).

Detector & Electronics – Flight Element

=======================================

The amplifier chain is a conventional heterodyne design (see the figure

below). The noise performance of the receiver has been improved over previous

implementations by locating the leading low-noise amplifier (LNA) close to the

antenna to reduce the effective temperature of the wave guide connecting the

LNA to the high-gain antenna (HGA). The various mixing frequencies, fLO, for

the intermediate frequency (IF) amplifier stages are derived from the USO, as

are the clock reference frequencies used to drive the analog-to-digital

converter. The REX portion of the system, which follows the 4.5 MHz buffer and

anti-aliasing filter, is made up of an analog-to-digital converter (ADC) which

feeds a triply redundant programmed gate array (FPGA). This gate array

implements the two data processing functions required by the REX experiment.

These are i) calculation of the total power in the 4.5 MHz bandwidth

containing the uplink signal that enters the antenna, and ii) processing of

the 4.5 MHz data stream to isolate the 1 kHz portion of the frequency spectrum

containing the occultation signals in order that these can be returned to the

ground efficiently. The output of both processes is passed to the NH on-board

data memory for later transmission to Earth.

 \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_NH Receiver\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

/ \

 HGA

\ \_ +---------+ \_ +-------------------> To NH Command

 \ +---+ / \ | IF | / \ | & Tracking

+-)--|LNA|-->|X|-->|Amplifier|-->|X|--+

 / +---+ \\_/ | Chain | \\_/ | +-------------+

/ ^ +---------+ ^ +-->|4.5MHz Filter|--> To REX

 7.2Ghz |f |f +-------------+

 from DSN | LO | LO

 | 1 | final

 | +---+ |

 +-----| |---------+

 +---+

 ^

 \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_REX Signal Conditioning\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

/ | \

 ~~~

 ==========REX Hardware==========================

 [ ]

 [ = = =FPGA = = = = = = = = = = = ]

 [ ]

 [ [ ] ]

 [ +----------+ ]

 [ [ |4MHz Power| ] ]~10 samples/s @

f =2.5MHz [ +-------+ +-->|Integrator|--(/40)-+ ] 5 bytes/sample

 IF [ | ADC | [ | +----------+ | ] ]

from ------->|(T ,f )|-(/12)-+ +--------> To NH SSR

4.5MHz [ | s s | [ | +----------+ | ] ]

Filter [ +-------+ +-->|1kHz I&Q |--(/16)-+ ] 1250 complex s/s @

 [ [ |Digital | | ] ] 2\*2 bytes/sample

 [ |Filter |--(/16)-+ ]

 [ [ +----------+ ] ]

 [ ]

 [ = = = = = = = = = = = = = = = = ]

 [ ]

 ================================================

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 | ~~~

 | |

 \_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_ | \_\_\_\_\_USO Frequency Distribution\_\_\_\_\_\_\_

/ | | \

 ===== | |

 ( USO )--------+-----+----> to Tranceiver

 =====

See also the description above and [TYLERETAL2008], which contains a better

figure than can be achieved by the ASCII graphics used above.

Operational Modes - REX

========

1) REX mode for occultation studies.

Returns 16-bit In-phase and Quadrature (I&Q) ADC value pairs from the input

signal. The input signal is normally from the HGA by way of the receiver

electronics, but the input select

command can make REX use any of seven internally generated signals, for which

the results can be compared with deterministic results to ensure consistent

operation of REX.

2) Radiometry mode for surface temperature measurement.

At those times when the New Horizons spacecraft high gain antenna (HGA) points

toward Pluto or Charon, the REX instrument, operating in a 'radiometry mode,'

will receive 7.2 GHz thermal radio emission from the two bodies.

Opportunities to observe radio thermal emission occur during the several

minutes of radio occultation measurements when the disks of Pluto and Charon

obscure the Earth. The REX instrument will detect radiation from the

obscuring body as an increase in the radio system noise level in the

radiometry channel and also an increase in the noise floor of the occultation

channel. These observations will be used to derive the nightside emission

temperatures of Pluto and Charon. Similar observations will be taken of the

day side emission temperatures on approach for comparison.

See [TYLERETAL2008] for further details.

Measured Parameters - REX

========

1) Instantaneous strength of

 - uplink baseband signal, heterodyned by the Intermediate Frequency (IF)

 amplifier, a conventional design, to an intermediate frequency of

 2.5MHz, and passed through a 4.5Mhz filter,

 - sampled at 10 Msample/s,

 - downconverted and output as I&Q value pairs

 - at a rate of 1250 I&Q value pairs per 1.024s.

The process of down conversion from 10 Msample/s is accomplished by

heterodyning to zero frequency the uplink carrier signal centered initially at

the 2.5MHz IF center frequency, followed by use of time-invarient baseband

filters to reduce the bandwidth. The details are too extensive to include

here, but are explained in detail in [TYLERETAL2008].

2) Integrated power

 - cumulative over 1.024 seconds,

 - reset every 1.024 seconds,

 - at 10 samples per 1.024 second.

The REX power integrator (see the figure above) follows the conversion of the

uplink NH transceiver signal to 10 bit digital samples. These data are passed

to the REX processor at a rate of 10 Msample/s, where they are processed to

extract the total power in the input stream. This is accomplished by squaring

and averaging input samples over 102.4ms for each output sample, as

 kN

 \_\_\_\_\_

 \

 1 \ 2

 P (k) = - / s(i)

 UP N /\_\_\_\_

 i=1

where

 s(i) = one input sample (12 bits, 10Ms/s)

 P (k) = one output power sample @ 40 bits

 UP

 k = the index of one output sample, 1 to 10

 i = the index of the input samples

 N = the number of input samples included in 102.4ms

See [TYLERETAL2008] for further details.

Instrument Overview - DSN

=========================

 Three Deep Space Communications Complexes (DSCCs) (near Barstow, CA;

 Canberra, Australia; and Madrid, Spain) compose the Deep Space

 (tracking) Network (DSN). Each complex is equipped with several

 antennas (including at least one each 70-m, 34-m High Efficiency

 (HEF), and 34-m Beam WaveGuide, BWG), associated electronics, and

 operational systems. A primary activity at each complex is radiation

 of commands to and reception of telemetry data from active spacecraft.

 Transmission and reception are possible in several radio frequency

 bands; the most common are S-band (nominally a frequency of 2100-2300

 MHz, or a wavelength of 14.2-13.0 cm) and X-band (7100-8500 MHz, or

 4.2-3.5 cm). Transmitter output powers of up to 100 kW S-band and 20

 kW X-band are available.

 Ground stations have the ability to transmit coded and uncoded

 waveforms which can be echoed by distant spacecraft. Analysis

 of the received coding allows navigators to determine the

 distance to the spacecraft; and analysis of Doppler shift on the

 carrier signal allows estimation of the line-of-sight

 spacecraft velocity. Range and Doppler measurements are used

 to calculate the spacecraft trajectory and to infer gravity

 fields of objects near the spacecraft.

 Ground stations can record spacecraft signals that have

 propagated through or been scattered from target media.

 Measurements of signal parameters after wave interactions with

 surfaces, atmospheres, rings, and plasmas are used to infer

 physical and electrical properties of the target. For New Horizons REX,

 the signals transmitted from the DSN served as the probe, and the

 scientific measurements were recorded on the spacecraft.

 The Deep Space Network (DSN) is managed by the Jet Propulsion

 Laboratory (JPL) of the California Institute of Technology for

 the U.S. National Aeronautics and Space Administration (NASA).

 Specifications include:

 Instrument Id : RSS

 Instrument Host Id : DSN

 Pi Pds User Id : N/A

 Instrument Name : RADIO SCIENCE SUBSYSTEM

 Instrument Type : RADIO SCIENCE

 Build Date : N/A

 Instrument Mass : N/A

 Instrument Length : N/A

 Instrument Width : N/A

 Instrument Height : N/A

 Instrument Manufacturer Name : N/A

 For more information on the Deep Space Network and its use in

 radio science see the report by Asmar & Renzetti, 1993

 [ASMAR&RENZETTI1993]. For design specifications on DSN subsystems see

 JPL Document 810-5 [DSN810-5]. For an example of use of the DSN for

 Radio Science see Tyler et al. (1992) [TYLERETAL1992].

Subsystems - DSN

================

 The Deep Space Communications Complexes (DSCCs) are an integral

 part of Radio Science instrumentation. Their system performance directly

 determines the

 degree of success of Radio Science investigations, and their

 system calibration determines the degree of accuracy in the

 results of the experiments. The following paragraphs describe

 the functions performed by the individual subsystems of a DSCC.

 For additional information, consult [DSN810-5], [DSN821-110],

 and [DSN821-104].

 Each DSCC includes a set of antennas, a Signal Processing

 Center (SPC), and communication links to the Jet Propulsion

 Laboratory (JPL). The general configuration is illustrated

 below.

 -------- -------- -------- --------

 | DSS 25 | | DSS 27 | | DSS 14 | | DSS 15 |

 |34-m BWG| |34-m HSB| | 70-m | |34-m HEF|

 -------- -------- -------- --------

 | | | |

 | v v |

 | --------- |

 --------->|GOLDSTONE|<----------

 | SPC 10 |

 |---------|

 | SPC |

 | COMM |

 ---------

 | |

 v v

 ------ ---------

 | NOCC |<--->| |

 ------ | CENTRAL |

 ------ | COMM | ----------

 |AMMOS |<--->| TERMINAL|<-------------->| NASCOM |

 ------ --------- ---------

 ^ ^

 | |

 CANBERRA (SPC 40) <---------------- |

 |

 MADRID (SPC 60) <----------------------

 The following table lists some of the DSN antennas that were available

 To REX. The DSS (Deep Space Station) is nomenclature carried over from

 earlier times when antennas were individually instrumented).

 GOLDSTONE CANBERRA MADRID

 Antenna SPC 10 SPC 40 SPC 60

 -------- --------- -------- --------

 34-m HEF DSS 15 DSS 45 DSS 65

 34-m BWG DSS 24 DSS 34 DSS 54

 DSS 25 DSS 55

 DSS 26

 34-m HSB DSS 27

 DSS 28

 70-m DSS 14 DSS 43 DSS 63

 Developmental DSS 13

 Subsystem interconnections at each DSCC are shown in the

 diagram below, and are described in the sections that follow.

 The Monitor and Control Subsystem is connected to all other

 subsystems; and the Test Support Subsystem can be.

 DSCC

 ----

 ----------- ------------------ ---------------------

 |TRANSMITTER|\_| UPLINK |\_| COMMAND |\_

 | SUBSYSTEM | | SUBSYSTEM | | SUBSYSTEM | |

 ----------- ------------------ --------------------- |

 | |

 ----------- ------------------ --------------------- |

 | MICROWAVE |\_| DOWNLINK |\_| TELEMETRY |\_|

 | SUBSYSTEM | | SUBSYSTEM | | SUBSYSTEM | |

 ----------- ------------------ --------------------- |

 | |

 ----------- ----------- --------- -------------- |

 | ANTENNA | | MONITOR | | TEST | | DIGITAL |\_|

 | SUBSYSTEM | |AND CONTROL| | SUPPORT | |COMMUNICATIONS|

 ----------- | SUBSYSTEM | |SUBSYSTEM| | SUBSYSTEM |

 ----------- --------- --------------

 DSCC Monitor and Control Subsystem

 ----------------------------------

 The DSCC Monitor and Control Subsystem (DMC) is part of the

 Monitor and Control System (MON) which also includes the

 ground communications Central Communications Terminal (CCT) and

 the Network Operations Control Center (NOCC) Monitor and Control

 Subsystem. The DMC is the center of activity at a DSCC. The

 DMC receives and archives most of the information from the

 NOCC needed by the various DSCC subsystems during their

 operation. Control of most of the DSCC subsystems, as well

 as the handling and displaying of any responses to control

 directives and configuration and status information received

 from each of the subsystems, is done through the DMC. The

 effect of this is to centralize the control, display, and

 short-term archiving functions necessary to operate a DSCC.

 Communication among the various subsystems is done using a

 Local Area Network (LAN) hooked up to each subsystem via a

 network interface unit (NIU).

 DMC operations are divided into two separate areas: the

 Complex Monitor and Control (CMC) and the Network Monitor and

 Control (NMC). The primary purpose of the CMC processor for

 Radio Science support is to receive and store all predict

 sets transmitted from NOCC -- such as antenna pointing,

 tracking, receiver, and uplink predict sets -- and then, at a

 later time, to distribute them to the appropriate subsystems

 via the LAN. Those predict sets can be stored in the CMC for

 a maximum of three days under normal conditions. The CMC also

 receives, processes, and displays event/alarm messages, and

 maintains an operator log. Assignment and configuration of

 the NMCs is done through the CMC; to a limited degree the CMC

 can perform some of the functions performed by the NMC. There

 are two CMCs (one on-line and one backup) and three NMCs at

 each DSCC. The backup CMC can function as an additional NMC

 if necessary.

 The NMC processor provides the operator interface for monitor

 and control of a link -- a group of equipment required to

 support a spacecraft pass. For Radio Science, a link might

 include one or more Radio Science Receivers (RSRs), the DSCC

 Tracking Subsystem (DTK), and special equipment required for

 Ka-band uplink and/or downlink (i.e., aberration correction,

 monopulse receiver, and advanced media calibration system).

 The NMC also maintains an operator log which includes all

 operator directives and subsystem responses. One important

 Radio Science-specific function that the NMC performs is

 receipt and transmission of the system temperature and signal

 level data from the PPM, for display at the NMC console and

 for inclusion in Monitor blocks. These blocks are recorded

 on magnetic tape as well as appearing in the NOCC displays.

 The NMC is required to operate without interruption for the

 duration of the Radio Science data acquisition period.

 The Area Routing Assembly (ARA), which is part of the Digital

 Communications Subsystem, controls all data communication

 between the stations and JPL. The ARA receives all required

 data and status messages from the NMC/CMC, and can record them

 to tape as well as transmit them to JPL via data lines. The

 ARA also receives predicts and other data from JPL, and passes

 them on to the CMC.

 DSCC Antenna Mechanical Subsystem

 ---------------------------------

 Multimission Radio Science activities require support from

 the 70-m, 34-m HEF, and 34-m BWG antenna subnets. The

 antennas at each DSCC function as large-aperture collectors

 which, by double reflection, cause the incoming radio

 frequency (RF) energy to enter the feed horns. The large

 collecting surface of the antenna focuses the incoming energy

 onto a subreflector, which is adjustable in both axial and

 angular position. These adjustments are made to correct for

 gravitational deformation of the antenna as it moves between

 zenith and the horizon; the deformation can be as large as

 7 cm. The subreflector adjustments optimize the channeling

 of energy from the primary reflector to the subreflector,

 and then to the feed horns. The 70-m and 34-m HEF antennas

 have 'shaped' primary and secondary reflectors, with forms

 that are modified paraboloids. This customization allows

 more uniform illumination of one reflector by another. The

 BWG reflector shape is ellipsoidal.

 On the 70-m antennas, the subreflector directs

 received energy from the antenna onto a dichroic plate, a

 device which reflects S-band energy to the S-band feed horn

 and passes X-band energy through to the X-band feed horn. In

 the 34-m HEF, there is one 'common aperture feed,' which

 accepts both frequencies without requiring a dichroic plate.

 In the 34-m BWG, a series of small mirrors (approximately 2.5

 meters in diameter) directs microwave energy from the

 subreflector region to a collection area at the base of

 the antenna -- typically in a pedestal room. A retractable

 dichroic reflector separates the S and X bands on some BWG

 antennas, or the X and Ka bands on others. RF energy to be

 transmitted into space by the horns is focused by the

 reflectors into narrow cylindrical beams, pointed with high

 precision (either to the dichroic plate or directly to the

 subreflector) by a series of drive motors and gear trains

 that can rotate the movable components and their support

 structures.

 The different antennas can be pointed by several means. Two

 pointing modes commonly used during tracking passes are

 CONSCAN and 'blind pointing.' With CONSCAN enabled and a

 closed-loop receiver locked to a spacecraft signal, the

 system tracks the radio source by conically scanning around

 its position in the sky. Pointing angle adjustments are

 computed from signal strength information (feedback) supplied

 by the receiver. In this mode the Antenna Pointing Assembly

 (APA) generates a circular scan pattern which is sent to the

 Antenna Control System (ACS). The ACS adds the scan pattern

 to the corrected pointing angle predicts. Software in the

 receiver-exciter controller computes the received signal

 level and sends it to the APA. The correlation of scan

 position with the received signal level variations allows the

 APA to compute offset changes which are sent to the ACS.

 Thus, within the capability of the closed-loop control

 system, the scan center is pointed precisely at the apparent

 direction of the spacecraft signal source. An additional

 function of the APA is to provide antenna position angles and

 residuals, antenna control mode/status information, and

 predict-correction parameters to the Area Routing Assembly

 (ARA) via the LAN, which then sends this information to JPL

 via the Ground Communications Facility (GCF) for antenna

 status monitoring.

 During periods when excessive signal level dynamics or low

 received signal levels are expected (e.g., during an

 occultation experiment), CONSCAN should not be used. Under

 these conditions, blind pointing (CONSCAN OFF) is used, and

 pointing angle adjustments are based on a predetermined

 Systematic Error Correction (SEC) model.

 Independent of CONSCAN state, subreflector motion in at least

 the z-axis may introduce phase variations into the received

 Radio Science data. For that reason, during certain

 experiments, the subreflector in the 70-m and 34-m HEFs may

 be frozen in the z-axis at a position (often based on

 elevation angle) selected to minimize phase change and signal

 degradation. This can be done via Operator Control Inputs

 (OCIs) from the NMC to the Subreflector Controller (SRC)

 which resides in the alidade room of the antennas. The SRC

 passes the commands to motors that drive the subreflector to

 the desired position.

 Pointing angles for all antenna types are computed by

 the NOCC Support System (NSS) from an ephemeris provided by

 the flight project. These predicts are received and archived

 by the CMC. Before each track, they are transferred to the

 APA, which transforms the direction cosines of the predicts

 into AZ-EL coordinates. The LMC operator then downloads the

 antenna predict points to the antenna-mounted ACS computer

 along with a selected SEC model. The pointing predicts

 consist of time-tagged AZ-EL points at selected time intervals

 along with polynomial coefficients for interpolation between

 points.

 The ACS automatically interpolates the predict points,

 corrects the pointing predicts for refraction and

 subreflector position, and adds the proper systematic error

 correction and any manually entered antenna offsets. The ACS

 then sends angular position commands for each axis at the

 rate of one per second. In the 70-m and 34-m HEF, rate

 commands are generated from the position commands at the

 servo controller and are subsequently used to steer the

 antenna.

 When not using binary predicts (the routine mode for

 spacecraft tracking), the antennas can be pointed using

 'planetary' mode -- a simpler mode which uses right ascension

 (RA) and declination (DEC) values. These change very slowly

 with respect to the celestial frame. Values are provided to

 the station in text form for manual entry. The ACS

 quadratically interpolates among three RA and DEC points

 which are on one-day centers.

 A third pointing mode -- sidereal -- is available for

 tracking radio sources fixed with respect to the celestial

 frame.

 Regardless of the pointing mode being used, a 70-m antenna

 has a special high-accuracy pointing capability called

 'precision' mode. A pointing control loop derives the

 main AZ-EL pointing servo drive error signals from a two-

 axis autocollimator mounted on the Intermediate Reference

 Structure. The autocollimator projects a light beam to a

 precision mirror mounted on the Master Equatorial drive

 system, a much smaller structure, independent of the main

 antenna, which is exactly positioned in HA and DEC with shaft

 encoders. The autocollimator detects elevation/cross-

 elevation errors between the two reference surfaces by

 measuring the angular displacement of the reflected light

 beam. This error is compensated for in the antenna servo by

 moving the antenna in the appropriate AZ-EL direction.

 Pointing accuracies of 0.004 degrees (15 arc seconds) are

 possible in 'precision' mode. The 'precision' mode is not

 available on 34-m antennas -- nor is it needed, since their

 beamwidths are twice as large as on the 70-m antennas.

 DSCC Antenna Microwave Subsystem

 --------------------------------

 70-m Antennas: Each 70-m antenna has three feed cones installed

 in a structure at the center of the main reflector. The feeds

 are positioned 120 degrees apart on a circle. Selection of the

 feed is made by rotation of the subreflector. A dichroic mirror

 assembly, half on the S-band cone and half on the X-band cone,

 permits simultaneous use of the S- and X-band frequencies. The

 third cone is devoted to R&D and more specialized work.

 The Antenna Microwave Subsystem (AMS) accepts the received S-

 and X-band signals at the feed horn and transmits them through

 polarizer plates to an orthomode transducer. The polarizer

 plates are adjusted so that the signals are directed to a pair

 of redundant amplifiers for each frequency, thus facilitating

 the simultaneous reception of signals in two orthogonal

 polarizations. For S-band these are two Block IVA S-band

 Traveling Wave Masers (TWMs); for X-band the amplifiers are

 Block IIA TWMs.

 34-m HEF Antennas: The 34-m HEF uses a single feed for both

 S- and X-band. Simultaneous S- and X-band receive as well as

 X-band transmit is possible thanks to the presence of an S/X

 'combiner' which acts as a diplexer. For S-band, RCP or LCP

 is user selected through a switch, so neither a polarizer nor

 an orthomode transducer is needed. The X-band amplification

 options include two Block II TWMs or a High Electron Mobility

 Transistor (HEMT) Low Noise Amplifier (LNA), while the S-band

 amplification is provided by a Field Effect Transistor (FET)

 LNA.

 34-m BWG Antennas: These antennas use feeds and low-noise

 amplifiers (LNA) in the pedestal room, which can be switched

 in and out as needed. Typically the following modes are

 available:

 1. downlink non-diplexed path (RCP or LCP) to LNA-1, with

 uplink in the opposite circular polarization;

 2. downlink non-diplexed path (RCP or LCP) to LNA-2, with

 uplink in the opposite circular polarization;

 3. downlink diplexed path (RCP or LCP) to LNA-1, with

 uplink in the same circular polarization;

 4. downlink diplexed path (RCP or LCP) to LNA-2, with

 uplink in the same circular polarization.

 For BWG antennas with dual-band capabilities (e.g., DSS 25)

 and dual LNAs, each of the above four modes can be used in a

 single-frequency or dual-frequency configuration. Thus, for

 antennas with the most complete capabilities, there are sixteen

 possible ways to receive (2 polarizations, 2 waveguide path

 choices, 2 LNAs, and 2 bands).

 DSCC Receiver-Exciter Subsystem

 -------------------------------

 The receiver-exciter subsystem is split into the exciter component

 (called the UPL or Uplink Subsystem) and a separate receiver

 component (called the DTT or Downlink Tracking and Telemetry

 Subsystem). The UPL comprises the Exciter, the Command Modulation,

 the Uplink Controller, and the Uplink Ranging assemblies. The DTT

 comprises the Downlink Controller, the Receiver and Ranging

 Processor (RRP), and the Telemetry Processor (TLP) assemblies.

 The exciter generates a sky-level signal which is provided to

 the Transmitter Subsystem for the spacecraft uplink signal.

 It is tunable under command of the DCO ( Digitally Controlled

 Oscillator).

 The diplexer in the signal path between the transmitter and

 the feed horn for all antenna types (used for simultaneous

 transmission and reception) may be configured such that it is

 out of the received signal path (in listen-only or bypass

 mode) in order to improve the signal-to-noise ratio in the

 receiver system.

 The DSCC subsystem is built around the Block V Exciter (BVE) and

 Block V Receiver (BVR) equipment. The output from the BVEs is

 uplink carrier and range phase, and the output from the BVRs is

 downlink carrier and range phase. These phase data (and not Doppler

 counts and ranging units) are what get delivered to the users.

 Furthermore, the UPL and DTT deliver these (phase) data directly to

 the Project, without passing it through any intervening system.

 Closed-Loop Receivers: The closed-loop group consists of the Block

 V Receiver (BVR) and the Block V Exciter (BVE). The BVR allows for

 simultaneous use of multiple receiver channels, each configured

 independently of the other (thus allowing for the reception of two

 different frequencies/wavelengths/bands, or different polarizations

 of the same downlink band). The closed-loop receivers support as

 many downlink channels as can be assigned by the NMC (up to a

 maximum of the total number of RRPs available at a given complex).

 The only other constraint is that any selected downlink band/bands

 must be supported by that antenna.

 The closed-loop receivers provide the capability for the rapid

 acquisition of a spacecraft signal, and telemetry lock-up. In

 order to accomplish signal acquisition within a short time, the

 receivers are predict driven to search for, acquire, and track

 the downlink automatically. Rapid acquisition precludes manual

 tuning, though that remains as a backup capability. The BVRs

 utilize FFT analyzers for rapid lock-up. The downlink predicts

 are generated by the NSS and then transmitted to the CMC, which

 sends them to the Receiver-Exciter Subsystem where two sets can

 be stored. The receiver starts acquisition at the beginning of

 a track (pass), or at an operator-specified time. The BVRs may

 also be operated from the NMC without local operators attending

 them. The receivers also send performance and status data,

 displays, and event messages to the NMC.

 With the BVRs, the simulation (SIM) synthesizer signal is used

 as the reference for the Doppler extractor. The synthesizer is

 adjusted before the beginning of the pass to a frequency that

 is appropriate for the channel (i.e., within the band) of the

 incoming signal; and will genarally remain constant during the

 pass.

 The closed-loop receiver AGC loop can be configured to one

 of three settings: narrow, medium, or wide. It will be

 configured such that the expected amplitude changes are

 accommodated with minimum distortion. The loop bandwidth

 (2BLo) will be configured such that the expected phase

 changes can be accommodated while maintaining the best

 possible loop SNR.

 DSCC Transmitter Subsystem

 --------------------------

 The Transmitter (TXR) Subsystem accepts a sky-level frequency

 exciter signal from the Uplink (Exciter) Subsystem exciter.

 This signal is routed via the diplexer through the feed horn

 to the antenna, where it is then focused and beamed to the

 spacecraft.

 The Transmitter Subsystem power capabilities range from 18 kW

 to 400 kW, for S- and X-band uplink. Power levels above 20 kW

 are available only at 70-m stations.

 DSCC Tracking Subsystem

 ----------------------------------

 All the Tracking Subsystem functions are incorporated within the

 Uplink Subsystem (UPL) and the Downlink Tracking and Telemetry

 Subsystem (DTT).

 The primary functions of the DSCC Tracking Subsystem (DTK) are

 to acquire and maintain communications with the spacecraft, and

 to generate and format radio metric data containing Doppler,

 range, and uplink frequencies (ramps).

 The DTK receives the carrier signals and ranging spectra from

 the Receiver-Exciter Subsystem. The Doppler cycle counts are

 computed from BVR-provided carrier phase measurements, and are

 then formatted and transmitted to JPL in real time. Ranging

 data are also formatted and transmitted to JPL in real time.

 Also contained in these blocks is the AGC information from the

 Receiver-Exciter Subsystem.

 In addition, the Tracking Subsystem receives from the CMC

 frequency predicts (used to compute frequency residuals and

 noise estimates), receiver tuning predicts (used to tune the

 closed-loop receivers), and uplink tuning predicts (used to

 tune the exciter). From the NMC, it receives configuration

 and control directives, as well as configuration and status

 information on the transmitter, microwave, and frequency and

 timing subsystems.

 DSCC Frequency and Timing Subsystem

 -----------------------------------

 The Frequency and Timing Subsystem (FTS) provides all of the

 frequency and timing references required by the other DSCC

 subsystems. It contains four frequency standards, of which

 one is prime and the other three are backups. Selection of

 the prime standard is done via the CMC. Of these four

 standards, two are hydrogen masers followed by clean-up loops

 (CUL) and two are cesium standards. These four standards all

 feed the Coherent Reference Generator (CRG), which provides

 the frequency references used by the rest of the complex. It

 also provides the frequency reference to the Master Clock

 Assembly (MCA), which in turn provides time to the Time

 Insertion and Distribution Assembly (TID), which provides UTC

 and SIM-time to the complex.

 JPL's ability to monitor the FTS at each DSCC is limited to

 the station-calculated Doppler pseudo-residuals, the Doppler

 noise, the RSR, the SSI, and to a system that uses the Global

 Positioning System (GPS). GPS receivers at each DSCC receive

 a one-pulse-per-second signal from the station's (hydrogen-

 maser-referenced) FTS and a pulse from a GPS satellite at

 scheduled times. After compensating for the satellite signal

 delay, the timing offset is reported to JPL, where a database

 is kept. The clock offsets stored in the JPL database are

 given in microseconds; each entry is a mean reading of the

 measurements from several GPS satellites, and a time tag

 associated with the mean reading. The clock offsets that are

 provided include those of SPC 10 relative to UTC (NIST), SPC

 40 relative to SPC 10, etc.

Optics - DSN

============

 X-Band performance of the DSN ground stations depends primarily

 on size of the antenna and capabilities of the electronics.

 These are summarized in the following table.

 Beamwidth is half-power full angular width. Polarization is

 circular; L denotes left circular polarization (LCP), and R

 denotes right circular polarization (RCP).

 DSS X-Band Characteristics

 70-m 34-m 34-m

 Transmit BWG HEF

 -------- ----- ----- -----

 Frequency (MHz) 7145- 7145- 7145-

 7190 7190 7190

 Wavelength (m) 0.042 0.042 0.042

 Ant Gain (dBi) 73.2 66.9 67

 Beamwidth (deg) N/A 0.074

 Polarization L or R L or R L or R

 Tx Power (kW) 20 20 20

 Receive

 -------

 Frequency (MHz) 8200- 8400- 8400-

 8600 8500 8500

 Wavelength (m) 0.036 0.036 0.036

 Ant Gain (dBi) 74.2 68.1 68.3

 Beamwidth (deg) 0.032 N/A 0.063

 Polarization L & R L & R L & R

 System Temp (K) 20 30 20

Calibration - DSN

=================

 Calibrations of hardware systems are carried out periodically

 by DSN personnel; these ensure that systems operate at required

 performance levels -- for example, that antenna patterns,

 receiver gain, propagation delays, and Doppler uncertainties

 meet specifications. No information on specific calibration

 activities is available. Nominal performance specifications

 are shown in the tables above. Additional information may be

 available in [DSN810-5].

 Prior to each tracking pass, station operators perform a series

 of calibrations to ensure that systems meet specifications for

 that operational period. Included in these calibrations is

 measurement of receiver system temperature in the configuration

 to be employed during the pass.

Operational Considerations - DSN

================================

 The DSN is a complex and dynamic 'instrument.' Its performance

 for Radio Science depends on a number of factors from equipment

 configuration to meteorological conditions. No specific

 information on 'operational considerations' can be given here.

Operational Modes - DSN

=======================

 DSCC Antenna Mechanical Subsystem

 ---------------------------------

 Pointing of DSCC antennas may be carried out in several ways.

 For details see the subsection 'DSCC Antenna Mechanical

 Subsystem' in the 'Subsystem' section. Binary pointing is

 the preferred mode for tracking spacecraft; pointing

 predicts are provided, and the antenna simply follows those.

 With CONSCAN, the antenna scans conically about the optimum

 pointing direction, using closed-loop receiver signal

 strength estimates as feedback. In planetary mode, the

 system interpolates from three (slowly changing) RA-DEC

 target coordinates; this is 'blind' pointing since there is

 no feedback from a detected signal. In sidereal mode, the

 antenna tracks a fixed point on the celestial sphere. In

 'precision' mode, the antenna pointing is adjusted using an

 optical feedback system. In addition, it is possible on most

 antennas to freeze the z-axis motion of the subreflector to

 minimize phase changes in the received signal.

Location - DSN

==============

 Accurate spacecraft navigation using radio metric data requires

 knowledge of the locations of the DSN tracking stations. The

 coordinate system in which the locations of the tracking stations

 are expressed should be consistent with the reference frame

 definitions used to provide Earth orientation calibrations.

 The International Earth Rotation Service (IERS) has established

 a terrestrial reference frame for use with Earth orientation

 measurements. The IERS issues a new realization of the terrestrial

 reference frame each year. The definition of the coordinate

 system has been changing slowly as the data have been improved,

 and as ideas about how to best define the coordinate system have

 developed. The overall changes from year to year have been at the

 few-cm level. The 1993 version of the IERS Terrestrial Reference

 Frame (ITRF1993) [BOUCHERETAL1994] is most used for DSN station

 locations.

 The DSN station locations have been determined by use of VLBI

 measurements, and by conventional and GPS surveying. Tables of

 station locations are available in either Cartesian or geodetic

 coordinates. The geodetic coordinates are referred to a geoid

 with an equatorial radius of 6378136.3 m, and a flattening factor

 f=298.257, as described in IERS Technical Note 13.

 The DSN Station Locations in ITRF1993 Cartesian reference frame

 at epoch 1993.0 (assuming subreflector-fixed configuration) are

 as follows:

 Antenna x(m) y(m) z(m)

 ------------------------------------------------

 DSS 13 -2351112.491 -4655530.714 +3660912.787

 DSS 14 -2353621.251 -4641341.542 +3677052.370

 DSS 15 -2353538.790 -4641649.507 +3676670.043

 DSS 34 -4461146.720 +2682439.296 -3674393.517

 DSS 43 -4460894.585 +2682361.554 -3674748.580

 DSS 45 -4460935.250 +2682765.710 -3674381.402

 DSS 63 +4849092.647 -0360180.569 +4115109.113

 DSS 65 +4849336.730 -0360488.859 +4114748.775

 The DSN Station Locations in ITRF1993 Geodetic reference frame

 at epoch 1993.0 (assuming subreflector-fixed configuration) are

 as follows:

 latitude longitude height

 Antenna deg min sec deg min sec (m)

 ----------------------------------------------------------

 DSS 13 35 14 49.79342 243 12 19.95493 1071.17855

 DSS 14 35 25 33.24518 243 6 37.66967 1002.11430

 DSS 15 35 25 18.67390 243 6 46.10495 973.94523

 DSS 34 -35 23 54.53984 148 58 55.06236 692.71119

 DSS 43 -35 24 8.74388 148 58 52.55394 689.60780

 DSS 45 -35 23 54.46400 148 58 39.65992 675.08630

 DSS 63 40 25 52.34908 355 45 7.16030 865.54412

 DSS 65 40 25 37.86055 355 44 54.88622 834.53926

Measurement Parameters - DSN

============================

 Closed-Loop System

 ------------------

 Closed-loop data are recorded in Tracking and Navigation Files

 (TNFs). TNFs comprise SFDUs that have variable-length,

 variable-format records with mixed typing (i.e., can contain ASCII,

 binary integer, and binary floating-point items in a single record).

 These files all contain entries that include measurements of

 Doppler, range, and signal strength, along with status and uplink

 frequency information. Refer to the TNFSIS.LBL product in the

 DOCUMENT/ directory of this data set for a description of the format

 and content of TNFs.

ACRONYMS AND ABBREVIATIONS - DSN

================================

 ACS Antenna Control System

 ADC Analog-to-Digital Converter

 AGC Automatic Gain Control

 AMMOS Advanced Multi-Mission Operations System

 AMS Antenna Microwave System

 APA Antenna Pointing Assembly

 ARA Area Routing Assembly

 ATDF Archival Tracking Data File

 AUX Auxiliary

 AZ Azimuth

 BPF Band Pass Filter

 bps bits per second

 BVE Block V Exciter

 BVR Block V Exciter

 BWG Beam WaveGuide (antenna)

 CCT Central Communications Terminal

 CDU Command Detector Unit

 CMC Complex Monitor and Control

 CONSCAN Conical Scanning (antenna pointing mode)

 CRG Coherent Reference Generator

 CSO Compensated Sapphire Oscillator

 CUL Clean-up Loop

 DANA a type of frequency synthesizer

 dB deciBel

 dBi dB relative to isotropic

 dBm dB relative to one milliwatt

 DCO Digitally Controlled Oscillator

 DEC Declination

 deg degree

 DMC DSCC Monitor and Control Subsystem

 DOD Differential One-Way Doppler

 DOR Differential One-way Ranging

 DSCC Deep Space Communications Complex

 DSN Deep Space Network

 DSS Deep Space Station

 DST Deep Space Transponder

 DTK DSCC Tracking Subsystem

 DTT DSCC Downlink Tracking and Telemetry Subsystem

 E east

 EIRP Effective Isotropic Radiated Power

 EL Elevation

 FET Field Effect Transistor

 FFT Fast Fourier Transform

 FSP Full Spectrum Processor Subsystem

 FTS Frequency and Timing Subsystem

 GCF Ground Communications Facility

 GHz Gigahertz

 GPS Global Positioning System

 GSFC Goddard Space Flight Center

 HA Hour Angle

 HEF High-Efficiency (as in 34-m HEF antennas)

 HEMT High Electron Mobility Transistor (amplifier)

 HGA High-Gain Antenna

 HSB High-Speed BWG

 I In-phase

 IERS International Earth Rotation Service

 IF Intermediate Frequency

 IVC IF Selection Switch

 JPL Jet Propulsion Laboratory

 K Kelvin

 Ka-Band approximately 32 GHz

 KAT Ka-Band Translator

 kbps kilobits per second

 KEX Ka-Band Exciter

 kHz kilohertz

 km kilometer

 kW kilowatt

 LAN Local Area Network

 LCP Left-Circularly Polarized

 LGA Low-Gain Antenna

 LMC Link Monitor and Control

 LNA Low-Noise Amplifier

 LO Local Oscillator

 Ms/s Million samples per second

 m meters

 MCA Master Clock Assembly

 MDA Metric Data Assembly

 MHz Megahertz

 MON Monitor and Control System

 MSA Mission Support Area

 N north

 NAR Noise Adding Radiometer

 NBOC Narrow-Band Occultation Converter

 NH New Horizons

 NIST SPC 10 time relative to UTC

 NIU Network Interface Unit

 NMC Network Monitor and Control

 NOCC Network Operations and Control System

 NRV NOCC Radio Science/VLBI Display Subsystem

 NSS NOCC Support Subsystem

 OCI Operator Control Input

 ODF Orbit Data File

 ODR Original Data Record

 OLR Open-Loop Receiver

 OSC Oscillator

 PDS Planetary Data System

 PPM Precision Power Monitor

 Q Quadrature

 RA Right Ascension

 REC Receiver-Exciter Controller

 REX Radio Science Experiment (a New Horizons instrument)

 RCP Right-Circularly Polarized

 RF Radio Frequency

 RFE (Probe) Receiver Front End

 RFIS Radio Frequency Instrument Subsystem

 RFS Radio Frequency Subsystem

 RMDCT Radio Metric Data Conditioning Team

 RMS Root Mean Square

 RNS Reliable Network Server

 RRP Receiver and Ranging Processor

 RSR Radio Science Receiver

 RSS Radio Science Subsystem

 RSSG Radio Science Systems Group

 RTLT Round-Trip Light Time

 S-band approximately 2100-2300 MHz

 SBT S-Band Transmitter

 sec second

 SEC Systematic Error Correction

 SFDU Standard Format Data Unit

 SIM Simulation

 SLE Signal Level Estimator

 SNR Signal-to-Noise Ratio

 SNT System Noise Temperature

 SOE Sequence of Events

 SPA Spectrum Processing Assembly

 SPC Signal Processing Center

 sps samples per second

 SRA Sequential Ranging Assembly

 SRC Sub-Reflector Controller

 SSI Spectral Signal Indicator

 SSR Solid State Recorder or Space Science Reviews, (publication

 journal)

 tbd to be determined

 TDDS Tracking Data Delivery Subsystem

 TID Time Insertion and Distribution Assembly

 TLM Telemetry

 TLP Telemetry Processor

 TSF Tracking Synthesizer Frequency

 TWM Traveling Wave Maser

 TWNC Two-Way Non-Coherent

 TWTA Traveling Wave Tube Amplifier

 TXR Transmitter (subsystem)

 UNK unknown

 UPL DSCC Uplink Subsystem

 USO UltraStable Oscillator

 UTC Universal Coordinated Time

 VCO Voltage-Controlled Oscillator

 VF Video Frequency

 VLBI Very Long Baseline Interferometry

 X-band approximately 7800-8500 MHz

 "

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