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

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Closed-Loop System

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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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