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.

 2014-10-31 SOC:Carcich Many more tweak to resolve liens from review

 2016-07-31 SOC:Carcich Added DSS 35 and DSS 36 per liens from review

 2016-10-31 SOC:Carcich Resolve liens from 2016-05 review

 2016-12-06 SOC:Carcich Remove unused references.

 "

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 UNDERSTANDING: THE REX AND THE NEW HORIZONS (NH) REGENERATIVE

RANGING TRACKER [DEBOLTETAL2005] ARE

 \*\*\*\*\*SEPARATE\*\*\*\*\* AND \*\*\*\*\*INDEPENDENT\*\*\*\*\*

SUBSYSTEMS THAT BOTH USE THE RADIO FREQUENCY (RF) AND TELECOMMUNICATIONS

SUBSYSTEMS. TRACKING DATA WILL NOT BE ARCHIVED IN REX DATA SETS.

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

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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 Deep

Space Network (DSN) hardware and operations facilities that support the New

Horizons (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 was 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 was focused on occultations, by Pluto

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

remained 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

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

investigation:

Investigation 1: Atmosphere characterization or detection

--------

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

there was 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 approached the limb, there were 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, provide the length of the occultation chords.

Investigation 3: Front and dark side thermal emission

--------

Just before closest approach, the HGA boresight was swept across Pluto's

surface. In one observation (DISKTHERM), the measurement was of sunlit

surface thermal emission. In the others (THERMSCAN), 34m DSN antennas

radiated Right- and Left-Circular Polar 7.2GHz signals timed to arrive

at Pluto during the observation. The HGA measured the reflected signal,

making this a Bi-Static Radar (BSR) measurement; one scan was directed

at the specular reflection point; the other BSR measurement was aimed off

of the Earth-Pluto-Spacecraft radio metric equator.

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

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

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

night side of Pluto and Charon while the pointing of the HGA remained 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. However,

the reader should note that the proposed gravity investigation is beyond the

chosen scope of this data set, and no ranging data will be included here.

Those four investigation descriptions are greatly simplified; see

[TYLERETAL2008] for more detail.

INSTRUMENT OVERVIEW - FLIGHT ELEMENT

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

On-board the NH spacecraft, hardware specific to REX are an analog-to-digital

converter and the REX Actel Field-Programmable Gate Array (FPGA). These are

on the Radiometrics card within the Integrated Electronics Module (IEM) that

is the NH transceiver [DEBOYETAL2004]. Since there are two redundant IEMs,

there are two REX units – sometimes designated Side A and Side B, or Channel A

and Channel B. Note that the word 'transceiver' is often used when describing

REX operations, here and elsewhere, because the REX hardware receives its

input signal via the transceiver hardware. Such usage does not imply REX has

any transmission capability; REX is uplink-only.

Other spacecraft hardware external to the REX hardware, but used by REX,

include a digital receiver on the uplink card of the NH transceiver IEM, the

2.1 meter high gain antenna (HGA) and an ultrasable oscillator providing the

precision frequency reference necessary for the uplink radio science

experiment. There are two redundant USOs. Refer to [TYLERETAL2008],

[FOUNTAINETAL2008] and [DEBOYETAL2004] for further 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.

REX is part of the redundant spacecraft telecommunication subsystems and

signal paths that use the single HGA in common. REX Side A always

received RCP (Right Circular Polarization) uplink signals from the DSN;

Side B always received LCP (Left Circular Polarization) uplink signals

from the DSN. This is unaffected by the switching described in the next

paragraph. See [REX Use of the DSN] topic below for a description of

uplink signal polarity sent during REX observations.

Sides A and B can be operated simultaneously, to increase SNR, using

uplink signals with RCP and LCP, respectively. Normally Side A

communicates with spacecraft CDH1 (Command and Data Handling) and B with

CDH2, but that can be switched if required by spacecraft events; as of the

end of 2015, this switch had never occurred. Each REX side is referenced to

a separate USO, and that must be considered when using the data. The USOs

are cross-strapped so either can provide a reference to both sides in the

event of a single USO failure. Execution of the command to do so would be a

one-time, irreversible event, and as of the end of 2015 that had not occurred.

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: 3E-13 (delta-f/f)

POWER CONSUMPTION: 1.6 W (per-side; see Note 1)

MASS: 160 g (per-side; see Note 1)

VOLUME: 520 cm\*\*3 (per-side; see Note 1)

Note 1: Resource usage values include those for the following components:

 Analog-to-Digital Converter (ADC), Field-Programmable Gate Array

 (FPGA), and Integrated Ciruit (IC) buffers.

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 2deg x 2deg 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, REX processed the uplink signal from the tranceiver, 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 samples are scaled to Volts based on the assumed-stable

reference voltage of the 12-bit ADC, plus the design of the digital filter

implemented within the FPGA. The net result is a gain-independent, direct

scaling factor, which value is in the Science Operation Center/Instrument

Interface Control Document - SOC\_INST\_ICD - provided with this data set.

N.B. the IQ data calibration is present only to satisfy a PDS requirement;

 it is more or less meaningless as it provides no additional information

 not already in the raw data, because the purpose of the IQ data is

 the signal phase relationship encoded in the Q:I ratio of each IQ pair.

 The calibrated IQ data provide no additional insight into that ratio

 not already present in the raw data. The noise inherent in any single

 measurement swamps any error in the calibration (e.g. fluctuation in

 the ADC reference voltage). Statistically, the radiometry values, by

 both intent and design, will be more useful in evaluating signal

 strength in scientific units.

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 and a gain setting (AGC or AGCGAIN).

Note that the acronym AGC comes from the nomenclature of the RF Uplink

hardware, which is separate from REX, and which uses Automatic Gain Control as

part of its carrier tracking loop. For REX there is no automatic gain control

and REX gain is manually set by commands from the ground based on the expected

uplink power, or radiometry, in the REX band.

Radiometer Calibration

--------

Summary: the System Noise Temperature of the REX instrument is 152K.

System Noise Temperature (SNT) is typically measured by injecting known

amounts of noise power into the signal path and comparing the total power

with the noise injection 'on' against the total power with the noise

injection 'off.' That operation is based on the fact that receiver noise

power is directly proportional to temperature. Normally, measuring the

relative increase in noise power due to the presence of an absolutely

calibrated thermal noise source allows direct calculation of SNT.

However, for the NH radio subsystem, which has no absolutely calibrated

thermal noise source, it is possible to calculate the SNT using multiple

standard radio sources and Cold Sky: 'on' is when the HGA is pointing at a

standard radio source; 'off' is when the HGA is pointing at Cold Sky.

The Cold Sky location chosen for NH REX is [RA,DEC] = [15.2deg, -8.1deg],

where the the sky temperature is within a few tenths of a Kelvin of the

Cosmic Microwave Background - CMB - over a section of the sky larger than

several times the half-power beam width of the HGA.

Using the ratios of radiometry measurements of multiple standard radio

sources to radiometry measurements of Cold Sky allows indirect calculation

of the SNT, as long as the relative power ratios between the standard radio

sources are known and are not unity, and with the following assumptions:

1) we assume that the REX radiometry system response is linear with power.

2) we assume that the maximum signal when the HGA scans across a standard

 radio source is proportional to the 7.2 GHz radio flux from that source.

 The peak in the HGA beam pattern is a significant fraction of a degree,

 which is much broader than the pointing deadband of 0.1deg used for

 these observations, so this assumption is reasonable.

3) we assume that the Standard radio sources chosen for this calibration

 are 'thermal', i.e. they possess blackbody radiation spectra that are

 constant, or at least interpolable, across the REX band.

Refer to DOCUMENT/NH\_REX\_RADIOMETER\_CALIB.LBL for more detail.

On 29 June, 2006, 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 X coordinate, 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.

Two of the targets were positioned on the sky where the galactic synchrotron

background was very low, and within a few tenths of a kelvin of the Cosmic

Microwave Background (CMB). These two targets were called the Cold Sky Cals.

The other targets were standard radio sources with known radio fluxes. The

calibration procedure then mapped the SNRs of the targets (the signal was

characterized by the radio sources; the noise was characterized by the Cold

Sky Cals) against the expected radio fluxes, and produced a log-log linear

relationship with a 1% standard deviation.

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

sliding window; the standard deviation of the 10s 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

one-sigma uncertainty of about 0.1K (1 part in 1000).

Gain Linearity tests

--------

The gain setting (AGC or AGCGAIN) is designed to produce linear results

in the radiometry calibration formula in units of dBm (the formula is

available in the Science Operations Center/Instrument Interface Control

Document - SOC\_INST\_ICD). These tests varied the gain setting (steps

of two in the gain setting, equivalent to ~1dB) while measuring a single

target source i.e. an unmodulated, constant-strength signal sent from the

DSN. The results indicated that the instrument performs as designed.

Instrument characterizations

--------

In addition to instrument calibration, the following activities were performed

as part of commissioning during the Launch mission phase.

Some of these tests were also performed during the Pluto Cruise mission phase

as part of spacecraft Annual CheckOut (ACO) activies to monitor instrument

functionality and stability.

Spur tests/Spurious signal tests/Find weak tones, no uplink

--------

The test for spurs in the REX band is part of the Annual Checkout activities

for New Horizons. The test involves setting the open-loop AGC to near the

upper end of its range and acquiring REX data with no uplink. A spur is a

narrowband frequency, revealed as a narrow spectral line in the

time-integrated spectrum of the REX band.

Interference tests

--------

During encounter, multiple instruments on-board New Horizons will operate

simultaneously. Tests were performed during Commissioning to verify that

simultaneous operation of these instrument suites did not cause mutual

interference. For REX, both REX and ALICE will operate simultaneously to

observe the occultations of the Earth and Sun by Pluto and Charon. At Pluto

Encounter, the Earth and Sun are separated by 1.5 degrees, and Earth

occultations for REX and the Solar occultation for ALICE by Pluto and Charon

will occur very close together in time. The mutual interference test for REX

and ALICE had both instruments on, i.e. both REX and ALICE were acquiring

data REX without an uplink and ALICE without the Sun in it's aperture.

Neither instrument found any artifacts during these tests.

Uplink simulates multi-tones to assess intermodulation distortion

--------

Two uplinks, close in frequency in the REX band, were transmitted to New

Horizons in each of Right-hand and Left-hand Circular Polarization (RCP and

LCP), to assess the incidence of intermodulation distortion. None was found

at a level of less than -60 dBc.

Miscellaneous characterizations and tests; see [TYLERETAL2008] section 6

--------

- Functional Verification

- Uplink Signal Acquisition (minimum SNR)

- USO Stability

- REX Passband Response

Summary

-------

All calibration and characterization activities indicate the REX instrument

operates as expected.

See section 6 of [TYLERETAL2008] for more details of the REX instrument

performance, as well as DOCUMENT/NH\_REX\_RADIOMETER\_CALIB.LBL.

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 gain setting (AGC). 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 and Time Tag anomalies

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

REX writes data to the SSR as a series of frames at 1 frame per 1.024s, from

the first 1PPS (One Pulse Per Second spacecraft timekeeping signal)

encountered after both the instrument is powered on and an SSR allocation goes

active, until either the instrument is powered off or the SSR allocation is

filled. For this reason, it is possible for the first frame written to the

SSR (due to the wait until the first 1PPS) and last frame written to the SSR

(due to a power off asynchronous with frame boundaries) to be incomplete.

When REX data are stored to the SSR 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). N.B. ApIDs are case insensitive.

REX Time Tags are used to keep track of REX Output Frames (ROFs) by

incrementing ten times within each frame and continuing to

increment once between consecutive frames. Inconsistencies in

the Time Tags can be used to locate errors due to the REX data compression

issue and any other corrupt frames. Any such frames are listed in file

ERRATA.TXT in this data set. Such frames are rare, so ignoring those frames

will not significantly affect REX data analysis.

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/1024ms

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

 [ [ |Digital | | ] ] samples/1024ms

 [ |Filter |--(/16)-+ ] @ 2\*2 bytes/sample

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

 [ ]

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

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

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 | ~~~

 | |

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

/ | | \

 ===== | |

 ( USO )--------+-----+----> to Transceiver

 =====

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

========

There are three controls on the REX hardware: the power; the input signal

source; a gain control. REX generates 1250 IQ sample pairs and 10

cumulative radiometry values per ROF any time it is powered on. In addition

to the HGA signal, REX can also be commanded to process any of a set of

internal test patterns stored in the REX signal processor: impulse

response; three square waves of different frequencies; two pseudo-random

number sequences of different amplitudes; all zeros. The gain control is

an integer value that is kept track of via monitoring of uplink commanding;

there is no feedback of the gain setting in the data downlink. The gain

control affects the radiometer calibration only; it does not affect the IQ

calibration.

The phrases 'REX mode' and 'Radiometry mode' are used in several documents;

they do not refer to specific instrument modes or configurations, but rather

to specific types of observation and whether the IQ pair or the radiometery

values are the focus of the observation. Although they are not strictly

operational modes, they are defined here for convenience.

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 digitally

shifting 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 12 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

 \_\_\_\_\_

 \

 \ 2

 P (k) = / s(i)

 UP /\_\_\_\_

 i=1

where

 s(i) = one input sample (12 bit register, 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.

Absolute time of Time Tags and Radiometry (10 samples per ROF)

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

 The Time Tags are absolute counters, starting at 0 for the START\_TIME

 from the PDS label of the first ROF in a run of ROFs, and incremented every

 102.4ms.

 The raw radiometer values accumulate squared ADC measurements over

 each ROF, with the first raw radiometer value, in any ROF after the

 first ROF, representing the accumulation for the preceding ROF. So

 the midpoint of the time period represented by each raw radiometer

 value is halfway between the time of the corresponding time tag and

 the previous START\_TIME. This means the midpoint for the first

 accumulated value, in any raw or calibrated (cal) ROF after the first

 ROF, is 512ms before START\_TIME i.e. in the middle of the previous

 ROF. The midpoint of the time period of the calibrated radiometer

 values, except the first in each ROF, is 51.2ms before the time of the

 corresponding time tag value.

 The items above are spelled out in the following table indicating the

 absolute timestamp for each of the column values in the ten rows of

 the EXTENSION\_RAD\_TIME\_TAGS\_TABLE OBJECT of the data files, where

 S0 = START\_TIME (in the PDS label)

 +-------+---------------+---------------------+----------------------+

 | Index | Time Tag time | Raw radiometer time | Cal radiometer value |

 +-------+---------------+---------------------+----------------------+

 | 0 | S0 + 0.0ms | S0 - 512.0ms | S0 - 512.0ms |

 | 1 | S0 + 102.4ms | S0 + 51.2ms | S0 + 51.2ms |

 | 2 | S0 + 204.8ms | S0 + 102.4ms | S0 + 153.6ms |

 | 3 | S0 + 307.2ms | S0 + 153.6ms | S0 + 256.0ms |

 | 4 | S0 + 409.6ms | S0 + 204.8ms | S0 + 358.4ms |

 | 5 | S0 + 512.0ms | S0 + 256.0ms | S0 + 460.8ms |

 | 6 | S0 + 614.4ms | S0 + 307.2ms | S0 + 563.2ms |

 | 7 | S0 + 716.8ms | S0 + 358.4ms | S0 + 665.6ms |

 | 8 | S0 + 819.2ms | S0 + 409.6ms | S0 + 768.0ms |

 | 9 | S0 + 921.6ms | S0 + 460.8ms | S0 + 870.4ms |

 +-------+---------------+---------------------+----------------------+

Absolute time of IQ pairs (1250 sample pairs per ROF)

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

 The timestamp apropos the first IQ pair in a ROF is (1024/1250)ms

 before the START\_TIME of that ROF; the timestamp of any other IQ pair

 is (1024/1250)ms after the previous IQ pair.

Instrument Overview - DSN

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

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

 Australia; and Madrid, Spain) compose the Deep Space Network (DSN). Each

 complex is equipped with several antennas, associated electronics, and

 operational systems. Transmission and reception are possible in several

 radio frequency bands; REX uses X-band (7100-8500 MHz, or 4.2-3.5 cm).

 The DSN is managed by the Jet Propulsion Laboratory (JPL), California

 Institute of Technology, for the U.S. National Aeronautics and Space

 Administration (NASA).

 For more information on the DSN and its use in Radio Science see

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

 [DSN810-5].

REX Use of the DSN

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

 When REX measures signals transmitted by the DSN, the transmitted frequency

 is corrected for station motion (e.g., Earth orbit and rotation) and

 spacecraft motion so that the signal received at the spacecraft is within a

 narrow fraction (a few hundred Hertz) of the 2.5 MHz IF after

 downconversion.

 For REX occultations, the DSN provides a frequency ephemeris (a description

 of the transmitted frequency as a series of linear ramps) in Tracking and

 Navigation Files (TNFs). REX radiometry observations do not require DSN

 signals. Hence, Tracking and Navigation Files are not required prior

 to arrival at Pluto, other than for Lunar occultations in 2011 and 2014.

 In general, any time REX was using DSN uplink signals, the DSN transmitted

 the polarization of uplink signal(s) apropos to the REX Sides (A and/or B)

 that were in operation at that time. That is, when only Side A was on,

 the DSN transmitted an RCP uplink signal; when only Side B was on, the DSN

 transmitted an LCP uplink signal; when both Sides A and B were on, the DSN

 transmitted both RCP and LCP uplink signals. The only exceptions to this

 were as follows:

 REX Sides Uplink

 Date in operation Polarity

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

 TBD TBD TBD

Subsystems - DSN

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

 The DSCCs are an integral part of Radio Science instrumentation. The

 following paragraphs describe the functions performed by individual

 subsystems of a DSCC. For additional information, consult [DSN810-5].

 Each DSCC includes a set of antennas, a Signal Processing Center (SPC),

 and communication links to JPL. The following table lists some of the DSN

 antennas available to REX. The Deep Space Station (DSS) nomenclature

 has been 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 35 DSS 55

 DSS 26 DSS 36

 34-m HSB DSS 27

 DSS 28

 70-m DSS 14 DSS 43 DSS 63

 Developmental DSS 13

 Antennas are grouped above by diameter and design. HEF is high efficiency,

 BWG is beam waveguide, and HSB is high-speed BWG.

 DSCC Receiver-Exciter Subsystem

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

 The receiver-exciter subsystem is split into the exciter component (UPL

 for Uplink Subsystem) and a separate receiver component, not used by REX.

 The UPL comprises the Exciter, the Command Modulation, the Uplink

 Controller, and the Uplink Ranging assemblies. The exciter generates

 a sky-level signal, which is provided to the Transmitter Subsystem (TXR)

 for transmission to the spacecraft. It is tunable under command of a

 Digitally Controlled Oscillator (DCO).

 DSCC Transmitter Subsystem

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

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

 the Uplink 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 X-band uplink. Power levels above 20 kW

 for NH REX operations were supplied only from 70-m stations.

 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).

 The DSCC Monitor and Control (DMC) subsystem 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 the Network Operations Control Center (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.

 The NMC processor provides the operator interface for monitor and control

 of a link -- a group of equipment required to support a spacecraft pass.

 DSCC Tracking Subsystem

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

 All Tracking Subsystem (DTK) functions are incorporated within the UPL

 and the Downlink Tracking and Telemetry Subsystem (DTT). The primary

 functions of the DTK are to acquire and maintain communications with

 the spacecraft and to generate and format radio metric data containing

 Doppler, range, and uplink frequency ramps. Only the ramps are used

 for REX.

 In addition, the Tracking Subsystem receives from the CMC uplink tuning

 predicts (used to program the DCO). 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.

 Allan Deviations of the signals sent to REX (derived from FTS) are:

 Integration Time (seconds) Allan Deviation

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

 1 2E-13

 10 8E-14

 100 2E-14

 1000 4E-15

Optics - DSN

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

 X-Band performance of the DSN ground stations depends primarily on the size

 of the antenna and capabilities of the electronics.

 Antenna Performance

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

 Performance of antennas is summarized in the following table. Beamwidth

 is half-power full angular width. Polarization is circular; X-Band can

 transmit either left or right circular polarization (LCP or RCP,

 respectively).

 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 67 67

 Beamwidth (deg) 0.038 0.077 0.077

 Polarization L or R L or R L or R

 Tx Power (kW) >=20 20 20

 Although some 34-m antennas were either upgraded or in the process of

 being upgraded during Pluto Encounter, only 70-m antennas were used

 to transmit at powers above 20kW for NH REX operations.

 Antenna Pointing

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

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

 mode antenna pointing is offset slightly, following a conical path around

 the nominal direction during routine uplink commanding and telemetry

 reception. The slight signal degradation during one time interval is used

 to correct the pointing for the next. In planetary mode, the system

 interpolates from three (slowly changing) RA-DEC target coordinates;

 this is 'planetary' 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. REX uses only planetary pointing.

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, and propagation delays

 meet specifications. Additional information may be available in [DSN810-5].

Location - DSN

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

 Accurate analysis of REX occultation 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 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. Refer to [DSN810-5] section 301 or the Navigation and

 Ancillary Information Facility at JPL SPICE kernels for the latest

 locations; the values provided here are only provided as examples.

 The DSN station locations have been determined by use of VLBI

 measurements and by conventional and GPS surveying.

 The DSN Station Locations in the ITRF1993 Cartesian reference frame

 at the epoch noted (assuming subreflector-fixed configuration)

 are as follows:

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

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

 DSS 13 -2351112.491 -4655530.714 +3660912.787 1993.0

 DSS 14 -2353621.251 -4641341.542 +3677052.370 1993.0

 DSS 15 -2353538.790 -4641649.507 +3676670.043 1993.0

 DSS 34 -4461146.720 +2682439.296 -3674393.517 1993.0

 DSS 35 -4461273.0838 +2682568.9220 -3674152.0885 2003.0

 DSS 36 -4461170.2358 +2682816.0240 -3674085.9737 2003.0

 DSS 43 -4460894.585 +2682361.554 -3674748.580 1993.0

 DSS 45 -4460935.250 +2682765.710 -3674381.402 1993.0

 DSS 63 +4849092.647 -0360180.569 +4115109.113 1993.0

 DSS 65 +4849336.730 -0360488.859 +4114748.775 1993.0

ACRONYMS AND ABBREVIATIONS - DSN

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

 ADC Analog-to-Digital Converter

 AGC Automatic Gain Control N.B. REX gain is not automatic

 BWG Beam WaveGuide (antenna)

 CCT Central Communications Terminal

 CMC Complex Monitor and Control

 CUL Clean-up Loop

 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

 DSCC Deep Space Communications Complex

 DSN Deep Space Network

 DSS Deep Space Station

 DTK DSCC Tracking Subsystem

 DTT DSCC Downlink Tracking and Telemetry Subsystem

 FTS Frequency and Timing Subsystem

 GHz Gigahertz

 GPS Global Positioning System

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

 HGA High-Gain Antenna

 HSB High-Speed BWG

 I In-phase

 IERS International Earth Rotation Service

 IF Intermediate Frequency

 JPL Jet Propulsion Laboratory

 K Kelvin

 LCP Left-Circularly Polarized

 LMC Link Monitor and Control

 LNA Low-Noise Amplifier

 LO Local Oscillator

 Ms/s Million samples per second

 m meters

 MHz Megahertz

 MON Monitor and Control System

 NH New Horizons

 NMC Network Monitor and Control

 NOCC Network Operations and Control System

 PDS Planetary Data System

 Q Quadrature

 RA Right Ascension

 REX Radio Science Experiment (a New Horizons instrument)

 RCP Right-Circularly Polarized

 RF Radio Frequency

 SPC Signal Processing Center

 SSR Solid State Recorder or Space Science Reviews, (publication

 journal)

 TBD to be determined

 TNF Tracking and Navigation File

 TXR Transmitter (subsystem)

 UPL DSCC Uplink Subsystem

 USO UltraStable Oscillator

 VLBI Very Long Baseline Interferometry

 X-band approximately 7100-8500 MHz

 "

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