PDS\_VERSION\_ID = PDS3

LABEL\_REVISION\_NOTE = "2005-12-19 RSR: L. Carone"

RECORD\_TYPE = STREAM

OBJECT = INSTRUMENT

 INSTRUMENT\_HOST\_ID = RO

 INSTRUMENT\_ID = RSI

 OBJECT = INSTRUMENT\_INFORMATION

 INSTRUMENT\_NAME = "ROSETTA RADIO SCIENCE

 INVESTIGATION"

 INSTRUMENT\_TYPE = "RADIO SCIENCE"

 INSTRUMENT\_DESC = "

 Instrument Overview

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

 Rosetta (RO) Radio Science Investigations utilized

 instrumentation with elements on both the spacecraft and ground

 (Earth). Much of this was shared equipment, being used for

 routine telecommunications as well as for Radio Science. Ground

 systems were provided by the European Space Agency (ESA) at New

 Norcia, Australia, and by the U.S.

 National Aeronautics and Space Administration (NASA) Deep Space

 Network (DSN) at sites in Australia, Spain, and the United

 States.

 Performance and calibration of both the spacecraft and ground

 systems directly affected the radio science data accuracy and

 played a major role in determining the quality of the results.

 The spacecraft was able to receive and transmit signals at both

 S-band (approximately 13 cm wavelength) and X-band

 (approximately 3.5 cm). The spacecraft transmissions could use

 either an onboard oscillator (for RSI the onboard ultra stable

 Oscillator USO was used.) for the frequency reference ('one-way'

 mode) or a signal transmitted from the ground ('two-way' mode);

 in the latter case, either an S- or X-band signal from the

 ground could be used as the reference.

 Science Objectives

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

 Two different types of radio science measurements were carried

 out with Rosetta:

 Radiometric Measurements: 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;

 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 and/or to investigate gas and dust mass

 flux from non-gravitational perturbations of the Rosetta S/C.

 NB: Doppler measurements can be made in one-way with USO on

 but are usually more accurate if carried out in two-way mode.

 Radio Propagation Measurements: 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. Radio propagation measurements can

 be conducted in either one-way or two-way mode.

 These measurements were applied - separately and together - to

 Rosetta science objectives such as determination of the gravity

 field of Churyumov-Gerasimenko and Asteroids Steins and Lutetia,

 mass of Churyumov-Gerasimenko and Asteroids Steins and Lutetia,

 temperature and pressure of the plasma and dust environment of

 the comet, electron density around the comet, scattering

 properties of the surface, and structure of the solar wind.

 Gravity Measurements

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

 Determination of the cometary mass and bulk density is a

 fundamental objective required to assess the validity and

 accuracy of various cometary models. Extensive simulation

 studies, in preparation for the Near Earth Asteroid Rendezvous

 (NEAR) mission to asteroid 433 Eros, demonstrate that orbiting

 a small asteroid will require a gravity field extraction process

 fundamentally different from previous gravity studies of the

 planets or moons [SCHEERES1995], [MILLERETAL1995].

 Upon arrival at the comet, the nucleus size, shape, mass,

 activity and spin state will be poorly known and will most

 likely be active during some portions of the gravity field

 investigation campaign.

 An initial flyby during the Rosetta approach phase should

 enable a mass determination to an accuracy of 10%. Injection

 into a bound high orbit allows iterative improvements of the

 mass determination down to the 1% level. The orbit can then be

 safely reduced to 20 - 30 cometary radii (depending on the

 actual mass of the comet) and mass determination will reach an

 accuracy of 0.1%.

 The second order and degree gravity coefficients (C20 and C22)

 can be estimated using the shape model (from imaging

 observations) and assuming constant density. The result is a

 constraint on the true gravity field. The most stable low orbits

 for the spacecraft will be in equatorial, retrograde orbits

 about the comet (no outgasing perturbations assumed). Beginning

 with these orbits, the second-order gravity field can be solved

 for in the orbit determination process.

 Higher-order gravity coefficients might be determined from low

 polar orbits. This strategy also assumes that cometary

 outgassing does not induce significant accelerations upon the

 spacecraft.

 The shape gravity model (with constant density) and the true

 gravity model (from spacecraft tracking) can then be compared to

 yield information on the mass heterogeneity of the comet

 nucleus.

 Asteroid flyby

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

 During the Rosetta Mission two close flybys at asteroids

 Lutetia and Steins will take place. RSI will be able to derive

 the mass and density of the asteroids.

 The spacecraft velocity is perturbed by the gravitational

 field of asteroids during sufficiently close flybys. The

 spacecraft is accelerated toward the asteroid along its flyby

 trajectory. The analysis of the resultant velocity changes

 ultimately yields a measure of its total mass or GM. The bulk

 density is determined from the mass determination and the

 volume estimate made by the camera experiment. Mass and bulk

 density estimates of asteroids have thus far only been

 obtained from the Galileo flyby at asteroid Ida and from the

 NEAR flybys at asteroid Mathilde and Eros. Asteroid Ida was

 too small to perturb the flyby trajectory of Galileo above the

 threshold of detectability. The discovery of Ida moon Dactyl,

 however, provided an unexpected opportunity to estimate Ida

 mass and bulk density. Mathilde bulk density was found to be

 surprisingly low.

 Radio Occultation Measurements and Coma sounding

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

 Atmospheric measurements by the method of radio occultation

 i.e coma sounding contribute to an improved understanding of

 structure and compostion of the plasma and dust environment of

 Churyumov-Gerasimenko.

 These results are based on detailed analysis of the radio

 signal phase as the ray path enters and exits occultation by

 the comet, leading to profiles of pressure for neutral

 particles and profiles of electron density for plasma. In

 addition the exact size and shape of the shape of the comet

 can be derived by determining at which time the occultations

 start and end exactly.

 Retrieval of such profiles requires coherent samples with a

 sample rate of at least 10 per second of the radio signal

 that has propagated through the atmosphere, plus accurate

 knowledge of the spacecraft trajectory. The latter was

 obtained from the ROS Flight Dynamics Team.

 Spatial and temporal coverage in radio occultation

 experiments are determined by the geometry of the spacecraft

 orbit and the dates and times at which occultation data are

 acquired.

 Bistatic Surface Scattering Measurements

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

 The spacecraft high-gain antenna (HGA) could also be pointed

 toward the surface of the planet. The strength of the signal

 scattered from the illuminated area could be measured and the

 results interpreted in terms of the dielectric constant of the

 surface material. The model for interpretation assumes Fresnel

 reflection at the specular angle.

 Under certain circumstances, the dispersion of the echo (its

 spectral width) could be interpreted in terms of the surface

 roughness on scales comparable to the wavelength. One such MGS

 bistatic radar was conducted over the Mars Polar Lander/Deep

 Space 2 site in May 2000 [SIMPSON&TYLER2001].

 For a few seconds before and after geometrical occultation

 the HGA illuminated a small strip of surface as well as the

 atmosphere. In some cases, an echo could be observed from the

 surface. The interpretation of these transient echoes is

 more difficult than for the case above, possibly involving

 diffraction and surface waves in addition to Fresnel

 reflection.

 Rosetta is the first spacecraft to use bistatic radar to

 explore the properties of the comet's surface and its

 interior. On Rosetta this operation will be done in ONED mode.

 That is no uplink but with X- and S-Band downlink. The HGA

 will be pointed towards the comet. Pointing will be inertial.

 That is no slew was performed during the measurement.

 Solar Scintillation and Faraday Rotation Experiments

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

 Solar scintillation and Faraday rotation experiments were

 conducted to improve understanding of the structure and

 dynamics of the solar corona and wind. On its route to the

 comet the Rosetta spacecraft will be behind the solar disk,

 as seen from Earth. Radio waves propagating between RO and

 Earth stations are refracted and scattered by the solar plasma

 [WOO1993]. Intensity fluctuations

 can be related to fluctuations in electron density along the

 path, while Doppler or phase scintillations can be related to

 both electron density fluctuations and also the speed of the

 solar wind. Many plasma effects decrease as the square of the

 radio frequency; scintillations are about an order of

 magnitude stronger at S-band than X-band.

 Measurements during solar conjunction should be typically

 been done in TWOD-S configuration. That is in two-way mode

 with S-Band uplink and coherent and simultanous in X- and

 S-Band. However, due to problems to lock S-Band in the 2004

 conjunction season. The TWOD-X configuration was used instead.

 That is in two-way mode with X-Band uplink and coherent and

 simultanous in X- and S-Band

 Investigators and Other Key Personnel

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

 Martin Paetzold University of Cologne Principal

 Investigator;

 solar physics

 Bernd Hausler Universitaet der Bundeswehr Experiment

 Munich Manager

 Richard Simpson Stanford University Data Manager;

 surface

 scattering

 Silvia Tellmann University of Cologne Operations

 Manager

 Sami Asmar Jet Propulsion Laboratory JPL/DSN

 operations

 G. Leonard Tyler Stanford University radio

 propagation

 David Hinson Stanford University atmosphere,

 ionosphere,

 radio

 occultation

 Jean-Pierre Barriot Centre National d'Etudes gravity

 Spatiale

 Toulouse

 Veronique Dehant Observatoire Royale gravity

 Brussels

 Instrument Specification - Spacecraft

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

 The Rosetta spacecraft telecommunications subsystem served as

 part of a radio science subsystem for investigations of Comet

 Churyumov-Gerasimenko. Many details of the subsystem are

 unknown; but they are not of importance for understanding the

 science.

 Instrument Id : RSI

 Instrument Host Id : RO

 Pi Pds User Id : MPAETZOLD

 Instrument Name : ROSETTA RADIO SCIENCE

 INVESTIGATIONS

 Instrument Type : RADIO SCIENCE

 Build Date : 2003-06-01

 Instrument Mass : UNK

 Instrument Length : UNK

 Instrument Width : UNK

 Instrument Height : UNK

 Instrument Manufacturer Name : UNK

 Subsystems

 ----------

 SWITCH TRANSPONDER 1

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

 \ | |---| TWTA |---|\ /|<--------| X-Band Transmitter |

 \ | | ------ | \ / | | |

HGA >--| | | X | ------| S-Band Transmitter |

 / | | ------ | / \ | | | |

 / | RFDU |---| TWTA |---|/ \| | --->| X-band Receiver |

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

 \ | | | | | |

MGA >---| |<---------------------- | ->| S-Band Receiver |

 / | | | | --------------------

 | | | | ^

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

 | | | -----

 | | | | USO |

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 | | | v

 | |---------------------------| TRANSPONDER 2

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

LGA >--| |---< LGA (rear) <---| X-Band Transmitter |

(front) -------- | |

 <---| S-Band Transmitter |

 TRANSPONDERS 1 and 2 were | |

 connected to provide fully --->| X-band Receiver |

 redundant, switchable | |

 functions. --->| S-band Receiver |

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

 The Rosetta radio subsystem comprised several components

 (shown above), configured to provide redundant functions

 should any single

 component fail (except the high-gain antenna).

 The high-gain antenna (HGA) was a body-fixed 1.60 m diameter

 parabolic dish which allowed transmission and reception at

 both S- and X-band.

 The HGA boresight was in the -X direction of the spacecraft

 coordinate system, offset 5 degrees in the +Z direction.

 Its gain was 29.56 dB and 41.43 dB at S- and X-band,

 respectively. Two low-gain antennas (LGA) were mounted on the

 front and rear of the spacecraft; they operated only at

 S-band. The HGA was the main antenna for receiving

 telecommands from and transmitting telemetry signals to the

 ground.

 The LGAs were used during the commissioning phase after

 launch and for emergency operations.

 The Radio Frequency Distribution Unit (RFDU) switched the

 onboard radio frequency hardware among the three antennas.

 Switchable Traveling Wave Tube Amplifiers (TWTA) provided 60

 watts of X-band transmitter power to the RFDU; their inputs

 could come from either Transponder 1 or Transponder 2.

 The S-band transmitter power was 5 watts, which was generated

 within the transponder units.

 The S-band uplink was received via the LGA or HGA. In the

 coherent two-way mode the received frequency was used to

 derive the downlink frequencies by using the constant

 transponder ratios 880/221 and 240/221 for X-band and S-band

 downlink, respectively.

 The X-band uplink was received via the HGA only. In the

 coherent two-way mode the received frequency was used to

 derive the downlink

 frequencies by using the constant transponder ratios 880/749

 and 240/749 for X-band and S-band downlink, respectively. An

 X-band uplink generally enhanced the performance of the radio

 link because X-band is less sensitive to the interplanetary

 plasma along the propagation path.

 The X-band and S-band frequencies were related by a factor of

 11/3. If an uplink existed, the downlinks were also coherent

 with the uplink by their respective transponding ratios.

 The dual-frequency downlink allowed separation of the

 classical Doppler shift, due to relative motion of the

 spacecraft and the ground station, from the dispersive media

 effects, due to the propagation of the radio waves through the

 ionosphere and interplanetary medium.

 In one-way mode, the downlink transmitter frequency was

 derived from either an onboard Temperature Controlled Crystal

 Oscillator (TCXO) or an Ultrastable oscillator (USO). The

 one-way mode could be selected by command from the ground. If

 the spacecraft receiver could not detect an uplink signal from

 the ground, the TCXO was selected by default. TCXO stability

 was several orders of magnitude less than the uplink

 reference.

 Radio Science in one-way link mode (ONES, ONED) are either

 conducted during bistatic radar experiments or during an

 occultation of the spacecraft by the nucleus as seen from

 Earth. This enables radio sounding of the immediate vicinity

 of the nucleus and perhaps even the nucleus itself, should the

 solid cometary body prove to be penetrable by microwaves.

 These one-way occultation experiments require an Ultra-Stable

 Oscillator (USO) added to the radio subsystem. The prime

 purpose of the USO is to serve as a phase-coherent frequency

 reference for the simultaneous one-way downlink transmissions

 at S-band and X-band. The required stability (Allan variance)

 of the USO is about (Delta)f /f = 1E-13 at 10-1000 seconds

 integration time. The one-way radio link can be transmitted

 either while receiving a noncoherent uplink or without any

 uplink contact at all. This radio subsystem design makes

 Rosetta one of the best equipped spacecraft (besides Galileo

 and Cassini) for radio science experiments.

 The redundant transponders each consisted of an S-band and

 X-band receiver and transmitter. The spacecraft was capable

 of receiving one uplink signal at S-band (2100 MHz) via the

 LGAs, or at either X-band (7100 MHz) or S-band via the HGA or

 MGA. The spacecraft could transmit a downlink signal at

 S-band (2300 MHz) and (simultaneously) a downlink signal at

 X-band (8400 MHz) using the HGA; or it could transmit one

 downlink signal at S-band via the LGAs.

 Operational Considerations

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

 Due to the fact that the HGA antenna can be directed within

 certain limits independent of the spacecraft, Radio Science

 observations are not so severely constrained due to spacecraft

 constraints, telecommunications, and requirements for other

 instruments as on other space missions (MEX/VEX).

 Calibration

 -----------

 For many experiments, calibration data were collected in

 conjunction with the scientific observations. For example,

 carrier power and frequency could be determined before and/or

 after bistatic radar and radio occultation experiments when

 the antenna was pointed toward Earth.

 The gain, beam patterns, and pointing of the HGA were

 calibrated during post-launch tests. The half-power points

 were about 2.6 and 0.8 degrees from the boresight at S- and

 X-band, respectively.

 For radio tracking data, error sources in two-way mode are

 shown below, where the tabulated error values are given in

 terms of equivalent spacecraft velocity error. These values

 were based on pre-launch tests.

 |======================================================|

 | Error Source | Equivalent Velocity |

 | | Error (mm/s) |

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

 | | S-band | X-Band |

 |================================+==========+==========|

 |Total phase error (thermal and | 1.0 | 0.3 |

 |ground station contributions) | | |

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

 |Transponder quantization error | 0.4 | 0.1 |

 |in frequency | | |

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

 |Transponder quantization error | 0.01 | 0.004 |

 |in phase | | |

 |================================+==========+==========|

 |Total error (coherent mode) | 1.1 | 0.32 |

 |======================================================|

 Platform Mounting

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

 The ROS High Gain Antenna was attached to the +X side of the

 spacecraft bus and is flexible. The ROS HGA frame

 (ROS\_HGA) was defined as a fixed offset frame with its

 orientation given relative to the ROS\_SPACECRAFT frame.

 For details please refer to INSTHOST.CAT also located in this

 folder.

 Operating Modes

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

 A two-way dual-frequency radio link was used for

 occultations, gravity observations, and solar corona

 investigations. Such a radio link benefited from the superior

 frequency stability of the ground station. The dual-frequency

 downlink at X-band and S-band was used to separate classical

 and dispersive Doppler shifts, allowing correction of the

 observed frequency shift by any plasma contribution. For some

 observations (e.g., solar corona) an S-band uplink was used to

 increase sensitivity to plasma effects along the path.

 In the above experiments, operation was usually preferred

 with full power in the carrier (no telemetry or other

 modulation on the downlink) to maximize signal-to-noise ratio.

 The dual-frequency one-way radio link at S- and X-band was

 used for bistatic radar experiments. In these experiments,

 the HGA will be pointed toward the Comet and could not be used

 to capture an uplink signal, receive commands, or transmit

 telemetry.

 The dual-frequency USO driven one-way radio link will also

 used for occultation experiments where there is no time to

 establish a two-way link. Stability of the one-way link is

 sufficient to allow scientifically useful probing of the

 neutral atmosphere; the ionospheric analysis can be carried

 out using the differential phase/frequency effects at S- and

 X-band which were proportional to each other.

 Instrument Specification - New Norcia

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

 ESA completed construction of a 35 m ground station at its

 complex near New Norcia, Australia, in the year before launch of

 Mars Express. The station provided uplink at either S- or

 X-band and simultaneous dual-frequency downlink at both bands.

 Specifications are given below. the 'build date' is taken

 arbitrarily to be 1 January 2003.

 Instrument Id : RSS

 Instrument Host Id : NNO

 Pi Pds User Id : MPAETZOLD

 Instrument Name : UNK

 Instrument Type : RADIO SCIENCE

 Build Date : 2003-01-01

 Instrument Mass : UNK

 Instrument Length : UNK

 Instrument Width : UNK

 Instrument Height : UNK

 Instrument Manufacturer Name : UNK

 The IFMS (Intermediate Frequency Modulation System) at NNO is a

 piece of equipment which mainly provides:

 - generation of the uplink IF carrier, possibly modulated with

 a TC signal (from an extrernal source) and a Ranging signal

 (internally generated)

 - reception of the downlink IF signal

 - diversity combination estimation

 - demodulation (remnant and suppressed carrier demodulators and

 Ranging demodulator) and generation of bit stream for the

 telemetry decoding system

 - collection of Doppler, Meteo and Ranging measurements into

 data sets, later available for local display and remote

 retrieval via DDS

 - telemetry decoding is provided by the integrated TCDS

 (Telemetry Channel Decoding System) functional unit (the

 presence of the TCDS may be optional)

 System overview

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

 Antenna

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

 | Front-End |

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 | |Meteo | |

 | |sensors| |

 | ------- |

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 | v |

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

| TC | |IFMS | v | |TM |

| | | v |-------------------------| | | |

| | | |---------| | Common Front End/ | | | |

| |---------->| Up-link | .>| Diversity Combiner | | | |

| | | |Modulator| . |-------------------------| | | |

| |<--------->|---------| . | | | | | |

| | Uplink | ^ . v v v | | |

| |handshake| . . ----- ------- -------- | | |

| | | . . | OLP | |RG Dmod| |R/S carr|--->| |

|----| | . . ----- ------- | Demod || | |

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 | . . . . | TCDS |---->| |

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

 | | System Monitoring & Control | |

 | | (UCPU software) | |

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

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

 | | |

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

 | DCP | |STC II| | OCC |

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

 IFMS software

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

 The IFMS software is mainly in charge of the following

 functions:

 - handle the Digital Signal Processing (DSP) units (Uplink

 Modulator, Common Front End, Diversity Combiner, Ranging

 Demodulator, Remnant Carrier Demodulator, Suppressed Carrier

 Demodulator, Meteo system and TCDS)

 - execute data acquisition requests and collect independently

 Doppler, AGC, Meteorological, Ranging and Open-Loop data

 - allow the Control Centre to retrieve the collected data

 - provide Monitoring & Control access to the Station Computer

 (STC)

 - provide Monitoring & Control access to an operator via the

 Development Control Position (DCP) for both local control

 and engineering purpose

 Subsystems

 ----------

 Of primary interest to radio science are the three

 Intermediate Frequency and Modem Systems (IFMS) at New Norcia

 which controlled both the uplink and downlink.

 The IFMS baseband processor operated on a 17.5 Msps 24-bit

 complex sample stream (12 bit words each for the I and Q

 channels) which resulted from filtering and decimating the 280

 Msps 8-bit stream output by the Common Front End (CFE)

 analog-to-digital converter. These channels were provided for

 both the right circular and left-circular polarizations (RCP

 and LCP, respectively).

 The Radio Science raw data could be directly transferred to a

 mass storage device and/or processed by a Fast Fourier

 routine. Data transfer rates from the digital signal processor

 to data storage (disk) were limited to 10 samples/s. Data

 transfer to the European Space Operations Center (ESOC) could

 be done at a rate of 2 ksps.

 Subsystems overview

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

 The IFMS is constituted of a 48.26 cm (19'') crate containing

 the UNIX CPU (UCPU), the Time Code Reader (TCR) and the DSP

 units (Uplink Modulator (ULM), CFE units, General DSP units

 (GDSP), except the Meteo unit which is external to the

 system).

 - Internal network and IP Processor (IPP):

 The Internet Protocol suite is used to interface most of

 the IFMS elements on an internal IP network. For this the

 GDSP units are equipped with an IPP (IP Processor), in

 charge of mamaging data communication with the UNIX-CPU

 (based on IP) and the DSP board controller (based on serial

 interface).

 - The Time Code Reader (TCR) receives:

 - the Time Reference (IRIG-B on 1 kHz or 5 MHz carrier)

 - the Frequency Reference (5 MHz or 10 MHz)

 It distributes Time to the other units to be used for

 measurement time-tagging.

 - Meteo Unit:

 The Meteo Unit includes outdoor sensors providing analogue

 data for humidity, pressure, temperature and indoor

 electronic equipment (located in fact outside of the IFMS

 rack). It provides ASCII formatted numerical measurement of

 humidity, pressure and temperature to the IFMS management

 processor.

 - Uplink Modulator (ULM):

 The ULM unit generates internally the ranging signal (Tone

 and Code) in digital form. It receives the telecommand

 signal in either digital or analogue form from external

 equipment. It outputs an IF signal (230 MHz or 70 MHz)

 modulated by the uplink ranging signal and/or the

 telecommand signal.

 - Common Front End Unit:

 The CFE unit receives (from the down-converters) the 70 MHz

 down-link IF signals modulated by telemetry and possibly

 ranging signals and digitises them for further processing.

 The digital data is propagated on the rack back-plane.

 Note: A second CFE can be present in the IFMS.

 - Diversity combiner:

 The DCE unit makes estimates of:

 - the depolarisation angle between the LH and RH channels

 - the phase error between the LH and the RH channels

 It then provides qualification information on the rack

 back-plane for further use by the demodulators.

 - Ranging receiver and demodulator:

 The RGD unit receives, from the Common Front End and

 Diversity Combiner units, the digital demodulated 70 MHz

 signal and qualification information. It demodulates the

 down-link signal and extracts Doppler measurement. It

 generates a replica Ranging signal and performs the Tone PLL

 and the Ambiguity Resolution in order to measure signal

 round-trip delay, modulo the maximum code length. It

 provides Doppler and Ranging measurement.

 - Remnant and Suppress Carrier demodulators:

 The RCD and SCD units receive, from the Common Front End

 and Diversity Combiner units, the digital demodulated 70 MHz

 signal and qualifier. They provide demodulated telemetry

 data and Doppler measurement.

 - Telemetry Channel Decoder System:

 The TCDS unit receives, from the demodulator units, the

 telemetry bit stream and performs Viterbi and Reed-Solomon

 decoding and frame synchronisation. It provides decoded and

 synchronised telemetry data emitted via a UDP/IP protocol.

 - Open-Loop Processor:

 The OLP unit receives, from the Common Front End and

 Diversity Combiner units, the digital demodulated 70 MHz

 signal and qualifier. It provides Open-Loop measurements.

 Operational Considerations

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

 By agreement between the Rosetta Radio Science (RSI) Team

 and the European Space Operations Centre (ESOC), the three

 IFMS units at New Norcia were configured as follows:

 IFMS 1: Controlled uplink, including choice of band (usually

 X-band, but S-band for solar conjunction). Two

 channels of closed-loop downlink were possible; these

 could be any two of the four X-RCP, X-LCP, S-RCP, and

 S-LCP combinations. If X-RCP and X-LCP were selected,

 then the IFMS computed polarization.

 IFMS 2: Backup for IFMS 1; RSI could specify its

 configuration if it was not assigned otherwise.

 IFMS 3: RSI could always specify the configuration

 Platform Mounting

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

 In the IRTF2000 reference system at epoch 2002-07-24 12:00:00,

 the cartesian coordinates of the intersection of the azimuth

 and elevation axes of the New Norcia antenna were (meters):

 X = -2414067.051

 Y = 4907869.387

 Z = -3270605.276

 Using the WGS84 reference ellipsoid with equatorial radius

 6378137 m and inverse flattening 298.257223563, the geodetic

 latitude, longitude, and height were

 geodetic latitude = -31.04822306 degrees north

 longitude = 116.19150227 degrees east

 height = 252.224 meters

 Calibration

 -----------

 See Calibration section for spacecraft.

 Modes

 -----

 See Modes section for spacecraft. In addition, there were

 two mode choices on the ground.

 Closed-loop data acquisition was done with a phase-locked

 loop receiver at the ground station. The downlink signal

 arriving at the station could be either one-way or two-way.

 Two-way Doppler shifts were extracted by comparing each

 measurement of the downlink carrier frequency from the

 phase-locked loop with a reference from the ground station

 frequency reference source -- e.g., a hydrogen maser with a

 frequency stability on the order of 1E-15 to 1E-16. Because

 this frequency reference source was also used for generation

 of the uplink carrier, the accuracy of the frequency

 determination was as good as the reference source. The

 Doppler integration time needed to achieve a certain signal to

 noise ratio determined the time between successive frequency

 determinations. The amplitude of the radio signal was

 estimated by the Automatic Gain Control (AGC).

 Open-loop data recording was done by filtering and

 down-converting the received radio carrier signal to baseband

 where it was digitally sampled and stored for subsequent

 analysis. The open-loop receiver was tuned by a local

 oscillator. The frequency of the local oscillator was given

 by the best available estimate of the carrier frequency

 transmitted by the spacecraft and applying Doppler

 corrections due to the relative spacecraft-to-Earth motion.

 Measurement Parameters

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

 Each IFMS generated up to four types of data records:

 Doppler, gain, range, and/or meteorology. Each included a

 header with the following information:

 station identifier;

 spacecraft identifier;

 time tag of the first and last samples;

 sample period;

 total number of samples; and

 several flags or other markers to identify the data.

 Doppler samples could be taken at 1000, 100, 10, 1, or 0.1

 per second; the data records contain:

 sample number and time;

 unwrapped phase and

 accumulated phase with respect to a reference.

 Gain records contain:

 sample number and time;

 carrier level and

 polarization angle.

 Range data could be taken every 1-120 seconds (in user

 selectable increments of 1 second); range records contain:

 sample number and time;

 round trip delay modulo the ranging code;

 current code number and

 several flags and status words.

 Meteorological records contain:

 sample number and time;

 humidity;

 pressure and

 temperature.

 Instrument Specification - DSN

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

 Three Deep Space Communications Complexes (DSCCs) (near

 Barstow, CA; Canberra, Australia; and Madrid, Spain) comprised

 the DSN tracking network. Each complex was 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. Primary activity at each

 complex was radiation of commands to and reception of telemetry

 from active spacecraft.

 Transmission and reception was possible in several

 radio-frequency bands, the most common being 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 400 kW were available.

 The Deep Space Network was managed by the Jet Propulsion

 Laboratory of the California Institute of Technology for the

 U.S. National Aeronautics and Space Administration.

 Specifications included:

 Instrument Id : RSS

 Instrument Host Id : DSN

 Pi Pds User Id : MPAETZOLD

 Instrument Name : RADIO SCIENCE SUBSYSTEM

 Instrument Type : RADIO SCIENCE

 Build Date : UNK

 Instrument Mass : UNK

 Instrument Length : UNK

 Instrument Width : UNK

 Instrument Height : UNK

 Instrument Manufacturer Name : UNK

 So far as radio science was concerned, the DSN was an evolving

 'instrument;' the paragraphs which follow describe its

 capabilities during the first year of Rosetta orbital

 operations. For more information on the Deep Space Network and

 its use in radio science see reports by [ASMAR&RENZETTI1993],

 [ASMAR&HERRERA1993], and [ASMARETAL1995]. For design

 specifications on DSN subsystems see [DSN810-5]. For DSN use

 with MGS Radio Science see [TYLERETAL1992A], [TYLERETAL2001],

 and [JPLD-14027].

 Subsystems - DSN

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

 The Deep Space Communications Complexes (DSCCs) were an integral

 part of Radio Science instrumentation. Their system performance

 directly determined the degree of success of Radio Science

 investigations, and their system calibration determined the

 degree of accuracy in the results of the experiments. The

 following paragraphs describe the functions performed by the

 individual subsystems of a DSCC. This material has been adapted

 from [ASMAR&HERRERA1993] and [DSN871-049-041]; for additional

 information, consult [DSN810-5], [DSN821-110], and [DSN821-104].

 Each DSCC included a set of antennas, a Signal Processing

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

 Laboratory (JPL). The general configuration is illustrated

 below; not all antennas are shown.

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

 | DSS 25 | | DSS 27 | | DSS 14 | | DSS 15 | | DSS 16 |

 |34-m BWG| |34-m HSB| | 70-m | |34-m HEF| | 26-m |

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

 | | | | |

 | v v | v

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

 --------->|GOLDSTONE|<---------- |EARTH/ORB|

 | SPC 10 |<-------------->| LINK |

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

 | SPC |<-------------->| 26-M |

 | COMM | ------>| COMM |

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

 | | |

 v | v

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

 | NOCC |<--->| JPL |<------- | |

 ------ | CENTRAL | | GSFC |

 ------ | COMM | | NASCOMM |

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

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

 ^ ^

 | |

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

 |

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

 The following table lists the DSN antennas (Deep Space Stations,

 or DSS's -- a term carried over from earlier times when antennas

 were individually instrumented) available for Rosetta. Not

 all antennas were actually used for ROS; their capabilities

 varied and some were more suitable for ROS Radio Science than

 others.

 GOLDSTONE CANBERRA MADRID

 Antenna SPC 10 SPC 40 SPC 60

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

 26-m DSS 16 DSS 46 DSS 66

 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 was connected to all other

 subsystems; and the Test Support Subsystem could have been.

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

 |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) was part of the

 Monitor and Control System (MON) which also included the

 ground communications Central Communications Terminal (CCT)

 and the Network Operations Control Center (NOCC) Monitor and

 Control Subsystem. The DMC was the center of activity at a

 DSCC. The DMC received and archived 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, was done through the

 DMC. The effect of this was to centralize the control,

 display, and short-term archiving functions necessary to

 operate a DSCC. Communication among the various subsystems

 was done using a Local Area Network (LAN) hooked up to each

 subsystem via a network interface unit (NIU).

 DMC operations were 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 was 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 could be stored in the CMC

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

 also received, processed, and displayed event/alarm messages,

 and maintained an operator log. Assignment and configuration

 of the NMCs was done through the CMC; to a limited degree the

 CMC could perform some of the functions performed by the NMC.

 There were two CMCs (one on-line and one backup) and three

 NMCs at each DSCC. The backup CMC could function as an

 additional NMC if necessary.

 The NMC processor provided 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

 Uplink Subsystem (UPL), and one or more DSCC Downlink Tracking

 and Telemetry Subsystems (DTTs). The NMC also maintained an

 operator log which included all operator directives and

 subsystem responses. One important Radio Science-specific

 function that the NMC performed was 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 were recorded on magnetic tape as well

 as appearing in the NOCC displays. The NMC was required to

 operate without interruption for the duration of the Radio

 Science data acquisition period.

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

 Communications Subsystem, controlled all data communication

 between the stations and JPL. The ARA received all required

 data and status messages from the NMC/CMC, and could record

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

 The ARA also received predicts and other data from JPL, and

 passed them on to the CMC.

 DSCC Antenna Mechanical Subsystem

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

 Radio Science activities generally required support from

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

 antennas at each DSCC functioned as large-aperture collectors

 which, by double reflection, caused the incoming radio

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

 collecting surface of the antenna focused the incoming energy

 onto a subreflector, which was adjustable in both axial and

 angular position. These adjustments were made to correct for

 gravitational deformation of the antenna as it moved between

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

 7 cm. The subreflector adjustments optimizde 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

 had 'shaped' primary and secondary reflectors, with forms

 that were modified paraboloids. This customization allowed

 more uniform illumination of one reflector by another. The

 BWG reflector shape was ellipsoidal.

 On the 70-m antennas, the subreflector directed

 received energy from the antenna onto a dichroic plate, a

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

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

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

 accepted both frequencies without requiring a dichroic plate.

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

 meters in diameter) directed 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 separated 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 was 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 could rotate the movable components and their support

 structures.

 The different antennas could be pointed by several means. Two

 pointing modes commonly used during tracking passes were

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

 closed-loop receiver locked to a spacecraft signal, the

 system tracked the radio source by conically scanning around

 its position in the sky. Pointing angle adjustments were

 computed from signal strength information (feedback) supplied

 by the receiver. In this mode the Antenna Pointing Assembly

 (APA) generated a circular scan pattern which was sent to the

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

 to the corrected pointing angle predicts. Software in the

 receiver-exciter controller computed the received signal

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

 position with the received signal level variations allowed the

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

 Thus, within the capability of the closed-loop control

 system, the scan center was pointed precisely at the apparent

 direction of the spacecraft signal source. An additional

 function of the APA was 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 sent 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 were expected (e.g., during an

 occultation experiment), CONSCAN could not be used. Under

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

 pointing angle adjustments were based on a predetermined

 Systematic Error Correction (SEC) model.

 Independent of CONSCAN state, subreflector motion in at least

 the z-axis could 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 was

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

 elevation angle) selected to minimize phase change and signal

 degradation. This could be done via Operator Control Inputs

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

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

 passed the commands to motors that drove the subreflector to

 the desired position.

 Pointing angles for all antenna types were computed by

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

 the flight project. These predicts were received and archived

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

 APA, which transformed the direction cosines of the predicts

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

 antenna predict points to the antenna-mounted ACS computer

 along with a selected SEC model. The pointing predicts

 consisted of time-tagged AZ-EL points at selected time

 intervals along with polynomial coefficients for interpolation

 between points.

 The ACS automatically interpolated the predict points,

 corrected the pointing predicts for refraction and

 subreflector position, and added the proper systematic error

 correction and any manually entered antenna offsets. The ACS

 then sent angular position commands for each axis at the

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

 commands were generated from the position commands at the

 servo controller and were subsequently used to steer the

 antenna.

 When not using binary predicts (the routine mode for

 spacecraft tracking), the antennas could be pointed using

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

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

 with respect to the celestial frame. Values were provided to

 the station in text form for manual entry. The ACS

 quadratically interpolated among three RA and DEC points

 which were on one-day centers.

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

 tracking radio sources fixed with respect to the celestial

 frame.

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

 had a special high-accuracy pointing capability called

 'precision' mode. A pointing control loop derived the

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

 axis autocollimator mounted on the Intermediate Reference

 Structure. The autocollimator projected a light beam to a

 precision mirror mounted on the Master Equatorial drive

 system, a much smaller structure, independent of the main

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

 encoders. The autocollimator detected elevation/cross-

 elevation errors between the two reference surfaces by

 measuring the angular displacement of the reflected light

 beam. This error was 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) were

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

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

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

 DSCC Antenna Microwave Subsystem

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

 70-m Antennas: Each 70-m antenna had three feed cones

 installed in a structure at the center of the main reflector.

 The feeds were positioned 120 degrees apart on a circle.

 Selection of the feed was made by rotation of the

 subreflector. A dichroic mirror assembly, half on the S-band

 cone and half on the X-band cone, permitted simultaneous use

 of the S- and X-band frequencies. The third cone was devoted

 to R&D and more specialized work.

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

 and X-band signals at the feed horn and transmitted them

 through polarizer plates to an orthomode transducer. The

 polarizer plates were adjusted so that the signals were

 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 were two Block IVA

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

 were Block IIA TWMs.

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

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

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

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

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

 an orthomode transducer was needed. The X-band amplification

 options included two Block II TWMs or a High Electron Mobility

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

 amplification was provided by a Field Effect Transistor (FET)

 LNA.

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

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

 in and out as needed. Typically the following modes were

 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 and dual LNAs,

 each of the above four modes could be used in a single- or

 dual-frequency configuration. Thus, for antennas with the

 most complete capabilities, there were sixteen possible ways

 to receive (2 polarizations, 2 waveguide path choices, 2

 LNAs, and 2 bands).

 DSCC Uplink Subsystem

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

 The Uplink Subsystem (UPL) comprised the Exciter, the Command

 Modulation, Uplink Controller, and Uplink Ranging assemblies.

 The UPL was based around the Block V Exciter (BVE) equipment.

 The BVEs generated uplink carrier and uplink range phase data,

 and delivered these data directly to the Project.

 The exciter generated a sky-level signal which was provided to

 the Transmitter Subsystem for the spacecraft uplink signal.

 Based on predicts from the CMC, the BVE provided a sky-level

 uplink signal to either the low-power or the high-power

 transmitter. It was 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) could be configured such that it

 was 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.

 DSCC Downlink Subsystem

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

 The Downlink Subsystem consisted of three groups of equipment:

 the closed-loop receiver group, the open-loop receiver group,

 and the RF monitor group.

 Closed-Loop Receivers: The current closed-loop group, called

 the Downlink Tracking and Telemetry Subsystem (DTK), consisted

 of the Downlink Controller, the Receiver and Ranging Processor

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

 was currently based around the Block V Receiver (BVR)

 equipment. The BVRs generated downlink carrier and downlink

 range phase data (not Doppler counts and ranging units, as had

 been the case before early 2003), and delivered these (phase)

 data directly to the Project.

 The DTT could simultaneously support as many downlink channels

 as could be assigned by the NMC, up to the total number of

 RRPs available at a given complex (allowing for the reception

 of several different frequencies/wavelengths/bands, or

 different polarizations of the same downlink band). The only

 other constraint was that any selected downlink band/bands had

 to be supported by that antenna.

 The closed-loop receivers provided the capability for rapid

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

 order to accomplish signal acquisition within a short time,

 the receivers were predict driven to search for, acquire, and

 track the downlink automatically. Rapid acquisition precluded

 manual tuning, though that remained as a backup capability.

 The BVRs utilized FFT analyzers for rapid lock-up. The

 downlink predicts were generated by the NSS and then

 transmitted to the CMC, which sent them to the Receiver

 Subsystem where two sets could be stored. The receiver

 started acquisition at the beginning of a track (pass), or at

 an operator-specified time. The BVRs could also be operated

 from the NMC without local operators attending them. The

 receivers also sent performance and status data, displays,

 and event messages to the NMC.

 With the BVRs, the simulation (SIM) synthesizer signal was

 used as the reference for the Doppler extractor. The

 synthesizer was adjusted before the beginning of the pass to a

 frequency that was appropriate for the channel (i.e., within

 the band) of the incoming signal; and would generally remain

 constant during the pass.

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

 of three settings: narrow, medium, or wide. It was configured

 such that the expected amplitude changes were accommodated

 with minimum distortion. The loop bandwidth (2BLo) was

 configured such that the expected phase changes could be

 accommodated while maintaining the best possible loop SNR.

 Open-Loop Receivers: The open-loop Radio Science Receiver

 (RSR) was a dedicated receiver that got a downconverted signal

 (about 300 MHz), filtered the signal to limit its bandwidth

 (to 265-375 MHz, centered at 320 MHz), and then further

 downconverted (to a center frequency of 64 MHz) and digitized

 the signal. The RSR filters were specified by their

 bandwidths, desired resolution, and offset from the predicted

 sky frequency.

 The open-loop receivers operated in both a link-assigned and a

 stand-alone mode. In the link-assigned mode, the NMC received

 monitor data from the RSR for incorporation into the data set

 for tracking support, and provided a workstation from which

 the RSR could be operated. RSRs that were not assigned to a

 link could be operated in a stand-alone mode without

 interference to any activities in progress at the complex.

 Monitor data were not sent to the NMC by RSRs operating in

 the stand-alone mode.

 DSCC Transmitter Subsystem

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

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

 exciter signal from the Uplink (Exciter) Subsystem exciter.

 This signal was routed via the diplexer through the feed horn

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

 spacecraft.

 The Transmitter Subsystem power capabilities ranged from 18 kW

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

 were available only at 70-m stations.

 DSCC Tracking Subsystem

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

 Beginning in early 2003, all the Tracking Subsystem functions

 were incorporated within the Uplink Subsystem (UPL) and the

 Downlink Tracking and Telemetry Subsystem (DTT) -- the DTK was

 eliminated.

 DSCC Frequency and Timing Subsystem

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

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

 frequency and timing references required by the other DSCC

 subsystems. It contained four frequency standards, of which

 one was prime and the other three were backups. Selection of

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

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

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

 fed the Coherent Reference Generator (CRG), which provided

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

 also provided the frequency reference to the Master Clock

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

 Insertion and Distribution Assembly (TID), which provided UTC

 and SIM-time to the complex.

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

 the station-calculated Doppler pseudo-residuals, the Doppler

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

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

 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 was reported to JPL, where a database

 was kept. The clock offsets stored in the JPL database were

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

 measurements from several GPS satellites, and a time tag

 associated with the mean reading. The clock offsets that were

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

 40 relative to SPC 10, etc.

 Optics - DSN

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

 Performance of the DSN ground stations depended primarily on

 the size of the antenna and capabilities of the electronics.

 These are summarized in the following set of tables. Beamwidth

 is half-power full angular width. Polarization is circular; L

 denotes left circular polarization (LCP), and R denotes right

 circular polarization (RCP).

 DSS S-Band Characteristics

 70-m 34-m 34-m

 Transmit BWG HEF

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

 Frequency (MHz) 2110- 2025- N/A

 2120 2120

 Wavelength (m) 0.142 0.142 N/A

 Ant Gain (dBi) 62.7 56.1 N/A

 Beamwidth (deg) 0.119 N/A N/A

 Polarization L or R L or R N/A

 Tx Power (kW) 20-100 20 N/A

 Receive

 -------

 Frequency (MHz) 2270- 2270- 2200-

 2300 2300 2300

 Wavelength (m) 0.131 0.131 0.131

 Ant Gain (dBi) 63.3 56.7 56.0

 Beamwidth (deg) 0.108 N/A 0.24

 Polarization L & R L or R L or R

 System Temp (K) 20 31 38

 DSS X-Band Characteristics

 70-m 34-m 34-m

 Transmit BWG HEF

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

 Frequency (MHz) 8495 7145- 7145-

 7190 7190

 Wavelength (m) 0.035 0.042 0.042

 Ant Gain (dBi) 74.2 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) 8400- 8400- 8400-

 8500 8500 8500

 Wavelength (m) 0.036 0.036 0.036

 Ant Gain (dBi) 74.2 68.1 68.3

 Beamwidth (deg) 0.031 N/A 0.063

 Polarization L & R L & R L & R

 System Temp (K) 20 30 20

 NB: The X-band 70-m transmitting parameters are given

 at 8495 MHz, the frequency used by the Goldstone

 planetary radar system. For telecommunications, the

 transmitting frequency was in the range 7145-7190

 MHz, the power would typically be 20 kW, and the gain

 would be about 72.6 dB (70-m antenna). When ground

 transmitters were used in spacecraft radio science

 experiments, the details of transmitter and antenna

 performance rarely impacted the results.

 Calibration - DSN

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

 Calibrations of hardware systems were carried out periodically

 by DSN personnel; these ensured that systems operated at

 required performance levels -- for example, that antenna

 patterns, receiver gain, propagation delays, and Doppler

 uncertainties met specifications. No information on specific

 calibration activities was 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 performed a

 series of calibrations to ensure that systems met specifications

 for that operational period. Included in these calibrations was

 measurement of receiver system temperature in the configuration

 to be employed during the pass. Results of these calibrations

 were recorded in (hard copy) Controller's Logs for each pass.

 Operational Considerations - DSN

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

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

 for Radio Science depended 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 could be carried out in several

 ways. For details see the subsection 'DSCC Antenna Mechanical

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

 the preferred mode for tracking spacecraft; pointing

 predicts were provided, and the antenna simply followed those.

 With CONSCAN, the antenna scanned conically about the optimum

 pointing direction, using closed-loop receiver signal

 strength estimates as feedback. In planetary mode, the

 system interpolated from three (slowly changing) RA-DEC

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

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

 antenna tracked a fixed point on the celestial sphere. In

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

 optical feedback system. In addition, it was possible on

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

 to minimize phase changes in the received signal.

 DSCC Downlink Tracking and Telemetry Subsystem

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

 The diplexer in the signal path between the transmitter and

 the feed horns on all antennas could be configured so that it

 was out of the received signal path in order to improve the

 signal-to-noise ratio in the receiver system. This was known

 as the 'listen-only' or 'bypass' mode.

 Closed-Loop vs. Open-Loop Reception

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

 Radio Science data could be collected in two modes: closed-

 loop, in which a phase-locked loop receiver tracked the

 spacecraft signal, or open-loop, in which a receiver sampled

 and recorded a band within which the desired signal presumably

 resided. Closed-loop data were collected using Closed-Loop

 Receivers, and open-loop data were collected using Open-Loop

 Receivers in conjunction with the Full Spectrum Processing

 Subsystem (FSP). See the Subsystems section for further

 information.

 Closed-Loop Receiver AGC Loop

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

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

 of three settings: narrow, medium, or wide. In general, it

 was configured so that expected signal amplitude changes were

 accommodated with minimum distortion. The loop bandwidth was

 typically configured so that expected phase changes could be

 accommodated while maintaining the best possible loop SNR.

 Coherent vs. Non-Coherent Operation

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

 The frequency of the signal transmitted from the spacecraft

 could generally be controlled in two ways -- by locking to a

 signal received from a ground station or by locking to an

 on-board oscillator. These were known as the coherent (or

 'two-way') and non-coherent ('one-way') modes, respectively.

 Mode selection was made at the spacecraft, based on commands

 received from the ground. When operating in the coherent

 mode, the transponder carrier frequency was derived from the

 received uplink carrier frequency with a 'turn-around ratio'

 as expressed in the table below:

 Uplink Downlink Turn-Around

 Band Band Ratio

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

 X X 880/749

 X S 240/749

 In the non-coherent mode, the downlink carrier frequency was

 derived from the spacecraft's on-board, crystal-controlled

 oscillator. Either closed-loop or open-loop receivers (or

 both) could be used with either spacecraft frequency reference

 mode. Closed-loop reception in the two-way mode was usually

 preferred for routine tracking/navigation. Occasionally the

 spacecraft operated coherently such that one ground station

 did the transmitting, and a second/different ground station

 received the 'downlink' signal -- this was referred to as the

 'three-way' mode.

 Media Calibration System

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

 The Earth's atmosphere contributes phase and amplitude noise

 to the spacecraft radio signal received at a ground station.

 Each DSCC had a GPS receiver subsystem to calibrate for both

 the ionosphere and troposphere (both wet and dry components),

 along the zenith direction. This subsystem also measured the

 temperature, pressure, humidity, wind speed and direction, and

 Faraday rotation.

 Location - DSN

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

 Accurate spacecraft navigation using radio metric data required

 knowledge of the locations of the DSN tracking stations. The

 coordinate system in which the locations of the tracking

 stations were expressed needed to be consistent with the

 reference frame definitions used to provide Earth orientation

 calibrations.

 The International Earth Rotation Service (IERS) had established

 a terrestrial reference frame for use with Earth orientation

 measurements. The IERS issued a new realization of the

 terrestrial reference frame each year. The definition of the

 coordinate system changed slowly as the data improved, and as

 ideas about how best to define the coordinate system developed.

 The overall changes from year to year were at the level of as

 few centimeters. The 1993 version of the IERS Terrestrial

 Reference Frame (IRTF1993) was most used for DSN station

 locations.

 The DSN station locations were determined by use of VLBI

 measurements, and by conventional and GPS surveying. Tables of

 station locations were available in either Cartesian or geodetic

 coordinates. The geodetic coordinates were 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) were

 as follows:

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

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

 DSS 12 -2350443.812 -4651980.837 +3665630.988

 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 16 -2354763.158 -4646787.462 +3669387.069

 DSS 17 -2354730.357 -4646751.776 +3669440.659

 DSS 23 -2354757.567 -4646934.675 +3669207.824

 DSS 24 -2354906.528 -4646840.114 +3669242.295

 DSS 25 -2355021.795 -4646953.325 +3669040.628

 DSS 26 -2354890.967 -4647166.925 +3668872.212

 DSS 27 -2349915.260 -4656756.484 +3660096.529

 DSS 28 -2350101.849 -4656673.447 +3660103.577

 DSS 33 -4461083.514 +2682281.745 -3674570.392

 DSS 34 -4461146.720 +2682439.296 -3674393.517

 DSS 42 -4460981.016 +2682413.525 -3674582.072

 DSS 43 -4460894.585 +2682361.554 -3674748.580

 DSS 45 -4460935.250 +2682765.710 -3674381.402

 DSS 46 -4460828.619 +2682129.556 -3674975.508

 DSS 49 -4554231.843 +2816758.983 -3454036.065 (Parkes)

 DSS 53 +4849330.129 -0360338.092 +4114758.766

 DSS 54 +4849434.496 -0360724.062 +4114618.570

 DSS 55 +4849525.318 -0360606.299 +4114494.905

 DSS 61 +4849245.211 -0360278.166 +4114884.445

 DSS 63 +4849092.647 -0360180.569 +4115109.113

 DSS 65 +4849336.730 -0360488.859 +4114748.775

 DSS 66 +4849148.543 -0360474.842 +4114995.021

 The DSN Station Locations in ITRF1993 Geodetic reference frame

 at epoch 1993.0 (assuming subreflector-fixed configuration) were

 as follows:

 latitude longitude height

 Antenna deg min sec deg min sec (m)

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

 DSS 12 35 17 59.77577 243 11 40.24697 962.87517

 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 16 35 20 29.54391 243 7 34.86823 944.71108

 DSS 17 35 20 31.83778 243 7 35.38803 937.65000

 DSS 23 35 20 22.38335 243 7 37.70043 946.08556

 DSS 24 35 20 23.61492 243 7 30.74701 952.14515

 DSS 25 35 20 15.40494 243 7 28.70236 960.38138

 DSS 26 35 20 8.48213 243 7 37.14557 970.15911

 DSS 27 35 14 17.78052 243 13 24.06569 1053.20312

 DSS 28 35 14 17.78136 243 13 15.99911 1065.38171

 DSS 33 -35 24 1.76138 148 58 59.12204 684.83864

 DSS 34 -35 23 54.53984 148 58 55.06236 692.71119

 DSS 42 -35 24 2.44494 148 58 52.55396 675.35557

 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 46 -35 24 18.05462 148 58 59.08571 677.55141

 DSS 49 -32 59 54.25297 148 15 48.64683 415.52885

 DSS 53 40 25 38.48036 355 45 1.24307 827.50081

 DSS 54 40 25 32.23152 355 44 45.24459 837.60097

 DSS 55 40 25 27.45965 355 44 50.51161 819.70966

 DSS 61 40 25 43.45508 355 45 3.51113 841.15897

 DSS 63 40 25 52.34908 355 45 7.16030 865.54412

 DSS 65 40 25 37.86055 355 44 54.88622 834.53926

 DSS 66 40 25 47.90367 355 44 54.88739 850.58213

 Measurement Parameters - DSN

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

 Open-Loop System

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 Output from the Open-Loop Receivers (OLRs), as sampled and

 recorded by the Radio Science Receiver (RSR), was a stream of

 1-, 2-, 4-, 8-, or 16-bit I (In-Phase) and Q

 (Quadrature-Phase) samples. The spacecraft transmitted an RF

 signal to an antenna, where the signal was downconverted to

 IF. The RSR selected an IF signal for a particular frequency

 band and passed it through a digitizer (where it was

 attenuated and then mixed with timing information). The

 signal was then decimated, filtered (to I&Q samples), and then

 multiplied by the signal from a numerically controlled

 oscillator. Finally, the RSR reduced the bandwidth

 and sample rate of the samples, and truncated the results

 (thus creating an offset of -0.5 in the output data). The

 samples of data were packed into SFDU blocks (nominally

 containing a single second's worth of data), and a header was

 attached to provide the following associated data for the

 record:

 - time tag for the first sample in the data block

 - data source identification (DSS, RSR, and sub-channel), and

 frequency band

 - data sample resolution (bits per sample) and rate (samples

 per second)

 - filter gain, ADC RMS amplitude, and attenuation

 - frequency and phase polynomial coefficients

 Closed-Loop System

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

 Since mid 2003, closed-loop data were recorded and provided in

 Tracking and Navigation Files (TNFs). The TNFs were comprised

 of SFDUs that had variable-length, variable-format records

 with mixed typing (i.e., can contain ASCII, integer, and

 floating-point items in a single record). These files all

 contained entries that included measurements of Doppler,

 range, and signal strength, along with status and uplink

 frequency information.

 Acronyms and Abbreviations

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

1PPS One Pulse per Second

ACS Antenna Control System

ADEV Allan Deviation

AGC Automatic Gain Control

APA Antenna Pointing Assembly

BPF Band Pass Filter

BWG Beam Wave Guide

CFE Common Front End

CONSCAN Connical Scanning

D/L downlink

dBi decibel relative to isotropic

DCP Development Control Position

DDC Digital Down Converter

DDS Data Distribution System

DSCC Deep Space Communications Complex

DSN Deep Space Network

DSP Digital Signal Processing

DSS Deep Space Network Station

ESA European Space Agency

ESOC European Space Operations Centre

FTS Frequency and Timing subsystem

HEF High Efficiency

HGA High Gain Antenna

HSB High-Speed BWG

IFMS Intermediate Frequency Modulation System

IVC Intermediate Frequency Selection Switch

JPL Jet Propulsion Laboratory

LCP Left Circular Polarization

LGA Low Gain Antenna

LNA Low Noise Amplifier

LPF Low Pass filter

MB Medium band

Mbit Mega bit

MOLA Mars Orbiting Laser Altimeter

N/A not applicable

NASA National Aeronautics and Space Administration

NMC Network Monitor and Control

NNO New Norcia

OCC Operation Control Centre

ODF Orbit Data File

OLR Open Loop Receiver

PDS Planetary Data System

PI Principal Investigator

pwr power

rcvrs receivers

RCP Right Circular Polarization

RF Radio Frequency

RFDU Radio Frequency Distribution Unit

RIV Radio Science IF-VF Downconverter

rms root mean square

RO Rosetta Orbiter

RSI Rosetta Radio Science Investigations

RSR Radio- Science Receiver

RSS Radio Science Subsystem

SIM Simulation

SNR Signal-Noise-Ratio

SNT System Noise Temperature

SPC Signal Processing Center

STC Station Computer

sps samples per second

STAT Science Time Analysis Tool

TCDS Telemetry Channel Decoding System

TCXO Temperature Controlled Crystal Oscillator

TID Time Insertion and Distribution Assembly

TNF Tracking and Navigation File

TWOD Two-way dual-frequency mode

TWOS Two-way single-frequency mode

TWTA Traveling wave tube amplifier

Tx Transmitter

U/L uplink

UNK unknown

UTC Coordinated Universal Time

USO Ultra stable Oscillator

VDP VME Data Processor

VF Video Frequency

VME Versa Module Eurocard (standard bus)

w watt "

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