Cassini's Science Data Connection: The Deep Space Network

Nationsl Aeronautics and Space Administration

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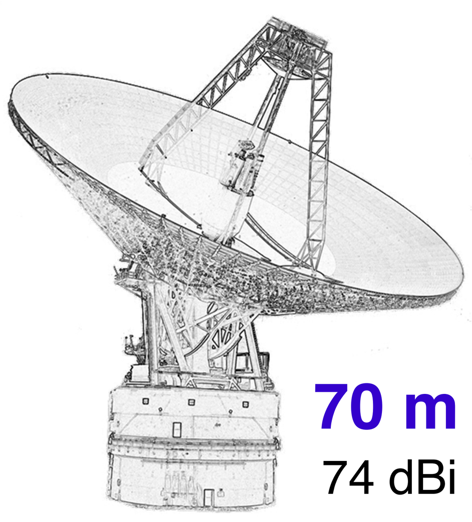
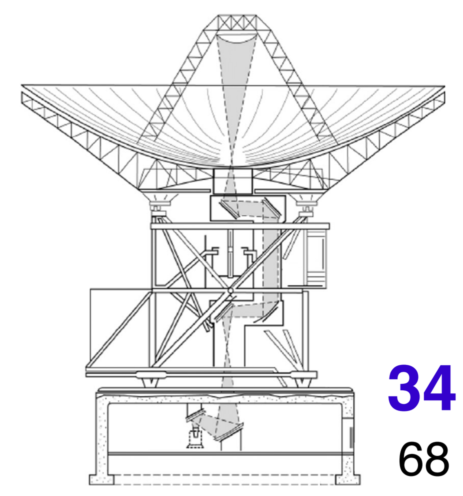
An essential resource for some 40 users, DSN served as the Cassini project's connection with the spacecraft for nearly 22 years, beginning in 1995 with compatibility and end-to-end testing in ATLO, and ending with its Grand Finale dive to destruction into Saturn's atmosphere. Cassini utilized DSN antennas about 8,700 times; roughly once a day using one or more apertures.[2]

ANT



70 m
74 dBi D/L gain



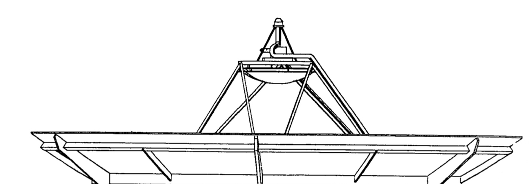
34 m
68 dBi gain

X-band 8 GHz: TRK, TLM, RS

S-band 5 GHz: RS, Huygens

Ka-band 32 GHz: RS

Ku-band 14 GHz: RADAR[3]

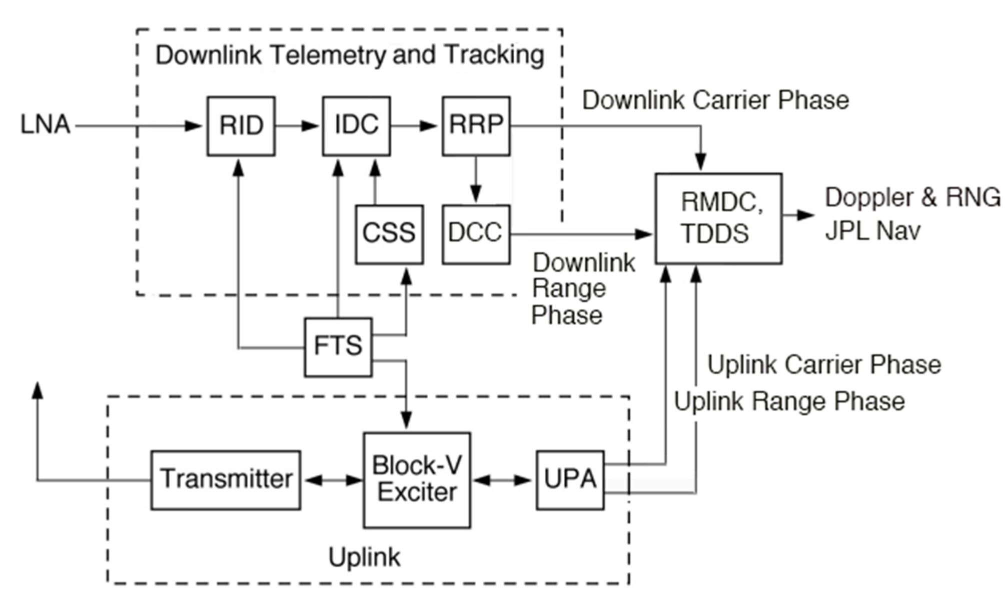


Cassini 4 m
47 dBi gain

LNA

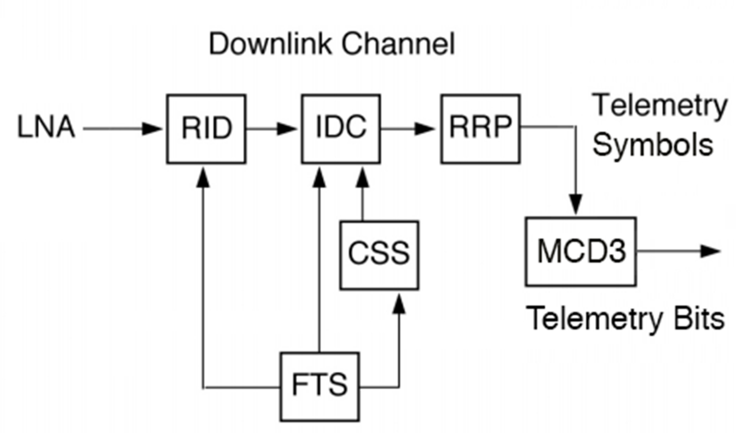
Low-Noise Amplifiers (LNA) in DSN are HEMTs and MASERs, cryogenically cooled to ~5 K to limit their contribution of electronic noise. HEMT performance has improved over the years to become equivalent to that of Block II X-band traveling-wave vacuum tube MASERs. DSN's LNAs have a 100-MHz bandwidth, and provide a gain of 25 dB.[4]

TRK

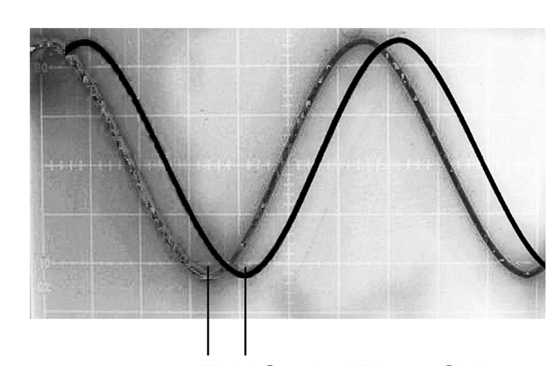


Radiometric Tracking data (TRK)[5] consists of Doppler and Range (RNG), and to a minor extent DSN antenna pointing angles. Doppler-shift measurements of the spacecraft carrier are accurate enough for use in navigation when the D/L frequency is phase-coherent with the highly stable DSN U/L carrier, in 2-way or 3-way mode. RNG measurements are based on timing U/L carrier-modulated tones as returned on the D/L carrier, compensated for atmospheric refraction and other factors. Doppler-based measurements of Cassini's velocity were typically accurate to the order of hundredths of millimeters per second ($m^{-5} \cdot s^{-1}$). RNG had a typical accuracy of single meters.

TLM

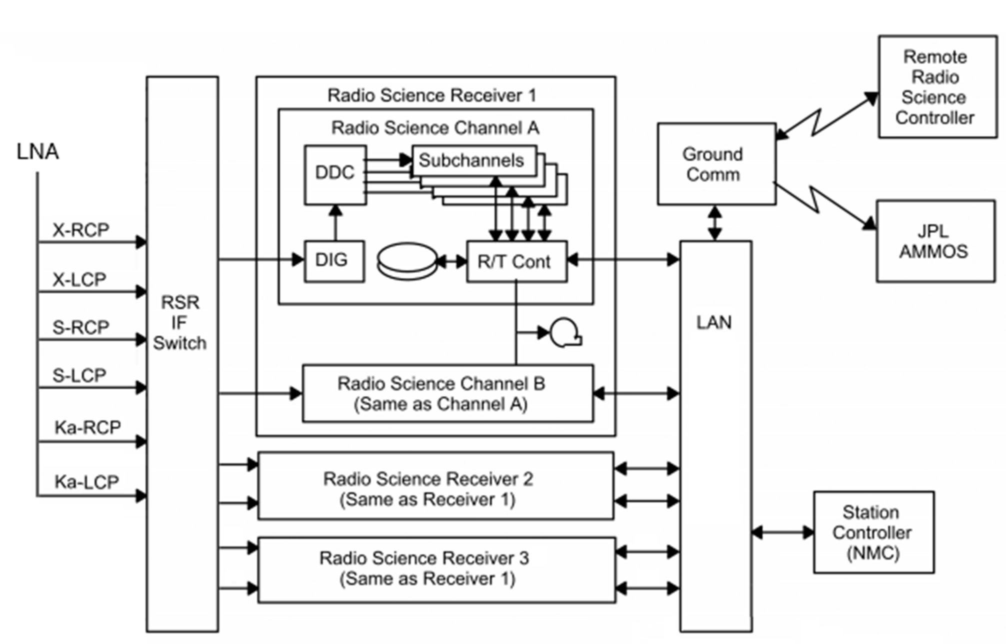


Telemetry (TLM)[5] is D/L digital data containing repetative engineering data from subsystems and instruments, and unique science data from payload instruments. Some Nav data came in TLM as OPNAV images; AACS TLM provided Nav other useful information on propulsive events such as RWA desaturation and bias maneuvers that were not tracked in real time. TLM is transmitted as phase-shift symbols (typically at 1.4 radians; see inset) on the spacecraft's carrier, up to 142 kbps given a 70m DSS, or 360 kHz subcarrier for bit rates below 41 kbps. Over 43-m DSSs the best rate was 35 kbps. TLM symbols were Viterbi decoded into bits at the rate of six symbols (phase-shifts) per bit with the MCD3. The bits were then Reed-Solomon decoded. The concatenated FEC scheme resulted in a digital data stream of basically perfect fidelity.



TLM Symbol Phase Shifts

RS



Radio Science (RS)[5] data type is high-rate sampling and recording of the D/L carrier at S-, X-, and Ka-band. RS had monopulse pointing refinement available, abberation correction when Ka-band U/L was in use, and an advanced media calibration system to quantify tropospheric delay. Based on type of experiment, the RS data is later mined for information in a wide variety of categories, such as ring and atmosphere occultations, celestial mechanics mass and mass distribution determinations, gravity field surveys, gravitational wave searches, general-relativistic bending, solar corona plasma characterisation, and more.

CMD

Command (CMD) data symbols were manchester-coded on an U/L 16-kHz subcarrier, typically at 500 bps for Cassini. The CMD data received by the spacecraft could represent weeks-long sequences of timed commands, shorter timed-sub-sequences, "do-this-now" untimed commands, or new flight software for AACS, CDS, and the payload instruments. Commands were sent to both CDSs twice a day, typically, to reset the CDS fault-protection timer known as "CMDLOSS."

VLBI, F&T, MON

VLBI (Very Long Baseline Interferometry) is another data type available to users, and it also contributes to DSN operational accuracy (e.g. monitoring DSS locations as the continents drift). VLBI observations of a spacecraft provide high-precision plane-of-sky determinations; they require two widely-separated DSSs to simultaneously view first a quasar, then the spacecraft, then if time permits, another slew back to the quasar. Cassini used VLBI only a few times, mostly in 2004 to support the accurate Huygens delivery. **F&T (Frequency and Timing)** delivered uninterrupted reference signals, of world-class stability and accuracy, to all DSN subsystems and many assemblies, making it possible for DSN to offer extraordinary navigation and telecommunications services. For most of Cassini's flight, a hydrogen MASER served as the main DSN frequency reference. **MON (Monitor)** data reported on DSN performance at subsystem and assembly levels in real time so that operations personnel could evaluate ongoing DSN performance.

Abbreviations

AACS Attitude and Articulation Control subsystem
AMMOS Advanced Multi-Mission Operations System
ANT DSN Antenna subsystem
ATLO Assembly, Testing, and Launch Operations
CDS Command Data Subsystem on spacecraft
CSS Channel-Select Synthesizer
dB Decibel
dBi Decibels relative to a hypothetical isotropic radiator
DCC Downlink Channel Controller
DDC Downlink Data Channel
DIG Digitizer assembly
D/L Downlink
FEC Forward Error Correction
FTS Frequency and Timing System
HEMT High-Electron-Mobility field-effect Transistor
IDC Intermediate-frequency to Digital Converter
IF Intermediate Frequency
LCP Left-hand Circular Polarization
MASER Microwave Amplification by Stimulated Emission of Radiation
MCD3 Maximum-liklihood Convolutional Decoder block 3
NMC Network Monitor & Control
RCP Right-hand Circular Polarization
RID Radio-frequency to Intermediate-freq Downconverter
RMDC Radiometric Data Conditioning
RRP Receiver and Range Processor (closed-loop)
RSR Radio Science Receiver (open-loop)
RWA Reaction Wheel Assembly
TDDS Tracking Data Delivery System
U/L Uplink
UPA Uplink Assembly

[1]Jet Propulsion Laboratory, California Institute of Technology. [2]*Cassini Final Mission Report,* JPL D-101143. [3]This frequency was not part of DSN services. [4]*Low-Noise Systems in the Deep Space Network,* M.S. Reid, Ed., (DESCANSO February 2008). [5]Diagrams adapted from *Cassini Orbiter/Huygens Probe Telecommunications,* J.Taylor, L.Sakamoto, J.Wong (DESCANSO January 2002).

Poster No. T14