The DSN Radio Science System

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The DSN Radio Science System recently supported the Radio Science experiments at Voyager 1 Saturn encounter. These experiments which included two atmospheric occultations, a planetary ring occultation, and ring scattering experiment were supported by Deep Space Stations in Australia (DSS 43) and Spain (DSS 63). This article describes the DSN Radio Science System data flow from receipt of the radio signals at the antenna to delivery of the recorded data to the project.

I. Introduction

Figure 1 is a block diagram representation of the DSN Radio Science System (DRS) recently used to successfully support the Voyager 1 Saturn encounter radio science experiments. The DSN Deep Space Stations (DSS) are the heart of this system. In particular DSS 63 and DSS 43 were the prime supporting stations for the radio science experiments at Voyager 1 Saturn encounter. DSS 63 supported the Titan occultation, the Saturn occultation egress, ring occultation, and ring scattering experiments with four-channel medium band open-loop-receiver recording. DSS 43 supported the Saturn occultation ingress with two channel narrow band open-loop-receiver recording. Both stations provided wide bandwidth open-loop-receiver recording capability as a backup to the prime narrow band and medium band open-loop systems.

In addition to the medium band open-loop recording capability at DSS 63, other new implementation provided to support the Voyager radio science experiments were the Precision Power Monitor, which measures system temperatures, and the Spectral Signal Indicator (SSI) that monitors the open-loop recording system at several points, providing spectral information for the monitored signal.

The following paragraphs describe the DSS subsystems that support the DSN Radio Science System in more detail. In addition, each of the other facilities supporting the DSN Radio Science System, Ground Communications Facility (GCF) and Network Operations Control Center (NOCC), and their support functions are described. The narrative in general will describe the flow of data from receipt at the antenna through the system as indicated on the Radio Science System block diagram (Fig. 1).

II. The Deep Space Stations

The Deep Space Station (DSS) is the Radio Science System instrument. DSS system performance directly determines the degree of success of the experiment and system calibration determines the degree of uncertainty in the results of the experiment. The following paragraphs describe those functions performed by the individual subsystems depicted in Fig. 1. Specific configuration and calibration requirements are

addressed in a separate paragraph after the functional descriptions of the subsystems.

A. The Antenna Mechanical Subsystem

The 64-meter Antenna Mechanical Subsystems function as large aperture collectors which by double reflection focus incoming radio frequency (S- and X-band RCP/LCP) energy into the S- and X-band feedhorns (part of the Antenna Microwave Subsystem).

The large collecting surface of the antenna focuses the incoming RF energy onto the hyperboloid subreflector which is adjustable in both axial and tilt positions to permit optimizing the focusing of energy into the feedhorns. The subreflector is locked into a fixed position for many radio science events. The subreflector then reflects the received energy to the dichroic plate, a device that reflects S-band energy to the S-band feedhorn and transmits X-band energy to the X-band feedhorn.

Transmitted S-band RF energy emanating from the feedhorn is focused by the same reflectors into a narrow cylindrical beam. Since the beam is very narrow, it must be pointed with high accuracy and precision. This is accomplished by a series of drive motors and gear trains which rotate those portions of the structure which support the reflectors, position sensors, and related electronics. Electronic servo amplifiers are used to amplify and condition the axes angle or position error signals, which are received and are provided to the drive-motor controls.

Pointing angles are computed from an ephemeris provided by the project, and the antenna is pointed to these angles. Once the receiver has acquired a signal to provide feedback, a radio source can be tracked by scanning around it (CONSCAN) and computing pointing angles from signal-level information supplied by the receiver. During periods when signal level dynamics are excessive or signal levels received are expected to be low, i.e., during occultations and some other radio science experiments, conscan cannot be used and angle pointing is accomplished by manually inserting offsets to the computed angle predict set.

B. The Antenna Microwave Subsystem

The Antenna Microwave Subsystem accepts the received S- and X-band RCP/LCP signals at the feedhorn from the Antenna Mechanical Subsystem. The received signals are transmitted through the polarizer plates to the orthomode transducer. The polarizer plates are adjusted so that RCP signals are directed to X-band Traveling Wave Maser 2 and S-band Traveling Wave Maser 1 so that LCP signals are directed to X-band Traveling Wave Maser 1 and S-band Traveling Wave

Maser 2. After amplification by the masers, the signals are routed to the Receiver-Exciter Subsystem via the Microwave Switching Assembly.

The S-band uplink signal is transmitted via the Diplexer Assembly through the feedhorn to the antenna where it is focused and beamed to the spacecraft.

The noise diode assemblies, under control of the PPM, inject known amounts of noise power into the received signal path so that accurate real-time system temperature measurements may be made.

C. The Transmitter Subsystem

The Transmitter Subsystem accepts the S-band frequency exciter signal from the Receiver-Exciter Subsystem and amplifies it to a transmitted output level of 20 kW. The signal is then routed via the diplexer to the antenna and then focused and beamed to the spacecraft.

D. The Receiver-Exciter Subsystem

The Receiver-Exciter Subsystem receives, amplifies, and frequency down converts spacecraft-radiated S- and X-band RCP/LCP signals. The closed-loop receivers provide doppler and ranging signals to the tracking subsystem. Dedicated open-loop receivers provide baseband signals to the Radio Science Subsystem and fixed-tuned wide bandwidth open-loop receivers provide backup systems to the narrowband and medium band open-loop receivers.

The exciter generates the S-band drive signal provided to the transmitter subsystem that provides the spacecraft uplink signal.

The Spectral Signal Indicator provides local displays of received signal spectrums and routes spectral data to the radio science subsystem. These displays are used to validate radio science system data at the DSS, NOCC, and project areas.

The Precision Power Monitor (PPM) measures system temperatures by injecting known amounts of noise power into the signal path and comparing the total power within a given bandwidth before and during periods of noise injection. System temperature measurements are made for each of the four masers by utilizing the closed-loop receivers as monitoring devices. This use of the receivers imposes a configuration constraint on them when they are used to monitor all four masers. That is, the BLOCK IV receivers must monitor X-band RCP/LCP masers and the BLOCK III receivers are used to monitor S-band RCP/LCP masers.

E. The Tracking Subsystem

The Tracking Subsystem receives the ranging spectrum and doppler signals from the Receiver-Exciter Subsystem. It generates a range code that is routed to the exciter and modulates the S-band uplink carrier. The demodulated range spectrum is compared to a model of the transmitted range code and the round trip signal delay to the spacecraft is computed, formatted and transmitted to the GCF data records subsystem which produces an Intermediate Data Record (IDR) tape upon which the data is delivered to the project. Similarly the doppler phase is counted, formatted, and delivered to the project. This radio metric data supports radio science celestial mechanics and general relativity experiments in addition to providing a partial backup to the open-loop system.

In addition, the Tracking Subsystem computes data residuals and noise estimates, receives and stores predicts, and provides partial status information to the Monitor and Control Subsystem including receiver AGC levels and lock status.

F. The Radio Science Subsystem

The Radio Science Subsystem digitizes, bandwidth reduces, and records (1) very narrow, (2) narrow, and (3) medium bandwidth radio science data and digitizes and records wide bandwidth radio science data. It receives radio science frequency predicts from NOCC, configuration and control data from the Monitor and Control Subsystem, and S- and X-band RCP/LCP signals from the Receiver-Exciter Subsystem. It transmits spectral information from the SSI to NOCC and the project mission support area via the GCF wideband data lines. It controls the narrow and medium band open-loop receiver LO by sending frequency control information to the Receiver-Exciter Subsystem.

G. Monitor and Control Subsystem

The Monitor and Control Subsystem provides control messages to the centrally controlled DSS Subsystems including the Radio Science and Tracking Subsystems. It provides partial status information for these same subsystems. It generates the angle drive tape needed by the Antenna Pointing Subsystem and, in addition, controls the SSI and PPM in the Receiver-Exciter Subsystem. It receives the system temperature information from the PPM and displays it on the data system terminal (DST). It relays the system temperature information to the NOCC Monitor Subsystem for display in NOCC and the project mission support area.

III. The Ground Communications Facility

The Ground Communications Facility (GCF) provides the communication networks required to support the communication requirements of the Radio Science System. These facilities exist at the DSS and JPL and are briefly described in the following paragraphs.

A. GCF High-Speed Data Subsystem

The High-Speed Data Subsystem transmits radio science predictions from the NOCC to the DSS and CTA-21, and Radio Science System performance validation data from the DSS to NOCC.

B. GCF Wideband Subsystem

In real time, the Wideband Subsystem transmits SSI data from the DSS to the NOCC.

C. GCF Data Records Subsystem

The GCF Data Records Subsystem formats and provides radio science data on computer-compatible tape to the flight projects.

IV. Network Operations Control Center

A. NOCC Radio Science Subsystem

The NOCC Radio Science Subsystem generates open and closed-loop radio science DTV graphics displays, and DRS status and configuration displays. In addition, the NRS provides the planetary atmosphere refracted trajectory input to the NOCC Support Subsystem for the purpose of generating radio science predicts.

B. NOCC Monitor Subsystem

The NOCC Monitor Subsystem displays system temperature information and provides the monitor IDR tape upon which system temperature information is delivered to the project.

C. NOCC Support Subsystem

The NOCC Support Subsystem generates DSS frequency and tracking predicts using a polynomial coefficient tape produced by the POEAS software as input. In addition, predicts can be generated using manual inputs.

D. NOCC Display Subsystem

The NOCC Display Subsystem provides the NOCC Radio Science Subsystem generated radio science displays to the Network Operations Control Area and to project radio science support areas, and provides control data to the NOCC Radio Science Subsystem.

E. NOCC Tracking Subsystem

The NOCC Tracking Subsystem generates tracking system status displays and transmits them to the display subsystem to be routed and displayed.

V. Network Radio Science Subsystem

The Network Radio Science Subsystem is located in CTA-21. It bandwidth-reduces wide bandwidth radio science data recorded at the DSS. It receives digital wide bandwidth and medium bandwidth radio science data from the DSS Radio Science Subsystem, generates bandwidth-reduced radio science data, and provides medium and wide bandwidth radio science data on computer-compatible tape to the flight project.

VI. Open-Loop Recording System Prepass Calibration

The recorded open-loop receiver signals were the prime deliverable data type for the Voyager, Titan, and Saturn ring occultations and the ring scattering experiment. For that reason, it was extremely important that the open-loop system be properly set up prior to the recording pass, and that a calibration tape be made. This calibration data serves as a calibration for the data later recorded and establishes the basic uncertainty in the results of the experiment. The following paragraphs describe these calibrations.

A. Purpose of the Calibration

The open-loop recording calibration tapes are made to accomplish the following:

(1) To establish the output of the open-loop receivers at a level that will not saturate the input to the Occultation Data Assembly (ODA) or Digital Recording Assembly (DRA) A/D converters.

(2) To provide data that will establish baseline values for the phase, frequency, and amplitude stability of the open-loop system.

To achieve goal (1) the calibration recording is made using a test signal generated by the exciter-translator that is set to provide the maximum predicted received signal level for the

recording period. Then the output level of the receivers is adjusted to the level determined by the equation

$$S = \left[\frac{SNR + 1}{(2\ SNR + 2\ k\ \sqrt{2\ SNR} + k^2)} \right]^{1/2} L \qquad (1)$$

where

S = receiver output levels (volts rms)

SNR = expected received signal-to-noise ratio

k = Number of sigma margin desired for saturation

L = A/D converter saturation level

In order to achieve goal (2) for medium-band recording it is necessary to step the test signal across the bandpass of the receiver filter. This is done in ten 5 kHz (at S-band) steps. Stepping the signal in frequency in this manner allows the necessary phase, frequency, and amplitude calibrations to be made.

Frequency stepping is not necessary for narrow-band recording.

So that an X-band RCP/LCP test signal may be generated, a cap is provided that is placed over the X-band feedhorn from which a linearly polarized signal is injected into the horn. This cap is oriented such that the linearly polarized signal is transmitted equally by the orthomode coupler to its RCP and LCP output ports, thus providing equal RCP/LCP calibration signals.

A consequence of using a cap over the feedhorn in this manner to generate a test signal is that the X-band system temperature has been increased approximately 10 dB. It has, in effect, been terminated into an ambient load. To counter the 10 dB increase in receiver output power due to the presence of the cap it is necessary to insert 10 dB pads into the signal path at appropriate points. These must be removed after the calibration recording is made.
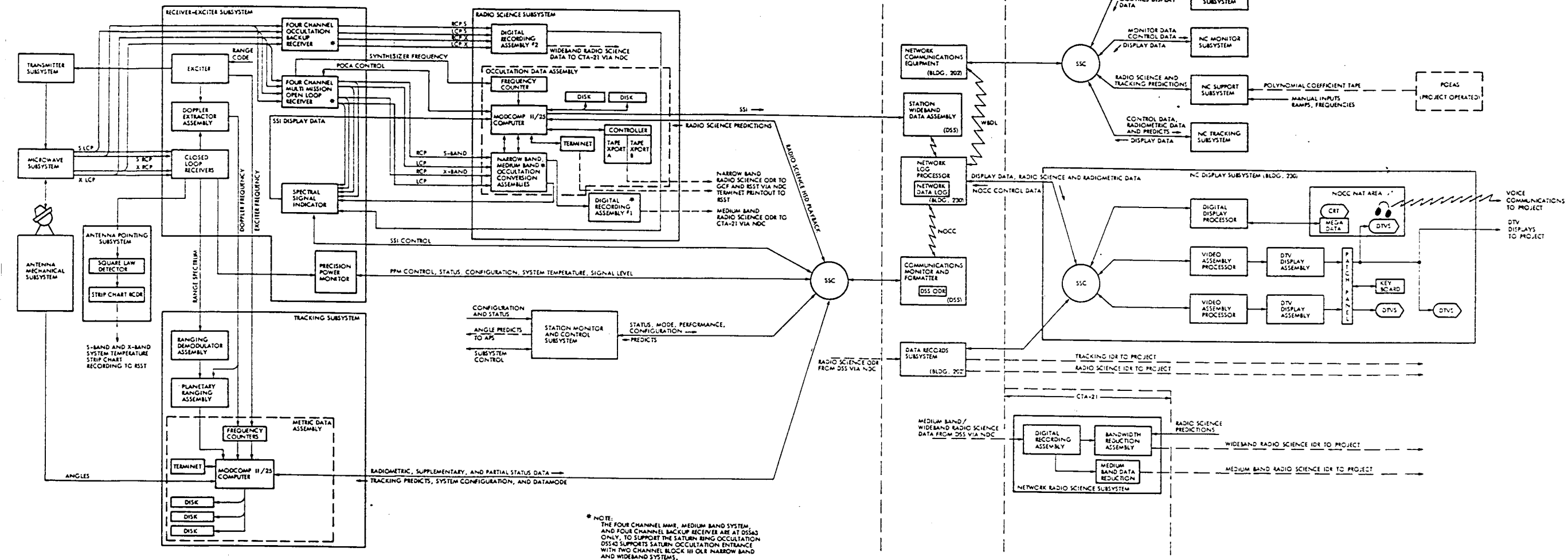
Fig. 1. Deep Space Network Radio Science System Block Diagram depicting the Radio Science System as configured to support the Voyager I Saturn encounter.