209
Open-Loop Radio Science

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Massimo Tinto 12/12/2000
Massimo Tinto Date

Approved by:

Massimo Tinto 12/13/2000
Massimo Tinto Date
Radio Science Services
System Development Engineer

Prepared by:

Robert W. Sniffin 12/11/00
R. W. Sniffin Date

Released by:

[Signature on file at TMOD Library]
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Note to Readers

There are two sets of document histories in the 810-005 document, and these histories are reflected in the header at the top of the page. First, the entire document is periodically released as a revision when major changes affect a majority of the modules. For example, this module is part of 810-005, Revision E. Second, the individual modules also change, starting as an initial issue that has no revision letter. When a module is changed, a change letter is appended to the module number on the second line of the header and a summary of the changes is entered in the module's change log.

This module documents the new Radio Science Receivers that will become operational in the year 2001 and the Ka-band capability at DSS 25. The equipment that was previously documented in module RSS-10 of 810-005, Rev. D has been removed from the network.

Contents

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1 Introduction

1.1 Purpose

This module describes the capabilities and performance of the Deep Space Network (DSN) Open-loop Radio Science equipment used for supporting radio science (RS) experiments.

1.2 Scope

This module discusses the open-loop radio science receiving equipment functions, architecture, operation, and performance. Although some RS experiments require uplink support and closed-loop Doppler and ranging data, this module emphasizes a description of the open-loop recording capability that is used solely during radio science experiments. Details of the closed-loop Doppler tracking system can be found in module 203, 34-m and 70-m Receiver Doppler. Details of the uplink functions can be found in the 70-m, 34-m High Efficiency (HEF), and 34-m Beam Waveguide (BWG) telecommunications interface modules 101, 103, and 104.

2 General Information

Radio science experiments involve measurements of small changes in the phase, frequency, amplitude, and polarization of the radio signal propagating from an interplanetary spacecraft to an Earth receiving station. By properly analyzing these data, investigators can infer characteristic properties of the atmosphere, ionosphere, and planetary rings of planets and satellites, measure gravitational fields and ephemeredes of planets, monitor the solar plasma and magnetic fields activities, and test aspects of the theory of general relativity. Details of the Radio Science System applications may be found in the JPL Publication 80-93, Rev. 1, written by S.W. Asmar and N.A. Renzetti, titled: *The Deep Space Network as an Instrument for Radio Science Research*.

2.1 Functions

The functions of the DSN with respect to conducting radio science experiments can be summarized as follows:

- Providing an uplink carrier signal to the spacecraft with a pure spectrum, including low phase noise and stable frequency.
- Acquisition, down conversion, digitization, and recording of the downlink carrier with minimal degradation to its frequency, phase, and amplitude stability.
- Providing assurance that the expected signals are being acquired and recorded.

2.2 Hardware Configuration

All radio science experiments require use of the antenna, microwave, antenna-mounted receiving, and frequency and timing equipment at the stations. They also require the Ground Communications Facility (GCF) to deliver the data from the stations to users and the Advanced Multi-mission Operations System (AMMOS) at JPL, where experiments are monitored. DSN stations are designed to meet radio science requirements for stability. However, one of the beam waveguide stations at the Goldstone Deep Space Communications Complex (DSCC), DSS 24, is not equipped with a high-quality frequency distribution system and is not recommended for radio science applications. A block diagram of the open-loop radio science receiving capability is shown in Figure 1.

The receiving equipment on each DSN antenna produces one or more intermediate frequency (IF) signals with a nominal center frequency of 300 MHz and a bandwidth that depends on the microwave and low noise amplifier equipment on the antenna as described in modules 101, 103, and 104. These IF signals are routed to a distribution amplifier (not shown in Figure 1) that provides multiple copies of each signal for use by the Radio-science Receivers (RSRs), the telemetry and tracking receivers, and other equipment in the signal processing center (SPC). One copy of each signal is provided to the RSR IF Switch that further divides and amplifies it with the result being that any of the RSR channels can be connected to any antenna IF signal.

There are two dedicated RSRs at the Goldstone Deep Space Communications Complex (DSCC) and one at the Canberra and Madrid DSCCs. Each complex also has an online spare that is shared with other functions including very-long baseline Interferometry (VLBI). Each RSR contains two channels however the design of the system software is such that, from the user's viewpoint, each RSR channel can be considered to be an independent open-loop receiver.

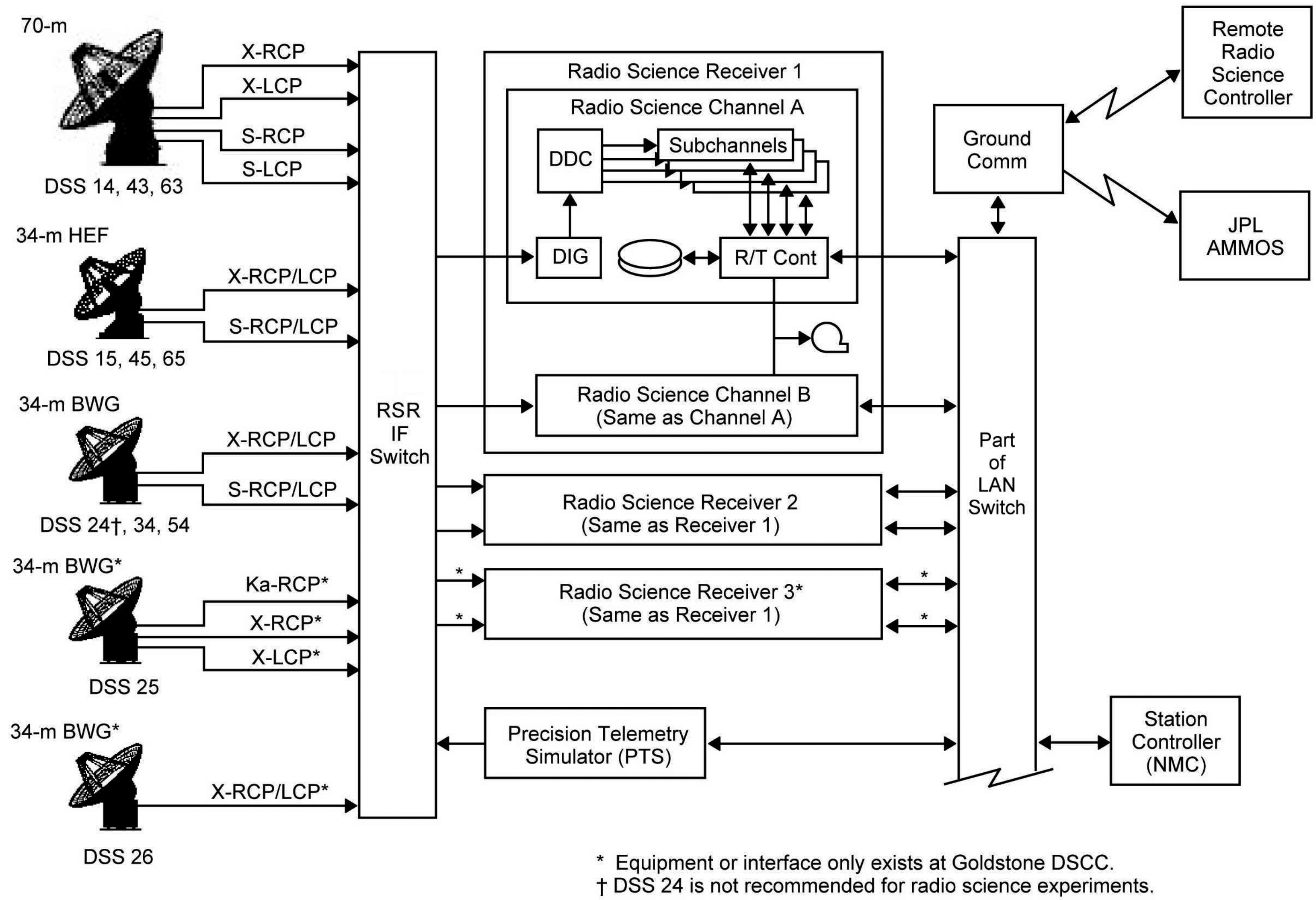

Figure 1. Radio Science Receiving Equipment Configuration

2.3 RSR Signal Processing

The IF signal selected by the RSR IF Switch is fed to the Digitizer (DIG) where it is filtered to limit its bandwidth to the range of 265–375 MHz centered at 320 MHz. This corresponds to a received frequency range of 2,265–2,375 MHz at S-band, 8,365–8,475 MHz at X-band, and 31,965–32,075 MHz at Ka-band. However, the actual received frequency range will depend on the characteristics of the equipment on the selected antenna. The filtered signal is downconverted to a center frequency of 64 MHz and digitized at 256 MHz with an 8-bit resolution. The resultant data are fed to the Digital Downconverter (DDC) that selects any 16-MHz bandwidth from the original bandpass with a resolution of 1 MHz and downconverts it to baseband in the form of a 16-Ms/s, 8-bit, complex data stream.

Baseband processing provides up to four subchannel filters to select frequency bands of interest for recording. The number of available filters depends on the selected bandwidths that can be broadly categorized as Narrowband, Medium Band, or Wideband. The following selection of filters is available:

- 4 Narrowband
- 2 Narrowband and 1 Medium Band
- 2 Medium Band
- 1 Wideband

The filters are specified by their bandwidths, the desired resolution (bits/sample) and an offset from the predicted sky frequency predict file. This frequency predict file is created by the DSN network support function and contains the spacecraft frequency altered by spacecraft trajectory and Earth-rotation. Table 1 lists the supported filter bandwidths and resolutions and gives the resultant data rate for each combination. Figure 2 shows the relationship between the frequency bands within the RSR

2.4 RSR Signal Detection

Because the RSR is an open-loop receiver, it does not have a mechanism to align its passband to (establish lock with, or track) the received signal. Instead, it relies on predicts to position its passband. This creates a risk that a predict error might result in the wrong portion of the received spectrum being processed. To assist in recognizing this, the RSR analyzes the data in each subchannel and provides a detected signal indication on the main display for that subchannel

In addition to the detected signal indication, the RSR provides a frequency-domain representation of the bandpass being recorded in each RSR subchannel using a Fast-Fourier Transform (FFT). Characteristics of the FFT such as number of points, averaging, and update rate are under user control.

Table 1. Supported Bandwiths and Resolutions with Resulting Data Rate

Category	Bandwidth	Resolution (b/sample)	Data Rate (b/s)
Narrowband	1 kHz	16	32,000
	2 kHz	16	64,000
	4 kHz	16	128,000
	8 kHz	16	256,000
	16 kHz	16	512,000
	25 kHz	16	800,000
	50 kHz	16	1,600,000
	100 kHz	16	3,200,000
	1 kHz	8	16,000
	2 kHz	8	32,000
	4 kHz	8	64,000
	8 kHz	8	128,000
	16 kHz	8	256,000
	25 kHz	8	400,000
	50 kHz	8	800,000
	100 kHz	8	1,600,000
Medium Band	250 kHz	16	8,000,000
	500 kHz	16	16,000,000
	250 kHz	8	4,000,000
	500 kHz	8	8,000,000
	1 MHz	8	16,000,000
	250 kHz	4	2,000,000
	500 kHz	4	4,000,000
	1 MHz	4	8,000,000
	2 MHz	4	16,000,000

Table 1. Supported Bandwiths and Resolutions with Resulting Data Rate (Continued)

Category	Bandwidth	Resolution (b/sample)	Data Rate (b/s)
Medium Band (Continued)	250 kHz	2	1,000,000
	500 kHz	2	2,000,000
	1 MHz	2	4,000,000
	2 MHz	2	8,000,000
	4 MHz	2	16,000,000
	250 kHz	1	500,000
	500 kHz	1	1,000,000
	1 MHz	1	2,000,000
	2 MHz	1	4,000,000
	4 MHz	1	8,000,000
Wideband	8 MHz	2	32,000,000
	8 MHz	1	16,000,000
	16 MHz	1	32,000,000

2.5 RSR Operation

The radio science equipment operates in both a link-assigned and a stand-alone mode. In the link-assigned mode, the Network Monitor and Control (NMC) function receives monitor data from the RSR for incorporation into the data set for tracking support and provides a workstation from which the RSR can be operated. RSRs that are not assigned to a link may be operated in a stand-alone mode without interference to any activities in process at the complex. Monitor data is not forwarded to the NMC by RSRs operating in the stand-alone mode.

The RSR employs a client-server architecture where each RSR channel acts as a server capable of accepting connections from up to five users operating the radio science client software at any time. In the link-assigned mode, one of these five clients is the NMC workstation. The RSR does not recognize any client as being superior to the others so it is up to the user to assign responsibility for control to one client with the other clients operating in a passive mode. One RSR client is required for each RSR channel being controlled or observed. Thus, a complex radio science experiment involving four RSR channels would require four RSR clients at the control point.

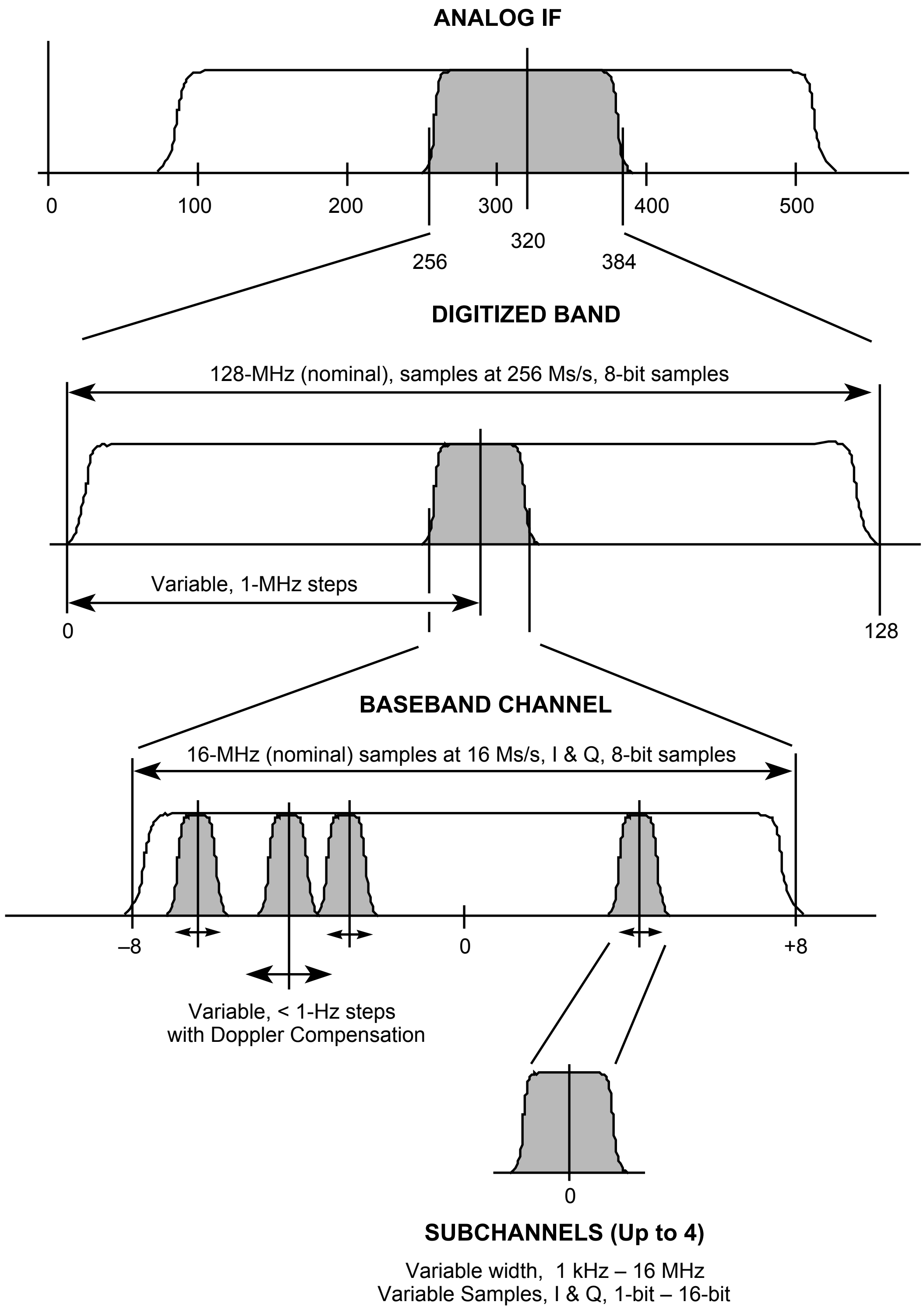

Figure 2. Relationships Between RSR Processing Bands

All functions of the RSR may be performed from the RSR client in real time. Of special interest to the RS experimenter are the ability to adjust (slew) the predicted frequency profile, to slew the individual subchannel frequencies, to adjust FFT parameters, and to enable or disable recording for each subchannel.

2.6 Data Delivery

When recording is enabled, baseband samples and ancillary information, discussed below, are formatted into a file of data blocks and stored on disk drives for delivery to JPL or other users. A separate data file is created for each subchannel. Data delivery is normally via the Reliable Network System (RNS). Data also may be obtained via File Transfer Protocol (FTP) or Digital Linear Tape (DLT) cartridges. The format is the same independent of the method of delivery.

2.6.1 Ancillary Data

The following ancillary data are included as a header for each data block. A detailed description of the data blocks is contained in TMOD Document 820-013, module 0159.

- Data record version
- Subchannel identification
- Time tag for first sample in block
- Station and pass identification
- Spacecraft identification
- Receiver configuration

2.7 Performance

The principal characteristics of the RSRs are summarized in Table 2. In addition, radio science experiments are influenced by the overall stability of equipment at the stations. The following sections provide information on the techniques used to validate RS equipment stability.

2.7.1 Frequency Stability

Long-term frequency stability tests are conducted with the exciter/ transmitter equipment and the Radio Science open-loop receiving equipment. An uplink signal generated by the exciter is translated at the antenna to a downlink frequency. The downlink signal is passed through the RF-IF downconverter at the antenna and into the RSR. In doing this test, however, instability in the frequency and timing equipment and the mechanical vibrations of the antenna are not included. This is because frequency and timing instability is cancelled out, while the mechanical vibrations of the antenna are not present in these data. Measurements of these items can however be obtained via other means, making it possible to provide an estimate of the

Table 2. Radio Science Receiver Characteristics

Parameter	Value	Remarks
Number of Channels		Note: Any channel may be connected to any received spectrum
Goldstone	4	2 additional channels are available shared with other applications
Canberra and Madrid	2	2 additional channels are available shared with other applications
Frequency Ranges Covered		
At RSR Input (MHz)	265 – 375	
Referenced to L-band (MHz)	1,645 –1,755	L-band receive capability at 70-m subnet is 1,628–1,708 MHz
Referenced to S-band (MHz)	2,265 – 2,375	S-band downlink allocation is 2,200–2,290 MHz for Earth orbiter application and 2,290–2,300 MHz for deep space applications
Referenced to X-band (MHz)	8,365 – 8,475	X-band downlink allocation is 8,400–8,450 MHz for deep space application and 8,450–8,500 MHz for Earth orbiter applications
IF Attenuation		
Range (dB)	0 – 31.5	
Resolution (dB)	0.5	
Doppler Compensation		
Maximum Doppler Shift (km/s)	30	At all downlink frequencies
Maximum Doppler Rate (m/s^2)	17	At all downlink frequencies
Maximum Doppler Acceleration (m/s^3)	0.3	At all downlink frequencies
Maximum Tuning Error (Hz)	0.5	At all downlink frequencies
Manual Offset (MHz)	–8.0 to +8.0	
Baseband Bandwidth (MHz)	16	

Table 2. Radio Science Receiver Characteristics (Continued)

Parameter	Value	Remarks
Baseband Resolution (MHz)	1	Positioning of baseband within IF or RF bandwidth
Number of Subchannels Available for each RSR	1 – 4	Configuration depends on data volume.
Subchannel Tuning		
Tuning (MHz)	±8	From center of baseband
Resolution (Hz)	<1	
Recording Bandwidths		See Table 2 for exact values.
Narrowband (NB), kHz	1 – 100	1 – 4-subchannels
Medium Band (MB), kHz	250 – 4,000	2 or 1 with 2 NB subchannels
Wideband (WB), MHz	8 or 16	NB and MB subchannels are not available
Resolutions (bits/sample)	16 – 1	Depends on selected bandwidth. See Table 2 for available resolutions.
Time Tagging		
Resolution (μs)	1	
Accuracy ((μs)	1	With respect to station clock
Signal Detection Display		1 for each subchannel being recorded
Number of points in FFT	100 – 4096	Default is 1000
Spectra Averaging	1 – 100	Default is 10
FFT Interval (s)	1 – 10,000	Default is 10

overall frequency stability of the stations. The long-term frequency stability is presented in terms of the Allan deviation over a specified integration time. Table 3 shows uplink and downlink Allan deviation requirements for the 34-m HEF, 34-m BWG, and 70-m antennas. Repeated testing has always produced estimates better than these requirements.

2.7.2 Phase Noise

Phase stability (Spectral Purity) testing characterizes stability over very short integration times. The region of the frequency band where phase noise measurements are performed can be as far as 10 kHz off the carrier frequency. Such measurements are reported in dB relative to the carrier (dBc), in a 1-Hz band at a specified distance from the carrier. Table 4 contains the required phase noise levels, at specified offsets, for the 34-m HEF, 34-m BWG, and 70-m subnets. As is the case with frequency stability measurements, repeated testing ensures these requirements are not exceeded.

2.7.3 Amplitude Stability

Amplitude stability tests measure the amplitude fluctuations produced by the open-loop receiving system relative to a constant (mean) amplitude input signal. The amplitude stability performance is specified in terms of a threshold on the amplitude fluctuations relative to the mean amplitude, and the corresponding probability that such fluctuations will not exceed such a threshold. An analysis indicates that 99.7% of the time, the amplitude stability at the 70-m, 34-m HEF, and 34-m BWG stations at S- and X-bands is less than 0.2 dB including the gain variation due to antenna pointing errors.

2.8 Precision Telemetry Simulator

The Precision Telemetry Simulator (PTS) is an external device that provides IF test signals for performance verification of the radio science equipment. Its signals are generated in the digital domain and subsequently converted to analog, with signal conditions driven from predicts. At least two simulated signals can be generated, each having its own characteristics in terms of Doppler and signal level, etc. The PTS signals are injected into the RSR via the RSR IF Switch.

3 Proposed Capabilities

The following paragraphs discuss capabilities that have not yet been implemented by the DSN but have adequate maturity to be considered for spacecraft mission and equipment design. Telecommunications engineers are advised that any capabilities discussed in this section cannot be committed to except by negotiation with the Telecommunications and Mission Operations Directorate (TMOD) Plans and Commitments Program Office.

3.1 70-m X-band Uplink Implementation

The 70-m X-band uplink implementation that has been completed at DSS 14 and DSS 43 will be extended to DSS 63. As a result, all 70-m stations will have the same capabilities and performance as described for DSS 14 and 43 in Tables 2, 3, and 4.

Table 3. Uplink and Downlink Allan Deviation Requirements

Averaging Time, s	**Allan Deviation**			
	1	**10**	**100**	**1000**
Station and Band				
34-m HEF				
X-band U/L	1.0×10^{-12}	1.1×10^{-13}	4.5×10^{-15}	4.3×10^{-15}
S-band D/L	4.1×10^{-13}	7.2×10^{-14}	9.1×10^{-15}	5.3×10^{-15}
X-band D/L	4.0×10^{-13}	4.9×10^{-14}	5.3×10^{-15}	4.7×10^{-15}
34-m BWG				
S-band U/L (DSS 24, 34, 54)	1.0×10^{-12}	1.1×10^{-13}	4.5×10^{-15}	4.3×10^{-15}
X-band U/L (DSS 25, 26, 34, 54)	1.0×10^{-12}	1.1×10^{-13}	4.5×10^{-15}	4.3×10^{-15}
S-band D/L (DSS 34, 54)	4.1×10^{-13}	7.2×10^{-14}	9.1×10^{-15}	5.3×10^{-15}
X-band D/L (DSS 25, 26, 34, 54)	4.0×10^{-13}	4.9×10^{-14}	5.3×10^{-15}	4.7×10^{-15}
Ka-band U/L (DSS 25)	No Rqmt.	No Rqmt.	1.1×10^{-14}	2.1×10^{-15}
Ka-band D/L (DSS 25)	1.3×10^{-13}	7.5×10^{-14}	6.8×10^{-15}	2.2×10^{-15}
70-m				
S-band U/L	1.5×10^{-12}	2.3×10^{-13}	1.1×10^{-14}	1.1×10^{-14}
X-band U/L (DSS 14, 43)	1.5×10^{-12}	2.3×10^{-13}	1.1×10^{-14}	1.1×10^{-14}
S-band D/L	4.1×10^{-13}	7.2×10^{-14}	9.1×10^{-15}	5.3×10^{-15}
X-band D/L	4.0×10^{-13}	4.9×10^{-14}	5.3×10^{-15}	4.7×10^{-15}

Table 4. Uplink and Downlink Phase Noise Requirements

Offset from Carrier, Hz	**Phase Noise, dBc**			
	1	**10**	**100**	**10 k**
Station and Band				
34-m HEF				
X-band U/L	–52.3	–61.8	–65.9	–65.9
S-band D/L	–62.8	–72.2	–76.7	–76.7
X-band D/L	–51.5	–60.9	–65.5	–65.5
34-m BWG				
S-band U/L (DSS 24, 34, 54)	–63.5	–72.5	–77.1	–77.1
X-band U/L (DSS 25, 26, 34, 54)	–52.3	–61.8	–65.9	–65.9
S-band D/L (DSS 34, 54)	–62.8	–72.2	–76.8	–76.8
X-band D/L (DSS 25, 26, 34, 54)	–51.6	–61.0	–65.5	–65.5
X-band D/L (DSS 25)	–59.7	–65.6	–66.0	–66.0
Ka-band D/L (DSS 25)	–55.2	–63.7	–64.0	–64.0
70-m				
S-band U/L	–63.5	–72.5	–77.1	–77.1
X-band U/L (DSS 14, 43)	–52.3	–61.8	–65.9	–65.9
S-band D/L	–62.8	–72.2	–76.7	–76.7
X-band D/L	–51.5	–60.9	–65.5	–65.5