Summary Report and Status of the Deep Space Network-Voyager Flight Project Telecommunications Compatibility

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The DSN-Voyager telecommunications compatibility tests are an ongoing series of Engineering level tests to determine the flight-ground interface compatibility and performance characteristics between these two systems. This report provides a summary and status of tests conducted between CTA 21-Voyager Flight 1 spacecraft, CTA 21-Voyager Flight 2 spacecraft, and MIL 71-Voyager Flight 1 spacecraft.

I. Introduction

The purpose of this report is to provide an assessment and status of telecommunications compatibility between the Deep Space Network (DSN) and the Voyager (VGR-77) spacecraft. This assessment and status is derived from test results obtained between the Network, as represented in the Compatibility Test Area (CTA 21) and Spacecraft Monitoring Station (MIL 71) and by the Voyager Flight 1 (VGR 77-2) and Voyager Flight 2 (VGR 77-3) Spacecraft Telecommunications Systems.

II. Test Objectives

The objectives of these tests were to verify telecommunications design compatibility between the DSN and the Voyager flight spacecraft. The test criteria and parameters simulated direct communications between a Voyager spacecraft and a Deep Space Station (DSS). DSN-Voyager flight spacecraft design compatibility had been previously established as reported in Ref. 1.

A selected set of standard tests, as specified in the Deep Space Network-Flight Project Interface Compatibility Test Design Handbook, were performed for verifying Telecommunications Radio Frequency, Command, Telemetry, and Radio Metric compatibility.

III. Test Conditions

The tests that were performed between CTA 21 and the Voyager flight spacecraft were conducted with the spacecraft located in the Space Simulator Facility (SSF) at JPL. CTA 21-

VGR 77-2 testing was performed during the period 9-12 March 1977, and CTA 21-VGR 77-3 testing was performed during the period 28-30 April 1977. During each of these tests the SSF was simulating environmental flight conditions. The Radio Frequency Subsystems were configured as follows:

(1) Voyager 77-2

(a) S-Band

(i) Receiver 1, Channel 18 (2114.676697 MHz).

(ii) Receiver 2, Channel 18 (2114.676697 MHz).

(iii) Ultra Stable Oscillator (USO), Channel 14 (2295.000000 MHz).

(iv) Exciter Chain 1, equipped with traveling wave tube (TWT) amplifier.

(v) Exciter Chain 2, equipped with solid state amplifier.

(b) X-Band

(i) Exciters, Chain 1 and Chain 2, equipped with TWT amplifiers.

(2) Voyager 77-3

(a) S-Band

(i) Receiver 1, Channel 14 (2113.312500 MHz).

(ii) Receiver 2, Channel 14 (2113.312500 MHz).

(iii) Ultra Stable Oscillator (USO), Channel 18 (2296.481481 MHz).

(iv) Exciter Chain 1, equipped with a Watkins-Johnson flight-rated TWT amplifier.

(v) Exciter Chain 2, equipped with a Ford Aerospace flight-rated solid state amplifier.

(b) X-Band

(i) Exciter Chain 1, equipped with a Hughes Aircraft Co. nonflight-rated TWT amplifier.

(ii) Exciter Chain 2, equipped with a Watkins-Johnson flight-rated TWT amplifier.

The DSN, as represented by CTA 21, was configured to simulate a Voyager Flight Project-committed 64-meter antenna station. The ground hardware included both Block III and Block IV Receiver-Exciter Subsystems and the new Mark III Data Subsystems (MDS) for telemetry, command, and radio metric data.

The S-band and X-band RF links between CTA 21 and the SSF were open air links which had previously been calibrated for amplitude and phase stability. The DSN software provided at CTA 21 was the operational 26-meter antenna station software for the MDS.

The test that was performed between MIL 71 and the Voyager Flight 1 spacecraft was conducted with the spacecraft located in Building AO, Cape Canaveral Air Force Station, Florida. This test was performed on 25 May 1977 and consisted of S-band testing only because of the excessive RF losses at X-band. The Radio Frequency Subsystem for this test was configured as follows:

Voyager 77-2

S-Band

(i) Receiver 1, Channel 18 (2114.676697 MHz).

(ii) Receiver 2, Channel 18 (2114.676697 MHz).

(iii) Ultra Stable Oscillator (USO), Channel 14 (2295.000000 MHz).

(iv) Exciter Chain 1, equipped with a Watkins-Johnson flight-rated TWT amplifier.

(v) Exciter Chain 2, equipped with a Ford Aerospace flight-rated solid state amplifier.

The DSN, as represented by MIL 71, Kennedy Space Center, Florida, was configured to simulate a Voyager Flight Project-committed 64-meter antenna station. The ground hardware included both Block III and Block IV Receiver-Exciter Subsystems and the new Mark III Data Subsystems (MDS) for telemetry, command, and radio metric data.

The S-band RF links between MIL 71 and Building AO were open air links which had previously been calibrated for amplitude stability. The DSN software provided at MIL 71 was the operational 64-meter antenna station software for the MDS.

In support of the Voyager Flight Project Mission specifications, the following uplink modulation indices were utilized:

(1) Ranging, 45° (-3.0 dB carrier suppression).

(2) Command, 20° (-0.54 dB carrier suppression for mission nominal) and 56° (-5.0 dB carrier suppression for mission threshold).

IV. Test Results

Tables 1, 2, and 3 (telecommunications compatibility test summaries) provide a listing of test configurations, test criteria, parameters, and results. Refer to Figs. 1 and 2 for DSN and spacecraft RFS mode configurations. Significant test results and comments are discussed below.

A. Radio Frequency Acquisition and Tracking

All objectives of these tests were met with no problems noted. In the CTA 21-Voyager Flight 1 test series, a special test was performed to simulate the approximate 1.5-MHz doppler shift when in the noncoherent mode of operation. Initial test conditions were as follows:

(1) Uplink frequency 2114.676697 MHz (Channel 18).

(2) Downlink frequency 2294.998855 MHz (Channel 14).

(3) Biased doppler frequency approximately 481 kHz.

In order to alleviate this condition, a possible work-around solution for the 26-meter DSS was tested and is illustrated in Fig. 3. A spare X-3 Frequency Multiplier and Distribution Amplifier was mounted on the Block III Receiver and its input jack (J1) was connected to the station spare Hewlett-Packard Synthesizer. The HP Synthesizer was driven by a spare station 1-MHz frequency standard. The X-3 Frequency Multiplier and Distribution Amplifier 22-MHz output (J4) was connected to J-2 of the 57/221 Frequency Shifter (module 4A210) and the 66-MHz output (J8) was connected to J1 of the 66/70 Balanced Mixer (module 4A205). The HP Synthesizer was programmed for a frequency of 22.0136609 Hz (a ratio of 240/221 for the Ultra Stable Oscillator, 2294.998855 MHz) and the biased doppler read 999998 Hz. This test verified that the 26-meter DSS can support noncoherent doppler conditions with existing station hardware resources.

In addition, in the CTA 21-Voyager Flight 2 test series, a special test was performed to simulate the 7.2-kbps coded data, 22.5-kHz subcarrier possible interference problem to be encountered during initial Goldstone acquisition. Initial test conditions were as follows:

(1) Spacecraft Configuration

(a) Downlink frequency 2296.481481 MHz (Channel 18).

(b) 40-bps uncoded data, 22.5-kHz subcarrier (launch mode).

(c) Downlink frequency ramp rate of -100 Hz per second at S-band (actual doppler expected during initial Goldstone pass).

(2) DSN Configuration

(a) Block III Receiver (input terminated in dummy load).

(b) Block III Subcarrier Demodulator Assembly (configured for proper data rate and subcarrier frequency).

(c) Telemetry Processor Assembly (Channel 1 configured for 7.2-kbps coded data, Channel 2 configured for 40-bps uncoded data).

The objectives of this test were really two fold: (1) to determine how fast the various steps of complete acquisition could be completed, and (2) would the 7.2-kbps, 22.5-kHz beat frequency (as observed on the receiver dynamic phase error) jeopardize or impede the overall acquisition sequence? The test is described below in the time sequence in which it was performed.

Sequence	Description
T = 0	The Block III Receiver input was switched to the receiving antenna and a sweep search of the VCO was initiated.
T + 10 s	RF acquisition was completed.
T + 20 s	Subcarrier Demodulation acquisition was completed.
T + 2 min 24 s	Symbol Synchronizer Assembly acquisition completed.

Sequence	Description
T + 5 min	Spacecraft switched from 40-bps uncoded data to 7.2-kbps coded data. 22.5-kHz subcarrier remained unchanged.
T + 5 min 18 s	Subcarrier Demodulation acquisition completed on new data rate.
T + 6 min 05 s	Maximum Likelihood Decoder acquisition.
T + 6 min 35 s	Symbol Synchronizer Assembly acquisition completed on new data rate.

Photographs of the Block III Receiver dynamic phase error for both the 40-bps uncoded data and the 7.2-kbps coded data modes were recorded. The 7.2-kbps - 22.5-kHz beat frequency is clearly distinguishable, but apparently does not hamper overall system data processing if RF acquisition has been established.

It is concluded from this test, therefore, that if Goldstone can definitely establish RF acquisition within the 5 minutes from their initial view period to the data rate switch, there should be no problem in providing maximum data recovery to the Project.

B. Telemetry

The CTA 21-Voyager Flight 1 tests were supported using a version of the standard 26-meter DSS telemetry software that would operate at all data rates, including the high rate 115.2 kbps. All lock status and signal-to-noise ratio data were processed and displayed. However, this version of the software did not provide Original Data Records or Wide-Band Data capability.

The CTA 21-Voyager Flight 2 tests were supported using the 64-meter DSS telemetry software. The software performed satisfactorily for processing and displaying all lock status and signal-to-noise data. However, a special test to transmit 115.2-kbps data to the MCCC was not fully successful. The MCCC was able to frame synchronize long enough to recognize that the data contained all ones, but were not able to maintain continuous lock (periodic frames were being lost). This condition was verified by the software CDE who acknowledged a known problem with the wide-band data communications buffer. A fix for this problem was initiated and was subsequently successfully demonstrated for rates up to 67.2-kbps during a GDS test during the week of 16 May 1977 between CTA 21 and the MCCC. The telemetry rates of 89.6-kbps and 115.2-kbps remained an open item. In addition, an Original Data Recording was made during this test and successfully played back to the MCCC.

The MIL 71-Voyager Flight 1 tests were supported using the 64-meter DSS telemetry software. The software performed satisfactorily for processing and displaying all lock status and signal-to-noise data.

The telemetry rates of 80 bps and 1280 bps were tested for the first time during this series of tests and operation was satisfactory.

The theoretical 3.0-dB difference between MCD SNR and SSA SNR values was not obtained during these compatibility tests. The actual difference observed was approximately 2.2-2.5 dB. This condition is apparently unique to the MIL 71 equipment as it has not been encountered at CTA 21 or DSS 12 during Systems Performance Testing. This condition was first observed during Systems Acceptance Testing at MIL 71 and was further verified during special rate 7:1/2 and rate 7:1/3 telemetry performance testing. This condition does not impact compatibility.

C. Command

Command testing at both CTA 21 and MIL 71 with both Voyager flight spacecraft was performed at nominal uplink signal levels and at signal levels below expected project mission conditions. Two separate, non-timed commands (2N: X-band ranging channel ON, and 2NR: X-band ranging channel OFF) were successfully sent to the spacecraft and successfully executed.

D. Radio Metric

The CTA-Voyager Flight 1 tests were designed to acquire spacecraft internal group delay measurements under both hot and cold conditions. Because of spacecraft constraints while in the environmental chamber, however, only one such set of measurements was possible for a particular RFS mode. A total of three tests were completed with test RM-2-6 performed while hot only. All tests included both S- and X-band measurements.

All objectives of the CTA 21-Voyager Flight 2 tests were successfully completed with the exception of a zero delay measurement. This measurement is required in order to compute the overall link delay so that the spacecraft delay can be determined. However, before the zero delay measurement could be performed, the Space Simulator Facility configuration was de-implemented and the Zero Delay Transponder was shipped to Florida. Therefore, the ranging tests that were performed provide only the overall measurement through the link and spacecraft. These tests will be repeated during the

DSN-Voyager Flight 2 testing with MIL 71 for the final ranging delay measurement and calibration.

Because of excessive RF link losses between MIL-71 and Building AO, there were no ranging tests performed at either S- or X-band during the MIL 71-Voyager flight tests.

V. Present Status and Future Plans

The DSN-Voyager Flight Project Telecommunications Compatibility Test Program has successfully verified compatibility for RF Acquisition and Tracking, Telemetry, Command, and Radio Metric Data (Ranging). All known problems encountered to date have been dealt with, and the solution to each problem has been resolved by either an engineering change or operational work-around.

The next DSN-Voyager Telecommunications Compatibility Test is scheduled for 14 June 1977 between MIL 71 and the Voyager 77-3 spacecraft. This test will be limited to S-band testing only as the spacecraft will be located in Building AO.

Additional test time has been scheduled for both flight spacecraft when they are located in the Spacecraft Assembly and Encapsulation Facilities (SAEF) 1 and 2 at Kennedy Space Center. These tests will be performed at X-band and will include extensive ranging delay calibrations and measurements.

Reference

1. Bryan, A. I., et al., "Summary Report and Status of the Deep Space Network – Mariner Jupiter/Saturn 1977 Flight Project Telecommunications Compatibility," *The Deep Space Network Progress Report 42-38*, pp. 16-37, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1977.

Table 1. DSN-Voyager Flight 1 spacecraft telecommunications compatibility test summary [a]

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
3/10/77	DL threshold one way	RF-1-2	$000\frac{1}{6}00$	4510-11	S-band DL frequency: 2294.998880 MHz 12 Hz, 2 BLo	-159.0 ± 1.0 dBm	-158.0 dBm	16
					X-band DL frequency: 8414.995955 MHz 30 Hz, 2 BLo		-145.3 dBm	
3/9/77	DL threshold one way	RF-1-3	$000\frac{1}{6}00$	6734-16	S-band DL frequency: 2294.998860 MHz 12 Hz, 2 BLo	-159.0 ± 1.0 dBm	-158.0 dBm	54
					X-band DL frequency: 8414.995785 MHz 30 Hz, 2 BLo		-145.7 dBm	
3/10/77	DL threshold two way	RF-1-4	$002\frac{1}{6}00$	4510-11	S-band DL frequency: 2296.481560 MHz 12 Hz, 2 BLo	-159.0 ± 1.0 dBm	-158.0 dBm	27
					X-band DL frequency: 8420.432470 MHz 30 Hz, 2 BLo		-144.5 dBm	
3/10/77	DL threshold two way	RF-1-5	$122\frac{1}{6}00$	6730-16	S-band DL frequency: 2296.481600 MHz 12 Hz, 2 BLo	-159.0 ± 1.0 dBm	-158.5 dBm	60
					X-band DL frequency: 8420.432555 MHz 30 Hz, 2 BLo		-145.5 dBm	
3/10/77	UL receiver threshold	RF-2-1	$002\frac{1}{6}00$	4510-11	S-band UL frequency: 2114.676672 MHz	⩽ 152.0 dBm	-155.0 dBm	13
3/10/77	UL receiver threshold	RF-2-4	122000	6630-16	S-band UL frequency: 2114.676768 MHz	⩽ 152.0 dBm	-156.0 dBm	19
3/10/77	Transmitter phase jitter	RF-5-1	$000\frac{1}{2}00$	4500-11	S-band DL frequency: 2294.998880 MHz (one-way)	⩽ 3.0 deg rms	1.04 deg rms	66
			$000\frac{5}{6}00$		X-band DL frequency: 8414.936540 MHz (one-way)	< 11.0 deg rms	5.35 deg rms	
					S-band UL frequency: 2114.676672 MHz			
			$002\frac{1}{2}00$	4510-11	S-band DL frequency: 2296.481504 MHz (two-way)	⩽2.3 deg rms	2.14 rms	
			$002\frac{5}{6}00$		X-band DL frequency: 8420.373140 MHz (two-way)	⩽ 8.4 deg rms	6.56 deg rms	
3/10/77	Transmitter phase jitter	RF-5-3	$002\frac{1}{2}00$		S-band UL frequency: 2114.676672 MHz			18

[a]See Table 4 for definition of terms used.

Table 1 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
3/10/77	Transmitter phase jitter (contd)				S-band DL frequency: 2296.481504 MHz (two-way)	⩽ 2.3 deg rms	1.68 deg rms	
			$002\frac{5}{6}00$		X-band DL frequency: 8420.373140 MHz (two-way)	⩽ 8.4 deg rms	6.20 deg rms	
3/12/77	DL RF spectrum analysis	RF-6-1	102300	7513-12	S-band UL frequency: 2114.676672 MHz S-band DL frequency: 2296.481420 MHz	Observe presence of unpredicted spectral components through the S-band solid state amplifier (SSA)	None observed	15
3/12/77	Special test for dual-doppler condition	RF-7-1	001100	7737-16	S-band UL frequency: 2114.676672 MHz (Channel 18) S-band DL frequency: 2294.998855 MHz (Channel 14) UL signal level: -107.5 dBm DL signal level: -93.0 dBm	Install spare synthesizer and X-3 Frequency Multiplier Distribution Amplifier; adjust Synthesizer for 1 MHz biased doppler and record synthesizer frequency of 22.0136609 MHz	Biased doppler read: 999998 MHz	15
3/9/77	Telemetry processing	TM-3-1	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	6730-16	S-band DL signal level: -120.0 dBm CTA 21 three-way (SE two-way)	0.0 BER Ability to process	MCD SNR: 9.6 dB X-band SSA SNR: 4.7 dB S-band SSA SNR: 26.3 dB	18
3/10/77	Telemetry	TM-3-2	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	6734-16	S-band DL signal level: -120.0 dBm X-band DL signal level: -120.0 dBm CTA 21 three-way (SE two-way)	0.0 BER Ability to process	MCD SNR: 10.1 dB X-band SSA SNR: 5.5 dB S-band SSA SNR: 30.7 dB	
3/9/77	Telemetry processing	TM-3-6	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	6730-16	S-band DL signal level: -120.0 dBm CTA 21 three-way (SE two-way)	0.0 BER Ability to process	MCD SNR: 10.175 dB X-band SSA SNR: 12.3 dB S-band SSA SNR: 25.5 dB	31

Table 1 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
3/10/77	Telemetry processing	TM-3-10	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	6734-16	S-band DL signal level: -120.0 dBm	0.0 BER	MCD SNR: 9.6 dB	23
					X-band DL signal level: -115.0 dBm	Ability to process	X-band SSA SNR: 5.0 dB	
					CTA 21 three-way (SE two-way)		S-band SSA SNR: 29.6 dB	
3/10/77	Command processing	CM-1-1	011000	4512-11	S-band UL frequency: 2114.676672 MHz	Proper subcarrier and bit sync acquisition. Verification of command execution		21
					UL carrier suppression: -5.0 dB			
					Subcarrier offset: 0.0 Hz @ -144 dBm, P_T		OK	
					+0.2 Hz @ -143 dB, P_T		OK	
					-0.2 Hz @ -143 dB, P_T		OK	
3/10/77	Command processing	CM-1-2	011000	4533-11	S-band UL frequency: 2114.676672 MHz	Proper subcarrier and bit sync acquisition. Verification of command execution		37
					UL carrier suppression: -5.0 dB			
					Subcarrier offset:			
					0.0 Hz @ -144 dBm, P_T		OK	
					+0.2 Hz @ -143 dBm, P_T		OK	
					-0.2 Hz @ -143 dBm, P_T		OK	
3/10/77	Range delay calibration verification test	RM-2-1	$102\frac{3}{6}00$	4513-11	S-band UL frequency: 2114.676672 MHz	< 1000 ns		90
					S-band DL frequency: 2296.481420 MHz			
					S-band DL signal level: -100.0 dBm			
					X-band DL frequency: 8420.431875 MHz			
					X-band DL signal level: -100.0 dBm			
					SPACECRAFT COLD			
					UL signal level: -110.0 dBm		'S' delay: 724.46 ns 'X' delay: 652.65 ns	
					-120.0 dBm		'S' delay: 733.04 ns 'X' delay: 657.40 ns	
					-130.0 dBm		'S' delay: 735.14 ns 'X' delay: 659.14 ns	

Table 1 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
3/10/77	Range delay calibration verification test (contd)				SPACECRAFT HOT			
					UL signal level: -112.0 dBm		'S' delay: 715.45 ns 'X' delay: 648.75 ns	
					-120.0 dBm		'S' delay: 739.92 ns 'X' delay: 651.05 ns	
					-130 dBm		'S' delay: 735.99 ns 'X' delay: 654.9 ns	
3/10/77	Range delay calibration verification test	RM-2-3	$102\frac{3}{6}00$	4533-11	S-band UL frequency: 2114.676672 MHz	< 1000 ns		43
					S-band DL frequency: 2296.481480 MHz			
					S-band DL signal level: -100.0 dBm			
					X-band DL frequency: 8420.432215 MHz			
					X-band DL signal level: -100.0 dBm			
					SPACECRAFT COLD			
					UL signal level: -110.5 dBm		'S' delay: 741.34 ns 'X' delay: 664.02 ns	
					-120.0 dBm		'S' delay: 747.51 ns 'X' delay: 668.4 ns	
					-130.0 dBm		'S' delay: 749.18 ns 'X' delay: 658.23 ns	
3/12/77	Range delay calibration verification test	RF-2-6	$102\frac{3}{6}00$	7733-16	S-band UL frequency: 2114.676768 MHz	< 1000 ns		
					S-band DL frequency: 2296.481600 MHz			
					S-band DL signal level: -100.0 dBm			
					X-band DL frequency: 8420.432555 MHz			
					X-band DL signal level: -100.0 dBm			

Table 1 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
3/12/77	Range delay calibration verification test (contd)				SPACECRAFT HOT			
					UL signal level: -111.0 dBm		'S' delay: 719.92 ns 'X' delay: 662.40 ns	
					-120.0 dBm		'S' delay: 720.81 ns 'X' delay: 665.35 ns	
					-130.0 dBm		'S' delay: 726.23 ns 'X' delay: 671.69 ns	

Table 2. DSN-Voyager Flight 2 spacecraft telecommunications compatibility test summary [a]

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
4/29/77	DL threshold one-way	RF-1-2	$000\frac{1}{6}00$	6554-11	S-band DL frequency: 2296.481100 MHz 12 Hz, 2 BLo	−158.0 ± 1.0 dBm	−157.5 dBm	18
					X-band DL frequency: 8420.430770 MHz 30 Hz, 2 BLo		−148.0 dBm	
4/30/77	DL threshold one-way	RF-1-3	$000\frac{1}{6}00$	6737-17	S-band DL frequency: 2296.481100 MHz 12 Hz, 2 BLo	−158.0 ± 1.0 dBm	−159.0 dBm	16
					X-band DL frequency: 8420.430600 MHz 30 Hz, 2 BLo		−149.0 dBm	
4/29/77	DL threshold two-way	RF-1-4	$002\frac{1}{6}00$	4550-11	S-band DL frequency: 2295.000240 MHz 12 Hz, 2 BLo	−158.0 ± 1.0 dBm		35
					X-band DL frequency: 8415.000885 MHz 30 Hz, 2 BLo			
4/30/77	DL threshold two-way	RF-1-5	$122\frac{1}{6}00$	6733-17	S-band DL frequency: 2295.000040 MHz 12 Hz, 2 BLo	−158.0 ± 1.0 dBm	−159.0 dBm	23
					X-band DL frequency: 8415.000205 MHz 30 Hz, 2 BLo		−149.0 dBm	
4/29/77	UL receiver threshold	RF-2-1	$002\frac{1}{6}00$	4550-11	S-band UL frequency: 2113.312512 MHz	≤152.0 dBm	−155.0 dBm	11
4/29/77	UL receiver threshold	RF-2-4	122000	4570-11	S-band UL frequency: 2113.312512 MHz	≤152.0 dBm	−155.5 dBm	12
4/29/77	Transmitter phase jitter	RF-5-1	$000\frac{3}{4}00$	4840-11	S-band DL frequency: 2296.481080 MHz (one-way)	≤3.0 deg rms	1.98 deg rms	109
			$000\frac{5}{6}00$		X-band DL frequency: 8420.430685 MHz (one-way)	≤11.0 deg rms	6.55 deg rms	
					S-band UL frequency: 2113.312512 MHz			
			$002\frac{3}{4}00$	4550-11	S-band DL frequency: 2295.000100 MHz (two-way)	≤2.3 deg rms	0.63 deg rms	
			$002\frac{5}{6}00$		X-band DL frequency: 8415.000205 MHz (two-way)	≤8.4 deg rms	10.09 deg rms	
4/30/77	Transmitter phase jitter	RF-5-3	$000\frac{3}{4}00$	6727-17	S-band DL frequency: (one-way) 2296.481100 MHz	≤3.0 deg rms	1.91 deg rms	109

[a] See Table 4 for definition of terms used.

Table 2 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
4/30/77	Transmitter phase jitter (contd)		$000\frac{5}{6}00$		X-band DL frequency: (one-way) 8420.430770 MHz	≤11.0 deg rms	6.55 deg rms	
			$002\frac{3}{4}00$	6737-17	S-band UL frequency: 2113.312512 MHz			
					S-band DL frequency: (two-way) 2295.000004 MHz	≤2.3 deg rms	2.21 deg rms	
					X-band DL frequency: (two-way) 8415.000205 MHz	≤8.4 deg rms	8.28 deg rms	
4/30/77	Special rf acquisition test (simulated Goldstone initial acquisition)	RF-7-2	000112	6713-17	Spacecraft simulated −100 Hz/s S-band doppler for initial Goldstone pass and data switch sequence	Acquire RF, SDA, TPA for 40-bps uncoded and then switch to 7.2-kbps coded data	Acquired satisfactorily	30
4/30/77	Command processing	CM-1-	011000	6713-17	S-band UL frequency: 2114.676672 MHz	Proper subcarrier and bit sync acquisition		12
					UL carrier suppression; −5.0 dB			
					Subcarrier offset:			
					0.0 Hz @ −144 dBm, P_T		OK	
					+0.2 Hz @ −144 dBm, P_T		OK	
					−0.2 Hz @ −144 dBm, P_T		OK	
4/30/77	Command processing	CM-1-2	011000	6733-17	S-band UL frequency: 2114.676672 MHz	Proper subcarrier and bit sync acquisition		50
					UL carrier suppression: −5.0 dB	Verification of command execution		
					Subcarrier offset:			
					0.0 Hz @ −144 dBm, P_T		OK	
					+0.2 Hz @ −144 dBm, P_T		OK	
					−0.2 Hz @ −144 dBm, P_T		OK	
4/29/77	Telemetry processing	TM-3-1	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	4570-11	S-band DL signal level: −122.8 dBm	0.0 BER	MCD SNR: 10.1 dB	83
					CTA 21 three-way (SE two-way)	Ability to process	X-band SSA SNR: 8.6 dB	

Table 2 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
4/29/77	Telemetry processing (contd)				X-band = 7.2 kbps coded S-band = 40 bps uncoded		S-band SSA SNR: 29.1 dB	
4/29/77	Telemetry processing	TM-3-2	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	4570-11	S-band DL signal level: −121.9 dBm X-band DL signal level: −122.9 dBm CTA 21 three-way (SE two-way) X-band = 29.9 kbps coded S-band = 40 bps uncoded	0.0 BER Ability to process	MCD SNR: 4.8 dB X-band SSA SNR: 1.8 dB S-band SSA SNR: 15.3 dB	24
4/29/77	Telemetry processing	TM-3-6	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	4553-11	S-band DL signal level: CTA 21 three-way (SE two-way) X-band = 44.8 kbps coded X-band = 40 bps uncoded	0.0 BER Ability to process	MCD SNR: 10.175 dB X-band SSA SNR: 8.4 dB	10
4/29/77	Telemetry processing	TM-3-10	$000\frac{3}{6}\frac{2}{1}\frac{1}{2}$	6733-17	S-band DL signal level: −111.0 dBm X-band DL signal level: −111.0 dBm CTA 21 three-way (SE two-way) X-band = 115.2 kbps coded S-band = 40 bps uncoded	0.0 BER Ability to process	MCD SNR: 9.9 dB X-band SSA SNR: 5.8 dB S-band SSA SNR: 19.2 dB	39
4/29/77	Range delay calibration verification test	RM-2-1	$102\frac{3}{6}00$		S-band UL frequency: 2113.312512 MHz S-band DL frequency: 2295.000080 MHz S-band DL signal level: −100.0 dBm X-band DL frequency: 8415.000290 MHz X-band DL signal level: −100.0 dBm SPACECRAFT HOT UL signal level: −110.0 dBm	<1000 ns	No zero delay obtained 'S' range 6055.04 ns 'X' range 6838.55 ns	90

Table 2 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
4/29/77	Range delay calibration verification test (contd)				−120.0 dBm		'S' range 6065.9 ns 'X' range 6844.7 ns	
					−130.0 dBm		'S' range bad data point	
					Receiver VCO temp: 36.35°C		'X' range bad data point	
4/29/77	Range delay calibration verification test	RM-2-3	$102\frac{3}{6}00$	4573-11	S-band UL frequency: 2113.312512 MHz S-band DL frequency: 2295.000080 MHz S-band DL signal level: −100.0 dBm X-band DL frequency: 8415.000290 MHz X-band DL signal level: −100.0 dBm	<1000 ns	No zero delay obtained	46
					SPACECRAFT HOT			
					UL signal level: −110.0 dBm		'S' range 6052.3 ns 'X' range 6818.7 ns	
					−120.0 dBm		'S' range 6079.5 ns 'X' range 6823.0 ns	
					−130.0 dBm		'S' range 6050.6 ns	
					Receiver VCO temp: 35.64°C		'X' range 6831.9 ns	
4/30/77	Range delay calibration verification test	RF-2-6	$102\frac{3}{6}00$	6713-17	S-band UL frequency: 2113.312512 MHz S-band DL frequency: 2295.000060 MHz S-band DL signal level: −100.0 dBm X-band DL frequency: 8415.000205 MHz X-band DL signal level: −100.0 dBm	<1000 ns	No zero delay obtained	45

Table 2 (contd)

Date	Test title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
4/30/77	Range delay calibration verification test (contd)				SPACECRAFT HOT			
					UL signal level:			
					−110.0 dBm			'S' range 6060.1 ns
								'X' range 6847.1 ns
					−120.0 dBm			'S' range 6070.8 ns
								'X' range 6850.0 ns
					−130.0 dBm			'S' range 6068.4 ns
					Receiver VCO temp: 37.77°C			'X' range 6851.8 ns

Table 3. DSN (MIL 71)-Voyager Flight 1 spacecraft telecommunications test summary [a]

Date	Test Title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
5/25/77	DL threshold one-way	RF-1-2	000300	4543-17	S-band DL frequency: 2294.998880 MHz 10 Hz, 2 BLo	−158.0 ± 1.0 dBm	−157.8 dBm	15
5/25/77	DL threshold one-way	RF-1-3	000300	6760-17	S-band DL frequency: 2294.998880 MHz 10 Hz, 2 BLo	−158.0 ± 1.0 dBm	−158.0 dBm	38
5/25/77	DL threshold two-way	RF-1-4	002300	4553-17	S-band DL frequency: 2296.481460 MHz 10 Hz, 2 BLo	−158.0 ± 1.0 dBm	−158.8 dBm	18
5/25/77	DL threshold two-way	RF-1-5	002300	6773-17	S-band DL frequency: 2296.481460 MHz 10 Hz, 2 BLo	−158.0 ± 1.0 dBm	−158.2 dBm	38
5/25/77	UL receiver threshold	RF-2-1	002300	4513-17	S-band UL frequency: 2114.676672 MHz	⩽−152.0 dBm	−152.0 dBm	20
5/25/77	UL receiver threshold	RF-2-2	002300	4533-17	S-band UL frequency: 2114.676672 MHz	⩽−152.0 dBm	−151.0 dBm	55
5/25/77	UL receiver threshold	RF-2-3	002300	4553-17	S-band UL frequency: 2114.676672 MHz	⩽−152.0 dBm	−154.2 dBm	11
5/25/77	UL receiver threshold	RF-2-4	002300	6773-17	S-band UL frequency: 2114.676672 MHz	⩽−152.0 dBm	−153.5 dBm	16
5/25/77	Command processing	CM-1-1	112300	4553-17	S-band UL frequency: 2114.676672 MHz UL carrier suppression: −5.0 dB Subcarrier offset: 0.0 Hz @ −144 dBm, P_T +0.2 H @ −144 dBm, P_T −0.2 Hz @ −144 dBm, P_T	Proper subcarrier and bit sync acquisition	 OK OK OK	19
5/25/77	Command processing	CM-1-2	112300	6773-17	S-band UL frequency: 2114.676672 MHz UL carrier suppression: −5.0 dB Subcarrier offset: 0.0 Hz @ −144 dBm, P_T	Proper subcarrier and bit sync acquisition Verification of command execution	 OK	38

[a]See Table 4 for definition of terms used.

Table 3 (contd)

Date	Test Title	Test No.	DSN mode	S/C RFS mode	Test conditions	Criteria	Performance	Time, min
5/25/77	Command processing (contd)				+0.2 Hz @ −144 dBm, P_T		OK	
					−0.2 Hz @ −144 dBm, P_T		OK	
5/25/77	Telemetry spectrum analysis and modulation index	TM-1-4	002311	4533-17	S-band UL frequency: 2114.676672 MHz S-band DL frequency: 2296.481460 MHz TLM bit rate: 7.2 kbps Subcarrier frequency: 360 kHz	No unexpected radiation components within 40 dB of carrier	None observed	8
5/25/77	Telemetry spectrum analysis and modulation index	TM-1-10	002311	4533-17	S-band UL frequency: 2114.676672 MHz S-band DL frequency: 2296.481460 MHz TLM bit rate: 1200 bps Subcarrier frequency: 22.5 kHz	No unexpected radiation components within 40 dB of carrier	None observed	10
5/25/77	Telemetry performance verification test	TM-2-10	002311	4533-17	S-band DL signal level: −141.0 dBm TLM bit rate: 1200 bps coded STb/No = 5.0 dB Subcarrier frequency: 22.5 kHz	Ability to process	MCD SNR: 4.144 dB SSA SNR: 1.64 dB	16
5/25/77	Telemetry performance verification test	TM-2-13	002311	4533-17	S-band DL signal level: −131.0 dBm TLM bit rate: 7.2 kbps coded STb/No = 8.0 dB Subcarrier frequency: 360 kHz	Ability to process	MCD SNR: 8.795 dB SSA SNR: 5.45 dB	40
5/25/77	Telemetry performance verification test	TM-2-14	002311	4533-17	S-band DL signal level: −141.0 dBm TLM bit rate: 1280 bps coded STb/No = 5.0 dB Subcarrier frequency: 22.5 kHz	Ability to process	MCD SNR: 3.992 dB SSA SNR: 1.81 dB	12
5/25/77	Telemetry performance verification test	TM-2-15	002311	4533-17	S-band DL signal level: −146.3 dBm TLM bit rate: 80 bps coded STb/No = 6.0 dB Subcarrier: 22.5 kHz	Ability to process	MCD SNR: 4.044 dB SSA SNR: 1.49 dB	40

Table 4. Definition of terms for Tables 1, 2, and 3

BER	bit error rate
BIT RATE	clock frequency of the telemetry bit information
bits/s	bits per second
BLo	two-sided receiver loop noise bandwidth at threshold
CPA	Command Processor Assembly
CMF	Communications Monitor and Formatting Assembly
CTA 21	The Deep Space Network Ground Station Compatibility Test Area at JPL
dB	decibel
dBm	decibel referenced to one milliwatt
DL	RF downlink signal
DSN mode	The Deep Space Network Ground Station operational configuration
FDS	Spacecraft Flight Data Subsystem
JPL	Jet Propulsion Laboratory
MCD	Maximum Likelihood Convolutional Decoder
MDA	Metric Data Assembly
MDS	Spacecraft Modulation/Demodulation Subsystem
MDS	The DSN-MARK III Data Subsystems Implementation Project
No	noise spectral density
P_C	Power in RF carrier
P_T	Power total
PRA	Planetary Ranging Assembly
PFR	Problem/Failure Report
RDA	Ranging Demodulator Assembly
RF	radio frequency
RFS	Spacecraft Radio Frequency Subsystem
RU	range unit
SAF	Spacecraft Assembly Facility (JPL Building 179)
S/C RFS Mode	The Spacecraft Radio Frequency Subsystem operational configuration
SDA	Subcarrier Demodulator Assembly
SER	symbol error rate
SNR	signal-to-noise ratio
SPS	symbols per second
SSA	Symbol Synchronizer Assembly
SSF	Space Simulator Facility (JPL Building 150)
STb/No	signal-to-noise spectral density ratio
SYMBOL RATE	clock frequency of the telemetry symbol information
TBD	to be determined
TBS	to be supplied
TDL	Telemetry Development Laboratory
TLM	telemetry
TPA	Telemetry Processor Assembly
TWT	Traveling Wave Tube Amplifier
UL	RF uplink signal
Uplink Doppler	ramp rate of uplink RF carrier frequency
Uplink Offset	uplink RF carrier frequency displacement relative to the spacecraft receiver rest frequency
USO	ultra stable oscillator
VCO	voltage controlled oscillator

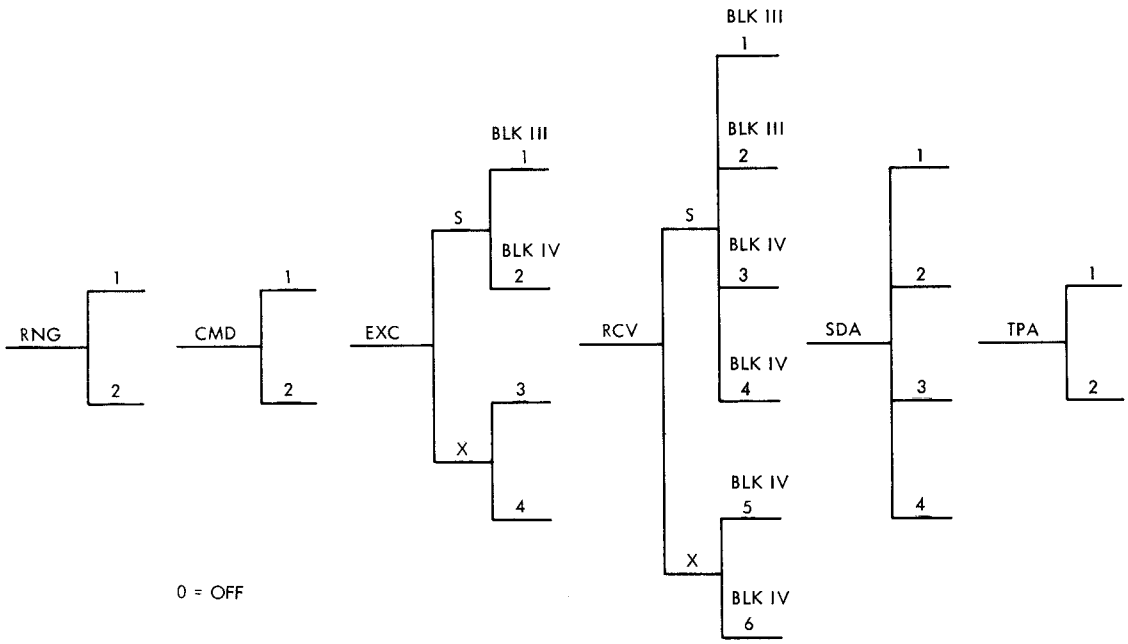

Fig. 1. DSN modes

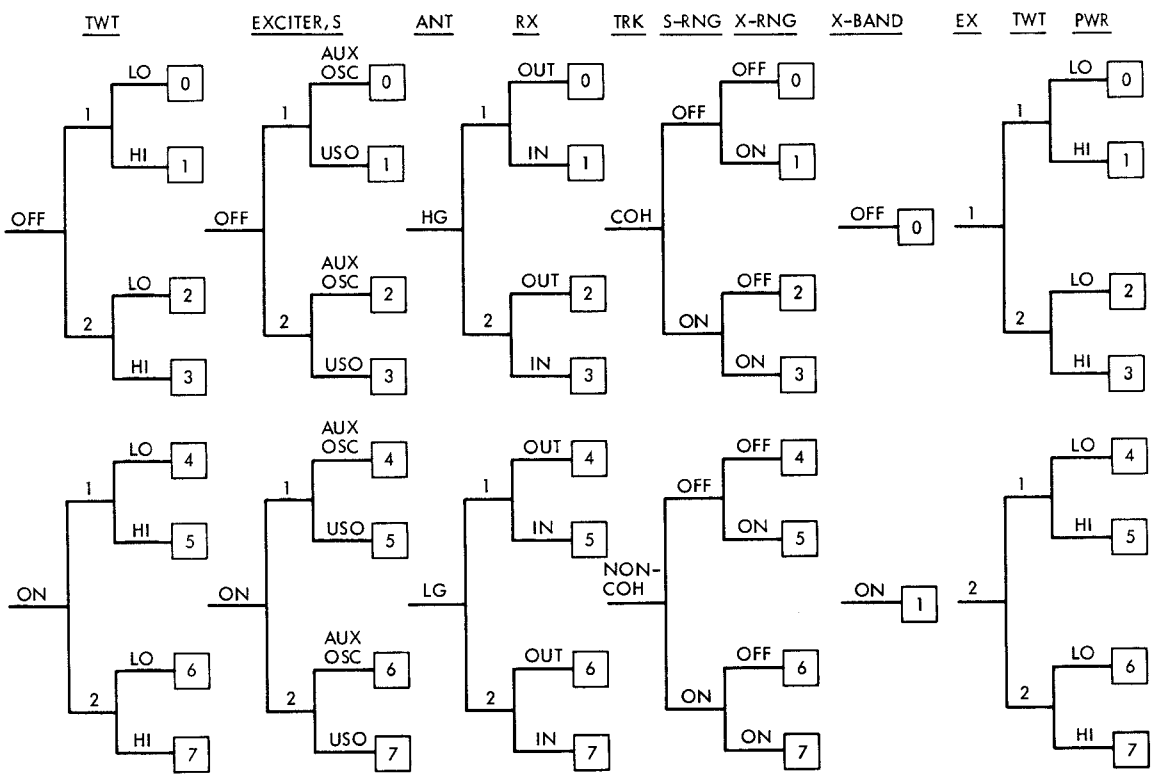

Fig. 2. Voyager operational RFS modes

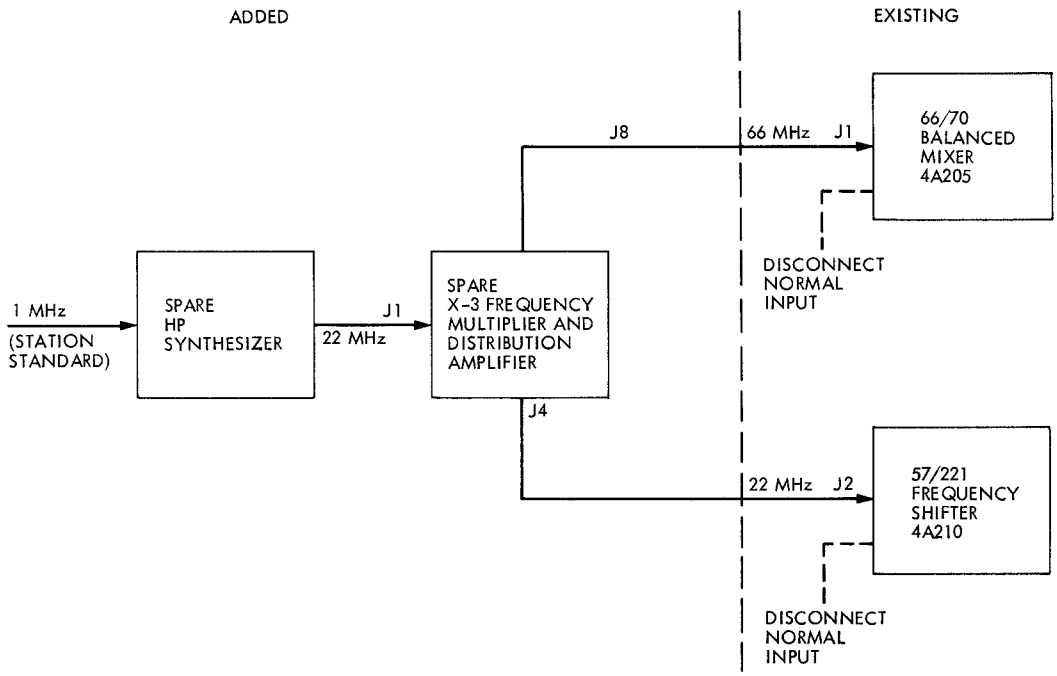

Fig. 3. Dual-channel 1.5-MHz doppler work-around block diagram