DSS-26 to DSS-13 Bistatic Radar Capability for Solar System Radar Service

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ABSTRACT. — The unavailability of the 70-m Deep Space Station 14 (DSS-14) antenna and its planned modernization created a prolonged gap in Goldstone Solar System Radar (GSSR) services. To preserve orbital debris measurements, asteroid characterization, cislunar surveillance, and emergency spacecraft tracking support, the Deep Space Network (DSN) utilized 80 kW at 34-m DSS-26 as an X-band uplink and 34-m DSS-13 as the bistatic receiver. GSSR's Signatec-based arbitrary waveform generator (S-AWG), located in the Signal Processing Center 10 (SPC-10), originates waveforms with an intermediate frequency (IF) of 290 MHz. The IF signal is upconverted to 7.190 GHz radio frequency (RF), which is transmitted to DSS-26 pedestal via radio frequency over fiber (RFoF), amplified by klystron, and then radiated out from the DSS-26 antenna. GSSR's backend receiver at DSS-13 receives, down-converts, and records the radar echoes. Initial testing of orbital debris shows detection, but experienced nuisance transmitter trips. Subsequent klystron conditioning with full-band continuous wave (CW), waveform path calibration, and RF interference (RFI) elimination, the binary phase code (BPC) and linear frequency modulation (LFM, a.k.a. chirp) tests demonstrated stable 80 kW operation. Several radar activities were conducted, including orbital debris radar (ODR) demonstrated detectability, a cislunar radar demonstrated measured echo power consistent with prediction, and an asteroid track produced consistent images. The resulting capability provides a reliable DSN asset–only mitigation. This article describes the setup, processing, and results of this added capability that can be used for the future DSN radar capability.

I. Introduction

The Goldstone Solar System Radar (GSSR) provides measurements for several operational and scientific services. The source material for this article identifies four primary uses: 1) millimeter-scale low Earth orbit (LEO) debris measurements for the National Aeronautics and Space Administration (NASA) Orbital Debris Program Office (ODPO), 2) near Earth orbit (NEO) object characterization for planetary science and planetary defense investigations, 3) cislunar surveillance of spacecraft near the Moon, and 4) emergency tracking of lost spacecraft. These services had historically relied heavily on the Deep Space Station 14 (DSS-14) antenna.

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An approximately 31-month service gap, from March 2026 to October 2028, DSS-14 will not be available due to planned 70-m antenna and GSSR modernization. Other viable alternatives involved uplink from DSS-13 to DSS-28 or the Green Bank Telescope (GBT). DSS-28 is currently decommissioned and the availability of GBT, not a Deep Space Network (DSN) asset, is not guaranteed. A survey within DSN identified DSS-26 for uplink and DSS-13 for receive as the best available DSN asset–only mitigation. Instead of GSSR, when an antenna other than DSS-14 is used for planetary radar, the configurations are termed DSN Solar System Radar (DSSR).

This article consolidates the operational report, the design and development Test Readiness Review (TRR) conducted in November 2025, and the DSN Service Readiness Review (DSRR) conducted in May 2026. This article describes the architecture and operating concept; documents the transmitter trips investigation and risk reduction campaign; summarizes orbital debris, asteroid waveform, and cislunar validation; and records the service readiness basis presented in the DSRR. Section II describes the service requirements and review approach, Section III describes the bistatic radar architecture, Section IV describes the concept of operations, Section V details the initial testing and transmitter trip investigation, Section VI focuses on the validation campaign, and Section VII describes the safety, maintenance, and operational readiness of the radar capability. We briefly discuss the remaining analysis and future improvements in Section VIII and reach the conclusions in Section IX.

II. Service Requirements and Review Approach

The development was conducted as a service continuity activity rather than delivery of a new antenna or transmitter. The TRR identified the governing GSSR functional requirements as the general solar system investigation capability, orbital debris radar (ODR) tracking, and bistatic operation.[1] The ODR associated service, for example, stated a best effort commitment to provide 288 hours' worth of ODR data per year.

A. Test Readiness Review

In November 2025, the TRR evaluated whether the existing equipment, temporary interfaces, procedures, test facilities, and personnel were ready for supervised test tracks.[2,3] The S-AWG successfully passed its own DSRR on June 18, 2024, and was operating under Information Technology Security Plan 11. The "Radar IF input" of the Block 6 exciter (see Figure 2) was used under a temporary Engineering Change Request (ECR), ECR-2025.0030, which was later approved through DSRR for this application on November 19, 2025. Because there is no new flight or station hardware delivered, several standard ModKit, sparing, and software release criteria were deemed unapplicable.

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[1] Jet Propulsion Laboratory, "Goldstone Solar System Radar Functional Requirements Document," 834-157, Rev. A, unpublished document.

[2] Jet Propulsion Laboratory, "DSN Lifecycle Definition and Review Standards," 810-101-N, unpublished document.

[3] C. Lee, J. Jao, W. Majid, and N. Rodriguez-Alvarez, "Orbital Debris Radar DSS-26 Design and Development Test Readiness Review," November 17, 2025, unpublished review.

B. Service Readiness Review

In May 2026, the DSRR assessed the first operational instance of the DSS-26 to DSS-13 radar service.[4] The review addressed system level test results, site training, operational procedures, maintenance responsibilities, safety, security, and readiness for customer commitments. The team presented all required tests and demonstrations as successful and identified no critical unresolved problems. A developmental DSSR temporal dependency network (TDN) was in place for both orbital debris and asteroid-like tracks; the readiness summary included final cislunar TDN testing as another near-term activity. Principal requirements and readiness controls are summarized in Table 1.

Table 1. Principal requirements and readiness controls.

Item	Source requirement or control	Implementation basis
Solar system radar service	GSSR_SS-27	Existing GSSR subsystem and trained operating teams
Orbital debris tracks	GSSR_SS-92	DSS-26 uplink and DSS-13 receive (DSSR), and standard ODR processing
Bistatic operation	GSSR_SS-304	Separated DSS-26 transmitter and DSS-13 receiver
Annual ODR support	288 hr/yr, best effort	Temporary service during DSS-14 unavailability
Interface control	Temporary ECR-2025.0030	Existing Block 6 exciter external radar IF input
Security	S-AWG plan 11	Previously reviewed waveform-generator computer

III. Bistatic Radar Architecture

A. DSS-26 Transmit Chain

The S-AWG generates the radar waveform at a 290 MHz intermediate frequency (IF) in the Signal Processing Center 10 (SPC-10). The generator is triggered by the station one-pulse-per-second (1 PPS) signal, uses a 10 MHz station reference, and produces in-phase and quadrature (I & Q) outputs. A quadrature modulator mixes the I & Q signals with a local oscillator (LO) of 290 MHz. The IF signal is routed to the S-X-K upconverter (SXKUP) of block 6 exciter (B6E) assembly of uplink (UPL) subsystem, as shown is Figure 1 below. Two frequency translations, using 1.8 GHz and 5.1 GHz LOs, produce the 7.190 GHz X-band signal. Radio frequency over fiber (RFOF) carries the signal to the DSS-26 pedestal for radiating with the 80 kW transmitter.

[4] J. Jao, C. Lee, N. Rodriguez-Alvarez, R. Liou, D. Kelley, and L. Snedeker, “DSS-26 to DSS-13 Radar Capability: Deep Space Network Service Readiness Review,” May 11, 2026, unpublished review.

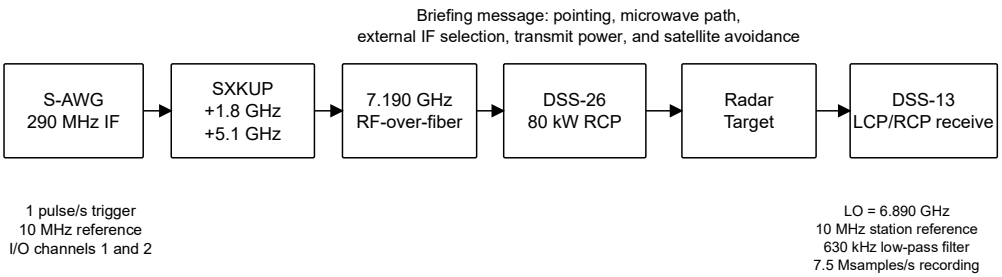


Figure 1. DSS-26 uplink and DSS-13 receive signal path used for the bistatic continuous wave radar service.

The "Radar IF input" port shown in Figure 2 is where GSSR's IF signal is patched into the DSN equipment via operator-controllable input.

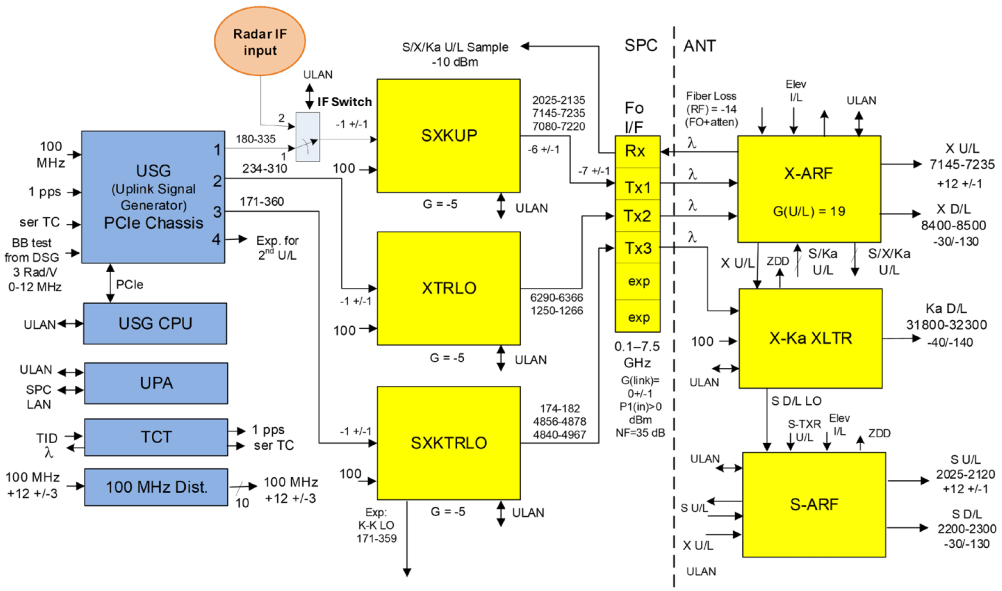


Figure 2. Block 6 exciter signal path diagram.

B. DSS-13 Receive and Data Acquisition Chain

The DSS-13 has been supporting GSSR for many years. The DSS-14 and DSS-13 bistatic radar are mainly used for observation in the cislunar space.

At DSS-13, the wideband low noise amplifier (LNA) located at position 4 can support both C-band (7190 MHz) and X-band (8560 MHz) receiving and provides both circularly polarized channels (left circular polarization, LCP, and right circular polarization, RCP). A remote-controllable dual channel RF/IF downconverter and fiber transceiver are utilized for signal transport to the control room, where GSSR's back-end receiver down-converts the IF signal to baseband for recording with adequate data acquisition (DAQ)'s analog-to-digital convertor (ADC). For absolute ranging consideration, all components in the DAQ

chain are referenced with the station's 10 MHz clock, and the ADC is synchronized with the station's 1 PPS signal. Table 2 shows the nominal station configurations.

Table 2. Nominal station configuration.

Element	Configuration
S-AWG	290 MHz IF; 1 pulse/s (1PPS) trigger; 10 MHz reference; I/Q channels 1 and 2
DSS-26 microwave path	SXKUP to 80 kW transmitter; 7.190 GHz; RCP
DSS-26 control	External IF selected for radar operation; internal IF restored at end of track
DSS-13 receiver	LNA position 4 dual polarization receiver; GSSR wideband downconverter
DSS-13 local oscillator	Transmit frequency minus 300 MHz; 6.890 GHz for 7.190 GHz operation
DSS-13 acquisition	630 kHz lowpass filter (LPF); 7.5 Msamples/s; 240 MHz Signatec clock

IV. Concept of Operations

The capability is operated as a coordinated bistatic service. The principal investigator supplies experiment information and receives real-time feedback and delivered data. The service request is translated into scheduling and TDN products. DSN operators control the antenna, microwave path, external Intermediate Frequency selection (IFSW), and transmit power after calibration. Goldstone Deep Space Communications Complex (GDSCC) Radio Astronomy and Radar Group (RARG) personnel configure the DSS-26 S-AWG and the DSS-13 receive chain, while JPL GSSR/DSSR personnel provide experiment-specific configuration, real-time support, and data handling.

For orbital debris observations, the briefing message specifies 1) static azimuth and elevation pointing for both antennas, 2) the microwave selection to the "radar input port" via IFSW switch, 3) the transmit power, and 4) completion of the required uplink X-band radar satellite avoidance analysis. The initial orbital debris TDN was exercised and then expanded into a development DSSR network that supports both orbital debris and asteroid/cislunar track types. The antenna block prompts the lead operator to select either orbital debris or asteroid operation and then applies azimuth/elevation or planetary pointing defaults as appropriate.

The operating sequence maintains continuous wave (CW) drive for transmitter calibration and power changes. Fixed waveforms, including CW, binary phase code (BPC), and linear frequency modulation (LFM), are configured while the transmitter is in the appropriate drive state. At the end of the track, the transmitter is taken offline and the IF switch restored to its internal input. Figure 3 shows an overview of the operational coordination.

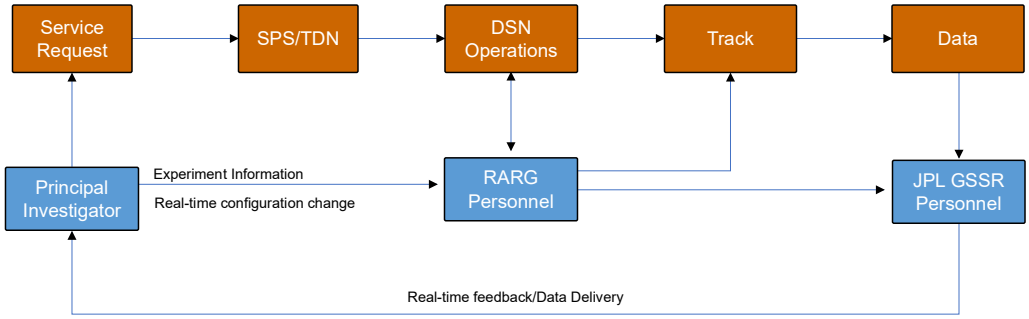


Figure 3. Operational coordination among the principal investigator, scheduling products, station operations, RARG personnel, and JPL GSSR/DSSR personnel.

V. Initial Testing and Transmitter Tripping Investigation

GSSR conducted five orbital debris simulation tracks initially using DSS-26 for uplink and DSS-13 for receive. Out of five tracks, debris were detected, and no multipath RF interference (RFI) was observed. The first three tracks used a CW-filled pulsed-chirp waveform and experienced multiple transmitter trips associated with Direct Coupler #1 (DC1) on reflected power.[5] The transmitter was declared unavailable by the DSN operators during day of year (DOY) 219. The later DOY 244 and 247 tracks used a continuous 300 kHz sawtooth LFM waveform at 80 kW and completed without transmitter issues. Table 3 provides a summary of observations.

Table 3. Initial orbital debris simulation tracks.

Day of year	Duration	Waveform	Result
207	3.5 hr	Filled pulsed chirp	Debris detected; beam trips
208	4.0 hr	Filled pulsed chirp	Debris detected; beam trips at multiple power levels
219	9.0 hr	Filled pulsed chirp	Early trip; transmitter declared unavailable
244	6.0 hr	300 kHz sawtooth	Debris detected; nominal transmitter operation
247	6.0 hr	300 kHz sawtooth	Debris detected; nominal transmitter operation

[5] J. Jao, T. Raney, and L. Snedeker, "Radar Operation Using DSS-26 Uplink to DSS-13," 2025–2026, unpublished operations report.

The figure below shows the two ODR waveforms used for the test tracks:

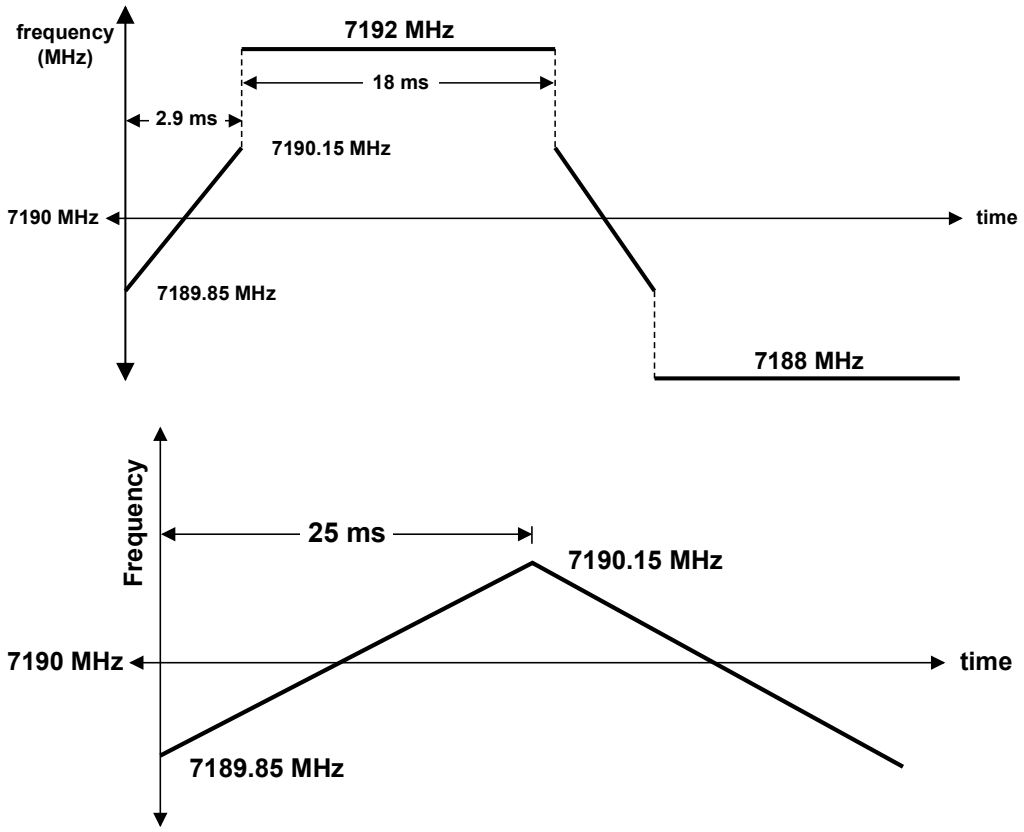


Figure 4. ODR waveforms: (top) CW-filled pulsed-chirp waveform and (bottom) sawtooth LFM waveform.

The investigation compared the S-AWG output, the signal after the SXKUP, the input and output of the X-band RF chain, and the klystron input. During the first dedicated measurement session, the filled pulsed-chirp signal exhibited spectral regrowth, approximately 2 MHz harmonic content, and apparent frequency shifting near the transmitter input. The continuous sawtooth waveform was contaminated less severely and did not cause the transmitter shutdown. Later measurements repeated on DOY 248 and 275 showed clean spectra throughout the signal path. An 80 kW water load test on DOY 275 ran from approximately 12:30 to 15:20 local time without any klystron trips.

The source report did not establish a definitive root cause because the first and later measurement sessions produced substantially different spectra.[6] The report identified asynchronous station clocks or amplitude saturation as possible contributors and noted that DSS-26 depot-level maintenance (DLM) occurred between the test sessions. The TRR therefore treated the issue through controlled conditioning, progressive power increases,

[6] J. Jao, T. Raney, and L. Snedeker, "Radar Operation Using DSS-26 Uplink to DSS-13," 2025–2026, unpublished operations report.

supervised test tracks, and operator training rather than by assigning a single confirmed hardware fault.[7]

VI. Validation Campaign

A. Orbital Debris Radar Demonstrations

Following transmitter conditioning and the TRR, GSSR conducted three more orbital debris demonstration tracks in December 2025. The method used static bistatic pointing, an 80 kW DSS-26 uplink, and DSS-13 recording for real-time or post-processed detection. The three tracks collected data, produced detections, and identified no major operational problems. On the basis of these tracks, the readiness package states that the orbital debris service was ready for operational use and was already producing data for the ODPO.[8] Table 4 shows the results for the ODR validation tracks.

Table 4. December 2025 orbital debris validation tracks.

Date	Scheduled duration	Station	Validation result
December 3	6.3 hr	DSS-26 uplink / DSS-13 receive	Data obtained; detections in real time and/or post processing
December 13	9.0 hr	DSS-26 uplink / DSS-13 receive	Data obtained; detections in real time and/or post processing
December 19	8.8 hr	DSS-26 uplink / DSS-13 receive	Data obtained; detections in real time and/or post processing

At the time this document is being written, the ODR tracks shown in Figure 5 have been conducted with a high success rate.

Jan	plan	actu	Feb	plan	actu	Mar	plan	actu	Apr	plan	actu	May	plan	actu	Jun	plan	actu	Jul	plan	actu	Aug	plan	actu	Sep	plan	actu
10	7.7	7.00	3	5.9	6.13	2	9.0	8.76	13	5.0	3.80	4	9.0	0.00	6	9.0	7.97	2	6.8	4.17	3	9.0	0.00	5	9.0	0.00
15	6.1	5.50	9	6.0	6.00	15	9.0	8.40	17	5.2	5.65	11	7.2	6.93	7	9.0	9.32	4	9.0	6.95	15	9.0	8.5	13	9.0	0.00
20	4.0	4.00	10	3.9	4.00	16	8.5	7.64	25	9.0	6.82	23	9.0	5.77	15	9.0	9.53	12	9.0	9.07	21	9.0	9.2	20	9.0	9.6
25	4.0	4.00	19	8.4	6.08	22	4.0	3.87	27	9.0	8.87	24	9.0	9.20	20	3.7	3.88	13	6.0	6.07	23	9.0	9.3	26	8.0	8.5
			28	6.7	6.17	28	6.0	5.78							21	7.0	6.32	17	6.0	6.15						
															27	9.0	0.00	26	9.0	9.6						

26 XMTR failure

13 ANT auto-stowed
13 LNA cooling failure
Zhuque-2E (ZQ-2E) breakiFt Irwin comm off

26 XMTR cannot cal. di26 SRC failed to move
13 SRC failed to track

Figure 5. ODR tracks supported in FY26. 6 tracks were declared failure due to DSS-26's 80 kW transmitter (XMTR) and sub-reflector (SRC), while DSS-13 suffered LNA and SRC problems.

[7] C. Lee, J. Jao, W. Majid, and N. Rodriguez-Alvarez, "Orbital Debris Radar DSS-26 Design and Development Test Readiness Review," November 17, 2025, unpublished review.

[8] J. Jao, C. Lee, N. Rodriguez-Alvarez, R. Liou, D. Kelley, and L. Snedeker, "DSS-26 to DSS-13 Radar Capability: Deep Space Network Service Readiness Review," May 11, 2026, unpublished review.

B. Asteroid Radar Waveform and Transmitter Tests

Asteroid radar testing addressed all CW, BPC, and LFM waveforms. On January 7, 2026, the DSS-26 80 kW transmitter verified the BPC and LFM waveforms, with klystron behavior consistent with earlier DSS-13 80 kW prototype radar development. On February 5, the team stepped through the full 90 MHz operating bandwidth in 5 MHz increments under CW drive and observed no adverse behavior. Forward power remained approximately 80 kW across the sweep, while body current increased toward the upper end of the band but remained within the values reported in the test table, Figure 6.

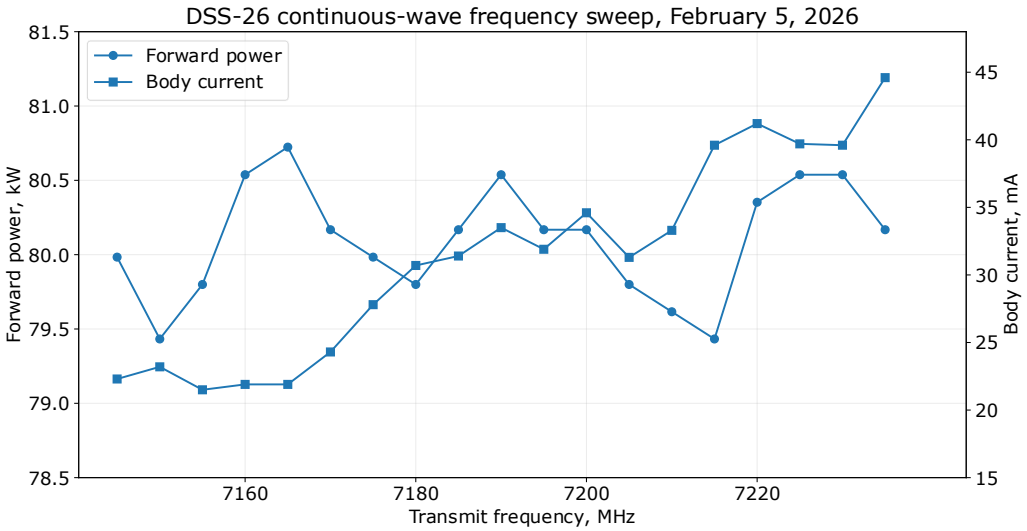


Figure 6. 80 kW klystron's forward power and body current during the February 5, 2026, CW frequency sweep from 7.145 to 7.235 GHz.

On March 6, the team further optimized beam voltage for all three modulation families. The resulting operating recommendation was a 37 kV beam voltage for CW, BPC, and LFM. The test produced approximately 80 kW output for all modulations, including an 80 MHz chirp, and kept body current below the 45 mA specified value. The readiness package characterized this as approximately 20 percent margin for the 80 MHz LFM case. A transmitter trip that occurred when frequency was changed while radiating at 80 kW was mitigated operationally by recalibrating after the required external IF selection. Table 5 shows the asteroid radar waveform validation results.

Table 5. Asteroid radar waveform validation summary.

Date	Test	Result
January 7, 2026	BPC and LFM verification	Responses consistent with prior 80 kW prototype radar development
February 5, 2026	CW sweep, 7.145-7.235 GHz in 5 MHz steps	Approximately 80 kW output across the 90 MHz band
March 6, 2026	Beam voltage optimization for CW, BPC, and LFM modulation	37 kV beam setting; approximately 80 kW; body current below 45mA

On June 25, DSSR conducted the first ever DSS-26 to DSS-13 80kW asteroid observation. Per principal investigator (L. Benner) comments, this track marked a significant milestone because radar echoes were obtained for the first time using DSS-26 as a transmitter with receive at DSS-13. Benner added that this effectively represented a new observing configuration that scientists plan to use during Green Bank downtime when the antenna is not available. Benner also added that this new capability enabled the first radar detection of 1997 NC1 and the discovery that the asteroid is a slowly rotating contact binary. The radar echoes will help resolve previously conflicting reports about 1997 NC1's physical properties. Figure 7 shows the 1997 NC1 images.

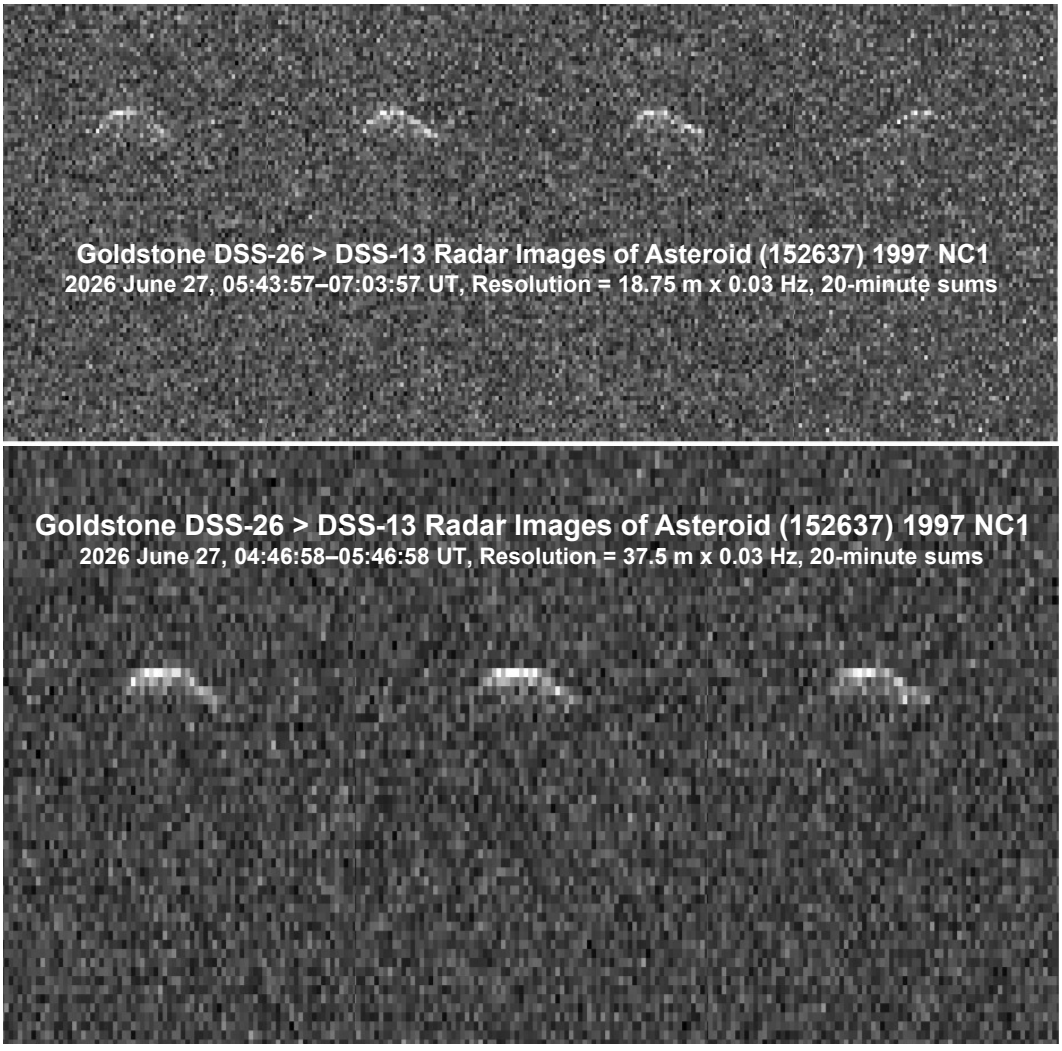


Figure 7. Images from June 27: Resolution of 37.5 m x 0.03 Hz. Each image shows an integration spanning 20 minutes.

C. Cislunar Demonstration

The same CW, BPC, and LFM families are required for cislunar radar. In preparation to support Artemis II, DSS-26 and DSS-13 provided preparatory tracks for Lunar Reconnaissance Orbiter (LRO). The demonstration included a parked antenna detection geometry near the lunar north pole and a tracking interval near the south pole. The

predicted echo power was approximately 2.85 dB above the noise level, while the measured result was approximately 2 to 4 dB above noise. The DSRR used this demonstration to support readiness for cislunar service and as a relevant end-to-end demonstration of asteroid-like waveforms at lunar distance.[9]

VII. Safety, Maintenance, and Operational Readiness

The DSRR safety assessment concluded that the service introduced no new hazard beyond normal DSS-26 operation. The waveform path and transmitter tests demonstrated that the radar waveforms did not post adverse effects on the klystron, and the satellite avoidance analysis process handled the spectrum management concerns. The S-AWG computer remained compliant under its existing Security Plan 11.

Maintenance responsibilities follow existing organizational boundaries. GDSCC personnel operate and maintain the DSS-26 X80 transmitter and the existing switch that selects the external waveform generator input. RARG personnel maintain the DSS-13 receiver and remotely operate the S-AWG. The Radio Science and Solar System Radar (361B) group at JPL maintains the S-AWG hardware in SPC-10. The DSRR package states that sparing is in place and five S-AWG units in total are available.

The readiness package presented all required operational capabilities as delivered and acceptable.[10] It identified minor test anomalies, including a transmitter trip during a frequency change, but stated that these were mitigated through operating procedure and did not affect operational capability. Calibration was completed as part of waveform validation and klystron testing, standard service procedures were in place, and site personnel had been trained.

VIII. Remaining Analysis and Future Improvements

The early operations report identified several technical follow-up items that were not required to declare the basic service operational.[11] These included characterization of RFI at the DSS-13's LNA input, resolution of a low system temperature / Y-factor that prevented a reliable system temperature measurement, and also measurement of propagation delays between SPC-10, the DSS-26 pedestal, the DSS-13 receiver, and the Venus control room for absolute ranging calculation.

Future work also includes installing orbital debris processing software at DSS-13, automating Valon synthesizer frequency control, supporting LRO Mini-RF experiments from DSS-26, and evaluating a "DSS-13 uplink to DSS-28" configuration. Further data reduction planned to estimate slant range and Doppler velocity and a comparative link

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[9] J. Jao, C. Lee, N. Rodriguez-Alvarez, R. Liou, D. Kelley, and L. Snedeker, "DSS-26 to DSS-13 Radar Capability: Deep Space Network Service Readiness Review," May 11, 2026, unpublished review.

[10] J. Jao, C. Lee, N. Rodriguez-Alvarez, R. Liou, D. Kelley, and L. Snedeker, "DSS-26 to DSS-13 Radar Capability: Deep Space Network Service Readiness Review," May 11, 2026, unpublished review.

[11] J. Jao, T. Raney, and L. Snedeker, "Radar Operation Using DSS-26 Uplink to DSS-13," 2025–2026, unpublished operations report.

budget study against the DSS-14 monostatic configuration are a few items remaining to be completed.

IX. Conclusion

The DSSR configuration from DSS-26 to DSS-13 bistatic radar provides a DSN asset– only radar capability during DSS-14 unavailability. The service reuses an approved arbitrary waveform generator (S-AWG), the Block 6 exciter external IF input, the DSS-26 80 kW transmitter, and the DSS-13 GSSR-based receive and acquisition chain. Early orbital debris tracks demonstrated target detection but exposed nuisance transmitter trips with the filled pulsed-chirp waveform. A structured investigation, transmitter conditioning, signal path measurements, and controlled power testing established operational configuration and procedures to ensure proper transmitter operations.

Subsequent orbital debris demonstrations produced detections; asteroid radar testing validated CW, BPC, and LFM across the required band and power range; and the cislunar demonstration measured echo power consistent with prediction. The successful outcome from the DSRR presented the capability as ready to support orbital debris, asteroid, cislunar, and emergency spacecraft tracking commitments, with remaining work focused on analysis refinement and operational automation rather than a critical readiness deficiency.

Acknowledgments

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APPENDIX

I. Operational Configuration Checklist

The following checklist consolidates the configuration elements. Note that it is not a substitute for the released station procedure or briefing message.

Table 6. Draft operational configuration checklist.

Phase	Required action
Pre-track	Complete uplink X-band radar satellite-avoidance analysis and issue experiment/briefing information.
Waveform generator	Reference S-AWG to station 1 pulse/s and 10 MHz; select the correct waveform and common start time.
DSS-26 path	Select SXKUP, 80kW transmitter, 7.190 GHz, and right-circular polarization; select external IF.
Transmitter	Calibrate in continuous wave before modulation or power changes; use approved beam-voltage and power procedure.
DSS-13 receiver	Select GSSR position 4, channel 1 LCP, and 6.890 GHz referenced local oscillator.
Acquisition	Verify blanking if used, 630 kHz LPF, 240 MHz Signatec clock, and 7.5 Msample/s recording.
End of track	Stop modulation and recording, return transmitter to normal shutdown state, and restore the IF switch to internal.