FY23 Strategic Initiatives Research and Technology Development (SRTD)

Proving the Uplink Array for Radar Observations

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Strategic Focus Area: Cis-Lunar Space Situational Awareness | **Strategic Initiative Leader:** Joseph Lazio

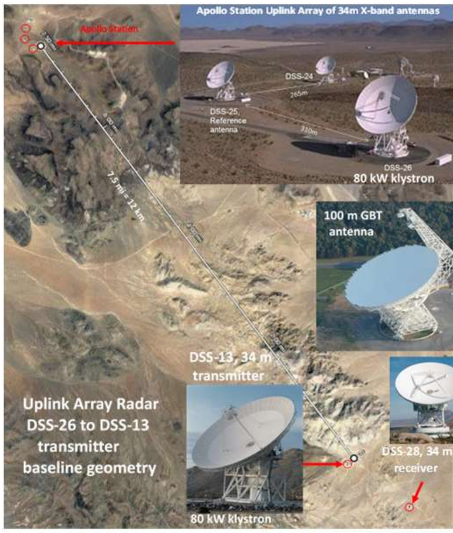

Figure 1. Geography of the DSN's 34 m transmitter antennas DSS-24/25/26; long baseline array composed of DSS-26/13, each equipped with 80 kW transmitters; and DSS-28 34 m and GBT 100 m receiving antennas.

Background:

The Uplink Array Radar is a phased array system that coherently combines signals from multiple 34 m antennas at the target, producing a high EIRP radar transmitter system.

Ideally, an array of N antennas with equal apertures and transmitter power, generates N^2 times the EIRP of a single antenna. DSS-13 and DSS-26 are the only 34 m antennas at the Goldstone Deep Space Communications Complex (GDSCC) with 80 kW transmitters. However, the DSS-13/26 baseline is 12 km long, much longer than the ~300 m DSS-24/25 Apollo Station baseline: hence the long-baseline (12 km) fringes are much narrower and more challenging to generate than with a short baseline.

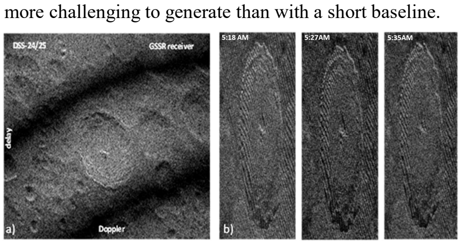

Figure 2. Array fringes: a) short-baseline 250 m DSS-24/25 image; b) long-baseline 12 km DSS-13/26 Uplink Array Radar image

Approach and Results:

Calibrating the Uplink Array Radar requires adjustment of group-delay and carrier phase, enabling coherent addition of transmitted microwave fields at the target, thus forming array fringes, as illustrated in Figures 2, 3 and 4. Extended targets (Central Peak of Tycho), and "point-sources" such as decommissioned geo-synchronous satellites.

Objectives:

Our goal is to demonstrate a high-EIRP Phased Array Transmitter concept capable of meeting NASA's future requirements, by configuring two of the Deep Space Network's (DSN) reliable 80 kW X-band transmitters at DSS-13 and DSS-26, as a stable phased array. This research and development effort has two major objectives:

1) Demonstrate high-resolution Uplink Array Radar capability for cis-lunar observations, thus providing **Doppler-delay images similar to those of Goldstone Solar System Radar (GSSR)**, with nominal **radar range resolution of 15 m** consistent with the current DSN Uplink Signal Generator's (USG) 10 MHz bandwidth.

2) Recommend potential approaches beyond the current Uplink Array Radar for equaling or exceeding the notional capability of the GSSR, but with greater reliability.

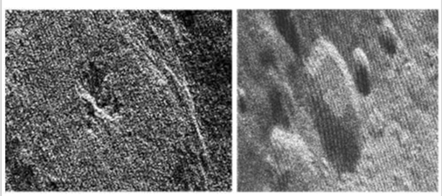

Figure 3. a) Continental (4000 km) transmit-receive baseline image of Tycho, DSS-13/25 transmitting and GBT receiving; b) high resolution image of narrow array fringes near Tycho.

Uplink Array Radar Calibration: The principle of Uplink Array Radar calibration is basically the same for both short- and long-range transmitter baselines. Since the pointing coordinates of the calibration target are assumed known, the line-of-sight (LOS) direction of the array beam is also known to the same degree of accuracy, hence the Uplink Array Radar is effectively calibrated and ready to image targets of interest.

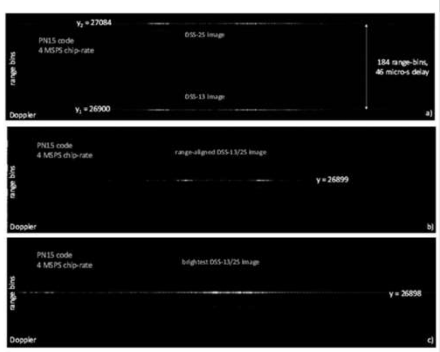

Figure 4. Doppler-delay images of GOES-9 satellites from the transmitting antennas DSS-13/25, using 20 kW C-band: a) before applying delay offset, showing large residual delay; b) combined image of GOES-9 after successful delay-alignment; c) brightest image of GOES-9 at 05:35:36, indicaing possible rough-calibration of the Uplink Array Radar system.

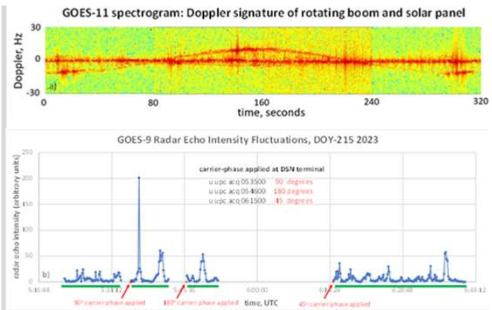

Figure 5. a) Doppler-compensated spectrogram obtained with DSN/GSSR Uplink Array Radar equipment, showing the spectral spin-signature of the GOES-11 spacecraft including the main body, solar panels and solar sail atop an 18m boom; b) Radar signature of GOES-9, recorded on DOY-215 2023. Gaps in the data are due to radar-avoidance restrictions, when transmitters on DSS-13 and DSS-2525 had to be shut OFF. Transmitter ON intervals are indicated by thick green lines along the time-axis.

Based on the results of Figure 5b, it is plausible to argue that approximate carrier-phase calibration may have been achieved with the first 90 degree carrier-phase adjustment. However, we cannot draw this conclusion with only one data-set. More experiments are needed to concusively demonstrate long-baseline Uplink Array Radar calibration.

Strategic Initiative R&TD Accomplishments:

- Generated "long transmitter baseline" array fringes on the Moon (Tycho), with continental receiver baseline.
- Developed ultra-precise Doppler/delay predicts suitable for continental-baseline configurations.
- Demonstrated 9.375 m range resolution using DSN and GSSR equipment. This exceeds our goal of 15m range resolution by nearly a factor of two.
- Developed and demonstrated a technique for carrier phase adjustment via DSN equipment, since the current version of the S-WFG does not have this capability.

Recommendations based on "lessons learned":

- Install C-band receivers on the 70 m antenna and one of the Apollo antennas, for cost-effective receive capability
- Upgrade the DSN USG bandwidths from 10 MHz to 30+ MHz, enabling better than 4 m range resolution.
- Upgrade new versions of the GSSR's S-WFG to include "carrier-phase adjustment" capability.
- Launch a 2m spherical microwave reflector into geo-synchronous orbit, to serve as an ideal "point source" radar calibration target.

Significance and Benefits to JPL and NASA:

As NASA returns to the Moon, there is increased emphasis on tracking spacecraft in cis-lunar space, in order to ensure the safety and health of NASA spacecraft. The two-antenna array fringes on the Moon demonstrate a critical step towards calibrating the Uplink Array Radar, which will enable routine observations of NEAs and other objects of interest, to ensure future monitoring of spacecraft and situational awareness in cis-lunar space and beyond.

Publications:

1) Victor Vilnrotter, Joseph Jao, Jon Giorgini, Dennis Lee, and Philip Tsao, "Proving the Uplink Array for Radar Observations," IPN Progress Report 42-223, JPL, November 15, 2020.

2) Marc Sanchez Net, Mark Taylor, Victor Vilnrotter, T. Joseph W. Lazio, "A Ground-Based Planetary Radar Array", IPN Progress Report 42-229, JPL, May 15, 2022.

3) Victor Vilnrotter, Jon Giorgini, Joseph Jao, Joseph Lazio, Lawrence Snedeker, "Development of an Uplink Array Radar System for Cis-Lunar and Planetary Observations," IEEE Aerospace Conference, Big Sky Montana, March 2023.

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