National Aeronautics and Space Administration

Proving the Uplink Array for Radar Observations

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Cis-Lunar Space Situational Awareness - Strategic Initiative Leader: Joseph Lazio

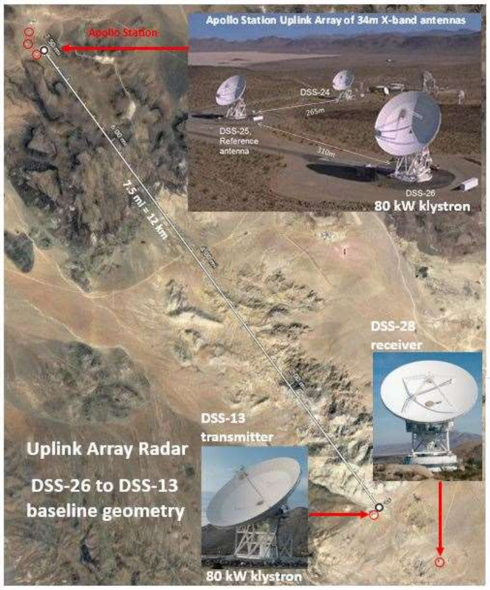


Figure 1. Geography of the short baseline Apollo Array of 3 DSN 34 meter BWG antennas (DSS-24/25/26), and the long baseline 2-element array of DSS-26/13, equipped with 80 kW transmitters.

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

1) Demonstrate high-resolution Uplink Array Radar for cis-lunar observations, thus providing high-resolution Doppler-delay imaging comparable to current Goldstone Solar System Radar (GSSR) performance.
2) Conduct analyses to evaluate and recommend potential approaches beyond the current Uplink Array Radar for equaling or exceeding the notional capability of the GSSR, but with greater reliability.

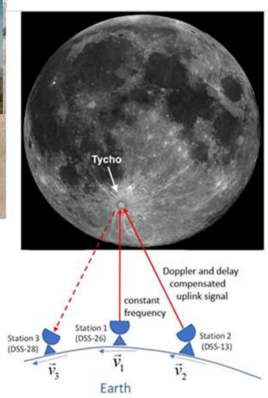
Background: The DSN Uplink Array at the Apollo Station is a phased array system that coherently combines signals from multiple 34 m antennas at the target, to produce a high EIRP phased array transmitter system.

First, the Uplink Array Radar offers advantages relative to the monolithic 70 m GSSR antenna because it uses smaller 34 m antennas, hence the effective solid-angle field of view is four times larger than that of the 70m antenna.

Second, the GSSR depends upon two ultra-high power klystrons that are challenging to design and maintain. Because the DSN Uplink Array uses multiple antennas, each equipped with lower power and more reliable klystrons, it is in principle more robust than the GSSR. In addition, Uplink Arrays are expandable to much higher EIRP simply by adding more antennas: for example, five 34 m antennas equipped with 80 kW klystrons would equal the EIRP of a 70 m antenna with a 500 kW transmitter.

Currently DSS-13 and DSS-26 are the only antennas at the GDSCC equipped with high-power 80 kW klystrons. However, the DSS-13/26 baseline is 12 km long, much longer than the roughly 300 m Apollo station baselines previously used to develop and demonstrate the Uplink Array concept for DSN Communications applications, hence the array fringes are much narrower, requiring greatly improved range and Doppler resolution.

Approach and Results: The implementation of a two-element Uplink Array Radar requires continuous adjustment of the carrier phase to enable coherent addition of the signals at the target as illustrated in Figure 2, and simultaneously adjusting the group delay of the modulation waveform to the required accuracy.



Both requirements can be met by illuminating a distant target with well-known ephemeris, such as the central peak of the crater Tycho on the Moon, and forming a Doppler-delay image of the target plus the array-fringes, as shown in Figures 3 and 4.

Figure 2. Fringe generation via Doppler-delay predicts at crater Tycho, showing transmit and receive paths needed to form Doppler delay images.

Uplink Array Radar Calibration: Calibration of the Uplink Array Radar consists of determining the direction of the array beam in the sky. For a two-element array, phase calibration is accomplished by measuring the phase offset between the target and the center of the brightest array fringe, and applying phase correction to center this fringe over the target. An example of a calibrated short-baseline two-element uplink array can be seen in Figure 3, which shows the brightest fringe generated by the Apollo antennas DSS-24/25 centered over the target, with the echoes received and processed by DSS-13, located 12 km from the transmitters.

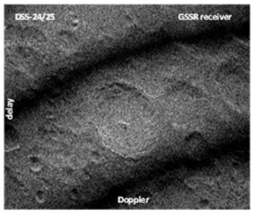


Figure 3. Short-baseline Uplink Array calibration by maximizing array fringe brightness over the target. Since angular direction to the target is known, the direction of the array beam is also known to the same accuracy, hence the Uplink Array is effectively calibrated.

Challenges with the DSS-28 Antenna: The radar echoes were initially received with the DSS-28 GAVRT antenna, located roughly 1.7 km from the DSS-13 antenna, as shown in Figure 1. However, this antenna suffered several failures disrupting our schedule. The most recent failure occurred in January of 2022, which is still being repaired and hence it is not operational.

Therefore, time was procured on the Green Bank Telescope (GBT) over the summer, to enable reception of the echoes generated by the radar trancmitters DSS-13 and DSS-25/26. However, roughly 3000 km distance between the Goldstone transmitters and GBT generated additional challenges that had to be understood and resolved.

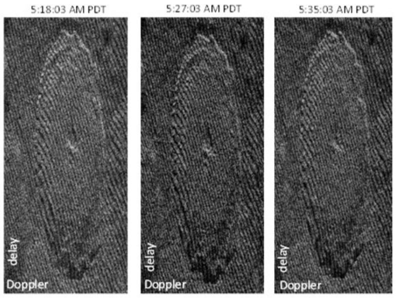


Figure 4. Array fringes over Tycho crater, DOY-093 2021, with DSS-13/25 transmitting and DSS-28 receiving.

Long Transmitter Baseline Uplink Array Radar Calibration: The basic principle of array calibration remains the same for long transmitter baselines such as the 12 km Apollo-DSS-13 baseline shown in Figure 1, however the array fringes are much narrower, as can be seen in Figure 4, hence it is necessary to improve Doppler and delay resolution to enable accurate calibration. Doppler resolution was improved to 0.0025 Hz by increasing the integration time to 400 seconds and delay resolution to 0.125 micro-seconds, which yields the required resolution shown in Figure 5, obtained at the GBT some 3000 km from the transmitters. However, array fringes could not be obtained over this long transmit-receive baseline, due to unexpected Doppler offsets that appeared in the received DSS-13 images.

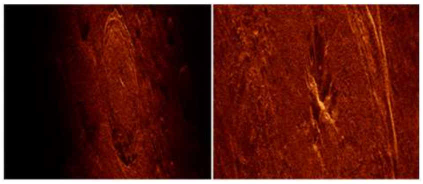


Figure 5. High-resolution image of Tycho crater obtained on DOY-164 2022, with DSS-25 transmitting, GBT receiving. Entire crater on the left, zoomed in on central peak on the right.

Resolution of Doppler Offset: An intensive investigation of the potential causes of the observed Doppler was initiated, where DSS-13 transmitter clock error, predicts error and software implementation errors were considered. This investigation led to the discovery of a problem in the sofware that failed to distinguish between transmit and receive round-trip delay coefficients correctly for this long baseline. It is believed that the problem has been corrected, and will be tested over the DSN/GBT baseline in the coming months.

Significance/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 ultimate goal of this research effort is the development and demonstration of long-baseline Uplink Array Radar calibration, stability on the time-scale of hours, and high resolution Doppler-delay imaging of lunar spacecraft and science-value targets including planets and near-earth asteroids.

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.

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