Proving the Uplink Array for Radar Observations

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Cis-Lunar Space Situational Awareness**

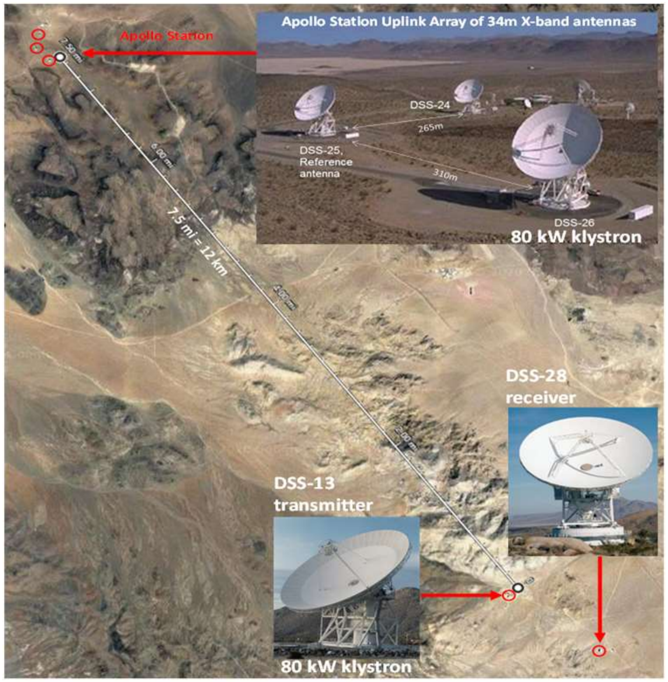

Figure 1. Comparative geography of the short baseline Apollo Array of 3 DSN 34 meter BWG antennas (DSS-24/25/26), and the long baseline 2-element array of DSS-26/13, equipped with 80 kW transmitters.

Background

As NASA returns to the Moon, there will be increased emphasis on tracking spacecraft in cis-lunar space, in order to ensure the safety and health of NASA spacecraft. The 70 m antenna of the Goldstone Solar System Radar (GSSR) has demonstrated the capability to detect and track spacecraft around the Moon, however the GSSR depends upon two ultra-high power 250 kW klystrons, which are challenging to design and maintain.

The Deep Space Network (DSN) has already developed a short-baseline X-band (nominally 7.2 GHz) Uplink Array capability, consisting of Deep Space Stations 24, 25, and 26 (DSS-24/25/26) at the Apollo Station. The long-baseline Uplink Array concept being developed in this effort and shown in **Figure 1** aims to demonstrate a coherent two-element Uplink Array Radar concept employing 80 kW klystrons, capable of providing EIRP equivalent to that of a 70 m antenna equipped with an 80 kW transmitter. However, Uplink Arrays are inherently expandable to much higher EIRP 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.

Publications

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

Objectives

The goal of this three-year research and technology development effort is to demonstrate a high-EIRP wideband Phased Array Transmitter capable of meeting NASA's future requirements for planetary science, planetary defense (NEA orbit determination), and cis-lunar space domain awareness, via the DSN's reliable 80 kW X-band Uplink Array Transmitters at DSS-13 and DSS-26 as a prototype. This effort has two major objectives:

1) Demonstrate high-resolution Uplink Array Radar capability for cis-lunar observations, meeting GSSR requirements for Doppler-delay imaging and range resolution at X-band frequencies
2) Conduct analyses in the third year 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.

Approach and Results

This year's effort (2021) was a direct continuation of the plan developed in 2019 to demonstrate the feasibility of a high-resolution Uplink Array Radar system, but revised to take into account the impact of the Covid-19 epidemic, including travel restrictions to Goldstone and workforce shortages at DSS-13. In addition, failure of the DSS-28 antenna receiver, and a freeze on DSN radar tracks due to concerns over cycling of klystrons to comply with radar-avoidance analysis, led to the cancellation of all scheduled Uplink Array Radar tracks in the spring and summer of 2021.

Implementation of Differential Doppler and Delay Predicts. The Apollo antennas were operated at constant 7150 MHz carriers, due to incompatibility between the GSSR WFG and the operational DSN Uplink Signal Generator (USG) at SPC-10. This required the development and implementation of ultra-precise **differential** Doppler and delay predicts applied to the WFG at DSS-13. A mathematical model describing the key components of the required differential predicts is shown in **Figure 2**, while a physical model of the signal path from the ground to the Moon and back is shown in **Figure 3**.

Higher-Resolution Two-Antenna Doppler-Delay Images. Comparing the geometry of the long-baseline array to that of the short-baseline Apollo Uplink Array, it was determined that roughly 24 array fringes will span Tycho with the longer baseline. Resolving such narrow fringes requires higher-resolution imaging, which implies higher chip-rates and improved delay-alignment of the transmitted PN codes: this capability was implemented by increasing the chip-rate from 200 kHz to 1 MHz, yielding range resolution of 150 meters during these tracks. Even higher-rate PN codes are being tested for future use.

Coherent Two-Transmitter Array Fringes on the Moon. After demonstrating higher-resolution single-transmitter and two-transmitter images of the target Tycho, the corresponding bright pixels in the two simultaneous Tycho images were identified, and their delay difference calculated in units of pixels, then converted to delay. This measured delay offset was then applied to the Waveform Generator (WFG) at DSS-13, and a new Doppler-delay image was obtained. It was immediately evident that bright and dark array fringes were superimposed on the crater Tycho, as shown in **Figure 4**. **This is believed to be the first time that long-baseline array fringes were generated over the Moon, at microwave frequencies.**

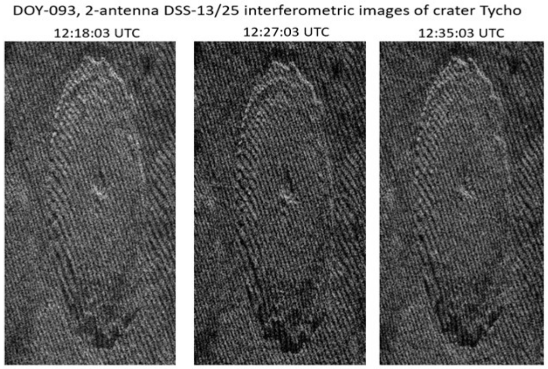

Figure 4. Array fringesover the lunar crater Tycho generated by coherently phased two-antenna DSS-13/25 Uplink Array Radar transmitter system currently under development at JPL.

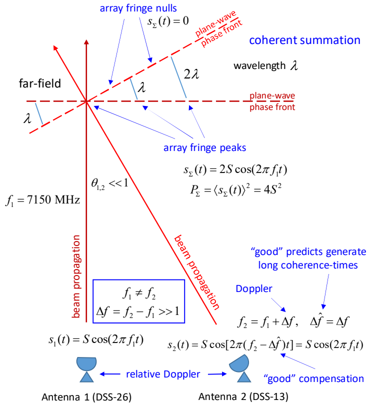

Figure 2. Mathematical model for generating "good" predicts suitable for array fringes on the Moon with two coherently phased transmitting antennas. One of the Apollo antennas (one of DSS-24/25/26) transmits a constant frequancy carrier, while the DSS-13 antenna transmits differential predicts designed to match the frequency of the Apollo antenna signal at the Moon.

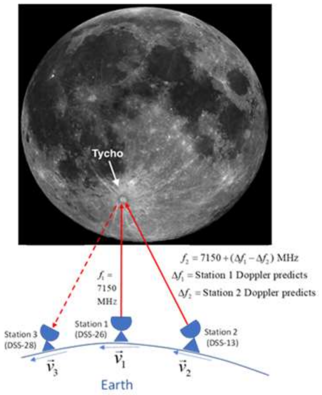

Figure 3. Physical model of array fringe generation at the Moon, illustrating both transmit and receive paths that require ultra-precise predicts in order to form a Doppler-delay image.

Images taken at roughly 9 minute intervals indicate "visually" stable array fringes, as can be seen in **Figure 4**. The three post-processed images of **Figure 5** include the first image; the sum of the first and second images; and the sum of the first and third images. Note that array fringes over the central peak of Tycho remain on target, despite fringe-rotation due to changing geometry that causes blurring of the fringes away from the target. However, the array fringes directly over the central peak remained relatively sharp, indicating stable fringes over the target. This indicates short-term stability, but more extensive tests will be required to demonstrate long-term stability of this two-element Uplink Array Radar system.

Significance/Benefits to JPL and NASA

The demonstration of stable long-baseline two-antenna array fringes on the Moon is a necessary condition for achieving N^2 array gain, hence this is a critical step towards calibrating the Uplink Array Radar system for routine observations in the future. Ultra-precise Doppler and delay predicts generation, timing accuracy, equipment stability and millimeter-level station-location accuracy were required to achieve this result, which is the key first step to achieving long-baseline Uplink Array Radar calibration. Array calibration, stability demonstration, and radar imaging of science-value targets including NEAs and possibly lunar spacecraft, is the goal of the third year's effort.

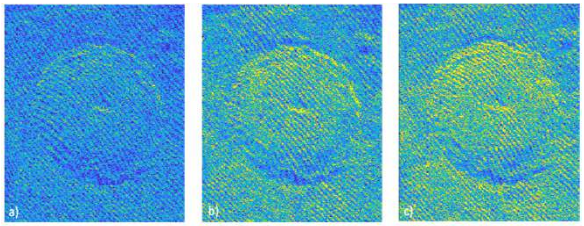

Figure 5. a) First Tycho image, generated with data collected starting at 12:18:03; b) sum of first and second (12:27:03) images; c) sum of first and third (12:35:03) images. Blurring of the fringes to the left and right from center in the summed images is due to fringe-rotation with changing geometry. Note that fringe-blurring occurs closer to the center in Figure 5c than in Figure 5b, because the fringes rotated more during the longer 17 minute interval than in the previous 9 minute interval in the second image.

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Clearance Number:
RPC/JPL Task Number: R20046