Virtual Research Presentation Conference

Proving the Uplink Array for Radar Observations

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Tutorial Introduction

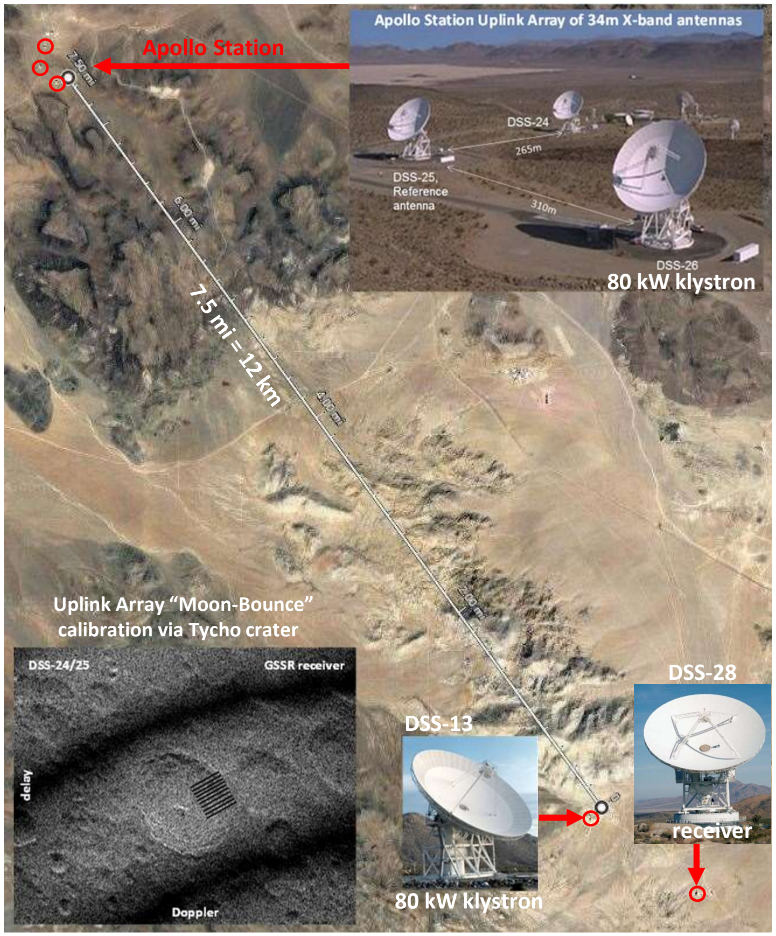
Our goal is to demonstrate a high-power wideband Phased Array Transmitter concept to meet requirements for planetary science, planetary defense, and cis-lunar space domain awareness, by configuring two of the Deep Space Network's (DSN) 34 meter antennas, DSS-13/26, as a phased array.

Currently DSS-13/26 are the only two antennas at the Goldstone Complex equipped with medium-power 80 kW klystrons, but the baseline is 12 km, much longer than the ~300 m Apollo baselines.

The two-element Phased Array Transmitter can be expanded to three or more antennas, as shown with the three-element short-baseline Apollo Uplink Array developed previously for spacecraft communication [1].

When coherently phased up, a two-element transmit array will generate "array fringes" in the far-field, as can be seen in the Doppler-delay image formed by the DSS-24/25 Uplink Array.

The Apollo Uplink Array relies on pairwise calibration by centering the brightest array fringe over the central peak of the crater Tycho. With the 12 km DSS-13/26 baseline the fringes will be much narrower, as illustrated in the insert, hence generating and aligning these fringes over the target is a challenging problem that needs to be demonstrated in the field [2].



Problem Description

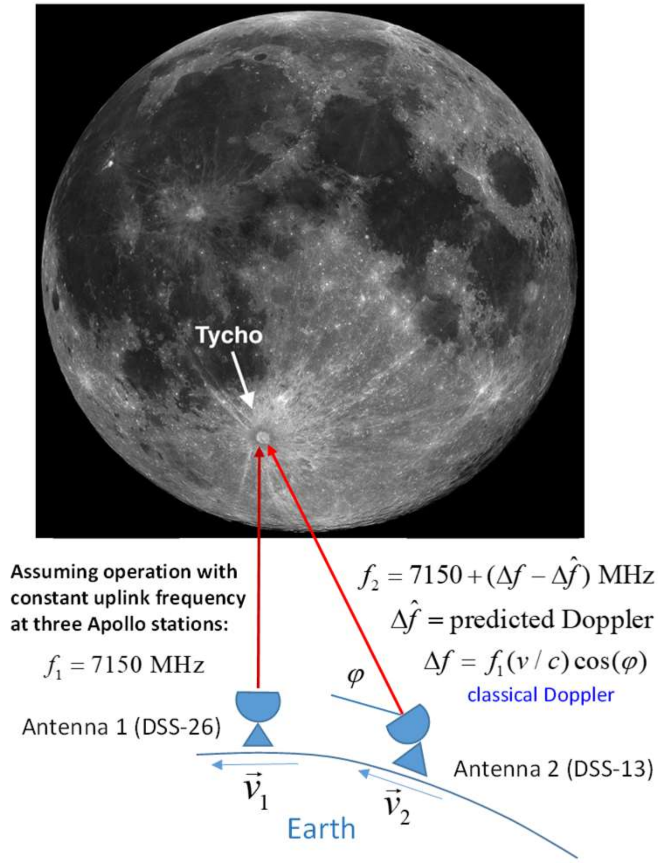
a) Context (Why this problem and why now): Due to the monolithic antenna design of the Goldstone Solar System Radar (GSSR), the transmitter power of the GSSR can only be increased by installing higher power klystrons, which are likely reaching their limit around 250 kW. These klystrons have not been very reliable in the past. By contrast, the Phased Array Transmitter concept is a distributed system that coherently combines signals from multiple 34 m antennas at the target, producing a reliable high power radar system that can serve as viable backup to the GSSR.

b) SOA (Comparison or advancement over current state-of-the-art): The relevant state-of-the-art comparison for this effort is the GSSR. The GSSR consists of the 70 m antenna at DSS-14 equipped with ultra-high power (250-500 kW) transmitters and wideband signal processing equipment. It has demonstrated the capability to detect and track spacecraft around the Moon, having detected both the Lunar Reconnaissance Orbiter (LRO) and the Chandrayaan-1 spacecraft.

The Phased Array Transmitter offers two potential advantages over the GSSR. First, because it uses 34 m antennas, the effective field of view is approximately four times larger than that of the 70m antenna, enabling faster acquisition of objects. Second, the GSSR depends upon two ultra-high power klystrons that are challenging to design and maintain. Because the Phased Array Transmitter uses multiple antennas, each with lower power and more reliable klystrons, it is expandable to larger arrays by adding more antennas, and it is more robust than the GSSR.

c) Relevance to NASA and JPL (Impact on current or future programs): As NASA returns to the Moon, there is increased emphasis on tracking spacecraft and other objects of interest in cis-lunar space. The Phased Array Transmitter is a flexible and reliable approach that enables high EIRP illumination of targets, with expandable capabilities to accommodate greater demands on distance or resolution in the future.

Methodology



Installation and Testing of Phased Array Transmitter Equipment

- Repaired and upgraded X-band receiver on the DSS-28 antenna
- Installed, tested and upgraded GSSR equipment at DSS-13
- Installed and tested Uplink Array and GSSR equipment at SPC-10

Developed Predicts to Generate Doppler-Delay Images

- Apollo antennas use constant carrier frequency signals, due to incompatibility of GSSR predicts with DSN predict formats
  - Mid-band carrier frequency of 7150 MHz was selected
- Developed and implemented novel differential transmitter predicts for DSS-13 based on the earlier Apollo Uplink Array predicts [3], to align the signal phase at the target
- Developed and implemented receiver predicts to remove residual Doppler and delay at DSS-28 , in order to generate Doppler-delay images of the radar target (Tycho crater)

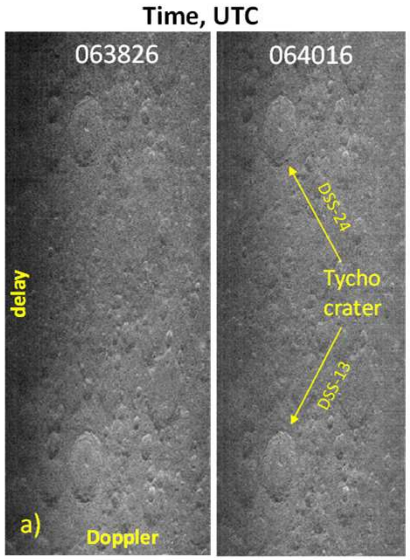
Conducted Field Experiments at Goldstone

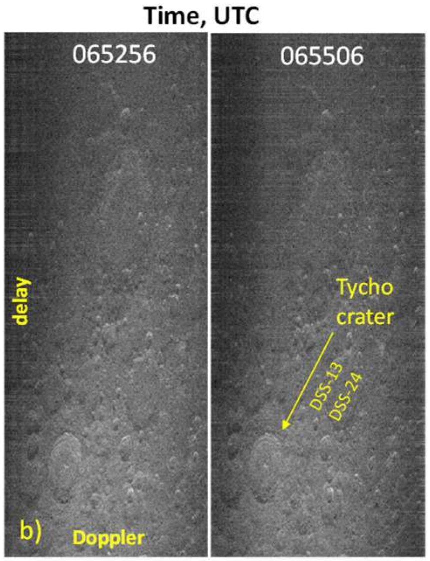
- Scheduled Goldstone tracks on DOY-035, -037, -073, -100
  - DOY-73 lost to bad weather, DOY-100 lost to COVID-19 restrictions
  - Single-antenna Doppler-delay images were obtained on DOY-037, validating receiver predicts for DSS-28

Results

Results of Goldstone Tracks to Validate Upgraded Equipment and Predicts

- **Following the successful launch of the Mars Science Laboratory (MSL) the Apollo antennas were released, and new tracks were scheduled on DOY-214,-215,-216 to demonstrate phase compensation via GSSR differential predicts, and to validate initial delay alignment**
    - **The DSS-28 receiver failed on DOY-214 due to excessive temperatures, but was repaired by DOY-215**





Successfully demonstrated two-antenna images of the crater Tycho on DOY-216, aligned in both Doppler and delay, validating the differential phase calibration approach and confirming our initial delay estimates.

a) DSS-13/24 transmitting, WITHOUT delay compensation

b) DSS-13/24 transmitting, WITH coarse delay compensation, showing nominally aligned 2-antenna image of crater Tycho

Note: generation of long-baseline array fringes is the next step, but this will require finer "sub-chip" delay estimates. Demonstration of array fringes will be carried out in FY-21.

Publications and References

Publications:

[1] Victor Vilnrotter, Joseph Jao, Jon Giorgini, Dennis Lee, Philip Tsao, “Proving the Uplink Array for Radar Observations,” *The Interplanetary Network Progress Report,* volume 42-223, November 15, 2020 (to be published)

References:

[1] Victor Vilnrotter, Dennis Lee, Timothy Cornish, Philip Tsao, Leslie Paal, Vahraz Jamnejad, “Uplink array concept demonstration with the EPOXI spacecraft,” *Proceedings of the IEEE Aerospace Conference*, Big Sky, Montana, March 2009.

[2] Victor Vilnrotter, Philip Tsao, Dennis Lee, Timothy Cornish, Loseph Jao, Martin Slade, “Planetary radar imaging with the Deep-Space Network’s 34 meter Uplink Array,” *Proceedings of the IEEE Aerospace Conference*, Big Sky, Montana, March 2011.

[3] Philip Tsao, Victor Vilnrotter, Vahraz Jamnejad, “Pointing-vector and velocity based frequency predicts for deep-space uplink array applications,” *Proceedings of IEEE Aerospace Conference*, Big Sky, Montana, March 2009.