Ground Array Calibration Using Lunar InSAR Imagery

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Ground array of reflector antennas is being considered for deep-space communications by NASA. This array which consists of a large number of sparse reflector antennas provides a unique approach to enhance the effective isotropic radiative power (EIRP) of the uplink radio from a ground station to a deep-space spacecraft. To utilize the maximum array gain, phase coherence of signals from all array elements is desired. Since the phase center location of each reflector antenna is very difficult to be determined accurately, an external phase calibration is necessary to ensure constructive interference of all array elements in a desired direction.

In past we have studied and demonstrated the uplink calibration using phase conjugation method that requires all elements to have both receivers and transmitters. The cost model and operational concerns favor array elements with only transmitters. Therefore the array calibration procedure must only rely on elements with only transmitters. In this paper, a bistatic radar calibration approach for the all-transmitter array is proposed, where all elements transmit simultaneously towards a calibration target and the mixed backscatter signals are received at a common receiver. Orthogonal PN (pseudo noise) codes are employed to modulate the transmit signals of different array elements, in order to distinguish their backscatter at the common receiver and then detect their respective phases. Such phase information accounts for both signal path-length difference and instrument dissimilarity of all array elements. Moon is selected as the calibration target since it falls within the array far-field and avoids the positioning error encountered by near-field calibration targets. Challenges come from the fact that Moon needs be treated as a distributed target instead of a point target. Such difficulty can be overcome with the help of SAR (Synthetic Aperture Radar) imaging technique, where the footprint of a ground transmit antenna on the lunar surface is divided into many small pixels and backscatter signals from each pixel are obtained at the ground receiver antenna. These pixels can be treated as “point targets”. Each array element can form a SAR image of a same pixel and the phase differences (interferograms) among these images can be used to perform phase calibration. Another challenge of this approach is the signal-to-noise ratio (SNR) due to the large path-loss and the PN-codes interference. Ways to enhance SNR such as increasing pixel size, extending observation time, and multi-pixel averaging are discussed. The maximum number of array elements allowed in the system must also be determined in order to achieve the required SNR.

Numerical simulations are conducted to evaluate the performance of the proposed calibration approach. PN-codes based on maximal length sequences are adopted. A 3D random rough surface generator is developed to simulate the lunar surface pixels. Then the standard rough surface scattering models are used to compute the backscatter signals from these pixels. Matched filtering is performed in the common receiver to isolate signals corresponding to different array elements and their phases calculated. Finally the phase differences between each two elements’ signals are examined in a statistical way via Monte-Carlo simulations.