Monostatic and Bistatic Delay Doppler Imaging of the Moon

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Abstract

Imaging results from monostatic and bistatic radar observations of the Moon made at a wavelength of 68 cm (440.2 MHz) with the Millstone MISA radar transceiving and the Arecibo Gregorian system receiving are presented. These images were generated so as to calibrate both the HPLA (High-Power Large Aperture) systems while simultaneous tracking the respective sub-radar points on the Moon. The delay-Doppler mapping technique along with appropriate Ephemeris data from JPL Horizons (http://ssd.jpl.nasa.gov/?horizons) system was used to confirm target tracking, time alignment of the bistatic observations, target motion compensation, relative and absolute delays, and to generate the high-resolution, focused radar images of the Moon. Both the Millstone monostatic and the Millstone-Arecibo bistatic images have the same resolution of 150m along the range/delay direction and of 0.083 Hz resolution along the Doppler direction. Generation of the two images demonstrates a wide range of physical phenomena associated with the observations along with some advanced signal processing techniques.

Introduction

This study is conducted with a motivation to calibrate the observational setup and data that were collected simultaneously at the two High Power Large Aperture radar systems located at Arecibo (AO) and Millstone (HO) to track the Moon and detect the transient phenomena. The calibration process involves generating Millstone monostatic, Millstone-Arecibo bistatic radar surface image at a wavelength of 68 cm from the returns of the same transmission pulse by using the Delay-Doppler Imaging technique. In this case, radar coded pulse was transmitted from Millstone and the reflections are received at both the observatories.

Observational Setup

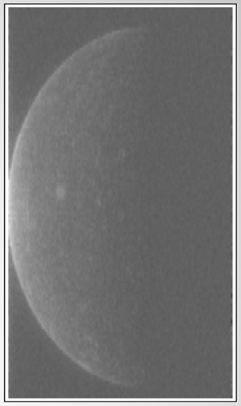
Haystack/AO multi-static lunar observations are governed by the limited pointing capability of AO (>20 degrees ZA). At Millstone antenna is fully steerable to the horizon and full Moon is visible. At Arecibo half of the Moon is visible while transiting near zenith due to the Antenna's narrow beamwidth. The Frequency of operation is 440.2 MHz and 845 barker code with 2 μs baud length was used[2]. High Sampling frequency of 25MHz at Millstone and 10 MHz at Arecibo was used. Inter Pulse Period is chosen such that moon's full echo falls in between two transmission signals

Delay Doppler Mapping Technique

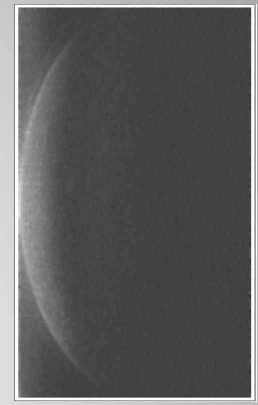
- Relative Motion between Moon and telescope is used to image the surface. The time delay of the reflected signal corresponds to all points on the circle centered on the subradar point and when the target spins about its axis, all the points on doppler circle move towards or away with respect to observer[3]. This method of mapping is also known as inverse-SAR imaging technique.
- First step involves Range compression i.e. decode the received reflected pulse using transmission code and match filtering. The decoded echo is exponential in nature.
- Translational motion has to be compensated to remove blurring effect. It is achieved by phase adjustment and aligning the ranges from the same scatterer using Monostatic and Bistatic Ephemeris data[4] and technique described in Chen [1980].
- Next in azimuth compression stage returns of each delay from all pulses are used to estimate doppler power spectrum. In this case 900 pulses are used. They are incoherently averaged to get delay-doppler image at desired range resolution of 150m.

RESULTS

Millstone-Monostatic Radar Image of Moon



Millstone-Arecibo Bistatic Radar Image of Moon



Discussion

The resultant bistatic image shows only one side of the moon, because at the AO, antenna has a narrow beam relative to Moon's size. The monstatic image has high intensity value than the bistatic image because of the strong backscattering. Further, generation of bistatic image calibrates both the datasets in time and frequency, as without proper alignment in time and frequency there would be no proper decoding and no delay-doppler mapping. Additionally, since the same crater with different intensity is seen in both datasets it can be confirmed that both telescopes are seeing the same region on the Moon's surface. In future, better focusing techniques will be used to improve the image qualities.

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