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To: Distribution

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Subject: Quick-look at bistatic SAR data collected on April 6, 2011

Introduction

Bistatic SAR data were collected during 2 passes on April 6, 2011 with the transmitter being the Arecibo Radio Telescope in Puerto Rico and the receiver being the Mini-RF radar carried by the LRO spacecraft in lunar orbit. This memo describes a quick-look at the raw data with the intent of verifying that there is a valid signal within the data and looking for indications of unwanted signal paths. Unwanted signal paths include the direct path between Arecibo and the Mini-RF antenna backlobe and the specular forward scattering from the lunar surface into the antenna backlobe or sidelobes. No SAR processing has been performed.

Radar Parameters

The pulses transmitted from Arecibo had the characteristics listed in Table 1. These parameters were in effect during the first portion of the data collection of the first pass. The latter portion of the first pass involved CW pulses with the same pulse length and PRI as the chirped pulses, but with a constant frequency of 2397.5 MHz.

Raw Pulse Power

Although the Mini-RF radar was operated in a continuous receive-only mode, the data are formatted into packets containing 8192 samples each. These packets are the equivalent of the samples corresponding to a single pulse in the normal SAR mode and these are most conveniently processed as "pulses" using existing analysis software. The transmitted pulses were generated at Arecibo and are asynchronous with the sampling by the Mini-RF receiver. There are approximately 6 transmitted pulses during the time in which one data packet is created (8192 samples at a rate of 2.0833 Msps with a transmitted PRI of 500 us).

Table 1. Radar waveform parameters for the bistatic SAR collections.

Parameter	Value
pulse length	100 us
pulse repetition interval	500 us
chirp start frequency	2379.2 MHz
chirp rate	0.016 MHz/us

The total digital power in each pulse is plotted in Figures 1 and 2 for the two bistatic collections. The dip in the power that is observed about three quarters of the way through the collections is due to an interruption in the transmitted power while the transmitter was reconfigured. The collections began at 17:33:27.8 and 19:26:35.8. For the first collection, the bounds on the dip in power indicated by the vertical lines in Figure 1 are at 17:37:33.5 and 17:37:54.5. For the second collection, they are at 19:30:07.3 and 19:30:31.3. Notes taken at the time of the collection indicate that the mode changes were complete at 17:38 and 19:30:38. Therefore, the dip in power correlates properly with the time during which the transmitted power was down for the switch. All times are UT.

It is seen in Figures 1 and 2 that there are some distinct intervals in which there is an increase in the total power. These have not yet been correlated with lunar features, but such a correlation should be possible.

Spectrum of the Pulsed-CW Data

The mode change during the first collection was from chirped pulses with a bandwidth of 1.6 MHz to CW pulses with a frequency that is 500 kHz below the receiver band center (i.e., at 2379.5 MHz). For both modes, the pulse length was 100 us and the pulse repetition interval is 500 us. A segment of the data following the mode change was Fourier transformed, packet-by-packet, and averaged over 1000 packets. The result is shown in Figures 3 and 4. What seems to be a single peak in Figure 3 is seen to be composed of a series of peaks that are separated by 2 kHz. This is as expected for the pulse repetition interval of 500 us. The signal-to-noise ratio implied by these spectra is approximately -13 dB. This calculation includes accounting for the 20% duty cycle of the pulses transmitted from Arecibo. The signal to noise ratio implied by these spectra is at the same level as that implied by the power dip in Figures 1 and 2.

The small peak at +500 kHz for the horizontal channel that is seen in Figure 3 is the result of a known bias in the horizontal channel. This resulted in a clipping of the data and the production of an image in the spectrum. The block adaptive quantization that is part of the Mini-RF receiver works less well for the receive-only mode, where the length of the transmitted pulse is much smaller than the length of the receiving interval, than it does for the normal SAR collection mode.

Link Calculation

A link calculation is outlined in Table 2. While there is variability in the lunar backscatter coefficient, a nominal value of -20 dB is used in the calculation. The result is an estimated SNR of -13 dB. The observed SNR of -13 dB is therefore consistent with the signal being the result of lunar backscatter. This calculation of the SNR involves some roughly estimated values such as the effective antenna temperature and too much significance should not be attached to the exact agreement with the value inferred form the spectra.

Indications of Unwanted Signal Paths

One of the goals of the test conduced on April 6 was to determine the extent to which unwanted signal paths may be present in the bistatic SAR data. The raw data samples are not very useful for investigating the presence of these signal paths because the signal-to-noise ratio is low and the data are quantized to only 3 bits each for the I and Q samples.

The chirped pulses are not visible in the data spectrum and are not expected. For the chirped data, the energy in the spectra shown in Figures 3 and 4 is spread across a bandwidth of 1.6 MHz. It is therefore a small contributor to the spectrum.

Signals that enter the receiver from the antenna backlobe or from forward scattering on the lunar surface will experience much less range broadening than the backscatter. Applying a pulse compression filter to the digital data did not result in any visible series of peaks with a period of 500 us. Such peaks were visible in data collected with the Mini-RF brassboard prior to the April collection with comparable signal levels. It is concluded that there is no strong evidence of significant energy from unwanted signal paths, although such energy may be present at low levels.

Table 2. Parameters used in the link calculation for the bistatic radar data collection.

Parameter	Value	Note
peak transmitted power	35.5 W	value at the antenna feed based on measurements made at the site prior to the collection
Arecibo antenna gain	72 dBi	
lunar surface reflectivity	-20 dB	-10 to -30 dB is a reasonable range
radar wavelength	0.126 m	2380 MHz S-band
receive aperture efficiency	50%	
distance	393000 km	Earth-to-Moon
antenna noise temperature	200 K	rough estimate for unlit portion of the Moon
noise bandwidth	2 MHz	anti-alias filter
receiver noise figure	6.5 dB	measured during pre-flight I&T
signal power	-117.4 dBm	
noise power	-104.4 dBm	
SNR	-13 dB	

Conclusions

Evidence exists that the data collected on April 6, 2011 contains backscatter from the lunar surface that should be suitable for processing into SAR products. The signal level is consistent with lunar backscatter and does not show strong interference from unwanted signal paths. The low per-pulse signal-to-noise ratio and the noise-like nature of the data are typical for SAR systems and do not preclude SAR processing

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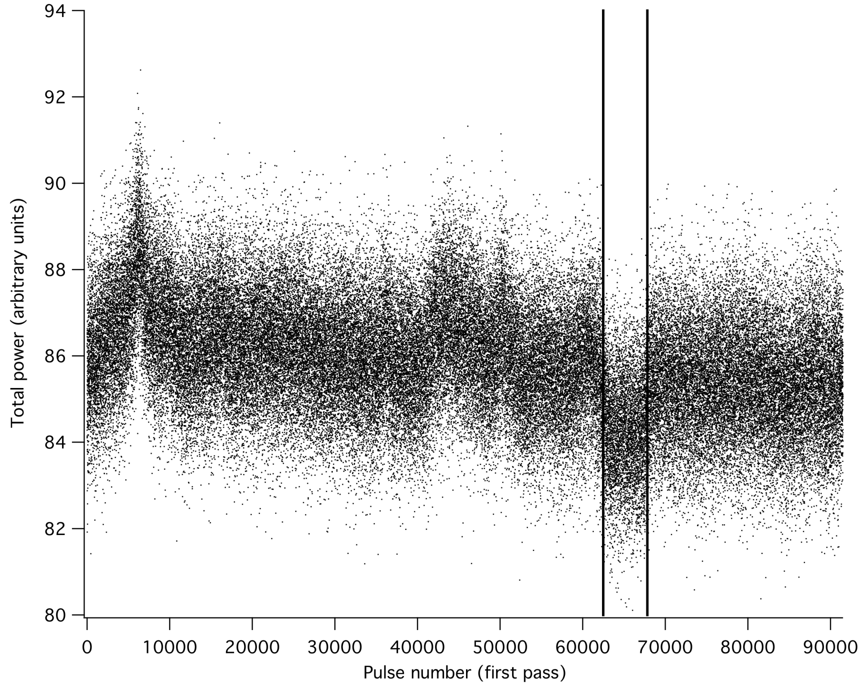

Figure 1. Total power as a function of pulse number for the first bistatic collection. The vertical lines are rough indications of the interval of the mode change at the transmitter.

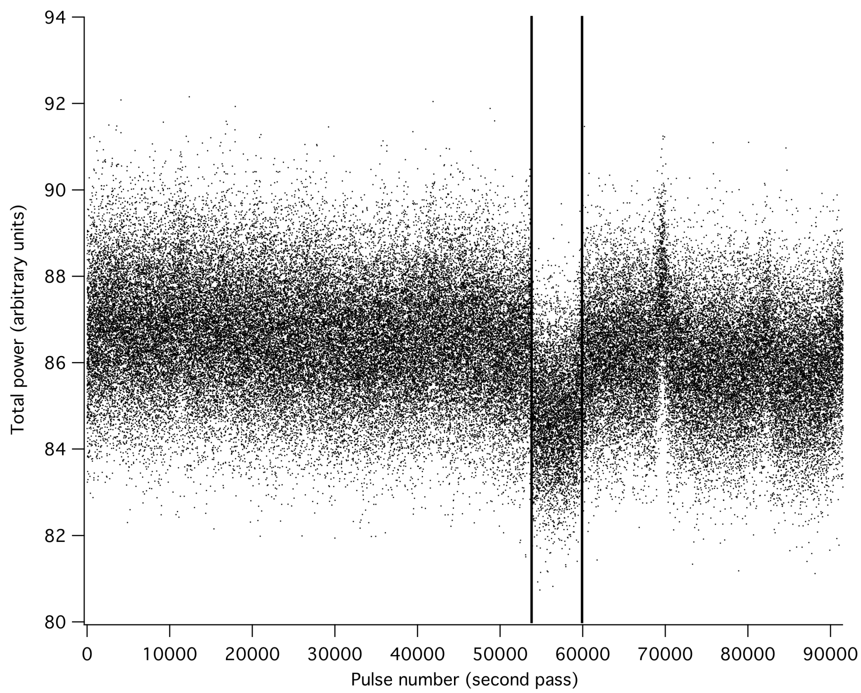

Figure 2. Total power as a function of pulse number for the second bistatic collection. The vertical lines are rough indications of the interval of the mode change at the transmitter.

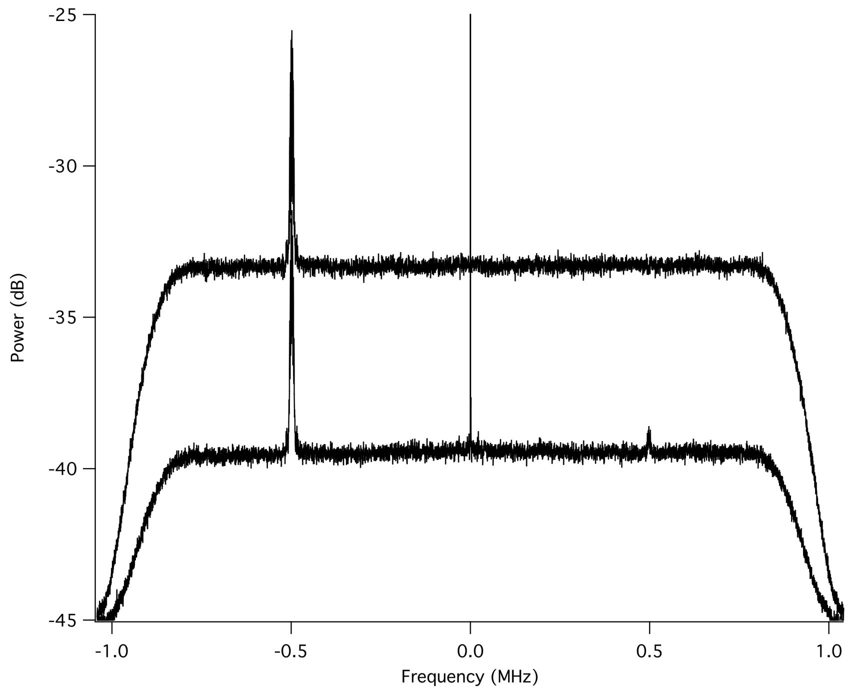

Figure 3. Spectrum of the data following the mode switch for the first bistatic collection. The signal is at -500 kHz. The sharp peak at the center is due to a DC bias in the digital data. The upper peak is the vertical channel, the lower is the horizontal.

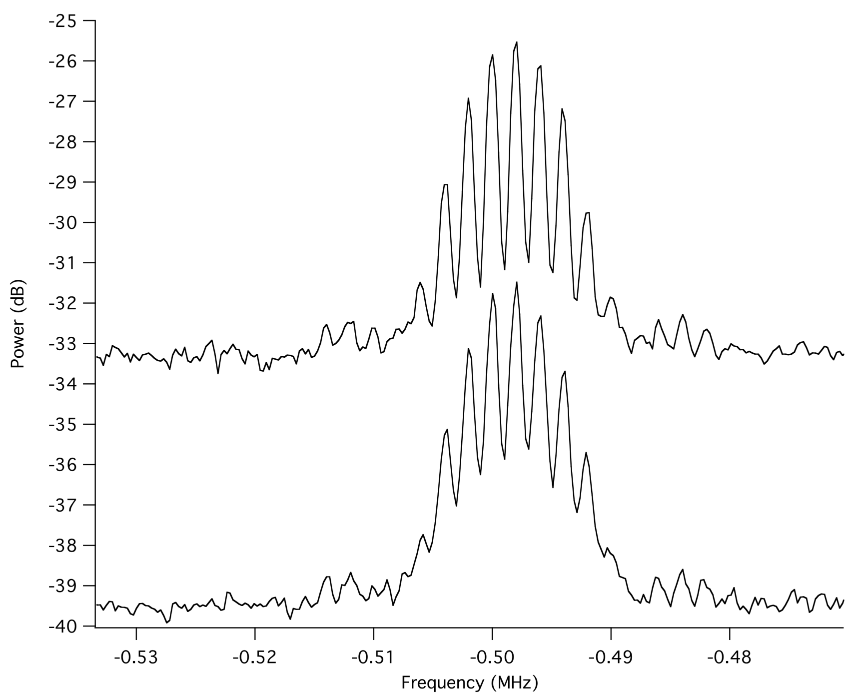

Figure 4. Close-up of the signal portion of the spectra shown in Figure 3. The separation of the peaks is 2 kHz, consistent with the 500 us PRI.