Lunar studies with the EISCAT UHF System
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Abstract
We present initial results from our efforts to produce a focused range-Doppler radar map of the Moon with the EISCAT UHF system. We discuss measurement geometry, transmission coding, and estimation theory. We present initial unfocused map produced during our November 2008 campaign.

1. Introduction
Polarimetric radar studies of the Moon are useful as they provide a way of probing the sub-surface geochemical properties and the rock abundance of lunar regolith [1]. Previously such maps have been produced at wavelengths of 3.8 cm [7], 70 cm [1, 6] and 7.5 m [5]. To our knowledge, the Doppler correction ζ defined as:

\[ \zeta = \frac{\lambda t}{2} \]

where vector \( \mathbf{c} \) contains parameters \( r(t,v) \) and \( v(t,v) \) contains the measurements \( s_i \) in such a way that the forward theory matrix \( \lambda \) describes the measurements in terms of the parameters \( \mathbf{m} = \lambda \).

3. Lunar ephemers
We will use the following lunar parameters for creating a focused map:

- \( r(t,v) \): Range to lunar center of mass.
- \( x(t,v) \): Lunar sub-radar point longitude angle.
- \( y(t,v) \): Lunar sub-radar point latitude angle.
- \( \phi(t) \): Angle between sub-radar point and lunar meridian.

In the monostatic case, a point in lunar longitude and latitude coordinates \((x, y)\) has a range to observer \( t \) and the Doppler shift of lunar coordinate \( s_i \) at time instant \( t \) is given by:

\[ s_i(t,x,y) = \sum_{r,t} f_{r,t}(x,y,t) \]

Similarly, the Doppler shift of the lunar center of mass is given as:

\[ p(t) = \frac{2}{f_{\text{peak}}} \sum_{r,t} f_{r,t}(x,y,t) \]

As we have already subtracted the lunar center of mass Doppler shift \( p(t) \) in the decoding phase, we get a residual librational Doppler spread of:

\[ \omega'(t,x,y) = \frac{1}{f_{\text{peak}}} \sum_{r,t} f_{r,t}(x,y,t) \]

4. Test run
To test the feasibility of the EISCAT system for lunar studies, we have conducted several test experiments during November 2008. We used the EISCAT Tromsø UHF system in monostatic mode at full 1.5 MW peak power. The coded transmission pulses were 200-182,152 μs long with bauds between 1-10 μs. The duty cycle was between 2-11%, with inter-pulse intervals carefully selected so that the lunar echoes would fit between transmission slots during the whole experiment. The echos were obtained from the NASA JPL’s Lunar system.

We sampled our data at 4 MHz using a Universal Software Radio Peripheral (USRP) and stored the 16-bits per sample raw voltage data to disk in baseband – all processing was done off-line to this data, so no modifications to the EISCAT system were required. We recorded the transmission envelope from the waveguide and used it for decoding in the off-line processing, although Doppler smearing is already expected with such a long integration time.

We used several different transmission codes with baud-lengths ranging from 1 μs to 10 μs. The codes were Kroenkeuer product (i.e., sub-pulse coded) codes derived from the 13-bit Barker code or an optimal sub-sequence of such a code.

5. Future Work
We have demonstrated the feasibility of creating a high-resolution 32-cm lunar map with the EISCAT UHF radar. We plan to continue the work to:

- Produce a full focused map using both same and opposite sense circular polarization
- Compare results to other measurements at different wavelengths
- Investigate the possibility of long baseline interferometric measurements using the EISCAT system
- Clock error recovery using lunar backscatter texture characteristics

References