**A SIMPLISTIC APPROACH TO MODEL RADAR BACKSCATTER FROM LUNAR REGOLITH.** Dharmendra Pandey, Sriram Saran, Anup Das and Manab Chakraborty, Space Applications Centre (ISRO), Ahmedabad, India-380015 (dkp@sac.isro.gov.in)

**Introduction:** Two orbital polarimetric synthetic aperture radars, the Chandrayaan-1 Mini-SAR (S-band) and the Lunar Reconnaissance Orbiter (LRO) Mini-RF (S and X-band), have imaged almost all regions of the Moon [1, 2]. Most of these regions are not visible from Earth-based radar observatories such as the Arecibo radar and Green Bank Telescopes. The high-quality scientific data returned from these radars require that we understand the radar backscattering characteristics of the lunar regolith sufficiently well to understand its physical properties. For this, we have implemented a parameterized model based on Integral equation method (IEM) for rough surface scattering [3] which gives a quantitative relationship between radar backscatter and the physical properties of the regolith layer. Here, we present a general description of our two-layer scattering model and some initial simulation results obtained.

**Model Description:** Our theoretical scattering model has been parameterized and simulated based on IEM for rough surface as a function of incident angle, regolith thickness, surface and subsurface roughness, abundance of buried rocks and $FeO+TiO_2$ content in regolith to calculate radar wave scattering and penetration at the top and bottom rough interfaces. The scattering mechanisms that influence the lunar backscatter include surface scattering from the top rough surface ($\sigma^0_{\mathbf{surface}}$), subsurface scattering from the bottom rough interface ($\sigma^0_{\mathbf{subsurface}}$), volume scattering from buried inclusion ($\sigma^0_{\mathbf{volume}}$), scattering at the lower interface followed by scattering from an inclusion ($\sigma^0_{\mathbf{subsurface\text{-}volume}}$) and scattering from a single inclusion followed by scattering at the base of the regolith ($\sigma^0_{\mathbf{volume\text{-}subsurface}}$) [4]. A simplified model of the lunar regolith that consists of a homogenous fine-grained layer of thickness'd' with embedded inclusions and with rough surface/subsurface layers is shown in Fig.1. Embedded inclusions were referred to as rocks. The complex dielectric permittivity of the regolith, buried inclusions and the underlying bedrock are indicated by $\varepsilon_1$, $\varepsilon_2$, and $\varepsilon_3$ respectively. The roughness of the surface and subsurface layers are characterized by their root mean square (RMS) height and correlation length, with $\sigma_1$ and $l_1$ for the surface and $\sigma_2$ and $l_2$ for the interface between the regolith and bedrock, respectively. For simplicity and ease of applications, the buried rock inclusions were modelled as a Rayleigh spherical scatterer. Although most scatterers are non-spherical, when they are randomly oriented and distributed within a layer, they act like spherical scatterers [3]. Considering the first-order radiative transfer solution, the total radar backscattered power can be written as

$$\sigma^o{}_{Total} = \sigma^o{}_{Surface} + \sigma^o{}_{Subsurface} + \sigma^o{}_{Volume} + \sigma^o{}_{Subsurface-Volume} + \sigma^o{}_{Volume-Subsurface}$$

this model, the component of multiple scattering among rocks was not taken into account.

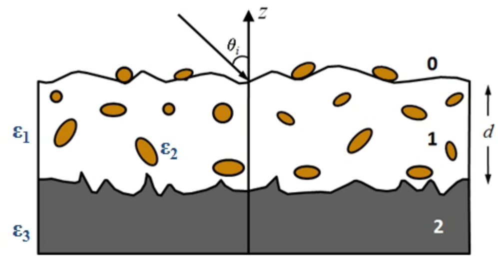


**Figure 1** Schematic diagram of the lunar surface that consists of a regolith, rocks inclusions, and underlying bedrock

**Model Validation:** As an initial approach, we have simulated the radar backscatter at S-band wavelength (12.6-cm) using our model near the Apollo 16 landing site where the regolith thickness and composition are known. Table 1 shows the various model parameters used for this study obtained from Apollo 16 landing site report.

| Parameters | Definition | Value |
|---|---|---|
| $f$ | Operating Frequency | S-Band (2380 MHz) |
| $\theta$ | Incidence angle | 49° |
| $d$ | Regolith thickness | 4 m |
| $F$ | Fractional volume of buried inclusions | 0.1 |
| $\varepsilon_{regolith}$ | Dielectric constant of lunar regolith | 2.84-j*0.003 |
| $\varepsilon_{buried\ rock}$ | Dielectric constant of underlying Bedrock | 8.0-j*0.05 |
| $\varepsilon_{rock}$ | Dielectric constant of Buried rock inclusions | 5.43- j*0.0084 |

**Table 1** Model parameters for simulation from Apollo-16 landing site

We have used backscatter obtained from the hybrid polarimetric [1, 5] Mini-RF data to validate our results. Even though our model employs backscatter returned from a fully polarimetric radar, we utilized the Mini-RF total backscattered power ($S_1$) for validation. Since it has been shown that Stokes parameters derived from fully polarimetric SAR data for circularly polarized transmissions and dual linear or dual circular received polarizations are essentially identical [1], we followed this approach. From the Mini-RF data, $S_1$ can be calculated as shown in [1]. The simulated backscatter from our model was compared with the mean $S_1$ value obtained from a Mini-RF image of the same region (Fig. 2). We have also obtained the surface RMS slope of the landing site region using data from LOLA [6] of the LRO.

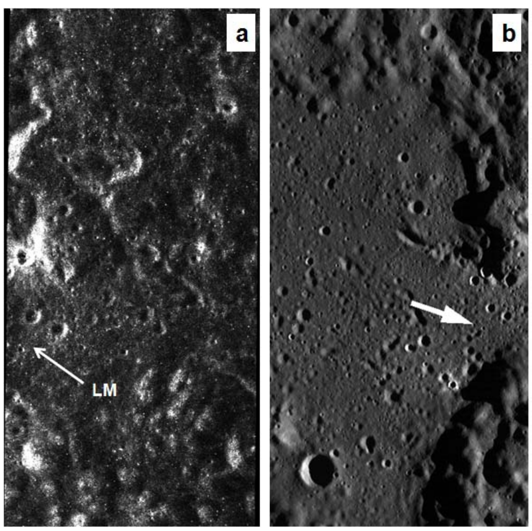


**Figure 2** Part of (a) Mini-RF total backscattered power ($S_0$) image and (b) LROC WAC image of the Apollo 16 landing site region. Arrows point out the location of LM.

**Results:** Figure 3 shows simulated backscatter vs. the surface RMS slope which implies that at the Mini-RF incidence angle, effect of slope on backscatter is almost negligible near the landing site. The mean backscatter obtained from the $S_1$ image near the Apollo 16 landing site was -10.453 ± 0.7 dB, agreeing closely with the simulated results.

**Conclusions**: With the radar scattering model implemented in this study, a significant range of lunar surface and subsurface properties can be studied quantitatively, such as lunar surface roughness, subsurface rock abundance, regolith thickness, and regolith dielectric properties. After further validation, we plan to invert the regolith physical properties like dielectric constant, regolith thickness and buried rock volume fraction using the Mini-RF backscatter observed at several regions over the Moon surface. From these estimated parameters it will be possible to address several important lunar issues like: global inversion for the regolith thickness, composition and distribution of pyroclastic deposits, lunar swirls and impact melts, etc. Further validation of our model using ground data from the remaining Apollo landing sites is in progress. We intend to extend our work by including multiple scattering from buried rocks into our model, at different frequencies and polarizations.

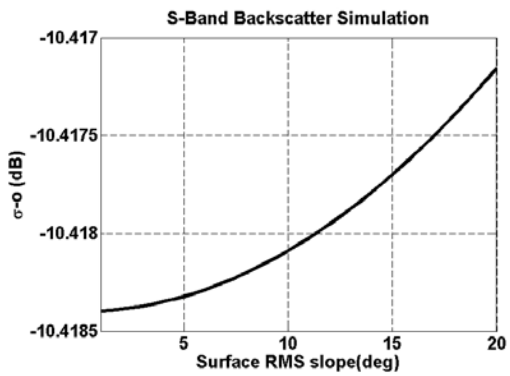


**Figure 3** Radar backscatter at S-band simulated from the model

**References:** [1] Raney R.K. et al. (2011) *Proc. IEEE, 99 (5),* 808–823. [2] Cahill. et al. (2012) *LPS XLIII*, Abstract #2590. [3] Fung A. K. (1994) *Artech House, Boston.* [4] Fa W. et al. (2011) *JGR, 116, E03005*. [5] Raney R. K. (2007) *IEEE Trans.Geosci. & Remote sens., 45 (11),* 3397-3404. [6] Smith D.E. et al. (2010) *GRL, 37, L18204*.