**SIMULATED LUNAR BRIGHTNESS TEMPERATURE IN L- AND S- BAND AND REGOLITH THICKNESS ESTIMATION USING AN INDEX-BASED APPROACH.** Vijayan S., Shiv Mohan and S.V.S. Murty, PLANEX, Physical Research Laboratory, Ahmedabad 380 009, India. (vijayan@prl.res.in)

**Introduction:** Lunar regolith, a mixture of fine and coarse grained fragmented material is spread across the lunar surface and almost completely covers the underlying bedrock. The estimated regolith thickness distribution is 4-5m for the mare region and 12-15m for the highland region [1]. The regolith had undergone continuous bombardment by small and large impactors, which significantly increased its bulk density below the surface. Using the passive microwave remote sensing, the distribution and cover of regolith below the lunar surface can be estimated better than any other orbiter based data. The penetrating capability of passive microwave signals help to explore the regolith distribution over the lunar surface and gives a global scenario of regolith distribution. In this study, the passive microwave brightness temperatures are simulated at L (1.25GHz) and S (2.1GHz) band with varying physical parameters. A model based on brightness temperature index is evolved for inverting the regolith depth. The regolith thickness is estimated and compared with the Apollo landing site locations.

**Simulating brightness temperature and regolith inversion:** To understand the thermo-physical properties of the lunar regolith, a three layer model has been proposed. The top layer consists of thin soil cover, which has a high insulating property, the middle layer consists of regolith, which has the conductive property and the bottom layer is the rock stratum below the regolith cover. The lower frequencies (L- and S-band) are chosen for this simulation, because of their higher penetrating capability. The lunar physical properties like depth, dielectric permittivity, bulk density, temperature, $FeO+TiO_2$ (ilmenite) content are varied accordingly to simulate various lunar surface conditions and the brightness temperature ($T_B$) is derived from equation given by [2]

$$T_B = (1-r_{01})(1-e^{-\alpha_1 \upsilon d_1})(1+r_{12}e^{-\alpha_1 \upsilon d_1})\,T_1 + (1-r_{01})(1-r_{12})(1-e^{-\alpha_2 \upsilon d_2})(1+r_{23}e^{-\alpha_2 \upsilon d_2})\,e^{\alpha_1 \upsilon d_1}\,T_2 + (1-r_{01})(1-r_{12})(1-r_{23})\,e^{\alpha_1 \upsilon d_1}\,e^{\alpha_2 \upsilon d_2}\,T_3$$

(r -Fresnel coefficient, alpha - loss tangent, T - temperature of the layer). The simulated Tb is fed as an input to the inversion algorithm, to retrieve the regolith thickness. In this study, two inversion algorithms (one from [2] and other this study) are modeled and compared for their retrieval accuracy. The first inversion model is from [2,3] and the regolith depth is inversion from equation given as

$$\text{depth} = -\frac{1}{2\alpha_2 \nu}\ln\left(\frac{1-T'_B}{r_{23}}\right)$$

For this model [2], the depth retrieval process was entirely recreated to suite the current frequencies used in this study. The second inversion model uses an index-based approach to retrieve the regolith thickness. The retrieval of regolith thickness is highly dependent on $FeO+TiO_2$ content, loss tangent, bulk density and dielectric permittivity. The $FeO+TiO_2$ distribution over the lunar surface is obtained from [4]. However, the other parameters are not available except for the Apollo landing sites. Thus, to retrieve the regolith depth using these known parameters this index based approach has been proposed in this work. An empirical relationship is derived from the known parameters using this index-based model and then it will be extended to unknown locations to retrieve the regolith thickness. The regolith depth index inversion approach takes following variable as input:

$$\textit{regolith depth index} = \frac{T_{BS} - T_{BL}}{T_{BS} + T_{BL}}$$

where, $T_{BS}$ and $T_{BL}$ represent the simulated S- and L-band brightness temperatures. The use of two lower frequency channels leads to estimate the regolith thickness better than the single lower frequency channel. The index-based model-1 takes ilmenite content as external input and their results are discussed, whereas model-2 takes all physical parameters into consideration which is still in progress.

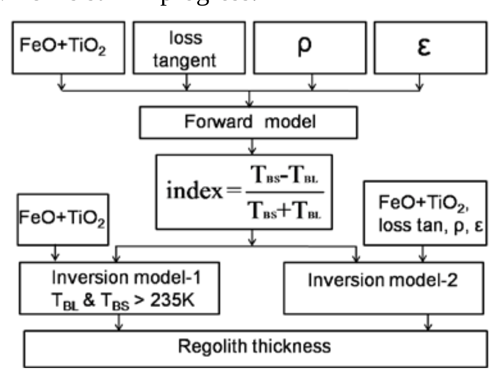


**Fig. 1.** Brightness temperature depth index model to estimate regolith thickness

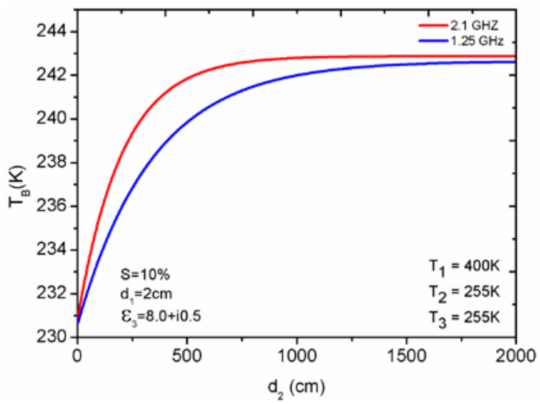


**Fig. 2.** Simulated brightness temperature for L- and S-band with $\varepsilon_2$=2.5+j0.01.

**Results:** Fig. 2. shows the simulated brightness temperature for day time temperature (400K) and for an ilmenite content assumed as 10%. The L-band shows relatively higher penetration than the S-band, whereas, $T_B$ is higher for S-band and vice versa. To validate the two inversion approaches ([2] and index-model-1), the brightness temperature is simulated for all the six Apollo landing locations [5]. The simulated $T_B$ is given as the input for the retrieval algorithm for regolith thickness estimation. Comparison to these sites will help in fine tuning the simulation to non-Apollo regions, where the regolith depth can be inverted using the proposed index based regolith inversion model.

The inversion model from [2] is applied for Apollo locations for the L- and S-band and their retrieved depths are given in Table 1. The highland site (Apollo 16) shows a higher regolith depth in the retrieval process, in accordance with earlier estimates [1].

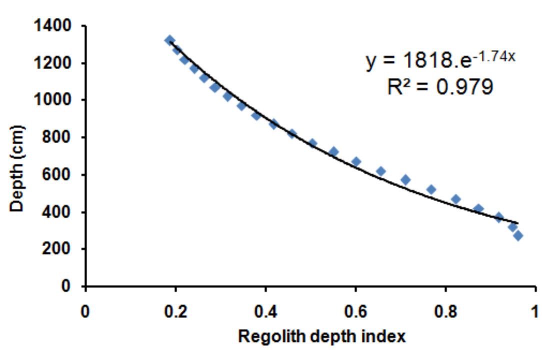


**Fig. 3.** Regolith depth index approach for estimating regolith thickness using model-1 for S=10%.

**Table 1. Regolith thickness estimation**

| Apollo | L-band (~m) | S-band (~m) | Depth Index_ Apollo | Depth Index_ Model-1 | Depth (m) [5] |
|---|---|---|---|---|---|
| A11 | 4 | 2 | 4 | 4 | 4-5 |
| A12 | 6 | 3 | 7 | 5 | 4-5 |
| A14 | 6 | 3 | 7 | 10 | 4-5 |
| A15 | 4 | 2 | 5 | 7 | 4-5 |
| A16 | 11 | 5 | 14 | 14 | 10-15 |
| A17 | 3 | 1 | 4 | 4 | 4-5 |

Fig. 3 shows the derived index-based empirical relationship from combining the L- and S-band for regolith retrieval. The index-based inversion approach carried out separately for the six Apollo locations (considered ground truth values) and the generalized model uses a model value of dielectric permittivity ($\varepsilon_2$) as 2.5+j0.01 and bulk density of 1.5g/cm$^3$, where the ilmenite content (S) varied from 5 to 30 wt%. Increase in ilmenite content is clearly reflected as a decrease in the penetration depth. In addition to this, the inversion from model-1 is carried out when the $T_{BL}$ and $T_{BS}$ > 235K. The regolith thickness values for both the process are given in Table 1 as Index_Apollo and Index_Model-1. The thickness derived from all the models are in agreement with few meter difference. Such variations are caused due to the difference in the physical parameters considered in the simulation.

**Discussion:** In this study, we have used a three layer model for simulating $T_B$ at L- and S-band. The forward model has been developed for understanding the variability of $T_B$ due to various physical and electrical properties of regolith. Based on the forward model, the inversion model-1 was carried out by deriving a new parameter called $T_B$ depth index. The regolith depth index has been used for inverting the regolith depth for all the Apollo landing sites. Model- 1 clearly brings out the effect of ilmenite on the regolith depth. Further it is planned to extend to model- 2, where all possible conditions and parameters will be taken care. This regolith depth index model can be used to generalize the regolith retrieval process to other regions on the Moon.

**References:** [1] Mckay, D., et al.(1991) *Cambridge Univ. Press.* [2] Fa, W. and Jin, Y.Q. (2007) *JGR*, 112, E05003. [3] Fa, W. and Jin, Y.Q. (2010) *ICARUS*, 207,605-615. [4] Lucey, P.G. et al., (2000) *JGR*, 105, 297- 305. [5] Heiken, G.H., et al. (1991), *Cambridge Univ. press*.