

# ANALYSIS OF DIELECTRIC CONSTANT & DENSITY OF APOLLO 17 SAMPLES

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## Abstract

Campbell's inversion model works for Dielectric Constant (DC) estimation when radar measurements are made in fully polarimetric mode over rock-poor dust surface. For studying the electrical behavior of lunar surface, there is a need of appropriate model for dielectric constant estimation which can be applied over hybrid polarimetric data obtained from Mini-RF. This will greatly help in identifying landing sites for future exploration, in locating potential resources, in describing the moon's radiation environment and in demonstrating new technologies. In this paper, Campbell's inversion model is applied over hybrid polarimetric data (from Mini-RF) for analyzing DC. In order to check its applicability, Apollo 17 landing site is selected as study area, since ground truth DC values of Apollo samples are available in literature. In this paper, DC values are estimated using Campbell's inversion model compared with available DC values ( $\epsilon'_m$ ) of Apollo17 in literature. For further validation of model,  $\epsilon'$  results are also compared with DC values of the terrestrial analogue of lunar soil ( $\epsilon'_{TALS}$ ), which are obtained at ICRS laboratory. Other parameters like Density ( $\rho$ ), loss factor ( $\epsilon''$ ) are calculated using  $\epsilon'$  values. The calculated results are found in good agreement with the results available in literature. From these results, it can be concluded that Campbell model is applicable over hybrid polarimetric data and it can also be applied over lunar equatorial region.

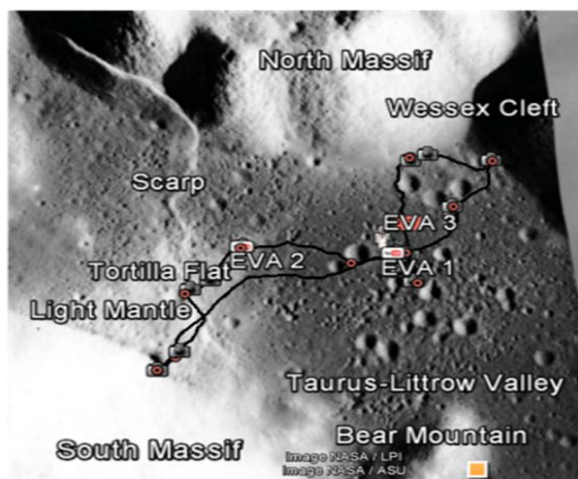
Keywords: Apollo Samples, TALS, Mini-RF, Dielectric Constant, Density.

## Introduction

The lunar regolith [1] is different from terrestrial materials. Continuous meteoroid impact has converted the lunar surface materials into well graded silty sand that has reached a "steady state" in thickness, particle size distribution, and other properties at most locations on the Moon.

## Apollo 17 Landing Site

The last Apollo Manned Mission [2] landed at Taurus-Littrow 20.19° N, 30.77° E to explore and sample the materials and surface features. In situ Soil and rocks from the floor of Taurus-Littrow Valley were mostly mare basalts. Varieties of very old rocks were also collected from the mountains in the north and south of the landing site [3]. Figure 1 shows the path traversed by Apollo 17.



Courtesy: Image NASA/LPI

**Fig1:** Shows the optical image of the Apollo 17 landing site from Google earth

In-situ observations indicate that few rare Apollo 17 basalts have very low titanium abundances and thickness of basalt layer is between 1.0 and 1.4 kilometers near the landing site [3]. Some of the rocks, known as impact melts, were melted by the heat of a very large impact event while other rocks include Norite, Troctolite, and Dunite etc. It gives the detailed information about the physical, electrical and chemical composition of lunar samples.

## Electrical Parameter

Electrical properties [4, 5] of a material are influenced by temperature, mineral content, grain size, moisture, density, frequency etc. DC is one of the important electrical parameter of the lunar surface and provides basic data necessary for further exploration. It can be calculated at microwave frequencies using scattering coefficient  $\sigma^{\circ}$  (from Mini-RF). Knowledge of parameters like storage and loss factor is of importance because by using DC, one can estimate emission, absorption and transmission parameters of a material to understand dielectric properties of media that interact with EM waves [5]. The dielectric constant is given by the relationship:

$$\epsilon = \epsilon' - j\epsilon'' \quad (1)$$

$$\epsilon'' = \epsilon' * 10^{(0.440 - \rho - 2.943)} \quad (2)$$

Where

$\epsilon'$  = storage factor which indicates how much energy has been reflected and how much energy is transmitted into it

$\epsilon''$  = loss factor [6] which measures how much energy is lost from the field and absorbed in the material which is converted into energy.  
 $\rho$  = density ( $\text{g/cm}^3$ ).

## Density

The bulk density ( $\rho$ ) [7] of soil is defined as a mass of a material contained within a given volume. The bulk density of the lunar surface increases rapidly up to a depth of 10 cm, then more gradually up to a depth of 100 cm. The density of a typical lunar soil particle or lunar rock is about  $3.1 \text{ g/cm}^3$ . The Apollo drive core tubes and drill cores have given us unambiguous measurements of in situ bulk density. According to equation (2), bulk density is an input parameter, in addition to  $\epsilon'$ , to calculate loss factor ( $\epsilon''$ ) [6]. Equation (3) gives the relationship between density and storage factor

$$\epsilon' = 1.919 \rho \quad (3)$$

## Data Used

NASA's Lunar Reconnaissance Orbiter (LRO) has returned its first RADAR [8] (Mini-RF) imagery of the Apollo moon landing sites. Mini-RF datasets with  $7.5 \text{ m/pixel}$  [9] are used to calculate Dielectric Constant over Apollo 17 landing site. In this paper, DC values of samples [6] are calculated using SAR data using Campbell's inversion model and these results are compared with the in-situ DC values available for Apollo 17 samples and with the DC values of Terrestrial Analogue of Lunar Soil (TALS) JSC-1A [10] estimated in ICRS Lab to check the applicability of model over lunar surface.



**Fig 2: Apollo TALS sample JSC-1A at ICRS Laboratory Model Used**

In the present paper, Campbell inversion model [11] is used for estimating dielectric constant. It works on Full-

polarimetry SAR data which uses all four polarization channels thus giving more information about various surface features [12]. This model is given in equation (2):

$$\epsilon_{\min} = \left( \sin \varphi / \sin \left[ \cos^{-1} \left( \frac{\sigma_{\text{HH}}^0}{\sigma_{\text{VV}}^0} \right)^{0.25} - \varphi \right] \right)^2 \quad (4)$$

Where,  $\varphi$  is the angle of incidence  
 $\sigma_{\text{HH}}^0$  = Horizontal backscattering coefficient  
 $\sigma_{\text{VV}}^0$  = Vertical backscattering coefficient

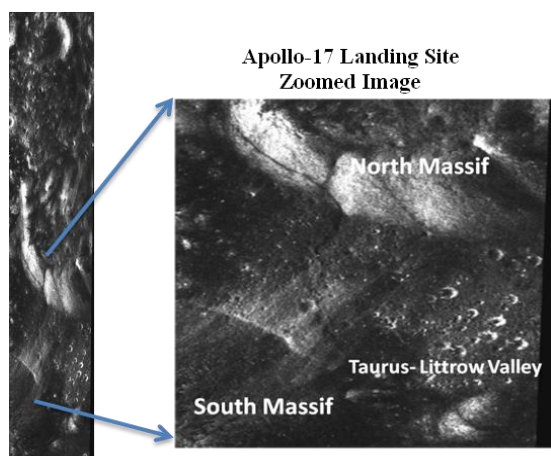
The Equation (4) shows Campbell Model's applicability to the fully polarimetric mode. This model was developed based on the relationship between measured radar backscatter and dielectric constant over Mars analogue environments on Earth. This model works for rock-poor dust surface and when radar measurements are made in linear horizontal and vertical polarizations.

Mini-RF is working in the hybrid polarimetric mode and in the literature no such models are available which can be used for estimating DC from Mini-RF data over hybrid polarimetric mode. In hybrid Polarimetry mode, transmitted polarization is either right circular or left circular with  $90^\circ$  phase angle between vertical and horizontal components and the ellipticity  $\chi = \pm 45^\circ$  or linearly polarized with an orientation angle of  $\chi = 45^\circ$  and both vertical and horizontal polarizations are received simultaneously [12]. Here authors have tried to validate the model for hybrid polarimetric data. Encouraging results are obtained when modeled data are compared with insitu results of Apollo samples and results of Terrestrial Analogue of Lunar Soil (TALS) JSC-1A obtained in ICRS laboratory.

## Analysis and Results

For analysis Mini-RF dataset in zoom mode `lsz_02595_2cd_eku_17n031_v1.img` with resolution of  $7.5 \text{ m/pixel}$  is used. Figure 3 shows Apollo 17 landing site over radar data.

Data strip is processed in ISIS3 software in order to get landing site coordinates over radar data. The Dielectric Constant values over Apollo 17 site are calculated using equation (1) with Mini-RF data. The calculated  $\epsilon'$  is then compared with ground truth Apollo 17 results. These DC results are summarized in the Table 1.



**Fig 3:** Shows the Radar image of the Apollo 17 landing site obtained from Mini-RF data in zoom mode `lsz_02595_2cd_eku_17n031_v1.img` with resolution of 7.4m/pixel. The image has been marked with major features.

**Table 1:** Comparison of DC from Campbell Model and Apollo 17 Ground based Results

Apollo 17 traversed path	Ground based Apollo Results		DC from Campbell
	Sample no.	DC	
Boulder	72441	3.12	3.16
Camelot Crater	75080/81	2.40	2.46
Near to Trident crater	75080/81	3.50	3.32
Shorty crater	74220	2.60	2.11
Shorty crater	74241	2.20	2.10

**Table 2:** In this table the measured DC of Terrestrial Analogue of Lunar Soil (TALS) that was measured at room temperature at ICRS is given for comparison with the estimated values of DC using Campbell and Apollo 17 samples that were brought from the landing site.

Temp. (°C)	DC from Apollo-17 Returned Samples (avg.)	DC from Campbell model using Mini-RF data (avg.)	Data obtained from ICRS Measurement of TALS 23°C (1.8 g/cm <sup>3</sup> )
23	2.764	2.629	3.61–4.22

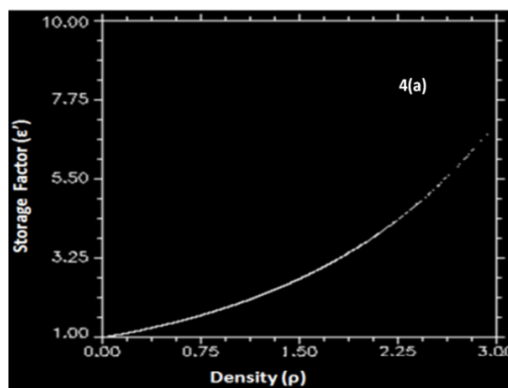
Results show that  $\epsilon'$  values are almost equal to the  $\epsilon'_m$  values of Apollo 17 samples and  $\epsilon'$  values of TALS, as shown in Table 2. Similarly other important parameters like loss factor and density are also calculated and compared with available values for Apollo17 in literature. By comparison, it is observed that the results are nearly equal. However, slight differences observed between the calculated and measured values is due to fact that the ground based results were ob-

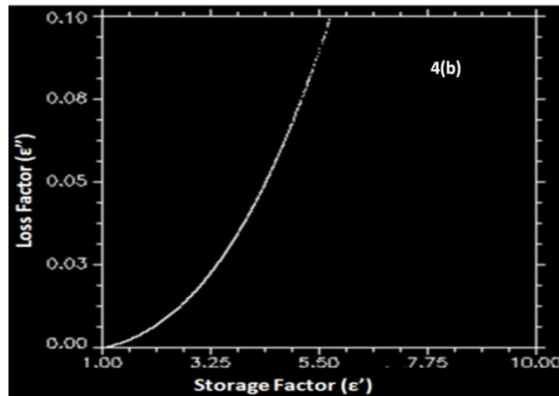
tained using particular amount of actual lunar soil sample at Apollo 17 site while the calculated results are obtained using radar data over 7.4m / pixel area, which is actually the average of DC values of the area covered under one pixel. These results are tabulated in Table 3.

**Table 3:** Comparison of Density ( $\rho$ ) and Loss Factor ( $\epsilon''$ ) from DC and Apollo 17 Ground based Results

Ground based Apollo Results			Calculated values using Model	
Sample no.	Density (g/cm <sup>3</sup> )	Loss Factor	Density (g/cm <sup>3</sup> )	Loss Factor
72441	1.8	.005	1.76	0.021
75080/81	2.08	.018	1.38	0.024
75080/81	1.9	.010	1.84	0.011
74220	1.37	.019	1.14	0.007
74241	1.38	0.10	1.14	0.007

All the soil samples mentioned in Table 3 are basically formed due to meteorite impact process [3]. Different Sample locations with their corresponding sample no. and value of storage factor are listed in Table 1. Thus, applicability of Campbell model is validated by comparing model results with the results obtained from laboratory experiments considering typical bulk density soil as 1.8 g/cm<sup>3</sup>. Figure 4 (a) shows relationship between permittivity ( $\epsilon'$ , storage factor) and density of lunar soil sample collected at Apollo 17 landing site. A scatter plot of real ( $\epsilon'$ ) and imaginary ( $\epsilon''$ ) parts of DC is shown in figure 4(b). The simple relationship shown in the figure holds for silicates and oxides with a few exceptions such as titanates [13].





**Fig 4:** Shows the relationship between (a) Real part of DC ( $\epsilon'$ ) and density ( $\rho$ ) (b) gives the scatter plot between real and imaginary part of DC.

## Conclusion

The analysis has been carried out over lunar equatorial region. DC ( $\epsilon'$ ) values have been calculated using Campbell's model and validated over Apollo sites using DC of Apollo samples obtained from available literature. Further,  $\epsilon_m$  has been compared with the measured  $\epsilon_{TALS}$  i.e. the measured dielectric constant of Terrestrial Analogue of LUNAR soil at ICRS laboratory. Comparison of terrestrial analogues of lunar soil and with Apollo sample will help in study of rocks and soil which were formed under extraterrestrial environments and to provide the basic data necessary for planning future exploration of the moon. Comparison illustrates that the results are nearly similar and Campbell model can be applied over hybrid polarimetric data. For future work this model can be applied over other Apollo sites and results can be also validated and compared with measured DC of TALS.

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