Using Multipath Interference to Probe Subsurface Soil Properties on Mars and Beyond

By

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Dedication

In loving memory of my mother, who always encouraged me to reach for the stars.

Ad Astra

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List of Acronyms

AU	Astronomical unit, 149 597 870 700 m
CAD	Computer Aided Design
DSN	Deep Space Network
DSS	Deep Space Station
DTE	Direct to Earth
EDL	Entry, Descent and Landing
EM	Electromagnetic
ESA	European Space Agency
GDSCC	Goldstone Deep Space Communications Complex
GNSS	Global Navigation Satellite Systems
GNSS-R	Global Navigation Satellite Systems Reflectometry
GPR	Ground Penetrating Radar
H-pol	Horizontal Polarization
HGA	High Gain Antenna
JPL	Jet Propulsion Laboratory
Ka-band	Region of the EM spectrum from 26.5 – 40.0 GHz
Ku-band	Region of the EM spectrum from 12.0 – 18.0 GHz
L-band	Region of the EM spectrum from 1.0 – 2.0 GHz
LGA	Low Gain Antenna
LHCP	Left Hand Circular Polarization
LIDAR	Light Detection and Ranging

LTST	Local true solar time
MARRSI	Mars Radar and Radiometry Subsurface Investigation
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MER	Mars Exploration Rover
MGA	Medium Gain Antenna
MGS	Mars Global Surveyor
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MY	Martian year, starting from the northern Spring equinox of April 11, 1955
NASA	National Aeronautics and Space Administration
PDS	Planetary Data System
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per thousand
pr-μm	Precipitable micrometer
PWC	Precipitable water content
RADAR	Radio Detecting and Ranging
RH	Relative humidity
RHCP	Right Hand Circular Polarization
RIMFAX	Radar Imager for Mars Subsurface Experiment
RSL	Recurring Slope Lineae
SHARAD	Shallow Radar sounder aboard the Mars Reconnaissance Orbiter
SDST	Small Deep Space Transponder
Sol	Martian solar day

STK	Satellite or Systems Tool Kit
UTC	Coordinated Universal Time
UHF	Ultra High Frequency, Region of the EM spectrum from 300 MHz – 3.0 GHz
VHF	Very High Frequency, Region of the EM spectrum from 30 MHz – 300 MHz
V-pol	Vertical Polarization
X-band	Region of the EM spectrum from 8.0 – 12.0 GHz

Abstract

Global Navigation Satellite Systems Reflectometry (GNSS-R) has shown that multipath interference signals offer an opportunity for passive devices to make measurements of the soil moisture, snow pack depth, and other quantities of scientific interest here on Earth. We expand upon this technique and propose that X-band microwave telecom signals can similarly be used to infer the sub-surface dielectric profile of the Earth, Mars, and other planetary bodies. The dielectric profile may reveal changes in the soil water content, the depth of a layer of sand, thickness of a layer of ice, and identify a subsurface layer of brine. We have created a numerical ray-tracing model to understand the potential of different microwave frequencies to probe the subsurface, to understand the trade between different polarizations, and to understand the sensitivity to changes in incidence angle and surface roughness features. This model has been validated through laboratory experiments using controlled layered beds of sand and bedrock. And finally, the model is used to extrapolate how this technique may be applied to future Mars missions.

Here we present new results demonstrating how to characterize a multipath interference pattern as a function of frequency and/or incidence angle to measure the thickness of a dielectric layer of sand or ice. Our results demonstrate that dielectric discontinuities in the subsurface can

be measured using X-band bistatic radar to effectively measure the thickness of a dielectric layer in the proximity of a landed spacecraft. In the case of an orbiter, we believe this technique would be effective at measuring the seasonal thickness of CO_2 ice in the polar regions and potentially identify the presence of brines underneath that ice. This is exciting because our method can produce results similar to traditional ground penetrating radar without the need to have an active radar transmitter onboard the spacecraft. It is possible that future telecommunications systems can serve as both a radio and a scientific instrument, thereby reducing the mass and power required for future interplanetary missions.