Measurement of Martian Soil Electromagnetic Absorption Cross Section from 800 MHz to 6 GHz for future Mars Cellular Telecommunication systems

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***Abstract*— In recent years, the colonization of the planet Mars has increasingly become a topic of discussion because of the many scientific and technological issues that such a challenge demands. Among all, it must be considered that the Martian soil has chemical composition different from the Earth's, so the atmosphere of Mars is also different. An open question is therefore to understand how suitable the Martian environment can be for the terrestrial TLC systems which are daily used, or whether it is necessary to study alternative stable systems on Mars, in particular of a different type from the conventional cellular systems installed on Earth. The electromagnetic fields used in mobile phone systems are subject to absorption and scattering by all the materials constituting the planet's surface as well as by all man-made objects. In this paper an experimental evaluation of the absorption cross section of a reproduction of Martian soil is carried out considering both the chemical composition of the soil itself and the Martian environment.**

Keywords—Mars, absorption cross section, EM field, Martian environment

I. INTRODUCTION

The electromagnetic fields used in mobile phone systems on Earth are subject to absorption and scattering by all the materials constituting the planet's surface as well as by all man-made objects such as houses, roads, vehicles, etc. In particular, the Earth's soil in its different configurations gives rise to a more or less known behavior towards electromagnetic fields depending on their wavelengths. One of the main problems with mobile TLC radio systems is the signal-to-noise ratio: as well known, such parameter depends on various factors, including the type of fading, which is influenced by the absorption and the reflection of the ground.

On Mars, the soil contains metallic components that are different from what is found in typical terrestrial soil; moreover, the dust that mostly covers the planet is widespread and contains iron oxide as well as other metallic chemical elements. One question that may therefore arise is how the Martian soil is able to modify the absorption and scattering of electromagnetic fields at the frequencies used by the main terrestrial cellular telephone systems.

This study considers various types of Martian soil conformation reproduced on the basis of literature data [1,2]. The electromagnetic measurement of the absorption cross section (ACS) is carried out inside a reverberation chamber, which is a fine-tuned facility able to simulate the space environment in terms of temperature and atmosphere as well as the related EM chaotic propagation. The ACS of an object is defined as the ratio of the power that is dissipated inside the object itself to the power density of the incident plane wave. By means of antennas placed inside the chamber and connected to a vector network analyzer, it is possible to measure the ACS of various types of Martian soil reproduced in volumes about 300 mm wide and 50 mm high. The ACS measurements obtained are compared with the properties of some typical terrestrial soil types: the comparison shows that the Martian soil tends to absorb and reflect electromagnetic fields in a different way from what occurs on Earth. It is therefore concluded that the effects of the surrounding environment on the electromagnetic propagation must be strictly considered in order to design efficiently mobile TLC systems operating on Mars.

II. EXPERIMENTAL ACTIVITY

A. Martian Soil Simulation

The term Martian soil typically refers to the finer fraction of the regolith-like sandy ground present on the surface of the "Red Planet" [1]. Its properties can differ significantly from those of terrestrial soil, including its toxicity due to the presence of perchlorates. So far, no samples have been returned to Earth (that is the goal of a Mars return mission), but the soil has been studied remotely with the use of Mars rovers and orbiters ([1], Fig. 1).

Martian dust generally connotes even finer materials than Martian soil, with fractions less than about 60 micrometers in diameter [3]. Disagreement over the significance of soil's definition arises due to the lack of an integrated concept of soil in the literature. The pragmatic definition "medium for plant growth" has been commonly adopted in the planetary science community, but a more complex definition describes the concept of soil as "(bio)geochemically/physically altered material at the surface of a planetary body that encompasses superficial extraterrestrial telluric deposits". Such definition emphasizes that soil is a body that retains information about its environmental history and that does not need the presence of life to form [1].

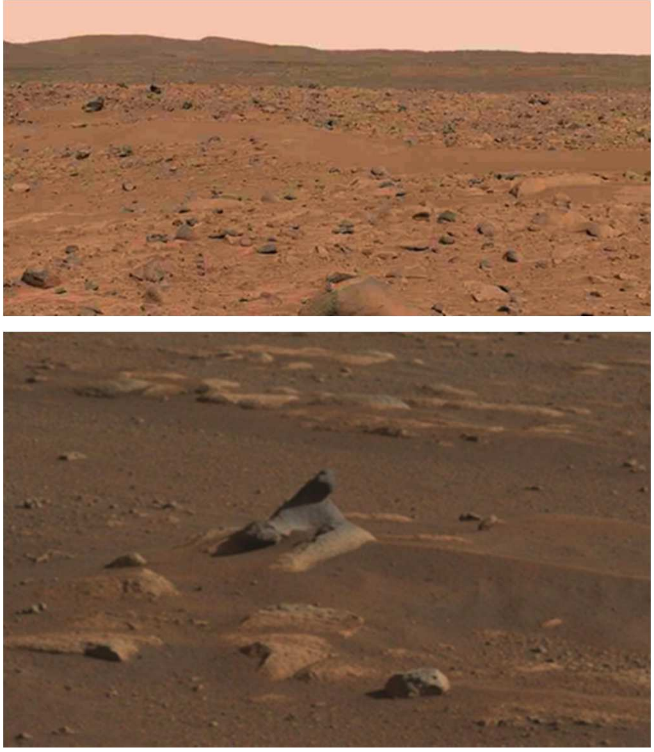

Fig. 1. Images from Mars surface. Above: Mars Exploration Rover Spirit, NASA March 18, 2004. Below: NASA's Perseverance images, 2021.

In this work, a common material known as "Pozzolana" is used as basic constituent to simulate Mars soil. Pozzolana is the merchandise term used to indicate dissolved pyroclastic materials, with granulometry variable from silt to sand, with gravelly inclusions of pumice and volcanic slags. They are constituted basically by reactive silicon dioxide (not less than 25wt%), aluminum oxide, and fractions of iron oxide, with negligible amount of reactive calcium oxide. Pozzolana is primarily employed in building industry, being used as type-II additive in different percentages to Portland cement for obtaining concrete composite matrix with improved thermo-chemical properties. The material used in the present work was brought from Italian volcanic Lazio region (Fig. 2), its composition is reported in Tab. I.

In order to achieve the suitable amount of iron oxide to approach the conditions of typical Martian ground [1], commercial Fe_2O_3 for civil and industrial purposes was added to the matrix by inclusions up to 30 wt% (0, 10, 20, 30%). The dispersion of Fe_2O_3 into the Pozzolana was performed by several cycles of mechanical mixing: the Pozzolana was weighted and then small quantities of Fe_2O_3 were added in a step-by-step mixing procedure until the desired percentage was reached.

This procedure allows to avoid conglomerates and therefore to reach a suitable degree of homogeneity in the final material; anyway, further analysis of granulometry will be provided in next works in order to assess how the grain size distribution may affect the measurement of EM/material interaction.

Fig. 2. "Red Pozzolana" used as basic constituent of the mix ground for martian soil reproduction.

TABLE I. CHEMICAL COMPOSITION OF THE 'RED POZZOLANA'

Component	Percentage in weight [%]
SiO_2	45 - 52%
Al_2O_3	15 - 23%
Fe_2O_3	6 - 12%
CaO	3 - 9%
MgO	1 - 4%
NaO + K_2O	3 - 13%

B. Martian Environment Simulation

The study of the electromagnetic behavior of the Martian soil cannot ignore the simulation of the environment in which future communication systems will have to operate. For this purpose, the atmosphere of Mars has been recreated inside the reverberation chamber, both in terms of atmospheric pressure and chemical composition. The pump system connected to the chamber allows to set the inner pressure in a very precise way. The pressure target was set to 6.4 mbar, accordingly to what reported in the main literature [1,2].

TABLE II. CHEMICAL COMPOSITION OF THE MARTIAN ATMOSPHERE

Component	Percentage in weight [%]
Carbon Dioxide	95.97%
Argon	1.93%
Nitrogen	1.89%
Oxygen	0.146%
Carbon Monoxide	0.0557%
Water Vapor	0.0210%
Nitrogen Oxide	0.0100%
Neon	0.00025%
Hydrogen Deuterium Oxide	0.00008%

Component	Percentage in weight [%]
Krypton	0.00003%
Xenon	0.00001%

In order to achieve an atmosphere composition as responsive as possible to Mars real environment (see Tab. II), a CO_2 gas tank was connected to the chamber air re-entry valve. The procedure to obtain an atmosphere almost completely composed of CO_2 was the following: first of all the chamber was emptied to a lower pressure value (up to around 10^{-1} mbar), then the blowing of CO_2 inside the chamber was carried out until the target pressure was reached.

C. Electromagnetic characterization

The electromagnetic characterization was performed by means of a reverberation chamber (RC), which is an environment very well suited for electromagnetic compatibility (EMC) testing and other electromagnetic investigations [4-13].

Future work will concern the possibility to relate the absorption cross section (ACS) measurements to real radar detection capability as well as to optical observation and detection. Basically, a reverberation chamber is a screened room with negligible electromagnetic energy absorption. Due to low absorption, a very high field strength can be achieved with moderate input power.

The chamber is a cavity resonator with high quality factor (Q), which represents the ratio between the EM stored energy of the cavity to the power loss within the cavity [14,15]: the spatial distribution of electrical and magnetic field strengths is thus strongly inhomogeneous (standing waves). To reduce such inhomogeneity, one or more tuners (stirrers) are used. A tuner is a structure with large metallic reflectors that can be moved to different orientations in order to achieve different boundary conditions.

The lowest usable frequency (LUF) of a reverberation chamber depends on the size of the chamber and on the tuner design; for example, small chambers have a higher LUF than large chambers. Although permittivity and permeability are intrinsic properties of the materials, the absorption properties of relatively large objects depend also on shape, volume, material type, and on the incoming wave polarization and direction of incidence. In real environment the excitation of any structure exhibits random characteristics, thus evaluating the absorption capability for a particular condition could be meaningless.

Therefore, a full characterization of EM absorption properties requires the measurement repetition using several angles of incidence and polarization. Reverberation chamber is in this context an excellent way to excite the absorbing material in a completely random way, thus overcoming the limitation of other measurement methods. The knowledge of the absorbed power allows to retrieve ACS and radar cross section (RCS) of the object under test. From a practical point of view, the ACS is recovered by measuring the Q factor variation between empty and loaded chamber condition (i.e., when the sample is inserted in).

The facility adopted for measuring the ACS of Martian soil is the “Simulatore di Ambiente Spaziale” (Space Environment Simulator - SAS) of Sapienza University of Rome, which is a big vacuum chamber for space environment simulation [16]: in particular, the SAS chamber is equipped with two cryo-pumps for LEO on-ground testing of materials, micro-satellites and scaled prototypes of assembled space structures (see Fig. 3 - SAS main characteristics and performances are listed in Tab. III). The chamber has a volume of about 5 m^3 and is of cylindrical shape. The fundamental mode resonance frequency is f_0 = 200 MHz, giving a lower usable frequency (LUF) of about $5f_0$ = 1000 MHz.

Two transmitting and receiving horn antennas are used for the characterization in the microwave range from 500 MHz to 6 GHz (Fig. 4). A vector network analyzer (VNA - Anritsu Model MS2026C) is connected to the system to measure the transmission coefficient between antennas in presence and absence of the sample in the chamber.

A vertical stirrer is placed inside the chamber: it is a Z-folded aluminum paddle which is moved in a stepped mode by a stepper motor, which assure a 1-degree resolution (Fig. 4). The number of independent positions of the stirrer can be calculated by testing the auto-correlation value of the measurements at each frequency against the threshold 1/e.

The reverberation chamber field/power can be evaluated statistically through an ensemble averaged over the stirrer rotation; therefore, the absorption cross section is obtained by averaging the quality factors Q over the established stirrer positions. A preliminary measurement result is given in the plots of Fig. 5, where the Q-factor and the ACS of the 0.5-6.0 GHz RC are reported for standard environment conditions. The full experimental findings about Earth/Mars soil comparison will be given in the ongoing work.

TABLE III. SAS OPERATING CONDITIONS

Space Environment Simulator	
Volume	4.7 m^3
Pressure	2^{-4} Pa
UV lamps power	410 mW/cm^2
Cryopanel dimensions	500 × 300 mm
Temperature range	± 150°C

Fig. 3. SAS chamber external view.

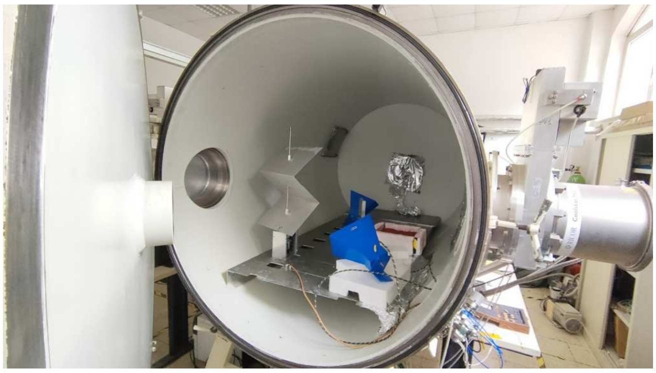

Fig. 4. SAS chamber internal view.

III. EXPERIMENTAL RESULTS AND DISCUSSION

In this section the experimental results are reported, giving Q factor and ACS values: given the highly chaotic feature of the physics involved in the analyzed phenomenon, in the reported plots the main curves are given as moving average (starting from the 'real' data, visible on underlay). First of all, the chamber characterization is shown in Fig. 5. The characterization shows off the Q factor of the chamber in different operative conditions, as air, vacuum and vacuum with CO_2 added to simulate Mars atmosphere condition. The two latest conditions have been considered in order to evaluate the effects of the CO_2 on the electromagnetic absorption process, at the same vacuum level.

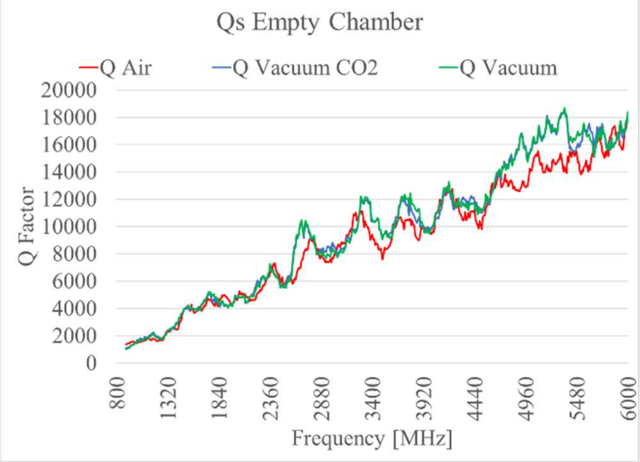

Fig. 5. SAS chamber characerization.

It can be noticed that there is a difference between the Air condition, used as a "terrestrial" reference, and the Vacuum and Vacuum plus CO_2 conditions. Especially at certain frequencies (2600 MHz, 4500 – 5100 MHz), the Q factor is higher for both the Vacuum conditions, meaning that the chamber electromagnetic reflectivity is higher for this configuration. For the rest of the measures the reference for Vacuum conditions was set to Vacuum plus CO_2.

Fig.s 6 - 9 show off the behavior of different soil configuration, where different percentages of Iron oxide have been considered. In the plots the authors considered a comparison between the measures in Air and in Martian atmosphere (p = 6.4 mbar, CO_2 added).

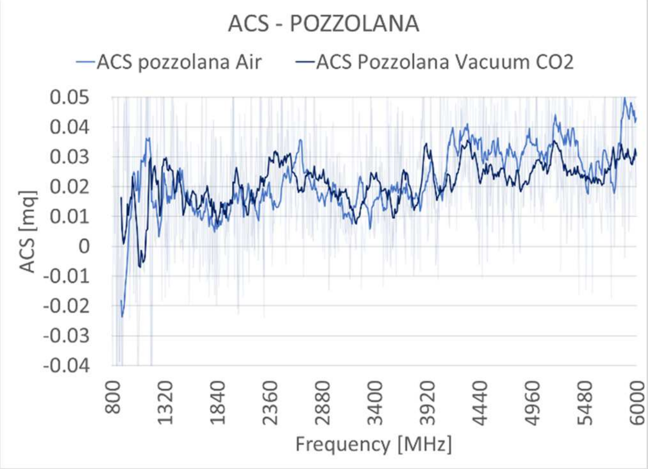

Fig. 6. ACS measures for 0% of Fe_2O_3.

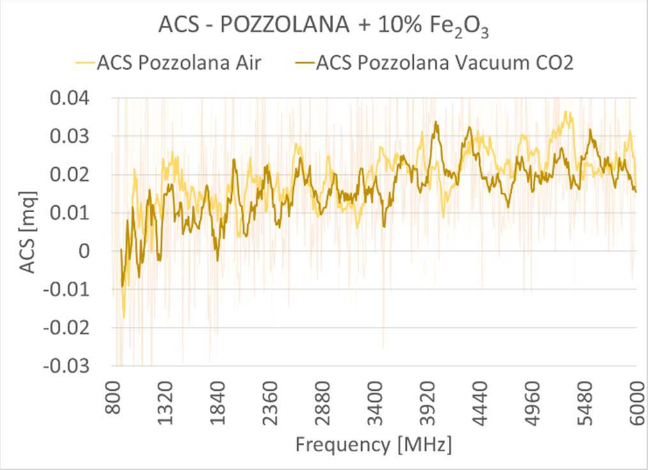

Fig. 7. ACS measures for 10% of Fe_2O_3.

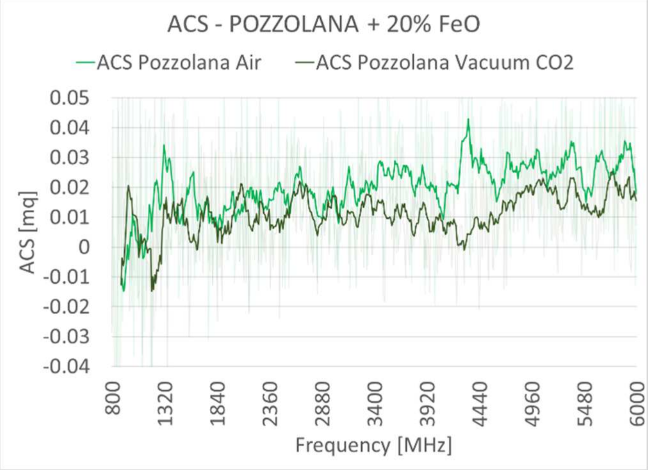

Fig. 8. ACS measures for 20% of Fe_2O_3.

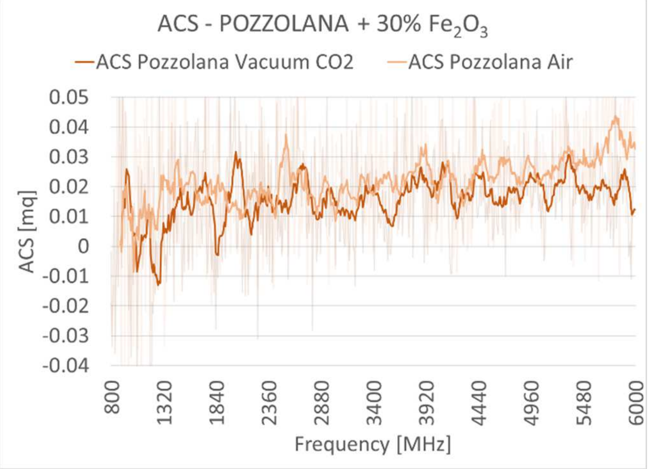

Fig. 9. ACS measures for 30% of Fe_2O_3.

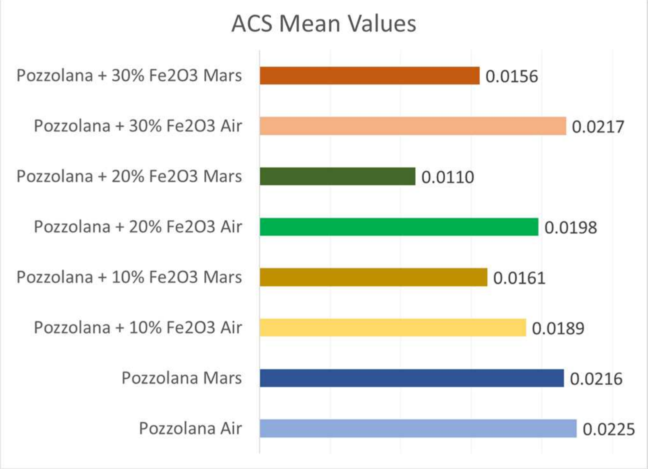

Fig. 10. ACS frequency averaged values.

A first important result is about the effects of the air on the ACS of the considered materials; the ACS, especially at certain frequencies, is higher in Earth conditions than in Mars conditions. That means that air itself absorbs a certain amount of EM field at certain frequencies, in particular the effect are well visible above 2.5 GHz. The frequencies where these effects can be easier noticed, are in particular around 3400 MHz for measures with Fe_2O_3. The same consideration can be done for frequencies from 4400 MHz to 4900 MHz for all the configurations and around 5500 MHz for 20% Fe_2O_3 and 30% Fe_2O_3 configurations. The 30% Fe_2O_3 configuration also presents an ascending trend form 5200 MHz to the end for the Air Measure.

Regarding the effects of the iron oxide, it can be noticed that the higher is the percentage, the higher is the difference between ACS in Air and in Martian Environment at higher frequencies (from 4500 MHz to 6000 MHz, for 20% Fe_2O_3 and 30% Fe_2O_3 measures). That means that for higher percentages of iron oxide, the EM absorption properties of the oxide are emphasized by the absence of Air.

In Fig. 10, the frequency averaged values of the ACS for the considered samples are shown. The main difference between Air measures and Mars Environment measures is at 20% of Fe_2O_3 with 0.0087, especially for the great difference in the central frequency range, followed by 30% of Fe_2O_3, with 0.0061, then by 10% measure with a difference of 0.0027. Pozzolana presents the lower ACS difference value with 0.0009. Moreover, the higher the percentage of Fe_2O_3, the higher is the ACS in Earth conditions. Measurements of Q, and ACS in reverberation chamber help to understand the basic properties of materials in terms of electromagnetic absorption and reflectivity. These factors in turns helps to study electromagnetic propagation in mobile telecommunication systems [17-20]. The higher the reflectivity the higher the multipath.

IV. CONCLUSIONS

In this paper, an evaluation of a Mars soil simulant EM absorption properties in the 800 MHz – 6 GHz frequency range, has been carried out by mean of Reverberation Chamber Method. Such methodology allows to measure the Absorption Cross Section (ACS) of the simulant, i.e. the ratio of the power that is dissipated inside the object itself to the power density of the incident plane wave.

The measures have been carried out inside the “Simulatore di Ambiente Spaziale” (Space Environment Simulator - SAS) of the Aerospace Systems Laboratory, DIAEE, Sapienza University of Rome, which is a big vacuum chamber for space environment simulation. Two set of measures were considered: in Air, thus considering Earth conditions, and in Martian Environment, maintaining a pressure of 6.4 mbar and insufflating CO_2 inside the Vacuum Chamber. The aim was comparing the two set of experimental findings.

The base material object of this study is the Red Pozzolana, a pyroclastic dust that well represent a basic constituent of the Martian soil. Percentages of 10, 20, 30% of Fe_2O_3 dust were added to the basic material in order to simulate different zones of the Martian soil itself, standing to the literature.

The effects of Fe_2O_3 depend on its percentage; lower percentages seem to facilitate electromagnetic reflectivity, whereas at higher percentage the electromagnetic absorption is faciltated.

The effect of the Air is quite interesting since, as clearly reported in the results section, it increases the electromagnetic absorption of the Earth atmosphere. This is probably due to its humidity and further analysis are needed. The effect of air is typically neglected in the most scenario since Atmosphere in the Earth permeate all the places where telecommunication systems are located and usually, we speak in terms of free space conditions. But this is not completely true, above all when frequency go beyond 2.5 GHz. The atmosphere and soil electromagnetic absorption are quite important points for Telecommunication, since they are able to modify the electromagnetic propagation in terms of multipath, fading and in general scattering phenomena.

In future studies, a spectroscopic analysis (Raman and infrared) will be carried out to evaluate the correspondence between the tested simulant and the simulant available on the market and between the tested simulant and studies of the Martian soil.

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