Scientific activity of Sapienza University of Rome aerospace systems laboratory on the study of lunar regolith simulants, focusing on their effect on the microwave fields propagation

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Abstract. The forthcoming space missions aiming at developing new habits on the Moon and into deep space are opening new challenges for materials scientists in enabling in-situ efficient systems and subsystems. During the last decades, Space Agencies programs of long-term missions addressed to the future Moon colonization moved the aerospace research interest toward the knowledge of how the lunar conditions could represent scientific and technological tasks to be tackled, to deal with such a big challenge. Among very many matters, a still open question is to understand how proper the lunar environment would be for TLC systems daily used on Earth, or whether it should be necessary to establish different stable systems on the Moon by finding alternative solutions with respect to the Earth conventional technologies. This paper introduces the scientific activity developed during recent years at the Aerospace Systems Laboratory of Sapienza University of Rome, concerning the study of lunar regolith with focus on its effect on the microwave fields propagation. The research addresses such task by simulating several representative Moon environmental conditions, reproducing well defined chemical/physical background in terms of atmospheric parameters and soil compositions, as from the available literature data, and analyzing the microwave propagation characteristics to design efficiently mobile TLC systems operating on the Moon. With the further objective of considering regolith as main routine resource for drawing up systems and facilities constituting lunar living structures, the analysis of regolith-microwave interaction is thus focused on two specific paths, such as building airtight structures by means of ISRU methodologies and the EM compatibility (EMC) analysis of simulated lunar environment & TLC systems design. This work can be thus considered as linked to the forthcoming projects aimed at enhancing the research community knowledge about the Moon environment, by assessing scientific background and establishing technological processes for lunar TLC systems development.

Introduction

The required degree of technical innovation will allow to achieve scientific outcomes of huge impact and industrial fallout, taking into account the utmost interest for the Moon occurring nowadays. It has to be stressed that Long Term Evolution (LTE)/4G technology promises to revolutionize lunar surface communications by delivering reliable, high data rates while containing power, size and cost. Communications will be a crucial component for NASA's Artemis program,

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which will establish a sustainable presence on the Moon by the end of the decade. Deploying the first LTE/4G communications system in space will pave the way towards sustainable human presence on the lunar surface: the network, in fact, will provide critical communication capabilities for many different data transmission applications, including vital command and control functions, remote control of lunar rovers, real-time navigation and streaming of high definition video. These communication applications are all vital to long-term mission on the lunar surface, since reliable, resilient and high-capacity communications networks will be key for supporting a sustainable human presence on the Moon. The same LTE technologies that have met the world's mobile data and voice needs for the last decade are well suited to provide mission critical and state-of-the-art connectivity and communications capabilities for any future space expedition. Commercial off-the-shelf communications technologies, particularly the standards-based fourth generation cellular technology, are mature, proven reliable and robust, easily deployable, and scalable. NASA plans to leverage these innovations for its Artemis program, which will establish sustainable operations on the Moon by the end of the decade in preparation for an expedition to Mars. Thus, the presented research aims at lay down useful guidelines to deploy advanced TLC technologies in the most extreme environments, in order to validate the solution's performance and technology readiness level, and further optimize it for future terrestrial and space applications.

Work Summary

The scientific activity developed during recent years at the Aerospace Systems Laboratory (LSA − "Sapienza" University of Rome) concerned the study of lunar regolith, focusing on its effect on the microwave fields propagation. The research addresses such task by carrying out a full experimental characterization performed by simulating several representative Moon environmental conditions − i.e., by reproducing well defined chemical/physical background in terms of atmospheric parameters and soil compositions, as from the available literature data − and analyzing the microwave propagation characteristics in order to design efficiently mobile telecommunications systems operating on the Moon. With the further objective of considering regolith as main routine resource for drawing up systems and facilities constituting lunar living structures, the analysis of regolith-microwave interaction is thus focused on two specific paths:

- Building airtight structures by means of ISRU methodologies: the study is framed within the field of EM characterization of hybrid materials for space application currently carried out at LSA laboratories, focusing on the properties of several typologies of regolith-based bulk materials in terms of microwave reflection, absorption and transmission properties, in order to assess the basic conditions for remote operations.
- EM compatibility (EMC) analysis of simulated lunar environment & TLC systems design: the open question of understanding how the Moon environment would be fit for communications systems daily used on Earth, or whether it should be necessary to establish alternative solutions, is carried out by means of advanced facilities available at LSA laboratories, by reproducing fully constrained chemical/physical background conditions in terms of atmospheric and soil compositions, and analyzing the free space EM field propagation characteristics within lunar simulated environment.

The proposed study considers various types of lunar regolith reproduced on the basis of literature findings (see data in [1-3]). The base material used is dark powder of volcanic origin (Black Pyroclastite), which is enriched with the inclusion of various weight percentages of Ilmenite, in order to make it more similar to the regolith found on the surface of the basaltic lunar seas (main components: Ilmenite, Iron and Titanium Oxide). In order to obtain samples as much as possible responsive to the reality, the percentage of Titanium Oxide present in the Ilmenite sand is set as a parameter, and the correspondent percentage in weight of Ilmenite is added to the pyroclastic sand by mechanical mixing.

The electromagnetic experimental characterization is performed by means of a reverberation chamber (RC), due to the intrinsic capability provided by such experimental equipment to perform electromagnetic compatibility (EMC) tests with high level of accuracy. The facility adopted is the 'Space Environment Simulator' (SAS) of the Aerospace Systems Laboratory (LSA) available @ DIAEE – Sapienza University of Rome, which is a cylindrical vacuum chamber (volume around 5m^3) adapted to perform microwave characterization in conditions of chaotic EM propagation (see Fig.1, [4-6]**)**. Basically, by using a reverberation chamber the knowledge of the absorbed power allows to retrieve the as-called absorption cross section (ACS) of the object under investigation. The inner SAS atmosphere is controlled in terms of vacuum level, temperature and percentage of humidity. In particular, the latter environmental parameter influence on materials ACS is investigated by exploring conditions of ultra-high vacuum, medium-low pressure, standard and increasingly moistened air, in order to discriminate the microwave absorption effects not due to lunar simulants intrinsic characteristics [7]. A representative result of the experimental characterization of the reverberation environment adopted is reported in Fig.2, where the measurements of the quality factor of the RC for different atmosphere conditions – i.e., max vacuum 'blank' level (~10^{-5} mbar), low pressure (~10^{-3} mbar) CO_2 filled and standard air – and the corresponding absorbing cross section (evaluated as discrepancy against the reference) are plotted over the microwave broadband considered. The influence of the partial presence of humidity in air is appreciable, especially at increasing frequency, giving evidence of the power absorbing effectiveness due to dipolar rotation resonances of the water vapor molecules in the EM range under investigation [8,9].

Fig.1. Inner view of the reverberation chamber for microwave characterization arranged by adapting the Space Environment Simulator of the Aerospace Systems Laboratory @ DIAEE – Sapienza Univ. of Rome.

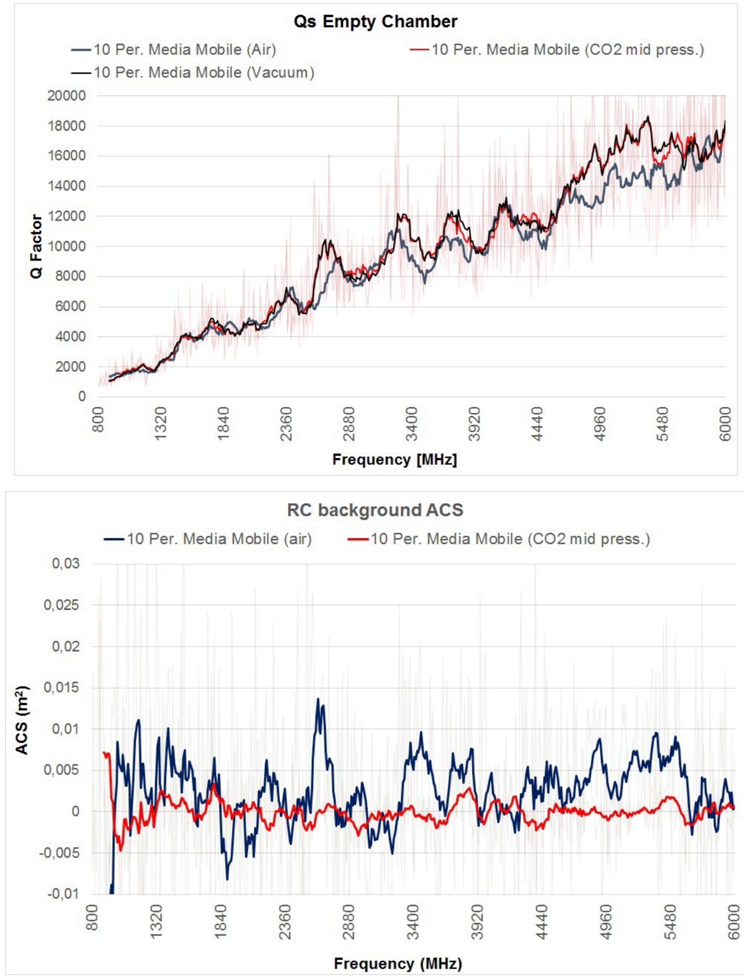

Fig.2. SAS chamber's quality factors and environments ACS measurements.

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