The Space Congress® Proceedings

2003 (40th) Linking the Past to the Future - A Celebration of Space

Apr 30th, 1:30 PM - 5:00 PM

Paper Session I-A - Dielectric Properties of Martian Soil Simulant

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Dielectric Properties of Martian Soil Simulant

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Abstract

NASA's Viking and Mars Pathfinder missions each used onboard instruments to determine the composition of the Martian soil at their respective landing sites. Those findings led to the development of a Martian soil simulant (JSC Mars-1) at NASA Johnson Space Center. However, in spite of the compositional studies conducted during those previous missions, no direct measurements were ever made of the dielectric properties of the Martian soil. Recently, instrumentation was developed at NASA Kennedy Space Center that enables investigations of the dielectric properties of granular materials to be conducted, including studies of Martian soil simulant. In the present study, a three-electrode system was used to measure the frequency response to an applied sinusoidal voltage of finely ground Martian soil simulant that was placed in a dry, low-vacuum environment. The data is shown to support a simple model of the granular system in which the resistances and capacitances of individual particles are connected in series by the resistance and capacitance of interparticle contacts.

1. Introduction

It is considerably more difficult to measure the dielectric properties of granular materials than it is to study large, single crystals. For example, four-point probe measurements of resistivity can be easily made on large crystals and then compared to theoretical calculations based on an ideal crystal model. But granular materials consist of many individual particles of various shapes and sizes, which have random orientations with respect to other particles. This makes it difficult to perform measurements on granular materials, and impossible to construct a precise theory when properties such as resistivity depend upon a knowledge of the nature of the interparticle contacts, which cannot be known with certainty.

Huggins and Sharbaugh[1] introduced a simple model for powdered organic semiconductors in which individual particles of resistance R_s and capacitance C_s are separated by series contacts having resistance R_c and capacitance C_c. The equivalent circuit, shown in Fig. 1 (d), consists of an effective resistance R_p in parallel with an effective capacitance C_p. The granular material was lightly packed between the parallel plates of a capacitor, and ac measurements of resistance were made.

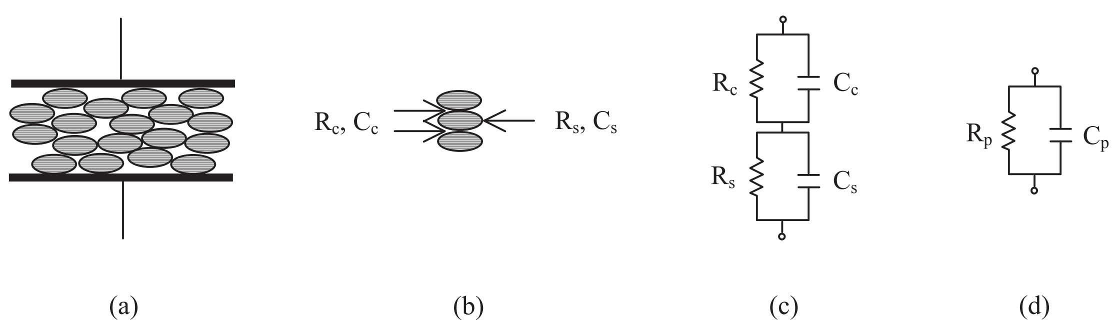

Figure 1. (a) Drawing of particles interspersed between two parallel metal plates. (b) Resistance R_s and capacitance C_s of individual particles, and contact resistance R_c and contact capacitance C_c between particles. (c) Circuit model for particles and interparticle contacts. (d) The equivalent circuit.

Previous experiments conducted on NASA's Viking and Mars Pathfinder missions have provided information on the composition of the Martian soil. Using that data, scientists at NASA Johnson Space Center were able to develop a Martian soil simulant using minerals found on earth [2]. This simulant is known as JSC Mars-1. The breakdowns by percentage weight of the actual soil as well as the soil simulant are shown in Table 1.

Oxide Type	Viking 1 Wt %	Viking 2 Wt %	Pathfinder Wt %	*JSC Mars-1 (A) Wt %*	*JSC Mars-1 (B) Wt %*
SiO_2	43	43	44	*34.5*	*43.5*
Fe_2O_3	18.5	17.8	16.5	*12.4*	*15.6*
Al_2O_3	7.3	7	7.5	*18.5*	*23.3*
SO_3	6.6	8.1	4.9	-	-
CaO	5.9	5.7	5.6	*4.9*	*6.2*
MgO	6	6	7	*2.7*	*3.4*

Table 1. Comparison of the composition of the Martian soil as determined by the Viking 1 and 2 lander missions and the Mars Pathfinder mission to the composition of two samples of the JSC Mars-1 simulant.

An ac capacitance measurement technique was developed by us in an effort to study the dielectric properties of the JSC Mars-1 soil simulant. This method consisted of placing the simulant particles between two metal parallel plates to form a capacitor similar to that shown in Fig.1(a). This capacitor uses the Martian soil simulant particles as a dielectric medium, and has an effective capacitance C_p and effective resistance R_p since some of the minerals in the simulant, such as iron oxide, are semiconductive. The capacitor containing the soil simulant was placed in series with a fixed capacitor C_A = 1 nF whose other terminal was grounded as shown in Fig. 2. A sinusoidal voltage of amplitude V_a and frequency f was applied to one of the electrodes of the capacitor containing the Martian soil simulant, and the voltage V_{out} was measured at the point between the two capacitors. Using a guard electrode (not shown) reduces edge effects significantly. The guard surrounds the sensing electrode of C_p where V_{out} is measured. An op amp circuit keeps the voltage at the guard electrode at the same level as the sensing electrode.

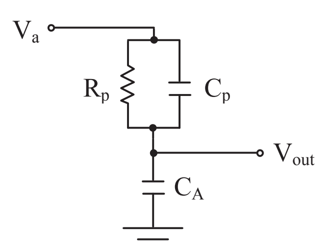

Figure 2. Schematic of the electronic circuit used in this study to measure the dielectric properties of a known volume of granular material that is assumed to have an effective capacitance C_p and an effective resistance R_p. The applied input voltage is V_a, which is a pure sinusoidal signal at the frequency f. The voltage V_{out} is measured across the fixed capacitor C_A = 1 nF as a function of the frequency.

Using standard circuit analysis, the circuit shown in Fig. 2 is found to have a voltage gain that is described by the equation

$$\left|\frac{V_{out}}{V_a}\right| = \frac{\sqrt{\left[\omega_p{}^2 + \left(1+\frac{C_A}{C_p}\right)\omega^2\right]^2 + \left[-\frac{C_A}{C_p}\omega_p\,\omega\right]^2}}{\omega_p{}^2 + \left(1+\frac{C_A}{C_p}\right)^2\omega^2} \tag{1}$$

where $\omega_p = 1/R_p C_p$ and $\omega = 2\pi f$. The phase difference between the input signal $V_a(t)$ and the output signal $V_{out}(t)$ may also be calculated, but it is not presented here. In the actual circuit used in this study, a non-inverting amplifier, whose gain was 39.5, was used to amplify the output signal.

2. Results and Discussion

Before conducting the experiment, the JSC Mars-1 soil simulant was baked in an oven at an elevated temperature in order to remove any water from the soil. The soil was then taken from the oven and poured into the testing apparatus to fill the volume between the plates of the capacitor C_p. The soil was not compressed between the capacitor plates but was shaken slightly, resulting in a lightly packed powder. The experiment was performed at room temperature in a vacuum chamber that had been purged with dry air, and then pumped down to a pressure of 0.3 Torr. A digital oscilloscope was used to measure the peak-to-peak voltages of the input signal V_a (2 $V_{p\text{-}p}$ at frequency f) and the output signal V_{out}. The data was was found to be reproducible, and is shown in Fig. 3 along with the theoretical calculation based on Eq. (1).

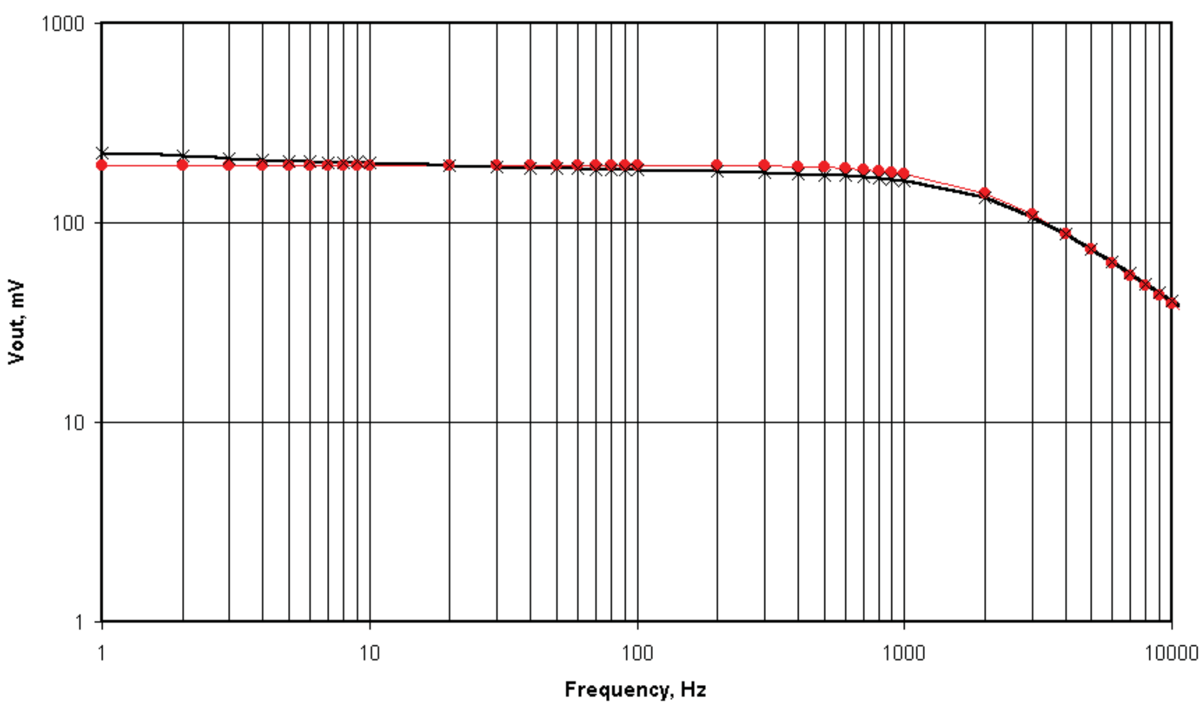

Figure 3. Measured V_{out} data is represented by the x symbols, and the calculated values of V_{out} using Eq. (1) are represented by the dots.

As Fig. 3 illustrates, we find that there is excellent agreement between the measured data and the theory we used to model the granular JSC Mars-1 soil simulant. This implies that it is possible to model a system of loosely packed Martian soil simulant particles in which the particles form series contacts as shown in Fig. 1. In order to construct the theoretical curve shown in Fig. 3 from Eq. 1, parameter values of $\omega_p = 2\text{x}10^8$ rad/s and $C_p = 0.01$ pF were used. Further studies are being planned to determine whether this particular combination of parameter values provides a unique best-fit to the observed data.

3. Conclusions

We have presented results of a study of the dielectric properties of Martian soil simulant that used an ac capacitance measurement, and have found that it is possible to model the interparticle contacts using an effective resistance and capacitance that are connected in parallel. This type of study will be useful to scientists involved in future Mars lander missions that plan to study the dielectric properties of the actual Martian soil. These results are also useful in extending our basic understanding of granular materials in general.

Acknowledgements

We are grateful to Dr. Charles Buhler of Swales Aerospace and to P. Keith Watson for many useful conversations regarding this research, and to Mr. Watson for directing us to previously published papers.

References:

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