Electrostatic sensor for a Martian lander mission

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Abstract. Spacecraft observations have established that the Martian surface is covered by soil material ranging from large sand particles to fine dust particles with diameters in the micrometer range. These materials form one soil unit due to mixing by repeated dust storm activity. Dust particle interactions due to atmospheric activity in the form of dust storms or the more frequent dust devils may electrify these particles. Soil particles on the surface of Mars may also become electrostatically charged due to incident UV radiation reaching the surface. To date, no *in situ* measurements have been done on surface or atmospheric electrostatic fields or on soil and dust electrification. This paper describes work leading toward the development of a possible flight instrument to be carried on a mission rover for measuring the distribution of electrostatic fields on or near the Martian surface, and for measuring variations in the planet's soil electrostatic response. This instrument would detect subtle changes in soil electronic properties along the Martian surface traversed by the rover, helping to identify and distinguish different soil surface units during the mission. In addition, the instrument would perform the first fundamental measurements of electrostatic fields generated by rover interactions with the Martian surface.

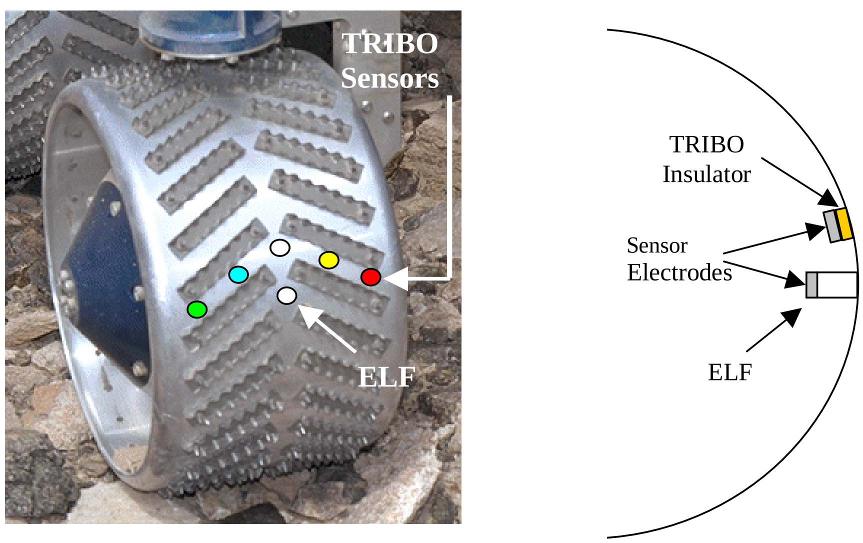
1. Introduction.

NASA's landing and orbiting missions to Mars together with earth-bound observations have established that the Martian surface is covered with a layer of fine soil material composed of particles vary in size from large sand particles to fine dust particles. Soil particle diameters range from micrometers to millimeters. Weather phenomena in the form of global dust storms and local dust devils have homogenized the Martian regolith into a single geological unit (Banin 1991). Martian dust storms reaching global proportions occur once every three years on average (Haberle 1986, Zurek and Martin 1993). Dust devils are more frequent in certain regions of the planet. NASA's Pathfinder mission of 1997 detected the presence of dust devils about once per Martian day.

Surface soil and dust particles on Mars may become electrostatically charged due to incident UV radiation reaching the surface. Although the total integrated UV flux over 200-400 nm on Mars is comparable to Earth's, shorter wavelengths contribute a larger proportion of this flux (Catling and Cockell 2000). Experiments have shown (Sickafoose 2002) that this process can electrify the soil and provide a photoelectron sheath that levitates charged particles about one meter above the surface, a phenomenon which was possibly seen on the Moon and that may also exist on Mars (Kolecki 1992). Contact charging may also occur due to collisions between wind-blown dust particles and stationary surface particulate matter. The high frequency of dust devil appearance and the presence of local and global dust storms produce a favorable environment for inter-particle contact charging in the Martian atmosphere. Electrostatic charging of dust and sand particles on Mars is exacerbated by the low humidities of the atmosphere near the dry surface. It has even been suggested that the formation of soil agglomerates and sand dune formation may be attributed to the electrostatic properties of the Martian soil (Kolecki, *et al*. 1991). To date, there has been no experiment on the surface of Mars to directly measure either the amount of charge contained on the surface dust and soil particles, or on the strength of the atmospheric electric fields that airborne dust might generate (Farrell *et al*. 1999).

2. Wheel Electrometer

A system of embedded sensors that can be incorporated into the wheel of any future mission rover would provide for a simple and fairly unobtrusive way to measure the distribution of electrostatic fields on the Martian surface and to measure variations in soil electrostatic response. For purposes of visualization, we will describe how our Wheel Electrometer System (WES) might be incorporated into one of the wheels of the Field Integrated Design & Operations (FIDO) rover (Figure 1(a)). FIDO is an advanced vehicle that is used in technology definition and field tests for future NASA Mars Program missions (Arvidson 2000 and Trebi-Ollennu 2001).



(a) **(b)**

Figure 1. **(a)** The Wheel Electrometer System (WES) shown on the FIDO wheel. **(b)** Cross-sectional view of the ELF and TRIBO modules. The ELF is recessed to allow measurement of an undisturbed soil plug that has not been compressed or rubbed by the wheel rim.

2.1 Description of Operation

The WES will consist of sensor modules (ELF and TRIBO described below). The sensors will be attached just beneath the rover wheel in such a way that each sensor will be exposed to the Martian regolith either by line of sight through a small amount of Martian atmosphere (ELF), or by direct contact with the regolith (TRIBO).

There will be two basic types of sensors. The first type of sensor is the Electric Field sensor (ELF) that will measure the regolith surface charge density (charge per unit area) as the rover wheel rolls over the Martian surface. The second type of sensor is the Triboelectric sensor (TRIBO) which will measure the amount of electrical charge that develops on a wheel-mounted insulator material through frictional contact as the rover wheel rolls over the Martian regolith.

Figure 1 (a) shows the FIDO wheel with the both the ELF and TRIBO sensor modules. The five TRIBO sensors utilize a different insulator material and are backed by independent miniature electrometers while the ELF is a bare sensor recessed back from the wheel surface. It would also be desirable to put the WES onto a front wheel of the rover since the ELF will monitor undisturbed electric fields on the surface.

2.2 Proposed Sensor Technology

The ELF and TRIBO sensors are actually based on the same technology. Each type of sensor simply measures the amount of charge that is induced on a metal electrode that has been exposed to some external distribution of electrostatic charge and has sensitivities that are achieved by adjusting circuit component values and the sensor area (Figure 1(b)).

In the case of the ELF sensor, the source of the charge would be any charged soil particles that may be present on the Martian surface at the time the rover wheel rolls over it. The ELF sensor electrode will be recessed several centimeters radially inward from the outer surface of the wheel through a hole in the wheel. This will ensure that the ELF directly measures any naturally occurring charge that may be present on a small patch of undisturbed Martian regolith as the wheel rolls forward. The ELF will provide an output voltage that is directly proportional to the amount of charged regolith that the sensor "sees" through the hole. The regolith's surface charge density will be determined using the charge measurement and the known hole area. As the rover travels across the Martian surface, the local surface charge density will be mapped using the ELF measurements. These data will provide scientists with direct measurements of the presence of electrically charged particles on the Martian surface.

The TRIBO sensor module will have five independent sensors. The electronic circuitry for each sensor is identical, but a different insulator material will cover the electrometer sensor electrode of each sensor (Figure 2). Our studies of the electrostatic properties of Martian regolith simulant JSC Mars-1 at NASA KSC indicate that the electrometer response to rubbing an insulator over the simulant will be significantly different for insulators made of Teflon, Rulon-J, Lexan, Lucite, and Fiberglass (Calle 2002). These materials were selected because they are known to span the "triboelectric series." As the rover wheel rolls over the Martian regolith, each of the five different insulators will make contact with the surface. The electrostatic response to contact charging of each insulator with the regolith will provide data regarding how the regolith fits into the triboelectric series. By making these measurements as the rover travels over the Martian surface, the TRIBO sensors will be able to provide a traverse record of electrostatic properties of the Martian regolith, properties that should fluctuate as changes in soil material properties are encountered.

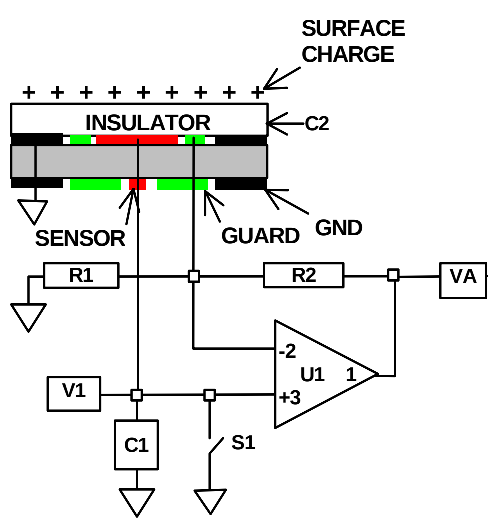


Figure 2. Front-end wheel electronics.

3. Demonstration of the Instrument

We have used a prototype electrometer to perform proof-of-concept experiments. Experiments on the Pathfinder indicated that when the wheel was dug into the surface to measure mechanical properties of the soil, visually distinct soils exhibited different mechanical properties (Moore 1999). From these experiments, one can expect to detect different electrostatic properties as well.

It has been well established that the sign and the amount of charging due to rubbing of insulators differs greatly depending on the material/mineral in contact. The TriboElectric Pen© is a commercially available device that is used to differentiate between plastics for the recycling industry (Eyre 1992). Here we intend to show that a similar process could be used on Mars to detect differences in the surface or subsurface soil characteristics. We will show that it will not only detect the net change of the electrostatic properties due to soil size, shape, moisture, texture or composition but also subsurface changes of the near-surface even when covered with a fine layer of a single material.

A prototype electrometer was built to test the expected performance of the WES under Martian environmental conditions in a CO_2 atmosphere at ~6 torr (see Figure 3). It was shown previously that temperature does not appear to affect the magnitude and sign of triboelectric charging (Calle 2002). Thus the experiments described here were performed at room temperature. The prototype shown in Figure 3 contains five sensors extending out of an electrically guarded box and are embedded inside five insulator materials: Fiberglass, Lexan, Polyethylene, Lucite, and Teflon. The protruding sensors are ideal for simulating the contact and rubbing expected while the rover wheels are traversing the soil.

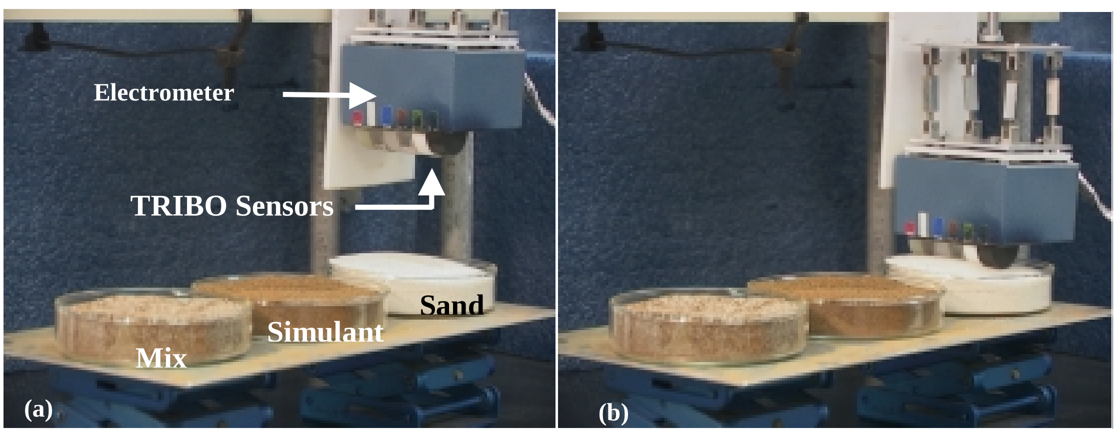


Figure 3. (a) The MECA-like Electrometer before contact with sand, JSC Mars-1 simulant and a 50/50 mixture by volume of the two. **(b)** The prototype Electrometer in contact with sand.

The prototype electrometer was placed in contact (under its own weight ~100 g) for approximately 3 seconds with different soil types: coarse JSC Mars-1 Martian soil simulant, coarse sand, and a 50/50 mixture by volume of each. After contact, the electrometer was lifted off the surface and placed over the next material. While off the surface, the resulting charge deposited onto the insulators was measured. Figure 4 shows the *cumulative* charge after two contacts. There were two contacts for each soil type since previous results showed that repeated contacts with the same material do not produce significant changes in the amount of charge deposited onto the insulators surface (Calle 2002). The data shown below was taken without cleaning or deionizing the prototype electrometer.

Upon separation, insulators charge up by a certain amount depending on the insulating material. Figure 4 trials 1, 2, and 3 show how its triboelectric response differs greatly without cleaning and/or deionizing the insulators between contacts. When contact was made with the JSC simulant, Fiberglass, Lexan, Lucite and Polyethylene tend to charge positively, while Teflon charges negatively by small amounts. This suggests a placement for the JSC simulant in the following triboelectric series (from positive to negative): Fiberglass, Lexan, Lucite, Polyethylene, JSC simulant, and Teflon. Switching from the simulant to sand, the net charging increases by a significant amount for each insulator. However, after contact with the 50/50 mixture, many of the insulators acquire little or no additional charge whereas Fiberglass and Teflon gain positive charge. Viewed simultaneously, distinctions can be made between the amount of charging, the sign of charging, and the lack of charging as the electrometer contacts different materials. Therefore, changes in the charging properties of the insulators after separation show that *differences* in soil types and mixtures can be detected through their triboelectric properties.

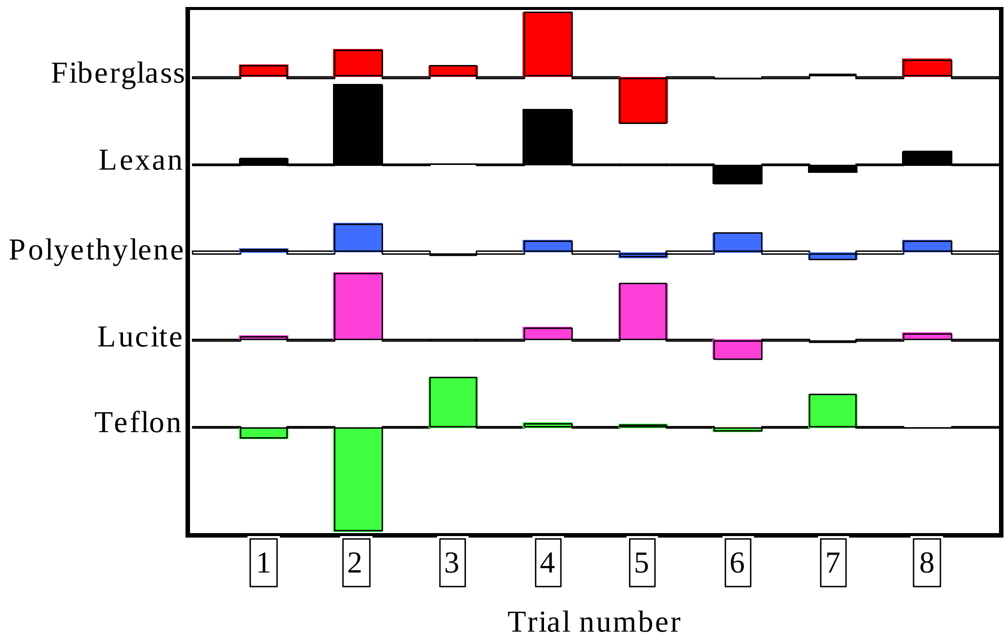


Figure 4. Results of eight experiments performed at 6 torr CO_2 using the prototype electrometer. Shown is the cumulative charge deposited onto Fiberglass, Lexan, Polyethylene, Lucite, and Teflon after making two contacts with each soil surface. Conditions for the experiments are: 1 dry, coarse JSC Mars-1 Martian regolith simulant; 2 dry coarse sand; 3 a dry 50/50 mixture by volume of simulant and sand; 4 dry, coarse JSC Mars-1 simulant coated with 5 μm simulant dust to a depth of ~2 mm; 5 dry coarse sand coated with 5 μm simulant dust; 6 dry, fine simulant alone; 7 moist and 8 dry JSC Mars-1 Martian regolith simulant. The individual response of each insulator is shifted by 25 pC (or 1.55×10^8 elementary charges).

The chemical composition of the Martian regolith did not vary significantly at the Viking and Pathfinder lander sites. The global dust storm occurrences help explain the existence of a dust layer on top of the Martian regolith of consistent average composition. The weathered soil or fine dust has been simulated by simply grinding the JSC Mars-1 Martian regolith simulant to a mixture in which 95% is below five microns in diameter. This fine simulant was then placed on top of both the coarse simulant and the sand to see if the triboelectric differences could still be seen even though covered with a similar material. The results are shown in Figure 4. Valuable information into the subsurface differences can be seen even though after a single contact is made, the insulators get completely covered by the fine dust. A completely covered insulator (as expected on Mars) can still be charged and uncharged during the contact process and crucial differences can be seen (see Figure 4 trial 4, 5, and 6). Fiberglass and Lexan show a striking behavior, while Teflon charges only slightly due to its proximity to the fine simulant in the Triboelectric series. Therefore, complicated signals can yield important results even under worse case scenarios in which soil differentiation is impossible with simple visual means.

We have seen that differences in soil texture, size, and shape can be detected with the prototype electrometer. It is also possible to distinguish between moist and dry simulant. Shown in Figure 4 are the results in which the JSC Mars-1 Martian simulant was either moist or dry. Moist simulant soil was exposed to normal humid (room) air while dry simulant was baked out at temperature in excess of 150°C for several hours. The results of

Figure 4 trials 7 and 8 suggest that differences in the triboelectric signal are expected as a function of soil moisture. All insulators except Teflon acquired a positive charge in contact with dry soil. The three insulators that charged negative in contact with moist simulant (Lexan, Polyethylene, and Lucite) now charge positive. The drier simulant is more insulating and is thus more efficient at charging materials (Buhler 2002). Therefore, moisture affects the triboelectric as well as the resistivity properties of the simulant.

4. Conclusions

From the results of the tests above, it is concluded that the ELF component of the WES can detect changes in soil properties while traveling over the Martian surface. The additional five TRIBO sensors on the WES will refine knowledge of how these surface materials react electrostatically to rover/regolith pressure and friction. Changes in soil properties such as mineral size, shape, texture and moisture content have shown to produce different triboelectric signals (Zimon 1969). It should be stressed that the WES cannot prove *which* property has changed, only that the soil's overall electrostatic (and physical) properties *have* changed. This information can then be used in conjunction with other instrumentation on board to help form a more complete picture of the Martian surface properties while simultaneously classifying its electrostatic properties.

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