Subject: Patent: MECA/Electrometer
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The commercially available electrometers are typically used to survey for ESD (Electrostatic Discharge) prone materials in electronic component assembly areas. These instruments operate using either DC (direct current) or AC (alternating current).

This description is concerned with a DC electrometer as shown in Fig. 1. The critical components are the detecting electrode, the input capacitance, operation amplifier (op amp), a shorting switch used to zero the instrument, and the charged surface. DC instruments are used to measure the change in charge placed in front of the instrument's detecting electrode after instrument is zeroed. These instruments have the feature that the input voltage will drift with time. This drift is typically hours in duration and depends on the op amp input current. The conventional ESD survey instrument is shown in Fig. 1. During a measurement, the conventional electrometer is held at a known distance from a charged surface.

The new DC electrometer, shown in Fig. 2, is used in a different manner than ESD survey instrument shown in Fig. 1. In the new instrument, triboelectric materials are placed in contact with the surface to be measured, rubbed against the surface, removed from the surface, and the triboelectrically-induced charge measured. Thus, the distance between the charged surface and the detecting electrode is a known distance leading to a direct measure of the electric field and deposited charge.

The innovation described in this disclosure consists of the following:

1. Triboelectric surfaces: The new instrument contains a charged surface that is an integral part of this instrument. Thus the distance between the charged and the detecting electrode is a known distance enabling the calculation of the electric field strength and induced charge.

2. Guard ring: The new instrument contains a guard ring which surrounds the detecting electrode. This eliminates leakage currents that could degrade the accuracy of the measurement.

3. Triboelectric array: The new instrument contains several (five) insulating materials with different triboelectric properties. This allows a rough determination where an unknown material is found on the triboelectric series.

4. A unique feature includes the attachment of insulators to the sensing electrodes. These insulators can be demounted and replaced with new ones if for instance they become contaminated or a different selection of insulators is desirable. As demonstrated in the prototype, the sensor head containing the five tribo-sensors can be easily replaced which makes changing the heads easy to do in the field.

5. The electrode configuration has a unique three element array containing sense, guard, and ground electrodes. This allows the measurement of small electric fields in the volts/cm range.

6. The initialization or zeroing of the instrument is accomplished by a very low leakage solid state switch. All known electrometers use mechanical switches to accomplish this function. The solid state switch allows the automation of the instrument.

7. The sensing head contains a triboelectric insulator which may be an insulator sandwich. This means that the insulator next to the sensing electrodes is a good insulator whereas the insulator to be rubbed can be a leaky insulator. This means that the triboelectric properties of leaky insulators can be characterized. The periphery of the insulator is connected to ground which serves to leak the charge away at a known rate.

8. Sensor array contains five triboelectric sensors, an electric field sensor, an ion gage, and temperature monitor. Such a configuration is unique.

9. Ion gage contains a three element array: sense, guard, and ground where the sense and guard are maintained at nearly the same potential. It also has a grounded anode which means that the anode of the ion gage can be touched without fear of harming the user.

10. Potential uses
   a. Process Control
   b. Material Identification.

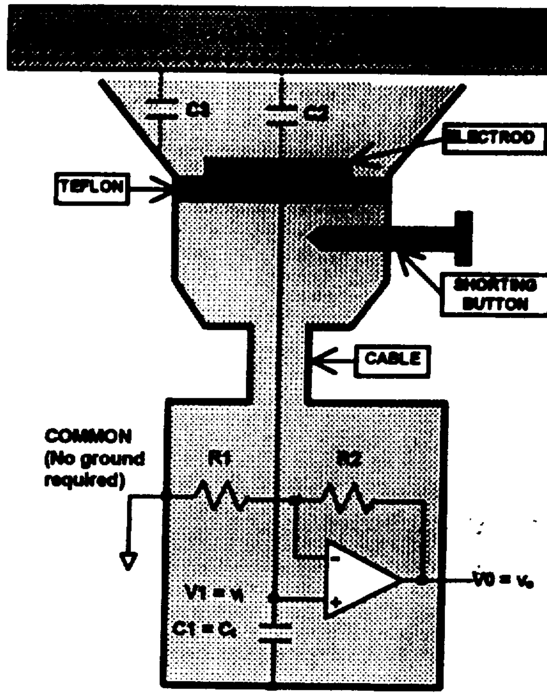

Fig. 1. Conventional DC electrometer.

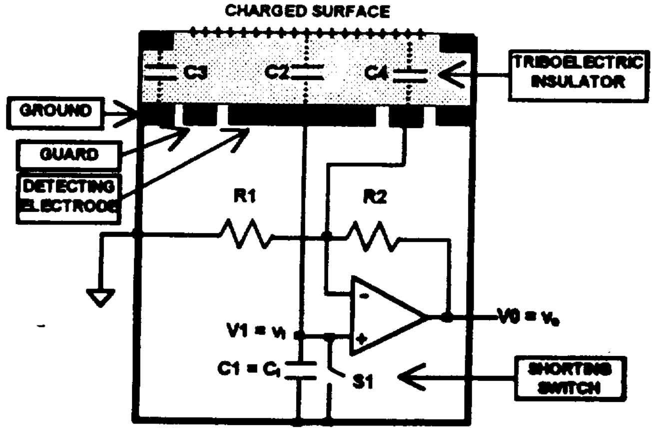

Fig. 2. New electrometer

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MECA Electrometer: Overview

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ABSTRACT

The Mars '01 lander contains an electrometer designed to evaluate the electrostatic nature of the Martian regolith and atmosphere. The objective is to gain a better understanding of the hazards related to the human exploration of Mars. The instrument has four sensor types: (a) triboelectric field, (b) electric-field, (c) ion current, (d) temperature. Only the triboelectric sensors are described in this paper

INTRODUCTION: The electrometer is part of MECA (Mars Environmental Compatibility Assessment) project. It will be built into the heel of the Mars '01 robot arm scoop as seen in Fig. 1. The robot arm is two-meters in length; thus, the electrometer must operate over an 8-wire serial interface. It will be housed in a volume of ~50 cm^3 and consume 150 mW.

The triboelectric field sensor array consists of five insulating materials to determine material charging effects as the scoop is dragged through the Martian regolith. These materials will be chosen after Earth-based tests using Mars simulant soils.

OPERATION: In operation the triboelectric sensors will be rubbed against the Martian soil as depicted in Fig. 2. After reaching the end of its traverse, the scoop will be abruptly removed from the soil at which time the triboelectric sensor response will be measured. The parameters for this operation are shown in Fig. 2 and typical values are listed in the figure caption.

DESIGN: The design of the triboelectric sensors follows from the traditional electrometer as depicted in Fig. 3. Here the electrometer has three capacitors, C1, C2, and C3 where C1 is connected to an operational amplifier that is operated in the follower mode. In the

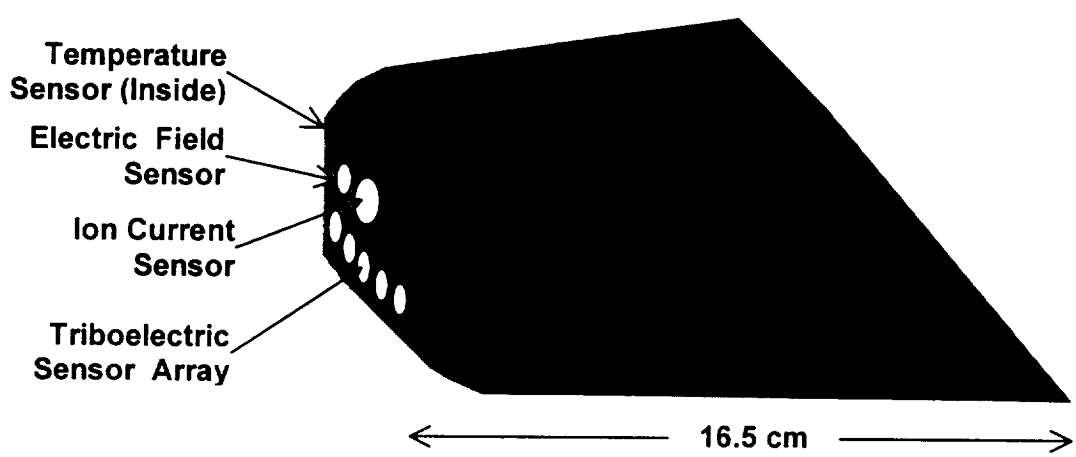

Figure 1. Electrometer sensor suite mounted in the heel of the Mars '01 scoop.

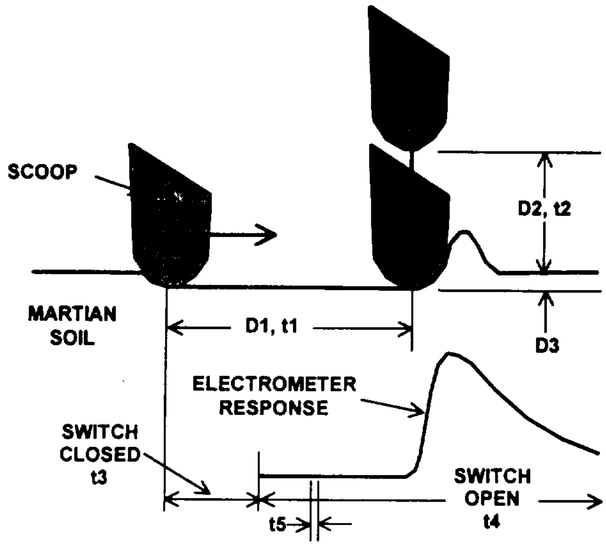

Figure 2. Operational scenario for the scoop where recommended operating parameters are: D1 = 10 cm, D2 = 1 cm, D3 = 0.5 to 1 cm, t1 = 10 s, t2 = 0.5 s, t3 = 1 s, t4 = 19 s, t5 = 0.1 s

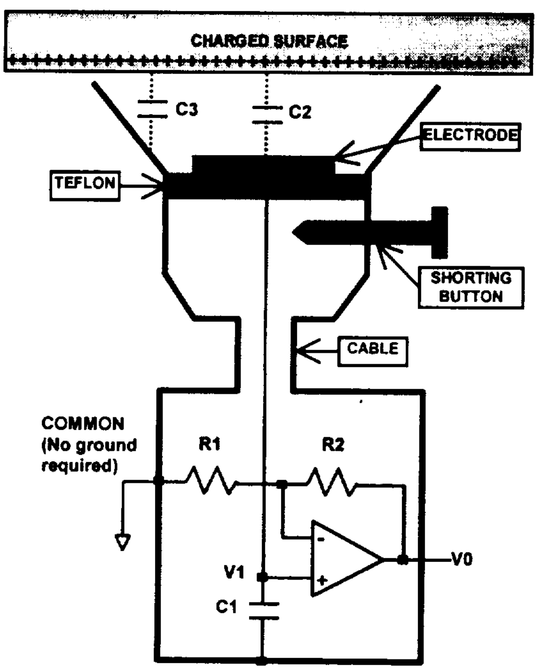

Figure 3. Traditional electrometer [1] typically used to measure ESD, electrostatic discharge, in a laboratory setting.

triboelectric sensor developed here, the mechanical switch has been replaced by a low-leakage solid-state switch and is used to remove the charge from C1. In addition C2 was replaced by an insulator that will be rubbed against the Martian soil so as to determine the potential for build up of charge on various insulating materials.

MODEL: An electric circuit model, shown in Fig. 4, was developed to aid in the design and analysis of the sensor. The model includes the previously described capacitors and switch. It also includes a resistor that represents the discharge mechanism for the insulator, C2.

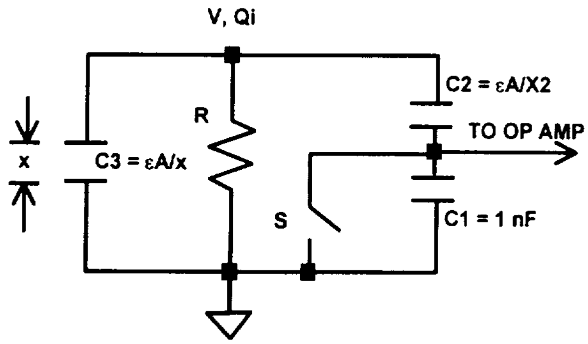

Figure 4. RC circuit model for the triboelectric sensors.

The model assumes that the triboelectric sensor, after rubbing the surface, lifts off from the surface with a constant velocity, v, and a charge Qi. The time from liftoff is t and the parameters are: Tau = R·C0, and T = εA/(v·C0) where C0 = C1·C2/(C1+C2) and C3 = εA/X, where A is effective area. Thus this model contains three critical parameters: Qi, Tau, and T.

The response curves shown in Fig. 5 illustrate how these parameter intermingle. For Tau very large which occurs in a leak free insulator, the response curves approach Qi. For a small Tau, the curves peak and decay rapidly. This response is the behavior that needs to be measured on Mars and is depicted in Fig. 2 along with the motion of the scoop.

EXPERIMENTS: Five different insulators were loaded into the triboelectric sensor head and were manually rubbed at room temperature with wool felt and the results are shown in Fig. 6. The response around 0.2 minutes is during the rubbing process. After secession of rubbing the curves show a small loss of charge which indicates that all these insulators have good

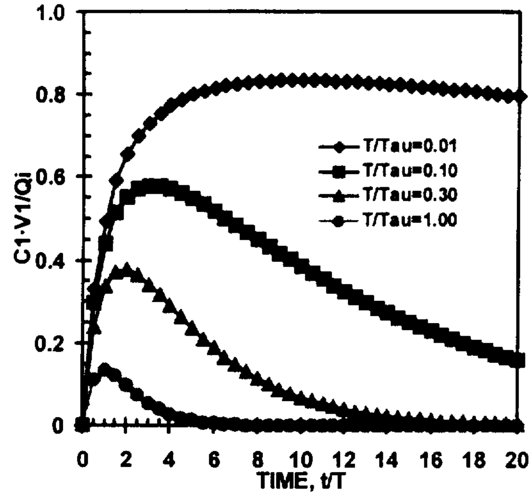

Figure 5. Time response predicted for the triboelectric sensors using the RC-circuit model shown in Fig. 4.

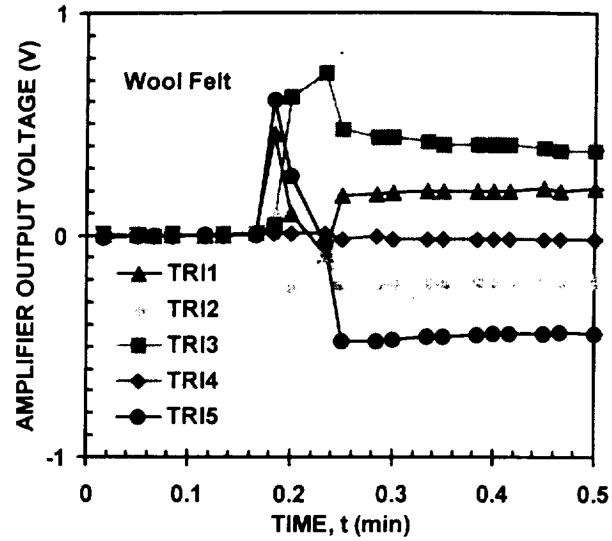

Figure 6. Experimental response curves from five triboelectric sensors where TRI1 is ABS, TRI2 is polycarbonate, TRI3 is linen filled phenolic, TRI4 is Rulon-J, and TRI5 is Teflon which were rubbed with wool felt.

insulating properties. In addition, the response shows both positive, zero, and negative behavior. The zero behavior may have identified an important antistatic material. The voltage response at the output of the amplifier had a gain of four with respect to the input.

Subsequent rubbings revealed similar response but differed in magnitude due to the relatively uncontrolled nature of the rubbing process. That is the velocity, pressure, and time of rubbing were not well controlled in this initial experiment.

MARS EXPERIMENTS: The five materials that can be triboelectrically rubbed on Mars must be chosen carefully. The materials will be chosen to span the electrostatic parameter space given by Qi, T, and Tau. Next Earth-bound tests will be developed to characterize candidate materials in simulated Martian soils. From these test results, the five triboelectric flight will be chosen.

DISCUSSION: A new triboelectric sensor instrument has been developed. It is about to under go extensive ground testing from which the five materials will be chosen. These materials will be flown to Mars and tested.

These results will be compared to Earth-bound tests. If the tests agree then new Mars bound materials can be evaluated with confidence. If significant discrepancies arise between the Earth and Mars tests, then one must proceed more cautiously and re-evaluate our understanding of how triboelectrically materials respond to the Martian environment.

REFERENCE:

1. Electrometer Measurements, Keithley Instruments, 1972

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