



SURFACE VEHICLE RECOMMENDED PRACTICE

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Fuel Systems and Components - Electrostatic Charge Mitigation

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1. SCOPE

This SAE Surface Vehicle Recommended Practice deals with electrostatic charge phenomena that may occur in automotive fuel systems and applies to the following:

- Fuels that are in a liquid state at ambient temperatures and atmospheric pressures and are contained in vehicle fuel tanks that operate at or near atmospheric pressure. This includes gasoline and diesel fuels, as well as their blends with additives such as alcohols, esters, and ethers, whether the additives are petroleum based or bio-fuel based.
- The group of components that comprise the fuel system (in contact and not in contact with fuels).
- Other components in proximity to the fuel system that may be affected by electrostatic fields caused by the fuel system.
- Electrostatic phenomena that arise from, or are affected by, the following aspects of vehicle or fuel system operation:
 - Flowing fuel in the fuel delivery system.
 - Flowing fuel being dispensed to the vehicle while it is being fueled.

1.1 Basic Approach

This recommended practice provides two approaches that may be used separately or collectively to ensure that there is no likelihood of adverse consequences resulting from electrostatic phenomena:

- a. Recommendations for materials, components, and subsystems to be used in conjunction with resistance, resistivity, and dissipation time tests, noting that this is the conservative approach and may result in unnecessary use of these designs and materials for some specific applications. See 4.1.
- b. Recommendations for the limits on electrical charge accumulation and transfer; with an indication of the advanced tests and analyses that must be conducted, noting that these tests and analyses require specialist personnel with the appropriate knowledge, experience, test equipment, and testing environment. See 4.2.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1681 Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D257 Standard Test Method for DC Resistance or Conductance of Insulating Materials

ASTM D991 Standard Test Method for Rubber Property - Volume Resistance of Electrically Conductive and Antistatic Products

ASTM D2624-02 Standard Test Method for Electric Conductivity of Aviation and Distillate Fuels

ASTM D4496 Standard Test Method for DC Resistance or Conductance of Moderately Conductive Materials

2.1.3 European Committee for Electrotechnical Standardization (CENELEC) Publications

Available from Cenelec Standards Inspections Ltd., Unit 22 Apex Business Village, Northumberland Business Park, Newcastle Upon Tyne NE23 7BF, United Kingdom, Tel: 44-0191-2502005, Email: info@cenelec.com.

CLC/TR 50404 Electrostatics - Code of Practice for the Avoidance of Hazards Due to Static Electricity

2.1.4 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 93 Methods of Test for Volume Resistivity and Surface Resistivity of Solid Electrical Insulating Materials

IEC 60079-0 Electrical Apparatus for Explosive Atmospheres

IEC 60243-2 Electric Strength of Insulating Materials - Test Methods - Part 2: Additional Requirements for Tests Using Direct Voltage

IEC 61340-2-1 Electrostatics Part 2-1: Measurement Methods - Ability of Materials to Dissipate Static Electric Charge

IEC 61340-2-3 Electrostatics Part 2-3: Methods of Test for Determining the Resistance and Resistivity of Solid Planar Materials to Avoid Electrostatic Charge Accumulation

2.1.5 Military Specifications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

MIL-STD-3010 Method 4046.1 - Antistatic Properties of Materials

2.1.6 API Publications

Available from API, 1220 L Street, NW, Washington, DC 20005-4070, Tel: 202-682-8000, www.api.org.

88-1-461 Potential Fire Hazards of Lowering Gasoline Volatility

API RP 2003 Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents (7th ed., Jan. 2008)

2.1.7 National Fire Protection Agency Publications

Available from NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA77 Recommended Practice on Static Electricity 2000 Edition

2.1.8 Electrostatic Discharge Association (ESDA) Publications

Available from Electrostatic Discharge Association, 7900 Turin Road, Building 3, Rome, NY 13440-2069, Tel: 315-339-6937, www.esda.org.

ESDA Adv.1.0	Glossary of Terms (1994 publication)
ESD STM 11.11	Surface Resistance Measurement of Static Dissipative Planar Materials (2006 publication)
ESD STM 11.12-2000	Volume Resistance Measurements of Static Dissipative Planar Materials (2000 publication)
ESD TR 02-99	High Resistance Ohmmeters - Voltage Measurements

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2044	Quick Connect Coupling Specification for Liquid Fuel and Vapor/Emissions Systems
SAE J2045	Performance Requirements for Fuel System Tubing Assemblies
SAE J2260	Nonmetallic Fuel System Tubing with One or More Layers

2.2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D150	Test Methods for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials
ASTM D2679	Electrostatic Charge
ASTM D3509	Electrostatic Field Strength Due to Surface Charges
ASTM D4470	Standard Test Method for Static Electrification
ASTM D4865	Standard Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems

2.2.3 Military Specifications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

MIL-PRF-81705D	Barrier Materials, Flexible, Electrostatic, Free, Heat Sealable
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2.2.4 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 330	Hose and Hose Assemblies for Dispensing Flammable Liquids
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2.2.5 DIN Publications

Available from Deutsches Institut für Normung e.V., Burggrafenstrasse 6, 10787 Berlin, Germany, www.din.de.

DIN 53-486/VDE 030 Part 8/4 75, VDE Specifications for Electrical Tests on Insulating Materials: Evaluation of Electrostatic Behavior (April, 1975)

2.2.6 Other Publications - Detailed Background

C. B. Shepherd Jr., Standard calibration fuels, WADC Technical Report 52-331, Wright Air Development Center, Ohio (1952)

Journal of Research Article (Oct-Dec, 1965) - Electric Currents and Potentials Arising from the Flow of Charged Liquid Hydrocarbons through Short Pipes

ISO 3915-1981 (E) - Plastics - Measurement of Resistivity of Conductive Plastics

IEEE Transactions on Electrical Insulation Volume 23, No. 1 (ISSN 0018-9367) (February, 1988) - Electrical Insulation and Breakdown in Vacuum

IEEE Transactions on Electrical Insulation Volume 23, No. 1 (ISSN 0018-9367) (February, 1988) - Flow Electrification in Electrical Power Apparatus

Naval Research Laboratory Report 8021 - Pro Static Agents in Jet Fuels (August 16, 1976)

Coordinating Research Council - Electrostatic Discharge in the Fuel Systems of Gasoline Powered Vehicles in North America (Paper by Ron Tharby, Nov., 1990)

ESSO Research and Engineering Company - Charging Tendency Test (April 9, 1959)

Naval Research Laboratory Report 8484 - Generation of Electrostatic Charge in Fuel Handling Systems: A Literature Survey (September 24, 1981)

January, 1988 issue of Plant/Operations Progress Magazine - Collection of articles on aspects of electrostatic charge concerns arising in handling chemicals

Research Studies Press, Inc., John Wiley and Sons - Electrostatic Hazards in the Petroleum Industry by W. M. Bustin and W. G. Duke

Analysis of "Flow Electrification in Fuel Distribution Systems" by J. C. Dean, G. H. Williams, and J. DeGiovann - IEEE Transactions on Industry Applications, vol. 29, No 3, pp 132-138, 1993

DGMK Project 508 - Avoidance of Ignition of Gasoline/Air Mixture During Refueling of Motor Vehicles at Filling Stations - DGMK German Society for Petroleum and Coal Science and Technology, Hamburg, Germany, February 1996

Report on the Risk of Static Ignition During Vehicle Refueling: A Study of Available Research - Institute of Petroleum, London, May 2001

American Institute for Chemical Engineers - Center for Chemical Process Safety - Electrostatic Ignitions of Fires and Explosions; Thomas H. Pratt, PhD, PE

American Institute for Chemical Engineers - Center for Chemical Process Safety - Avoiding Static Ignition Hazards in Chemical Operations, Laurence G. Britton

Electrostatic Ignition Hazards in Motor Cars - Occurrence, Detection and Prevention - Proceedings ESA/IEEE Joint Meeting on Electrostatics, June 24-27, 2003, University of Arkansas, Little Rock, 78-89, U. von Pidoll

3. DEFINITIONS

In addition to this section, refer also to the Electrostatic Discharge Association publication: Glossary of Terms (ESDA Adv. 1.0).

3.1 ACCUMULATION

An increase in the amount of electrostatic charge present on a fuel system component resulting from a rate of charge dissipation that is slower than the rate at which charge develops.

3.2 ASSEMBLY

A group of parts or components that form a self-contained unit designed to perform two or more specific functions. Examples are fuel pump/sender assembly, fuel tank assembly, fuel rail assembly, and fuel line assembly.

3.3 BONDING

An intentional electrical connection made between conductive components for equalizing electrical potential between the components.

3.4 BREAKDOWN FIELD STRENGTH

In an insulative material, it is the critical electric field strength that causes dielectric breakdown.

See also dielectric breakdown, field strength.

3.5 BREAKDOWN VOLTAGE

The potential difference between two objects that causes breakdown of the dielectric (insulative) material between the objects. It is the potential difference that causes the electric field strength to exceed the breakdown field strength over a sufficient part of the gap.

3.6 CAPACITANCE

A measure of the amount of electric charge stored for a given electric potential. The capacitance is defined as the total electric charge (measured in coulombs) placed on an object divided by the potential of the object (measured in volts):

$$C = Q/V \quad (\text{Eq. 1})$$

where:

C = capacitance of the body, measured in farads (F)

V = difference in electrical potential between the body and ground, measured in volts (V)

Q = amount of charge, measured in coulombs (C)

The unit of measure is the farad (F).

3.7 CHARGE (OR ELECTRIC CHARGE)

Quantity of unbalanced electricity on (or in) a body; i.e., an excess or deficiency of electrons, giving the body negative or positive electrification, respectively.

The unit of measure is the coulomb (C).

$$Q = CV \quad (\text{Eq. 2})$$

where:

C = capacitance of the body, measured in farads (F)

V = difference in electrical potential between the body and ground, measured in volts (V)

Q = amount of charge, measured in coulombs (C)

3.8 CHARGE DENSITY

The net electric charge per unit volume (volume charge density) or electric charge per unit area (surface charge density).

The unit of measure is coulombs per cubic meter (C/m³) or coulombs per square meter (C/m²).

3.9 CHARGED PLATE MONITOR

An electrical measuring system that employs a high voltage source, an isolated test surface, timing circuitry, and an electrostatic fieldmeter to provide quantitative measurements of the rate of decay of static charges on a component or assembly.

3.10 COMPONENT

A part or product that performs a single function in its smallest assembled state. Examples are fuel pump, float rod, in-line external fuel filter, and fuel tank shell.

3.11 CONDUCTANCE

A property of a component or sub-system indicating how easily it allows the flow of electric current through it - as measured between two electrodes placed in specified positions. Reciprocal of resistance (1/Ω).

The unit of measure is the siemens (S).

See also conductivity.

3.12 CONDUCTION

Flow of electricity in a medium that does not involve movement of the medium itself. An example of this is the flow of electrons or ions in a material.

3.13 CONDUCTIVE MATERIALS

Materials exhibiting resistance low enough to prevent any meaningful electrostatic charge to accumulate by allowing those charges to be rapidly conducted (dissipated) to system or earth ground.

3.14 CONDUCTIVITY

A property of a material indicating how easily the flow of electric current passes through it; denoted by σ . The reciprocal of volume resistivity.

The unit of measure is siemens per meter (S/m).

See also conductance.

3.15 CORONA DISCHARGE

Luminous discharge due to ionization of the air surrounding a conductive material, around which the electric field strength exceeds the breakdown field strength, but only over a limited distance.

3.16 COULOMB

The unit of electric charge. The coulomb is the quantity of electric charge that passes a given cross-section of a conductor in one second when the current is maintained at 1 A.

3.17 DIELECTRIC (OR DIELECTRIC MATERIAL)

A material with very few free charges throughout its volume. Electrons are closely bound to atomic nuclei and cannot drift or diffuse about the material as in a conductor or semiconductor. A perfect dielectric (an insulator) has no free charge and therefore zero conductivity.

3.18 DIELECTRIC BREAKDOWN

Condition arising when a dielectric (insulative) material is subjected to an electric field that exceeds the breakdown field strength. Electrons are pulled out of molecular bonds and accelerated until they collide with other parts of the molecular lattice, causing chemical changes or physical damage to the material. After breakdown occurs, a dielectric (insulative) material may become irreversibly more conductive.

3.19 DISCHARGE

A rapid reduction in the amount of electrostatic charge accumulated in a particular region caused by the flow of electric current following a dielectric breakdown.

3.20 DISSIPATION

A gradual decay, over time, of the amount of a physical quantity such as electrostatic charge or heat in a particular region. In this Recommended Practice, the term is used exclusively for the loss of electrostatic charge (charge dissipation).

3.21 DISSIPATIVE (MATERIALS)

Materials that prevent the accumulation of electrostatic charges to hazardous levels by allowing charge dissipation to either system or earth ground. In the context of this Recommended Practice, these materials are characterized by level of volume resistivity.

3.22 ELECTROMETER

A refined DC voltmeter exhibiting very high input resistance and negligible leakage current or an equivalent ammeter with a low voltage burden.

3.23 ELECTROSTATIC CHARGE

An accumulation of essentially stationary electric charges on the surface or in the volume of a material. (Volume charges can only exist in a dielectric material, not in a conductor.) Associated with the charge distribution is its surrounding electrostatic field.

3.24 ELECTROSTATIC (OR ELECTRIC) FIELD

The (vector) electric force exerted on a charge divided by the amount of charge. See also field strength.

The unit of measure is the volt per meter (V/m).

3.25 ELECTROSTATIC POTENTIAL

The electrostatic potential (voltage) at a point is the energy required to move a charge from a specified reference location to that point, divided by the amount of charge moved. The reference location is usually called ground or zero potential.

The unit of measure is the volt (V).

3.26 ENERGY OF SPARK DISCHARGE

The energy (W) of a spark discharge to ground is described by the following equations:

$$W = 1/2 CV^2, W = 1/2 QV, W = 1/2 Q^2/C \quad (\text{Eq. 3})$$

where:

C = capacitance of the discharging body, measured in farads (F)

V = difference in electrical potential between the discharging body and ground, measured in volts (V)

Q = amount of charge, measured in coulombs (C)

W = amount of energy, measured in joules (J)

3.27 EROSION, ELECTRICAL

The progressive deterioration of a dielectric material by the action of electrical discharges through the material.

3.28 FARADAY CUP OR CAGE

An apparatus for measuring electric charge that consists of two conducting enclosures: an inner conductor and an outer conductor, which are insulated from each other. The grounded outer enclosure shields the inner one from external electric fields; the charged object to be characterized is placed within the inner enclosure.

3.29 FIELD STRENGTH METER

A non-contact measuring instrument for detecting and quantifying the presence of electrostatic fields and potentials on items and surfaces. Electrostatic fieldmeters can be calibrated to provide accurate potential measurements when used at a fixed distance from a surface. Key factors affecting the measurement are object size and the proximity of other objects or ground surfaces.

3.30 FIELD STRENGTH

The magnitude of the electric field vector. See electric field.

The unit of measure is volts per meter (V/m).

3.31 FUEL CONTAINMENT BOUNDARY

That portion of the fuel system that is in direct contact with liquid fuel or the vapor space directly above liquid fuel. Vapor management systems that are connected to the fuel tank interior via liquid/vapor discriminating valves are not considered part of the liquid containment boundary, although the valves are.

3.32 GROUNDING (EARTHING)

The intentional electrical connection of a component or vehicle to a ground plane, the earth, or a large conductor taken as the zero potential reference, thus eliminating the electrical potential difference between the component and the ground plane, earth, or reference conductor.

NOTE: Earthing is also used interchangeably for grounding.

3.33 HALF LIFE

For the purposes of this Recommended Practice, half life refers to the time required for the charge level on or in a body of material to decay to 1/2 of its original value (rather than 1/e, as in 3.39).

3.34 INSULATIVE (of Materials)

Allowing the accumulation of electrostatic charges to values above a defined acceptable limit by preventing adequate dissipation of those charges to either system or earth ground. (In the context of this Recommended Practice, this is characterized either by volume resistivity or rate of static decay.)

3.35 PERMITTIVITY OF FREE SPACE (ϵ_0)

A universal constant such that in a vacuum, the product of ϵ_0 and the electric field, E, is equal to the electric flux density.

$D = \epsilon_0 E$. The numerical value for ϵ_0 is 8.854×10^{-12} .

The unit of measure is Farad per meter (F/m).

3.36 PRO-STATIC AGENT

A substance that increases the charge density generated on a fuel in a particular operation without increasing its conductivity.

3.37 QUENCHING DISTANCE

The minimum gap through which a flame can propagate between parallel plates. The quenching distance for typical hydrocarbon gasoline components in air at atmospheric pressure is approximately 2 mm.

3.38 RELATIVE PERMITTIVITY (ϵ_R)

The permittivity of a medium, ϵ , divided by the permittivity of free space, ϵ_0 . See 3.35.

$$\epsilon_R = \epsilon / \epsilon_0 \quad (\text{Eq. 4})$$

Relative permittivity is dimensionless.

3.39 RELAXATION

The return of a system to electrical charge equilibrium. It may follow an exponential form, a hyperbolic form, or a combination of the two. Exponential relaxation is the most common example. It is characterized by a time constant, τ , for a system with a capacitance, C, and a resistance, R, the time constant is:

$$\tau = RC \quad (\text{Eq. 5})$$

If the dissipation results from current flow within a dielectric material:

$$\tau = (\epsilon_R \cdot \epsilon_0) / \sigma \quad (\text{Eq. 6})$$

where:

ϵ_R = relative permittivity of the dielectric material

ϵ_0 = free space permittivity

σ = conductivity of the dielectric material

In Equation 6, τ is also called the material's dielectric relaxation time. See relaxation time.

The unit of measure is the second (s).

3.40 RELAXATION TIME

The time required for the charge in a system to drop to $1/e$ of its original value (e = base of the natural log system and is equal to 2.718). For an exponential decay, this is τ , the relaxation time constant. See also half life and relaxation.

3.41 RESISTANCE

A property of component or sub-system indicating how strongly it opposes the flow of electric current through it as measured between two electrodes placed in specified positions.

The unit of measure is the ohm (Ω).

See also volume resistivity, surface resistivity, and surface resistance.

3.42 SHEAR RATE

The gradient of flow velocity in a gas or liquid perpendicular to the flow direction.

The unit of measure is $1/s$.

3.43 STREAMING CURRENT

The current carried by an electrically charged fluid as a result of its movement or flow. The streaming current, I_s , is given by:

$$I_s = F \rho_c \quad (\text{Eq. 7})$$

where:

F = volumetric flow rate (in m^3/s)

ρ_c = charge density of the fluid (in C/m^3)

The unit of measure is the ampere (A).

3.44 SURFACE RESISTIVITY

A property of a material indicating how strongly it opposes the flow of electric current across its surface; defined as the ratio of DC voltage drop per unit length to the surface current per unit width. Denoted by ρ_s .

The unit of measure is the ohm (Ω).

NOTE: To differentiate from surface resistance, the unit ohms/square (Ω/sq) is often used. This arises from the units of length and width in the above definition. For every square surface area, i.e., an area in which the length equals the width, the surface resistance numerically equals the surface resistivity.

See also volume resistivity, volume resistance, and surface resistance.

3.45 SURFACE RESISTANCE

A property of a component or sub-system indicating how strongly it opposes the flow of electric current across its surface, as measured between two electrodes placed in specified positions. For example, the resistance, R , of a component consisting of a flat, rectangular surface with width, d , and length, l , (where d and l are at right angles) and surface resistivity, ρ_s , is represented as:

$$R = \rho_s l/d \quad (\text{Eq. 8})$$

In measuring this resistance, it is assumed that current flows along the direction of length, l , in response to a voltage applied to the edge of width, d . For a more arbitrarily shaped component the current flow is more complicated, but the resultant total resistance between the two points of measurement is still the relevant quantity.

NOTE: There is a standard surface resistance test with a 10:1 ratio of d and l . When using the term surface resistance, it is necessary to be clear whether a general value, or this specific test value, is intended. The general meaning is used throughout this Recommended Practice.

The unit of measure is the ohm (Ω).

See also volume resistivity, volume resistance, and surface resistivity.

3.46 SYSTEM

A combination of components and assemblies that accomplishes the full function of the subject system, including interfacing with features outside of the system that may be required to accomplish a vehicle function level. (Examples are fuel [liquid] system and powertrain system.)

3.47 VEHICLE GROUND

Basic metallic structure of the vehicle that includes such major elements as chassis, engine, and body that are electrically bonded to each other and to the negative terminal of the battery. (Note that "chassis ground" is often used and is considered synonymous with vehicle ground.)

3.48 VIRTUAL CHARGE (ALSO CALLED MIRROR CHARGE, INDUCED CHARGE, OR CHARGE BY INFLUENCE)

Conductive bodies near a charged object tend to acquire a charge of opposite sign (virtual charge) under the influence of the electric field created by the charged object. Under some circumstances, discharges can occur from the object with the virtual charge. For example, a plastic fuel tank can contain a large charge during refueling with no adverse effects inside the tank. However, an ungrounded metal object near the tank exterior can acquire a virtual charge and discharge, possibly igniting vapors resulting from the refueling event.

3.49 VOLUME RESISTIVITY

A property of a material indicating how strongly it opposes the flow of electric current through it; denoted by ρ_v , the reciprocal of conductivity.

$$\rho_v = R(A/L) \quad (\text{Eq. 9})$$

where:

R = resistance

A = minimum cross sectional area through which the current flows

L = mean length of part in the direction of current flow

The unit of measure is the ohmmeter (Ω -m).

See also resistance, surface resistance, volume resistivity, and surface resistivity.

4. RECOMMENDED PRACTICES FOR MINIMIZING ELECTROSTATIC CHARGE ACCUMULATION

Uncontrolled electrostatic charging in liquid fuel systems can have damaging effects on vehicle systems including:

- i. Electromagnetic interference (EMI) effects on electronic components and computers up to, and including, component damage.
- ii. Electrical erosion of fuel system components resulting in pinhole leaks.
- iii. Unintended ignition of combustible air-fuel mixtures that might occur under certain conditions.

This document recommends the use of materials, components, and fuel system designs that can help prevent the above-mentioned damaging effects as follows:

- a. Reducing charge separation.
- b. Reducing charge accumulation.
- c. Recombining separated charges.
- d. Preventing discharge.

NOTE: Fuel is a highly significant variable that controls whether harmful electrostatic charges develop or not. Marketplace fuels are constantly being revised to address issues relating to emissions, economics, climate change, etc.; for example, ultra-low sulfur diesel (ULSD) and biodiesel. The effect of changes to marketplace fuel must be continuously monitored for their effects on any given fuel system design particularly those that are not fully compliant with 4.1.

4.1 Specifications for Materials, Components and Subsystems to be Used in Conjunction with Resistance and Resistivity Tests

NOTE: Each of the following recommendations apply unless they individually can be shown to be unnecessary, as described in 4.2.

4.1.1 Recommendations for Flow Channels

For all flow channels within the fuel system that are specifically designed to transport fuel from one component to another, the electrical resistance measured between points A and B and between points A and C must not exceed $1 \times 10^8 \Omega$ (100 M Ω) when measured by procedure 5.2. Definitions of point A, B, and C are as follows:

Point A: Any point on any surface that is in contact with flowing liquid fuel and is part of a grounding strategy for the fuel system (see 3.32).

Point B: Vehicle ground (see 3.46).

Point C: Any metallic component with a capacitance greater than 3 pF located within 25 mm of any ungrounded or non-conductive component in the fuel system that could develop a virtual charge from within the fuel system. See A.2.1.3.

NOTE: The above must be verified as installed in a representative vehicle environment.

4.1.2 Recommendations for Filler Nozzle Grounding

The electrical resistance measured between a typical marketplace nozzle inserted into the filler pipe (point A above) and the vehicle ground (point B above) must not exceed $1 \times 10^6 \Omega$ (1 M Ω) when measured by procedure 5.2.

The electrical resistance measured between a typical marketplace nozzle inserted into the filler pipe (point A above) and a metallic plate on which each tire sits in succession must not exceed $5 \times 10^8 \Omega$ (500 M Ω) measured with up to 1000 V applied and with all other tires sitting on an insulating surface. (Refer to ASTM D991.)

4.1.3 Recommendations for Conductive Components Inside the Fuel Containment Boundary

The resistance between installed conductive components and vehicle ground (with all relevant ground connections in place) must not exceed $1 \times 10^8 \Omega$ (100 M Ω) when measured by relevant procedure of 5.2.

4.1.4 Durability Recommendations

The recommendations of 4.1.1, 4.1.2, and 4.1.3 should be met for the vehicle life under expected conditions of vehicle usage, representative of the marketplaces in which the vehicle is intended for sale and at the time of initial retail sale. The fuels and exposure conditions to be considered to meet this recommendation should be agreed upon between the end user and the producer of a particular component or subsystem (see 5.4).

4.1.5 Component Recommendations

The off-vehicle (i.e., bench test) performance of individual components and sub-assemblies that contribute to compliance with 4.1.1, 4.1.2, and 4.1.3 must be separately verified by means of a specified test procedure. Such specification must include details of simulated or actual mating component(s) where these form part of the required electrical path. Except where otherwise determined by expert testing and/or expert judgment, one of the following acceptance criteria must be applied:

- a. The resistance between any point on a component and a ground point on the same component must not exceed $1 \times 10^6 \Omega$ (1 M Ω) as measured by procedure 5.2.3. (Examples of a ground point for a component may include the fluid inlet or outlet, if mounted on metal brackets, or a designated vehicle ground point, if separately provided.)
- b. The static dissipation time of the component as measured by the procedure specified in 5.3 (the decay time required for the charge level to reach 10% of an initial value of the applied voltage) must not exceed 0.5 second.

NOTE: The resistance criterion is considerably more conservative than the dissipation time criterion in order to allow for the simplified resistance measurement procedures; thus, the resistance limits are reduced by a factor of ten below what is strictly necessary (see B.1.4 for details).

4.1.6 Material Recommendation

The relevant electrical properties (i.e., surface resistance and/or volume resistivity) for each individual material that contributes to compliance with 4.1.1, 4.1.2, and 4.1.3 must be separately verified by means of the test procedures specified in 5.2.2 and (for fuel-exposed testing) 5.4. Except where otherwise determined by expert testing and/or judgment, and except where susceptibility to prolonged fuel immersion is found, the following must be applied to virgin material that is representative of the intended production process:

- a. Volume resistivity must not exceed $1 \times 10^4 \Omega\cdot\text{m}$. See 3.49.
- b. Surface resistivity must not exceed an empirically derived value consistent with the recommendations of 4.1.5. See 3.4.5.

Examples of appropriate test methods are given in 5.2.2.

The effect of prolonged immersion in fuels must be evaluated by physical testing as described in 5.4. If this immersion adversely affects the material such that the recommendations of 4.1.1, 4.1.2, or 4.1.3 cannot be reliably met, then the recommendations provided in 4.2 must be invoked.

Materials and combinations of materials must be specified such that the recommendations of 4.1.1 to 4.1.5 can be met.

4.2 Specifications for the Limits on Electrical Charge Accumulation and Transfer

Designs that do not conform to the recommendations of 4.1 might, nevertheless, be judged acceptable on the basis of the criteria and testing presented in this section. Verification testing to demonstrate compliance with this section and engineering judgments made on the basis of such testing require specialist personnel with the appropriate knowledge, experience, test equipment, and testing environment. See Appendices C and D for further details.

Examples of designs or circumstances that meet the criteria stated in 4.2 and therefore do not have to meet the recommendations of 4.1 are presented in Appendix E.

4.2.1 Vehicle Grounding During Refueling

If the tire or nozzle contact resistance does not meet the requirements in 4.1.2, it is necessary to verify through flow testing, as referenced in 5.5 and described in Appendix D, that the stored energy on the vehicle does not exceed 0.2 mJ or that the potential on the vehicle does not exceed 1000 V (1 kV).

4.2.2 Conductive Components That Do Not Meet the Recommendations of 4.1

All of the following must be demonstrated by means of suitable testing involving expert practitioners:

- a. Charge accumulation on such components cannot result in a spark discharge having an energy exceeding 0.2 mJ in a zone that could contain a flammable atmosphere.
- b. Discharges that would cause “significant cumulative damage” to materials over the intended operational life cannot occur from the component. In this context, “significant cumulative damage” is that which could cause potential migration of fuel, unless the migration of the fuel does not have reasonable safety implications.
- c. Discharges that would cause damage to electronic systems over the intended operational life cannot occur.

Items b. and c. apply regardless of the presence of a flammable atmosphere.

NOTES:

For components or assemblies that are inaccessible to people while the engine is running or during re-fueling, it may be possible to meet the criterion in item a., even if the stored energy exceeds 0.2 mJ. For example, the objects may have large radii of curvature and/or be separated by large gaps such that the voltages and electric fields are too low for breakdown.

For components that are accessible to people (e.g., those around the filler opening), the discharge geometry cannot be predicted in advance (e.g., people may introduce metal tools). In these areas of unknown geometry, the only way to ensure that discharge energies cannot exceed 0.2 mJ is to ensure that the stored energy on every ungrounded metal component or sub-assembly is less than 0.2 mJ (here, ungrounded sub-assemblies that are bonded together should be considered as a single item, and the total energy on the whole bonded item must be used in the assessment).

4.2.3 Non-Conductive Components

Both of the following must be demonstrated by means of suitable testing involving expert practitioners:

- a. Brush discharges with charge transfers that exceed 60 nC in any one event cannot occur with any foreseeable fuel in any zone that could contain a flammable atmosphere.
- b. Regardless of the presence of a flammable atmosphere, discharges cannot occur that would cause cumulative damage to materials over the intended operational life, which could cause unspecified migration of fuel, unless such migration has no reasonable safety implication.

5. TESTING PROCEDURES

5.1 General Comments for Resistance and Static Dissipation Testing

5.1.1 Instrumentation

Instrumentation details can be found by consulting the various test procedures referred to throughout the text. Whatever instrumentation is utilized, the user should refer to the manufacturer's instructions and follow them carefully.

5.1.2 Sequence of Testing

The suggested sequence of testing for components is as follows:

- a. Measure resistance first. If the resistance meets the acceptance criterion, then no further testing is necessary.
- b. If the resistance does not meet the acceptance criterion, then perform a static dissipation test.

If the requirements of either the dissipation test or the resistance test are met, then the component or material is considered acceptable. This order of testing is implied in 5.2 and 5.3, and specifically mentioned in 5.4. If the OEM/end user and the supplier agree, then the sequence can be changed to include only the static dissipation test or only the resistance test.

5.1.3 Sequence of Voltage Level Utilized

Whenever a test procedure includes more than one level of voltage, the lowest must be utilized first. Subsequent voltage levels must then be increased stepwise up to the highest indicated level.

5.2 Resistance and Resistivity Test Procedures

5.2.1 Factors that Influence Measured Resistance Values

Measured resistance values can be influenced by a number of factors including:

- a. Sample preparation
- b. Relative humidity (see C.2.2.1.1, in particular)
- c. Temperature
- d. Test voltage
- e. Electrode configuration

Consequently, the steps of a specific procedure must be followed carefully. All the considerations and guidelines of Appendix C must be followed to ensure the accuracy and repeatability of the measurements taken.

When results are obtained, the conditions of the test and other pertinent factors must also be recorded (see 5.6).

5.2.2 Test Procedures for Materials

5.2.2.1 Surface Resistivity/Resistance

To measure the surface resistance of the material, follow the procedure described in ESD STM 11.11. The following modifications to the standard procedures must be used for conductive or dissipative materials:

5.2.2.1.1 Instrumentation

The instrumentation must be capable of taking measurements from less than $1 \times 10^3 \Omega$ to greater than $5 \times 10^8 \Omega$. A humidity/temperature meter is recommended to record the test conditions.

5.2.2.1.2 System Verification Fixtures

This fixture need only conform to the lower resistance range fixture specified in 6.4.1 of ESD STM 11.11.

5.2.2.1.3 Test Specimens

Procedures must be performed on flat plaques that are molded without use of mold release using recommended molding conditions for the material being tested. The dimensions of the plaques must be 70 to 80 mm wide, 120 to 130 mm long, and 3 mm thick.

5.2.2.1.4 Test Procedure

Measure and record the resistance after 5 seconds using a voltage that is as low as practical (at no time should this voltage exceed 100 V). If the instrumentation cannot measure resistance below $1 \times 10^6 \Omega$ using 100 V, report only lower voltage measurement. If the resistance is very low and no resistance value can be measured, then report the results as < (lowest meter reading) Ω .

See 4.1.6 for guidelines on acceptance criteria for measured resistivity values.

5.2.2.1.5 Volume Resistivity

Refer to ASTM D4496 specification, with the following modifications for conductive or dissipative materials:

5.2.2.1.6 Relating to Sample Preparation

- a. Accepted methods for reading the volume resistivity of a material include breaking the surface, painting silver paint for contact, and/or puncturing surface electrodes such as described in ASTM D4496.
- b. In order to account for surface effects caused by moisture, dirt, oil, and skinning effects caused by molding conditions, the volume resistivity must be measured through the volume by some means of breaking the surface. Sample preparation is outlined in Annex A1 of ASTM D4496; further information can also be found in C.2.2.1.1.
- c. ISO or ASTM tensile bars are molded on a standard injection-molding machine without mold release. A total of ten bars are molded for each resistivity test. The bars are then placed into a jig, cut with a razor knife, and the two ends are removed. This leaves the middle 60 mm of the tensile bars.
- d. The broken ends are painted with conductive paint, along with 4 mm wide stripes across the face of the bar, 3 mm from each end. The paint is allowed to dry for a minimum of 1 hour.

5.2.2.1.7 Relating to the Test Procedure

- a. With the test apparatus set at the lowest voltage range resulting in a measurable current, the current in milliamps (mA) through the volume of the part and across the surface of the part is determined.
- b. During the test, the voltage used must be recorded, and must be greater than 9 V, and no more than 510 V.

See 4.1.6 for guidelines on acceptance criteria for measured resistivity values.

5.2.3 Resistance Tests for Components (Not Installed in the Vehicle)

The following test procedures must be followed for measuring the resistance of components where they have not been exposed to fuel. When fuel exposure has occurred, follow the test sequence of 5.4.

5.2.3.1 Test Procedure

See C.2.2.1.2 for recommendations concerning clamps and contacts.

Place the component being measured on a surface having a resistance at least two orders of magnitude higher than the upper resistance limit (greater than $1 \times 10^{11} \Omega$ is suggested).

Verify the test set up by clamping the electrodes to a 100 M Ω , 1% resistor and measuring its resistance at a low level of voltage, 10 V, 100 V, or 1000 V (if available, 10 V is recommended).

Connect the positive electrode to the designated point where a measurement is to be taken. The electrode must have a contact surface of $18 \text{ mm}^2 \pm 0.5 \text{ mm}^2$. Connect the meter lead to its banana jack. For most tests, more than one ground connection may be required to match the links that will exist when the component is mounted in the vehicle. The contacts for these links should be provided in a realistic way and should be brought to a common point to which the negative electrode must be connected.

In all cases, make sure that the contact electrodes sit as flat as possible and make maximum surface contact with the part.

If the part has a metal ground strap, take measurements at the point on the plastic part where the ground strap is attached, and also at the point on the strap where the strap is connected to the vehicle.

If the resistance meter used designates “source” and “sense” inputs, connect the voltage source to the positive electrode and the “sense” input to the negative electrode.

If the resistance meter used allows manual selection of the test voltage, select the lowest level of voltage (identified in 5.2.3.1). Apply the voltage for 5 seconds, then take and record the reading. If the reading is unstable and the values drift outside the acceptable range, record the reading as “unstable.” If the reading is stable or unstable but all values are less than or equal to the acceptance criterion, the test is passed, and no further measurements are needed. If the reading is unstable with values outside of the acceptable requirement, or stable but greater than the acceptance criterion, repeat the test at successively higher voltage levels at the settings available on the insulation/megaohm meter being used (e.g., 100 V, 250 V, 500 V, and 1000 V).

If the reading at any voltage up to 1000 V is stable and less than or equal to the acceptance criterion, the test is passed. The test is failed if all readings are above the acceptance criterion or are unstable for any reason other than those given in the note below. The recorded resistance value is that obtained at the highest voltage that gives a stable reading.

For acceptance criteria, see 4.1.

NOTE: Parts that exhibit unstable resistance values during measurement are considered acceptable for use if any of the following are true:

- A measured resistance may be unstable at lower voltage levels, but stable and within the specified limit at 100 V or 1000 V.
- The resistance may be below the measurement capability of the instrument (e.g., less than $1 \times 10^3 \Omega$) at the lower voltage level or at 100 V. If so, record this fact in the data.

5.2.4 Resistance Test for Installed Components, Assemblies, and Systems

5.2.4.1 Test Procedure and Voltage

The procedure is the same as 5.2.3 with the following exceptions:

The test item must be installed in the vehicle rather than lying on an insulating surface.

Complete assemblies with several interfaces may have higher resistance than individual components. Consequently, it is more likely that voltages of 1000 V will have to be used. The maximum current when measuring at 1000 V must not exceed 1 mA. Extreme care must be exercised when testing at this voltage. DO NOT touch the electrodes while the measurement is being taken.

5.2.4.2 Test Setup

5.2.4.2.1 The aim of testing is to measure the highest resistance to vehicle ground from any point on the installed assembly/system. Therefore, the setup must include the ground path connections that would occur on the vehicle. Make sure all ground connections are secure during the test.

5.2.4.2.2 If serviceable fluid couplings are part of the system/assembly being tested, then those couplings must be set up in a way that simulates how they would be configured during vehicle operation. For example, a pressurized system will extend metal tubing slightly within a connector. Thus, it would be acceptable to pull the metal tube so it “bottoms out” within the connector. It is also acceptable to apply up to a 2 N side load to the barbed end of a fitting to create the type of internal contact that would be present in the coupling “as installed” on a vehicle.

Care must be taken for environmental conditions of testing to be controlled adequately. (See C.2.2.1.1.)

5.3 Static Charge Dissipation Test Procedure for Components

5.3.1 Sample Preparation

Prepare the samples to be tested in the same manner as described in 5.2.3 for parts not assembled in the vehicle.

5.3.2 Calibration/Verification

Verify the test set up by measuring the dissipation time for a 10 M Ω , 1% resistor. Connect the positive electrode to the charge plate monitor (CPM) detector plate and the resistor. Connect the negative electrode to ground such as the ground connection at the wall outlet. If a battery powered CPM is used, make sure it is also connected to ground. Leave the clamp unconnected.

Set the measurement parameters for voltage level up to 5000 V. Using 5000 V as an example, the actual charging voltage is approximately 5300 to 5600 V or more, but the decay time measurement starts when the voltage on the plate reaches 5000 V. Set the stops to 10% of the initial applied voltage as the cut off value (500 V in our example). Apply the charging voltage for approximately 2 seconds. Release the “arm” button and quickly connect the grounded negative electrode to the resistor. Record the dissipation time. Repeat the measurement three times. Dissipation time must be less than 0.5 second. If a grounding module is used, charge the system as above then depress the “reset” push button and record the reading from the device.

NOTE: Do not use the grounding function of the CPM to perform this test. This function only grounds the detector plate.

5.3.3 Test Procedure

Connect the electrodes to the assembly in the same manner as outlined in 5.2.3.1 (including the reference to C.2.2.1.2 for clamp and contact details). Place the assembly on a highly insulative surface having a surface resistivity greater than 10¹² Ω , such as acrylic, PTFE, polycarbonate, etc., to ensure there is no secondary leakage path for the applied charge to bleed off.

Apply the charging voltage for approximately 2 seconds. Immediately ground the assembly by clamping the negative electrode to the desired point. Repeat the measurement three times and record the results.

If the grounding module is utilized follow the same procedure described for system verification.

5.3.4 Acceptance Criteria

See 4.1.5.

5.4 Test Procedures for Fuel Exposed Components

When testing parts or materials that have been exposed to fuel, a maximum relative humidity must be specified by the OEM/end user due to the effects of fuel exposure on material properties of the components under test. (See Appendices C and D.)

5.4.1 Types of Fuel

The test fluid used in exposure testing must be a non-alcohol containing fuel such as test fluid C, U.S. EPA certification gasoline, or similar grades per SAE J1681. Alcohol fuels can be used in exposure testing, but care must be taken because results can be misleading. (See A.5.1.) If exposure to alcohol fuels is required by the end user, the specific sequence of testing described in 5.4.4 and 5.4.5 must be followed. (Specific fuels to be used should be decided between the OEM/end user and the producer.) Whenever handling fuel in any situation, the appropriate safety measures must be taken.

5.4.2 Fuel Soak Preconditioning

The time and temperature used to pre-condition the components in the fuel are to be decided between the OEM/end user and the producers. The time and temperature chosen must be sufficient to allow the fuel to fully equilibrate with the materials prior to testing.

5.4.3 Time After Fuel Exposure

The time between completion of fuel exposure and the start of the test procedures must be as short as practical and consistent with safe laboratory practice. Minimizing the time between removal from fuel soak and electrical testing will minimize the changes that can occur due to fuel evaporating out of the material; thus, the time must not exceed 2 hours.

5.4.4 Recommended Test Sequence

When exposure to fuel is required, resistance can increase; for example, due to swelling of a material. If capacitance decreases at the same time, then the rate of electrostatic charge dissipation can improve even though resistance may have increased to a level that might be considered unacceptable when compared to test results for unexposed conditions. For these reasons, the sequence of tests identified in 5.4.5 is recommended for fuel-exposed components.

5.4.5 Components/Assemblies Tests (after Fuel Exposure)

- a. Measure the resistance first as in 5.2. If acceptable values are obtained, then no further testing is needed (the component is acceptable).
- b. If the resistances do not meet the acceptance criteria, then conduct the appropriate static decay test as in 5.3. If the results of static decay tests are acceptable, the component performance is considered acceptable.

5.5 Flow Test Procedures

Flow test procedures for the approach outlined in 4.2 are not sufficiently well defined to be described as standard test methods. Therefore, detailed procedures are not given in the main body of this standard. However, there are basic minimum requirements that must be met by any successful flow test procedure; these are given Appendices C and D.

5.6 Recording and Reporting Results

For any procedure that is performed, the specific results must be recorded and retained for future consideration. In addition, there are a number of other factors that must be recorded and included when results are reported to an interested party. The level of data required for processing is a function of end user requirements. The following list is recommended (key parameters are discussed in Appendix C).

- a. The specific procedure performed.
- b. Date, time, and location.
- c. The specific instrumentation used.
- d. Electrode configuration or any other pertinent details about the nature of the contacts made.
- e. Environmental conditions of the test (temperature and relative humidity at a minimum). (See A.5.2 and C.2.2.1.1.)
- f. Specific test voltages and the sequence in which they were used.

- g. Specific resistance meter range if selected manually.
- h. Description of the test sample used and how it was prepared for the procedure. If components or assemblies were used, an adequate description of those components or assemblies must be included.
- i. For any procedures involving fuel or test fluid, the description of the type of fuel or test fluid and the nature of the exposure (time, temperature, etc.) must be included. Additionally, the length of time between fuel or test fluid exposure and conducting the test procedure must also be provided.
- j. For flowing fuel/fluid tests:
 - i. The conductivity of the fuel or test fluid.
 - ii. The level of streaming current that was generated and the means of generating it.
 - iii. Details of any pass/fail criteria employed.

6. NOTES

6.1 Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. However, this revision is so extensive that changes bars have not been used. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications nor in documents that contain editorial changes only.

PREPARED BY THE SAE J1645 TASK FORCE OF THE SAE FUEL SYSTEMS TECHNICAL
STANDARDS COMMITTEE

APPENDIX A - BACKGROUND INFORMATION

A.1 GENERAL COMMENTS

A.1.1 Liquid Fuel Phenomenon

Electrostatic charge separation can be generated when sufficiently non-conductive materials move past each other in a shear mode. The effect can occur both at solid-solid interfaces and at solid-liquid interfaces such as those between fuel system components and liquid hydrocarbon fuels including biofuel blends. Charge generation does not occur to any significant degree in gases that flow at rates encountered in fuel vapor management systems; therefore, fuel vapor systems are not affected.

A.1.2 Development of Electrostatic Charge

There are two primary functional areas of fuel systems where an electrostatic charge might develop:

- a. The vehicle liquid fuel delivery system.
- b. The refueling system.

During refueling, electrostatic charges can be produced by:

- a. Charges introduced into the fuel as it is pumped through fuel dispensing equipment.
- b. Charges introduced into the incoming fuel as it flows through the fuel filler neck into the fuel tank.

A.1.3 Background Literature

Five documents that offer extensive background information on the electrostatic charge phenomenon are:

- a. NFPA 77 - National Fire Protection Association - Recommended Practice on Static Electricity 2000 Edition.
- b. American Petroleum Institute - Recommended API RP 2003, 7th ed., Jan 2008 - "Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents."
- c. Electrostatic Ignitions of Fires and Explosions. American Institute for Chemical Engineers - Center for Chemical Process Safety; Thomas H. Pratt, PhD, PE.
- d. Avoiding Ignition Hazards in Chemical Operations. American Institute for Chemical Engineers - Center for Chemical Process Safety, Laurence G. Britton.
- e. CLC/TR 50404 Electrostatics - Code of Practice for the Avoidance of Hazards Due to Static Electricity.

While these publications do not specifically address automotive applications, they contain thorough discussions of the physics of the electrostatic charge phenomenon as well as recommendations for preventing or mitigating the formation of significant electrostatic charge accumulation. For additional background, the references cited in Section 2 may also be consulted.

A.2 HOW FUEL SYSTEM COMPONENTS CONTRIBUTE TO THE ELECTROSTATIC CHARGE PHENOMENON

A.2.1 The Four Processes

Electrostatic charges can be generated in a fuel system by fuel flowing against and through fuel system components. Due to subtle chemical, electrical, fluid, and thermal forces, a charge separation occurs between the liquid and the surfaces the liquid contacts. Local velocity conditions can further enhance the separation of charges contributing to an electrically unbalanced condition. Each component of a fuel system can participate in this phenomenon in one or more of the following four processes.

A.2.1.1 Charge Separation

The interactions between flowing fuels and the solid surfaces of the fuel delivery system or vehicle fuel system components can lead to the separation of (initially balanced) charges of opposite polarity at contact surfaces. This allows both the fuel and the fuel system components to develop electrostatic charges. Significant electrostatic charging is associated mainly with the action of flowing, low-conductivity fuels (with conductivity ranging between 5×10^{-11} siemens per meter (50 pS/m) and 2.5×10^{-10} siemens per meter (250 pS/m)).

A.2.1.2 Charge Transport

Separated charges move from one part of the system to another, within the flowing, low-conductivity fuel, and conductive or semi-conductive fuel system components.

A.2.1.3 Charge Accumulation

Separated charges can accumulate in areas with a poorly conductive path to vehicle ground. These accumulations grow until the rate of dissipation (determined by the resistance of the conductive path to vehicle ground) equals the rate of accumulation or until some limiting mechanism (such as an electrical discharge) causes a sudden reduction in the accumulated charge.

For example, a plastic fuel tank may become charged by fuel entering it during refueling and that charge could remain in place until it is dissipated through the fuel to the (grounded) sender unit.

NOTE: The exterior surface of the tank will exhibit a virtual charge (due to dielectric polarization) that is of similar magnitude, and of the same polarity as the interior charge. Nearby ungrounded metal components will become polarized by the charge in the interior of the tank and discharges may occur from the ungrounded metal component either to the surface of the tank, or to other nearby grounded metal components.

A.2.1.4 Charge Dissipation

Dissipation is the gradual loss of electrostatic charge to regions where it can recombine with charge of the opposite sign or give rise to only a low voltage (e.g., by arriving at a location where the capacitance to ground is high). Mechanisms of dissipation are discussed in Section A.3.

A.2.2 Contributions of Various Components

Tables A1 and A2 present the relative contribution of fuel system components to the processes described in A.2.1.

Table A1 shows the relative contribution of the various components of an operating fuel delivery system to electrostatic charge processes. Note that the information in Table A1 is independent of the information in Table A2.

Table A2 shows the relative contribution of the various components of a vehicle's fuel system to electrostatic charging processes during refueling. Note that the information in Table A2 is independent of the information contained in Table A1.

**Table A1 - Relative contribution of fuel system components
to electrostatic charge processes during operation
of the fuel delivery system**

DEGREE OF CONTRIBUTION OF VARIOUS FUEL SYSTEM COMPONENTS										
Charge Process	Tank (Containing Liquid Fuel)	Fuel Pump	Fuel Lines and Connectors Conductive (and Properly Bonded)	Fuel Lines and Connectors Dissipative (and Properly Bonded)	Fuel Lines and Connectors Insulative	Fuel Filter Conductive (and Properly Bonded)	Fuel Filter Dissipative (and Properly Bonded)	Fuel Filter Insulative	Fuel Rail ⁽¹⁾	Pressure Regulator
Separation	---	Large	Small to Medium ⁽²⁾	Small to Medium ⁽²⁾	Small to Medium	Very Large	Very Large	Very Large	---	Medium
Transport	---	Medium	Large	Large	Large	Medium	Medium	Medium	Small ⁽²⁾	Medium
Accumulation	Medium	Small	---	Small	Medium	Small	Medium	Very Large	Small	Small
Decay or Dissipation	Large	Small	Medium	Medium to Small	Small	Medium	Medium to Small	Small	Medium	---

⁽¹⁾ Contribution depends on type of material.

⁽²⁾ Degree of grounding to the engine block depends on configuration.

**Table A2 - Relative contribution of fuel system components
to electrostatic charge processes during the refueling process**

DEGREE OF CONTRIBUTION OF VARIOUS FUEL SYSTEM COMPONENTS					
Charge Process	Filler Neck Conductive (and Properly Bonded)	Filler Neck Dissipative (and Properly Bonded)	Filler Neck Insulative	Fuel Tank (Containing Liquid Fuel)	Fuel Sending Unit
Separation	Small	Medium	Large	Small	---
Transport	Medium	Medium	Medium	---	---
Accumulation	---	Small	Medium to Large	Large	Small
Decay or Dissipation	Large	Small	---	Medium	Large

Tables A1 and A2 describe components as "insulative," "dissipative," or "conductive." These terms are given in 3.34, 3.21, and 3.13, respectively. Material properties are usually measured on samples that have not been exposed to fuel and properties may be altered by fuel exposure. Experience has shown that fuel system materials do not need to exhibit the high levels of conductivity associated with "conductive," such as metals, in order to avoid the adverse effects of electrostatic charging. It is sufficient for them to have the intermediate, "dissipative" level of conductivity.