Electrostatic Discharge Testing for Automotive Applications

Understanding Differences from Commercial ESD Testing is Key to Successful Compliance

by Martin O'Hara

The international automotive ESD standard (ISO 10605: 2001) has significant differences from the commercial ESD testing standard (IEC 61000-4-2). Differences include the human body model (HBM) used to simulate a person's electrical network and the utilization of significantly higher discharge voltages, up to ±25kV air discharge.

Why is the automotive standard so different? Does it make sense for it to be different and what are the implications for testing to this standard for non-automotive applications?

This article aims to examine the differences and consider why they exist. The test methods will be explained and the similarities between the automotive and commercial product standards also highlighted. A discussion will also be forwarded on why other non-automotive products might be improved if they were designed to meet the automotive ESD standard and why this standard might be more appropriate in some non-automotive situations than IEC 61000-4-2.

Background

The automotive ESD standard (ISO 10605: 2001) is based on similar models and premises as the commercial standard, essentially derived from IEC 801-2:1991 (Electromagnetic compatibility for industrial process measurement and control equipment – Part 2: Electrostatic discharge requirements, now IEC 61000-4-2). The test simulates the effect of a human body discharge of static electricity, a relatively common occurrence experienced by most vehicle users, usually when entering or exiting the vehicle.

Until 2001, the standard was only released at the level of technical report (ISO TR 10605: 1994) and had not been fully adopted as an international standard. The changes between 1994 and 2001 were mainly the inclusion of an unpowered ESD test that reflects handling of an electronic sub-assembly (ESA) while in transit or during assembly fit (i.e., not in-situ on the vehicle). The ISO 10605 standard includes testing on-vehicle as well as testing of individual ESAs.

The standard was widely used by vehicle manufacturers (VMs) prior to its full adoption by ISO and included within many VM EMC specifications, including the unpowered test before this was included in this ISO standard. The unpowered test was also included in the U.S. automotive ESD standard SAE J1113-13 prior to the adoption by ISO.

The Human Body Model

The human body model (HBM) consists of a single capacitor that is charged up to the required test voltage, and then discharged through a series resistor to the ESA under test, simulating the charge accumulation on a person then discharge to the ESA/vehicle. Although the HBM premise and component types are the same as commercial standards, the HBM component values are different for the automotive test, in particular the resistance is typically several hundred Ohms in commercial test standards (330Ω) rather than 2kΩ used for vehicle test.

At first, many observers coming from the commercial field have difficulty understanding why the HBM has different values. The commercial standard is derived for products that essentially have a reference that can connect directly or indirectly to the ground/earth reference that the body has been charged in reference to. However, in an automotive application, the vehicle and/or ESA during handling is in fact isolated from the earth reference. Hence, the discharge is capacitor (human) to capacitor (ESA or vehicle). Consequently, not only does it make sense for the HBM to be different for the automotive environment, it would be wrong to test automotive components with the earth referenced discharge model of the commercial standard. It could even be argued that any equipment that is powered solely by battery power should also be only tested to this automotive ESD standard rather than the commercial IEC 61000-4-2.

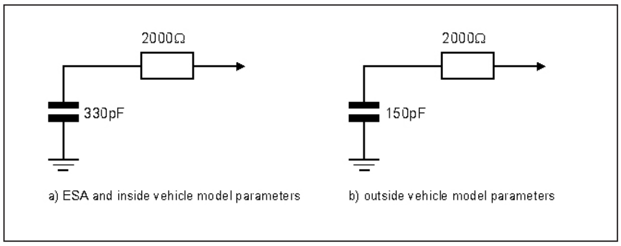

Figure 1: ESD Models

Some commentators believe the higher resistance gives the impression that automotive ESD is an easier standard to meet than commercial ESD. However, the discharge voltages are higher (up to ±25kV), hence the actual energy impact is similar. In fact, most automotive ESAs tend to have a higher immunity to ESD in practice than many commercial equivalents when tested under the same discharge and HBM conditions.

Test Equipment

The test equipment for ESD testing is relatively simple in comparison to most EMC tests. The tests can be performed over a simple 1mm thick metal ground plane at least $1m^2$, and the ESD discharge device (usually termed an ESD "gun") consists of a power supply capable of generating the appropriate test voltage and a test discharge head containing the appropriate human model components with switch. The tests do not need to be conducted in a screened room, although this is occasionally the case within test laboratories as the air discharge tests can register as radiated noise on nearby sensitive receivers if not shielded.

The ESD power supply should to be capable of generating ±25kV to meet ISO 10605 requirements, although this level may not be required for many tests. The discharge head is usually changeable with loads for the 2 human body models (both resistor and capacitor are usually contained in the test head) and combined with a spherical test probe for air discharge and a pointed probe for contact discharge (see Figure 2). These probes are identical to non-automotive ESD test probes based on IEC 61000-4-2.

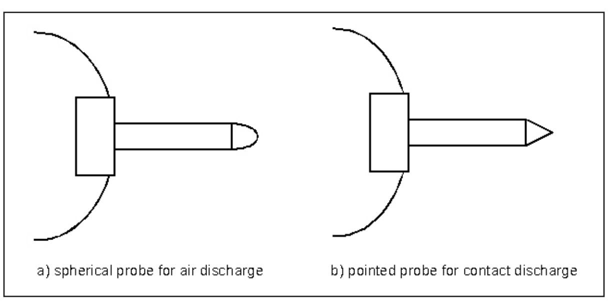

Figure 2: ESD Test Probes

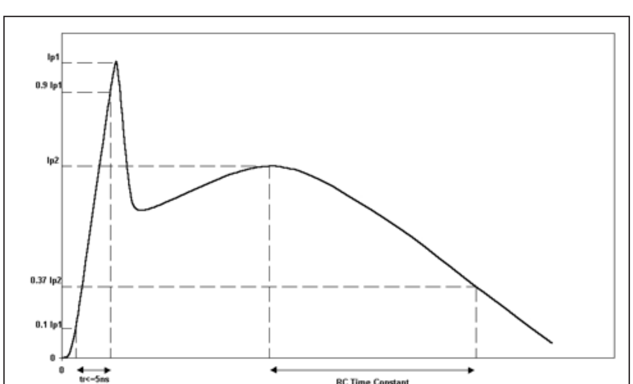

Figure 3: Test Pulse Shape

Test Pulse

The output pulse shape from the ESD gun is not usually displayed and, if it is, it is usually in volts, but the ISO standard gives the pulse shape in amperes for calibration purposes (see Figure 3). The automotive ESD test can appear less severe than some of the commercial standard tests, not only due to using a higher resistor value in the HBM, but also a slower minimum rise time of 0.7ns compared to 0.4ns that can be used in contact discharge in commercial standards. Rise time for air discharge is also relatively slow at under 5ns. These rise times are calibrated from test contact discharges into 2Ω test loads.

The slower rise time for air discharge reflects the isolation of a vehicle from the common "earth" reference. Even during transport and handling of ESAs (particularly user installed after-market products) the device is still isolated from the "earth reference." Hence, it could be argued that the automotive ESD standard is still applicable for any device (automotive or otherwise) that is either battery powered or handled when disconnected from its supply. As with most automotive EMC standards, there are options on the severity of discharge used (although not on the rise time itself).

The peak currents contained in the test pulse give some indication of how severe these tests can be and the peak current levels used in automotive ESD testing are comparable to commercial ESD standards.

The peak current is applied for a very short period if a discharge occurs (insulated bodied devices may experience no discharge), but this is followed by a longer discharge at lower current level after this initial peak (see Figure 3). The second discharge time is dependant on the human body model used (i.e. the capacitance of the model).

Test Voltage Level

There are 6 different voltage levels that can be applied to a powered ESA, depending on the severity level and the method of discharge (air or contact). There are 4 severity

Level	Indicated Voltage (kV)	First Peak Current (A)	Rise Time (ns)
1	2	7.5	0.7 - 1.0
2	4	15	
3	6	22.5	
4	8	30	

Table 1: ESD Test Pulse Parameters

Human Body Model	C (pF)	RC (ns)
a) Inside Vehicle	330	600
b) Outside Vehicle	150	300

Table 2: Time Constants for Human Body Models

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In Europe, call ar emv United Kingdom 441-908-282766 • ar emv France 33 -1-47-91-75-30 • emv Germany 89-614-1710 • emv Netherlands 31-172-423-000 classifications, labelled I to IV, but the standard contains no information on which to apply or how they reflect the place or function of the ESA on a vehicle. Unlike other EMC tests, the ESD test can not be as easily classified, for example safety critical ESAs may not have the highest severity test since these products are often the least accessible and consequently could have the lowest severity pulses applied if required.

Unpowered tests have an additional test voltage at ±25kV that is not used for powered ESA tests, but the number of severity classifications is reduced. The lowest and highest severity tests are comparable with the powered tests. It needs to be remembered that unpowered units have no direct return path for the static charge. Hence, often the higher voltage levels do not cause a problem, as the ESA may be uniformly charged and the differential potential across individual components can remain low.

On-vehicle tests have 5 test voltage levels in 4 severity classifications, encompassing the full voltage range available from the ESD test gun.

There is also a "manufacturer specified" option for the test severity level for all test types, where essentially any level the manufacturer requests are applied to the ESA or vehicle. The manufacturer may specify either lower or higher than the ISO 10605 standard, or just different.

Test Time

The minimum number of pulses is specified as 3 for all tests, but it is not unusual to attempt between 5 and 10 per test point. The minimum number of pulses applies to both polarities and to each test point, rather than each test level. Hence, if say 10 test points are determined for a single severity level, then at least 60 pulses should be applied (3 discharges of each polarity, 10 test points). Although ESD testing is generally quicker than most EMC testing, it is a manual test technique for the most part and can be quite laborious with a large number of discharges specified at each test point.

There is a minimum delay of 5 seconds between pulses, so with a large number of test points or discharges the test time can increase significantly. Increasing the delay between pulses can allow any static build up to discharge via leakage paths; however, 5 seconds is usually long enough and increasing the delay has little effect in practice. Unpowered tests require active discharging via a 1MΩ bleed resistor to prevent the build up of static due to successive discharges.

Severity

The severity levels are usually applied progressively (step-stressed). Hence, almost all ESAs are tested at ±4kV up to the highest required severity level. The discharge methods are also applied progressively, air then contact where severity levels are equal.

Severity for ESD tests should be applied by accessibility of the ESA. Hence, cabin mounted, driver or passenger accessible ESAs (ICE, HVAC, telematic units) should have the highest severity as these are likely to receive most impacts, as should door modules, security products, switchgear and instrumentation. Some VMs may classify ESAs accessible in the trunk (e.g., CD multi-changers, lighting modules) as "outside vehicle," and use the lower capacitance test head.

(*Note on step-stress testing*: The ISO 10605 standard only explicitly specifies step-stress testing for the unpowered test case. However, it can also be conducted for the powered test case. The main benefit of step-stress testing is that there can be an indication of the level at which an ESA can pass ESD testing if a failure occurs at the highest stress. The downside of step-stress testing is that the number of stresses applied to the ESA is significantly higher and this has a significant consequence on test time.)

Functional Status

There are 5 levels of functional status, the term concerns only the electronic functions of the ESA. The classes of functional status are common to the ISO standards for automotive EMC. Class A is the highest pass classification; basically, this is a device that can continue functioning, without exceeding any parametric limits, during a discharge. The lowest class E is essentially a catastrophic failure. The most common pass levels are class B where a device continues to work during an impact but may exceed some parameter (e.g., a HVAC system where the temperature control may loose accuracy during the discharge) and class C where a device may not function during a discharge but returns to normal operation afterwards (e.g., in-car entertainment that may switch off during a discharge but resumes afterwards). (The complete list of functional classifications for all the ISO automotive standards is given in the Sidebar to this article on page 20.)

The level of functional status after application of the ESD test pulse is chosen by the manufacturer; the status should reflect the expected operating classification of the ESA. The lowest status (class E) is basically a catastrophic failure and should be considered as such. ESD testing should not be catastrophic on the ESA. Hence, a suitable applied voltage level should be chosen and adhered to so that the ESA does not have to be tested to the highest available voltage level or to destruction.

ESAs that are intended to be constantly accessible while the vehicle is in use (i.e., cabin-mounted equipment) should be class A functional if they are safety related or affect the control of the vehicle (e.g., airbag sensors, instrumentation). Other cabin-mounted equipment that does not directly affect safety or control can be class B or class C functional (e.g., body or door modules, telematic units, in-car entertainment). Under hood and non-user-accessible body modules only require class C functionality since these will not be subject to discharge during normal operation (driving). Exceptions to this last suggestion may be the engine management unit and associated ESAs that need to be class A functional during servicing. (Although we all know that service mechanics adhere to strict ESD precautions!)

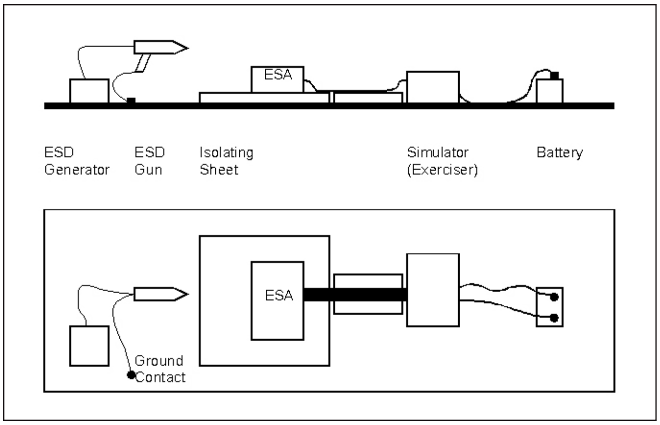

Figure 4: ESD Test Set-Up for Powered ESA Testing

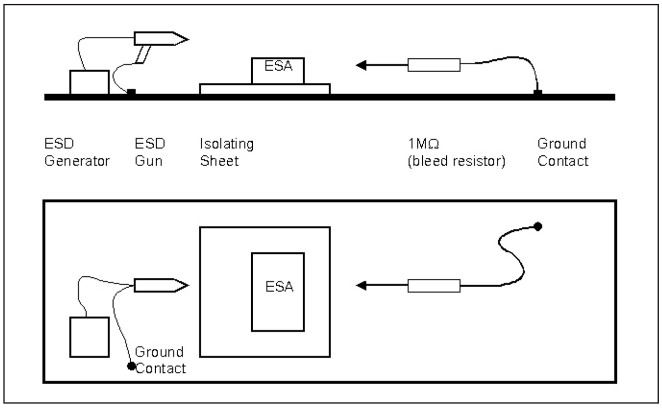

Figure 5: ESD Test Set-Up for Unpowered ESA Testing

Figure 6: Example of Proper Vehicle Grounding

Figure 7: Testing of Airbags Requires Special Care

Testing for Automotive ESD Immunity

Laboratory bench testing of an ESA is performed over a ground plane of at least $1m^2$ and 1mm thick, with over 100mm from the edge of the plane to the ESA, and connected to the facility ground by a strap of less than 2m in length and 50mm wide. Often, the facility grounding is made by multiple straps. The test equipment (ESD gun) is referenced to the ground plane directly. The grounding to the facility of the plane and test equipment is primarily for the safety of the test personnel rather than the ESA.

A metal-bodied ESA that is connected to the vehicle ground via the casing is connected directly to the test ground plane and may be placed directly on the plane for the tests. If the ESA casing is insulated from ground, such as a plastic bodied unit, the device is mounted on an insulated block (25mm high, extending 20mm beyond the ESA casing on all sides). If the ESA is insulated, the connecting control lines and support equipment are also usually mounted on insulating blocks (see Figure 5).

Powered Tests

The ESA is mounted approximately centrally on the ground plane, operating or powered and in an idle mode. Although operating during test and connected to a vehicle simulator, it is only the ESA that is tested and not its interface components or support equipment (the interface components should be independently tested and will be tested in-system during any on-vehicle tests). The test is intended to test discharge during operation. Hence, the ESA connectors are not accessible (unless exposed, e.g., spade connectors) to the test probe.

If there are obvious places to test a discharge (e.g., a hinge, opening, metal protrusion, metal fasteners), a test plan is drawn up and these places only need be tested. With no test plan, the ESA should be tested across the enclosure, but there are usually more obvious points to test, since even plastic enclosures have seams and entry/exit points for cabling.

Air Discharge: The spherical probe is brought to within 15mm from the ESA and the voltage applied. The tip is then moved towards the ESA until either a discharge occurs or the probe makes contact with the ESA without discharging.

Contact Discharge: The pointed probe is placed in contact with the ESA, and the discharge voltage applied.

If a discharge occurs, then the test is repeated at this voltage for the required minimum number of discharges, of both polarities. If no discharge occurs, the reverse polarity is attempted. If still no discharge has occurred, then the test at that test voltage can be abandoned at that test point and a pass assumed (although the comment “no discharge” should be recorded in the test report).

The operation of the ESA is usually examined after the completion of testing at each test point (i.e. after all discharges of each polarity at each test voltage). If testing for class A or class B functionality, the operation of the ESA has to be examined during ESD testing. This will most likely be via the support equipment, unless there is some other means of proving operation (e.g., flashing light/LED). It is particularly difficult to truly test if class A or B is achieved without some sophisticated test equipment connected to the ESA (digital multi-meters and/or oscilloscopes). Some of the parametric tolerances of the ESA can really only be tested with full automated test equipment and this is not often used during ESD testing (the test equipment itself may not be capable of surviving the discharges). Hence, class A or class B is essentially implied from available data.

Unpowered Testing

The testing of an unpowered ESA is similar to a powered unit, without the power! The support equipment is not required during the ESD test, only after each successive series of impacts, and the unit is discharged (charge-bled or drained) to ground via a 1MΩ resistor after each ESD discharge.

The ESA is placed approximately centrally on the ground plane on 25mm insulating blocks. The ESA has any charge dissipated after each ESD discharge via a 1MΩ resistor connected to the ground plane. This can be a simple leaded resistor and is contacted to the discharge test point.

Recessed pins are considered accessible during handling; if necessary, an insulated solid core (0.5mm^2 to 2mm^2 in cross-section, 0.8mm to 1.6mm diameter) wire up to 25mm long can be used to access these pins. If the recessed pins are in a grounded metal connector shell, not easily accessed with a finger, then these need not be tested. The majority of automotive connectors are plastic bodied and the use of a metal probe to simulate discharge to specific pins is a valid controlled approach, even though it is sometimes considered "unfair" by some ESA suppliers.

Functional testing is required before testing commences and after each test sequence. The ESA should be fully functional after the testing (effectively class A). There are really only two classifications for unpowered testing, the device either passes (class A) or fails (class E).

On-Vehicle Testing

Testing on-vehicle is always via air discharge. The test equipment will require grounding to the vehicle, usually to the chassis/body at an exposed metal point (a door hinge, lock hasp etc.). The test plan on-vehicle includes all accessible switches, buttons within the cabin and from outside the vehicle (door locks, braking systems, lamps). The term "accessible" includes items that can be reached through open doors and windows and items accessible under-hood and in the vehicle truck and/or cargo area. Externally accessed ESAs use the lower capacitance model.

(Note on testing airbags: As airbags are explosive devices, it is usual to have a remote arm to test the airbag sensors and locations around the airbag itself. The main reason for this

is to avoid potential injuries to the test personnel should an airbag deploy and the ESD gun is driven into the tester.)

Results

Tests are normally conducted up to a specified severity, typically after-market products at levels II or III depending on location and functional classification between A and C. Line fit products typically require the highest severity levels (III and IV) and often only class A or B functionality is accepted.

The ISO 10605 standard includes example test tables listing functional classification for various severity levels for powered ESA and on-vehicle tests. These are not particularly useful as they include the example of catastrophic failure for the highest severity level (see Table 6) and, as already mentioned, testing should not necessarily be destructive.

ESD testing is always done progressively, so the manufacturer only needs specify the highest severity requirement and acceptable pass criteria at this severity. A better example of a test specification is simply to specify the maximum level and acceptable functional classification (see Table 7). The test house will make an assessment of classification of pass regardless of what the supplier specifies.

The on-vehicle category is rarely supplied to a test house when an ESA is submitted for testing and the powered test is intended to be equivalent. On-vehicle testing is mainly performed by the VM or their test service, sometimes at a higher severity level than that to which the component was tested to in the laboratory. The vehicle itself (the bodywork and chassis) provide a degree of protection from ESD as this provides a return current path for the discharge that is likely to be much lower impedance than any wired return. Consequently, it is not untypical to have ±8kV limit for laboratory tests and a ±15kV for on-vehicle tests for the same ESA.

Summary

ESD testing for the automotive environment is well established and practiced in the automotive electronics industry. The test method maintains many similarities with the commercial standard it is derived from, with the main difference being the HBM change to reflect the discharge of capacitor-to-capacitor of two systems isolated from earth reference (the human and the vehicle or ESA). It could be argued that this use of the charge transfer HBM is, in fact, more appropriate to equipment outside the automotive environment that is primarily battery powered (i.e., where there is no mains charging unit, e.g., battery operated toys) or handling tests on any product while not connected to a supply. But the probability is that this change would be more confusing to the commercial test field and I expect the test methods and HBMs will remain divergent. ☐

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Sidebar

ISO Failure Mode Severity Classification

All classifications given below are for the total device/system functional status.

Note: The word "function" as used here concerns only the function performed by the electronic system.

Class A: All functions of a device or system perform as designed during and after exposure to interference.

Class B: All functions of a device/system perform as designed during exposure, but one or more of them may go beyond the specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain class A.

Class C: One or more functions of a device or system do not perform as designed during exposure but return automatically to normal operation after exposure is removed.

Class D: One or more functions of a device or system do not perform as designed during exposure and do not return to normal operation until exposure is removed and the device or system is reset by a simple "operator/use" action.

Class E: One or more functions of a device or system do not perform as designed during and after exposure and cannot be returned to proper operation without repairing or replacing the device or system.