
ESD considerations for touch sensing applications on MCUs

Introduction

The electrostatic discharge (ESD) is often used to describe a high voltage that may produce a permanent damage. ESD can be destructive and may leave a system in an unknown state from which recovery is impossible.

Fortunately, this damage can be prevented by several methods; some of these methods are cheap but other methods can modify the behavior of the equipment. The ideal situation is to find a balance and to obtain a robust application which is not too expensive and which is unlikely to behave erratically.

This document describes ESD causes and risks. Several models and standards relating to ESD simulation are outlined and some typical ESD protection techniques are explained.

Table 1. Applicable products

Type	Product series
Microcontrollers	STM32F0 Series, STM32F3 Series, STM32L0 Series, STM32L1 Series, STM32L4 Series, STM32L4+ Series, STM32L5 Series, STM32U5 Series, STM32WB Series

1 What is ESD ?

ESD is the sudden and momentary electric current that flows between two objects at different electrical potentials. ESD immunity is a category of electromagnetic compatibility (EMC). EMC is the branch of electrical sciences which studies the unintentional generation, propagation and reception of electromagnetic energy with reference to its unwanted effects.

EMC describes the ability of a piece of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Causes of ESD

One of the causes of ESD events is static electricity. Static electricity is often generated through the separation of electric charges when two materials are brought into contact and then separated, for example, rubbing a plastic comb against dry hair or removing some types of plastic packaging. In these cases, the friction between two materials creates a difference of electrical potential that can lead to an ESD stress.

Another cause of ESD damage is through electrostatic induction. This occurs when an electrically charged object is placed near a conductive object isolated from ground. The presence of the charged object creates an electrostatic field that causes electrical charges on the surface of the other object to redistribute. Even though the net electrostatic charge of the object has not changed, it now has regions of excess positive and negative charges.

An ESD stress may occur when the object comes into contact with a conductive path. For example, charged regions on the surfaces of styrofoam cups or plastic bags can induce potential on nearby ESD sensitive components via electrostatic induction and an ESD stress may occur if the component is touched with a metallic tool.

2 Risks of ESD

ESD is a serious issue in solid state electronics, such as integrated circuits (ICs). ICs are made from semiconductor materials such as silicon and insulating materials like silicon dioxide. Either of these materials can suffer permanent damage when subjected to high voltages.

The damaging effects of ESD poses unacceptable risks in many areas of technology and it is necessary to control such interference and reduce the risks to acceptable levels through;

- Simulation and testing of electronic devices using models
- Definition of standards.

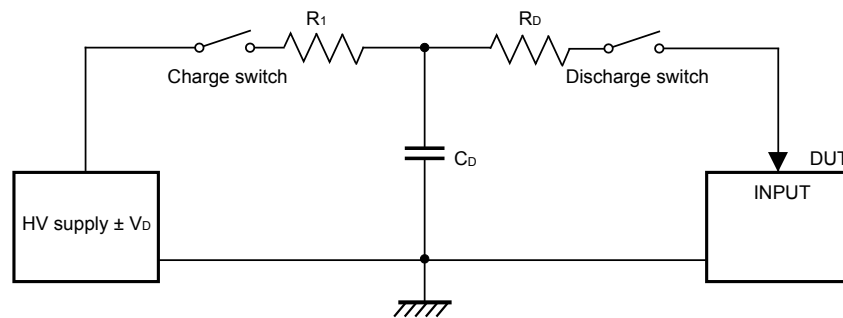
The following sections focus on the ESD protection of STM32 (based on Arm® cores) microcontrollers listed in Table 1.

Note: Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.

2.1 Simulation and testing of electronic devices using models

Several models describe how to simulate an ESD stress. The schematic circuit in the figure below shows how to generate an ESD event to a device under test (DUT). It is the basis of these models.

Figure 1. Electrostatic discharge test (ESD generator and DUT)



Notes: - R_1 = resistor 1, R_D = discharge resistor, C_D = discharge capacitor, HV = high voltage, V_D = discharge voltage (R_1 , R_D , and C_D defined according to a standard).
 - The charge and discharge switches are not closed simultaneously.

2.1.1 Human body model (HBM)

An ESD simulator with a special output circuit called the human body model (HBM) is often used to test the susceptibility of electronic devices to ESD stress from human contact. This model simulates the discharge that may occur when a human touches an electronic device (either a system or a component).

The HBM consists of a capacitor in series with a resistor (see Figure 1). The capacitor is charged to a specified voltage from an external source, and then suddenly discharged through the resistor into an electronic terminal of the DUT.

2.1.2 Machine model (MM)

This model simulates what happens when a machine becomes electrostatically charged and subsequently discharges into an electronic device when it comes in contact with it.

The MM test circuit consists of charging up a 200 pF capacitor to a certain voltage and then discharging this capacitor directly into the DUT.

2.2 Standards overview

Some standards exist for the following reasons:

- to reproduce well-defined tests in terms of setup (bench size, type of isolating area) and conditions (such as temperature and pressure)
- to eliminate misunderstandings between manufacturers and purchasers
- to facilitate interchangeability and improvement of products
- to assist the purchaser in selecting and obtaining the appropriate product for his particular needs

None of these reasons are paramount. Each depends on the needs of the customer who must also discuss with his purchaser.

The subsections below provides an overview of the most important ESD standards.

2.2.1 JS-001-2010 international standard

The ESD association and JEDEC solid state technology association have established a joint standard procedure for testing, evaluating, and classifying components and microcircuits according to their susceptibility to damage or degradation by exposure to a defined HBM ESD (1.5 k Ω , 100 pF and 8 kV).

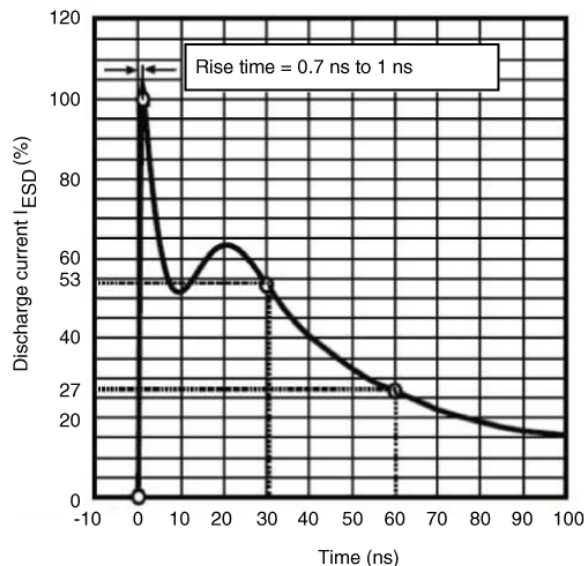
2.2.2 SP723 EIAJ IC121 standard

The SP723 EIAJ IC121 MM standard ensures that the ESD capability is typically greater than 2 kV (from 200 pF) with no serial resistor. For this standard, R_D and C_D of Figure 1 are respectively 0 Ω and 200 pF.

2.2.3 IEC61000-4-2 international standard

The IEC61000-4-2 standard for ESD protection is ± 15 kV for air and ± 8 kV for contact. The typical waveform of the output current of the ESD generator is described in the figure below.

Figure 2. IEC61000-4-2 ESD current waveform ($R_D = 330 \Omega / C_D = 150$ pF)



For this standard, R_D and C_D of Figure 1 are respectively 330 Ω and 150 pF. This standard is more accurate for performing tests at system level rather than at electronic device level.

2.2.4 MIL-STD-883H

This standard method classifies microcircuits according to their susceptibility to damage or degradation by exposure to ESD. For this standard R_D is 1.5 k Ω and C_D is 100 pF. This standard is well suited for electronic device tests as ESD stress can be applied directly onto the pins.

2.2.5 ESD standard summary

The application must be aligned with one or more standards as agreed with the customer. The table below summarizes the test conditions for the ESD standards.

Table 2. Test conditions for ESD standards

Standard	Model	R_D (Ω)	C_D (pF)	$\pm V_D$ (kV)
JS-001-2010	HBM	1.5 k	100	8
SP723 EIAJ IC121	MM	0	200	2
IEC61000-4-2 (level 4) ⁽¹⁾	HBM and air discharge	330	150	15
	HBM, and direct discharge	330	150	8
MIL-STD-883H (class 3B) ⁽²⁾	HBM	1.5 k	100	≥ 8

1. Level 4 = maximum level of test voltage in the IEC61000-4-2 standard.

2. Class 3B = maximum level of test voltage in the MIL-STD-883H standard.

When an ESD event occurs, the standards outlined in [Section 2.2](#) describe four test results that can occur in a real application.

2.2.6 Test results of ESD standards

The test results are as follows:

- normal performance continues within the specification limits
- temporary degradation or loss of function or performance that is self-recoverable
- temporary degradation or loss of function or performance which requires operator intervention or system reset (the operator can be the end user)
- degradation or loss of function that is not recoverable due to damage of equipment (components) or software, or loss of data

The risk of failure is the same for touch sensing application as for other applications. When a touch occurs, the system or equipment can fail if it is not sufficiently robust.

3 Protecting against ESD

An effective approach for protecting any electronic system against ESD is to mechanically minimize the pathways by which high voltages enter the system from the outside environment. This can be especially difficult if the user needs to touch the application or if there is a void or other opening in the packaging.

Mechanical switches and control potentiometers are classic system entry points for ESD stress. Changing from mechanical controls to capacitive touch controls eliminates the voids for these traditional ESD entry paths.

The elements listed below are used in some methods that protect against ESD stress:

- dielectric overlays (see [Section 3.1](#))
- spark gaps (see [Section 3.2](#))
- ground rings (see [Section 3.3](#))
- additional resistance (see [Section 3.4](#))
- additional diodes (see [Section 3.5](#))
- ESD protection devices (see [Section 3.6](#))
- Firmware (see [Section 3.7](#))

3.1 Dielectric overlays

In the touch sensing application domain, a protective layer of "dielectric" material (any insulating material that can intrinsically withstand high voltages without breaking down) can be placed between the ESD source and the touch sensing application. For example, one layer of 5 mil Kapton® tape withstands 18 kV. Other dielectric overlay materials are listed in the table below together with their dielectric strengths.

Table 3. Dielectric overlay materials and their dielectric strength

Material	Breakdown voltage (V/mm) (1)	Min. overlay thickness at 12 kV (mm)
Air	1200–2800	10
Dry wood	3900	3
Common glass	7900	1.5
Borosilicate glass (example Pyrex®)	13000	0.9
Polymethyl methacrylate (PMMA) plastic (example Plexiglas®)	13000	0.9
Acrylonitrile butadiene styrene (ABS) plastic	16000	0.8
Polycarbonate (example Lexan®)	16000	0.8
Formica plastic	18000	0.7
FR-4 ⁽²⁾	28000	0.4
Polyethylene terephthalate (PET) film (example Mylar®)	280000	0.04
Polymide film (example Kapton®)	280000	0.04

1. The breakdown voltage of an insulating material is the minimum voltage that causes a portion of the insulator to become electrically conductive.

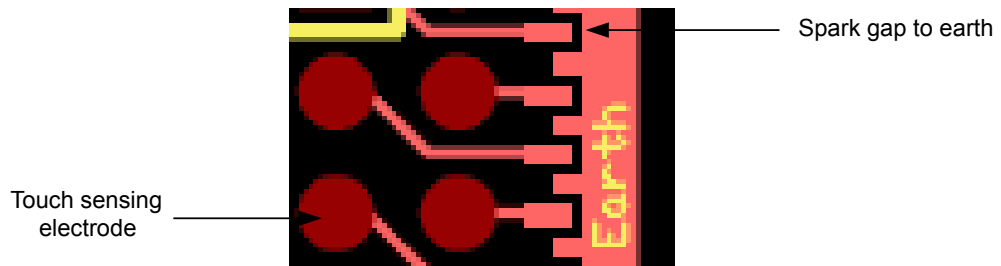
2. FR-4 is a widely accepted international grade designation for fiberglass reinforced epoxy laminates that are flame retardant.

The use of the dielectric overlay is effective and is almost mandatory for many applications. However, there are some drawbacks, namely that the overlay does not surround the whole application and that an ESD event can bypass the overlay. If the user can avoid accessing the application through the front panel (example, by accessing it from the back or elsewhere) or if the ESD event can bypass the front panel, one of the other methods that protect the device against an ESD event must be considered.

3.2 Spark gaps

Physical techniques, such as the addition of spark gaps, can give supplementary protection to the input/output lines of a circuit board that are susceptible to extraneous voltage such as ESD. For example, printed circuit board (PCB) spark gaps can be used to route ESD to earth in products using capacitive sensing electrodes (see the figure below).

Figure 3. PCB with spark gap



Note: The contact area of this spark gap needs to be free of solder resist, in order to function as a spark gap.

A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air which is designed to allow an electric spark to pass between the conductors. When the voltage difference between the conductors exceeds the breakdown voltage of the gap, a spark forms, ionizing the gas and drastically reducing its electrical resistance.

The spark gap shown in the above figure is an 8 mm gap that is a common PCB tolerance. The approximate breakdown of such a small spark gap is given in the following equation:

$$V = (3000 \times p \times d) + 1350$$

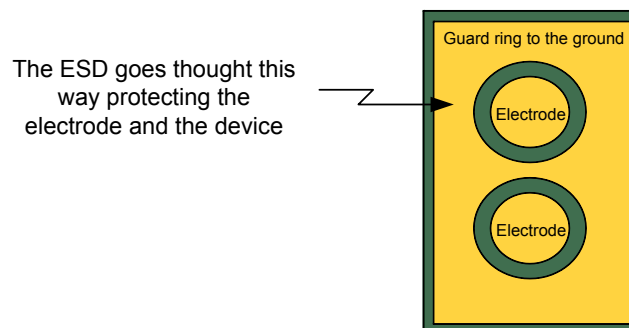
where p is the pressure in atmospheres and d is the distance in millimeters.

This spark gap can be expected to have a peak voltage of about 2000-2500 V.

3.3 Ground rings

To protect against ESD stress on the touch sensing surface, a low impedance path to ground must exist through the device. The touch sensor can be protected using a ground ring (also called a guard ring) which is a ring around all the system electrodes (see the figure below). It is placed in the border area. The ground ring can be a simple metal foil. It is necessary to ensure that there is a firm connection between the ground ring and the device system ground.

Figure 4. Ground ring



If the product is densely packed, it may not be possible to prevent an ESD stress. Consequently, the touch sensing device can be protected by controlling where the discharge occurs. This can be achieved through a combination of the following elements:

- PCB layout
- mechanical layout of the system
- conductive tape or other shielding material

These three items avoid an ESD stress reaching the electrodes (and therefore the MCU) because they form a sufficient shield. For example, an ESD stress goes directly to ground if it occurs in the ground ring.

As recommended in section 3.5 of the application note *Guidelines for designing touch sensing applications with surface sensors* (AN4312), a hatched ground plane around the touchkey or rotary or linear sensors (other types of electrode with different shapes) can redirect the ESD stress away from the electrodes and touch sensing device.

3.4 Additional resistance

The most common method of external ESD protection is to add a small serial resistor in-line between the ESD energy source and the touch sensing device pin to be protected. A resistor as small as 50 Ω can double the ESD immunity of a CMOS device. A higher level of protection is somewhat proportional to increased serial resistance so, higher immunity is possible.

This method works for the following reasons:

- The serial resistor works with the parasitic pin capacitance (typically 5 to 10 pF) of the device to create a single-pole low-pass filter with a cutoff frequency below 1 GHz. This causes the serial resistor to attenuate most of the high-frequency energy of an ESD event (as much as 90 % of the rising-edge power in an HBM discharge).
- When the protection circuits of the device are operating normally, their impedance is very low (in the order of tens of ohms or less). This low impedance works with the serial resistor to create a voltage divider, so that the high voltage from an ESD stress can only bias the built-in protection circuits of the device with a portion of the total ESD voltage. This attenuation is in addition to rising-edge filtering. The sum of these effects from a simple external serial resistor dramatically improves ESD performance in a demanding application.
- Usually for touch sensing, a 10 k Ω sampling resistor R_S is used to improve conducted noise immunity (IEC61000-4-6).

3.5 Additional diodes

Input/output lines that are susceptible to ESD stress are sometimes protected by adding external diodes that shunt the high energy of the ESD stress before it can reach the device input pin. These diodes may either pass the current to the power-supply rails or may internally dissipate the unwanted power. External diodes are similar to the diodes built into a device (internal diodes) for protection but they are designed differently. External diodes have the following significant advantages:

- They can switch faster and at a lower excursion voltage than the internal diodes of the device.
- They can have much better connections to the supply rails and can carry more power.

The effects of external diodes on circuit operation are different from internal diodes, because the connections used internally cannot be achieved with external devices.

The following types of protection diode are typically used against ESD stress:

- Transient voltage suppression (TVS) diodes can be placed between an input signal and ground. In this configuration, the diode protects the CMOS input by reverse conduction whenever its voltage rises above the specified diode breakdown voltage. Negative ESD excursions are shunted to ground through normal diode action.
- Diode pairs (such as schottky diodes due to their lower forward voltage drop) are placed between the input line and the power and ground rails. These devices protect the CMOS input by normal diode conduction whenever the input line voltage moves outside the range of the power supply rails.

Usually for touch sensing, an additional schottky diode, like the ST BAS70, is used to improve conducted noise immunity (IEC61000-4-6). Using the BAS70 low-capacitance schottky diode increases the noise immunity. ESD, in this case, is not the main concern.

Diodes placed on capacitive sensed lines present the same problems to capacitive sensing circuits as they do with any analog circuit input: they can be highly capacitive (over 100 pF) and leaky. Some schottky pairs leak over 20 μ A; some avalanche diodes leak over 1 mA when operated near their reverse-standoff voltage (generating significant noise voltage as well).

Although these given numbers are for the least suitable devices, the most commonly-used schottky and TVS diodes have parasitic parameters that make them unacceptable for use in capacitive sensing applications. If the diode circuit can be designed to add only a very small amount of additional capacitance, capacitance sensing solutions can be adjusted to match.

Compensation mechanisms are usually built into the touch sensing device for adaptation to the naturally-occurring changes in capacitance that result from environmental changes. However, leakage and bulk capacitance can create problems for any sort of capacitive sensing method, some more than others.

External diodes with high reverse leakage make the test capacitance look larger because their leakage drains test current from the circuit. This disappearing test current (which should fill the capacitance under test) has no dV/dt effect on the test load.

As diode leakage currents approach the level of the test current, the apparent load capacitance approaches infinity. Also, the amount of current required to detect a 0.1 pF change in capacitance is less than 20 pA, many orders of magnitude less than the leakage current for some protection diodes. For this reason, where external diodes must be used, it is essential to specify devices with extremely low reverse leakage.

The ST ESD protection diodes are designed to resist multiple ESD stresses. Their low capacitance (1 pF) and low leakage (less than 100 nA) reduce the problems encountered with schottky protection diodes. The bidirectional protection ESDAXLC6 diode, with even lower capacitance (0.5 pF) can be used instead of the ESDAULC6 diode to prevent the occurrence of negative and positive pulses.

3.6 ESD protection devices

A very effective method to protect input/outputs lines from ESD discharges is to provide special-purpose ESD protection devices on the vulnerable traces. ESD protection devices for touch sensing devices need to have a low capacitance.

The table below lists the ESD protection devices recommended for touch sensing microcontrollers.

Table 4. ESD protection devices

ST ESD protection diode (maximum number of protected lines)	Input capacitance (pF)	Leakage current	Contact discharge maximum limit (kV)	Air discharge maximum limit (kV)
ESDAXLC5-1U2	0.55	4 nA	±16	±30
ESDAXLC6-1MY2 (single line)	0.6 (max)	≤100 nA	±8	-
HSP053-4M5 (four lines)	0.25	1 nA	±10	±25
HSP054-4N10 (four lines)	0.45	5 nA	±15	±30

3.7 Firmware

When permanent damage occurs, the firmware is inefficient but, irreversible damage is not always the only consideration of an ESD stress.

The maximum risk due to an ESD stress is degradation. However, in some less negative cases (such as temporary degradation or loss of function) when a simple system reset is needed, a self-recoverable application can be implemented by using the “watchdog timer on”. The system can restart from a known state and resume normal operations. The final outcome is a robust application.

The debounce firmware method is used to filter some unwanted signals and therefore helps reduce ESD stress effects.

3.8 Guidelines for touch sensing design

Refer to application note *Guidelines for designing touch sensing applications with surface sensors* (AN4312) for detailed information.

4 Conclusion

Among the techniques to protect electronic systems against ESD stress, the cheapest and simplest method is to add a small serial resistor of about 50 Ω . For greater robustness a diode or an ESD protection device can be added. The drawbacks of these choices are price, leakage, and input capacitance.

In an environment where ESD can strike frequently, the most effective way is to use a combination of the techniques described in [Section 3 Protecting against ESD](#). For example, use simultaneously a spark gap (with a 10 k Ω serial resistor), a ground ring and robust firmware.

In any touch sensing domain, most of the protection is provided by a dielectric overlay which is nearly always used. However, an ESD stress can strike from anywhere so, other methods are recommended in parallel with a dielectric overlay.

Revision history

Table 5. Document revision history

Date	Version	Changes
3-Oct-2011	1	Initial release.
20-May-2016	2	Deleted Section 4: STM8T142-EVAL evaluation board: ESD tests. Added Table 1: Applicable products and updated scope of the document to the listed RPNS. Added. Section 3.8: Guidelines for touch sensing design.
16-Jan-2019	3	Updated: <ul style="list-style-type: none"> • Table 1. Applicable products • Section 2 Risks of ESD
16-Apr-2019	4	Updated: <ul style="list-style-type: none"> • Section 3.4 Additional resistance • Section 3.5 Additional diodes • Section 3.6 ESD protection devices
04-Oct-2021	5	Updated: <ul style="list-style-type: none"> • Table 1. Applicable products • Section 3.6 ESD protection devices • Removed all information related to STM8 MCUs

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