EMC - system immunity against electrostatic discharges webinar

How to protect applications against ESD

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EMC Immunity is the ability of an equipment to properly operate in its electromagnetic environment by limiting the interference of electromagnetic energy that may cause physical damage.

- Radiated immunity
- Radiated emission
- Electronic application
- Conducted immunity
- Conducted emission
EMC immunity example
discovery kit: STM32MP157A-DK1

- **USB Host x2 (Dual USB Type-A)**
  - ESDA7P120-1U1M (x2), ECMF02-2AMX6 (x2)
  - VBUS, DP, DM

- **USB Type-C DRP (Source Only)**
  - ESDA7P120-1U1M, ESDA25L, ECMF02-2AMX6
  - CC1, CC2, VBUS, DP, DM

- **USB Host x2 (Dual USB Type-A)**
  - ESDA7P120-1U1M (x2), ECMF02-2AMX6 (x2)
  - VBUS, DP, DM

- **HDMI**
  - ECMF04-4HSWM10 (x2), ESDALC6V1-5M6
  - CEC, I2C, HPD, TMDS datalines

- **MicroSD Card**
  - HSP051-4M10 (x2)
  - SDMMC dataline

- **Ethernet**
  - HSP053-4M5
  - DP, DM, VBUS

- **Audio**
  - ESDA6V1BC6: 4-line ESD protection
  - OUTA, OUTB, MIC IN

- **User Buttons**
  - ESDALC6V1-1U2

- **Morpho Connector**
  - ESDA7P120-1U1M
  - 5V Vin

- **Stmicro Connector**
  - ESDA7P120-1U1M
  - 5V Vin

- **MicroSD Card**
  - HSP051-4M10 (x2)
  - SDMMC dataline

- **USB Type-C Power Delivery**
  - ESDA7P120-1U1M, ESDA25L
  - VBUS, CC1, CC2
• ESD Protection at System Level
• How to select an ESD protection device?
• ESD Layout Guidelines
• Application Examples
ESD protection at system level
How ESD is generated?

Table 1: Examples of Static Generation - Typical Voltage Levels

<table>
<thead>
<tr>
<th>Means of Generation</th>
<th>10-25% RH</th>
<th>65-90% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking Across Carpet</td>
<td>35,000V</td>
<td>1,500V</td>
</tr>
<tr>
<td>Walking Across Vinyl Tile</td>
<td>12,000V</td>
<td>250V</td>
</tr>
<tr>
<td>Worker at a Bench</td>
<td>6,000V</td>
<td>100V</td>
</tr>
<tr>
<td>Poly Bag Picked up from Bench</td>
<td>20,000V</td>
<td>1,200V</td>
</tr>
<tr>
<td>Chair with Urethane Foam</td>
<td>18,000V</td>
<td>1,500V</td>
</tr>
</tbody>
</table>

Source: https://www.esda.org/about-esd/esd-fundamentals/part-1-an-introduction-to-esd/
In preparation for this white paper, the Industry Council conducted a worldwide survey of the electronics industry concerning EOS. Results confirmed the long held view that EOS is consistently one of the “high bars” on product failure Pareto charts. Looking at the EOS survey, respondents reported greater than 20% of total failures being EOS-related or 30% of total electrical failures being EOS-related, making EOS the largest bar on the Pareto chart of that responder’s known causes of returns.

Source:https://pdfs.semanticscholar.org/235b/0bfd01dd5f0c6c2c99df3b93bc27f56a9cfd.pdf

“30% of total electrical failure is EOS-related”

Source: STMicroelectronics
ESD sensitivity is increasing

\[ V_{dd} = \text{power supply voltage} \]
\[ V_{BD} = \text{breakdown voltage} \]
ESD and EOS standards

ESD
Electro-Static Discharge

Component level
to ensure manufacturability

System level
to assure robustness

EOS
Electrical Over Stress

System level
to simulate car behavior

HBM
Human Body Model

MM
Machine Model

CDM
Charged Device model

IEC 61000-4-2
ISO10605 (auto)
Final user simulation

ISO7637
ISO16750

These standards have low-level surges as factories are well-controlled environments.

System robustness for end users. Uncontrolled environment.
HBM and IEC standards

Difference in standards: IEC 61000-4-2 carries more energy than HBM

IEC 61000-4-2 for system
(+/-8kV for level 4)

Human Body Model for IC
(+/-2kV for most of IC)
Component level vs system level silicon die area comparison

Silicon die area for component level ESD (2 kV HBM)

Silicon die area for system level ESD (8 kV IEC contact)
System-level ESD protection standard

IEC 61000-4-2 test bench

<table>
<thead>
<tr>
<th>Stress Level</th>
<th>Contact discharge</th>
<th>Air discharge</th>
<th>Number of discharges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>At least 10 single discharges at 1 Hz in the most sensitive polarity</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

System state as a result of system–level ESD stress

<table>
<thead>
<tr>
<th>A</th>
<th>Normal performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Temporary loss of function or degradation of performance which cease after the disturbance ceases. The DUT recover its normal performance, without operator intervention</td>
</tr>
<tr>
<td>C</td>
<td>Temporary loss of function or degradation of performance, the correction of which requires operator intervention</td>
</tr>
<tr>
<td>D</td>
<td>loss of function or degradation of performance, no recovery possible</td>
</tr>
</tbody>
</table>

Self-restored
Require a system reset
## ESD in automotive: ISO10605

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Mode</th>
<th>Component accessible from:</th>
<th>Test (A= Air C= contact)</th>
<th>Capacitance</th>
<th>Resistance</th>
<th>Max test voltage</th>
<th>Operating conditions</th>
<th>Min number of discharges</th>
<th>Min. time interval</th>
<th>Max suggested severity levels (ISO10605 Annex C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Direct</td>
<td>Inside</td>
<td>A &amp; C</td>
<td>330 pF</td>
<td>330 ohm</td>
<td>-</td>
<td>Powered</td>
<td>3</td>
<td>1s</td>
<td>15 kV C 25kV A</td>
</tr>
<tr>
<td>Component</td>
<td>Direct</td>
<td>Outside</td>
<td>A &amp; C</td>
<td>150 pF</td>
<td>330 ohm</td>
<td>-</td>
<td>Powered</td>
<td>3</td>
<td>1s</td>
<td>15 kV C 25kV A</td>
</tr>
<tr>
<td>Component</td>
<td>Indirect</td>
<td>Inside</td>
<td>C</td>
<td>330 pF</td>
<td>330 ohm</td>
<td>-</td>
<td>Powered</td>
<td>50</td>
<td>50ms</td>
<td>20kV C</td>
</tr>
<tr>
<td>Component</td>
<td>Indirect</td>
<td>Outside</td>
<td>C</td>
<td>150 pF</td>
<td>330 ohm</td>
<td>-</td>
<td>Powered</td>
<td>50</td>
<td>1s</td>
<td>20kV C</td>
</tr>
<tr>
<td>Component</td>
<td>Direct</td>
<td>NA</td>
<td>A &amp; C</td>
<td>150 pF</td>
<td>330 or 2000 ohm</td>
<td>-</td>
<td>Unpowered</td>
<td>3</td>
<td>1s</td>
<td>8kV C 15kV A</td>
</tr>
<tr>
<td>Vehicle test</td>
<td>Direct</td>
<td>Inside</td>
<td>A &amp; C</td>
<td>330 pF</td>
<td>330 or 2000 ohm</td>
<td>15 kV</td>
<td>Engine drive or idle</td>
<td>3</td>
<td>1s</td>
<td>8kV C 15kV A</td>
</tr>
<tr>
<td>Vehicle test</td>
<td>Direct</td>
<td>Outside</td>
<td>A &amp; C</td>
<td>150 pF</td>
<td>330 or 2000 ohm</td>
<td>25 kV</td>
<td>Engine drive or idle</td>
<td>3</td>
<td>1s</td>
<td>8kV C 25kV A</td>
</tr>
</tbody>
</table>
How to select ESD protection device
### Key Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{RM}$</td>
<td>Stand-off voltage (normal condition voltage)</td>
</tr>
<tr>
<td>$I_{RM}$</td>
<td>Leakage current</td>
</tr>
<tr>
<td>$V_{BR}$</td>
<td>Breakdown voltage (voltage when the ESD protection starts working)</td>
</tr>
<tr>
<td>$V_{CL}$</td>
<td>Clamping voltage (maximum voltage across the ESD protection)</td>
</tr>
<tr>
<td>$I_{PP}$</td>
<td>Peak Pulse Current (maximum current in the ESD protection)</td>
</tr>
<tr>
<td>$C$</td>
<td>Line capacitance (impacts signal integrity)</td>
</tr>
</tbody>
</table>
Protection selection
key parameter : voltage

No TVS protection

With TVS protection
• Mandatory for audio and RF signals
Key parameters capacitance value

- Example of the impact of parasitic capacitance on high-speed signal simulated with discrete capacitance

\[ fc = \frac{1}{\pi t_r} \]

\( fc \) is high enough to comply with HDMI 1.485 Gbps
Eye diagram
what is an eye diagram?
Impact on data-lines eye diagram integrity

- USB 3.1 Gen2 mask at 10.0 Gbps per channel (Type-C connector, reference cable, EQ with DC=6dB and DFE)

Line without HSP053-4M5

Line with HSP053-4M5
Impact on data-lines time domain reflectometer impedance

TDR with 200ps pulse rise time impedance of 100Ω line without / with HSP053-4M5

HDMI 2.0b TDR specification : 100Ω ±15Ω
• **ESDARF02-1BU2CK S21**
  - 30 GHz at -3 dB
  - 8 GHz at -0.5 dB

• **Negligible impact major frequencies for teleco**
  - FM radio: 87.5 MHz - 108.0 MHz
  - Numerical TV: 400 MHz – 900 MHz
  - Cellular phones: 700 MHz … 4.7 GHz
  - GNSS: 1.6 GHz
  - Bluetooth: 2.4 GHz
  - Sub-GHz industrial: 400 MHz … 1.1GHz
  - WiFi: 2.4 / 5.0 GHz

Impact on rf-signal

S21 attenuation
• IEC 61000-4-2 response of ESD051-1BF4:
  • First peak: 23V (low energy, CDM like)
  • 30ns clamping: 11V (clamping voltage)
ESD protection transmission line pulse

- IEC 61000-4-2 8 kV 30 ns clamping voltage ↔ TLP* 16 A 100 ns 70 - 90% voltage

Injected current:
16A – 100ns square current

Measured voltage on 70% – 90% windows on ESD051-1BF4 : 10.5V

*ANSI / ESD STM5.5.1-2014
ESD protection transmission line pulse* I/V curve

- I/V TLP* curve is done with several pulses

ESD051-1BF4 TLP* I/V curve
• TLP input current shared between high performance MCU FT input and ESDA5-1BF4

• High performance MCU + ESDA5-1BF4 robustness reach more than 8kV IEC 61000-4-2
  • Even if, ESD5-1BF4 clamping voltage > High Performance

• ESD051-1BF4
  • 11V clamping voltage at +8kV ESD 61000-4-2

• High Performance MCU FT input
  • 3.6 V max operating
  • 2 kV HBM ESD
  • 250 V CMD ESD
  • 5.5 V AMR

System-efficient ESD design methodology

MCU working voltage : 3.3V
MCU destruction voltage : 12.5V
• Snap-back protection (ESDZV5-1BF4) clamping voltage lower than standard protection (ESD051-1BF4) clamping voltage

• Protected line DC voltage MUST be lower than holding voltage
  • To avoid protection latch-up
    i.e. continuous leakage current flowing into the protection

Snap-back protections system integration
Recap basics of ESD protection

• Transparency:
  • Capacitance must be in-line with application bandwidth / data rate

• Efficiency:
  • VRM must be slightly higher than maximum line voltage
    To obtain a low clamping voltage

• System integration of snap-back protection:
  • Holding voltage must be higher than DC voltage

AN5241, Fundamentals of ESD protection at system level
ESD layout guidelines
• PCB Tracks must be under control!

• For protection device length connection of ~1cm from side to side, 35µm copper, 0.5mm wide (microstrip)

• $2 \times L = 5 \text{ nH}$!
ESD surge is 8 kV/0.8 ns rise time, this makes 37.5 A/ns

Assuming that lines inductance is \( L = 5 \text{nH} \)

\[
\frac{di}{dt} = 37.5 \text{ A/ns}
\]

\[
\text{Vic} = V + 2 \times L \frac{di}{dt}
\]

\[
\text{Vic} = V + 375 \text{ V}
\]
VIAs to GND plane as close as possible to the product GND
• PCB Layout recommendations in Application note AN1751

• ESD protection must be placed as close as possible to the ESD source, to avoid any coupling between tracks on the PCB.

In this case, \( \text{Vic} \leq V \)
Application examples recommended protection devices and PCB layouts
Protections and filters around MCUs

- ESDA7P120-1U1M
- ECDF04-4HSWM10
- High Speed Differential
- MIPI, USB 3.1, Display port, HDMI
- ESDALC6V1W5
- ESDA6V1BC6
- SPT01-335DEE
- HSP051-4M10
- ETH 1G, secondary
- ESDA7P120-1U1M
- USBLC6-2SC6
- SMA6F
- SMAJ40CA
- PLC inputs
- CLT03-2Q3
- TCPP01-M12
- Type-C Port Protection
- ESDA5V3L
- ECMF04-4HSWM10
- High Speed Differential MIPI, USB 3.1, Display port, HDMI
- ESDALC6V1W5
- SD 2.0
- RS-232
- RS-485
- SWD & JTAG
- ESDA6V1BC6
- SPT01-335DEE
- SMAJ40CA
USB 2.0 full speed without OTG

DESIGN TIP:
Place the ESD protection close to ESD source: here close to USB connector

USBLC6-2SC6

- Compliant with USB 2.0 eye diagram
- ESD robustness: ± 15 kV contact discharge IEC61000-4-2

SOD323-6L

Reuse gerber file
STM32L4R9I-EVAL
RS232

**DESIGN TIP:**
Place the ESD protection close to ESD source: here close to RS232 connector

**ESDA14V2BP6**
- Low capacitance, 4-line, bi-directional ESD protection
- ESD protection as per IEC61000-4-2 Level 4: ± 8kV contact

Reuse gerber file
STM32L4R9I-EVAL
**USER BUTTON**
**MCU GPIO input**

**Design note:**
Although buttons are not made of conductive materials, they are highly sensitive to ESD air discharge used during IEC certification tests.

**ESDA5V3L**
- PCB space saving: 2 diodes array
- ESD robustness: ± 30 kV contact discharge IEC61000-4-2

**SOT23-3L**

Reuse gerber file
STM32L4R9I-EVAL
Any electronic board must be protected

3D printer control board

- Protections on the application PCB
  - Power lines → surge protection : IEC 61000-4-5
  - Connector
  - Button
  - SD card
  - Integrated on all IC’s → ESD protection for manufacturing is JEDEC HBM

ESD protections for system: IEC 61000-4-2

- SMAJ12A
- SMBJ24A
- EMI06-MS02N16
- ESDA5V3L
- 3x USBLC6-2SC6
Resources
Application notes and Videos

• AN5241, Fundamentals of ESD protection at system level
• AN4871, USB Type-C protection and filtering
• AN5121, HDMI ESD protection and signal conditioning products for STBs
• AN3353, IEC 61000-4-2 standard testing
• AN2689, Protection of automotive electronics from electrical hazards, guidelines for design and component selection
• AN1826, TRANSIENT PROTECTION SOLUTIONS: Transil™ diode versus Varistor
• AN5241 : Fundamentals of ESD Protection
• Video - ESD Protection: why and how to protect microcontrollers efficiently
ST protection finder mobile App

- ST PROTECTION FINDER is an application available for Android™ and iOS™ that allows you to explore ST’s TVS product portfolio.
  - Parametric or series search engine
  - Efficient part number search engine
4 steps to discover ST’s portfolio

1. OPEN application
   - ST Protection Finder (1.0.1 ML off)
   - Parameter Search
   - ESD Protection (EESOP80A-4.2)
   - TVS clamping diodes
   - Current-Limiting Termination
   - MY FAVORITES

2. SELECT parameter
   - Stand off Voltage
     - 100 mV to 36 V
     - 36 V
   - Breakdown voltage
     - 700 mV to 39 V
     - 39 V
   - Line Capacitance I/O-GND
     - 300 fF to 350 pF
     - 350 pF

3. CHOOSE product
   - EMIF02-020ABRY
     - V_{RM} Typ 5 V
     - V_{BR} Min 6 V
     - C_{LINE} Typ 0.85 pF
     - Nb of Line 4
     - Directionality UNI-DIRECTIONAL
   - Package SOT23-6L

4. GET datasheet
   - EMIF02-020ABRY
     - Technical Documentation
     - Key Features
     - Dimensions: 3.0 x 3.0 mm
     - Pitch: 1.1 µm
     - Wettability flank QFN
     - AEC-Q101 compliant
   - Data Sheet
     - Version 1.0
     - Size 115 KB
Thank you