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Team Nexperia
AN10753
ESD protection for USB 2.0 interfaces
Rev. 3 — 5 February 2013 Application note

Document information

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<td>Keywords</td>
<td>ESD, USB, PESD5V0X1BL, PESD12VS1UL, PRTR5V0U2F, PRTR5V0U2K</td>
</tr>
<tr>
<td>Abstract</td>
<td>This application note describes how to protect USB 2.0 ports with NXP general-application discretes parts, i.e. low-capacitance ElectroStatic Discharge (ESD) protection diodes PESD5V0X1BL, PRTR5V0U2F and PRTR5V0U2K.</td>
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1. Introduction

An Integrated Circuit (IC) connected to external ports can be damaged by ElectroStatic Discharge (ESD) from the operating environment.

The result of ever-shrinking IC process technology is the decrease of ESD robustness because of the smaller geometry of the silicon die.

Traditional methods to prevent ICs from ESD damage are the implementation of additional devices such as:

- Zener diodes
- Varistors
- Transient Voltage Suppressor (TVS) diodes
- Bipolar clamp diodes

However, at much higher data rates, the parasitic characteristics can distort or deteriorate signal integrity. This application note examines the general parameters the hardware designer should look at to increase the ESD robustness of the application, e.g. USB interfaces.

2. ElectroStatic Discharge (ESD) basics

ESD events are one of the most challenging issues in the semiconductor industry these days due to ever-shrinking IC structures of semiconductor devices.

The smaller the geometry of the silicon die, the more ESD sensitive are the ICs, and the more IC area is required for the ESD protection of the device (see Figure 2).
An ESD event is the transfer of energy between two bodies of different electrostatic potential.

ElectroStatic Discharge can happen by contact, or via an ionized ambient discharge.

There are several models known:

- Human Body Model (HBM) - A human body is discharged to an electronic component.
- Machine Model (MM) - A machine or tool is discharged to an electronic component.
- Charged Device Model (CDM) - An electronic component is discharged to the ambient.
- System Level (IEC) - A human body is discharged to a powered system.

This application note covers the difference between the Human Body Model and the System Level Model which are both Human Body Models, but the System Level Model is relevant for a complete solution, e.g. a portable multimedia device.

**Fig 2.  Required IC area as a function of chip size; typical values**

<table>
<thead>
<tr>
<th>Gate Oxide Thickness</th>
<th>IC area</th>
<th>Required IC area to achieve 2 kV HBM ESD protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>350 nm</td>
<td>8 nm</td>
<td></td>
</tr>
<tr>
<td>180 nm</td>
<td>12.5 nm</td>
<td></td>
</tr>
<tr>
<td>140 nm</td>
<td>50 nm</td>
<td></td>
</tr>
<tr>
<td>90 nm</td>
<td>4.15 nm</td>
<td></td>
</tr>
<tr>
<td>65 nm</td>
<td>3 nm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.6 nm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;1.5 nm</td>
<td></td>
</tr>
</tbody>
</table>
2.1 Human Body Model (HBM) - Standards IEC/EN 61340-3-1 or MIL-STD 883

This standard covers the manual handling of none-powered electronic components. The handling can be picking up a device for testing or mounting the device on a Printed-Circuit Board (PCB).

A capacitor of 100 pF is charged and then discharged via a 1.5 kΩ resistor to the Device Under Test (DUT).

The waveform of IEC 61340-3-1 is shown in Figure 3, the rise time is defined up to 10 ns.

Table 1. Waveform parameters according to MIL-STD 883

<table>
<thead>
<tr>
<th>Step</th>
<th>Test voltage (kV)</th>
<th>Peak current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.33</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.67</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1.33</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2.67</td>
</tr>
</tbody>
</table>

Table 2. Device ESD failure threshold classification according to MIL-STD 883

<table>
<thead>
<tr>
<th>Class</th>
<th>Threshold voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt; 250</td>
</tr>
<tr>
<td>1A</td>
<td>250 to 499</td>
</tr>
<tr>
<td>1B</td>
<td>500 to 999</td>
</tr>
<tr>
<td>1C</td>
<td>1000 to 1999</td>
</tr>
<tr>
<td>2</td>
<td>2000 to 3999</td>
</tr>
<tr>
<td>3A</td>
<td>4000 to 7999</td>
</tr>
<tr>
<td>3B</td>
<td>≥ 8000</td>
</tr>
</tbody>
</table>
2.2 System Level (IEC) - Standard IEC 61000-4-2

This standard covers the manual handling of a powered electronic system, e.g. touching an interface connector.

A capacitor of 150 pF is charged and then discharged via a 330 Ω resistor to the DUT.

The waveform of IEC 61000-4-2 is shown in Figure 4, the rise time is defined between 0.7 ns and 1 ns.

There are different levels for test proposals mentioned.

For contact or air discharge test, they differ in the voltage values (see Table 3).

Table 3. Waveform parameters according to IEC 61000-4-2

<table>
<thead>
<tr>
<th>Level</th>
<th>Test voltage (kV)</th>
<th>Current (A)</th>
<th>Peak current</th>
<th>After 30 ns</th>
<th>After 60 ns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contact</td>
<td>Air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>7.5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
<td>15</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>8</td>
<td>22.5</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>15</td>
<td>30</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>
2.3 Standard comparison

Both models differentiate concerning the test voltages.

One can see that a 2 kV discharge voltage refers to different discharge currents.

Therefore, NXP recommends external ESD protection to be compliant with the IEC 61000-4-2 standard.

3. USB interface protection

The USB 2.0 standard covers several data transmission rates. It is also compliant to the former specification USB 1.1.

Following data transmission rates are covered:

- 1.5 MBit/s (low speed)
- 12.0 MBit/s (full speed)
- 480 MBit/s (hi-speed)

For the hi-speed mode, the maximum allowed capacitance according to the USB 2.0 specification is 10 pF overall.

These 10 pF are shared by a maximum of 5 pF for the transceiver itself, and the other 5 pF for the connector, PCB traces, and additional components.

Figure 5 shows the maximum allowable line capacitance at different data speeds.

![Fig 5. Line capacitance as a function of line frequency; typical values](image)

To expose any issue in USB data lines, the measurement method “eye pattern”, also known as “eye diagram”, is used.

It represents a digital signal that provides minimum and maximum voltage levels and signal jitter.
One can also measure the signal rise time and the fall time, as well as overshoot and undershoot.

Line capacitance and bandwidth effects of the USB data transmission can be evaluated. USB 2.0 signal mask specifications are provided by the USB Implementers Forum. Figure 6 shows an “eye pattern” with the critical issues of a USB 2.0 data signal.

### 3.1 Component differences

The NXP product portfolio offers two different approaches:

One component for each single line to be protected:

- Single-line protection for D+ and D− bidirectional configuration (PESD5V0X1BL).
- Single-line protection for VBUS unidirectional configuration (PESD12VS1UL).

One package for complete USB interface protection:

- Dual line protection in rail-to-rail configuration, i.e., D+, D− and VBUS (PRTR5V0U2x).
4. Measurement methods

4.1 USB 2.0 protection with PESD5V0X1BL

To evaluate the PESD5V0X1BL behavior in USB 2.0 applications, a reference board (see Figure 7) was designed.

Fig 7. USB 2.0-ESD-Protection-V2-board

Fig 8. USB 2.0-ESD-Protection-V2-assembly diagram
An image of the PCB layer structure having two controlled impedance lines is shown in Figure 9.

Figure 10 provides the schematic of the demo board using PESD5V0X1BL for D1 and D2 each. In order to meet the USB charging requirements of even more than 5 V, there was a PESD12VS1UL chosen for D3.

---

**Fig 9.** USB 2.0 PCB layer structure

**Fig 10.** USB 2.0 ESD-Protection-V2-schematic
4.1.1 Reference measurements

To evaluate the influence of different ESD protection components, the measurements were done in several steps.

A board without a device was evaluated as reference.

Comparing all “eye patterns” demonstrates the degradation caused by the ESD protection devices.

The first test was done without any protection diode (see Figure 11), the result pattern is shown in Figure 13.

Fig 11. USB 2.0 “eye pattern” without DUT

Fig 12. Test setup for USB 2.0 “eye pattern” without DUT
4.1.2 DUT measurements

DUT measurements done on three different PCBs using two different PESD5V0X1BL diodes each are shown below.

Fig 13. USB 2.0 “eye pattern” with a 0.9 pF PESD5V0X1BL ESD protection diode; PCB1

Fig 14. USB 2.0 “eye pattern” with a 0.9 pF PESD5V0X1BL ESD protection diode; PCB2
Fig 15. USB 2.0 “eye pattern” with a 0.9 pF PESD5V0X1BL ESD protection diode; PCB3

Fig 16. Test setup for USB 2.0 “eye pattern” with a 0.9 pF PESD5V0X1BL ESD protection diode
4.2 USB 2.0 protection with PRTR5V0U2F/K

In order to evaluate the PRTR5V0U2F/K behaviors in USB 2.0 applications, two reference boards were designed (see Figure 17 and Figure 18).

Fig 17. USB 2.0 ESD-Protection-V3-board

Fig 18. USB 2.0 ESD-Protection-V4-board
The PCB layer structure for the USB 2.0-ESD-Protection-V3/V4-assembly diagram as shown in Figure 19 is similar to the USB 2.0-ESD-Protection-V2-board (see Figure 9).

Figure 20 provides the schematic of both, V3 and V4 reference boards, with only slight differences with respect to the packages. PRTR5V0U2F is housed in an SOT886 package of dimensions $1.45 \times 1 \times 0.5$ mm, and PRTR5V0U2K is housed in an SOT891 package of dimensions $1 \times 1 \times 0.5$ mm.
4.2.1 Reference measurements

To evaluate the influence of different ESD protection components, the measurements were done in several steps.

A board without a device was evaluated as reference.

Comparing all “eye patterns” demonstrates the degradation caused by the ESD protection devices.

The first test was done without any protection diode (see Figure 21) using a similar test setup to Figure 12.

Fig 21. USB 2.0 “eye pattern” without DUT
4.2.2 DUT measurements

The DUT measurements were done on three different PCBs using PRTR5V0U2F and PRTR5V0U2K on a similar test setup to Figure 16.

Fig 22. USB 2.0 “eye pattern” with PRTR5V0U2F protection diode; PCB1

Fig 23. USB 2.0 “eye pattern” with PRTR5V0U2F protection diode; PCB2
Fig 24. USB 2.0 “eye pattern” with PRTR5V0U2F protection diode; PCB3

Fig 25. USB 2.0 “eye pattern” with PRTR5V0U2K protection diode; PCB1
5. Summary

The NXP low-capacitance ESD protection devices offer best results for USB 2.0 hi-speed applications.

The “eye pattern” evaluations show that NXP’s low-capacitance ESD protection devices have an extremely low impact on the USB 2.0 data signals.

This option gives the hardware designer some space for additional capacitance on the USB 2.0 signal lines!
6. Appendix

6.1 USB 2.0 ESD protection portfolio

Table 4. USB 2.0 ESD protection portfolio

<table>
<thead>
<tr>
<th>Type number</th>
<th>C_{line} [^1]</th>
<th>V_{BUS(\text{max})}</th>
<th>ESD rating</th>
<th>Package</th>
<th>AEC-Q101</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRTR5V0U2X</td>
<td>1.0 pF</td>
<td>5.0 V</td>
<td>8 kV</td>
<td>SOT143B</td>
<td>YES</td>
</tr>
<tr>
<td>PRTR5V0U2AX</td>
<td>1.8 pF</td>
<td>5.0 V</td>
<td>8 kV</td>
<td>SOT143B</td>
<td>YES</td>
</tr>
<tr>
<td>PRTR5V0U4D</td>
<td>1.0 pF</td>
<td>5.0 V</td>
<td>8 kV</td>
<td>SOT457</td>
<td>YES</td>
</tr>
<tr>
<td>PRTR5V0U2F</td>
<td>1.0 pF</td>
<td>5.0 V</td>
<td>8 kV</td>
<td>DFN1410-6</td>
<td>NO</td>
</tr>
<tr>
<td>PRTR5V0U2K</td>
<td>1.0 pF</td>
<td>5.0 V</td>
<td>8 kV</td>
<td>DFN1010-6</td>
<td>NO</td>
</tr>
<tr>
<td>PUSBM5V5X4-TL</td>
<td>1.0 pF</td>
<td>5.5 V</td>
<td>8 kV</td>
<td>DFN1616-6</td>
<td>NO</td>
</tr>
<tr>
<td>PUSBM12VX4-TL</td>
<td>1.0 pF</td>
<td>12 V</td>
<td>8 kV</td>
<td>DFN1616-6</td>
<td>NO</td>
</tr>
<tr>
<td>PUSBM15VX4-TL</td>
<td>1.0 pF</td>
<td>15 V</td>
<td>8 kV</td>
<td>DFN1616-6</td>
<td>NO</td>
</tr>
<tr>
<td>PUSBM30VX4-TL</td>
<td>1.0 pF</td>
<td>30 V</td>
<td>8 kV</td>
<td>DFN1616-6</td>
<td>NO</td>
</tr>
<tr>
<td>IP4369CX4</td>
<td>0.8 pF</td>
<td>only D- lines</td>
<td>8 kV</td>
<td>WLCSP4</td>
<td>NO</td>
</tr>
</tbody>
</table>

[^1]: Data lines (D+/D–)

6.2 USB 3.0 ESD protection portfolio

Table 5. USB 3.0 ESD protection portfolio

<table>
<thead>
<tr>
<th>Type number</th>
<th>C_{line}</th>
<th>V_{BUS(\text{max})}</th>
<th>ESD rating</th>
<th>Package</th>
<th>AEC-Q101</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP4294CZ10-TBR</td>
<td>0.50 pF</td>
<td>only D– lines</td>
<td>10 kV</td>
<td>DFN2510A-10</td>
<td>NO</td>
</tr>
<tr>
<td>IP4292CZ10-TBR</td>
<td>0.55 pF</td>
<td>only D– lines</td>
<td>8 kV</td>
<td>DFN2510A-10</td>
<td>NO</td>
</tr>
</tbody>
</table>
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