ESD protection – USB 3.2
Protected connection for mobile devices
Contents

The new Type-C connector ........................................................................ 3
Categories of USB data lines to protect ................................................. 4
Single-line protection concept ................................................................ 5
Multi-line protection concept ................................................................. 6
Common mode filter with ESD protection concept ............................... 7
Application of the USB Type-C connector .......................................... 8
Product selection for data lines............................................................... 9
Product selection for $V_{bus}$ / $V_{bat}$ protection ..................................... 10
ESD protection for USB 3.2: signal integrity ......................................... 11
System-level ESD protection for USB 3.2 .............................................. 12
Common mode filters for USB 2.0 and USB 3.2 ................................. 16

Introducing USB

The Universal Serial Bus (USB), one of the industry's most widely used standard for data transfer.

<table>
<thead>
<tr>
<th>Name</th>
<th>Protocol</th>
<th>Max. data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced SuperSpeed</td>
<td>USB 3.2</td>
<td>20 Gbit/s *</td>
</tr>
<tr>
<td>SuperSpeed+</td>
<td>USB 3.1</td>
<td>10 Gbit/s</td>
</tr>
<tr>
<td>SuperSpeed</td>
<td>USB 3.0</td>
<td>5 Gbit/s</td>
</tr>
<tr>
<td>Hi-Speed</td>
<td>USB 2.0</td>
<td>480 Mbit/s</td>
</tr>
<tr>
<td>Full Speed</td>
<td>USB 1.1</td>
<td>12 Mbit/s</td>
</tr>
<tr>
<td>Low Speed</td>
<td>USB 1.0</td>
<td>1.5 Mbit/s</td>
</tr>
</tbody>
</table>

* USB 3.2 is doubling the data rate by utilizing all Tx and Rx lines of USB Type-C.

This application guide covers:
Solutions for USB ESD protection
(USB 3.2, 3.1, 2.0, Supply voltage configuration)
The new Type-C connector

... was introduced as a part of the new USB 3.2 specification.
... will make USB 3.2 very attractive for portable devices:
  › Very small outline
  › Connector can be plugged in using either orientation
  › Higher charging currents possible
  › Eliminates the need for a second data connector
# Categories of USB data lines to protect

<table>
<thead>
<tr>
<th></th>
<th>Trends in system-level ESD protection</th>
<th>USB data lines of this category</th>
<th>System-level ESD requirements</th>
<th>Data rate</th>
<th>Data rate requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High-speed ESD protection with optional common mode filters</strong></td>
<td>- Extremely sensitive SoCs</td>
<td>- Tx +/-, Rx +/-, D +/-</td>
<td>- Extremely low clamping&lt;br&gt;- SCRs&lt;br&gt;- Low dynamic resistance&lt;br&gt;- High surge robustness</td>
<td>- 480 Mbit/s to 20 Gbit/s and increasing</td>
<td>- RF-friendly routing mandatory&lt;br&gt;- Integrated concept for target data rate</td>
</tr>
<tr>
<td><strong>Low-speed ESD protection</strong></td>
<td>- Very sensitive SoCs</td>
<td>- SBU, CC</td>
<td>- Very low clamping (protection with low $V_{br}$ and low $R_{dyn}$)&lt;br&gt;- Very high surge robustness</td>
<td>- Low</td>
<td>- RF friendly routing advisable to minimize influence on high-speed lines</td>
</tr>
<tr>
<td><strong>$V_{bus}$ surge protection</strong></td>
<td>- Increasing energies of possible surge pulses&lt;br&gt;- Type-C allows higher energies</td>
<td>- $V_{bus}$</td>
<td>- Extremely high surge robustness</td>
<td>- DC</td>
<td>- None</td>
</tr>
</tbody>
</table>
Single-line protection concept

USB SuperSpeed interface

Vbus

Hi-speed USB interface

A12 GND
A11 RX2+
A10 RX2-
A9 Vbus
A8 SBU1
A7 D-
A6 D+
A5 CC1
A4 Vbus
A3 TX1-
A2 TX1+
A1 GND
GND B1
TX2+ B2
TX2- B3
Vbus B4
CC2 B5
D+ B6
D- B7
SBU2 B8
RX1- B10
RX1+ B11
Vbus B9
GND B12

Type-C receptacle back side view
(matching to plug)

Super/Hi-speed ESD protection
Low-speed ESD protection
Vbus surge protection
Multi-line protection concept

USB SuperSpeed interface

V_bus

Hi-speed USB interface

PUSB3xx6

IP4283CZ10

USB SuperSpeed interface

V_bus

Hi-speed USB interface

PUSB3xx4

Type-C receptacle back side view (matching to plug)

Hi-speed ESD protection

Low-speed ESD protection

V_bus surge protection
Common mode filter with ESD protection concept

Type-C receptacle back side view (matching to plug)

USB SuperSpeed interface

High-speed ESD protection with optional common mode filters
Low-speed ESD protection
V_{bus} surge protection
Application of the USB Type-C connector

Single-line

Multi-line

Common mode filter

Type-C receptacle back side view (matching to plug)

USB Type-C test dongles
Nexperia has designed Type-C test dongles, which are using protection and filtering solutions. They can be used for a quick check of device suitability. They can also be used by RF board-designers for inspiration.

There are three test dongles:
› Single-line ESD protection
› Multi-line ESD protection
› Common mode filters with integrated ESD protection
# Product selection for data lines

<table>
<thead>
<tr>
<th>Type number</th>
<th>Application</th>
<th>No. of protected lines</th>
<th>SuperSpeed</th>
<th>HighSpeed</th>
<th>Configuration</th>
<th>Cd (typ) (pF)</th>
<th>Package version</th>
<th>Package name</th>
<th>Size (mm)</th>
<th>V&lt;sub&gt;ESD&lt;/sub&gt; ICC 1000-4-2 (kV)</th>
<th>I&lt;sub&gt;lim&lt;/sub&gt; 8/20µs [max] (A)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>PESD5V0C1BSF</td>
<td>ESD protection</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,2</td>
<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>20</td>
<td>9</td>
<td>Very high robustness for single data lines</td>
</tr>
<tr>
<td>PESD5V0C1USF</td>
<td>ESD protection</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,45</td>
<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>20</td>
<td>9</td>
<td>Extremely low clamping and high robustness for single data lines</td>
</tr>
<tr>
<td>PESD3V321BSF</td>
<td>ESD protection</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,28</td>
<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>20</td>
<td>9,5</td>
<td>Extremely low clamping and high robustness for single data lines</td>
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<tr>
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<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,45</td>
<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>30</td>
<td>&gt; 15</td>
<td>Extremely low clamping and high robustness for single data lines</td>
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<tr>
<td>PESD5V0H1BSF</td>
<td>ESD protection</td>
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<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,15</td>
<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>15</td>
<td>7</td>
<td>First offer for single data lines</td>
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<tr>
<td>PESD5V0R1BSF</td>
<td>ESD protection</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,1</td>
<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>10</td>
<td>4,5</td>
<td>Extremely low capacitance for single data lines</td>
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<tr>
<td>PESD5V0S1USF</td>
<td>ESD protection</td>
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<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>35</td>
<td>SOT962-2</td>
<td>DSN0603-2</td>
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<td>30</td>
<td>3,5</td>
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<td>yes</td>
<td>Unidirectional</td>
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<td>SOD962-2</td>
<td>DSN0603-2</td>
<td>0.6 x 0.3 x 0.3</td>
<td>30</td>
<td>8</td>
<td></td>
<td></td>
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<tr>
<td>IP3319C6</td>
<td>Common mode filter + ESD</td>
<td>2+1 *</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,3</td>
<td>OLIP3319C6</td>
<td>WLCSP6</td>
<td>0,95 x 1,34 x 0,6</td>
<td>15</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IP4283C10-TBR</td>
<td>ESD protection</td>
<td>4</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,6</td>
<td>SOT1176-1</td>
<td>DFN2310A-10</td>
<td>2.5 x 1.0 x 0,5</td>
<td>8</td>
<td>&gt; 3</td>
<td>Allows a combination of CC/SBU protection</td>
</tr>
<tr>
<td>PCMF1USB3S</td>
<td>Common mode filter + ESD</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,3</td>
<td>WLCSP5, 2-1-2</td>
<td>WLCSP5</td>
<td>0,77 x 1,17 x 0,57</td>
<td>15</td>
<td>7</td>
<td>Very easy routing for USB Type-C connector</td>
</tr>
<tr>
<td>PCMF2USB3S</td>
<td>Common mode filter + ESD</td>
<td>4</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,3</td>
<td>WLCSP10, 4-2-4</td>
<td>WLCSP10</td>
<td>1,57 x 1,17 x 0,57</td>
<td>15</td>
<td>7</td>
<td>Two line pairs</td>
</tr>
<tr>
<td>PCMF3USB3S</td>
<td>Common mode filter + ESD</td>
<td>6</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,3</td>
<td>WLCSP15, 6-3-6</td>
<td>WLCSP15</td>
<td>2,37 x 1,17 x 0,57</td>
<td>15</td>
<td>7</td>
<td>Three line pairs</td>
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<tr>
<td>PESD5V0V2BM</td>
<td>ESD protection</td>
<td>2</td>
<td>yes</td>
<td>Bidirectional</td>
<td>18</td>
<td>SOT883</td>
<td>DFN1006-3</td>
<td>1,0 x 0,6 x 0,37</td>
<td>30</td>
<td>9</td>
<td>Extremely low clamping and robustness for two data lines</td>
<td></td>
</tr>
<tr>
<td>PESD5V0V2BMB</td>
<td>ESD protection</td>
<td>2</td>
<td>yes</td>
<td>Bidirectional</td>
<td>18</td>
<td>SOT883B</td>
<td>DFN1006B-3</td>
<td>1,0 x 0,6 x 0,37</td>
<td>30</td>
<td>9</td>
<td>Extremely low clamping and robustness for two data lines</td>
<td></td>
</tr>
<tr>
<td>PESD5V0X1BCAL</td>
<td>ESD protection</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,85</td>
<td>SOD882</td>
<td>DFN1006-2</td>
<td>1,0 x 0,6 x 0,3</td>
<td>15</td>
<td>1,8</td>
<td></td>
</tr>
<tr>
<td>PESD5V0X2UAM</td>
<td>ESD protection</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,8</td>
<td>SOT883</td>
<td>DFN1006-3</td>
<td>1,0 x 0,6 x 0,48</td>
<td>15</td>
<td>2,5</td>
<td>0,37 thickness: …UAMB</td>
</tr>
<tr>
<td>PESD1USB3S</td>
<td>ESD protection</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,3</td>
<td>WLCSP5, 2-1-2</td>
<td>WLCSP5</td>
<td>0,77 x 1,17 x 0,57</td>
<td>15</td>
<td>7</td>
<td>Allows changing between ESD and filter</td>
</tr>
<tr>
<td>PESD2USB3S</td>
<td>ESD protection</td>
<td>4</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,3</td>
<td>WLCSP10, 4-2-4</td>
<td>WLCSP10</td>
<td>1,57 x 1,17 x 0,57</td>
<td>15</td>
<td>7</td>
<td>Allows changing between ESD and filter</td>
</tr>
<tr>
<td>PESD3USB3S</td>
<td>ESD protection</td>
<td>6</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,5</td>
<td>WLCSP15, 6-3-6</td>
<td>WLCSP15</td>
<td>2,37 x 1,17 x 0,57</td>
<td>15</td>
<td>7</td>
<td>Allows changing between ESD and filter</td>
</tr>
<tr>
<td>PUSB3A86</td>
<td>ESD protection</td>
<td>6</td>
<td>yes</td>
<td>yes</td>
<td>Bidirectional</td>
<td>0,15</td>
<td>SOT1358-1</td>
<td>XSON7</td>
<td>1,1 x 2,1 x 0,5</td>
<td>15</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>PUSB3FR4</td>
<td>ESD protection</td>
<td>4</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,29</td>
<td>SOT1176-1</td>
<td>DFN2310A-10</td>
<td>2,5 x 1,0 x 0,5</td>
<td>15</td>
<td>7</td>
<td>First offer for 4 data lines</td>
</tr>
<tr>
<td>PUSB3FR6</td>
<td>ESD protection</td>
<td>6</td>
<td>yes</td>
<td>yes</td>
<td>Unidirectional</td>
<td>0,35</td>
<td>SOT1358-1</td>
<td>XSON7</td>
<td>1,1 x 2,1 x 0,5</td>
<td>15</td>
<td>7</td>
<td>First offer for 6 data lines</td>
</tr>
</tbody>
</table>

* On The Go
## Product selection for $V_{\text{bus}} / V_{\text{bat}}$ protection

<table>
<thead>
<tr>
<th>Type</th>
<th>$V_{\text{bus}}$ (V)</th>
<th>8/20µs pulse</th>
<th>10/1000µs pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$I_{\text{ppm}}$ [max] (A)</td>
<td>$V_{\text{cl}} @ I_{\text{ppm}}$ [max] (V)</td>
<td>$I_{\text{ppm}}$ [max] (A)</td>
</tr>
<tr>
<td>PTV5SV5Z1USKP</td>
<td>5</td>
<td>100</td>
<td>20.4</td>
</tr>
<tr>
<td>PTV5SV6Z1USKP</td>
<td>5</td>
<td>80</td>
<td>18</td>
</tr>
<tr>
<td>PTV5SV7Z1USKP</td>
<td>7.5</td>
<td>100</td>
<td>22</td>
</tr>
<tr>
<td>PTV5SV10VZ1USK</td>
<td>10</td>
<td>75</td>
<td>27</td>
</tr>
<tr>
<td>PTV5SV12VZ1USK</td>
<td>12</td>
<td>65</td>
<td>29</td>
</tr>
<tr>
<td>PTV5SV15VZ1USK</td>
<td>15</td>
<td>52</td>
<td>36</td>
</tr>
<tr>
<td>PTV5SV18VZ1USK</td>
<td>18</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td>PTV5SV20VZ1USK</td>
<td>20</td>
<td>41</td>
<td>48.3</td>
</tr>
<tr>
<td>PTV5SV22VZ1USK</td>
<td>22</td>
<td>41</td>
<td>39.5</td>
</tr>
<tr>
<td>PTV5SV26VZ1USK</td>
<td>26</td>
<td>32</td>
<td>57.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>$V_{\text{bus}}$ (V)</th>
<th>8/20µs pulse</th>
<th>10/1000µs pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$I_{\text{ppm}}$ [max] (A)</td>
<td>$V_{\text{cl}} @ I_{\text{ppm}}$ [max] (V)</td>
<td>$I_{\text{ppm}}$ [max] (A)</td>
</tr>
<tr>
<td>PTV5SV7VU1UPA</td>
<td>7.5</td>
<td>178</td>
<td>19.7</td>
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<tr>
<td>PTV5SV10VU1UPA</td>
<td>10</td>
<td>148</td>
<td>23</td>
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<tr>
<td>PTV5SV12VU1UPA</td>
<td>12</td>
<td>131</td>
<td>25.2</td>
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<td>PTV5SV15VU1UPA</td>
<td>15</td>
<td>111</td>
<td>28.8</td>
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<tr>
<td>PTV5SV18VU1UPA</td>
<td>18</td>
<td>97</td>
<td>32</td>
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<td>PTV5SV20VU1UPA</td>
<td>20</td>
<td>98.5</td>
<td>38.7</td>
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<tr>
<td>PTV5SV22VU1UPA</td>
<td>22</td>
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<td>41</td>
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<tr>
<td>PTV5SV24VU1UPA</td>
<td>24</td>
<td>79</td>
<td>44.2</td>
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<tr>
<td>PTV5SV26VU1UPA</td>
<td>26</td>
<td>69</td>
<td>43.5</td>
</tr>
</tbody>
</table>

**V_{\text{bus}}$ surge protection**

All devices offer 30 kV ESD ruggedness.

- **SOD964**
  - DSN1608-2
  - 1.6 x 0.8 x 0.29 mm

- **SOT1061**
  - DFN2020-3
  - 2.0 x 2.0 x 0.65 mm
**Eye diagrams**

Differential signals are applied to the Device-Under-Test (DUT). An overlay of sweeps of different 0-1 and 1-0 transitions is shown in the eye diagram:

- Due to imperfections and suppression of higher harmonics, the signal after a system looks like an eye – hence the name of the measurement
- A mask, that surrounds the eye but is not touched by it, defines the maximum allowed signal degradation that is acceptable to all receivers
- Differential signals are measured after a comparator
System-level ESD protection for USB 3.2

Protection of the SoC

With system-level ESD protection, the greater part of an ESD pulse is kept away from the protected System-on-Chip (SoC) and signal integrity is maintained for all frequencies used in the application. System-level protection can be improved by providing fast diode reaction time, low dynamic resistance, deep snap-back and low inductance package concepts. An eye diagram for the highest frequency used by the application will show the signal integrity Walso with onboard.

System-level test

› Stresses the pins with an ESD gun until an increase in leakage current shows signs of failure which is the most straight forward way to measure system-level robustness
› In Nexperia tests on commonly available USB applications, the USB system chip failed but the ESD protection remained undamaged
› System level protection is achieved by reducing the ESD stress on the system:
  - Deep snap-back
  - Low dynamic resistance
  - Fast diode switching time
  - Low inductance package concept
System-level ESD protection for USB 3.2

TLP measurements

Transmission Line Pulse (TLP) measurements are a way to characterize the I(V) behaviour of ESD protection devices without overstressing them. First, a defined transmission-line is charged. Next, this line is discharged over the Device Under Test (DUT), which can be a single component or a complete system. Current and clamping voltage are recorded, with a pair of single current (voltage) measurements forming one point in the TLP diagram. The leakage current is measured after each discharge to establish any signs of damage to the DUT.

The dynamic resistance $R_{\text{dyn}}$ is derived from the steepness of the TLP graph: $\frac{\Delta V}{\Delta I}$

For each TLP measurement voltage and current samples are averaged over 20 ns and denoted as single point in the TLP graph.
System-level ESD protection for USB 3.2

Transmission Line Pulse (TLP) measurements (100 ns pulse)

Comparing the TLP I(V) behaviour of three bi-directional ESD protection devices with SCR for USB 3.2. Nexperia offers the lowest clamping voltages, leading to the best system-level protection.

Very-fast TLP (vfTLP) measurements (5 ns pulse)

Comparing three bi-directional SCR ESD protection devices for USB 3.2 in their vfTLP behaviour. Nexperia’s SCR is the only device, which triggers for vfTLP pulses. Untriggered, the system-level protection is reduced to the level of a standard device.
System-level ESD protection for USB 3.2

Comparing switching speeds for 100 ns TLP measurements @ 10 A TLP. Nexperia offers the shortest switching times to the lowest clamping voltage compared to the next best devices on the market.

Comparing switching speeds of three SCR devices for 5 ns very-fast TLP (vfTLP) measurements @ 1 A vFTLP. Nexperia offers the only SCR in this comparison, which triggers for very fast pulses.

Measurement of switching time (turn-on time) based on vfTLP test pulse.
Common mode filters for USB

› Increased integration, in portable devices, of different signals in the Gigahertz range has led to higher demands for EMI suppression
› Nexperia offers a selection of common mode filters with integrated ESD protection to protect and filter USB 2.0 and 3.x interfaces
› Details are in our dedicated application guide for common mode filters
Common mode filters for USB 2.0 and USB 3.2

IP3319CX6 for USB 2.0 OTG (On-The-Go)

Key features:
› Common mode filter for one differential line pair
› 3-line ESD protection for one line pair plus one pin (ID for OTG)
› Best common mode protection in this footprint
› Best-in-class ESD protection due to deep snap-back and very low $R_{\text{dyn}}$
› Very compact WLCSP6 package:
› 0.95 x 1.34 x 0.57 mm

USB 2.0 eye diagram with IP3319CX6 on test board

IP3319CX6 insertion losses for differential and common modes

Typical IP3319CX6 application using Micro USB connector Type B
Common mode filters for USB 2.0 and USB 3.2

PCMFxUSB3y for USB 3

**Key features:**
- Common mode filter with ESD protection for one, two and three differential line-pairs
- Extremely wide differential pass band of 6.5 GHz
- Very wideband common mode suppression between 0.7 to 10 GHz
- Excellent system-level ESD protection due to
  - Very fast ESD diode switching speeds
  - Very deep snap-back
  - Very low dynamic resistance
  - Low inductance WLCSP package
- Extremely strong common mode suppression for the 5 Gbps USB3 fundamental @ 2.5 GHz

![USB 3.1 / 3.2 eye @ 5 Gbps PCMFxUSB3y](image1)

![USB 3.1 / 3.2 eye @ 10 Gbps PCMFxUSB3y](image2)