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## USB Type-C protection and filtering

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### Introduction

The USB interface has been present on the market for nearly 2 decades and thanks to that, nowadays it is quite obvious for everybody to connect electronic devices in this manner. However, the presence of different types of connectors: type A, type B, mini USB, micro USB etc., makes difficult and complicated the choice of the right one. For this reason USB Type-C, a unique connector to drive audio and power data up to 5 or 10 Gbps, is now available.

Due to the fact that for its own nature a connector is a link to the outside world, it may be exposed to a lot of disturbances which can ruin the transceivers. Moreover, the high-speed links radiate therefore an efficient filter has to be used to solve antenna desense.

STMicroelectronics has developed some specific protection devices and common mode filters with optimized performance and layout.

This application note proposes different solutions in order to simplify the designer's work and explain their benefits.

Further information about protection and filtering devices for USB Type-C are available on [www.st.com/protection-typec](http://www.st.com/protection-typec).

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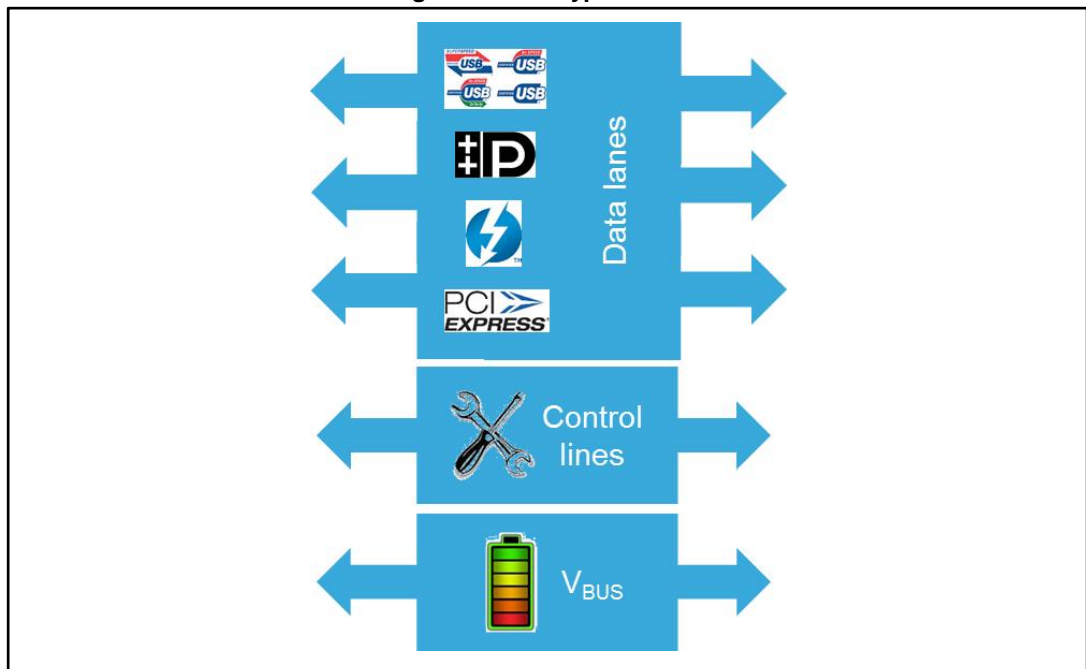
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# 1 USB Type-C

## 1.1 Overview

This connector includes three groups of differential lanes that drive standards such as: USB 3.1, DisplayPort, ThunderBolt™, PCI Express etc., and two control lines (configuration channel and sideband use). Furthermore, it embeds a power line,  $V_{BUS}$ , which drives high current for charging and supply (figure below).

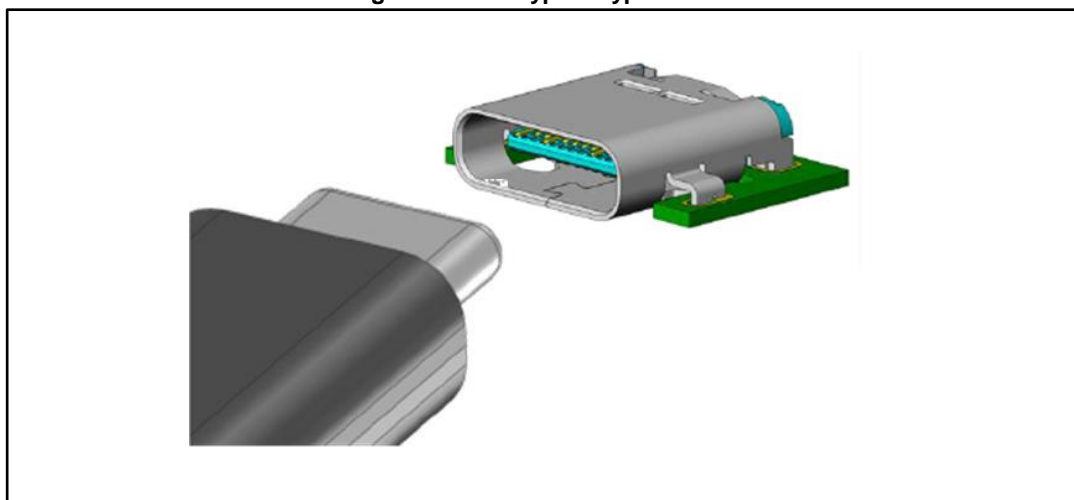
Figure 1: USB Type-C links



Actually, data rates go up to 10 Gbps for data lines in order to drive high resolution video or high-speed data transfer.

This connector is highly integrated and compact. It is particularly suitable for small applications such as: tablet PC, laptops, phablets and even smart phones. A typical view of the USB Type-C is shown in the figure below.

Figure 2: USB Type-C typical view



The figure below describes the different pins of the receptacle connector.

Figure 3: Receptacle interface pinout (front view)

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

The following table describes the function of each pin:

Table 1: Definition of the pin functions

Pin #	Pin name	Function
A1 / A12 B1 / B12	GND	Ground return
A4 / A9 B4 / B9	V <sub>BUS</sub>	Bus power supply
A2 / A3 B11 / B10	TX1+ / TX1- RX1+ / RX1-	Positive and negative of the first SuperSpeed T <sub>x</sub> differential pair Positive and negative of the first SuperSpeed R <sub>x</sub> differential pair
B2 / B3 A11 / A10	TX2+ / TX2- RX2+ / RX2-	Positive and negative of the second SuperSpeed T <sub>x</sub> differential pair Positive and negative of the second SuperSpeed R <sub>x</sub> differential pair
A6 / B6 A7 / B7	D+ / D-	Positive half of the USB 2.0 differential pair (position 1 and 2) Negative half of the USB 2.0 differential pair (position 1 and 2)
A5 / B5	CC1 / CC2	Used to detect connections and configure the interface One CC pin repurposed as V <sub>CONN</sub> for powering electronics
A8 / B8	SBU1 / SBU2	Sideband use: Audio adapter accessory configuration Additional function to be defined

Furthermore, Type-C is compliant with USB Power Delivery that allows a maximum current up to 5 A and a maximum voltage up to 20 V.

## 1.2 Power supply

### 1.2.1 Power supply options

USB standard defines  $V_{BUS}$  as the path to deliver power between a host and a device or between a charger and a host/device.

The table below summarizes the available power options.

**Table 2: Power supply options**

Mode of operation	Nominal voltage	Maximum current	Notes
USB 2.0	5 V	500 mA	Default current, based on definitions in the base specifications
USB 3.1	5 V	900 mA	
USB BC 1.2	5 V	Up to 1.5 A	Legacy charging
USB Type-C current @ 1.5 A	5 V	1.5 A	Supports higher power devices
USB Type-C current @ 3.0 A	5 V	3 A	Supports higher power devices
USB PD	Configurable up to 20 V	Configurable up to 5 A	Directional control and power level management

USB 2.0 and USB 3.1 are the only ones with a default level of 5 V nominal voltage and current up to 900 mA. Legacy charging increases maximum current to 1.5 A.

Configuration channels (CC1 and C2) detect the cable position on the connector. Pull-up resistor on provider gives some information on current capability (22 k $\Omega$  +/- 5% for 1.5 A and 10 k $\Omega$  +/- 5% for 3 A on host associated with 5.1 k $\Omega$  +/- 10% pull-down resistor on the device).

### 1.2.2 USB Power Delivery

The USB Power Delivery (USB PD) communication over CC is used for the advanced power delivery negotiation with current up to 5 A and voltage up to 20 V. 300 kbit/s BMC (biphase mark code) controller negotiates power profile and directivity.

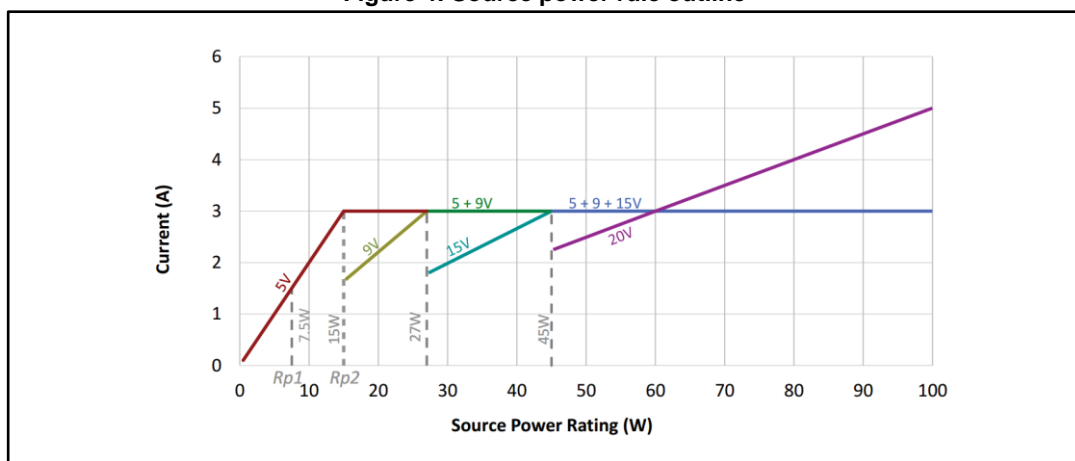
USB PD rules are fixed by USB Power Delivery revision 3, where voltages and currents for each power are defined.

Normative voltages are as follows:

- 5 V to reach 15 W maximum
- 9 V to reach 27 W maximum
- 15 V to reach 45 W maximum
- 20 V to reach 100 W maximum but 5 A cable is required for power higher than 60 W

The figure below illustrates the maximum current and power rails that the USB PD source can deliver.

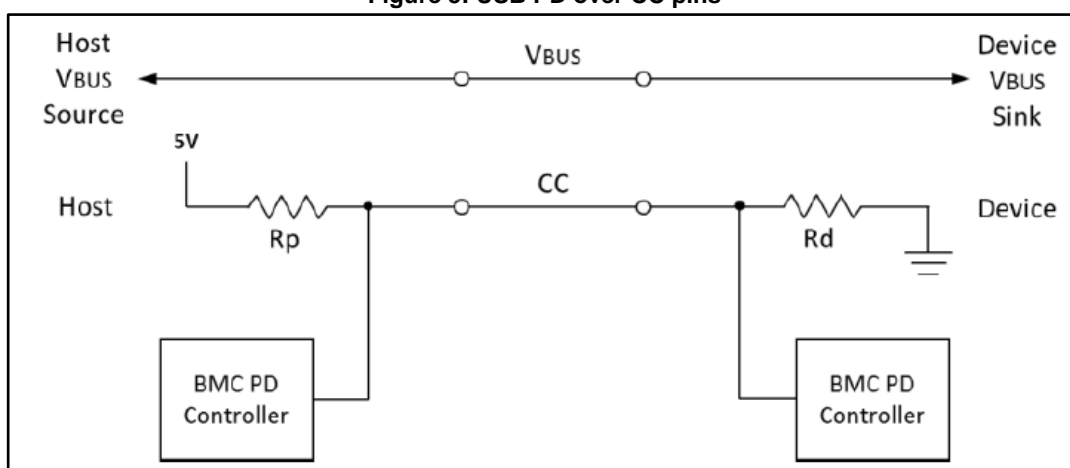
Figure 4: Source power rule outline



The maximum power is 100 W. These power rules respect safety requirements imposed by IEC/UL 60950 regulation.

The figure below shows USB PD over CC pins on host, the device configuration with pull-up ( $R_p$ ) and pull-down ( $R_d$ ) resistors.

Figure 5: USB PD over CC pins



The receptacle is specified up to 5 A current but Type-C cables are rated for 3 A. So, for current higher than 3 A, the electronic marking of the cable is mandatory.

### 1.3 Differential lines

The USB type receptacle delivers 6 differential pairs dedicated to high-speed signals:

- 2 differential pairs drive USB2 high-speed signal, up to 480 Mbps
- 4 differential pairs dedicated to super speed signal, drive USB 3.1 Gen 2 signal up to 10 Gbps

All hosts and devices with USB Type-C receptacle show the USB interface. According to the USB Type-C standard, alternate modes are allowed only when host and device are directly connected, while they are not allowed when the connection is through USB hub.

## 1.3.1 USB interface

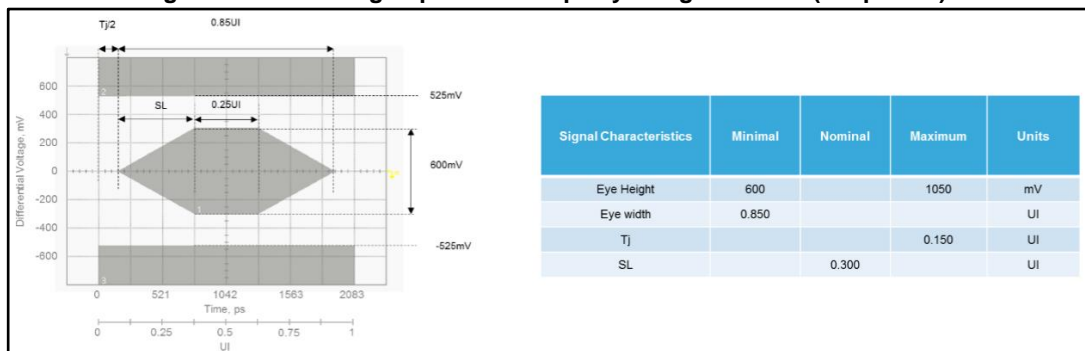
### 1.3.1.1 USB 2.0 interface

The USB Type-C connector exhibits 4 pins A6, A7, B6 and B7 dedicated to USB 2. On the USB Type-C plug connector, B6(D+) and B7(D-) should not be present. The plug orientation determines which differential pair A6/A7 or B6/B7 is used on the receptacle side.

Dp1 (A6) and Dp2 (B6) pins may be shorted together on the PCB as close as possible to the receptacle to minimize the stub length, with trace length shorter than 3.5 mm as specified in the standard. Dn1 (A7) and Dn2 (B7) may be also shorted together.

The signal on Dp/Dn data lines fulfills USB 2.0 electrical requirements, in particular the eye diagram pattern (figure below) measured on the connector output of the device under test.

**Figure 6: USB 2.0 high-speed 480 Mbps eye diagram mask (template 1)**



### 1.3.1.2 USB 3 interface

SuperSpeed data lanes fulfill USB 3.1 electrical requirements. USB 3.1 standard defines the eye pattern mask for USB Gen 1, i.e. 5 Gbps data rate (figure below) and that for USB Gen 2, i.e. 10 Gbps data rate ([Figure 8: "USB 3.1 Gen 2, 10 Gbps eye diagram mask"](#)). The eye pattern is measured at the end of a reference cable and after an equalizer.

**Figure 7: USB 3.1 Gen 1, 5 Gbps eye diagram mask**

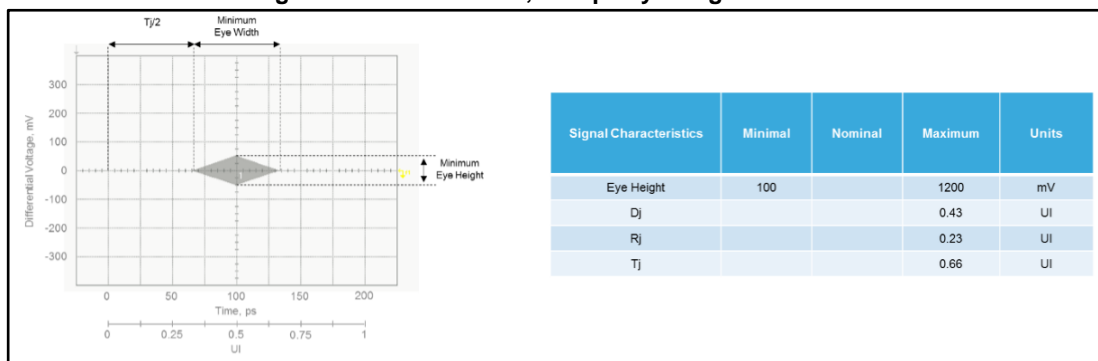
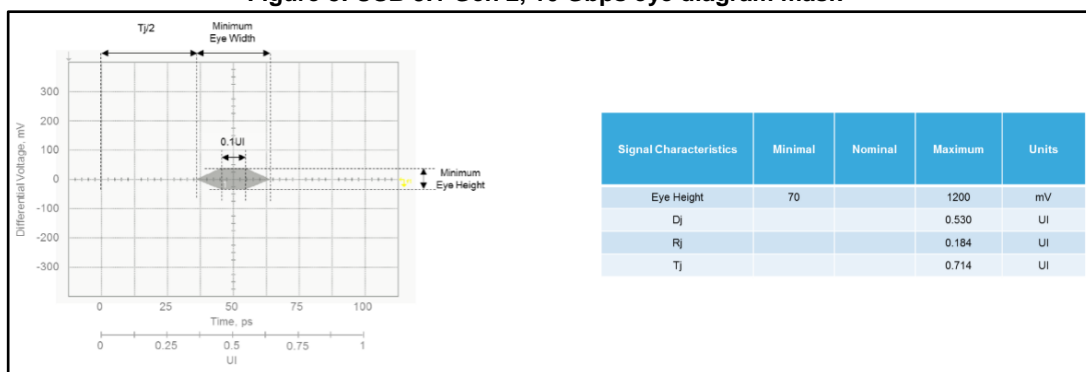


Figure 8: USB 3.1 Gen 2, 10 Gbps eye diagram mask



During standard mode, only one Tx differential pair and one Rx differential pair is used. In alternate mode, all Tx and Rx differential pairs can be used simultaneously.

### 1.3.2 Alternate mode

The alternate mode allows non-USB signal to be transmitted through USB Type-C cable and connectors. In this configuration, all high-speed lanes can be used.

The alternate mode is configured through the configuration channel (contact CC1 and CC2).



## 2 Constraints to be faced

Due to fast transition times of high-speed links, the risk of EMI is real and can cause some issues in mobile applications such as antenna desense. In this case, the use of common mode filters on the data lines is recommended.

Since  $V_{BUS}$  connection and command lines are directly exposed to external stresses, they also need protections and filters, which have to be chosen by taking into account different constraints:

- **Data rates and voltage levels:** they give the minimum differential bandwidths, which have to comply with the eye diagram templates specified by the different standards.
- **Rejection:** the common mode rejection has to be better than -20 dB in the frequency range where the device can get some issues (from 700 MHz up to 2.7 GHz in mobile applications, 2.4 GHz / 5 GHz for WiFi).
- **Protection:** the clamping voltage levels must secure the transceivers and enable the application to withstand standard such as IEC61000-4-2 up to level 4 and sometimes IEC61000-4-5 on the  $V_{BUS}$ .

### 3 Power supply protection

$V_{BUS}$  line can be used to charge mobile devices or share power with other devices/hosts.

European standard EN 55024 (information technology equipment - immunity characteristics - limits and methods of measurement) requires the following ESD discharge robustness: IEC 61000-4-2 4 kV contact and 8 kV air, criteria B (temporary perturbation and self-recovery).

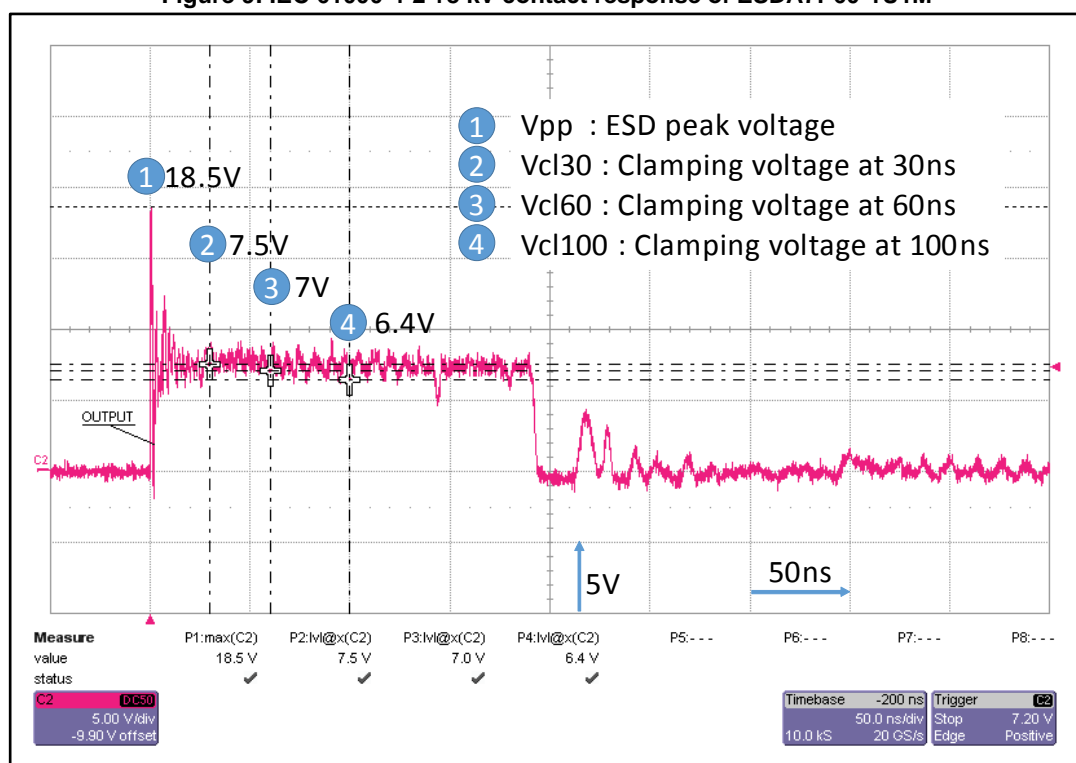
EOS (electrical overstress) can appear due to unstable power supply. As consequence, TVS protection devices with high surge current capability are expected.

Protection voltage must be in accordance with maximal  $V_{BUS}$  voltage, and protection capacitance is not limited due to DC voltage.

The ESDA7P60-1U1M is a product dedicated to protect systems with  $V_{BUS}$  maximum voltage equal to 5 V.

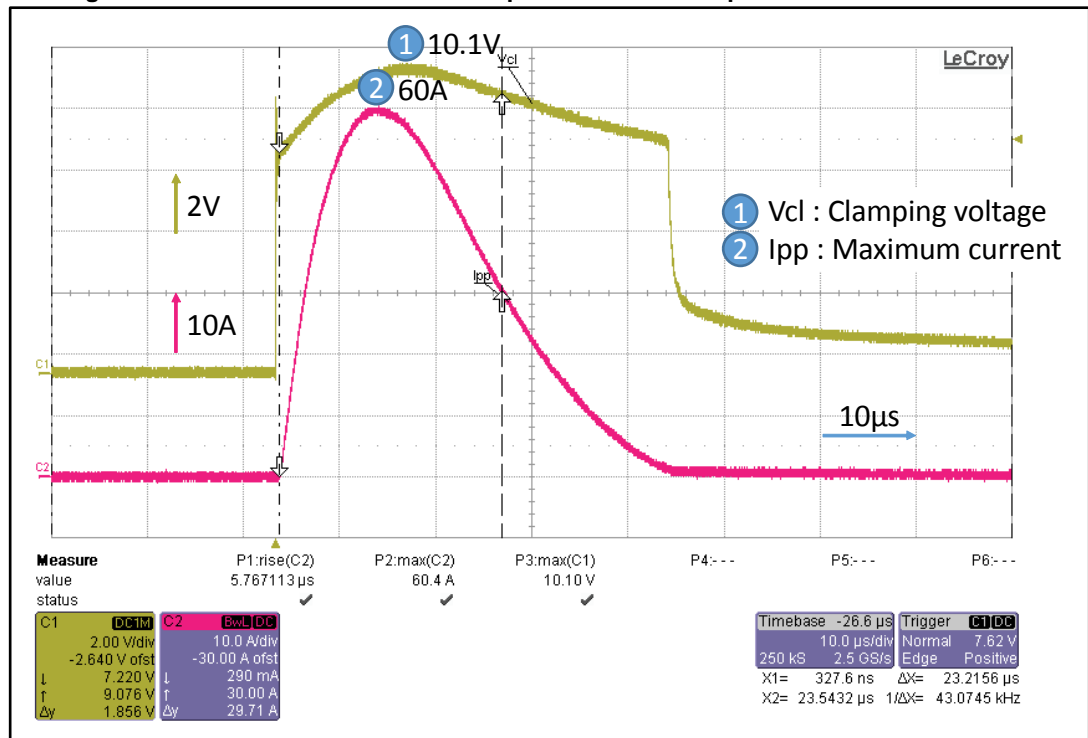
The figure below presents the ESDA7P60-1U1M response towards 8 kV ESD discharge.

**Figure 9: IEC 61000-4-2 +8 kV contact response of ESDA7P60-1U1M**



This protection presents a very low ESD peak voltage (18.5 V) and 30 ns clamping voltage (7.5 V) very close to the maximal working voltage (5.5 V) when 8 kV ESD is applied. Both results show a very good quality protection, 5 V  $V_{BUS}$ .

The figure below presents the response of the ESDA7P60-1U1M towards 60 A 8/20  $\mu$ s surge and resulting clamping voltage. It illustrates the current capability (60 A peak pulse current for this product) and associated low clamping voltage (10.1 V at maximum current). The resulting peak pulse power is 600 W. This parameter sometimes used to rank TVS is not the key. Indeed, the current must be as high as possible (protection robustness) and the clamping voltage must be as low as possible (protection quality).

Figure 10: IEC61000-4-5 with 60 A 8/20  $\mu$ s max. current response of ESDA7P60-1U1M

## 4 Configuration line protection

Configuration channel lines are not only used to establish and manage DFP-to-UFP connection but also to transmit USB PD communication using BMC coding. Protection constraints are the following:

- Maximal voltage is 5.5 V when  $V_{\text{CONN}}$  is used and no negative signal
- Protection capacitance and receiver capacitance must be between 200 pF and 600 pF

These lines require classical unidirectional ESD protections with low constraints on capacitance and no special feature on peak pulse current.

## 5 Differential line ESD protection

The ESD protection device must be carefully chosen in order not to compromise the signal transmission. In particular, the frequency bandwidth of the protection device defined by its cut-off frequency must be quite high in comparison to the signal bandwidth.

### 5.1 Signal bandwidth

The signal bandwidth of an aperiodic trapezoidal signal depends on minimum value of signal rise or fall time as shown by the equation below:

$$BW = \frac{0.35}{t_{r(10\%-90\%)}}$$

or

$$BW = \frac{0.22}{t_{r(20\%-80\%)}}$$

To minimize the impact of the ESD protection on the transmitted signal, the frequency bandwidth of the ESD protection must be higher than the signal bandwidth.

### 5.2 Impact of ESD protection device on transmitted signal rise time

The intrinsic capacitance of ESD protection device influences the signal rise time and the TDR response. The equation below gives the signal rise time on the output of the ESD protection assuming an input square signal.

$$t_{r\_ESD} = 0.35 * Z_0 * \pi * C_{ESD}$$

Considering ESD protection as a low pass filter instead of a parallel capacitor, ESD protection rise time can be evaluated function of the filter cut-off frequency  $f_{ESD\_3\text{ dB}}$ , as shown in the following equation:

$$t_{r\_ESD} = \frac{0.35}{f_{ESD\_3\text{ dB}}}$$

The following equation gives the system rise time with ESD protection:

$$t_{r\_system} = \sqrt{t_{r\_signal}^2 + t_{r\_ESD}^2}$$

Assuming an impact of ESD protection on rise time lower than 10% of initial rise time, the intrinsic capacitance maximum value for the rise time frequency is given by the equation below:

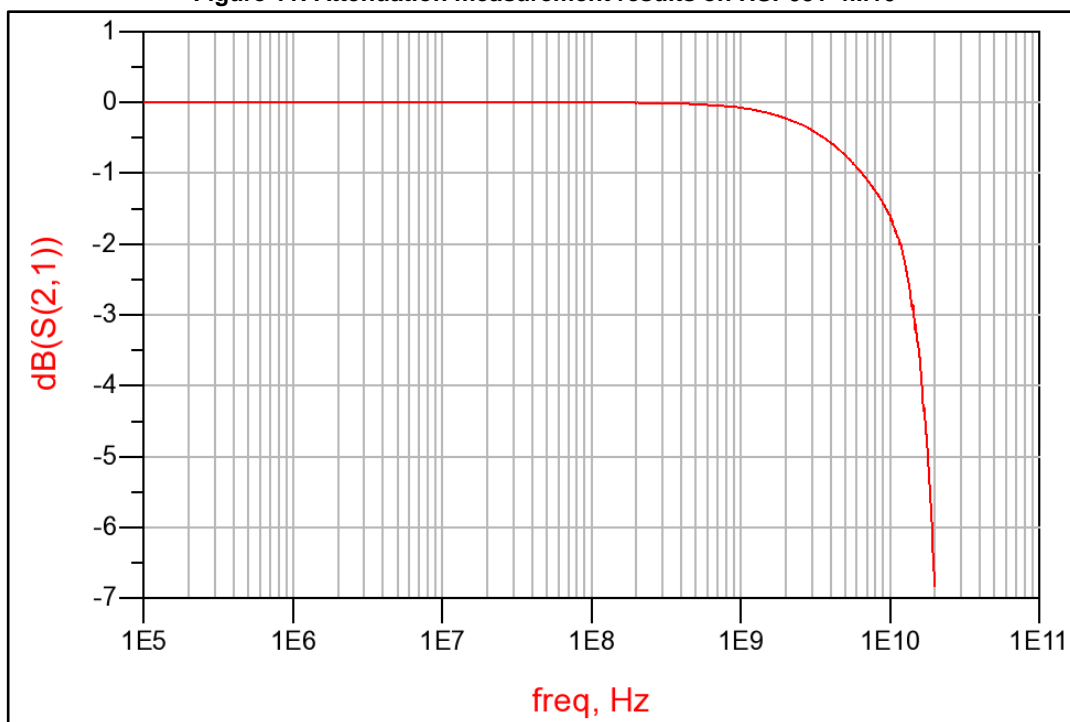
$$C_{ESD\_max} = \frac{\sqrt{0.21} t_{r\_signal}}{Z_0 * 0.35 * \pi}$$

The minimum cut-off frequency of the protection device is given as follows:

$$f_{-3\text{ dB\_ESD\_min}} = \frac{0.35}{\sqrt{0.21} t_{r\_signal}}$$

An example of attenuation curve measurement performed on the HSP051-4M10 is presented in the following figure. The cut-off frequency is measured at 14.5 GHz.

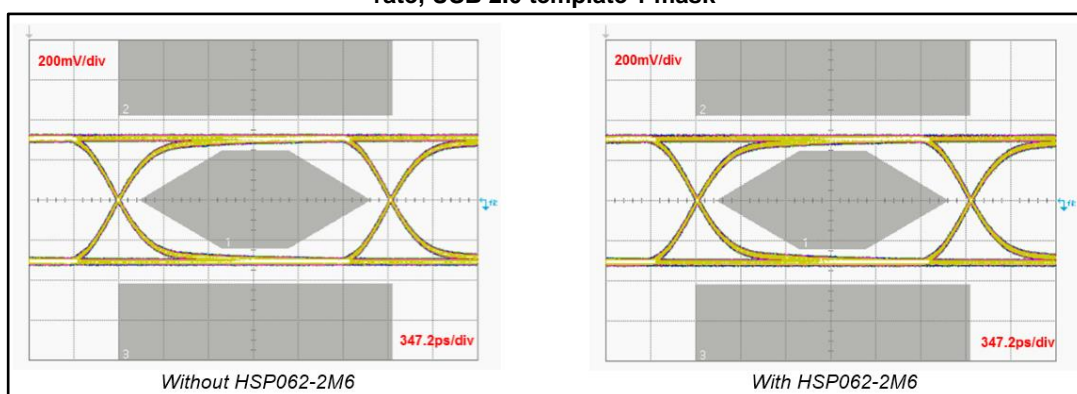
Figure 11: Attenuation measurement results on HSP051-4M10



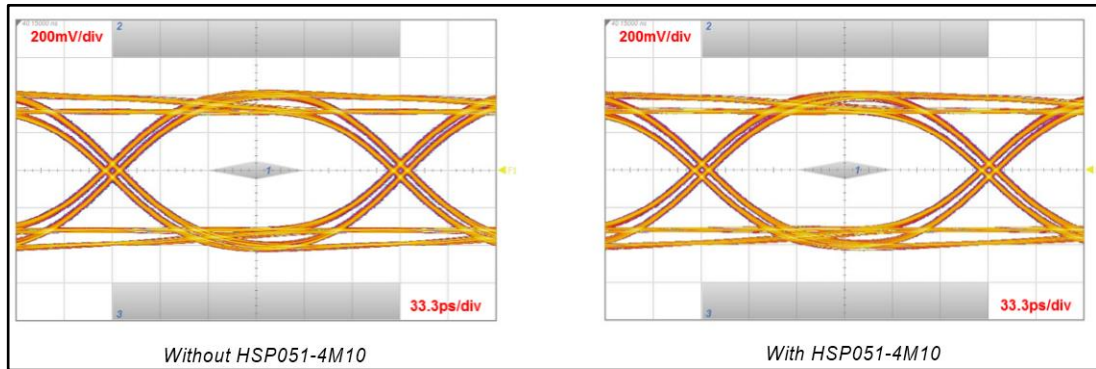
### 5.3 Eye diagrams

The impact of the protection device on the transmitted signal is illustrated by the eye diagram measurements during compliance certification. Examples of eye diagram measurements performed with and without ESD protection devices are presented in the figure below with a data rate of 480 Mbps, USB 2.0 template 1 eye mask, in [Figure 13: "USB 3.1 Gen 1 eye diagram example without and with HSP051-4M10, after reference cable and equalizer"](#) with a data rate of 5 Gbps and [Figure 14: "USB 3.1 Gen 2 eye diagram example for HSP051-4M10, after reference cable and equalizer"](#) with a data rate of 10 Gbps, USB 3.1 eye masks.

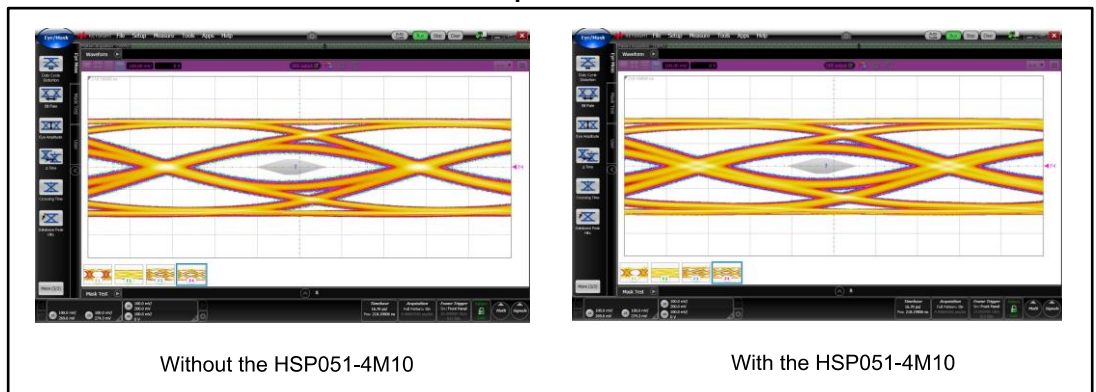
Figure 12: Eye diagram measurements without and with the HSP062-2M6 for 480 Mbps data rate, USB 2.0 template 1 mask



**Figure 13: USB 3.1 Gen 1 eye diagram example without and with HSP051-4M10, after reference cable and equalizer**

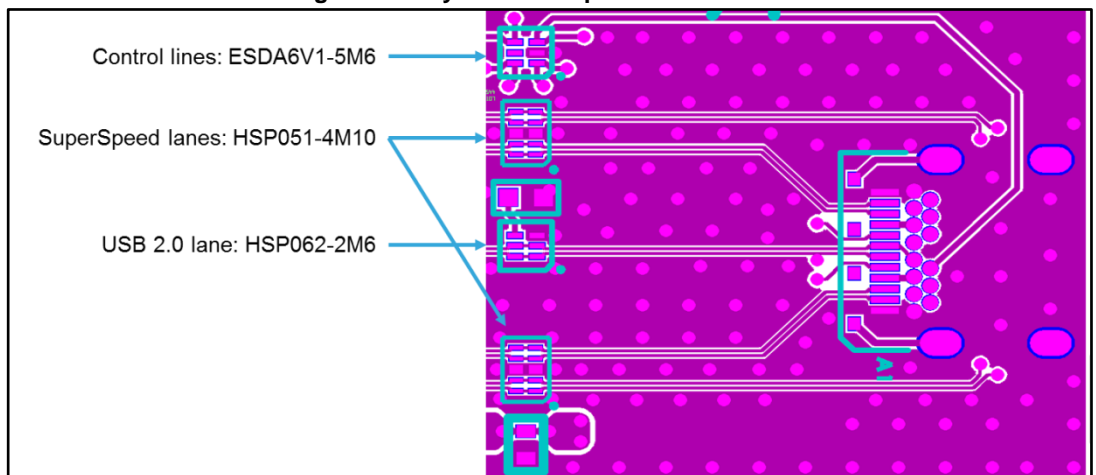


**Figure 14: USB 3.1 Gen 2 eye diagram example for HSP051-4M10, after reference cable and equalizer**



ESD protection devices are usually placed close to the connector. An example of layout is given in the following figure.

**Figure 15: Layout of ESD protection devices**

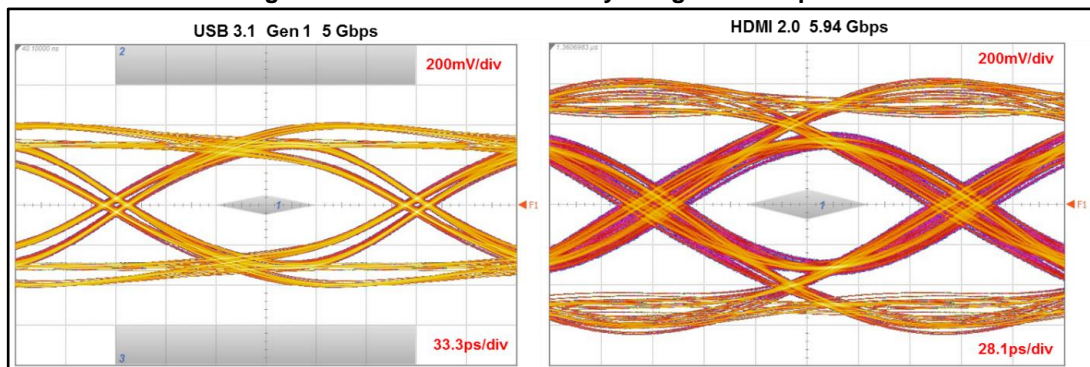


## 6 Antenna desense and noise rejection: common mode filters

### 6.1 Choosing the right bandwidth

As explained above, the maximum value of the data rate used defines the bandwidth of the common mode filter. To be sure that CMF is compliant with the standard, each datasheet includes an eye diagram in various standard configurations. Figure below shows an example of the ECMF04-4HSWM10 in USB 3.1 Gen 1 and HDMI 2.0 test conditions. It fulfills the templates and in that manner, the choice of the suitable device is easier.

Figure 16: ECMF04-4HSWM10 eye diagram examples

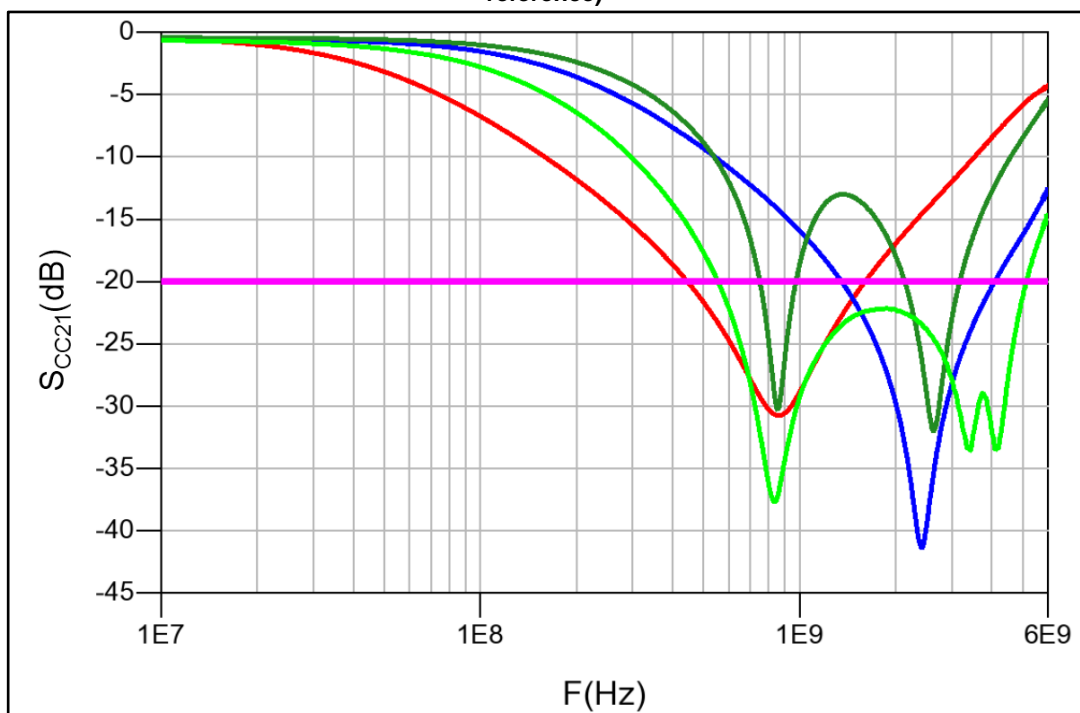


### 6.2 Common mode rejection

For each lane of the high-speed links, a common mode filter dedicated to the range of frequency, which can cause some issues to the application, exists. The following figure presents various  $S_{CC21}$  common mode rejections.



Figure 17: Typical STMicroelectronics ECMF/CMF common mode rejection (in red, the market reference)



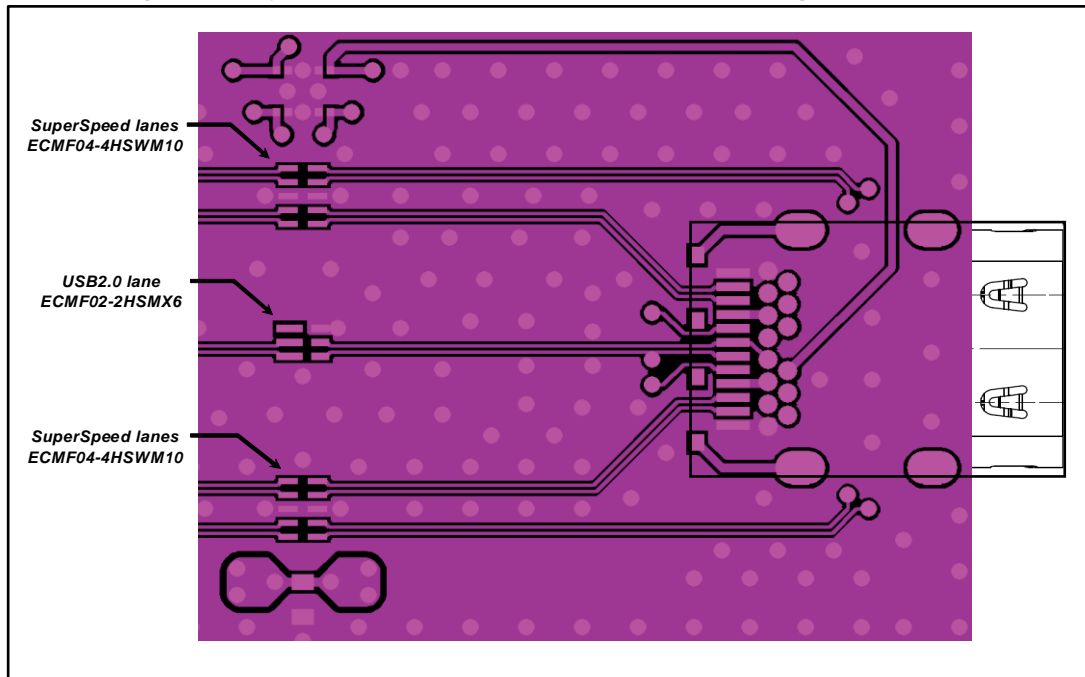
The purple line represents the optimized common mode rejection, generally set to -20 dB. For example, if the sensitivity in LTE RX Band-5 of the application decreases, due to a lot of noise generated by digital traffic, CMF with the light green  $S_{CC21}$  characteristic must be chosen. It assumes a deep rejection in this frequency range, better than -30 dB. If the application encounters issues in Wi-Fi 2.4 GHz reception, CMF with blue characteristic is recommended. Its  $S_{CC21}$  characteristic is better than -35 dB at this frequency.

### 6.3 The PCB layout

Filters are user-friendly and ensure a simple layout around the Type-C connector. This helps to keep the differential impedance of the lane to 100  $\Omega$  or 90  $\Omega$ .

The figure below presents a typical layout around a USB Type-C connector.

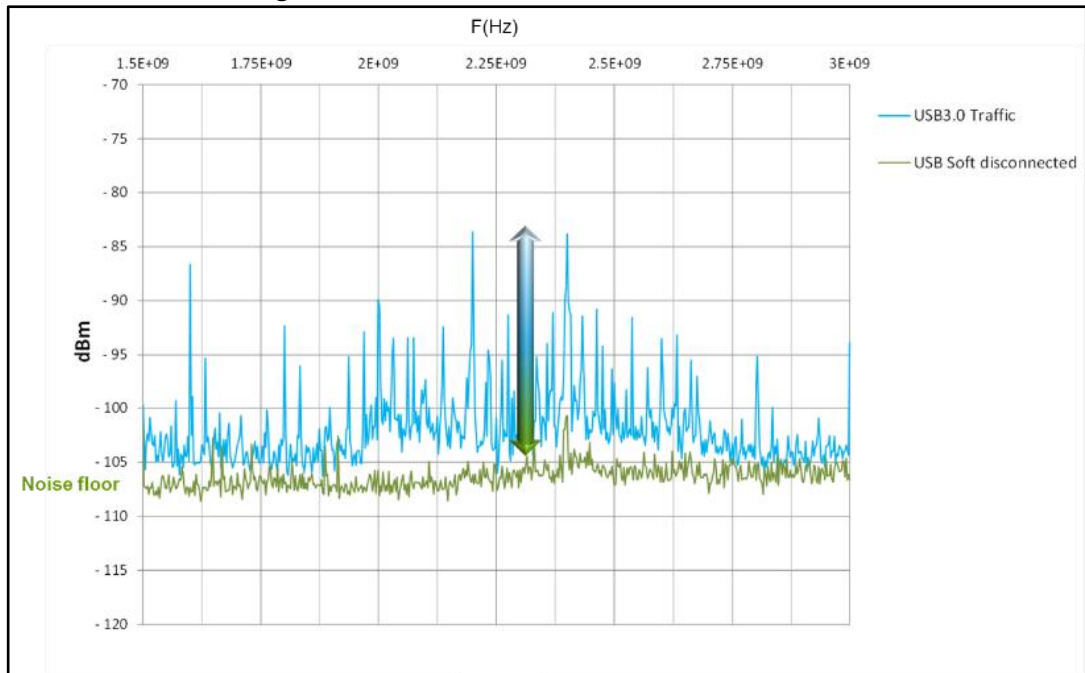
Figure 18: Layout example with three ECMF filters on the high-speed lanes



## 6.4 Benefits of the common mode filters

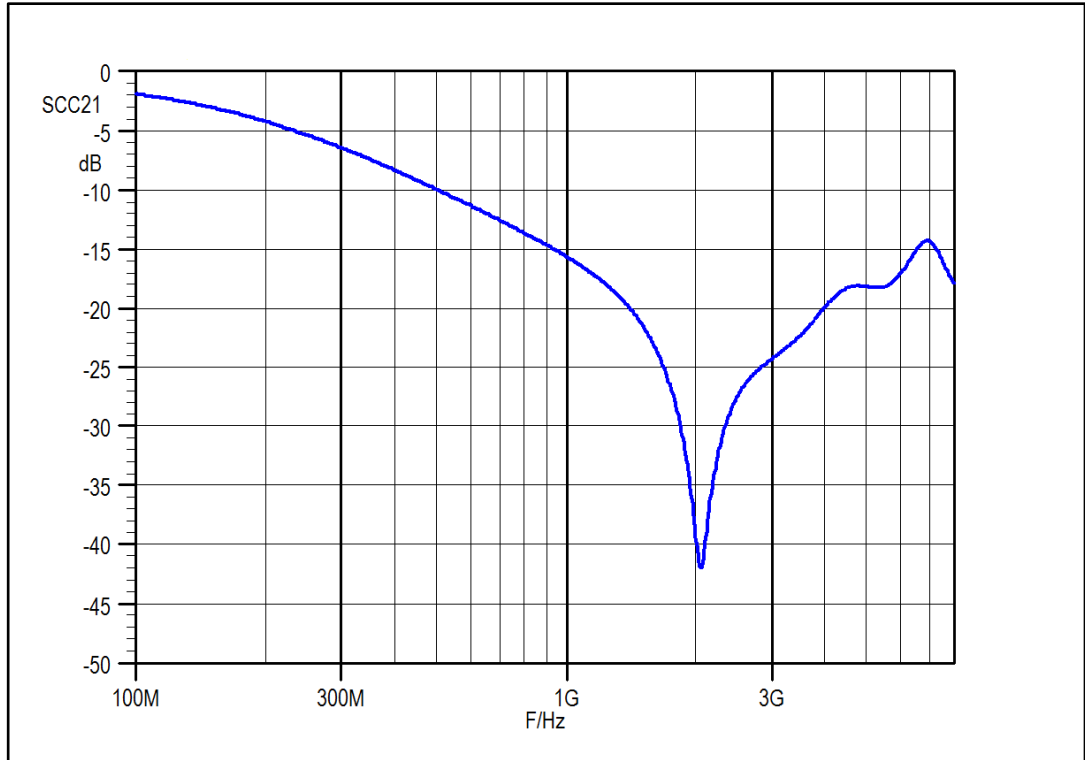
The figure below shows the noise radiated by a USB 3.1 Gen 1 cable, measured between 1.5 GHz and 3 GHz. It is possible to see that high level spikes can appear with a difference up to 20 dB respect to the noise floor. These spikes are in the same frequency range as Bluetooth or Wi-Fi, and antenna desense occurs, causing disruptions on the signal reception.

Figure 19: Noise measured on a USB 3.0 Gen 1 link



This kind of noise can be filtered by common mode filters. In this example, the ECMF04-4HWSM10 filter (from ST's ECMF™ series) has been placed on each side of the link with common mode rejection centered on 2 GHz. The figure below shows its typical rejection  $S_{CC21}$ , better than 25 dB between 1.8 GHz up to 2.9 GHz.

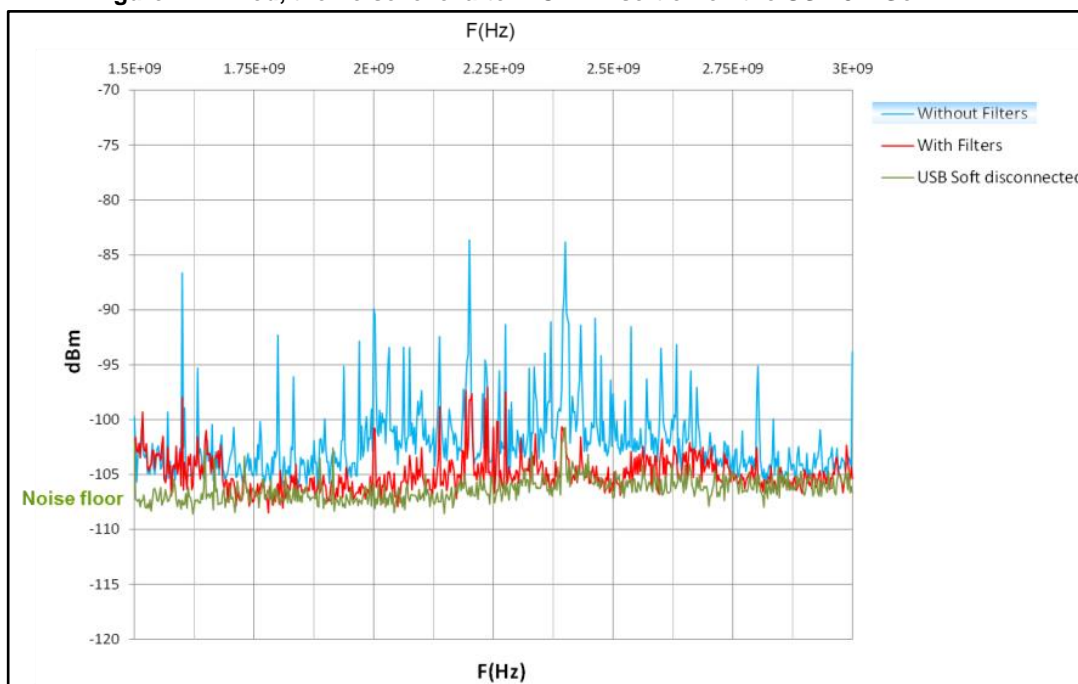
**Figure 20: Typical common mode rejection of the ECMF04-4HWSM10 dedicated to 2.4 GHz application**



Next figure shows the attenuation on the common mode noise thanks to the ECMF.

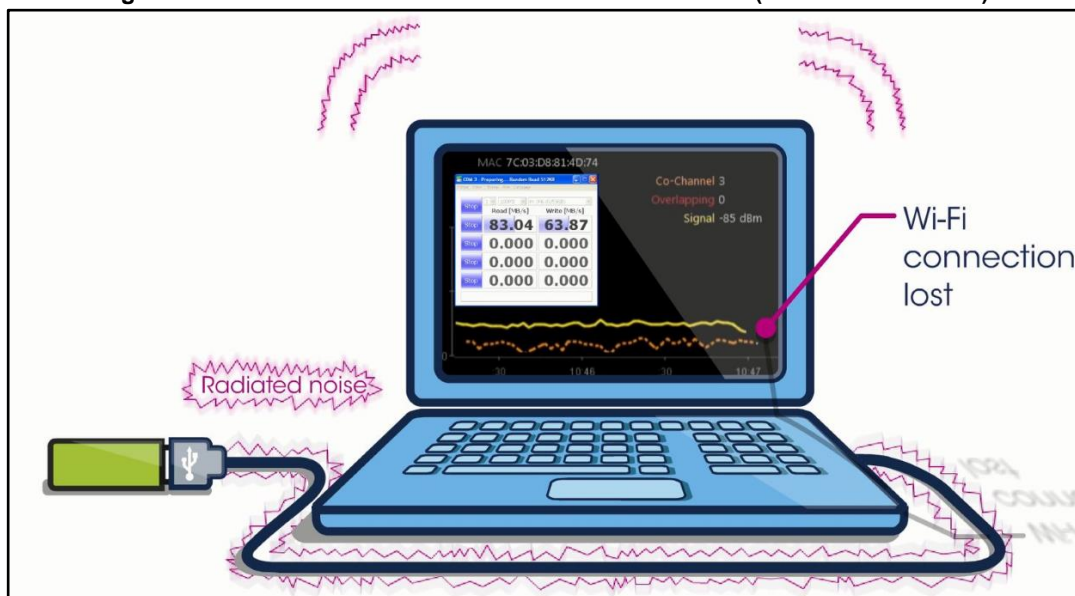
The average gain is around -25dB. However, the result on a standard application is not known yet.

Figure 21: In red, the noise level after ECMF insertion on the USB 3.1 Gen 1 link



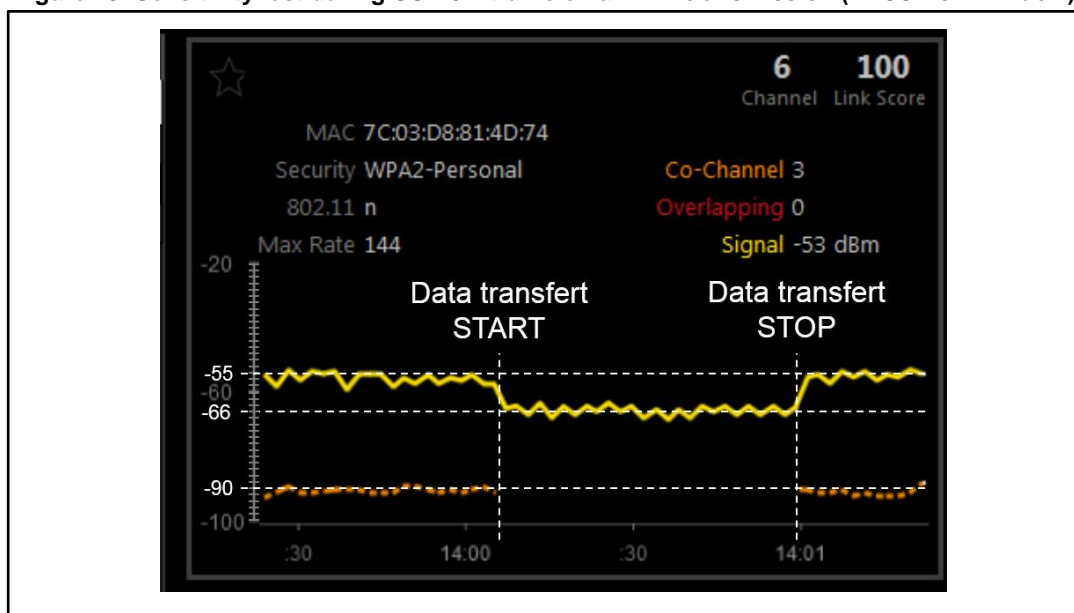
Below a trial on Wi-Fi gateway. On a PC connected to the internet, a USB 3.1 Gen 1 external device is plugged. When the USB 3.1 Gen 1 communication is established, the low power Wi-Fi connection evaluated by the received signal strength indication (RSSI) is lost (figure below). The radiated noise, generated by the digital link, influences the transmission.

Figure 22: RSSI Wi-Fi behavior with USB 3.1 Gen 1 traffic ("InSSIDER" window)



Next figure shows more in detail the noise influence on Wi-Fi transmission. When the USB 3.1 Gen 1 traffic starts, the RSSI level (yellow curve) decreases by 11 dB, and during this time the low level Wi-Fi is lost (orange curve).

Figure 23: Sensitivity lost during USB 3.1 traffic on a Wi-Fi transmission ("inSSIDer" window)



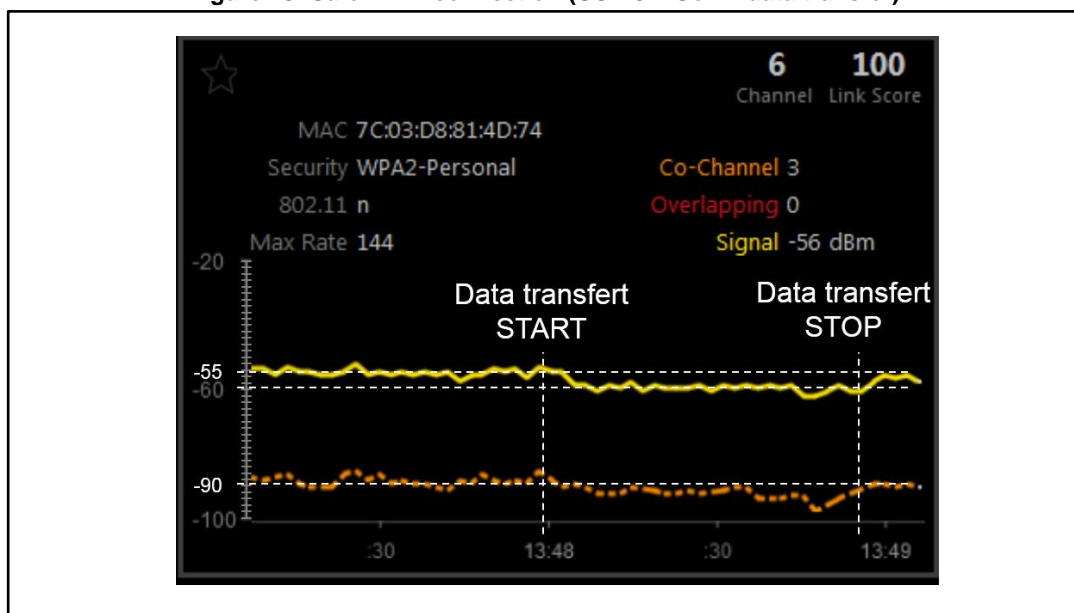
Thanks to the insertion of the ECMF02-2HSMX6 (in this case) on the link, the Wi-Fi connection is safe (figure below).

Figure 24: Safe Wi-Fi connection



After CMF insertion, during the USB 3.1 Gen 1 data transfer, the high level Wi-Fi communication is just slightly affected and the low level communication is maintained (figure below).

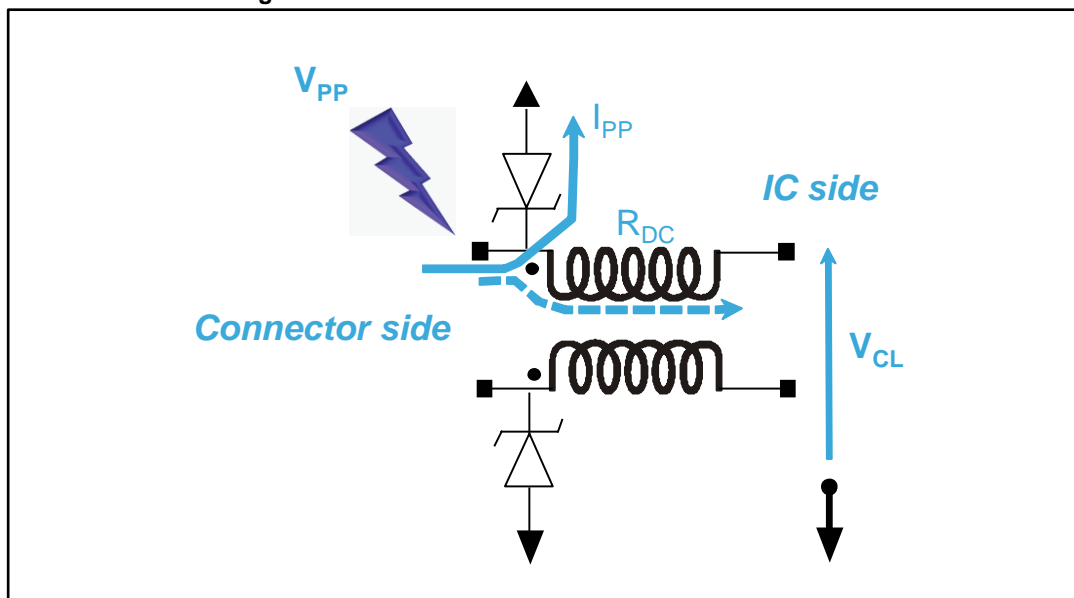
Figure 25: Safe Wi-Fi connection (USB 3.1 Gen 1 data transfer)



Moreover, the ECMF family integrates ESD protection. Therefore, it is not necessary to add TVS to the data lines to ensure efficient protection and it saves room on the PCB. Some of these filters include in the same package a high energy protection up to 60 A (8/20  $\mu$ s wave) for the  $V_{BUS}$  line and an additional TVS, which can be used for control lines (ECMF2-0730V12M12).

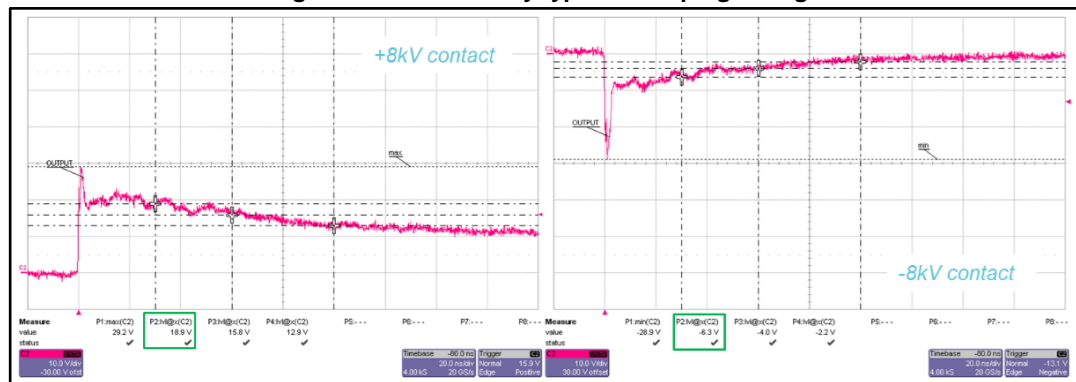
Another benefit of this family is to limit the current through the transceiver to protect, thanks to the internal resistance  $R_{DC}$  of the common mode filter (figure below).

Figure 26: Resistance  $R_{DC}$  of the common mode filter



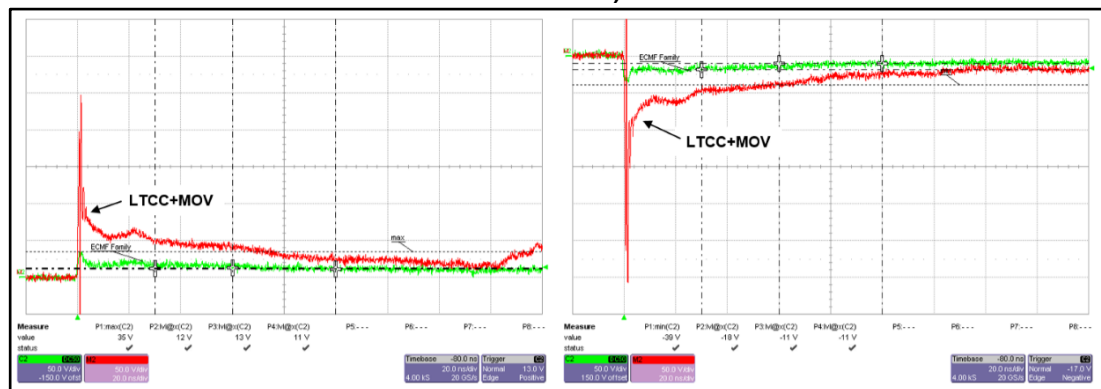
Next figure shows typical clamping voltage that can be obtained by ECMF during IEC61000-4-2 surge at  $\pm 8$  kV contact. Thirty nanoseconds after the surge, the voltage level is less than 19 V during positive surge and 6.5 V during negative surge.

Figure 27: ECMF family typical clamping voltage



These results are much better than MOV protection embedded in some LTCC common mode filters. The following figure presents the comparison between the two devices. The green curve is the ECMF clamping characteristic.

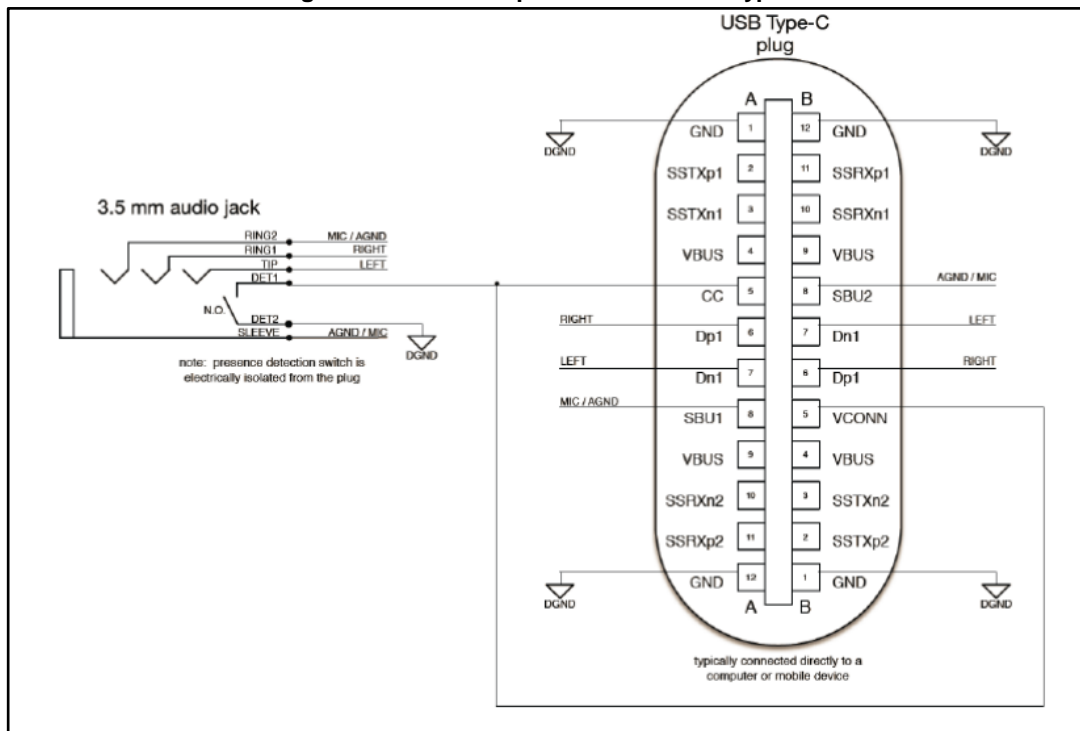
Figure 28: Clamping comparison between ECMF and LTCC+MOV technology (IEC61000-4-2 ± 8 kV contact)



## 6.5 Audio properties

The USB Type-C connector allows audio signals to be delivered. An adapter example with 3.5 mm jack is shown in the figure below. In this case, the USB 2.0 lane Dp1/Dn1 [A6-A7/B6-B7] is used to drive right and left signals.

Figure 29: Audio adapter 3.5 mm / USB Type-C



It is mandatory to have bidirectional protection devices on the USB lane to meet audio signal voltage and to avoid demodulation due to any diode junction in forward-bias. Unpleasant buzzing induced by time domain multiple access noise in GSM applications could appear and cause audio distortion. Some ECMF devices have this kind of characteristic such as the ECMF2-0730V12M12.

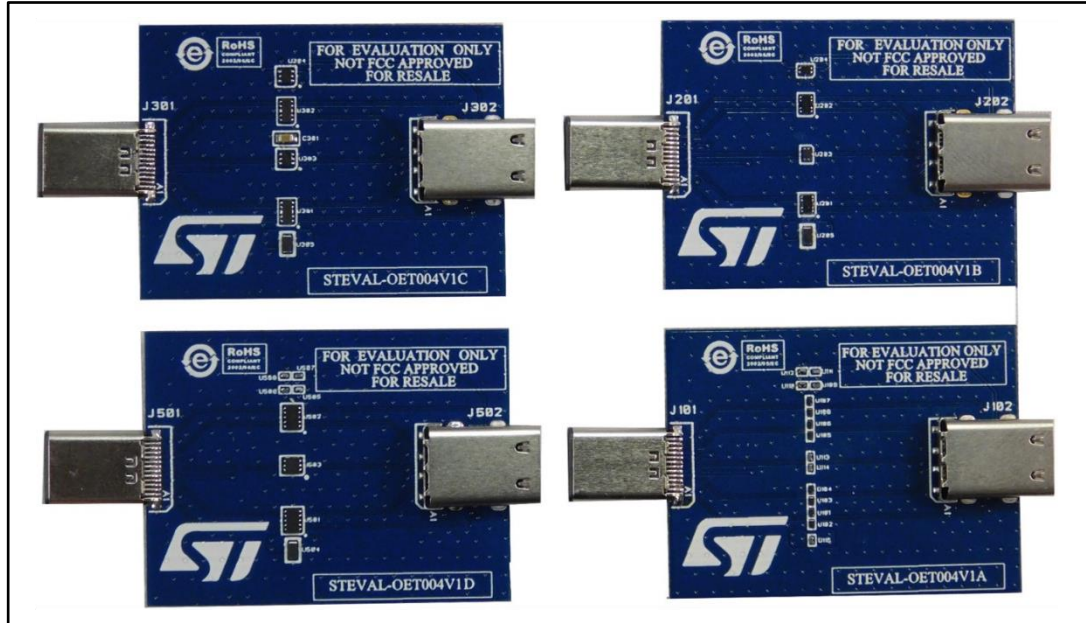


## 7 Available solutions for testing

In order to easily verify the functionality of our devices, several evaluation boards are available with many configurations, such as protection on each line and protection with filtering. An example is shown below.

They can be ordered on ST web site, reference is [www.st.com/oet004v1](http://www.st.com/oet004v1).

Figure 30: Evaluation board Type-C connector



## 8 Conclusion

USB Type-C is the future of the USB. High-speed data, audio, high current charging and reversibility, all in the same small connector is a must.

However, although it is a good and cheap connector, it cannot protect and filter all its pins against external aggressions, exposing to damage or disturb the device where it is being used.

STMicroelectronics offers a wide range of transient voltage suppressors and common mode filters allowing the designer to choose the right solution to ensure reliability and good performance, avoiding electrical overstress or antenna desense.

A secure Type-C connector is the guarantee of a satisfied user.

## 9 Revision history

**Table 3: Document revision history**

Date	Revision	Changes
02-Sep-2016	1	First release.
15-Dec-2016	2	Updated <i>Figure 14: "USB 3.1 Gen 2 eye diagram example for HSP051-4M10, after reference cable and equalizer"</i> . Changed <i>Figure 30: "Evaluation board Type-C connector"</i> . Minor text changes.

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