Introduction

In our connected world, data exchange very fast and their content is shown in a large screen with high-definition capabilities. These features include high-speed serial links, working in different modes and increasing data rate. However, fast transition times and long lines may induce radiations due to common mode noise. In order to avoid these issues, the most efficient device to use is a common mode filter. In this article, the basic parameters of this device and its benefits are described.
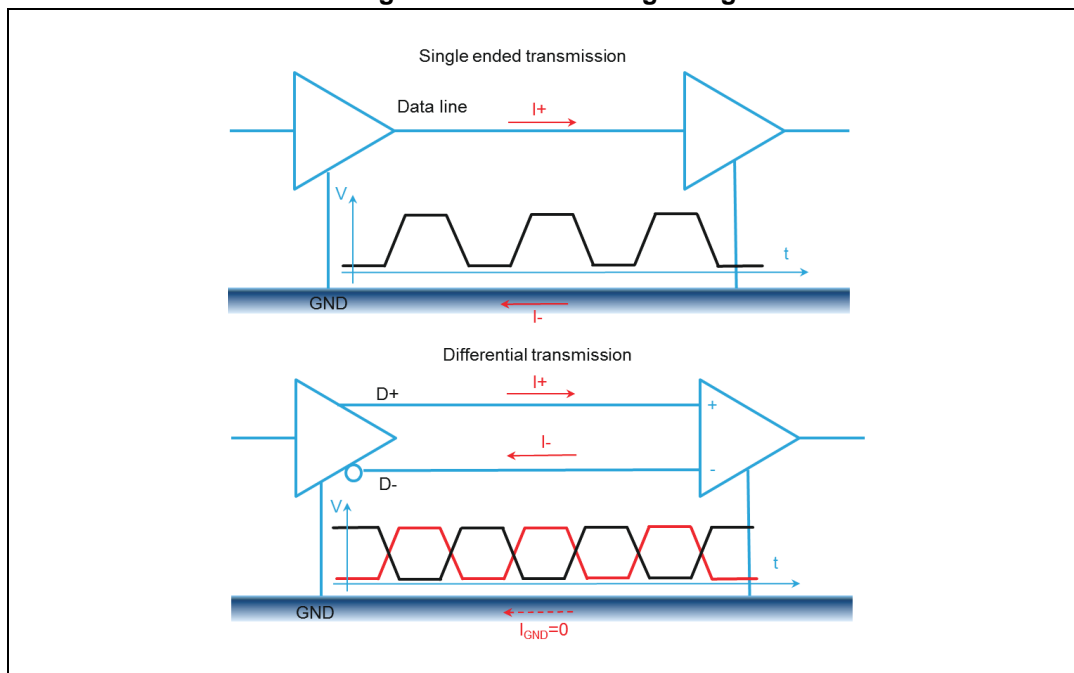
Contents

1 Single-ended and differential links

Single-ended configuration is dedicated to frequencies lower than 300 MHz. For higher data rates, differential signaling is preferred. One advantage of this method is that the return current to ground is near zero and there isn't any ground bounce issue (*Figure 1*).
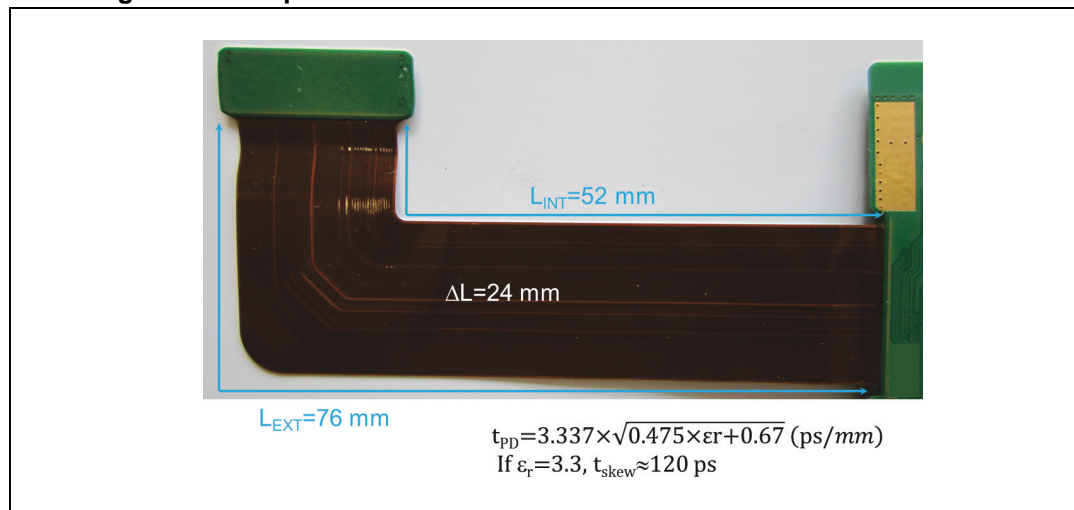
Figure 1. Differential signaling

The ideal differential link presents two tracks with tightly-controlled impedance, same length and perfect symmetry. Radiation, from low to high transition on a track, is canceled by the radiation from high to low transition on the other track. Therefore, the ideal differential link does not radiate.

2 Risks of EMI on differential links

Flex connectors, like processors or camera, are quite used. *Figure 2* presents an extreme case.

Figure 2. Example of skew between interior and exterior traces on a flex

L_{INT}=52 mm

ΔL=24 mm

L_{EXT}=76 mm

$$t_{PD}=3.337\times\sqrt{0.475\times\varepsilon r+0.67}\ (ps/mm)$$
If ε_r=3.3, $t_{skew}\approx120$ ps

Flex connector is shielded and the link radiates and generates a large amount of noise, which causes antenna desense on the mobile handset limiting drastically the receiver sensitivity (*Figure 3*).

Figure 3. Radiations induced by skew on a differential link
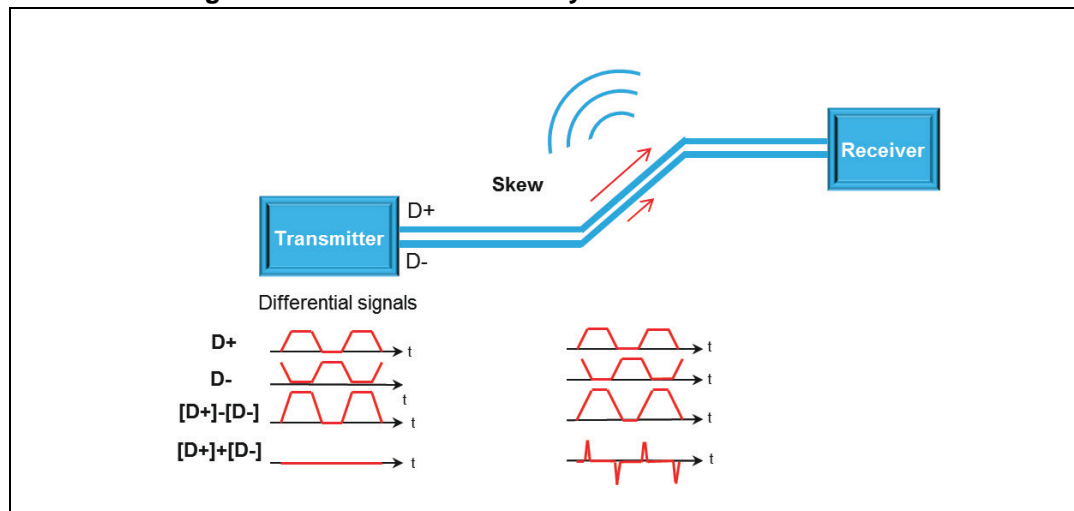
The most efficient way to cancel this noise is to insert a filter to suppress it. This filter is called: common mode filter (*Figure 4*).
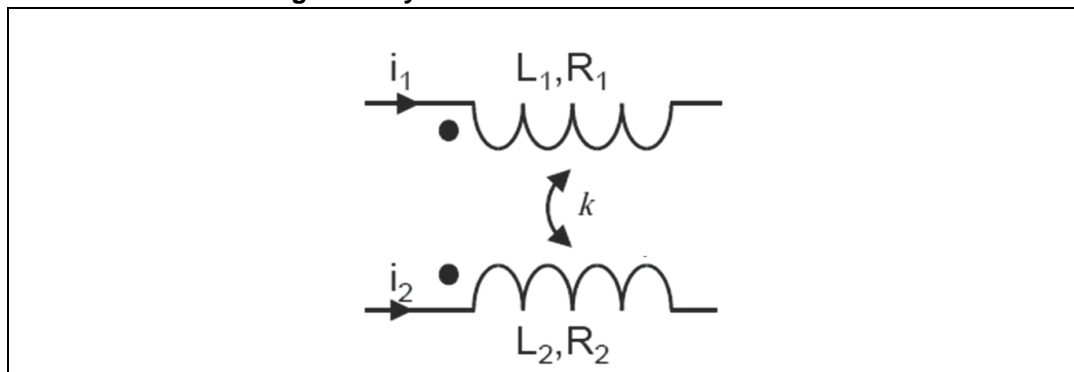
Figure 4. Common mode filter on a differential link
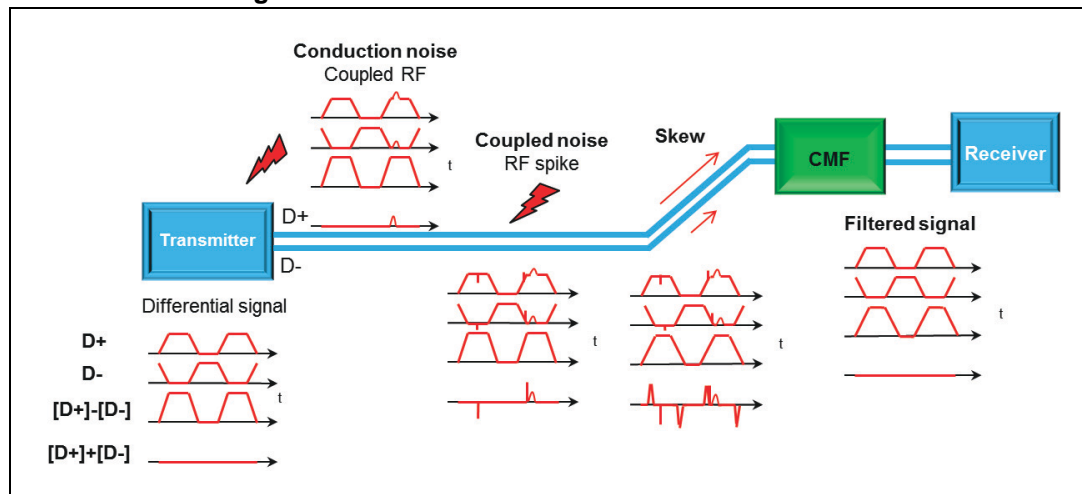
3 Common mode filters

The common mode filter is based on two coupled inductors (*Figure 5*).

Figure 5. Symbol of the common mode filter

The couple coefficient is called k. If L1 and L2 are two inductance values and M the mutual inductance, the following equation is given:

Equation 1

$$k = \frac{M}{\sqrt{L_1 \times L_2}}$$

If I_1 and I_2 are the currents flowing to each inductor, and R1 and R2 their DC resistance, their impedances are as follows:

Equation 2

$$Z_1 = R_1 + j\omega L_1 + j\omega M \times \frac{I_2}{I_1}$$

and

Equation 3

$$Z_2 = R_2 + j\omega L_2 + j\omega M \times \frac{I_1}{I_2}$$

assuming that $L_1 \approx L_2 = L$ and $k \approx 1$:

Equation 4

$$M = k \times \sqrt{L_1 \times L_2}$$

so

Equation 5

$$M = L$$

in differential mode, $I_2 = -I_1$

Equation 6

$$Z_1 = R_1 + j\omega((L_1 - M) \approx R_1)$$

and

Equation 7

$$Z_2 = R_2 + j\omega((L_2 - M) \approx R_2)$$

The filter presents a low resistive impedance equal to DC resistance of inductances therefore a low attenuation of the high-speed differential signal (see *Figure 6*).

In common mode $I_2 = I_1$, therefore

Equation 8

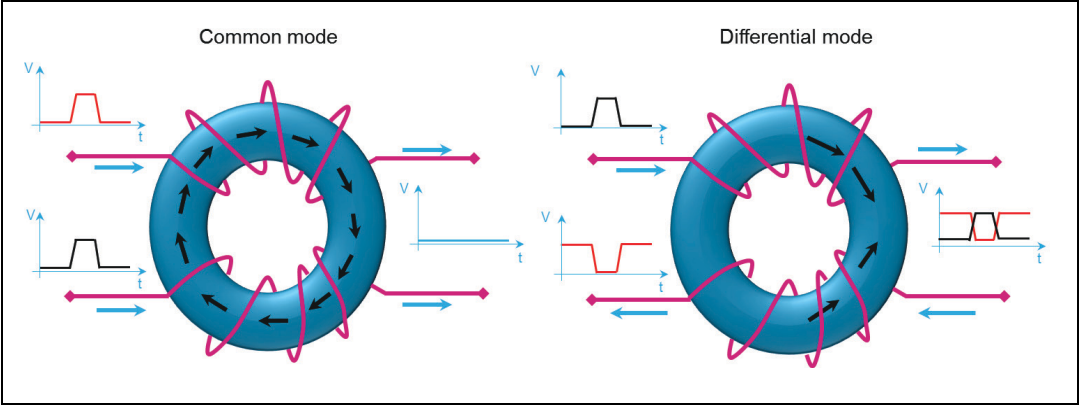$$Z_1 = R_1 + j\omega(L_1 + M) = R_1 + j\omega \times 2L$$

and

Equation 9

$$Z_2 = R_2 + j\omega(L_2 + M) = R_2 + j\omega \times 2L$$

The filter presents a high inductive impedance, therefore a high rejection of the common mode noise (see *Figure 6*).
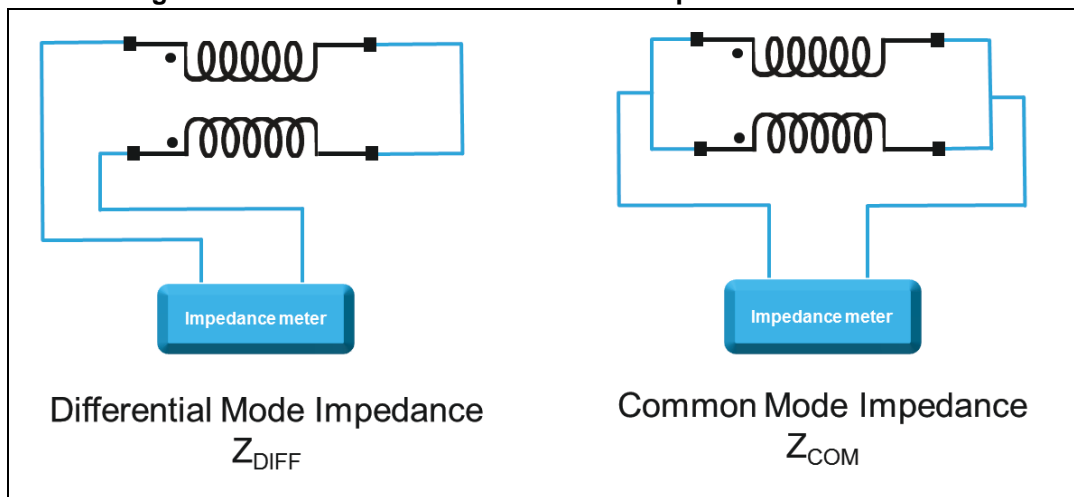
Figure 6. Common mode and differential mode in CMF

4 The main parameters

This section shows how to measure the common mode and the differential mode impedance, see *Figure 7*. The equipment can be an impedance meter such as the E4991A from Agilent technology, working up to 3 GHz.

Figure 7. Differential and common mode impedance measurement

Figure 8 shows the variation of impedance versus frequency. Differential impedance at low frequency represents the sum of inductance resistances of the filter.

Figure 8. Typical common mode and differential mode impedance vs. frequency (ECMF04-4HSM10)
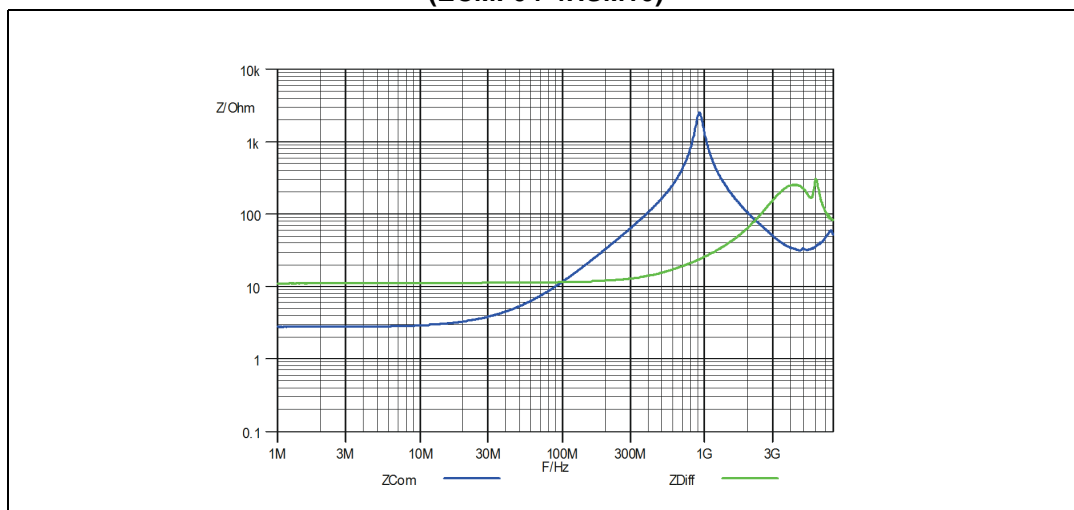
However, CMF can be chosen by using insertion losses. Two main parameters are defined:

- S_{CC21} common mode rejection, the filter efficiency cuts the unwanted noise in a specific frequency range
- S_{DD21} defines the differential bandwidth of the filter, the filter ability to drive the main signal without distortion

Two other parameters, defining the differential return losses of the filter are below indicated:

- S_{DD11} and S_{DD22}

These four characteristics, called mixed-mode S parameters, are calculated by S parameter results of four-port measurements (see *Figure 9*).

Figure 9. CMF four-port measurements
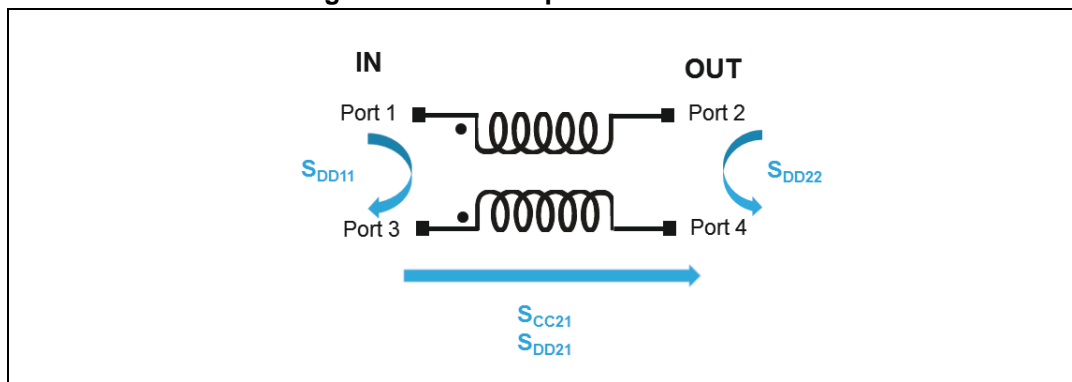
Equations are below indicated:

- $S_{CC21} = 0.5 \times (S_{21}+S_{23}+S_{41}+S_{43})$
- $S_{DD21} = 0.5 \times (S_{21}+S_{23}+S_{41}+S_{43})$
- $S_{DD11} = 0.5 \times (S_{11}+S_{31}+S_{13}+S_{33})$
- $S_{DD22} = 0.5 \times (S_{22}+S_{42}+S_{24}+S_{44})$

Figure 10 shows the typical common mode rejection versus ECMF04-4HSM10 frequency. In this curve, t the maximum rejection level of -32 dB is achieved at 900 MHz which is a critical area in mobile applications.

**Figure 10. Typical common mode rejection vs. frequency (ECMF04-4HSM10)**
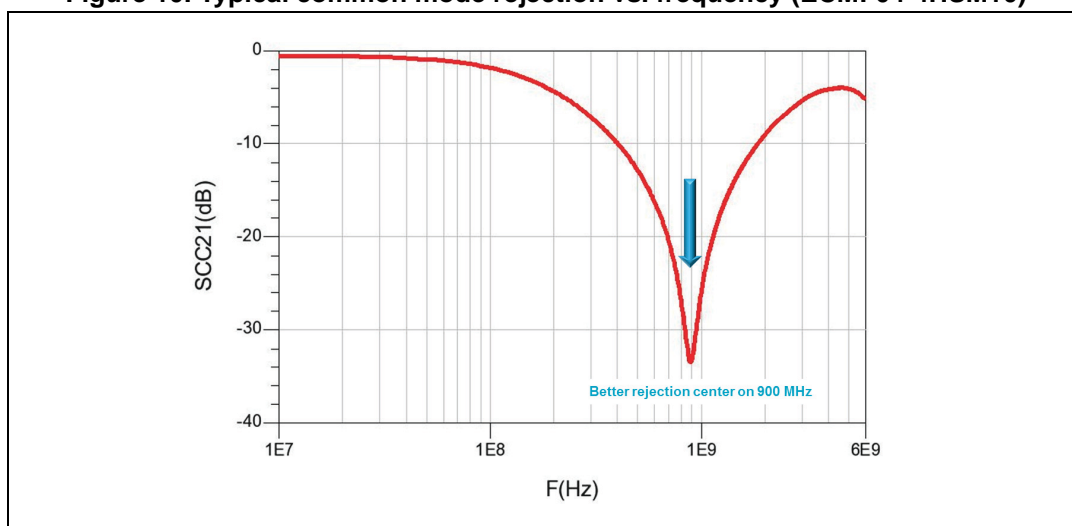
Other filters can be chosen according to the application. *Figure 11* shows S_{CC21} response of the device with USB3.0 filtering. The rejection range is wider, and a specific rejection point at 5 GHz of -20 dB is implemented to eliminate this unwanted harmonic, which can disturb some systems.

Figure 11. Typical common mode rejection response of ECFM02-2HSMX6 (USB3.0 dedicated device)
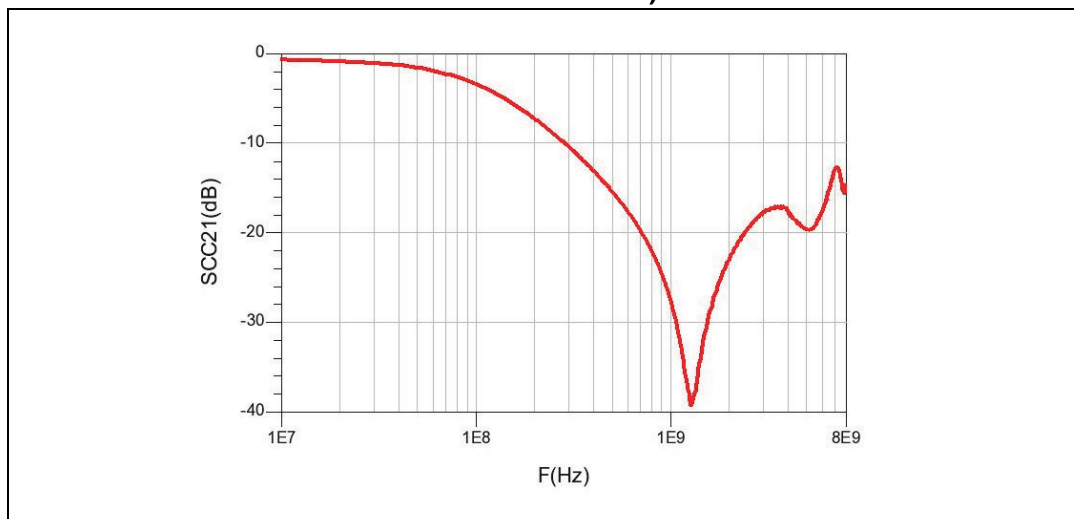

To keep the integrity of the differential signal, S_{DD21} parameter has to be considered. The lower the attenuation, the better the bandwidth. This parameter is measured at -3dB (see *Figure 12*).

**Figure 12. Typical differential mode attenuation (ECMF04-4HSM10)**
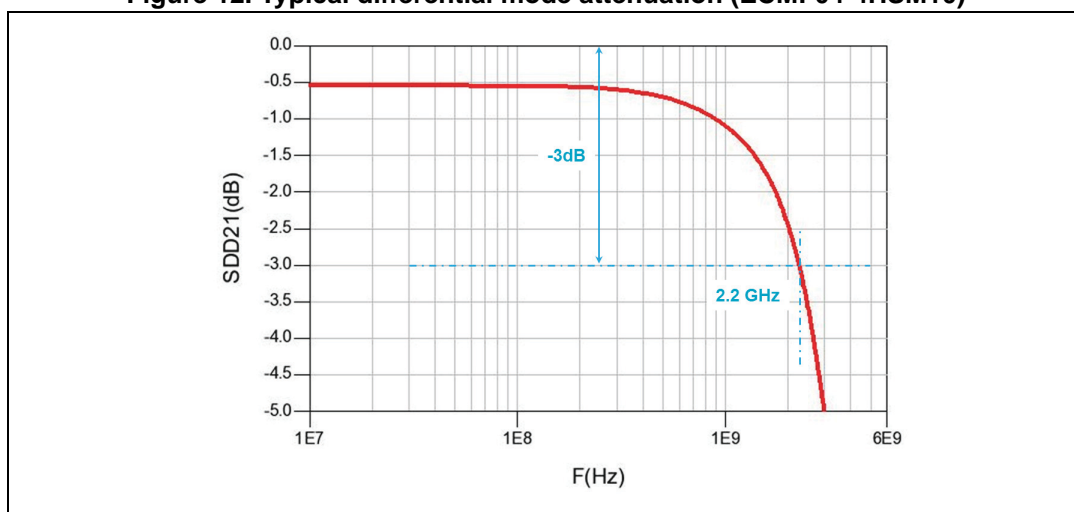
The right filter bandwidth has to be chosen, therefore the filter should pass the eye diagram template of the standard. *Figure 13* shows the eye diagram of a device dedicated to HDMI filtering application. This device works up to 3.35 Gbps.

Figure 13. ECMF04-4HSM10 HDMI eye diagram compliance
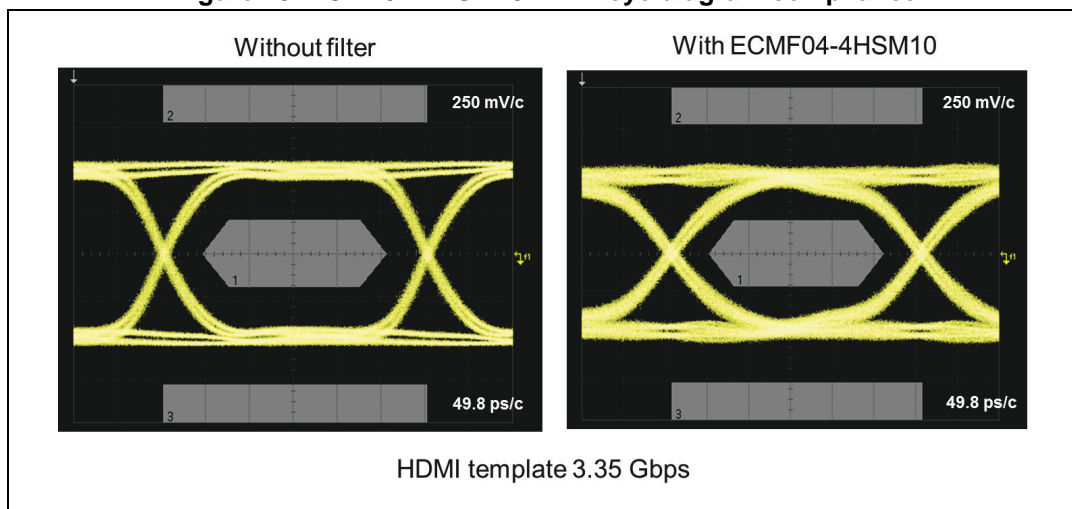
Some standards also specify the minimum return losses on the link, and CMF has to comply with these limits. *Figure 14* shows an example of these values for MIPI D-PHY standard, coming from the interconnection specification.

Figure 14. S_{DD11} and S_{DD22} characteristics of ECMF04-4HSM10 vs. MIPI D-PHY standard
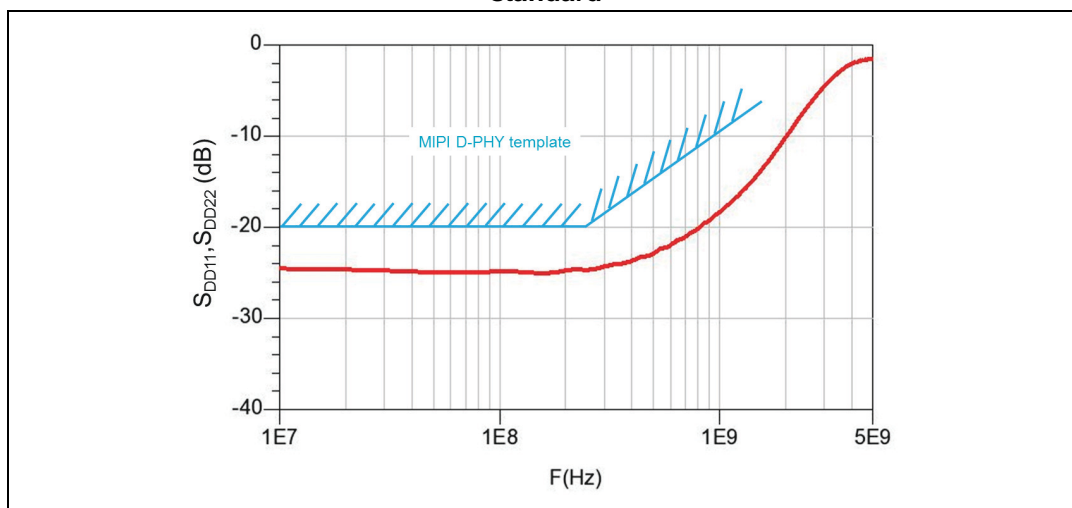
5 Benefits of the common mode filter
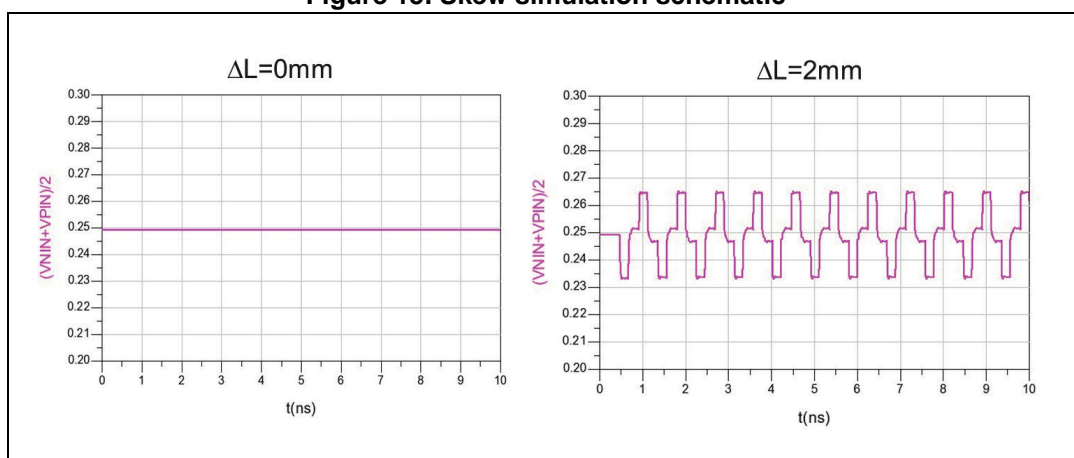
The improvement given by the common mode filter is shown by two examples:
1. The skew brought by two different trace lengths
2. Radiated noise on a USB-MHL cable

Another example is described in AN4356.

5.1 Effect on skew

Figure 15 shows the used simulation schematic. MHL link is built at 2.25 Gbps.
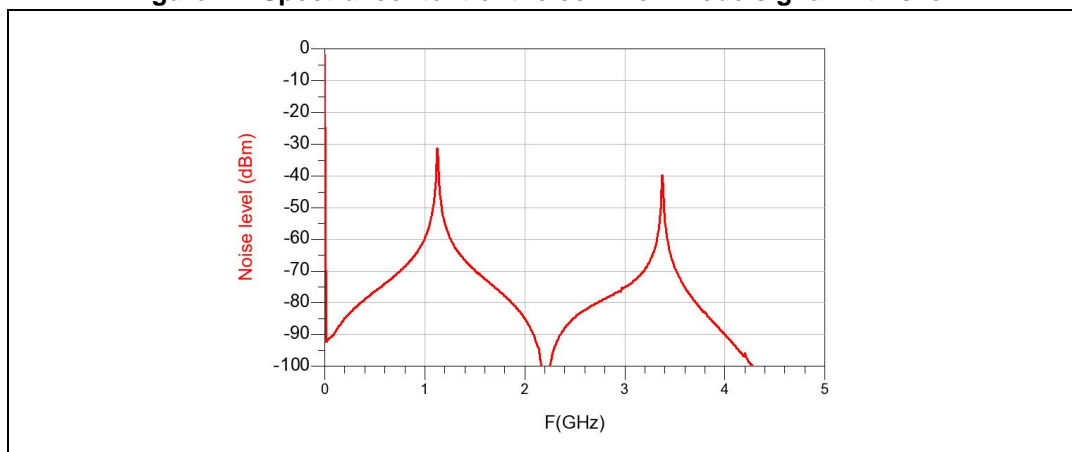
Figure 15. Skew simulation schematic

The common mode noise levels are compared when the two lines have the same length and when there is a difference of two millimeters, 10% difference. The common mode noise is not equal to zero (*Figure 16*).

Figure 16. Common mode noise with and without skew
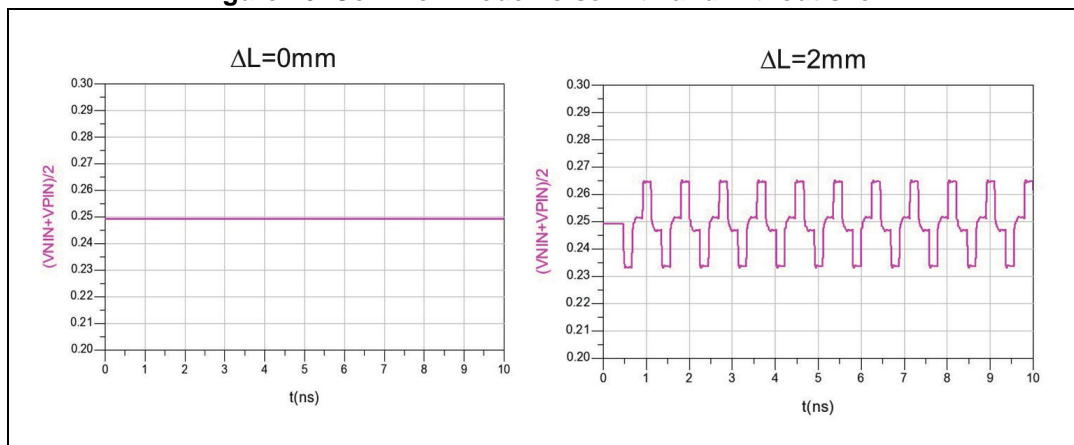
The spectral content of the common mode signal is shown in *Figure 17*. This figure shows the more polluting frequencies. In this case filtering is necessary.

**Figure 17. Spectral content of the common mode signal with skew**

In the ECMF02-3HSM6 a link can be inserted, a common mode filter dedicated to MHL link (*Figure 18*). Its S parameter represents the device.

Figure 18. Skew simulation schematic with ECMF02-3HSM6 common mode filter
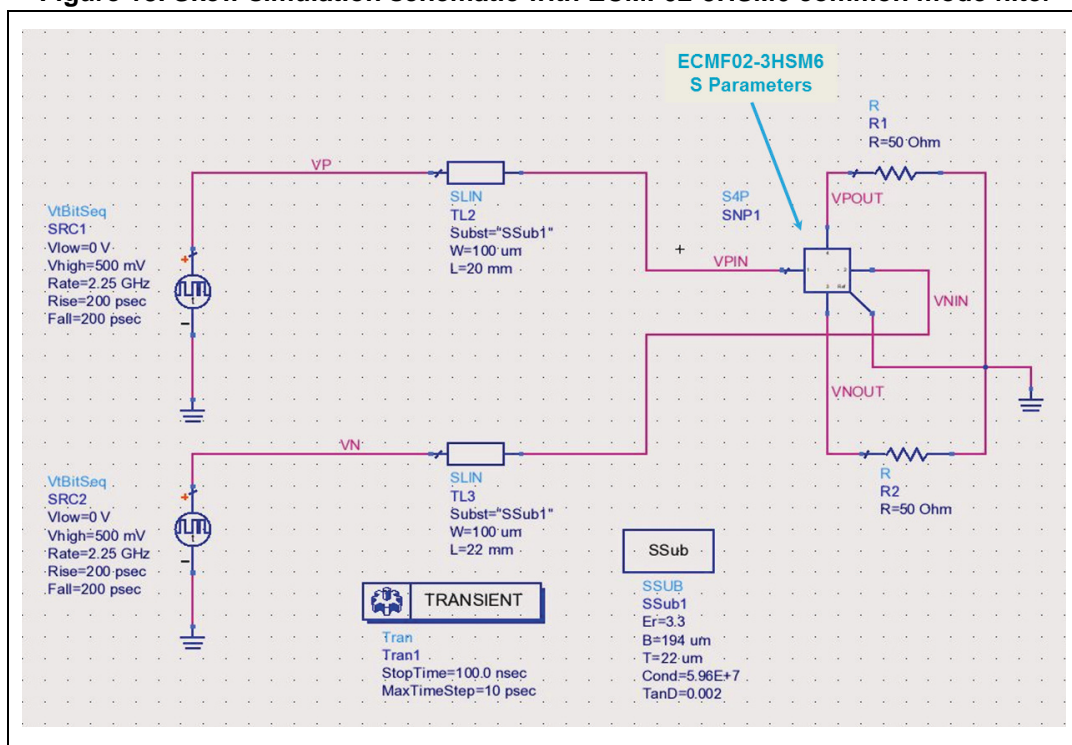
The spectral content of the common mode signal on the filter output can be observed. Noise level decreases drastically up to 20 dB (*Figure 19*).

Figure 19. Improvement on the noise level due to ECMF02-3HSM6
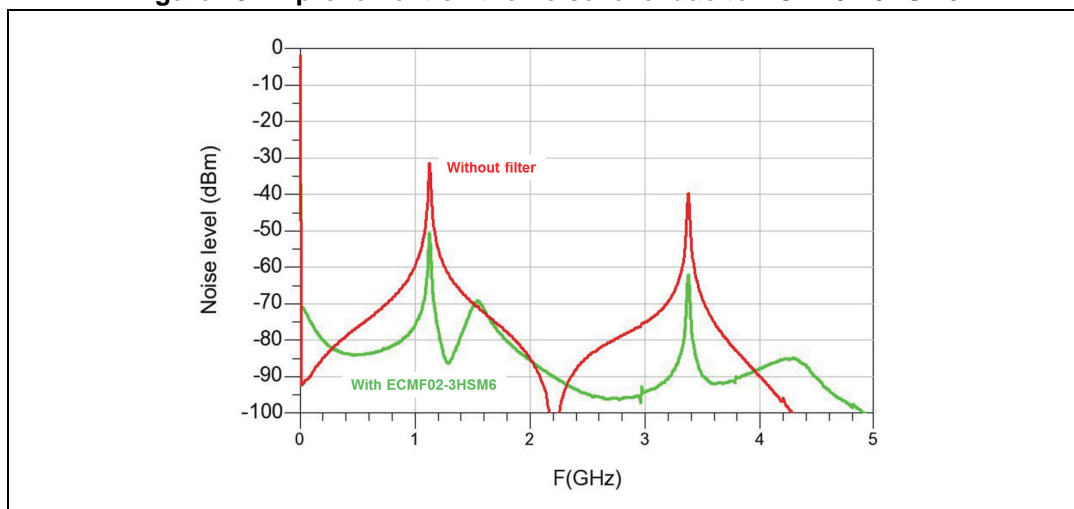
5.2 Effect on the radiated noise

To establish CMF effect of the radiated noise, a phone is placed into an anechoic chamber. To avoid measuring unwanted frequencies, the phone is in a shielded box.

The ECMF02-3HSM6 is inserted on USB connector output. A one-meter MHL cable is connected from MHL to HDMI converter, which is connected to a TV set outside the chamber.

The phone plays a video. To get the noise, an antenna connected to a spectrum analyzer is placed 3 m far from the system (*Figure 20* and *Figure 21*).

Figure 20. Radiated noise test setting (anechoic chamber view)
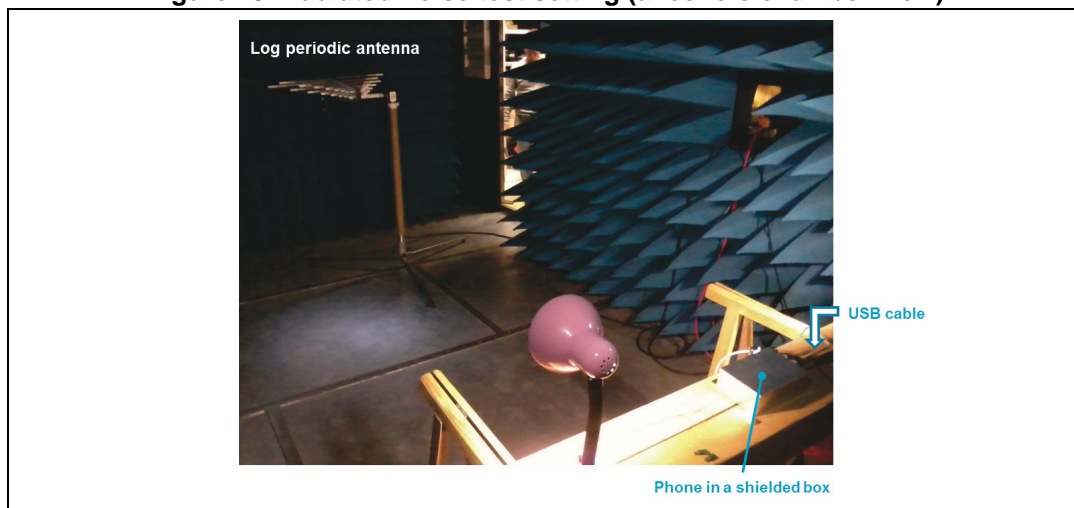
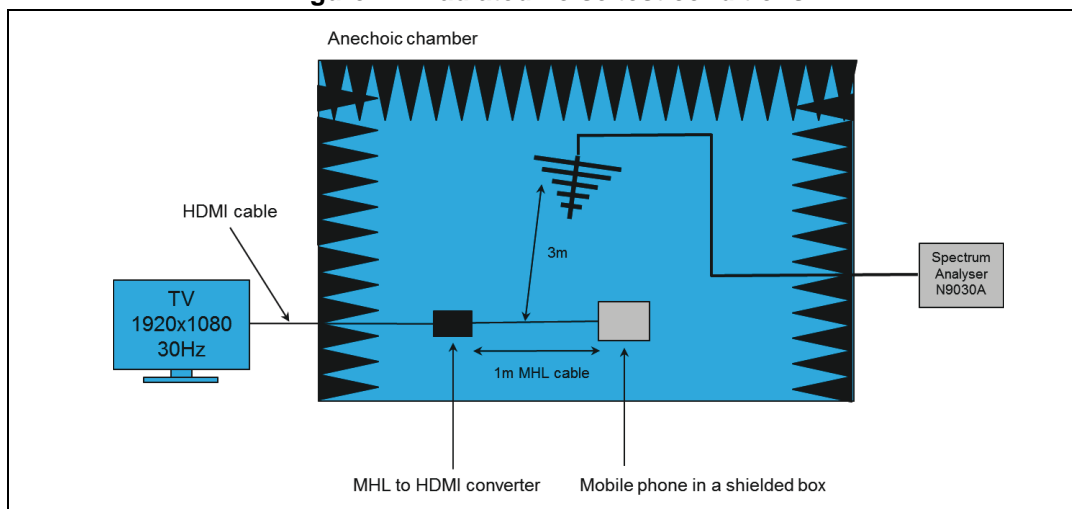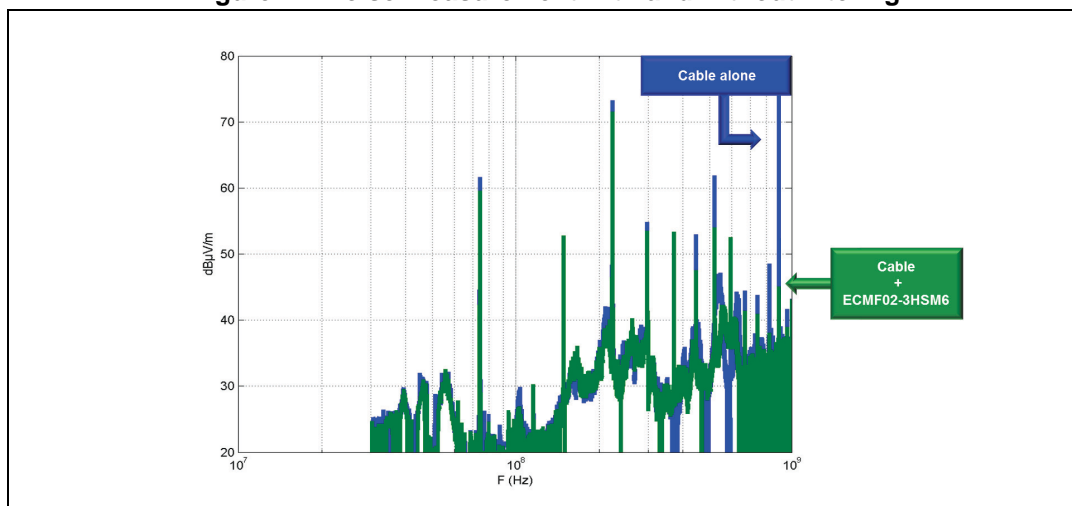**Figure 21. Radiated noise test conditions**

Figure 22 shows the spectral density measured with and without filtering. The noise level is drastically reduced, especially in the range where the filter gets its better rejection, from 700 MHz to 900 MHz.

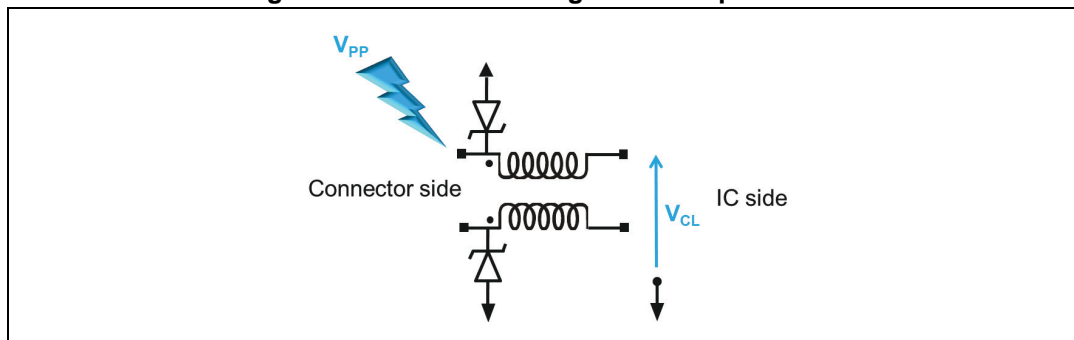**Figure 22. Noise measurement with and without filtering**

6   Specific benefits of ECMF series

The ECMF series integrates ESD protection clamping the surges up to acceptable levels thanks to sensitive digital circuits (*Figure 23*), improving system quality and reliability.

Figure 23. ECMF with integrated ESD protection

Figure 24 shows a typical TLP characteristic. If a +8 kV ESD surge (IEC61000-4-2 standard) is applied to the device, only 16 V are measured on the output after 30 ns. This value is also measured on the application environment, see *Figure 25*.

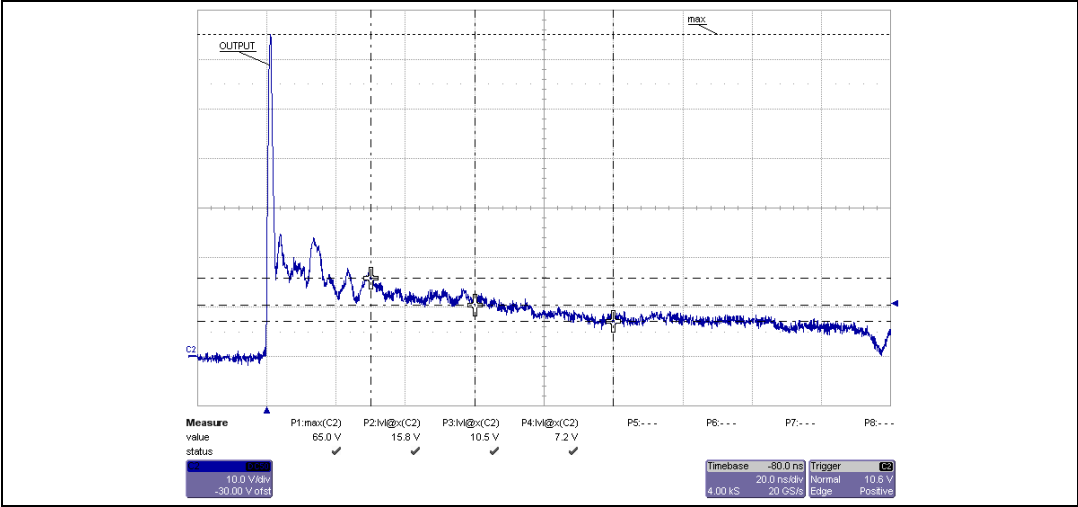**Figure 24. ECMF02-2HSLMX6 TLP characteristic**
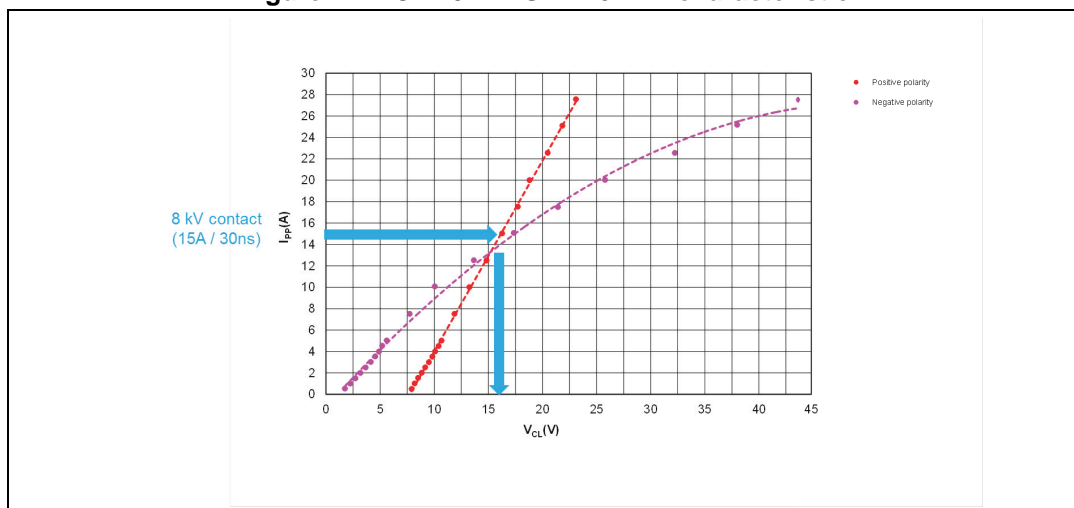
Figure 25. ECMF02-2HSLMX6 +8 kV contact (IEC61000-4-2) ESD clamping

Varistor solutions do not provide a protection level, even on clamping voltage and robustness against repetitive strikes. The difference is very important in low capacitance devices for high-speed links at low ESD strike, here +1 kV (*Figure 26*).

Figure 26. Varistor and ECMF clamping comparison
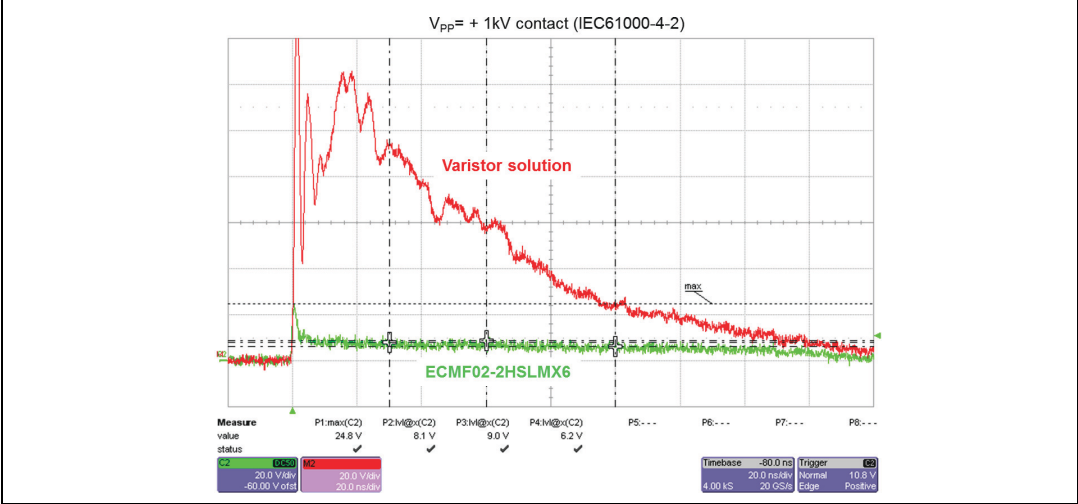
7   Conclusion

The common mode filter is the best solution to avoid issues like common mode noise induced by radiated or conducted RF or skew between tracks. It allows a system to improve its EMI robustness.

This application note helps the user to choose the filter with more accuracy, fitting it to his needs, the equipment and the standards used.

The wide range of filters offered by STMicroelectronics covers many applications (MIPI, HDMI, MHL, USB.) and includes internal ESD protection allowing the equipment to be more robust against external disturbances.

8   Revision history

Table 1. Document revision history

Date	Revision	Changes
29-Jul-2014	1	Initial release.

IMPORTANT NOTICE – PLEASE READ CAREFULLY