How to solve antenna desense issue with ECMF

Introduction

Electronic systems feature high-speed links to provide high-definition video and high data rate storage and transfer. To carry this kind of data, these systems implement multiple connectors with high-speed differential pair signals.

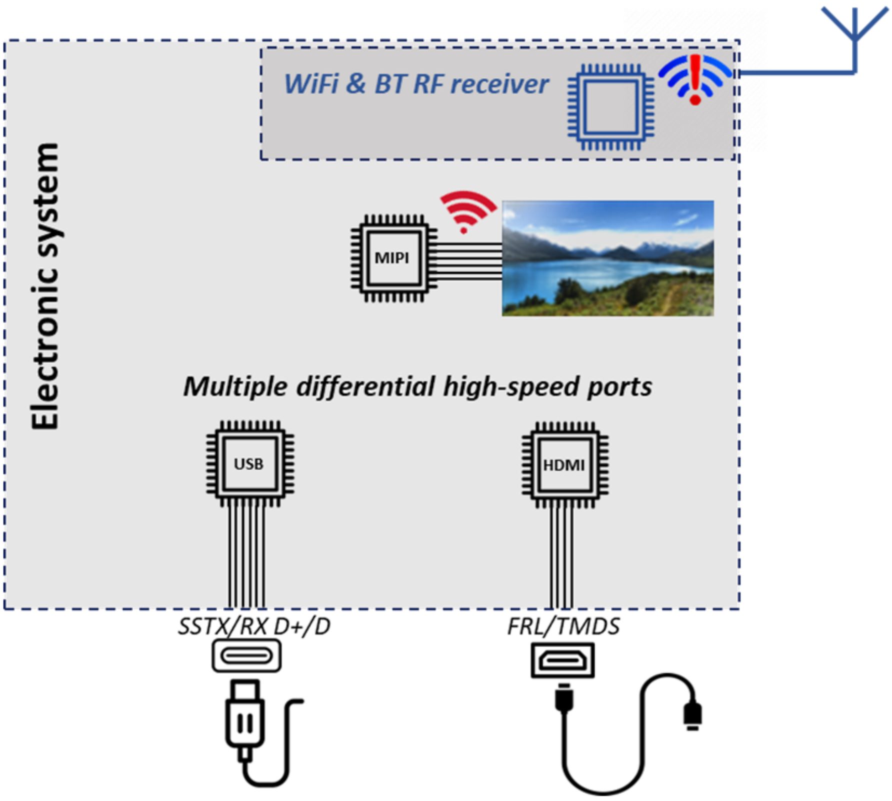
Furthermore, the antennas used by theses systems to communicate with their environment (for example a streaming box communicating with a wireless interface) are now wide-band or smart antenna. They are more sensitive to electro-magnetic interferences.

We explain in this document how differential lines can generate electromagnetic noise. This noise can affect the receiver sensitivity. Then we describe how to maintain a correct noise-free reception of RF signals.

1 EMI and noise issues

Inside consumer and industrial applications, such as industrial computer, medical equipment, game console, tablet, or docking station, there are multiple subsets of the circuits, which communicate together or with other electronic equipment's. These communications use several wired links. Close to these electronic circuits, we often find a WiFi or Bluetooth RF link with an antenna connected to the RF power amplifier, and to the receiver.

Figure 1. An electronic system with various high-speed links



Standards used in this kind of applications present high data rates. Here are some examples of speeds rates per data lane:

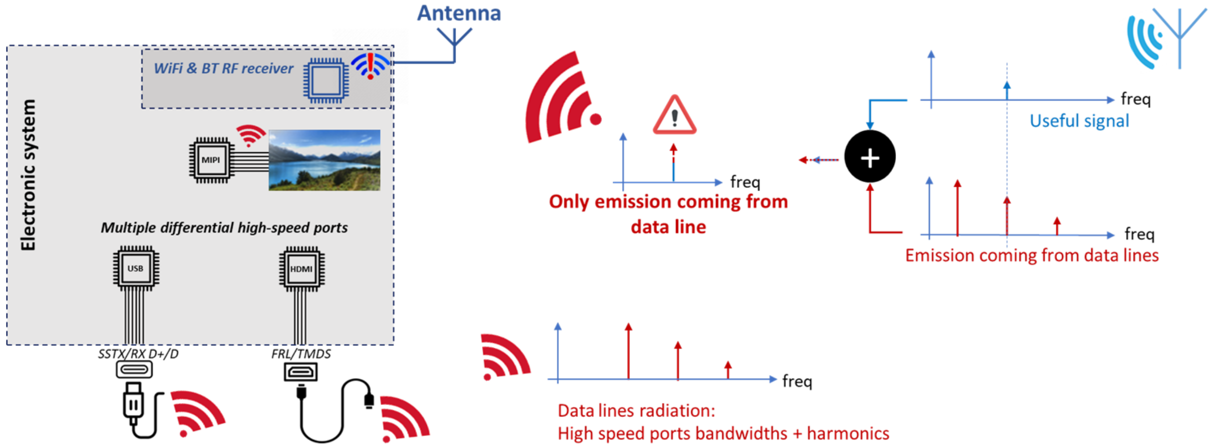
- MIPI D-PHY up to 9 Gbps
- HDMI 2.1 up to 12 Gbps
- USB 2.0 up to 480 Mbps
- USB 3.2 up to 10 Gbps
- USB4 up to 20 Gbps
- MIPI M-PHY up to 11.66 Gbps

The spectral content of these signals can overlap Bluetooth, WiFi and WiFI 6E frequencies. It is between 2.4 GHz and 7.1 GHz, which can reduce the sensitivity of the RF receiver.

Indeed, in the Figure 2 below, we can see electromagnetic emission (in red) from high-speed signals radiation that creates harmonics. These harmonics are figured out in the frequency domain by spectral rays (in red). They can be received by the antenna with the useful signal that we expect to receive (WiFi or BT in this case).

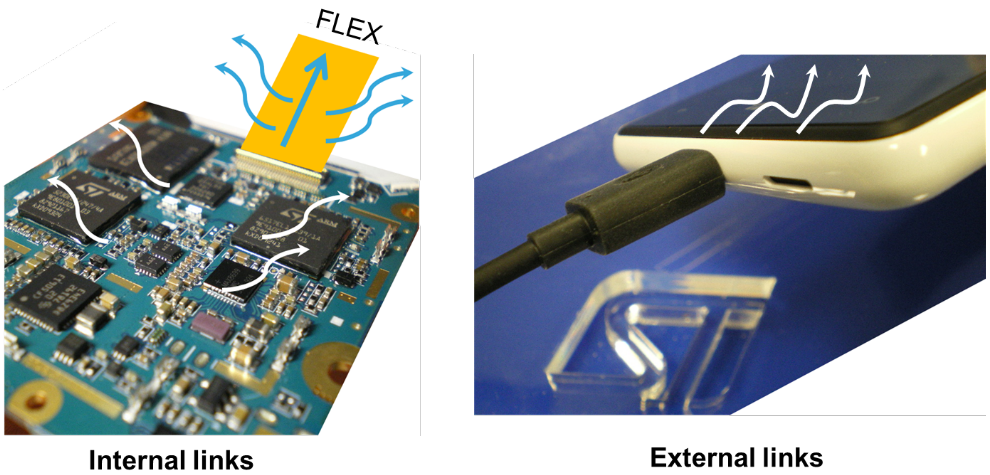
If the power of the useful signal (in blue) is lower than the high-speed signal radiation (in red), the RF antenna receiver is eventually not able to detect the useful signal. This jamming of the signal or S/N ratio weakening is called antenna de-sense or desensitization.

Figure 2. **High speed links radiated noise and antenna desensitization**



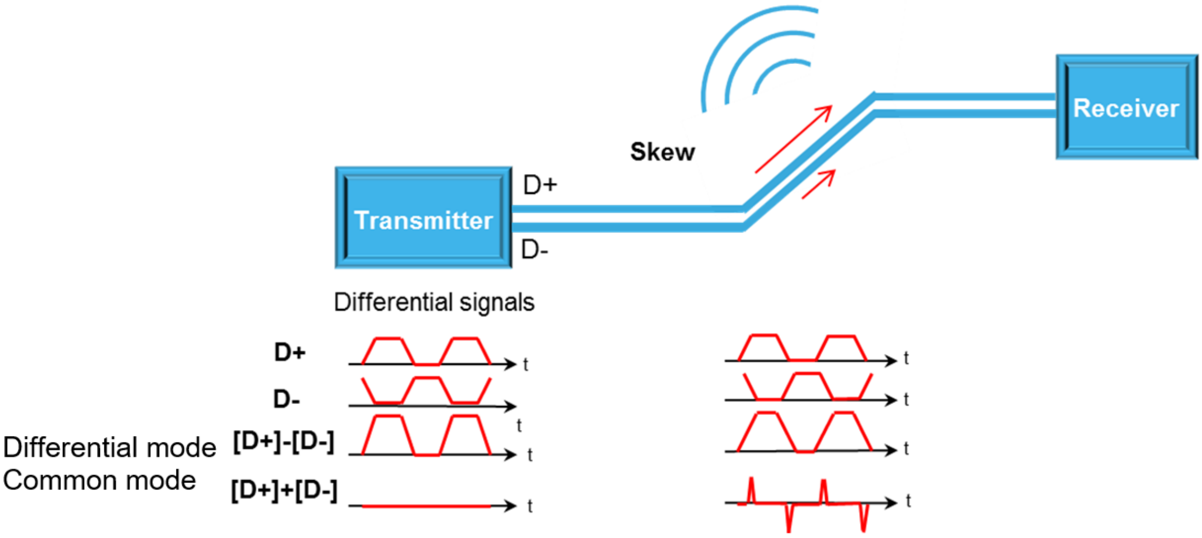
These high data rates links use clocks and data signals with very fast transition in the range of hundreds of picoseconds or lower. It is leading to strong radiation fields. This effect is amplified when more complex subcircuits are implemented and together with flex connectors. The flex connectors behave like transmission antenna and spread unwanted frequencies and noise (Figure 3).

Figure 3. **Radiated and conducted emissions**



The skewed signal that can occur between two lines of the differential pair link of a flexible PCB induce an important source of radiated noise. The resulting common mode signal is the source of the radiated noise (Figure 4).

Figure 4. **Effect of the skew on a differential pair link**

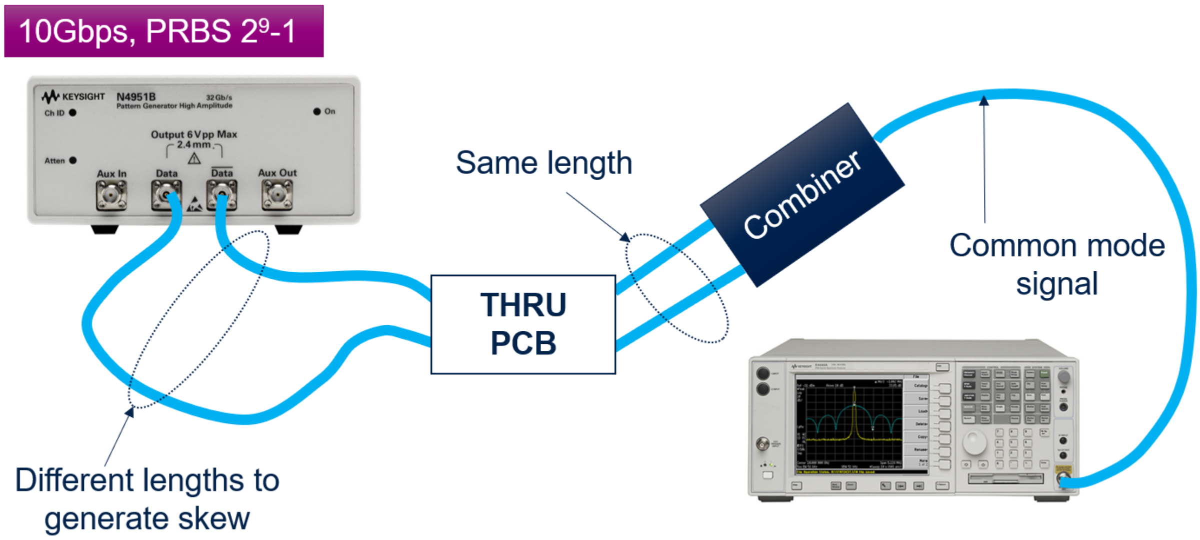


The common mode noise can be generated by a line length difference and as shown in the test setup of Figure 5.

The common mode signal was introduced by a line pair with different length of the two conductors. This emulates the case of a skewed differential pair.

This test setup provides high-speed “pseudo random binary sequence” (PRBS) differential signal, with the same data rate and the same electrical features as a 10 Gbps USB 3.2 signal. We use an RF combiner to add the D+ and D- signals and to extract the common mode signal. This signal is then measured with a spectrum analyzer.

Figure 5. **USB 3.2 at 10 Gbps with skew test setup**



The Figure 6 and the Figure 7 shows the spectral content of the resulting common mode signal. We can observe the impact of the signal skew. We show that high-speed differential pair signals like USB 3.2 at 10 Gbps can generate noise in all WiFi and Bluetooth frequency bands.

Figure 6. **Spectral content of PRBS at 10 Gbps common mode noise within 2.4 GHz WiFi and Bluetooth frequency bands**

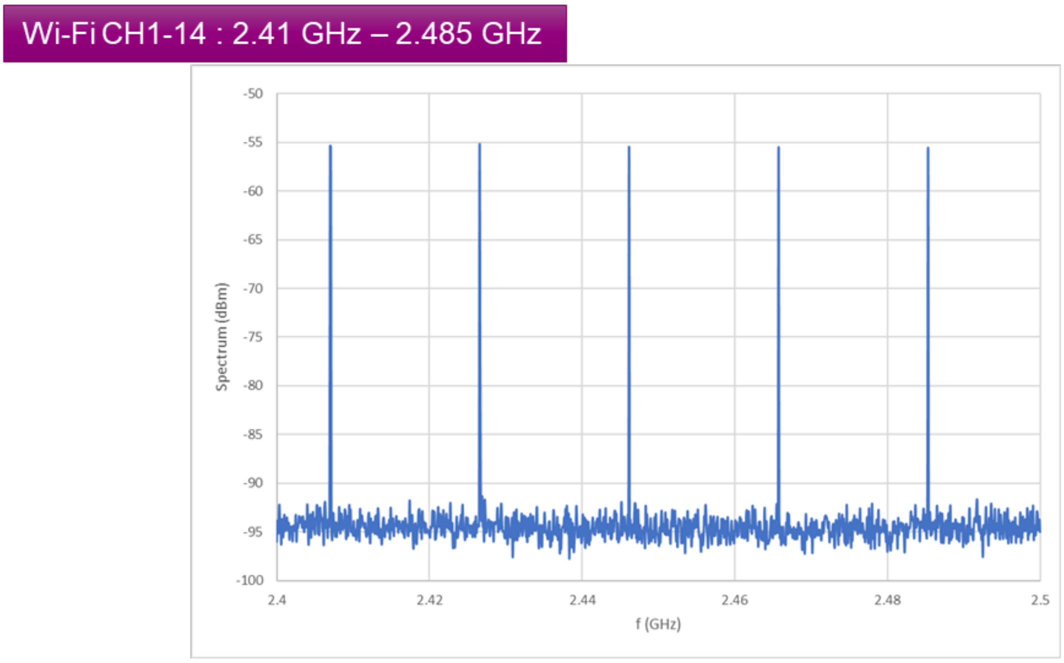
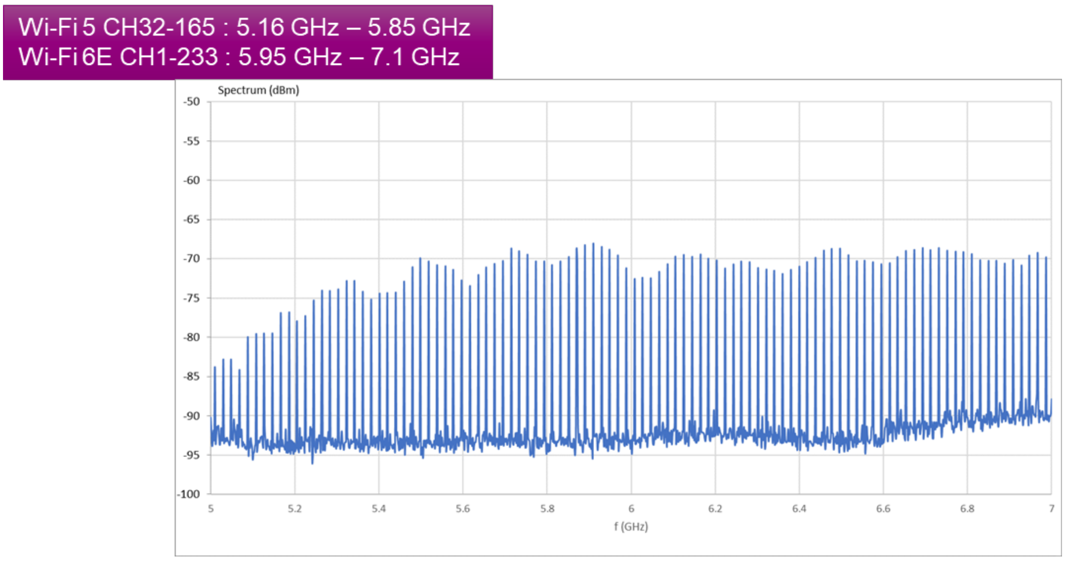


Figure 7. **Spectral content of PRBS at 10 Gbps common mode noise within WiFi 5 and 6E frequency bands**

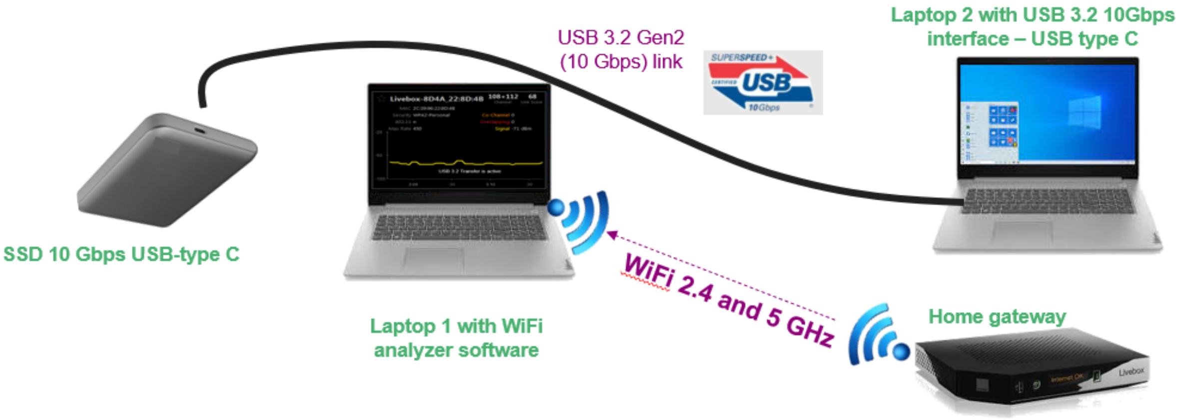


The noise amplitude, and its adverse effects on the equipment, depends on the PCB layout, shielding and the proximity of the sensitive parts.

A second test has been performed to show the impact of the antenna desense on a real application. A home gateway, which works at a 2.4 GHz and 5 GHz WiFi dual frequency was used. This box communicates with a computer (number 1), which analyzes the WiFi signal received using a software. The software analyzes the power of the received signal and the frequency channels used.

At the same time, data are exchanged between a “solid state drive” and a computer (number 2) communicating in USB 3.2 at 10 Gbps through a USB Type-C® cable (Figure 8).

Figure 8. Antenna desense demonstration test setup



The Figure 9 and the Figure 10 shows screenshots of the WiFi analyzer software for respectively 2.4 GHz and 5 GHz WiFi. The yellow curve gives the WiFi signal RSSI, showing the power of the received signal.

When the USB 3.2 transfer is inactive, we have a good WiFi signal reception. On the other hand, when we start to exchange data between the laptop and the SSD we lose the WiFi connection. Then, the signal and its detection reappear at once when the USB 10 Gbps data transfer is stopped. For this test, we used a standard shielded USB Type-C® cable.

This behavior appears on both 2.4 GHz and 5 GHz WiFi.

Figure 9. WiFi 2.4 GHz signal RSSI for channel 1

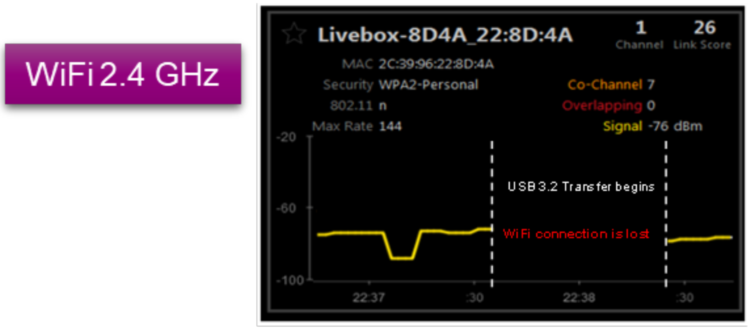
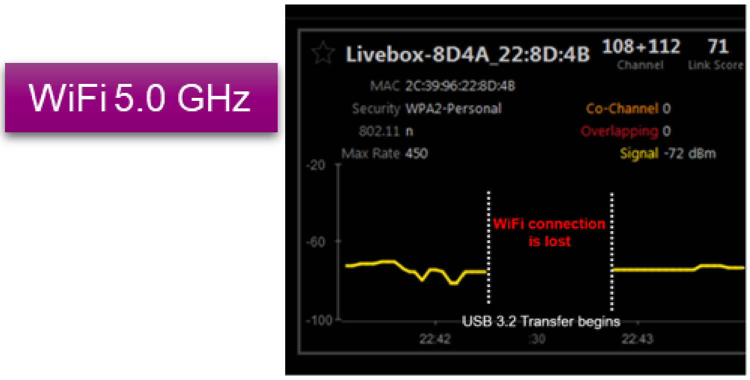


Figure 10. WiFi 5 signal RSSI for channels 108 and 112

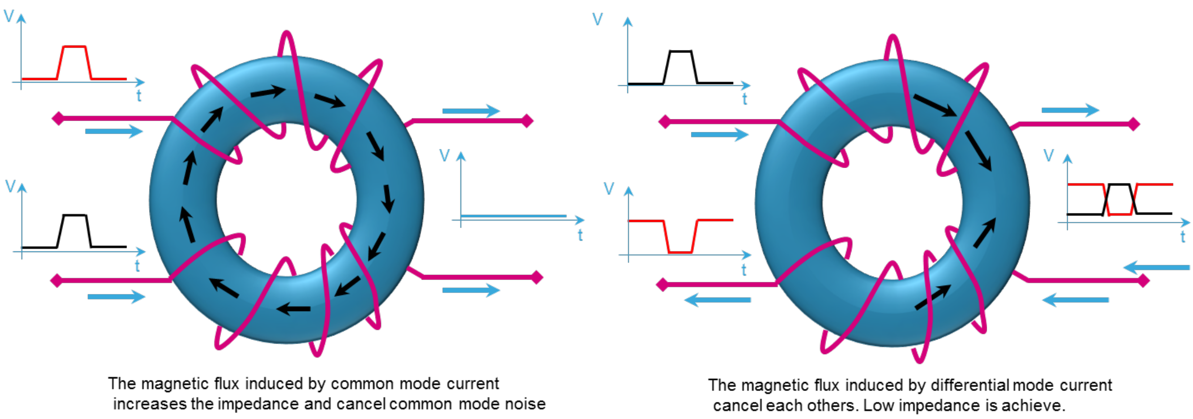


The conclusion of this test is that the USB 3.2 at 10 Gbps can generate radiated noise in the 2.4 GHz WiFi and the 5 GHz WiFi frequency range. As a matter of fact, it decreases the sensitivity of the WiFi antenna receiver. This phenomenon is called antenna desense or antenna desensitization.

2 Solution to avoid antenna desense

The best method to prevent antenna desense is to insert a common-mode filter on the differential pair link. This device includes two coupled inductances. They act as a subtracter for common-mode noise thanks to the magnetic flux accumulation. It induces high-Z for the common-mode noise path. The differential signal is not affected (Figure 11).

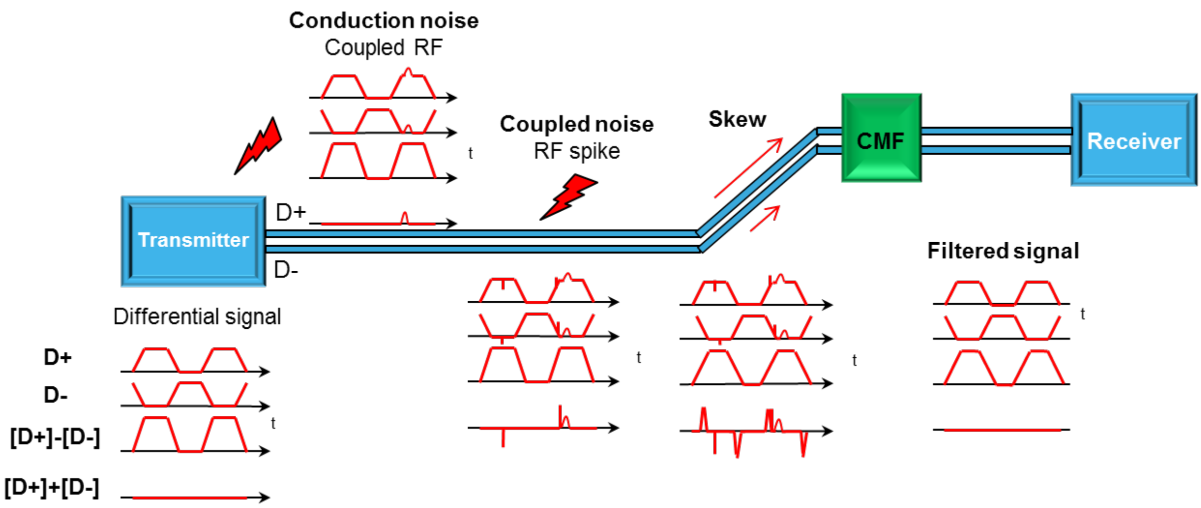
Figure 11. Common mode filter basics



The common-mode filter is efficient on all the common-mode noises induced on the link (see Figure 12):

- Conduction noise
- Radiated noise
- Noise induced by signal skew.

Figure 12. Common Mode Filter against various noise sources



The key points on the selection criteria for a common-mode filter are:

- High common-mode rejection (S_{CC21}) in the targeted frequency range to reject the unwanted common-mode noise.
- High differential bandwidth (S_{DD21}) to pass the useful high data-rate signals without distortion.
- Low DC resistance to ensure lossless signal and impedance matching.

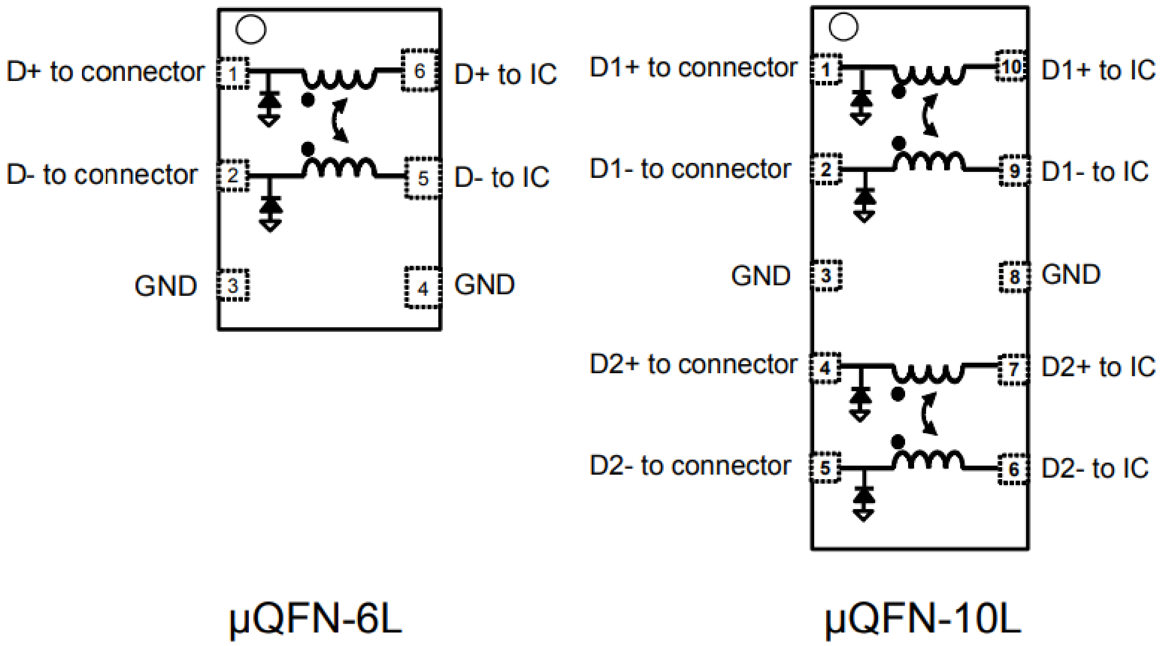
2.1 ECMF Family

The STMicroelectronics ECMF device range combines a common-mode filter with ESD protection in a single device.

A wide range of products is available. All are dedicated to high-speed links.

For example, Figure 13 shows the pinout and the functional schematic of the ECMF2-40A100N6 and the ECMF4-40A100N10 common-mode filters.

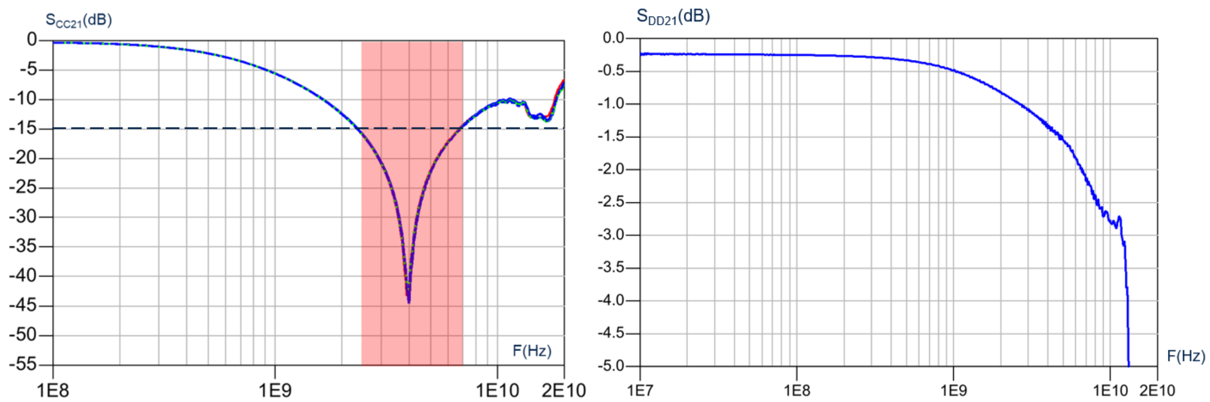
Figure 13. ECMF2-40A100N6 and ECMF4-40A100N10 pinout and functional schematic



Common mode rejection (S_{CC21}) and differential frequency response (S_{DD21}) are shown in Figure 14.

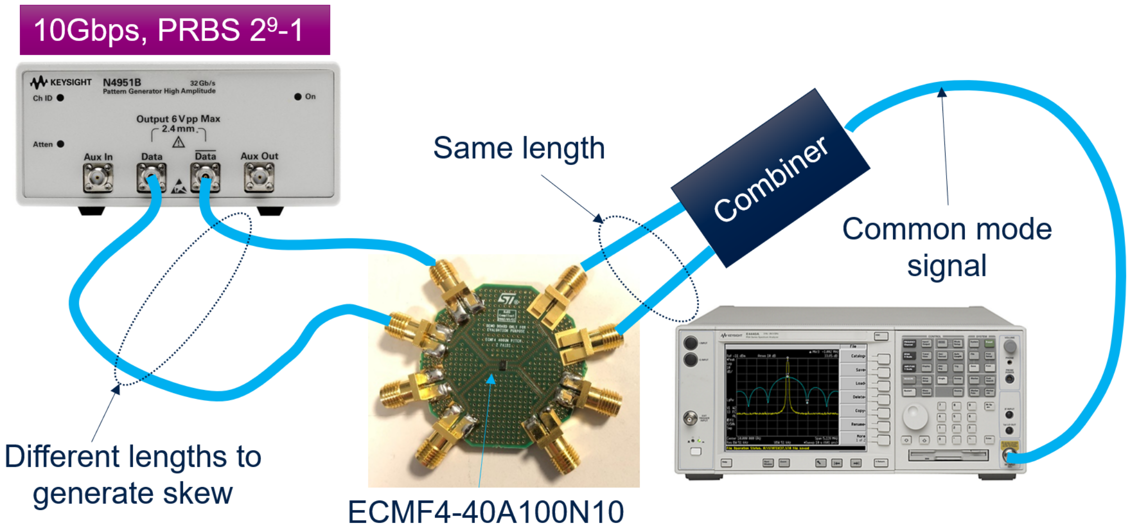
This device provides a high differential bandwidth, which is compatible with high-speed standards like USB 4, USB 3.2 Gen 2, MIPI M or D-PHY, HDMI 2.1 and so on. It also integrates an ESD protection. This product also provides a good common-mode rejection between 2.4 GHz and 7 GHz, which are inside the Bluetooth, WiFi, and WiFi 6E frequencies channels.

Figure 14. ECMF4-40A100N10 common mode rejection versus frequency and differential frequency response



In the Figure 15, the same test setup as the Figure 5. USB 3.2 at 10 Gbps with skew test setup is performed, but we add ECMF4-40A100N10 to filter the common mode noise generated by the skew.

Figure 15. USB 3.2 at 10 Gbps with skew test setup with ECMF4-40A100N10



The Figure 16 and the Figure 17 shows the spectral content of the resulting common-mode signal without any filter (in blue) and with ECMF4-40A100N10 (in orange). We have a good attenuation of around -15 dB on the whole WiFi and Bluetooth frequency bands. This is in line with the specification of this product shown in the Figure 14. With this attenuation, we can allow the antenna to receive the desired signal and to secure the communication.

Figure 16. Common-mode signal spectrum with and without ECMF4-40A100N10 on WiFi 2.4 GHz and Bluetooth frequency bands

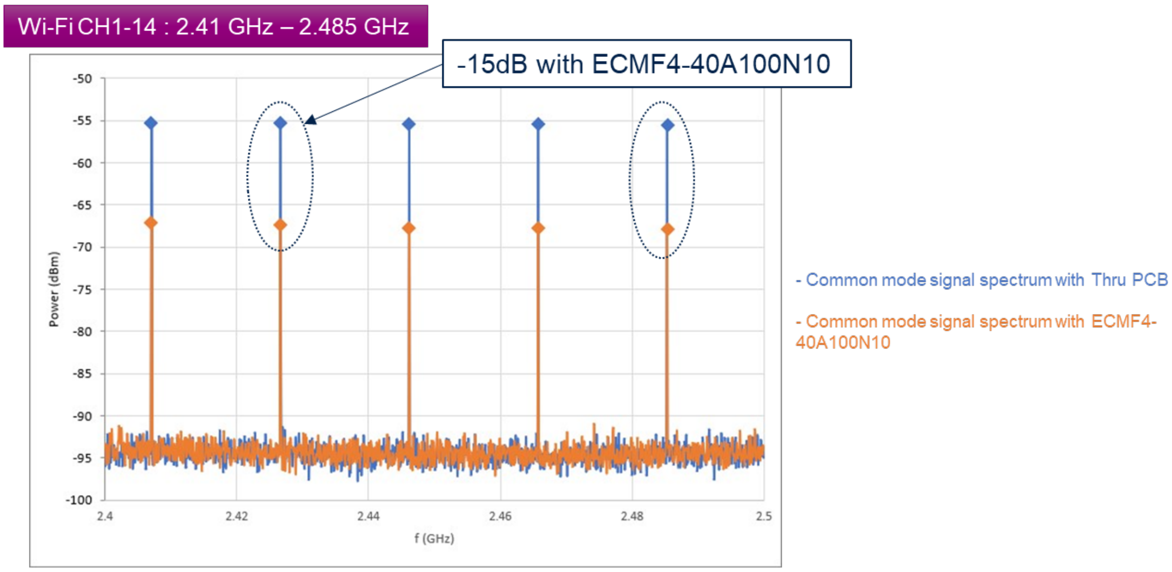
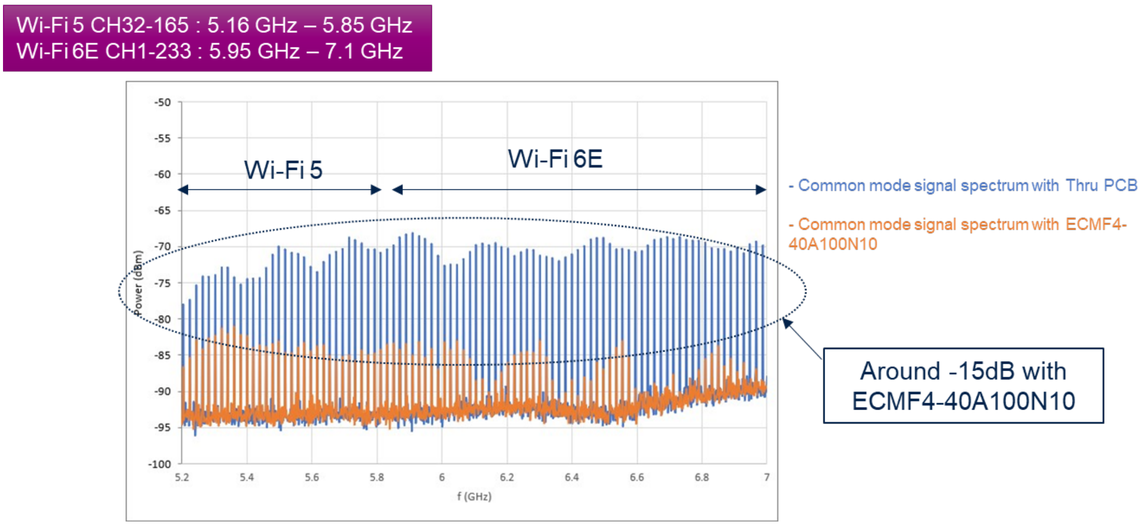
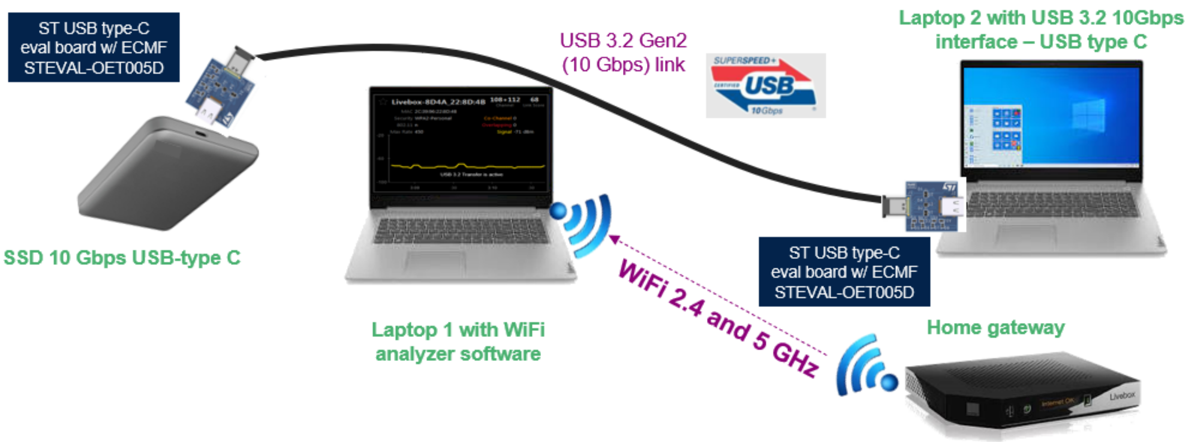


Figure 17. **Common-mode signal spectrum with and without ECMF4-40A100N10 on WiFi 5 and WiFi 6E frequency bands**



We repeated the test shown in the Figure 5, but we added the STEVAL-OET005VD with ECMF4-40A100N10 to filter the common mode noise generated by USB 3.2 at 10 Gbps link.

Figure 18. **Antenna desense reduction test setup with ECMF4-40A100N10 common-mode filtering**



The Figure 19 and the Figure 20 summarize the results obtained in the 2.4 and 5 GHz WiFi bands with the addition of the ECMF. We can see the benefit of this solution to keep a good reception of the WiFi signal.

For comparison, the Figure 9 and the Figure 10 snapshots were taken before common mode filtering.

Figure 19. WiFi 2.4 GHz signal RSSI for channel 1 with ECMF4-40A100N10

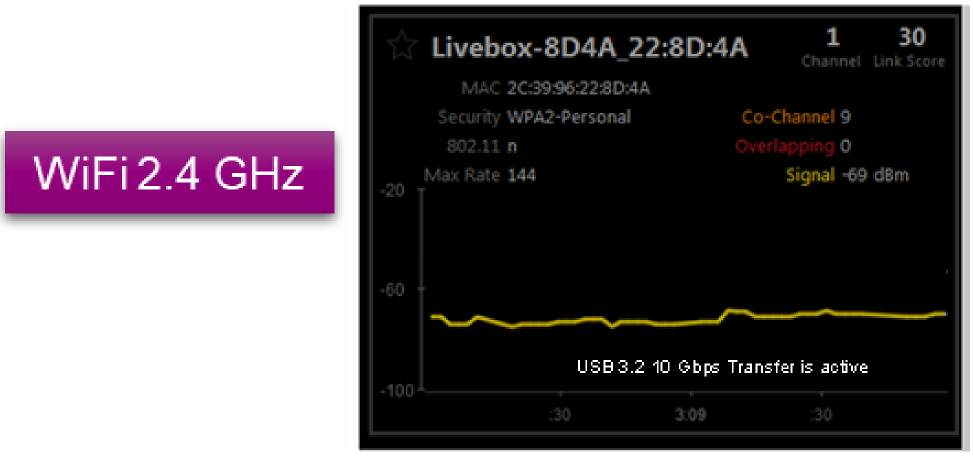
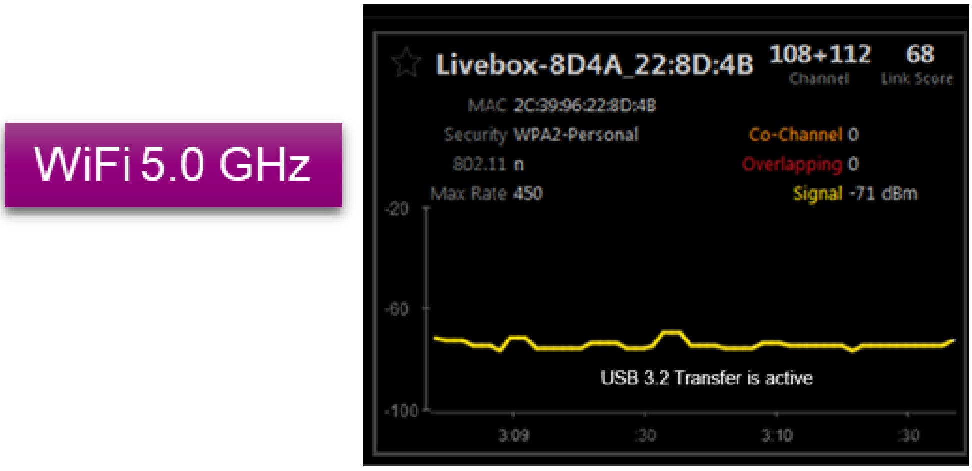


Figure 20. WiFi 5 signal RSSI for channels 108 and 112 with ECMF4-40A100N10



With the ECMF, cable radiations effects are attenuated, removing the antenna desense effect of the USB 3.2 on WiFi bands.

These trials have been performed on the USB 3.2 interface, but the same issues could be encountered on other links such as MIPI, display Port, HDMI…

STMicroelectronics also provides automotive-grade ECMF devices for various automotive applications.

Depending on the useful signals used in the application and the frequencies to be rejected, a proper selection of the ECMF device could help to solve these kinds of problems.

Indeed, as a reminder, the S_{DD21} parameter is the high differential bandwidth to pass the useful high data-rate signals without distortion. The S_{CC21} parameter is the high common-mode rejection in the targeted frequency range to reject the unwanted common-mode noise. These parameters, in addition to those for ESD protection, must be chosen in relation to the intended application.

The two first tests performed before have shown the efficiency of a common-mode filter to suppress unwanted common-mode noise that can be responsible for the desensitization of the antenna.

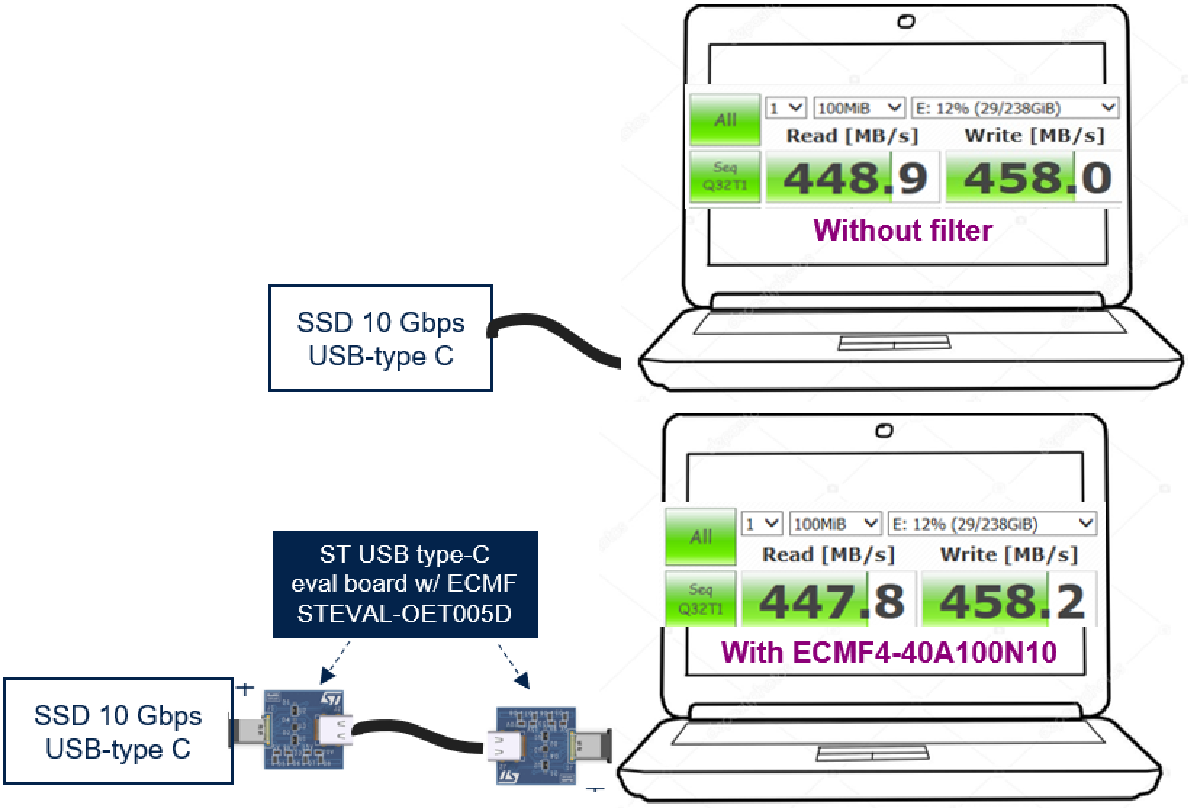
2.2 ECMF transparency for differential signals

A second important point is the transparency of the ECMF in the application, meaning the filters should not affect the useful high-speed signal transmitted between transceivers. To verify the transparency, we carried out mixed mode S-parameters measurement and eye-diagrams measurements.

To see the transparency of our filter in the application, we measured the speed of the data transmission between the PC and the 10 Gbps SSD with and without the ECMF4-40A100N10. This measurement was done using a data-rate measurement software (Figure 21). The software measures the read and write speeds of the SSD for sequential and random operations.

As we have similar values for both read and write operations, we can conclude that our filter does not affect the transmission speed of the useful signal.

Figure 21. Test setup for USB 3.2 data speed transmission measurement, with and without ECMF

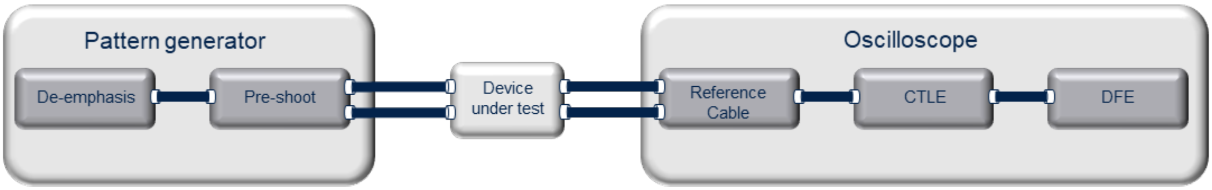


Many high-speed digital standards like HDMI 2.1, USB 3.2, or USB 4 provide eye diagram mask templates to pass the standards.

An eye diagram is produced by repetitively sampling a digital signal on an oscilloscope's vertical axis, while triggering the horizontal sweep with the data rate.

In the Figure 22, eye-diagrams measurements on a USB3.2 standard are performed. A PRBS pattern generator is used with de-emphasis and preshoot functions to simulate the real digital signal of the standard being tested. The oscilloscope integrates a USB3.2 type-C® reference cable insertion losses, CTLE, and DFE that are signal processing algorithms defined in the standard.

Figure 22. Eye-diagrams test setup for USB 3.2 standard



The test is performed in two steps:

- the first one (Figure 25) is measured on a perfect calibration through (it means without filter),
- the second one (Figure 26) is performed with ECMF4-40A100N10.

As we can see, there is a very low eye diagram distortion with the addition of the filter, and the template of the standard is respected.

Figure 23. USB4 20.0 Gbps eye diagram without ECMFx-40A100Nx (with preset 0, reference cable 0.8m, equalizer with ADC = 0dB and DFE)

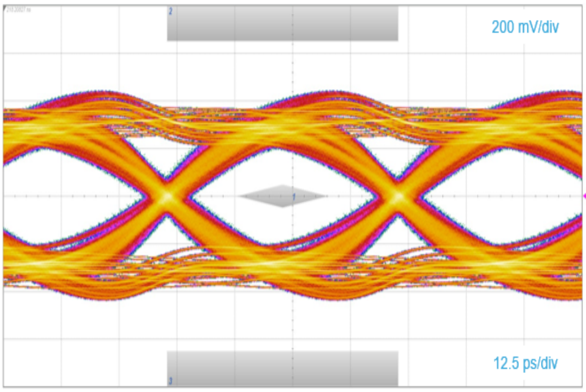


Figure 24. USB4 20.0 Gbps eye diagram with ECMFx-40A100Nx (with preset 0, reference cable 0.8m, equalizer with ADC = 0dB and DFE)

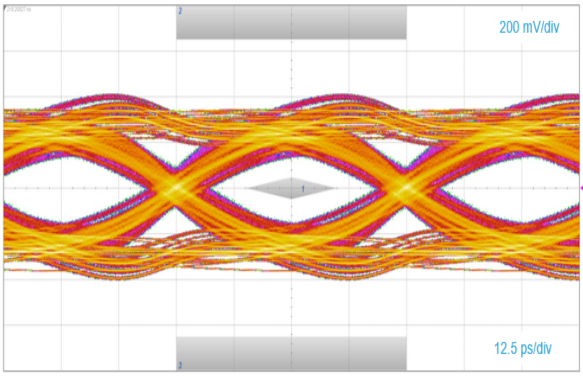


Figure 25. USB3.2 Gen 2 10.0 Gbps eye diagram without ECMFx-40A100Nx (with type C connector, reference cable, equalizer with ADC = 5 dB and DFE)

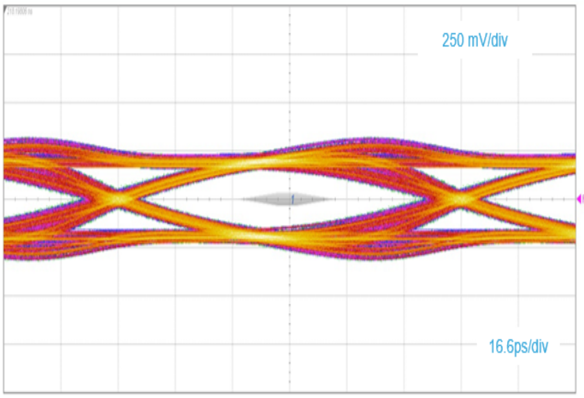


Figure 26. USB3.2 Gen 2 10.0 Gbps eye diagram with ECMFx-40A100Nx (with type C connector, reference cable, equalizer with ADC = 5 dB and DFE)

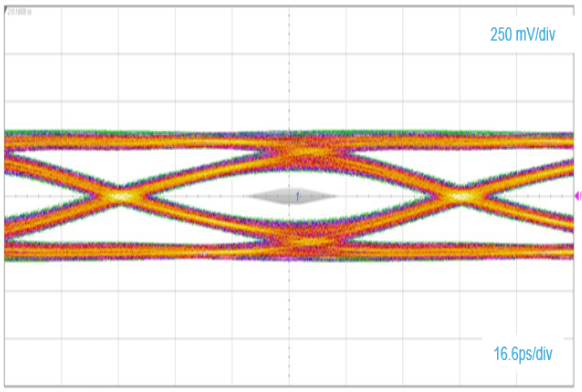


Figure 27. HDMI2.1 12 Gbps eye diagram without ECMFx-40A100Nx (with worst cable model (WCM3), EQ with 8 dB CTLE and one-tap DFE)

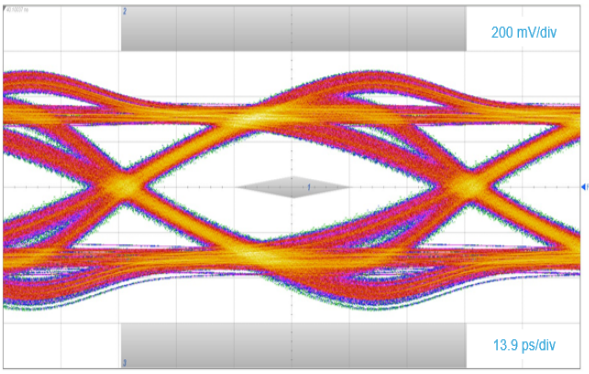


Figure 28. HDMI2.1 12 Gbps eye diagram with ECMFx-40A100Nx (with worst cable model (WCM3), EQ with 8 dB CTLE and one-tap DFE)

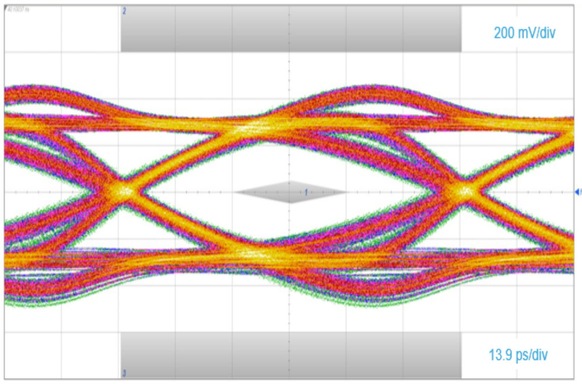


Figure 29. USB 2.0 High Speed 480 Mbps eye diagram, template 1, without ECMFx-40A100Nx

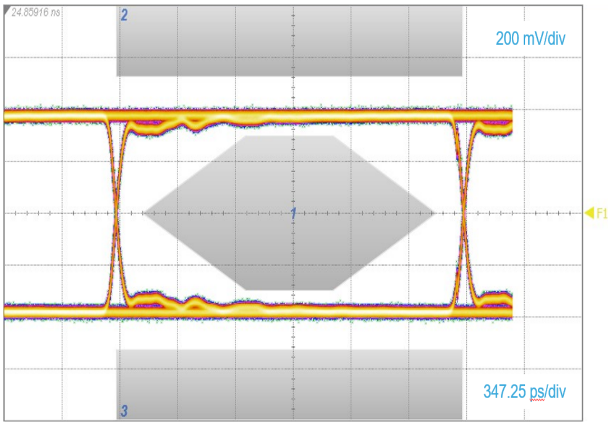


Figure 30. USB 2.0 High Speed 480 Mbps eye diagram, template 1, with ECMFx-40A100Nx

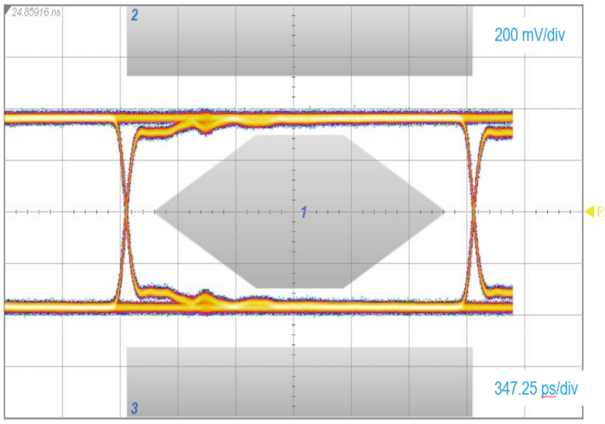


Figure 31. MIPI M-PHY–Gear 4 at 11.66 Gbps eye diagram without ECMFx-40A100Nx

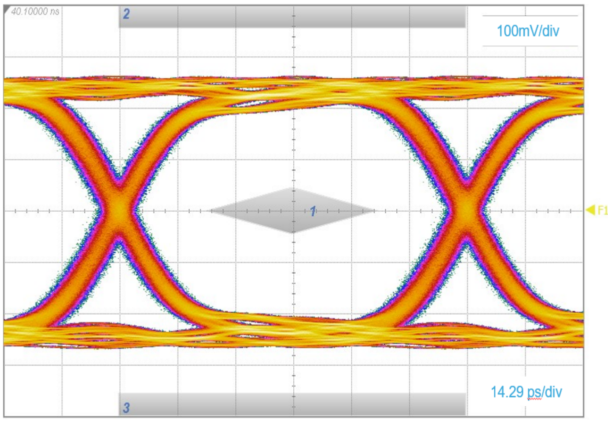
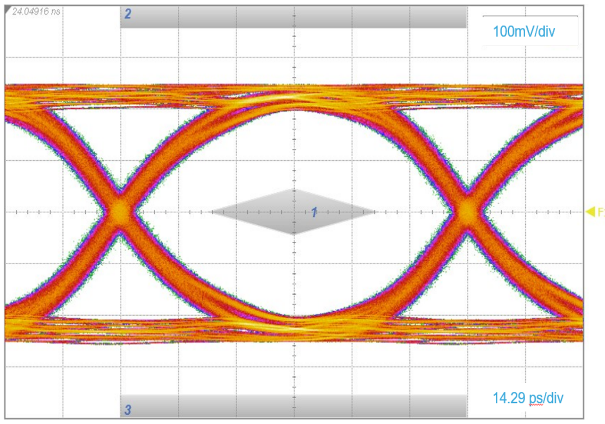


Figure 32. MIPI M-PHY–Gear 4 at 11.66 Gbps eye diagram with ECMFx-40A100Nx



2.3 ECMF layout recommendations

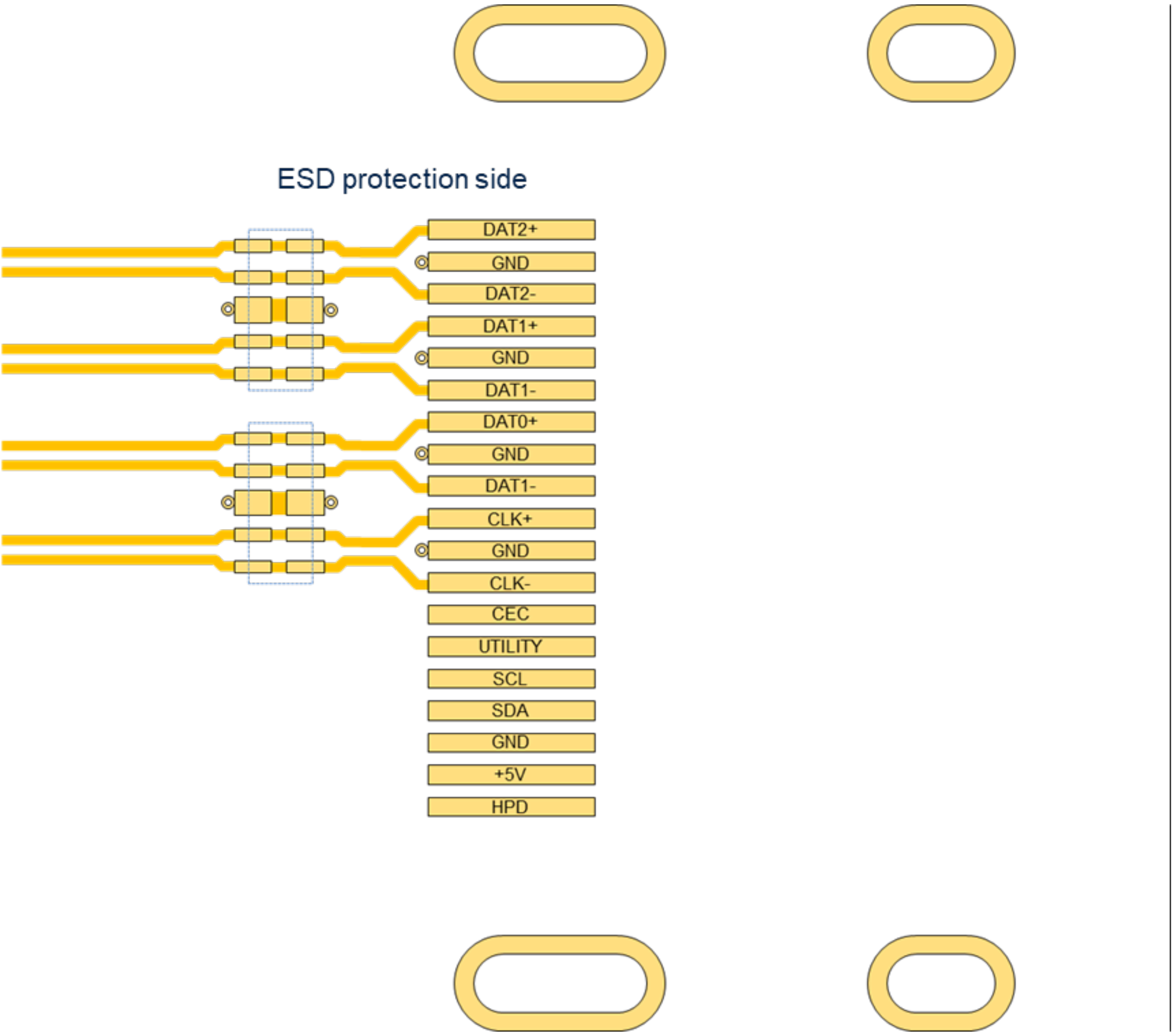
The ECMF4-40A100N10, structure is symmetrical: D+ or D- can be swapped.

The most important recommendation is to connect the device to the external connector on the side where ESD protection diodes are implemented.

The best position for the ECMFs is as close as possible to the connectors for the external links, and as close as possible to the flex connector for the internal ones. For long flex or cables, one ECMF at each end is more efficient.

Finally, ECMF connection to the ground needs to be as short as possible, with multiple vias to minimize parasitic inductance.

Figure 33. Layout example for HDMI TMDS type A connector



3 Conclusion

Loosing sensitivity due to EMI is usual: cables, PCB, or flexes can radiate a lot of noises. Maintaining a low noise level during reception is a key point on various applications to ensure their qualification and to keep good reliability results.

Common-mode filters are the suitable device to guard against this issue. But it must be chosen correctly as regards to the various application constraints such as attenuation level in the right frequency bands, frequency bandwidth, being in common mode or in differential mode.

Another benefit of ECMF technology is for highly disturbed places like, for example, industrial environments. Indeed, in that kind of environments, we can have strong magnetic fields, which can create saturation of ferromagnetic materials. With ECMF, there is no saturation phenomenon because there is no magnetic material. Inductors coupling is done without magnetic materials.

STMicroelectronics presents a wide range of devices dedicated for each application (including automotive grade solutions), that provide a good fit to customer needs and offer the integration of function not allowed by using discrete devices. It also takes less PCB surface area and improves assembly cost.

Revision history

Table 1. Document revision history

Date	Revision	Changes
03-Oct-2013	1	Initial release.
09-Jan-2023	2	Updated for current products. Minors text changes.

Contents

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