AN6331

Application note

GMSL2 and GMSL3 ESD protection and filtering

Introduction

Advanced automotive image sensors, displays, telematics, and infotainment systems require a high-speed, high-bandwidth architecture to improve safety and performance in the car cabin of the future. Gigabit multimedia serial link (GMSL™) technology provides a single-strand solution to transmit all video in the car over a single bidirectional cable that supports data transfer speeds of up to 12 Gbps.

You can see more information on the GMSL™ website.

This application note provides context for various electrical and electromagnetic constraints in the automotive environment.

It then offers an overview of the GMSL2 and GMSL3 physical (PHY) layers and specifications relevant to electrostatic discharge (ESD) protection and filtering devices.

Finally, ST's offer in ESD protection and filtering for GMSL2 and GMSL3 are described.

Related links

GMSL™ web site.

1 Electrical hazards in the automotive environment

The automotive environment presents various electrical hazards. These hazards, such as electromagnetic interference (EMI), electrostatic discharge (ESD), and other electrical disturbances, are generated by components like ignition systems, relay contacts, alternators, injectors, and high dV/dt or dI/dt during normal operation.

These hazards can occur in the following ways:

- Directly: In the wiring harness due to conducted disturbances
- Indirectly: In electronic modules through radiation and coupling.

The generated hazards can impact electronics in two ways, depending on the environment:

- On the data lines
- On the supply rail wires.

This section focuses only on the impacts on the data lines.

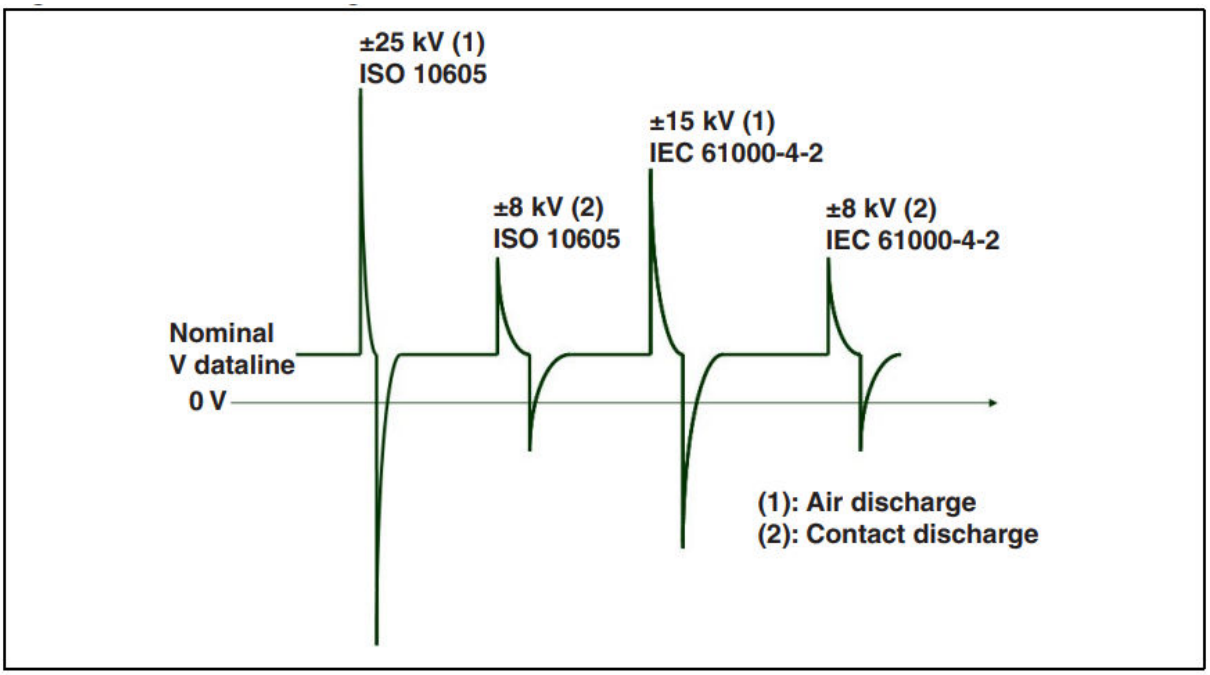
For impacts on supply lines, refer to *AN2689 - Protection of automotive electronics from electrical hazards, guidelines for design and component selection*.

1.1 Propagation of electrical hazards on data lines

Transients generated on data lines are primarily electrostatic discharge (ESD) surges. These surges have low energy but exhibit a very high dV/dt, which generates a strong electromagnetic field. The *ISO 10605* and *IEC 61000-4-2* standards define ESD surges. Affected data lines include communication lines such as media transfer lines, video links, data buses, sensor data lines, and control lines.

The Figure 1 illustrates the surge forms of hazards that occur on data lines.

Figure 1. Types of surges on data lines



The ESD surge test is applied to a complete system to simulate ESD events, such as those caused by human body contact or connector plug-ins on an electronic module.

1.2 Standards for the protection of automotive electronics

Several standards bodies, such as the *society of automotive engineers (SAE)*, the *automotive electronics council (AEC)*, and the *international organization for standardization (ISO)*, describe the hazards indicated above.

ISO 10605 and *ISO 7637-3* are the most important automotive standards regarding electrical hazards.

2 GMSL2 and GMSL3 PHY

2.1 AC coupling and termination

GMSL2 and GMSL3 consist of one coaxial line (Z_0 = 50 Ω) or one differential lane (Z_{0DIFF} = 100 Ω), AC-coupled. These are bidirectional links. Additionally, they can carry a power supply.

The schematic below illustrates the use of coaxial and shielded twisted-pair (STP) cables.

Figure 2. Coax termination scheme

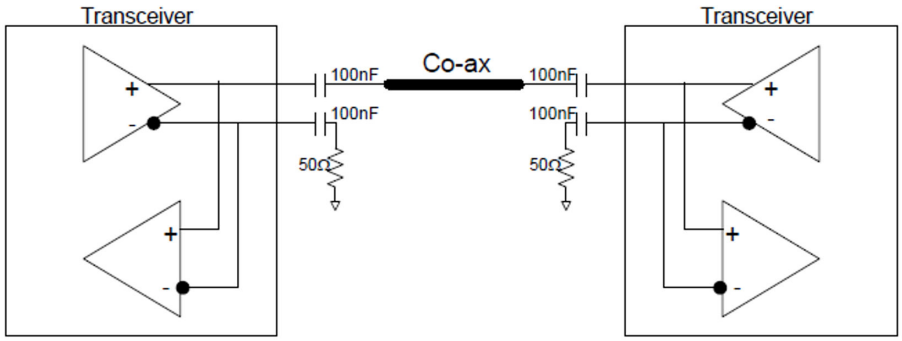
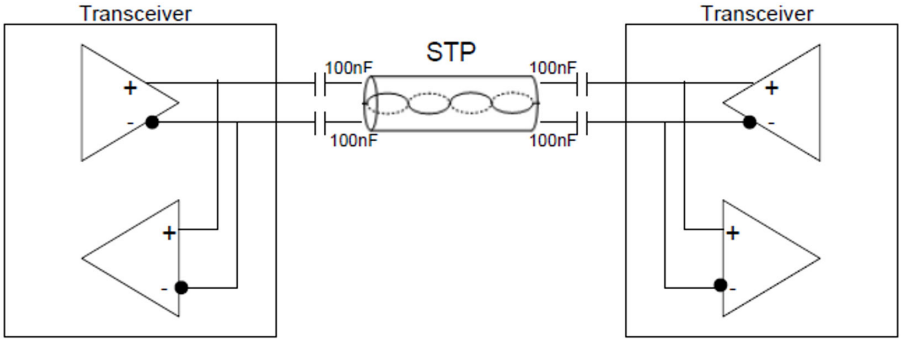


Figure 3. STP termination scheme



Related links

Public GMSL2 Hardware Design and Validation Guide, UG-2212, Revision 2

GMSL2 Channel Specification User Guide, Revision 1

Public GMSL3 Hardware Design and Validation Guide, UG-2208, Revision 1

GMSL3 Channel Specification User Guide

2.2 Data rate

The Table 1 shows GMSL2 speeds:

- 3 Gbps or 6 Gbps for forward channel
- 187 Mbps for reverse channel.

Table 1. Frequency bandwidth allocation for GMSL2

GMSL speed	Minimum frequency	f half-linkrate	Maximum frequency in channel specification
Forward channel (3 Gbps)	50 MHz	1.5 GHz	2.0 GHz
Forward channel (6 Gbps)	100 MHz	3 GHz	3.5 GHz
Reverse channel (187 Mbps)	2 MHz	93.5 MHz	400 MHz

For GMSL3, PAM 4 is used:

- 12 Gbps for forward channel, but a symbol rate divided by 2, so same key frequency as GMSL2 6 Gbps speed
- 187.5 Mbps for reverse channel.

The Table 2 shows GMSL3 speeds.

Table 2. Frequency bandwidth allocation for GMSL3

GMSL speed	Minimum frequency	Key frequency	Maximum frequency in channel specification
Forward channel (12 Gbps)	2 MHz	3 GHz	3.5 GHz
Reverse channel (187.5 Mbps)	2 MHz	93.75 MHz	3.5 GHz

2.3 Transmitter output levels

Below values are from the MAX96793 datasheet (CSI-2 to GMSL3/2 serializer):

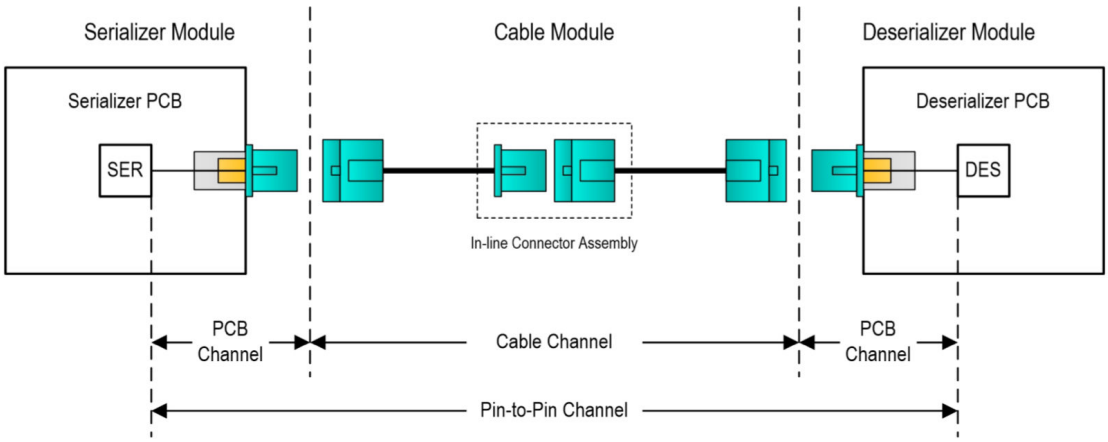
- Single-ended offset: 400 mV minimum, 600 mV maximum
- Single-ended output voltages swing: 600 mV maximum for PAM4 modulation.

Thus, the single-ended minimum voltage is 100 mV (min. offset - output voltage swing / 2), and the single-ended maximum voltage is 900 mV (max. offset + output voltage swing / 2).

2.4 Channel definition

Protection and filtering devices are implemented between connector and *SerDes* IC, so part of the PCB channel.

Figure 4. Channel definition



Parameter templates are defined for PCB channel, for 3 Gbps, 6 Gbps and 12 Gbps speeds:

- Template for insertion loss (IL), S_{21} or S_{DD21}, see Figure 5
- Template for return loss (RL), S_{11}/S_{22} or S_{DD11}/S_{DD22}, see Figure 6

Figure 5. Template for insertion loss

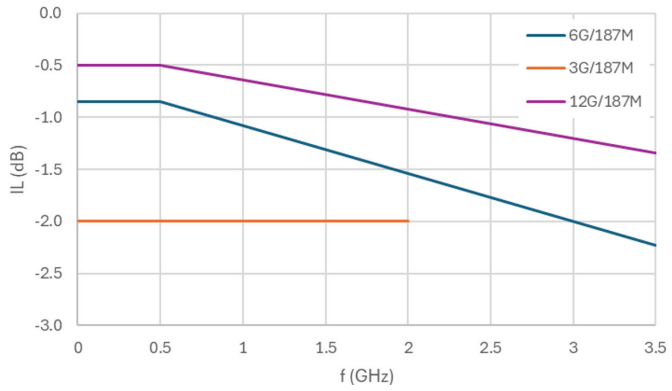
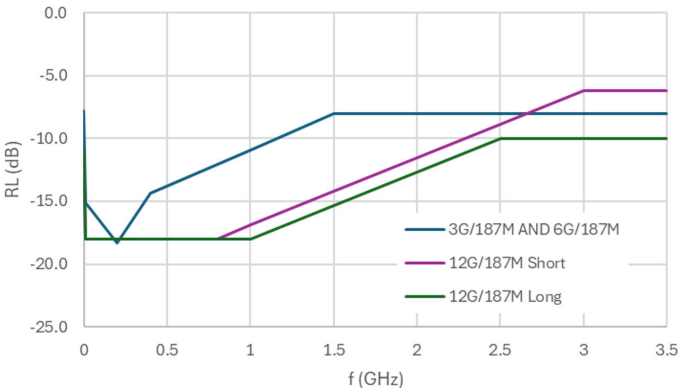


Figure 6. Template for return loss



Protection and filtering devices must be compliant with these specifications.

3 ST offers for ESD protection

In ST's product portfolio, you can find ESD protection devices compatible with the GMSL2 and GMSL3.

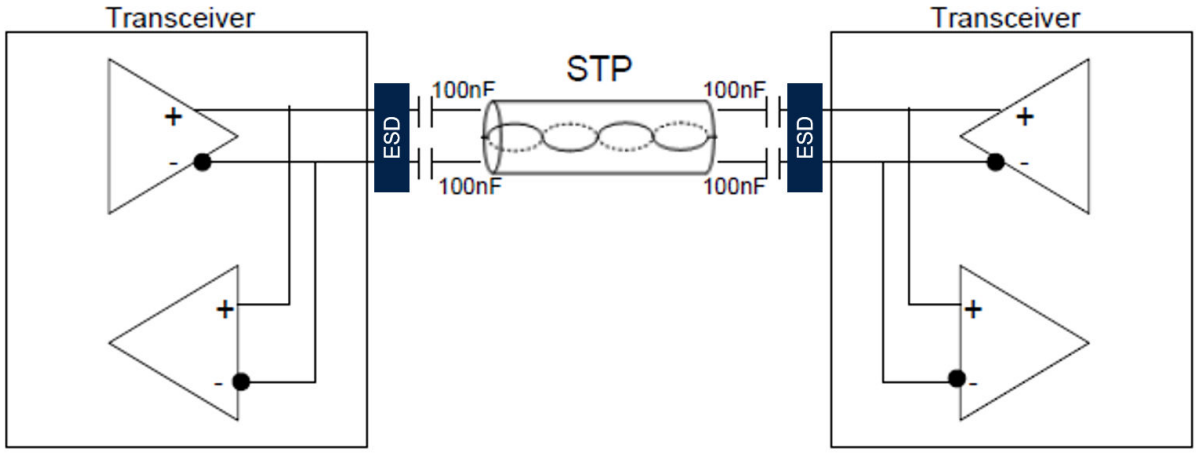
For ESD protection, placement at the connector is always preferred. An AC capacitor cancels the DC bias voltage, so only the data signal levels need to be considered.

The tracks between the ESD protection device and the line to be protected must be as short as possible to minimize the inductive effect on the clamping voltage value. The same rule applies between the protection device and the ground plane.

The track's parasitic inductance adds extra voltage to the clamping voltage of the ESD protection device.

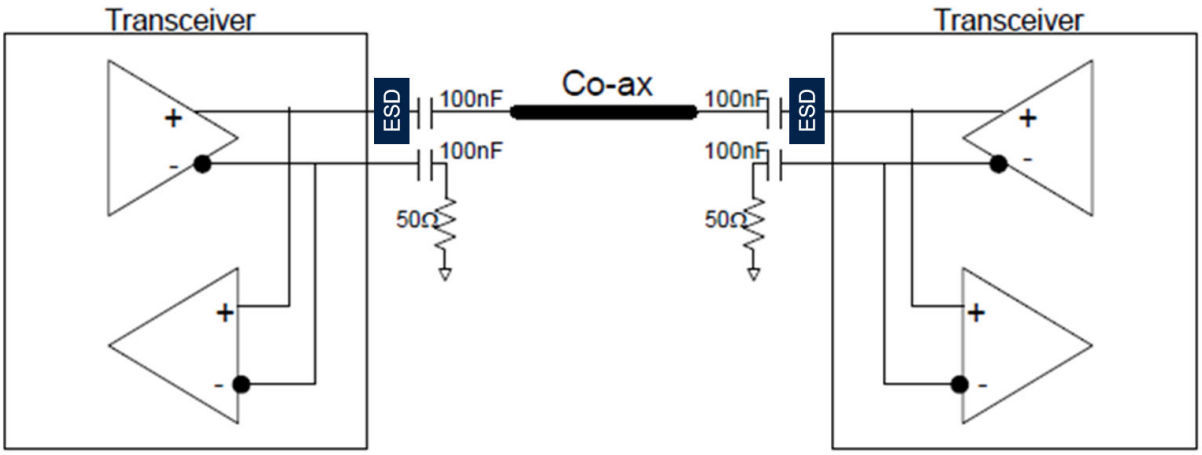
For more details, see *AN5686 - PCB layout tips to maximize ESD protection efficiency*.

Figure 7. ESD protection implementation on a differential system



Our ESD protections devices can be used on differential lines as well as on coaxial lines.

Figure 8. ESD protection implementation on a single-ended system



According to GMSL2 and GMSL3 characteristics, shown above, ESD protection requirements are:

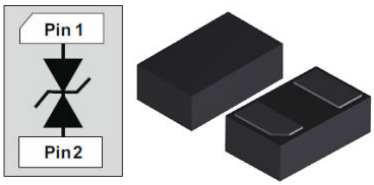
- Unidirectional / Bidirectional devices are suitable
- Compliant with PCB channel IL and RL templates
- V_{RM} ≥ 0.9 V (maximum voltage is 0.9 V)
- ESD robustness complies with *ISO 10605* and *IEC 61000-4-2* standards.

Also, to respect insertion loss template, the package should not be SOT323-3L and SOT23-3L. Indeed, internal long wire bonding can decrease the resonance frequency, so insertion loss is not compliant with PCB channel requirement.

ESDAXLC6-1BT2Y is a single-line ESD device designed for high-speed lines protection.

This part is on NRND status following PTN15673 related to new front-end location and technology, with deliveries secured till H2 2026. Development of a new product using this upgraded technology with reference *ESDXLC6-1BT2Y* is planned.

Figure 9. ESDAXLC6-1BT2Y functional schematic and package (0402)



Its line capacitance is lower than 0.5 pF and it provides a high robustness against ESD stress.

Below figures show PCB channel templates and *ESDAXLC6-1BT2Y* measurements:

- For insertion loss (S_{21})
- For return loss (S_{11}).

ESDAXLC6-1BT2Y is compliant with GMSL2 and GMSL3 requirements.

Figure 10. ESDAXLC6-1BT2Y S_{21} versus PCB channel requirement

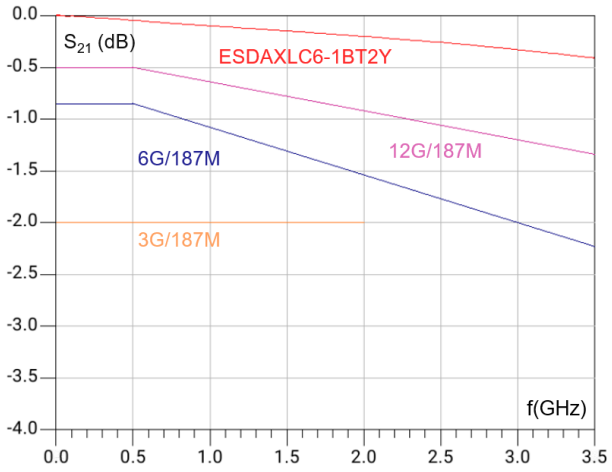
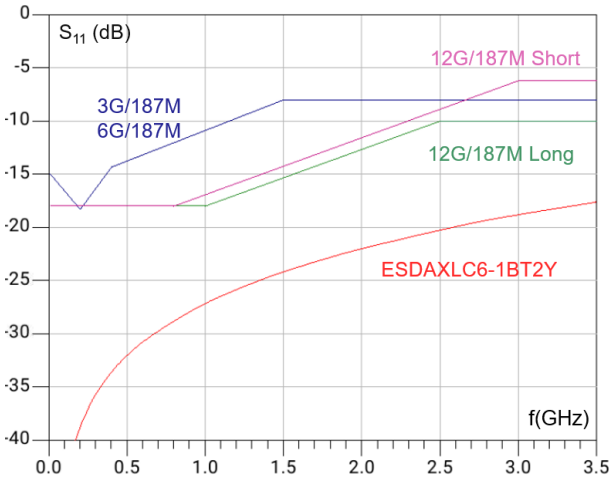


Figure 11. ESDAXLC6-1BT2Y S_{11} versus PCB channel requirement



ESDAXLC6-1BT2Y datasheet can be downloaded from st.com website.

4 ST offering for filtering and protection (ECMF)

An ECMF is a common-mode filter that integrates an ESD protection die. This integration allows for space savings compared to using discrete common-mode filters (CMFs) and discrete ESD protection components.

Additionally, the performance of ECMFs includes ESD protection, which must be added to the CMF performance in the case of discrete implementations.

Why use a common-mode filter?

The automotive environment increasingly includes high-speed lines and antennas. These high-speed transmission lines generate frequency harmonics.

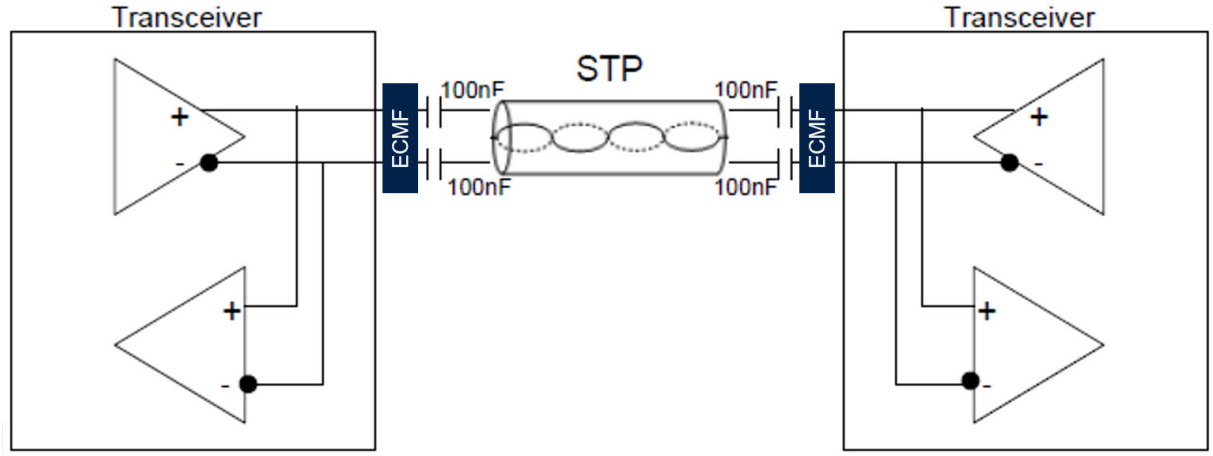
To ensure good sensitivity of the RF receiver, the system must limit emissions at RF receiver frequencies. High-speed differential links can radiate at these frequencies, and emissions can be attenuated by using a common-mode filter. This approach prevents the antenna desense phenomenon.

For more details, see *AN4356 - Antenna desense on handheld equipment*.

For additional information on ECMFs, refer to *AN4511 - Common-mode filters*.

ECMF must be placed after the capacitor and as close as possible to the connector for the same ESD safety reasons explained before.

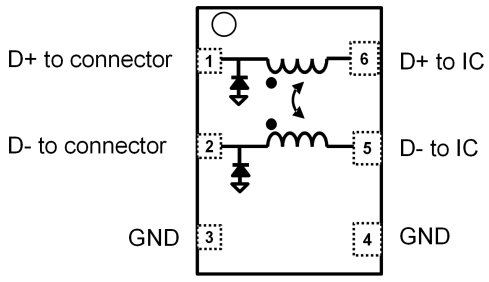
Figure 12. ECMF implementation on a differential system



The *ECMF2-40A100M6Y* is a one-pair common-mode filter that also integrates ESD protection.

Figure 13 is the functional diagram:

Figure 13. ECMF2-40A100M6Y functional diagrams



The performance of the *ECMF2-40A100M6Y* is compared with PCB channel requirements in the below figures. As it is a differential link, S_{DD21}, S_{DD11}, and S_{DD22} are plotted.

Figure 14. **ECMF2-40A100M6Y S_{DD21} versus PCB channel requirements**

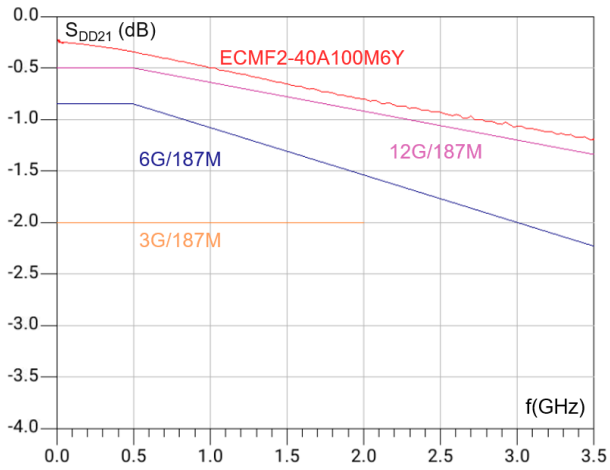
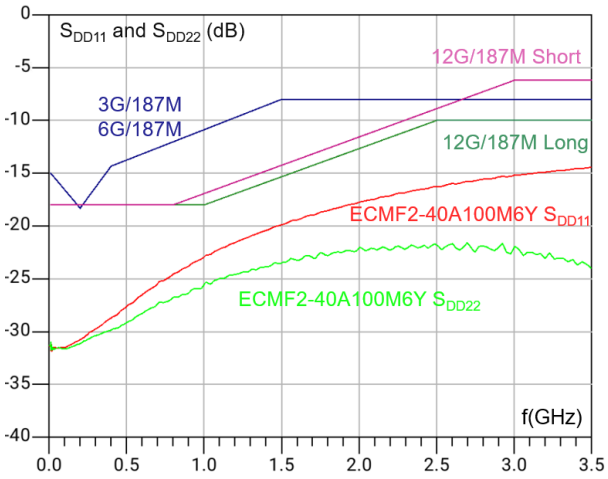


Figure 15. **ECMF2-40A100M6Y S_{DD11} and S_{DD22} versus PCB channel requirements**



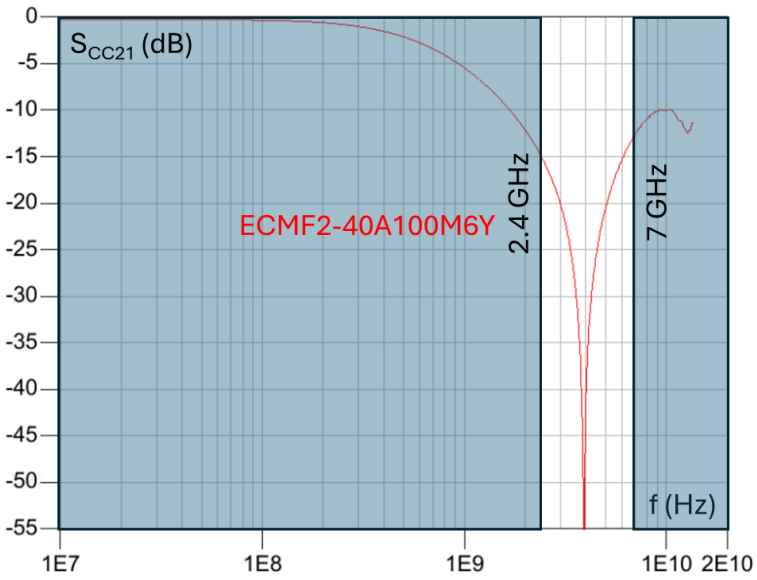
These two figures demonstrate that the *ECMF2-40A100M6Y* complies with PCB channel requirements.

Common-mode rejection

The Figure 16 shows that the common-mode rejection of the *ECMF2-40A100M6Y* is optimized to reject noise for the following standards:

- Bluetooth (2.4 GHz)
- Wi-Fi 2 (2.4 - 2.5 GHz)
- Wi-Fi 5 (5 - 6 GHz)
- Wi-Fi 6, 7, 8 (6 - 7 GHz)
- V2X (5.9 GHz).

Figure 16. Common-mode rejection of the ECMF2-40A100M6Y



Protection features

The ECMF also includes protection features. For detailed information, refer to the datasheet, which can be downloaded from the ST website at: *ECMF2-40A100M6Y*.

5 Conclusion

After detailing the requirements of the GMSL2 and GMSL3 specification applicable to ESD protection and filtering devices, compliant ST solutions are presented:

- *ESDAXLC6-1BT2Y* for ESD protection
- *ECMF2-40A100M6Y* for common-mode filtering and ESD protection.

Both components are automotive grade and in mass production. They ensure the following:

- Immunity to external surges
- Low radiation allows maintaining good sensitivity of RF receivers.

Revision history

Table 3. **Document revision history**

Date	Revision	Changes
22-Aug-2025	1	Initial release.

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