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GMSL3 Channel Specification User Guide

Rev 4; 09/24

Abstract

The GMSL3 Channel Specification defines the hardware system design requirements necessary for proper operation of GMSL3 devices. It should be used in conjunction with the relevant GMSL3 serializer and deserializer data sheets to develop compliant GMSL3 systems.

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Purpose and Scope

The GMSL3 Channel Specification defines the hardware system design requirements necessary for proper operation of GMSL3 systems as specified by device datasheets. It contains both the GMSL3 System Channel Specification and the *GMSL3 Module Channel Specifications*. Within this document, “GMSL3 Channel Specification” is used to collectively refer to the specifications.

This document describes important system design considerations and should be used as a reference for system development and component evaluation. Relevant system elements include PCB material, PCB layout, passive PCB components, cable(s), and connectors.

Compliant GMSL3 systems meet or exceed the S-parameter curves, crosstalk specifications, and link margin requirements detailed in this document.

A compliant GMSL3 system channel has an expected bit error ratio (BER) of 10^{-30} or better when FEC is used.

GMSL3 Channel Descriptions and Definitions

GMSL3 Overview

GMSL3 devices use ADI's proprietary third-generation gigabit multimedia serial link (GMSL3) technology to transport high-speed serialized data over coax or shielded twisted-pair cable for automotive camera and display applications.

GMSL3 devices use a pulse amplitude modulation – 4 Level (PAM4) encoding scheme to allow links to operate at a fixed data rate of 12Gbps on the forward channel, the reverse channel operates at 187.5Mbps.

PAM4 is an encoding scheme that uses four discrete voltage levels. This differs from the encoding scheme used for GMSL2 devices, which uses non-return-zero (NRZ) encoding. PAM4 has 2 bits per symbol, whereas NRZ is only 1 bit per symbol, which is why GMSL3 has double the data rate with the same symbol rate. The PAM4 eye height is reduced by 8dB when compared to a NRZ eye. GMSL3's 12Gbps PAM4 link utilizes forward error correction (FEC) to increase robustness of the link on very long channels.

NRZ vs. PAM4 Encoding Scheme differences is shown below in *Figure 1*.

A block diagram of a typical GMSL3 system is shown below in *Figure 2*.

***Note:** The forward channel is defined as serializer-to-deserializer transmission; the reverse channel is defined as deserializer-to-serializer transmission.

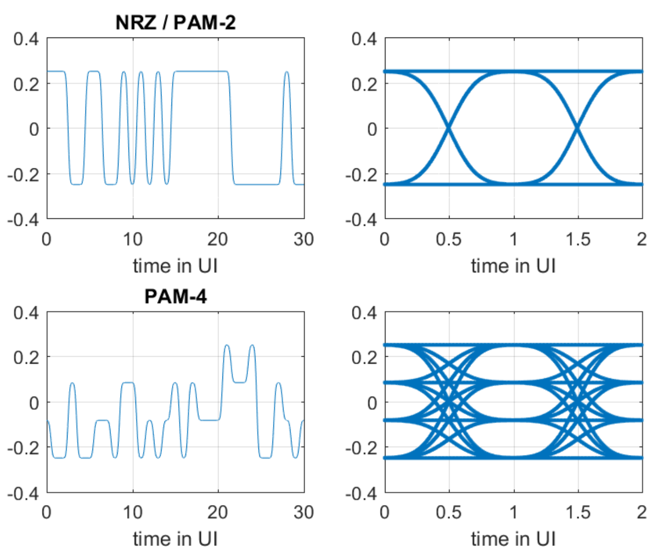


Figure 1 NRZ vs. PAM4 Encoding Temporal Characteristics

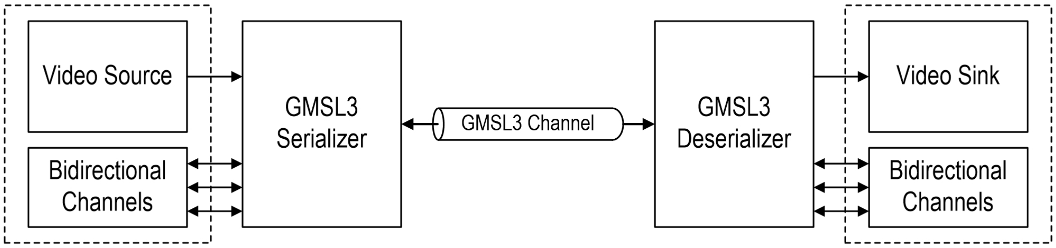


Figure 2 GMSL3 System Block Diagram

GMSL3 Channel Definition

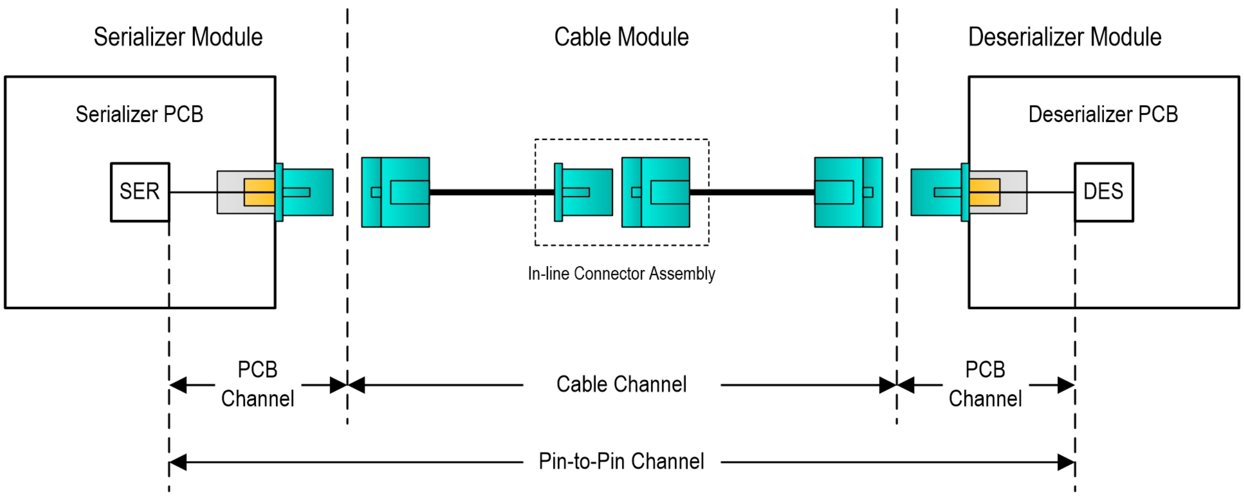


Figure 3 GMSL3 Channel Definition

Note: AC-coupling capacitors and optional power-over-coax (PoC) or line-fault components are not depicted in *Figure 3*.

The **GMSL3 System Channel** is defined as the pin-to-pin channel from the SIO pin(s) of the serializer to the SIO pin(s) of the deserializer and consists of the following:

- Serializer PCB Channel
- Cable Channel
- Deserializer PCB Channel

Note: For multi-link configurations (i.e., Dual Link, Splitter mode, and Reverse Splitter mode), each GMSL link is treated as an independent pin-to-pin channel.

The **GMSL3 Module Channels** are defined as the individual sub-channels within the GMSL3 system channel.

The PCB channel is defined as the channel from the device SIO pin to the end of the PCB-mounted connector. It includes the trace itself and any PCB components on the trace (e.g., line-fault resistors, PoC components, ESD diodes, common mode chokes, and other passive components). This channel is also referred to as the Serializer or Deserializer PCB Channel Module and can be evaluated for GMSL3 module compliance.

The cable channel is defined inclusively as the channel comprising all components from the cable connector on the serializer side to the cable connector on the deserializer side, including the cable(s) and any in-line connector(s). For applications using cable bundles, the cable crosstalk specification must consider the other conductors in the cable harness. This channel is also referred to as the Cable Module and can be evaluated for GMSL3 module compliance.

Note: Meeting module compliance requirements guarantees GMSL3 system channel compliance when implemented with other compliant modules and cable(s).

GMSL3 Channel Frequency Bands

GMSL3 is a packet-based protocol operating at a fixed link-rate. The GMSL3 forward channel data rate is 12Gbps, the reverse channel data rate is 187.5Mbps. The transmitted/received data rate is a fixed rate based on the data rate setting and is independent of the payload. For example, if a camera or display application requires 10Gbps, the forward channel data rate on the link must be set to 12Gbps, and idle data will fill the unused link capacity.

Forward Channel:

The GMSL3 forward channel uses PAM4 encoding scheme and transfers 2 bits per symbol. A key frequency for PAM4 encoding is ¼ bit rate, for a 12Gbps PAM4 channel (GMSL3 forward channel) it is 3GHz.

Reverse Channel:

The GMSL3 reverse channel uses a non-return to zero (NRZ) encoding scheme. A key frequency of NRZ encoding is ½ bit rate, for a 187.5Mbps NRZ channel (GMSL3 reverse channel) it is 93.75MHz.

Note: The maximum frequency defined in the channel specification is higher than the key frequencies listed above. This is due to the energy content of the rise/fall times of the transmitters. The attenuation (due to insertion loss) of the signal at the key frequencies is the most critical value to consider when exploring the maximum channel length that can be used in a system. However, the specification must be met across the entire frequency band defined.

Table 1. Frequency Bandwidth Allocation for GMSL3

GMSL – Speed	Minimum Frequency	Key Frequency	Maximum Frequency Specified in Channel Specification
Forward Channel – 12Gbps	2MHz	3GHz	3.5GHz
Reverse Channel – 187.5Mbps	2MHz	93.75MHz	3.5GHz

Note: The crosstalk specifications extend across a greater frequency band than the return loss and insertion loss specifications.

The bidirectional transmitter/receiver of GMSL3 necessitates emphasis on return loss. The energy of the forward and reverse channels overlap in frequency, so reflections in the band of the low-speed transmitter and receiver are especially important to consider when designing the channel. For system optimization, insertion loss must be minimized and return loss must be optimized.

Network Analyzer Settings:

The recommended settings for data capture are 100kHz to 4GHz with 1MHz or smaller step size. The frequency steps should be linear and not logarithmically spaced.

GMSL3 Channel S-Parameter Definitions

The GMSL3 Channel Specification defines minimum or maximum values of scattering parameters (S-parameters) across the frequency band of interest in a 50Ω environment. S-parameters are defined for insertion loss and return loss. Reference *Figure 4* and the corresponding sections below. For the GMSL3 Channel Specification, the serializer is defined as Port 1 and the deserializer is defined as Port 2.

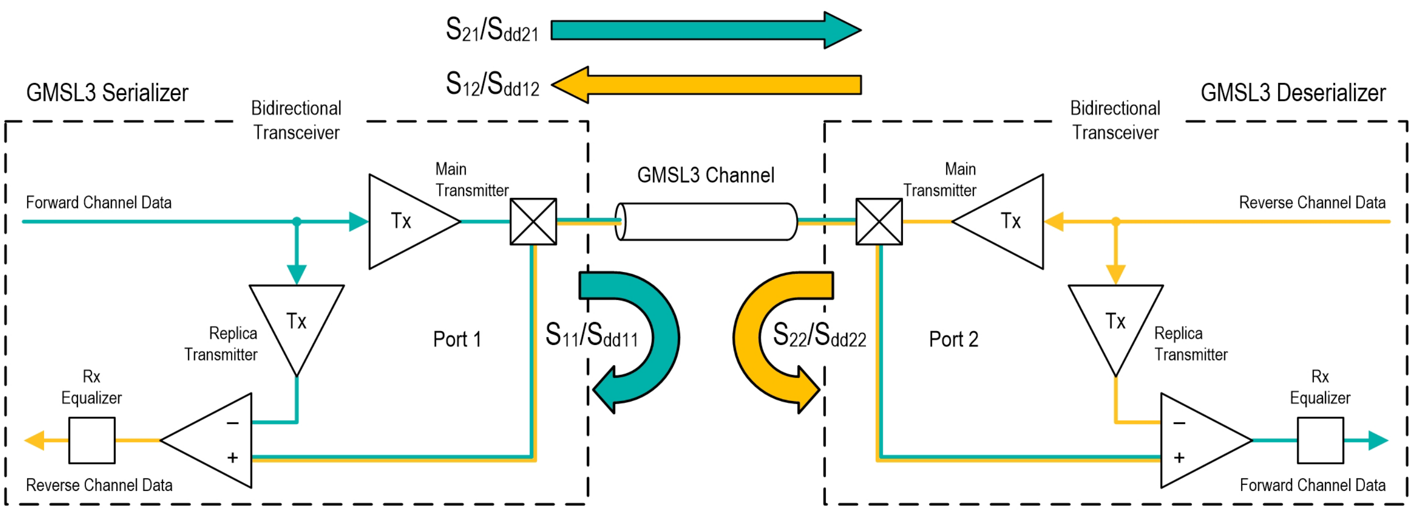


Figure 4 GMSL3 Channel S-Parameter Definitions

Insertion Loss (S21/Sdd21, S12/Sdd12)

Insertion loss is the energy loss across the transmission channel.

- S_{21}/S_{dd21} – Forward channel insertion loss
- S_{12}/S_{dd12} – Reverse channel insertion loss

S_{21}/S_{dd21} defines the amount of energy loss for the high-speed channel (forward channel), and S_{12}/S_{dd12} defines the amount of energy loss for the low-speed channel (reverse channel). For typical GMSL3 channels consisting of passive PCB components and cables, S_{21}/S_{dd21} and S_{12}/S_{dd12} are equal.

For differential applications (i.e., STP), use differential S-parameters (S_{dd21} and S_{dd12}). For more information regarding S-parameter definitions, see *Appendix A: Single-Ended and Differential S-parameters*.

Return Loss (S11/Sdd11, S22/Sdd22)

Return loss is the reflected energy back to the transmitter.

- S_{11}/S_{dd11} – Forward channel return loss
- S_{22}/S_{dd22} – Reverse channel return loss

S_{11}/S_{dd11} is used to evaluate the high-speed transmitter energy reflected into the low-speed receiver; S_{22}/S_{dd22} is used to evaluate the reflected energy of the low-speed transmitter back into the high-speed receiver.

For differential applications (i.e., STP), use differential S-parameters (S_{dd11} and S_{dd22}). For more information regarding S-parameter definitions, see *Appendix A: Single-Ended and Differential S-parameters*.

GMSL3 System Channel Specification

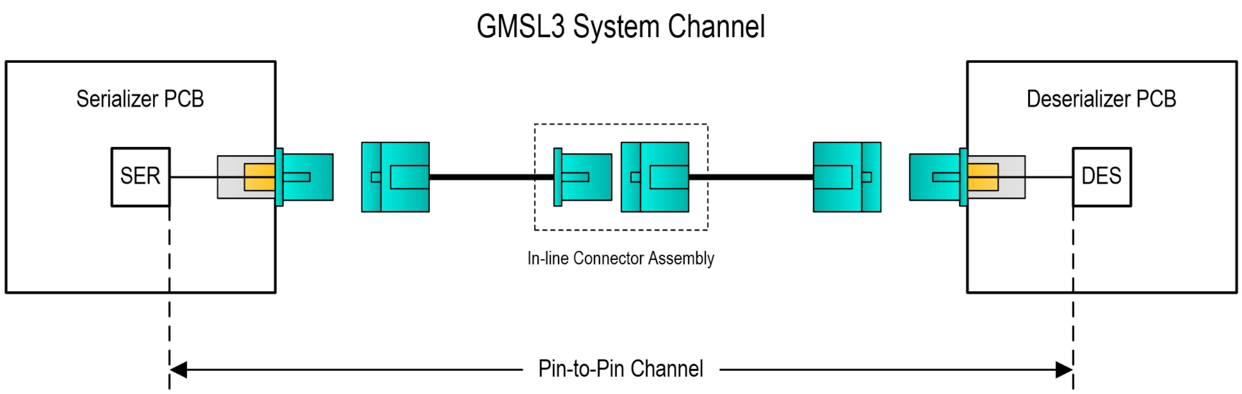


Figure 5 GMSL3 System Channel

GMSL3 System Channel Compliance

A compliant GMSL3 system must meet the overall Pin-to-Pin Channel Specification, including the S-parameter curves, crosstalk specification, and the link margin requirements under worst-case conditions* as defined by the system designer.

A short channel limit allows low-loss links to have increased return loss. Low insertion-loss links have a large FWD channel amplitude allowing the return loss limit to be relaxed.

*Worst-case conditions include longest cable (highest insertion loss), cable aging effects, channel degradation due to temperature, PCB impedance variation, min/max system PoC loads. Worst-case conditions can be simulated; contact cable manufacturer and PCB designer for technical advice.

Note: The PCB and Cable Channels comprising a compliant GMSL3 System Channel may not meet the standards required for GMSL3 Module Compliance. Modules must be independently evaluated for module compliance. See the *GMSL3 Module Channel Specifications* section for additional information.

Filtering S-parameter Data

The S-parameter data must be filtered before comparing it to the GMSL3 Insertion Loss and Return Loss limits. A 100MHz wide filter is applied to the data across the full range. Unfiltered data should be used from the lowest frequency captured up to 50MHz. Beyond 50MHz the filtered data should be used to compare against the limits. Data capture should be set to linear frequency spacing so that filtering of data is simpler.

The filtering is accomplished by running a 100MHz wide moving average of the S-parameter data once converted to linear power amplitude. After the averaging has been accomplished the data is converted back to power in decibels for plotting against the limits.

Below are equations for converting S-parameters to linear power and back to dB power.

$$S_{XY\ linear\ power} = {S_{XY\ real}}^2 + {S_{XY\ imaginary}}^2$$

Equation 1. Conversion of real-imaginary S-parameters to linear power

$$S_{XY\ linear\ power} = 10^{\frac{S_{XY}(dB)}{10}}$$

Equation 2. Conversion of dB power S-parameters to linear power

$$S_{XY}(dB) = 10 \times log_{10}(S_{XY\ linear\ power})$$

Equation 3. Conversion of linear power S-parameters to dB power

Examples of filtering s-parameters are in *Appendix B: Examples of Filtered S-parameters using MATLAB*

GMSL3 Pin-to-Pin Channel Specification

Maximum Insertion Loss Specifications (Pin-to-Pin)

- Defined by filtered S_{21} and S_{12} (or S_{dd21} and S_{dd12} for differential channels)
- Separate short and long channel limits

Table *2*. Maximum Insertion Loss (Pin-to-Pin)

Channel	Maximum Insertion Loss at Nyquist Frequency
Short (low loss)	–10dB @ 3GHz
Long (high loss)	–18dB @ 3GHz

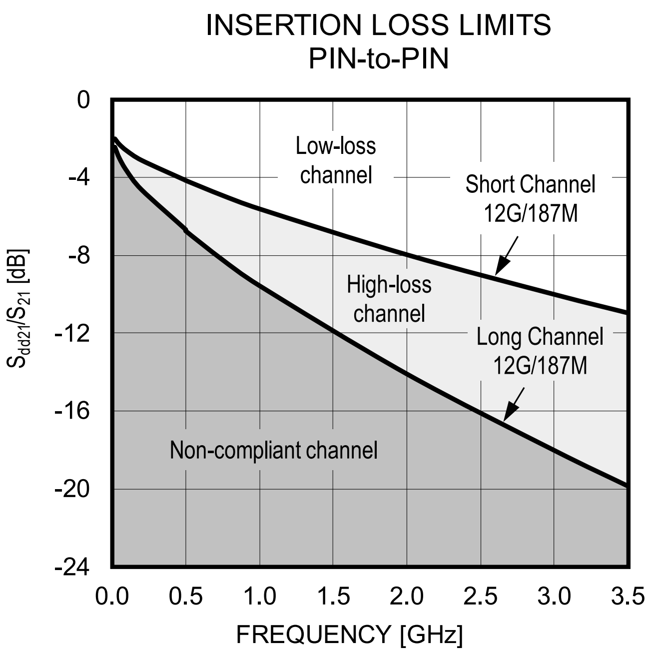


Figure 6 Pin-to-Pin Maximum Insertion Loss

Short channel: links that have loss falling within the "short channel" **insertion loss** limit only need to meet the "short channel" **return loss** limit which is more lenient. The equations provided below can be used to calculate and plot insertion loss profiles of each forward/reverse channel configuration.

Table 3. Pin-to-Pin Insertion Loss Limits

Channel	Measurement Frequency Range [MHz]	Insertion Loss [dB] (f = Frequency [Hz])
Short (low loss)	2–3500	$-\left(1.45 + 0.101\sqrt{(f \times 10^{-6})} + 1.01(f \times 10^{-9})\right)$
Long (high loss)	2–3500	$-\left(1.62 + 0.182\sqrt{(f \times 10^{-6})} + 2.14(f \times 10^{-9})\right)$

Refer to *Appendix B: Examples of Filtered S-parameters using MATLAB*.

Maximum Return Loss Specification (Pin-to-Pin Channel)

- Defined by filtered S_{11} and S_{22} (or S_{dd11} and S_{dd22} for differential channels)
- Separated into short-channel and long-channel limits
- Short channels have a relaxed return loss limit above 800MHz

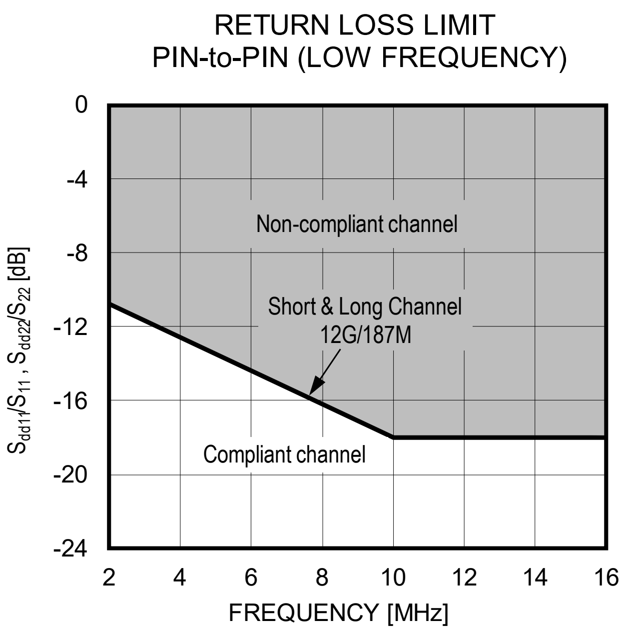


Figure 7 Pin-to-Pin Max Return Loss (Low-Frequency)

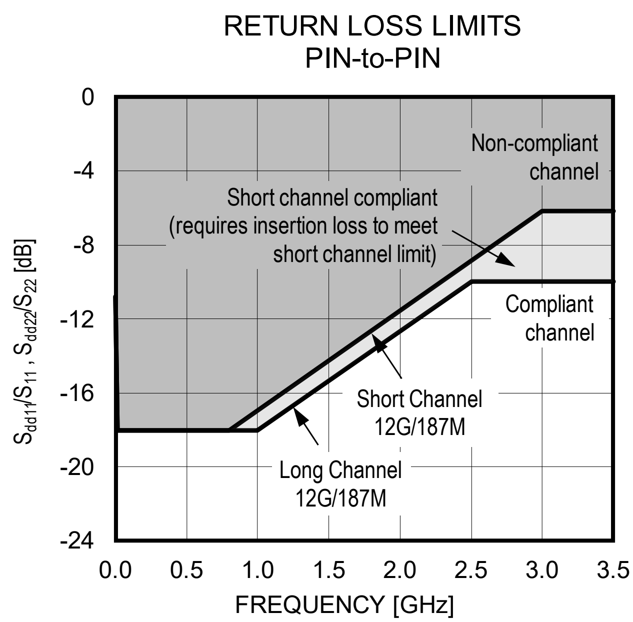


Figure 8 Pin-to-Pin Max Return Loss

The equations provided below can be used to calculate and plot return loss profiles of each forward/reverse channel configuration.

Table *4*. Pin-to-Pin Return Loss Limits

Channel	Measurement Frequency Range [MHz]	Return Loss [dB] (f = Frequency [Hz])
Short **(low loss)**	2–10	$-9-0.9(f \times 10^{-6})$
	10–800	–18
	800–3000	$-16.9+8(f \times 10^{-9}-1)/1.5$
	3000–3500	–6.2
Long **(high loss)**	2–10	$-9-0.9(f \times 10^{-6})$
	10–1000	-18
	1000–2500	$-23.33+5.33(f \times 10^{-9})$
	2500–3500	–10

Refer to Appendix B: Examples of Filtered S-parameters using MATLAB.

GMSL3 Crosstalk Specification

The GMSL3 crosstalk specification places limits on the permissible parasitic coupling from GMSL3, other high-speed links (“aggressors”), and/or noise sources onto a GMSL3 link. Separate specification items for the PCB Module at the end of a link and the cable bundle allow system components to be individually developed and evaluated for crosstalk.

Crosstalk Specification for the PCB Module

Crosstalk between multiple ports on a PCB (e.g., an ECU) can be characterized in different ways depending on the source of the crosstalk and whether the interfering signals are narrowband or broadband in nature.

Crosstalk from GMSL or Other Broadband Signals

The setup shown in *Figure 9* is used to measure crosstalk between the different ports (connectors) on a PCB. The data traffic causing interference is running on Ports 1..N, and crosstalk is measured on Port M of the PCB. The worst-case crosstalk condition occurs with cables with minimum insertion loss. This maximizes the received signal power on Port M. Crosstalk is measured as peak amplitude on Port M using an oscilloscope. Broadband crosstalk limits are presented in *Table 5.* Broadband Crosstalk Limits The GMSL3 device on Port M should be configured in squelch mode.

Table *5*. Broadband Crosstalk Limits

Forward Data Rate [Gbps]	Reverse Data Rate [Mbps]	Measurement Frequency Range [MHz]	Maximum Crosstalk	Conditions
12	187.5	1-4000	<3mV(p-p)	Interferers are any combination of high-speed links

In *Figure 9*, links from Devices 1..N are active. Crosstalk is measured on Port M with Device M in squelch mode.

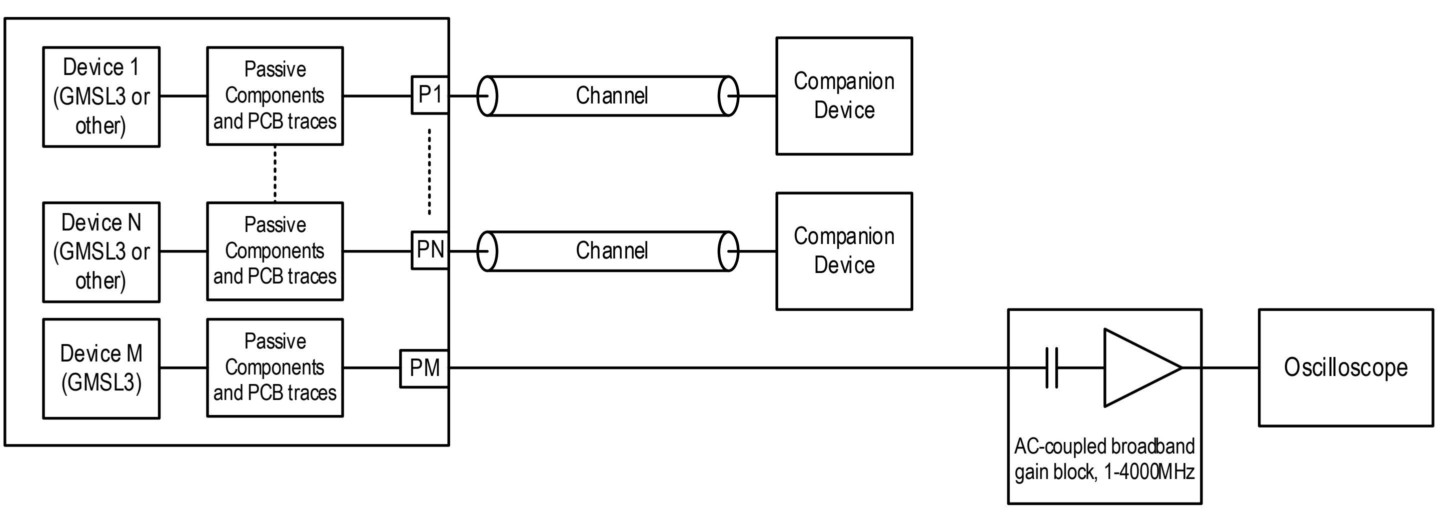


Figure 9 Broadband Crosstalk Characterization Method

Crosstalk from Narrowband Signals

If the interfering signal is a continuous wave or narrowband signal (e.g., a clock or switching frequency from a voltage regulator or a PoC circuit), the crosstalk into the GMSL port is measured in mV as shown in *Figure 10* If the measured signal is a continuous wave, an oscilloscope or a spectrum analyzer can be used to measure the crosstalk voltage on the disturbed port (convert from dBm to mV). If the interfering signal is a complex waveform (e.g., a modulated waveform), an oscilloscope should be used. A low-noise amplifier and a bandpass filter may be required to obtain a clean measurement.

The limits in *Table 6* are frequency-dependent because the GMSL receiver input amplifier adaptively compensates for the frequency-dependent loss of the cable by boosting high-frequency gain. The higher the frequency-dependent attenuation of the cable, the more the high-frequency portion of the received signal will be boosted by the serial link receiver. An unwanted side effect of this high-frequency boost is increased sensitivity to high-frequency crosstalk.

Table *6*. Narrowband Crosstalk Limits

Device	Forward/Reverse Data Rate	Measurement Frequency Range [MHz]	Peak-to-Peak Voltage Limit [mV] (f = Frequency [MHz])
Serializer	12Gbps/187.5Mbps	0.1–2	$10 - 20 \times log_{10}\left(\frac{f}{2}\right)$
		2–4500	10
		4500–10000	$10 + 80 \times log_{10}\left(\frac{f}{4500}\right)$
Deserializer	12Gbps/187.5Mbps	0.1–2	$10 - 20 \times log_{10}\left(\frac{f}{2}\right)$
		2–50	10
		50–4500	$10 - 9 \times \frac{log_{10}\left(\frac{f}{50}\right)}{log_{10}\left(\frac{4500}{50}\right)}$
		4500–10000	$1 + 10 \times log_{10}\left(\frac{f}{4500}\right)$

***Note:** These limits include ripple injected by the PoC circuit.

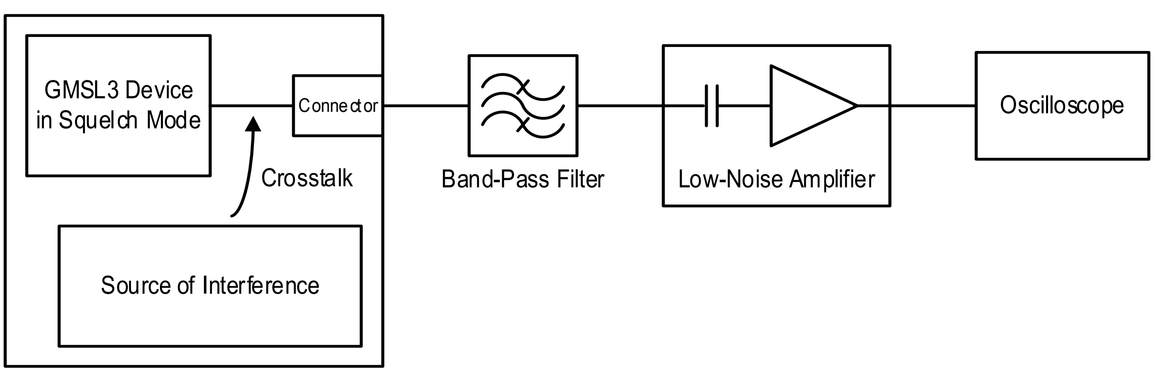
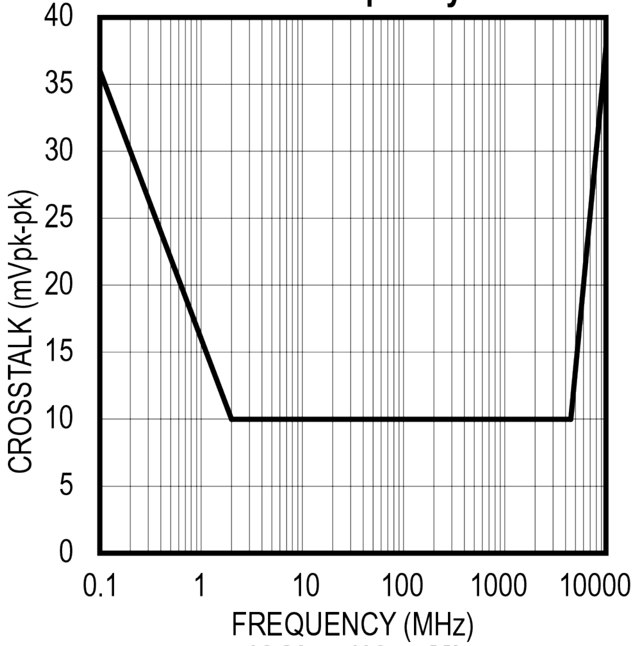


Figure 10 Measurement Setup for Narrowband Crosstalk

12Gbps/187.5Mbps
SERIALIZER INPUT CROSSTALK LIMIT
vs. Frequency



12Gbps/187.5Mbps
DESERIALIZER INPUT CROSSTALK LIMIT
vs. Frequency

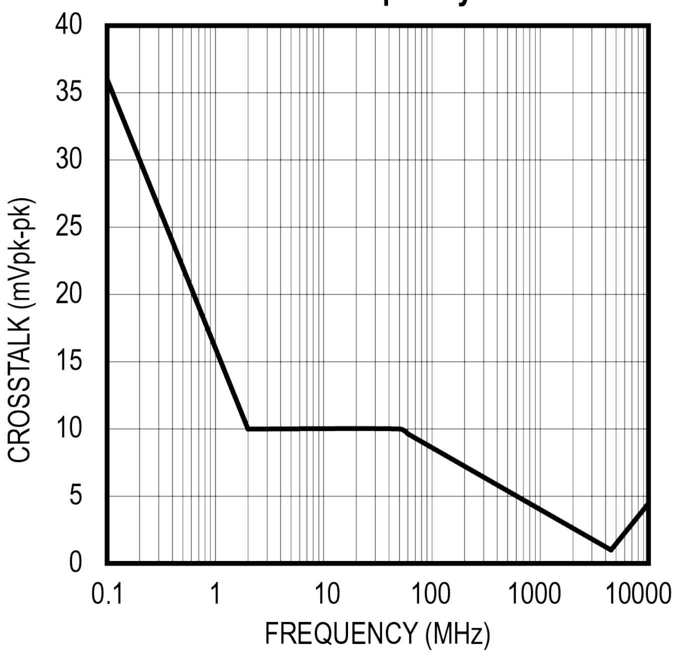


Figure 11 Narrowband Crosstalk Limits

Crosstalk Specification for the Cable Bundle

Crosstalk occurs when multiple cables are routed together in a harness. ADI specifies both near-end crosstalk (NEXT) and far-end crosstalk (FEXT) for the case that multiple GMSL3 links are routed in the same harness.

Table 7. Maximum System Channel Crosstalk Limits for Cable Bundles

Data Rate	Noise source → GMSL Device	Frequency Range [MHz]	Specification Limit
12Gbps forward, 187.5Mbps reverse	Serializer → Serializer	1–4000	NEXT < -35dB PS_ACR_F < -45dB
12Gbps forward, 187.5Mbps reverse	Deserializer → Serializer Serializer → Deserializer Deserializer → Deserializer	1–4000	NEXT < -45dB PS_ACR_F < -45dB

***Note**: The metric for FEXT is Power-Sum Adjusted Crosstalk Ratio – Far End (PS_ACR_F). See

Far-End Cable Bundle Crosstalk for additional information.

Near-End Cable Bundle Crosstalk

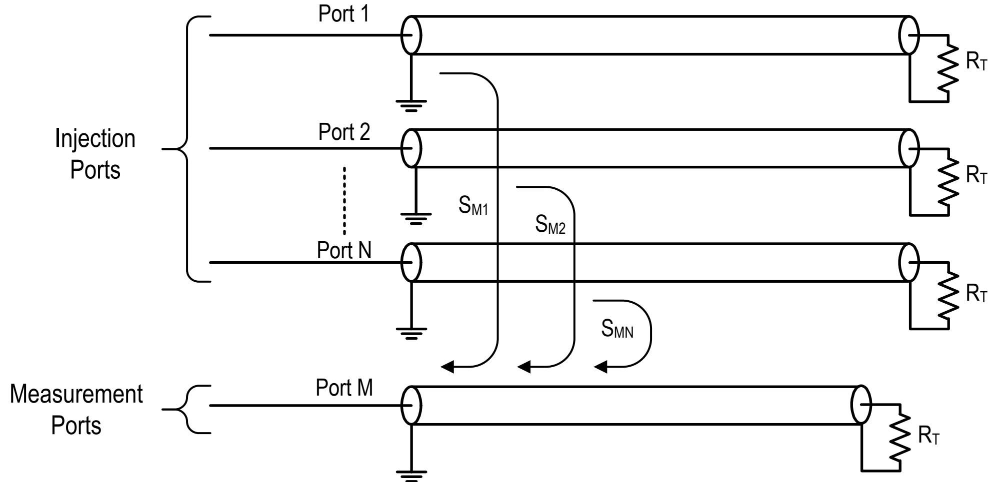


Figure 12 Near-End Crosstalk (NEXT)

The near-end crosstalk is usually dominant. NEXT is based on the injection and measurement ports shown in *Figure 12* and is specified as the power sum of the coupling from Ports 1..N into Port M (*Equation 4*).

$$NEXT = 10 \times \log\left(\sum_{i=1}^{N} S_{Mi}\right) [\text{dB}]$$

Equation 4. Near End Crosstalk Equation

The NEXT measurement is performed as a sequence of multi-port S-parameter measurements using a vector network analyzer (VNA). The transfer functions from injection port to measurement port are added in the power domain.

***Note:** During measurement, all unused ports must be terminated in 50Ω for coax or 100Ω for STP.

As an example, assume two interferers with transfer functions S_{M1} = -60dB and S_{M2} = -66dB. The power sum of S_{M1} and S_{M2} is found by converting both parameters from dB to power and converting the sum of power back to dB. NEXT is calculated as:

$$NEXT = 10 \times \log\left(10^{\left(\frac{-60\text{dB}}{10}\right)} + 10^{\left(\frac{-66\text{dB}}{10}\right)}\right) = -59\text{dB}$$

The resulting NEXT = -59dB, which satisfies the requirement for NEXT in *Table 7.* Maximum System Channel Crosstalk Limits for Cable Bundles

Far-End Cable Bundle Crosstalk

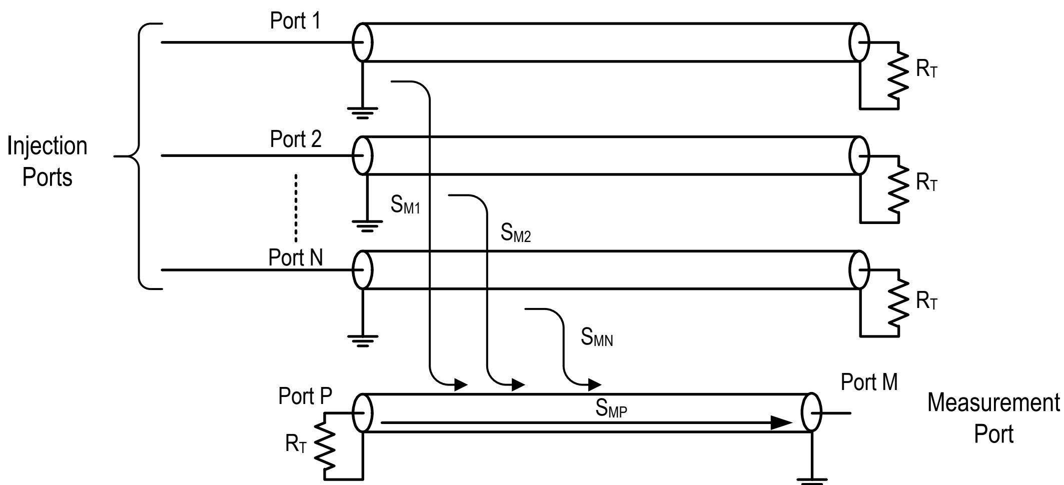


Figure 13 Far-End Crosstalk (FEXT)

Far-end crosstalk (FEXT) is a measure of the crosstalk received at the far end of the cable with the disturbance applied at the near-end of the cable (*Figure 13* Far-End Crosstalk (FEXT)). The metric for FEXT is Power-Sum Adjusted Crosstalk Ratio – Far End (PS_ACR_F). The received amplitude on the measurement Port M of each interferer is attenuated by the transfer function S_{Mi}. Similarly, the wanted signal received at Port M will be attenuated by the insertion loss S_{MP} of the disturbed cable. Assuming that the transmitted amplitude of all the interfering signals is the same, the far-end crosstalk measure, PS_ACR_F, represents the ratio of the interferers to the received wanted signal, providing a measure of interference-to-signal ratio in the disturbed cable. In the dB domain, this becomes a simple subtraction (*Equation 5.* Power-Sum Adjusted Crosstalk Ratio – Far-End Crosstalk Equation).

$$\text{PS\_ACR\_F} = 10 \times \log\left(\sum_{i=1}^{N} S_{Mi}\right) [\text{dB}] - S_{MP}[\text{dB}]$$

Equation 5. Power-Sum Adjusted Crosstalk Ratio – Far-End Crosstalk Equation

The PS_ACR_F measurement is performed as a sequence of two-port measurements using a VNA, and the results are added in the power domain as shown in *Equation 5.* Power-Sum Adjusted Crosstalk Ratio – Far-End Crosstalk Equation

***Note:** During measurement, all unused ports must be terminated in 50Ω for coax or 100Ω for STP.

As an example, assume two interferers with transfer functions S_{M1} = -70dB and S_{M2} = -70dB. S_{MP} = -11dB. The power sum (calculated in the same manner as NEXT above) of S_{M1} and S_{M2} is -67dB. The resulting far-end crosstalk is PS_ACR_F = -67dB – (-11dB) = -56dB, which meets the requirement for FEXT in *Table 7.* Maximum System Channel Crosstalk Limits for Cable Bundles.

GMSL3 Link Margin Specification

Link margin is specifically used to quantitatively test the signal integrity of the GMSL link. The link margin test starts at the default transmit voltage amplitude for both the forward and reverse channels.

Forward Channel:

The test decreases the forward transmit amplitude in 10mV steps and monitors the Forward Error Correction block input Bit Error Ratio (Link error ratio before FEC). The test stops when the FEC block input BER is > 1e-7 or there are un-corrected FEC blocks. The link margin is reported as the difference between the default transmitter amplitude and when the link margin test stops.

Reverse Channel:

The test decreases the transmit amplitude in 10mV steps and performs an error check before proceeding to the next test amplitude. The test ends at any point an error is detected. The link margin is reported as the difference between the default transmitter amplitude and the amplitude at which the error was detected.

Table 8. Minimum Required Link Marginbelow contains the required minimum link margin for both the forward and reverse channels.

Table 8. Minimum Required Link Margin

Cable	Data Rate (Forward/Reverse)	Minimum Required Forward Channel Link Margin [mV]	Minimum Required Reverse Link Margin [mV]
COAX/STP	12Gbps/187.5Mbps	100	50

***Note:** A link margin tool is available through the ADI GMSL GUI. Alternatively, software support is available for customers who wish to develop their own implementation of these tools in their software.

GMSL3 Module Channel Specifications

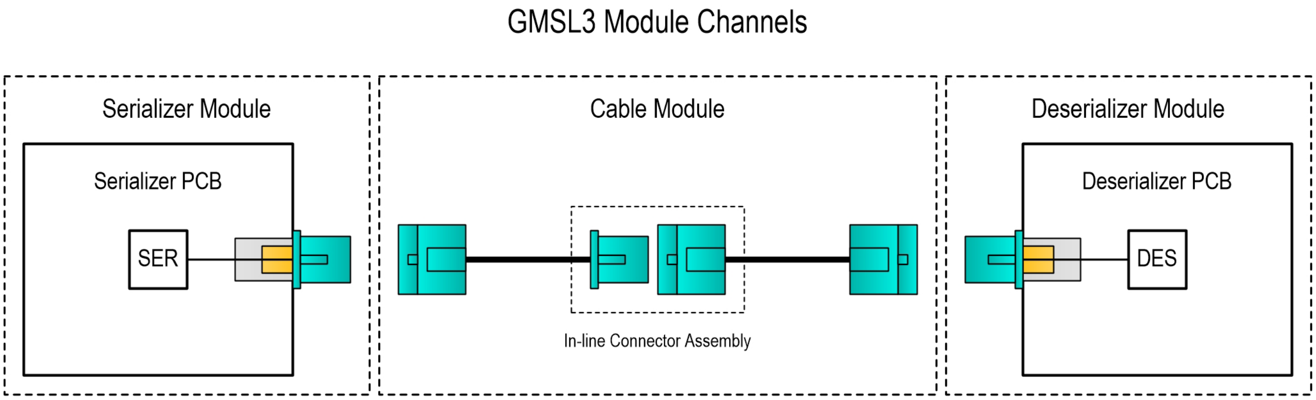


Figure 14 GMSL3 Module Channels

GMSL3 Module Compliance

Meeting module compliance requirements assists in meeting GMSL3 System Channel Compliance when implemented with other compliant modules and cable(s).

For GMSL3 Module Compliance:

- Serializer/Deserializer Module Channels must meet the PCB insertion loss and return loss requirements under worst-case conditions* as defined by the system designer.
- Cable Module Channels must meet the cable insertion loss and return loss requirements under worst-case conditions* as defined by the system designer.

* Worst-case conditions include longest cable (highest insertion loss), cable aging effects, channel degradation due to temperature, PCB impedance variation, min/max system PoC loads. Worst-case conditions can be simulated; contact cable manufacturer and PCB designer for technical advice.

***Note:** A module meeting the GMSL3 Module Compliance Specification is interoperable with other compliant modules.

***Note:** The PCB and Cable Channels comprising a compliant GMSL3 System Channel may not meet the standards required for GMSL3 Module Compliance. Modules must be independently evaluated for GMSL3 Module Compliance.

Maximum Insertion Loss Specification (PCB & Cable Modules)

- Defined by filtered S_{21} and S_{12} (or S_{dd21} and S_{dd12} for differential channels)
- Separate short and long channel limits for cable modules

Table 9. Maximum Insertion Loss at Nyquist (PCB & Cable Modules)

GMSL – Speed	Minimum Frequency	$f_{½Linkrate}$
Cable	Short (low loss)	–7.6dB @ 3GHz
	Long (high loss)	–15.6dB @ 3GHz
PCB	Short & Long	–1.2dB @ 3GHz

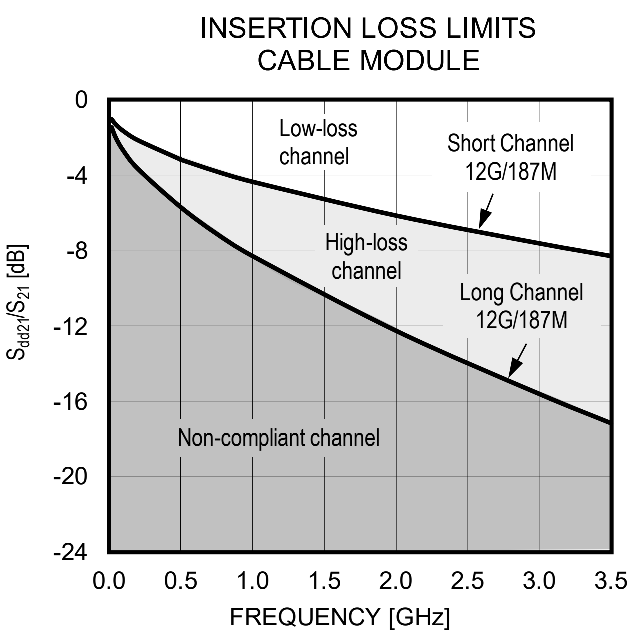


Figure 15 Maximum Cable Insertion Loss

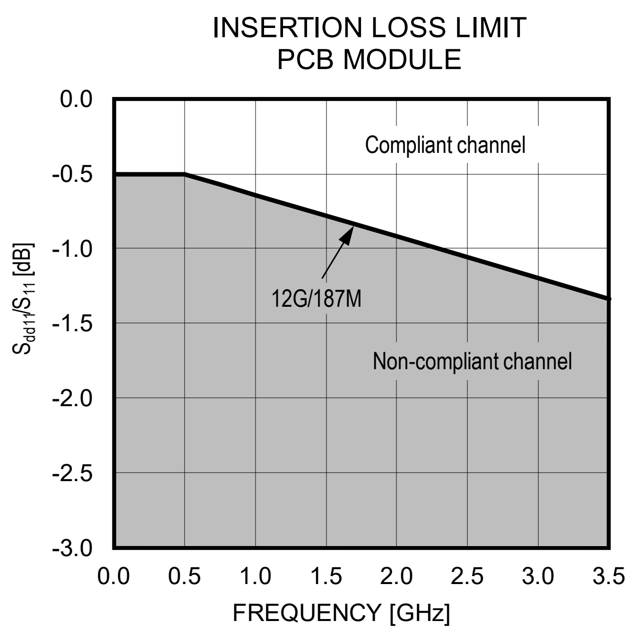


Figure 16 Maximum PCB Insertion Loss

The equations provided below can be used to calculate and plot insertion loss profiles for both PCB and Cable system segments of each forward/reverse channel configuration.

Table 10. Insertion Loss Limits for PCB and Cable Modules

Module	Channel	Measurement Frequency Range [MHz]	Insertion Loss [dB] (f = Frequency [Hz])
PCB	Low Loss and High Loss	2–500	-0.5
		500–3500	$-\left(0.36 + 0.28(f \times 10^{-9})\right)$
Cable	Short (Low Loss)	2–3500	$-\left(0.43 + 0.12\sqrt{f \times 10^{-6}} + 0.2(f \times 10^{-9})\right)$
	Long (High Loss)	2–3500	$-\left(0.6 + 0.2\sqrt{f \times 10^{-6}} + 1.35(f \times 10^{-9})\right)$

Maximum Return Loss Specification (PCB and Cable Modules)

- Defined by filtered S_{11} and S_{22} (or S_{dd11} and S_{dd22} for differential channels)
- Separate short and long channels limits
- Short channels have a relaxed return loss limit above 800MHz

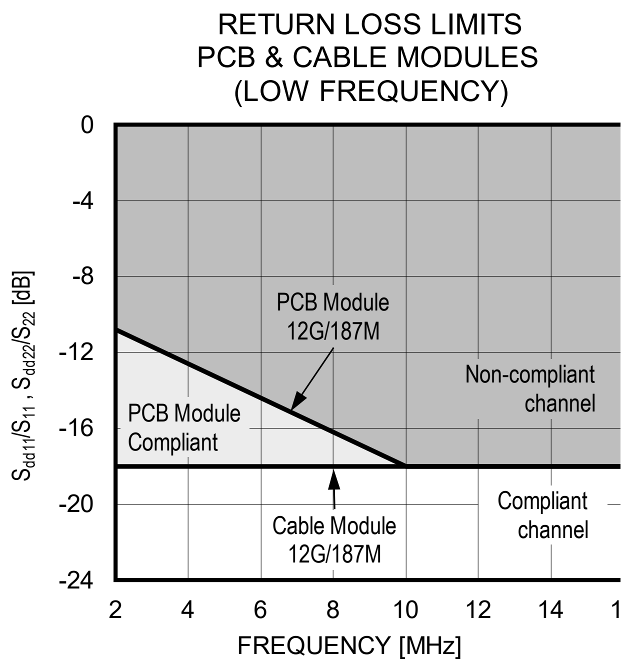


Figure 17 Maximum Return Loss (PCB & Cable, low freq.)

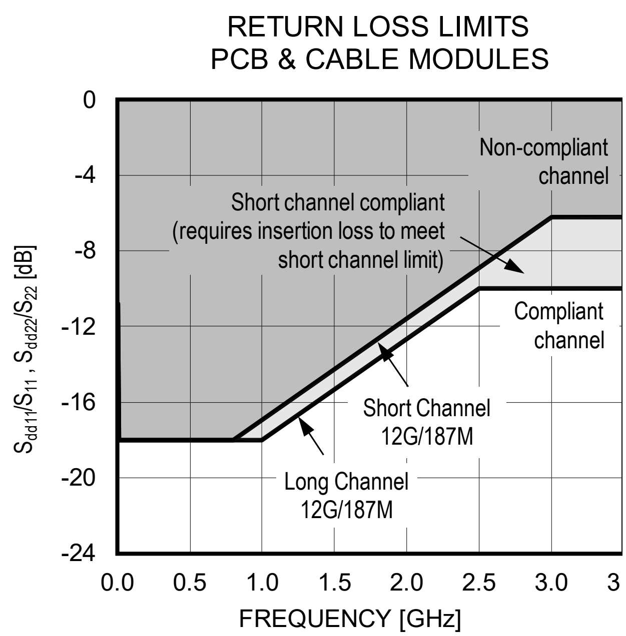


Figure 18 Maximum Return Loss (PCB & Cable)

*Note:** Return loss is not additive. Thus, there is not an “allowable” dB value of return loss for each section of the GMSL3 link (i.e., PCBs and Cable); the full link (i.e., pin-to-pin) must meet the pin-to-pin specified return loss allocation. For links that achieve the short-channel insertion loss specification, the relaxed return loss specification (short channel) applies.

*Between the frequency range of 2-10MHz, PCB and Cable channels have a different return loss specification to allow for power-over-coax (PoC) networks on the PCBs. Do not use filtered data below 50MHz. Reference equations below for more information.

The equations provided below can be used to calculate and plot return loss profiles for both PCB and Cable system segments of each forward/reverse channel configuration.

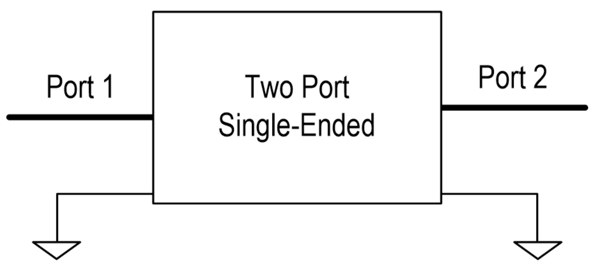
Table 11. Return Loss Limits for PCB and Cable Module

Module	Channel	Measurement Frequency Range [MHz]	Return Loss [dB] (f = Frequency [Hz])
PCB	Short (low loss)	2–10	$-9-0.9(f \times 10^{-6})$
		10–800	−18
		800–3000	$-16.9+8(f \times 10^{-9}-1)/1.5$
		3000–3500	–6.2
	Long (high loss)	2–10	$-9-0.9(f \times 10^{-6})$
		10–1000	-18
		1000–2500	$-23.33+5.33(f \times 10^{-9})$
		2500–3500	−10
Cable	Short and Long	2–1000	–18
		1000–2500	$-23.33+5.33(f \times 10^{-9})$
		2500–3500	–10

Appendix A: Single-Ended and Differential S-parameters

S-parameters (scattering parameters or scattering matrix) are used to characterize the ADI GMSL3 channel specification requirement. S-parameters are used to quantify how RF energy propagates through a multi-port network. For COAX mode, which uses single-ended signaling, the channel is characterized as a two-port, single-ended network (*Figure 19*). These networks have one input port and one output port. Signals on the input and output ports are referenced to ground. Measurements should be made using a vector network analyzer.

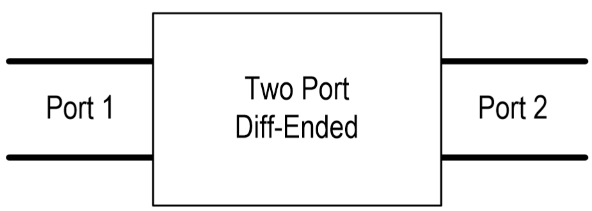
***Note:** The GMSL3 Channel Specification applies to the componentry and cabling from the pin(s) of the transmitter to the pin(s) of the receiver. See *GMSL3 Channel Definition* above for additional information.



$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

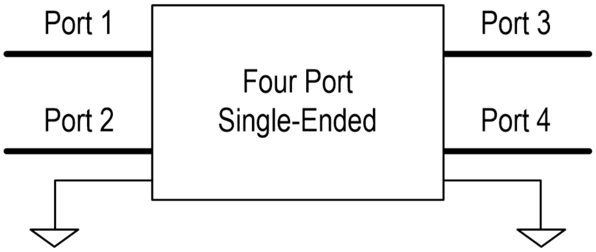
Figure 19 Two-Port, Single-Ended Network

STP mode requires the use of differential S-parameters (S_{dd}) to evaluate the network. Differential S-parameters can be taken as single-ended, four-port measurements and converted to differential parameters using matrix math. For measurement purposes, the two-port differential network (*Figure 20*) can be considered a four-port, single-ended network (*Figure 21*).



$$[S_{dd}] = \begin{bmatrix} S_{dd11} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix}$$

Figure 20 Two-Port, Differential Network



$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

Figure 21 Four-Port, Single-Ended Network

Note: Mixed-mode S-parameters can be extracted from S4P files (or four-port, single-ended S-matrix) with the standard formula or professional tools. Some network analyzers will output differential S-parameters directly when set up to do so.

Appendix B: Examples of Filtered S-parameters using MATLAB

The return loss data must be filtered before comparing it to the GMSL3 return loss limit. A 100MHz filter is applied to the S-parameters across the full range. Unfiltered data should be used from the lowest frequency captured up to 50MHz. Beyond 50MHz the filtered data should be used to compare to the limit. Data capture should be set to linear frequency so that filtering of data is simpler.

Single Ended S-parameters

The following is an example of MATLAB code used to filter S-parameter data and plots showing difference between unfiltered and filtered data. The S-parameter data is in real-imaginary format and is of a s2p file. The function includes the GMSL3 pin-to-pin limits.

```
function [freq, Sxy_dB, Sxy_filt_dB, RL_lim_short, RL_lim_long, IL_lim_short, IL_lim_long] = filterSxy(x)
    Sxy = sparameters(x);
    freq = (Sxy.Frequencies);
    f_window = 100*10^6;
    points = numel(freq);
    f_step_size = (max(Sxy.Frequencies)-min(Sxy.Frequencies))/(points - 1);
    w_size = round(f_window/f_step_size);
    Sxy_array = [rfparam(Sxy,1,1) rfparam(Sxy,1,2) rfparam(Sxy,2,1) rfparam(Sxy,2,2)];
    Sxy_V_mag = abs(Sxy_array);
    Sxy_Power_mag = Sxy_V_mag.^2;
    Sxy_dB = 10*log10(Sxy_Power_mag);
    Sxy_filt = smoothdata(Sxy_Power_mag,"movmean",w_size);
    Sxy_filt_dB = 10*log10(Sxy_filt);
    RL_lim_short = [0.002 -10.8; 0.01 -18; 0.8 -18; 3 -6.2; 3.5 -6.2];
    RL_lim_long = [0.002 -10.8; .01 -18; 1 -18; 2.5 -10; 3.5 -10];
    IL_range_GHz = transpose(0.01 : 0.01 : 3.5);
    IL_lim_short = [IL_range_GHz -(1.45+0.101*sqrt(IL_range_GHz*1000)+1.01*IL_range_GHz)];
    IL_lim_long = [IL_range_GHz -(1.62+0.182*sqrt(IL_range_GHz*1000)+2.14*IL_range_GHz)];
end
```

The function can be saved in a MATLAB workspace and a set of S-parameters can be filtered and plotted by typing the following commands:

```
[freq, Sxy_dB, Sxy_filt_dB, RL_lim_short, RL_lim_long, IL_lim_short, IL_lim_long] =
filterSxy ('filename.s2p');
plot(freq/10^9, Sxy_filt_dB);
xlim([0 4]);
hold on;
plot(RL_lim_short(:,1), RL_lim_short(:,2));
plot(RL_lim_long(:,1), RL_lim_long(:,2));
plot(IL_lim_short(:,1), IL_lim_short(:,2));
plot(IL_lim_long(:,1), IL_lim_long(:,2));
ylabel('Sxy [dB]');
xlabel('Frequency [GHz]');
legend('S11','S12','S21','S22','RL Limit Short', 'RL Limit Long', 'IL Limit Short', 'IL
Limit Long');
```

To plot the unfiltered data use the command: `plot(freq/10^9, Sxy_dB);`

Differential S-parameters

The following example shows the MATLAB code to take single-ended, 4-port measurements of a differential channel and convert it to differential S-parameters (S_{dd11}, S_{dd12}, S_{dd21}, S_{dd22}) and filter the results for comparison to the pin-to-pin GMSL3 channel specifications.

```
function [freq, Sxy_dB, Sxy_filt_dB, RL_lim_short, RL_lim_long, IL_lim_short, IL_lim_long] = filterSxydiff(x)
    Sxy = sparameters(x);
    freq = (Sxy.Frequencies);
    f_window = 100*10^6;
    points = numel(freq);
    f_step_size = (max(Sxy.Frequencies)-min(Sxy.Frequencies))/(points - 1);
    w_size = round(f_window/f_step_size);
    S1 = Sxy.Parameters;
    S2 = s2sdd(S1);
    S3 = [S2(1,1,:) S2(1,2,:) S2(2,1,:) S2(2,2,:)];
    S4 = squeeze(S3);
    S5 = transpose(S4);
    Sxy_Vmag = abs(S5);
    Sxy_Power_mag = Sxy_Vmag.^2;
    Sxy_dB = 10*log10(Sxy_Power_mag);
    Sxy_filt = smoothdata(Sxy_Power_mag,"movmean",w_size);
    Sxy_filt_dB = 10*log10(Sxy_filt);
    RL_lim_short = [0.002 -10.8; 0.01 -18; 0.8 -18; 3 -6.2; 3.5 -6.2];
    RL_lim_long = [0.002 -10.8; .01 -18; 1 -18; 2.5 -10; 3.5 -10];
    IL_range_GHz = transpose(0.01 : 0.01 : 3.5);
    IL_lim_short = [IL_range_GHz -(1.45+0.101*sqrt(IL_range_GHz*1000)+1.01*IL_range_GHz)];
    IL_lim_long = [IL_range_GHz -(1.62+0.182*sqrt(IL_range_GHz*1000)+2.14*IL_range_GHz)];
end
```

The function can be saved in a MATLAB workspace and a set of S-parameters can be filtered and plotted by typing the following commands:

```
[freq, Sxy_dB, Sxy_filt_dB, RL_lim_short, RL_lim_long, IL_lim_short, IL_lim_long] =
filterSxydiff ('filename.s4p');
plot(freq/10^9, Sxy_filt_dB);
xlim([0 4]);
ylim([-35 0]);
hold on;
plot(RL_lim_short(:,1), RL_lim_short(:,2));
plot(RL_lim_long(:,1), RL_lim_long(:,2));
plot(IL_lim_short(:,1), IL_lim_short(:,2));
plot(IL_lim_long(:,1), IL_lim_long(:,2));
ylabel('Sxy [dB]');
xlabel('Frequency [GHz]');
legend('Sdd11','Sdd12','Sdd21','Sdd22','RL Limit Short', 'RL Limit Long', 'IL Limit
Short', 'IL Limit Long');
```

To plot the unfiltered data use the command: `plot(freq/10^9, Sxy_dB);`

Example of a Passing Channel

The example below is of three series 0.5m coaxial cables and includes the replica traces of the IC to cable connectors on each end of the link such that it represents the pin-to-pin S-parameters of the GMSL3 channel.

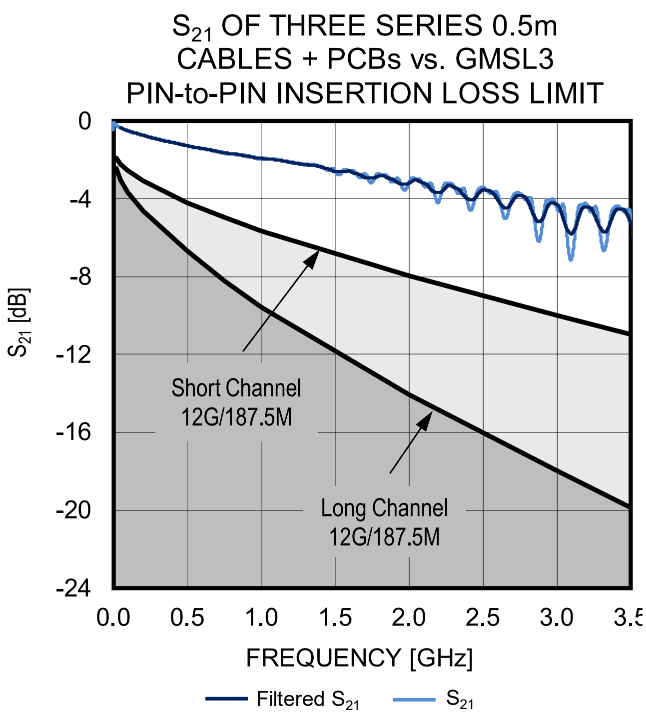


Figure 22 Pin-to-Pin Insertion Loss vs. Limit

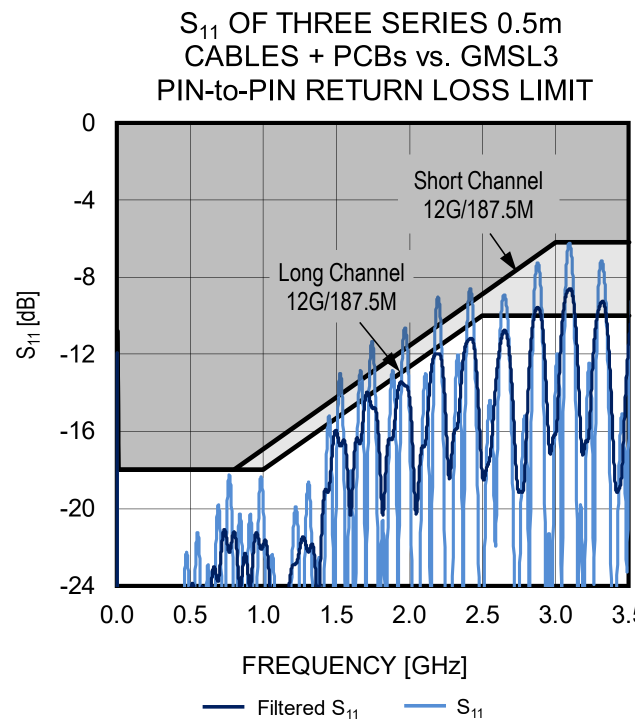


Figure 23 Pin-to-Pin Return Loss vs. Limit

The combination of the PCBs plus three series 0.5m cables creates significant reflected energy, but the insertion loss is low and falls within the “short channel” category, hence the filtered S_{11} passes the short channel return loss limit. Note that analysis must be completed for S_{12} and S_{22} as well.

RESULTS: Passes GMSL3 insertion loss and return loss limits.

Example of a Failing Channel

The example below is of a 5m STP cable and includes the replica traces of the IC to cable connectors on each end of the link such that it represents the pin-to-pin S-parameters of the GMSL3 channel.

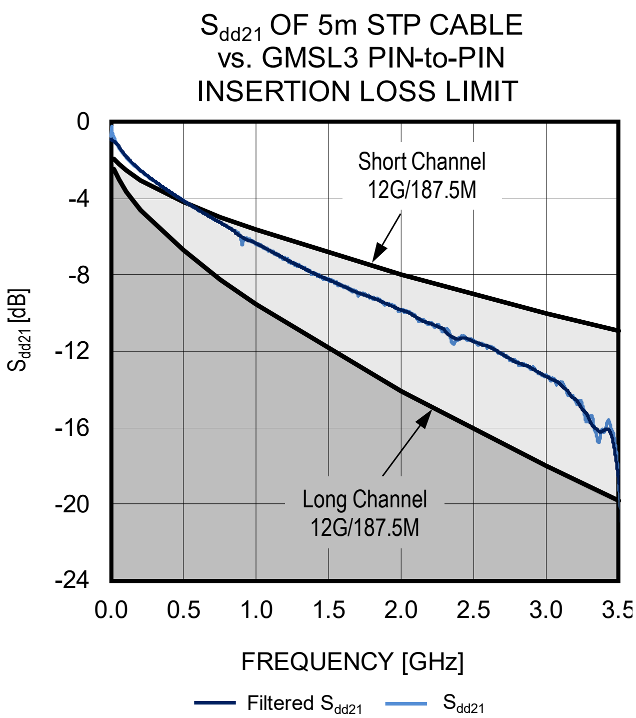


Figure 24 Pin-to-Pin Insertion Loss vs. Limit

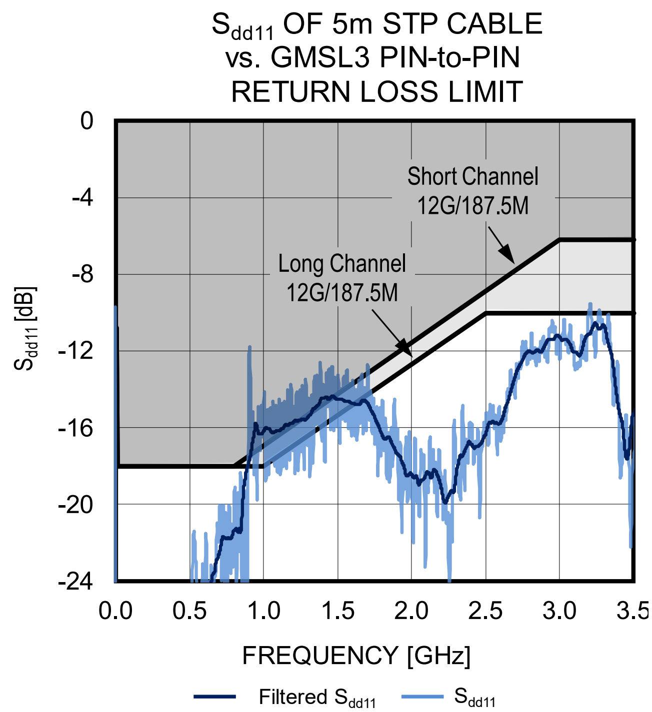


Figure 25 Pin-to-Pin Return Loss vs. Limit

In this example, the differential data from MATLAB was plotted in Excel. The poor layout of the PCBs creates significant reflected energy. The filtered insertion loss falls within the long channel limit and the return loss is compared to the long channel return loss limit. The filtered S_{11} fails the long channel return loss limit.

RESULTS: Fails GMSL3 return loss limit.

Example of a Channel with Power-Over-Coax (PoC)

The following example is for a coaxial link that includes three series cables (10m + 3m + 0.5m) along with a PoC network on the PCBs operating with 600mA current.

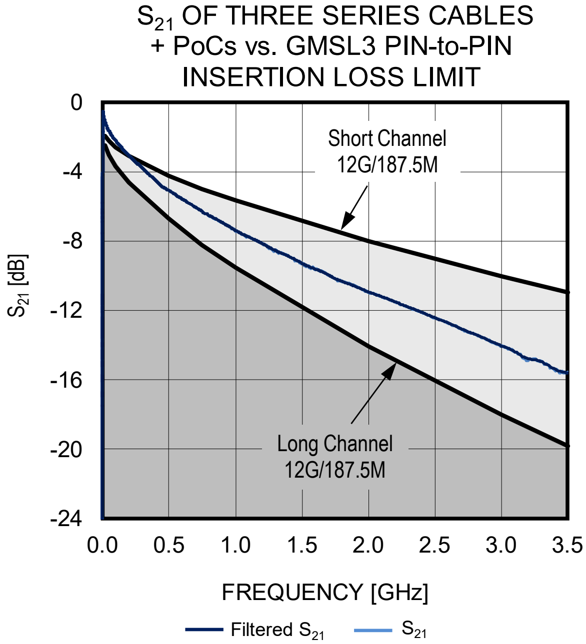


Figure 26 Pin-to-Pin Insertion Loss vs. Limit

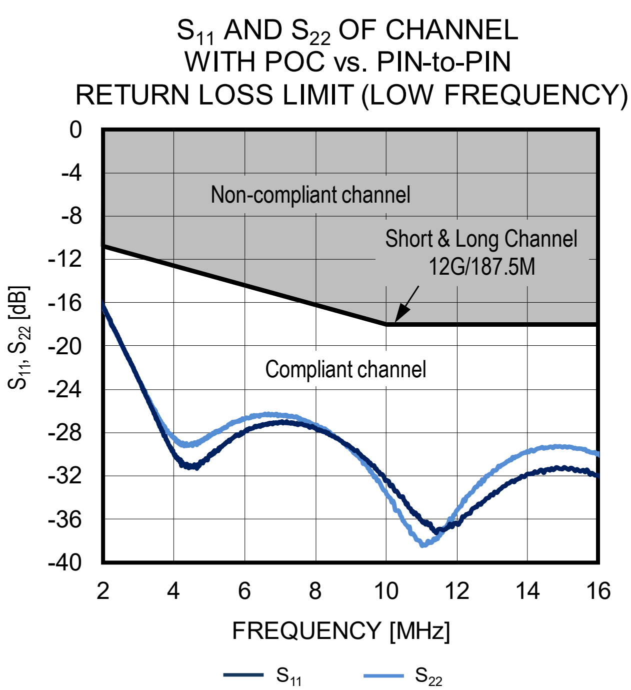


Figure 27 Pin-to-Pin Return Loss vs. Limit (low frequency)

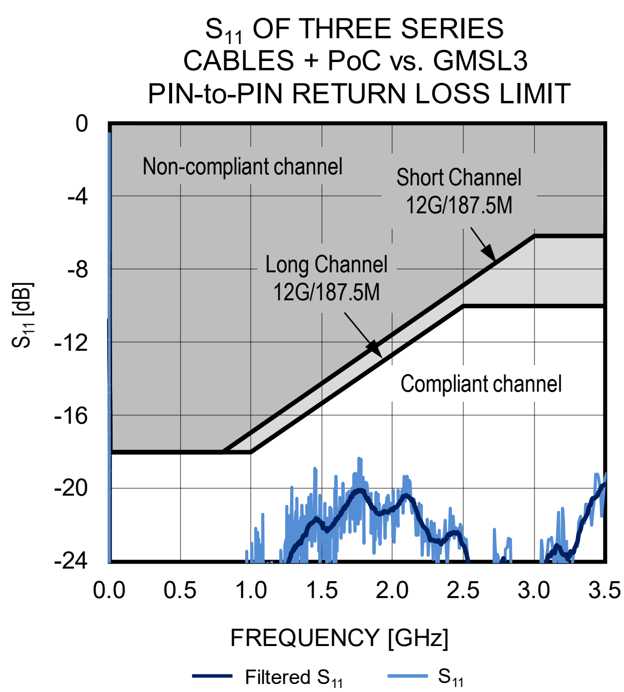


Figure 28 Pin-to-Pin Return Loss vs. Limit

RESULTS: Passes GMSL3 insertion loss and return loss limits.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION/CHANGE(S)	Comment(s)
1	7/20	Initial release	
2	12/20	• Combined Display and Camera Specifications • Updated Return Loss Specification	
3	2/21	• Updated Insertion Loss Specification (P2P, PCB, Cable Allocations) • Updated Return Loss Specification (P2P, PCB, Cable Allocations) • Re-formatted to match GMSL2 channel spec • Added expected Bit Error Rate (BER) of a compliant GMSL3 channel • Relaxed return loss specification between 2-10MHz for Pin-to-Pin and PCB channels • Removed comment about 15m LD302 cable • Added Crosstalk spec limits • Changed expected Bit Error Ratio (BER) of a compliant GMSL3 link to show as the ratio for an FEC enabled link • Relaxed Crosstalk spec limits according to new data • Enlarged spec to include 100kHz – 1 MHz • Added a short (low loss) specification to ease the return loss limit for short channels • Simplified and moved equations into tables • Removed unnecessary tables • Added appendix B	
4	9/24	• Moved the content to the new template • Updated the figures • Updated note to not use filtered data below 50MHz, instead of 10MHz.	