What you need to know about high-speed cables for FPD-Link III SerDes

By T. K. Chin
Systems Manager, Ethernet and FPD-Link Product Line

Introduction

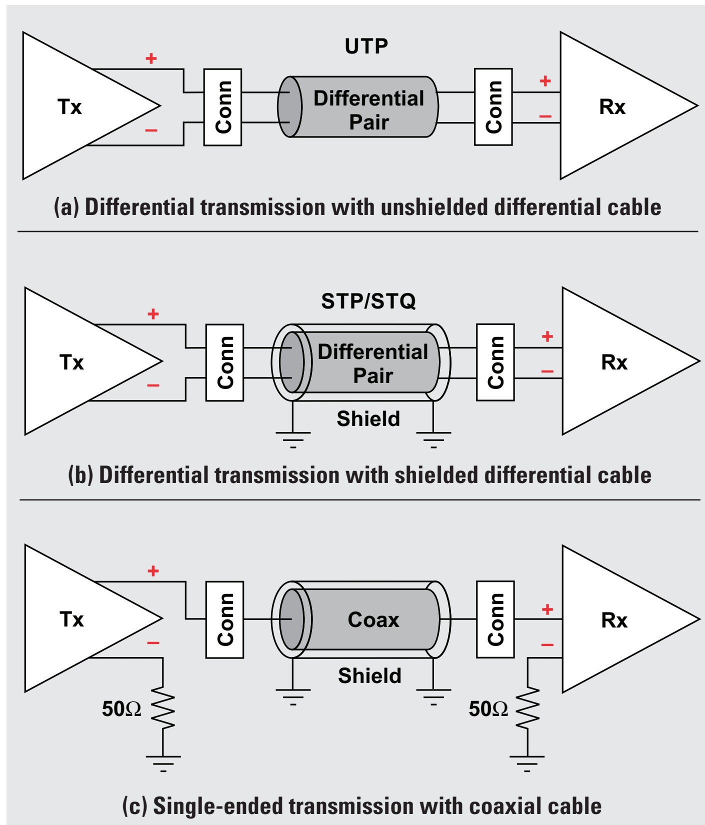
Modern-day automobiles are packed with electronics, infotainment and driver-assistance subsystems. Ethernet uses *unshielded twisted-pair* (UTP) cables, while *shielded twisted-pair* (STP) or coaxial cables are used for *flat-panel display* (FPD)-Link III *serializers/deserializers* (SerDes).

Understanding the transmission medium is essential to designing a robust communication system for any interface. In this article, I'll discuss the design parameters of high-speed cables and how they affect system performance. If you have a good understanding of the parameters, you'll be better prepared to select cost-effective and high-performance cables for robust systems.

Signaling topologies

Cable selection depends on interface speed and signal topologies. Many communication interfaces use one of the two signaling topologies: single-end signaling using a coaxial cable or differential signaling using a differential cable. Figure 1 shows both topologies.

Figure 1. Single-end and differential signaling topologies



Transmission speeds

UTP cables are popular for low-speed transmissions that use protocols such as *controller area network* (CAN) and *Ethernet*. For transmissions with higher speeds and short distance use, such as *high-definition multimedia interface* (HDMI), DisplayPort and USB protocols, STP cables offer better control over electromagnetic interference. Very-high-speed data transmissions employing the *serial attached small computer system interface* (SAS) protocol or *peripheral component interconnect express* (PCIe) standard use higher-performance shielded twin-axial cables. Finally, high-speed and long-distance transmissions over *serial digital video interface* (SDI) use coaxial cables.

You must choose the cable and its associated connector type such that their electrical parameters support the chosen communication technology. Table 1 lists some example cables and connectors.

Table 1. Examples of cables and connectors

Technology	Cable	Connector	Descriptions
Ethernet	Category 5 (CAT5) UTP	RJ-45	Four pairs, 100 Ω, 100Base-T, 1000Base-T
HDMI	STP	HDMI Type A-C	Four pairs, 100 Ω, up to 6 Gbps per pair
SDI	Coax	Bayonet Neill-Concelman (BNC)	75 Ω, up to 12 Gbps, long distance transmission
PCIe	Twin axial	PCIe connector	Multipairs, 100 Ω
FPD-Link III	STP, shielded twisted quad (STQ)	High-speed data (HSD), HSAutoLink	One or two pairs, 100 Ω, 4 Gbps and beyond
FPD-Link III	Coax	Fachkreis Automobil (FAKRA), mini-FAKRA	50 Ω, 4 Gbps and beyond

FPD-Link III signaling topologies

FPD-Link III SerDes supports both single-end and differential signaling topologies. The FPD-Link III serializer sends high-speed video data and control data in a forward direction to the deserializer and the deserializer sends lower-speed back-channel control data to the serializer. FPD-Link III is a full-duplex, bidirectional-communication link sharing the same transmission medium.

Figure 2 shows an FPD-Link III subsystem using a differential pair that is comprised of *high-speed data* (HSD) connectors and an automotive-grade STQ cable. Figure 3 illustrates a FPD-Link III driver-assistance subsystem using FAKRA coaxial connectors and an automotive-grade coaxial cable. *Power-over-coax* (PoC) is a scheme to provide power to a remote camera module on the serializer side.

Cable and connector impedance

The characteristic impedance of a cable and its connectors should match the impedance of the transmitter and receiver. A differential cable is usually constructed with a UTP, STP, STQ or twin-axial configuration and achieves 100-Ω differential impedance. A coaxial cable is designed with 50-Ω or 75-Ω characteristic impedance.

When an STP cable terminates into a connector, a short length of the STP is untwisted for mounting onto the connector—but untwisting the wires raises the wire impedance at the connector. Similarly, removing the shielding braid on a short length of a coaxial cable in order to mount the coaxial cable onto its connector results in an impedance increase. Thus, a larger impedance tolerance is allocated to the connector region to account for the impedance increase, while the cable itself has a tighter manufacturing tolerance.

Figure 2. FPD-Link III infotainment subsystem using HSD connectors with a STQ differential cable

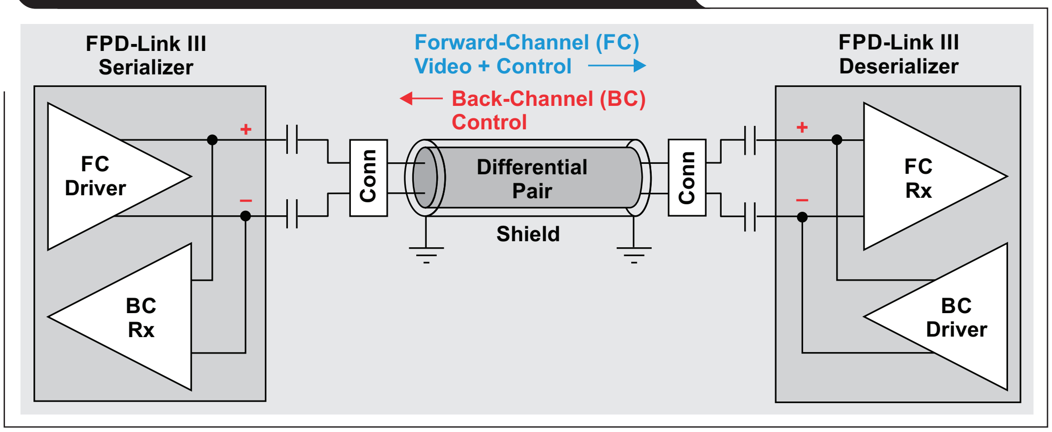


Figure 3. FPD-Link III driver-assistance subsystem using FAKRA connectors with a coaxial cable

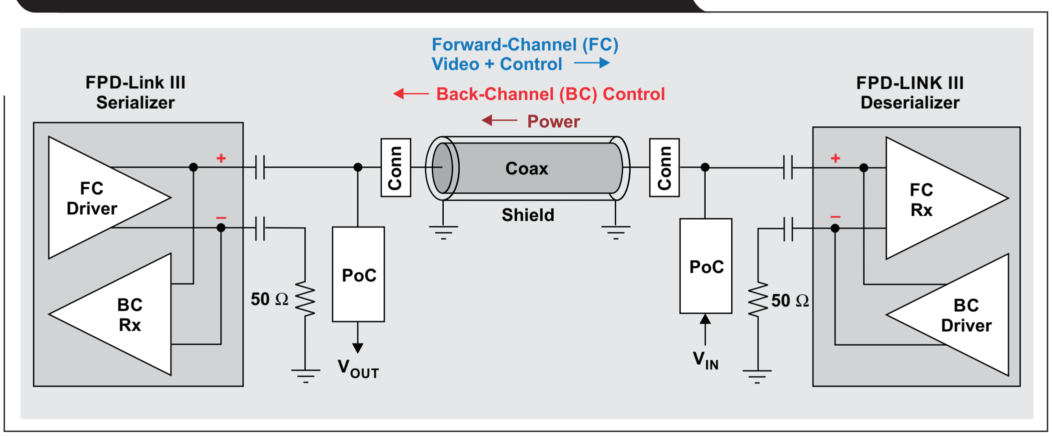


Figure 4. Impedance of a 100-Ω STP cable with differential connectors

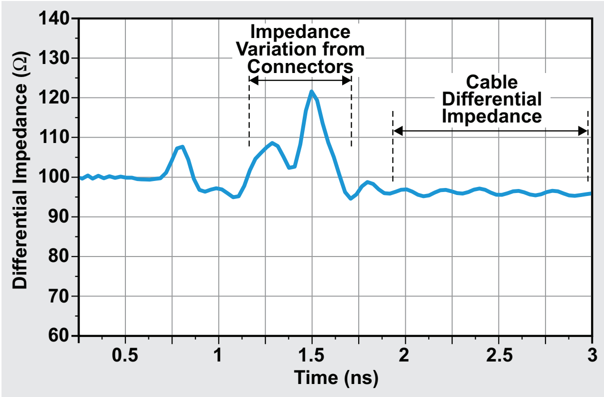


Figure 5. Impedance of a 50-Ω coaxial cable with RF connectors

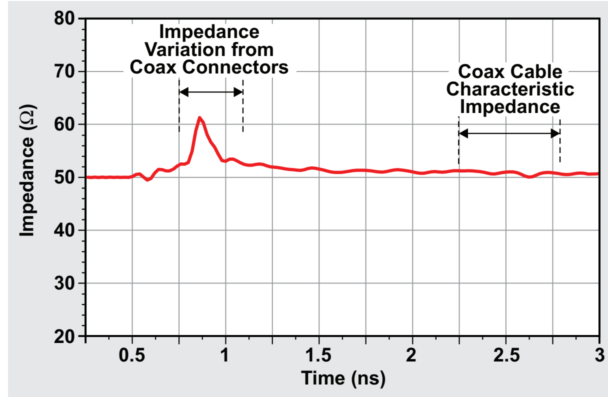


Figure 4 illustrates the impedance of a differential STP and its connectors. Figure 5 illustrates the impedance of a coaxial cable and its *radio-frequency* (RF) connectors.

Return loss

Return loss is another way to look at impedance in the frequency domain. Return loss is an important parameter that indicates how well the impedance matches with a reference impedance over frequency. Figure 6 illustrates the definition of return loss. Figure 7 shows the return loss of a coaxial cable and an *shielded twisted quad* (STQ) cable.

A good cable assembly has a low return loss that indicates its ability to avoid generating reflection. In a full-duplex system such as FPD-Link III, the cable's return loss also affects a receiver's ability to reduce echo that impacts the received signal.

Figure 6. Definition of return loss

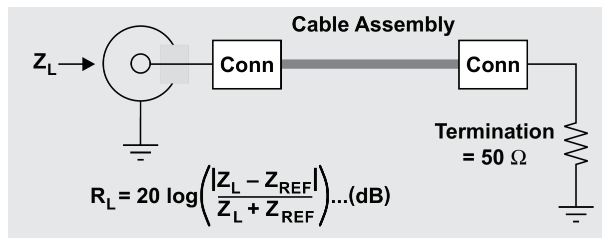
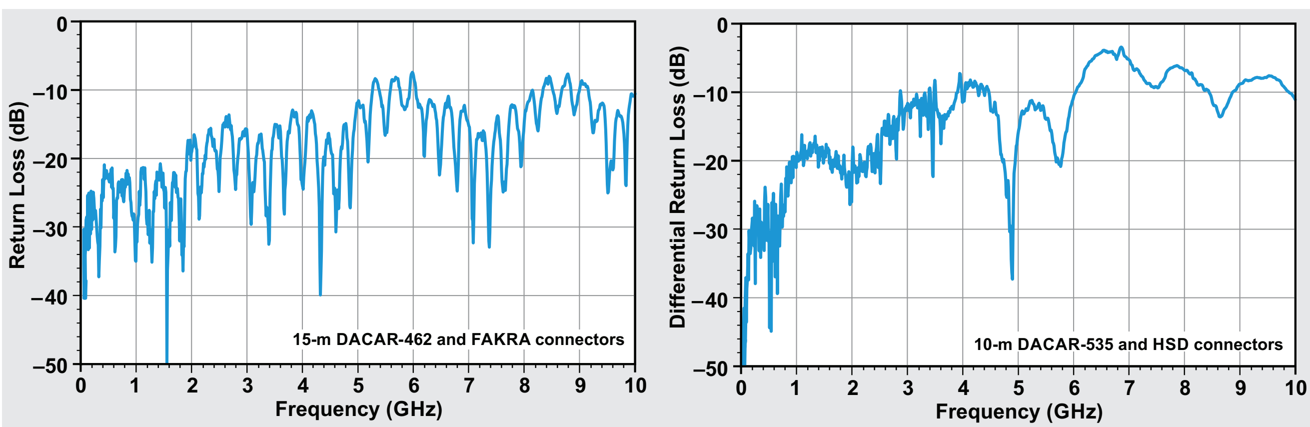


Figure 7. Return-loss comparison of coaxial and differential cables



(a) Coaxial cable

(b) STQ differential cable

Insertion loss

Insertion loss is another key parameter of a high-speed cable assembly that indicates the amount of signal loss from transmitter to receiver. Figure 8 depicts the loss characteristics of a 15-m coaxial cable.

At DC (frequency = 0 Hz), the internal resistance of the copper wire causes insertion loss. At low frequencies (below about 500 MHz), skin effect dominates insertion loss, when electrons tend to move on the outer surface of the wire, effectively increasing the wire's resistance. Skin loss is proportional to the inverse of frequency. At higher frequencies, dielectric loss dominates insertion loss, which depends on the electrical properties of the dielectric material surrounding the wire. Dielectric loss is proportional to frequency.

The insertion-loss characteristic of a cable behaves as a low-pass filter, which adds inter-symbol interference (ISI) jitter to a high-speed serial bit-stream propagating through the cable. The receiver usually has a built-in equalizer circuit, which implements a high-pass filter to counteract the low-pass filter effect from the cable. An adaptive equalizer includes a control loop that automatically selects a high-pass filter setting that closely matches the cable's loss characteristic.

Selecting a suitable high-speed cable depends on:

- The operating frequency range.
- The linear region, where there is no abrupt drop in insertion loss within the frequency range.
- Whether the insertion loss is within a range that the receiver's equalizer can compensate.

Figure 8. Insertion loss of a 15-m coaxial cable

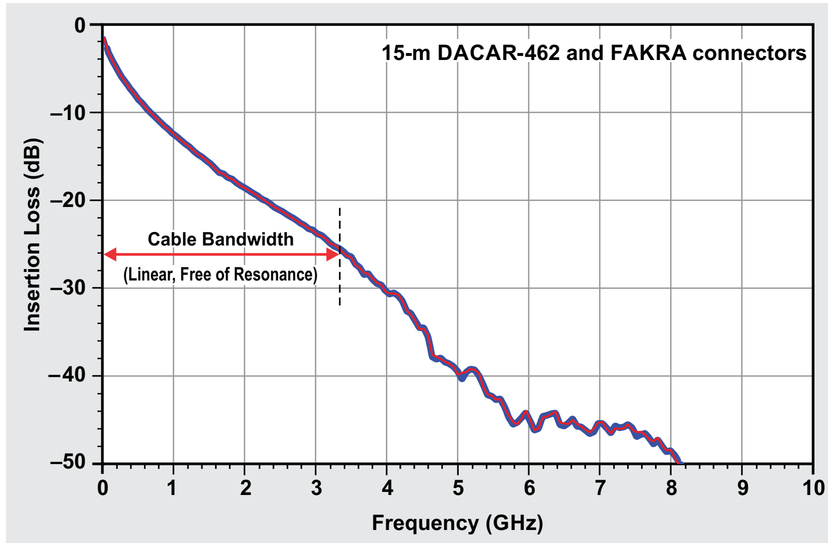
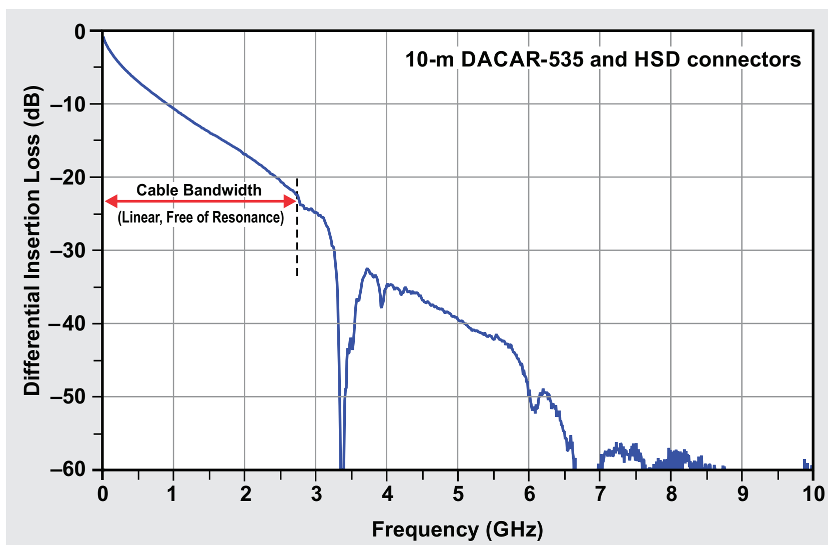


Figure 9. Insertion loss of a 10-m STQ differential cable



As Figure 8 shows, a 15-m coaxial cable has a usable bandwidth of 3 GHz and is capable of supporting data rates up to about 6 Gbps.

Figure 9 illustrates the insertion loss of an STQ differential cable. As you can see, there is an abrupt drop in loss caused by the wires' twisting properties. The 10-m differential cable has a usable bandwidth of 2.5 GHz and is capable of supporting data rates up to about 5 Gbps.

Cable symmetry

Cable symmetry is critical in a differential signaling topology to ensure that the received signals at the end of a differential cable continue to maintain their complementary properties of equal amplitudes but opposite phases. Cable symmetry means that the two wires of a differential pair have identical physical properties such as wire diameter, length and twisting, as well as material properties such as dielectric constant.

An asymmetric cable introduces mode conversion, where part of the transmitted differential signals are converted into a common-mode signal and impact the receiver's signal quality. Figure 10 illustrates the differential-to-common-mode conversion of a differential cable. A high-speed cable should be highly symmetrical and its mode conversion should be lower than insertion loss by more than 10 dB.

In the time domain, an asymmetric cable usually exhibits one or both of the following behaviors:

- Intra-pair skew—the complementary signals arrive at the destination at slightly different times.
- Unequal amplitude—the complementary signals have slightly different amplitudes or wave shapes.

Excessive mode conversion causes distortion in the received differential signal. As a remedy to an asymmetric cable, a common-mode choke can usually reduce unwanted common-mode signals at the receiver's input.

Crosstalk

Crosstalk refers to the interference signal at a "victim" receiver from a nearby "aggressor" transmitter. Figure 11 illustrates *far-end crosstalk* (FEXT) in unidirectional transmission and *near-end crosstalk* (NEXT) in bidirectional transmission.

Figure 10. Insertion loss and mode conversion of a 10-m STQ differential cable

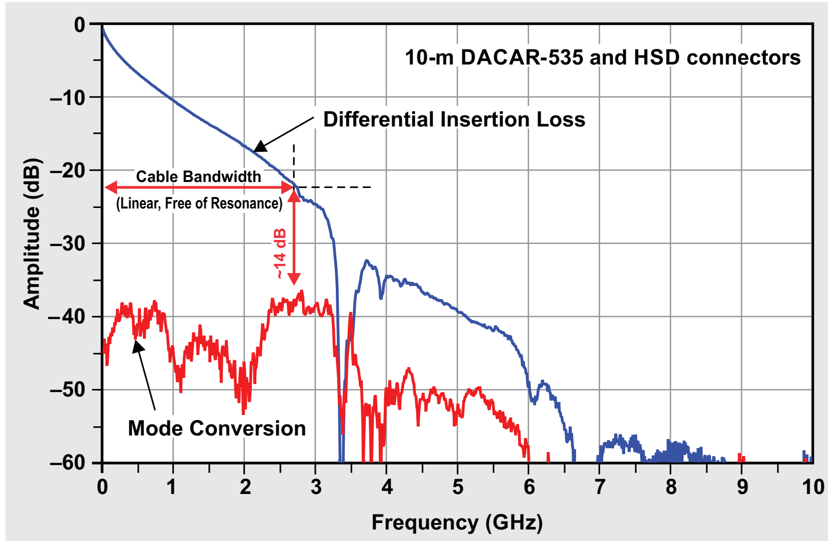
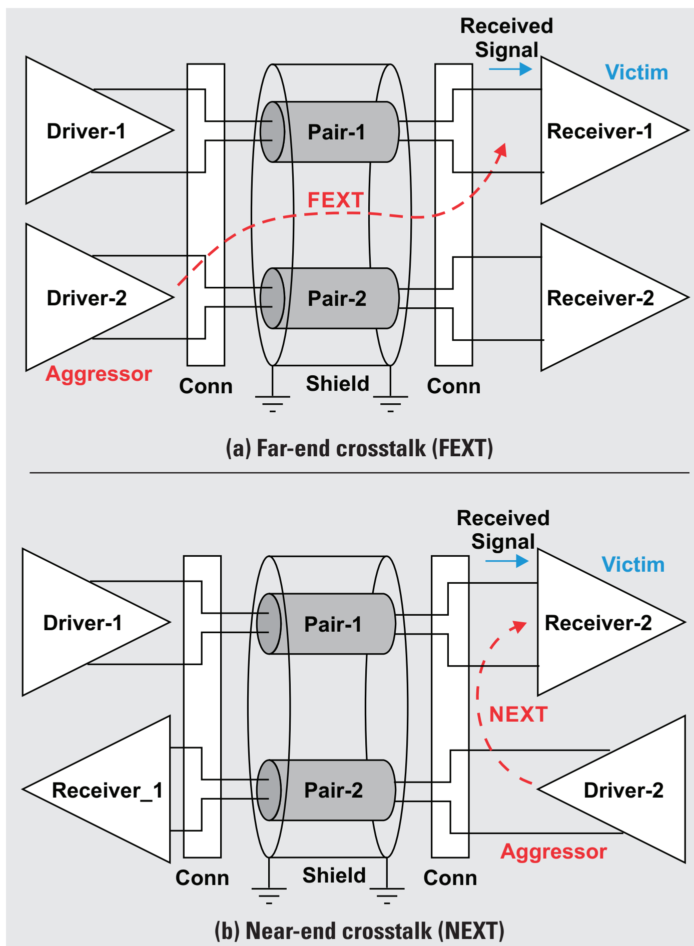


Figure 11. Crosstalk from adjacent differential pairs in a cable



Adjacent signal pins in a connector have strong crosstalk contributions. Crosstalk degrades the receiver's input signal-to-noise ratio. At higher frequencies, the received signal is smaller due to higher insertion loss, while crosstalk increases and degrades the received signal quality more. Figure 12 illustrates insertion loss and crosstalk from a STQ cable. Selecting a well-designed cable assembly ensures an acceptable signal-to-crosstalk ratio. In Figure 12, the cable's bandwidth drops about 2 GHz due to the presence of FEXT.

Crosstalk is not unique to multi-pair cables. Figure 13 shows a quad receiver in a camera hub connected to four camera modules through four separate coaxial cables. The crosstalk from the other three aggressor transmitters will affect each receiver; therefore, choose a quad connector with low crosstalk performance.

Figure 12. Crosstalk from an adjacent differential pair in a two-pair STQ cable

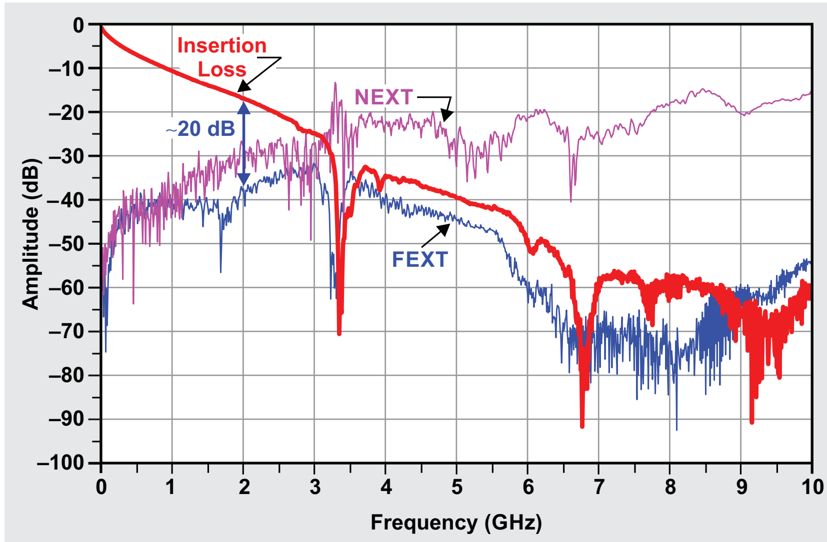
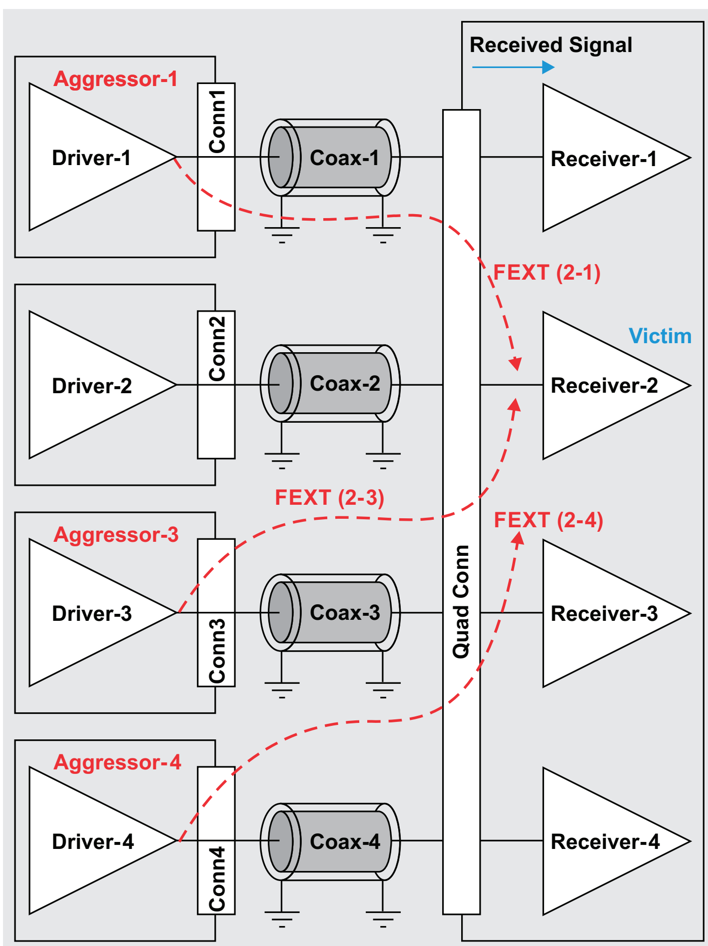


Figure 13. Crosstalk from adjacent coaxial cables in a quad receiver



Other automotive considerations

An automotive cable assembly must be able to withstand high temperatures and other harsh working environments. To make cable routing and equipment installation easier, cables in a vehicle usually have multiple in-line connectors. As shown in Figures 4 and 5, each connector introduces impedance mismatches, and multiple in-line connectors degrade the cable assembly's return loss. Reflected signals due to impedance mismatch also introduce some insertion-loss variations. Figure 14 illustrates the effect of in-line connectors on return loss and insertion loss compared to a straight cable of the same length.

Once a cable assembly is mounted inside a vehicle, it endures harsh temperatures and mechanical stress caused by bending. Performing temperature-cycling and mechanical stress tests on a cable assembly ensures that the cable will be able to perform over the vehicle's lifetime. Figure 15 shows an example of insertion loss change after temperature-cycling and mechanical stress tests.

Conclusion

Not all cables are built the same. Having a good understanding of cable parameters is essential to the creation of a cost-effective and high-performance cable assembly for robust infotainment and automotive driver-assist subsystems. The return loss and insertion loss of the cable assembly should be compatible with FPD-Link III SerDes chipsets. Cable symmetry and crosstalk are also important considerations to ensure an adequate signal-to-noise ratio and ensure link robustness.

Related Web sites

Product information:

TI's portfolio of FPD-Link III SerDes
DS90UB949-Q1
DS90UB940-Q1
DS90UB933-Q1
DS90UB934-Q1
DS90UB964-Q1

Figure 14. Effect of in-line connectors on insertion loss and return loss

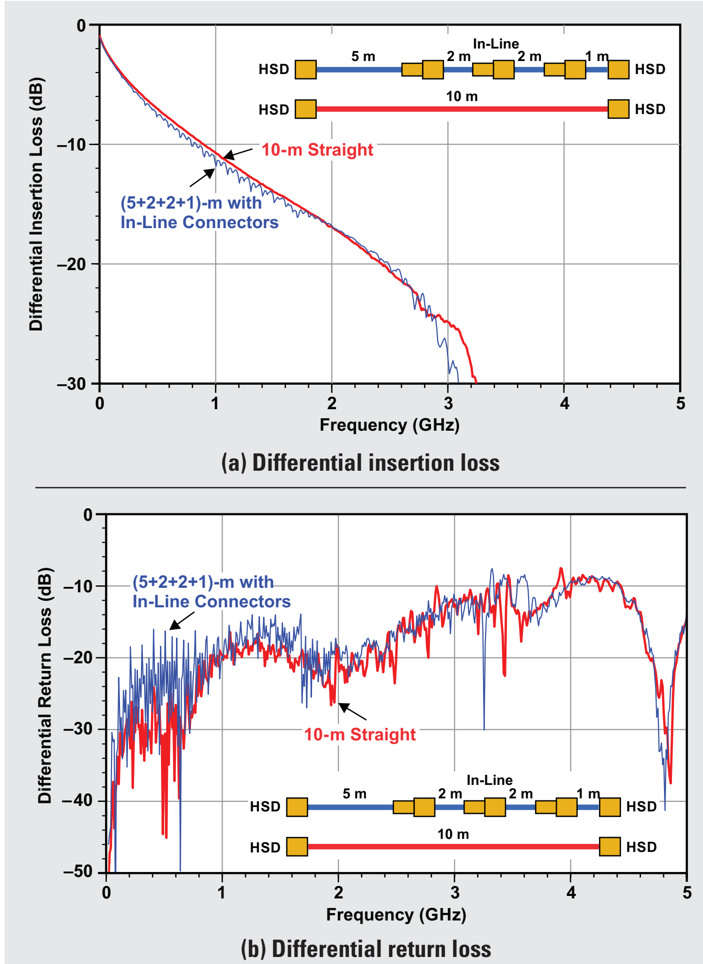
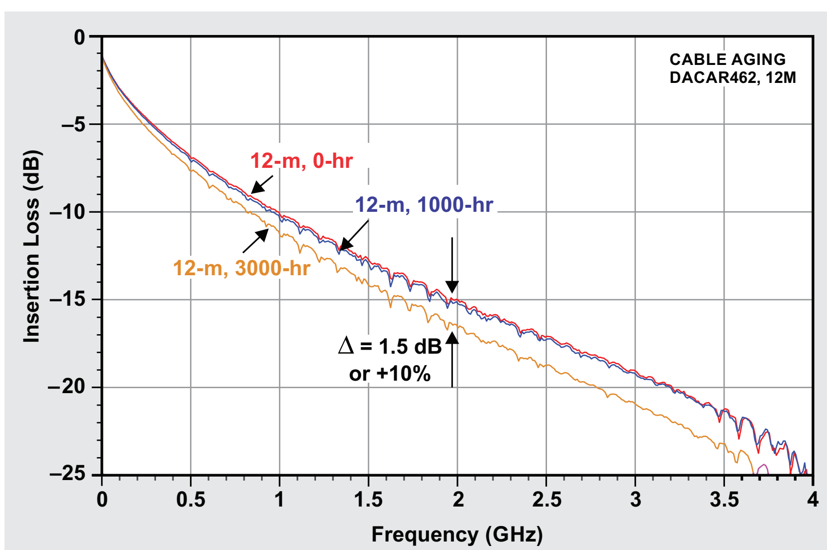


Figure 15. Effect of temperature cycling and mechanical stress



TI Worldwide Technical Support

TI Support

Thank you for your business. Find the answer to your support need or get in touch with our support center at

www.ti.com/support

China: http://www.ti.com.cn/guidedsupport/cn/docs/supporthome.tsp

Japan: http://www.tij.co.jp/guidedsupport/jp/docs/supporthome.tsp

Technical support forums

Search through millions of technical questions and answers at TI's E2E™ Community (engineer-to-engineer) at

e2e.ti.com

China: http://www.deyisupport.com/

Japan: http://e2e.ti.com/group/jp/

TI Training

From technology fundamentals to advanced implementation, we offer on-demand and live training to help bring your next-generation designs to life. Get started now at

training.ti.com

China: http://www.ti.com.cn/general/cn/docs/gencontent.tsp?contentId=71968

Japan: https://training.ti.com/jp

A011617

SLYT726

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated (‘TI”) technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, “TI Resources”) are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI’s provision of TI Resources does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI’s standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).