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

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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.

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

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.
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:
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DS90UB933-Q1
DS90UB934-Q1
DS90UB964-Q1
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