Technical White Paper

Signal Conditioners for Reliable and Robust Industrial High Speed Links

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ABSTRACT

High speed signal conditioners such as redrivers and retimers, when used in a data or video link, improve overall signal integrity by eliminating loss and jitter. Such signal conditioning components improve link margin, extend physical reach, and provide reliable and robust operation over environmental variations. The signal conditioning elements are discussed for common data and video interfaces used in industrial applications especially in industrial PC systems. Specific signal integrity solutions for USB, HDMI, Display Port, PCIe and Ethernet are introduced and analyzed.

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1 Introduction

Industrial automation has become much more sophisticated with integrated image processing, video analytics and sensor networks. High bandwidth data communication has imposed significant challenges on preserving signal integrity to avoid data loss across high speed industrial communication links. Ensuring reliable and low latency communication from one machine to another is critical to achieve the precision of the industrial operation.

Various high-speed communication protocols such as USB, PCIe, HDMI, Display Port and Ethernet are being used in industrial interface links. These interfaces have been increased to multi-gigabit speed level to facilitate the increasing bandwidth needs of the data processing. The high-speed signals face significant challenges to maintain signal integrity (SI) when transmitting over long printed circuit board (PCB) traces or cables. To combat signal integrity challenges and provide a reliable and error free link signal conditioning components such as redrivers, retimers or active multiplexers are often required. The signal conditioners help compensate for and overcome signal impairments and losses of a high speed link. A signal conditioning element in a link can help pass standard compliance and provide margin in a cost effective way.

2 Signal Conditioners

High speed data and video links in industrial application must be reliable and robust for efficient operation with seamless and consistent data throughput. The links often suffer from too much loss, low margin, susceptibility to environmental condition such as supply voltage and temperature variation, internal and external noise. High speed signal conditioners when used in a data or video link improve overall signal integrity by eliminating loss and jitter.

A signal conditioning element such as a redriver or retimer in a high speed industrial link provides equalization to eliminate inter symbol interference (ISI) effectively, increasing overall link reach and SI margin. Additionally a retimer component has clock and data recovery circuits (CDR) that can eliminate SI impairments such as random jitter, cross-talk and reflection. For addional differences between a redriver and retimer see TI Precision lab video. Figure 2-1 shows what redrivers, retimers and active muxs can provide in a link.

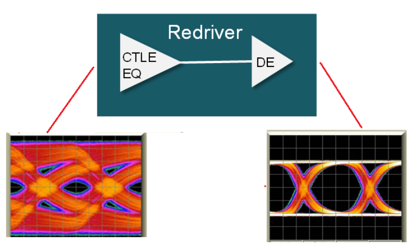
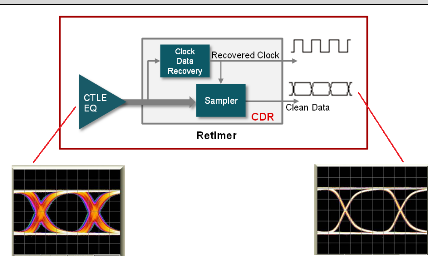
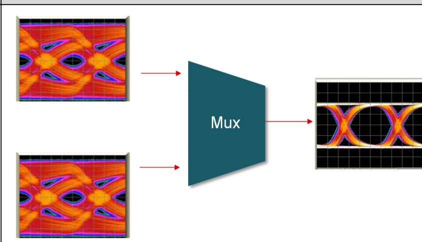
Redriver	Retimer	Active Mux
		
• Cost effective signal conditioner • Solves signal intergrity degradation casued by ISI • Compensates for channel loss	• Best performing signal conditioner • Eliminates input jitter • Compensate for both channel loss and jitter	• Facilitates signal routing options while compensating for channel loss • Active mux can be with integrated redriver or retimer

Figure 2-1. Functions of Redriver, Retimer, and Muxes

Industrial PCs likely use the most diverse set of high speed interface links in industrial applications. These systems can be considered as the brain of industrial automation. They process and analyze vast amount of data to implement critical functions, interface with human operators, and display the results in to industrial monitors. Mutliple CPUs are often connected together to form a powerful compute cluster in an industrial PC. Multiple systems are also connected together over a back plane or network to implement a complex function. Figure 2-2 shows the most commonly used interfaces inside a industrial PC system. In this article, industrial PC system is used an example to discuss different high speed interfaces. However this can be extended into other relevant industrial applications also.

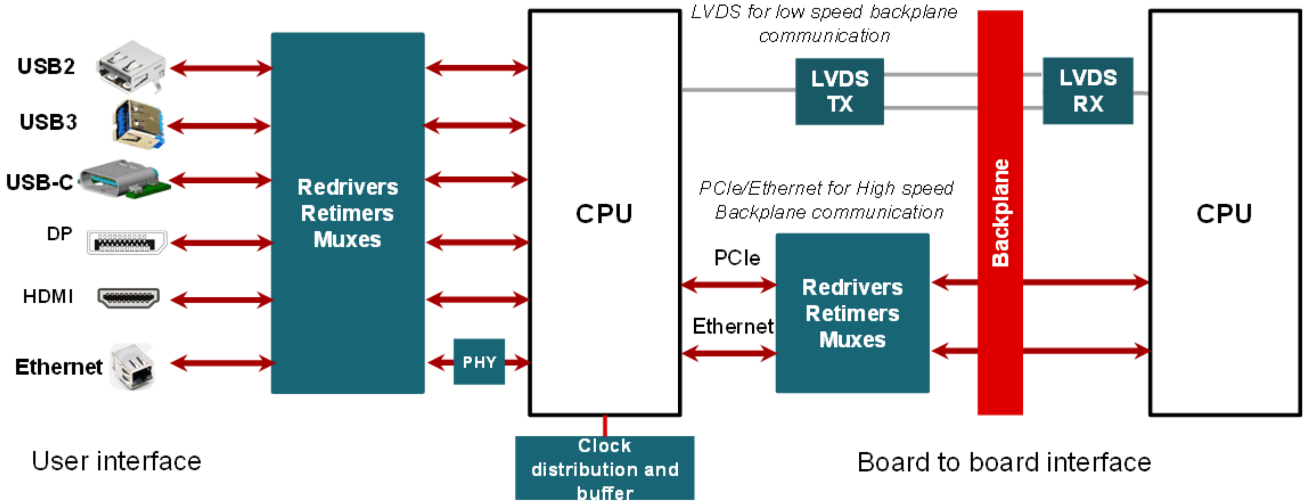


Figure 2-2. High speed interfaces inside an industrial PC system

User interfaces include USB, Display Port, HDMI and Ethernet which are external interfaces that provide access for operators and allow connectivity to additional functional end equipment such as display monitors, Ethernet networks, USB disks etc. Board to board interfaces illustrate system connectivity between different boards through a back plane. LVDS are typically used for lower speed data, while PCIe and Ethernet are used for high bandwidth data connections in back plane application.

A user interface port typically needs to meet industry compliance so that it can inter-operate and communicate with any device connecting to it. Compliance tests require a signal to meet certain eye-opening margin and jitter performance criteria which can be challenging since signal degradation can occur for high speed data after traversing along PCB traces and connectors. The same signal integrity challenge can also be imposed for signals traveling through a back plane for board to board communications. Long PCB traces and connectors can degrade signal quality causing compliance issues, downgrade of data throughput and even resulting in communication failure. By adding signal conditioners, such as redrivers, retimers and active muxes, in a CPU system, the designer can ensure compliance at the connectors per standard specifications, while also improving the signal quality at the receiver side to enable a more robust communication system.

Now let's look at more detailed examples on how to use signal conditioners to solve signal impairment problems for USB, PCIe, Display Port, HDMI, and Ethernet interfaces.

2.1 USB Interface

USB is a ubiquitous interface that is found in almost all electronic gadgets. To provide easy user interface options for operators in industrial applications, USB is widely used. The interface is also used for expanding the functionality of the equipment through connecting external devices into the system. Depending on the data bandwidth needs of the intended function, either USB2, USB3 or USB Type-C can be used for industrial communications.

USB2 interface has widespread use for user interface and is typically used for management or control interface in industrial applications. The USB2 can support up to 480Mbps speed. Even though when compared with other Gigabit interfaces, USB2 is considered a relatively low speed interface, USB2 has a very stringent compliance standard that is difficult to meet without violating the eye mask at the connector. Adding a redriver to a USB2 data path design can easily solve these challenges.

Figure 2-3 demonstrates the signal integrity of a USB2 data path both with and without a USB2 redriver. Without a redriver, the USB2 signal can only pass compliance with a 1-meter cable. Adding a USB2 redriver such as TUSB216 to the system, it is able to pass compliance with up to 5-meters of cable in this specific link example.

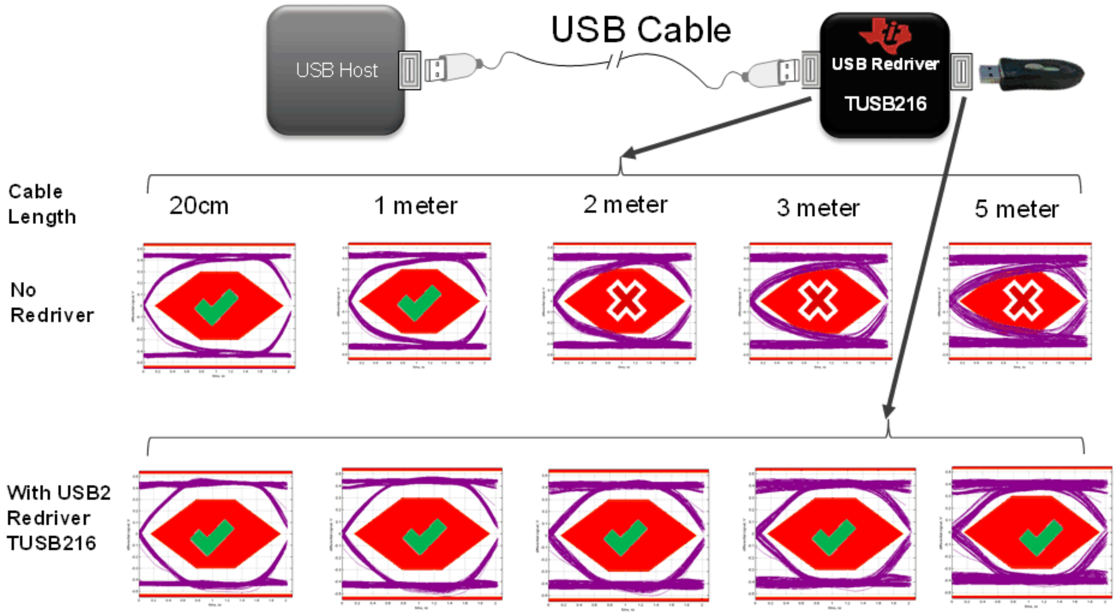


Figure 2-3. Using USB2 Redriver to Pass Compliance

USB3 and USB Type-C can support 5Gbps, 10Gbps and even 20Gbps data rates. These high speed interfaces are typically used when video or other high bandwidth data need to be sent across USB interface. In an industrial PC system, the distance between the USB host and the USB connector is fixed, the channel loss profile can be predetermined, and a redriver with a fixed equalization (FEQ) can work to compensate for the egress data path loss of the link. However, on the host ingress path, since the signal loss from the connector is dependent on what device and cable the remote side is connected to, it is beneficial to have adaptive equalization (AEQ) to compensate variety of channel loss profile as illustrated in Figure 2-4. Adaptive EQ offers the capability to adjust a receiver's EQ setting based on the quality of the incoming signal. For example, if a USB device is plugged directly into a USB receptacle without a cable, the redriver's AEQ algorithm will select a lower EQ setting than it would if the USB device was plugged into receptacle through a cable. Adaptive EQ enables the redriver to be more intelligent and provide best signal quality at its output while saving design effort on device tuning.

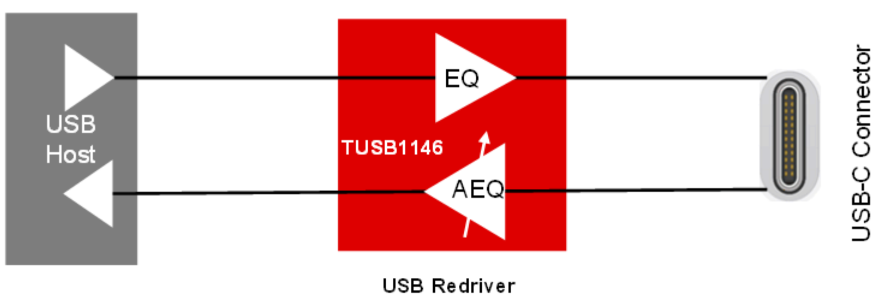


Figure 2-4. USB3 and Type-C Redriver with Adaptive EQ

2.2 HDMI and DisplayPort Interface

In an industrial PC system, HDMI and DisplayPort are used to connect external displays for high resolution videos or human machine interface (HMI). HDMI can support 3.4Gbps, 6Gbps and 12Gbps. DisplayPort can support 5.4Gbps, 8.1Gbps and 10Gbps and beyond. These video interfaces are facing the same challenge as USB- signal loss from PCB trace and cable, as well as jitter can impact the video fidelity and decrease the display quality.

Signal Conditioners such as redrivers and retimers can implement several features to improve signal integrity. A good signal conditioner can support adaptive or fixed equalization to clean up inter-symbol interference jitter or loss from bandwidth limited board traces and cables. Retimers use clock data recovery circuits (CDR) to clean up random, phase and sinusoidal jitter. Good retimers have wide band CDR tracking and narrow band jitter cleansing as well as the capability to work with wide frequency ranges. They also have selectable source termination to match traces and impedance to reduce reflections in the signal path. It provides several features for passing compliance and reducing system-level design issues, which compensates for the attenuation when driving long cables or high loss board traces.

Figure 2-5 shows example of an HDMI connectivity in a typical industrial PC. In this implementation SN65DP159, which is a dual mode DisplayPort to HDMI2.0 retimer up to 6Gbps, is used as level shifter retimer. SN65DP149 is a retimer supporting HDMI1.4b up to 3.4Gbps. Both can provide AC coupled to DC coupled physical layer conversion (level shifting).

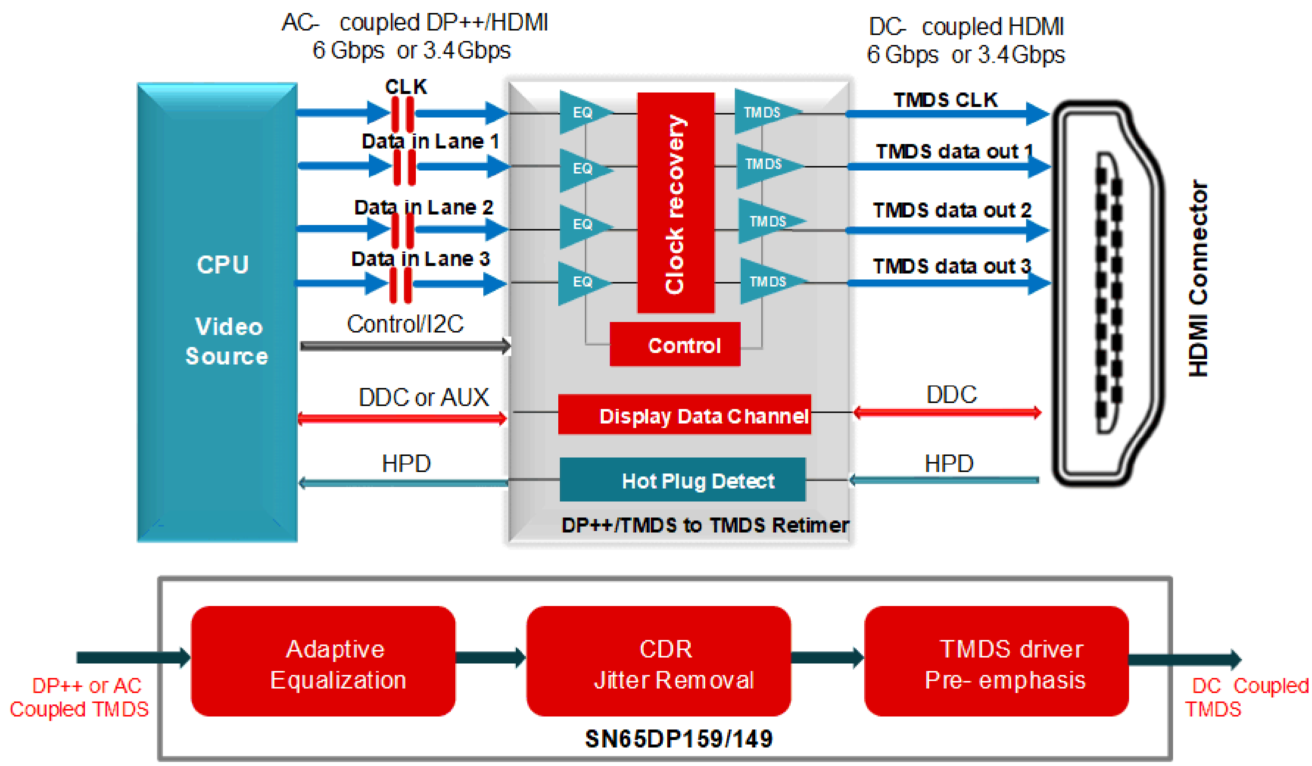


Figure 2-5. HDMI2.0 Retimer Example Using TI SN65DP159

2.3 PCIe Interface

A PCI Express interface is an efficient way to transfer high bandwidth data between different elements in a system such as in between CPUs, CPU to add on functions (End Points) and CPU to storage devices. While the interface is the main backbone of bulk data transfer for PC and server applications today, its use is diverse and includes industrial applications. With increasing need for large data handling and transport within industrial PCs, test equipment, factory automation, IOTs, the popularity of PCIe is growing.

A PCIe link can be within a single PCB or through cables or across a back plane. A PCIe link can be of different data rates up to 32 Gbps PCIe 5.0. Loss profile of the electrical link and its speed will determine signal integrity fidelity. Recommended loss budget for a PCIe 4.0/5.0 link is maximum 28/36 dB respectively. Often real implementation suffers from impairments such as non-ideal transmission lines, discontinuity of different elements of the channel, cross talk etc. that decreases the link reach from ideal loss budget. Furthermore, many system implementations require reach extensions to be able to go further. To increase signal reach and or improve signal integrity fidelity there are likely three choices each with its tradeoffs:

- low loss board material - increases board cost significantly,
- linear redriver – good fit in systems where eye masks fail due to excessive deterministic jitter (DJ) from additional channel loss, and
- protocol aware retimer – good fit for systems with too much loss or un-equalizable loss such as crosstalk, reflections, skew and random jitter.

Depending on application use case, signal integrity situation and other factors signal conditioning can be achieved by a linear redriver or retimer. Linear redrivers such as DS160PR810 and DS160PR410 are simple components that helps with insertion loss. They are typically low power, low cost, low latency options. However, linear redrivers have limited capability compared to retimers. Linear redrivers are an excellent choice where the main objective is to offset for some additional channel loss. On the other hand retimers such as DS160PT801 are more potent signal conditioners that can address link impairments such as insertion loss, jitter, crosstalk, reflections & skew. However the added benefit comes with increased price tag and additional complexity and power consumption.

Depending on actual topology and PCIe link bus width, the system implementation may require linear redriver or retimer of various configuration that include unidirectional, bidirectional, multiplexer, demultiplexer and cross point mux devices. Figure 2-6 outlines various such options for 16 Gbps PCIe 4.0.

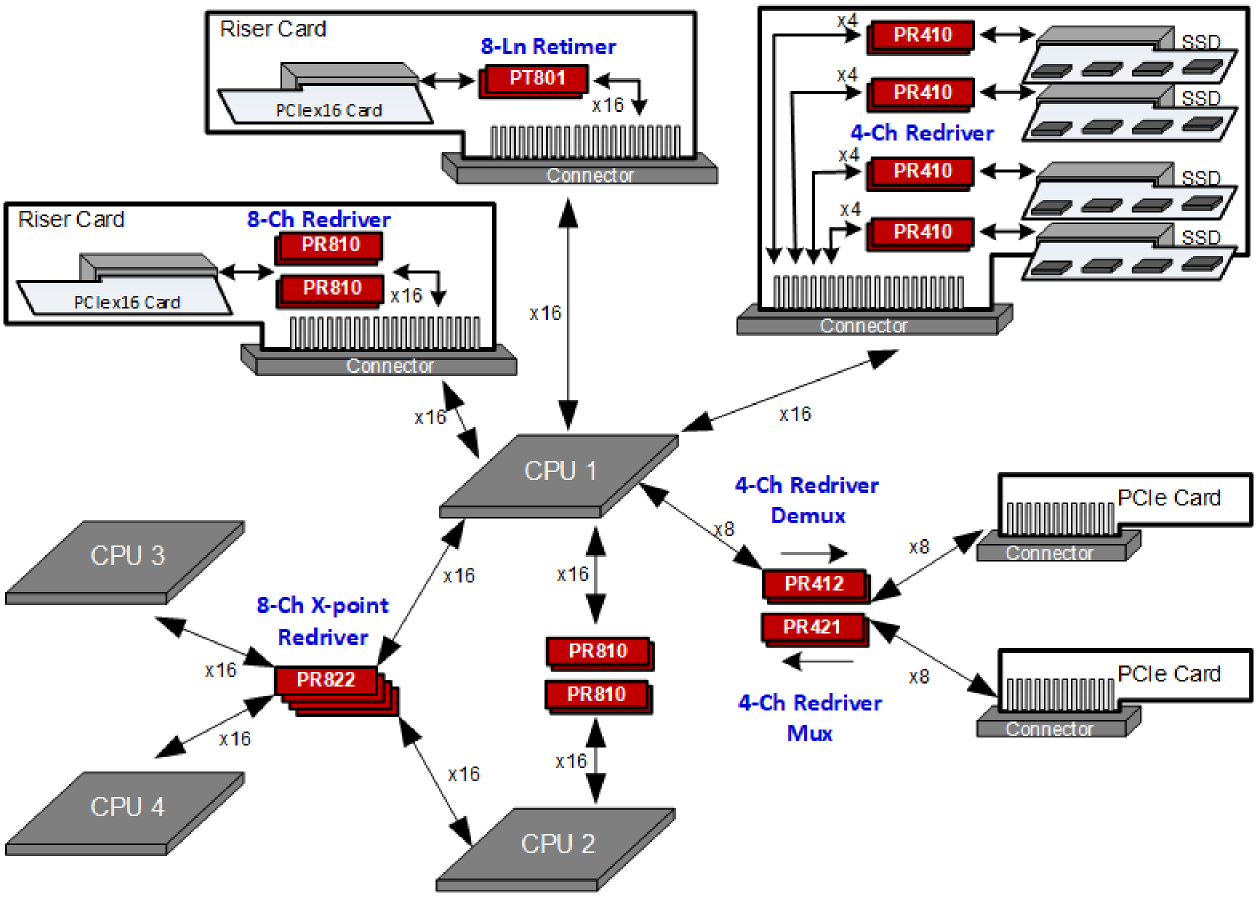


Figure 2-6. PCIe 4.0 Signal Conditioner Functions Using TI Redriver and Retimers

In addition to PCIe-compliant retimers and redrivers, clock buffers are often used in industrial system implementations. Clock buffers such as LMK00334 , LMK00338, and clock generators, such as CDCE6214 and CDCM6208 can help to achieve end-to-end PCIe-compliance for PCIe links.

2.4 Ethernet Interface

Ethernet is used in industrial PC communication modules and communication switch applications to inter-connect different industrial automation networks. Industrial communication switches are starting to adopt 1GbE, 10GbE, 25GbE interface and above to aggregate or distribute Ethernet traffic.

Ethernet data can be sent through front port optical or copper interfaces to remote devices, or sent through a backplane to another CPU or ASIC for processing. To deliver the best signal quality, a 10GbE redriver or retimer can be placed between the processor and front port interface or between ASIC through the back plane to compensate for the channel loss. DS110DF111 is an example of a high performance retimer with adaptive CTLE and decision feedback equalizer (DFE) that can be used for single port small form-factor pluggable (SFP) interface. It can provide up to 34dB equalization together with the CDR and transmit driver to overcome any signal impairment in data path and enable high reliability of the communication channel. DS100DF410 is a 4 channel retimer with similar performance, typically used at quad (4-channel) small form-factor pluggable (QSFP) interface for signal cleansing. The 10Gbps Ethernet redriver and retimer application report and Optimal implementation of 25G retimers vs redrivers provide more details on Ethernet redriver and retimer selections [VG1] and benefits. Adding a signal conditioner in the Ethernet data path can improve system interoperability and enable robust industrial communications.

The data aggregated and distributed by these 10Gb interfaces is tranceived via multiple, slower Ethernet PHYs. These PHYs must adhere to the same interoperability and conformance requirements addressed earlier, plus meet the robustness and timing requirements introduced in nodes further afield. For example, surviving unplanned electrical events during manufacturing (e.g. ESD) and during active operation (e.g. EFT) is critical to minimize both manufacturing and maintenance costs. In addition, deterministic timing characteristics provide optimal system accuracy, providing additional design headroom for other parts of the system. The DP83867IR and DP83867IS family provides multiple options to meet a specific system need, while providing industrial application level robustness and timing characteristics.

To maintain compliance to the synchronous Ethernet and the IEEE 1588 Precision Time Protocol standard, leverage TI's ultra-low jitter and phase noise network synchronizers, including the LMK05318B, LMK5B12204, and LMK5C33216.

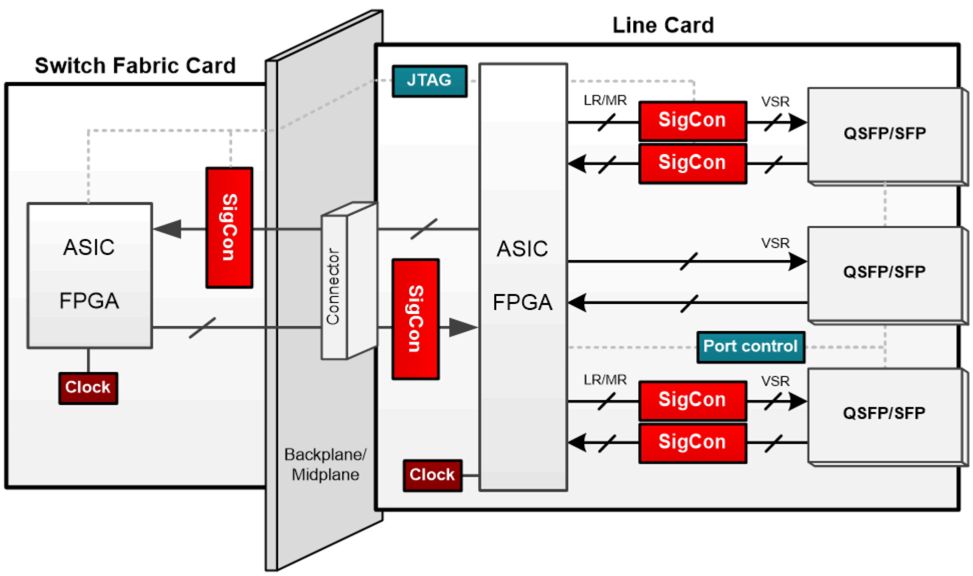


Figure 2-7. 10GbE Communication Switch using Ethernet Retimer

3 Summary

The fourth industrial revolution is underway with large scale machine to machine communications combined with high bandwidth network for increased automation. The amount of data communications between machines, devices, sensors and human interface drive the speed of the CPU interface in order to be able to process the data quickly and intelligently. The signal integrity challenges over the high speed interface can be overcome by adding redriver or retimer in high speed links such as USB, HDMI, DisplayPort, PCIe and Ethernet to ensure the data integrity and to minimize signal loss due to noise or jitter. Texas Instruments offers complete, scalable, high performance and low latency signal conditioning solutions to enable quality and precision in industrial communication for modem factories.

4 References

1. Texas Instruments, TI Precision Labs - Signal Conditioning: What is the difference between a linear and limited redriver? training and videos.
2. Texas Instruments, 10Gbps Ethernet Redriver and Retimer application report.
3. Texas Instruments, Optimal implementation of 25G Retimers versus Redrivers application report.