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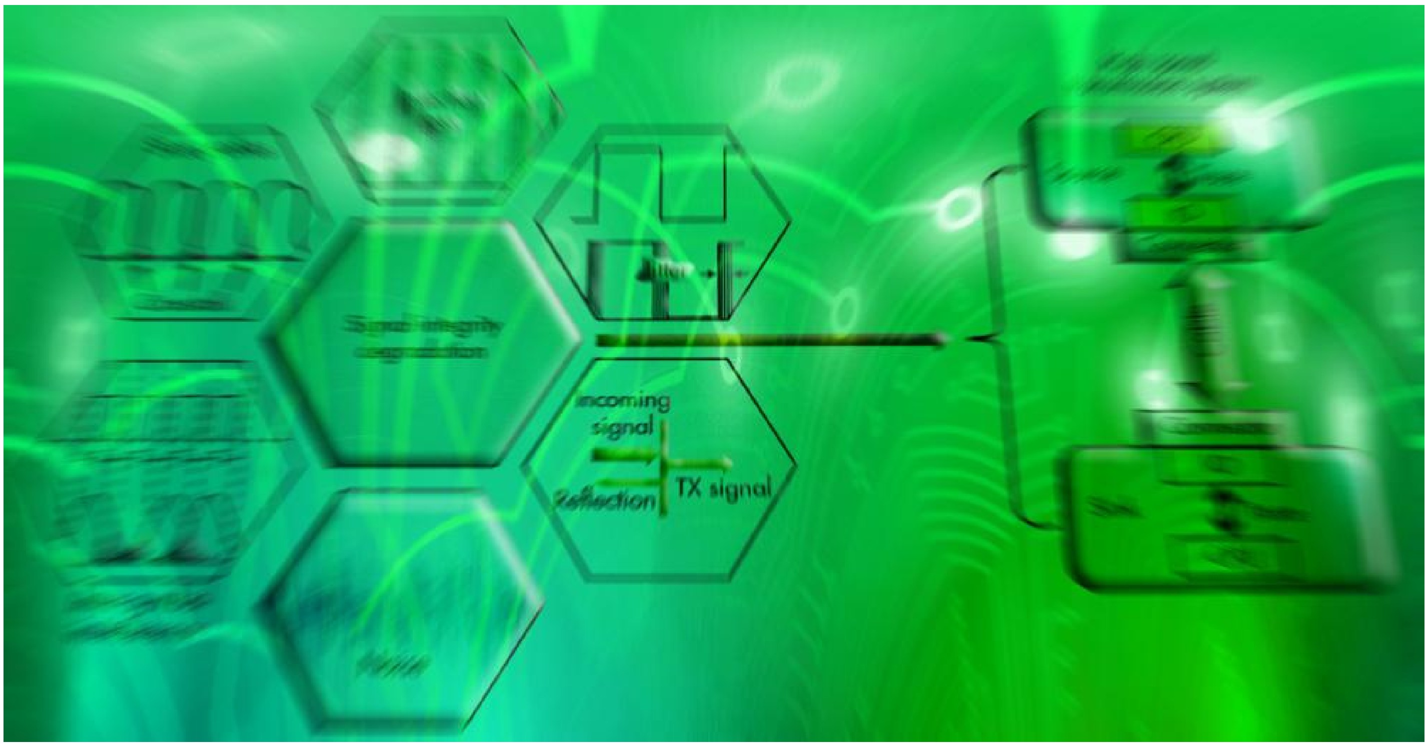

TECHNOLOGIES > POWER

Don't Leave Home Without It: Redrivers for USB Type-C Designs

Sponsored by: Texas Instruments. To overcome signal-integrity issues that crop up in circuits incorporating USB Type-C, USB 3.1, and Alternate Mode, designers should consider adding a redriver.

Paul Pickering | Jul 26, 2017

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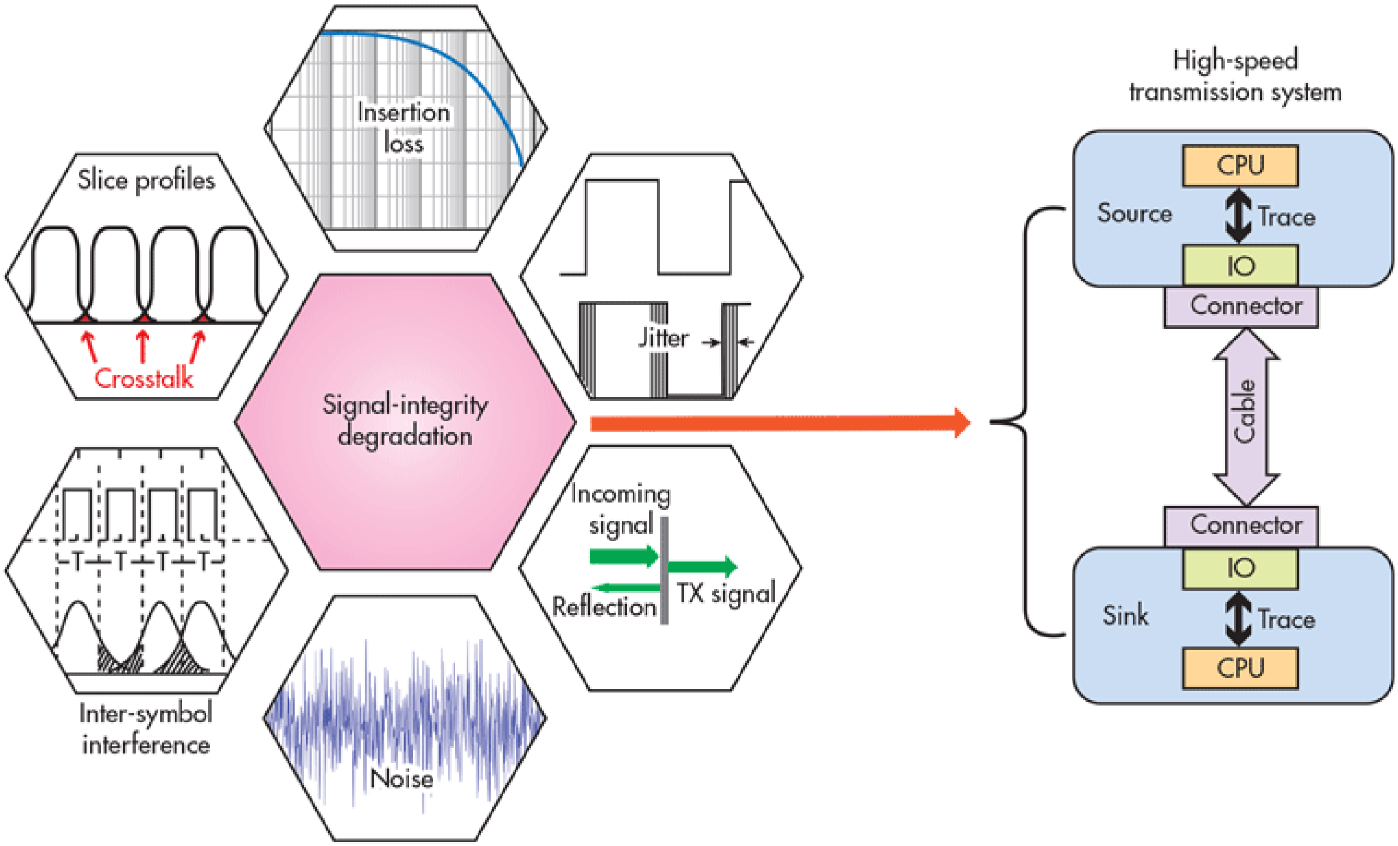
The advertising slogan in the title refers to the American Express card, a classic ad campaign that began in 1975. That year was also when Microsoft was founded, and a year when your humble writer finally abandoned dreams of musical fame and fortune and applied to engineering school.

Back then, the newest thing in serial communications for the home was the X10 protocol that used the ac power line to send control signals to lamps and thermostats; the X.10 data rate was a leisurely 120 bits per second (b/s).

We’ve raised the bar a little since those days: In 2017, the USB Type-C set of specifications rules the roost. The complete set comprises the USB Type-C connector specification: the USB 3.1 interface specification with a maximum data rate of 10 Gb/s; and the USB Power Delivery specification (USB PD) for power-related functions. Although they’re often mentioned in same breath, a USB system can support one specification but not the others—USB Type-C but not USB 3.1 or USB PD, for example.

Two problems confronting X.10 design engineers in 1975 were excessive attenuation of signals as they propagated down the ac wires, and interference caused by nearby equipment.

Plus ça change, plus c’est la même chose… Although the data rate has increased by orders of magnitude compared to X.10, signal integrity issues still plague designers today. At gigabit-per-second speeds, a host of variables can affect signal integrity, including transmission-line effects, impedance mismatches, crosstalk, signal routing, bus termination designs, electrostatic-discharge (ESD) protection devices, and printed-circuit-board (PCB) grounding.



1. High-speed data traveling from one board to another—or even across a single PCB—can experience several types of degradation, potentially resulting in an increased error rate and lost information. (Source: TI, "Enhancing System Performance with Signal Conditioners")

What are some contributors to loss of signal integrity? *Figure 1* tells the tale.

- **Insertion loss** is the loss of signal power resulting from any device added in the signal path between transmitter and receiver. In this context, a "device" can be a component, a connector, a cable, or even a PCB trace. The loss increases with the number of added devices or the length of the trace or cable.

- **Crosstalk** occurs when a signal propagating in one channel creates an undesired effect by coupling into another channel. The coupling mechanism can be capacitive, inductive, or conductive.

- **Inter-symbol interference** (ISI) is a form of signal distortion in which one symbol interferes with subsequent symbols. This is an unwanted phenomenon that makes the communication less reliable, since the current symbol sees the previous symbols as noise. The interval between symbols becomes smaller with increasing transmission speed, so a high-speed channel is more prone to ISI.

- **Signal reflections** occur when a signal encounters a change in impedance as it propagates from source to receiver. A portion of the signal power is reflected back to the transmitter while the rest continues in the original direction. Many elements may cause an impedance change, including connectors, in-line components, PCB vias, or a change in trace width.

- **Jitter** is any deviation from the true periodicity of a digital signal. The deviation can be in terms of amplitude, phase timing, or the width of the signal pulse. Among the causes of jitter are EMI and crosstalk with other signals. Jitter can create flicker in a display, extraneous noise or clicks in an audio signal, or affect the ability of a processor in a desktop or server to perform as intended.

- **Noise** is the portion of the signal that doesn't carry useful information. A signal must maintain a minimum signal-to-noise ratio (SNR) in order to be decoded properly by the receiver.

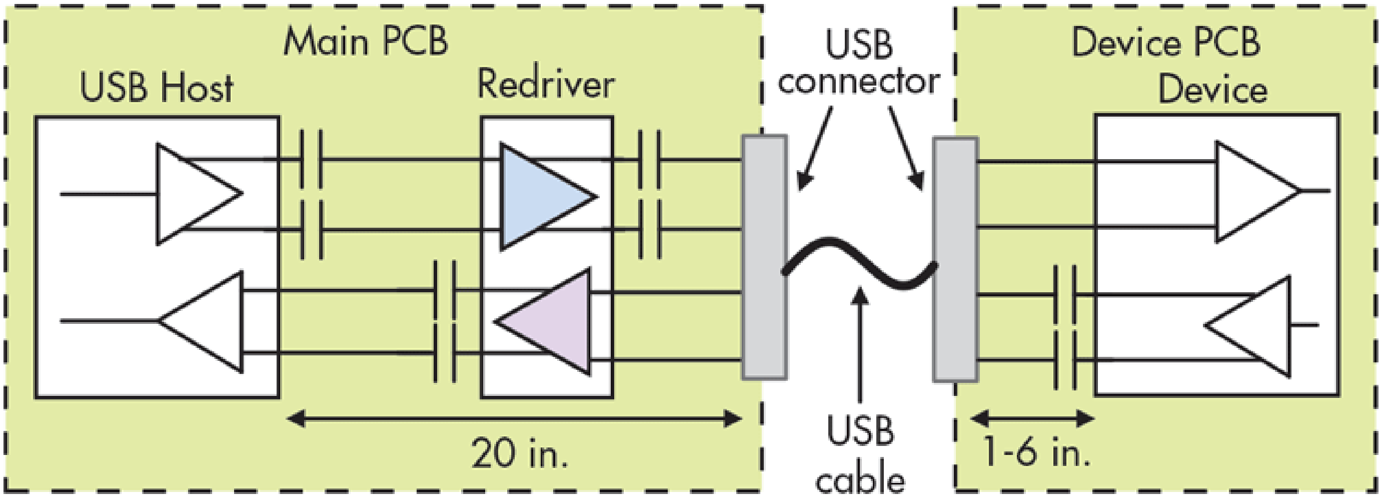
Any of these factors will cause high-speed signals to suffer signal degradation.

Use Equalization to Compensate for Signal-Integrity Problems

Adding equalization is a powerful technique to improve the integrity of high-speed data signals.

Equalization compensates for channel insertion loss and ISI in the system before the transmitted signal reaches the receiver. Pre-emphasis is one form of equalization. It boosts high-frequency signals before transmission. De-emphasis is the opposite of pre-emphasis. It reduces the magnitude of selected frequencies in the transmitter to compensate for downstream losses.

The Redriver to the Rescue

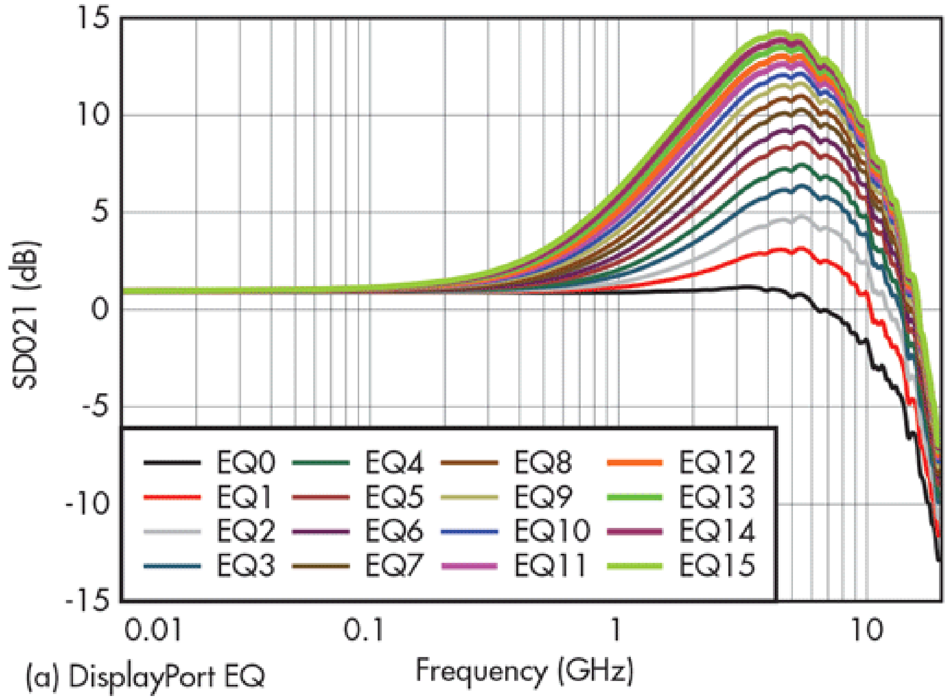


2. The redriver compensates for both intra-board and inter-board losses in high-speed USB data channels. (Source: TI, TUSB522P PDF)

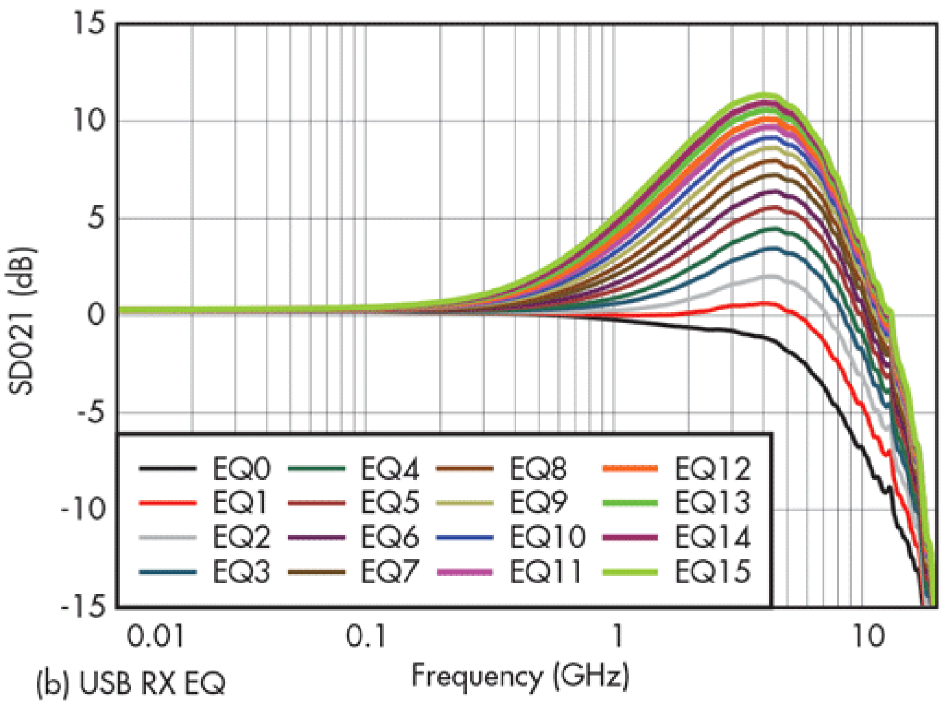
Adding a redriver is a convenient way to improve signal quality. Simply put, a redriver recovers and boosts a degraded signal. It’s a linear device that receives the incoming signal, applies an adjustable amount of equalization and gain, and then retransmits the recovered signal. *Figure 2* shows where the redriver fits into the data channel.

As a passive medium, a PCB trace attenuates the signal linearly by a certain ratio. The redriver's function is to amplify the signal by the same ratio, regardless of the signal amplitude at its input. A redriver outputs a linear function of its input-signal amplitude. The effect is the same as removing or shortening the PCB trace.

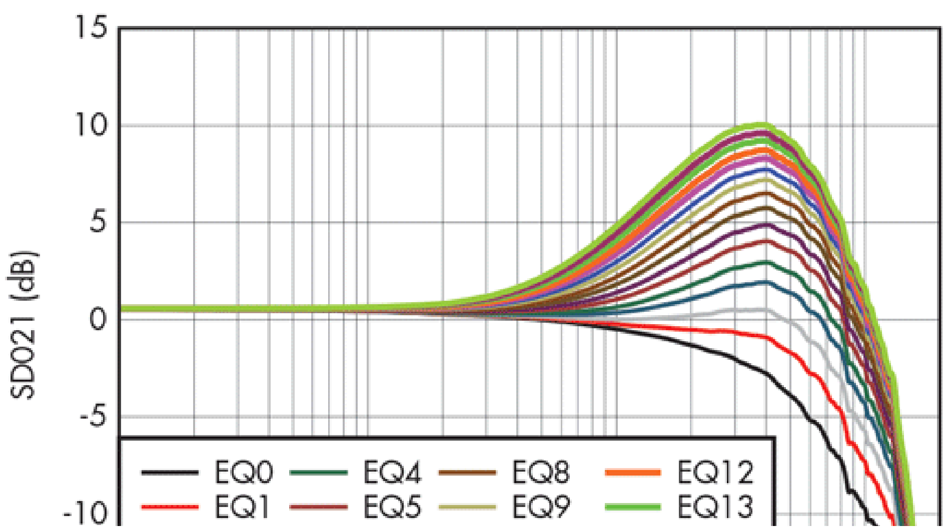
The USB TX and RX channels each have different equalization curves. A protocol such as DisplayPort has yet another set of curves *(Fig. 3)*.

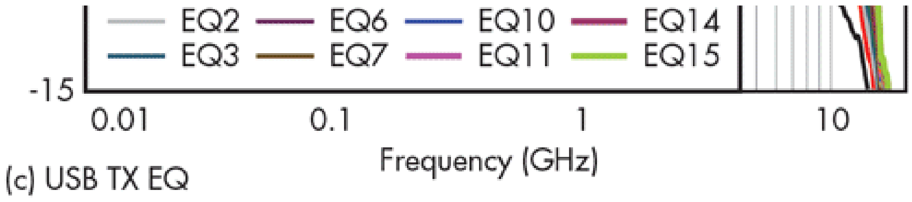


(a) DisplayPort EQ



(b) USB RX EQ





3. A configurable redriver offers a range of EQ curves according to the protocol being used. (Source: TI, TUSB1046-DCI PDF)

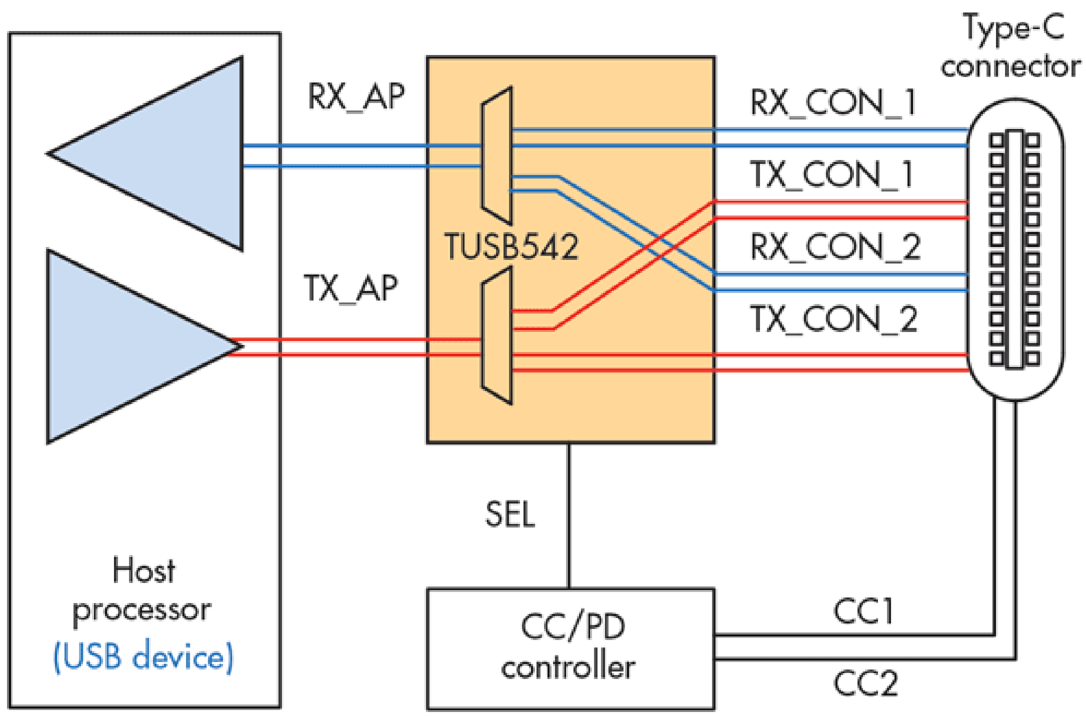
In addition to equalization, a redriver can increase the dc portion of a recovered signal. Both the configurable equalization and dc gain can help the system pass electrical and protocol compliance testing, and boost device interoperability.

Omitting the redriver can limit the total transmission channel distance for a given signal. A redriver is directional—it can drive the signal in only one direction, so separate redrivers are required for both source and sink sides.

The Linear Redriver, USB 3.1, and USB Type-C

Texas Instruments offers a range of redrivers for different applications. The TUSB522 , for example, is a dual-channel, single-lane USB 3.1 redriver that supports 5-Gb/s (Gen 1) operation. The device incorporates receiver equalization with multiple gain settings, and selectable transmitter de-emphasis and output swing control to compensate for downstream losses.

The TUSB522 also features an intelligent low-frequency periodic-signaling (LFPS) controller. LFPS is a communication sideband sent on the normal USB 3.0/3.1 data lines, but at a lower frequency of 10-50 MHz instead of the usual 5/10 Gb/s. This sideband signals initialization and low-power management information when the bus is in the idle state (no signaling occurring). The controller senses the low-frequency LFPS signals and automatically disables the de-emphasis function. This is required for full USB 3.1 compliance.

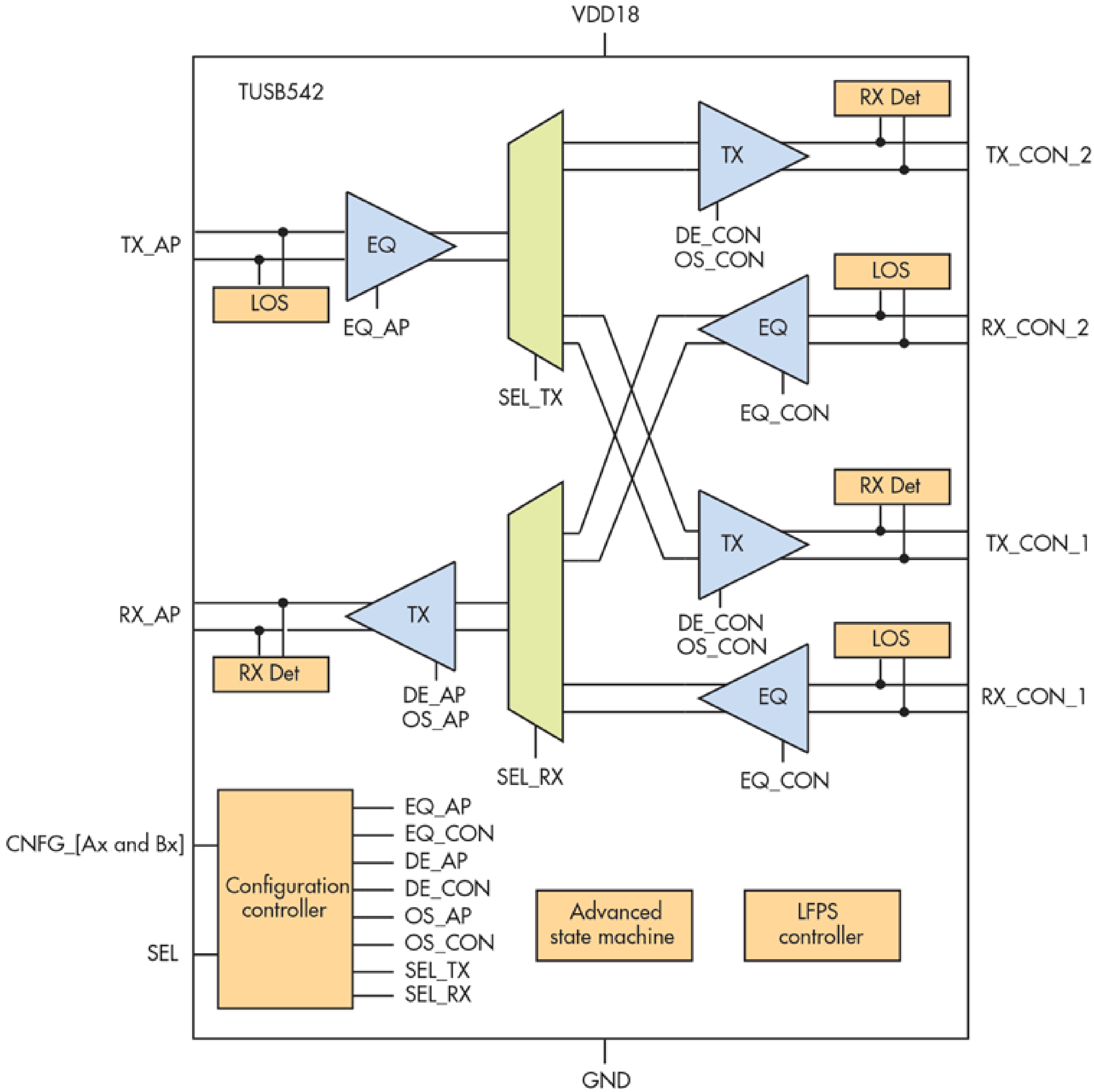


4. A USB Type-C redriver such as the TUSB542 can accommodate the reversible nature of the Type-C connector. (Source: TI, TUSB542 PDF, pg. 1)

Although redrivers such as the TUSB522 have all of the features needed for a USB 3.1 system with a Type-A or Type-B connector, the USB Type-C connector requires additional switching circuitry to accommodate connector flipping *(Fig. 4)*.

The TUSB542 is a dual-channel USB 3.1 Gen 1 (5 Gb/s) Type-C capable redriver. In addition to the redriver features of the TUSB522, the TUSB542 supports USB Type-C connector flipping by including the ability to switch the USB SS signals via the SEL pin. An external Type-C port controller monitors the configuration-channel (CC) pins to determine the connector orientation.

Figure 5 shows the internal block diagram of the TUSB542, revealing the connector-flipping circuitry, the LFPS controller, and the configuration block.



5. Shown is the internal block diagram for the TUSB542. (Source: TI, TUSB542 PDF, pg. 13)

USB Type-C Alternate Mode and Signal Degradation

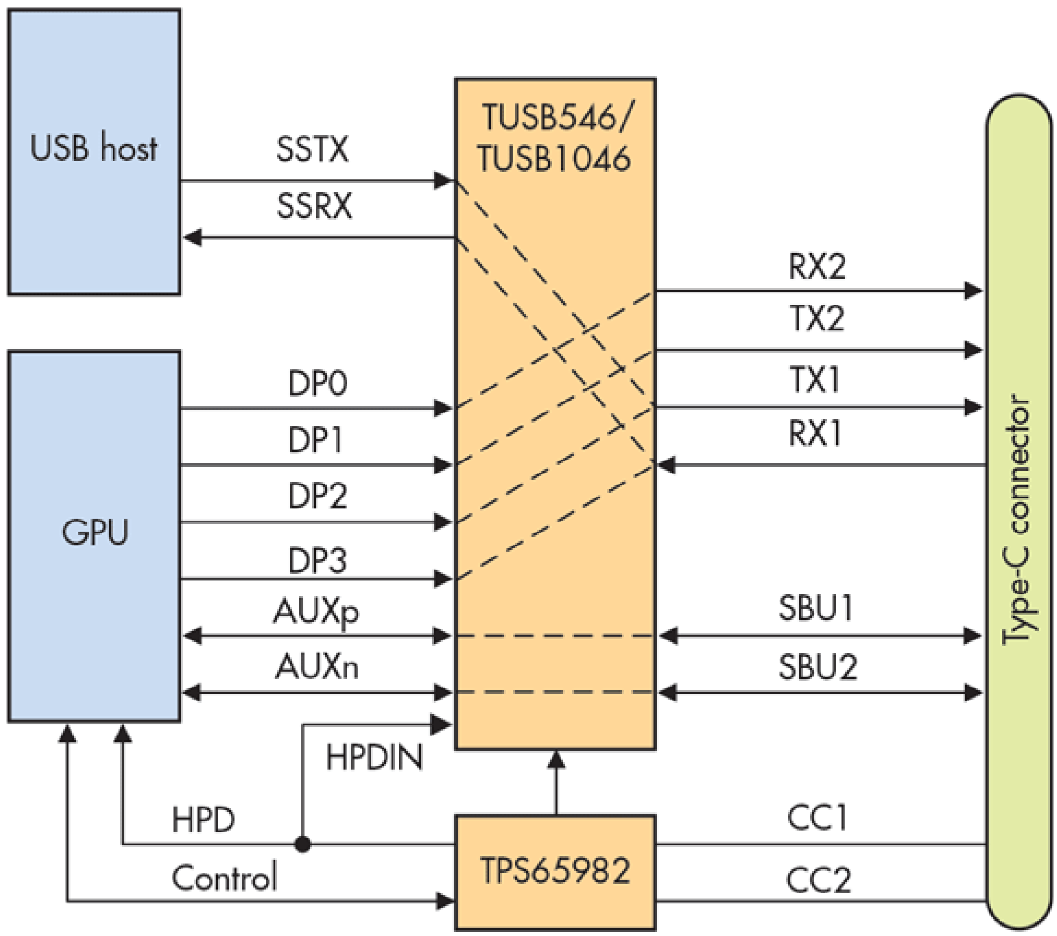
The addition of USB Type-C Alternate Mode (AM) contributes to signal degradation, too.

Bolstering its reputation as “one connector to rule them all,” the USB Type-C AM specification, which requires both USB Type-C connector and USB PD compliance, allows non-USB protocols (e.g., DisplayPort, HDMI, MHL, and Thunderbolt) to be transferred over a USB connection. These serial communication standards operate at similar speeds to USB 3.1—HDMI 2.0 checks in at 6 Gb/s, and DisplayPort 1.4 reaches 8.1 Gb/s.

To switch between standard USB operation and DP or another protocol, an Alternate Mode design requires a high-speed crosspoint switch to select between USB and non-USB signals, as well as longer trace routing for the alternate protocol processor. Both additions degrade the signal further.

Using a Linear Redriver in a USB Type-C Alternate Mode System

A redriver provides a much-needed improvement to signal quality in a USB Type-C AM application—combining the redriver and crosspoint switch into one device saves board space. The TUSB1046-DCI , for example, includes a redriver and a Type-C AM switch in a single WQFN (4.00 × 6.00 mm) package. In a downstream-facing port (Host), the device can support USB 3.1 SuperSpeed+ and DisplayPort 1.4 data rates.



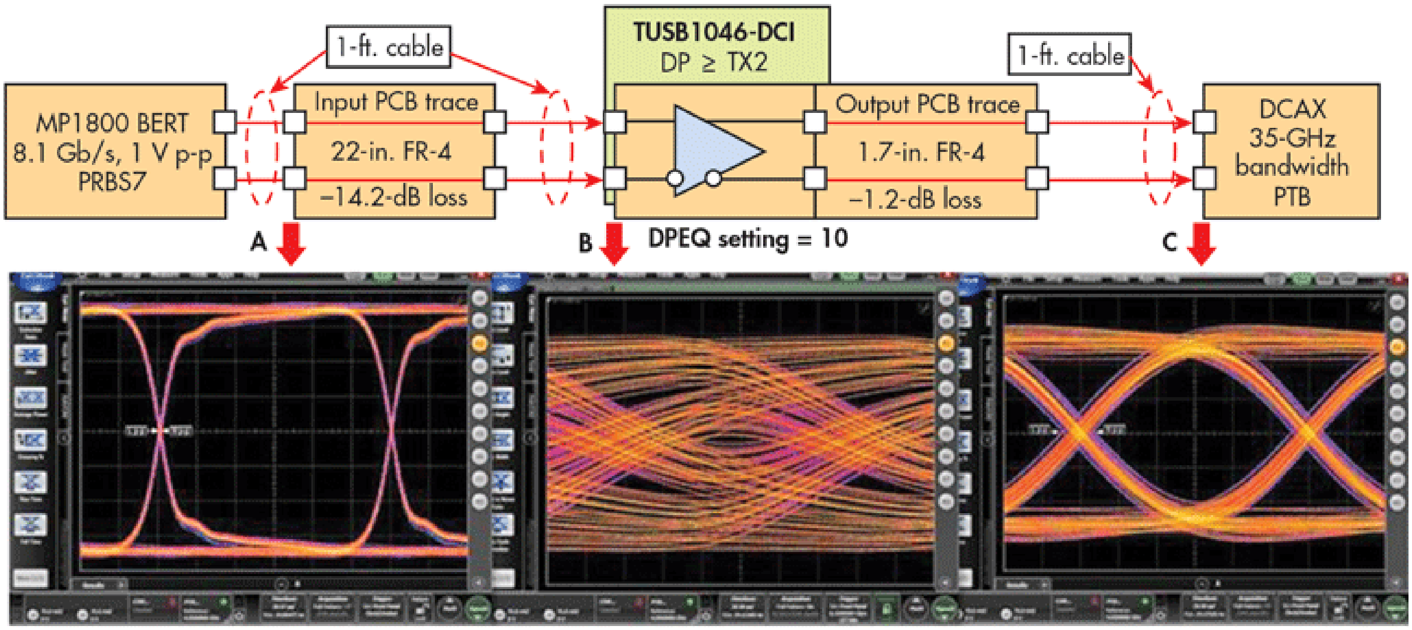
6. The TUSB546/1046 redrivers include a crosspoint switch for USB Type-C Alternate Mode operation. (Source: TI, "Why use a USB Type-C redriver in your personal electronics designs?")

The TUSB1046 can supply up to 14-dB equalization. It is protocol-agnostic, so it can support other USB Type-C Alt Mode standards in addition to DisplayPort. *Figure 6* shows the function of the TUSB1046 in an AM application, switching between the USB host device and the DisplayPort graphics processing unit (GPU) as needed. The TPS65982 is a combination USB Type-C and USB PD Controller, Power Switch, and High-Speed Multiplexer.

For a host application, the TUSB1046-DCI enables the system to pass both transmitter compliance and receiver jitter tolerance tests for USB 3.1 Gen1/Gen2 and DisplayPort version 1.4 HBR3. The TUSB546-DCI is a similar device for USB 3.1 Gen 1 operation up to 5 Gb/s.

Performance Demonstration of the TUSB1046-DCI

Figure 7 demonstrates the performance improvement achieved by adding the TUSB1046-DCI to the DisplayPort channel in a USB Type-C application.

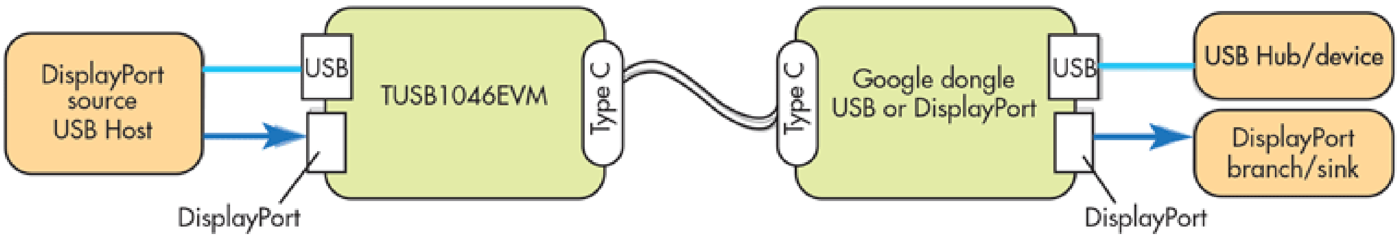


7. Adding a USB1046 redriver to a DisplayPort channel opens up the eye diagram, allowing the received signal to meet the DP standard. (Source: TI, "How to correct 10Gbps performance issues with a USB Type-C active redriver multiplexer")

The test setup consists of a bit-error-rate tester (BERT) that sends an 8.1-Gb/s pseudorandom binary sequence (PRBS7) signal through a one-foot cable and 22 inches of FR4 PCB trace to a TUSB1046-DCI. The TUSB1024 processes the signal, and then drives it through 1.7 inches of trace and another one-foot cable to the measuring instrument—a wide-bandwidth oscilloscope with a precision timebase.

Before the 22 inches of trace (point A), the eye diagram is open, with little to no jitter. After the trace (point B), the eye is closed entering the TUSB1046-DCI DisplayPort input. The TUSB1046-DCI corrects the closed eye at the input and outputs a low-jitter open eye (point C). This eye has enough width and height margin to pass DisplayPort 1.4 standard compliance tests.

For optimum performance, choose a specific equalization setting to match the PCB trace loss. In this case, EQ10 *(see Fig. 3a)* matched the 14.2-dB loss of the 22-inch length of PCB trace at 4.05 GHz.



8. Here's a typical test setup to evaluate TUSB1046 performance in an AM application with DisplayPort. (Source: TI, TUSB1046 USB Type-C Enabler EVM PDF)

The TUSB1046 USB Type-C Enabler evaluation module (EVM) is available to evaluate the TUSB1046 in a typical Alternate Mode application. *Figure 8* shows a test setup.

Conclusion

USB Type-C, USB 3.1, and Alternate Mode combine to present a considerable number of signal-integrity challenges to the communication system engineer. Adding a redriver to the circuit helps alleviate problems by compensating for channel losses and other degradation.

Texas Instruments offers a family of redriver products that cover a broad range of USB Type-C use cases, plus an evaluation module to help designers get started quickly.

- Enhancing System Performance with Signal Conditioners

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