Strengthening the USB Type-C™ signal chain through redrivers

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The speed of information delivery has been a constant pursuit for designers of cutting-edge technologies. The benefit of getting a lightning-fast response regardless of the amount of data requested has been motivating the high-speed data standard body to increase the data rate over the years.

Products such as PCs, notebooks, tablets, virtual reality devices, high-definition TVs, Blu-ray players, hard drives, car infotainment systems and data center servers all include one or more multi-gigabit interfaces such as USB, USB Type-C™, DisplayPort™ or High Definition Multimedia Interface (HDMI) for data and high-resolution video.

The need for a signal conditioner

USB Type-C allows multiple standards on the USB Type-C interface; USB Type-C can support USB 2.0, USB 3.0 and USB 3.1 Gen 2 up to 10 Gbps. It also can deliver DisplayPort and HDMI over the USB Type-C interface as Alternate Mode. Currently, USB Type-C can support DisplayPort 1.4 up to 8.1 Gbps and HDMI 1.4 b up to 3.4 Gbps.

Figure 1 shows popular high-speed signal speeds based on standard revision and the growing data-rate trends.

Typical high-speed transmission systems include a transmitter and receiver. There are traces, connectors and cables in-between to properly transfer information. Maintaining signal integrity without signal distortion over the transmission media is very important, but quite challenging.

The transmission media will cause insertion loss, resulting in signal power loss. The longer the cable or trace, the higher the data rate and the more losses incurred, in turn causing signal degradation and a high bit-error rate at the receiver.

For example, **Figure 2** shows USB 3.1 10 Gbps signal insertion loss over 1 meter to 5 meter cables. As you can see, the loss is proportional to the cable length. You will see similar insertion loss with printed circuit

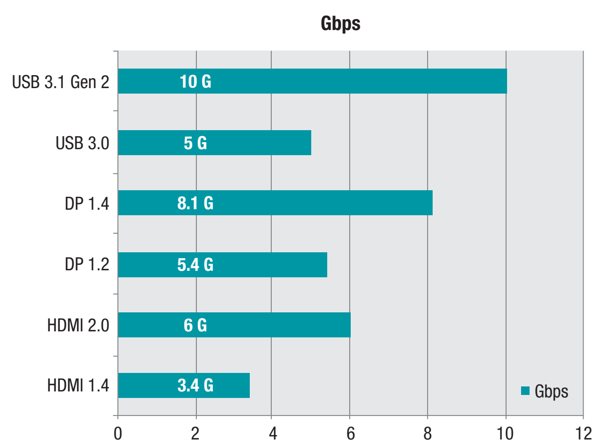

***Figure 1**. USB, DisplayPort and HDMI speed based on standard revision.*

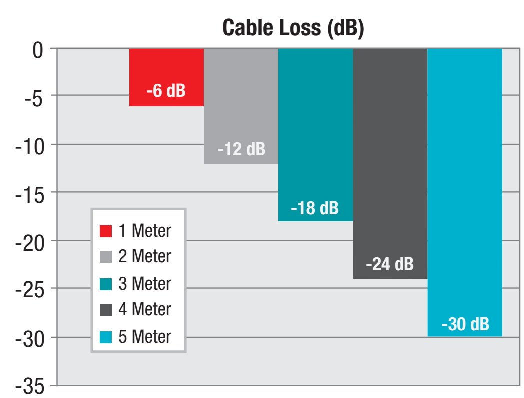

***Figure 2**. USB Type-C cable loss profiles for 10 Gbps signals.*

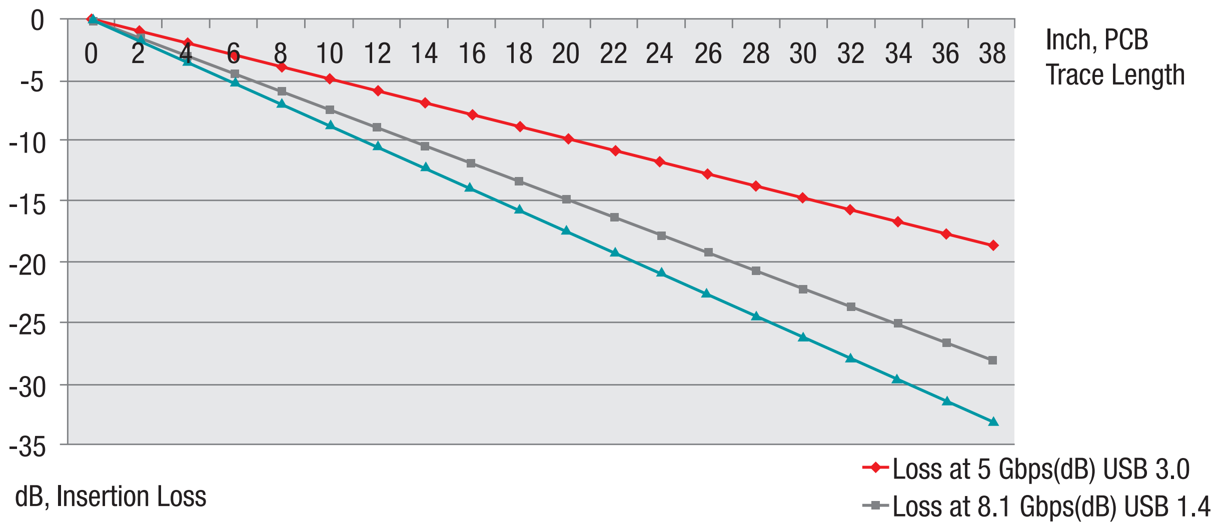

***Figure 3**. USB Type-C USB/DisplayPort insertion loss profile for 4-mil-wide FR-4 PCB trace loss.*

board (PCB) traces. **Figure 3** shows USB Type-C and DisplayPort signal loss with a 4-mil FR-4 PCB trace length. With a 10-inch PCB trace, USB 3.0 at 5 Gbps will suffer a 5 dB loss; DisplayPort 1.4 at 8.1 Gbps will suffer a 7.3 dB loss; and USB 3.1 Gen 2 will suffer an 8.7dB loss.

The accumulation of system insertion loss from PCB traces and cables may result in a signal that's not compliant with the USB, DisplayPort or HDMI specification, thus causing interoperability issues with other devices. In a USB system, certain loss budgets are allowed for electrical compliance. In the USB 3.0 5 Gbps compliance environment, the total end-to-end channel loss allowed is about 20 dB. The USB 3.1 Gen 2 10 Gbps compliance environment allows a total end-to-end channel loss of -23 dB.

In USB Type-C ecosystems, the USB host and device are interchangeable because of the flip-ability of the connector, and dual-role data; thus, the loss budget is evenly distributed to both host and device. In USB 3.0, both host and device have a -6.5 dB allowable channel loss and -7 dB allowable loss at the cable. In a USB 3.1 Gen 2 system, both host and device have an allowable -8.5 dB loss, while the cable has an allowable -6 dB loss that will still pass USB certification.

Figures 4 and 5 show channel-loss allocation by the USB specification at 5 Gbps and 10 Gbps, respectively.

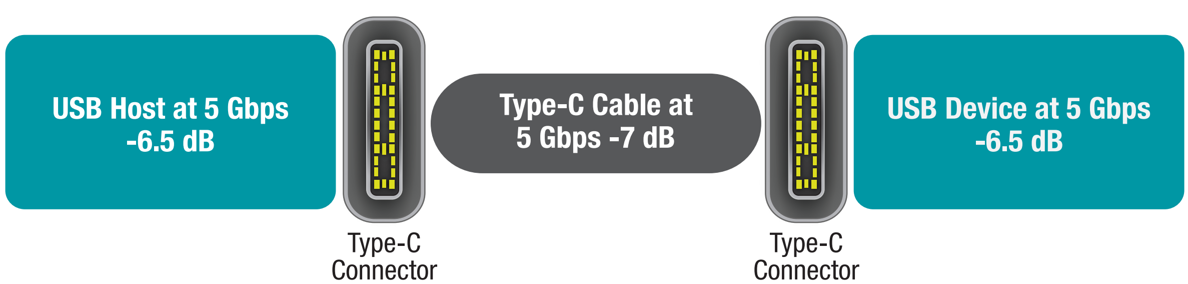

***Figure 4**. USB 3.0 at 5 Gbps USB Type-C channel-loss budget.*

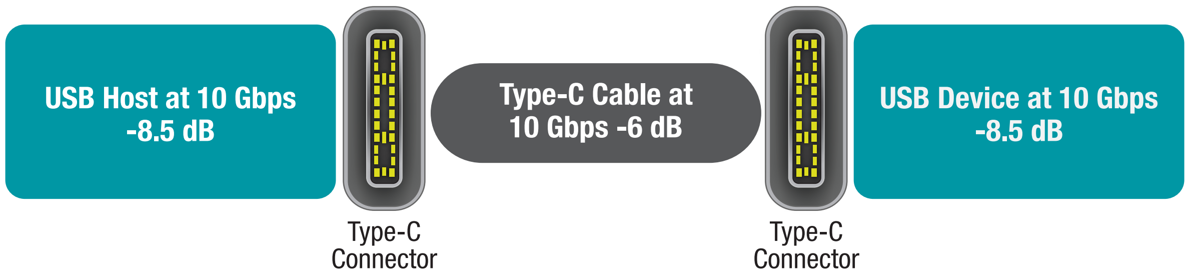

***Figure 5**. USB 3.1 Gen 2 at 10Gbps USB Type-C channel-loss budget.*

If the PCB trace or cable length is long enough such that USB channel losses exceed the allocated loss budget for the host, device or cable, using a signal conditioner in the data path reduces the channel insertion loss.

Signal conditioners clean up system jitter caused by insertion loss or other factors. There are two types of system jitters: deterministic jitter and random jitter. Channel insertion loss is one kind of deterministic jitter, causing inter-symbol interference (ISI) that a redriver can remove. Random jitter is often caused by thermal noise that a retimer can remove. See my blog post, How to select a redriver or retimer for HDMI 2.0 jitter cleansing, for more information on redrivers vs. retimers.

A redriver uses equalization techniques to compensate the high-frequency element of the channel loss and realize an equalized output frequency response. Pre-emphasis and de-emphasis are a couple of techniques often used together. Pre-emphasis (also called pre-shoot) boosts the high-frequency signal before transmission. De-emphasis reduces the low-frequency signal. Both pre-emphasis and de-emphasis can achieve the same frequency equalization results. As the majority of jitter comes from channel insertion loss, a redriver is the most simple and cost-effective solution for compensating ISI jitters in order to meet standards compliance.

The benefit of linear redrivers

You can think of a linear redriver as a trace shortener. It creates frequency-dependent gains for the channel to compensate insertion loss without incurring any channel distortion. From an electrical standpoint, it makes a longer trace behave as a shorter trace. **Figure 6** shows the insertion loss of a 28-inch trace (purple) and a 12-inch trace (red). Placing a linear redriver at the end of the 28-inch trace reduces the channel insertion loss, while the channel output results equal a PCB trace shortened by 16 inches. As long as the incoming signal is within the linear redriver's defined linearity range, the incoming signal will be faithfully passed through its output, together with its pre-emphasis, or de-emphasis inherent with the original signal.

There are a few distinct advantages of linear redrivers compared to limiting redrivers. The fact that a linear redriver preserves source de-emphasis and pre-emphasis allows it to truthfully represent the original source signal at the receiver end. Even though a limiting redriver can generate de-emphasis, it cannot produce pre-emphasis, which is a normative requirement for USB 3.1 Gen 2 at 10 Gbps. Thus, a limiting redriver could cause channel distortion.

A linear redriver is particularly beneficial in the DisplayPort ecosystem. It is transparent to DisplayPort link training because it preserves

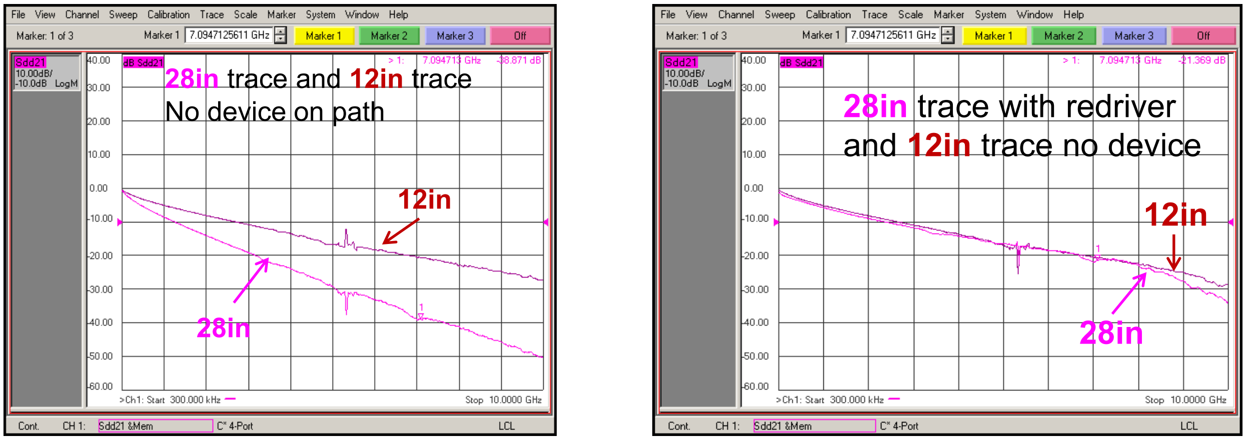

Figure 6. The benefit of linear redrivers.

source capability. To achieve the best channel quality with a linear redriver, you should establish link training between source and sink. While a limiting redriver will break a DisplayPort electrical link due to the introduced channel distortion, link training is established between the limiting redriver and the source or sink, this will result in less-than-optimal channel quality and a higher bit-error rate in the channel.

Given its transparent channel nature, a linear redriver can also enable an effective decision feedback equalizer (DFE) for better system performance in the receiver. Discontinuities before the linear redriver are visible to the receiver and can be compensated by the DFE loop, whereas with a limiting redriver, the information is lost and compensation cannot occur.

A linear redriver also offers the flexibility of device placement and channel equalization (EQ) flexibility between long and short receive channels. A certain level over EQ is acceptable for linear redrivers because it enables optimization between the long and short channel; going over EQ effectively becomes a pre-emphasis-provided swing that is within the linearity range. With a limiting redriver, going over EQ will result in uncorrectable jitter.

On the other hand, if the source is noncompliant due to voltage swing or de-emphasis and pre-emphasis, a limiting redriver can launch a large swing signal with de-emphasis and potentially make the channel compliant.

TI redriver solutions for USB Type-C ecosystems

For both host and device, it is important to make sure that the total channel losses are within the USB Implementers Forum-defined budget. By adding a redriver into the system, you can ensure system compliance and compensate channel losses to meet specifications.

TI's TUSB542 is a USB 3.0 5 Gbps USB Type-C 2-to-1 redriver switch. It provides up to 9 dB equalization and 6 dB de-emphasis with output swing settings of 900 mV and 1.1 V. The TUSB542 has very low power and a small footprint, thus providing a cost-effective solution to improve USB 3.0 signal quality.

The TUSB211 is a USB 2.0 bidirectional redriver. Without breaking the D+ and D- trace, using advanced analog edge-boosting technology, it can offset signal-integrity impairments caused by external switches, connectors and electrostatic discharge (ESD) to pass USB certification.

Both the TUSB542 and TUSB211 can be used on either the host or device side in applications such as PCs, laptops, smartphones and any USB Type-C interface requiring USB 3.0 and USB 2.0 data rates. **Figure 7** shows how the TUSB542 and TUSB211 enable reliable USB Type-C data transfer.

The TUSB546 and TUSB1046 are USB Type-C DisplayPort and HDMI Alternate Mode linear redriver switches. The TUSB546 supports 5 Gbps USB and 8.1 Gbps DisplayPort 1.4, while the TUSB1046 supports 10 Gbps USB and 8.1 Gbps DisplayPort 1.4. Both devices are pin-to-pin compatible, enabling smooth USB speed upgrades without design changes. **Figure 8** shows the TUSB546 and TUSB1046 interconnect; they take the DisplayPort and USB input, based on the USB Power Delivery Alternate Mode protocol, multiplex and redrive the signal over the USB Type-C interface.

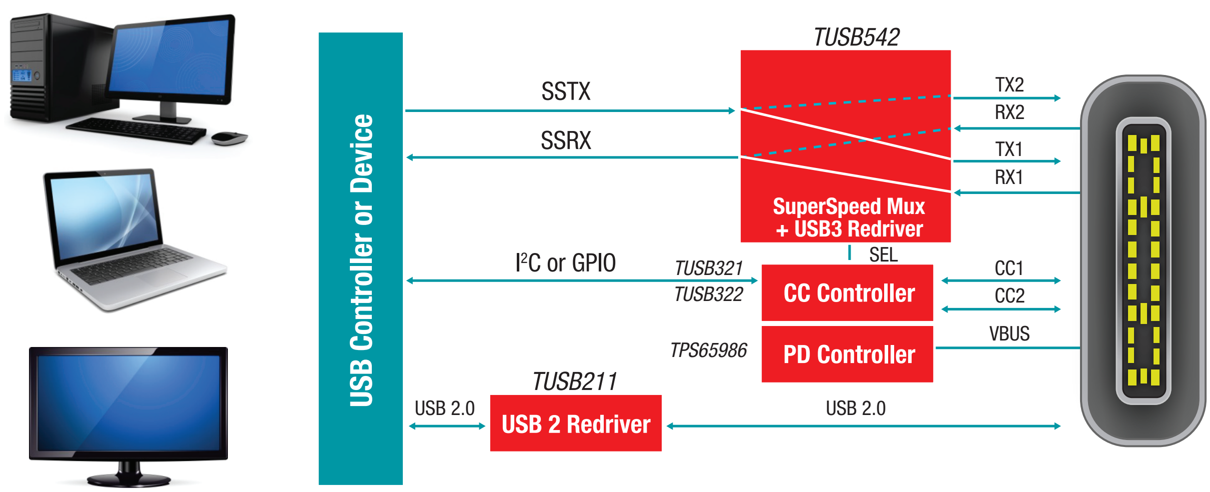

Figure 7. Enabling reliable USB Type-C data transfer with the TUSB542 and TUSB211.

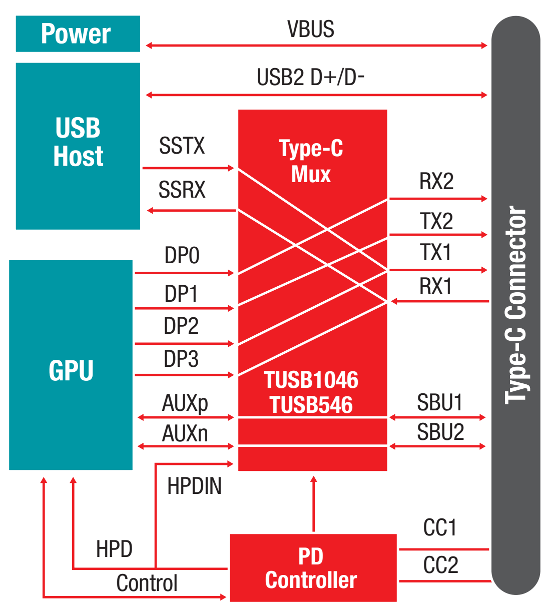

Figure 8. The TUSB546 and TUSB1046 enable better USB Type-C Alternate Mode signal quality.

You can observe excellent performance from the 10 Gbps and 5 Gbps USB and 8.1 Gbps DisplayPort signal when using the TUSB546 and TUSB1046 at the USB Type-C connector. The TUSB1046 can support up to 11 dB of EQ for 10 Gbps USB and 14 dB EQ for 8.1 Gbps DisplayPort, with very little jitter added in the system. **Figure 9** shows how the TUSB546 can improve the eye diagram over a 14-inch PCB trace, applying 4.4 dB of EQ on the 10 Gbps USB interface.

The TUSB544 is a multiprotocol bidirectional linear redriver that can redrive four USB Type-C high-speed lanes based on the DisplayPort Alternate Mode configuration; each USB Type-C lane can be either DisplayPort or USB. This device can work on both the source or sink side as well as inside a USB Type-C cable to extend trace or cable lengths with good signal integrity. **Figure 10** shows an end-to-end USB Type-C solution with the TUSB544. You can use this device when USB and DisplayPort multiplexers are integrated into the central processing unit (CPU) and help transfer USB Type-C signals over longer distances.

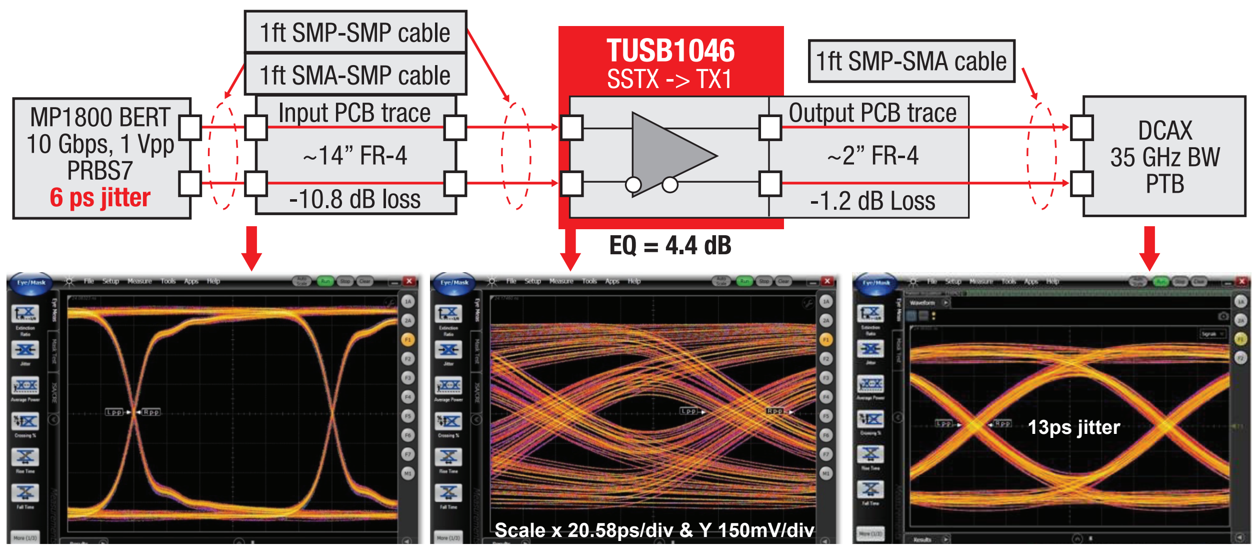

__Figure 9.__ Excellent USB 10 Gbps performance with the TUSB1046.

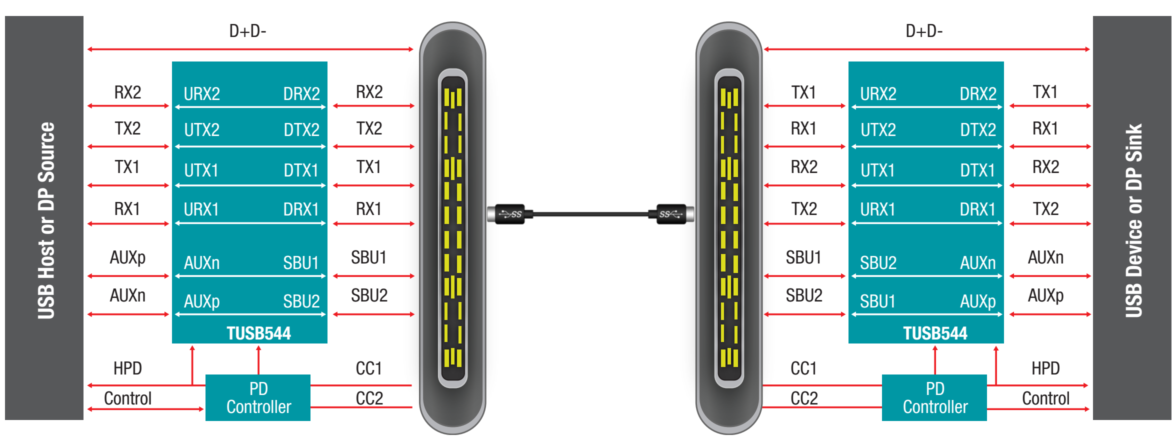

__Figure 10.__ End-to-end USB Type-C Alternate Mode solution with the TUSB544.

Conclusion

Based on the USB Type-C report from IHS, potential USB Type-C device shipments will reach 2 billion by 2019. Having a robust interconnect between these devices will become a critical requirement. Texas Instruments has USB Type-C redrivers for every application need. The TUSB211, TUSB542, TUSB546, TUSB1046 and TUSB544 can support USB Type-C ranging from USB 2.0, USB 3.0 5 Gbps, USB 3.1 10 Gbps and DisplayPort up to 8.1 Gbps data rates. These devices not only provide excellent performance for USB across all speed grades, but the linear redriver is particularly good at enabling a better DisplayPort signal over USB Type-C, providing a smooth user experience and ease of design for greater USB Type-C system performance.

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