

Strengthening the USB Type-C™ signal chain through redrivers



Zhihong Lin,
Product Marketing
Texas Instruments

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

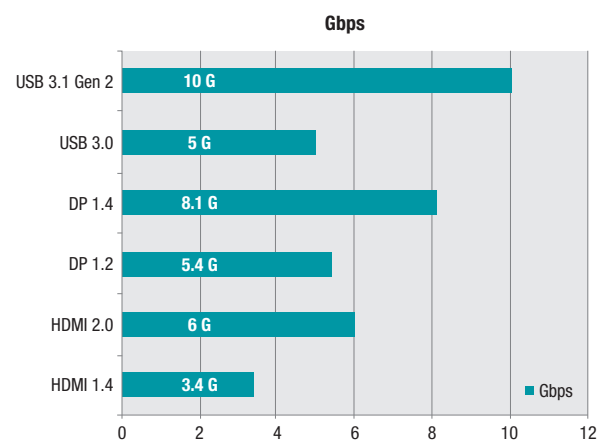


Figure 1. USB, DisplayPort and HDMI speed based on standard revision.

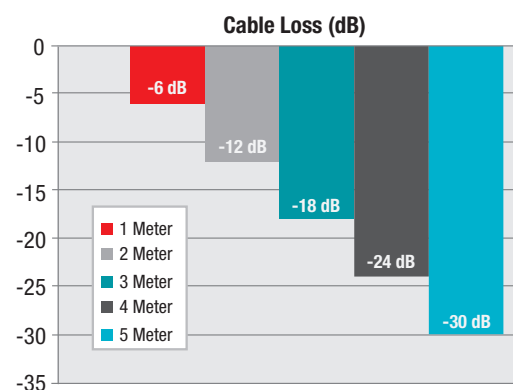


Figure 2. USB Type-C cable loss profiles for 10 Gbps signals.

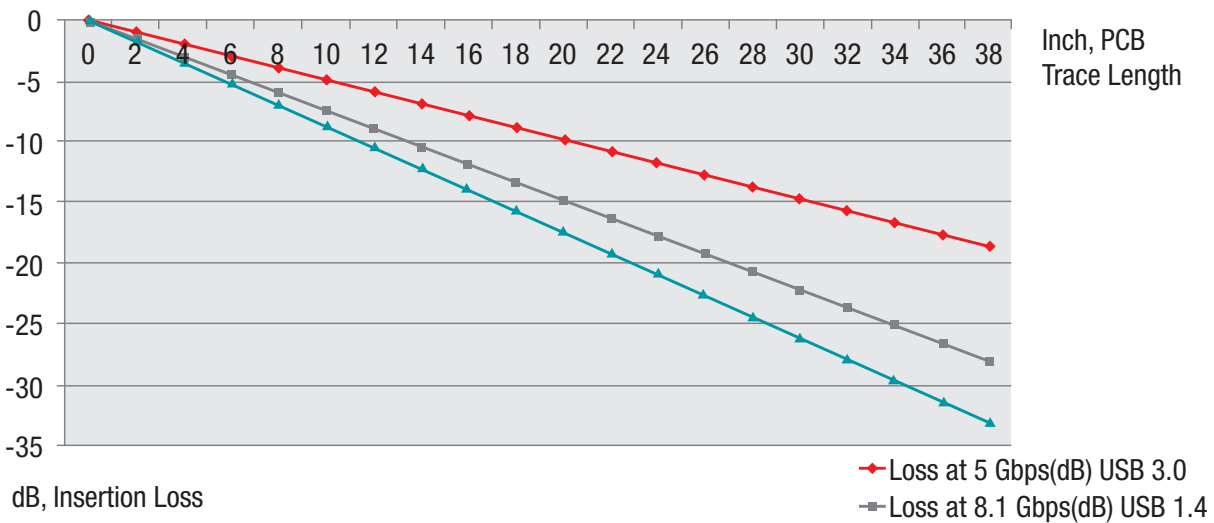


Figure 3. USB Type-C USB/DisplayPort insertion loss profile for 4-mil-wide FR-4 PCB trace loss.

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 8.7 dB 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.

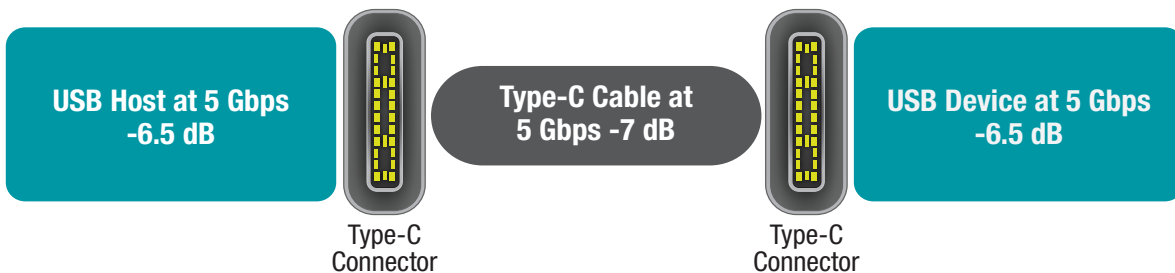


Figure 4. USB 3.0 at 5 Gbps USB Type-C channel-loss budget.

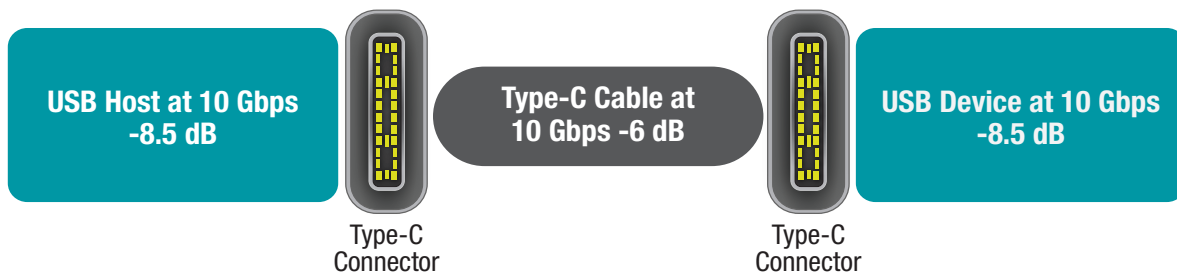


Figure 5. USB 3.1 Gen 2 at 10Gbps USB Type-C channel-loss budget.

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

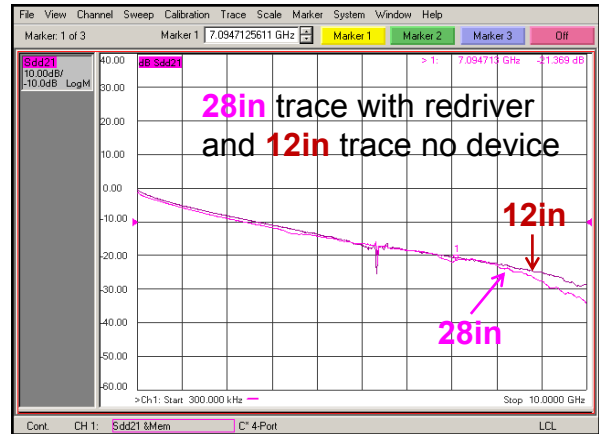
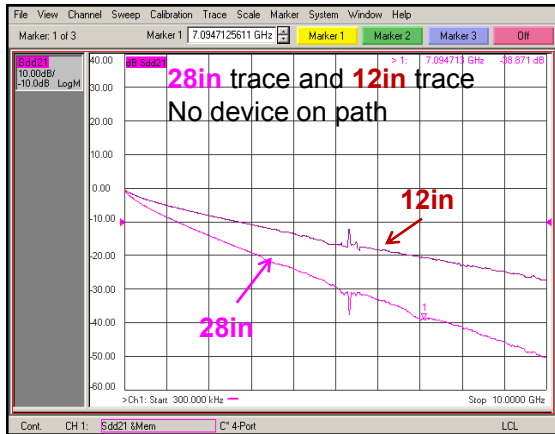


Figure 6. The benefit of linear redrivers.

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.

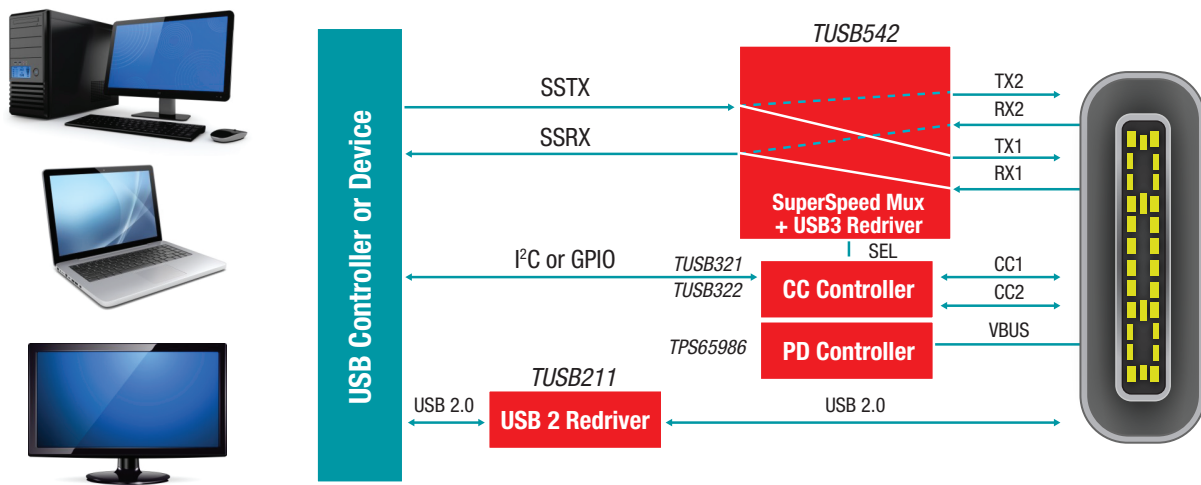


Figure 7. Enabling reliable USB Type-C data transfer with the [TUSB542](#) and [TUSB211](#).

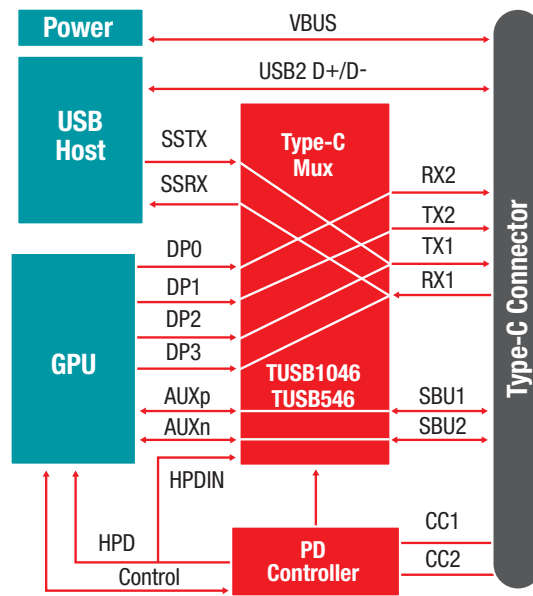


Figure 8. The [TUSB546](#) and [TUSB1046](#) enable better USB Type-C Alternate Mode signal quality.

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.

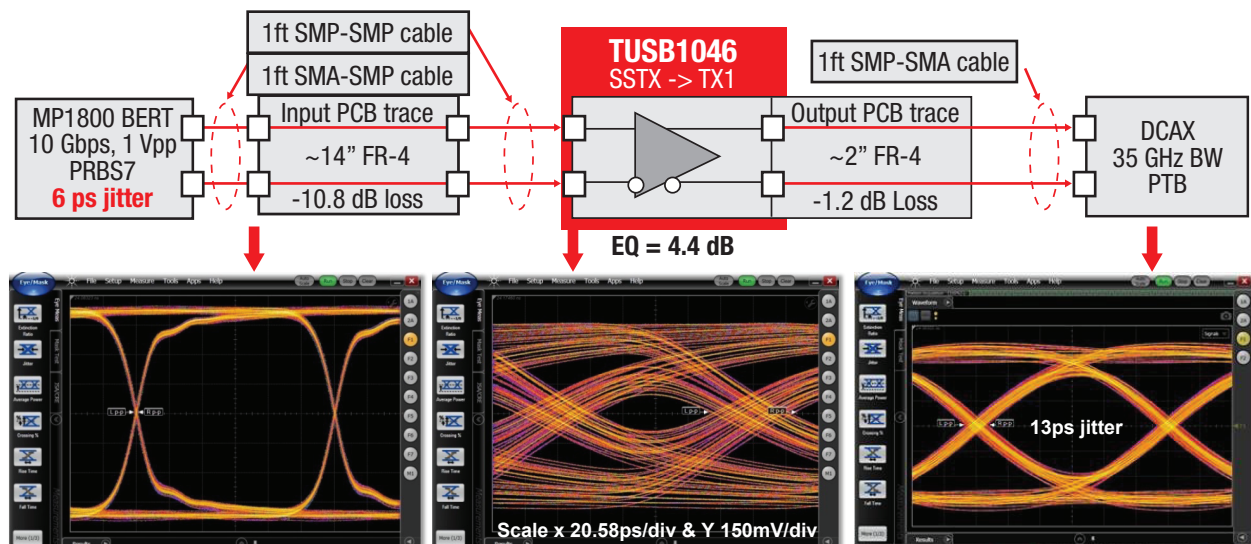


Figure 9. Excellent USB 10 Gbps performance with the TUSB1046.

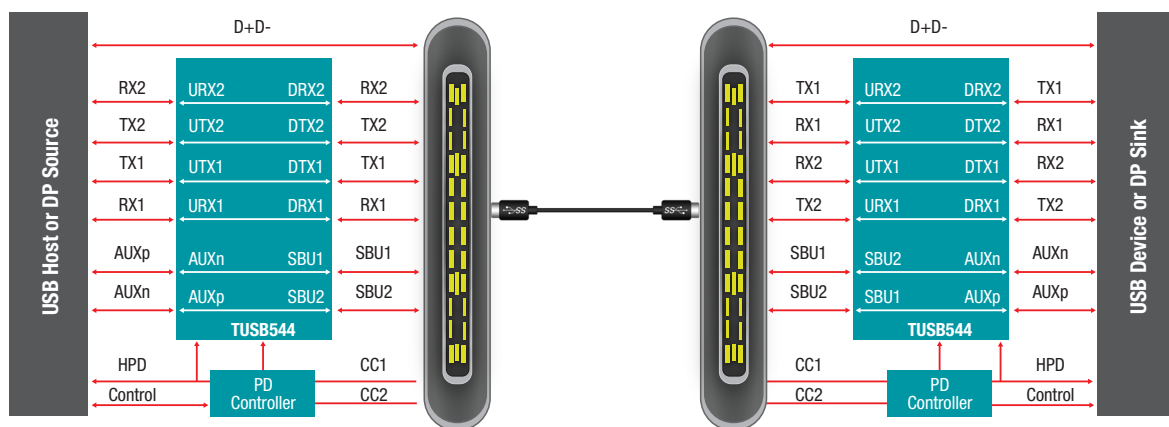


Figure 10. End-to-end USB Type-C Alternate Mode solution with the TUSB544.

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.

Acknowledgments

The author would like to thank Chris Griffith, Anwar Sadat, Mike Campbell, Hassan Ali for their contribution to this paper.

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

The platform bar is a trademarks of Texas Instruments. All other trademarks are the property of their respective owners.

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/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated