Addressing Power And Data Integrity Challenges For USB Type-C Applications

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The latest iteration of the USB standard, USB Type-C redefines integrated data, power and connectivity by providing a small, versatile interface that allows use of a reversible-plug connector. USB Type-C connects to both hosts and devices, thus replacing Type-A and Type-B connectors and cables. Building on the continued success of the USB standards, USB-C combines the SuperSpeed USB 10Gbps (USB3.1) data rates and the USB Power Delivery (PD) specification with a new miniaturised, flippable connector and bidirectional cable specification that offers extra convenience and versatility for end users.

Fundamental to successful USB Type-C designs is the implementation of circuitry for management of power and maintenance of data integrity. This requires careful selection of key components for power and data switching as well as interface protection.

In this whitepaper, Toshiba looks at the challenges of power and data transmission faced by engineers working on USB-Type C designs and identifies the latest semiconductor technologies that can help to address those challenges.

Introduction

The latest evolution of the USB standard is the USB type-C interface. It combines three essential features to address user requirements:

- The implementation of the USB power delivery (PD) specification to improve charging capabilities.
- The implementation of USB 3.1 Super Speed data transmission to tackle the increasing need for bandwidth in data transmission.
- The introduction of a reversible connector to ensure ease of usability for the end user.
- Bi-directional capability - any end can fit a device, without the user worrying about what goes where.

Charging power up to 100W

The USB Power Delivery (PD) specification responds to the success of initiatives to standardise chargers for mobile devices, leveraging the existing 5V USB 2.0VBUS supply voltage and Micro-USB connector. These moves have eliminated the need for manufacturers to ship each device with its own dedicated charger, which reduces waste when the user upgrades to a later phone. USB PD raises the maximum power that can be distributed via a USB connection, and specifies profiles at 18W, 36W, 60W and 100W (limited by safety legislation on power distribution). The capability to transmit more power to devices brings two opportunities:

- Faster charging
- More devices can be powered via USB, reducing the need to manufacture and dispose of large numbers of external AC/DC power adapters

There are multiple power profiles, operating at voltages between 5V and 20V and at currents up to 5A, as shown in figure 1. Power-consuming devices must negotiate for the power they need after the connection has started up in the default 5V/2A mode (that ensures the safety of older USB2.0 devices).

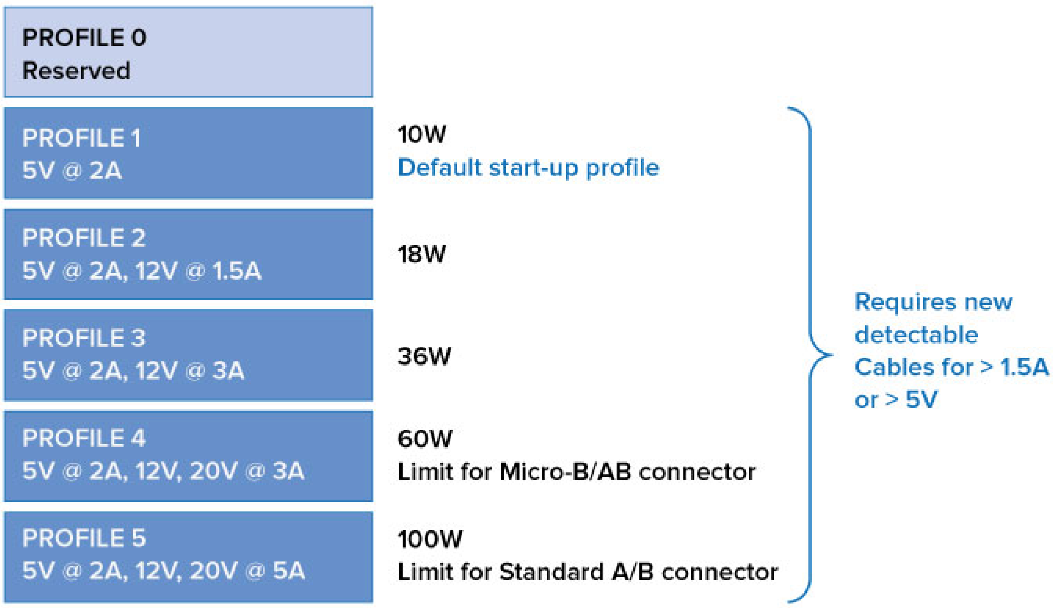

Figure 1. Support for multiple profiles ensures devices can negotiate for the power they need.

The PD specification also allows devices to act as either a source or a consumer of power via the USB connection. A monitor with a mains supply, for example, can power a laptop through its USB-C port, and act as a hub for other devices such as external disk drives. This eliminates the need to plug the laptop into a mains power socket. Data exchanges between the two devices are unaffected by the exchange of power.

Data Speeds to USB 3.1 and Beyond

USB-C supports all previous USB data rates up to SuperSpeed USB 10Gbps as defined in the USB 3.1 specification. Moreover, USB-C has scope to support data rates up to 20Gbps ensuring future-proof scalability.

The USB-C physical layer interface contains two sets of data pairs (D+/D-) to maintain backwards compatibility with the older specifications such as USB 2.0, while supporting the higher speeds of USB 3.0 and USB 3.1. USB-C also incorporates alternate mode support to allow a guest standard such as HDMI. This allows video/audio to be transmitted over the same cable as USB data and power if required.

Reversible Connector Interface

The USB-C plug is not polarised, and can be inserted either way. In addition, only one style of plug and socket is defined: hence cables are reversible, and power and data can flow in either direction between devices.

A USB-C cable can be used with legacy USB type-A/B, Mini-USB and Micro-USB connectors by using an adapter. No electrical modification is required. As various items of older equipment become upgraded over time, fewer and fewer adapters will be needed. The alternate connectivity standards (e.g. VGA, HDMI and DisplayPort) can also be accommodated using adapters.

The USB-C connector has 24 pins, on a 0.5mm pitch, and an 8.4mm-by-2.6mm form factor. Pin assignments are shown in figure 2. This diagram illustrates how the new standard is backwards compatible with legacy USB 2.0 equipment, while catering for USB 3.1 and PD specifications. The Configuration Channel (CC) pins shown are used for determining cable orientation and providing the PD negotiations between power-source and consumer devices.

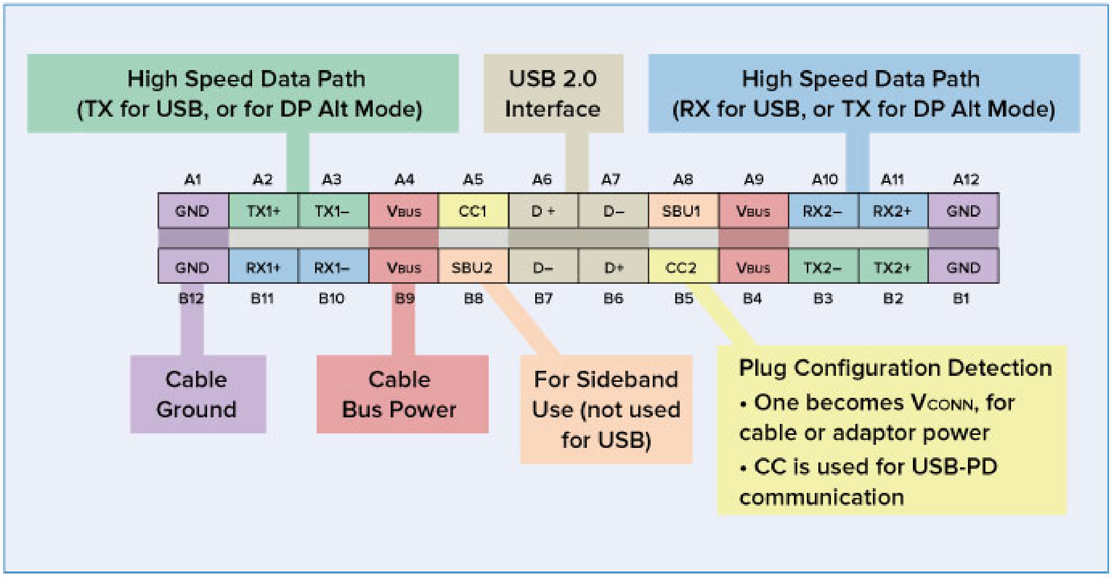

Figure 2. USB-C pin assignments.

Design Requirements for USB-C

The extra performance and convenience offered by USB-C makes for more complex circuitry on the PCB behind the sleek external port seen by the user.

In contrast with USB 2.0 and USB 3.0/3/1 connections, the inclusion of USB PD in the USB-C interface requires power control switches to be capable of withstanding 20V or higher. At the same time, low on-resistance is a pre-requisite to minimise energy loss, unwanted thermal challenges, and to comply with USB minimum-voltage regulations.

For USB-C data lines external protection against electrostatic discharge (ESD) is needed as the high-speed transceivers are increasingly susceptible to these kinds of events. Transient Voltage Suppression (TVS) diodes are commonly used. However, the extremely high maximum data speed (10Gbps, per USB 3.1) requires designers to pay careful attention to the trade-off between TVS terminal capacitance (Ct) and the available ESD protection level. The first is mandatory to avoid data distortion, while the latter is needed to ensure robustness of the design against ESD events

The final challenge is to be addressed comes from the new reversible connector interface. This requires internal switching devices to ensure data-bus pin mapping according to how the connector is inserted, while maintaining high-speed data transmission via two different paths.

Power Control Solutions

As mentioned, several approaches to controlling power delivery are viable. The most suitable for a given application is likely to be governed by component cost, solution size, power consumption, and demand for extra protection features (e.g. over-voltage or thermal-shutdown).

The simplest two-MOSFET power switch as shown in figure 3 can be implemented by using P-channel MOSFETs. Due to the increase in allowable maximum voltages adequate voltage ratings need to be observed. A -30V MOSFET such as those in Toshiba's SSN6J50xNU series is suitable for this task. These devices allow designers to take advantage of the +20/-25V VGSS to control the gate directly from the PMIC eliminating the need for a separate driver IC. Suitable devices include the SSM6J507NU with its low on-resistance of just 19mΩ (typical, at VGSS -4.5V), or the competitively priced SSM6J509NU. Both can be used in applications operating in any of the five profiles defined in the PD specification.

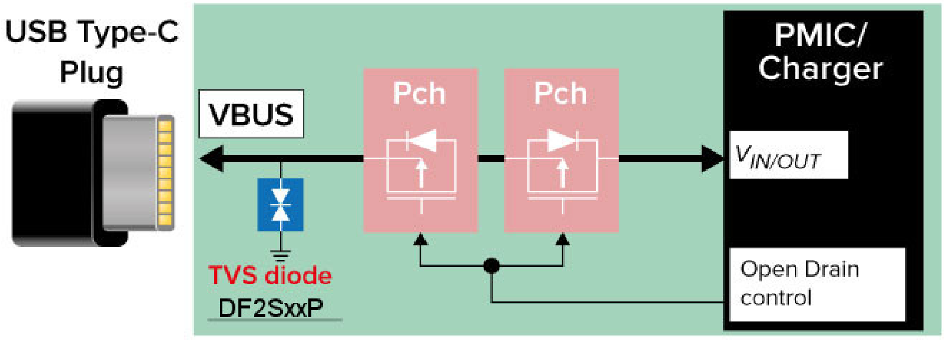

Figure 3. Simple power-switch solution using two Toshiba SSN6J50xNU P-channel MOSFETs.

As an alternative to the simple MOSFET solution, an integrated load switch can be selected. This creates a more compact solution that occupies less PCB real-estate as well as providing built-in protection features. Toshiba's TCK30xG 28V load switches have integrated thermal shutdown and under-voltage lockout, and are available with 6.6V, 10.5V or 15.5V fixed over-voltage protection. Additional features that are valuable in USB-C applications include low on-resistance (in the region of 35-65mΩ), adjustable over-current protection up to 3.0A (set by a single external resistor), and adjustable slew rate (determined by an external capacitor). This combination of capabilities makes the TCK30xG family the most compact solution for USB charging up to Profile 3.

Furthermore, by using two switches in a Daisy Chain configuration it is possible to realize a circuit consisting of a primary and a secondary charging option as shown in Figure 4 (USB and wireless charging combination). The TCK30xG devices are used in a 2-input/1-output configuration that supports two different charging options with the USB port being the default source.

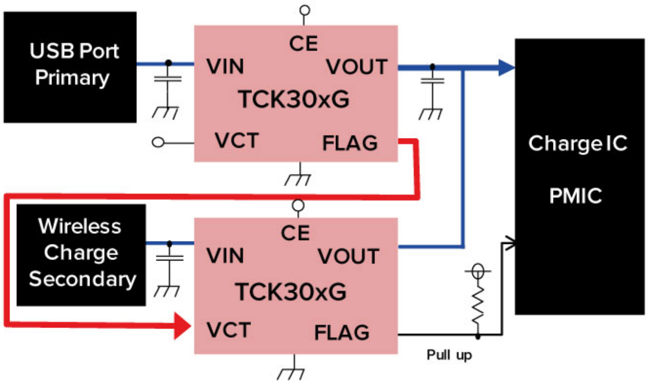

Figure 4. Power control using 28V load-switch IC.

As an alternative to the TCK30xG family, the new TCK34xG series offers additional features such as adjustable slew rate control and current limitation. These values are adjusted with external capacitors and resistors as shown in figure 5.

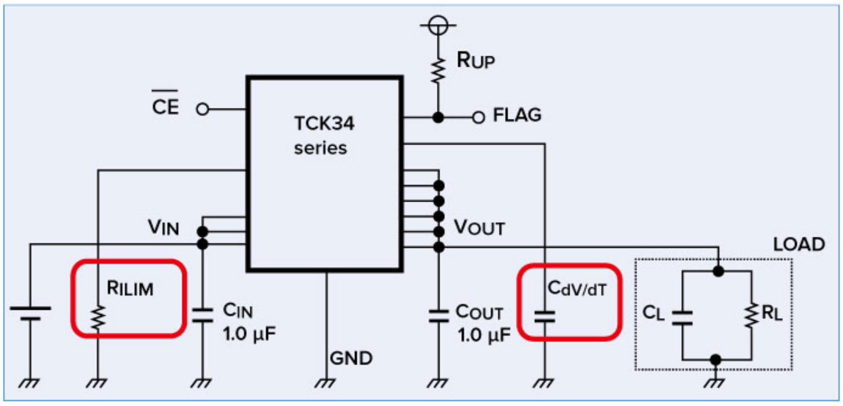

Figure 5. The TCK34xG series allows over-current limit and slew rate to be set by external components.

As the new TCK34xG family also offers an over voltage lockout function beyond 20V this switch family is the ideal integrated solution to support USB charging with Profile 4.

To take full advantage of the lowest on resistance provided by N-channel MOSFETs it will be necessary to move from the integrated load switch solution back to a solution comprising of discrete MOSFETs and a suitable driver IC. A dedicated gate driver IC for this application is the TCK40xG shown in figure 6, Based on a high voltage IC process the TCK40xG can withstand up to 40V and has a built-in charge-pump circuit to generate the 4V-12V gate drive to control the external low RDS(on) n-channel MOSFETs.

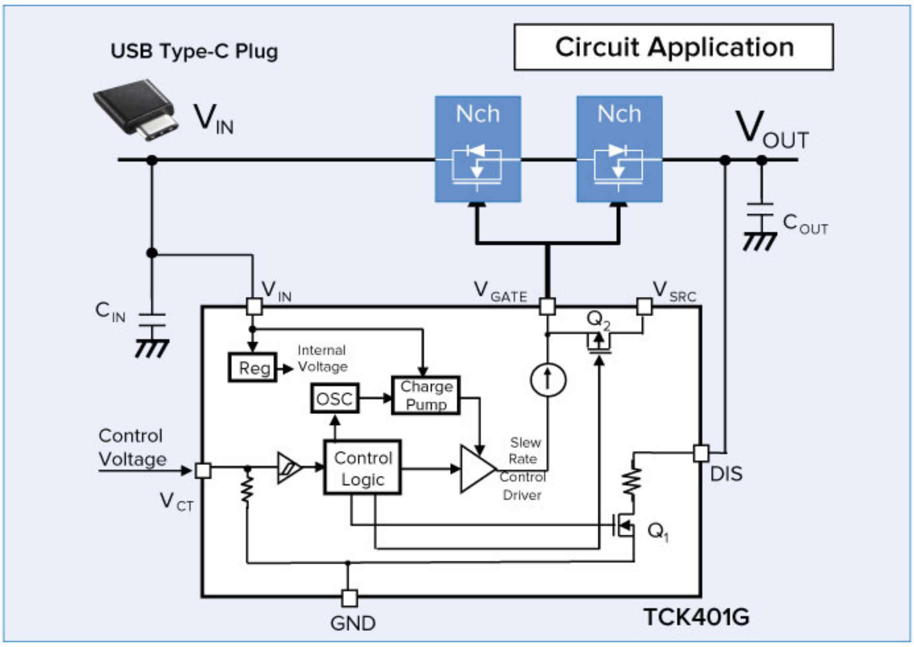

Figure 6. USB-C power control with the TCK40xG and two N-channel MOSFETs.

A suitable MOSFET is the SSM6K513NU, which has an extremely low on-resistance of 8mΩ (typical at VGS 4.5V).

Figure 7 shows the effect on thermal performance, due to the low on-resistance of the SSM6K513NU when controlled using the TCK40xG external gate driver. The SSM6K513NU pair, on the left, run 16°C cooler than comparable devices by a competing manufacturer (shown on the right), when simulating Profile 5 (100W) power delivery at 5A.

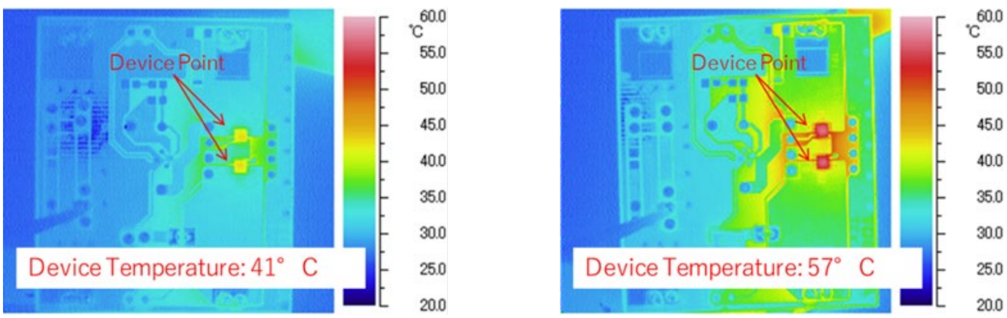

Figure 7. Low on-resistance translates into lower operating temperatures.

Considering the space requirements, it is worth noting that the combination of two n-channel MOSFETs with the TCK40xG driver IC can be built within a PCB area of 15mm2 (2x2mm SOT1220 packages, combined with the 0.8mm x

1.2mm 6-ball WCSP TCK40xG driver). This is a compact solution considering the very low overall on-resistance of the power switches. Compared to the other approaches, the dual P-channel MOSFET solution requires about 10mm2, while a circuit using a single-chip load-switch IC such as the TCK30xG has an extremely small footprint of about 2.3mm2. However, as usual, the smaller PCB space offers less performance considering the intrinsic losses and the supported power profiles.

Surge Protection Diodes

When it comes to considering surge protection devices for the VBUS lines it is important to ensure that the working voltage of the selected device covers the maximum possible voltage as the different power profiles allow for VBUS voltages between 5V and 20V. With its new DF2SxxP- family, Toshiba provides high peak pulse current TVS diodes that address this issue by supporting contact discharge protection up to ±30kV in a compact package

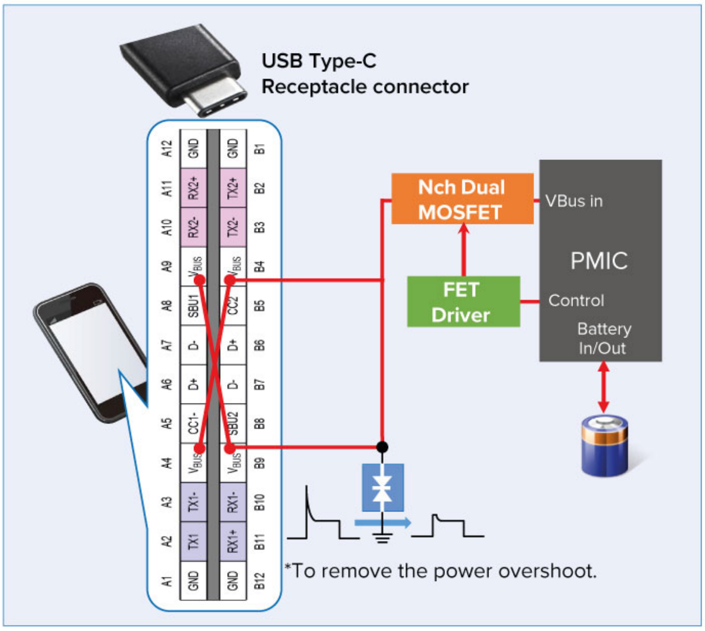

Figure 8. Surge protection for VBUS must perform well at any voltage specified in the USB PD profile.

Protecting Data Lines

In contrast to VBUS protection where high peak pulse current capability as well as support of 20V VBUS voltage are essential for the data line protection, minimum distortion of the high-speed data is key. Therefore, TVS diodes that protect the data lines of the USB-C interface against ESD events should provide protection in accordance with the IEC-61000-4-2 standard (including contact discharge up to ±20kV) as well as having small footprint and low Ct.

A straightforward approach to the ESD protection problem is the use of single low capacitance (0.2pF) TVS diodes such as the DF2B5M4SL, which comes in a SOD962 package (0.6mmx0.3mm). Looking to the future, next generation SOD992 packaging measuring just 0.4mmx0.2mm is already on the horizon.

In addition to the single TVS diode it is also possible to use a multi-bit low capacitance TVS diode array such as the Toshiba DF5G5M4N. This array can provide protection for two signal pairs (RX1+/RX1-, TX1+/TX1-). The devices feature a DFN5 package outline measuring only 1.3mm x 0.8mm and enable a space-efficient flow-through layout where a single package can be mounted onto the data bus. The selected capacitance Ct of just 0.2pF is required to preserve signal integrity and minimise insertion loss. Figure 9 illustrates the effect of increasing Ct on insertion loss, as seen in the graph to the left, and on signal integrity expressed in the eye diagrams on the right.

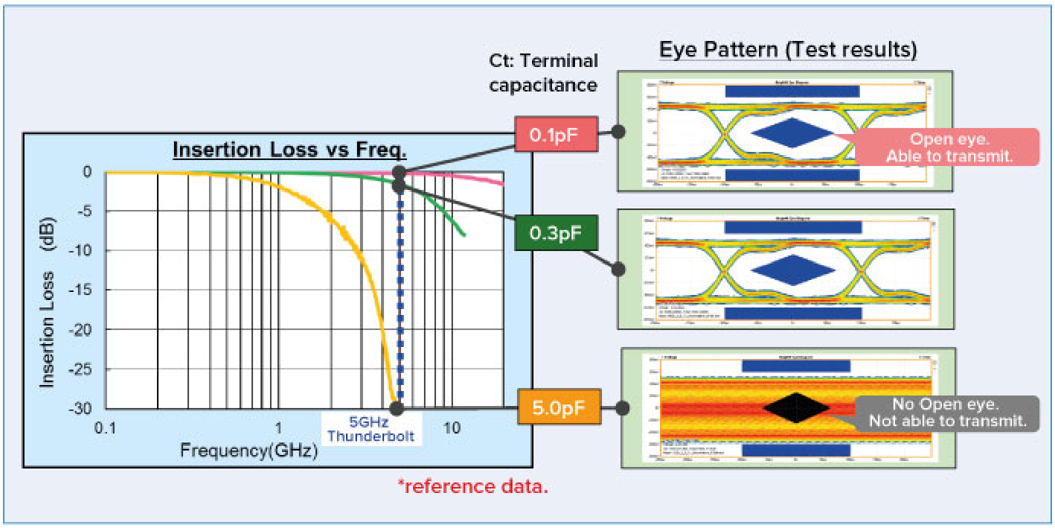

Figure 9. Effect of TVS diode Ct on eye pattern and insertion loss.

Switching Data Lines

One final challenge in a USB type-C design might arise from the requirement to switch the data lines, as the reversible connector provides a separate data path on each side, which means the active USB path needs to be switched externally. In this case, a bus switch can provide the final element in solving the data-line protection and control challenges implicit in the high-speed nature of USB-C interconnects. A switch such as the Toshiba TC7PC13212MT, for instance, is needed to adapt the bus pin assignments depending on which way the USB-C plug is flipped upon insertion (figure 10). Figure 11 shows the result of compliance testing at USB3.1 data rates, illustrating how signal integrity can be maintained at up to 10Gbps.

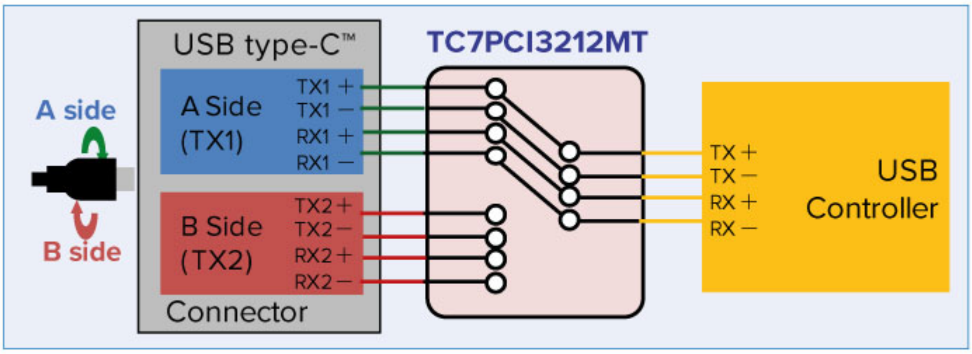

Figure 10. A low-loss SPDT bus switch for two differential channels supports the ‘flippable’ freedom.

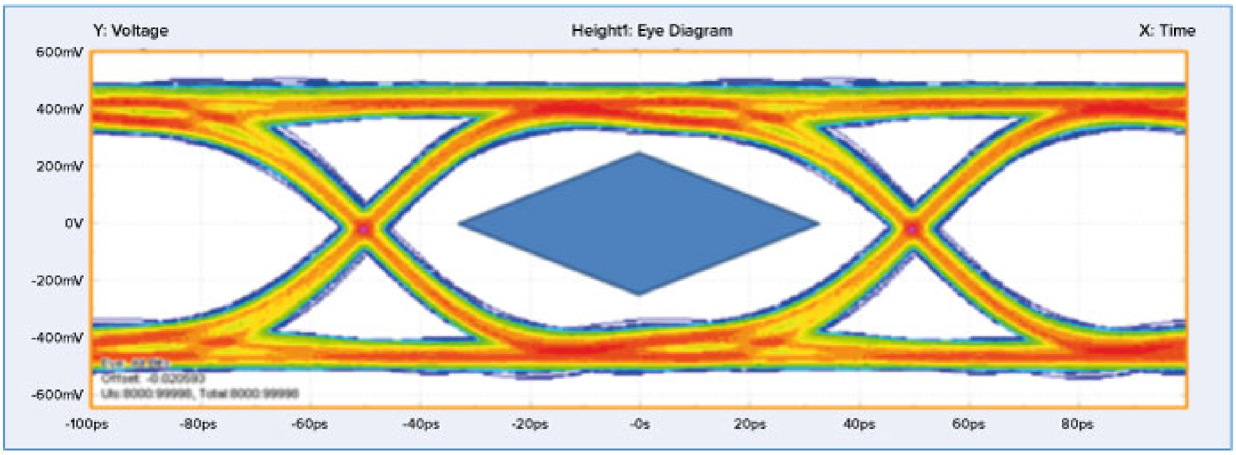

Figure 11. USB 3.1 compliance test result for TC7PC13212MT at 10Gbps.

Conclusion

USB-C is in the market now and offers important benefits:

- OEMs can create advanced, slimline designs, and so offer attractive new products
- Reducing the number of chargers/adapters for more types of equipment
- Increased ease of use, flexibility and affordability of backwards compatibility for continued use of legacy equipment

Delivering these advantages demands more complex circuit design. The transmit/receive data pairs require ESD protection comparable to that provided for USB 3.1 ports, while the power-line control and protection requirements will become considerably more challenging.

There are several ways to provide the required control and protection. These involve various combinations of discrete and integrated components, as described in this paper. These choices give equipment designers the flexibility to trade PCB footprint, bill of materials and efficiency/thermal performance to achieve an optimal solution depending on their specific application.

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