

40 Gbps High-Speed Interface Cable “Thunderbolt 3”

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Thunderbolt 3 is a high-speed and high-capacity input/output standard that enables bi-directional 40 Gbps transmission using a reversible USB Type-C connector. Based on Intel Corporation's technical specifications, Sumitomo Electric Industries, Ltd. has developed Thunderbolt 3 cables by combining its flexible and durable cables and high-speed transmission technologies to be the world's first approved vendor of Thunderbolt 3 cables. This paper presents an overview of Thunderbolt 3 cables using Sumitomo Electric's coaxial cables.

Keywords: Thunderbolt, USB Type-C, high-speed transmission, coaxial cable

1. Introduction

The speed of external interfaces for consumer use has been continuously increasing. Figure 1 shows the trend of increasing transmission speed per lane*1 of major external interfaces.

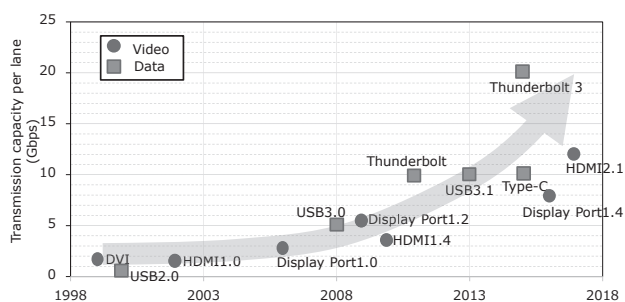


Fig. 1. Increasing speed of consumer external interfaces

These interfaces are mainly used to support video streaming and data transmission. For video streaming, 8K (Super Hi-Vision) broadcasting, which features 16 times more pixels than the Full HD (Hi-Vision) standard, is scheduled to start in 2018. To cope with this development, HDMI 2.1,*2 released in 2017, can handle the transmission capacity of up to 12 Gbps per lane and enables uncompressed transmission of 8K (7,680 × 4,320 pixels) at the frame rate*3 of 60 Hz.

For data transmission, USB has been developing as the general standard. USB Type-C⁽¹⁾ (“Type-C”) is the latest standard. Table 1 shows the comparison between the USB

standard and USB Type-C standard.

In line with the launch of Type-C in 2015, the Type-C connector was introduced for both PCs and peripheral devices. The maximum transmission speed of 10 Gbps per lane has been fully attained. Power supply of up to 100 W has been enabled by USB Power Delivery*4 (a power supply standard).

The Type-C connector is smaller than conventional connectors and enables reversible connectivity. The scope of application has been expanding from PCs and peripheral devices to mobile terminals and monitors. The Type-C connector is considered to be the most likely candidate as the standard consumer connector.

In 2012, Sumitomo Electric Industries, Ltd. released a Thunderbolt cable that achieves a bi-directional transmission speed of up to 20 Gbps to meet the needs of high-speed external interfaces. The Thunderbolt 3⁽²⁾ cable presented in this paper is the latest version of Thunderbolt, which achieves a bi-directional transmission speed of up to 40 Gbps (the highest speed for consumer interfaces).

This paper contains an overview and an application example of Thunderbolt 3, and presents the structure, characteristics, and reliability evaluation results of our Thunderbolt 3 cable.

2. Overview of Thunderbolt 3

Thunderbolt is the ultra-high-speed interface standard for PCs jointly developed by Intel Corporation and Apple Inc. Table 2 shows the Thunderbolt specifications.

Table 1. USB standard and USB Type-C

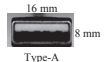

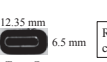
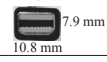

Standard	USB2.0	USB3.1	USB Type-C
Signal speed	• Low Speed: 1.5 Mbps • Full Speed: 12 Mbps • High Speed: 480 Mbps	• Super Speed: 5 Gbps • Super Speed Plus: 10 Gbps	For all speeds
Power Supply	2.5 W (5 V, 0.5 A)	4.5 W (5 V, 0.9 A)	Up to 100 W by Power Delivery (20 V, 5 A)
Connector	Type-A (for PCs and hubs) 	Type-B (for peripheral devices) 	Type-C (for both PCs and peripheral devices) (Type-A and Type-B can also be used.) 
	16 mm 8 mm Non-reversible connectivity	10.5 mm 11.5 mm	12.35 mm 6.5 mm Reversible connectivity

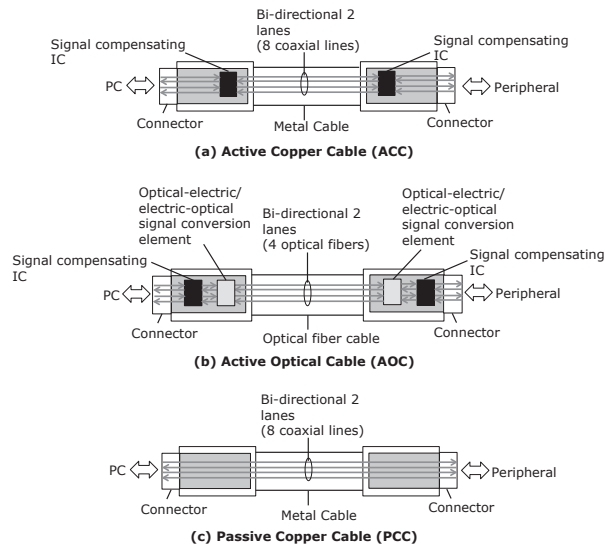
Table 2. Thunderbolt standards

Standard	Thunderbolt 1	Thunderbolt 2	Thunderbolt 3
Speed	Bi-directional 10 Gbps (bi-directional 10 Gbps × 1 lane)	Bi-directional 20 Gbps (bi-directional 10 Gbps × 2 lanes)	Bi-directional 40 Gbps (bi-directional 20 Gbps × 2 lanes)
Signal	Thunderbolt		Thunderbolt, USB3.1, USB2.0
Connector	Mini Display Port  7.9 mm 10.8 mm		Type-C  6.5 mm 12.35 mm
Power supply	10 W		100 W
Cable Type	ACC (Active Copper Cable): Up to 3 m AOC (Active Optical Cable): Up to 30 m		PCC (Passive Copper Cable): Up to 0.5 m ACC (Active Copper Cable): Up to 2 m
Established	2011	2013	2015

Thunderbolt 1 and Thunderbolt 2 are used for Mini DisplayPort*5 connectors, and are incompatible with the USB standard. Thunderbolt 1 and Thunderbolt 2 bi-directional 10 Gbps transmission lines can be used as one lane and two lanes, respectively.

Meanwhile, Thunderbolt 3, presented in this paper, uses Type-C connectors, and is compatible with the USB standard. Thus, Thunderbolt 3 is distinctively different from Thunderbolt 1 and Thunderbolt 2. The transmission speed per lane is 20 Gbps, which is double that of Thunderbolt 1 and Thunderbolt 2. Thus, higher performance cables are required for Thunderbolt 3.

Figure 2 shows the types of Thunderbolt cables. There are three types of cables depending on the length.



Thunderbolt uses differential transmission mode. To transmit a high-speed signal, a pair of signal lines is used as one lane. The inverted phase signal is transmitted through the two signal lines. The number of coaxial cables and optical fibers required for an ACC, PCC, and AOC is as follows:

ACC and PCC: $8 (= 2 \text{ [differential transmission pairs]} \times 2 \text{ [bi-directional]} \times 2 \text{ [lanes]})$
 AOC: $4 (= 1 \times 2 \text{ [bi-directional]} \times 2 \text{ [lanes]})$
 One optical fiber can transmit one high-speed signal.

Fig. 2. Types of Thunderbolt cables

Two types of cables are used for Thunderbolt 1 and Thunderbolt 2. An active copper cable (ACC) can be used for up to 3 m due to the electric signal correction function achieved by an integrated circuit (IC) built into the connector of both terminals. An active optical cable (AOC) uses optical fibers to achieve transmission of up to 30 m. The connectors of both terminals perform electric-optical and optical-electric signal conversion.

For Thunderbolt 3, a passive copper cable (PCC) has been introduced in addition to an ACC. A PCC can be used only up to 0.5 m because it does not have the signal correction function using ICs, but is less expensive. No AOC is available for Thunderbolt 3 at the time of writing this paper (November 2017).

3. Application Example of Thunderbolt 3

A docking station (see Fig. 3) is one of the applications that take full advantage of the high-speed transmission performance of up to 40 Gbps.

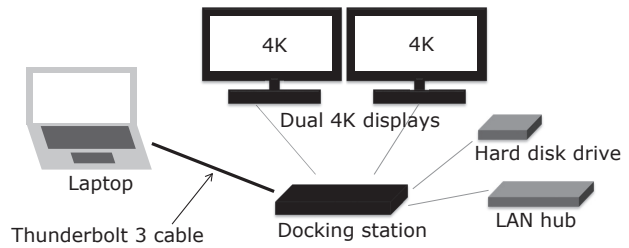


Fig. 3. Docking station

A docking station is designed to expand the functionality of laptops. A thin laptop has a limited number of connectors due to limited space, but its functionality can be expanded by connecting with a docking station using a single ultra-high-speed Thunderbolt 3 cable to collectively handle various interfaces. The functionality of a thin, lightweight, and highly portable laptop can be expanded to that equivalent to a desktop computer.

4. Cable Structure

Photo 1 shows the appearance of our Thunderbolt 3 cable. As discussed above, the cable is equipped with Type-C connectors. The outside diameter of the cable is 4.4 mm for a PCC and 4.6 mm for an ACC.

The cross section of the cable developed for Thunderbolt 3 is shown in Fig. 4. The cable uses a coaxial cable for the high-speed signal line, and is characterized by a small outside diameter, high flexibility, and easy handling by users.

As explained in Fig. 2, Thunderbolt uses differential transmission mode, with four pairs of coaxial cables (i.e., eight cables) arranged in a concentric circle. The Thunderbolt cable also incorporates power lines, low-speed signal lines, a braided shield, and a jacket.

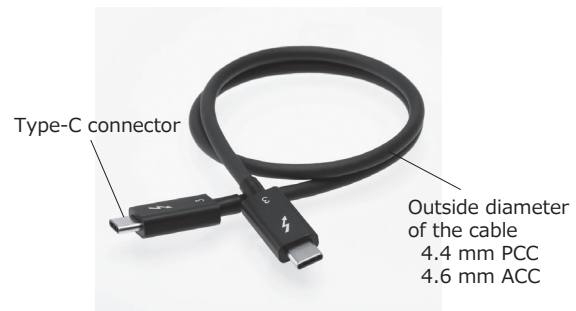


Photo 1. Thunderbolt 3 cable

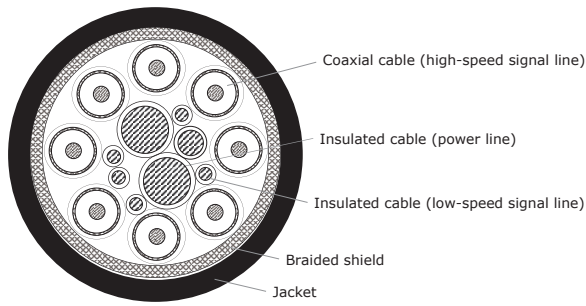


Fig. 4. Cable structure

5. Characteristics of the Thunderbolt 3 Cable

Figure 5 shows the Sdd21 (differential insertion loss) of our Thunderbolt 3 PCC. Signals are not interrupted up to the high frequency of 20 GHz. Satisfactory characteristics have been attained.

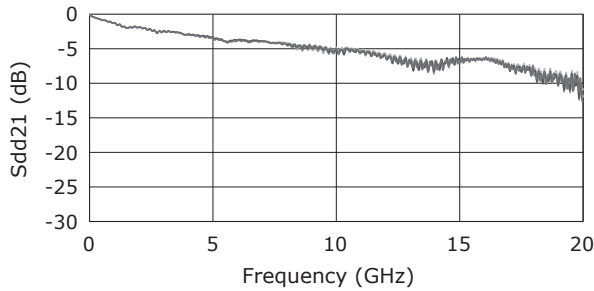


Fig. 5. Sdd21 of a Thunderbolt 3 PCC

The Scd21 (amount of conversion from differential mode to common mode) of the Thunderbolt 3 PCC cable is shown in Fig. 6. Common mode represents the noise of in-phase components in the differential pair, and is generated by the imbalance of the differential pair cable. It distorts the signal waveform and generates electromagnetic radiation.

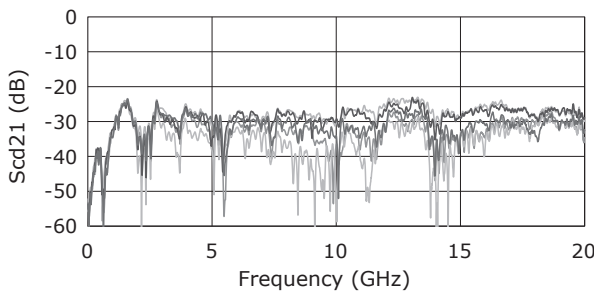


Fig. 6. Scd21 of a Thunderbolt 3 PCC

6. Reliability Evaluation Results of the Thunderbolt Cable

Table 3 shows the results of reliability evaluation. The criteria were based on a functionality check using Thunderbolt equipment. The cable passed the functionality test for all items after a reliability test. The results showed that the cable can be used properly in practical use.

Table 3. Results of a reliability test on the Thunderbolt 3 cable

Item	Condition	Result	Criteria		
Environmental test	High temperature	90°C × 456 hours	Passed	There is no problem in the functionality inspection using Thunderbolt equipment before and after the test. There is no abnormality in appearance.	
	Temperature-humidity cycle	RH95%@25-85°C 24 hours/cycle × 4 cycles	Passed		
	Temal shock	-55 to +85°C 1 hour/cycle × 10 cycles	Passed		
Mechanical test	Bending test	100 cycles in 2 directions, load: 454 gf	Passed		The above standard applies except for factors.
	Mating durability test	10000 cycles	Passed		
	Cable pull out	40 N × 1 min.	Passed		
	Vibration test	50-2000 Hz, amplitude: 1.52 mm 20 min./cycle × 12 cycles each in the X, Y, and Z directions	Passed		
Wrenching test	<ul style="list-style-type: none"> Durable for 10 sec. each in four directions (up, down, left, and right) with a moment of 0.75 Nm Fractured within 2.0 Nm in the up and down directions Fractured within 3.5 Nm in the left and right directions 	Passed			

As discussed above, the coaxial cables used in the Thunderbolt 3 cable are more flexible and easier to handle for users compared to the balanced cables that have been used for differential transmission. In addition, the coaxial cables are characterized by excellent durability against repeated bending.

Figure 7 shows the measured changes in the attenuation characteristics when the cable was subjected to repeated bending as an additional test. The attenuation characteristics remained unchanged and stable after a bending test of 7,000 cycles.

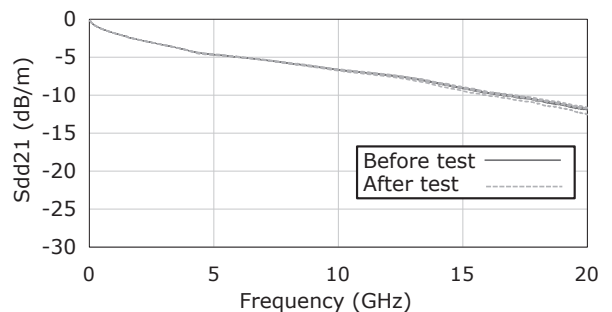


Fig. 7. Changes in Sdd21 before and after a repeated bending test of the cable

7. Conclusion

We have developed the Thunderbolt 3 cable by applying our cable technology and high-speed transmission technology to meet the technical specifications for the Thunderbolt 3 cable disclosed by Intel Corporation.

In this paper, we presented an overview and an application example of Thunderbolt 3, and described the structure, characteristics, and reliability evaluation results of our Thunderbolt 3 cable. We confirmed that the cable can be used properly in practical use.

8. Acknowledgements

We have received tremendous support from Intel Corporation in the course of this development project. We express our deepest appreciation.

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- HDMI is a trademark or registered trademark of HDMI Licensing Administrator, Inc. in the U.S. and other countries.

Technical Terms

- *1 Lane: A lane refers to the unit of transmission line required to transmit a single signal. In the case of high-speed electric signals, differential transmission mode is used to transmit inverted phase signals using a pair of cables. The pair of cables constitutes one lane.
- *2 HDMI: HDMI is one of the standard interfaces to output digital video signals. It was established in 2002 by HDMI Licensing, LLC, the predecessor of the current HDMI Licensing Administrator, Inc. HDMI 2.1, the latest standard at the time of writing this paper, was announced in 2017.
- *3 Frame rate: Frame rate refers to the frequency at which the image of a video is displayed per second. The higher the value, the smoother the video.
- *4 USB Power Delivery: USB Power Delivery is the standard to mutually supply power between pieces of equipment connected by a USB cable. It was established by the USB Implementers Forum in 2012.
- *5 Mini DisplayPort: Mini DisplayPort is one of the standard interfaces for outputting digital video signals. It was established by the Video Electronics Standard Association (VESA) in 2006.

References

- (1) USB Type-C Specification Release 1.3
- (2) Thunderbolt™ 3 Technology

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