Development of High-Speed 10-Gb/s Interface Cable "Thunderbolt Cable"

Wataru SAKURAI*, Tatsunori HAYASHISHITA, Yoshimasa WATANABE, Tooru TAKAHASHI, Kenji TSUKUI, Hiroshi UMETSU, Hirokazu TAKAHASHI, Mitsuaki TAMURA and Yoshiki CHIGUSA

Thunderbolt is an innovative high-speed input/output (I/O) technology developed by Intel Corporation. It enables 10-Gbp/s transmission between a computer and peripheral devices. Based on Intel's technical specifications, Sumitomo Electric Industries, Ltd. developed a Thunderbolt electrical cable by combining its advanced cable and high-speed transmission technologies. The Thunderbolt cable utilizes differential data transmission technology using pairs of coaxial cables that boast excellent signal integrity, low skew and low attenuation. The cable has advanced signal processing circuits in the connectors at both ends for signal compensation. This paper describes the results of signal integrity evaluation and reliability tests.

Keywords: Thunderbolt, high-speed I/O, coaxial cable

1. Introduction

Tablet PCs are rapidly expanding their market to become a formidable competitor of PCs because of their excellent usability including portability, quick start capability, and sophisticated user interface. Meanwhile, notebook PCs are also becoming thinner and lighter, and thin models based on the Ultrabook(1), a new concept proposed by Intel, USA, have been released one after another. Ultrabooks are thin and lightweight next-generation notebook PCs equipped with Intel's high-performance CPU. They are more portable than ever with a thin and lightweight body while maintaining basic notebook PC functions, as well as quick start capability, which is a feature of tablet PCs. Among the notebook PCs to be released in the days ahead, a substantial percentage are anticipated to be Ultrabooks. However, as notebook PCs become thinner, the physical space to accommodate interface connectors is restricted. In order to maintain the current interface functions and secure expandability at the same time, more than one existing interface component must be integrated into one. Thunderbolt has been proposed to solve this problem.

We have received the technological specifications for the Thunderbolt cable from Intel, and developed the Thunderbolt electric cable by combining our electric cable and high-speed transmission technologies. This paper presents an overview of Thunderbolt, and describes examples of its application, as well as signal transmission evaluations and reliability test results of the cable.

2. Overview of Thunderbolt (2)

Thunderbolt is the standard for an ultra high-speed PC interface jointly developed by Intel Corp. and Apple Inc. **Table 1** shows comparisons between Thunderbolt and typical PC interface standards.

Thunderbolt provides two lanes of 10Gb/s bidirectional transmission channels, enabling high-speed data transmission that is significantly faster than other standards. It uses metal cables up to three meter long and, for longer distances, uses optical fiber cables (active optical cables*1). Thunderbolt is to support two protocols*2 (PCI Express*3

Table 1. Comparisons between Thunderbolt and typical PC interface standards

Standard	Thunderbolt	USB2.0	USB3.0	IEEE 1394b
Transmission speed	Bidirectional 10 Gb/s 2 lanes	Bidirectional 480 Mb/s 1 lane	Bidirectional 5 Gb/s 1 lane	Bidirectional 800 Mb/s 1 lane
Cable length	Maximum 3 m For distances longer than 3 m, optical fiber cables (active optical cables*1) are used.	Maximum 5 m	Maximum 3 m	Maximum 4.5 m
Feature	· Conforms to two protocols for data and image transmission. (PCI Express*3 and Display Port*4) · Can be daisy-chained*5 · Maximum power supply: 10 W	· Data transmission · Tree connection*6 · Maximum sharing power: 2.5 W	· Data transmission · Tree connection · Maximum sharing power: 4.5 W	· Data transmission · Tree connection · Maximum power supply: 18 W
Established	2011	2000	2008	2002

for data, and Display Port[*4] for video data), which allows the use of one cable for both data and video data transmission. Up to seven external devices, including a host (PC), can be daisy chained[*5], and the host can supply power up to 10 W for other devices. The maximum delay time is specified to be 8 ns so that video data can be handled smoothly.

3. Examples of Thunderbolt Applications

Figure 1 shows applications based on the features mentioned earlier.

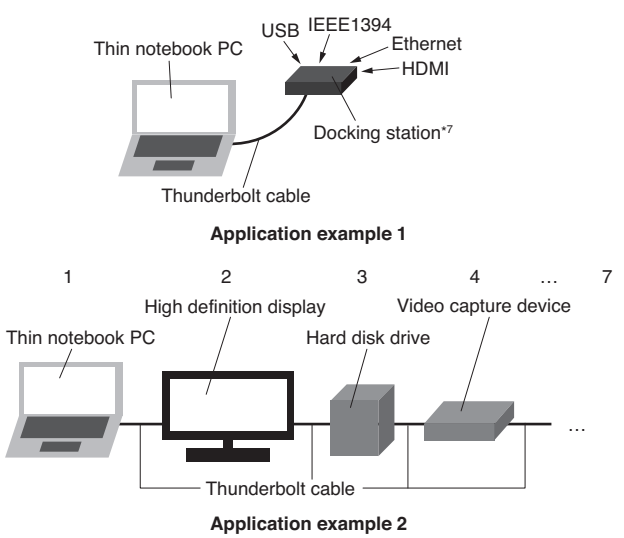


Fig. 1. System setup examples using Thunderbolt

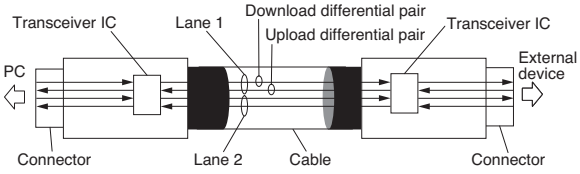
Application example 1 is a functionality expansion example using a docking station[*7]. Even a thin notebook PC with a small space for a limited number of connectors can be functionally expanded to be comparable with a desktop by connecting to a docking station with a single ultra-speed Thunderbolt cable to use various interface connections. Using the Thunderbolt's feature that makes PCI Express, an input/output standard, work outside a PC, all interface functions of a thin notebook PC can be integrated to use one connector.

Application example 2 is a functionality expansion example of a notebook PC using the daisy chain function of Thunderbolt. The high-speed transmission capability of Thunderbolt allows the connection of up to seven devices including a host (PC) by daisy-chain. Various types of functionality expansion include: adding a large high-definition display compatible with Display Port; high-speed transfer of high-volume data to a hard drive; and editing high-definition images with a video capture device.

4. Thunderbolt Transmission Method

As high-speed 10-Gb/s signals supported by Thunderbolt propagate via cables and connectors, their waveforms are degraded along the way to become too weak to be detected by receiver circuits. Dedicated transceiver ICs, installed inside connectors on both ends of a Thunderbolt cable as shown in **Fig. 2**, amplify signals, and compensate time delay.

Upload and download differential pairs form one lane unit for up/down bidirectional communication (Dual simplex method), and Thunderbolt has two lanes.



Lane: A unit of an upload-dedicated and a download-dedicated differential pair; upload and download transmission can be carried out independently and simultaneously.

Differential pair: A pair of wires used for the differential transmission method, which transmits signals on a pair of wires with a phase on one of the pair opposite to the one on the other. The differential transmission method is suitable for high-frequency transmission.

Fig. 2. Thunderbolt transmission method

5. Cable Structure

Photo 1 shows the appearance of the newly developed Thunderbolt cable. The connector is the Mini Display Port, a standard connector for video data transmission with an outer cable diameter of 4.2 mm. Our metal cables transmit signals up to three meters.

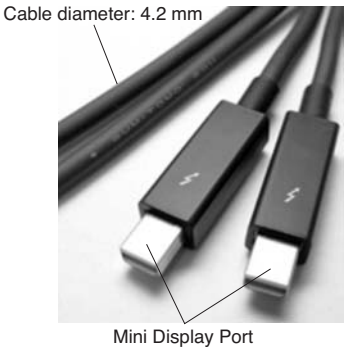


Photo 1. Thunderbolt cable

6. Cable Structure and Characteristics

Figure 3 shows the cross-section of the newly developed Thunderbolt cable.

As mentioned earlier, Thunderbolt has two units of dual unidirectional transmission lanes, for which four pairs (eight) of coaxial wires are arranged in a concentric pattern. In addition, two power source lines, two GND lines, and two control lines add up to form a 14-core cable. **Figure 4** shows typical attenuation data for differential pair lines. **Figure 5** shows typical skews.

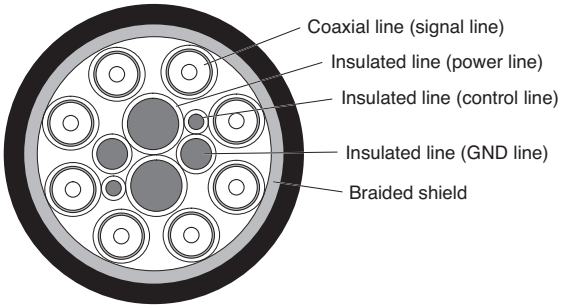


Fig. 3. Cable structure

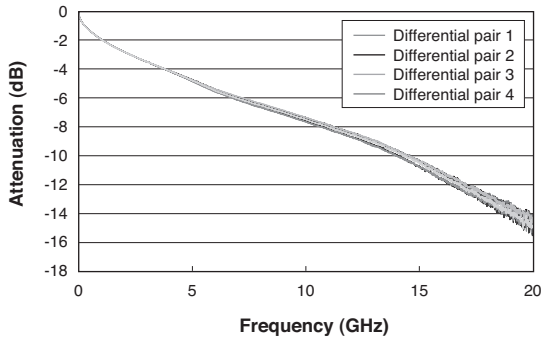


Fig. 4. Attenuation on differential pair lines

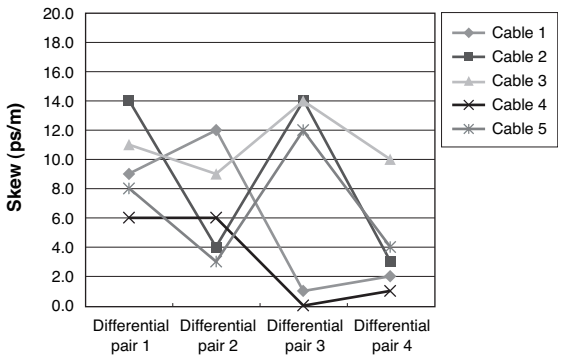


Fig. 5. Skew measurement data

7. Transmission Characteristics of the Thunderbolt Cable

Figure 6 shows the transmission signal quality checking results and the measurement system of the newly developed Thunderbolt cable.

Eye pattern 1 is the reference signal for testing Thunderbolt generated by the signal generator. Eye pattern 2 is the signal that has passed through the two evaluation boards, and this is inputed to the cable to be evaluated. Eye pattern 3 represents the signal after passing through the cable. It has as good eye opening as before passing through the cable, which assures an error free transmission.

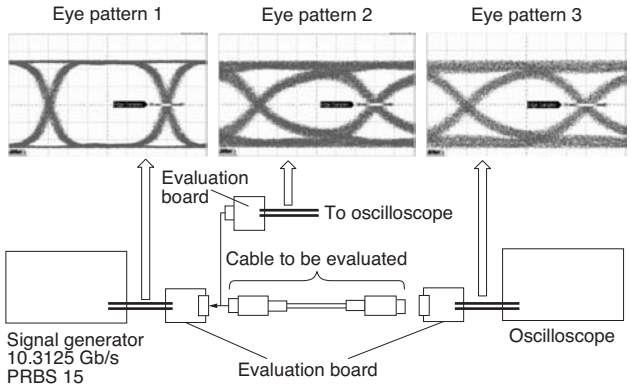


Fig. 6. Transmission signal quality checking system and measurement results

8. Reliability Evaluation Results of the Thunderbolt Cable

Table 2 shows the list of reliability evaluation results. Checking the performance with Thunderbolt devices was chosen as the criterion. The cable showed stable characteristics after these tests, which assures no problems in practical use.

In addition, as an additional reliability test item, a complex test of cable pinching and temperature and humidity tests were carried out. As shown in **Photo 2**, the cable was pinched 180 degrees in twelve areas and inserted into a gap double the size of the cable diameter. The cable characteristics were checked before and after the test, and the sample worked with no problems when connected to Thunderbolt devices after the test. It was confirmed that our cables are resistant to the complex environment of pinching and temperature and humidity changes.

Table 2. List of reliability evaluation results

	Item	Condition	Criterion	Result
Environ-mental test	High temperature burn-in	90˚C, 456 hours	Thunderbolt devices show no problems during the performance check before and after each test; and no abnormal appearance is found.	Acceptable
	Temperature and humidity cycle	RH95% at 25 to 85˚C, 4 cycles (24 hr/cycle)		Acceptable
	Heatshock	-55 to 85˚C, 10 cycles (1 hr/cycle)		Acceptable
Mechanical test	Vibration test	50 to 2000 Hz, Amplitude 1.52 mm, XYZ directions, 12 times with 20 min each		Acceptable
	Flexing test	Two directions, 100 cycles, with a load of 454 gf		Acceptable
	Removing test	10,000 cycles		Acceptable
	Vertical tensile test	4 kgf, 1 min		Acceptable
Electrical characteristics test	EMI	30 MHz to 26.5 GHz, PRBS31, SSC on	FCC, CE, VCCI	Acceptable
	ESD	Aerial and contact discharge with 8 kV	No abnormal performance	Acceptable

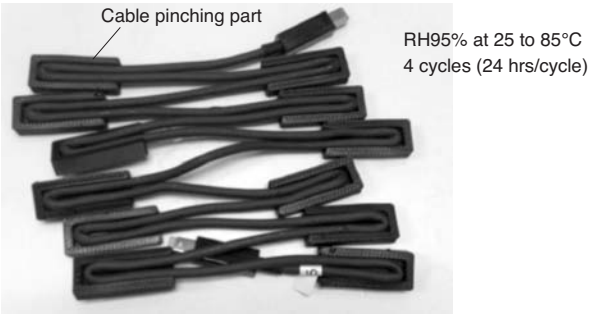


Photo 2. Test sample for a complex test of cable pinching and temperature and humidity changes

9. Conclusion

We have received the Thunderbolt cable technological specifications from Intel, and developed the Thunderbolt electric cable by combining our electric cable and high-speed transmission technologies. This paper has presented an overview of Thunderbolt, and described examples of its application. Also, the signal transmission and reliability evaluations of the newly developed Thunderbolt cable were carried out to ensure no problems in practical use.

10. Acknowledgements

We thank Intel Corporation for the great deal of support they offered during development.

Technical Terms

*1 Active optical cable: A cable used for the method that uses metal interface connectors and converts electrical signals into optical signals with a circuit installed in the transmission connector, transmits the optical signals through an optical cable, and converts the optical signals back into electrical signals with a circuit installed in the receiver connector. This method uses conventional metal interface connections, and assures a good transmission quality even for long-distance communications.

*2 Protocol: Rules for communication between PCs.

*3 PCI Express: One of the interface standards for communication inside a PC. It is also a standard specification for expansion of input/output interfaces. It was established by PCI-SIG in 2002.

*4 Display Port: One of the interface standards for digital image signals output. It was established by VESA in 2006.

*5 Daisy chain: A connection method that connects devices sequentially.

*6 Tree connection: A connection method that provides branching connections similar to the branches of a tree.

*7 Docking station: A device that expands notebook PC functionality. It allows notebook PCs to have performance comparable with desktops while ensuring they are thin, lightweight and portable. The docking station for Thunderbolt converts the signal between PCI Express and other conventional interfaces.

References

(1) http://www.intel.com/content/www/us/en/sponsors-of-tomorrow/ultrabook.html

(2) Thunderbolt Technology Transformational PC I/O http://www.intel.com/content/www/us/en/architecture-and-technology/thunderbolt/thunderbolt-technology-brief.html

Contributors (The lead author is indicated by an asterisk (*).)

W. SAKURAI*

- Assistant General Manager, Sumitomo Electronic Wire Inc. and Optical Communications R&D Laboratories
  He has been engaged in the development of electrical and optoelectronic harnesses.

T. HAYASHISHITA
- Sumitomo Electronic Wire Inc.

Y. WATANABE
- Sumitomo Electronic Wire Inc.

T. TAKAHASHI
- Sumitomo Electronic Wire Inc.

K. TSUKUI
- Sumitomo Electronic Wire Inc.

H. UMETSU
- Sumitomo Electronic Wire Inc.

H. TAKAHASHI
- Assistant General Manager, Sumitomo Electronic Wire Inc.

M. TAMURA
- Manager, Optical Communications R&D Laboratories

Y. CHIGUSA
- Ph.D,
  Senior Assistant General Manager, Electronic Wire Division