# Active Optical Cable Using USB Type-C Connector

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Demand for high-resolution displays and virtual reality applications is increasing and the use of these devices is spreading rapidly in the consumer electronics market. Cables attached to these devices are required to support high-speed and long-distance transmission, while maintaining their plug size. We have developed an active optical cable with a USB Type-C connecter (a small-sized multifunctional interface) and a plug of the same size as that of a conventional cable. This paper introduces the new cable, describing its design, transmission characteristics, and results in a reliability test.

Keywords: active optical cable (AOC), USB Type-C connector, 4K/8K, USB, DisplayPort

## 1. Introduction

In recent years, the quality of images and video has improved (4K/8K). In the consumer electronics market, ultra-high-resolution displays and head-mounted displays intended for immersive experiences have emerged, including virtual reality (VR). Table 1 lists the transmission rates required to enable 2K, 4K, and 8K. Compared with conventional 2K, the transmission capacity required for 4K and 8K is substantially larger.

Table 1. Transmission Rates Required for 2K/4K/8K (Non-Compressed)

| Resolution | Frame Rate | Color Depth [Unit: Gb/s] | | |
|---|---|---|---|---|
| | | **8 bit** | **10 bit** | **12 bit** |
| **2K** 1,920 × 1,080 | 60 fps | 3 | 3.7 | 4.5 |
| | 90 fps | 4.5 | 5.6 | 6.7 |
| | 120 fps | 6 | 7.5 | 9 |
| **4K** 3,840 × 2,160 | 60 fps | 11.9 | 14.9 | 17.9 |
| | 90 fps | 17.9 | 22.4 | 26.9 |
| | 120 fps | 23.9 | 29.3 | 35.8 |
| **8K** 7,680 × 4,320 | 60 fps | 47.8 | 59.7 | 71.7 |
| | 90 fps | 71.7 | 89.6 | 107.5 |
| | 120 fps | 95.6 | 119.4 | 143.3 |

This sector requires cables with small connector plugs and with compatibility with broadband and long-distance transmission. However, metal wire-based cables, which are the mainstream consumer electronics interfaces, suffer attenuation of transmission signals increasing with transmission distance. Specifically, signal attenuation is noticeable with high-speed transmission. Consequently, the challenge is a shorter transmission distance with increasing transmission capacity.

Meanwhile, with fiber optic cables, transmission signals attenuate very little even over a long distance. Accordingly, fiber optic cables work properly for transmitting 4K/8K signals at distances required in the consumer electronics market (up to 100 m).

Table 2 presents transmission rates and maximum cable lengths of major consumer electronics interfaces used with metal-based cable products.[1]

Table 2. Trends in Transmission Rate and Maximum Cable Length

| Standard | **USB2.0** | **USB3.0** | **Thunderbolt 2** | **Thunderbolt 3** |
|---|---|---|---|---|
| Transmission rate | **Max. 480 Mb/s** | **Max. 5 Gb/s** | **Max. 20 Gb/s** | **Max. 40 Gb/s** |
| Cable length | **Max. 5 m** | **Max. 3 m** | | **Max. 2 m** |
| Connector design | USB Type A/B | | Mini DisplayPort | USB Type C |
| Established | 2000 | 2008 | 2013 | 2015 |

Meanwhile, USB Type-C is expected to prevail as a data/video/audio transmission interface for consumer electronics. Since its establishment in 2014, USB Type-C has been rapidly and increasingly adopted for personal computers, peripherals, mobile terminals, and monitors. The USB Type-C connector is smaller than conventional consumer electronics interfaces. In addition, the connector is advantageous in that it can be plugged in a reversible manner and substitutes as various existing interfaces. Figure 1 gives examples of interfaces that USB Type-C can substitute for.

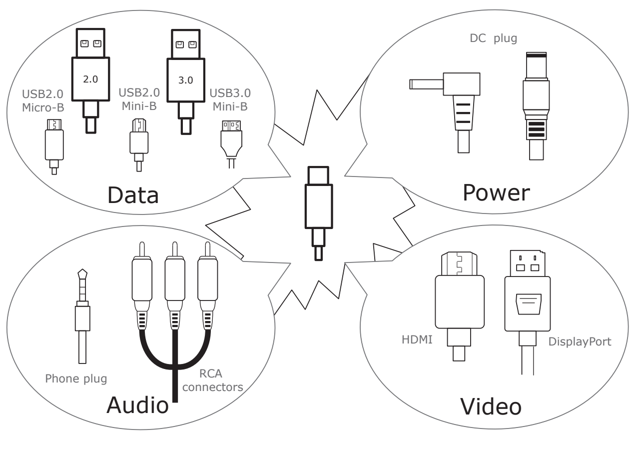


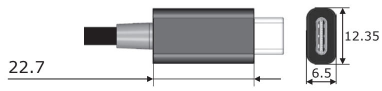
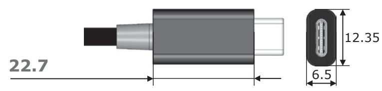

Fig. 1. Example interfaces that can be substituted by USB Type-C

Sumitomo Electric Industries, Ltd. has developed a USB Type-C connector-compatible active optical cable (USB Type-C AOC). The USB Type-C AOC reported in this paper complies with the DisplayPort 1.4 (8.1 Gb/s × two lanes; unidirectional) and USB 3.1 Gen 1 (5 Gb/s × one lane; bi-directional) transmission standards. This paper outlines the newly developed cable design, and reports on the evaluation results regarding strength characteristics, transmission characteristics, and reliability.

## 2. USB Type-C AOC Overview

As described in Chapter 1, there is strong market demand in this sector for smaller connector plugs. Table 3 compares connector plugs manufactured by Sumitomo Electric for high-speed transmission cables for consumer electronics. The USB Type-C AOC introduced in this paper is approximately 40% smaller in size than Sumitomo Electric's AOC product Thunderbolt 2 AOC.(2) The plug size is comparable to that of Sumitomo Electric's metal cable product USB Type-C passive copper cable (USB Type-C PCC).

Table 3. Size Comparison of Sumitomo Electric High-Speed Transmission Cables for Consumer Electronics

| Product name | Connector plug size (mm) |
|---|---|
| USB Type-C PCC (Passive Copper Cable) |   |
| USB Type-C ACC (Active Copper Cable) |   |
| Thunderbolt 2-AOC (For reference) |   |
| USB Type-C AOC (Newly developed product) |   |

## 3. Design Overview of USB Type-C AOC

Photo 1 shows the exterior features of the USB Type-C AOC. The designs of the constituent technologies, indicated in the photo, used to build the product are outlined below.

### 3-1 Cable design

This cable is a composite cable comprising optical fibers and metal wires. The cable has two unidirectional 8.1 Gb/s lanes and one bi-directional 5 Gb/s lane. Signal transmission in these lanes is carried by four optical fibers. Figure 2 illustrates the configuration of the cable. The optical fibers are GI fibers.*1 To construct the cable with superb mechanical strength, the optical fibers and strength fiber are encased in the inner tube located at the center of the cable. Four power wires—one ground wire and three control wires, all of which are metal wires—are concentrically placed around the inner tube. These wires are covered around with a braided shield and a sheath. The outside diameter of the cable is 4.0 mm.

Moreover, the cable's performance passed a number of strength tests conducted assuming the use environments of consumer devices and video equipment, as given in Table 4.

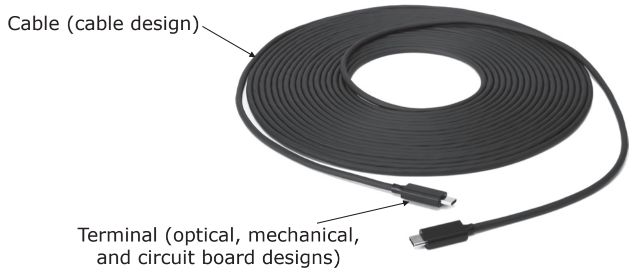



Photo 1. USB Type-C AOC and constituent technologies

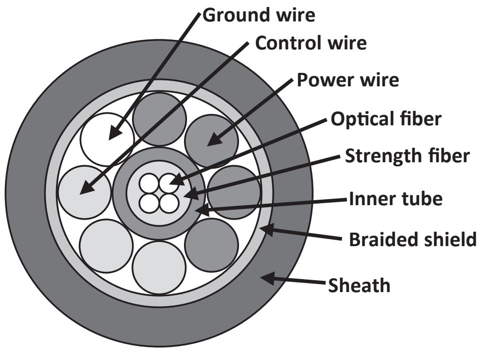
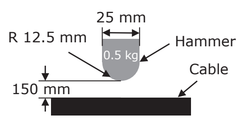



Fig. 2. Cable cross section

Table 4. Cable Characteristics

| Test | Test condition | Test result | Judgment |
|---|---|---|---|
| Pinch test | Bend the cable 180° and retain for 5 s. Bends: 3 | No transmission error | Pass |
| Knot test | Tie knots in the cable and apply a 40 N force to the cable for 1 h. Knots: 2 | No transmission error | Pass |
| Impact test | Conduct testing by dropping a hammer onto the cable as instructed in the figure below. Number of test cycles: 2   | No transmission error | Pass |

### 3-2 Optical and mechanical designs

The AOC makes long-distance signal transmission possible via optical transmission through the cable by converting from electrical to optical signals at the connector plug. A molded plastic component, known as a lens module, is used to optically couple light from (or to) the optoelectronic transducer VCSEL*2/PD*3 mounted on a circuit board located in the connector plug. The lens module and an optical fiber-lens module coupling method have been newly developed with the aim of reducing the plug size.

Use of the newly developed lens module and coupling method has enabled substantial depth-wise downsizing of the connector plug as compared with the Thunderbolt 2 AOC manufactured by Sumitomo Electric, as shown in Table 3.

**3-3 Circuit board design and optical Characteristics**

Figure 3 presents a functional block diagram of the cable terminal. It comprises drive control ICs and VCSELs/PDs used for conversion between electrical signals on the connector side and optical signals on the cable side.

Figure 4 shows, along with the evaluation system used, optical signal output waveforms of transmission via USB 3.1 Gen 1 and DisplayPort 1.4 at room temperature. To evaluate the transmission characteristics therein, the cable was cut, an optical fiber was fusion-spliced between the cut ends, and the optical signal waveforms were measured. Both interfaces exhibited a sufficient level of open eye patterns, proving the favorable quality of the optical signal waveforms.

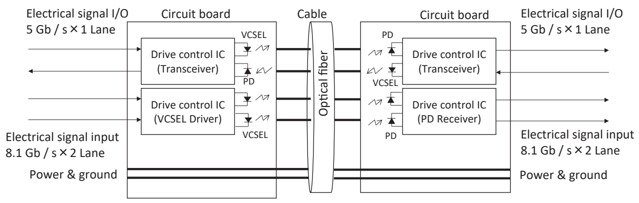



Fig. 3. Functional block diagram

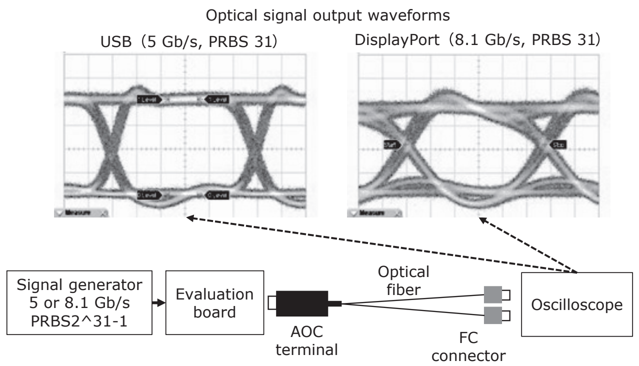



Fig. 4. Optical signal output waveforms and evaluation system

Figure 5 illustrates typical receiving sensitivity characteristics of transmission via USB 3.1 Gen 1 and DisplayPort 1.4 at room temperature. As in the evaluation of optical signal output waveforms, the cable was cut and an optical fiber was fusion-spliced between the cut ends to conduct measurements. Favorable measurement results were obtained for the minimum receiving sensitivity (bit error rate = 1E-12), namely, −19 dBm and −14 dBm for USB and DisplayPort transmissions, respectively. For both interfaces, the optical signal output of the transmitter was approximately 2 dBm. Hence, the transmission margins were 21 dB and 16 dB, respectively, for the USB and the DisplayPort. The magnitudes of these margins are sufficient even with various transmission losses and degradations, given in Table 5, taken into account. Thus the cable proved to work satisfactorily for transmission via USB 3.1 Gen 1 and DisplayPort 1.4.

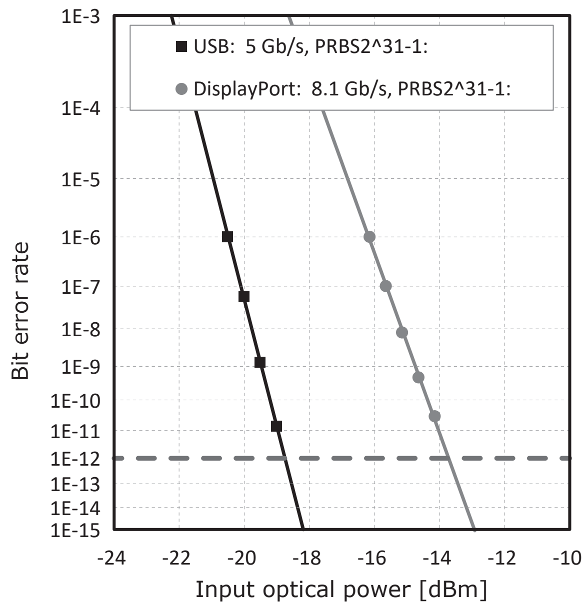



Fig. 5. Receiving sensitivity characteristics at room temperature

Table 5. Various transmission losses and degradations

| Parameter | Value (dB) |
|---|---|
| Optical power loss due to transmission through or bends in optical fiber | ~1.0 |
| Receiving sensitivity degradation due to modal dispersion*4 | ~0.5 |
| Decrease in VCSEL's optical power due to aging | ~0.5 |
| Decrease in VCSEL's optical power due to high temperatures | ~0.5 |
| Decrease in receiving sensitivity on transmitter side due to high temperatures | ~1.0 |
| Total | ~3.5 |

## 4. Evaluation of Transmission Characteristics

Figure 6 presents a USB Type-C AOC transmission characteristic evaluation system and cable signal output waveforms (room temperature) transmitted via USB 3.1 Gen 1 and DisplayPort 1.4. Both the USB and DisplayPort exhibit a sufficient level of open eye patterns. Moreover, using a bit error rate tester, it was ascertained that both interfaces worked free of transmission errors at ambient temperatures between 0°C and 50°C.

Figure 7 shows a function evaluation system incorporating a USB-compatible device and a DisplayPort-compatible device. The personal computer was connected via the USB to the hard disk drive and connected via the

DisplayPort to the display. The interfaces proved to perform data communications properly with the USB-compatible device and the DisplayPort-compatible device.

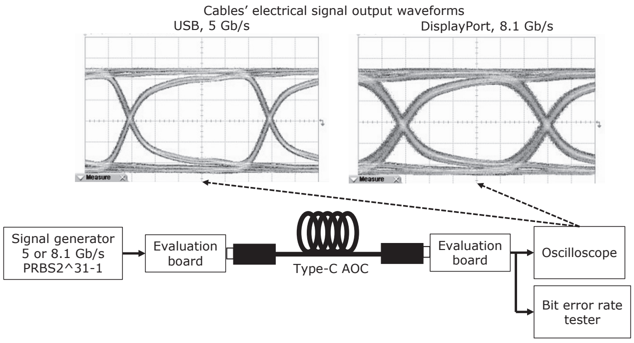



Fig. 6. Transmission characteristics evaluation system and cables' electrical signal output waveforms

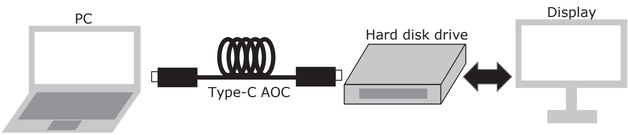



Fig. 7. USB and DisplayPort function evaluation system

## 5. Reliability Test Results

Table 6 presents reliability test results. The transmission characteristics evaluation system was used to check functions for pass/fail grading. Regarding all tests, the cables functioned properly after testing, proving that they are sufficiently reliable.

Table 6. Reliability Test Results

| Category | Test | Test condition | Criterion | Result |
|---|---|---|---|---|
| Environmental testing | High-temperature energization | 80 °C<br>2,000 h | Before and after the test, check the following two features.<br>• The cable has no faulty condition in terms of appearance.<br>• The cable exhibits no transmission errors. | Pass |
| | High-temperature high-humidity storage | 85°C/85%RH<br>500 h | | Pass |
| | Thermal shock | -40°C/30 min, +85°C/30 min.<br>Perform 500 cycles, with one cycle consisting of the above conditions. | | Pass |
| Mechanical testing | Flex test | Flex angle: ±90°<br>Mandrel dia.: φ50 mm<br>Tensile load: 400 gf<br>Number of flex cycles: 1,000 | | Pass |
| | Tensile test | 40 N 1min | | Pass |
| | Twist test | Twist angle: ±180°<br>Number of twist cycles: 1,000 | | Pass |
| | Pinch test | Bend the cable 180° and retain for 5 s.<br>Bends: 3 | | Pass |
| | Knot test | Tie knots in the cable and apply a 40 N force to the cable for 1 h.<br>Knots: 2 | | Pass |
| Electrical characteristics | ESD | 8 kV<br>Electrical discharge via air and via contact | The cable shows no operation error | Pass |

## 6. Conclusion

For the newly developed active optical cable, we successfully downsized connector plugs (to the same size as the USB Type-C PCC) by newly developing lens module components and a fiber-to-lens module coupling system. Furthermore, we evaluated the signal transmission and reliability of the newly developed USB Type-C AOC, which proved to be satisfactory in terms of practical use. It is anticipated that the small USB Type-C AOC will come into popular use even more in the future in the market of consumer active optical cables used typically with displays and for virtual reality (VR) applications.



### Technical Terms

∗1 GI fiber: An abbreviation for graded index fiber. This fiber is a type of multimode fiber. GI fibers are designed so that the fiber has a refractive index distribution with the aim of reducing differences in propagation time between modes.

∗2 VCSEL: An abbreviation for vertical-cavity surface-emitting laser. VCSEL is a type of semiconductor laser. Its features include light emission perpendicular to the substrate surface and low power dissipation. VCSEL is widely used in consumer devices such as computer mice and laser printers, as well as in communications equipment.

∗3 PD: An abbreviation for photo diode. A photo diode, which uses a semiconductor diode, is a type of photo detector.

∗4 Modal dispersion: The phenomenon of differences in propagation time between modes in multimode fibers. Modal dispersion affects fiber signal output waveforms.

### References


(1) Wataru Sakurai et. al., "40 Gbps High-Speed Interface Cable 'Thunderbolt 3'," SEI Technical Review, No. 86 (Apr. 2018)

(2) Yasuhiro Maeda et. al., "Optical Thunderbolt Cable," SEI Technical Review, No. 77 (Oct. 2013)

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