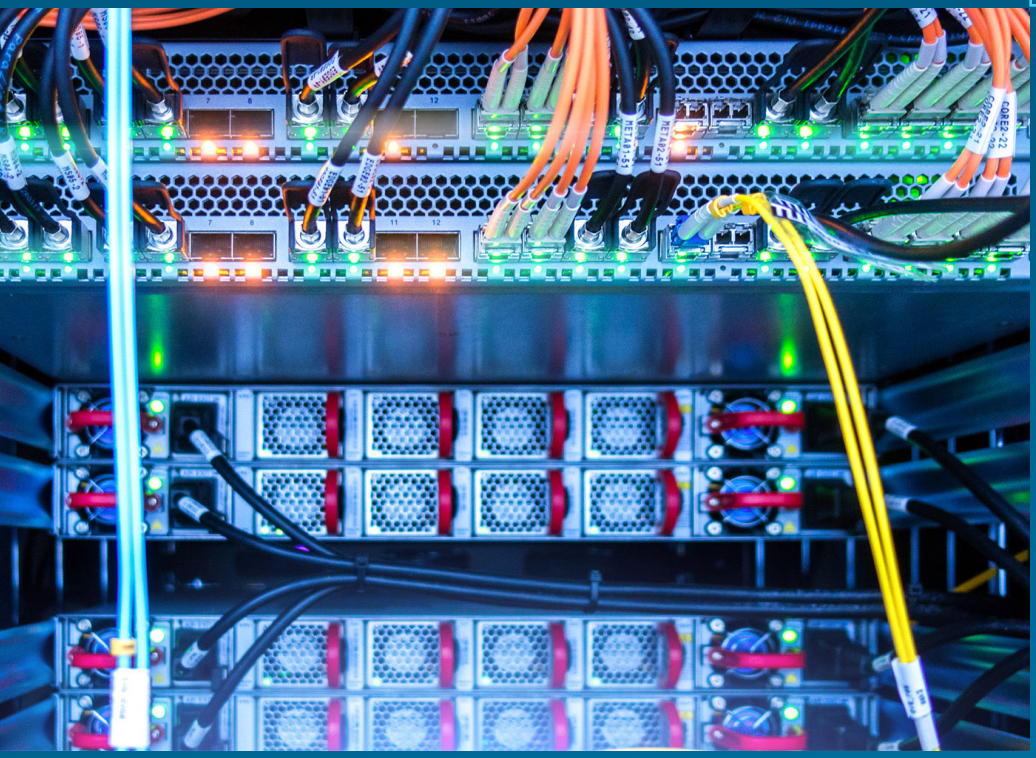
Technology Guide



Cables and Transceivers Overview

Intel® Ethernet network adapters support a broad number of standards compliant to the Institute of Electrical and Electronics Engineers (IEEE). This document contains a basic overview of the types of Ethernet connectors, transceivers, and cables commonly used in Ethernet network connectivity.

intel®

Twisted-Pair BASE-T Connectivity

Since the ratification of the Ethernet standard, the most common type of connectivity has been based on copper wires and related connectors. New IEEE and consortium standards are focused on the growing need to support higher bandwidth, but copper connectivity still brings unique value, even when compared to newer technologies.

Registered Jack (RJ45)

The RJ45 (figure 1) connection was originally developed for the telephone industry as a less-expensive connection method compared to hardwiring. A modular connection was developed to connect computer networks for similar reasons. The 8P8C (eight-pin, eight-contact) connector is an Ethernet-specific network connection. This connector is very similar to the original RJ45 and over time became commonly referred to by the industry as RJ45. The RJ45 supports a wide range of speeds, depending on the category of the cable and connected network adapters.

While the RJ45 form factor has not changed, new categories of twisted-pair cables have emerged to support higher bandwidth connections. Keeping the RJ45 connector constant allows for easier infrastructure upgrades to higher speeds.

Figure 1: RJ45 connection

Twisted-Pair Copper Cable

Twisted-pair copper cable is a type of cabling where internal pairs of wires are twisted together to provide protection against crosstalk, the electromagnetic noise generated by adjacent pairs. Compared to a single conductor or an untwisted balanced pair, a twisted pair guarantees better resiliency of transmitted signals on external disturbance.

There are several forms of the twisted-pair cable, each of which comes with different levels of electromagnetic protections: unshielded, or twisted-pair (figure 2), and shielded (figure 3). Shielded-pair wires are covered with foil or braided screen to provide added protection against alien crosstalk, but can also increase cable diameter, depending on the manufacturer.

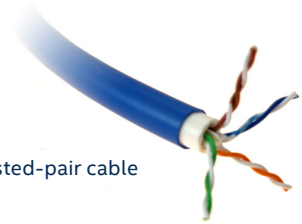


Figure 2: Twisted-pair cable

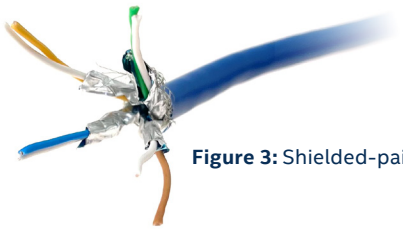


Figure 3: Shielded-pair cable

Classes and Categories of Twisted-Pair Cables

Requirements for bandwidth are constantly increasing. New categories of cables are developed to support the higher frequencies required and to protect signals from electromagnetic interference.

One of the main benefits of twisted-pair copper cables is that newer categories are backward compatible, providing better total cost of ownership and easy upgrades. Newer categories of twisted-pair cables can support high-bandwidth standards. However, these kinds of cables are more costly and less flexible, potentially impacting their use throughout a network.

Today there are two main standards that stipulate the division of twisted-pair categories and classes: the International ISO/IEC 11801 Standard[1] and American TIA/EIA-568B Standard.

The shielding types have clearly defined markings that are recognized by international TIA/EIA-568B Standard. A special code designates the type of cable (figure 4).

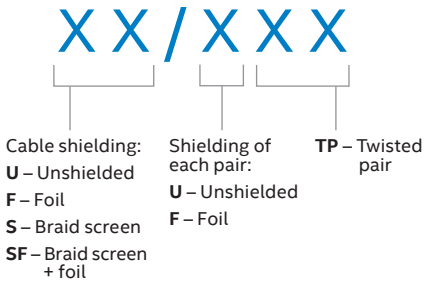


Figure 4: Classes and categories

Category 5e (CAT5e) standard cables are defined in TIA/EIA-586 and are available in three types. Each cable type uses 1.5—two twists of pairs per centimeter of cable:

- **UTP** – Unshielded twisted pairs—pairs of conductors without additional protection of the cable from interference
- **F/UTP** – Foil shielded with unshielded twisted pairs—where the whole cable has an additional foil shield and the individual pairs of conductors are unshielded
- **U/FTP** – Unshielded with shielded twisted pairs—where only the pairs of conductors are foil shielded

The Category 6 (CAT6) standard provides the same levels of additional shielding as CAT5e with the main difference being the number of twists per centimeter in the conductor pairs. According to the TIA/EIA-568B standard, CAT6 cables must have two or more twists for each centimeter and may additionally include a nylon spline to reduce crosstalk between pairs. This type of cable can provide 10GBASE-T connectivity but is limited to 55 meters.

Category 6A (CAT6A) provides the same shielding configurations as the previous categories and includes S/FTP, a braided shielding outer layer, and foil shielding for each twisted pair of conductors. This type of protection allows 10GBASE-T connectivity over a full 100 meters.

Table 1 shows the types of BASE-T cables and maximum distances for each.

	CAT5e	CAT6	CAT6A
1000BASE-T	100 m	100 m	100 m
2.5GBASE-T	100 m	100 m	100 m
5GBASE-T	N/A	100 m	100 m
10GBASE-T	N/A	55 m	100 m

Table 1: BASE-T cables

Fiber Optic Connectivity

Over the past 40 years, the industry has developed several standards for Ethernet optical connectors. The type of connectivity to use depends on the medium available for connectivity to existing network infrastructure and the form factor of the cage in the network adapter.

Optical Transceivers

Transporting Ethernet traffic over an optical network requires an optical transceiver. Transceivers are pluggable adapters with wavelength-specific lasers that convert electrical data signals from data switches to optical signals.

Small Form-Factor Pluggable Transceivers

The small form-factor pluggable (SFP) transceiver is a compact, hot-pluggable network interface module used for both telecommunication and data communications applications. This form factor is a popular industry format jointly developed and supported by many network component vendors.[2]

While there are SFP transceivers that support RJ45 connections (figure 5), the majority of SFPs in the market support optical connections.

SFP transceivers can be used with several types of cables:

- **Copper twisted-pair cable** with **RJ45** connector (figure 5)
- **Multimode fiber** or **single-mode fiber** optical cables (figure 6)
- **Direct attach cable (DAC) also known as a Twinax copper cable** where the transceiver is built in to a fixed-length copper cable
- **Active optical direct attached cable** where the transceiver is built in to fixed-length optical cable

Figure 5: RJ45 SFP transceiver

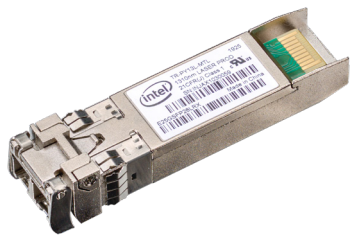


Figure 6: Optical SFP transceiver

A wide range of speeds are supported depending on specific standards and media. Table 2 shows popular types of SFP transceivers, with differing baud rates and modulation types. Newer SFP transceivers can often support lower speeds; SFP28 might support 10GbE and lower.

Transceiver type	Number of data lanes	Baud rate per data lane	Modulation type	Speed
SFP	1	1.25Gbps 3.1Gbps 6Gbps	NRZ (PAM2)	1GbE 2.5GbE 5GbE
SFP+	1	11Gbps	NRZ (PAM2)	10GbE
SFP28	1	28Gbps	NRZ (PAM2)	25GbE
SFP56	1	56Gbps	PAM4	50GbE

Table 2: SFP transceivers

Quad Small Form-Factor Pluggable Transceivers

The quad small form-factor pluggable (QSFP) transceiver (figure 7) uses four electric data lanes to deliver its total supported bandwidth. The advantage of using QSFPs instead of fixed interfaces is that the interface port is pluggable, allowing different transceiver types to use the same cage and support higher bandwidth rates.

Figure 7: QSFP transceiver

QSFP transceivers support three types of media:

- **Multimode fiber** or **single-mode fiber** optical cables
- **Direct attach cable (DAC), also known as a Twinax copper cable,** where the transceiver is built in to a fixed-length copper cable
- **Active optical cable (AOC)** where the transceiver is built in to a fixed-length optical cable

QSFP supports a wide range of speeds, depending on supported standards and media. Table 3 shows popular types of QSFP transceivers.

The type of transceivers depends on cable type, distance, and the medium used to connect. Optical transceivers are available that adhere to a variety of transmitter and receiver specifications, allowing users to select the appropriate transceiver for each link to provide the required optical reach over the available fiber.

Transceivers are also designated by their transmission speed, type of fiber supported, and available distance. Table 4 shows the types of small form-factor pluggable transceivers and supported distances.

Transceiver type	Number of data lanes	Baud rate per data lane	Modulation type	Speed
QSFP	4	11Gbps	NRZ (PAM2)	40GbE
QSFP28	4	28Gbps	NRZ (PAM2)	100GbE

Table 3: QSFP transceivers

Transceiver type	Application	Multimode fiber	Single-mode fiber		
			2 km	10 km	40 km
SFP+	10GBASE-	SR		LR	ER
SFP28	25GBASE-	SR		LR	ER
QSFP	40GBASE-	SR4/eSR4	FR	LR4	ER4
QSFP28	100GBASE-	SR4 SR2	CLR4	LR4	ER4

Table 4: SFP and QSFP transceivers

Fiber Optic Cables

Multimode Fiber Optic Cables

Multimode fiber (MMF) optic cable (figure 8) is a type of optical fiber primarily used for communication over short distances. The fairly large core diameter, which enables multiple light modes to be transmitted, also limits the maximum length of a transmission link because of modal dispersion. MMF optic cables can support data rates up to 100Gbps, and because of its high capacity and reliability, MMF is generally used for backbone applications. The transceivers used for multimode fiber optics are less expensive compared to single-mode.

Newer deployments often use laser-optimized 50/125 µm MMF (OM3). Fibers that meet this designation provide sufficient bandwidth to support 10 Gigabit Ethernet (GbE) up to 300 meters. Fiber optic manufacturers have greatly refined their manufacturing processes since the standard was issued, and cables can be made that support 10GbE up to 400 meters. Laser-optimized multimode fiber (LOMMF) is designed for use with 850 nm VCSELs. Table 5 shows cable categories and distances supported.

Figure 8: Multimode fiber cable

Cable category	SFP+ 10GBASE-SR	SFP28 25GBASE-SR	QSFP 40GBASE-SR4	QSFP28 100GBASE-SR4
OM3 (50/125) LOMMF	300 m	70 m	100 m	70 m
OM4 (50/125) LOMMF	400 m	100 m	125 m	100 m
OM5 (50/125)				

Table 5: Fiber optic cables

Single-Mode Fiber Optic Cables

As the name of the medium explains, single-mode fiber (SMF) (figure 9) is designed to carry data using a single mode of light. SMF cables are better at retaining the fidelity of each light pulse over longer distances than MMF cables. For these reasons, SMF cables can provide higher bandwidth than MMF cables.

Transceivers for SMF are more expensive and more complex than equipment for MMF, though the SMF cabling itself is usually less expensive.

The two categories of SMF cables, OS1 and OS2, are defined by ITU-T specifications. OS1 cables are intended for tight-buffered, indoor applications, have a maximum distance of 10 km, and are less expensive than OS2 cables.

OS2 cables use loose tube construction. They are primarily used for outdoor applications and are designed to withstand severe weather. OS2 cables support a much longer maximum distance of 200 km.

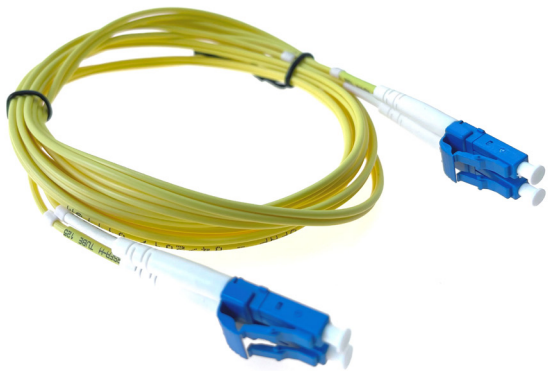


Figure 9: Single-mode fiber cable

Direct Attach Cables

Direct Attach Cables

Direct attach cables (DAC), or Twinax copper cable, is a type of cable with copper medium and active electronics components on both ends in the form of SFP (figure 10) or QSFP transceivers. They are cost efficient for very short-range high-speed connectivity and are often used in data center or enterprise environments.

Figure 10: Direct attach cable

The cable comes in either an active or passive Twinax cable assembly and connects directly into an SFP/QSFP cage. An active Twinax cable has powered electronic components in the SFP/QSFP housing to improve the signal quality and available distance. A passive Twinax cable is a simple two-conductor cable and contains few components. SFP+ DAC is a popular choice for 10GbE due to lower latency and low cost. Table 6 show the different cable types and supported distances.

Cable type	Physical port	Transceiver	Lanes	Distance
Passive	SFP+	10GBASE-SFI	1	Up to 7 m
Active	SFP+	10GBASE-SFI	1	Up to 15 m
Passive	SFP28	25GBASE-CR	1	Up to 5 m
Passive	QSFP	40GBASE-CR4	4	Up to 5 m
Active	QSFP	40GBASE-CR4	4	Up to 10 m
Passive	SFP56	50GBASE-CR	1	Up to 3 m
Passive	QSFP28	100GBASE-CR4	4	Up to 7 m

Table 6: Direct attach cables

Breakout Twinax Copper Cables

Breakout Twinax copper cables (figure 11) divide a single physical port into four separate ports. The copper-based connectivity is more cost effective but usually cables are thicker and heavier than optical solutions and support shorter distances. Table 7 shows the different breakout types and supported distances.

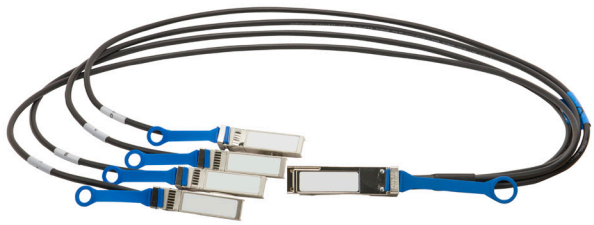


Figure 11: Breakout Twinax copper cable

Physical port 1	Transceiver	Lanes	Split to	Physical port 2	Transceiver	Distance
QSFP	40GBASE-CR4	4	4 x SFP+	SFP+	10GBASE-SFI	7 m
QSFP28	100GBASE-CR4	4	4 x SFP+	SFP+	10GBASE-SFI	7 m
QSFP28	100GBASE-CR4	4	4 x SFP28	SFP28	25GBASE-GAUI	5 m

Table 7: Breakout Twinax copper cables

Active Optical Cables

Active optical cables (AOCs) (figure 12) have optical transceivers on both ends of the cable and use fiber as the transmission medium. Because of the integrated transceivers and longer distances supported, they are becoming popular in modern, short- to mid-range, high-speed applications. They are often used for inter-rack or intra-building connectivity.

Figure 12: Active optical cables

The AOC has active electronic components in the SFP/QSFP housing to support optical transmission over the attached fiber. AOCs support a wide range of speeds over longer distances compared to DAC. Table 8 shows types of AOCs, number of lanes, and distances supported.

Physical port	Transceiver type	Lanes	Distance
SFP+	10GBASE-SFI	1	Up to 100 m
SFP28	25GBASE-CR	1	Up to 100 m
QSFP	40GBASE-CR4	4	Up to 100 m
QSFP28	100GBASE-GAUI4	4	Up to 100 m

Table 8: Active optical cables

Breakout Active Optical Cables

The 40GbE and 100GbE standards have been influenced by previous generations of Ethernet speeds. Breakout cables combine up to four electric data lanes of lower speeds to achieve a higher total bandwidth (figure 13). Transmission over multiple lanes allows the splitting of existing transmission channels on the port of the network adapter or switch over several separate electric data lanes. Aggregating up to four physical connections into one switch port can provide budget savings or an additional layer of separation for physical connectivity.

Figure 13: Breakout active optical cables

Connecting a single server with four physically isolated networks, different workloads, and security levels can add complexity. Four-lane connectivity on QSFP/QSFP28 ports can be split for different security or application networks. Each lane can be physically connected to a separate network to provide redundancy and an additional layer of security. Table 9 shows available breakout configurations and supported distances.

Physical port 1	Transceiver	Lanes	Split to	Physical port 2	Transceiver	Distance
QSFP	40GBASE-CR4	4	4 x SFP+	SFP+	10GBASE-SFI	100 m
QSFP28	100GBASE-GAUI4	4	4 x SFP+	SFP+	10GBASE-SFI	100 m
QSFP28	100GBASE-GAUI4	4	4 x SFP28	SFP28	25GBASE-GAUI	100 m

Table 9: Breakout active optical cables

BASE-T Connectivity

BASE-T (copper-based) networks are probably the best known of all the Ethernet connections. BASE-T has been used to connect Ethernet networks for more than 30 years. Similar cabling can be used to connect a variety of speeds up to 10GbE. It is likely the easiest to deploy and the most budget-friendly to implement.

Fiber Optic Connectivity

When looking for higher throughput and available distance, fiber optic connectivity is the better option. Fiber optics can support higher network speeds and a wide range of transmission media. Fiber connectivity is also able to fulfill additional requirements for demanding applications, justifying the higher cost of infrastructure. The complexity of these connections also requires additional knowledge about a wide range of cables, connectors, and their appropriate combinations.

Direct Attach Connectivity

Direct attach cables are easier to deploy than fiber with the same achievable speeds, but at shorter distances. This type of connectivity offers a cost-friendly solution for host-to-host or rack-to-rack connectivity.

Additional Resources

For more information about IEEE standards, visit ieee.org.

For specific product information including product briefs, see Intel Ethernet Optics.

To learn more about all Intel Ethernet products and technologies, visit intel.com/ethernet.

intel®

1. https://www.iso.org/standard/66182.html
2. https://members.snia.org/document/dl/26184

0621/ED/CMD/PDF