Assignment: Current I/O Interface
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Serial AT Attachment (SATA)

Serial ATA (Serial Advanced Technology Attachment or SATA) is a command and transport protocol that defines how data is transferred between a computer's motherboard and mass storage devices, such as hard disk drives (HDDs), optical drives and solid-state drives (SSDs). As its name implies, SATA is based on serial signaling technology, where data is transferred as a sequence of individual bits. SATA refers to the communication protocol itself and the industry standards adhered to by the OEMs that produce SATA-compatible cables, connectors and drives. It was introduced in 2003 as a replacement for the older IDE (Integrated Drive Electronics) interface and has since become the standard for connecting internal storage devices.

Evolution

SATA is a serial version of the Integrated Drive Electronics (IDE) specification for PATA hard drives that use parallel signaling. SATA cables are thinner, more flexible and less massive than the ribbon cables required for conventional PATA hard drives.

SATA Revision 1. These devices were widely used in personal desktop and office computers, configured from PATA drives daisy chained together in a primary/secondary configuration. SATA Revision 1 devices reached a top transfer rate of 1.5 Gbps.
SATA Revision 2. These devices doubled the transfer speed to 3.2 Gbps with the inclusion of port multipliers, port selectors and improved queue depth.
SATA Revision 3. These interfaces supported drive transfer rates up to 6 Gbps. Revision 3 drives are backward-compatible with SATA Revision 1 and Revision 2 devices, though with lower transfer speeds.
SATA Revision 3.1. This intermediate revision added final design requirements for SATA Universal Storage Module for consumer-based portable storage applications.
SATA Revision 3.2. This update added the SATA Express specification. It supports the simultaneous use of SATA ports and PCI Express (PCIe) lanes.
SATA Revision 3.3. This revision addressed the use of shingled magnetic recording
SATA Revision 3.5. This change promoted greater integration and interoperability with PCIe flash and other I/O protocols.

Interface connector

SATA uses a small, rectangular connector that is easy to plug and unplug. It is designed to be compatible with both 3.5-inch and 2.5-inch hard drives, as well as solid-state drives.

Applications

- Connecting hard drives and solid-state drives (SSDs) to a computer or other device.
- Connecting optical drives: *ex.* DVD and Blu-ray drives to computer.
- Creating RAID arrays for improved performance or data redundancy.
- Connecting internal storage devices in servers, workstations, and other enterprise-level equipment.
- Connecting external storage devices: *ex.* using an eSATA port on a laptop to connect an external hard drive.
- Connecting high-speed data storage devices: *ex.* high-speed solid-state drives (SSDs) that require the high data transfer rates provided by SATA.
- Connecting Serial Attached SCSI (SAS) devices to a computer through a SATA port using a compatible converter.

Universal Serial Bus (USB)

Universal Serial Bus (USB) is a widely used computer interface for connecting peripherals, such as keyboards, mice, printers, external hard drives, and smartphones, to a computer system. It was first introduced in 1996 and has since become one of the most popular interfaces in the world. The USB interface allows for easy

plug-and-play connectivity and supports hot-swapping, meaning that devices can be connected and disconnected from the system without requiring a restart.

Evolution

USB 1.0 is the first version of USB was introduced in 1996 with a maximum data transfer rate of 12 Mbit/s (megabits per second). It is rarely used today.

USB 2.0 (High-speed USB) provides additional bandwidth for multimedia and storage applications and has a data transmission speed 40 times faster than USB 1.1. To allow a smooth transition for both consumers and manufacturers, USB 2.0 has full forward and backward compatibility with original USB devices and works with cables and connectors made for original USB, too. Supporting three speed modes (1.5, 12 and 480 megabits per second), USB 2.0 supports low-bandwidth devices such as keyboards and mice, as well as high-bandwidth ones like high-resolution webcams, scanners, printers and high-capacity storage systems. The deployment of USB 2.0 allowed PC industry leaders to forge ahead with the development of PC peripherals to complement existing high-performance PCs. In addition to improving functionality and encouraging innovation, USB 2.0 increases the productivity of user applications and allows the user to run multiple PC applications at once or several high-performance peripherals simultaneously.

The USB 3.0 (SuperSpeed USB) standard became official on Nov. 17, 2008. USB 3.0 boasts speeds 10 times faster than USB 2.0 at 4.8 gigabits per second. It's meant for applications such as transferring high-definition video footage or backing up an entire hard drive to an external drive. As hard drive capacity grows, the need for a high-speed data transfer method also increases. Adoption of the USB 3.0 standard has been slow. Chip manufacturers must design motherboard hardware that supports USB 3.0. Computer owners have the option to purchase cards that they can install in their computers to give USB 3.0 support. But hardware support is just part of the problem; you also need support from your operating system. Even though Microsoft announced that Windows 7 would eventually support the USB 3.0 standard, the company shipped its operating system without USB 3.0 support. Recent distributions of the Linux operating system support USB 3.0.

USB 3.1 Introduced in 2013, USB 3.1 doubles the data transfer rate of USB 3.0 to 10 Gbit/s. It also introduced a new connector type called USB Type-C, which is reversible and supports faster charging.

USB 3.2 is a USB version introduced in 2017, offering even faster transfer speeds, with a maximum data transfer rate of 20 Gbit/s. It is backward compatible with USB 3.0 and USB 2.0 devices.

Interface connector

The USB connector is typically rectangular in shape and comes in different sizes, with a varying number of pins depending on the version. The connector is designed to be universal, allowing it to be used with a wide range of peripherals, including mice, keyboards, printers, cameras, and external hard drives.

Applications

- Connecting peripherals to a computer: *ex. keyboards, mice, printers, scanners, and external hard drives*
- Charging smartphones, tablets, and other portable devices.
- Transferring data between devices: *ex.* transferring files from a camera or smartphone to a computer.
- Creating bootable devices: *ex.* creating a bootable USB drive to install an operating system.
- Running portable applications: *ex.* running a portable version of a web browser or productivity software from a USB drive.
- Connecting game controllers: *ex.* USB gamepad to play games on a computer.
- Connecting audio devices: *ex.* USB microphone or headset for recording or communication.
- Using USB devices for security: *ex.* USB key for two-factor authentication or encryption.

Additional! Enumeration

When the host powers up, it queries all of the devices connected to the bus and assigns each one an address. This process is called enumeration; devices are also enumerated when they connect to the bus. The host also finds out from each device what type of data transfer it wishes to perform:

- ***Interrupt:*** a device like a mouse or a keyboard, which will be sending very little data, would choose the interrupt mode.
- ***Bulk:*** a device like a printer, which receives data in one big packet, uses the bulk transfer mode. A block of data is sent to the printer (in 64-byte chunks) and verified to make sure it's correct.

- ***Isochronous:*** a streaming device (such as speakers) uses the isochronous mode. Data streams between the device and the host in real-time, and there is no error correction.

The host can also send commands or query parameters with control packets. As devices are enumerated, the host is keeping track of the total bandwidth that all of the isochronous and interrupt devices are requesting. They can consume up to 90 percent of the 480 Mbps of bandwidth that's available (USB 3.0 increases that speed to 4.8 gigabits per second). After 90 percent is used up, the host denies access to any other isochronous or interrupt devices. Control packets and packets for bulk transfers use any bandwidth left over (at least 10 percent). The Universal Serial Bus divides the available bandwidth into frames, and the host controls the frames. Frames contain 1,500 bytes, and a new frame starts every millisecond. During a frame, isochronous and interrupt devices get a slot so they're guaranteed the bandwidth they need. Bulk and control transfers use whatever space is left.

Thunderbolt

Thunderbolt is a high-speed input/output interface developed by Intel and first introduced in 2011. It combines high-speed data transfer, high-definition video, and power delivery in a single port, making it a versatile and powerful interface for connecting various peripherals to a computer.

Evolution

Thunderbolt 1: Introduced in 2011, Thunderbolt 1 had a maximum data transfer rate of 10 Gbps (Gigabits per second) and used a Mini DisplayPort connector.
Thunderbolt 2: Introduced in 2013, Thunderbolt 2 doubled the data transfer rate of Thunderbolt 1 to 20 Gbps and introduced support for DisplayPort 1.2.
Thunderbolt 3: Introduced in 2015, Thunderbolt 3 increased the data transfer rate to 40 Gbps and introduced a new connector type called USB Type-C. Thunderbolt 3 also supports dual 4K displays and can provide up to 100W of power delivery.
Thunderbolt 4: Introduced in 2020, Thunderbolt 4 is an incremental upgrade over Thunderbolt 3, offering the same data transfer rate of 40 Gbps but with stricter hardware requirements, including support for 2 4K displays, and enhanced power delivery.

Interface connector

Thunderbolt uses a USB Type-C connector, which is reversible and supports a wide range of protocols, including Thunderbolt, USB, DisplayPort, and power delivery. Thunderbolt cables can be up to 2 meters long and can daisy-chain up to six devices.

Data transfer speed/rate

Thunderbolt 1 has a maximum data transfer rate of 10 Gbps, Thunderbolt 2 has a maximum data transfer rate of 20 Gbps, while Thunderbolt 3 and Thunderbolt 4 both have a maximum data transfer rate of 40 Gbps. This makes Thunderbolt one of the fastest interfaces available for connecting high-speed storage devices, displays, and other peripherals to a computer.

Applications

- Connecting high-speed storage devices: *ex.* external hard drives and solid-state drives (SSDs) for fast data transfer rates.
- Connecting high-resolution displays: *ex.* 4K and 5K displays for high-quality video playback and graphic design work.
- Daisy-chaining multiple devices: *ex.* connecting multiple hard drives or displays in a single chain for more efficient use of ports and cables.
- Connecting audio devices: *ex.* audio interfaces for recording and mixing music.
- Connecting Ethernet networks: *ex.* Thunderbolt to Ethernet adapter for faster network speeds.
- Connecting video capture devices: *ex.* cameras and video recorders, for live video streaming and video production.
- Connecting expansion cards: *ex.* Thunderbolt expansion chassis to add additional PCIe slots for specialized hardware like graphics cards.
- Powering and charging devices: *ex.* Thunderbolt port to charge a laptop or power a device.

High Definition Media Interface (HDMI)

High-Definition Multimedia Interface (HDMI) is a digital interface used to transmit audio and video signals between devices. It was introduced in 2002 and has since become the standard for connecting high-definition devices such as TVs, monitors, and gaming consoles.

Evolution

HDMI 1.0: Introduced in 2002, HDMI 1.0 supported a maximum video resolution of 1080p and a maximum data transfer rate of 4.9 Gbps.
HDMI 1.3: Introduced in 2006, HDMI 1.3 introduced support for higher video resolutions such as 1440p and 1600p, as well as improved audio support with the introduction of Dolby TrueHD and DTS-HD Master Audio.
HDMI 1.4: Introduced in 2009, HDMI 1.4 introduced support for 3D video, Ethernet connectivity, and audio return channel (ARC) support.
HDMI 2.0: Introduced in 2013, HDMI 2.0 increased the maximum video resolution to 4K (2160p) at 60 frames per second, and increased the maximum data transfer rate to 18 Gbps.
HDMI 2.1: Introduced in 2017, HDMI 2.1 increased the maximum video resolution to 10K, added support for dynamic HDR (high dynamic range), and introduced a new feature called eARC (enhanced audio return channel) for improved audio support.

Interface connector

HDMI uses a small, rectangular connector that is easy to plug and unplug. It is compatible with a wide range of devices, including TVs, monitors, gaming consoles, and Blu-ray players.

Data transfer speed/rate

The data transfer rate of HDMI varies depending on the version. HDMI 1.0 has a maximum data transfer rate of 4.9 Gbps, while HDMI 2.1 has a maximum data transfer rate of 48 Gbps.

Applications

- Connecting high-definition TVs and monitors to computers, gaming consoles, and Blu-ray players
- Transmitting high-quality audio and video signals between devices
- Enabling 3D video playback and HDR support
- Supporting high-resolution video up to 10K
- Providing Ethernet connectivity through the HDMI cable.

Digital Video Interface (DVI)

Digital Visual Interface (DVI) is a video interface used to transmit digital video signals between devices. It was first introduced in 1999 and was widely used for connecting computers to monitors, projectors, and other display devices.

Evolution

DVI-I (Integrated): Introduced in 1999, DVI-I supports both analog and digital signals, making it compatible with a wide range of devices.
DVI-D (Digital): Introduced in 1999, DVI-D supports only digital signals, providing a clearer and sharper picture than DVI-I.
DVI-A (Analog): Introduced in 1999, DVI-A supports only analog signals, and is rarely used today.
DVI-DL (Dual-link): Introduced in 2002, DVI-DL doubles the number of TMDS (Transition Minimized Differential Signaling) channels in the cable, allowing for higher resolutions and refresh rates.

Interface connector

DVI uses a rectangular connector with multiple pins that are arranged in a specific pattern. There are several different types of DVI connectors, including DVI-A, DVI-D, and DVI-I, each of which is designed to work with specific types of devices.

Data transfer speed/rate
The data transfer rate of DVI varies depending on the version and the number of channels in the cable. DVI-D and DVI-I can support resolutions up to 1920x1200 at 60Hz, while DVI-DL can support resolutions up to 2560x1600 at 60Hz.

Applications
- Connecting computers to monitors, projectors, and other display devices
- Transmitting high-quality digital video signals between devices
- Providing a clear and sharp picture for gaming and video playback
- Supporting high-resolution video up to 2560x1600 at 60Hz

Video Graphics Adapter (VGA)
VGA (Video Graphics Array) is an analog video interface used to transmit video signals between devices. It was introduced in 1987 by IBM and was widely used for connecting computers to monitors and other display devices.

Evolution
VGA has only one version, and it was introduced in 1987. However, there are several variations of VGA connectors that have been developed over the years, including HD-15, mini-VGA, and micro-VGA.

Interface connector
VGA uses a rectangular connector with 15 pins that are arranged in three rows. The connector is commonly referred to as an HD-15 connector, and it is designed to be compatible with a wide range of devices.

Data transfer speed/rate
VGA is an analog interface, which means that the data transfer rate is dependent on the quality of the signal and the length of the cable. VGA can support resolutions up to 640x480 at 60Hz, which is lower than the resolutions supported by newer digital interfaces like HDMI and DisplayPort.

Applications
- Connecting computers to monitors and other display devices
- Transmitting analog video signals between devices
- Supporting lower resolution video up to 640x480 at 60Hz
- Providing backward compatibility with older devices

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