



BSI Standards Publication

Universal Serial Bus interfaces for data and power

Part 4-1: Universal Serial Bus 4™ Specification

National foreword

This British Standard is the UK implementation of EN 62680-4-1:2022. It is identical to IEC 62680-4-1:2022.

The UK participation in its preparation was entrusted to Technical Committee EPL/100, Audio-visual equipment.

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UNIVERSAL SERIAL BUS INTERFACES FOR DATA AND POWER

Part 4-1: Universal Serial Bus 4™ Specification

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The text of this standard was prepared by the USB Implementers Forum (USB-IF). The structure and editorial rules used in this publication reflect the practice of the organization which submitted it.

The text of this International Standard is based on the following documents:

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100/3754/CDV	100/3813/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

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This standard is the USB-IF publication, USB4™ Specification, Version 1.0 with Errata and ECN through May 19, 2021.

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Universal Serial Bus 4 (USB4™) Specification

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1 Introduction

1.1 Scope of the Document

The specification is primarily targeted at peripheral developers and platform/adaptor developers, but provides valuable information for platform operating system/BIOS/device driver, adaptor independent hardware vendors/independent software vendors, and system OEMs. This specification can be used for developing new products and associated software.

1.2 USB Product Compliance

Adopters of the USB4™ specification have signed the USB4 Adopters Agreement, which provides them access to a royalty-free reasonable and nondiscriminatory (RAND) license from the Promoters and other Adopters to certain intellectual property contained in products that are compliant with the USB4 specification. Adopters can demonstrate compliance with the specification through the testing program as defined by the USB Implementers Forum (USB-IF). Products that demonstrate compliance with the specification will be granted certain rights to use the USB-IF logos as defined in the logo license.

1.3 Document Organization

Chapters 1 and 2 provide an overview for all readers, while Chapters 3 through 13 contain detailed technical information defining USB4.

1.4 Design Goals

USB 3.1 and USB 3.2 were evolutionary steps to increase bandwidth. The goal for USB4 remains the same with the added goal of helping to converge the USB Type-C® connector ecosystem and minimize end-user confusion. Several key design areas to meet this goal are listed below:

- Offer display, data, and load/store functionality over a single USB Type-C connector.
- Retain compatibility with existing ecosystem of USB and Thunderbolt™ products.
- Define Port Capabilities for predictable and consistent user experience.
- Provide increased host flexibility to configure bandwidth, power management, and other performance-related parameters for system needs.

1.5 Related Documents

Universal Serial Bus 3.2 Specification, Revision 1.0, September 22, 2017 (USB 3.2 Specification)

USB Type-C® Cable and Connector Specification, Release 2.0 (USB Type-C Specification)

USB 3.0 Jitter Budgeting white paper (USB Jitter Paper)

Universal Serial Bus Power Delivery Specification, Release 3.0, Version 2.0, August 2019 (USB PD Specification)

PCI Express® Base Specification, Revision 4, Version 1, September 27, 2017 (PCIe Specification)

VESA DisplayPort™ Standard, Revision 1.2a, May 2012 (DisplayPort 1.2a Specification)

VESA DisplayPort™ Standard, Revision 1.4a, April 19, 2018 (DisplayPort 1.4a Specification)

VESA DisplayPort™ 1.4a PHY Layer Compliance Test Specification, Revision 1.0, 27 July, 2018 (DisplayPort 1.4a PHY CTS)

VESA DisplayPort™ Alt Mode on USB Type-C Standard, Revision 1.0b, November 03, 2017 (DisplayPort Alt Mode Specification)

eXtensible Host Controller Interface for Universal Serial Bus, Revision 1.1 (xHCI Specification)

USB4 Connection Manager (CM) Guide, Revision 1.0, [to be published] – (Connection Manager Guide)

USB4 Re-Timer Specification, [to be published] – (USB4 Re-Timer Specification)

USB4 Device ROM (DROM) Specification, Revision 1.0, [to be published] – (USB4 DROM Specification)

USB4 Inter-Domain Specification, Revision 1.0, [to be published] – (USB4 Inter-Domain Specification)

HDCP on DisplayPort™ Specification, Revision 2.3, January 22, 2019 (HDCP Specification)

1.6 Conventions

1.6.1 Precedence

If there is a conflict between text, figures, and tables, the precedence shall be tables, figures, and then text.

Note: The text, figures, and tables in this specification all contain necessary information for building an implementation and need to be read together to get a full understanding of USB4 technology.

1.6.2 Keywords

The following keywords differentiate between the levels of requirements and options.

1.6.2.1 Informative

Informative is a keyword that describes information with this specification that intends to discuss and clarify requirements and features as opposed to mandating them.

1.6.2.2 May

May is a keyword that indicates a choice with no implied preference.

1.6.2.3 N/A

N/A is a keyword that indicates that a field or value is not applicable and has no defined value and shall not be checked or used by the recipient.

1.6.2.4 Normative

Normative is a keyword that describes features that are mandated by this specification.

1.6.2.5 Optional

Optional is a keyword that describes features not mandated by this specification. However, if an optional feature is implemented, the feature shall be implemented as defined by this specification (optional normative).

1.6.2.6 Reserved

Reserved is a keyword indicating reserved bits, bytes, words, fields, and code values that are set-aside for future standardization. The use and interpretation of these may be specified by future extensions to this specification and, unless otherwise stated, shall not be utilized or adapted by vendor implementation. A reserved bit, byte, word or field shall be set to zero by the sender and shall be ignored by the receiver. Reserved field values shall not be sent by the sender and, if received, shall be ignored by the receiver.

1.6.2.7 Shall

Shall is a keyword indicating a mandatory (normative) requirement. Designers are mandated to implement all such requirements to ensure interoperability with other compliant devices.

1.6.2.8 Should

Should is a keyword indicating flexibility of choice with a preferred alternative. Equivalent to the phrase “it is recommended that”.

1.6.3 Capitalization

Some terms are capitalized to distinguish their definition in the context of this specification from their common English meaning. Words not capitalized have their common English meaning.

1.6.4 Italic Text

Italic text is used to identify variable names, register field and packet field names, or reference document titles.

1.6.5 Numbering

Numbers that are immediately followed by a lowercase “b” (e.g. 01b) are binary values. Numbers that are immediately followed by an uppercase “B” are byte values. Numbers that are immediately followed by a lowercase “h” (e.g. 3Ah) are hexadecimal values. Numbers not immediately followed by either a “b”, “B”, or “h” are decimal values.

1.6.6 Bit, Byte, DW, and Symbol Conventions

A bit, byte, DW, or Symbol residing in location *n* within an array is denoted as bit(*n*), byte(*n*), DW(*n*), or Symbol(*n*).

A sequence of bits, bytes, DWs, or Symbols residing in locations *n* to *m* (inclusive) within an array is denoted as bit[*m:n*], byte[*m:n*], DW[*m:n*], or Symbol[*m:n*].

1.6.7 Implementation Notes

Implementation Notes are not a normative part of this specification. They are included for clarification and illustration only. Implementation Notes within this specification are marked as such and set apart from the other text.

1.6.8 Connection Manager Notes

Connection Manager Notes provide requirements and recommendations for building a Connection Manager. Connection Manager Notes within this specification are marked as such and set apart from the other text.

Router behavior is undefined if a Connection Manager does not follow the requirements in a Connection Manager Note.

See the Connection Manager Guide for an example Connection Manager implementation.

1.6.9 Pseudocode

Throughout this specification, pseudocode is used to illustrate operating principles. Comments are demarcated by double forward slashes (“//”). The pseudocode conventions include:

```
if/else conditions:

    if (condition)

        // true operations

    else

        // false operations

for loops:

    for (conditions)
```

// operations

1.6.10 CRC Algorithms

The CRC algorithms used in the specification are defined according to the following values:

- **WIDTH:** This is the width of the algorithm expressed in bits. This is one less than the width of the POLY.
- **POLY:** This is a binary value that should be specified in a hexadecimal number. The top bit of the polynomial should be omitted. For example, if the polynomial is 10110, the POLY equals 06. An important aspect of this parameter is that it represents the un-reflected polynomial; the bottom bit of this parameter is always the LSB of the divisor during the division regardless of whether the algorithm being modeled is reflected.
- **INIT:** This parameter specifies the initial value of the register when the algorithm starts. This is the value that is to be assigned to the register in the direct table algorithm. In the table algorithm, we may think of the register always commencing with the value zero, and this value being XORed into the register after the Nth bit iteration. This parameter should be specified as a hexadecimal number.
- **REFIN:** This is a Boolean parameter. If it is FALSE, inputs bytes are processed with bit 7 being treated as the most significant bit (MSB) and bit 0 being treated as the least significant bit. If this parameter is TRUE, each byte is reflected before being processed.
- **REFOUT:** This is a Boolean parameter. If it is set to FALSE, the final value in the register is fed into the XOROUT stage directly, otherwise, if this parameter is TRUE, the final register value is reflected first.
- **XOROUT:** This is a W-bit value that should be specified as a hexadecimal number. It is XORed to the final register value (after the REFOUT) stage before the value is returned as the official checksum.

For more information, see *A Painless Guide to CRC Error Detection Algorithms*, by Ross N. Williams, Version 3, August 19, 1993.

1.6.11 FourCC

A FourCC is a sequence of four bytes used to represent ASCII strings. It is limited to ASCII printable characters (one byte per character), with space characters reserved for padding shorter sequences.

For example, the FourCC string "ABC" is represented by a hexadecimal value of 20434241h, where the rightmost byte (41h) represents the first ASCII character ("A").

1.7 Reserved Values and Fields

Unless otherwise specified, fields and values marked "Rsvd" shall be handled as described in Table 1-1.

Table 1-1. Rsvd Value and Field Handling

Type	Handling
Packet Values	A transmitter shall not use a value in this specification that is marked as "Rsvd". The target of a packet shall ignore a packet that has any of its defined fields set to an Rsvd value and proceed as if the packet was never received.
Transaction Values	A transmitter shall not use a value in this specification that is marked as "Rsvd". The target of a Transaction shall ignore a Transaction that has any of its defined fields set to an Rsvd value and proceed as if the Transaction was never received.

Type	Handling
Ordered Set Values	A transmitter shall not use a value in this specification that is marked as "Rsvd". The target of an Ordered Set shall ignore an Ordered Set that has any of its defined fields set to an Rsvd value and proceed as if the Ordered Set was never received.
Register Values	The Connection Manager shall not write a register with a value that is marked as "Rsvd". Writing a register with a value that is marked as "Rsvd" results in undefined behavior.
Packet Fields	A transmitter shall set a field that is marked "Rsvd" to zero. A receiver shall ignore any fields that are marked "Rsvd".
Transaction Fields	A transmitter shall set a field that is marked "Rsvd" to zero. A receiver shall ignore any fields that are marked "Rsvd".
Register Fields	See Section 8.1.
Host Interface Descriptor Fields	A Host shall only write a zero value to a field that is marked "Rsvd". A Router may write any value in a field marked "Rsvd". See Section 12.6.1.

1.8 Terms and Abbreviations

This section lists and defines the terms and abbreviations used throughout this specification. Note that terms and abbreviations not defined here, use their generally accepted or dictionary meaning.

Term/Abbreviation	Description
Active Cable	A cable with additional electronics to condition the data path signals.
Adapter	An addressable Router interface that includes additional functionality based on type. There are three types of Adapters: Lane Adapter, Protocol Adapter, and Control Adapter.
Adapter Configuration Space	The Configuration Space for Lane Adapters and Protocol Adapters. Control Adapters do not have an Adapter Configuration Space.
AT Transaction	A type of Transaction that is used by a Router to read from or write to the SB Register Space of a Link Partner.
Big Endian	A method of storing data that places the most significant byte of multiple-byte values at a lower storage address. For example, a 16-bit integer stored in Big Endian format places the least significant byte at the higher address and the most significant byte at the lower address. See also Little Endian.
Bit Error Rate (BER)	The ratio between the number of incorrect bits received to the total number of received bits.
Byte	A data element that is 8 bits in size.
Cable Re-timer	A Re-timer that is part of an Active Cable.
Captive Device	A Captive Device is device that is plugged directly to a USB Type-C Receptacle. A Captive Device can include a cable at its front-end as an integral part, providing access to a single test point at the connector.
CLx	Refers to any of CL0s, CL1, and/or CL2 Adapter states.
Configuration Layer	The protocol stack layer responsible for configuration tasks and handling Control Packets.
Configuration Space	An address space used by the Connection Manager to access a set of configuration registers. The USB4 architecture defines four Configuration Spaces: Router Configuration Space, Adapter Configuration Space, Path Configuration Space, and Counters Configuration Space.
Connection Manager (CM)	The software-based configuration entity that is responsible for managing a Domain.
Control Adapter	The Adapter within a Router that handles Control Packets and Router configuration tasks. The Control Adapter implements a Transport Layer and a Control Layer. The Control Adapter is assigned Adapter Number = 0.
Control Packet	A type of Transport Layer Packet that is used for configuration-related communication between a Connection Manager and a Router.

Term/Abbreviation	Description
Counters Configuration Space	An optional Configuration Space that collects statistics within an Adapter.
Credit	The unit used to track receive buffer space.
Cyclic Redundancy Check (CRC)	A check performed on data to see if an error has occurred in transmitting, reading, or writing the data. The result of a CRC is typically stored or transmitted with the checked data. The stored or transmitted result is compared to a CRC calculated from the data to determine if an error has occurred.
Crosstalk	A situation arising from one transmitted signal inadvertently causing an unwanted effect on another signal. Minimizing or (optimally) preventing cross-talk is a major consideration in maintaining signal integrity.
Data Dependent Jitter	A specific class of timing jitter. It is a form of deterministic jitter which is correlated with the sequence of bits in the data stream. It is also a form of Inter-Symbol Interference.
dBm	An abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt (mW).
dequeue	The process of removing a packet from a buffer so that the buffer is free to be used for other packets.
device	A logical or physical entity that performs one or more functions. The entity described depends on the context of the reference. For example, "device" can refer to a single component such as a Router or a Re-timer, or it can refer to a collection of components that perform a particular function such as a USB4 Device.
Device Router	The Router in a USB4 hub or USB4 peripheral device. A Device Router has an Upstream Facing Port and optionally one or more Downstream Facing Ports.
De-Scrambling	Restoring a scrambled bit stream to its original state. See also Scrambling.
De-Skew	The procedure of aligning Symbols received across multiple Lanes of a Dual-Lane Link.
Destination Adapter	A Protocol Adapter that is the final recipient of Tunneled Packets routed through the USB4 Fabric. Note that a Protocol Adapter may be a Source Adapter on one Path and a Destination Adapter on another.
Domain	A collection of interconnected Routers managed by a single Connection Manager.
Doubleword, DW	4 bytes.
Down-spread	Spreading a clock frequency downward from a peak frequency. As compared to "center-spread" which evenly splits the frequency around the center frequency.
Downstream	The direction of data flow away from the Connection Manager.
Downstream Facing Port (DFP)	A USB4 Port that is not an Upstream Facing Port. <i>Note: The DFP is not necessarily the power provider. Power roles are determined by USB PD negotiation as defined in the USB PD Specification.</i>
DP	DisplayPort™.
DPRX	DisplayPort receiver.
DPTX	DisplayPort transmitter.
Dual-Lane Link	A USB4 Link that uses two bonded Lanes to transmit and receive data.
Egress Adapter	An Adapter that transmits outgoing traffic.
Electrical Layer	The protocol stack layer that directly interacts with the communication medium between two Routers. The Electrical Layer decouples data transmission electrical specifications from the Logical Layer.
EMI	Electromagnetic interference.
FEC	Forward Error Correction.
Gen 2	Refers to speeds of 10 Gbps (USB4) and/or 10.3125 Gbps (TBT3-Compatibility Mode).

Term/Abbreviation	Description
Gen 3	Refers to speeds of 20 Gbps (USB4) and/or 20.625 Gbps (TBT3-Compatibility Mode).
Host Router Clock	The clock that is the ultimate source of time for clock synchronization, either within a single Domain or between multiple interconnected Domains.
Host Router Time	The time as captured from the Host Router Clock.
HopID	A number assigned to a Transport Layer Packet to identify its Path in the context of a Link.
Host	The host computer system that interfaces with a Host Router. A Host includes the host hardware platform (CPU, bus, etc.) and the operating system in use.
Host Interface	The interface between a Host and a Host Router.
Host Router	The Router in a USB4 host. A Host Router has one or more Downstream Facing Ports. It does not have an Upstream Facing Port (the Host Interface Adapter serves as the Upstream Adapter).
Ingress Adapter	An Adapter that receives incoming traffic.
Inter-Domain Link	A USB4 Link that connects two Routers belonging to different Domains.
Lane	The dual simplex high speed differential signaling pair that provides communication between two interconnected Routers. The signaling rate at which a Lane operates defines the speed of communication for that Lane.
Lane 0	The Lane associated with the Lane 0 Adapter.
Lane 1	The Lane associated with the Lane 1 Adapter.
Lane Adapter	The Adapter that interfaces to a Lane. A USB4 Port contains two Lane Adapters: a Lane 0 Adapter and a Lane 1 Adapter. A Lane Adapter implements an Electrical Layer, a Logical Layer, and a Transport Layer.
Lane 0 Adapter	The lowest numbered Adapter in a USB4 Port. For example, in a USB4 Port containing Adapters 3 and 4, Adapter 3 is the Lane 0 Adapter.
Lane 1 Adapter	The highest numbered Adapter in a USB4 Port. For example, in a USB4 Port containing Adapters 3 and 4, Adapter 4 is the Lane 1 Adapter.
Lane Bonding	The process of turning two Single-Lane Links into a Dual-Lane Link.
Link	See USB4 Link.
Link Management Packet	A type of Transport Layer Packet that is used to communicate Link-specific information between two Link Partners.
Link Partner	The relationship between the two USB4 Ports on either end of a Link. For example, given two USB4 Ports (Port A and Port B) that are connected by a Link, Port B is the Link Partner of Port A and vice versa.
Little Endian	Method of storing data that places the least significant byte of multiple-byte values at lower storage addresses. For example, a 16-bit integer stored in Little Endian format places the least significant byte at the lower address and the most significant byte at the next address. See also Big Endian.
Local Clock	The free-running clock within a Router. The Local Clock is used for time synchronization purposes.
Local Time	The time as captured from the Local Clock.
Logical Layer	The protocol stack layer below the Transport Layer and on top of the Electrical Layer. The Logical Layer performs Link management tasks and transmission/reception of Symbols over a Link.
LTTPR	LT-tunable PHY Repeater. Defined by the DisplayPort 1.4a Specification.
LT Transaction	A Type of Transaction that is used by a Router during USB4 Link initialization and to signal a change in Adapter state.
MFDP	Multi-Function DP. A DisplayPort link which operates as part of a Multi-Function configuration.
Multi-Function	Configuration on the USB Type-C connector that supports USB 3.2 SuperSpeed signaling at the same time as DP Standard signaling.
NVM	Non Volatile Memory.