USB4™ System Overview

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Presentation Agenda

• USB Type-C® Vision
• USB4™ Specification Overview
USB Type-C® Vision

- One simple connector for data, video, and power
  - Small, flippable connector with symmetrical cables
  - Compatible systems, cables, and devices at various performance levels
- Scalable
  - Across form factors (phone to workstation), and peripherals (displays, docks, storage)
  - Across usages (low power / performance, to 8k uncompressed video)
- USB and Thunderbolt™ architecture as the foundation
Delivering the USB Type-C® Vision

- **USB4™ Specification Goals:**
  - Help converge USB Type-C connector ecosystem to minimize end-user confusion
  - Drive broad adoption of USB4 architecture

- **What the Specification Enables:**
  - Standards-based ownership for specifications and certification
  - Third party vendors can build Thunderbolt™ 3 compatible SOC or peripheral silicon
Presentation Agenda

• USB Type-C® Vision
• USB4™ Specification Overview
10,000 Foot View

- Runs over USB Type-C® interconnect
- Tunnels USB3, PCIe and DP protocols
- Signaling rates of 10 or 20 Gbps (10 to 40Gbps aggregated b/w)
- Utilizes passive and active cables (longer reach)
- Topologies with up to 6 routers
- Time sync accuracy support across USB4™ Fabric
USB4™ System Description

- Routers are the fundamental building block of any USB4 Product
  - Host Router resides at the top of the tree
    - All other Routers are Device Routers
  - Connection Manager (CM) runs on the platform that includes the Host Router

- Domain
  - A collection of interconnected Routers managed by a single CM
  - Contains one USB4 Host
  - Contains zero or more USB4 Hubs
  - Contains zero or more USB4 Devices
  - Each USB4 Hub/Device is reachable by one or more USB4 Links
Elements of a Router

- A router core that interconnects between ports and provides router-wide services
- A Control Adapter
- USB4™ Ports, connected to USB4 Links
- Optional Protocol Adapters
- A Time Management Unit (TMU)
USB4™ Host

• A USB4 host contains:
  • A Host Router
  • An internal USB host controller
  • A DisplayPort Source
    • At least one DP IN Adapter
• Optionally support PCIe Tunneling
  • Supports a PCIe Controller
• A USB4 host supports 20 Gbps operation and optionally 40 Gbps operation
• A USB4 host is required to support DisplayPort™ Alt Mode on all of its DFP
USB4™ Hub

• USB4 Hub
  • One Upstream Facing USB4 Port and one or more Downstream Facing USB4 Ports
  • Provides backward-compatibility
  • Contains:
    • A Device Router
    • A USB3 and a USB2 hub
    • A PCIe switch
  • Supports DP Tunneling
    • Requires at least one DP OUT Adapter to support DP Alt Mode on DFPs
  • Supports 40 Gbps operation

• USB4-Based Dock
  • Combines a USB4 Hub with additional capabilities to expose other connector types and/or include other user-visible functions
USB4™ Peripheral Device

- One Upstream Facing Port and zero Downstream Facing Ports
- Contains a Device Router and optionally contain one or more of the following:
  - An Enhanced SuperSpeed hub
  - An Enhanced Superspeed function
  - A PCIe switch or endpoint
  - A DisplayPort™ Source or Sink
- Supports 20 Gbps and optionally 40 Gbps operation
USB4™ Functional Stack

- **Protocol Adapter Layer**: Maps an I/O protocol (PCIe, DP, USB, Host Interface) to USB4.
- **Configuration Layer**: Performs Router setup, configuration and management.
- **Transport Layer**: Handles packet multiplexing, routing, QoS, flow control and time synch.
- **Physical Layer**: Defines Electrical signaling across High-Speed Lanes.
- **Logical Layer**: Establishes a High-Speed Link between two routers, encodes/decodes byte streams, and performs Link PM services.
- **Electrical Layer**:
USB4™ Adapters

- A Router can contain up to 64 Adapters
- Provide an interface between a Router and an external entity
- Addressable using Adapter Number

- Maps a Tunneled Protocol to USB4™
- Four types of Protocol Adapters:
  - USB3 Adapters
  - DP Adapters
  - PCIe Adapters
  - Host Interface Adapters

- Configuration and management interface
- Logical Adapter

- Provides an interface for a Lane
- A USB4 Port has two Lane Adapters
USB4™ Links and Lanes

- **USB4 Link** = the logical connection between two USB4 ports
  - Transports USB4 packets between connected USB4 products
- **USB4 Lane**
  - Two differential signal pairs (Tx/Rx)
  - Operates at Gen2 (10 Gbps) or Gen3 (20 Gbps)
  - Used for tunneled protocol and control traffic
- **Sideband (SB) Channel**
  - Two-wire channel
  - Used for link initialization and management

**Dual-Lane USB4 Link**

Lane 0 and Lane 1 are bonded

**Single-Lane USB4 Link**

Lane 1 is disabled in fallback operation
Connection Manager

- Interfaces to a Domain via the USB4™ Host
  - Communicates to a Router through the Control Adapter
- Enumerates and configures all USB4 Routers
  - Hot Plug and Hot Unplug
  - Path setup and teardown
  - Path bandwidth allocation
  - Path Flow control setup
- Enables Host-to-Host Tunneling
- Implementation choices:
  - Device Driver for the Host Router in the OS or VMM
  - Part of system BIOS
USB4™ Topology

• Typically a tree topology
  • Host Router at the top with device Routers connected downstream
    • CM runs on the Host Router platform
  • The CM creates a Spanning Tree to configure/manage the Domain

• Device Routers are downstream of Host Router

• CM detects loops in the physical topology
  • Invalid “DFP-DFP” connections made by users possible for hosts and hubs
  • Loops occur if there are multiple connections between two Routers
  • CM ignores them in the Spanning Tree
Paths and Tunnels

• Path is a one-way logical connection between two Adapters
  • Two types:
    • Protocol Adapter-to-Protocol Adapter
    • Connection Manager-to-Control Adapter
  • Represents a “virtual wire” for a Tunneled Protocol
  • Identified by a Link-specific HopID in packet headers
• Tunnel is a logical connection between two USB4™ products
  • For Display and Host-to-Host tunneling, tunnel is one end-to-end path
  • For USB3 and PCIe tunneling, tunnel is a series of paths
• USB4 is a connection-oriented architecture
  • One or more paths can be established after a Router is enumerated
  • Tunnel is configured end-to-end before data transfer can take place
Adapter/Transport Layer Communication

- Control Packets
  - Used for Router configuration

![Diagram of USB4 Link](image_url)
Adapter/Transport Layer Communication

- Tunneled Packets
  - Used for tunneling protocol data

Native Protocol Traffic (e.g. USB3, DP, etc.)

- Tunneled Packets
- Protocol Adapter Layer
- Configuration Layer
- Transport Layer
- Physical Layer
- Logical Layer
- Electrical Layer

USB4 Link
Adapter/Transport Layer Communication

- Link Management Packets
  - Used for flow control and time sync
Logical Layer Communication

- Low-Speed Link Transactions
  - Used for link initialization

USB4 Sideband Channel
Logical Layer Communication

• LFPS*
  • Used for exiting low power state

* Low Frequency Periodic Signaling
Logical Layer Communication

- **Ordered Sets**
  - Used for logical layer functions (e.g. symbol sync, de-skew)
## Configuration Spaces

<table>
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<th>Description</th>
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<tr>
<td><strong>Router Configuration Space</strong></td>
<td>• Router Capabilities</td>
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<tr>
<td><strong>Adapter Configuration Space</strong></td>
<td>• Contains capabilities, configuration, and error statistics for an Adapter</td>
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<tr>
<td><strong>Path Configuration Space</strong></td>
<td>• Contains an entry for each supported Path</td>
</tr>
<tr>
<td><strong>Counter Configuration Space (Optional)</strong></td>
<td>• Contains performance statistics for a set of selected Paths</td>
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</table>

**One instance of each per Protocol and Lane adapter in the Router**

**One instance per Router**

**NOTE:** Control Adapters do not have Configuration Space
Life of a Router

1. Router loads default values into the Configuration Space registers
2. When Router is hot-plugged, Link Initialization brings up the USB4™ Link
3. Router enables Control Packet routing and scheduling
4. Connection Manager (CM) enumerates and configures the Router
   • CM sets up any Paths in the Router
5. Router is ready to route and process Tunneled Protocol traffic
6. When a USB4 Device is plugged into a Router’s Downstream Facing Port (DFP):
   • Link Initialization on the Router’s DFP
   • After Link Initialization, Router sends a Hot Plug Event Packet to the CM
7. When the USB4 Device is unplugged from Router’s DFP:
   • Router discards any packets that would otherwise be routed to the unplugged device
   • Router performs a DFP disconnect
8. If the Router is disconnected, it performs a UFP disconnect
USB3 Tunneling

- USB 3.2 Enhanced SuperSpeed (ESS) protocol is tunneled over the USB4™ fabric
  - To USB3 software, the USB3 topology remains the same

- Internal ESS Host in USB4 Hosts
- Internal ESS Hub and/or ESS Function in USB4 Devices
- ESS Hub provides fan-out to:
  - Internal ESS Peripheral Devices
  - External USB4 Ports via USB3 DN Adapters

- USB3 Adapter Layer:
  - USB3 DN Adapter receives USB3 packets from internal USB3 hub/functions and encapsulates them in tunnel packets
  - USB3 UP Adapter receives tunnel packets from USB4 fabric and passes USB3 packets to internal USB3 hub/functions
**DP Tunneling**

- DisplayPort™ protocol is tunneled over the USB4™ Fabric
  - To DP Source, the USB4 Fabric and the Adapters are either totally transparent or act as an LTTPR*
  - DP links at each end are identical down to the symbol level

- Supports: [SST & MST], [1,2 & 4] Lanes at [RBR, HBR, HBR2 & HBR3] Rates
  - Data sent in 8-bit representation, stuffing symbols not sent

- DP Adapter Layer:
  - DP IN Adapter packs the DisplayPort video stream into tunnel packets
  - DP OUT Adapter unpacks it and recreates the DP stream

* Link-Training Tunable PHY Repeater
**PCle Tunneling**

- PCIe protocol is tunneled over the USB4™ Fabric
  - To PCIe software, the PCIe tree remains the same

- Internal PCIe Controller in USB4 Hosts
- Internal PCIe Switch and/or PCIe Endpoint in USB4 Hubs/Devices
- PCIe Switch provides fan-out to:
  - Internal PCIe Switches or Endpoints
  - External USB4 Ports via PCIe DN Adapters
- PCIe Adapter Layer:
  - PCIe DN Adapter receives PCIe packets from the internal Switch/Endpoint and encapsulates them in tunnel packets
  - PCIe UP Adapter receives tunnel packets from the USB4 fabric and passes PCIe packets to the internal Switch/Endpoint
Time for Q&A
# USB Developer Days – Technical Session Schedule

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<td><strong>USB Type-C® System Overview</strong></td>
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<td><strong>USB4™ Logical Layer, Re-Timer and Transport</strong></td>
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<td><strong>Microsoft/Intel: USB4™ on Windows</strong></td>
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<td><strong>Google: CTVPD, a new PD stack and Making USB-C® thingamajigs</strong></td>
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<td><strong>USB4™ Cable Electricals and System Design</strong></td>
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<td><strong>VESA: DisplayPort™ Alt Mode</strong></td>
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