Architecture Overview

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Purpose

- Discuss usage model for USB
- Provide introductory technical overview
- Lead into detailed sessions to follow
Historical PC Perspective

- 15-year Baggage: Incremental addition of an interface per device
  - Limited application model for PC
  - Ports not designed for sharing
    - PS/2, parallel, serial, joystick
    - Interface speeds were much lower
  - Add-in cards were typical method for adding a high-bandwidth device
- Real-time & MM stretch these interfaces

Why USB?

- Ease of Use
  - Plug and Play capabilities for “Outside the Box” peripherals
- “PC/Phone Integration”
  - Windows*/TAPI based Adaptors and Communication Applications
**External Bus Taxonomy**

<table>
<thead>
<tr>
<th>BANDWIDTH</th>
<th>DEVICE COST</th>
<th>APPLICATIONS</th>
<th>ATTRIBUTES</th>
<th>STD FEATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW 10 - 100 Kb/s</td>
<td>$5-25</td>
<td>Input Devices, Control Functions</td>
<td>Very Low cost, Ease of Use, Lots of fanout</td>
<td>1997</td>
</tr>
<tr>
<td>MEDIUM 200K - 10Mb/s</td>
<td>$15-150</td>
<td>Telephony, Modem, Audio, Scanner</td>
<td>Low cost, Guaranteed latency</td>
<td>1997</td>
</tr>
<tr>
<td>HIGH 100 - 400 Mb/s</td>
<td>$100-500</td>
<td>Entertainment, A/V, Imaging</td>
<td>Peer-to-peer, Multiple channels</td>
<td>TBD</td>
</tr>
<tr>
<td>COMPUTE 1+ Gb/s</td>
<td>$200-500</td>
<td>Primary Disk, Home Backbone</td>
<td>Very High bandwidth, Fiber capability</td>
<td>1999+</td>
</tr>
</tbody>
</table>

**USB Focus on Low Cost, High Volume Applications**

**PC Connectivity Vision**

**USB in 1996:** Initially introduced as an incremental connector for new applications.

**USB Future:** The PC evolves into a simpler, easier to use appliance.
Universal Serial Bus Focus

♦ For today’s PC at current cost points
  – Optimized for high-integration
    ■ Medium speed signalling with commodity HW
    ■ Practical for wider range of peripherals
  – Common attach point
    ■ Intelligent interfaces allow sharing
    ■ Simple user paradigm
    ■ Enables port consolidation (mouse, keyboard, gameport, serial & parallel)

Standards Alternatives

Standards Body
  e.g. IEEE, ANSI, CCITT

Industry Leadership
  e.g. TAPI, PCI, IrDA

It Happened One Day
  e.g. ISA, SoundblasterTM

Michael Slater: 
Industry led standards are effective !!
Technical Overview

- Hardware Architecture
- Bus Topology
- Client Model and Transaction Formats
- Transfer Types, Packet Formats
- Frame Structure
- Physical Layer

USB Hardware Overview

- Topology
  - Tiered Star (Distributes Connectivity Points)
  - 126 devices
  - Up to 6 tiers (up to 5 metres per segment)
- Bus transactions
  - Speed: 12Mbps aggregate
  - 1.5Mbps sub-channel
  - Isochronous and Asynchronous
  - Media access controlled by host
- Configuration
  - Dynamic insertion-removal
  - Autoconfiguration on change
- Physical Layer
  - 2-wire differential signaling, NRZI coded with bit stuffing
  - Supply Sourcing +5V
  - Signaling at CMOS 3.3V
  - 4 pin connector, 4 wire cable
USB Topology

- **Host**
  - One PC host per system
- **Hub**
  - Provides connecting ports, power, terminations
  - Self-Powered or Bus Powered
- **Device, Interfaces and Endpoints**
  - Device is a collection of interface(s)
  - Interface is a collection of endpoints
  - Addressing up to 126 devices and 16 endpoints

USB Hub Function

- **Port Control**
  - Connection detect
  - Port Enable/Disable
  - Reset/Resume Signaling
- **Data Switch**
  - Signal Regeneration
  - Robustness/Recovery
- **Power Distribution**
### Basic USB Model

**Host Layers**

- **USB Bus Interface**
  - Physical interface to wire
  - Manages low-level protocol
- **USB System Software**
  - Provides interfaces to driver layers
  - Manages standard device objects
- **Client Software**
  - E.g. device drivers
  - Manages capability

**Actual communications flow**

**Logical communications flow**

**Implementation Focus Area**

**Physical Interface, Signalling**

**Provides common device abstraction**

**Capability**
Device Layers

- **USB Bus Interface**
  - Physical interface to wire
  - Manages low-level protocol
- **USB Logical Device**
  - Defines common view of device by host
  - Manages high-level protocol
- **Function**
  - Represents capability delivered by the device

Device Abstractions

- **End Point**
  - Ultimate data source or sink at the device end
  - Unique address, unidirectional, transfer characteristics
- **Pipe**
  - Association of endpoint with host SW owner
- **Interface**
  - Collection of pipes
  - Map to a capability
  - Owned by exactly 1 software client
**Detailed Host / Device View**

- **Host**
  - Endpoint 0
    - Required, shared
    - Configuration access
    - Capability control
  - Client SW manages an interface
  - USB System manages devices

- **Device**
  - Function manages a function
  - Interface to an endpoint
  - USB Bus Interface

**Client Software <-> Function**

- **Host**
- **Client Software**
- **Buffers**
- **Pipes**
- **Data Flows**
- **Endpoints**
- **USB Device**
- **Interface**

Pipe represents connection abstraction between two horizontal layers.
Interfaces

- Made of 0 or more pipes
- Has a client owner
  - Accesses individual pipes
  - Shares default pipe
- More dynamically configured than devices

Endpoints

- One endpoint for each pipe
Endpoints

- One endpoint for each pipe
- Endpoint zero

Other Endpoints
- Optional, up to 15 IN, 15 OUT at fullspeed
- Optional, up to 2 additional at lowspeed
- Determined by implementation requirements
- Endpoint characteristics vary
Pipes

- Connect host memory buffer to endpoint FIFO
- Stream Type
  - No USB imposed data format
  - Unidirectional
- Message Type
  - USB imposed data format
  - Bidirectional

Communications Layers

- Physical
- Packets
- Transactions
  - 3 phases (token, data, handshake)
  - Token phase has token packet sent by host
    - Always present
    - Packet ID (PID) identifies transaction type
  - Other phases have 0 or more packets
- Transfers
Transfers to Transactions

Transaction Protocol

- Host based token polling
  - Data from host-to-function and function-to-host
  - Host handles most of the protocol complexity
  - Peripheral design is simple and low-cost
Robustness

- Handshake to acknowledge data transfer and flow control
- Very low raw physical bit error rate ( <10^{-10} )
- PID check bits, CRC protection, plus hardware retry option
- Data Toggle Sequence bits

Bounded transfer characteristics

- Data transfer bandwidth and latency prenegotiated
- Flow control for peripheral buffer management
USB Transfer Types

- Isochronous (e.g.: Audio, Telephony, Motion camera.....)
- Interrupt (e.g.: Mouse, Joystick....)
USB Transfer Types

- Isochronous (e.g.: Audio, Telephony, Motion camera.....)
- Interrupt (e.g.: Mouse, Joystick....)
- Bulk (e.g.: Printer, Scanner, Still camera.....)

- Control (e.g.: Configuration, Messages)
  - Bursty, bi-directional, higher level protocol
  - Used for bus management, configuration, device control
Packet Formats

**PID**

8 bits

**ADDR**

7 bits

**ENDP**

4 bits

**CRC5**

5 bits

**Token (In/Out)**

- **PID** 8 bits
- **DATA** 0-1023 bytes
- **CRC16** 16 bits

**Data (Toggle)**

- **PID** 8 bits
- **DATA** 0-1023 bytes
- **CRC5** 5 bits

**Handshake/Low Speed Preamble**

- **PID** 8 bits

**Start of Frame**

- **PID** 8 bits
- **Frame Number** 11 bits
- **CRC5** 5 bits

*All Packets Are Prefaced With SYNC Field and Terminated With EOP*

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**USB Frame Model**

- **Frame** = 1ms
- **Slot**

- **Stereo Audio**
- **Low Speed**
- **BULK**

(not to scale)
Connectors and Cables

- Connectors
  - 4-Position with shielded housing
  - Positive Retention
  - Blind Mating Capabilities
- Cables
  - 28 AWG twisted pair for signalling
  - 20-28 AWG pair for power
  - Shielding for fully rated segments

Power Distribution

- Significant capability of USB
  - Eliminate wall adaptors
- Hubs may be self-powered or bus-powered
  - Two current levels: 100 & 500 mA
  - Overcurrent protection for safety
  - Wire gauge options: 20-28 AWG
**Voltage Drop**

- Voltage drop per wire/connector: 0.125 V
- Budget for power switch: 0.100 V

**USB Connections and Terminations**

- Twisted Pair Shielded: 2c = 90W±19%, 5 Meters Max.
  - R1 = 19KW±19%
  - R2 = 1.5KW±19%

- Untwisted, Unshielded: 2 Meters Max.
  - R1 = 19KW±19%
  - R2 = 1.5KW±19%

- Hub Port 0 or Full Speed Function
- Low Speed Function
**Data Signaling**

- Bi-directional, half-duplex link
- Embedded clock and data
- Differential signal pair
- 12 Mbit / sec Full Speed (F.S.) bit rate
- 1.5 Mbit / sec Low Speed (L.S.) bit rate

**Signaling States**

- J-state
Signaling States

- J-state
- K-state (Inverse of J-state)

- Single ended zero (SE0) state
  - End of Packet identifier (EOP)
  - Signaling reset
  - Disconnected line
**USB Transceiver**

- **Differential Driver**
  - Slew rate controlled
  - SE0 drive capability
- **Differential Receiver**
  - Sensitivity <200mV
  - Common mode range: <1.0V to >3.0V
- **Single-Ended Receivers**
  - Threshold: 0.6V - 1.5V

**Low-Speed Mode**

- Allows very-low-cost devices to be built without compromising data rate for faster devices
  - Mice, keyboards, most user interface peripherals don't need fast data rate
- Eliminates need for shielded twisted pair cable
- Allows use of less-expensive IC process technology
- But reduced functionality
Low Speed

- 1.5 Mb/s
  - Unshielded, untwisted cable
  - Saves EMI suppression costs
  - 1.5% Frequency tolerance
- Driver characteristics
  - Rise/ Fall time: Min 75ns, Max 300ns
  - Required on low speed functions and on the downstream ports of Hubs

Suspend & Resume

- Suspend
  - All devices support suspend
  - Enter suspend state after seeing idle bus for 3 ms
  - Suspend current ≤ 500 μA from bus
- Resume
  - Devices resume on seeing non-J state
  - USB devices can cause “remote wake-up” by signaling with a K-state
Enumeration

- Hubs detect attachments
  - Report via status change endpoint
- Host RESETs port
  - If new device is a hub, disables new hub’s ports
- Host read configuration information and configures device

Architecture Summary

**USB uses a host-directed protocol which:**

- Supports dynamic attachment of large number and variety of devices
- Provides power distribution and power management facilities
- Is abstracted as a transfer model for host software clients
### Complete USB Standard

#### Compelling Applications
- **End User Marketing**
  - End User Apps
  - PC and Telephone Industry & Media
  - Telephony, Gaming, Productivity

#### Breadth of Peripherals
- **Peripheral Marketing**
  - Integrated Products
  - S/W Ingredients
  - H/W Ingredients
  - PC & Telephone IHVs
  - Devices: Input, Telephony, Hubs, etc.
  - New Std. DDs, SDKs
  - Microcontrollers, FPGA/ASIC, Codecs, DAA, ...

#### Volume Platform
- **OEM Marketing**
  - Integrated Products
  - S/W Ingredients
  - H/W Ingredients
  - PC OEM
  - Motherboards
  - Dev Kit, Std. DDs, Next OS update
  - Chipsets

#### Industry Forum
- **Industry Marketing**
  - OS Support
  - STDS Mechanism
  - S/W Standards
  - H/W Standards
  - Industry Leaders + USB-IF
  - Microsoft, IBM, etc.
  - USB-IF: Licensing, Compliance
  - Specification: 1.0
  - Specification: 1.0

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### Industry Forum

- Specification is royalty-free and openly available
- USB Implementers Forum for product support and event coordination
  - >400 member companies
  - 8 Developer’s Conferences
  - 11 Compliance Workshops
- Intel providing visible leadership
Product Momentum

- All major OEMs now shipping systems with connectors and Windows drivers installed
- Device and hub building blocks from Intel CEG and several other vendors
Product Momentum

◆ All major OEMs now shipping systems with
collectors and Windows drivers installed
◆ Device and hub building blocks from
  Intel CEG and several other vendors
◆ OEM bundles and retail channel peripherals