Universal Serial Bus (USB)

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USB

- USB Goals and Characteristics
- USB Connection Model
- USB Protocol
USB Goals and Characteristics

- **Motivation**
  - Connection of PC to cell phones
  - Easy of use
  - Port Expansion

- **Characteristics**
  - Low-cost
  - Transfer rates up to 5 Gbps
    - Four speeds 1.5 Mbps, 12 Mbps, 480 Mbps, 5 Gbps
  - Mixed isochronous and asynchronous transfers
  - Enabling new classes of devices
Physical Bus Topology

- Single managing host
- Hubs -- expand connection points
- Devices -- perform a function

Figure 5-5. USB Physical Bus Topology
Logical Bus Topology

Figure 5-7. USB Logical Bus Topology
Typical Installation

Figure 4-4. Hubs in a Desktop Computer Environment
Typical USB Device Interface
USB Protocol Stack

Figure 5.2. USB Implementation Areas
USB Protocol Stack -- Physical

Figure 5-2. USB Implementation Areas
USB Protocol Stack -- System Mgmt

Figure 5-2. USB Implementation Areas
USB Protocol Stack -- Client Software

Figure 5-2. USB Implementation Areas
Physical Layer

Figure 4-2. USB Cable

<table>
<thead>
<tr>
<th>Series &quot;A&quot; Connectors</th>
<th>Series &quot;B&quot; Connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>♦ Series &quot;A&quot; plugs are always oriented <strong>upstream</strong> towards the <em>Host System</em></td>
<td>♦ Series &quot;B&quot; plugs are always oriented <strong>downstream</strong> towards the <em>USB Device</em></td>
</tr>
<tr>
<td><img src="image1" alt="A Plugs" /> (From the USB Device)</td>
<td><img src="image2" alt="B Plugs" /> (From the Host System)</td>
</tr>
<tr>
<td><img src="image3" alt="A Receptacles" /> (Downstream Output from the USB Host or Hub)</td>
<td><img src="image4" alt="B Receptacles" /> (Upstream Input to the USB Device or Hub)</td>
</tr>
</tbody>
</table>

Figure 6-1. Keyed Connector Protocol
Physical Features

- Power distribution -- at least 500 mA per device at +5 V DC
- Power management
- Bus Protocol -- USB is a polled protocol
- Error Detection
- Error Handling
- System Configuration -- attachment and removal of devices
- Data Flows
  - Control, Bulk, Interrupt, Isochronous, Bandwidth allocation
USB Protocol -- Data Out

Host

Token

Write

Ack

Device

Time
USB Protocol -- Data In
USB -- Protocol Layer

- Bytes are sent least-significant-bit first
- Bytes are sent least-significant-byte first
- Sync -- 8 bits for full-speed, 32-bits for high-speed
- PacketId -- 4 bits
- Address -- 7-bits device address, 4-bits endpoint
- FrameId -- 11-bits
- Data -- 0..1023 bytes
- CRC -- Error Control Code; 5-bits Poll; 16-bits Data
Packet Formats -- Token

<table>
<thead>
<tr>
<th>Field</th>
<th>PID</th>
<th>ADDR</th>
<th>ENDP</th>
<th>CRC5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bits</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 8-5. Token Format
## USB -- PID Types

### Table 8-1. PID Types

<table>
<thead>
<tr>
<th>PID Type</th>
<th>PID Name</th>
<th>PID&lt;3:0&gt;*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Token</strong></td>
<td>OUT</td>
<td>0001B</td>
<td>Address + endpoint number in host-to-function transaction</td>
</tr>
<tr>
<td></td>
<td>IN</td>
<td>1001B</td>
<td>Address + endpoint number in function-to-host transaction</td>
</tr>
<tr>
<td></td>
<td>SOF</td>
<td>0101B</td>
<td>Start-of-Frame marker and frame number</td>
</tr>
<tr>
<td></td>
<td>SETUP</td>
<td>1101B</td>
<td>Address + endpoint number in host-to-function transaction for SETUP to a control pipe</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>DATA0</td>
<td>0011B</td>
<td>Data packet PID even</td>
</tr>
<tr>
<td></td>
<td>DATA1</td>
<td>1011B</td>
<td>Data packet PID odd</td>
</tr>
<tr>
<td></td>
<td>DATA2</td>
<td>0111B</td>
<td>Data packet PID high-speed, high bandwidth isochronous transaction in a microframe (see Section 5.9.2 for more information)</td>
</tr>
<tr>
<td></td>
<td>MDATA</td>
<td>1111B</td>
<td>Data packet PID high-speed for split and high bandwidth isochronous transactions (see Sections 5.9.2, 11.20, and 11.21 for more information)</td>
</tr>
</tbody>
</table>
## USB -- PID Types

<table>
<thead>
<tr>
<th>Handshake</th>
<th>ACK</th>
<th>0010B</th>
<th>Receiver accepts error-free data packet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NAK</td>
<td>1010B</td>
<td>Receiving device cannot accept data or transmitting device cannot send data</td>
</tr>
<tr>
<td></td>
<td>STALL</td>
<td>1110B</td>
<td>Endpoint is halted or a control pipe request is not supported</td>
</tr>
<tr>
<td></td>
<td>NYET</td>
<td>0110B</td>
<td>No response yet from receiver (see Sections 8.5.1 and 11.17-11.21)</td>
</tr>
<tr>
<td>Special</td>
<td>PRE</td>
<td>1100B</td>
<td>(Token) Host-issued preamble. Enables downstream bus traffic to low-speed devices.</td>
</tr>
<tr>
<td></td>
<td>ERR</td>
<td>1100B</td>
<td>(Handshake) Split Transaction Error Handshake (reuses PRE value)</td>
</tr>
<tr>
<td></td>
<td>SPLIT</td>
<td>1000B</td>
<td>(Token) High-speed Split Transaction Token (see Section 8.4.2)</td>
</tr>
<tr>
<td></td>
<td>PING</td>
<td>0100B</td>
<td>(Token) High-speed flow control probe for a bulk/control endpoint (see Section 8.5.1)</td>
</tr>
<tr>
<td></td>
<td>Reserved</td>
<td>0000B</td>
<td>Reserved PID</td>
</tr>
</tbody>
</table>
Packet Formats -- Data

<table>
<thead>
<tr>
<th>Field</th>
<th>PID</th>
<th>DATA</th>
<th>CRC16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bits</td>
<td>8</td>
<td>0-8192</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 8-15. Data Packet Format
Packet Formats -- Handshake

<table>
<thead>
<tr>
<th>Field</th>
<th>PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bits</td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 8-16. Handshake Packet
Host-Device Communication Flows

Host

Client Software

Buffers

Pipes

USB Logical Device

Communication Flows

Endpoints

Interface

Figure 5-10. USB Communication Flow
Transfer Types

- Transfer between memory buffer in application and endpoint in USB device
- Transfer over USB message pipes
- Transfer in USB defined protocol structure
- No USB constraint on contents of protocol data unit (PDU)
  - Defined by USB device and application software
Transfer Types -- Characteristics

• Each transfer type determines various characteristics of the communication flow including the following:
  • Data format imposed by the USB
  • Direction of communication flow
  • Packet size constraints
  • Bus access constraints
  • Latency constraints
  • Required data sequences
  • Error handling
Physical Bus Topology

Figure 5-5. USB Physical Bus Topology
Logical Bus Topology

Figure 5-7. USB Logical Bus Topology
Host-Device Connection Model

Host

\[\downarrow\]

Interconnect

\[\downarrow\]

Device

\[\downarrow\]

Client

\[\downarrow\]

USB System

\[\downarrow\]

USB Bus Interface

\[\downarrow\]

Actual communications flow

\[\downarrow\]

Logical communications flow

Function

\[\downarrow\]

USB Device

\[\downarrow\]

USB Bus Interface

Figure 10.1. Interlayer Communications Model