Chapter 22
USB: Universal Serial Bus

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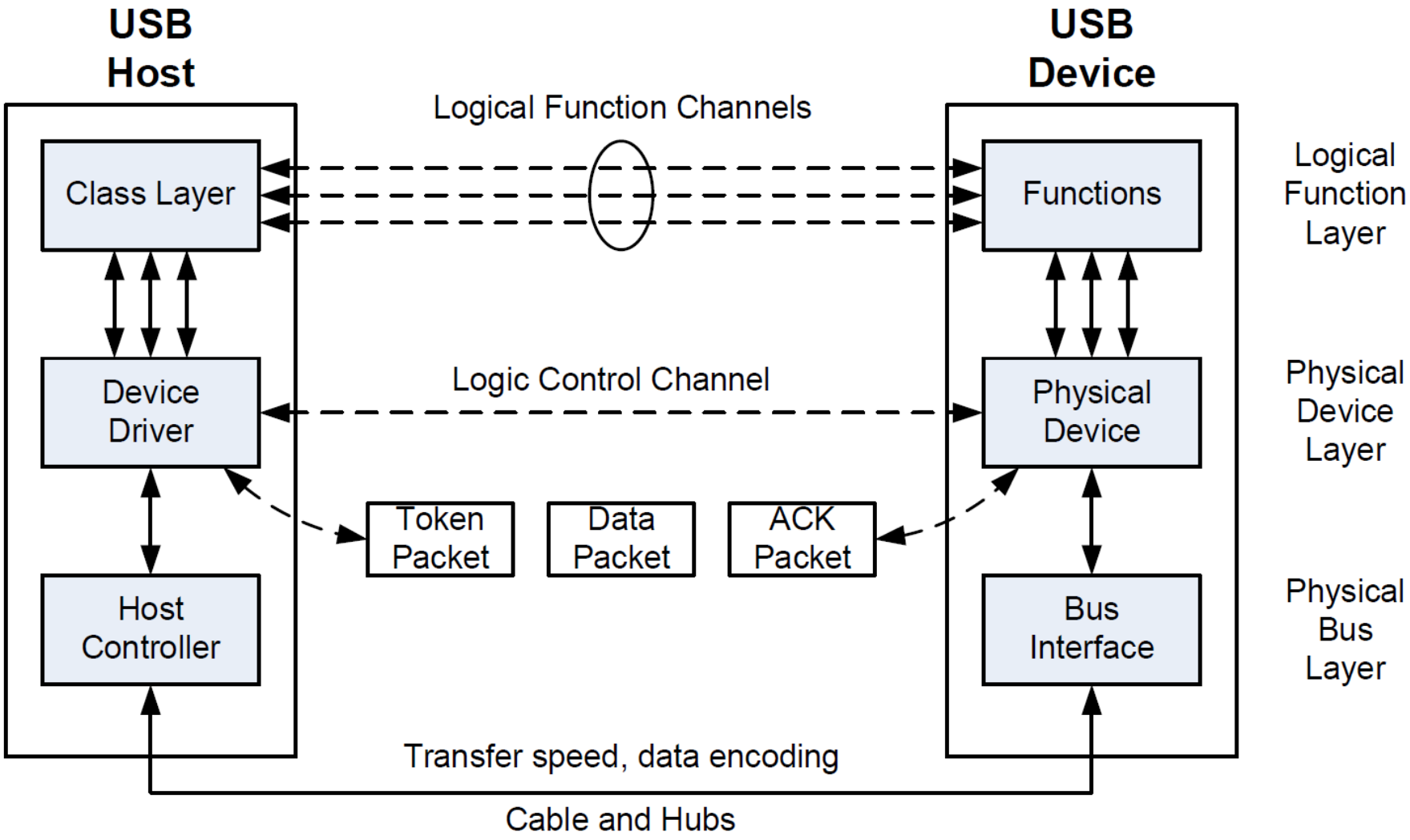
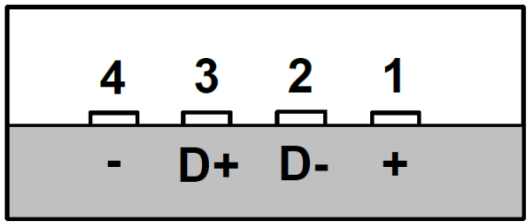
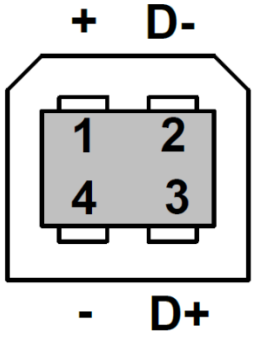
USB Layers


USB Host
USB Device
Logical Function Channels
Class Layer
Functions
Logical Function Layer
Device Driver
Logic Control Channel
Physical Device
Physical Device Layer
Token Packet
Data Packet
ACK Packet
Host Controller
Bus Interface
Physical Bus Layer
Transfer speed, data encoding
Cable and Hubs

USB Connection



Standard A



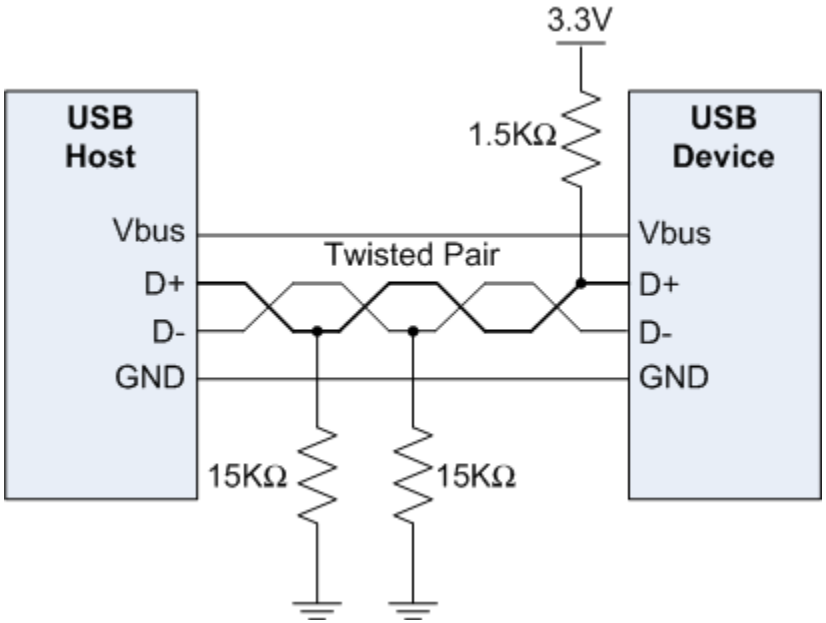
Standard B

- Four shielded wires: two for power (+5V, ground), two for data (D+, D-)
- D+ and D- are twisted to cancel external electromagnetic interference

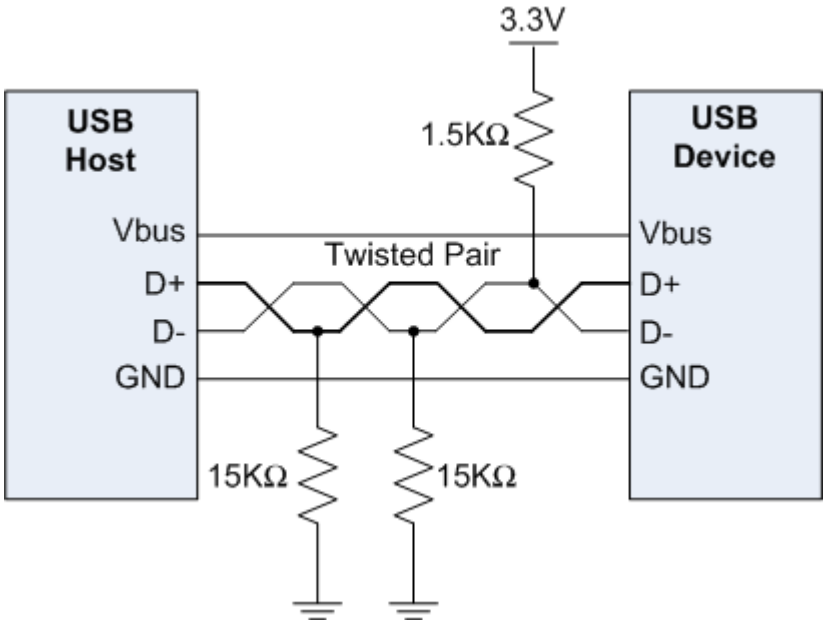
Image from wiki.com

USB Speed Identification

- USB supports four transmission speeds:
  - low speed (1.5 Mbit/s = 187 KB/s)
  - full speed (12 Mbit/s = 1.5 MB/s)
  - high speed (480 Mbit/s = 60 MB/s)
  - super speed (4.8 Gbit/s = 600 MB/s)

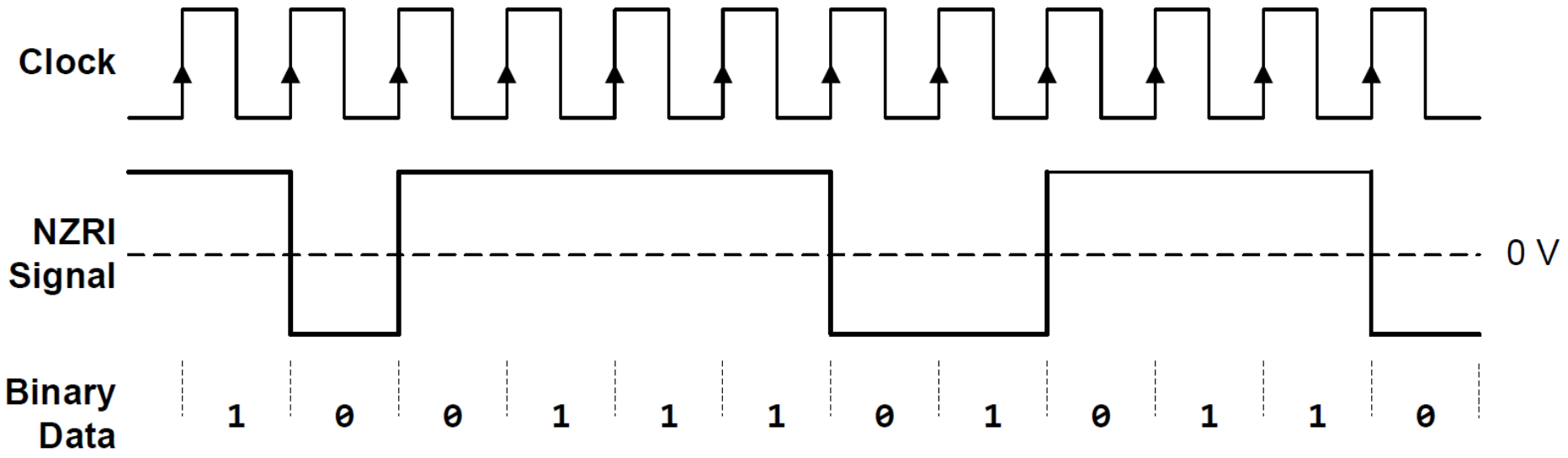


Full-speed mode (12 Mbits/s) identified by 1.5KΩ pull-up on D+



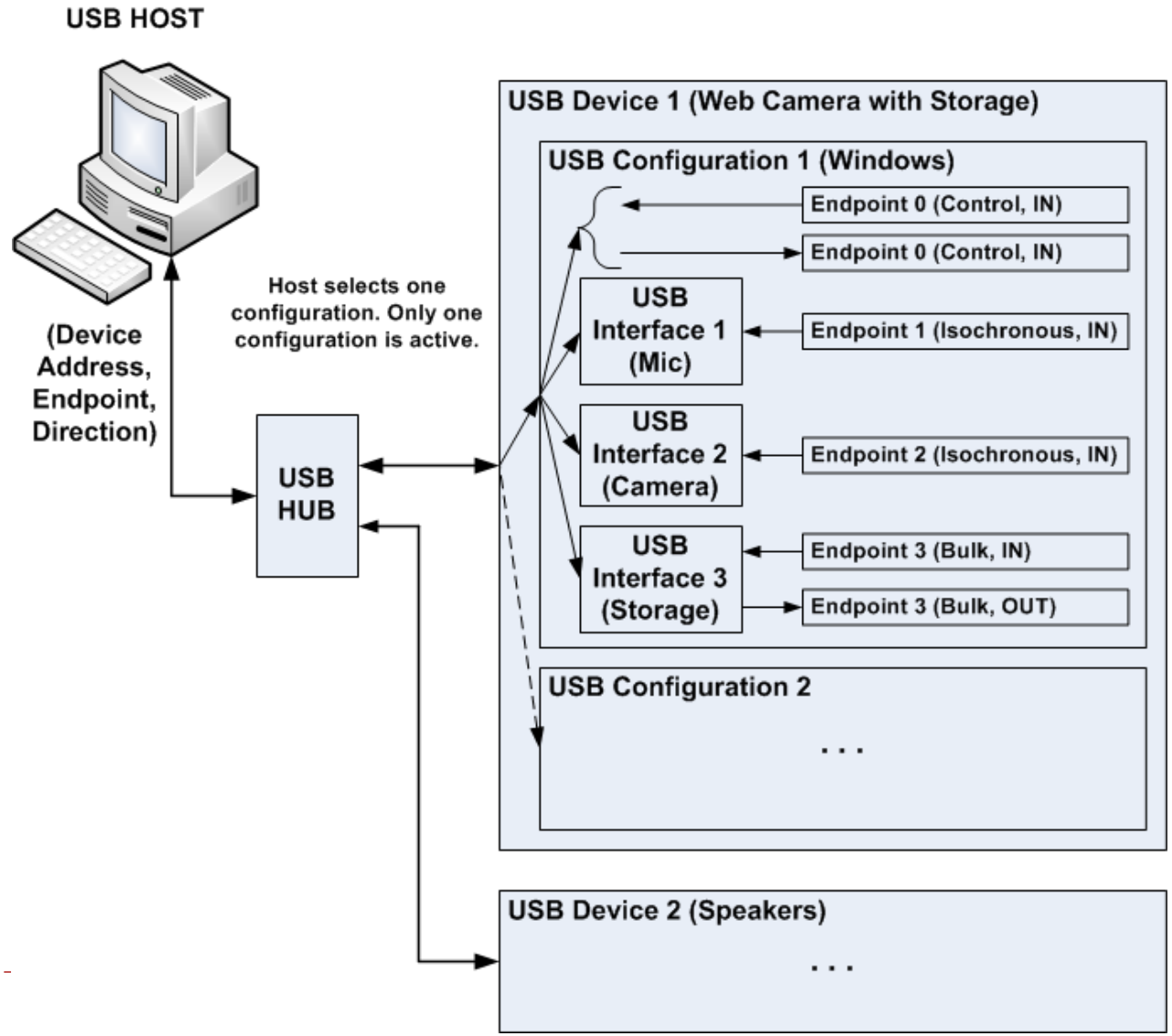
Low-speed mode (1.5Mbits/s) identified by 1.5KΩ pull-up on D-

Non-Return-to-Zero Inverted (NRZI)

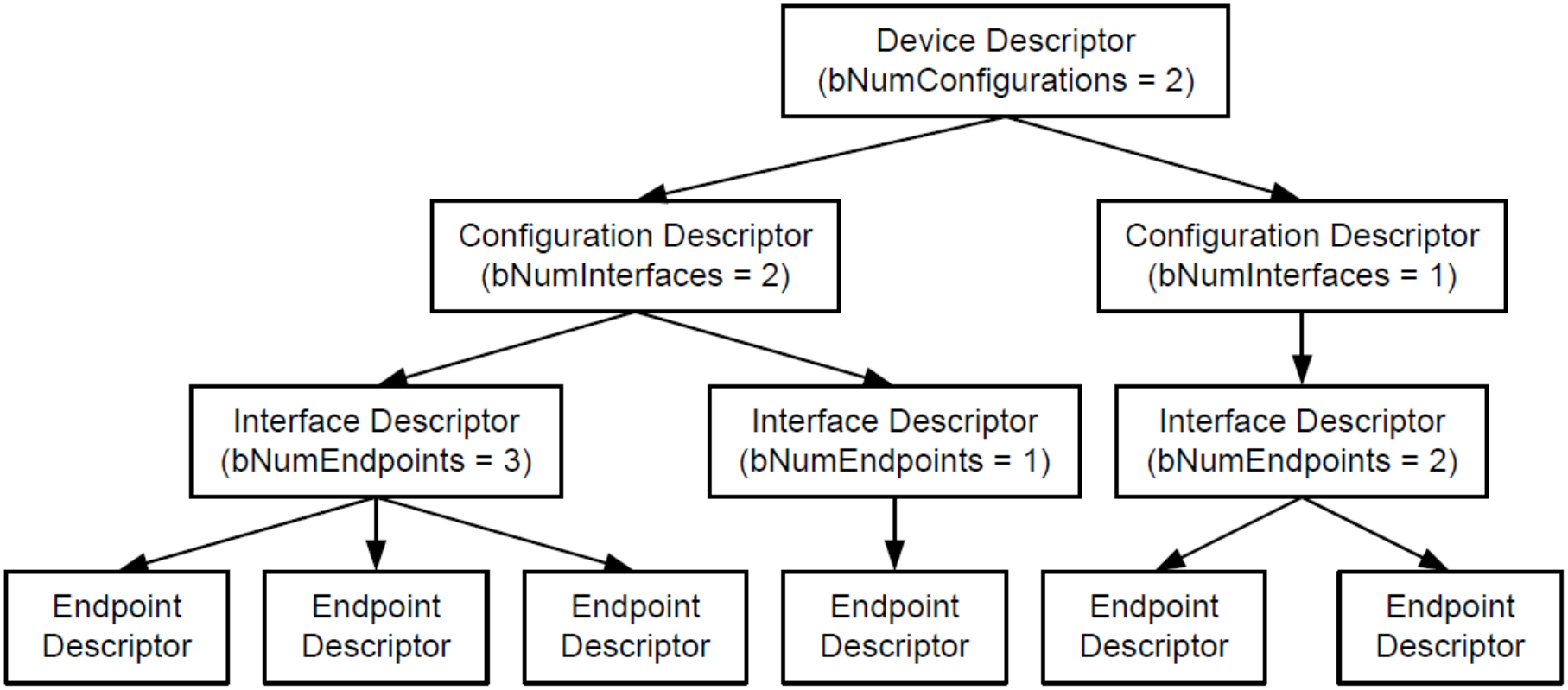


- Logic **0**: represented by a transition of the voltage level
- Logic **1**: represented by no transition

Interface


USB HOST
(Device Address, Endpoint, Direction)
Host selects one configuration. Only one configuration is active.
USB HUB
USB Device 1 (Web Camera with Storage)
USB Configuration 1 (Windows)
Endpoint 0 (Control, IN)
Endpoint 0 (Control, IN)
USB Interface 1 (Mic)
Endpoint 1 (Isochronous, IN)
USB Interface 2 (Camera)
Endpoint 2 (Isochronous, IN)
USB Interface 3 (Storage)
Endpoint 3 (Bulk, IN)
Endpoint 3 (Bulk, OUT)
USB Configuration 2
. . .
USB Device 2 (Speakers)
. . .

USB Descriptors



Field Name	Size	Offset
bLength	1	0
bDescriptorType	1	1
bcdUSB	2	2
bDeviceClass	1	4
bDeviceSubClass	1	5
bDeviceProtocol	1	6
bMaxPacketSize	1	7
idVendor	2	8
idProduct	2	10
bcdDevice	2	12
iManufacturer	1	14
iProduct	1	15
iSerialNumber	1	16
bNumConfigurations	1	17

Device descriptor

Field Name	Size	Offset
bLength	1	0
bDescriptorType	1	1
wTotalLenght	2	2
bNumInterfaces	1	4
bConfigurationValue	1	5
iConfiguration	1	6
bmAttributes	1	7
bMaxPower	1	8

Configuration descriptor

Field Name	Size	Offset
bLength	1	0
bDescriptorType	1	1
bInterfaceNumber	1	2
bAlternateSetting	1	3
bNumEndpoints	1	4
bInterfaceClass	1	5
bInterfaceSubClass	1	6
bInterfaceProtocol	1	7
iInterface	1	8

Interface descriptor

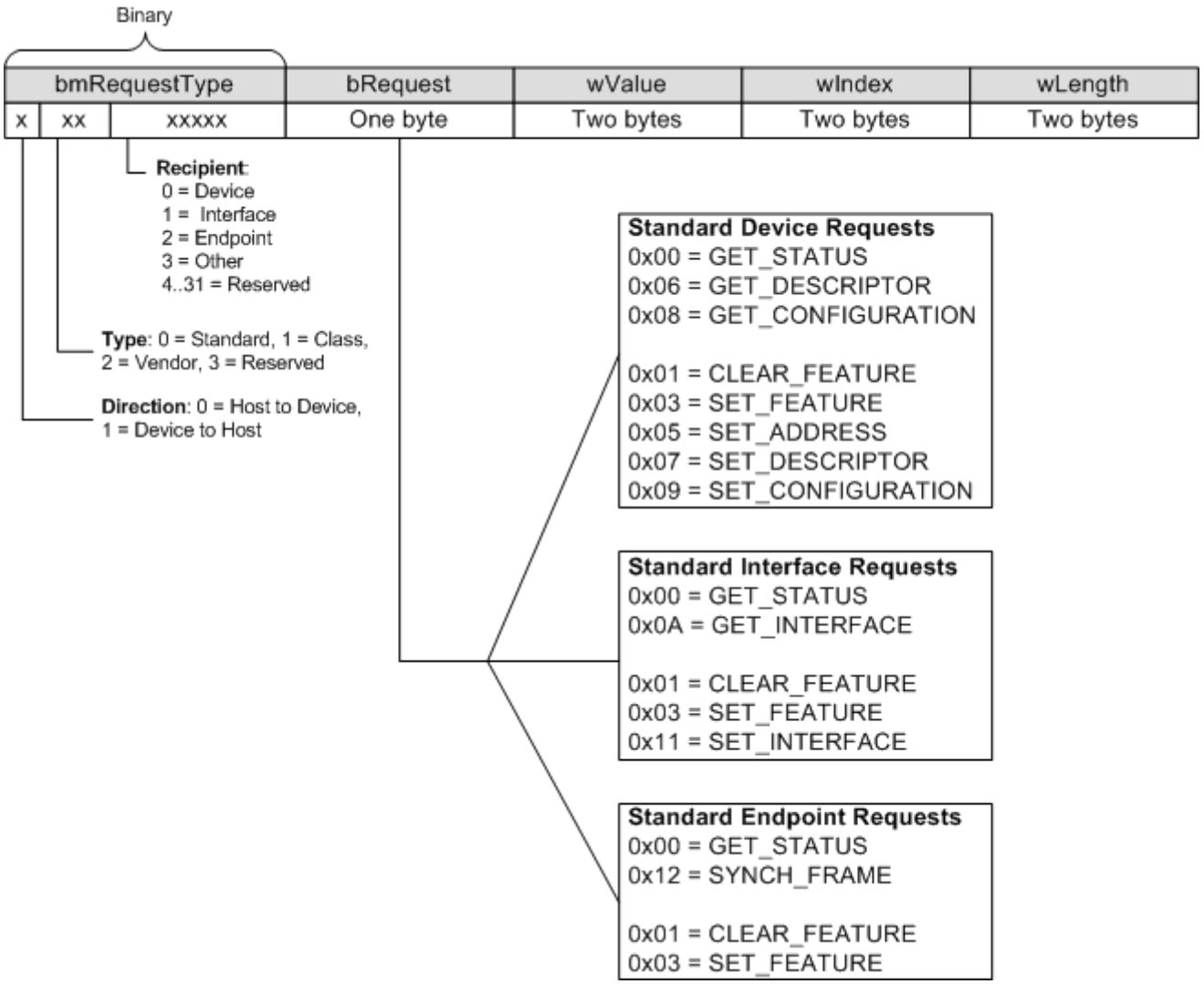
Field Name	Size	Offset
bLength	1	0
bDescriptorType	1	1
bEndpointAddress	1	2
bmAttributes	1	3
wMaxPacketSize	2	4
bInterval	1	6

Endpoint descriptor

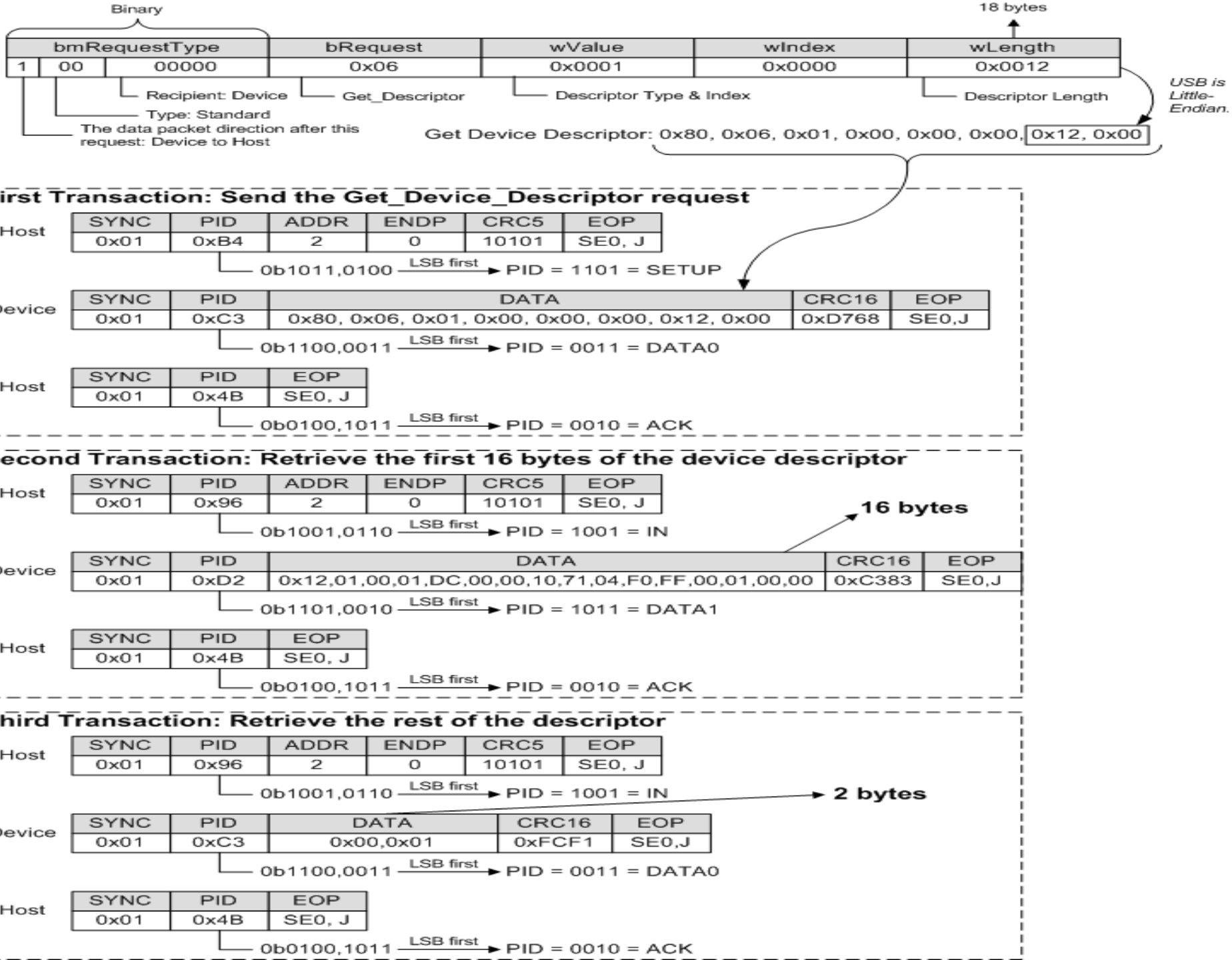
USB Enumeration

1. Detecting a device has been connected. When a USB device is plugged into a host, there is a change on the USB D+ or D- line since one of them is pulled up by the device.
2. Determining the USB speed. As introduced previously, pulling up D- via 1.5KΩ pull-up to 3V indicates a low-speed device. The same pull-up on D+ specifies a high-speed device.
3. Retrieving the device descriptor and determining what device is attached.
4. Retrieving all configuration descriptors. This process may take milliseconds to complete. The host selects one configuration.
5. Retrieving all interface descriptors.
6. Loading the corresponding device driver. This is typically handled by the operating systems on the host. The host typically uses idVendor and idProduct to match a driver.

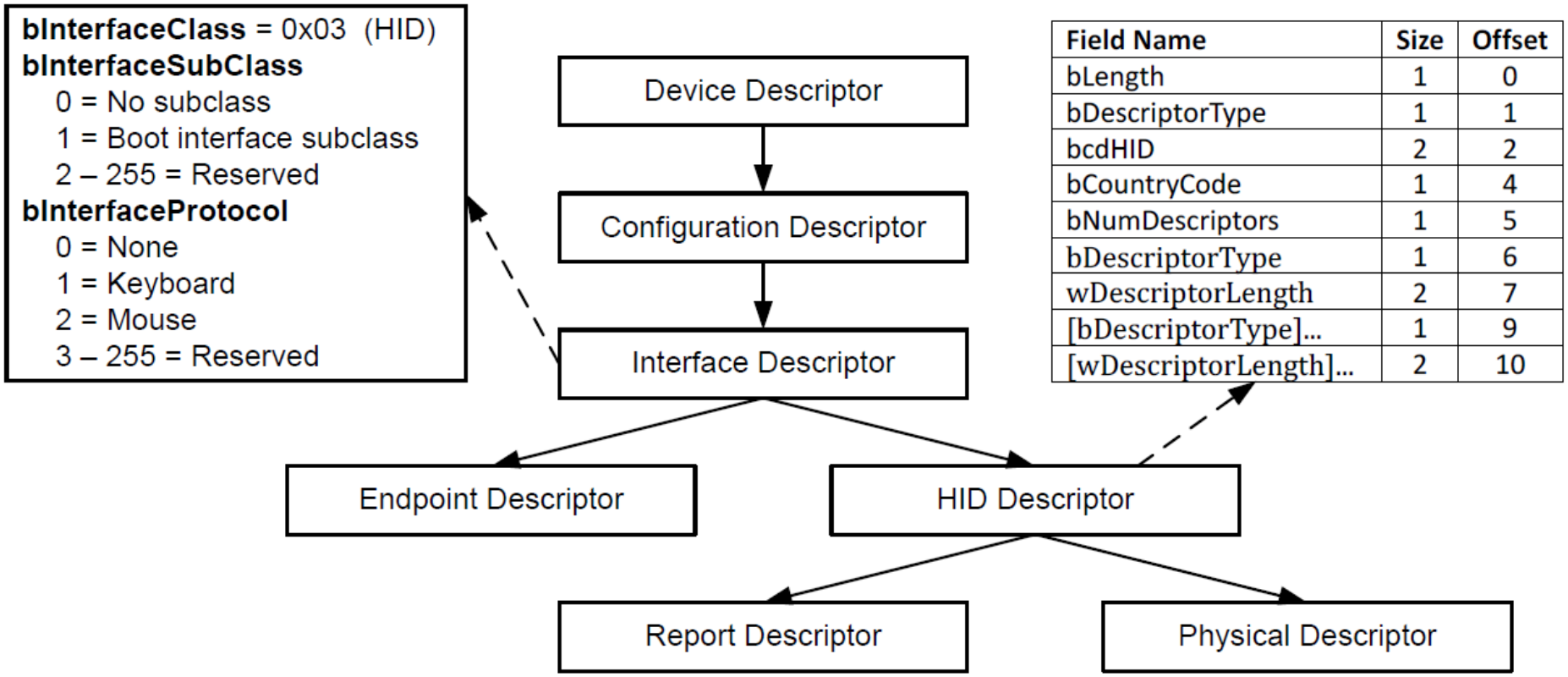
USB Enumeration



Format of Setup Request


Binary
18 bytes
bmRequestType
bRequest
wValue
wIndex
wLength
1
00
00000
0x06
0x0001
0x0000
0x0012
Recipient: Device
Get_Descriptor
Descriptor Type & Index
Descriptor Length
USB is Little-Endian.
Type: Standard
The data packet direction after this request: Device to Host
Get Device Descriptor: 0x80, 0x06, 0x01, 0x00, 0x00, 0x00, 0x12, 0x00
First Transaction: Send the Get_Device_Descriptor request
Host
SYNC PID ADDR ENDP CRC5 EOP
0x01 0xB4 2 0 10101 SE0, J
0b1011,0100 LSB first PID = 1101 = SETUP
Device
SYNC PID DATA CRC16 EOP
0x01 0xC3 0x80, 0x06, 0x01, 0x00, 0x00, 0x00, 0x12, 0x00 0xD768 SE0,J
0b1100,0011 LSB first PID = 0011 = DATA0
Host
SYNC PID EOP
0x01 0x4B SE0, J
0b0100,1011 LSB first PID = 0010 = ACK
Second Transaction: Retrieve the first 16 bytes of the device descriptor
Host
SYNC PID ADDR ENDP CRC5 EOP
0x01 0x96 2 0 10101 SE0, J
0b1001,0110 LSB first PID = 1001 = IN
16 bytes
Device
SYNC PID DATA CRC16 EOP
0x01 0xD2 0x12,01,00,01,DC,00,00,10,71,04,F0,FF,00,01,00,00 0xC383 SE0,J
0b1101,0010 LSB first PID = 1011 = DATA1
Host
SYNC PID EOP
0x01 0x4B SE0, J
0b0100,1011 LSB first PID = 0010 = ACK
Third Transaction: Retrieve the rest of the descriptor
Host
SYNC PID ADDR ENDP CRC5 EOP
0x01 0x96 2 0 10101 SE0, J
0b1001,0110 LSB first PID = 1001 = IN
2 bytes
Device
SYNC PID DATA CRC16 EOP
0x01 0xC3 0x00,0x01 0xFCF1 SE0,J
0b1100,0011 LSB first PID = 0011 = DATA0
Host
SYNC PID EOP
0x01 0x4B SE0, J
0b0100,1011 LSB first PID = 0010 = ACK

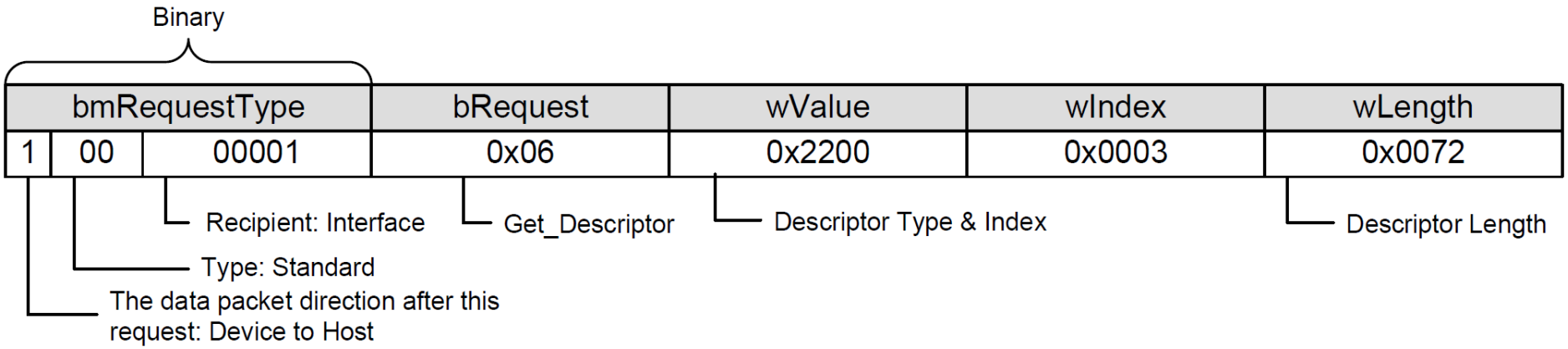
Human Interface Device



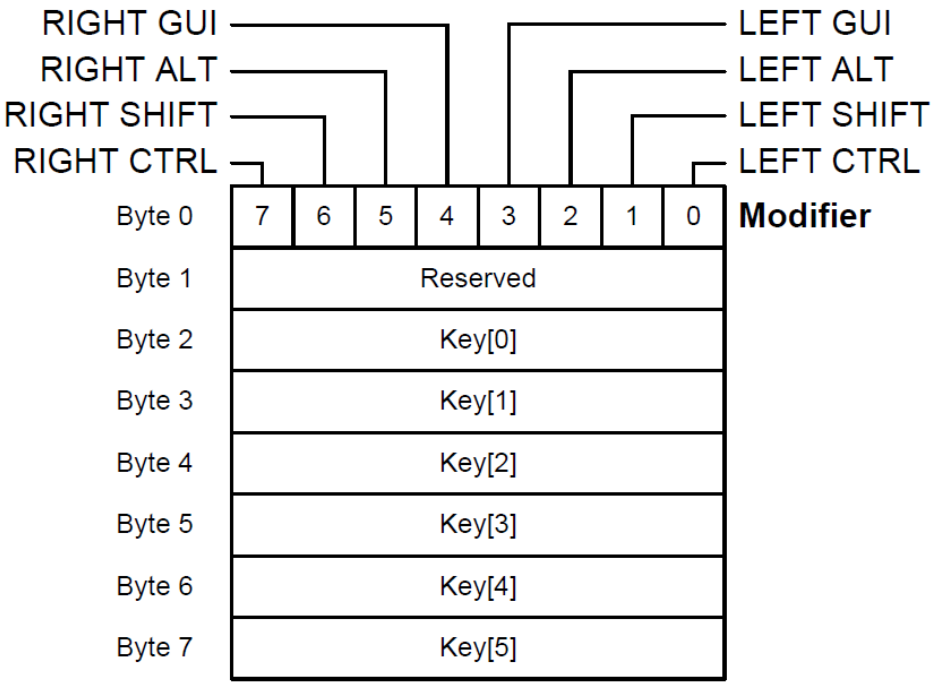
Field Name	Size	Offset
bLength	1	0
bDescriptorType	1	1
bcdHID	2	2
bCountryCode	1	4
bNumDescriptors	1	5
bDescriptorType	1	6
wDescriptorLength	2	7
[bDescriptorType]...	1	9
[wDescriptorLength]...	2	10

GET HID Descriptor

Get HID Descriptor: 0x81, 0x06, 0x00, 0x22, 0x03, 0x00, 0x72, 0x00



HID Report Format of Keyboard



HID Report Format of Mouse