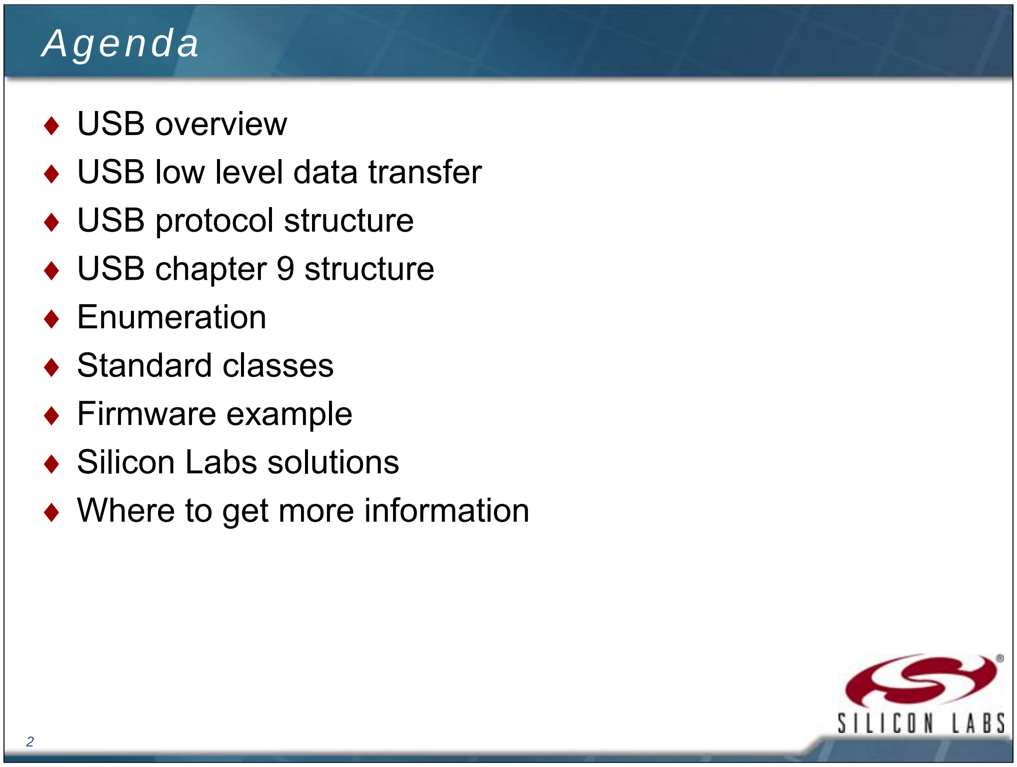
USB Overview

This course serves as an introduction to USB.



Agenda

- USB overview
- USB low level data transfer
- USB protocol structure
- USB chapter 9 structure
- Enumeration
- Standard classes
- Firmware example
- Silicon Labs solutions
- Where to get more information

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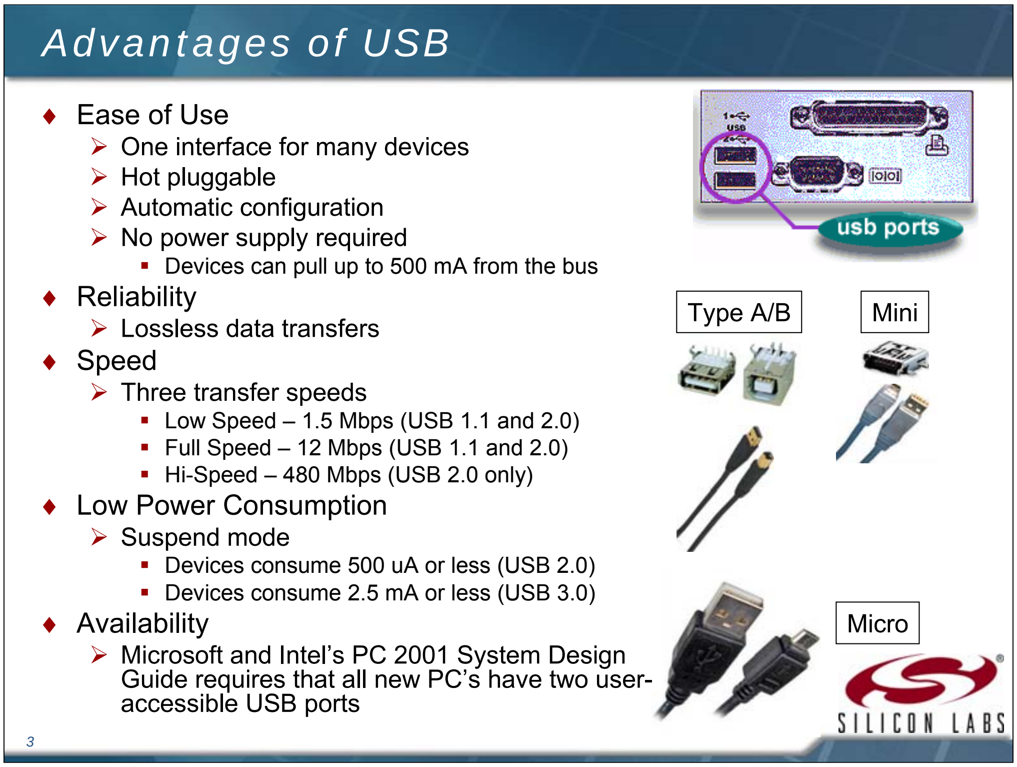
We are going to cover fairly in depth overview of USB, the device families that support USB connectivity, and some of the tools available to the support customer designs. At then end we will illustrate how Silicon Labs supports USB efforts and can abstract all of what you are about to learn.



Advantages of USB

- Ease of Use
  - One interface for many devices
  - Hot pluggable
  - Automatic configuration
  - No power supply required
    - Devices can pull up to 500 mA from the bus
- Reliability
  - Lossless data transfers
- Speed
  - Three transfer speeds
    - Low Speed – 1.5 Mbps (USB 1.1 and 2.0)
    - Full Speed – 12 Mbps (USB 1.1 and 2.0)
    - Hi-Speed – 480 Mbps (USB 2.0 only)
- Low Power Consumption
  - Suspend mode
    - Devices consume 500 uA or less (USB 2.0)
    - Devices consume 2.5 mA or less (USB 3.0)
- Availability
  - Microsoft and Intel's PC 2001 System Design Guide requires that all new PC's have two user-accessible USB ports

USB is proliferating due to the fact that RS232 is disappearing and that the end user's experience is very simple. Everything is strictly specified. The USB cable and connector have been defined by the USB consortium all the way down to the USB symbol dimensions. This provides confidence that any device will connect to another device.

Hot pluggable/Automatic configuration – Enumeration (which we will get into detail later) enables a device to be plugged in and its operating parameters communicated to the host. Also, the USB spec takes into account inrush currents for devices that are going to draw their power from the bus.

When we refer to lossless data transfers we are referring to the fact that the protocol provides a mechanism to retransmit data if required in all but one transfer type. This enables the data transfers to be reliable and we will go over that later in the course. There are three transfer speeds for USB 2.0. The transfer speed number listed here is the bandwidth on the bus. This is not directly equal to data throughput. The throughput is less than these numbers for any USB device due to USB overhead. Later in the presentation we will show some numbers for actual throughput.

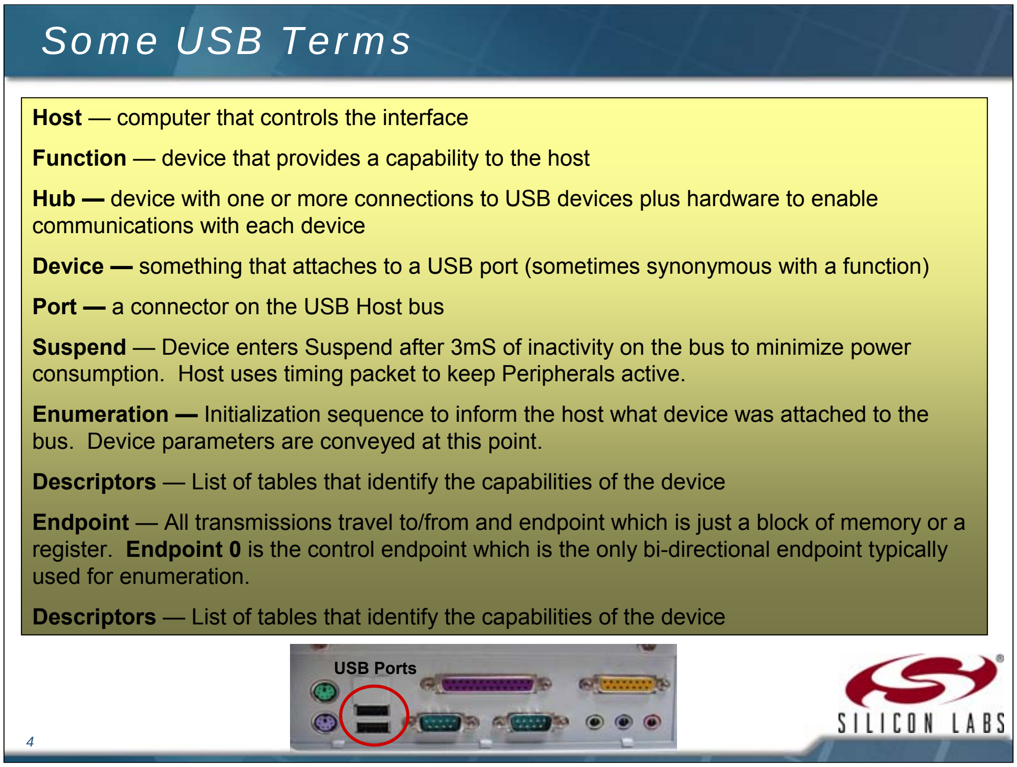
The USB 2.0 protocol is fully backwards compliant. This is why the C8051F32x and 34x devices are full speed devices and also USB 2.0 compliant.

The 500 uA listed here applies to devices that are consuming power from the USB host. If a device is fully self-powered, the Suspend mode current is not applicable because it is not drawing power from the USB host. Note that the USB 3.0 specification allows for 2.5mA suspend current. Another aspect of the newer specification is that the micro connectors are now the preferred connector solution. The USB implementers forum deprecated the use of the mini-A and mini-AB (May 23, 2007).

The benefit of this aspect of the System Design Guide means that user's don't need to buy external hardware and developers know that USB is an interface their customers will definitely have.

USB3.0 Notes:

Existing USB root hubs and external hubs in the field (and still manufactured by most companies) that are USB 2.0 compliant based on the pre-ECN spec will still enforce the 500 uA limitation. Only newly certified hubs would need to comply with the post-ECN spec. In summary, it is best to make your product obey the stricter rule of 500 uA for the widest compatibility with existing PCs and hubs.



Some USB Terms

Host — computer that controls the interface

Function — device that provides a capability to the host

Hub — device with one or more connections to USB devices plus hardware to enable communications with each device

Device — something that attaches to a USB port (sometimes synonymous with a function)

Port — a connector on the USB Host bus

Suspend — Device enters Suspend after 3mS of inactivity on the bus to minimize power consumption. Host uses timing packet to keep Peripherals active.

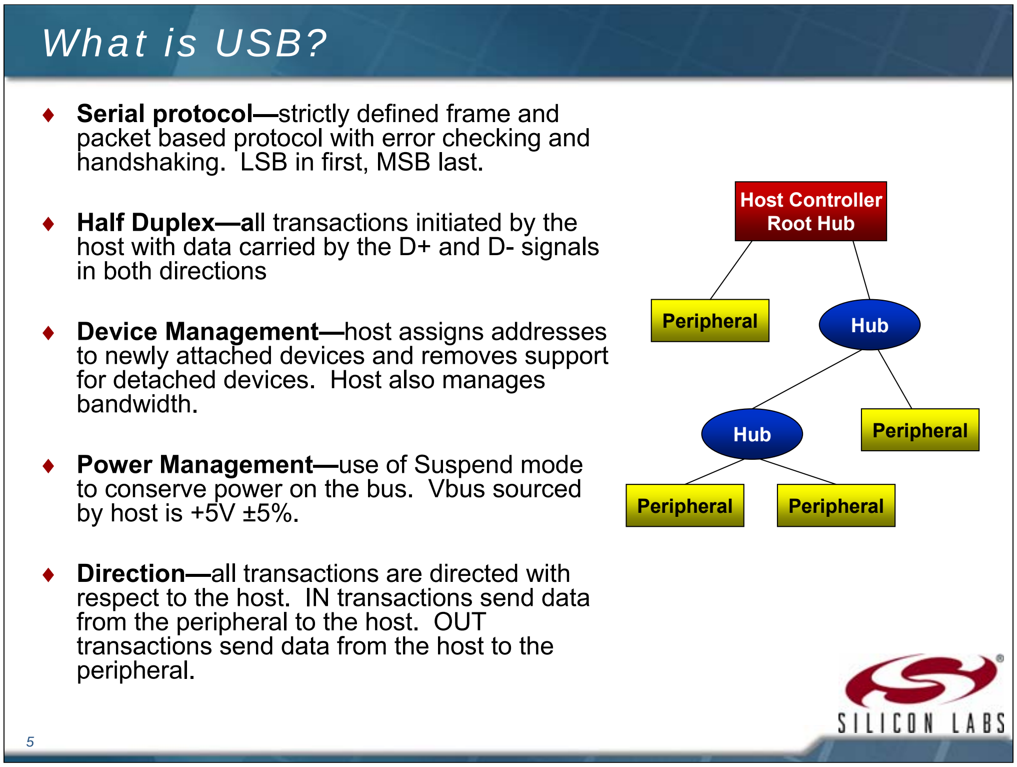
Enumeration — Initialization sequence to inform the host what device was attached to the bus. Device parameters are conveyed at this point.

Descriptors — List of tables that identify the capabilities of the device

Endpoint — All transmissions travel to/from and endpoint which is just a block of memory or a register. **Endpoint 0** is the control endpoint which is the only bi-directional endpoint typically used for enumeration.

Descriptors — List of tables that identify the capabilities of the device

Here are some common terms when discussing USB. Take a moment to familiarize yourself with these terms.



What is USB?

- **Serial protocol—**strictly defined frame and packet based protocol with error checking and handshaking. LSB in first, MSB last.
- **Half Duplex—**all transactions initiated by the host with data carried by the D+ and D- signals in both directions
- **Device Management—**host assigns addresses to newly attached devices and removes support for detached devices. Host also manages bandwidth.
- **Power Management—**use of Suspend mode to conserve power on the bus. Vbus sourced by host is +5V ±5%.
- **Direction—**all transactions are directed with respect to the host. IN transactions send data from the peripheral to the host. OUT transactions send data from the host to the peripheral.

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The USB protocol is a packet based architecture with start frame, transactions, and handshaking with ack and nak controls. These will be covered later. Within the host there is the USB controller and the root hub. The Host controller formats the data for the OS on read and write as well as manages communications on the bus. The Root Hub provides the connection point to the host for peripheral devices as well as detects attach/removal events, carries out requests from the host and is the means to pass data. USB is a half duplex protocol where all data is passed via a two wire interface called D+ (D plus) and D- (D minus). The host processor is responsible for all communications on the bus including device addressing and bus bandwidth. It is also responsible for determining and conserving the power requirements for the bus. If devices do not meet the requirements for all of the above conditions then the host can refuse to enumerate. When we discuss data transfer across the USB we always use the vantage point of the host for reference. For example, if there is an IN transfer that means the host is going to receive the data. An OUT transfer means the host is going to transmit data.

Before proceeding let’s quickly discuss the data transfer hierarchy. The term “pipe” is used to define a logical association between the host and the endpoint device and is the connection point for the host software and the device. There are two types of pipes identified in the USB specification. The stream pipe is used for unidirectional communications and comprises most of the transfer types defined. The Message pipe is a bidirectional pipe and is typically used only for control transfers or the transfers that the USB uses for configuring devices and the bus. The control transfer is a transfer using endpoint 0 which is the only bidirectional transfer and therefore a message pipe. There are IN/OUT transfers, however each endpoint is either an IN or an OUT transfer. This is where the unidirectional stream pipes come into play. The transfer is the highest level of the USB protocol and is used to define the structure of the information that is sent across the wires. The transfer is broken up into a set of transactions. These transactions are then subdivided into a set of packets that are the lowest level defined in the USB specification. The following slides build the data from when we plug in the cable all the way up to the transfer format. This will become more evident as we progress through the course.

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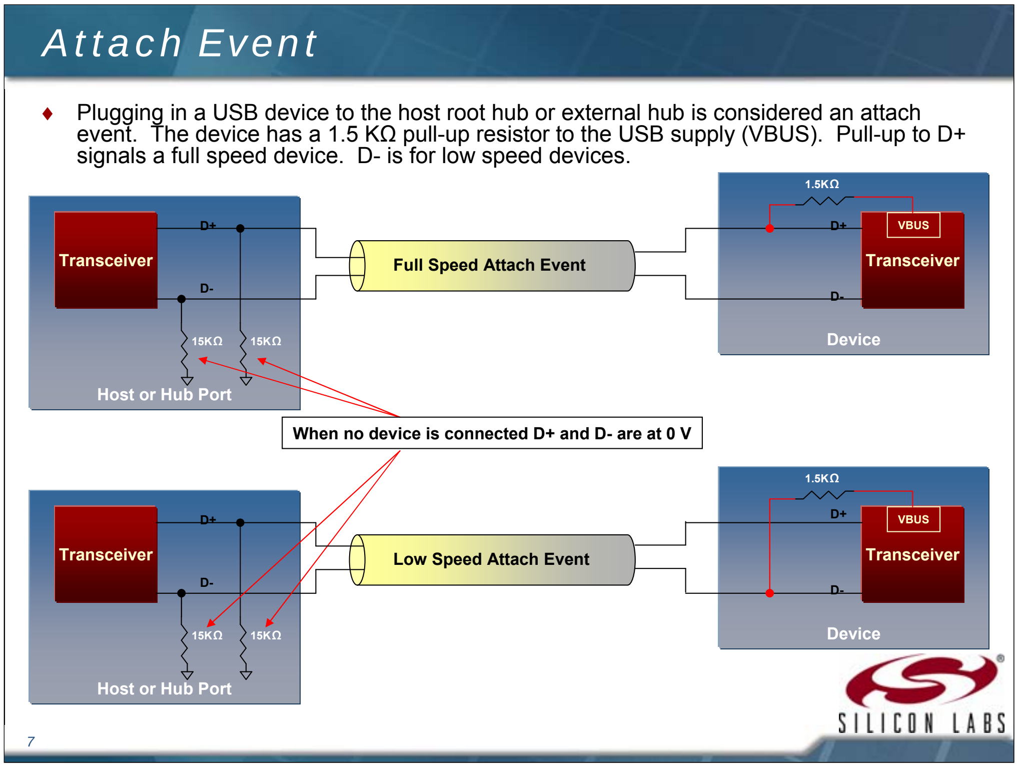
USB Lower Layer

In this course serves as an introduction to USB.

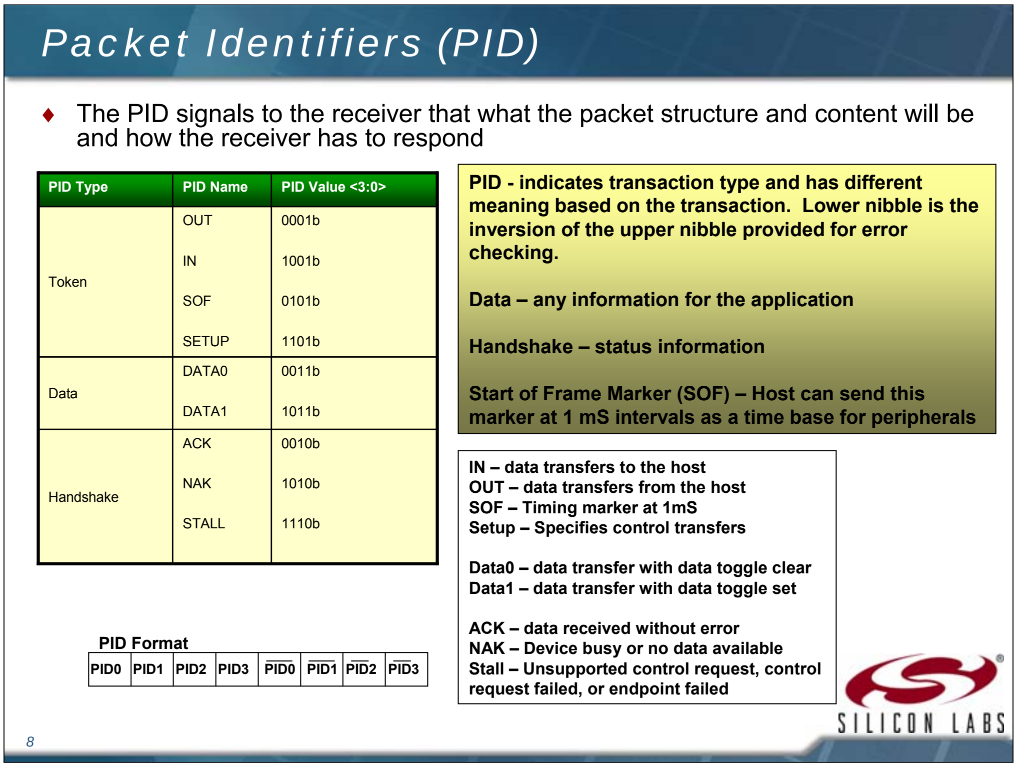


Attach Event

- Plugging in a USB device to the host root hub or external hub is considered an attach event. The device has a 1.5 KΩ pull-up resistor to the USB supply (VBUS). Pull-up to D+ signals a full speed device. D- is for low speed devices.

When no device is connected D+ and D- are at 0 V

So we have a USB device, a host and a USB cable. How does all of this communication work? We have to first connect everything together. When we plug the device together with the host it is called an Attach Event (similarly, when we disconnect it is called a detach event). If you look at the initial condition for the bus with no devices attached you will notice that the D+ and D- are at the same 0 V potential because of the 15 Kohm resistors found on the host side. When the cable is plugged in an endpoint device will provide a pull up resistor on either D+ or D- depending on its speed capabilities. For a full speed device, the pull-up is attached to the D+ signal. When the host detects this voltage change it will begin what is called enumeration process at the full speed rate. If the voltage change is detected on the D- line, then the enumeration happens at low speed. This attach event is what signals the host that there is a new device attached to the bus. In MCU devices the pull-up resistor should be integrated and it is just a matter of setting the bit in a control register (i.e. the Pull-up Resistor Enable or PREN bit in the USB0XCN register for the Silicon Labs USB family of MCUs). This is what gets everything started.



Packet Identifiers (PID)

- The PID signals to the receiver that what the packet structure and content will be and how the receiver has to respond

PID Type	PID Name	PID Value <3:0>
Token	OUT	0001b
	IN	1001b
	SOF	0101b
	SETUP	1101b
Data	DATA0	0011b
	DATA1	1011b
Handshake	ACK	0010b
	NAK	1010b
	STALL	1110b

PID - indicates transaction type and has different meaning based on the transaction. Lower nibble is the inversion of the upper nibble provided for error checking.

Data – any information for the application

Handshake – status information

Start of Frame Marker (SOF) – Host can send this marker at 1 mS intervals as a time base for peripherals

IN – data transfers to the host
OUT – data transfers from the host
SOF – Timing marker at 1mS
Setup – Specifies control transfers

Data0 – data transfer with data toggle clear
Data1 – data transfer with data toggle set

ACK – data received without error
NAK – Device busy or no data available
Stall – Unsupported control request, control request failed, or endpoint failed

PID Format

PID0	PID1	PID2	PID3	$\overline{\text{PID0}}$	$\overline{\text{PID1}}$	$\overline{\text{PID2}}$	$\overline{\text{PID3}}$

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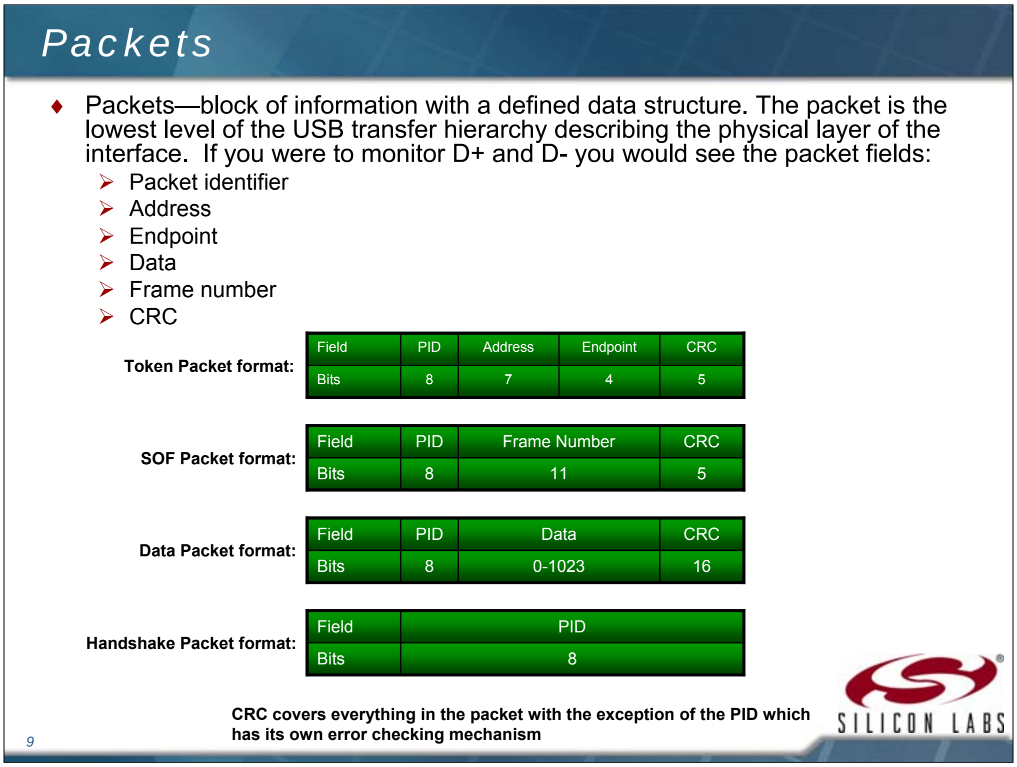
Here we see the Packet Identifier (PID) structure. Be aware that “PID” is used for two different things in USB (the second reference we will discuss later). The PID we refer to here is what is sent out on the USB to define the transaction type. An example PID, the Start of Frame (SOF) PID, is sent to provide a 1ms time base and tells the receiving devices that the frame number associated with the current 1ms timer marker follows the PID. The Data PID tells the system that the data for the associated transfer is located in this transaction. Remember in USB the host always initiates the transfer and data direction is with respect to the host. IN transfers data from a peripheral device to the host. OUT transfers data from the host to the device. From the table we can see that there are separate PID values associated with each of the transaction types, IN or OUT and we can write the firmware to respond accordingly based on the token that we receive. Do we need to be concerned with the PID at the firmware level? No, as the hardware engine manages moving the data between the FIFOs and the USB.

We mentioned the that the host in a USB system is responsible for power management. The host sends the SOF every 1ms as mentioned. Devices are required to enter a Suspend state after 3mS of inactivity per the USB specification. Since there is constant activity on the bus when sending SOF PIDs, the peripheral devices will stay out of suspend mode as the spec states that there is a 3mS inactivity window before peripherals should enter suspend.

The Setup transaction specifies a control transfer. Control transfers MUST be supported by all devices and their functions are defined by the USB spec. With these, the host can gather data about the endpoint, set addresses etc. We get into control transfers in detail later in the class.



Packets

- Packets—block of information with a defined data structure. The packet is the lowest level of the USB transfer hierarchy describing the physical layer of the interface. If you were to monitor D+ and D- you would see the packet fields:
  - Packet identifier
  - Address
  - Endpoint
  - Data
  - Frame number
  - CRC

Token Packet format:

Field	PID	Address	Endpoint	CRC
Bits	8	7	4	5

SOF Packet format:

Field	PID	Frame Number	CRC
Bits	8	11	5

Data Packet format:

Field	PID	Data	CRC
Bits	8	0-1023	16

Handshake Packet format:

Field	PID
Bits	8

CRC covers everything in the packet with the exception of the PID which has its own error checking mechanism

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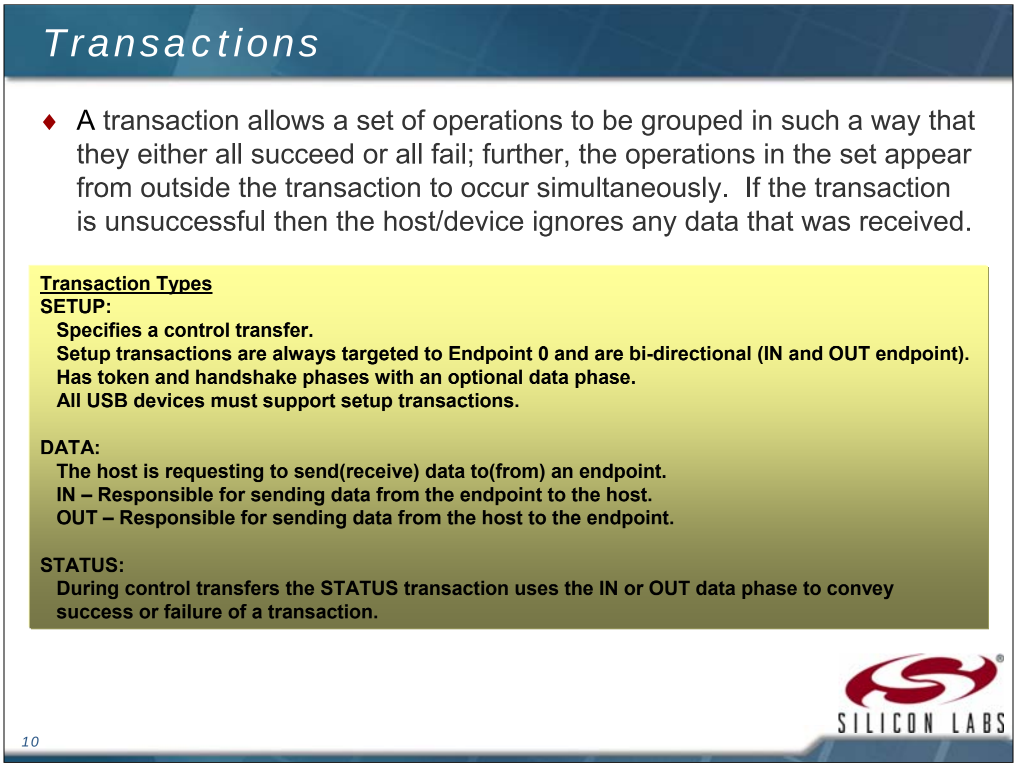
The Packet Identifiers we just reviewed are actually used to identify the packet type being transmitted on the USB. We can see from the diagram above that the packet format is defined by the PID we have outlined on the previous slide. For example, if we see a PID of 0101b then we know to expect the data format of the SOF packet. From that we know that the USB frame number will follow the PID. The frame number is just a rolling count that will rollover on overflow. If we were to see a PID of 1101b then we would expect a completely different transfer type and there may be additional packets associated with the complete data transfer. So we can see that the packet structure is a subset of the entire transfer protocol defined by the USB. There are 4 packet types defined.

1) The token packet would be used to identify the transfer (setup, IN, OUT).

2) The SOF packet is sent on the frame boundaries to provide timing and frame counts.

3) Data packet is the payload.

4) Handshake packets provide for comms robustness to verify that the data was receive/transmitted properly.



Transactions

- A transaction allows a set of operations to be grouped in such a way that they either all succeed or all fail; further, the operations in the set appear from outside the transaction to occur simultaneously. If the transaction is unsuccessful then the host/device ignores any data that was received.

Transaction Types

SETUP:
Specifies a control transfer.
Setup transactions are always targeted to Endpoint 0 and are bi-directional (IN and OUT endpoint).
Has token and handshake phases with an optional data phase.
All USB devices must support setup transactions.

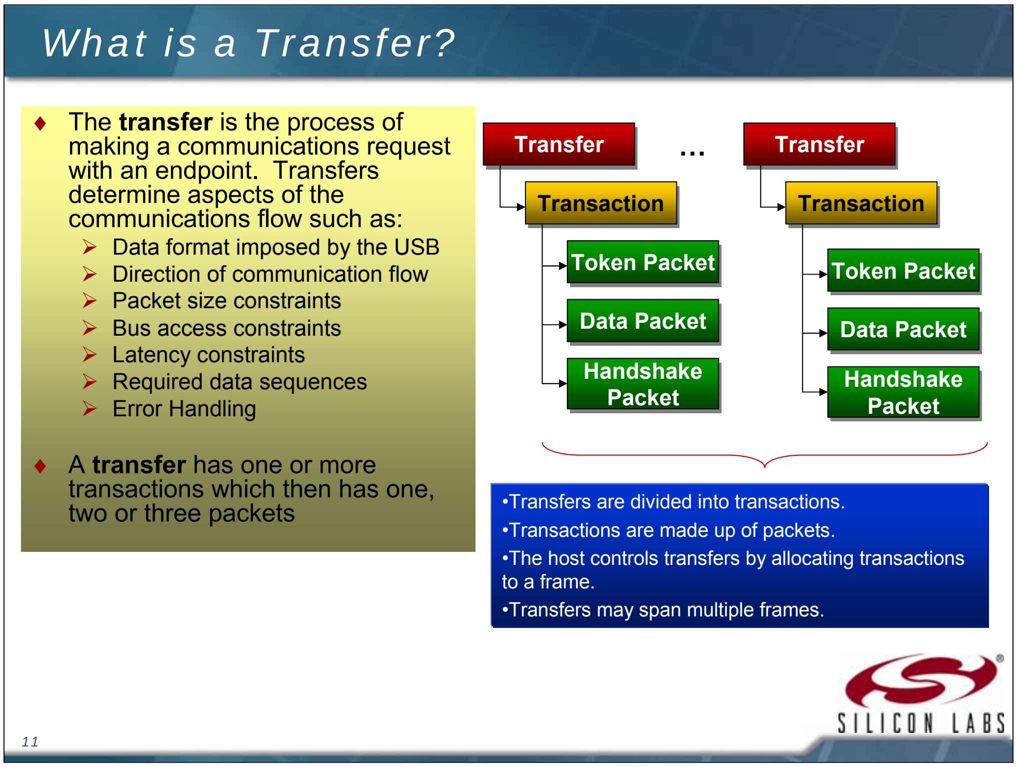
DATA:
The host is requesting to send(receive) data to(from) an endpoint.
IN – Responsible for sending data from the endpoint to the host.
OUT – Responsible for sending data from the host to the endpoint.

STATUS:
During control transfers the STATUS transaction uses the IN or OUT data phase to convey success or failure of a transaction.

Take a moment to read the text in this slide as it conveys the key message regarding transactions. A transaction is a combination of packets. For example, the Setup transaction contains the Token packet we saw from the previous slide. With the Token packet the host is transmitting the PID, the address and the endpoint number of the device it wants to communicate with. The next packet it sends is the Data Packet which tells the device that it wants to get/set some information from/to the device. Next there is a handshake packet to signify a success or failure of the transaction. So to review, the transaction is made up of multiple packets. In the example provided, the setup transaction had 3 packets associated with it: token, data and handshake.

There are three transaction types as listed in the slide. The Setup, Data and Status transactions. Setup is used during the configuration process after a device reset. The Data phase is used to transfer data to/from the device as requested by the host. Taking the example we just gave with the Setup transaction it could be followed by a Data transaction where the device can receive data that will set its address or it could send data that tells the host what its vendor ID is. The Status transaction identifies to the USB at a higher level than the handshake packet that a complete transfer (multiple structured transactions) was successful. We will look at transfers next.

After the device has been powered, it must not respond to any bus transactions until it has received a reset from the bus. After receiving a reset, the device is then addressable at the default address. The default address is address 0 and is termed the Control Pipe.



What is a Transfer?

- The **transfer** is the process of making a communications request with an endpoint. Transfers determine aspects of the communications flow such as:
  - Data format imposed by the USB
  - Direction of communication flow
  - Packet size constraints
  - Bus access constraints
  - Latency constraints
  - Required data sequences
  - Error Handling
- A **transfer** has one or more transactions which then has one, two or three packets

Transfer … Transfer

Transaction

Token Packet

Data Packet

Handshake Packet

- Transfers are divided into transactions.
- Transactions are made up of packets.
- The host controls transfers by allocating transactions to a frame.
- Transfers may span multiple frames.

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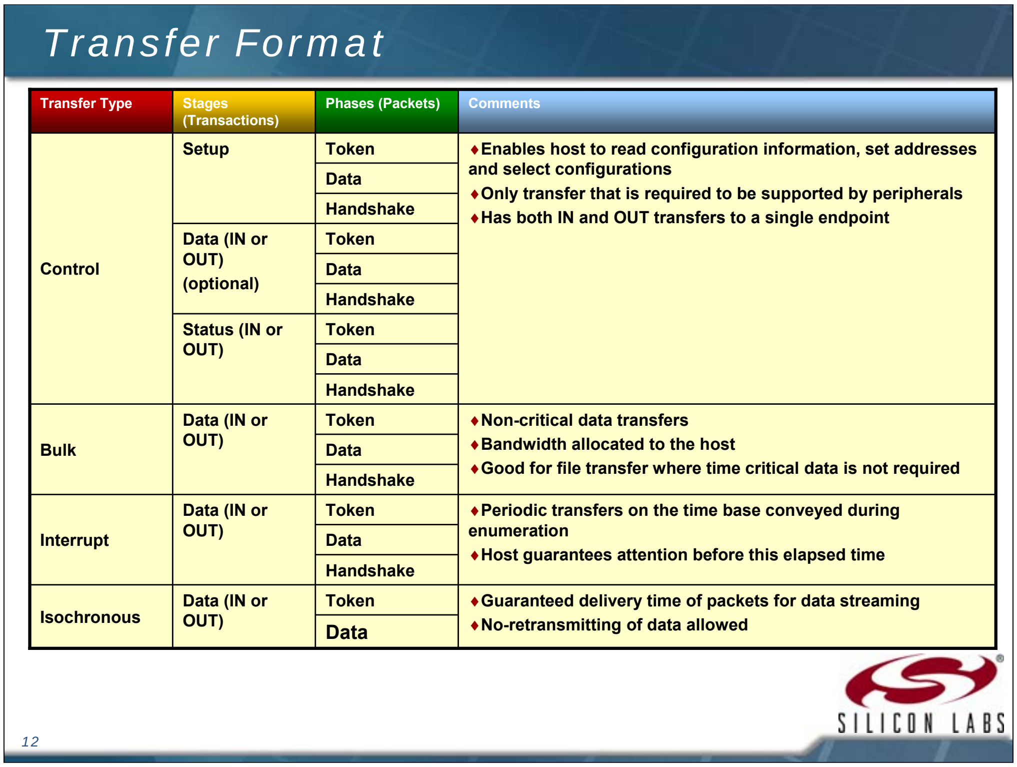
We previously discussed how transactions are formed using multiple packets. Well transfers are formed using multiple transactions. You can see from the slide that hierarchy of the Transfer-Transaction-Packet relationship. The transfer is the highest level followed by the transaction and then at the lowest level is the packet. The red denotes the top level or Transfer, the yellow denotes the Transaction and the green represents the actual packets. Both the transfer and the transaction are logical implementations whereas the packets denote what you actually transmit across the bus. A transfer is comprised of one or more transactions. Our example from the previous slide showed three packets forming a single transaction. Lets take that a step further. The example we gave is actually one transaction of what is called a Control transfer that is formed by a total of three transactions. That first transaction made up the Setup phase of the transfer. This is the phase that told the device that the host is getting or sending configuration information and what that information is going to be. A Data transaction then follows whereby the host either sends the data it wants the device to use in order to configure certain parameters (like its USB address) or it receives configuration data from the device that tells how the device is set up to communicate. We would then have another transaction to complete what is called the Status phase. This is a transaction that validates the complete transfer (all three transactions).



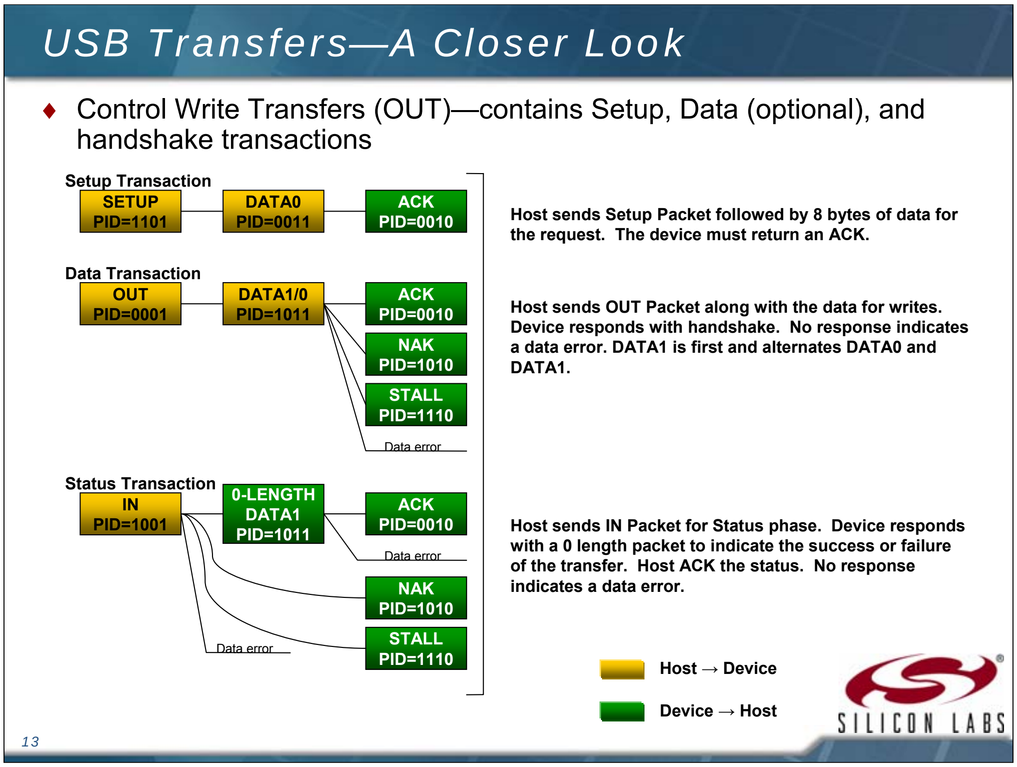
Transfer Format

Transfer Type	Stages (Transactions)	Phases (Packets)	Comments
Control	Setup	Token	♦Enables host to read configuration information, set addresses and select configurations ♦Only transfer that is required to be supported by peripherals ♦Has both IN and OUT transfers to a single endpoint
		Data	
		Handshake	
	Data (IN or OUT) (optional)	Token	
		Data	
		Handshake	
	Status (IN or OUT)	Token	
		Data	
		Handshake	
Bulk	Data (IN or OUT)	Token	♦Non-critical data transfers ♦Bandwidth allocated to the host ♦Good for file transfer where time critical data is not required
		Data	
		Handshake	
Interrupt	Data (IN or OUT)	Token	♦Periodic transfers on the time base conveyed during enumeration ♦Host guarantees attention before this elapsed time
		Data	
		Handshake	
Isochronous	Data (IN or OUT)	Token	♦Guaranteed delivery time of packets for data streaming ♦No-retransmitting of data allowed
		Data	

Now that we have discussed the hierarchy of the USB protocol lets take a look at the different transfer types. Remember, that these transfers are made up of transaction which are made up of packets. Each of the transfer types is listed in the table along with the associated transaction and packet types supported. The control transfer is the only bidirectional transfer allowed by the USB. It is the transfer type used to communicate all of the configuration information between the host and a device. Our example we provide on the previous slides illustrated the control transfer. It had the three transactions associated with it. All devices on the bus MUST support control transfers to endpoint 0. This is the default endpoint after reset and is at address 0. For Control transfers the status phase is a zero length packet in the opposite direction of the transfer. For example, let's say the host is going to request a device descriptor which is a table we have loaded in flash. The direction of the transfer would be IN since the data flows to the host. The status phase in this example would be a zero length packet with an OUT token to terminate the transfer. Control transfers are used for things like setting the device address to a value other than 0 for subsequent accesses, getting configuration information on how the device wants to communicate using the other transfer types like Bulk. Remembering our original example, we can see here that there are three transactions (Setup, Data, and Status) comprised of nine packets (Token, Data, Handshake – three times) that make up the Control transfer. The Bulk transfer uses three packets for the single transaction.

The Bulk transfer is used for non-critical data meaning data that is not required to be transferred on any time base. It provides the highest data throughput as well so it is useful for applications like printers, scanners or even USB to UART bridges. Remember that the host is responsible for managing the bandwidth of the USB. One aspect of the Bulk transfer is that the host schedules bandwidth as it becomes available, hence the non-critical nature of this type of transfer.

The interrupt transfer is used for periodic transfers where a time period is requested by the device and the host will guarantee that the data transfer will be scheduled within that time period. It does not guarantee that the data is transferred on a consistent time basis all the time, just that it will schedule the transfer prior to the time period expiration. The data throughput is lower for interrupt transfers and is useful for applications like mice, keyboards where user input is continually needing to be sent to the host.



USB Transfers—A Closer Look

- Control Write Transfers (OUT)—contains Setup, Data (optional), and handshake transactions

Setup Transaction

SETUP PID=1101 — DATA0 PID=0011 — ACK PID=0010

Host sends Setup Packet followed by 8 bytes of data for the request. The device must return an ACK.

Data Transaction

OUT PID=0001 — DATA1/0 PID=1011 — ACK PID=0010 / NAK PID=1010 / STALL PID=1110 / Data error

Host sends OUT Packet along with the data for writes. Device responds with handshake. No response indicates a data error. DATA1 is first and alternates DATA0 and DATA1.

Status Transaction

IN PID=1001 — 0-LENGTH DATA1 PID=1011 — ACK PID=0010 / Data error

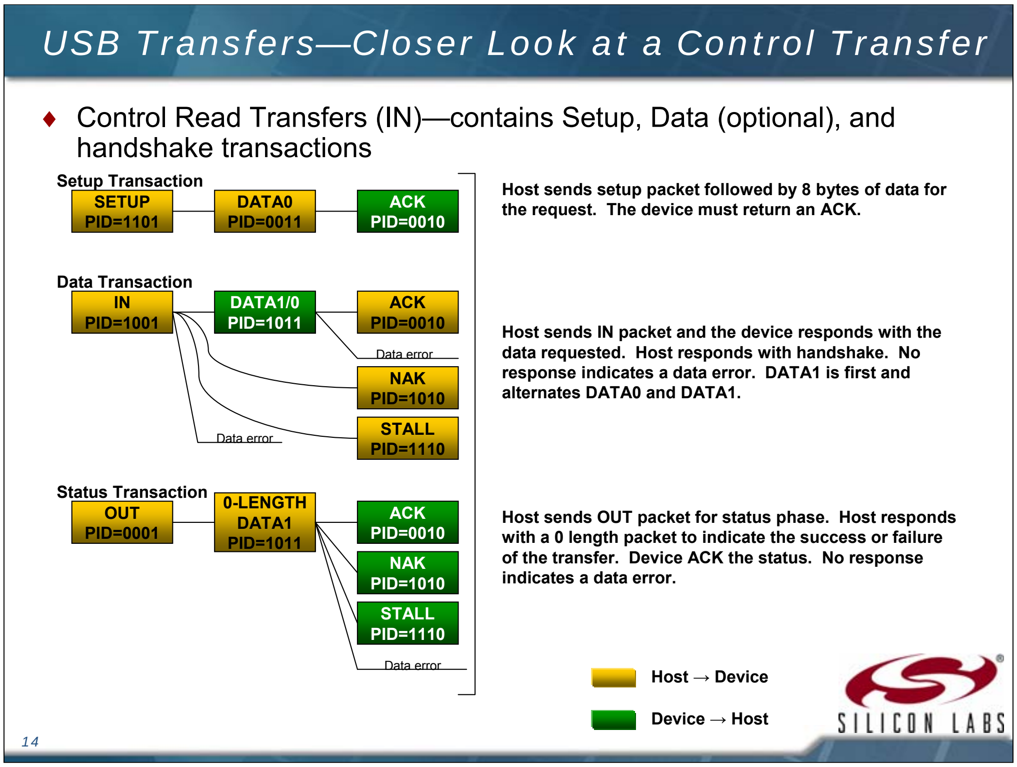
IN PID=1001 — NAK PID=1010 / STALL PID=1110 / Data error

Host sends IN Packet for Status phase. Device responds with a 0 length packet to indicate the success or failure of the transfer. Host ACK the status. No response indicates a data error.

🟨 Host → Device

🟩 Device → Host

In the next set of slides we are taking a look at the transactions and packets that make up the different transfers and this slide shows the Control Transfer that is sending data to the device. The colored boxes denote which direction the data is flowing, whether it is from the host or the device. Keep in mind the host initiates all transfers so the first box will always be yellow. The first transaction is the Setup which is defined by the setup packet. Next we see the data that is sent in the request from the host. The data sent in this phase is 8 bytes long and contains info about the request, for example, if the host wants a device's configuration or to set the device address. After the data transaction the device ACKs the transaction. Next is the data phase. Since this is an OUT control transfer the Data is yellow. The device can either ACK, NAK or Stall the request. The ACK signifies that the transaction was successful, the NAK means that the data either was not received correctly or the device is not ready for the data. A Stall would mean that the device does not support the requested feature. The Status phase for control transfers is just a 0 length packet in the opposite direction of the data phase. In this diagram the host was sending the device information (OUT transfer) in the data transaction, therefore, the in the status phase the host sends an IN token and the device responds with a 0 length packet. These diagrams and the following flow diagrams like it can be found in the book from Jan Axelson titled, "USB Complete."



USB Transfers—Closer Look at a Control Transfer

- Control Read Transfers (IN)—contains Setup, Data (optional), and handshake transactions

Setup Transaction

SETUP PID=1101 — DATA0 PID=0011 — ACK PID=0010

Host sends setup packet followed by 8 bytes of data for the request. The device must return an ACK.

Data Transaction

IN PID=1001 — DATA1/0 PID=1011 — ACK PID=0010

Data error

NAK PID=1010

STALL PID=1110

Data error

Host sends IN packet and the device responds with the data requested. Host responds with handshake. No response indicates a data error. DATA1 is first and alternates DATA0 and DATA1.

Status Transaction

OUT PID=0001 — 0-LENGTH DATA1 PID=1011 — ACK PID=0010

NAK PID=1010

STALL PID=1110

Data error

Host sends OUT packet for status phase. Host responds with a 0 length packet to indicate the success or failure of the transfer. Device ACK the status. No response indicates a data error.

🟨 Host → Device

🟩 Device → Host

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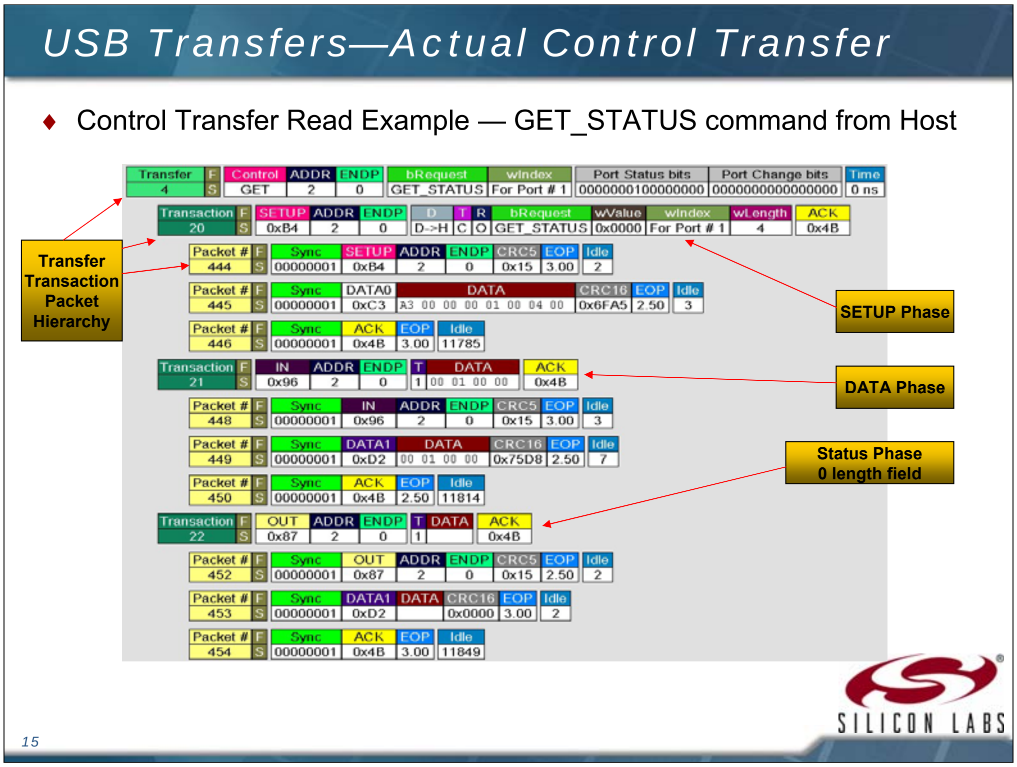
Here we have the same transfer type as the previous slide except that the host is now requesting data from the device. Therefore, the data direction for the Data transaction and the Status transaction are reversed.



USB Transfers—Actual Control Transfer

- Control Transfer Read Example — GET_STATUS command from Host

```
| Transfer | F | Control | ADDR | ENDP | bRequest   | wIndex       | Port Status bits | Port Change bits | Time |
| 4        | S | GET     | 2    | 0    | GET_STATUS | For Port # 1 | 0000000100000000 | 0000000000000000 | 0 ns |

    | Transaction | F | SETUP | ADDR | ENDP | D    | T | R | bRequest   | wValue | wIndex       | wLength | ACK  |
    | 20          | S | 0xB4  | 2    | 0    | D->H | C | O | GET_STATUS | 0x0000 | For Port # 1 | 4       | 0x4B |

        | Packet # | F | Sync     | SETUP | ADDR | ENDP | CRC5 | EOP  | Idle |
        | 444      | S | 00000001 | 0xB4  | 2    | 0    | 0x15 | 3.00 | 2    |

        | Packet # | F | Sync     | DATA0 | DATA                    | CRC16  | EOP  | Idle |
        | 445      | S | 00000001 | 0xC3  | A3 00 00 00 01 00 04 00 | 0x6FA5 | 2.50 | 3    |

        | Packet # | F | Sync     | ACK  | EOP  | Idle  |
        | 446      | S | 00000001 | 0x4B | 3.00 | 11785 |

    | Transaction | F | IN   | ADDR | ENDP | T | DATA        | ACK  |
    | 21          | S | 0x96 | 2    | 0    | 1 | 00 01 00 00 | 0x4B |

        | Packet # | F | Sync     | IN   | ADDR | ENDP | CRC5 | EOP  | Idle |
        | 448      | S | 00000001 | 0x96 | 2    | 0    | 0x15 | 3.00 | 3    |

        | Packet # | F | Sync     | DATA1 | DATA        | CRC16  | EOP  | Idle |
        | 449      | S | 00000001 | 0xD2  | 00 01 00 00 | 0x75D8 | 2.50 | 7    |

        | Packet # | F | Sync     | ACK  | EOP  | Idle  |
        | 450      | S | 00000001 | 0x4B | 2.50 | 11814 |

    | Transaction | F | OUT  | ADDR | ENDP | T | DATA | ACK  |
    | 22          | S | 0x87 | 2    | 0    | 1 |      | 0x4B |

        | Packet # | F | Sync     | OUT  | ADDR | ENDP | CRC5 | EOP  | Idle |
        | 452      | S | 00000001 | 0x87 | 2    | 0    | 0x15 | 2.50 | 2    |

        | Packet # | F | Sync     | DATA1 | DATA | CRC16  | EOP  | Idle |
        | 453      | S | 00000001 | 0xD2  |      | 0x0000 | 3.00 | 2    |

        | Packet # | F | Sync     | ACK  | EOP  | Idle  |
        | 454      | S | 00000001 | 0x4B | 3.00 | 11849 |
```

Transfer
Transaction
Packet
Hierarchy

SETUP Phase

DATA Phase

Status Phase
0 length field

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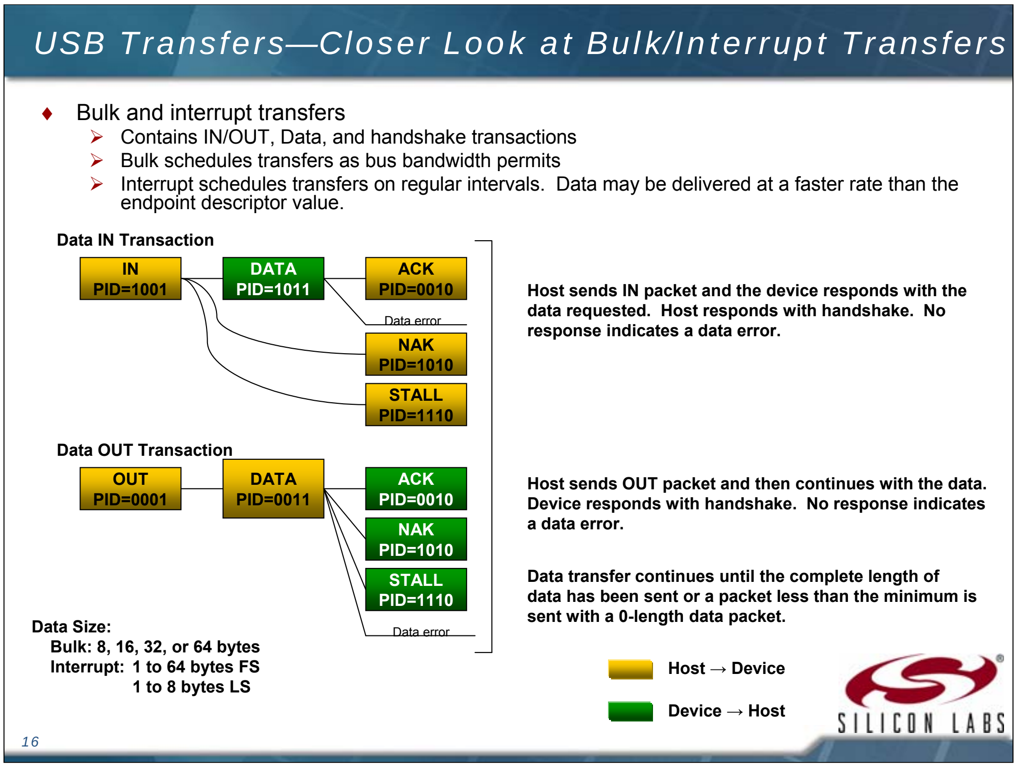
Here is an actual USB analyzer capture of data traffic for a control transfer. This is a control transfer (Get_Status) that a host has sent out to a device. Keeping in mind our packet formats we can see the token packet identifies the first transaction as the setup providing us with the device address and endpoint information. The second transaction is the data phase using the address and endpoint and then the device adds the data requested. The final transaction is the status phase using a 0-length data packet to signify that the transfer completed successfully.

Note: Not all USB tools provide the data in the same format.



USB Transfers—Closer Look at Bulk/Interrupt Transfers

- Bulk and interrupt transfers
  - Contains IN/OUT, Data, and handshake transactions
  - Bulk schedules transfers as bus bandwidth permits
  - Interrupt schedules transfers on regular intervals. Data may be delivered at a faster rate than the endpoint descriptor value.

Data IN Transaction

Host sends IN packet and the device responds with the data requested. Host responds with handshake. No response indicates a data error.

Data OUT Transaction

Host sends OUT packet and then continues with the data. Device responds with handshake. No response indicates a data error.

Data transfer continues until the complete length of data has been sent or a packet less than the minimum is sent with a 0-length data packet.

Data Size:
Bulk: 8, 16, 32, or 64 bytes
Interrupt: 1 to 64 bytes FS
1 to 8 bytes LS

🟨 **Host → Device**

🟩 **Device → Host**

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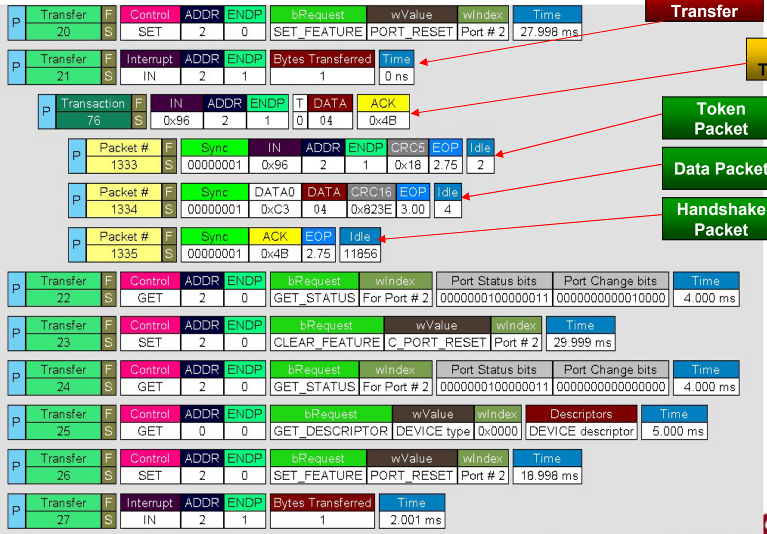
All of the transfer types follow the same convention as the control transfer with the exception that they differ in the number of transactions that are required to complete the transfer. The Bulk and Interrupt transfers each have the same format and are denoted by the IN and OUT PIDs. These transfer types use what is called the MAX_PACKET_SIZE parameter (which is a USB parameter defined by in the USB peripheral) to transfer the data. All data transactions must transfer the data in multiples of the maximum packet size. If a packet less than the maximum number of bytes is sent then it tells the host that there is not more data. If the data being transferred is an even multiple of the MAX_PACKET_SIZE parameter then an additional Data transaction needs to added with a Zero Length Packet (ZLP).

USB Transfers—Actual Interrupt Transfer

- Bulk/interrupt transfer read example:



P	Transfer	F	Control	ADDR	ENDP	bRequest	wValue	wIndex	Time
	20	S	SET	2	0	SET_FEATURE	PORT_RESET	Port # 2	27.998 ms

P	Transfer	F	Interrupt	ADDR	ENDP	Bytes Transferred	Time
	21	S	IN	2	1	1	0 ns

P	Transaction	F	IN	ADDR	ENDP	T	DATA	ACK
	76	S	0x96	2	1	0	04	0x4B

P	Packet #	F	Sync	IN	ADDR	ENDP	CRC5	EOP	Idle
	1333	S	00000001	0x96	2	1	0x18	2.75	2

P	Packet #	F	Sync	DATA0	DATA	CRC16	EOP	Idle
	1334	S	00000001	0xC3	04	0x823E	3.00	4

P	Packet #	F	Sync	ACK	EOP	Idle
	1335	S	00000001	0x4B	2.75	11856

P	Transfer	F	Control	ADDR	ENDP	bRequest	wIndex	Port Status bits	Port Change bits	Time
	22	S	GET	2	0	GET_STATUS	For Port # 2	0000000100000011	0000000000010000	4.000 ms

P	Transfer	F	Control	ADDR	ENDP	bRequest	wValue	wIndex	Time
	23	S	SET	2	0	CLEAR_FEATURE	C_PORT_RESET	Port # 2	29.999 ms

P	Transfer	F	Control	ADDR	ENDP	bRequest	wIndex	Port Status bits	Port Change bits	Time
	24	S	GET	2	0	GET_STATUS	For Port # 2	0000000100000011	0000000000000000	4.000 ms

P	Transfer	F	Control	ADDR	ENDP	bRequest	wValue	wIndex	Descriptors	Time
	25	S	GET	0	0	GET_DESCRIPTOR	DEVICE type	0x0000	DEVICE descriptor	5.000 ms

P	Transfer	F	Control	ADDR	ENDP	bRequest	wValue	wIndex	Time
	26	S	SET	2	0	SET_FEATURE	PORT_RESET	Port # 2	18.998 ms

P	Transfer	F	Interrupt	ADDR	ENDP	Bytes Transferred	Time
	27	S	IN	2	1	1	2.001 ms

Interrupt Transfer

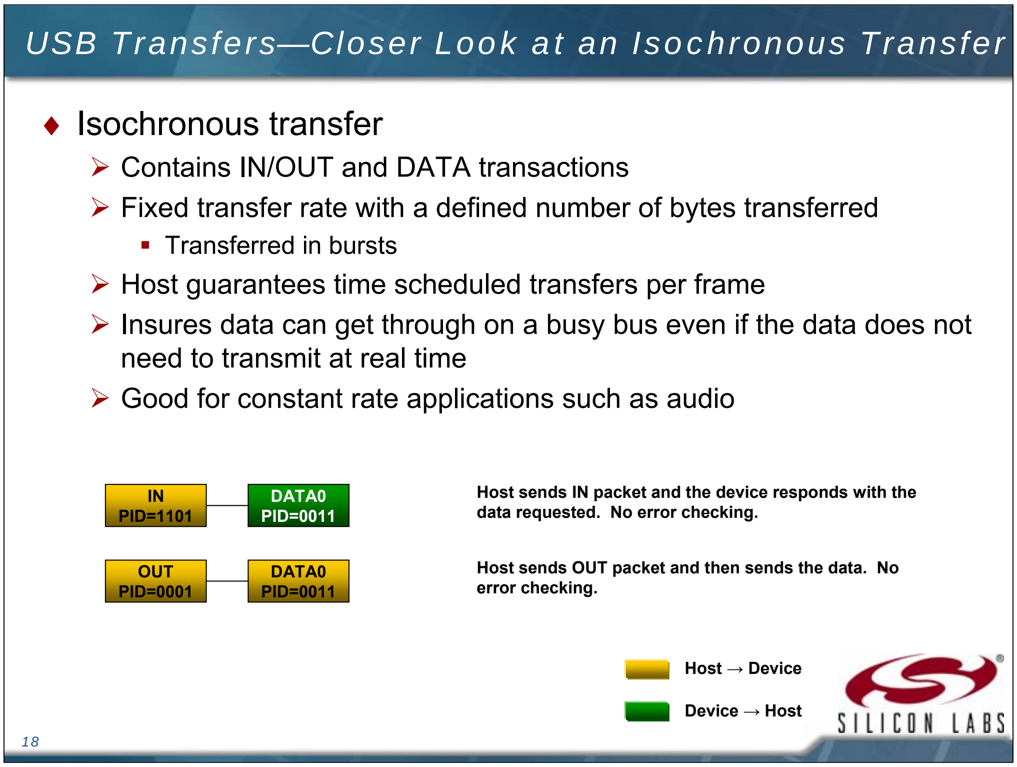
IN Transaction

Token Packet

Data Packet

Handshake Packet

Here is a screen capture of actual USB data traffic using these Bulk/Interrupt transfer type. Notice that the transfer is composed of a single transaction.



USB Transfers—Closer Look at an Isochronous Transfer

- Isochronous transfer
  - Contains IN/OUT and DATA transactions
  - Fixed transfer rate with a defined number of bytes transferred
    - Transferred in bursts
  - Host guarantees time scheduled transfers per frame
  - Insures data can get through on a busy bus even if the data does not need to transmit at real time
  - Good for constant rate applications such as audio

Host sends IN packet and the device responds with the data requested. No error checking.

Host sends OUT packet and then sends the data. No error checking.

🟨 Host → Device

🟩 Device → Host

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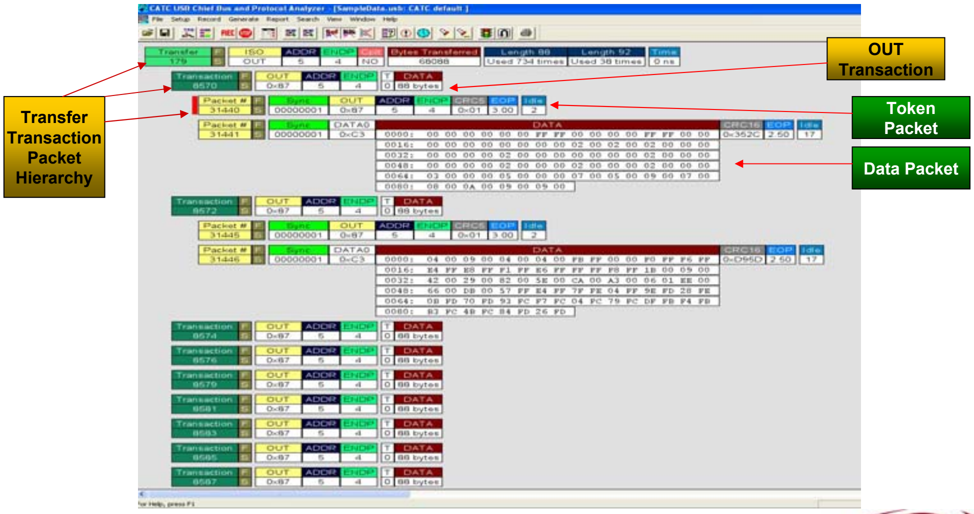
This is the Isochronous transfer and as we mentioned earlier there is no handshake packets associated with this transfer type.

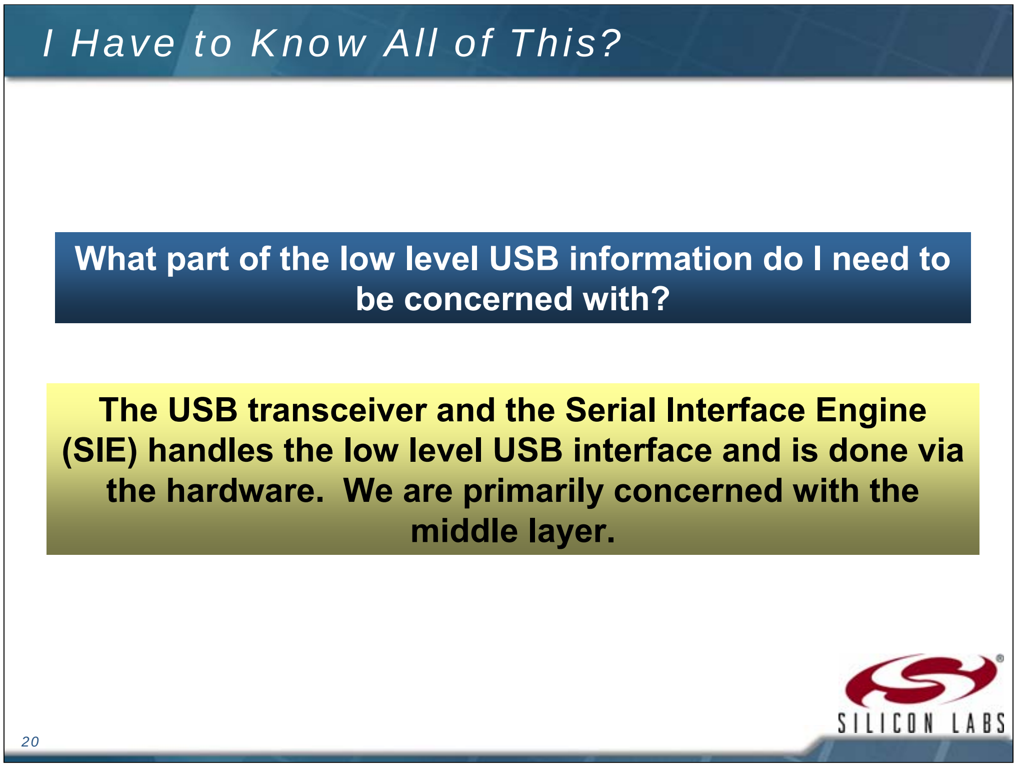
USB Transfers—Actual Isochronous Transfer

- Isochronous transfer OUT example:



```
CATC USB Chief Bus and Protocol Analyzer - [SampleData.usb: CATC default ]

Transfer | F | ISO | ADDR | ENDP | Cpl | Bytes Transferred | Length 88        | Length 92       | Time
179      | S | OUT | 5    | 4    | NO  | 68088             | Used 734 times   | Used 38 times   | 0 ns

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8570        | S | 0x87 | 5    | 4    | 0 | 88 bytes

    Packet # | F | Sync     | OUT  | ADDR | ENDP | CRC5 | EOP  | Idle
    31440    | S | 00000001 | 0x87 | 5    | 4    | 0x01 | 3.00 | 2

    Packet # | F | Sync     | DATA0 | DATA                                                     | CRC16  | EOP  | Idle
    31441    | S | 00000001 | 0xC3  | 0000:  00 00 00 00 00 00 FF FF 00 00 00 00 FF FF 00 00 | 0x352C | 2.50 | 17
                                    | 0016:  00 00 00 00 00 00 00 00 02 00 02 00 02 00 00 00
                                    | 0032:  00 00 00 00 02 00 00 00 00 00 00 00 02 00 00 00
                                    | 0048:  00 00 00 00 02 00 00 00 02 00 00 00 02 00 00 00
                                    | 0064:  03 00 00 00 05 00 00 00 07 00 05 00 09 00 07 00
                                    | 0080:  08 00 0A 00 09 00 09 00

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8572        | S | 0x87 | 5    | 4    | 0 | 88 bytes

    Packet # | F | Sync     | OUT  | ADDR | ENDP | CRC5 | EOP  | Idle
    31445    | S | 00000001 | 0x87 | 5    | 4    | 0x01 | 3.00 | 2

    Packet # | F | Sync     | DATA0 | DATA                                                     | CRC16  | EOP  | Idle
    31446    | S | 00000001 | 0xC3  | 0000:  04 00 09 00 04 00 04 00 FB FF 00 00 F0 FF F6 FF | 0xD95D | 2.50 | 17
                                    | 0016:  E4 FF E8 FF F1 FF E6 FF FF FF F8 FF 1B 00 09 00
                                    | 0032:  42 00 29 00 82 00 5E 00 CA 00 A3 00 06 01 EE 00
                                    | 0048:  66 00 DB 00 57 FF E4 FF 7F FE 04 FF 9E FD 28 FE
                                    | 0064:  0B FD 70 FD 93 FC F7 FC 04 FC 79 FC DF FB F4 FB
                                    | 0080:  B3 FC 4B FC 84 FD 26 FD

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8574        | S | 0x87 | 5    | 4    | 0 | 88 bytes

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8576        | S | 0x87 | 5    | 4    | 0 | 88 bytes

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8579        | S | 0x87 | 5    | 4    | 0 | 88 bytes

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8581        | S | 0x87 | 5    | 4    | 0 | 88 bytes

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8583        | S | 0x87 | 5    | 4    | 0 | 88 bytes

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8585        | S | 0x87 | 5    | 4    | 0 | 88 bytes

  Transaction | F | OUT  | ADDR | ENDP | T | DATA
  8587        | S | 0x87 | 5    | 4    | 0 | 88 bytes

For Help, press F1
```

And a screen capture of the Isochronous transfer.



I Have to Know All of This?

What part of the low level USB information do I need to be concerned with?

The USB transceiver and the Serial Interface Engine (SIE) handles the low level USB interface and is done via the hardware. We are primarily concerned with the middle layer.

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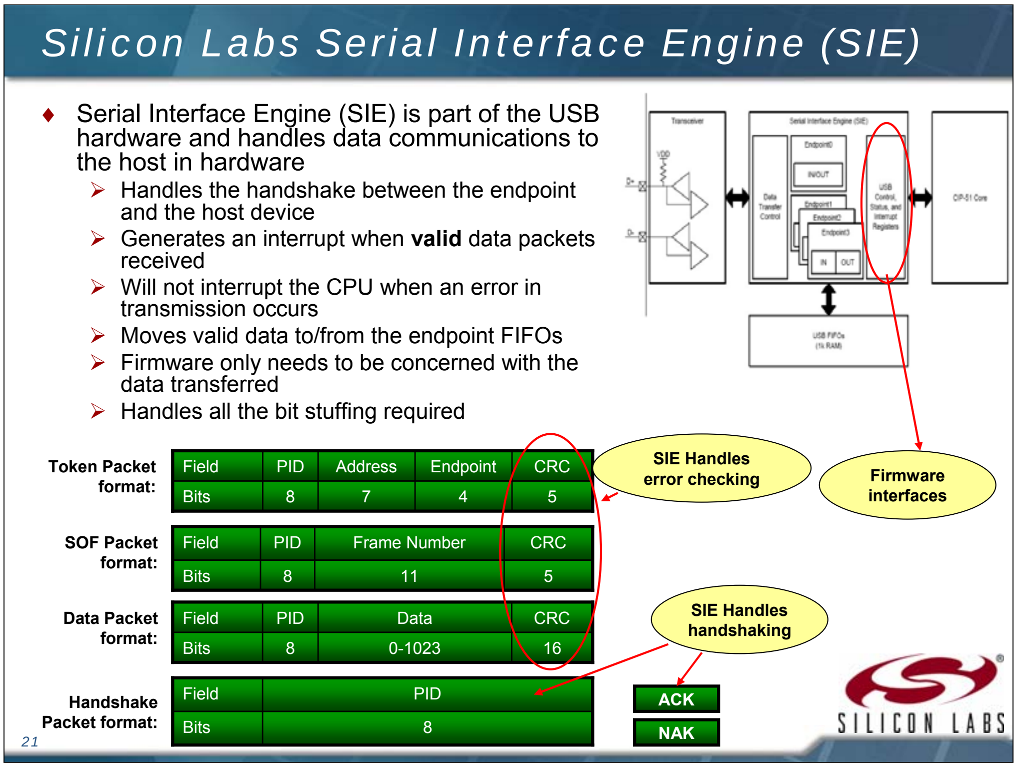

Silicon Labs Serial Interface Engine (SIE)

- Serial Interface Engine (SIE) is part of the USB hardware and handles data communications to the host in hardware
  - Handles the handshake between the endpoint and the host device
  - Generates an interrupt when **valid** data packets received
  - Will not interrupt the CPU when an error in transmission occurs
  - Moves valid data to/from the endpoint FIFOs
  - Firmware only needs to be concerned with the data transferred
  - Handles all the bit stuffing required

Token Packet format:

Field	PID	Address	Endpoint	CRC
Bits	8	7	4	5

SOF Packet format:

Field	PID	Frame Number	CRC
Bits	8	11	5

Data Packet format:

Field	PID	Data	CRC
Bits	8	0-1023	16

Handshake Packet format:

Field	PID
Bits	8

SIE Handles error checking

Firmware interfaces

SIE Handles handshaking

ACK

NAK

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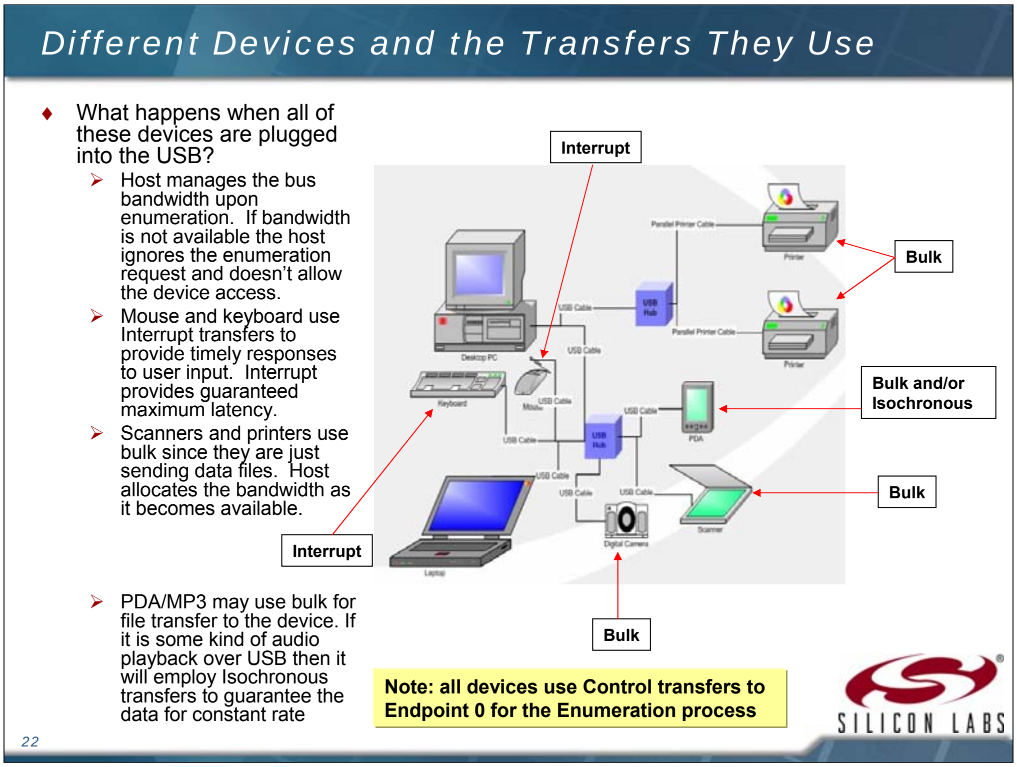
The hardware inside the MCU handles the low level communications in conformance with the USB specification. The integrated transceiver handles all of the electrical requirements for the differential signaling and the pull-ups etc. The Serial Interface Engine (SIE) is a powerful peripheral that provides all of the low level error checking and packet handling. When the packets come in from the host the SIE will determine if the packet is valid based on the address and endpoint number specified. It will also automatically generate the appropriate handshake packet based on the current state of the MCU. The USB peripheral integrated provides two interface points: the USB FIFOs and the USB control, status and interrupt interfaces to the C8051F core. That is where the firmware developer can read and write the data to be transferred as well as set the state of the USB peripheral and service interrupts.



Different Devices and the Transfers They Use

- What happens when all of these devices are plugged into the USB?
  - Host manages the bus bandwidth upon enumeration. If bandwidth is not available the host ignores the enumeration request and doesn't allow the device access.
  - Mouse and keyboard use Interrupt transfers to provide timely responses to user input. Interrupt provides guaranteed maximum latency.
  - Scanners and printers use bulk since they are just sending data files. Host allocates the bandwidth as it becomes available.
  - PDA/MP3 may use bulk for file transfer to the device. If it is some kind of audio playback over USB then it will employ Isochronous transfers to guarantee the data for constant rate

Note: all devices use Control transfers to Endpoint 0 for the Enumeration process

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So now that we have covered the different types of transfers used in the USB specification how do we apply those principals to our applications? Let's say all of these products are plugged into the USB and you turn the power strip switch ON. We learned that all of these devices will initialize and be ready to respond to endpoint 0 address 0, right? Well…there is always a hub (either external or the root hub) and within the hub spec those ports are required to be enabled to operate. There is a standard request SetPortFeature(RESET_PORT) which enables a port. Technically the device should not be ready for endpoint 0 address 0 until the host resets it anyway. It works because the host will enable one port that shows an attach event, assign an address to that device and then can move on from there to the next port. And so on, and so on…

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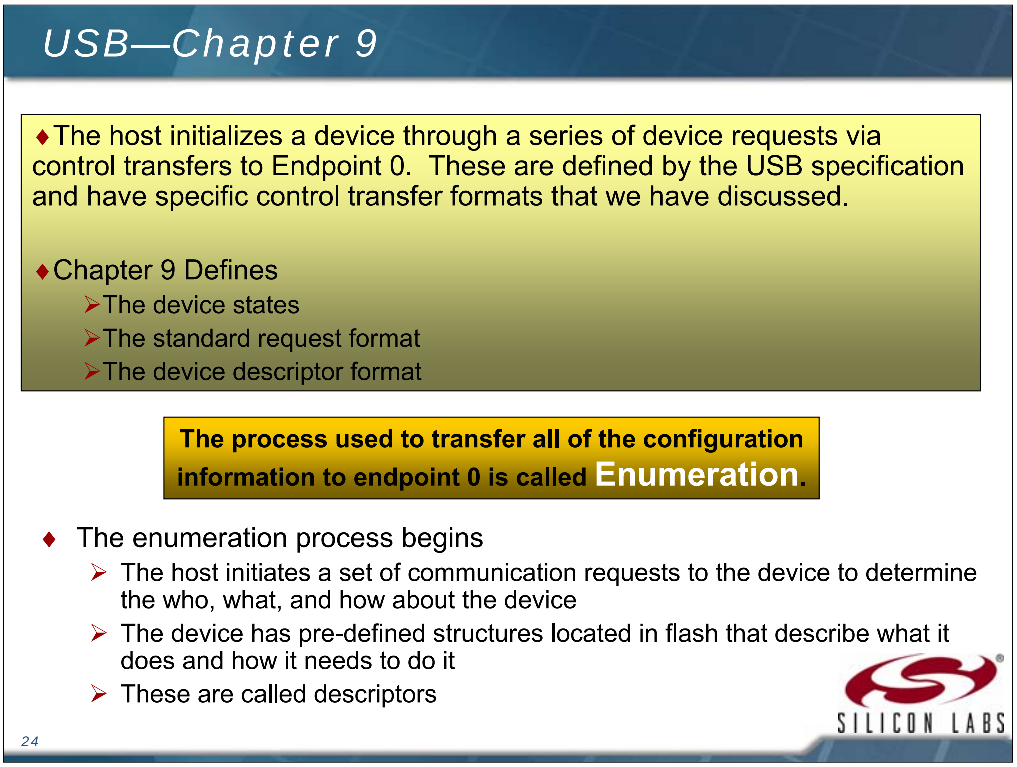
USB Middle Layer



USB—Chapter 9

♦ The host initializes a device through a series of device requests via control transfers to Endpoint 0. These are defined by the USB specification and have specific control transfer formats that we have discussed.

♦ Chapter 9 Defines

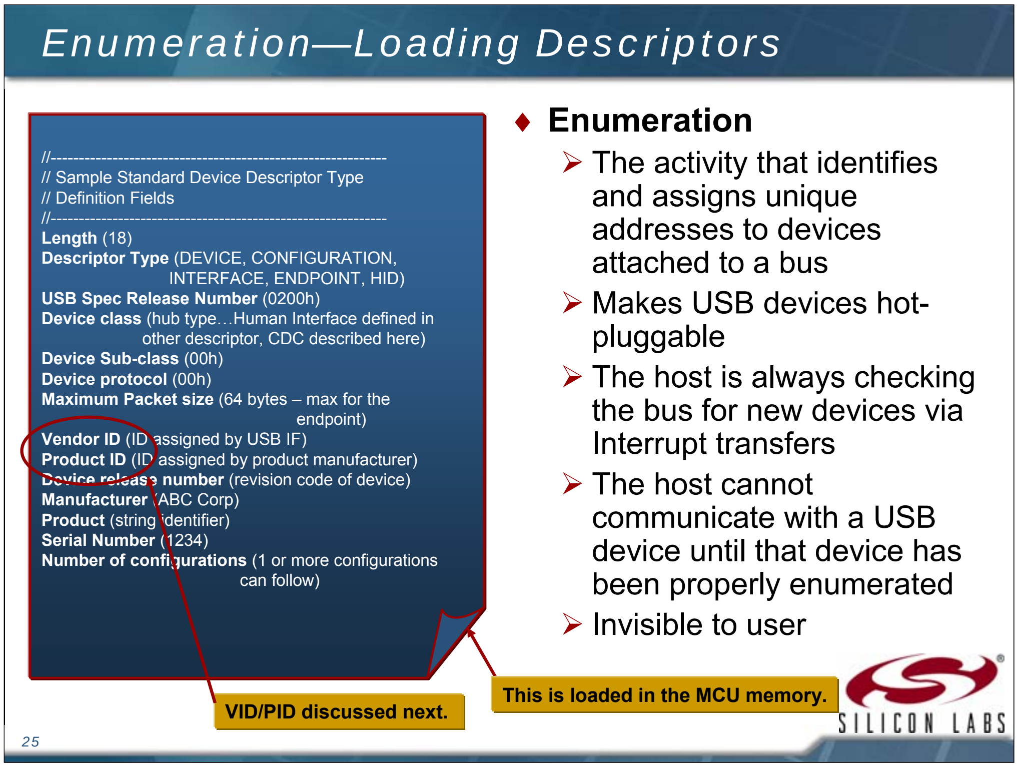
- ➢ The device states
- ➢ The standard request format
- ➢ The device descriptor format

The process used to transfer all of the configuration information to endpoint 0 is called Enumeration.

♦ The enumeration process begins

- ➢ The host initiates a set of communication requests to the device to determine the who, what, and how about the device
- ➢ The device has pre-defined structures located in flash that describe what it does and how it needs to do it
- ➢ These are called descriptors

Chapter 9 of the USB Specification calls out the routing of data between the bus interface (lowest layer) and various endpoints on the device. An endpoint is the ultimate consumer or provider of data. It may be thought of as a source or sink for data. We covered all of the different transfer types and how they are composed of the different packet structures and also discussed that data phase of the transfers and in which direction the data flows based on the request type. We have eluded to things called request but really haven’t delved into it so far. Chapter 9 of the USB specification outlines what all of the data in the Control Transfers means. If you recall in our outline of the control transfer we mentioned that there are 8 data bytes that get sent in the Setup phase. Those eight data bytes tells the device what information the host is requesting. All of these requests are defined in the USB specification, hence the term Standard Requests. In addition, the USB specification outlines the format for the data that the host wants to receive from devices which provides firmware developers the template required to store all of the configuration information for the end device.



Enumeration—Loading Descriptors

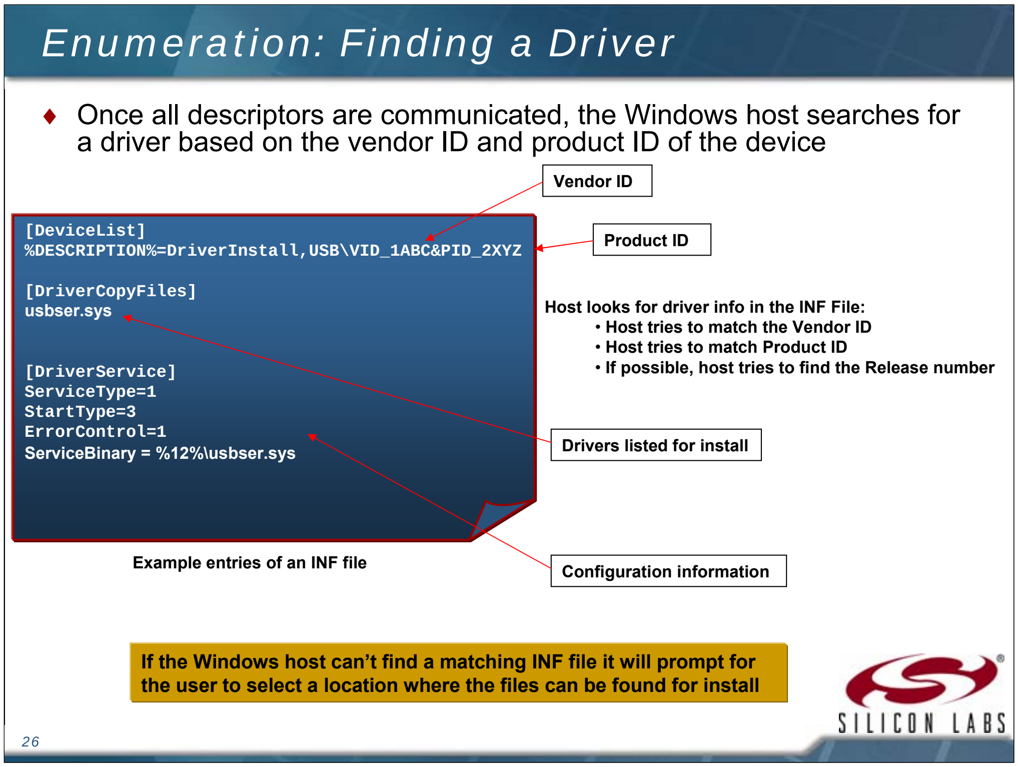
```
//------------------------------------------------------------
// Sample Standard Device Descriptor Type
// Definition Fields
//------------------------------------------------------------
Length (18)
Descriptor Type (DEVICE, CONFIGURATION,
                 INTERFACE, ENDPOINT, HID)
USB Spec Release Number (0200h)
Device class (hub type…Human Interface defined in
              other descriptor, CDC described here)
Device Sub-class (00h)
Device protocol (00h)
Maximum Packet size (64 bytes – max for the
                     endpoint)
Vendor ID (ID assigned by USB IF)
Product ID (ID assigned by product manufacturer)
Device release number (revision code of device)
Manufacturer (ABC Corp)
Product (string identifier)
Serial Number (1234)
Number of configurations (1 or more configurations
                          can follow)
```

- **Enumeration**
  - The activity that identifies and assigns unique addresses to devices attached to a bus
  - Makes USB devices hot-pluggable
  - The host is always checking the bus for new devices via Interrupt transfers
  - The host cannot communicate with a USB device until that device has been properly enumerated
  - Invisible to user

VID/PID discussed next.

This is loaded in the MCU memory.

We covered a lot of detail regarding USB transfers and the means by which the host retrieves descriptors from the device. This whole process we are describing is called Enumeration. After the attach event the host begins by resetting the device and then sends a series of standard request to retrieve the descriptors. If the host can accommodate the required bandwidth request by the device as well as the power consumption if it is bus powered, then the host will go ahead and enumerate the device and normal operation would begin. There can be no communication on the bus without a successful enumeration. Once again this diagram is showing the device descriptor as part of the enumeration. This is important because when we attach a device there is a software driver that has to be loaded on the host in order to let an application communicate over the USB to the device. We will cover that next.



Enumeration: Finding a Driver

- Once all descriptors are communicated, the Windows host searches for a driver based on the vendor ID and product ID of the device

```
[DeviceList]
%DESCRIPTION%=DriverInstall,USB\VID_1ABC&PID_2XYZ

[DriverCopyFiles]
usbser.sys


[DriverService]
ServiceType=1
StartType=3
ErrorControl=1
ServiceBinary = %12%\usbser.sys
```

Example entries of an INF file

Vendor ID

Product ID

Host looks for driver info in the INF File:
- Host tries to match the Vendor ID
- Host tries to match Product ID
- If possible, host tries to find the Release number

Drivers listed for install

Configuration information

If the Windows host can't find a matching INF file it will prompt for the user to select a location where the files can be found for install

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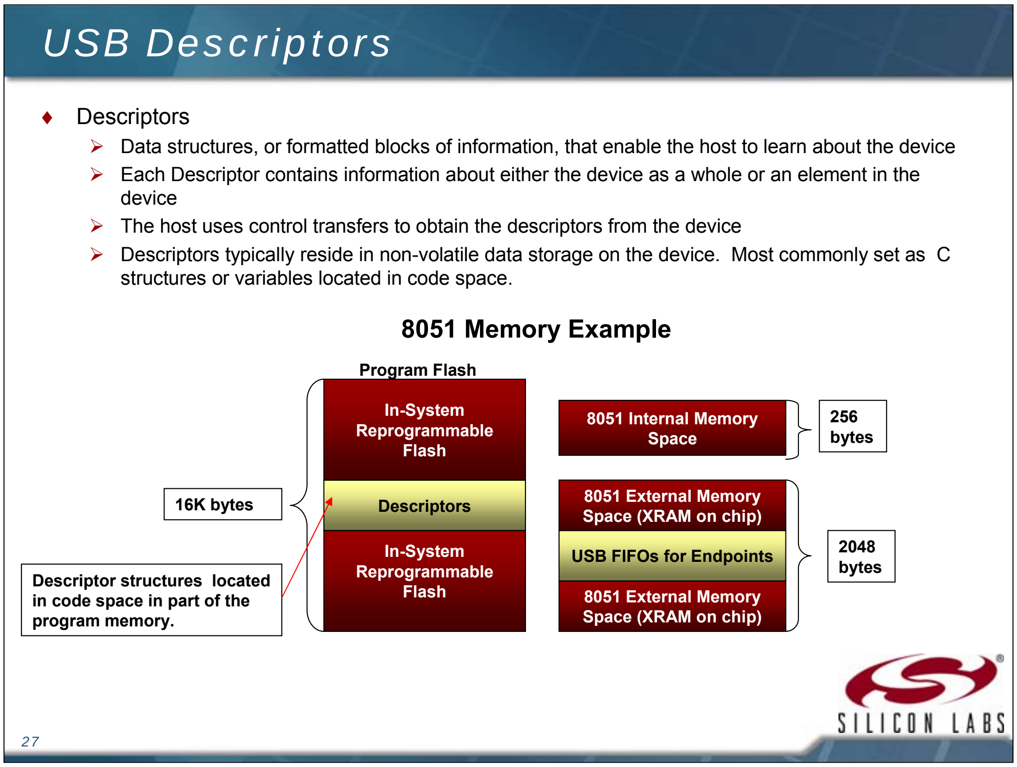
Remember that two of the fields in the device descriptor are the Vendor ID (VID) and the Product ID (PID). The first descriptor the host will request is the device descriptor and as such it will know what device it is communication with. The Windows operating system (OS) will be able to search an inf file to see if it can find a match between the VID and PID and what was received. If a match is found then the driver that the OS needs to install will be called out and the OS can start it. If a match is not found then the OS will prompt the user to find the driver to load. This slide shows some excerpts from an INF file and is provided to show what the host would be looking for in order to get the device up and running. In this case, a CDC class device using the usbser.sys driver.



USB Descriptors

- Descriptors
  - Data structures, or formatted blocks of information, that enable the host to learn about the device
  - Each Descriptor contains information about either the device as a whole or an element in the device
  - The host uses control transfers to obtain the descriptors from the device
  - Descriptors typically reside in non-volatile data storage on the device. Most commonly set as C structures or variables located in code space.

8051 Memory Example

Program Flash

In-System Reprogrammable Flash

Descriptors

In-System Reprogrammable Flash

16K bytes

Descriptor structures located in code space in part of the program memory.

8051 Internal Memory Space

256 bytes

8051 External Memory Space (XRAM on chip)

USB FIFOs for Endpoints

8051 External Memory Space (XRAM on chip)

2048 bytes

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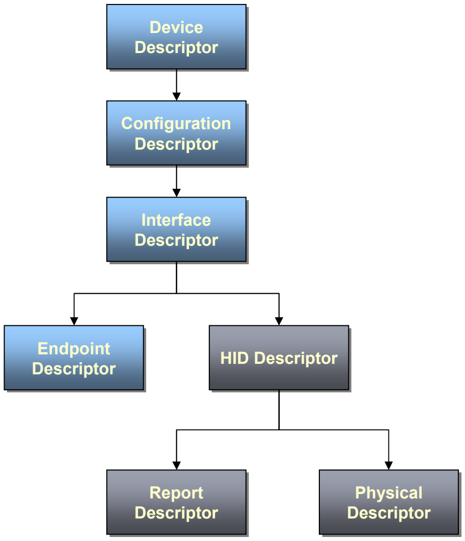
In our discussions about control transfers and standard requests we have touched on the information that is stored in the end device that the host reads to determine the configuration and operating parameters of the device.   The information is stored in what is called descriptors. There are several types of descriptors that get stored in the memory of the device and each provides configuration information associated with a different aspect of the USB communications. For example, the device descriptor provides high level information about the device. The endpoint descriptor contains low level communication protocol specific information like endpoint number etc. In this diagram we see that the descriptors would be stored in the flash memory such that they are available after each power up and reset in order for the host to read them. They are just variables in the memory that get passed to the USB peripheral when the request is made by the host.

USB Descriptors Types

- Device descriptor
  - General info about a USB device (vendor ID, etc)
  - Contains info that applies globally to the device
  - Only one device descriptor
- Configuration descriptor
  - USB devices can have multiple configurations
  - Each configuration contains one or more interfaces
  - All associated interface and endpoint descriptors get loaded with a request from the host for the configuration descriptor
  - Contains fields like remote wake-up capability and max power requirements
- Interface descriptor
  - Lists the endpoint descriptors for the interface
  - Identifies if the interface belongs to a predefined Class (such as the Human Interface Device or HID)
- Endpoint descriptor
  - Info required by host to determine bandwidth requirements
  - Describes endpoint number and address, IN or OUT endpoint and the transfer types requested



Device Descriptor

Configuration Descriptor

Interface Descriptor

Endpoint Descriptor

HID Descriptor

Report Descriptor

Physical Descriptor

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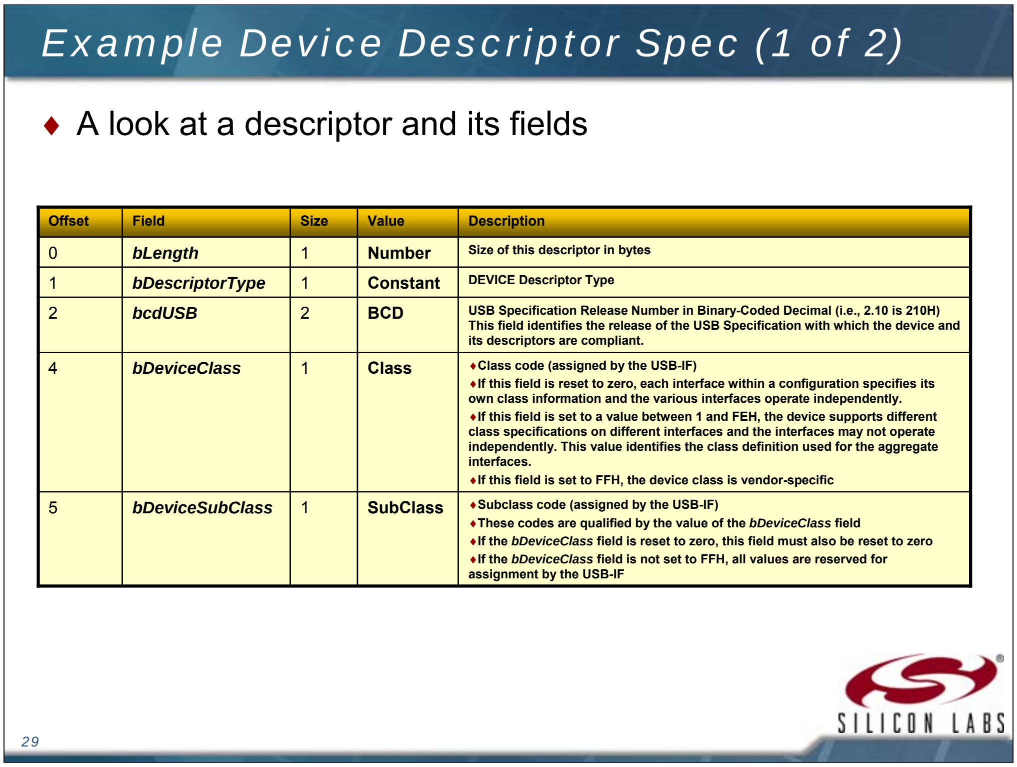
There is a hierarchy of descriptors specified in the USB specification. The device descriptor is the top level descriptor that has global information about the device, in particular are the maximum packet size (we touched on this earlier), the VID/PID combination and serial number.   Following the Device Descriptor is the Configuration descriptor. Devices can have multiple configurations and they are selected by the host. One of the key points when generating descriptors is that when the host requests the Configuration Descriptor the device is required to send all of the interface descriptors associated with that configuration as well as the endpoint descriptors associated with the interface. The first field in a descriptor is the size of the descriptor. In the case of the device descriptor the length is defined as the length of just that descriptor. When the host asks for the configuration descriptor the length field must be the sum of all of the descriptors to follow including the configuration descriptor.



Example Device Descriptor Spec (1 of 2)

- ♦ A look at a descriptor and its fields

Offset	Field	Size	Value	Description
0	***bLength***	1	**Number**	**Size of this descriptor in bytes**
1	***bDescriptorType***	1	**Constant**	**DEVICE Descriptor Type**
2	***bcdUSB***	2	**BCD**	**USB Specification Release Number in Binary-Coded Decimal (i.e., 2.10 is 210H) This field identifies the release of the USB Specification with which the device and its descriptors are compliant.**
4	***bDeviceClass***	1	**Class**	**♦Class code (assigned by the USB-IF)** **♦If this field is reset to zero, each interface within a configuration specifies its own class information and the various interfaces operate independently.** **♦If this field is set to a value between 1 and FEH, the device supports different class specifications on different interfaces and the interfaces may not operate independently. This value identifies the class definition used for the aggregate interfaces.** **♦If this field is set to FFH, the device class is vendor-specific**
5	***bDeviceSubClass***	1	**SubClass**	**♦Subclass code (assigned by the USB-IF)** **♦These codes are qualified by the value of the *bDeviceClass* field** **♦If the *bDeviceClass* field is reset to zero, this field must also be reset to zero** **♦If the *bDeviceClass* field is not set to FFH, all values are reserved for assignment by the USB-IF**

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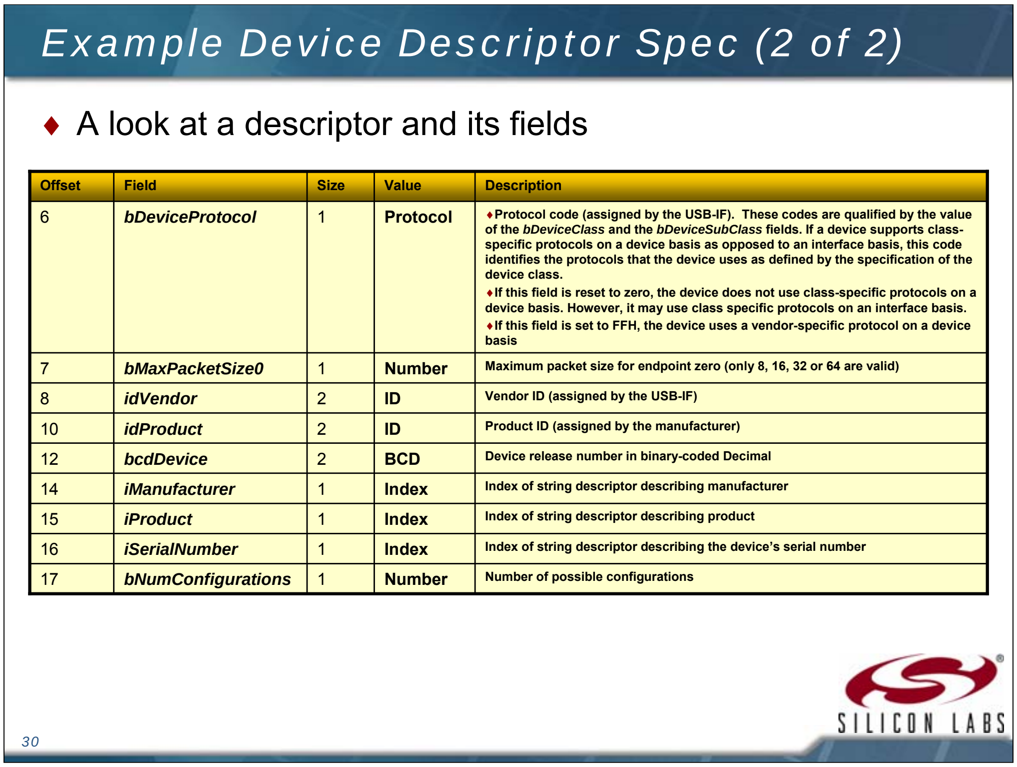
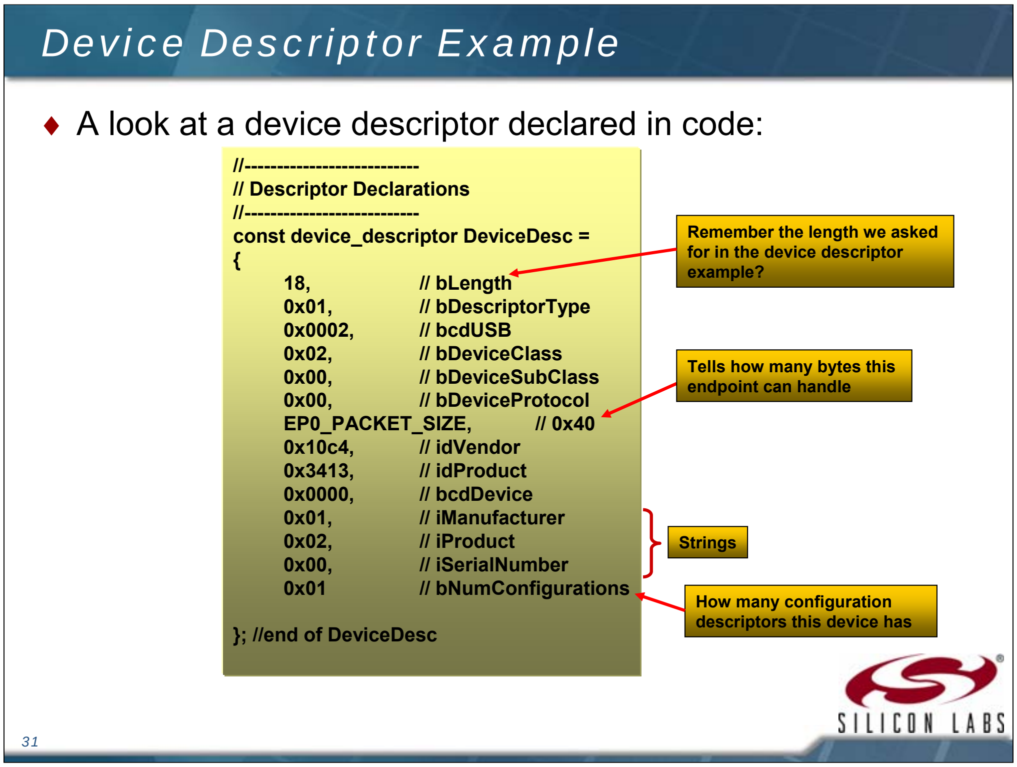
Now that we understand how the host requests data from a device and how the device responds to the request by passing along the descriptors that are stored in memory, we can take a deeper look at the descriptors. One example of a descriptor is the Device Descriptor and is transferred to the host as a result of the Get_Descriptor(DEVICE) standard request. The table in the slide shows the fields associated with the device descriptor. The first field identifies the length of the data including the size field. For the device descriptor the size field is always 18 bytes (0x12). The next is the descriptor type field which identifies the data as the device descriptor. Many different fields follow including what revision of the USB specification is supported by the endpoint device, the vendor ID and Product ID, as well as the maximum packet size supported for the endpoint. Take a look at the table on this slide and the next to see how the fields are defined for the device descriptor.



Example Device Descriptor Spec (2 of 2)

- A look at a descriptor and its fields

Offset	Field	Size	Value	Description
6	***bDeviceProtocol***	1	**Protocol**	♦**Protocol code (assigned by the USB-IF). These codes are qualified by the value of the *bDeviceClass* and the *bDeviceSubClass* fields. If a device supports class-specific protocols on a device basis as opposed to an interface basis, this code identifies the protocols that the device uses as defined by the specification of the device class.** ♦**If this field is reset to zero, the device does not use class-specific protocols on a device basis. However, it may use class specific protocols on an interface basis.** ♦**If this field is set to FFH, the device uses a vendor-specific protocol on a device basis**
7	***bMaxPacketSize0***	1	**Number**	**Maximum packet size for endpoint zero (only 8, 16, 32 or 64 are valid)**
8	***idVendor***	2	**ID**	**Vendor ID (assigned by the USB-IF)**
10	***idProduct***	2	**ID**	**Product ID (assigned by the manufacturer)**
12	***bcdDevice***	2	**BCD**	**Device release number in binary-coded Decimal**
14	***iManufacturer***	1	**Index**	**Index of string descriptor describing manufacturer**
15	***iProduct***	1	**Index**	**Index of string descriptor describing product**
16	***iSerialNumber***	1	**Index**	**Index of string descriptor describing the device's serial number**
17	***bNumConfigurations***	1	**Number**	**Number of possible configurations**



Device Descriptor Example

- A look at a device descriptor declared in code:

```
//---------------------------
// Descriptor Declarations
//---------------------------
const device_descriptor DeviceDesc =
{
        18,                 // bLength
        0x01,               // bDescriptorType
        0x0002,             // bcdUSB
        0x02,               // bDeviceClass
        0x00,               // bDeviceSubClass
        0x00,               // bDeviceProtocol
        EP0_PACKET_SIZE,           // 0x40
        0x10c4,             // idVendor
        0x3413,             // idProduct
        0x0000,             // bcdDevice
        0x01,               // iManufacturer
        0x02,               // iProduct
        0x00,               // iSerialNumber
        0x01                // bNumConfigurations

}; //end of DeviceDesc
```

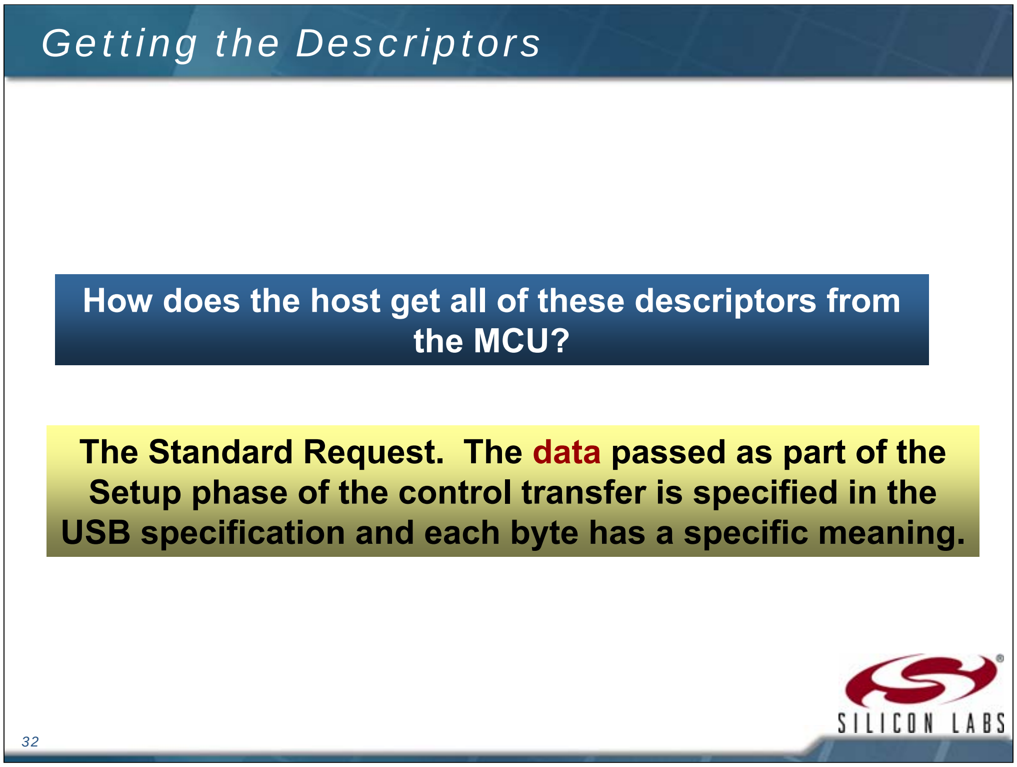
Remember the length we asked for in the device descriptor example?

Tells how many bytes this endpoint can handle

Strings

How many configuration descriptors this device has

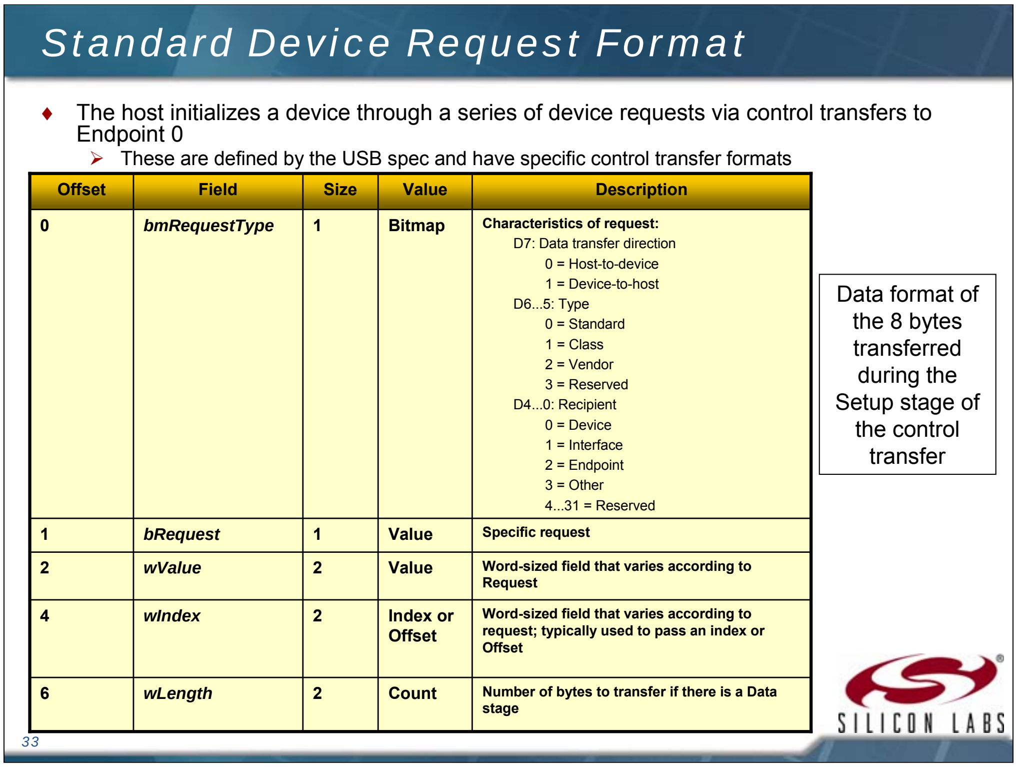
So what would a device descriptor look like when we determine all of the values required? Here is an example of a device descriptor. You can compare these values to the fields identified in the table to see how each value maps to the specification. Shown in the slide is a descriptor for a standard class called CDC as the values reflect the requirements of both specifications (USB 2.0 and the CDC class specification). We have this labeled as const in order to have this stored in the non-volatile flash memory so that we have them available all the time.



Getting the Descriptors

How does the host get all of these descriptors from the MCU?

The Standard Request. The data passed as part of the Setup phase of the control transfer is specified in the USB specification and each byte has a specific meaning.



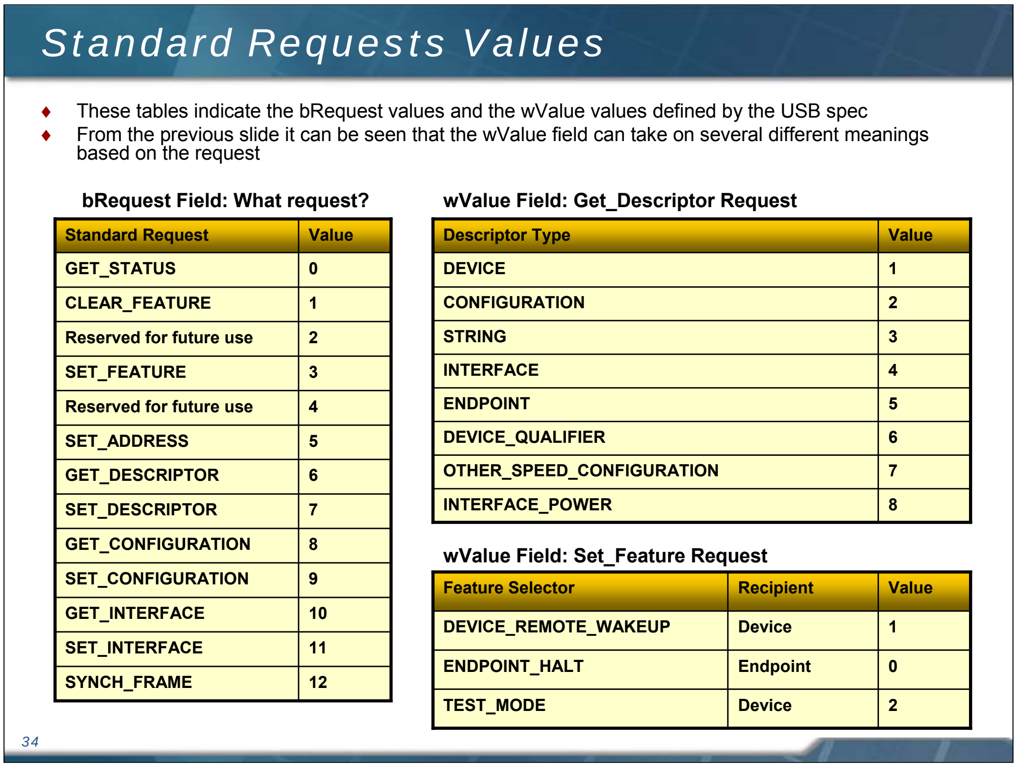
Standard Device Request Format

- The host initializes a device through a series of device requests via control transfers to Endpoint 0
  - These are defined by the USB spec and have specific control transfer formats

Offset	Field	Size	Value	Description
0	*bmRequestType*	1	Bitmap	**Characteristics of request:** D7: Data transfer direction 0 = Host-to-device 1 = Device-to-host D6...5: Type 0 = Standard 1 = Class 2 = Vendor 3 = Reserved D4...0: Recipient 0 = Device 1 = Interface 2 = Endpoint 3 = Other 4...31 = Reserved
1	*bRequest*	1	Value	**Specific request**
2	*wValue*	2	Value	**Word-sized field that varies according to Request**
4	*wIndex*	2	Index or Offset	**Word-sized field that varies according to request; typically used to pass an index or Offset**
6	*wLength*	2	Count	**Number of bytes to transfer if there is a Data stage**

Data format of the 8 bytes transferred during the Setup stage of the control transfer

Now we are getting into what is termed the Standard Requests or Chapter 9 of the USB spec. Remember those 8 data bytes that was sent with the Setup token for control transfers? The data that was sent during that request conformed to this table. The first section defines the direction of the data flow with respect to the host and what the target is, endpoint for example. On the next slide we will see the values that can be used to fill the bRequest field as well as the others. Essentially how these fields are set determine what the host is asking for and it is up to the firmware to parse these fields and make decisions based on the values received.



Standard Requests Values

- These tables indicate the bRequest values and the wValue values defined by the USB spec
- From the previous slide it can be seen that the wValue field can take on several different meanings based on the request

bRequest Field: What request?

Standard Request	Value
GET_STATUS	0
CLEAR_FEATURE	1
Reserved for future use	2
SET_FEATURE	3
Reserved for future use	4
SET_ADDRESS	5
GET_DESCRIPTOR	6
SET_DESCRIPTOR	7
GET_CONFIGURATION	8
SET_CONFIGURATION	9
GET_INTERFACE	10
SET_INTERFACE	11
SYNCH_FRAME	12

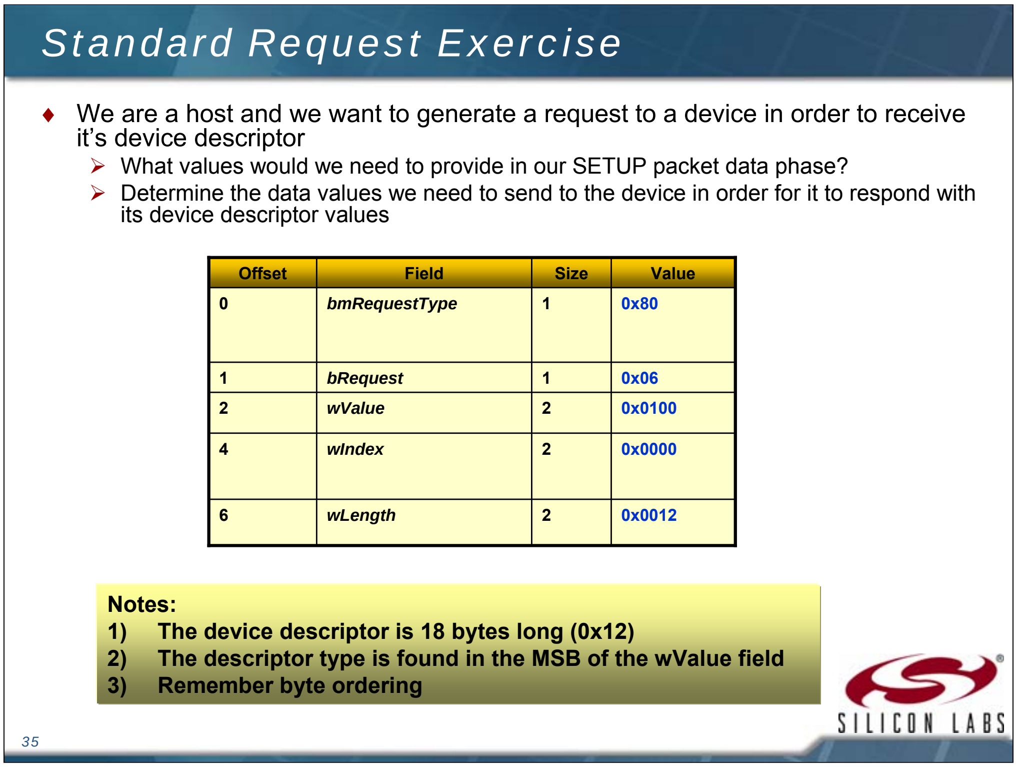
wValue Field: Get_Descriptor Request

Descriptor Type	Value
DEVICE	1
CONFIGURATION	2
STRING	3
INTERFACE	4
ENDPOINT	5
DEVICE_QUALIFIER	6
OTHER_SPEED_CONFIGURATION	7
INTERFACE_POWER	8

wValue Field: Set_Feature Request

Feature Selector	Recipient	Value
DEVICE_REMOTE_WAKEUP	Device	1
ENDPOINT_HALT	Endpoint	0
TEST_MODE	Device	2

Let’s take a look at some of the values that are defined. Above we see the different values associated with the fields that were in the table on the previous slide. These are the values that get populated in the data for the setup phase of the standard request (the 8 data bytes). For example, if the second byte (bRequest) is 0x06 the host is requesting a descriptor or if it is a 0x05 the host is going to set our address. The wValue field shown above goes deeper into the request. If we receive a 0x06 and have determined that the host is asking for a descriptor the wValue field will tell us which descriptor the host is asking for. For example, if wValue is set to 0x01 then the host wants our device descriptor. As firmware developers we need to be able to parse through the data received and take appropriate action.



Standard Request Exercise

- We are a host and we want to generate a request to a device in order to receive it’s device descriptor
  - What values would we need to provide in our SETUP packet data phase?
  - Determine the data values we need to send to the device in order for it to respond with its device descriptor values

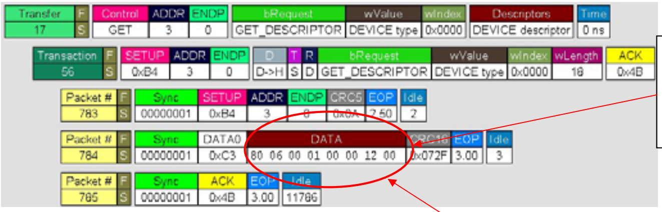
Offset	Field	Size	Value
0	*bmRequestType*	1	0x80
1	*bRequest*	1	0x06
2	*wValue*	2	0x0100
4	*wIndex*	2	0x0000
6	*wLength*	2	0x0012

Notes:
1) The device descriptor is 18 bytes long (0x12)
2) The descriptor type is found in the MSB of the wValue field
3) Remember byte ordering

Here is an example of the values we would be parsing for a Get_Descriptor(DEVICE) request from the host.

Standard Requests Example

- Get_Descriptor(DEVICE): Standard request to get the device descriptor

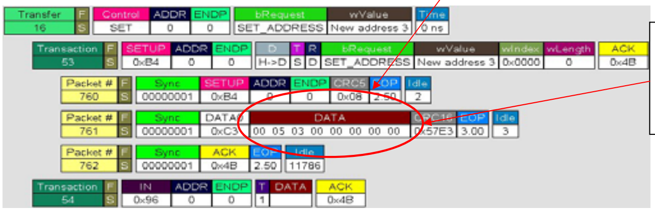


```
Transfer | F | Control | ADDR | ENDP | bRequest       | wValue      | wIndex | Descriptors       | Time
17       | S | GET     | 3    | 0    | GET_DESCRIPTOR | DEVICE type | 0x0000 | DEVICE descriptor | 0 ns

  Transaction | F | SETUP | ADDR | ENDP | D    | T | R | bRequest       | wValue      | wIndex | wLength | ACK
  56          | S | 0xB4  | 3    | 0    | D->H | S | D | GET_DESCRIPTOR | DEVICE type | 0x0000 | 18      | 0x4B

    Packet # | F | Sync     | SETUP | ADDR | ENDP | CRC5 | EOP  | Idle
    783      | S | 00000001 | 0xB4  | 3    | 0    | 0x0A | 2.50 | 2

    Packet # | F | Sync     | DATA0 | DATA                    | CRC16  | EOP  | Idle
    784      | S | 00000001 | 0xC3  | 80 06 00 01 00 00 12 00 | 0x072F | 3.00 | 3

    Packet # | F | Sync     | ACK  | EOP  | Idle
    785      | S | 00000001 | 0x4B | 3.00 | 11786
```

bmRequestType = 80h, bRequest = 06h
(Get_Descriptor())
wValue = 0100h (DEVICE)
wIndex = 0000h
wLength = 0012h (18 bytes)

8 bytes of data found within the setup phase of the control transfer.

Set_Address(3): Standard request to set device address to 3.



```
Transfer | F | Control | ADDR | ENDP | bRequest    | wValue        | Time
16       | S | SET     | 0    | 0    | SET_ADDRESS | New address 3 | 0 ns

  Transaction | F | SETUP | ADDR | ENDP | D    | T | R | bRequest    | wValue        | wIndex | wLength | ACK
  53          | S | 0xB4  | 0    | 0    | H->D | S | D | SET_ADDRESS | New address 3 | 0x0000 | 0       | 0x4B

    Packet # | F | Sync     | SETUP | ADDR | ENDP | CRC5 | EOP  | Idle
    760      | S | 00000001 | 0xB4  | 0    | 0    | 0x08 | 2.50 | 2

    Packet # | F | Sync     | DATA0 | DATA                    | CRC16  | EOP  | Idle
    761      | S | 00000001 | 0xC3  | 00 05 03 00 00 00 00 00 | 0x57E3 | 3.00 | 3

    Packet # | F | Sync     | ACK  | EOP  | Idle
    762      | S | 00000001 | 0x4B | 2.50 | 11786

  Transaction | F | IN   | ADDR | ENDP | T | DATA | ACK
  54          | S | 0x96 | 0    | 0    | 1 |      | 0x4B
```

bmRequestType=00h, bRequest=05h
(Set_Address())
wValue = 0300h (Address 3)
wIndex = 0000h
wLength = 0000h (0 bytes)

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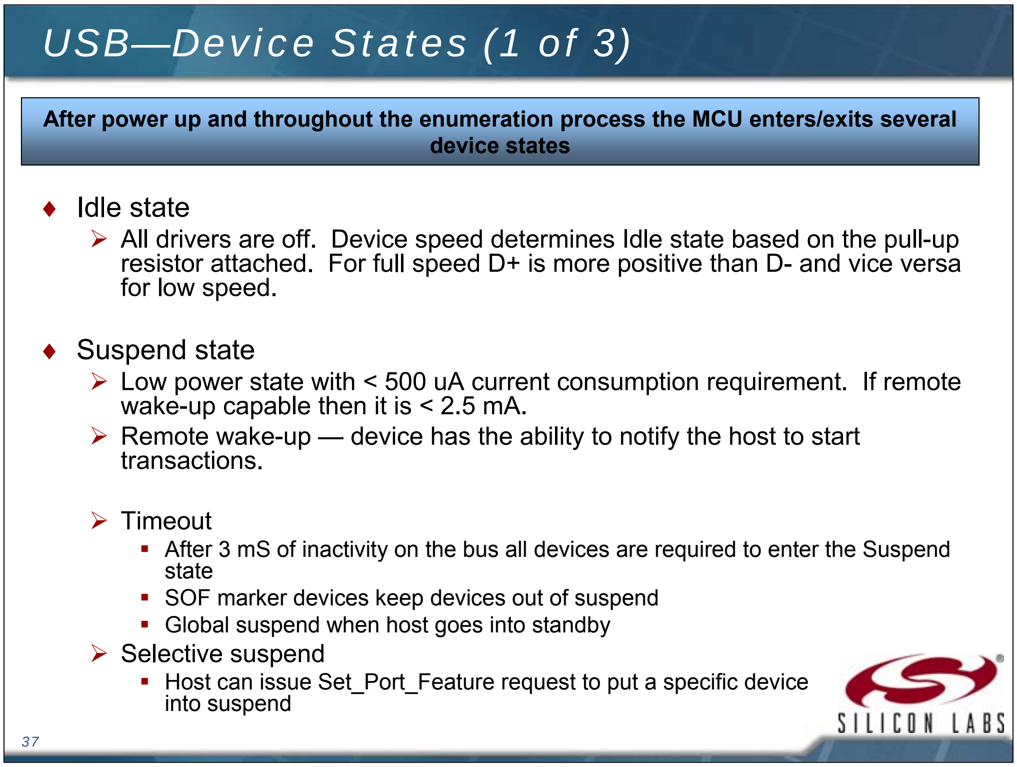
Here are some captures of data highlighting the requests. The first is the Get_Descriptor(DEVICE) standard request and the second is the Set_Address(3) request. In the first example we would provide the USB peripheral with the data that is stored that conforms to the descriptors for the device descriptor. When we receive the second request we will update the address register with the value transferred by the host, in this case we would become address 3.

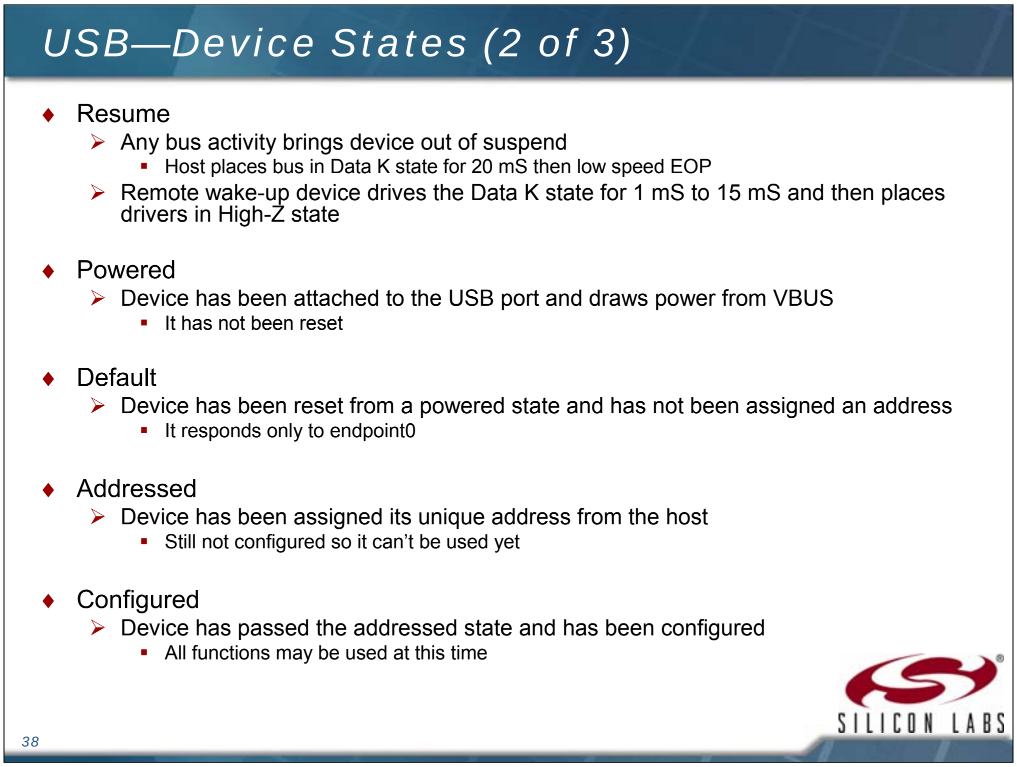


USB—Device States (1 of 3)

After power up and throughout the enumeration process the MCU enters/exits several device states

- Idle state
  - All drivers are off. Device speed determines Idle state based on the pull-up resistor attached. For full speed D+ is more positive than D- and vice versa for low speed.
- Suspend state
  - Low power state with < 500 uA current consumption requirement. If remote wake-up capable then it is < 2.5 mA.
  - Remote wake-up — device has the ability to notify the host to start transactions.
  - Timeout
    - After 3 mS of inactivity on the bus all devices are required to enter the Suspend state
    - SOF marker devices keep devices out of suspend
    - Global suspend when host goes into standby
  - Selective suspend
    - Host can issue Set_Port_Feature request to put a specific device into suspend

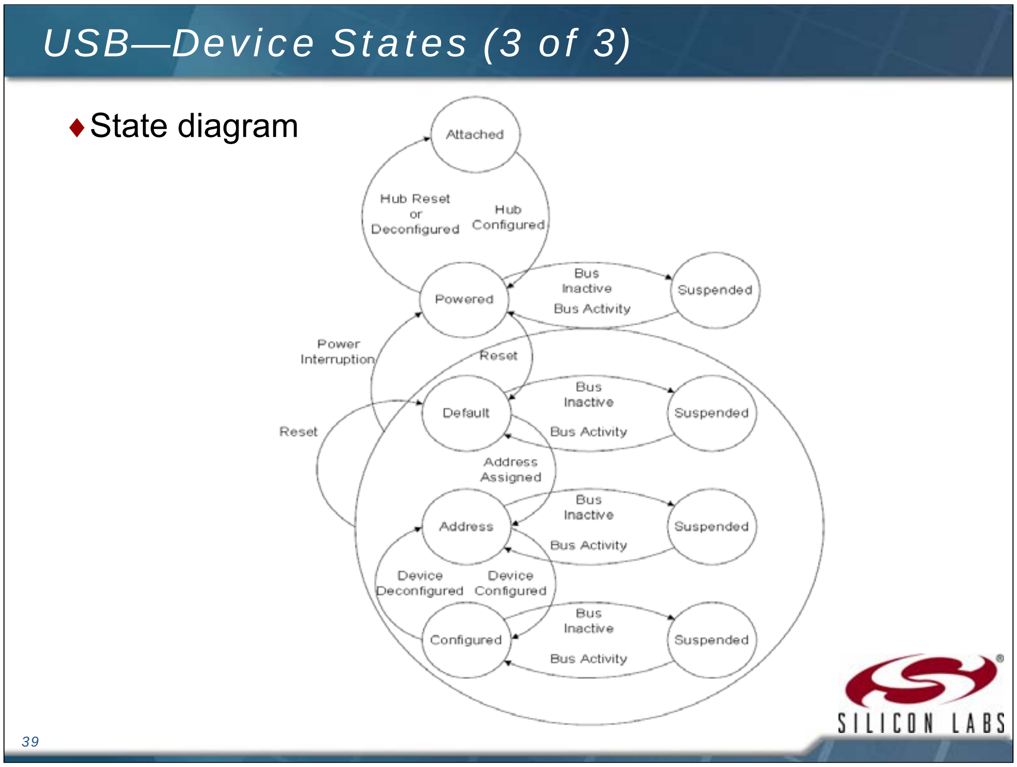
There are different device states defined in the USB specification. Take a minute to familiarize yourself with those outlined here.



USB—Device States (2 of 3)

- Resume
  - Any bus activity brings device out of suspend
    - Host places bus in Data K state for 20 mS then low speed EOP
  - Remote wake-up device drives the Data K state for 1 mS to 15 mS and then places drivers in High-Z state
- Powered
  - Device has been attached to the USB port and draws power from VBUS
    - It has not been reset
- Default
  - Device has been reset from a powered state and has not been assigned an address
    - It responds only to endpoint0
- Addressed
  - Device has been assigned its unique address from the host
    - Still not configured so it can't be used yet
- Configured
  - Device has passed the addressed state and has been configured
    - All functions may be used at this time

There are different device states defined in the USB specification. Take a minute to familiarize yourself with those outlined here.



USB—Device States (3 of 3)

- State diagram

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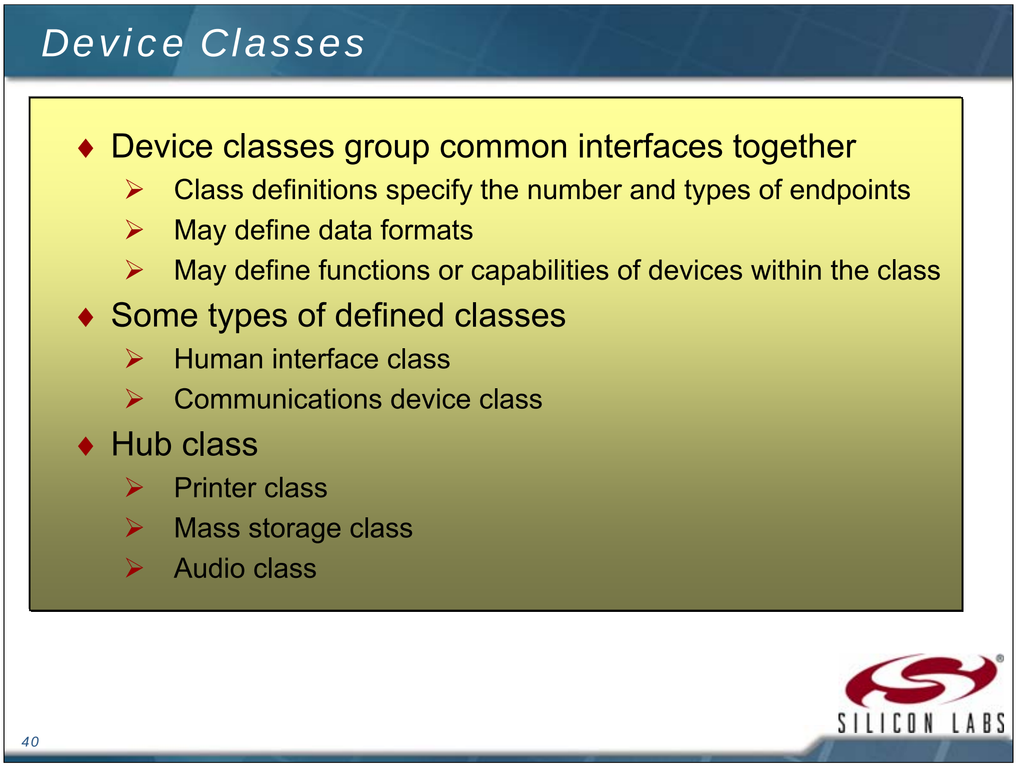
There are different device states defined in the USB specification. Here is a graphical view of the device states. As you can see they progress from the attach event all the way to configured.



Device Classes

- Device classes group common interfaces together
  - Class definitions specify the number and types of endpoints
  - May define data formats
  - May define functions or capabilities of devices within the class
- Some types of defined classes
  - Human interface class
  - Communications device class
- Hub class
  - Printer class
  - Mass storage class
  - Audio class

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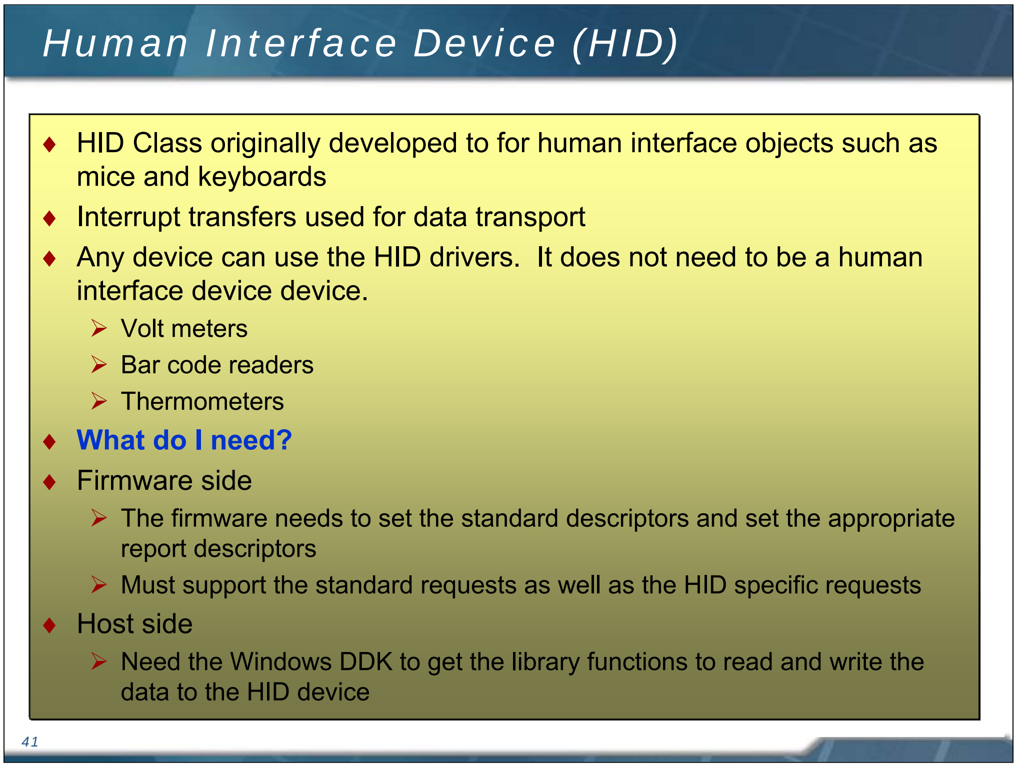
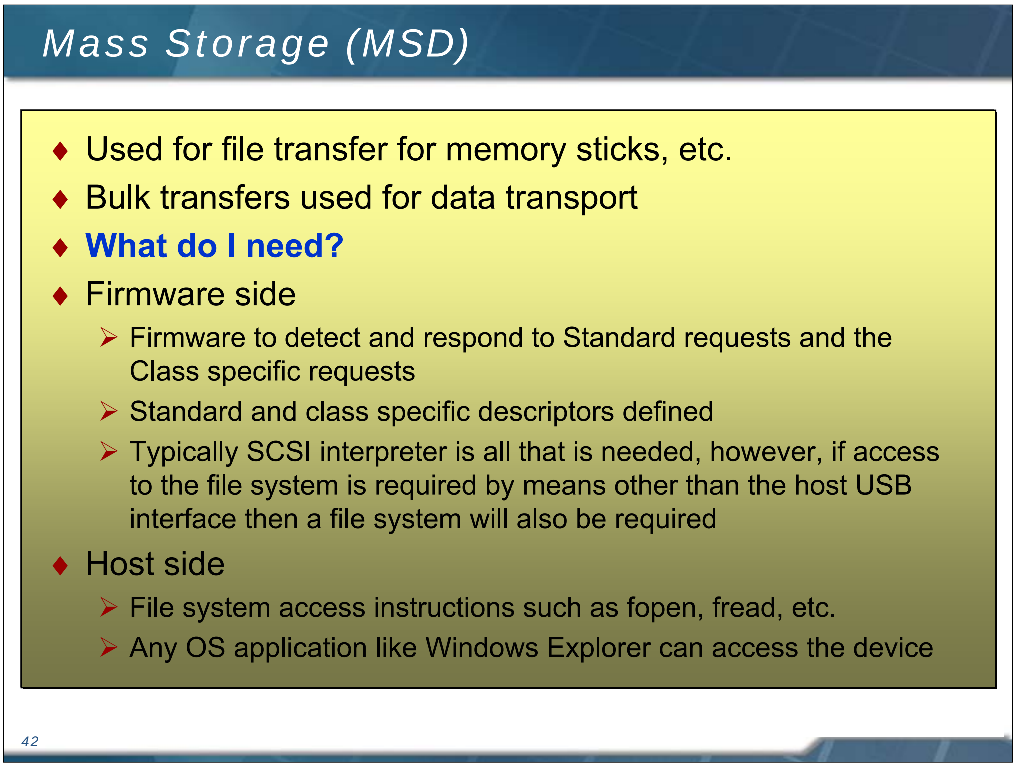
An additional set of specifications has been added to the overall USB 2.0 specifications. These additional specifications provide standard functionality using a predefined set of rules to set up and enumerate as well as the endpoint types and transfer types required. Along with defining exactly how the device will be configured, there is also an associated driver already integrated to the OS. That alleviates the need to write a custom drivers to suit the application. If the application data bandwidth requirements can fit within one of these pre-defined classes defined by the USB consortium then you can use that class and the driver that is built into the OS. For example, we can configure our device to enumerate as a Human Interface Device (HID) class and transfer data according to the HID specification. The driver that communicates with our Windows application is already a part of Windows and we didn’t have to write any driver code. Another application is the use of the Communications Device Class (CDC) that can be used for USB to UART applications and uses the built in Windows driver usbser.sys.



Human Interface Device (HID)

- HID Class originally developed to for human interface objects such as mice and keyboards
- Interrupt transfers used for data transport
- Any device can use the HID drivers. It does not need to be a human interface device device.
  - Volt meters
  - Bar code readers
  - Thermometers
- **What do I need?**
- Firmware side
  - The firmware needs to set the standard descriptors and set the appropriate report descriptors
  - Must support the standard requests as well as the HID specific requests
- Host side
  - Need the Windows DDK to get the library functions to read and write the data to the HID device

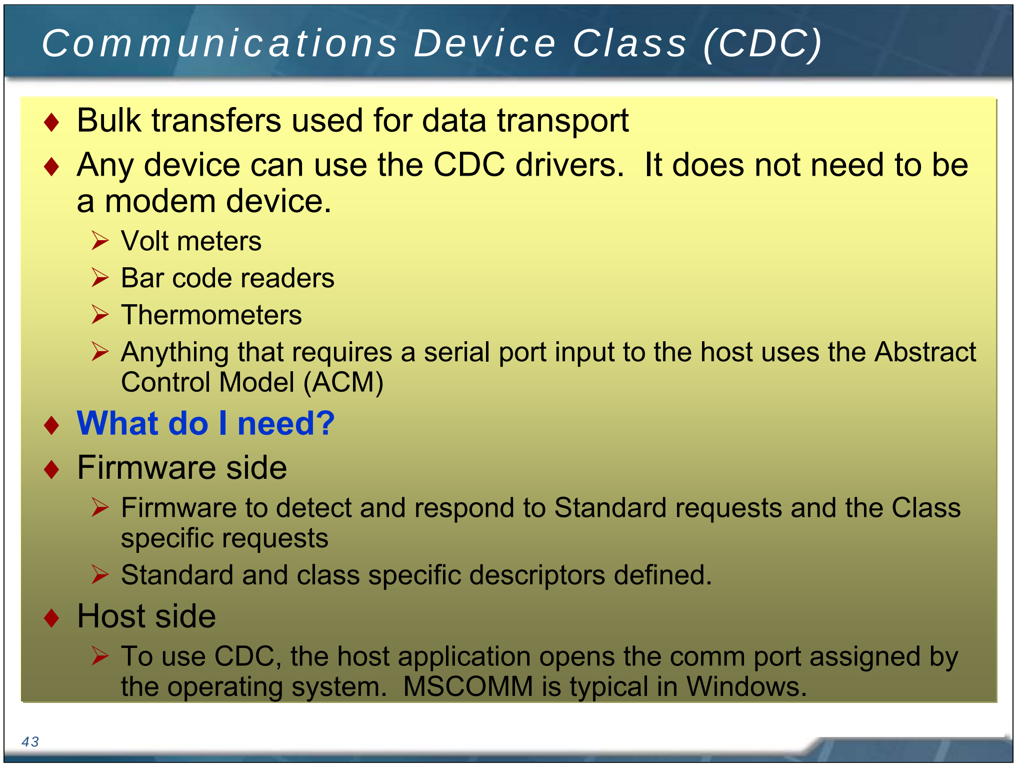
There are some things to be considered based on the class definition chosen for the application. The next few slides discuss some of the standard classes and what is required to implement them. For example, the HID class is useful for applications where the data transfer rate is less than 64Kbps. This is due to the fact that it uses interrupt transfers and they have a maximum packet size of 64 bytes and a minimum interval of 1ms. If the application fits within those requirements then the descriptors on the device side will need to reflect those called out in the HID specification. The firmware will have to support the standard requests associated with the USB 2.0 specification as well as those for the HID specification such as Get_Report. On the host side the calls to the driver are available in the Windows Driver Development Kit (DDK) or a manufacturer like Silicon Labs can provide their own API.



Mass Storage (MSD)

- Used for file transfer for memory sticks, etc.
- Bulk transfers used for data transport
- **What do I need?**
- Firmware side
  - Firmware to detect and respond to Standard requests and the Class specific requests
  - Standard and class specific descriptors defined
  - Typically SCSI interpreter is all that is needed, however, if access to the file system is required by means other than the host USB interface then a file system will also be required
- Host side
  - File system access instructions such as fopen, fread, etc.
  - Any OS application like Windows Explorer can access the device

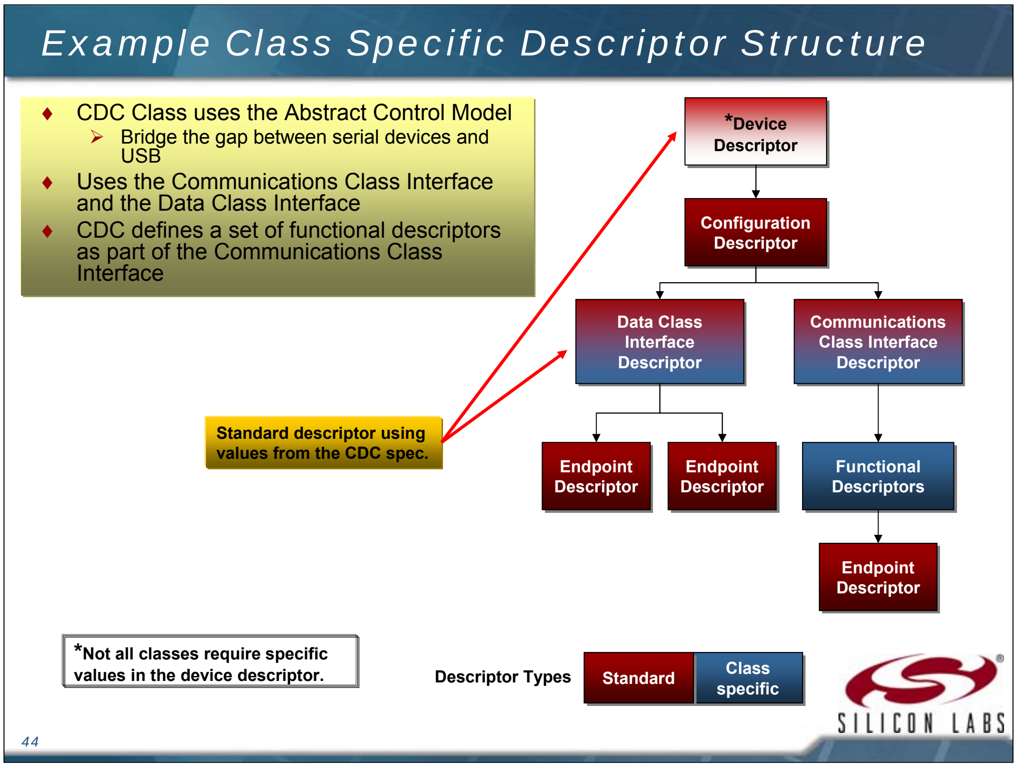
The same rules apply to the Mass Storage Device Class (MSD). When implementing mass storage (like a USB drive) there are several firmware considerations and application trade-offs to consider. Use this class when you want to arrange data as files in order to move and copy them easily to other locations. Typically, a SCSI interpreter is used and all of the file system structure is maintained on the host PC. This is equivalent to a USB flash drive and using Windows Explorer to access the files. One consideration to using the mass storage device class is whether or not file access is to be given to another port other than the host. In that case the firmware will have to implement its own files system and need to respond to commands like fopen, fclose etc.



Communications Device Class (CDC)

- Bulk transfers used for data transport
- Any device can use the CDC drivers. It does not need to be a modem device.
  - Volt meters
  - Bar code readers
  - Thermometers
  - Anything that requires a serial port input to the host uses the Abstract Control Model (ACM)
- **What do I need?**
- Firmware side
  - Firmware to detect and respond to Standard requests and the Class specific requests
  - Standard and class specific descriptors defined.
- Host side
  - To use CDC, the host application opens the comm port assigned by the operating system. MSCOMM is typical in Windows.

The communications device class (CDC) is used for quite a few applications. Where it is most beneficial to embedded designers is the implementation of the Abstract Control Model (ACM) which is a sub part of the CDC specification. The ACM allows a USB device to operate as a USB to RS232 bridge. It requires the descriptors to call out the CDC class and the firmware to be compliant to the USB 2.0 and the CDC specification.   In addition the firmware is required to respond to the class specific requests. An example would be the Set_Line_Coding which sends the baud rate information in order to configure the integrated UART. So does a CDC class device have to use a UART on the other end? No. We can just use the class specific enumeration and the built in driver to the OS to provide the means to pass data back and forth to the host. Once we receive it we can do anything we want with it.



Example Class Specific Descriptor Structure

- CDC Class uses the Abstract Control Model
  - Bridge the gap between serial devices and USB
- Uses the Communications Class Interface and the Data Class Interface
- CDC defines a set of functional descriptors as part of the Communications Class Interface

*Device Descriptor

Configuration Descriptor

Data Class Interface Descriptor

Communications Class Interface Descriptor

Endpoint Descriptor

Endpoint Descriptor

Functional Descriptors

Endpoint Descriptor

Standard descriptor using values from the CDC spec.

*Not all classes require specific values in the device descriptor.

Descriptor Types: Standard | Class specific

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Now that we have discussed the different classes and we have mentioned that our descriptors have to be compliant to the class specification as well as the USB 2.0 specification, let’s take a look again at the descriptor hierarchy for a standard class implementation. In this case we will look at the CDC class. Notice that the standard descriptors we had before are still there, however, we now have class specific values populated in some of the fields of the descriptors. Looking at our device descriptor example again, there are device specific fields added for a CDC class device. In addition to the standard descriptors, deice, configuration, interface and endpoint, there are additional descriptors the host will request based on the class. Here we see Data Class and Communications Class descriptors added as part of the CDC specification. The multi-colored boxes are a standard descriptor populated with values from the CDC class spec.

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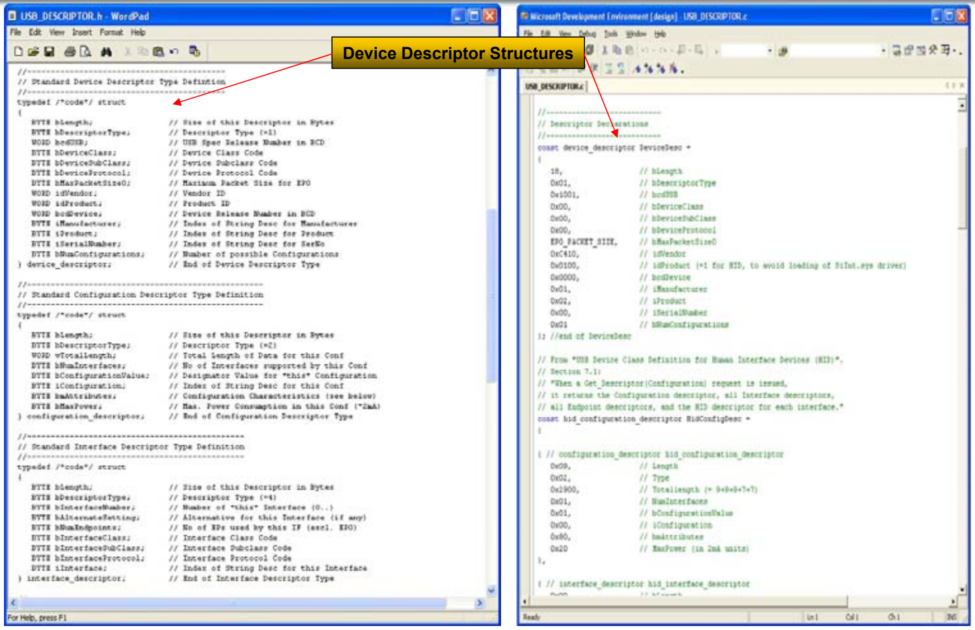
USB Firmware

USB Firmware Descriptor Variable Defined

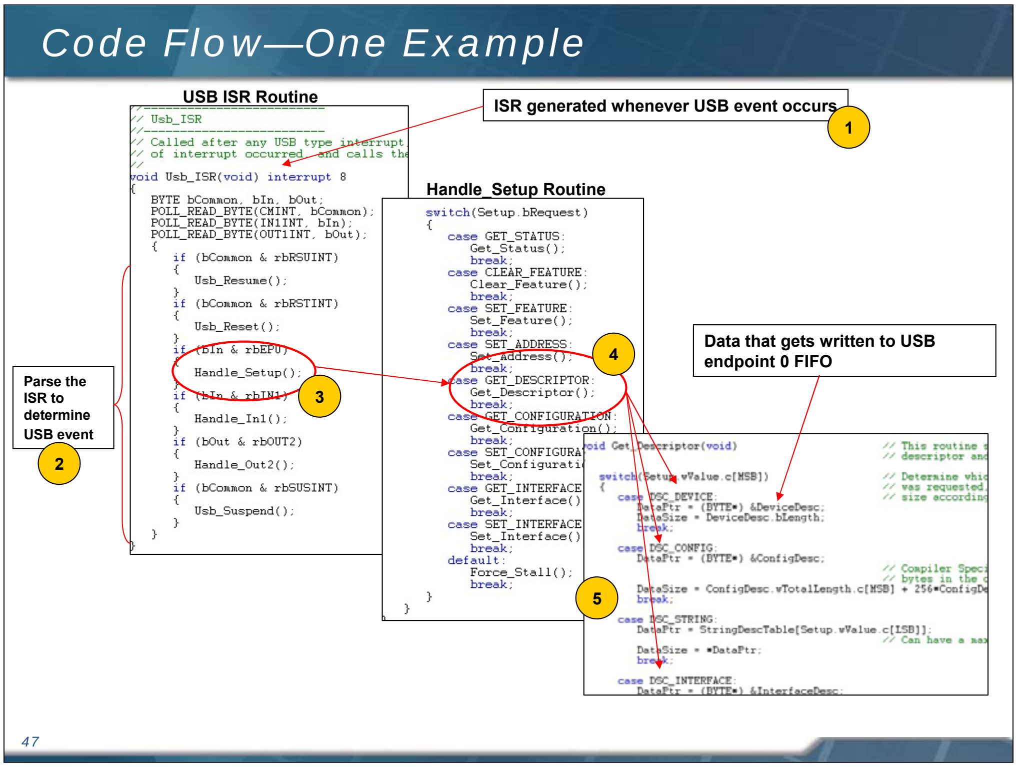

USB_DESCRIPTOR.h - WordPad
File Edit View Insert Format Help
For Help, press F1
Microsoft Development Environment [design] - USB_DESCRIPTOR.c
File Edit View Debug Tools Window Help
USB_DESCRIPTOR.c
Ready
Ln 1
Col 1
Ch 1
INS

Device Descriptor Structures

```
//------------------------------------------
// Standard Device Descriptor Type Defintion
//------------------------------------------
typedef /*code*/ struct
{
   BYTE bLength;                // Size of this Descriptor in Bytes
   BYTE bDescriptorType;        // Descriptor Type (=1)
   WORD bcdUSB;                 // USB Spec Release Number in BCD
   BYTE bDeviceClass;           // Device Class Code
   BYTE bDeviceSubClass;        // Device Subclass Code
   BYTE bDeviceProtocol;        // Device Protocol Code
   BYTE bMaxPacketSize0;        // Maximum Packet Size for EP0
   WORD idVendor;               // Vendor ID
   WORD idProduct;              // Product ID
   WORD bcdDevice;              // Device Release Number in BCD
   BYTE iManufacturer;          // Index of String Desc for Manufacturer
   BYTE iProduct;               // Index of String Desc for Product
   BYTE iSerialNumber;          // Index of String Desc for SerNo
   BYTE bNumConfigurations;     // Number of possible Configurations
} device_descriptor;            // End of Device Descriptor Type

//--------------------------------------------------
// Standard Configuration Descriptor Type Definition
//--------------------------------------------------
typedef /*code*/ struct
{
   BYTE bLength;                // Size of this Descriptor in Bytes
   BYTE bDescriptorType;        // Descriptor Type (=2)
   WORD wTotalLength;           // Total Length of Data for this Conf
   BYTE bNumInterfaces;         // No of Interfaces supported by this Conf
   BYTE bConfigurationValue;    // Designator Value for *this* Configuration
   BYTE iConfiguration;         // Index of String Desc for this Conf
   BYTE bmAttributes;           // Configuration Characteristics (see below)
   BYTE bMaxPower;              // Max. Power Consumption in this Conf (*2mA)
} configuration_descriptor;     // End of Configuration Descriptor Type

//----------------------------------------------
// Standard Interface Descriptor Type Definition
//----------------------------------------------
typedef /*code*/ struct
{
   BYTE bLength;                // Size of this Descriptor in Bytes
   BYTE bDescriptorType;        // Descriptor Type (=4)
   BYTE bInterfaceNumber;       // Number of *this* Interface (0..)
   BYTE bAlternateSetting;      // Alternative for this Interface (if any)
   BYTE bNumEndpoints;          // No of EPs used by this IF (excl. EP0)
   BYTE bInterfaceClass;        // Interface Class Code
   BYTE bInterfaceSubClass;     // Interface Subclass Code
   BYTE bInterfaceProtocol;     // Interface Protocol Code
   BYTE iInterface;             // Index of String Desc for this Interface
} interface_descriptor;         // End of Interface Descriptor Type
```

```
//----------------------------
// Descriptor Declarations
//----------------------------
const device_descriptor DeviceDesc =
{
   18,                 // bLength
   0x01,               // bDescriptorType
   0x1001,             // bcdUSB
   0x00,               // bDeviceClass
   0x00,               // bDeviceSubClass
   0x00,               // bDeviceProtocol
   EP0_PACKET_SIZE,    // bMaxPacketSize0
   0xC410,             // idVendor
   0x0100,             // idProduct (*1 for HID, to avoid loading of SiInt.sys driver)
   0x0000,             // bcdDevice
   0x01,               // iManufacturer
   0x02,               // iProduct
   0x00,               // iSerialNumber
   0x01                // bNumConfigurations
}; //end of DeviceDesc

// From "USB Device Class Definition for Human Interface Devices (HID)".
// Section 7.1:
// "When a Get_Descriptor(Configuration) request is issued,
// it returns the Configuration descriptor, all Interface descriptors,
// all Endpoint descriptors, and the HID descriptor for each interface."
const hid_configuration_descriptor HidConfigDesc =
{

{ // configuration_descriptor hid_configuration_descriptor
   0x09,               // Length
   0x02,               // Type
   0x2900,             // Totallength (= 9+9+9+7+7)
   0x01,               // NumInterfaces
   0x01,               // bConfigurationValue
   0x00,               // iConfiguration
   0x80,               // bmAttributes
   0x20                // MaxPower (in 2mA units)
},

{ // interface_descriptor hid_interface_descriptor
```

Here is a snapshot of some sample code that implements USB. On the left are the definitions for the specific descripors and on the right is the actual code that places these descriptor values into the flash of the MCU.



Code Flow—One Example

USB ISR Routine

```
//-------------------------
// Usb_ISR
//-------------------------
// Called after any USB type interrupt
// of interrupt occurred, and calls the
//
void Usb_ISR(void) interrupt 8
{
   BYTE bCommon, bIn, bOut;
   POLL_READ_BYTE(CMINT, bCommon);
   POLL_READ_BYTE(IN1INT, bIn);
   POLL_READ_BYTE(OUT1INT, bOut);
   {
      if (bCommon & rbRSUINT)
      {
         Usb_Resume();
      }
      if (bCommon & rbRSTINT)
      {
         Usb_Reset();
      }
      if (bIn & rbEP0)
      {
         Handle_Setup();
      }
      if (bIn & rbIN1)
      {
         Handle_In1();
      }
      if (bOut & rbOUT2)
      {
         Handle_Out2();
      }
      if (bCommon & rbSUSINT)
      {
         Usb_Suspend();
      }
   }
}
```

ISR generated whenever USB event occurs

1

Parse the ISR to determine USB event

2

3

Handle_Setup Routine

```
      switch(Setup.bRequest)
      {
         case GET_STATUS:
            Get_Status();
            break;
         case CLEAR_FEATURE:
            Clear_Feature();
            break;
         case SET_FEATURE:
            Set_Feature();
            break;
         case SET_ADDRESS:
            Set_Address();
            break;
         case GET_DESCRIPTOR:
            Get_Descriptor();
            break;
         case GET_CONFIGURATION:
            Get_Configuration();
            break;
         case SET_CONFIGURA
            Set_Configurati
            break;
         case GET_INTERFACE
            Get_Interface()
            break;
         case SET_INTERFACE
            Set_Interface()
            break;
         default:
            Force_Stall();
            break;
      }
   }
```

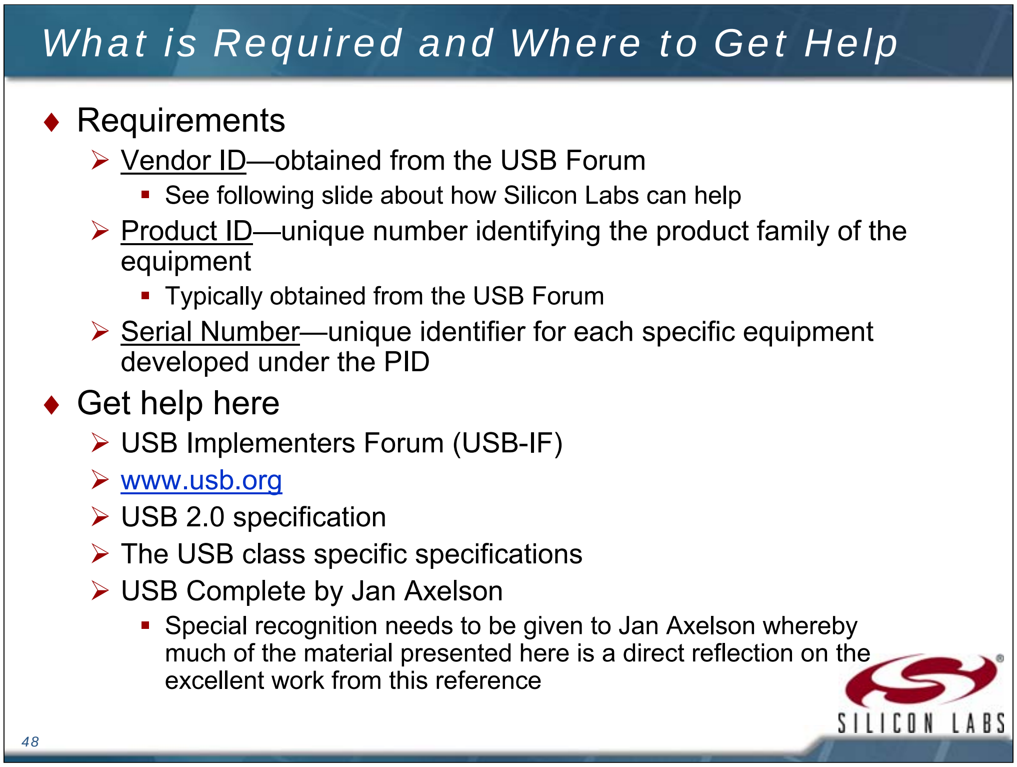
4

Data that gets written to USB endpoint 0 FIFO

```
void Get_Descriptor(void)                                      // This routine s
                                                               // descriptor and

   switch(Setup.wValue.c[MSB])                                 // Determine whic
   {                                                           // was requested,
      case DSC_DEVICE:                                         // size according
         DataPtr = (BYTE*) &DeviceDesc;
         DataSize = DeviceDesc.bLength;
         break;

      case DSC_CONFIG:
         DataPtr = (BYTE*) &ConfigDesc;
                                                               // Compiler Speci
                                                               // bytes in the c
         DataSize = ConfigDesc.wTotalLength.c[MSB] + 256*ConfigDe
         break;

      case DSC_STRING:
         DataPtr = StringDescTable[Setup.wValue.c[LSB]];
                                                               // Can have a max
         DataSize = *DataPtr;
         break;

      case DSC_INTERFACE:
         DataPtr = (BYTE*) &InterfaceDesc;
```

5

In these samples we can follow the firmware after the interrupt is received. The example here is showing how the firmware determines what type of request was received and how the data is returned to the host.



What is Required and Where to Get Help

- Requirements
  - Vendor ID—obtained from the USB Forum
    - See following slide about how Silicon Labs can help
  - Product ID—unique number identifying the product family of the equipment
    - Typically obtained from the USB Forum
  - Serial Number—unique identifier for each specific equipment developed under the PID
- Get help here
  - USB Implementers Forum (USB-IF)
  - www.usb.org
  - USB 2.0 specification
  - The USB class specific specifications
  - USB Complete by Jan Axelson
    - Special recognition needs to be given to Jan Axelson whereby much of the material presented here is a direct reflection on the excellent work from this reference

So we have completed the main portion of the training module that covers USB and how it works. We have shown how the standard classes can benefit an application by reduces development effort. Now that you understand USB we are going to give a few tools that can abstract the entire USB operation to get a design communicating via USB quickly. First, if you are going to be compliant to USB and provide open functionality then you will have to obtain a VID from the USB Implementer’s Forum. You can use the Silicon Labs VID and they can assign a PID under their VID for customers to use. Also listed here are some useful guides to learn USB in more detail. Thanks to Jan Axelson for the book “USB Complete” as it has been an invaluable resource when putting this material together.

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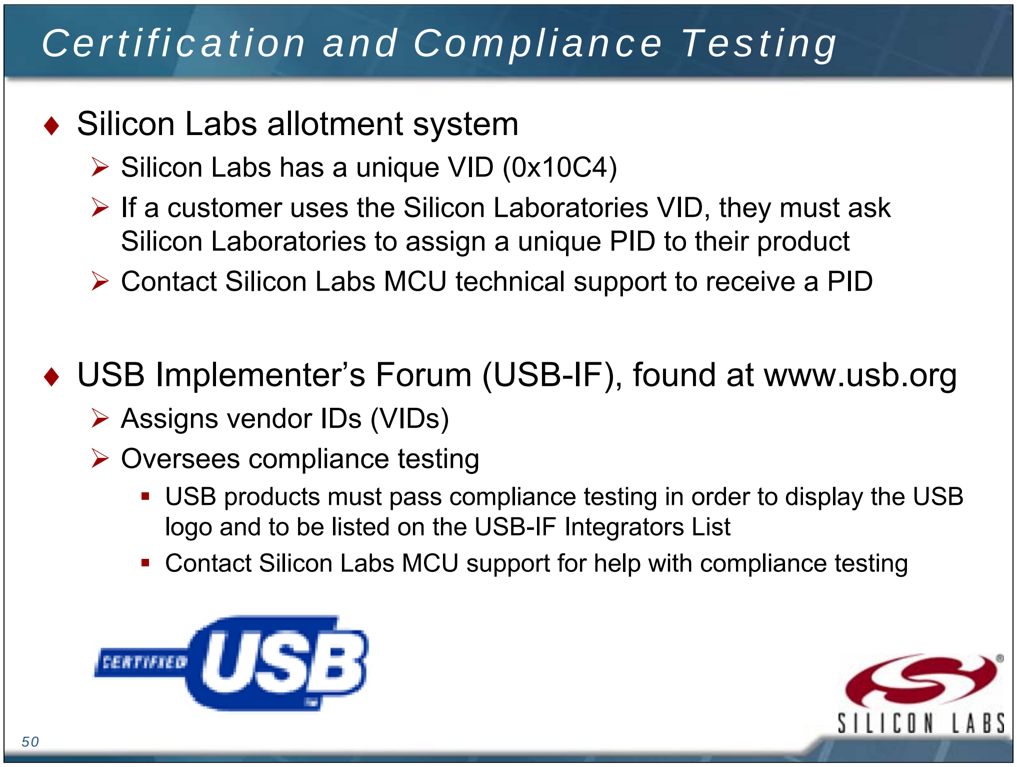
USB Solutions Offered by Silicon Labs



Certification and Compliance Testing

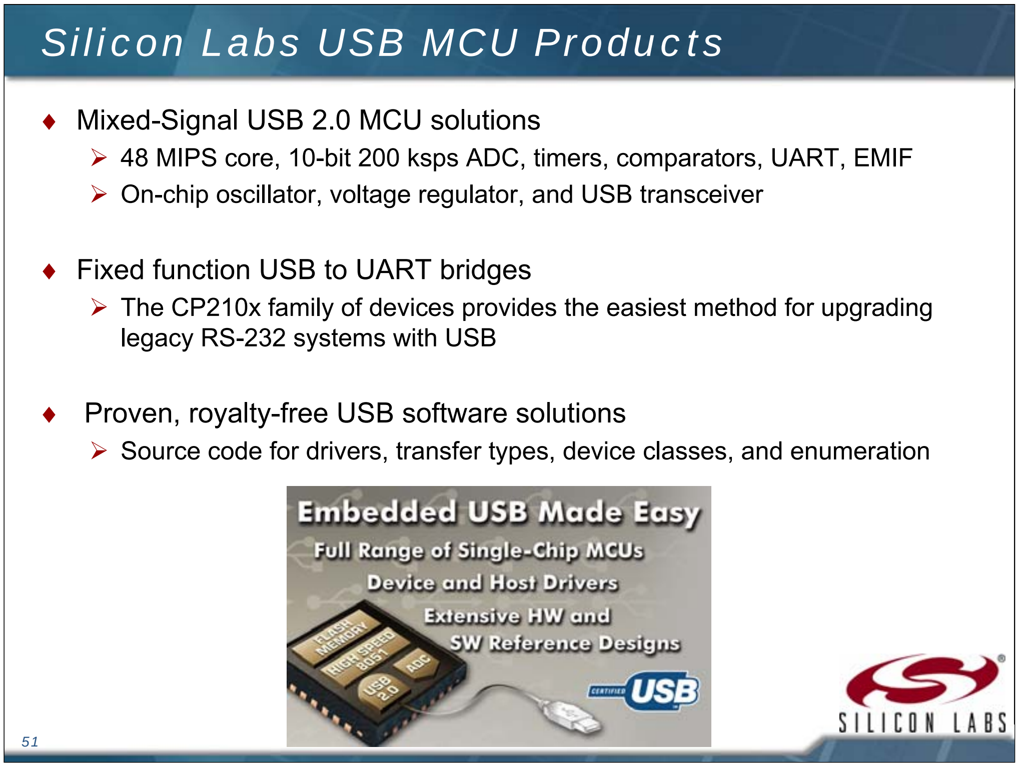
- Silicon Labs allotment system
  - Silicon Labs has a unique VID (0x10C4)
  - If a customer uses the Silicon Laboratories VID, they must ask Silicon Laboratories to assign a unique PID to their product
  - Contact Silicon Labs MCU technical support to receive a PID
- USB Implementer's Forum (USB-IF), found at www.usb.org
  - Assigns vendor IDs (VIDs)
  - Oversees compliance testing
    - USB products must pass compliance testing in order to display the USB logo and to be listed on the USB-IF Integrators List
    - Contact Silicon Labs MCU support for help with compliance testing

Silicon Labs has an agreement with NTS (National Testing Services) to provide discount USB Compliance testing for Silicon Labs customers. Contact mcutools@silabs.com for more details.

In order to display a USB certified logo on the end product or packaging, the designers will have to undergo compliance testing. The USB implementer's forum has a list of approved compliance testing vendors. Once a product passes, the vendor then has the product listed.

The forum also assigns a vendor ID (or VID) so that the designer can assign the product with a unique ID number.

You can contact silicon labs for assistance.



Silicon Labs USB MCU Products

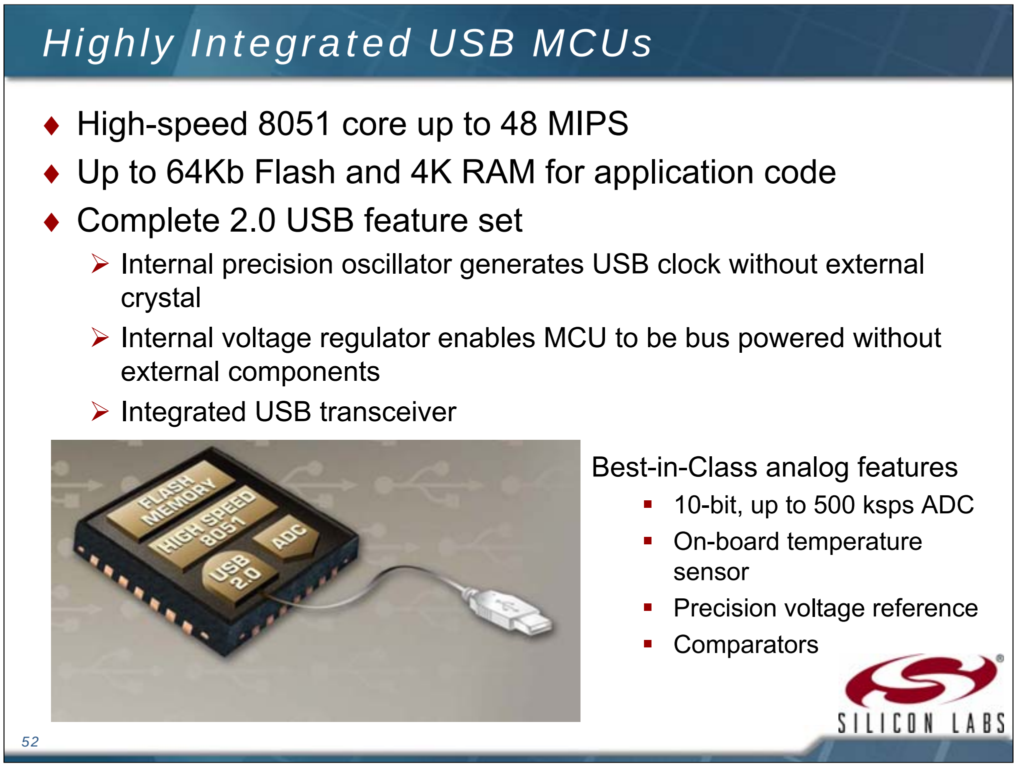
- Mixed-Signal USB 2.0 MCU solutions
  - 48 MIPS core, 10-bit 200 ksps ADC, timers, comparators, UART, EMIF
  - On-chip oscillator, voltage regulator, and USB transceiver
- Fixed function USB to UART bridges
  - The CP210x family of devices provides the easiest method for upgrading legacy RS-232 systems with USB
- Proven, royalty-free USB software solutions
  - Source code for drivers, transfer types, device classes, and enumeration

Silicon labs controller solutions fall into two main classes: fixed function and fully-programmable mixed-signal MCUs with integrated USB controller.

Fixed function CP210x USB to UART bridge devices with royalty-free VCP drivers are the easiest and fastest way to add USB communication to your design – with no changes to the controller firmware or PC application.

Mixed-signal MCUs are fully-programmable, featuring ISP FLASH (great for USB bootloaders), a wide array of memory sizes, port I/O, and analog data converters.

All of these feature a calibrated oscillator, and so do not require an external crystal!


FLASH MEMORY
HIGH SPEED 8051
ADC
USB 2.0

Highly Integrated USB MCUs

- High-speed 8051 core up to 48 MIPS
- Up to 64Kb Flash and 4K RAM for application code
- Complete 2.0 USB feature set
  - Internal precision oscillator generates USB clock without external crystal
  - Internal voltage regulator enables MCU to be bus powered without external components
  - Integrated USB transceiver

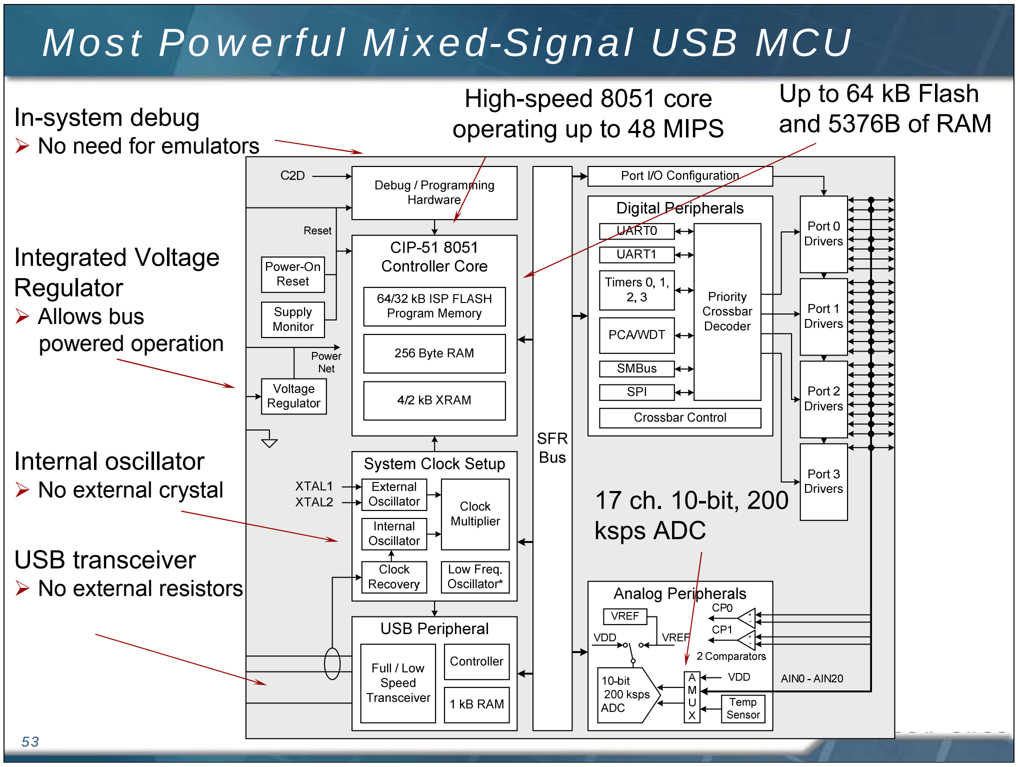
Best-in-Class analog features

- 10-bit, up to 500 ksps ADC
- On-board temperature sensor
- Precision voltage reference
- Comparators

Digital peripherals include a SMBus, two UARTs, and an enhanced SPI module. Timing functions can be achieved though the four general-purpose 16-bit timers or a 5-channel PCA. Five full ports offer 40 controllable I/O lines which are all 5V tolerant. The external memory interface provides access to data storage well beyond the on-chip XRAM or provides an easy interface into external peripherals. System reliability features include a watchdog timer, integrated power-on reset, a supply voltage monitor, and a missing clock detector.

The F340 truly provides system on chip integration eliminating the unnecessary cost and problems associated with adding external components.

The F340 and the other family members include everything needed to accomplish even the most challenging embedded projects that also require USB connectivity. However, having a powerful MCU is only the first step. A strong complement of hardware and software development tools is a must if the overall project is to succeed.



Most Powerful Mixed-Signal USB MCU

In-system debug
- No need for emulators

High-speed 8051 core operating up to 48 MIPS

Up to 64 kB Flash and 5376B of RAM

Integrated Voltage Regulator
- Allows bus powered operation

Internal oscillator
- No external crystal

USB transceiver
- No external resistors

17 ch. 10-bit, 200 ksps ADC

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Silicon labs controller solutions fall into two main classes: fixed function and fully-programmable mixed-signal MCUs with integrated USB controller.

Fixed function CP210x USB to UART bridge devices with royalty-free VCP drivers are the easiest and fastest way to add USB communication to your design – with no changes to the controller firmware or PC application.

Mixed-signal MCUs are fully-programmable, featuring ISP FLASH (great for USB bootloaders), a wide array of memory sizes, port I/O, and analog data converters.

All of these feature a calibrated oscillator, and so do not require an external crystal!

Single-Chip USB to UART Bridge

- CP210x family of devices
  - Fixed function USB to UART bridges provide the easiest method for upgrading legacy RS-232 systems with USB
  - Requires no firmware or driver development

- Most integrated USB to UART bridge solution
  - 1024 Bytes of EEPROM for customization
  - Integrated transceiver
  - Integrated precision clock
  - On-chip voltage regulator
  - 5x5 mm^2 QFN28 package

- Simplifies and enables legacy system upgrades
  - Full royalty-free driver support
  - No software design needed

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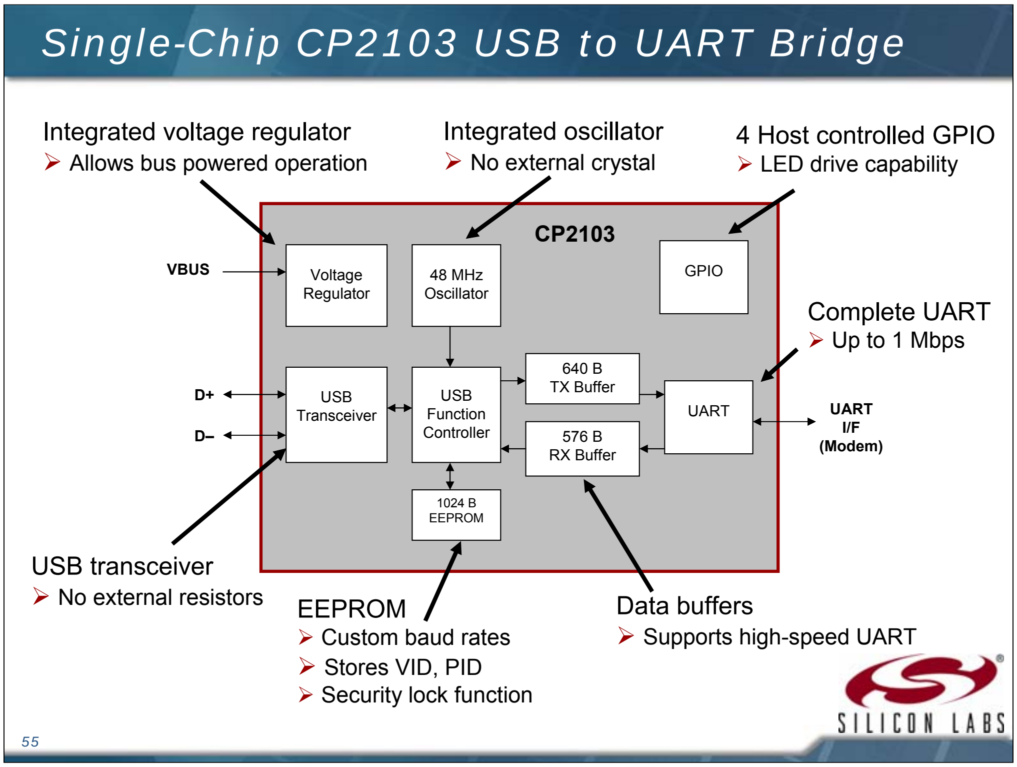

Single-Chip CP2103 USB to UART Bridge

Integrated voltage regulator
- ➢ Allows bus powered operation

Integrated oscillator
- ➢ No external crystal

4 Host controlled GPIO
- ➢ LED drive capability

Complete UART
- ➢ Up to 1 Mbps

USB transceiver
- ➢ No external resistors

EEPROM
- ➢ Custom baud rates
- ➢ Stores VID, PID
- ➢ Security lock function

Data buffers
- ➢ Supports high-speed UART

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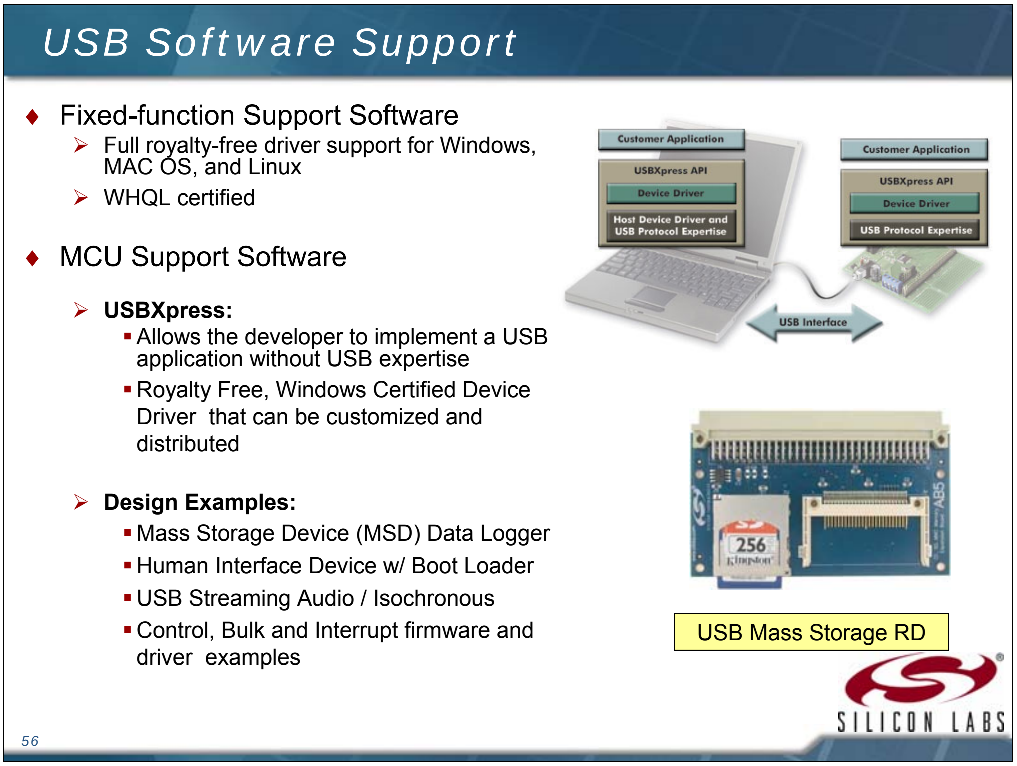


USB Software Support

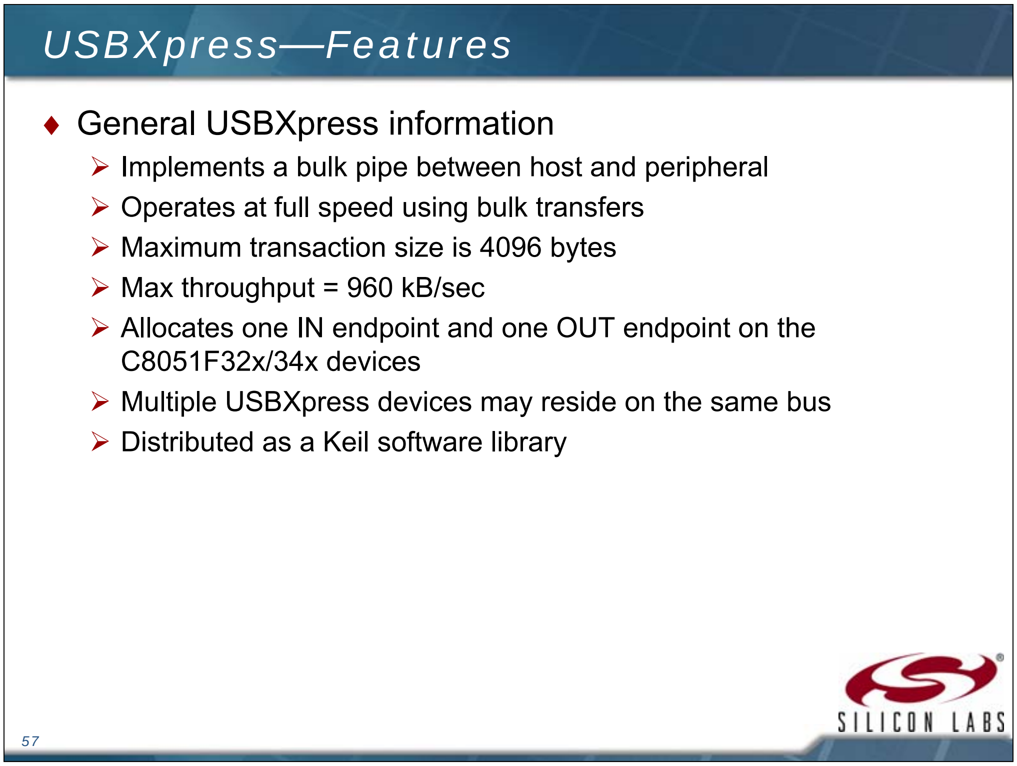
- Fixed-function Support Software
  - Full royalty-free driver support for Windows, MAC OS, and Linux
  - WHQL certified
- MCU Support Software
  - **USBXpress:**
    - Allows the developer to implement a USB application without USB expertise
    - Royalty Free, Windows Certified Device Driver that can be customized and distributed
  - **Design Examples:**
    - Mass Storage Device (MSD) Data Logger
    - Human Interface Device w/ Boot Loader
    - USB Streaming Audio / Isochronous
    - Control, Bulk and Interrupt firmware and driver examples

USB Mass Storage RD

Once the appropriate MCU or fixed-function solution is chosen, silicon labs also provides a wide range of software solutions to enable the designed to quickly enable the end application to communicate with the user's application on the PC.

If this is your first time designing with USB connectivity, you may be interested in some of the innovative reference design applications developed by silicon labs, such as the USB FM radio or mass storage example.

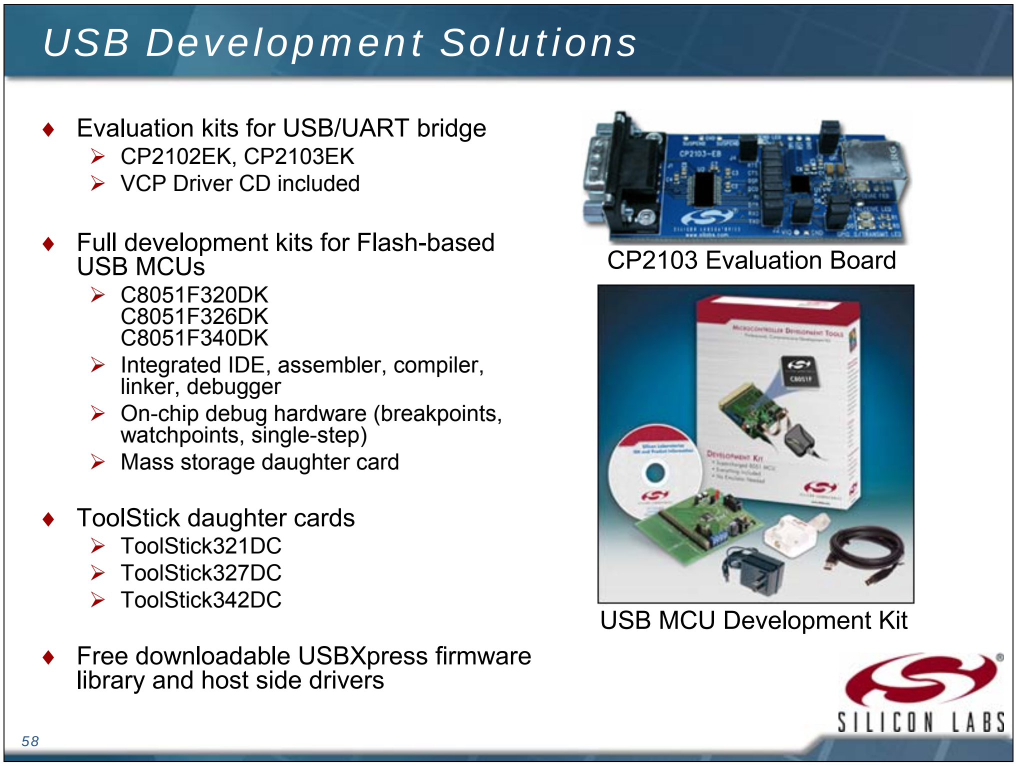
As with all silicon labs MCU products, comprehensive, low-cost development tools are available for easy evaluation and design.



USBXpress—Features

- General USBXpress information
  - Implements a bulk pipe between host and peripheral
  - Operates at full speed using bulk transfers
  - Maximum transaction size is 4096 bytes
  - Max throughput = 960 kB/sec
  - Allocates one IN endpoint and one OUT endpoint on the C8051F32x/34x devices
  - Multiple USBXpress devices may reside on the same bus
  - Distributed as a Keil software library

After the previous slides all of this makes sense right? The key to USBXpress is that there is no OS driver development and it is easy to use. There is an Application Programming Interface (API) that is defined that simplifies adding USB to a system and it runs on any of the Silicon Labs USB product portfolio.



USB Development Solutions

- Evaluation kits for USB/UART bridge
  - CP2102EK, CP2103EK
  - VCP Driver CD included
- Full development kits for Flash-based USB MCUs
  - C8051F320DK
C8051F326DK
C8051F340DK
  - Integrated IDE, assembler, compiler, linker, debugger
  - On-chip debug hardware (breakpoints, watchpoints, single-step)
  - Mass storage daughter card
- ToolStick daughter cards
  - ToolStick321DC
  - ToolStick327DC
  - ToolStick342DC
- Free downloadable USBXpress firmware library and host side drivers

CP2103 Evaluation Board

USB MCU Development Kit

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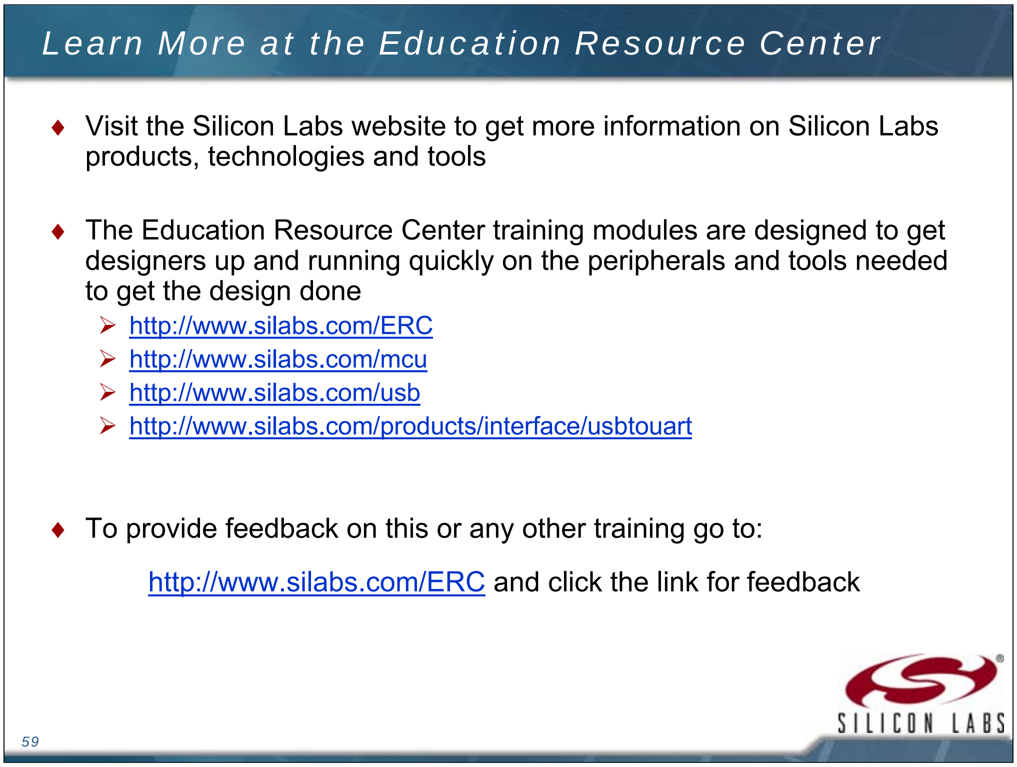
As with all silicon labs MCU products, comprehensive, low-cost development tools are available for easy evaluation and design.

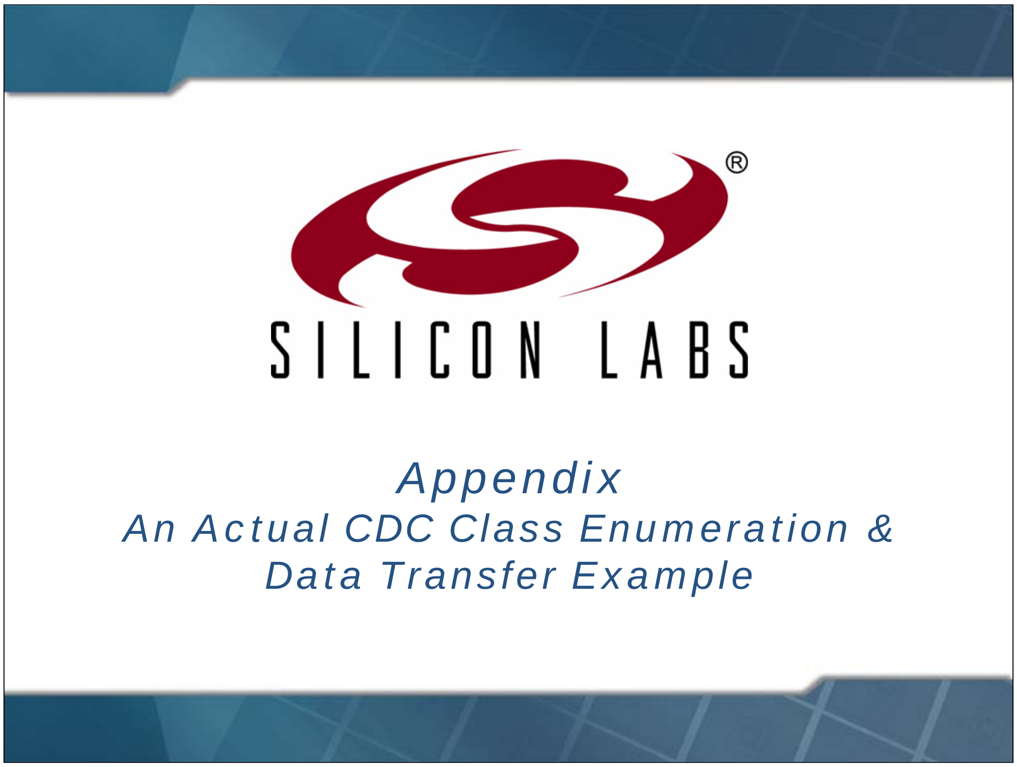


Learn More at the Education Resource Center

- Visit the Silicon Labs website to get more information on Silicon Labs products, technologies and tools
- The Education Resource Center training modules are designed to get designers up and running quickly on the peripherals and tools needed to get the design done
  - http://www.silabs.com/ERC
  - http://www.silabs.com/mcu
  - http://www.silabs.com/usb
  - http://www.silabs.com/products/interface/usbtouart
- To provide feedback on this or any other training go to:

  http://www.silabs.com/ERC and click the link for feedback

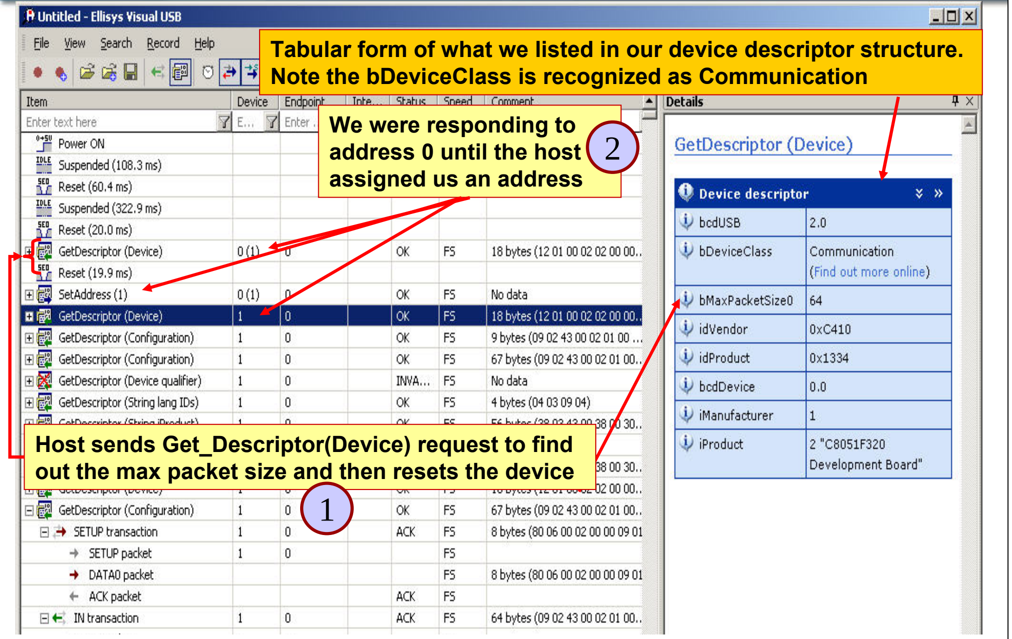
Visit the Silicon Labs Education Resource Center to learn more about the MCU products.



Appendix

An Actual CDC Class Enumeration & Data Transfer Example

Enumeration



Item	Device	Endpoint	Inte...	Status	Speed	Comment
Power ON						
Suspended (108.3 ms)						
Reset (60.4 ms)						
Suspended (322.9 ms)						
Reset (20.0 ms)						
GetDescriptor (Device)	0 (1)	0		OK	FS	18 bytes (12 01 00 02 02 00 00..
Reset (19.9 ms)						
SetAddress (1)	0 (1)	0		OK	FS	No data
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00..
GetDescriptor (Configuration)	1	0		OK	FS	9 bytes (09 02 43 00 02 01 00 ...
GetDescriptor (Configuration)	1	0		OK	FS	67 bytes (09 02 43 00 02 01 00..
GetDescriptor (Device qualifier)	1	0		INVA...	FS	No data
GetDescriptor (String lang IDs)	1	0		OK	FS	4 bytes (04 03 09 04)
GetDescriptor (String iProduct)	1	0		OK	FS	56 bytes (38 03 43 00 38 00 30..
						38 00 30..
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00..
GetDescriptor (Configuration)	1	0		OK	FS	67 bytes (09 02 43 00 02 01 00..
SETUP transaction	1	0		ACK	FS	8 bytes (80 06 00 02 00 00 09 01
SETUP packet	1	0			FS	
DATA0 packet					FS	8 bytes (80 06 00 02 00 00 09 01
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	64 bytes (09 02 43 00 02 01 00..

GetDescriptor (Device)

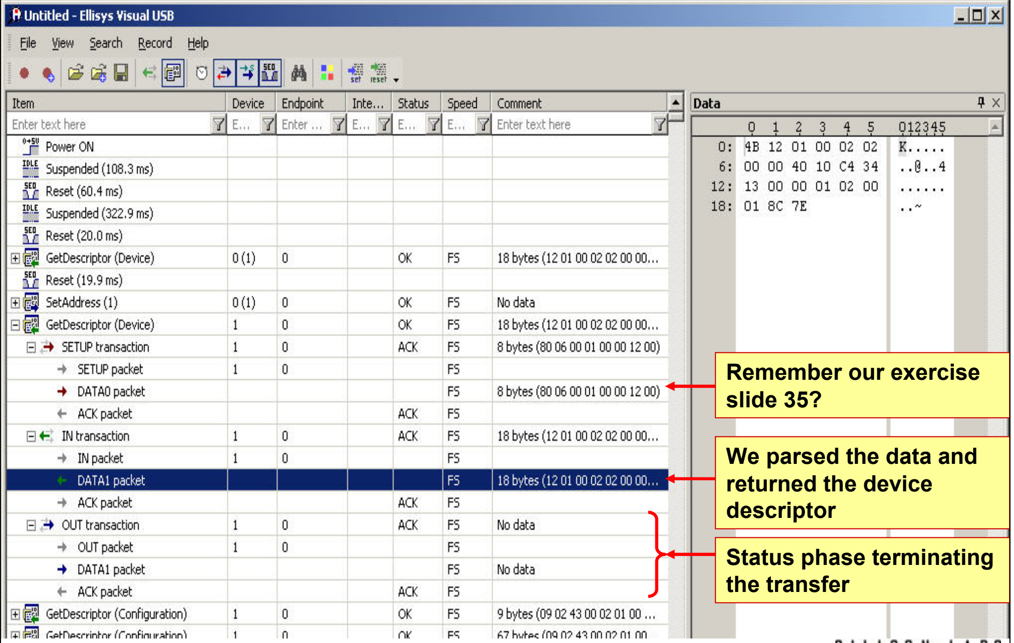
Device descriptor	
bcdUSB	2.0
bDeviceClass	Communication (Find out more online)
bMaxPacketSize0	64
idVendor	0xC410
idProduct	0x1334
bcdDevice	0.0
iManufacturer	1
iProduct	2 "C8051F320 Development Board"

Tabular form of what we listed in our device descriptor structure. Note the bDeviceClass is recognized as Communication

We were responding to address 0 until the host assigned us an address

Host sends Get_Descriptor(Device) request to find out the max packet size and then resets the device

Get_Descriptor (Device)



Item	Device	Endpoint	Inte…	Status	Speed	Comment
Enter text here	E…	Enter …	E…	E…	E…	Enter text here
Power ON						
Suspended (108.3 ms)						
Reset (60.4 ms)						
Suspended (322.9 ms)						
Reset (20.0 ms)						
GetDescriptor (Device)	0 (1)	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
Reset (19.9 ms)						
SetAddress (1)	0 (1)	0		OK	FS	No data
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
SETUP transaction	1	0		ACK	FS	8 bytes (80 06 00 01 00 00 12 00)
SETUP packet	1	0			FS	
DATA0 packet					FS	8 bytes (80 06 00 01 00 00 12 00)
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	18 bytes (12 01 00 02 02 00 00…
IN packet	1	0			FS	
DATA1 packet					FS	18 bytes (12 01 00 02 02 00 00…
ACK packet				ACK	FS	
OUT transaction	1	0		ACK	FS	No data
OUT packet	1	0			FS	
DATA1 packet					FS	No data
ACK packet				ACK	FS	
GetDescriptor (Configuration)	1	0		OK	FS	9 bytes (09 02 43 00 02 01 00 …
GetDescriptor (Configuration)	1	0		OK	FS	67 bytes (09 02 43 00 02 01 00

Data

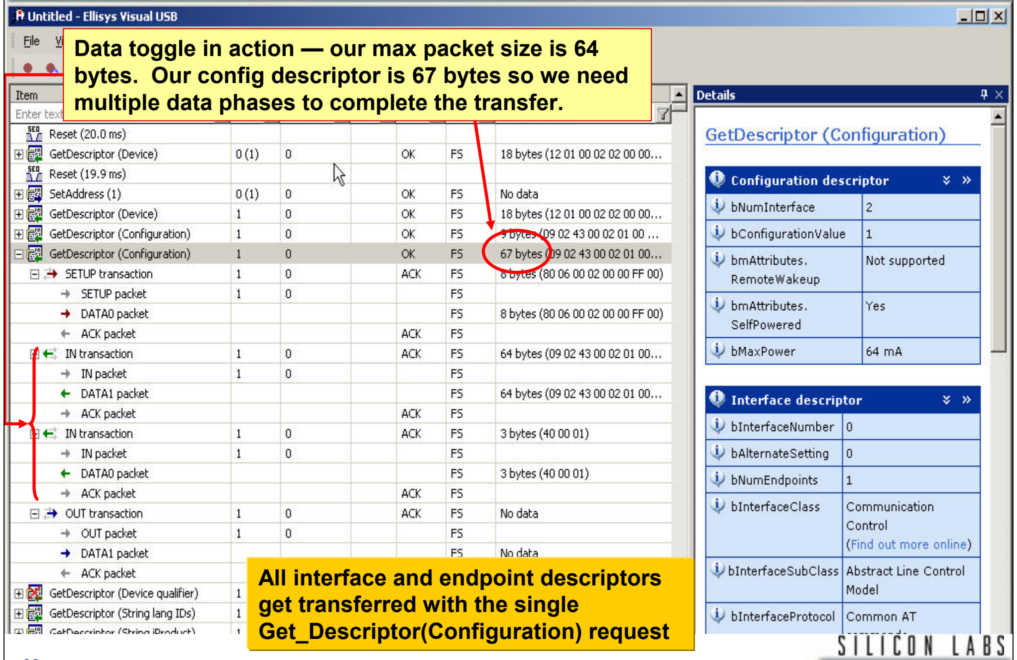
```
       0  1  2  3  4  5   012345
  0:  4B 12 01 00 02 02   K.....
  6:  00 00 40 10 C4 34   ..@..4
 12:  13 00 00 01 02 00   ......
 18:  01 8C 7E            ..~
```

Remember our exercise slide 35?

We parsed the data and returned the device descriptor

Status phase terminating the transfer

Passing the Config Descriptor (1 of 2)



Untitled - Ellisys Visual USB

Data toggle in action — our max packet size is 64 bytes. Our config descriptor is 67 bytes so we need multiple data phases to complete the transfer.

Item						
Enter text						
Reset (20.0 ms)						
GetDescriptor (Device)	0 (1)	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
Reset (19.9 ms)						
SetAddress (1)	0 (1)	0		OK	FS	No data
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
GetDescriptor (Configuration)	1	0		OK	FS	9 bytes (09 02 43 00 02 01 00 …
GetDescriptor (Configuration)	1	0		OK	FS	67 bytes (09 02 43 00 02 01 00…
SETUP transaction	1	0		ACK	FS	8 bytes (80 06 00 02 00 00 FF 00)
SETUP packet	1	0			FS	
DATA0 packet					FS	8 bytes (80 06 00 02 00 00 FF 00)
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	64 bytes (09 02 43 00 02 01 00…
IN packet	1	0			FS	
DATA1 packet					FS	64 bytes (09 02 43 00 02 01 00…
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	3 bytes (40 00 01)
IN packet	1	0			FS	
DATA0 packet					FS	3 bytes (40 00 01)
ACK packet				ACK	FS	
OUT transaction	1	0		ACK	FS	No data
OUT packet	1	0			FS	
DATA1 packet					FS	No data
ACK packet						
GetDescriptor (Device qualifier)	1					
GetDescriptor (String lang IDs)	1					
GetDescriptor (String iProduct)	1					

All interface and endpoint descriptors get transferred with the single Get_Descriptor(Configuration) request

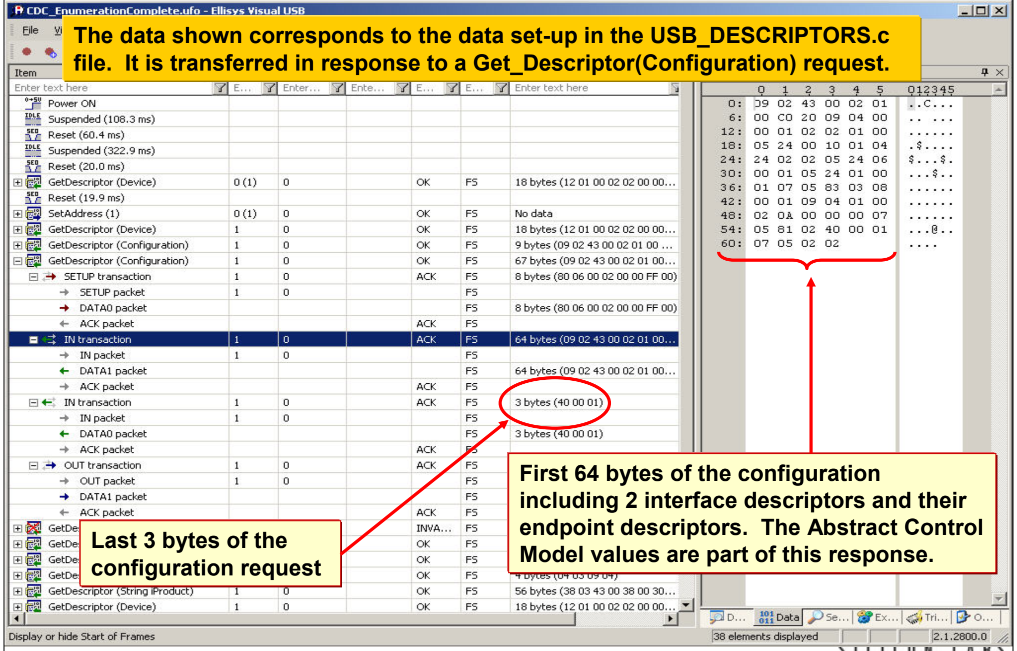
Details

GetDescriptor (Configuration)

Configuration descriptor	
bNumInterface	2
bConfigurationValue	1
bmAttributes.RemoteWakeup	Not supported
bmAttributes.SelfPowered	Yes
bMaxPower	64 mA

Interface descriptor	
bInterfaceNumber	0
bAlternateSetting	0
bNumEndpoints	1
bInterfaceClass	Communication Control (Find out more online)
bInterfaceSubClass	Abstract Line Control Model
bInterfaceProtocol	Common AT commands

Passing the Config Descriptor (2 of 2)



The data shown corresponds to the data set-up in the USB_DESCRIPTORS.c file. It is transferred in response to a Get_Descriptor(Configuration) request.

Enter text here	E…	Enter…	Ente…	E…	E…	Enter text here
Power ON						
Suspended (108.3 ms)						
Reset (60.4 ms)						
Suspended (322.9 ms)						
Reset (20.0 ms)						
GetDescriptor (Device)	0 (1)	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
Reset (19.9 ms)						
SetAddress (1)	0 (1)	0		OK	FS	No data
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
GetDescriptor (Configuration)	1	0		OK	FS	9 bytes (09 02 43 00 02 01 00 …
GetDescriptor (Configuration)	1	0		OK	FS	67 bytes (09 02 43 00 02 01 00…
SETUP transaction	1	0		ACK	FS	8 bytes (80 06 00 02 00 00 FF 00)
SETUP packet	1	0			FS	
DATA0 packet					FS	8 bytes (80 06 00 02 00 00 FF 00)
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	64 bytes (09 02 43 00 02 01 00…
IN packet	1	0			FS	
DATA1 packet					FS	64 bytes (09 02 43 00 02 01 00…
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	3 bytes (40 00 01)
IN packet	1	0			FS	
DATA0 packet					FS	3 bytes (40 00 01)
ACK packet				ACK	FS	
OUT transaction	1	0		ACK	FS	
OUT packet	1	0			FS	
DATA1 packet					FS	
ACK packet				ACK	FS	
GetDe				INVA…	FS	
GetDe				OK	FS	
GetDe				OK	FS	
GetDe				OK	FS	4 bytes (04 03 09 04)
GetDescriptor (String iProduct)	1	0		OK	FS	56 bytes (38 03 43 00 38 00 30…
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00…

Display or hide Start of Frames

```
      0  1  2  3  4  5   012345
 0:  09 02 43 00 02 01   ..C...
 6:  00 C0 20 09 04 00   .. ...
12:  00 01 02 02 01 00   ......
18:  05 24 00 10 01 04   .$....
24:  24 02 02 05 24 06   $...$.
30:  00 01 05 24 01 00   ...$..
36:  01 07 05 83 03 08   ......
42:  00 01 09 04 01 00   ......
48:  02 0A 00 00 00 07   ......
54:  05 81 02 40 00 01   ...@..
60:  07 05 02 02         ....
```

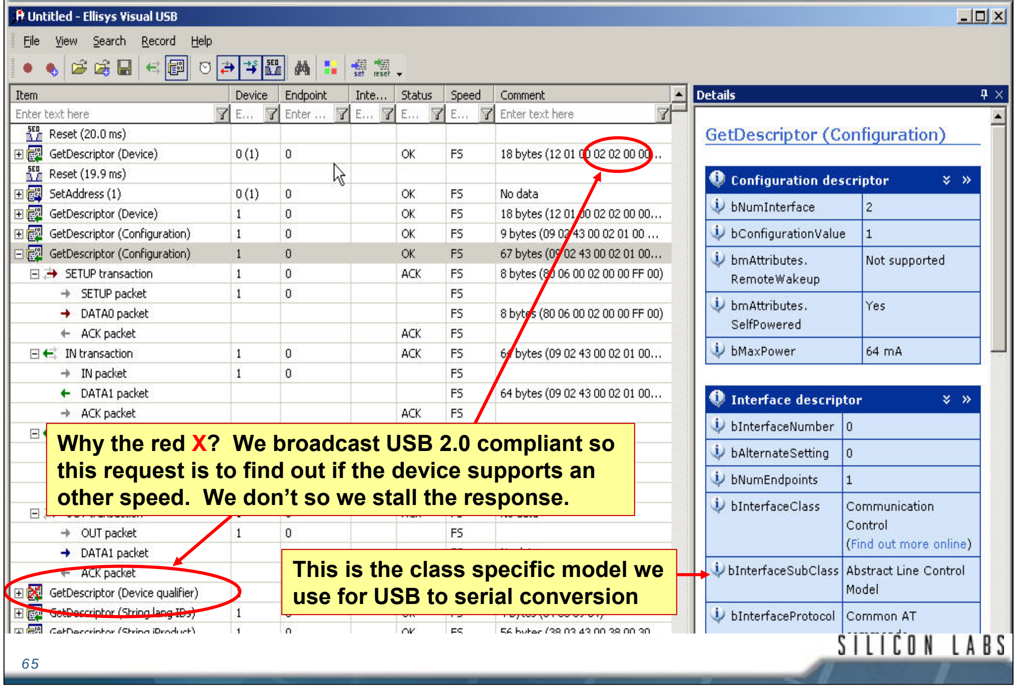
38 elements displayed

2.1.2800.0

Last 3 bytes of the configuration request

First 64 bytes of the configuration including 2 interface descriptors and their endpoint descriptors. The Abstract Control Model values are part of this response.

More Enumeration



Item	Device	Endpoint	Inte…	Status	Speed	Comment
Enter text here	E…	Enter …	E…	E…	E…	Enter text here
Reset (20.0 ms)						
GetDescriptor (Device)	0 (1)	0		OK	FS	18 bytes (12 01 00 02 02 00 00..
Reset (19.9 ms)						
SetAddress (1)	0 (1)	0		OK	FS	No data
GetDescriptor (Device)	1	0		OK	FS	18 bytes (12 01 00 02 02 00 00…
GetDescriptor (Configuration)	1	0		OK	FS	9 bytes (09 02 43 00 02 01 00 …
GetDescriptor (Configuration)	1	0		OK	FS	67 bytes (09 02 43 00 02 01 00…
SETUP transaction	1	0		ACK	FS	8 bytes (80 06 00 02 00 00 FF 00)
SETUP packet	1	0			FS	
DATA0 packet					FS	8 bytes (80 06 00 02 00 00 FF 00)
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	64 bytes (09 02 43 00 02 01 00…
IN packet	1	0			FS	
DATA1 packet					FS	64 bytes (09 02 43 00 02 01 00…
ACK packet				ACK	FS	
OUT packet	1	0			FS	
DATA1 packet						
ACK packet						
GetDescriptor (Device qualifier)						
GetDescriptor (String lang IDs)	1					
GetDescriptor (String iProduct)	1	0		OK	FS	56 bytes (38 03 43 00 38 00 30

GetDescriptor (Configuration)

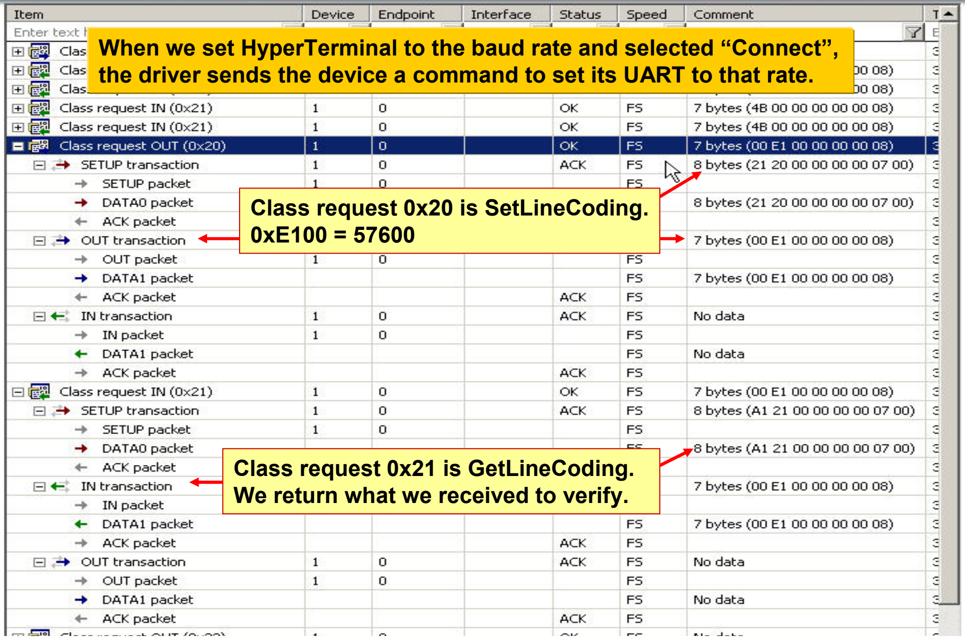
Configuration descriptor	
bNumInterface	2
bConfigurationValue	1
bmAttributes. RemoteWakeup	Not supported
bmAttributes. SelfPowered	Yes
bMaxPower	64 mA

Interface descriptor	
bInterfaceNumber	0
bAlternateSetting	0
bNumEndpoints	1
bInterfaceClass	Communication Control (Find out more online)
bInterfaceSubClass	Abstract Line Control Model
bInterfaceProtocol	Common AT

Why the red X? We broadcast USB 2.0 compliant so this request is to find out if the device supports an other speed. We don't so we stall the response.

This is the class specific model we use for USB to serial conversion

USB Setting the Baud Rate



When we set HyperTerminal to the baud rate and selected “Connect”, the driver sends the device a command to set its UART to that rate.

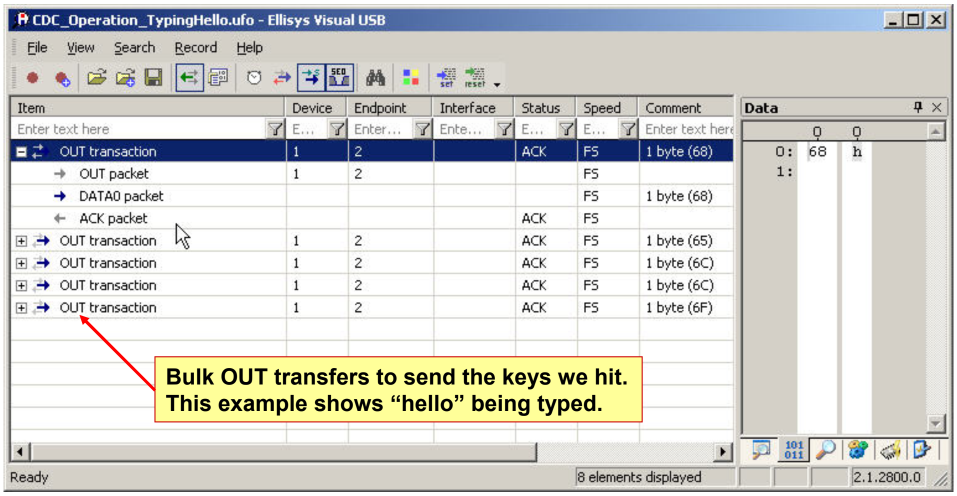
Class request 0x20 is SetLineCoding. 0xE100 = 57600

Class request 0x21 is GetLineCoding. We return what we received to verify.

Item	Device	Endpoint	Interface	Status	Speed	Comment
Clas						
Clas						00 08)
Clas						00 08)
Class request IN (0x21)	1	0		OK	FS	7 bytes (4B 00 00 00 00 00 08)
Class request IN (0x21)	1	0		OK	FS	7 bytes (4B 00 00 00 00 00 08)
Class request OUT (0x20)	1	0		OK	FS	7 bytes (00 E1 00 00 00 00 08)
SETUP transaction	1	0		ACK	FS	8 bytes (21 20 00 00 00 00 07 00)
SETUP packet	1	0			FS	
DATA0 packet						8 bytes (21 20 00 00 00 00 07 00)
ACK packet						
OUT transaction						7 bytes (00 E1 00 00 00 00 08)
OUT packet	1	0			FS	
DATA1 packet					FS	7 bytes (00 E1 00 00 00 00 08)
ACK packet				ACK	FS	
IN transaction	1	0		ACK	FS	No data
IN packet	1	0			FS	
DATA1 packet					FS	No data
ACK packet				ACK	FS	
Class request IN (0x21)	1	0		OK	FS	7 bytes (00 E1 00 00 00 00 08)
SETUP transaction	1	0		ACK	FS	8 bytes (A1 21 00 00 00 00 07 00)
SETUP packet	1	0			FS	
DATA0 packet						8 bytes (A1 21 00 00 00 00 07 00)
ACK packet						
IN transaction						7 bytes (00 E1 00 00 00 00 08)
IN packet						
DATA1 packet					FS	7 bytes (00 E1 00 00 00 00 08)
ACK packet				ACK	FS	
OUT transaction	1	0		ACK	FS	No data
OUT packet	1	0			FS	
DATA1 packet					FS	No data
ACK packet				ACK	FS	

We Use Our Bulk Endpoints

Now that the communications link is established we are ready to transfer data. We hit keys while the HyperTerminal window is active and the host is using the Bulk transfers we set up during enumeration to send data.



Item	Device	Endpoint	Interface	Status	Speed	Comment
Enter text here	E…	Enter…	Ente…	E…	E…	Enter text here
⊟ OUT transaction	1	2		ACK	FS	1 byte (68)
OUT packet	1	2			FS	
DATA0 packet					FS	1 byte (68)
ACK packet				ACK	FS	
⊞ OUT transaction	1	2		ACK	FS	1 byte (65)
⊞ OUT transaction	1	2		ACK	FS	1 byte (6C)
⊞ OUT transaction	1	2		ACK	FS	1 byte (6C)
⊞ OUT transaction	1	2		ACK	FS	1 byte (6F)

```
     0    0
0:  68    h
1:
```

Ready | 8 elements displayed | 2.1.2800.0

Bulk OUT transfers to send the keys we hit. This example shows “hello” being typed.

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