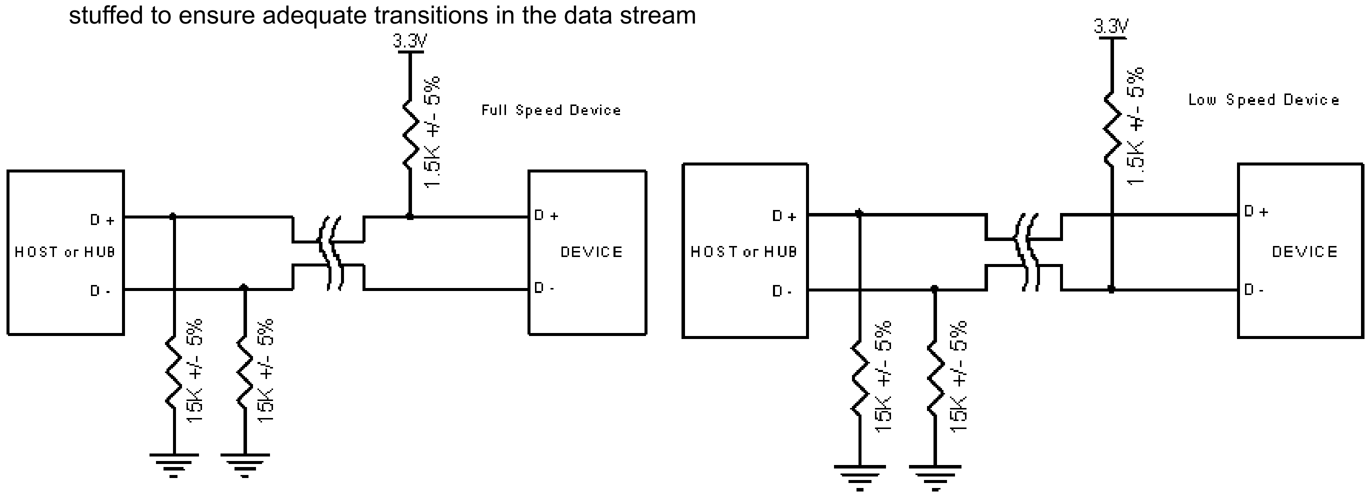
Physical layer

USB uses a differential transmission pair for data. This is encoded using NRZI and is bit stuffed to ensure adequate transitions in the data stream



The states: LOW speed: J= D+: 0, D:- 1, K= D+ :1, D- :0
HIGH/FULL speed: J= D+:1, D-:0, K= D+:0, D-:1
SE0 = D+:0, D-:0,
SE1 = D+:1, D-:1

The protocol

Common USB Packet Fields

PID stands for Packet ID. This field is used to identify the type of packet that is being sent.First 4 bits - essential.Last 4 - the same, for error correcting.

Token	OUT Token	0001	
	IN Token	1001	
	SOF Token	0101	Start the frame
	SETUP Token	1101	
Data	DATA0	0011	
	DATA1	1011	
	DATA2	0111	
	MDATA	1111	
Handshake	ACK Handshake	0010	
	NAK Handshake	1010	
	STALL Handshake	1110	
	NYET (No Response Yet)	0110	
Special	PREamble	1100	
	ERR	1100	
	Split	1000	
	Ping	0100	

SYNC .The sync field is 8 bits long at low and full speed or
32 bits long for high speed and is used to synchronise the clock of the receiver with that of the transmitter.The format is: KJKJKJKK

ADDR The address field specifies which device the packet is designated for.
Being 7 bits in length allows for 127 devices to be supported.

ENDP The endpoint field is made up of 4 bits, allowing 16 possible endpoints.

CRC Cyclic Redundancy Checks are performed on the data within the packet payload.

EOP End of packet.

USB Packet Types

1.Token packets:

In -A host Informs the USB device "I want to read".
Out - A host Informs the USB device "I want to write".
Setup - For designation of the begin control transfers.

Sync	**PID**	**ADDR**	**ENDP**	**CRC5**	**EOP**

2.Data packets

Maximum payload:
low speed - 8bytes,
full speed - 1023 bytes
high speed - 1024 bytes

SYNC	PID	DATA	CRC16	EOP

3.Handshake packets

ACK - a packet has been received successfully
NAK - a device can`t send/receive data temporary.
It also used in interrupt transaction to inform the host "there is no data to send"
STALL- the device finds in a state that is requires interventionfrom a host

SYNC	PID	EOP

4.Start of frame packet

Sends by a host :
full speed - 1±0.5mS
. high speed: 125uS±0.0625uS

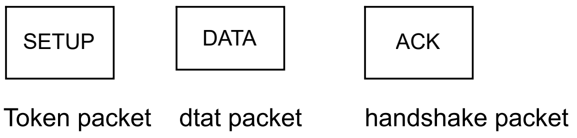
sync	PID	Frame Number	CRC5	EOP

Endpoints

Each device must have the endpoint 0: IN and OUT. Endpoint /transform may be the following types:

✓ ***1.Control transfers***

Set up an USB device with "standard device requests" functions, also in enumeration phase.The transfer consists of three stages: SETUP, DATA, HANDSHAKE



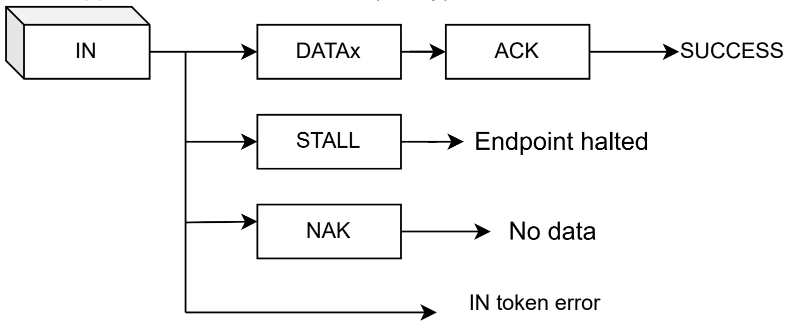
✓ ***2. Interrupt transfers***

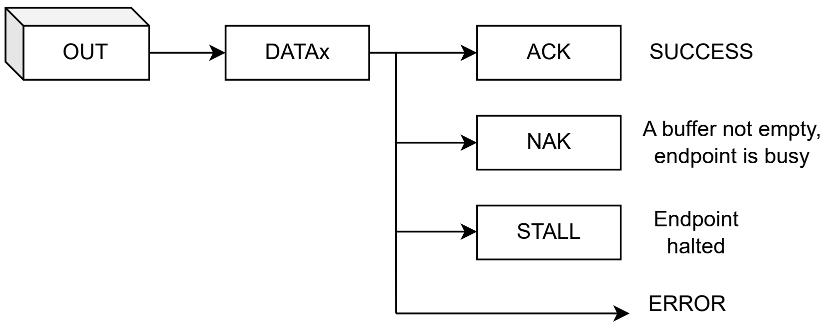
-Guaranted latency,
-Stream pipe- unidirectional (*Only one-way data direction*),
-Error detection and period retry

NOTE: *in all the types of transfers the* ***Host is always the initiator*** *of a transaction, it always begin.Interrupt NOT means that a device interrupts a host. The device MUST wait until enumeration has finished until eny Tx/Rx actions - to avoid errors.*
Payload (max): low sp-8bytes, full sp.-64bytes, high sp.1024bytes.
The bInterval may be 1-255

IN:The host periodically pooling to a device with "IN" token.The device is waiting for this token. When a device has a data for the host, it send the data to the host and waiting for ACK/NACK host`s response.The period of pooling described in the endpoint descriptor, **bInterva**

OUT:.The host sends OUT token with followed data.When a device has not empty buffer or busy now - it sends NAK.When there a data error happened - STALL returned (rarely)

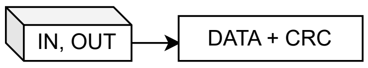




CONCLUSIONS: interrupt transfers used for time sensetive precise transactions: the host sending the "IN" tokens-asks every bInterval (1-250mS) time, so a packet sends each bInterval exactly on-time. The maximum packet size is 64bytes.A *Packet size is FIXED* and described in the endpoint descriptor - wMaxPacketSize?**Every interrupt transaction** must use **this exact size or smaller**. .Devivery guaranteed because of ACK.Interrupt used for small periodic time sensetive data transmissions.Avoid large data - it can leads to blocking other devices on USB bus

✓ ***3.Isochronous transfers***

- Guaranted access to USB bandwith
- Stream pipe-unidirectional
-Error detection via CRC? but no retry guarantee to delivery
-No ACK, NAK, STALL handshake - only data and CRC

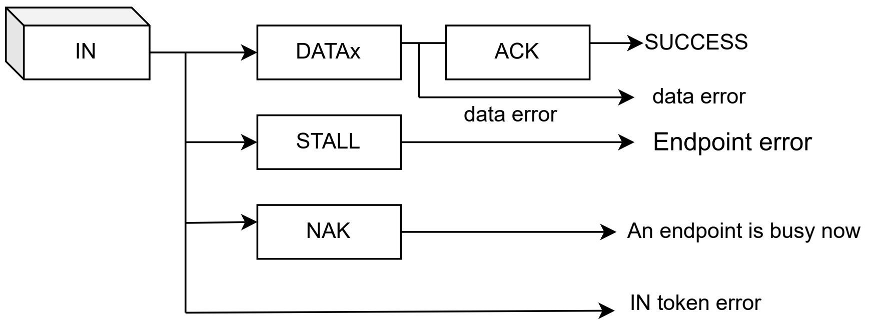


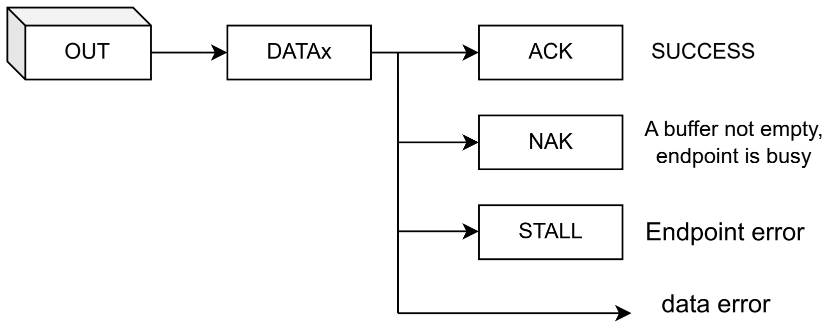
payload: hifg sp-1204 Bytes, full sp.- 1023 Bytes
Used for audio/video stream, or application where allows data loose
bInterval must be 1 for FS and 1-16 for HS
NOTE:*The device MUST wait until enumeration has finished until eny Tx/Rx actions - to avoid errors.*

✓ **4.Bulk transfers**

- Used to transfer large bursty data.
- Error detection via CRC, with guarantee of delivery.
- No guarantee of bandwidth or minimum latency.
- Stream Pipe - Unidirectional
- Full & high speed modes only

The maximum packet size : Full Speed - 8,16,32,64Bytes,
High Speed - 512Bytes
NOTE: the data size can be less that maximun defined amount, even no data (zero)

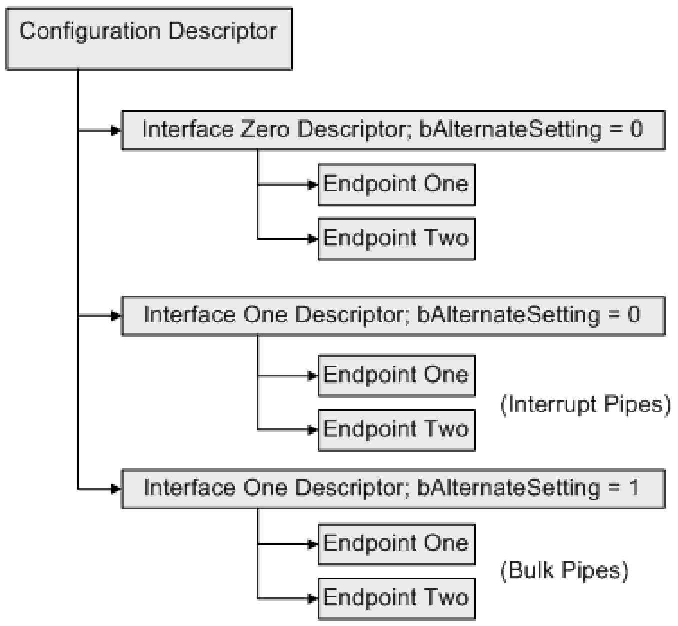




CONCLUSIONS: bulk transfers used for not time sensetive transactions: the host sending the "IN" when has a scheduled time, so there may be random delays. The maximum packet size is 64bytes. A *Packet size is FIXED* and described in the endpoint descriptor - wMaxPacketSize?**Every interrupt transaction** must use **this exact size or smaller**.Devivery guaranteed because of ACK.Bulk used for large data transmission.

USB descriptors

A USB device can have only one device descriptor


Configuration Descriptor
Interface Zero Descriptor; bAlternateSetting = 0
Endpoint One
Endpoint Two
Interface One Descriptor; bAlternateSetting = 0
Endpoint One
Endpoint Two
(Interrupt Pipes)
Interface One Descriptor; bAlternateSetting = 1
Endpoint One
Endpoint Two
(Bulk Pipes)

<u>DEVICE DESCRIPTOR</u>

One USB device can have only one device descriptor

bLength = 0x12 ,	// Size of this descriptor (always 18 bytes).
bDescriptorType = 0x01	// Tells host “this is a device descriptor.”
bcdUSB = 0x0200	// The USB specification version device complies with.
bDeviceClass = 0x00	//0 means “I have multiple interfaces; check them individually.” But when not 0, it can be:0x02 = CDC, 0x03 = HIDm 0x08 = Mass Storage
bDeviceSubClass = 0x00	// Class-specific. Here unused → 0.
bDeviceProtocol = 0x00	// Protocol-specific. Here unused → 0.
bMaxPacketSize0 = 0x40	//Maximum packet size on **endpoint 0** (control).

<u>Configuration descriptor</u>

Total power need, bus powered or selfpowered, how many interfaces belongs to this config, total size of all descriptors in this config

bLength = 09	//Size of this descriptor in bytes.
bDescriptorType = 02	//Descriptor type = **Configuration** descriptor.
wTotalLength = 0x0020	//Total length of entire configuration, including: *Configuration descriptor (9 bytes) *Interface descriptor *Endpoint descriptors *Class descriptors (if any)

bNumInterfaces = 01 //Number of **Interfaces** inside this configuration

bConfigurationValue = 01 //The ID of this configuration.Passed later to SET_CONFIGURATION(1)

iConfiguration = 00 //Index of a **string descriptor** describing this configuration., 0-no string

bmAttributes = 0x80 //

Bit	Meaning
7	Must be 1
6	Self-powered (1 = yes, 0 = bus-powered)
5	Remote wakeup capability
4–0	Reserved

bMaxPower = 0x32 //(50 × 2mA = 100mA)

Interface descriptor

It is a "function" inside the device, for example: mouse, keyboard, audio...
-class(HID, CDC, Audio...)
-Subclass/Protocol
-How many endpoints belong to this function

bLength = 09 //A Size of this descriptor in bytes (always 9 for an interface descriptor)

bDescriptorType = 04 //Descriptor type 4 = Interface Descriptor

bInterfaceNumber = 00 //Index of this interface inside the configuration. If your device has multiple interfaces (CDC, HID, Audio) they get numbers 0, 1, 2….

bAlternateSetting = 00 //Allows different settings for the same interface. Usually 0 unless
// using ISO endpoints with different bandwidths

bNumEndpoints = 01 //Number of endpointsDoes NOT count endpoint 0.Here: 1 endpoint
//(usually interrupt IN for keyboard).

bInterfaceClass = 03 //USB Class Code. 0x03 = HID (Human Interface Device).

bInterfaceSubClass = 01 //HID subclass.0x01 = Boot Interface (keyboard or mouse that BIOS can use).

bInterfaceProtocol = 01 //Protocol ID. 0x01 = Keyboard (0x02 would be mouse)

iInterface = 00 //Index of a string descriptor describing this interface. 0 → no string.

Endpoint descriptor

Description of data-pipe inside an interface.
-Direction (IN/OUT),
-Transfer type (Interrupt, isocronous, bulk , control)
-Maximum packet size
-pooling interval (for interrpt/isocronous transfers)

bLength = 0x09 //Length of this descriptor (always 9 bytes)

bDescriptorType = 0x05 //Value 5 means: Endpoint Descriptor

bEndpointAddress = 0x81

//Binary: 1000 0001
Bit 7 = direction
1 = IN (device → host)
0 = OUT (host → device)
Bits 0-3 = endpoint number → Endpoint 1.

bmAttributes = 0x02 //Bits meaning:
Bits 0–1 = transfer type
00 = Control
01 = Isochronous
10 = Bulk
11 = Interrupt
Bits 2–7 = reserved

wMaxPacketSize = 0x0040 //Maximum size of one DATA packet.At Full Speed:Bulk/Interrupt max = 64 bytes

bInterval = 0x00 //Used only by Interrupt and Isochronous endpoints.For Bulk endpoints: ignored.

*

String descriptor

Format breakdown

- ***bLength***: A 1-byte field indicating the total length of the descriptor in bytes.
- ***bDescriptorType***: A 1-byte field with a value of `0x03` to identify it as a string descriptor.
- ***bString***: A variable-length field containing the Unicode string data. Each character in the string uses two bytes (UTF-16LE), and a `0x00` byte is added after each standard ASCII character to convert it to UTF-16LE.

Standard USB device requests

1. ***GET_STATUS*** (0x00) A host asks the device :
   -are you self powered or bus powered?
   -are you remote wake-up enable?
   -For an n endpoint: is it halted?

2. ***CLEAR_FEATURE*** (0x01)
Tells device to disable some feature
most commonly used to clear "ENDPOINT_HALT"
This re-enable an endpoint

3. ***SET_FEATURE*** (03h)
opposite to CLEAR_FEATURE.Most commonly used for:
-SLALL an endpoint,
-enable remote wake-up

4.***SET_ADDRESS*** (05h) A host assigns to a device a unique address (1-127).Mandatory for all the USB devices.

5.***GET_DESCRIPTOR*** (06h) A host requests one of three descriptors:
-Device
-Interface
-Configuration
-Endpoint
-String
-HID or class specific

6. ***SET_DESCRIPTOR*** (07h) most never used

7. ***GET_CONFIGURATION*** (08h)
A host asks a device: which configuration is active now?

8. ***SET_CONFIGURATION*** (09h) A host select, which configuration on a device should
It activates all the interfaces and endpoints in sel

9.***GET_INTERFACE*** (0Ah) For devices with alternate interfaces.A host asks, which interf

10. ***SET_INTERFACE*** (0Bh) Select an alternate settings.Used for example in USB Audio
packet size or bandwidth.

11. ***SYNC_FRAME*** (0x0C) Used only in isocronous endpoints.A host asks - what is your curr

Enumeration

The process identical for all USB devices, no matter the transform type is.Enumeration used the Endpoint 0 and Address 0

1) The device plug-in.The host resets the device, a device enty into default state, address=0
2) A host sends GET_DESCRIPTOR (Device, it is recommended first 8 bytes but not mandatory 8), a device responds with 8 bytes of the Device Descriptor.Important fields: -USB version, -PID, -VID, -DeviceClass, -number of configurations, maximal endpoint 0 packet size
3) A host reset the device

4)A host sends the request SET_ADDRESS in range 1-127, tthe device switches in addressed mode

5) A host sends GET_DESCRIPTOR (Device , full) request.Now a host asks for 18 byte Device Descriptor Used to determine:

- -Which driver category (CDC,HID...)
- -Whether the device is composite:
- -How many configuration exists

6) A host sends the request GET_DESCRIPTOR (Configuration). This descriptor includes whole hierarchy:

```
Configuration descriptor:
      Interface0:
            Endpoint 1
            Endpoint 1
            (maybe class specific)
      Interface 1:
            Endpoint 2
            Endpoint 2
```

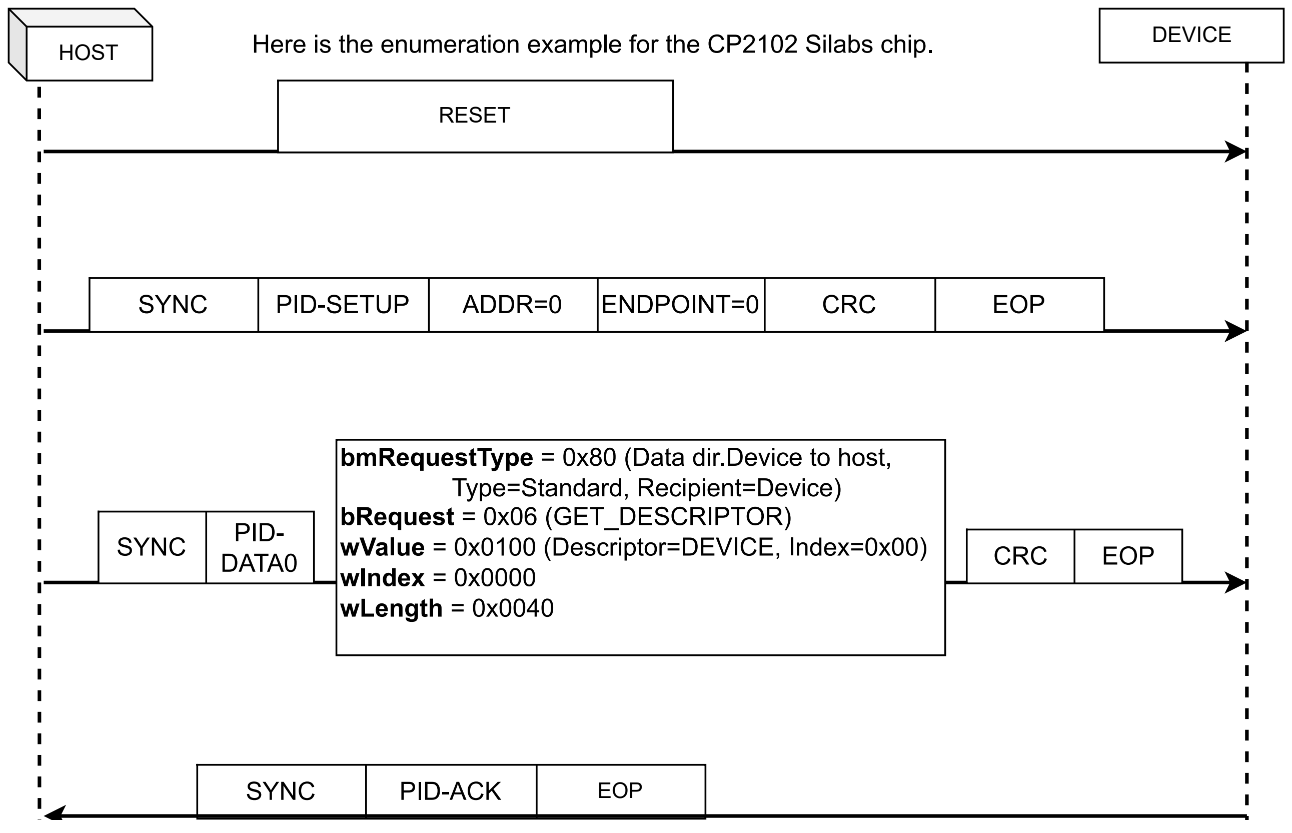
It tells to a host - how many interfaces , type of each interface, (HID, CDC, e.t.c.), what endpoints exists, their directon and transfer type, polling interval, maximal packet size.

7) Host sends the request SET_CONFIGURATION. A host selects a configuration number (usually 1).The devices switched to the Configured state.Now:

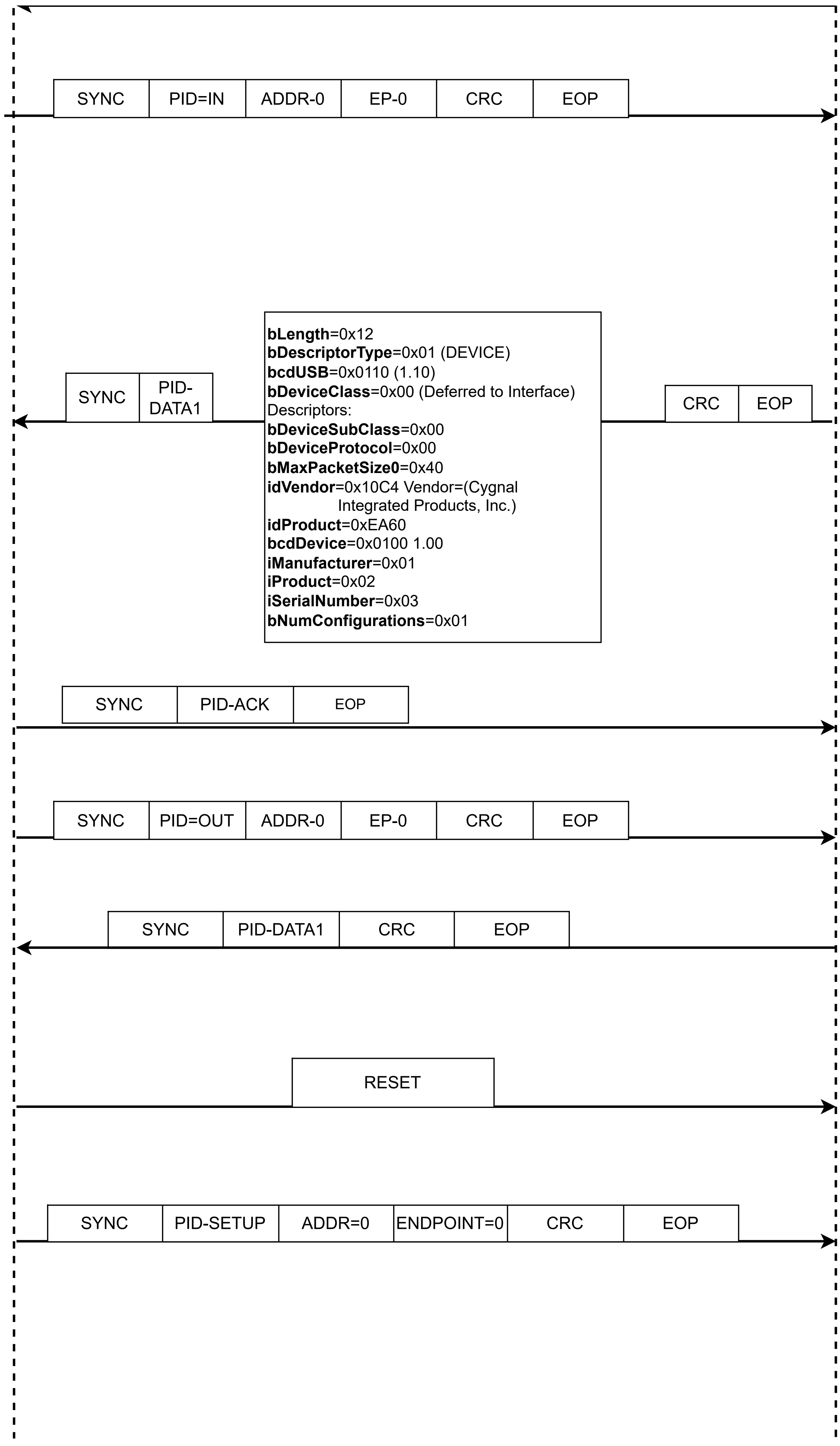
- -All endpoints are in active state
- -Drivers can start usig them
- -The device is ready for normal operatoin

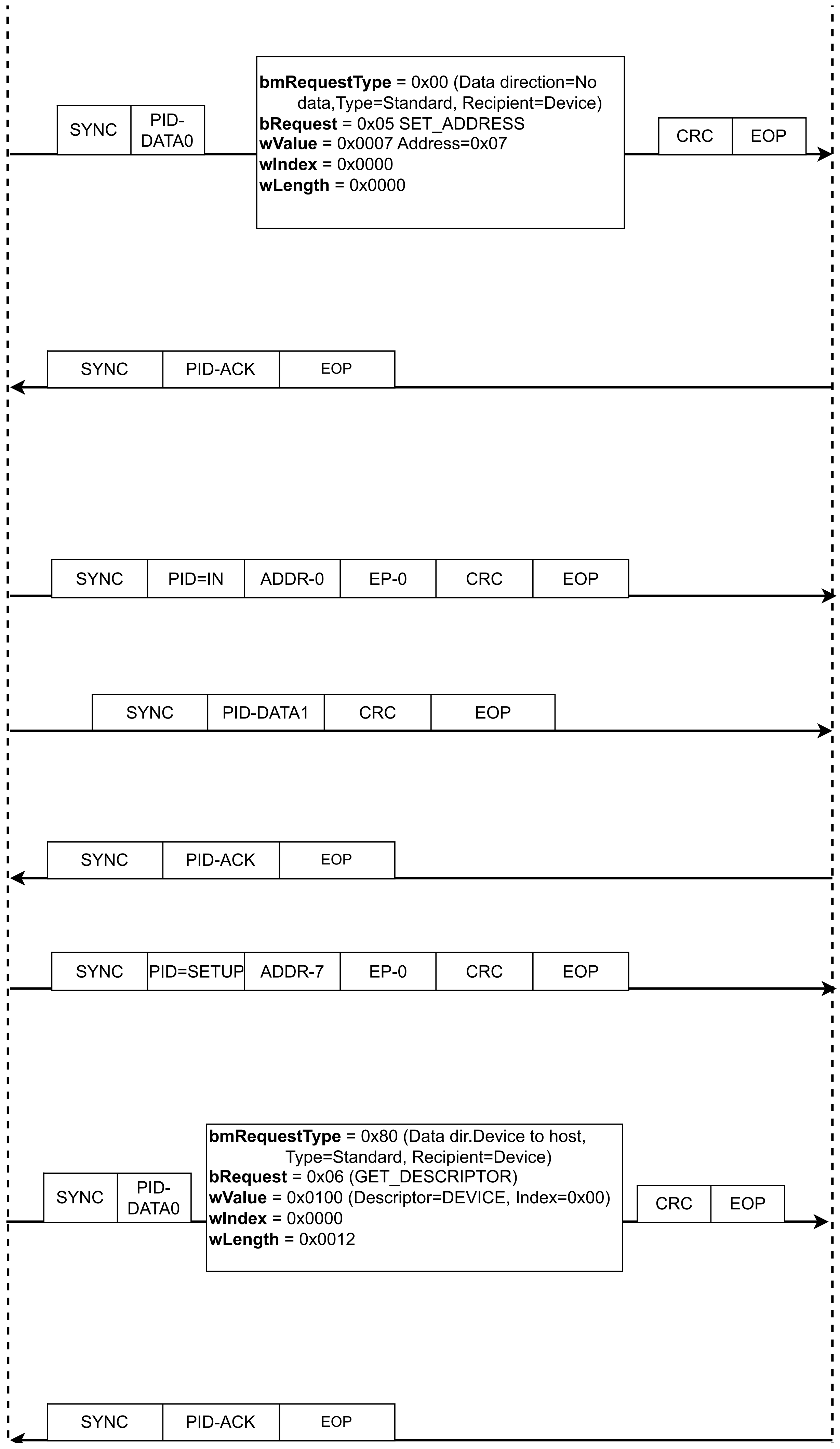
Enumeration example

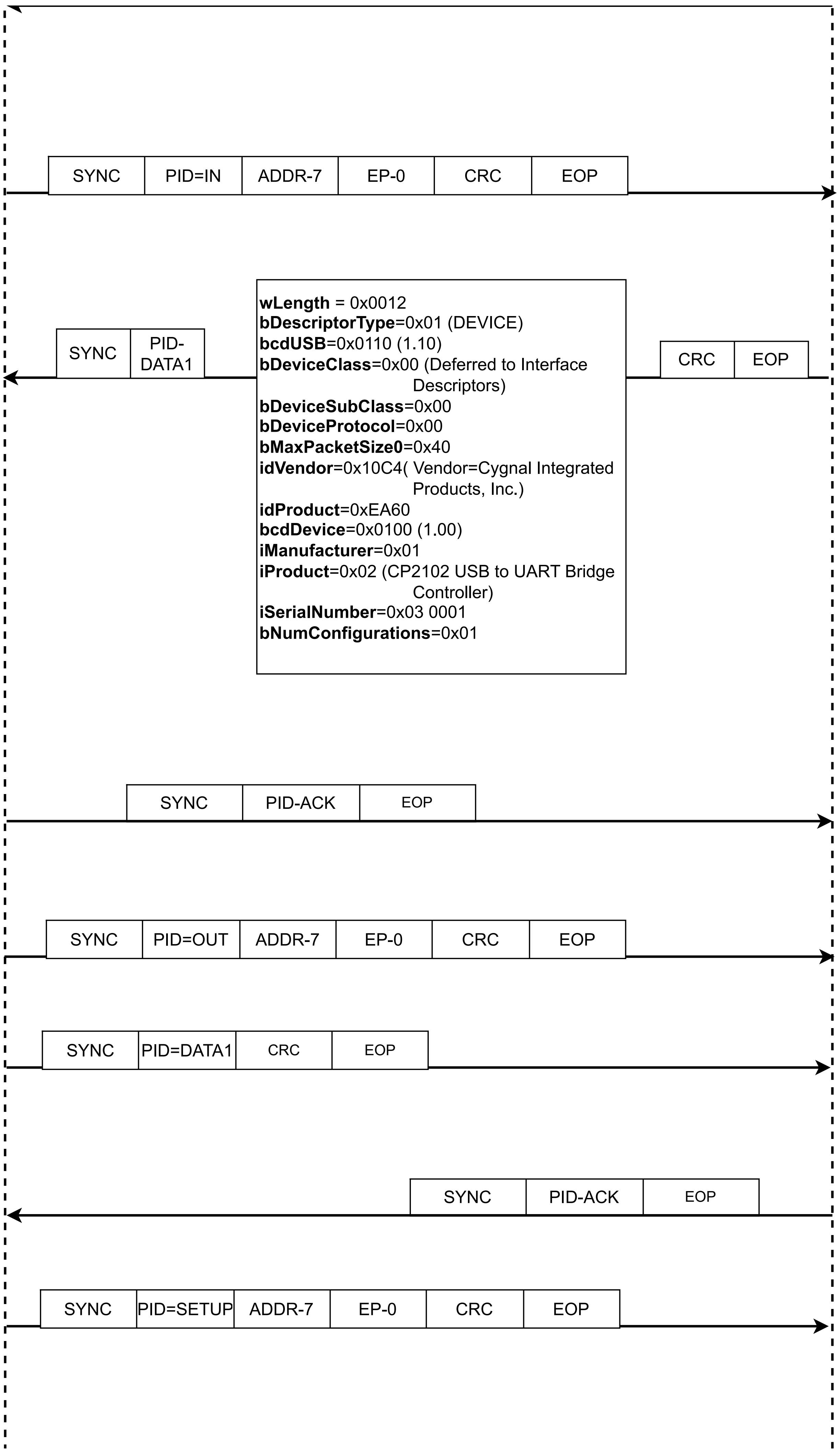
Here is the enumeration example for the CP2102 Silabs chip.

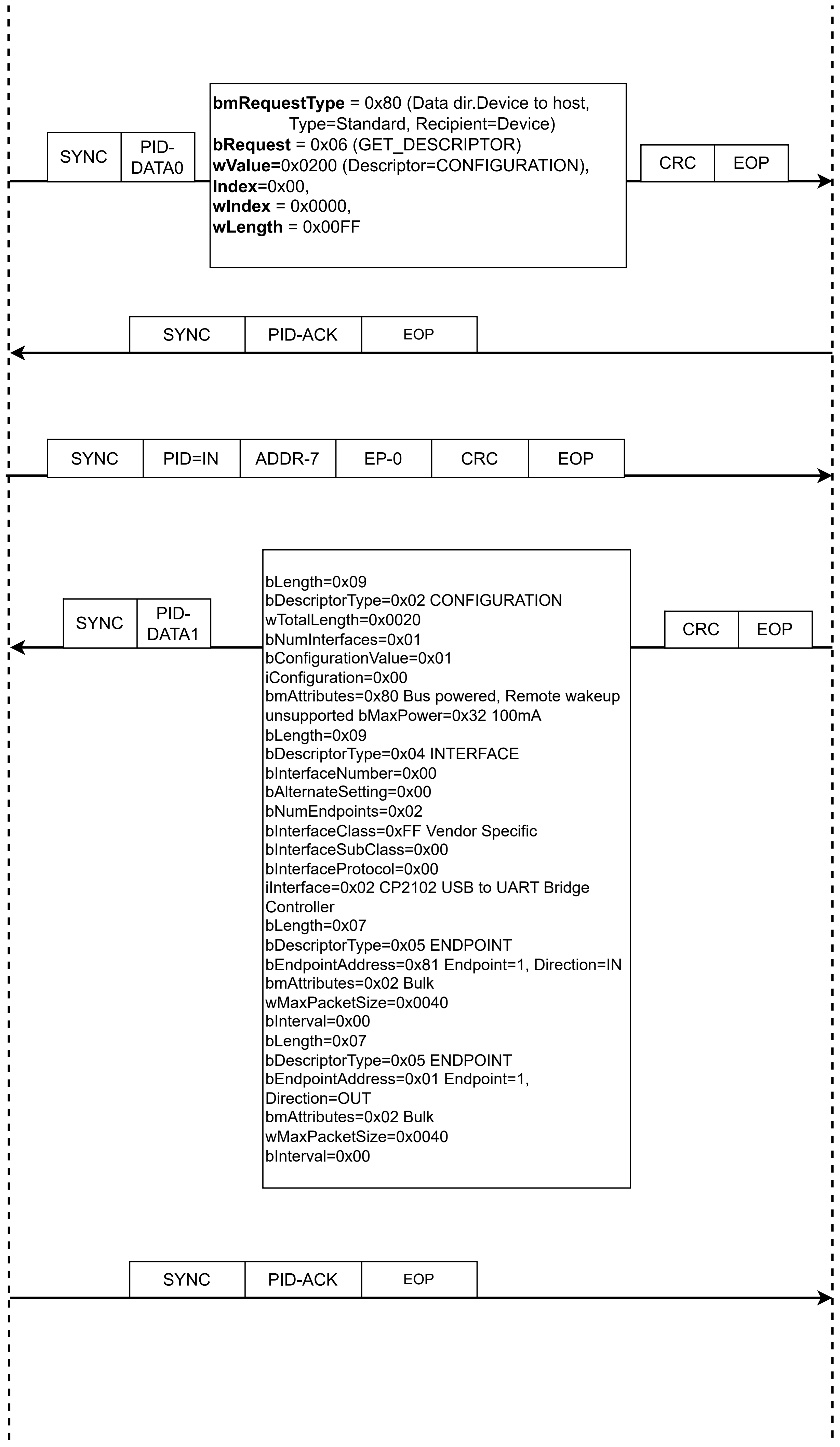


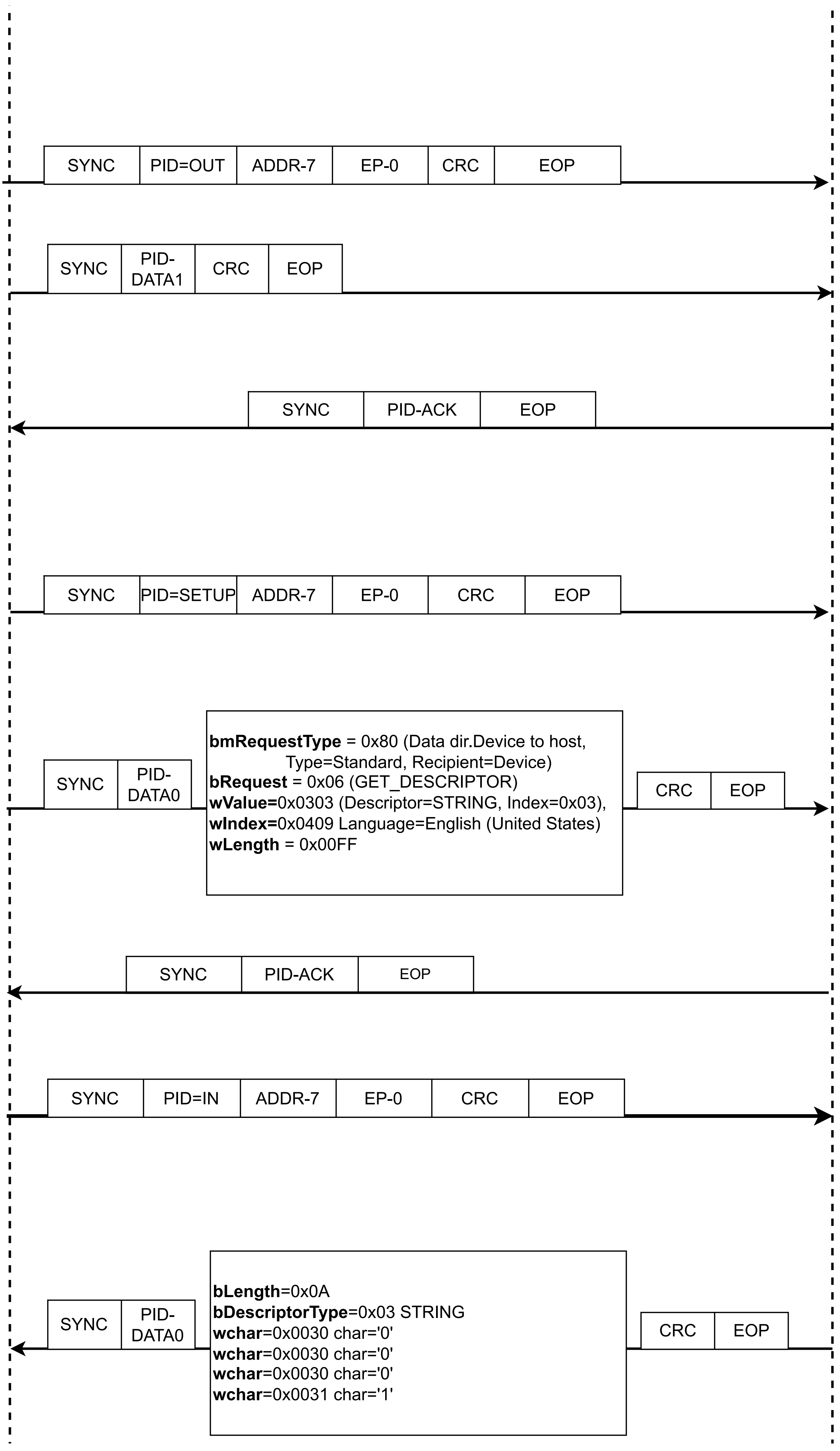
bmRequestType = 0x80 (Data dir.Device to host, Type=Standard, Recipient=Device)
bRequest = 0x06 (GET_DESCRIPTOR)
wValue = 0x0100 (Descriptor=DEVICE, Index=0x00)
wIndex = 0x0000
wLength = 0x0040


SYNC
PID=IN
ADDR-0
EP-0
CRC
EOP
SYNC
PID-DATA1
bLength=0x12
bDescriptorType=0x01 (DEVICE)
bcdUSB=0x0110 (1.10)
bDeviceClass=0x00 (Deferred to Interface) Descriptors:
bDeviceSubClass=0x00
bDeviceProtocol=0x00
bMaxPacketSize0=0x40
idVendor=0x10C4 Vendor=(Cygnal Integrated Products, Inc.)
idProduct=0xEA60
bcdDevice=0x0100 1.00
iManufacturer=0x01
iProduct=0x02
iSerialNumber=0x03
bNumConfigurations=0x01
CRC
EOP
SYNC
PID-ACK
EOP
SYNC
PID=OUT
ADDR-0
EP-0
CRC
EOP
SYNC
PID-DATA1
CRC
EOP
RESET
SYNC
PID-SETUP
ADDR=0
ENDPOINT=0
CRC
EOP


SYNC
PID-DATA0
bmRequestType = 0x00 (Data direction=No data,Type=Standard, Recipient=Device)
bRequest = 0x05 SET_ADDRESS
wValue = 0x0007 Address=0x07
wIndex = 0x0000
wLength = 0x0000
CRC
EOP
SYNC
PID-ACK
EOP
SYNC
PID=IN
ADDR-0
EP-0
CRC
EOP
SYNC
PID-DATA1
CRC
EOP
SYNC
PID-ACK
EOP
SYNC
PID=SETUP
ADDR-7
EP-0
CRC
EOP
SYNC
PID-DATA0
bmRequestType = 0x80 (Data dir.Device to host, Type=Standard, Recipient=Device)
bRequest = 0x06 (GET_DESCRIPTOR)
wValue = 0x0100 (Descriptor=DEVICE, Index=0x00)
wIndex = 0x0000
wLength = 0x0012
CRC
EOP
SYNC
PID-ACK
EOP

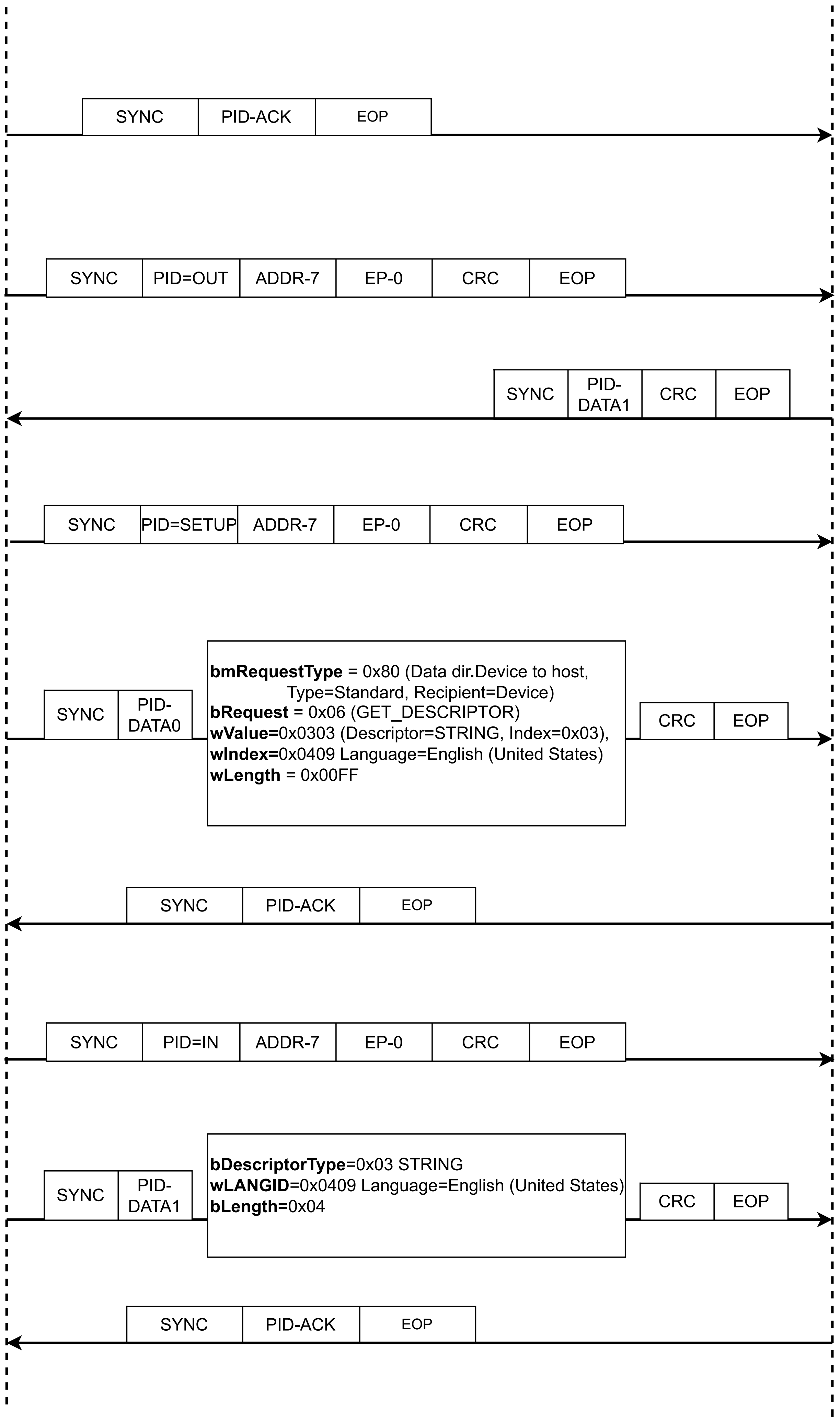

SYNC
PID=IN
ADDR-7
EP-0
CRC
EOP
SYNC
PID-DATA1
CRC
EOP
wLength = 0x0012
bDescriptorType=0x01 (DEVICE)
bcdUSB=0x0110 (1.10)
bDeviceClass=0x00 (Deferred to Interface Descriptors)
bDeviceSubClass=0x00
bDeviceProtocol=0x00
bMaxPacketSize0=0x40
idVendor=0x10C4(Vendor=Cygnal Integrated Products, Inc.)
idProduct=0xEA60
bcdDevice=0x0100 (1.00)
iManufacturer=0x01
iProduct=0x02 (CP2102 USB to UART Bridge Controller)
iSerialNumber=0x03 0001
bNumConfigurations=0x01
SYNC
PID-ACK
EOP
SYNC
PID=OUT
ADDR-7
EP-0
CRC
EOP
SYNC
PID=DATA1
CRC
EOP
SYNC
PID-ACK
EOP
SYNC
PID=SETUP
ADDR-7
EP-0
CRC
EOP


SYNC
PID-DATA0
bmRequestType = 0x80 (Data dir.Device to host, Type=Standard, Recipient=Device)
bRequest = 0x06 (GET_DESCRIPTOR)
wValue=0x0200 (Descriptor=CONFIGURATION)**,**
Index=0x00,
wIndex = 0x0000,
wLength = 0x00FF
CRC
EOP
SYNC
PID-ACK
EOP
SYNC
PID=IN
ADDR-7
EP-0
CRC
EOP
SYNC
PID-DATA1
bLength=0x09
bDescriptorType=0x02 CONFIGURATION
wTotalLength=0x0020
bNumInterfaces=0x01
bConfigurationValue=0x01
iConfiguration=0x00
bmAttributes=0x80 Bus powered, Remote wakeup unsupported bMaxPower=0x32 100mA
bLength=0x09
bDescriptorType=0x04 INTERFACE
bInterfaceNumber=0x00
bAlternateSetting=0x00
bNumEndpoints=0x02
bInterfaceClass=0xFF Vendor Specific
bInterfaceSubClass=0x00
bInterfaceProtocol=0x00
iInterface=0x02 CP2102 USB to UART Bridge Controller
bLength=0x07
bDescriptorType=0x05 ENDPOINT
bEndpointAddress=0x81 Endpoint=1, Direction=IN
bmAttributes=0x02 Bulk
wMaxPacketSize=0x0040
bInterval=0x00
bLength=0x07
bDescriptorType=0x05 ENDPOINT
bEndpointAddress=0x01 Endpoint=1, Direction=OUT
bmAttributes=0x02 Bulk
wMaxPacketSize=0x0040
bInterval=0x00
CRC
EOP
SYNC
PID-ACK
EOP



bmRequestType = 0x80 (Data dir.Device to host, Type=Standard, Recipient=Device)
bRequest = 0x06 (GET_DESCRIPTOR)
wValue=0x0303 (Descriptor=STRING, Index=0x03),
wIndex=0x0409 Language=English (United States)
wLength = 0x00FF

bLength=0x0A
bDescriptorType=0x03 STRING
wchar=0x0030 char='0'
wchar=0x0030 char='0'
wchar=0x0030 char='0'
wchar=0x0031 char='1'


SYNC
PID-ACK
EOP
SYNC
PID=OUT
ADDR-7
EP-0
CRC
EOP
SYNC
PID-DATA1
CRC
EOP
SYNC
PID=SETUP
ADDR-7
EP-0
CRC
EOP
SYNC
PID-DATA0
bmRequestType = 0x80 (Data dir.Device to host, Type=Standard, Recipient=Device)
bRequest = 0x06 (GET_DESCRIPTOR)
wValue=0x0303 (Descriptor=STRING, Index=0x03),
wIndex=0x0409 Language=English (United States)
wLength = 0x00FF
CRC
EOP
SYNC
PID-ACK
EOP
SYNC
PID=IN
ADDR-7
EP-0
CRC
EOP
SYNC
PID-DATA1
bDescriptorType=0x03 STRING
wLANGID=0x0409 Language=English (United States)
bLength=0x04
CRC
EOP
SYNC
PID-ACK
EOP