

USB

Part 1: Wires, packets, transactions



David Grayson
2015-07-23

Pololu

Which USB are we talking about?

- Full speed (12 Mbps)
- Universal Serial Bus Specification
Revision 2.0, April 27, 2000
- 650 page document
- Engineering Change Notices (ECNs)

Types of USB

- Low Speed: 1.5 Mbps
- Full Speed: 12 Mbps
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Bus topology

- One host
 - Detects devices, initiate communication
- Multiple devices
 - Provides one or “functions” to the host

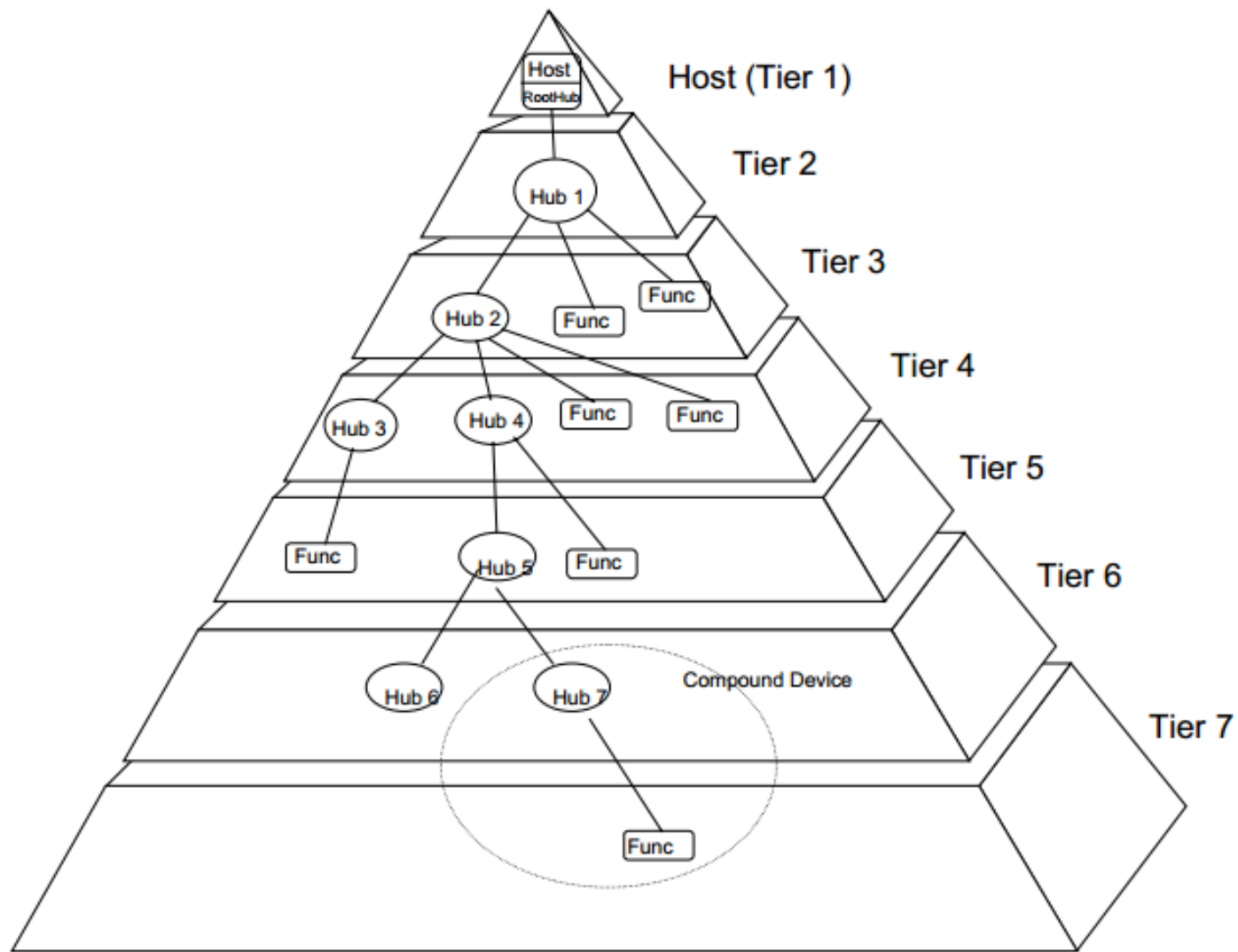


Figure 4-1. Bus Topology

Topology is enforced by connectors



A receptacle

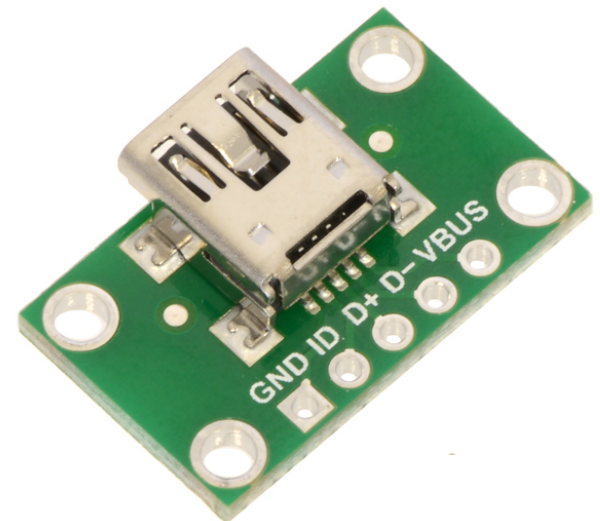


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A plug

B plug

B receptacle



Prohibited cable assemblies

“USB is optimized for ease of use. The expectation is that if the device can be plugged in, it will work.”

Prohibited cable assembly: Extension cables assembly



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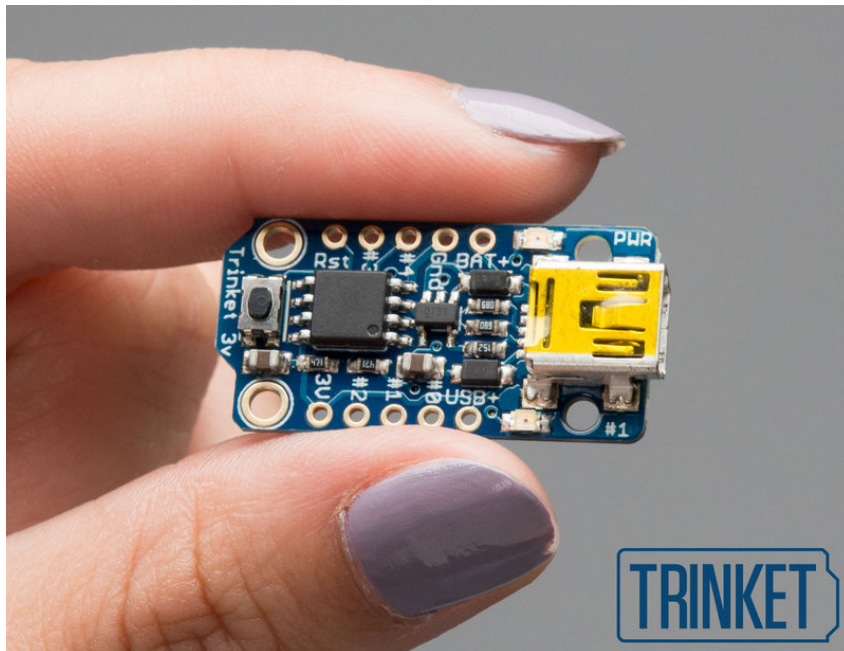
Prohibited cable assembly: Cable that violates USB topology rules



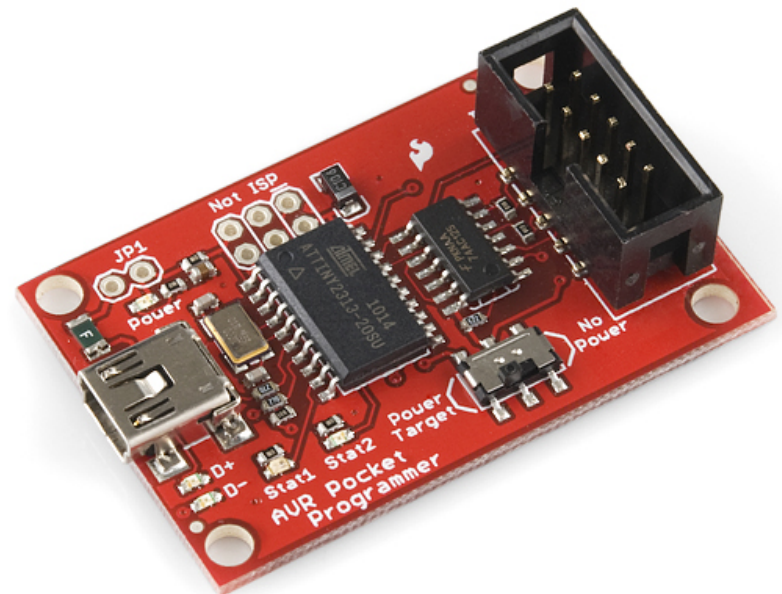
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Prohibited cable assembly: Standard detachable cables for low-speed devices

- “Using a long high-/full-speed cable exceeds the capacitive load of low-speed.”



<https://learn.adafruit.com/introducing-trinket/introduction>



<https://www.sparkfun.com/products/9825>

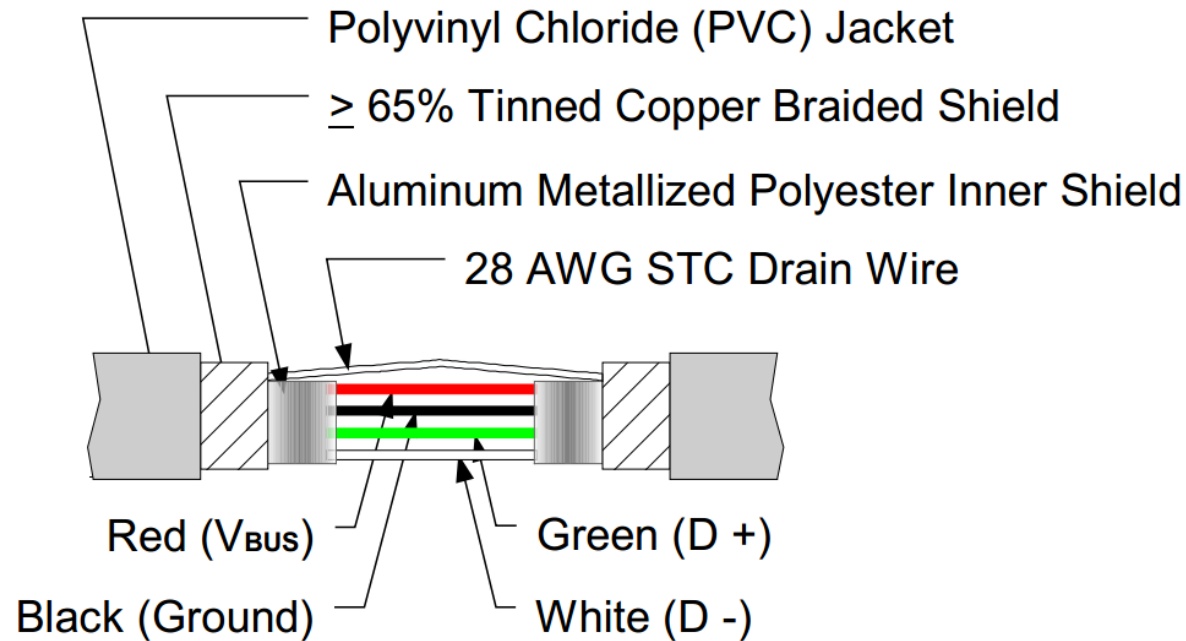
- Chapter 6 has more mechanical specifications
- My favorite part:

	Capacitance between conductive elements of a USB connector.		
Insertion Force	EIA 364-13 The object of this test is to detail a standard method for determining the mechanical forces required for inserting a USB connector.	35 Newtons maximum at a maximum rate of 12.5 mm (0.492") per minute.	7.9 lbs
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Let's talk about the electronics....

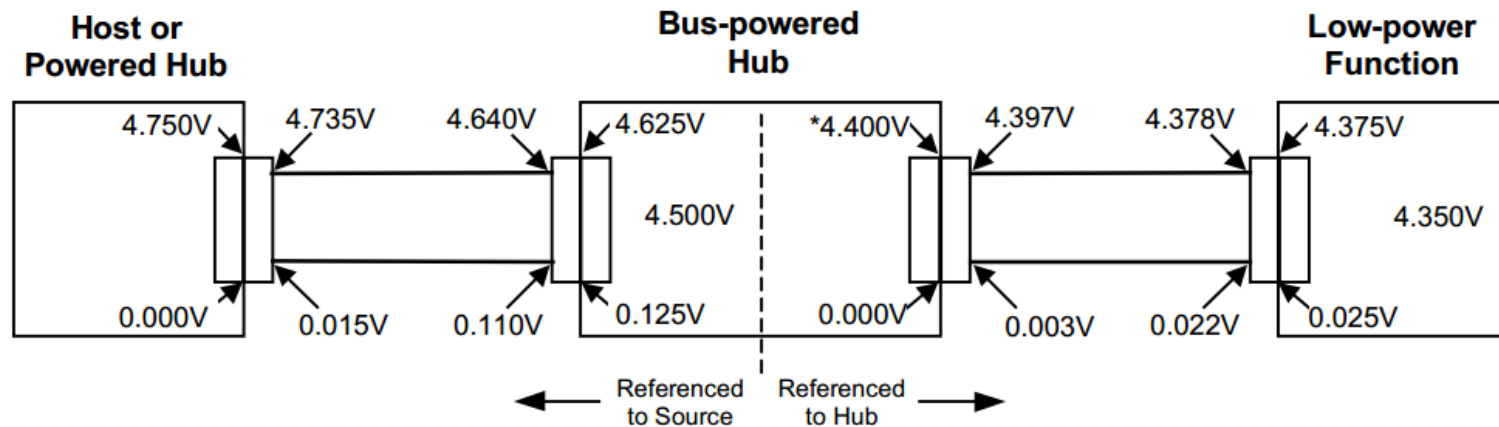
USB wires

Detail C - C **(Typical USB Shielded Cable)**



Power distribution: Voltage

Devices typically get 5.0 V but it could be as low as 4.35 V.



*Under transient conditions, supply at hub can drop from 4.400V to 4.070V

Figure 7-47. Worst-case Voltage Drop Topology (Steady State)

Current limits

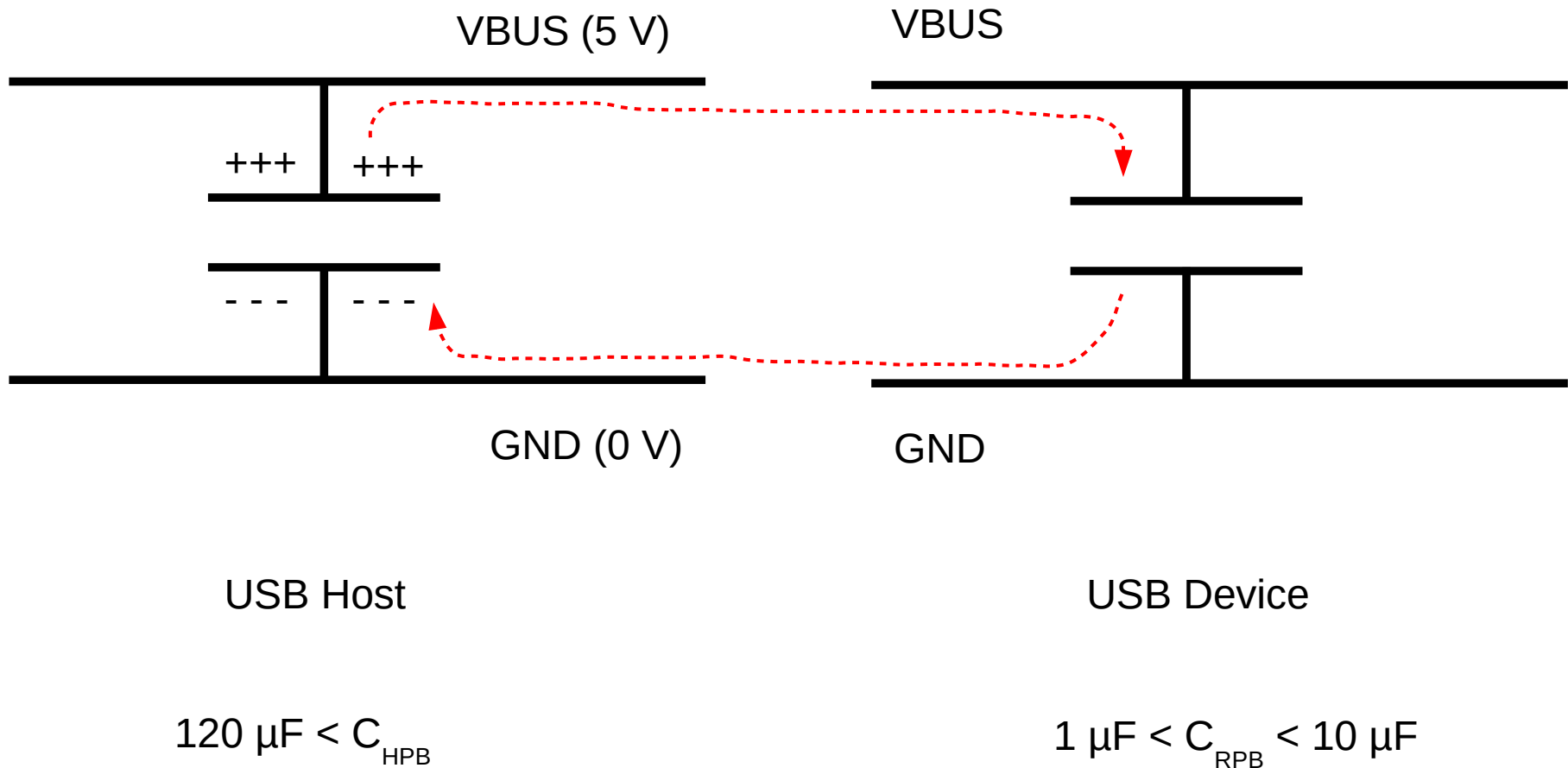
- “Unit load” is defined to be 100 mA
- Low power device: 1 unit load (100 mA)
- High power device: up to 5 unit loads (500 mA)
- Devices cannot draw more than 1 unit load until the device is configured by the host.
- (Later USB specifications allow for a lot more current.)
- Suspend mode: 2.5 mA

Sourcing VBUS

“No device shall supply (source) current on VBUS at its upstream facing port at any time.”

Arduino Uno does it though

Inrush current limiting



USB data lines

USB resistors

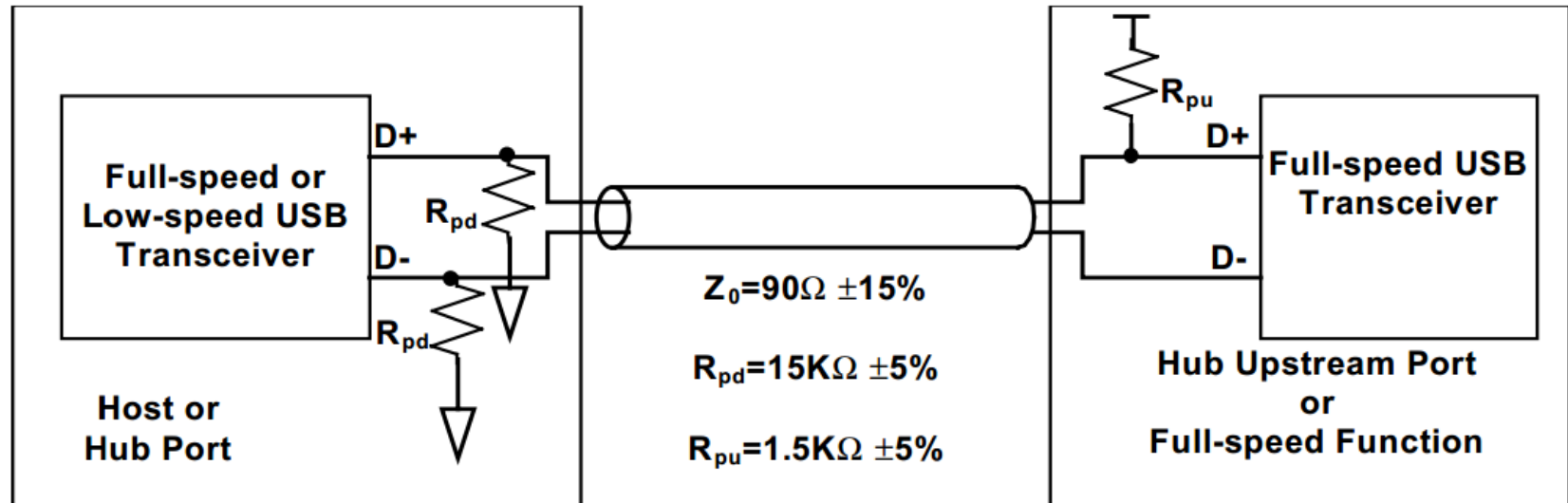


Figure 7-20. Full-speed Device Cable and Resistor Connections

- D+ pull-up should be controllable so you can disconnect from the bus.
- D+ pull-up should only be powered when VBUS is present.
- D+ and D- use 0 V to 3.3 V signalling levels.

Signalling levels

- J: D+ high, D- low: default
- K: D+ low, D- high
- SE0: both low: signals reset or end of packet
- SE1: both high: not used

Packet boundaries

- Start of packet:
Data lines switch from idle (J) to K.
- End of packet:
SE0 for 2 bit times, J for 1 bit time.

Sync pattern

Every packet starts with KJKJKJKK:

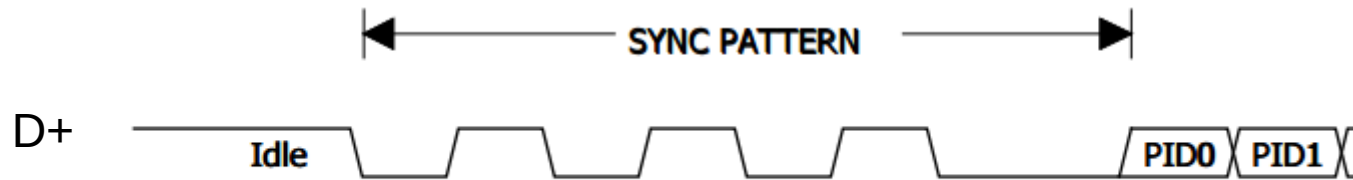


Figure 7-35. Sync Pattern (Low-/full-speed)

NRZI: Non Return to Zero Invert

- Changing voltage level represents a 0
- Same voltage level represents a 1

K J K J K J K K J J J K K J J K J K K J K K K J SE0
----- sync ----- 0 1 1 0 1 0 1 0 0 0 1 0 0 1 1 0

Bit stuffing

A zero is inserted after every six consecutive ones in the data stream, to force a transition.

00101111110110110

That's how packets work.
Now we can just think of each
packet as a sequence of 0s and 1s.

Start, 0111011010111010101110000, End

Packet identifier (PID)

Every packet starts with a 4-bit PID and its inverse.

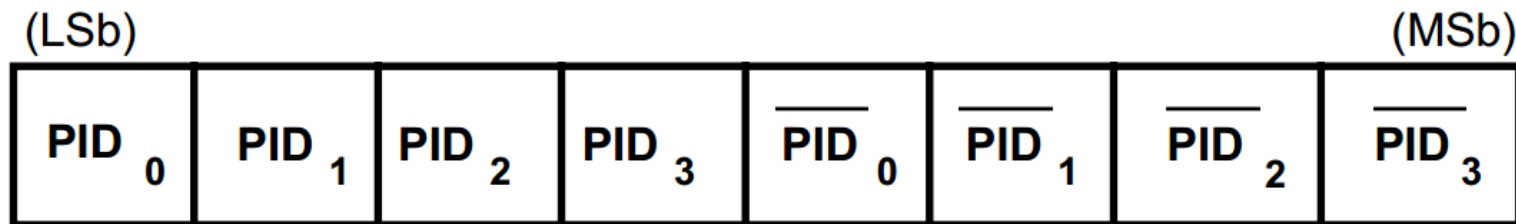


Figure 8-1. PID Format

PID types (the important ones)

- 0001: OUT token
- 1001: IN token
- 0101: SOF token
- 1101: SETUP token
- 0011: DATA0
- 1011: DATA1
- 0010: ACK handshake
- 1010: NAK handshake
- 1110: STALL handshake

Packet types and their fields

- OUT, address, endpoint, CRC5
- IN, address, endpoint, CRC5
- SOF, frame number, CRC5
- SETUP, address, endpoint, CRC5
- DATA0, data, CRC16
- DATA1, data, CRC16
- ACK
- NAK
- STALL

address: 7-bit
endpoint: 4-bit
data: 0 to 1024 bytes

Packets are combined to form transactions.

OUT transaction

- Transfers data out from the host to the device
 - 1) Host: OUT (address, endpoint)
 - 2) Host: DATA0 or DATA1 packet
 - 3) Device: ACK, NAK, STALL

IN transaction

- Transfers data in to the host from the device
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 - 2) Device: DATA0, DATA1, or NAK packet
 - 3) Host: ACK

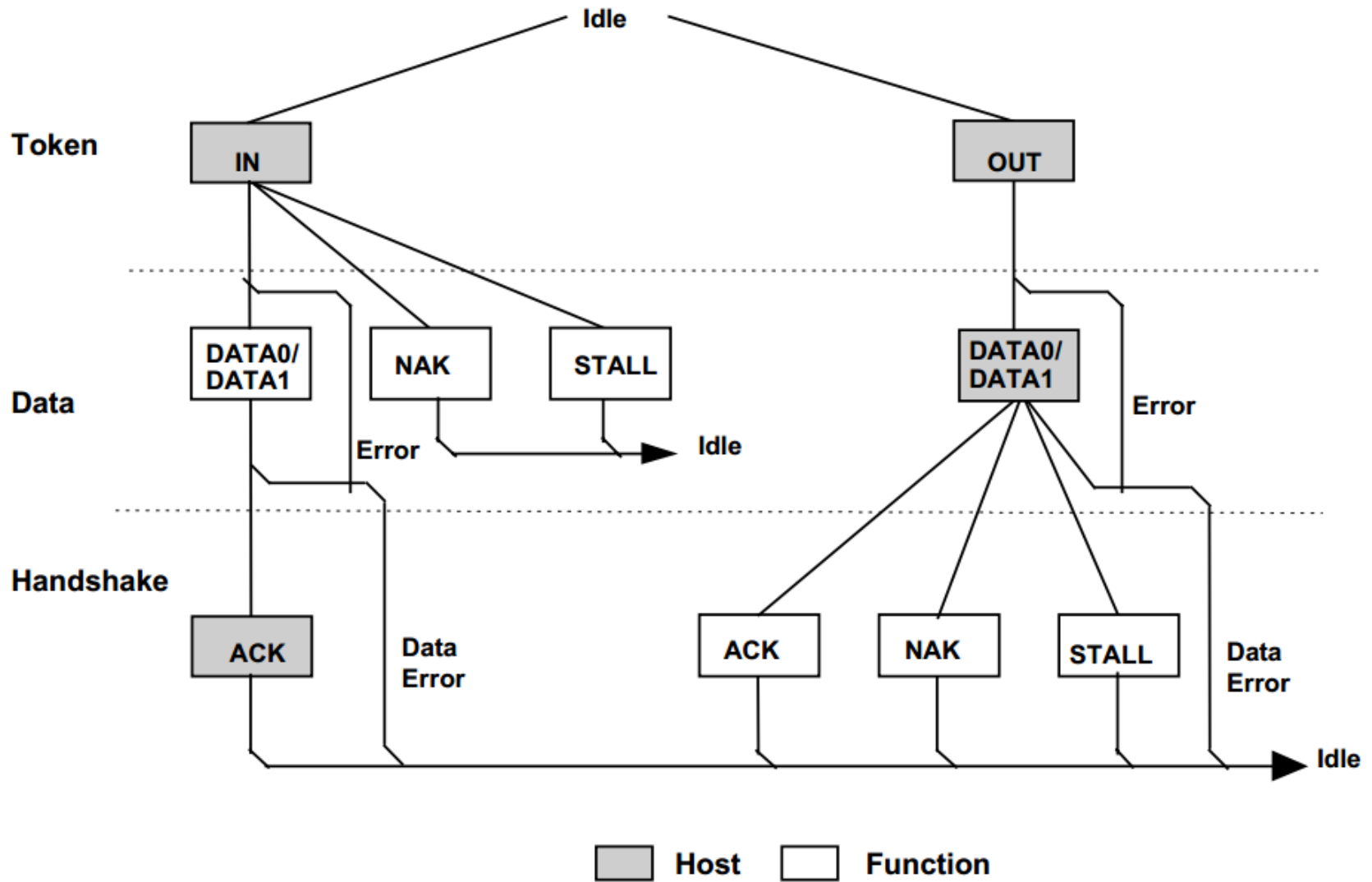


Figure 8-38. Interrupt Transaction Format

Transaction considerations

- Host initiates all transactions
- Device must respond very fast
- Device responses are usually queued up ahead of time and then handled entirely by hardware
- Can't easily make wireless USB

Data toggle and error handling

- We already have ACK packets, but what happens if the ACK is lost?
- The sender must resend packet until ACKed.
- Receiver must be able to detect duplicate packets.
- Solution: data toggle bit included with every DATA packet in the PID (DATA0 or DATA1)

Endpoint types

- Interrupt: guaranteed latency
- Bulk: best effort
- Control: requests and responses
- Isochronous: streaming, no error handling

EOP

Universal Serial Bus Specification

Compaq

Hewlett-Packard

Intel

Lucent

Microsoft

NEC

Philips

Revision 2.0

April 27, 2000

Address and endpoint fields

- Only present for OUT, IN, and SETUP packets
- 7-bit device address
 - Devices use address 0 after being reset (D+ and D-low for a while), and then the host assigns another address.
- 4-bit endpoint number

Data field

- Only present for DATA0 and DATA1 packets.
- Integral number of bytes from 0 to 1024

Cyclic Redundancy Checks (CRCs)

- 5-bit CRC for IN/OUT/SETUP packets.
- 16-bit CRC for DATA0/DATA1 packets.
- Packets with failed CRCs must be ignored.

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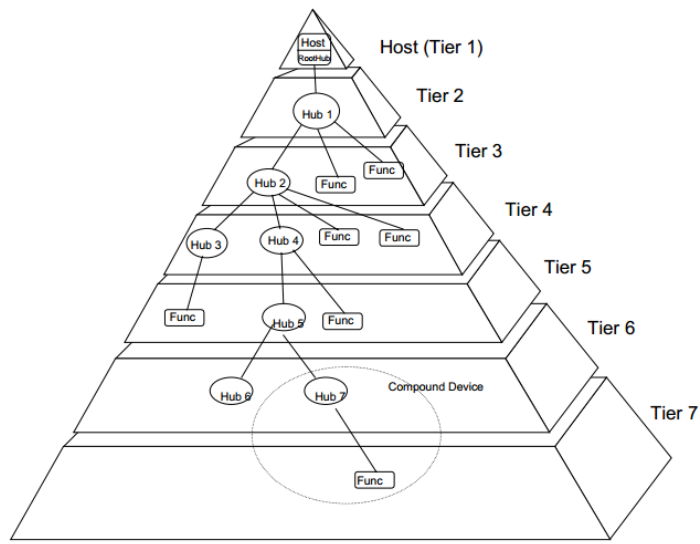


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USB 2.0 section 4.1.1

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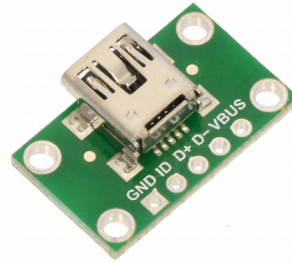


www.pololu.com

A plug

B plug

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<http://uk.farnell.com/multicomp/mc32593/usb-2-0-type-a-receptacle-th/dp/1696534>

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USB 2.0 section 6.4.4

Prohibited cable assembly: Extension cables assembly

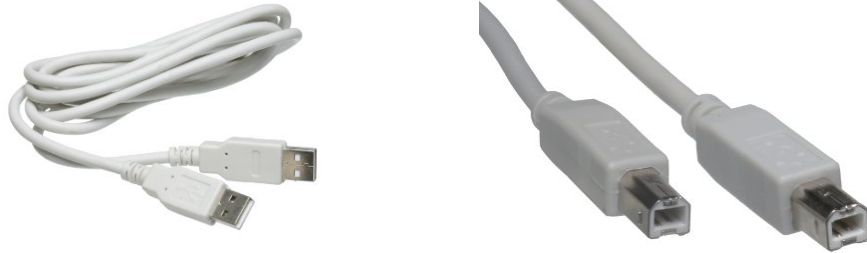


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<http://www.amazon.com/Belkin-USB-Extension-Cable-10-Feet/dp/B00001ZWXA>

USB 2.0 section 6.4.4

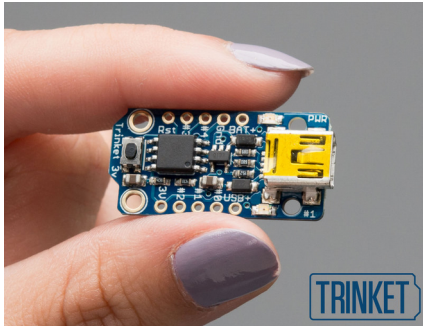
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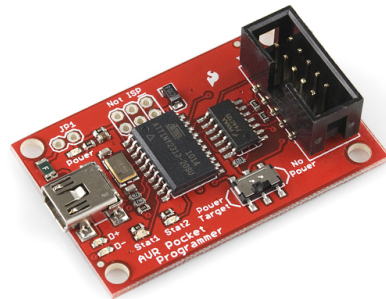
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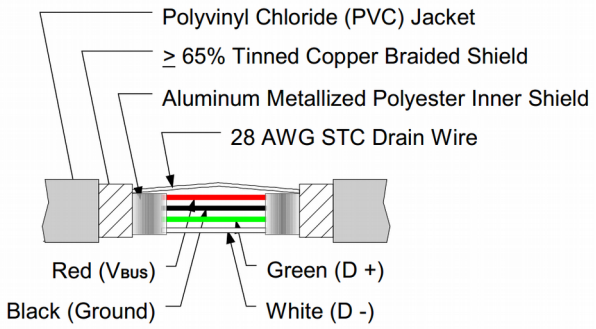
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USB 2.0 section 6.7

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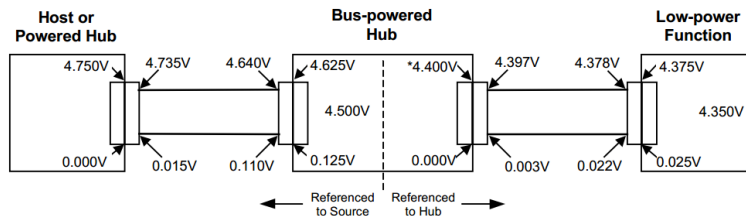
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USB 2.0 section 6.3

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USB 2.0 section 7.2.1, Suspend Current ECN

Sourcing VBUS

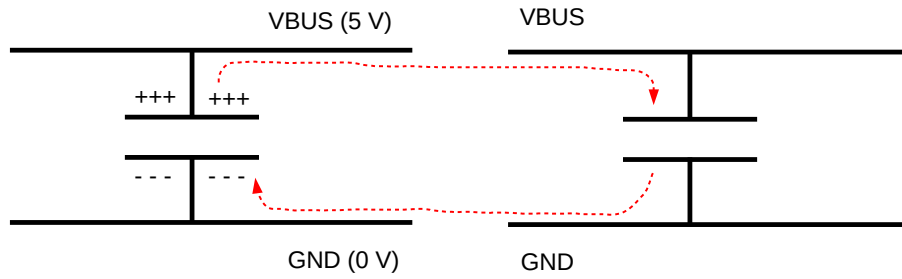
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<http://forum.pololu.com/viewtopic.php?f=3&t=3083>

USB 2.0 section 7.2.1

Inrush current limiting



USB Host

USB Device

$$120 \mu\text{F} < C_{HP}$$

$$1 \mu\text{F} < C_{RPB} < 10 \mu\text{F}$$

USB 2.0 section 7.2.4.1; Device Capacitance ECN

USB data lines

USB resistors

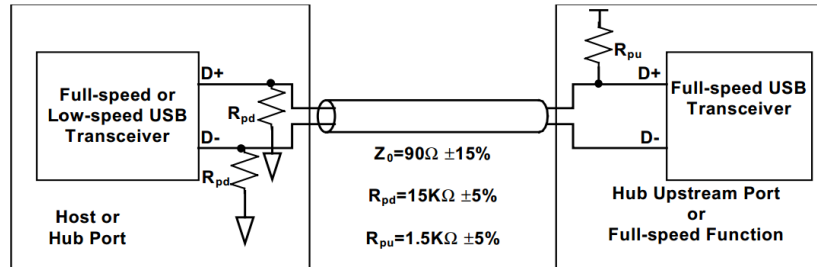


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USB 2.0 figure 7-20; Pull-up/pull-down resistors ECN

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USB 2.0 section 7.1.7.1

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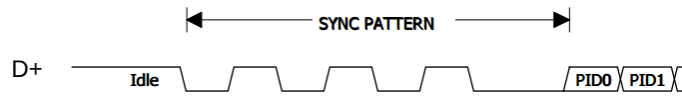


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----- sync ----- 0 1 1 0 1 0 1 0 0 0 1 0 0 1 1 0

USB 2.0 section 7.1.8

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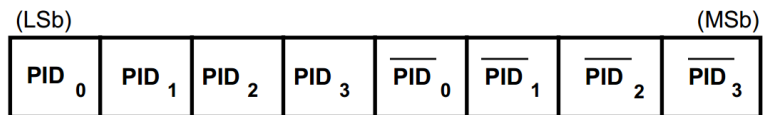


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USB 2.0 section 8.3.1

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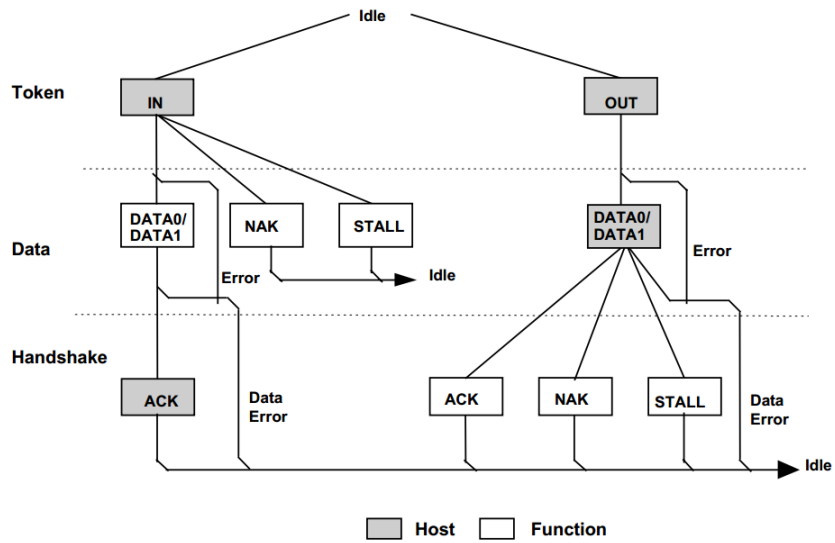


Figure 8-38. Interrupt Transaction Format

USB 2.0 figure 8-38

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USB 2.0 section 8.3.4

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USB 2.0 section 8.3.5