

USB introduction

- Do you know what is USB?
 - It's easy, just check-out WIKI 😊 <http://en.wikipedia.org/wiki/USB>
- Which are your USB projects?
- What are your key USB requirements?
- Who are the main competitors of ST and WHY?

the Universal Serial Bus

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- The USB - Universal Serial Bus is an industry standard **developed** in the mid-1990s that **defines**
 - Bus architecture
 - Cables, Connectors, Electrical levels
 - Communications protocols
- USB was designed to **standardize** the connection of computer peripherals
 - keyboards, pointing devices, digital cameras, printers, portable media players, disk drives and network adapters
- It has become common interface on **other devices**, such as smartphones, PDAs and video game consoles.
- USB has effectively **replaced** a variety of earlier interfaces, such as serial and parallel ports.



the Universal Serial Bus

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Hot pluggable	YES
Protocol	Serial, pooled, host centric
Bitrate	1.5/ 12/ 480/ 5,000/ 10,000/ 20,000 Mbit/s
Max Length	5m
Max Voltage	5V (without PD)
Max Current	0.5A general 0.1A from USB-powered HUB 5A charging device Up to 100W over USB-C power delivery
Max Devices	127
Pins	4-5 (USB 2.0) 1 supply, 2 data, 1 ground (optional ID signal)
Topology	Tired star



- The original USB **1.0** specification was introduced in January 1996
 - Defined data transfer rates of **1.5 Mbit/s** "Low Speed" and **12 Mbit/s** "Full Speed" The first widely used version of USB was **1.1**, was released in September 1998.
 - Low speed designed for MCUs without USB peripheral (software emulation)
- The USB **2.0** specification was released in April 2000
 - Develop a higher data transfer rate achieving **480 Mbit/s**
 - a 40-times increase over the original USB 1.1 specification
- The USB **3.0** specification was published on 12 November 2008.
 - Increase the data transfer rate (up to **5 Gbit/s**)
 - decrease power consumption, increase power output
 - backwards-compatible with USB 2.0. USB 3.0 includes a new, higher speed bus called SuperSpeed in parallel with the USB 2.0 bus.
- The USB **3.1** specification was released on 31 July 2013
 - Introducing a faster transfer mode called "SuperSpeed USB **10 Gbps**"

- The **USB 3.2** specification was announced on 25 September 2017
 - Enhancing SuperSpeed up to 20 Gbps with existing SuperSpeed physical layer
 - Two-lane operation using USB-C cables

Universal Serial Bus

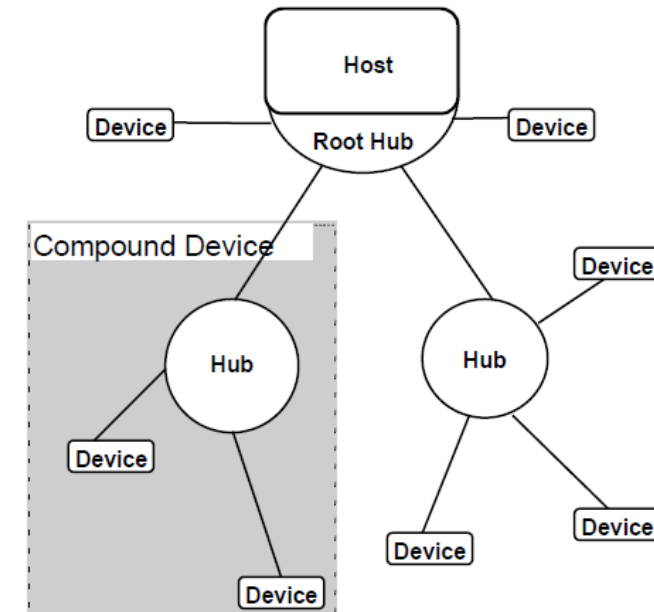
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- USB Implementers Forum, Inc.
 - is a non-profit corporation that **developed** the USB **specification**
 - The Forum **facilitates the development** of high-quality compatible USB peripherals (devices), and the quality of products that have passed **compliance testing**. Some of the many activities that the USB-IF supports include:
 - ☐ USB **Compliance Workshops** and **compliance test** and tool development
 - ☐ USB Developer **Conferences**
 - ☐ Assignment of a **vendor ID**
 - ☐ www.usb.org **Web site**
 - ☐ and many more...

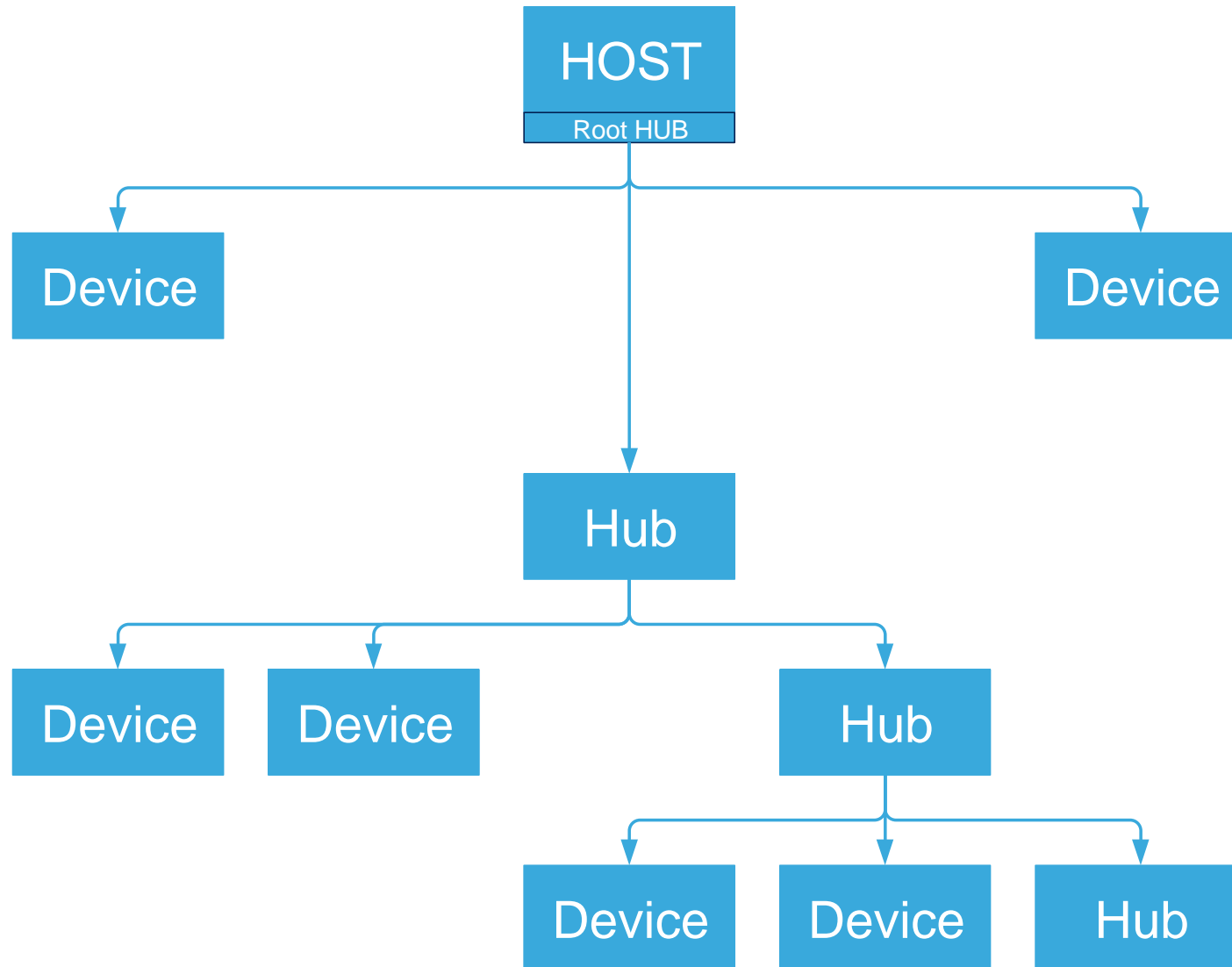
Bus Topology 8

- The USB physical interconnect is a **tiered star** topology.
- The USB **connects** USB devices with the USB host.
- A hub is at the **center** of each star. Each wire segment is **a point-to-point** connection.
- The maximum of **127 devices** can be connected in the bus
 - Each device has assigned 7-bit address
 - Address 0 reserved for not enumerated device
- The maximum of **5 hubs** can be connected in series
- The maximum number of tiers allowed is **seven**
- The maximum cable length is **5meter**



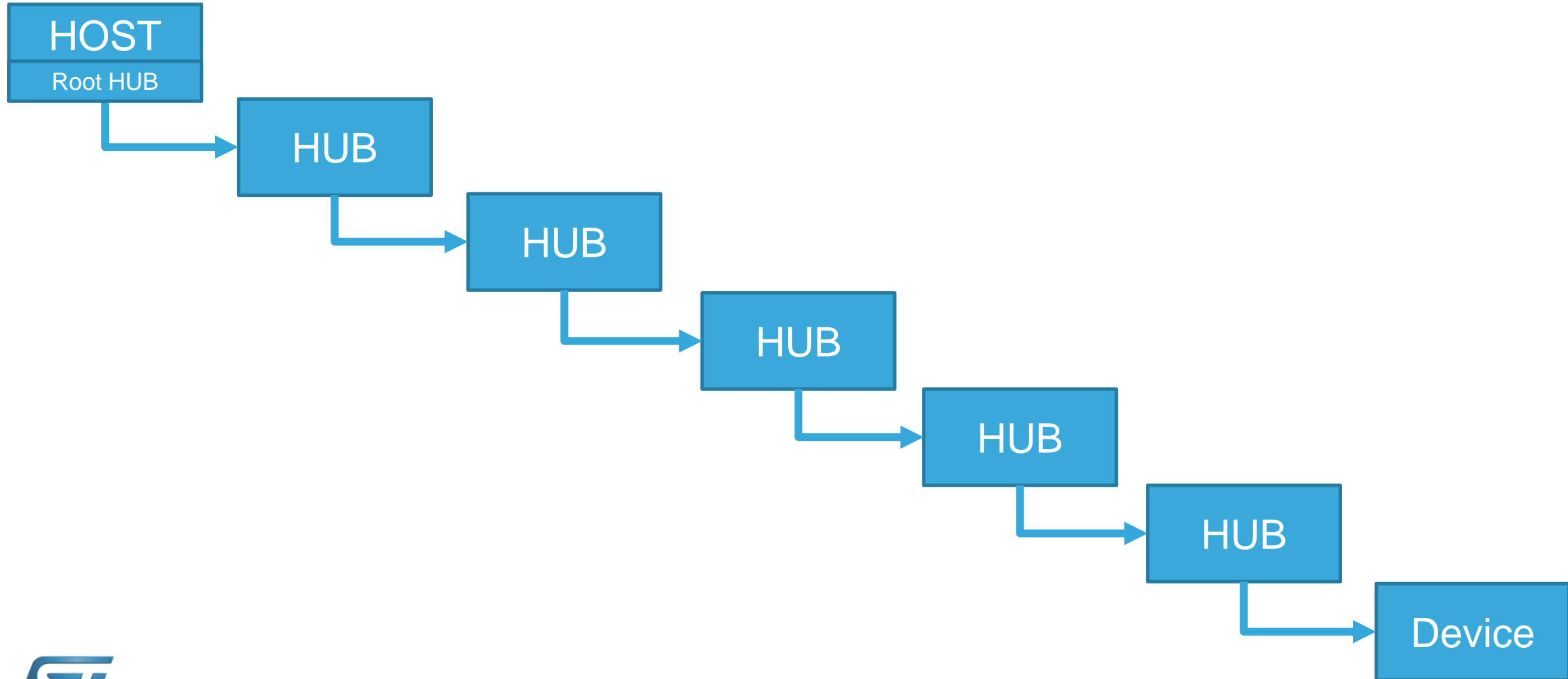
Tiered star topology

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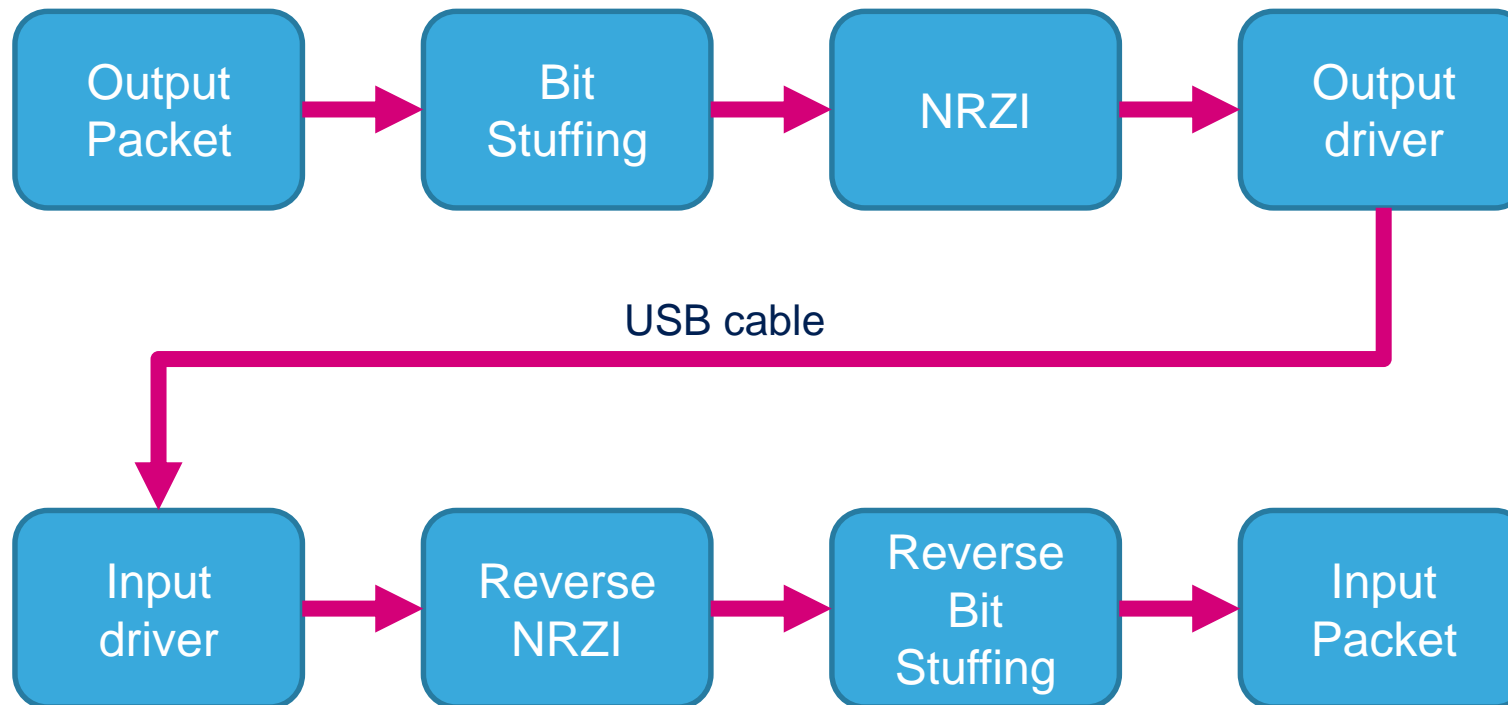
The maximum of **5 hubs** can be connected in series

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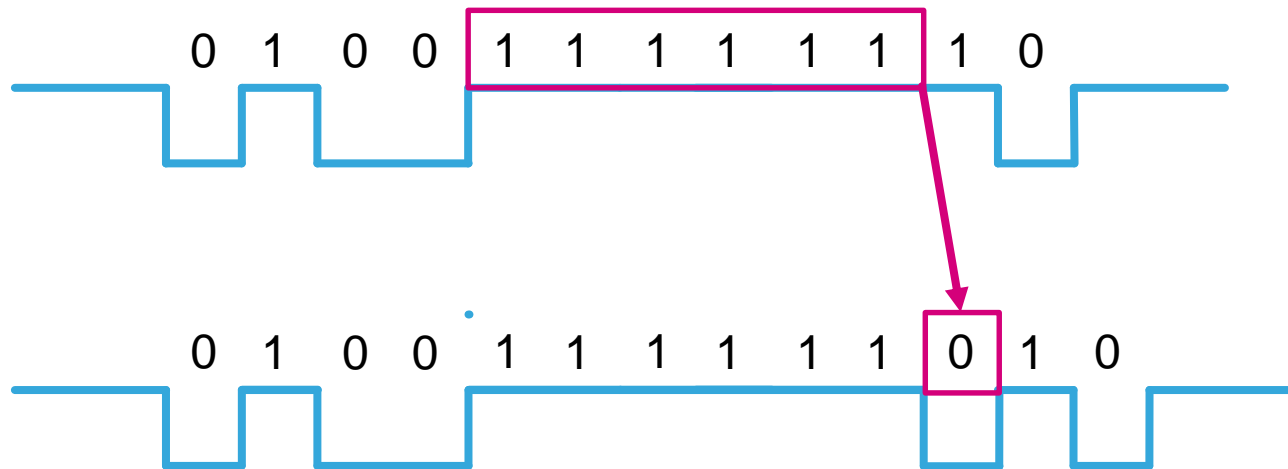


Physical layer flow 11

- Packed is coded to NRZI with Bit Stuffing
 - This ensures there are enough edges for synchronization
- Then is send over differential bus



- Bit stuffing
 - Insert “0” after six consecutive “1”

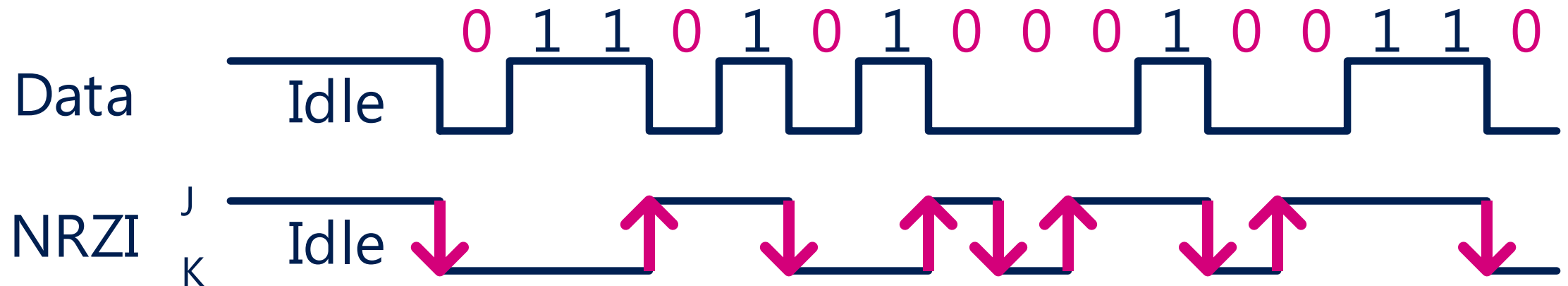


NRZI (non return to zero inverted)

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- NRZI (non return to zero inverted)

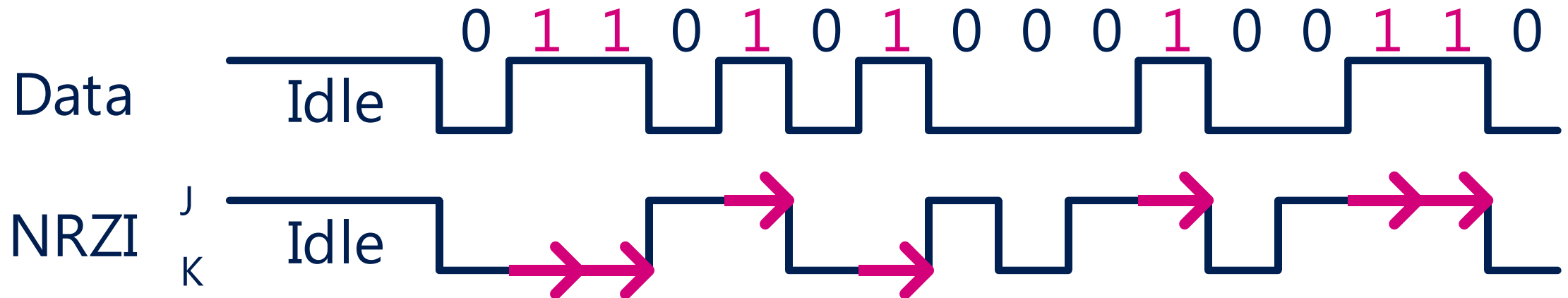
- Toggle the voltage value for 0
- Keep the voltage value for 1



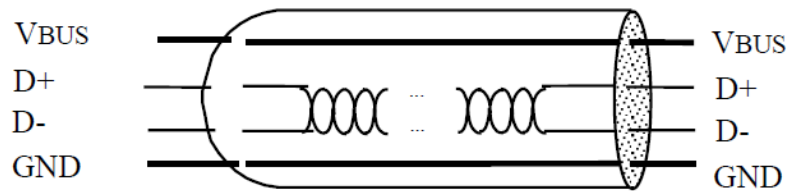
NRZI (non return to zero inverted)

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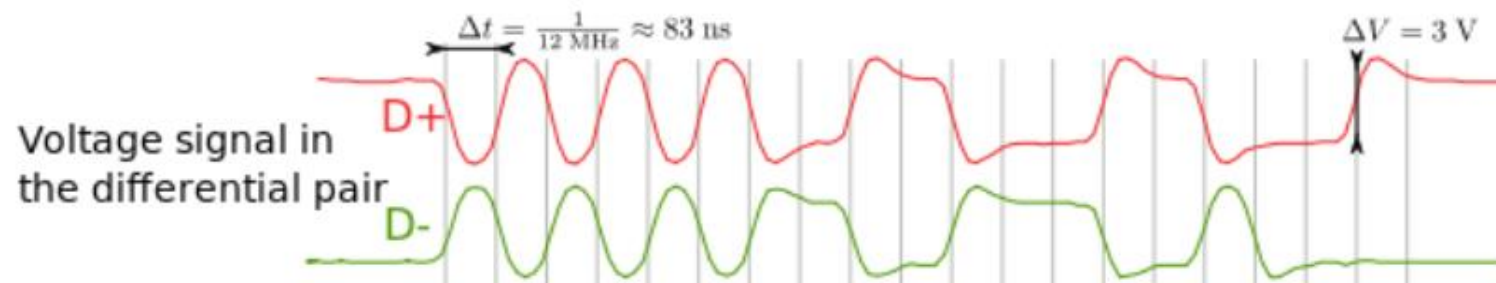
- USB is a serial bus, using **four** shielded **wires** for the USB 2.0 variant:
 - two for power (VBUS and GND),
 - two for differential data signals (D+ and D-).



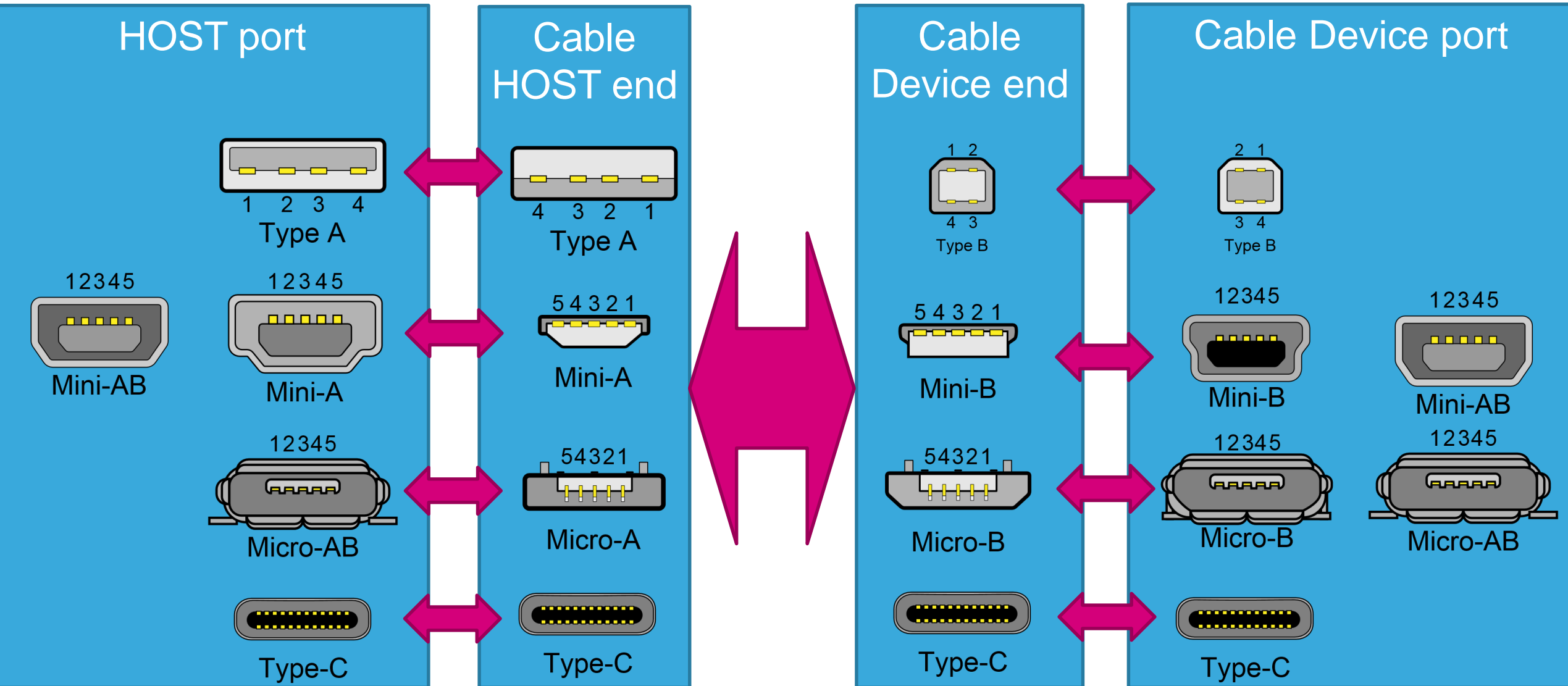
USB 1.x/2.0 standard pinout

Pin	Name	Wire color	Description
1	V _{BUS}	Red (or Orange)	+5 V
2	D ⁻	White (or Gold)	Data ⁻
3	D ⁺	Green	Data ⁺
4	GND	Black (or Blue)	Ground

- Example for full-speed:



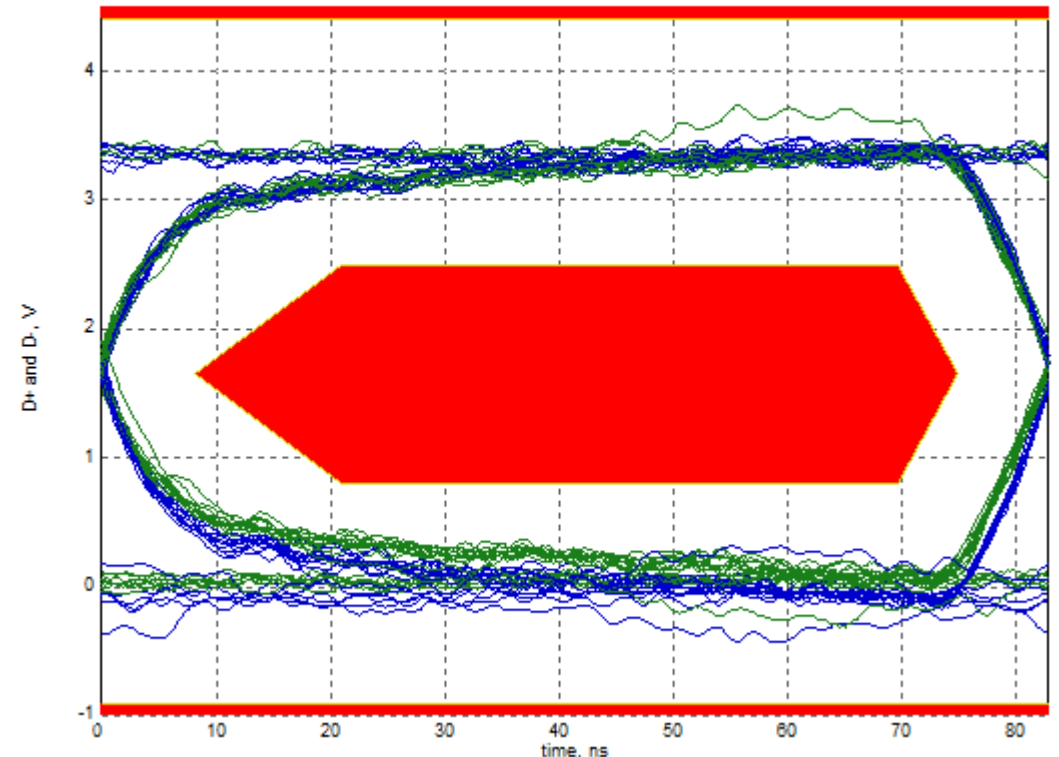
- For hosts, hubs and high-speed capable functions(=USB device) required data-rate accuracy when transmitting at any speed is $\pm 0.05\%$ (500 ppm)
- For full-speed only functions required data-rate when transmitting is 12 Mb/s $\pm 0.25\%$ (2500 ppm)
 - USB specification chapter 7.1.11 – Data Signaling Rate
- Clock accuracy is very strict for USB
 - If no advance solution for clock synchronization (e.g. Clock Recovery System) is supported by the MCU, HSE usage is mandatory



Measuring signal quality

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- USBET20 PC tool – can be downloaded at <http://www.usb.org/>
- Loads CSV file with signals
 - Should be measured on the other end of the USB cable
- Generates eye diagram
- Checks timing
- Checks voltage levels
- Inrush current measurement

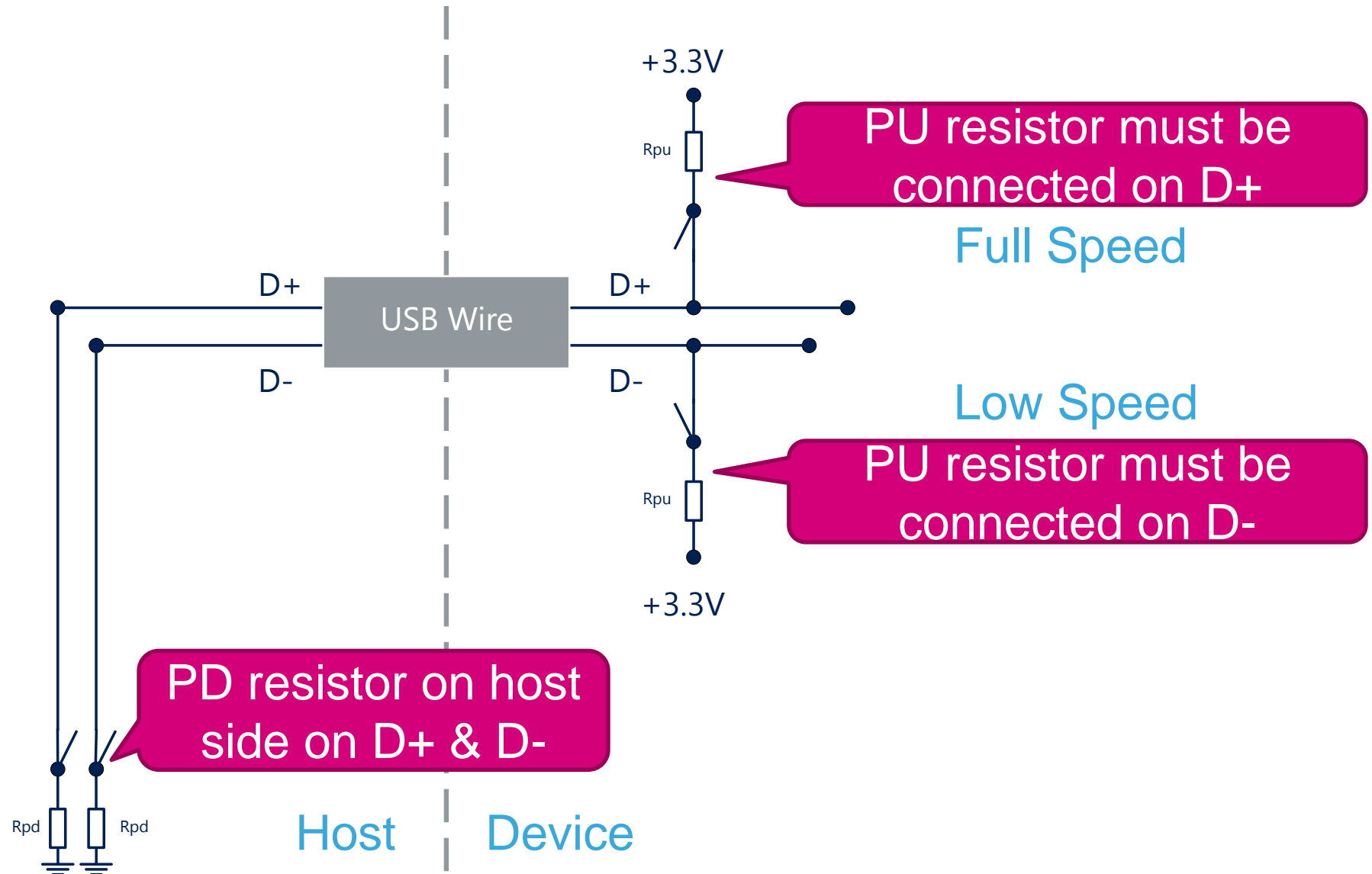


USB bus states

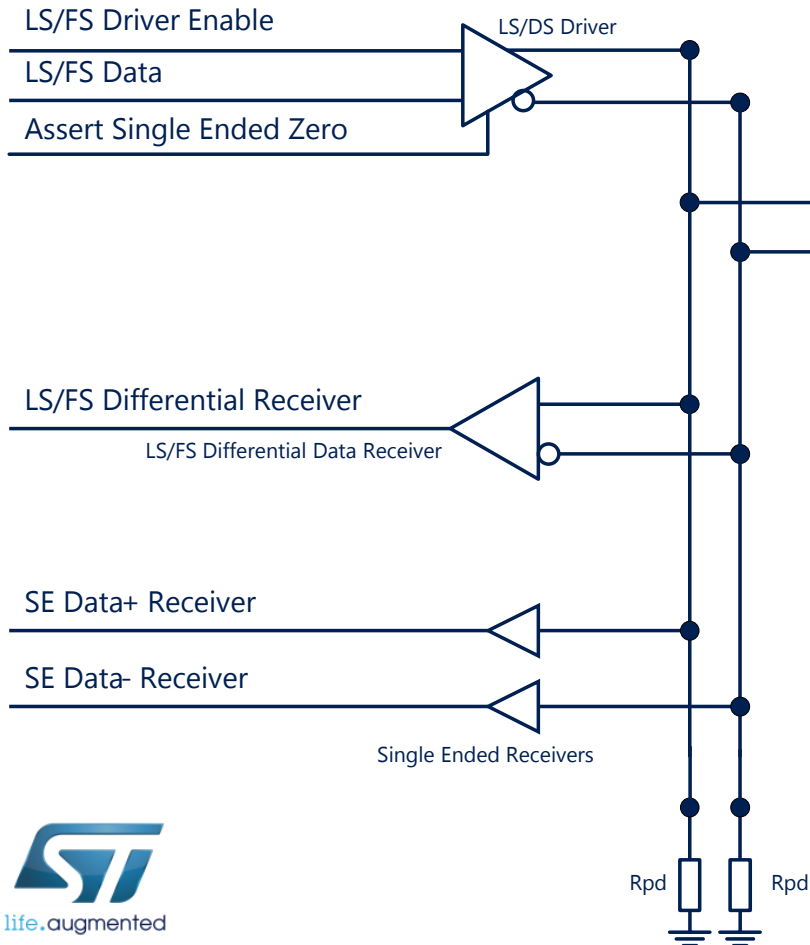
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Bus State	Condition
Differential 1	D+ high, D- low
Differential 0	D- high, D+ low
Single Ended Zero (SE0)	D+ and D- low
Single Ended One (SE1)	D+ and D- high
Data J	Low Speed: Differential 0 Full Speed: Differential 1
Data K	Low Speed: Differential 1 Full Speed: Differential 0

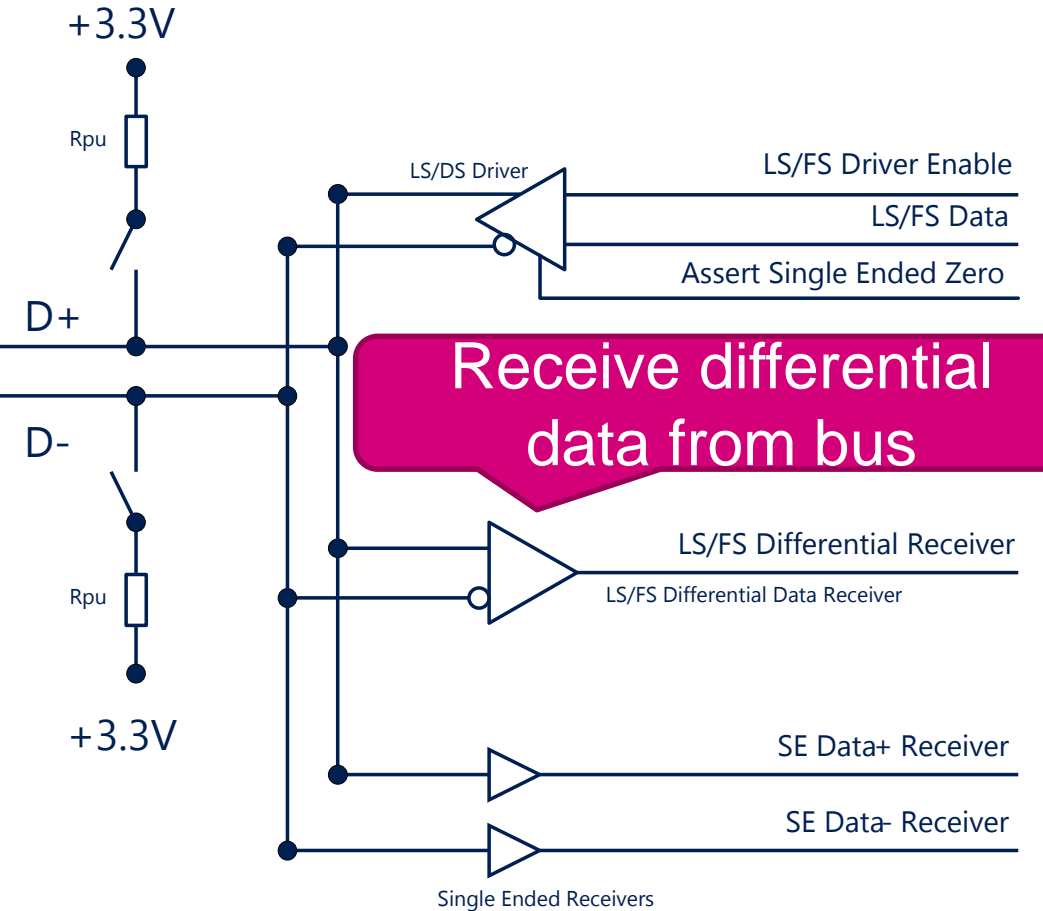
Bus State	Condition
Start of Packet (SOP)	Switching from Idle to K state
End of Packet	SE0 for 2 bit times followed by J state for 1 bit time
Disconnect	SE0 for more than 2 us
Connect	Idle for more than 2.5 us
Reset	SE0 for more than 2.5 us acceptable (required ≥ 10 us)



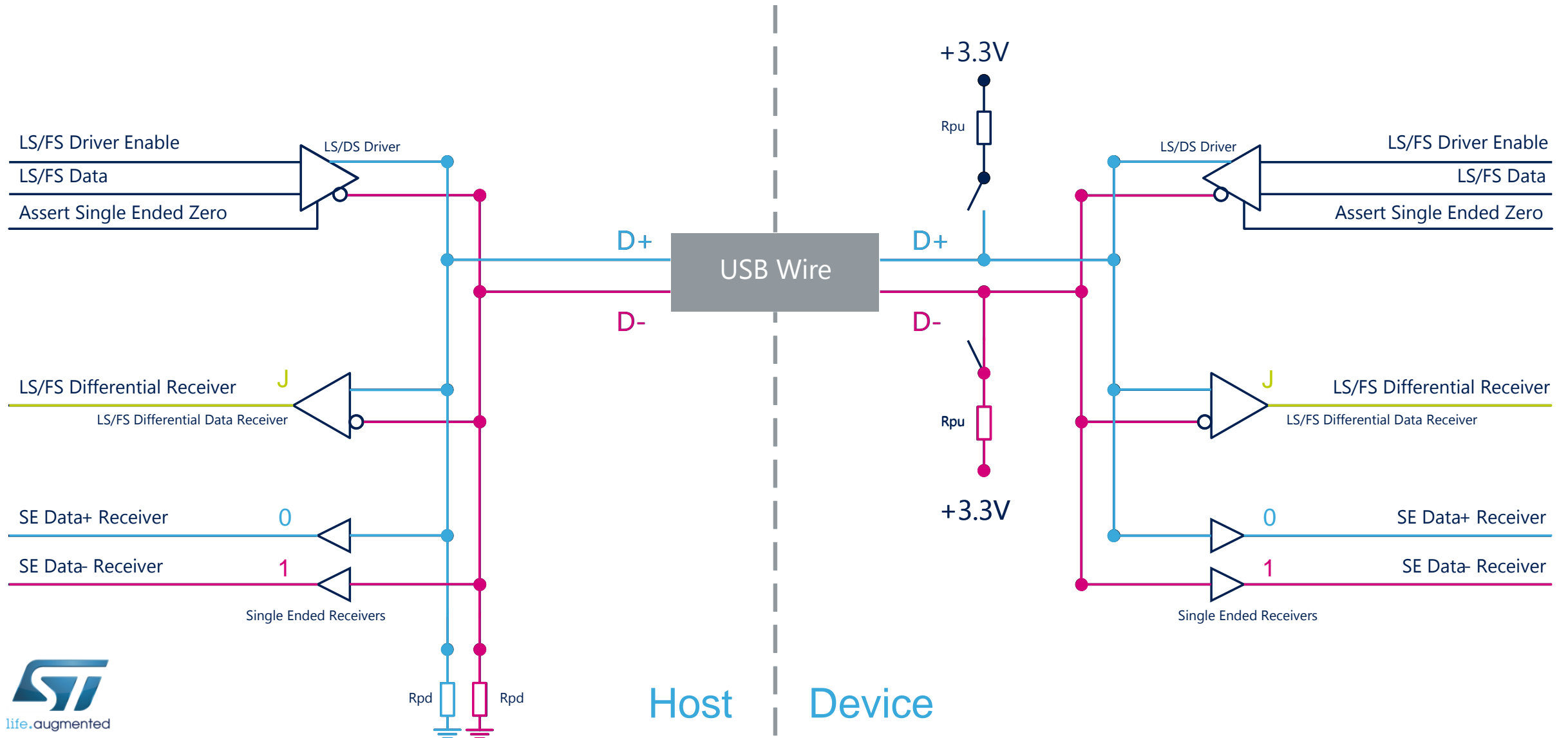
Transmits differential data over bus

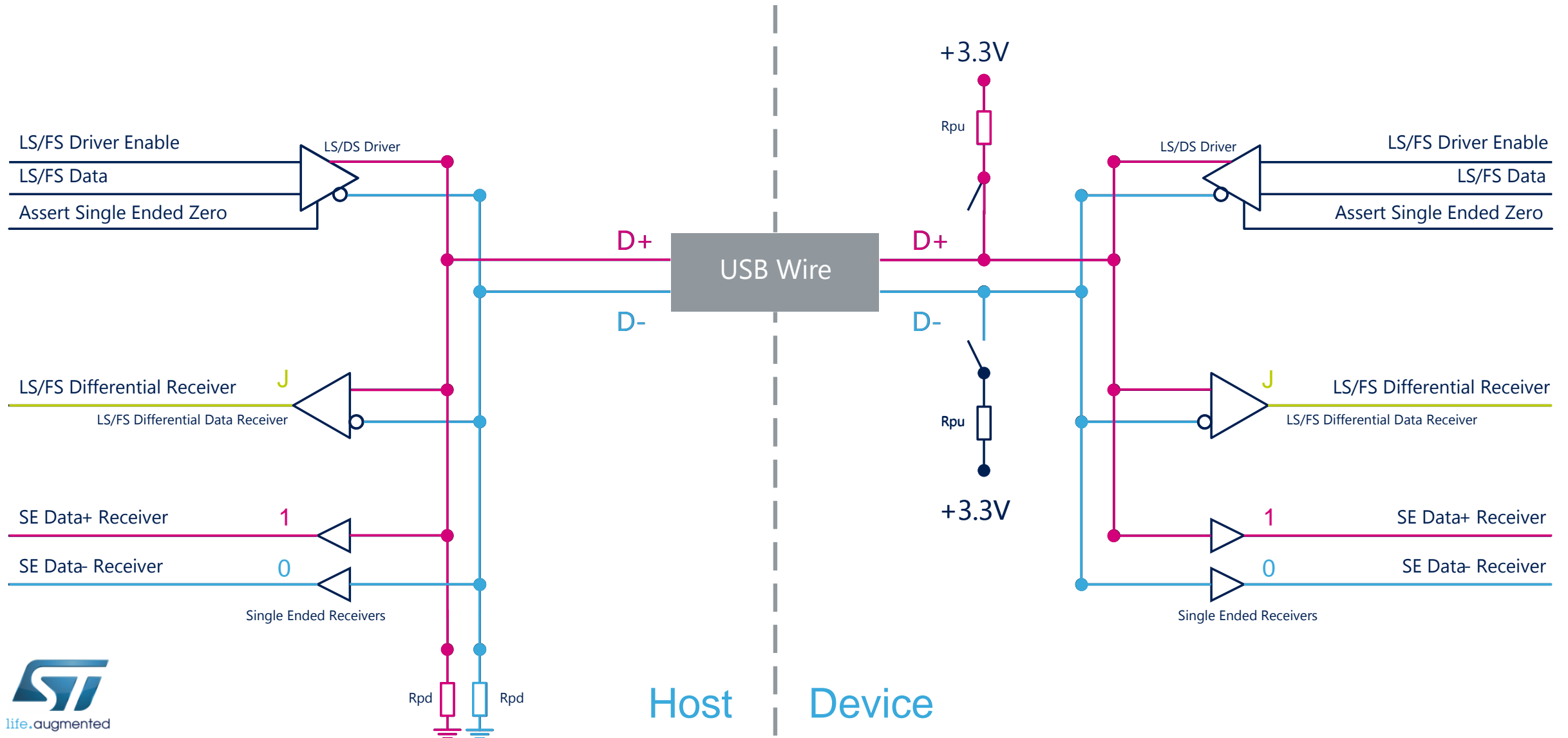


Receive differential data from bus



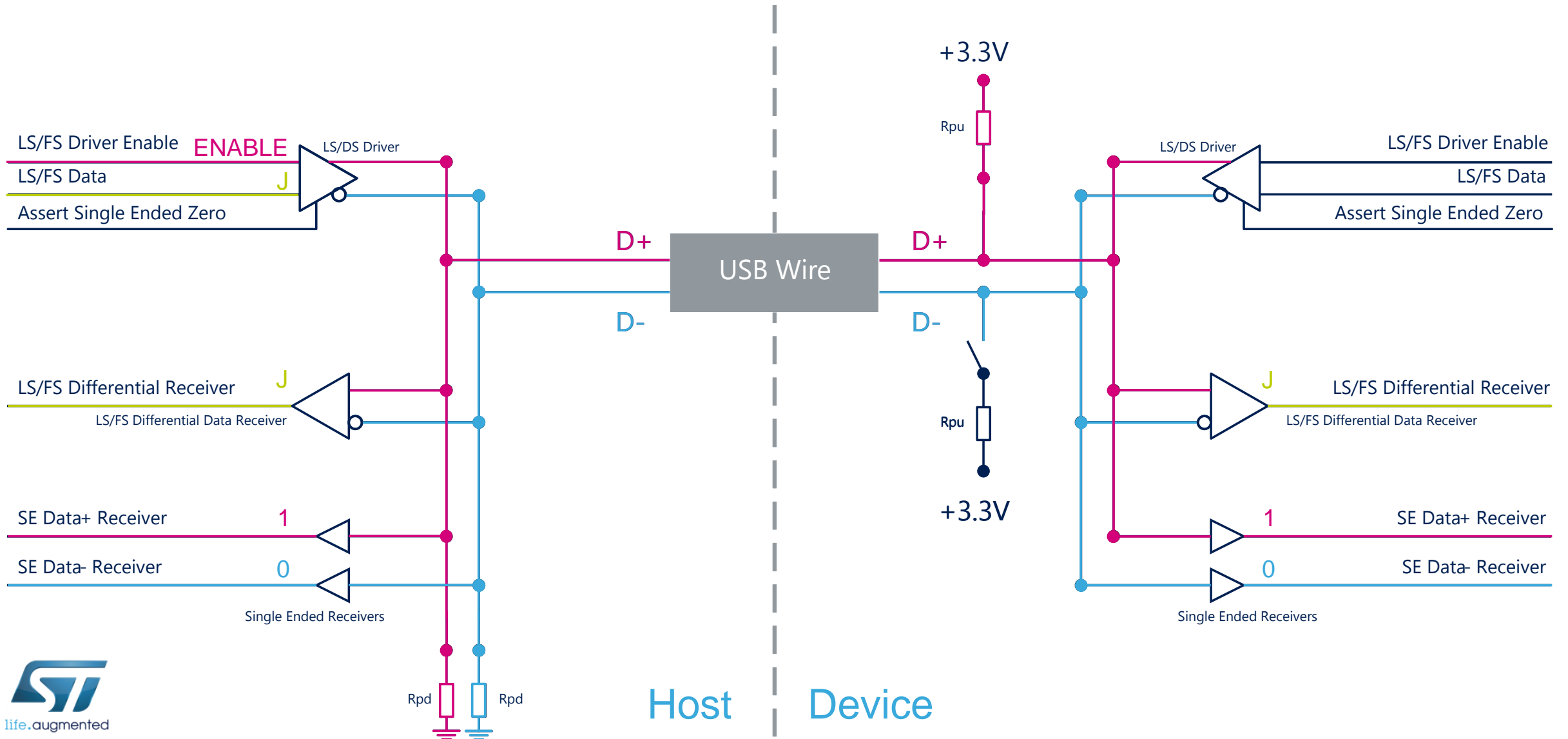
Give information about D+ & D- state





J-State (FS)

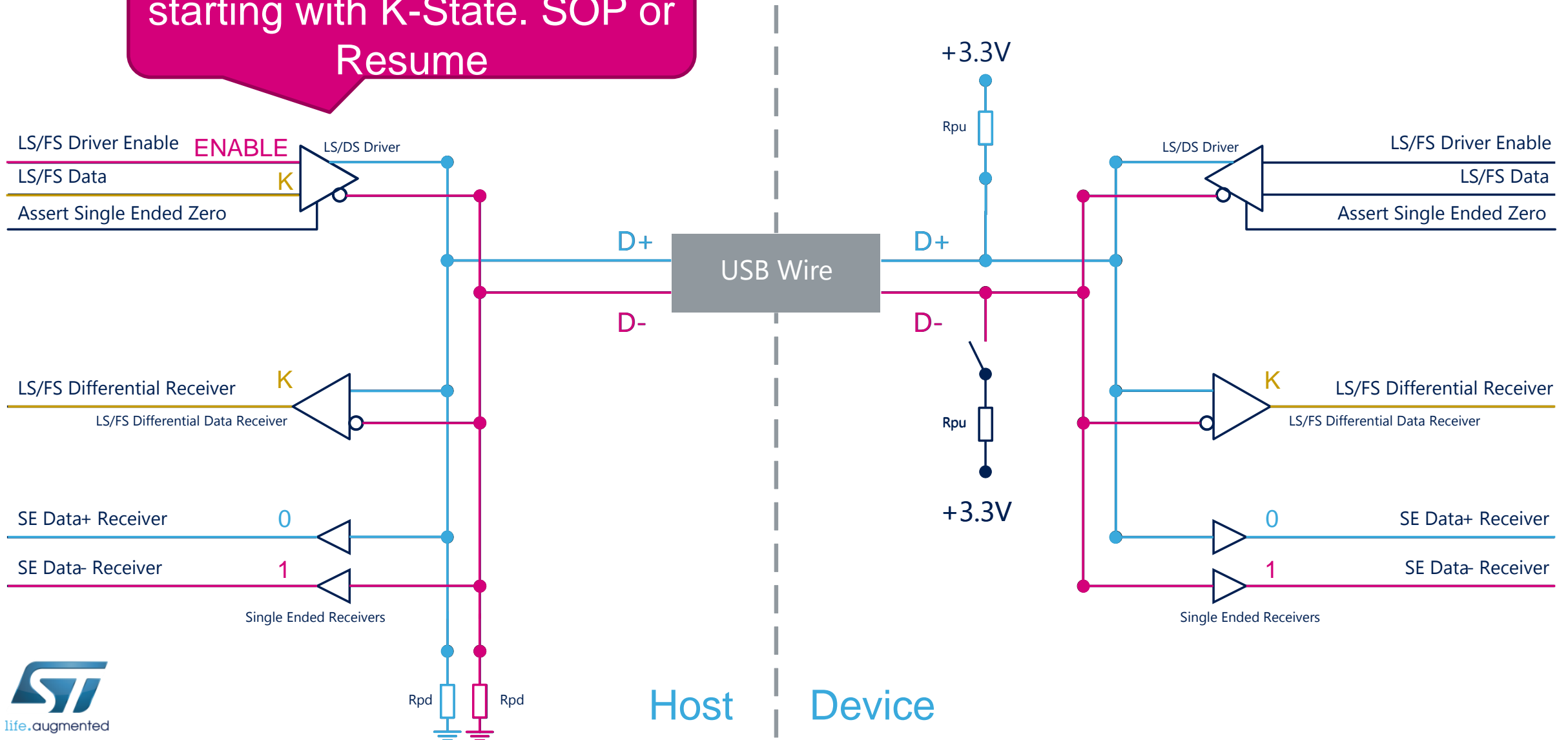
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K-State (FS)

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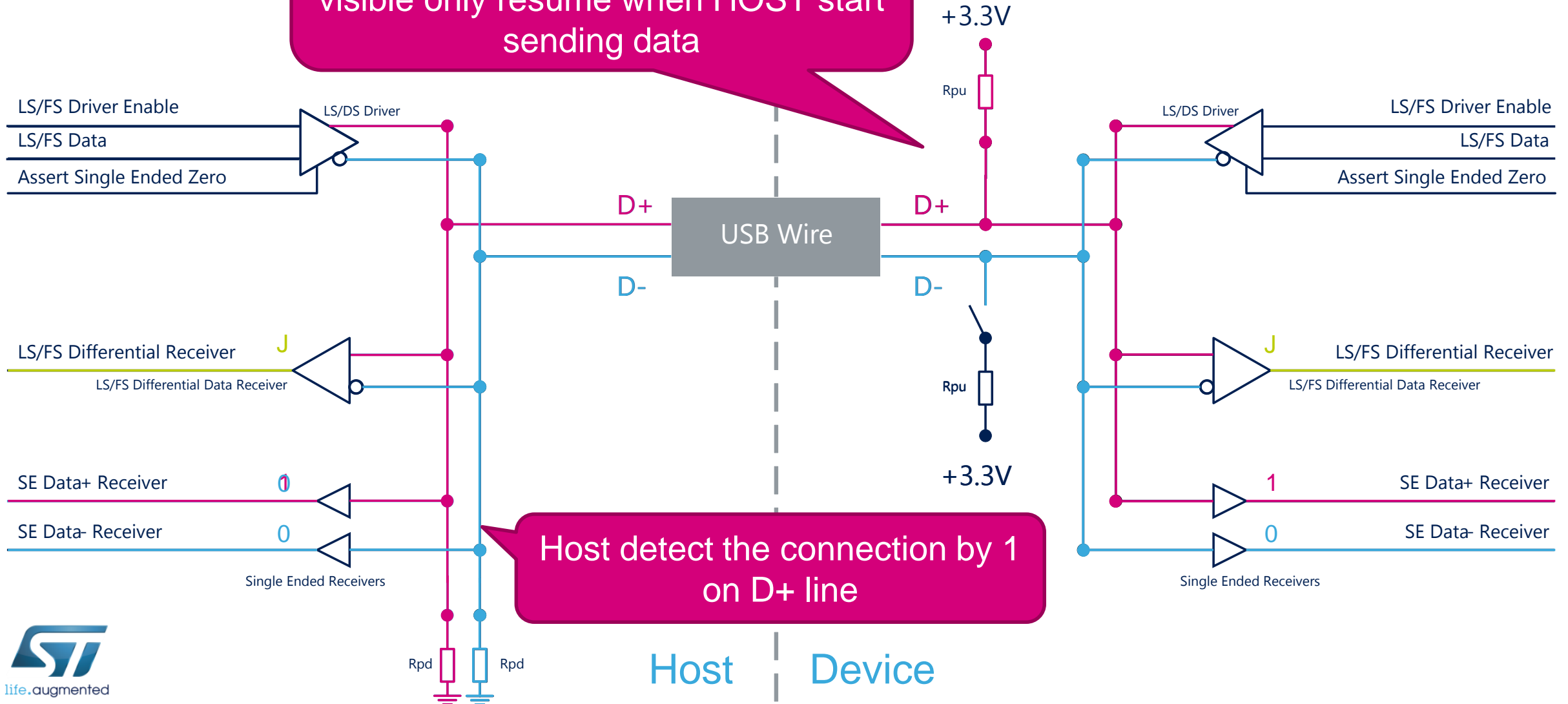
Each communication starting with K-State. SOP or Resume



Connect (FS)

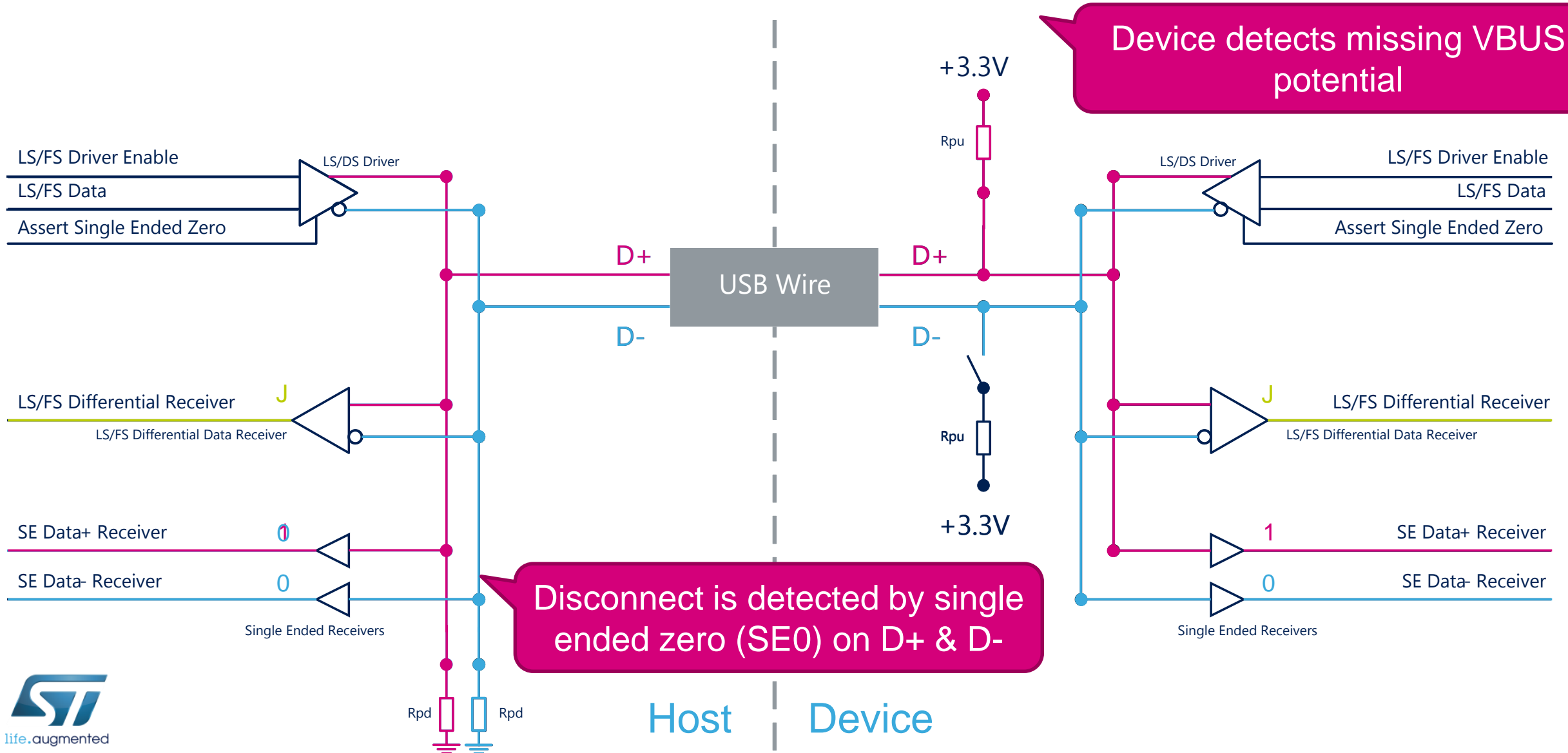
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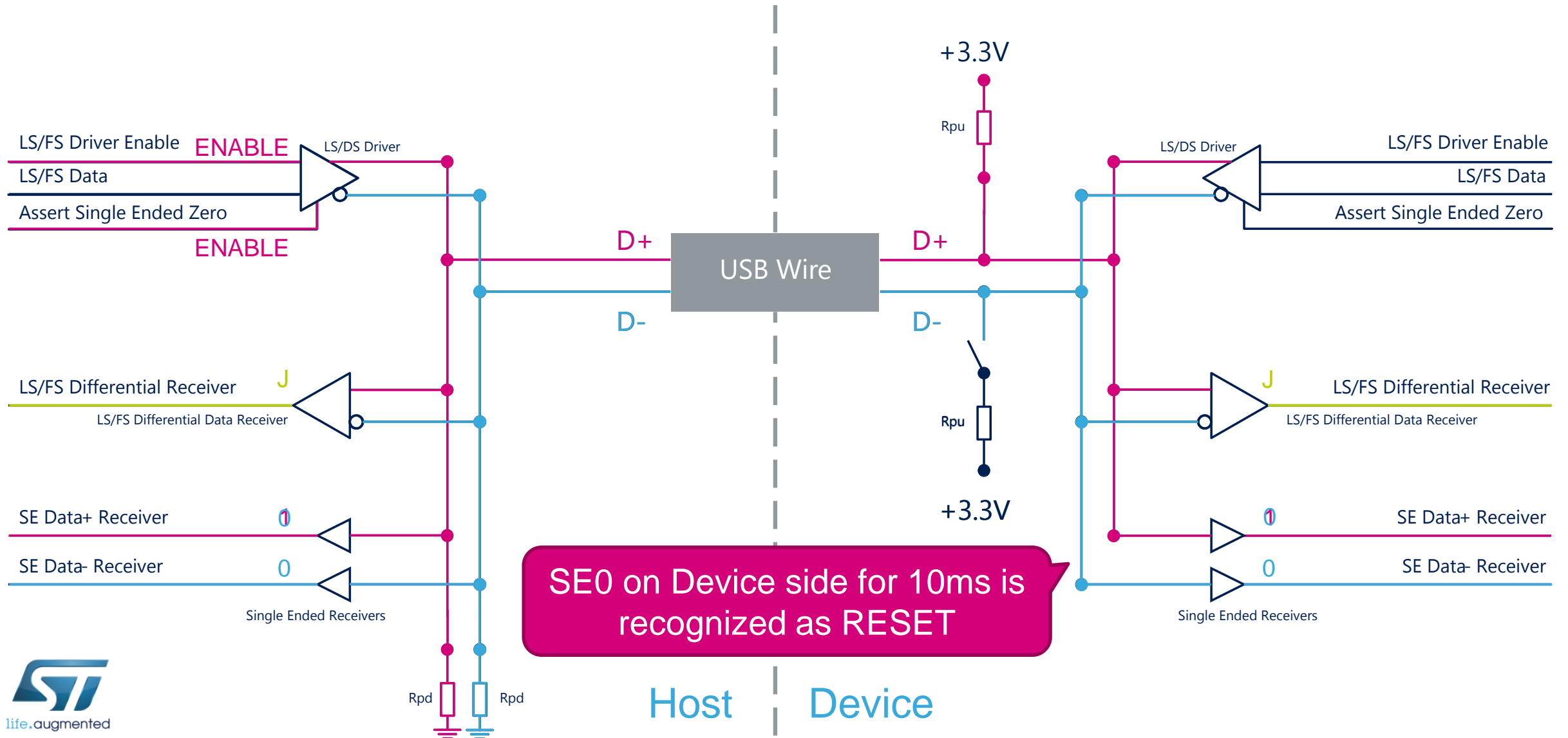
Device detect the connection from VBUS +5V presence, on bus is visible only resume when HOST start sending data



Connect (FS)

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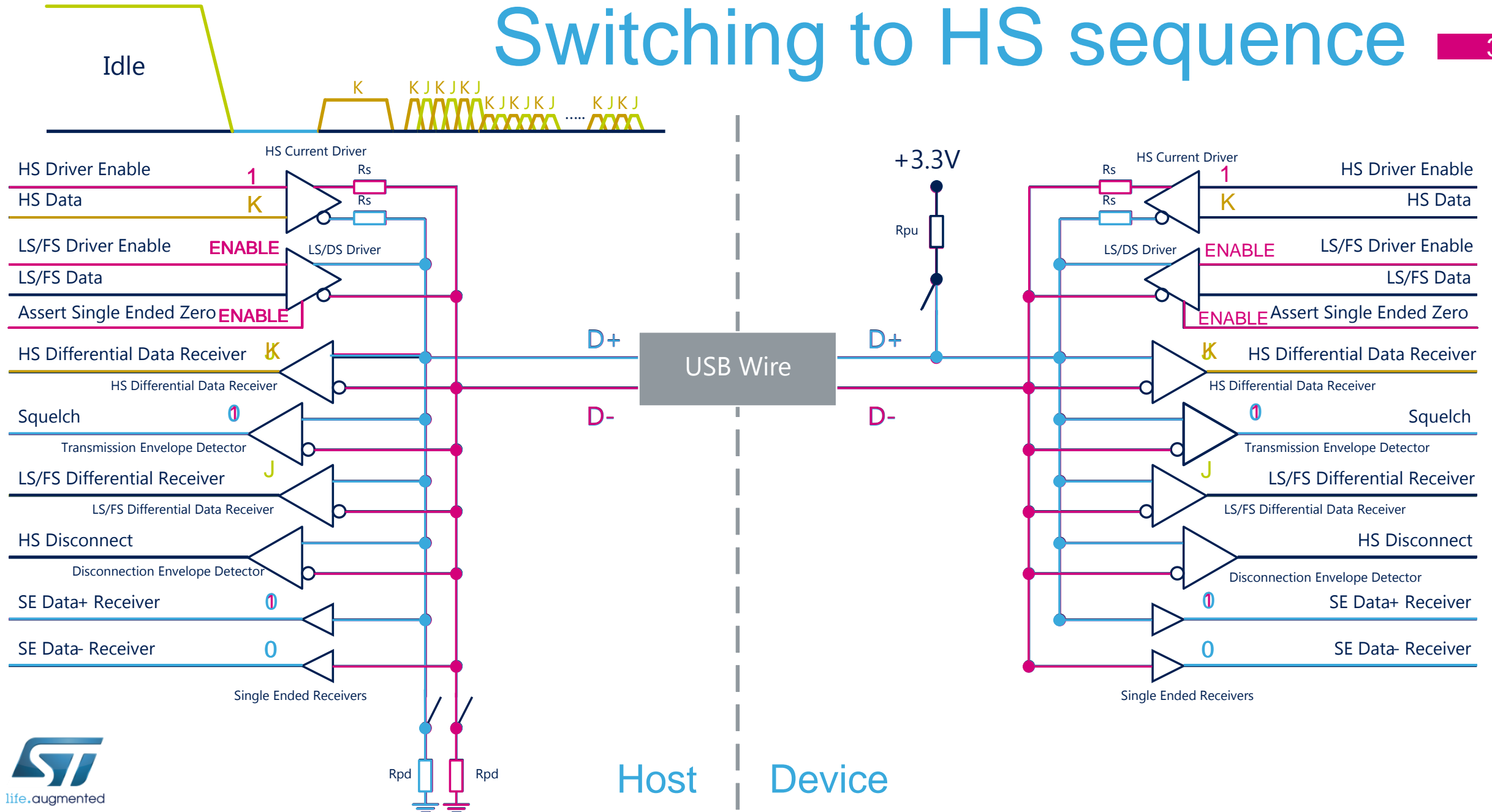
Switching to high-speed

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- USB reset signaled by driving both lines (D+ and D-) low by host for 10ms
- High-speed uses different signaling than full-speed / low-speed
- Special chirp handshake done during USB reset
 - Device sends the chirp sequence (if it supports HS)
 - Host/HUB sends response to chirp sequence (if it supports HS)
 - If handshake was successful, communication starts in HS with pull-up disconnected after USB reset is finished
- Also additional descriptors must be defined
 - Full-speed only USB host/hub can recommend user to switch to high-speed port
- Every HS device must support FS communication

Switching to HS sequence

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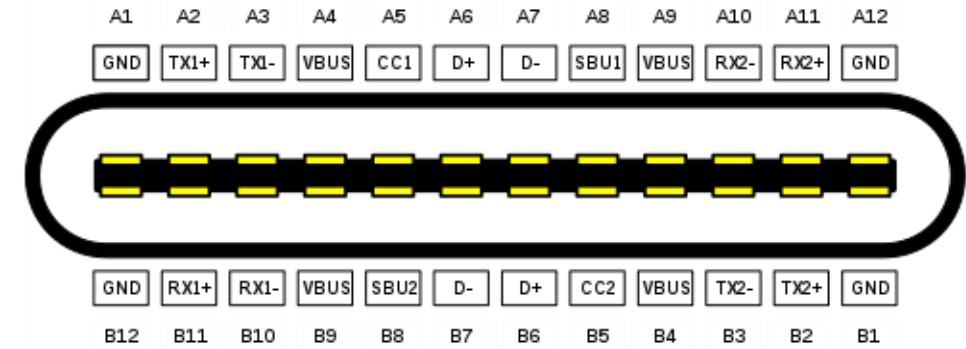


- Link power management
 - Specifies **2 additional** low-power states
 - L0 On – device running
 - **L1 Sleep – Same as suspend, but faster entry and no consumption limitation**
 - L2 Suspend – suspend by missing SOFs
 - **L3 Off – Device powered down**
- Battery charging detection
 - Can detect USB charging equipment
 - Device can draw more current from the port

USB-C and power delivery

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- USB-C is new type of connector for both host and device
 - Can be plugged both ways (180° rotation)
 - Supports other interfaces (HDMI, Display port, Ethernet, audio, authentication)
 - Need special negotiation / error handling (e.g. when 2 hosts are connected)
 - USB-C ≠ USB 3.x
- It allows “USB power delivery”
 - Higher voltage and current flow through the cable
 - This requires good quality cable
 - Power flow doesn't depend on host / device role
 - Can work as separate channel (independent of the USB communication)
 - Communication on CC lines
- Example: Power bank connected to laptop via USB-C
 - When laptop is not connected to power source, it will be powered from power bank
 - When laptop is connected to power source, it will charge the power bank



- USB On-the-Go (OTG)

- Selecting the default role (device / host) based on the connected cable

- Detected through the ID signal
- Allows compatibility with device-only and host-only devices

- Can switch roles at runtime through negotiation process

- Host negotiation protocol (HNP)
- Only point-to-point connection
- Not supported by ST library, but HW is capable

- Requires micro-AB receptacle

- It accepts both micro-A and micro-B connectors

- Examples:

- Smart phones, tablets, cameras (file storage)
 - device when connected to PC
 - host when USB disk is connected or HID device (keyboard, mouse) is connected

