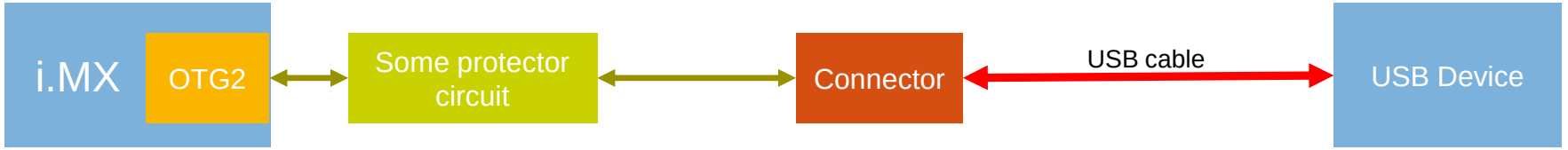
USB ISSUE CASE STUDY:
HIGH SPEED DISCONNECTION ISSUE

I.MX CAS

2023/05

Issue Description

- SoC Platform: i.MX8QXP C0
- USB design:
  - USB3 (OTG2) port used as USB2.0 in host mode to connect to an external modem (device).



- Issue Description:
  - Reported through production line: <0.1% of unit failed to recognize the external device.
  - System log shows USB recognition started but failed at several different stages during handshake.

System log analysis:

From Linux driver perspective, several different phenomenon found while the final result is the same: enumeration failure

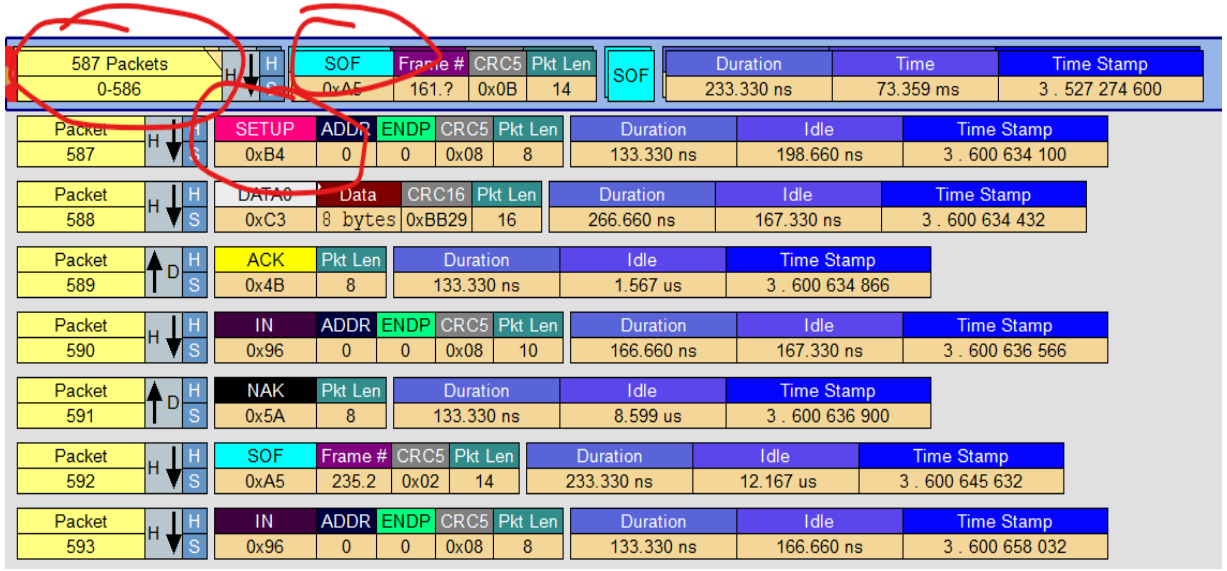
usb usb1-port1: Cannot enable. Maybe the USB cable is bad?
usb usb1-port1: Cannot enable. Maybe the USB cable is bad?
usb usb1-port1: attempt power cycle
usb usb1-port1: Cannot enable. Maybe the USB cable is bad?
usb usb1-port1: Cannot enable. Maybe the USB cable is bad?
usb usb1-port1: unable to enumerate USB device

new high-speed USB device number 13 using cdns-usb3
Device not responding to setup address.
Device not responding to setup address.
device not accepting address 13, error -71

new high-speed USB device number 6 using cdns-usb3
USB disconnect, device number 6

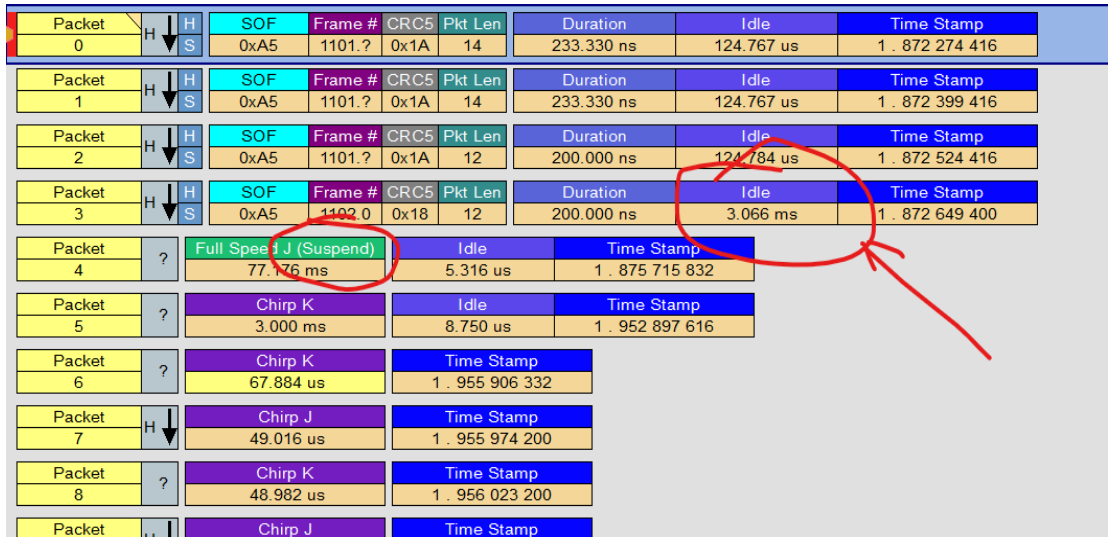
USB protocol analysis

- USB packet analysis done through USB analyzer (LeCroy)



587 Packets 0-586			SOF	Frame #	CRC5	Pkt Len	SOF	Duration	Time	Time Stamp
	H	H S	0xA5	161.?	0x0B	14		233.330 ns	73.359 ms	3 . 527 274 600

Packet			SETUP	ADDR	ENDP	CRC5	Pkt Len	Duration	Idle	Time Stamp
587	H	H S	0xB4	0	0	0x08	8	133.330 ns	198.660 ns	3 . 600 634 100
Packet			DATA0	Data	CRC16	Pkt Len		Duration	Idle	Time Stamp
588	H	H S	0xC3	8 bytes	0xBB29	16		266.660 ns	167.330 ns	3 . 600 634 432
Packet			ACK	Pkt Len				Duration	Idle	Time Stamp
589	D	H S	0x4B	8				133.330 ns	1.567 us	3 . 600 634 866
Packet			IN	ADDR	ENDP	CRC5	Pkt Len	Duration	Idle	Time Stamp
590	H	H S	0x96	0	0	0x08	10	166.660 ns	167.330 ns	3 . 600 636 566
Packet			NAK	Pkt Len				Duration	Idle	Time Stamp
591	D	H S	0x5A	8				133.330 ns	8.599 us	3 . 600 636 900
Packet			SOF	Frame #	CRC5	Pkt Len		Duration	Idle	Time Stamp
592	H	H S	0xA5	235.2	0x02	14		233.330 ns	12.167 us	3 . 600 645 632
Packet			IN	ADDR	ENDP	CRC5	Pkt Len	Duration	Idle	Time Stamp
593	H	H S	0x96	0	0	0x08	8	133.330 ns	166.660 ns	3 . 600 658 032



Packet			SOF	Frame #	CRC5	Pkt Len	Duration	Idle	Time Stamp
0	H	H S	0xA5	1101.?	0x1A	14	233.330 ns	124.767 us	1 . 872 274 416
Packet			SOF	Frame #	CRC5	Pkt Len	Duration	Idle	Time Stamp
1	H	H S	0xA5	1101.?	0x1A	14	233.330 ns	124.767 us	1 . 872 399 416
Packet			SOF	Frame #	CRC5	Pkt Len	Duration	Idle	Time Stamp
2	H	H S	0xA5	1101.?	0x1A	12	200.000 ns	124.784 us	1 . 872 524 416
Packet			SOF	Frame #	CRC5	Pkt Len	Duration	Idle	Time Stamp
3	H	H S	0xA5	1102.0	0x18	12	200.000 ns	3.066 ms	1 . 872 649 400
Packet			Full Speed J (Suspend)				Idle	Time Stamp	
4	?		77.176 ms				5.316 us	1 . 875 715 832	
Packet			Chirp K				Idle	Time Stamp	
5	?		3.000 ms				8.750 us	1 . 952 897 616	
Packet			Chirp K				Time Stamp		
6	?		67.884 us				1 . 955 906 332		
Packet			Chirp J				Time Stamp		
7	H		49.016 us				1 . 955 974 200		
Packet			Chirp K				Time Stamp		
8	?		48.982 us				1 . 956 023 200		
Packet			Chirp J				Time Stamp		

Normal Case

Failure Case

- Comparing to normal case, the host doesn't send out SOF packet in failure case. The USB bus enters suspend state.
- From the USB spec. a disconnection event is one of the major cause for host to stop sending SOF in this case.

USB Spec – Host Disconnect behavior

UTMI+ Specification, Revision 1.0, February 25th , 2004

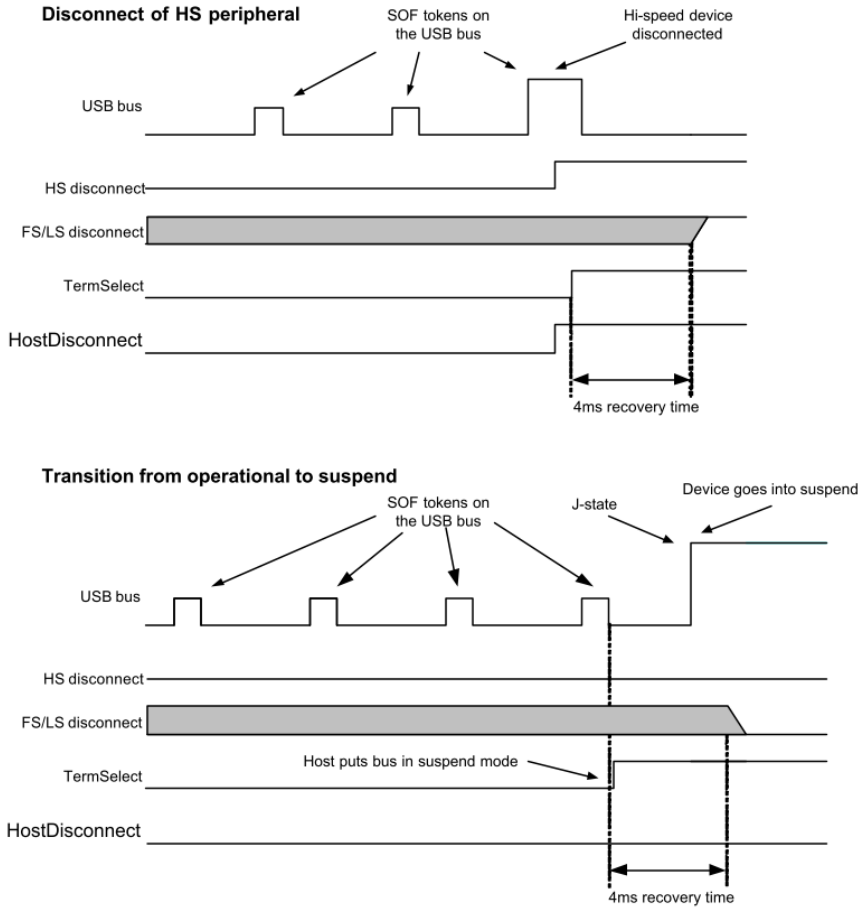


Figure 4 : HostDisconnect behaviour (signals are not on scale)

In HS mode, a disconnect condition is evaluated every time a HS SOF packet is sent. If a disconnect is detected, hostdisconnect is asserted.

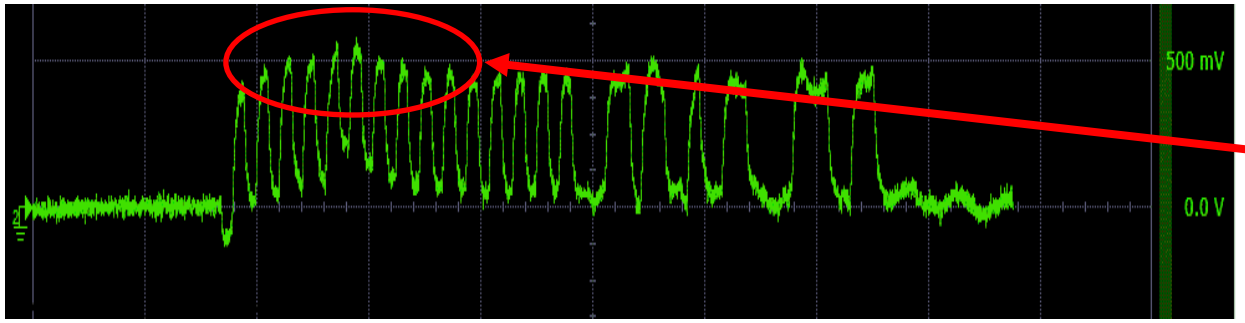
When hostdisconnect is asserted in high-speed mode the transceiver is placed into full-speed mode by the host core. Also when the host core wants to put the USB bus (which has a hi-speed device connected) into suspend mode, it switches the transceiver from hi-speed mode into full-speed mode. At that moment the connected hi-speed device is still in hi-speed and the USB bus state is still in SE0. To prevent false full-speed connect/disconnects, the hostdisconnect signal cannot be updated for 4 ms from the transition into full-speed. After the 4 ms recovery time the status of the full-speed connect/disconnect can be determined and the hostdisconnect signal updated accordingly. The 4 ms of recovery time allows the peripheral device connected to the host to detect the suspend signaling on the USB bus, move into the FS suspend mode and bring the USB bus to the Full Speed Idle state (Jstate).

- Disconnection Envelope Detector

This envelope detector is required in downstream facing ports to detect the high-speed Disconnect state on the line (VHSDSC). Disconnection must be indicated when the amplitude of the differential signal at the downstream facing drivers connector is more than 625 mV, and it must not be indicated when the signal amplitude is below 525 mV. The output of this detector is sampled at a specific time during the transmission of the high-speed SOF EOP,

- According to UTMI+ spec, a disconnect condition is evaluated every time a HS SOF packet is sent. If a disconnect is detected , USB bus may put into Full speed Idle state(J state).

USB Signal Analysis



Failure Case – USB DP signal

By default, the threshold of USB disconnection detector is 575mV.

USB DP voltage was found to be very close to this threshold. This may lead to un-expected disconnection event during HS stage (SOF, SETUP, etc.)

Address [bits]	value	Comments
0x5B198034[7:6]	00	By default, and the threshold is 575mv
	01,10	Increase threshold by ~35mv
	11	Increase threshold by ~70mv

- The disconnection is detected by sampling the transmission of high-speed SOF EOP at a specific time, if the swing of DP/DM is higher than the threshold. The threshold could range from 525mv to 625mv according to USB2.0 spec. Register 0x5B198034[7:6] could be used to adjust it.

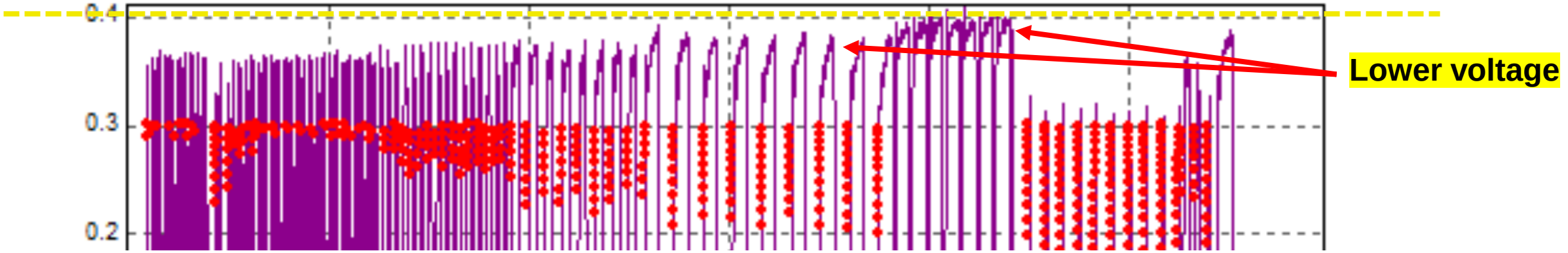
After increasing threshold of disconnection detector by 35mv (0x5B198034[7:6] = 01), USB device can be recognized on failure unit.

Additional experiment on signal

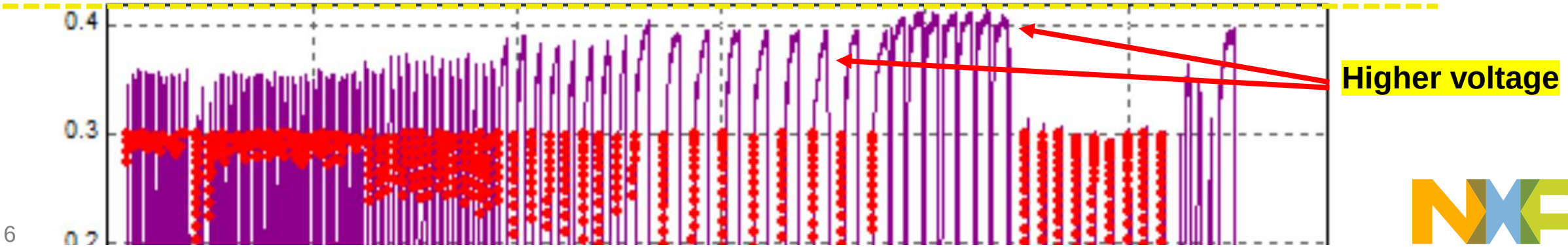
To double confirm the analysis in USB signal: On failure unit, the following experiment was also performed:

Enable HS Tx De-emp Amplitude tuning process and lower the swing of DP/DM slightly. So the voltage of SoF EOP will be lower than the disconnection threshold (575mv). The issue was gone after this change.

Good Case with Updated Tx Amplitude setting(REG1=0x3f &REG12=0x03)



NG Case with default setting (REG1=0x00 &REG12=0x00)



Leading Theory and Proposed solution

Leading theory:

- Disconnection is detected during enumeration process, which may cause USB bus enter idle and suspend state without sending SOF packet, finally fail to recognize USB device.

- The ramp of the single-ended voltage on DP/DM during HS stage might be caused by multiple reasons. Major contributor is the signal reflect due to impedance discontinuous. This reflection may strengthen the level of the signal due to phase superposition.

- USB signal integrity depends on many factors, such as circuit design, Impedance etc. Users can fine-tune parameters in order to obtain the best signal quality and meet application requirements.

Proposed solution:

- Increase threshold of disconnection detector by 35mv (0x5B198034[7:6] = 01). New threshold of disconnection detector will be 610mv.

Impact Analysis

According to USB spec, disconnection must be indicated when the amplitude of differential signal is more than 625mv, and must no be indicated when it’s below 525mv. New threshold value (610mv) follows the spec.

Some possible impacts even new value is in-spec:

- This change will directly affect how the host recognize a device. So, if this USB port requires to support USB hot-plug feature, recommend to perform USB hot-plug stress tests.
- USB signal integrity is also related to temperature. Recommend to consider temperature test.
- USB related system stress test.

FTA – USB CONNECTION ISSUE

POSSIBLE FACTORS WHICH MAY CAUSE USB CONNECTION ISSUE (HOST)

- **Hardware:**
  - **High speed signal integrity**

    Will ensure the high speed differential signal compliant with the standard. Normally guaranteed by USB-IF test which includes eye pattern test.
  - **Single-ended electrical characteristic**

    Will impact some stages of the recognition, such as insert detection and disconnection detection.
  - **Connector and cable electrical characteristic**

    Will normally impact the recognition during hot-plug. Static characteristic of the connector and cable are guaranteed by the standard. But dynamic factor, such as how the connector is plugged into the female connector will have dramatical impact on recognition.
- **Software:**
  - **Negotiation scheme**

    Different USB host/device implementation may have different logic for improving compatibility. For Linux, some parameters can be tuned to adapt more devices. Refer to: "drivers/usb/core/hub.c".
  - **Recognition workaround/quirks**

    Some special devices can't be recognized correctly through "standard" sequence. Linux provides some workarounds to adapt some special needs from these kind of devices, which is called as "quirks". Refer to: "drivers/usb/core/quirks.c".

Possible factors which may cause USB connection issue (HOST), Cont'd

- **Software:**
  - **Driver, especially gadget/class driver**

    Gadget driver will be involved in second stage of USB handshake. If the SETUP package for this stage is not properly handled by gadget driver, the handshake/recognition will also fail. This normally happens on some customized gadget drivers.
- **Power management:**
  - **Auto suspend**:

    This is a USB feature which can let host enter suspend status under defined condition. This may cause problem in some use scenarios.
  - **Dynamic PM:**

    This is a Linux kernel feature which allows device to be put into suspend when not used. This will also impact USB under some corner cases.
  - **Link Power Management (LPM)**:

    Some devices may not be able to support this feature and requires host driver to disable it manually. This can also be done through quirk (USB_QUIRK_NO_LPM).
- **Others**
  - **Device type:** Different device types have different HW/SW standards and also require different power supply. LS (Low Speed)/FS (Full Speed)/HS (High Speed)/SS (Super Speed).

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