Universal Serial Bus

- Universal Serial Bus is a new synchronous serial protocol for low to medium speed data transmission
- Full speed signaling 12 Mbs
- Low Speed signaling 1.5 Mbs
- Intended devices are keyboards, mice, joysticks, speakers; other low to medium speed IO devices

PERFORMANCE	APPLICATIONS	ATTRIBUTES
LOW SPEED •Interactive Devices •10-100 Kb/s	Keyboard, Mouse Stylus Game peripherals Virtual Reality peripherals Monitor Configuration	Lower cost Hot plug-unplug Ease of use Multiple peripherals
MEDIUM SPEED •Phone, Audio, Compressed Video 500Kb/s - 10Mbp/s	ISDN PBX POTS Audio	Low cost Ease of use Guaranteed latency Guaranteed Bandwidth Dynamic Attach- Detach Multiple devices
HIGH SPEED •Video, Disk •25-500 Mb/s	Video Disk	High Bandwidth Guaranteed latency Ease of use

Figure 3-1. Application Space Taxonomy

Physical Topology is point-to-point tree.

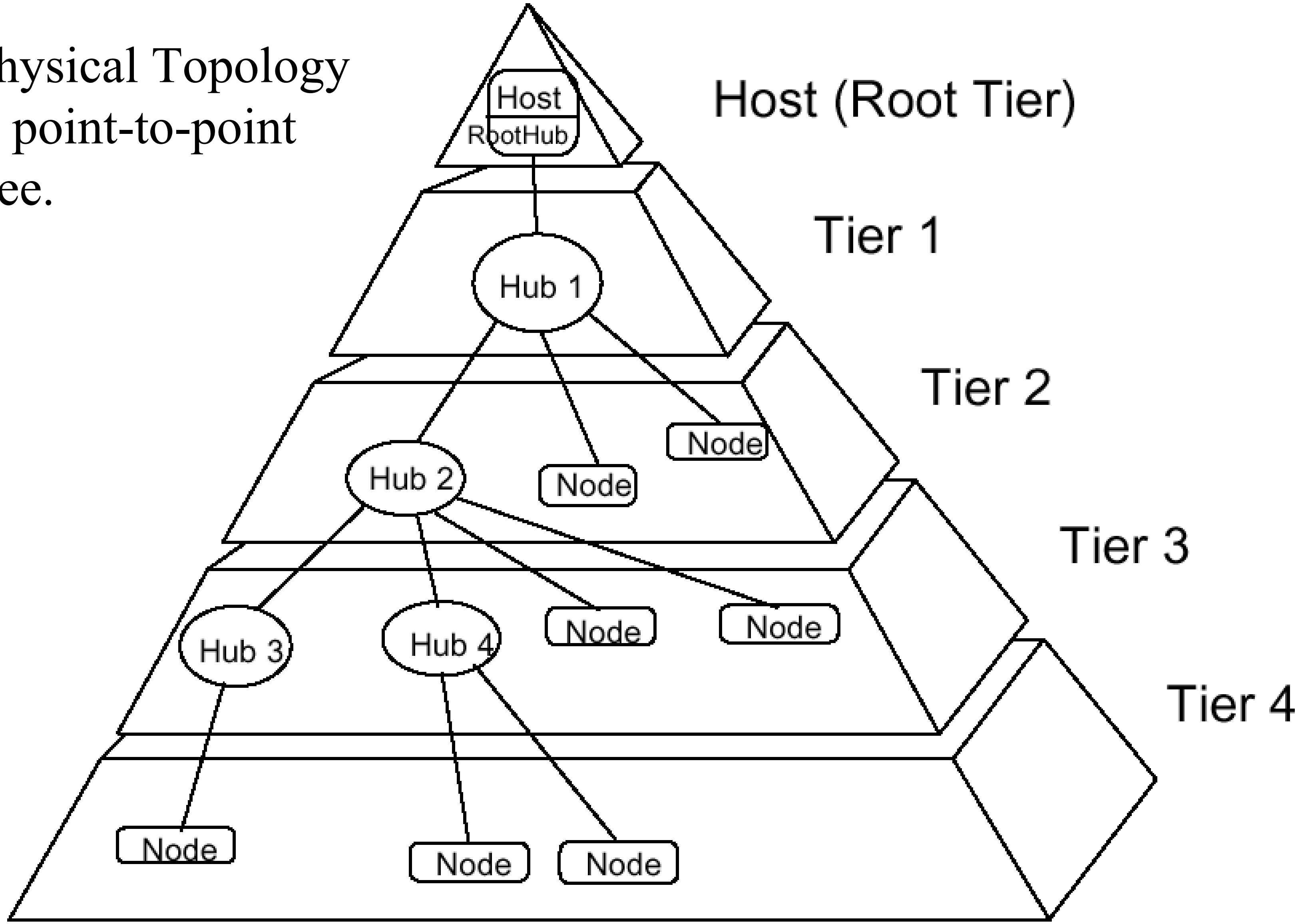


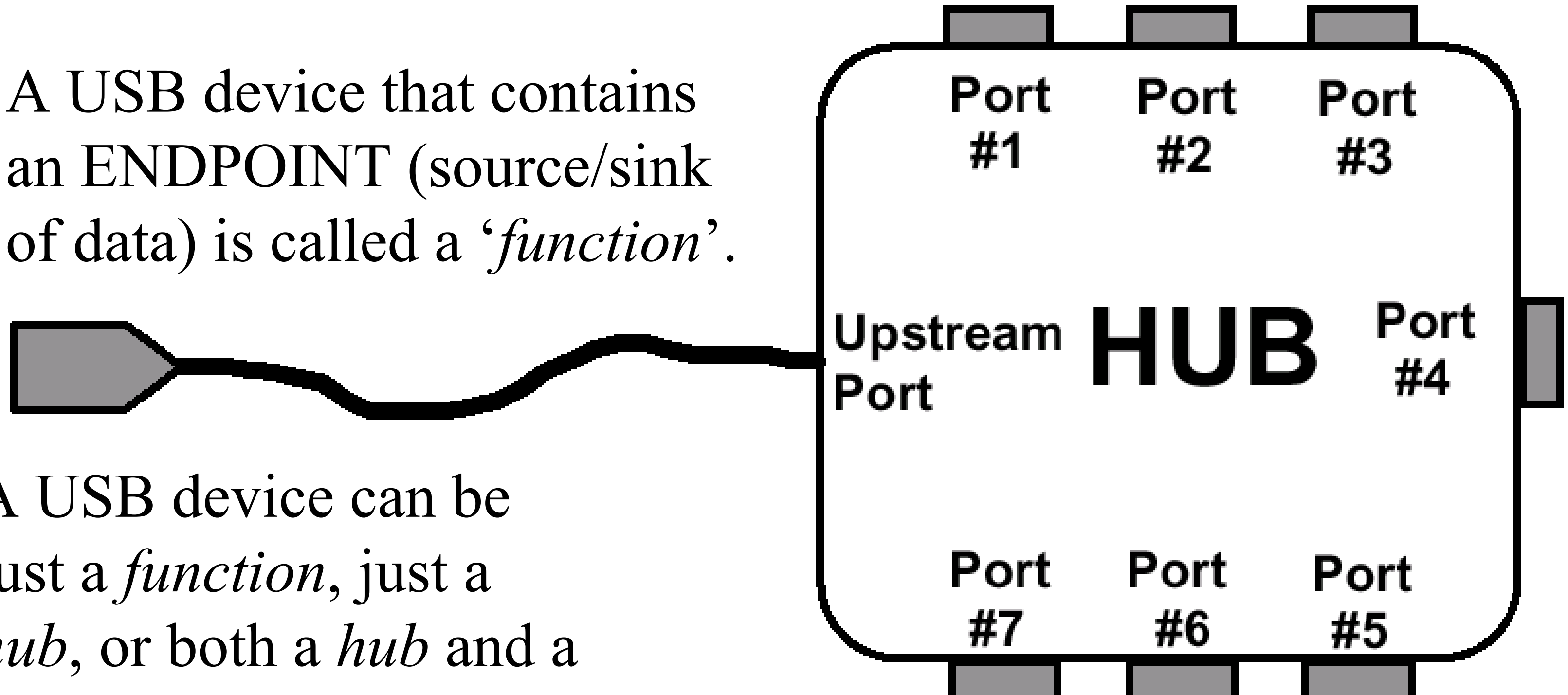
Figure 4-1. Bus Topology

Root: primary contoller

Hub: allows the connection of multiple USB devices

Endpoint: Source or sink of information within a USB device

A USB device that contains an ENDPOINT (source/sink of data) is called a '*function*'.



A USB device can be just a *function*, just a *hub*, or both a *hub* and a *function*.

Figure 4-3. A Typical Hub

Figure 4-4 illustrates how hubs provide connectivity in a desktop computer environment.

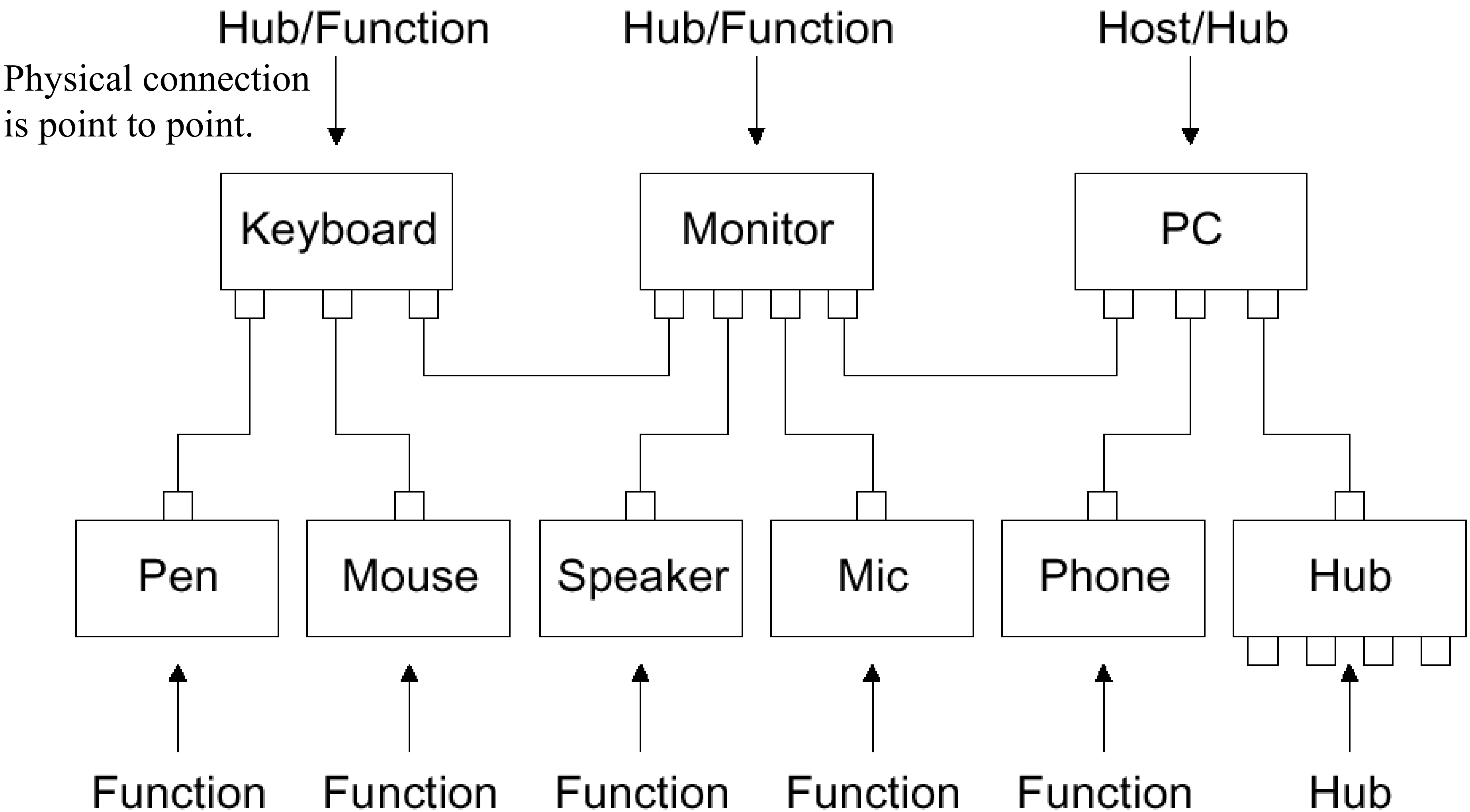


Figure 4-4. Hubs in a Desktop Computer Environment

Physical Interface

Differential Signaling, Half duplex

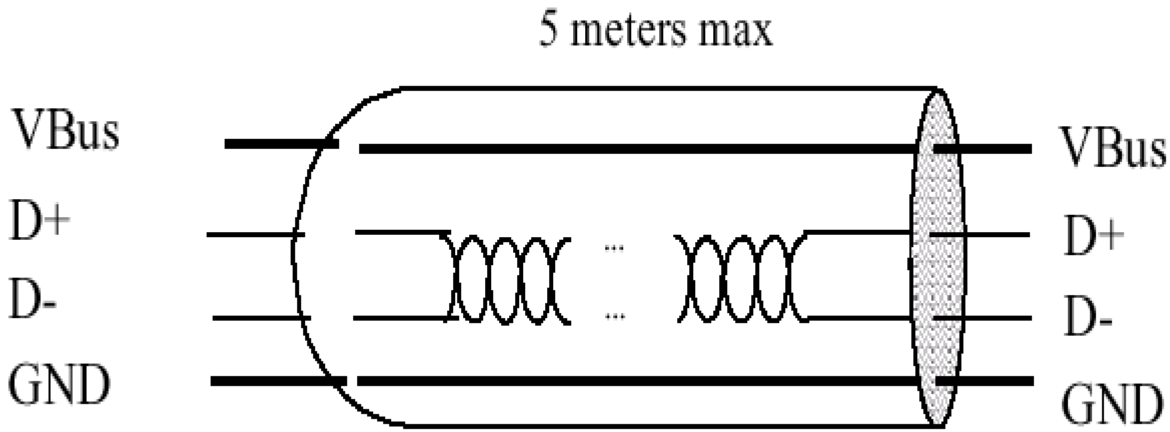


Figure 4-2. USB Cable

Full Duplex: data transmission can occur in both directions at the same time

Half Duplex: data transmission can go in only one direction at a time

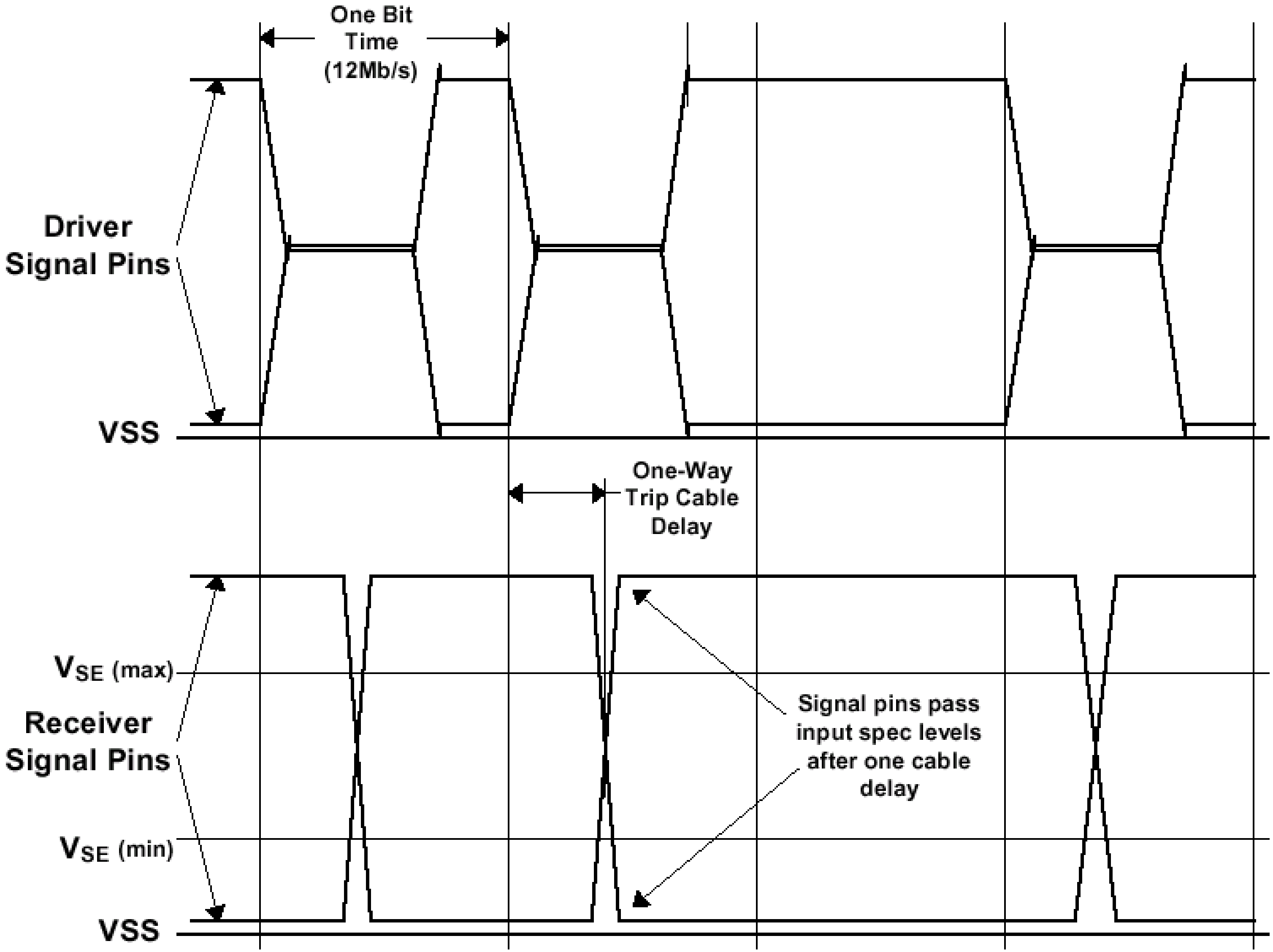


Figure 7-2. Full Speed Driver Signal Waveforms

Table 7-1. Signaling Levels

Bus State	Signaling Levels	
	From Originating Driver	At Receiver
Differential "1"	(D+) - (D-) > 200 mV and D+ or D- > V_{SE} (min.)	
Differential "0"	(D+) - (D-) < -200 mV and D+ or D- > V_{SE} (min.)	

Input Levels:					
Differential Input Sensitivity	V_{DI}	|(D+)-(D-)|, and Figure 7-4	0.2		V
Differential Common Mode Range	V_{CM}	Includes V_{DI} range	0.8	2.5	V
Single Ended Receiver Threshold	V_{SE}		0.8	2.0	V
Output Levels:					
Static Output Low	V_{OL}	RL of 1.5 kΩ to 3.6 V		0.3	V
Static Output High	V_{OH}	RL of 15 kΩ to GND	2.8	3.6	V

Vse = Voltage Single Ended threshold

On disconnect, D+, D- become same voltage value (Vss). Condition is known as a Single-Ended 0.

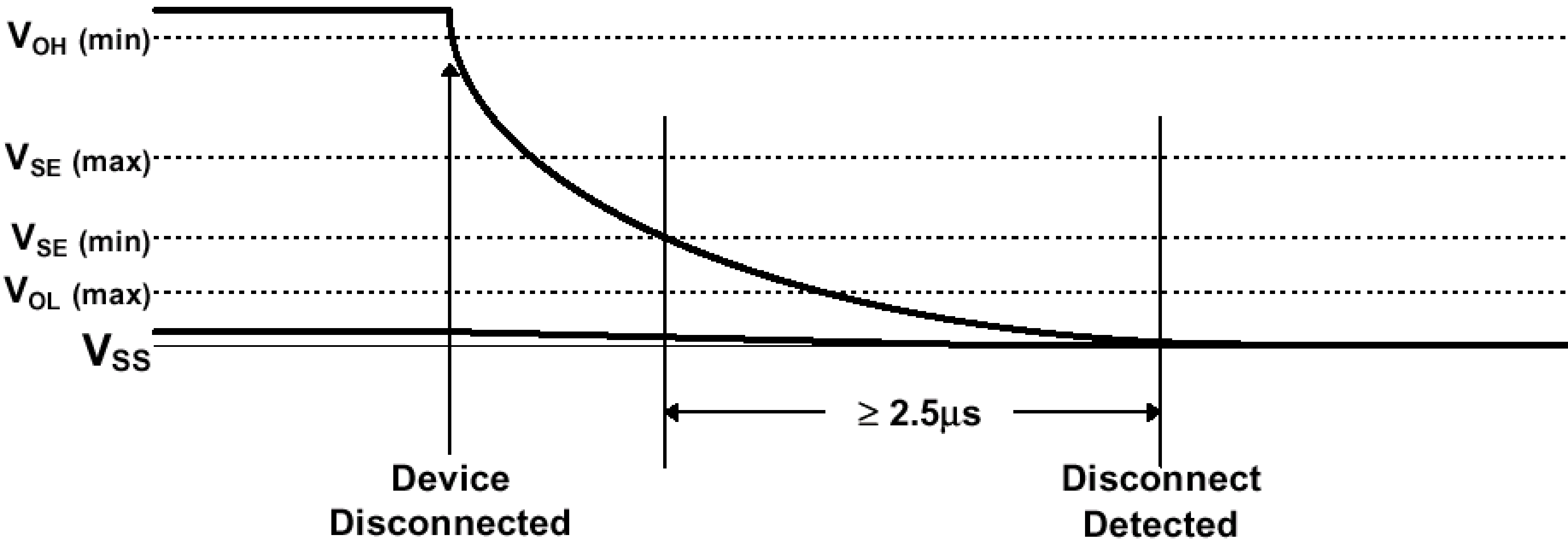


Figure 7-7. Disconnect Detection

On connection of a high-speed device, D+ > D-.
Idle state is D+ > D-, so idle state is a differential ‘1’.

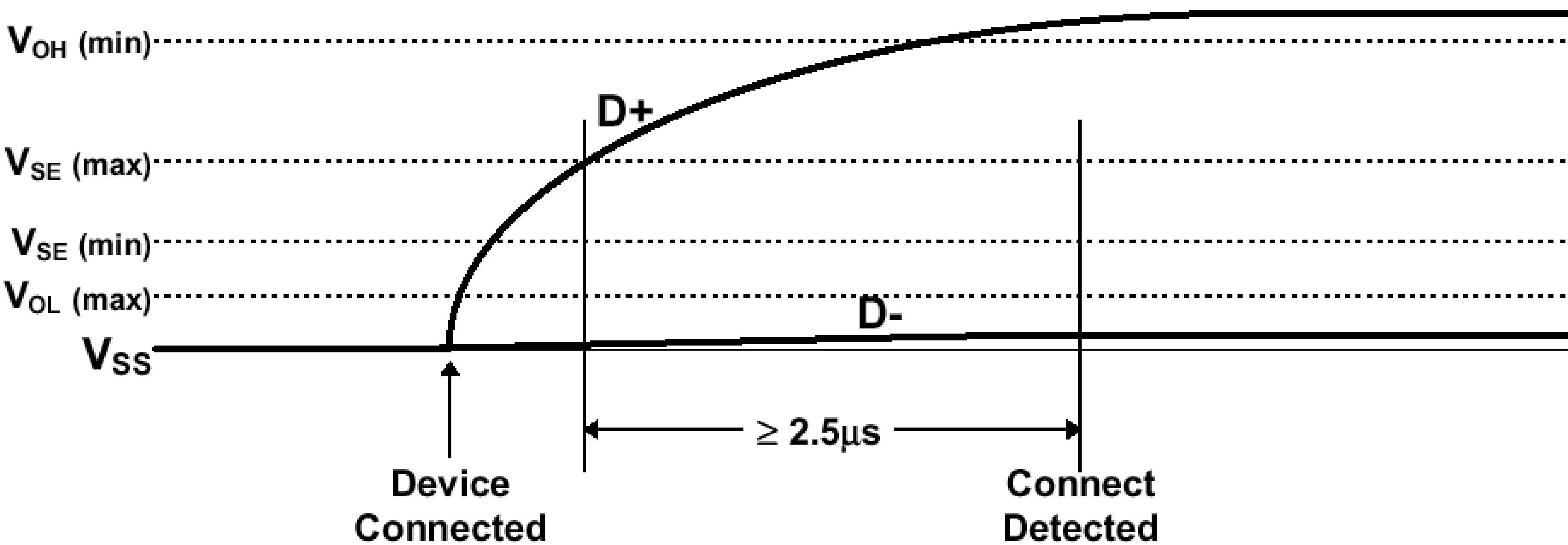


Figure 7-8. Full Speed Device Connect Detection

On connection of a low-speed device, D- > D+.
Idle state is D- > D+, so idle state is a differential '0'.

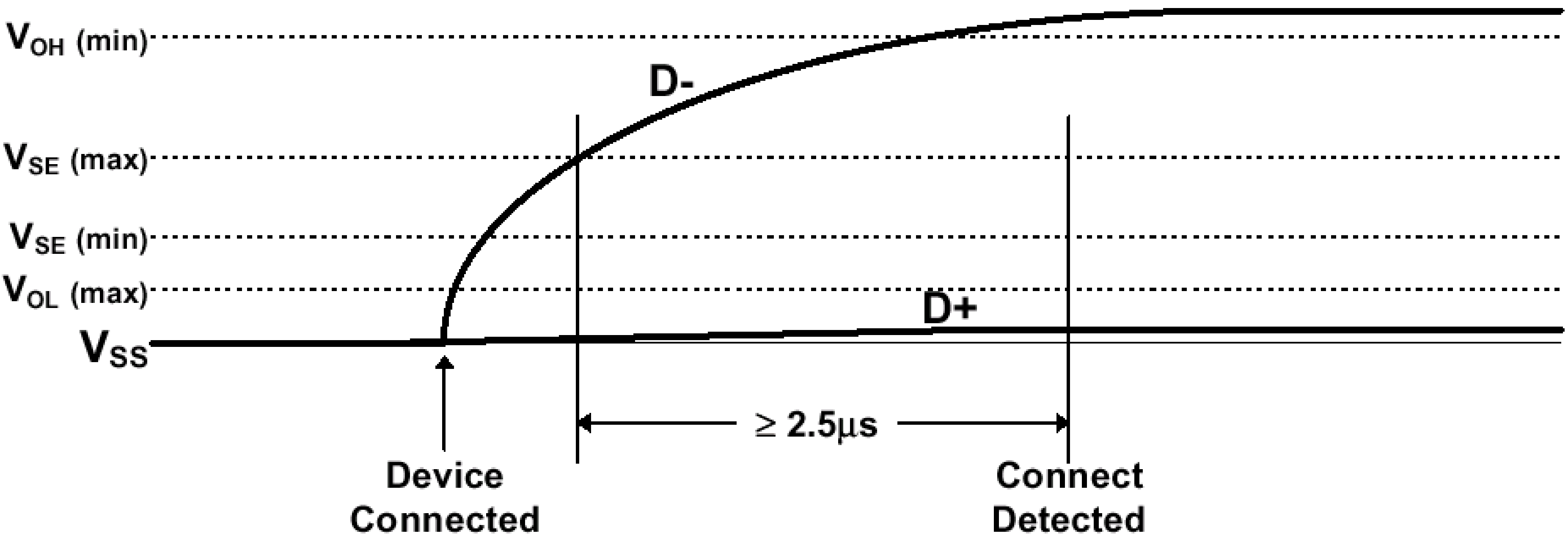
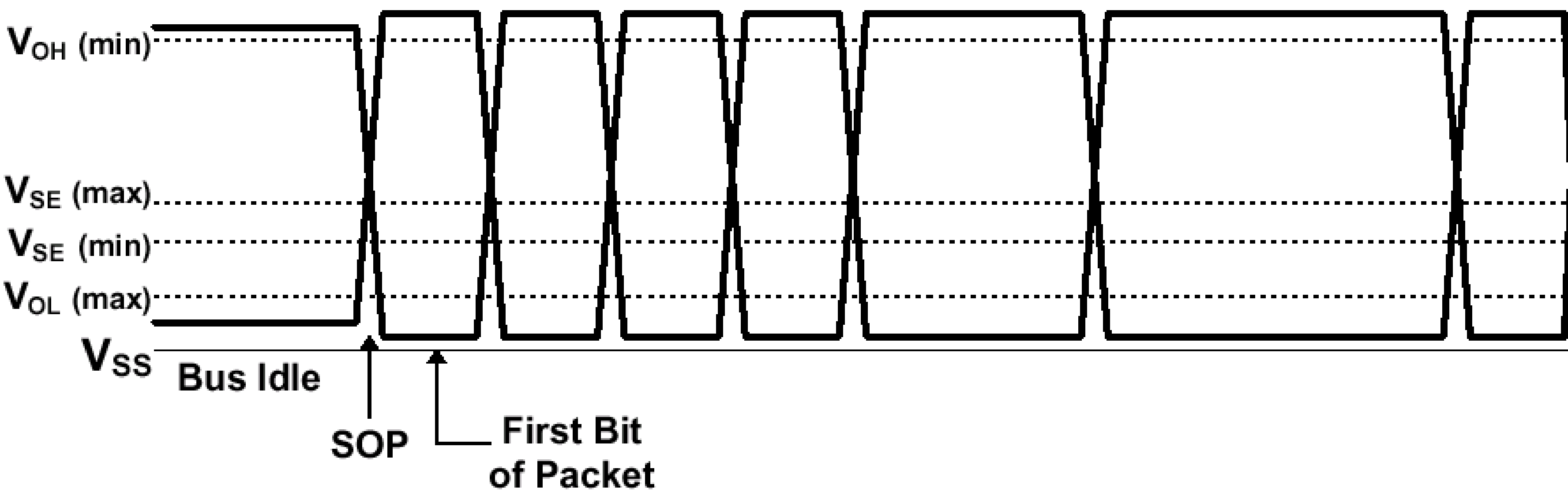


Figure 7-9. Low Speed Device Connect Detection

Data transmission



Idle State: D+, D- outside of range of VSE, at either a differential '1' (high speed) or '0' (low speed).

Active State: D+, D- transition to signal a 1 or 0

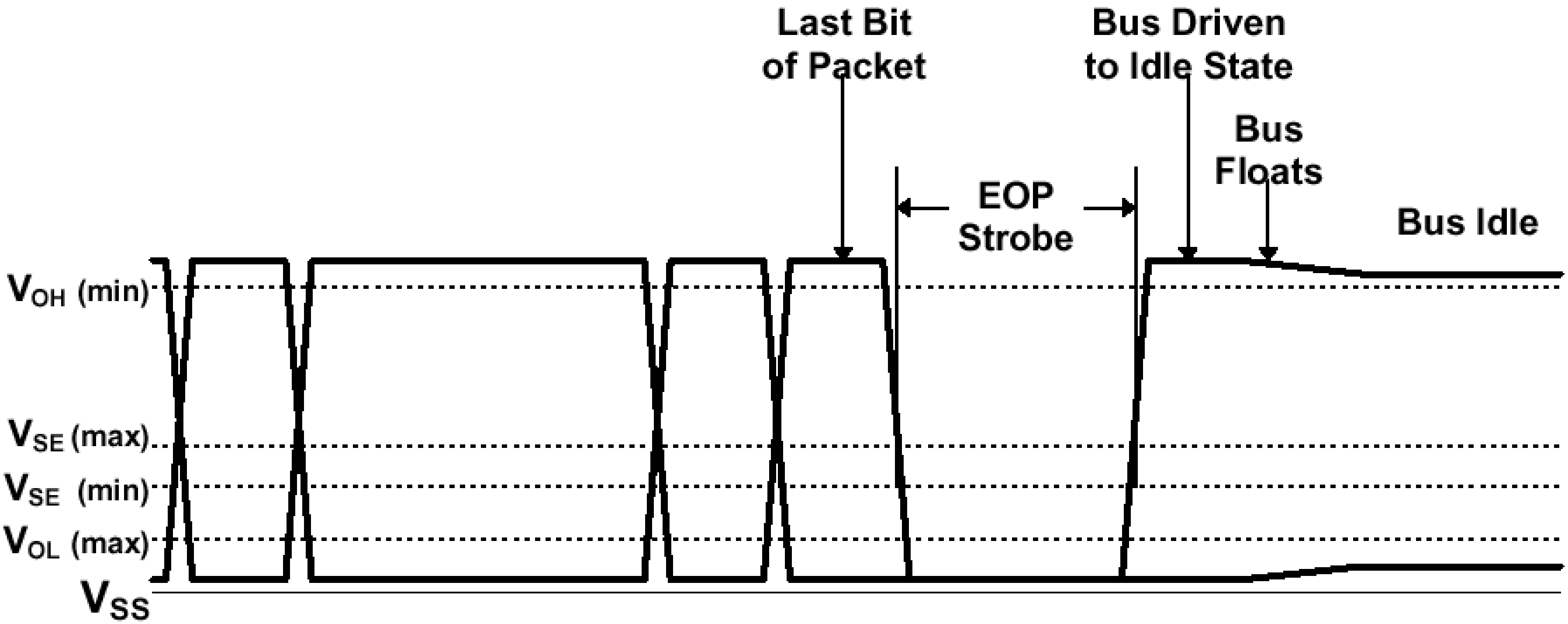


Figure 7-10. Packet Transaction Voltage Levels

Note that END OF PACKET (EOP) has D+ = D-.

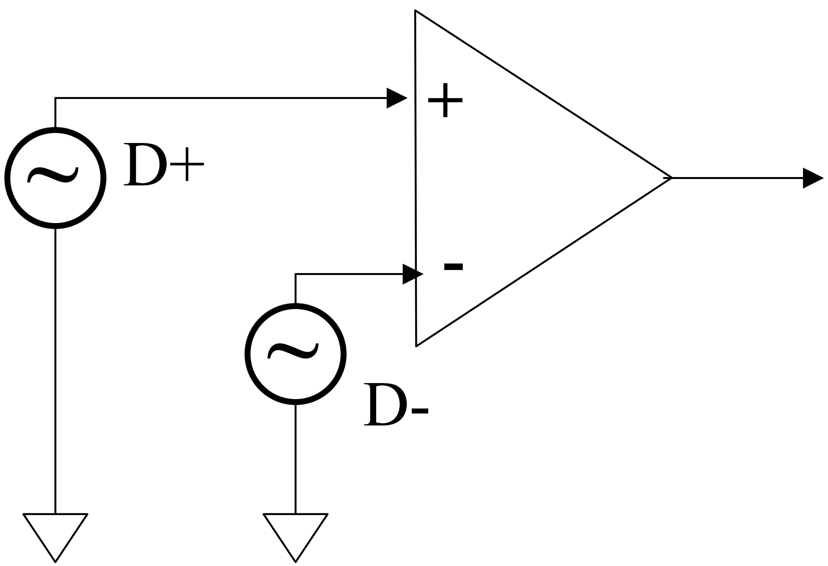
Also note 'idle' time is for turnaround time on bus to drive the other way (necessary for half-duplex communication).

Data J State:		
Low Speed	Differential "0"	
Full Speed	Differential "1"	
Data K State:		
Low Speed	Differential "1"	
Full Speed	Differential "0"	
Idle State:		
Low Speed	Differential "0" and D- > V_{SE} (max.) and D+ < V_{SE} (min.)	
Full Speed	Differential "1" and D+ > V_{SE} (max.) and D- < V_{SE} (min.)	
Resume State:		
Low Speed	Differential "1" and D+ > V_{SE} (max.) and D- < V_{SE} (min.)	
Full Speed	Differential "0" and D- > V_{SE} (max.) and D+ < V_{SE} (min.)	
Start of Packet (SOP)	Data lines switch from Idle to K State	
End of Packet (EOP)	D+ and D- < V_{SE} (min) for 2 bit times[1] followed by an Idle for 1 bit time	D+ and D- < V_{SE}(min) for ≥ 1 bit time[2] followed by a J State

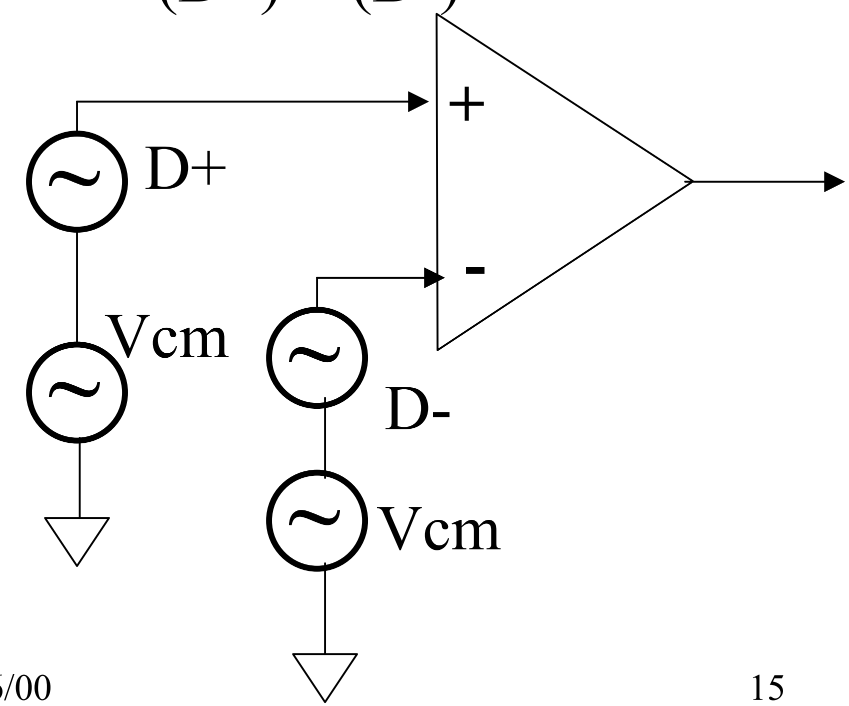
Why differential signaling??

Differential signaling very good at rejecting common-mode noise. If noise is coupled into a cable, then usually it is coupled into all wires in the cable. This 'common-mode' noise (Vcm) can be rejected by input amplifier.

$$Vo = (D+) - (D-)$$



$$Vo = (Vcm + D+) - (Vcm + D-) = (D+) - (D-)$$



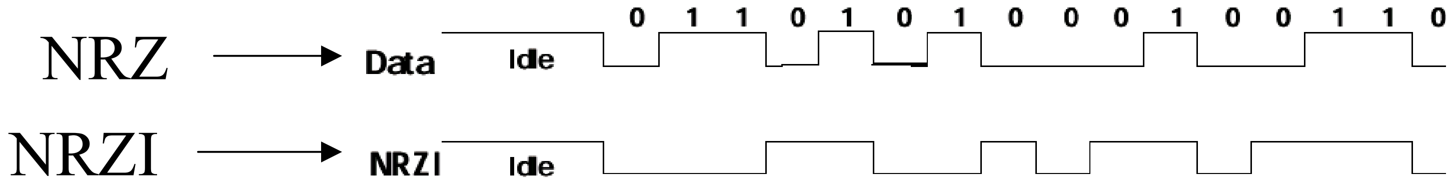


Figure 7-11. NRZI Data Encoding

Non-return to zero (NRZ) - normal data transitions.

NRZ – Inverted (not a good description, is not inverse of NRZ). A transition for every zero bit.

Strings of zeros means lots of transitions. Strings of '1's means steady line.

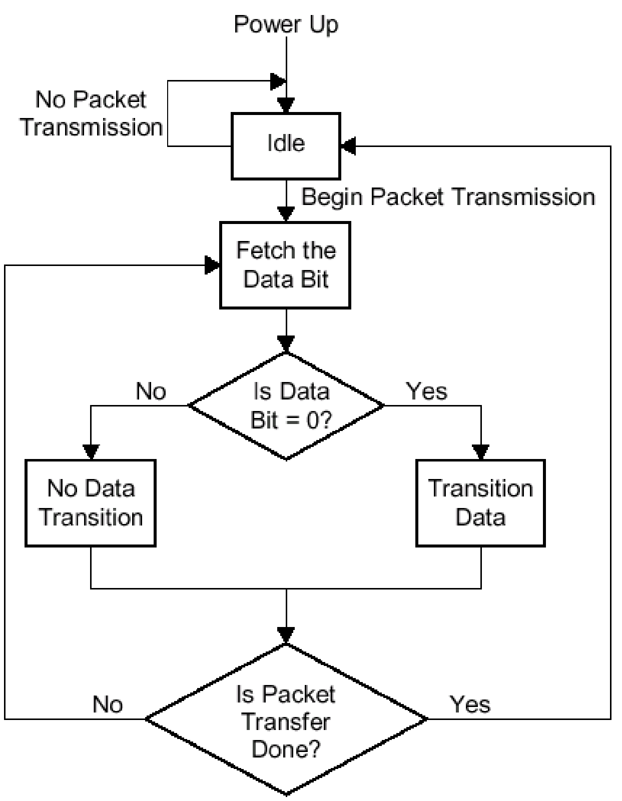


Figure 7-12. Flow Diagram for NRZI

Bit Stuffing – a ‘0’ is inserted after every six consecutive ‘1’s in order to ensure a signal transition so that receiver clock can remain synchronized to the bit stream.

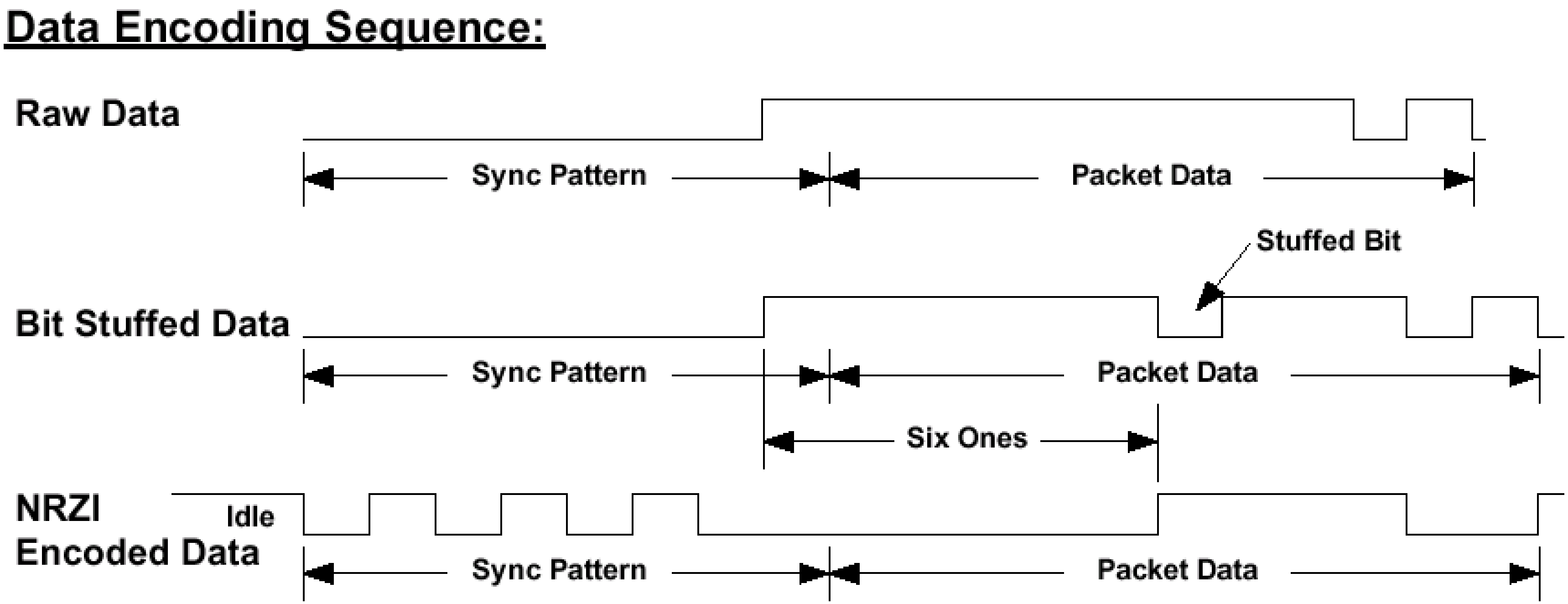


Figure 7-13. Bit Stuffing

Bit stuffing done automatically by sending logic. Sync pattern starts data transmission and is seven ‘0’s followed by a ‘1’.

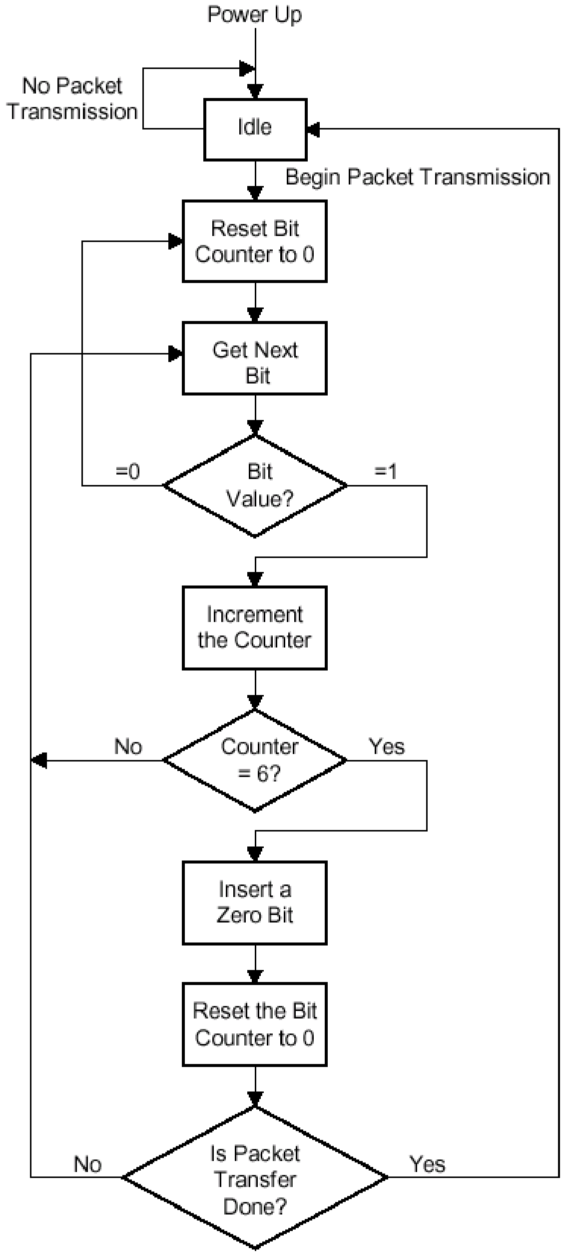


Figure 7-14. Flow Diagram for Bit Stuffing

Receiver/Xmitter logic uses a 48 Mhz internal local clock.

48Mhz/ 12Mbs = 4 clocks per bit time for high speed signaling.

48Mhz/1.5 Mbs = 32 clocks per bit time for low speed signaling.

A guaranteed transition every 7 bit times allows local clock synchronization to the serial data stream. Sync pattern allows clock sync at beginning of packet.

Data Formatting

- Data sent in packets
- Packets will have:
  - Start of Packet Sync Pattern (8 bits, 7 zeros + 1 one)
  - Packet ID (PID) – identifies type of packet. 8 bits total, but only 4 unique bits
  - Address field - 11 bits. 7 bits for USB device (so 128 possible USB devices on bus, host is always address 0), 4 bits for internal use by USB device .
  - Frame number field (11 bits) – incremented by host
  - Data Payload (up to 1023 bytes for high-speed connection)
  - CRC bits - 5 bits for address field, and 16 bits for data field
  - EOP strobe – single ended 0 (160ns-175 ns for high speed, 1.25 us to 1.75 us for high speed)
- Not all packets sent over USB bus have all of these fields (always have SOP, EOP and PID). Packet without data field is a token packet.

Packet Types

Table 8-1. PID Types

PID Type	PID Name	PID[3:0]	Description
Token	OUT	b0001	Address + endpoint number in host -> function transaction
	IN	b1001	Address + endpoint number in function -> host transaction
	SOF	b0101	Start of frame marker and frame number
	SETUP	b1101	Address + endpoint number in host -> function transaction for setup to a control endpoint
Data	DATA0	b0011	Data packet PID even
	DATA1	b1011	Data packet PID odd
Handshake	ACK	b0010	Receiver accepts error free data packet
	NAK	b1010	Rx device cannot accept data or Tx device cannot send data
	STALL	b1110	Endpoint is stalled
Special	PRE	b1100	Host-issued preamble. Enables downstream bus traffic to low speed devices.

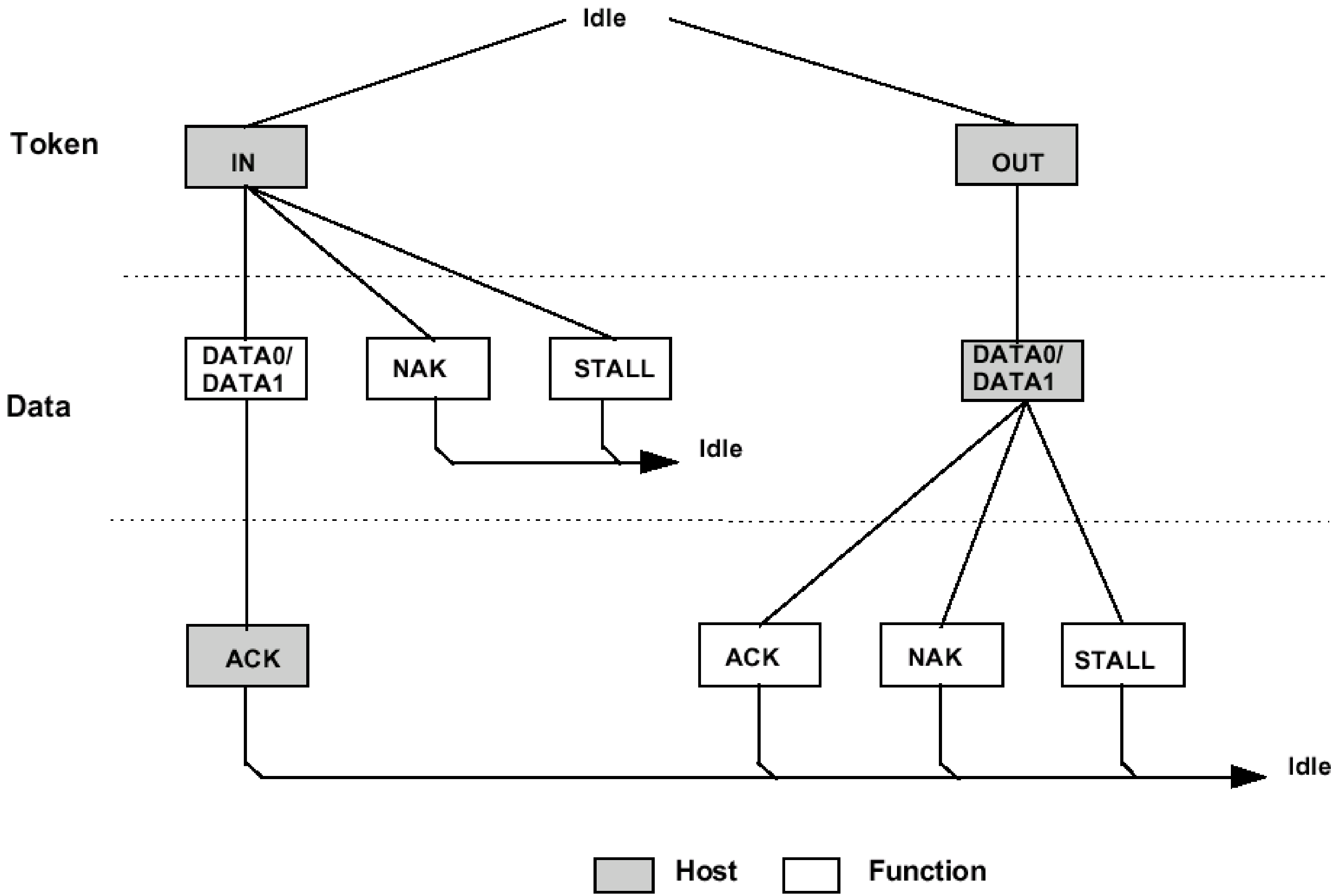


Figure 8-9. Bulk Transaction Format

Transactions

- A transaction is transfer of data between host and USB device (*function*) - either Host to Function (OUT) or Function to Host (IN)
- For IN transaction: Host transmits IN packet
  - Function responds with data packet, or with NAK packet if can't return data, or with STALL packet if permanently stalled
  - If host receives valid DATA packet, then host returns an ACK packet to complete transaction.
- OUT transaction is handled similarly.

More on HUBs

A HUB simply allows multiple connection point. A HUB acts as repeater (max delay 70 ns) for all data coming from host to all connection points. Any data coming from a connection port is sent to the 'host' port.

Even though the physical topology is a 'tree', the logic topology has the host directly connected to all of the 'functions'. Any packet from the host is sent to ALL functions. Any packet from a function is sent up the tree to the host. Max # of hops between host/function is 5.

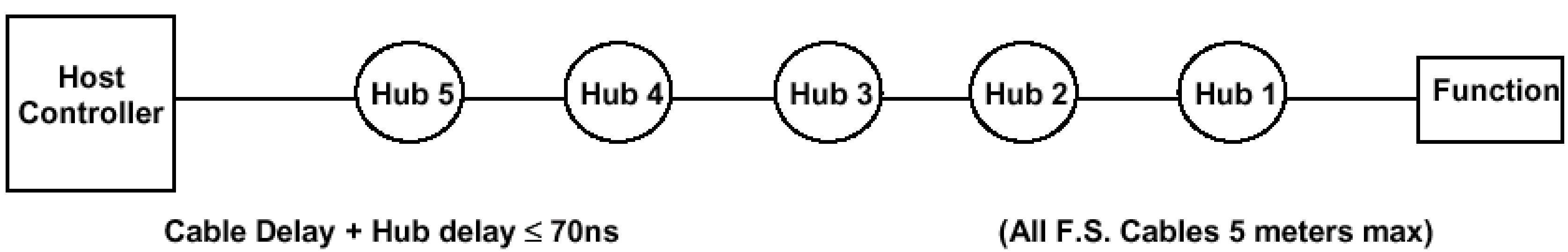


Figure 7-22. Worst Case End to End Signal Delay Model

Supported Data Transfer types

- Control Transfers – used to configure devices at power up
- Bulk Transfers – large amounts of data transferred sequentially (i.e., printers, scanners)
- Interrupt transfers – small, spontaneous data transfer from devices (mouse, keyboard, joystick). Interrupt transfers are scheduled transfers.
- Isochronous Transfers – continuous, real-time data. Guaranteed bandwidth; data is sensitive to delivery delays. Examples are audio, low-bandwidth video. Only used by full speed devices.

Frames

- Frames are the way that the bandwidth of the USB bus is allocated among the different devices that are connected to the USB
- A Frame is a 1.0 ms period whose time is divided up among the various connected USB devices by the host.
- Start-of-Frame packets are sent over bus every 1.0 ms so that high-speed devices can keep a 1 Khz clock that is synchronized to the host 1 Khz clock
- An example of dividing up the frame bandwidth is that any device that needs interrupt transfers is allocated a period within the frame
  – Host accesses the endpoint and checks to see if it has pending interrupt data. If data ready, grabs the data in the next frame.

Maximum bits per frame?

High Speed = 12 Mbps = 12 e 06 bits/per sec

1 Frame = 1.0 ms = 0.001 sec

.001 sec * 12e06 bits/sec = 12,000 bits / frame

12,000 bits/frame = 1500 Bytes/frame maximum bytes

Maximum data payload is 1023 bytes – so only one maximum data payload can be sent in one frame (and only from a high speed device).

Summary of USB

- 127 Connected devices + host
- half-duplex data transmission using different signaling (200 mv differential signal)
- Data format is NRZI, with bit stuffing every six ‘1’s
- Idle state is different for low speed and high speed connections (this is how they are distinguished)
- Data transmitted in packets, maximum data payload is 1023 bytes
- Time is split into 1.0 ms segments called frames, and bus bandwidth within a frame is allocated by the host to the different devices connected to the bus.

IEEE FireWire (IEEE 1394)

High Speed Serial Interconnect standard – offers speeds of 100 Mbps to 400 Mbps

USB

PERFORMANCE	APPLICATIONS	ATTRIBUTES
LOW SPEED •Interactive Devices •10-100 Kb/s	Keyboard, Mouse Stylus Game peripherals Virtual Reality peripherals Monitor Configuration	Lower cost Hot plug-unplug Ease of use Multiple peripherals
MEDIUM SPEED •Phone, Audio, Compressed Video 500Kb/s - 10Mbp/s	ISDN PBX POTS Audio	Low cost Ease of use Guaranteed latency Guaranteed Bandwidth Dynamic Attach- Detach Multiple devices
HIGH SPEED •Video, Disk •25-500 Mb/s	Video Disk	High Bandwidth Guaranteed latency Ease of use

Firewire

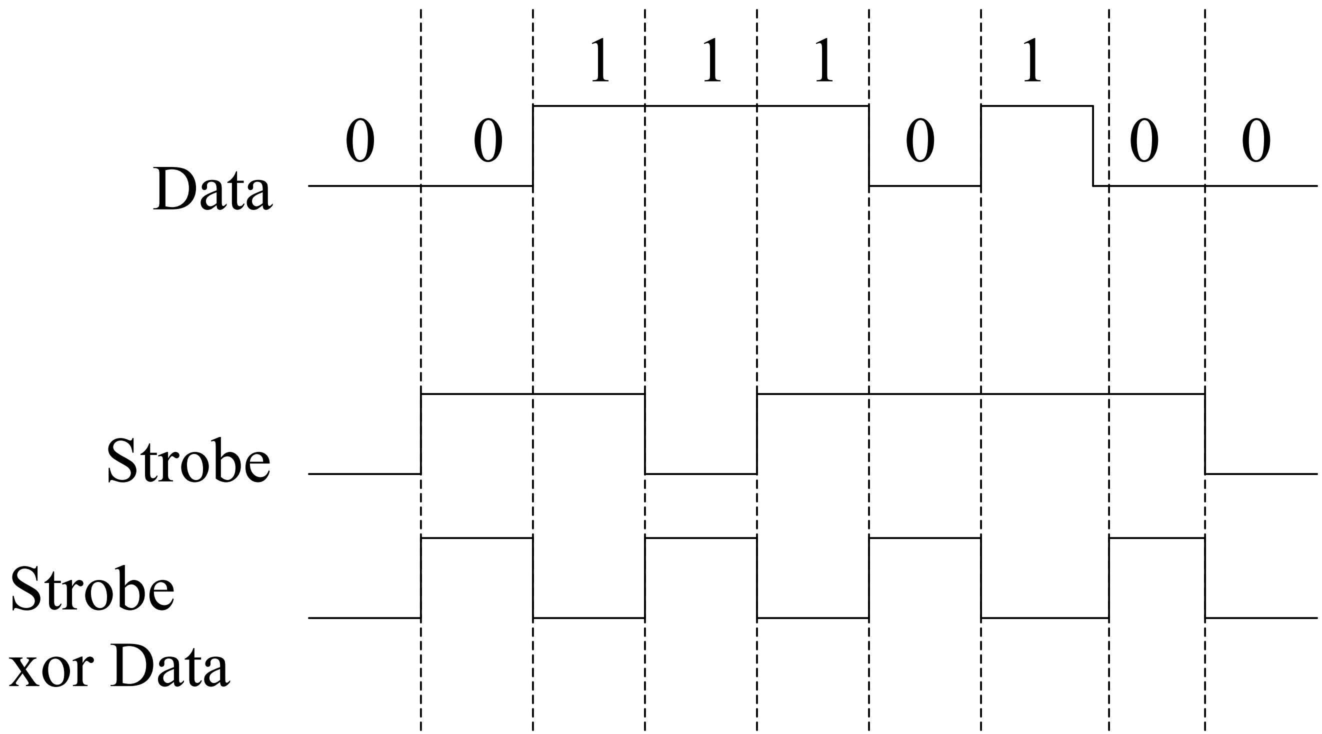
Figure 3-1. Application Space Taxonomy

Firewire Details

- Tree topology like USB, maximum of 63 nodes + host
- Maximum of 16 hops between host and node
- Signaling is bi-directional, half duplex as in USB
- Signaling is Data Strobe signaling – requires two binary signals to send one bit, each binary signal is represented by a differential pair of signals (so 4 wires total). Cable also has VDD, GND signals for 6 wires total (USB has 4 wires total).

Data Strobe Signaling

Serial Encoding method first used in a multicomputer called the *Transputer*, invented by SGS-Thompson



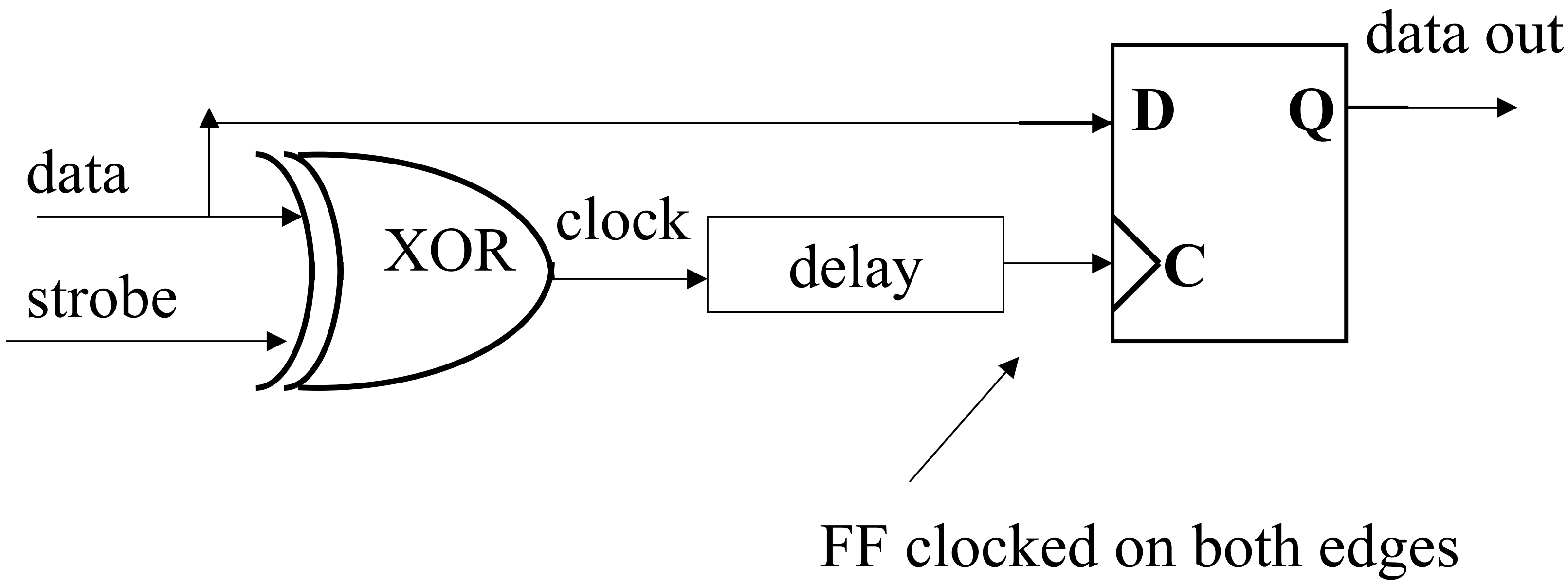
Strobe changes when Data does not.

Extract clock from data and strobe as:

Clock = Data XOR Strobe ; Data clocked on both edges

Extracting the clock from data/strobe, latching the data. Data stream is 'self-clocking'. Can vary speed of data stream and circuit will still work.

No bit stuffing needed.



Cabling, Electrical Specs

- Cabling uses three pairs:
  - one pair for Vdd/GND
  - one pair for Data (differential Signaling)
  - one pair for Strobe (differential Signaling)
- 200 mV differential on Data (D+, D-), Strobe (S+, S-) centered about Vdd/2
- Cabling can provide power to nodes same as in USB spec.