IBIS Modeling of USB Buffers

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Agenda

- Introduction
- Modes of USB
- Block Diagram
- Skeleton of USB IBIS Model
- Driver Operation.
- Receiver Operation.
- Application view of USB IBIS Models.
- Summary.
- Questions/Suggestions.

Introduction

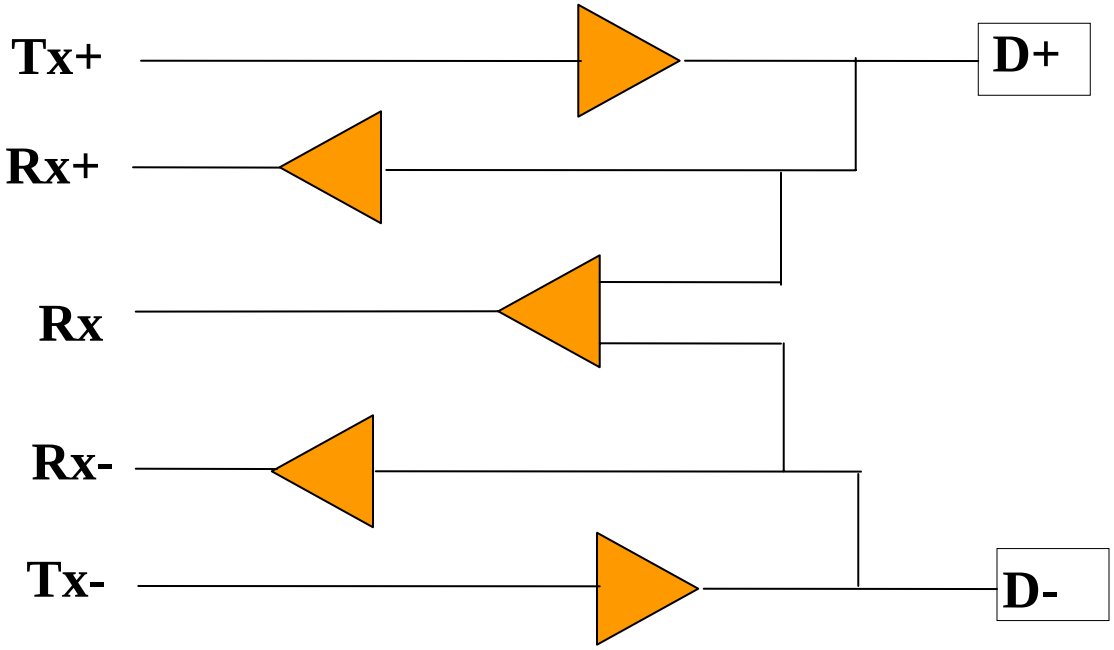
- What's special in USB ?
  - Single ended and Differential Receivers connected to the same node.

- What's the problem ?

Modes of USB

PERFORMANCE	APPLICATIONS	ATTRIBUTES
LOW-SPEED • Interactive Devices • 10 – 100 kb/s	Keyboard, Mouse Stylus Game Peripherals Virtual Reality Peripherals	Lowest Cost Ease-of-Use Dynamic Attach-Detach Multiple Peripherals
FULL-SPEED • Phone, Audio, Compressed Video • 500 kb/s – 10 Mb/s	POTS Broadband Audio Microphone	Lower Cost Ease-of-Use Dynamic Attach-Detach Multiple Peripherals Guaranteed Bandwidth Guaranteed Latency
HIGH-SPEED • Video, Storage • 25 – 400 Mb/s	Video Storage Imaging Broadband	Low Cost Ease-of-Use Dynamic Attach-Detach Multiple Peripherals Guaranteed Bandwidth Guaranteed Latency High Bandwidth

Block Diagram



- Driver is essentially two parallel single ended buffers (D+ & D-)
- Receiver has 2 parts
  - 2 parallel single ended buffers carrying complementary signals (Rx+ & Rx-)
  - Differential receiver (Rx)
- Signals at both the driver and receiver side are **full swing signals**.

Skeleton of USB IBIS model

[IBIS Ver] 3.2
⋮
[Manufacturer] NXP Semiconductors

[Pin]	signal_name	model_name	R_pin	L_pin	C_pin
1	D+	two_speed_buffer_D+	0.2	5.0n	2.0p
2	D-	two_speed_buffer_D-	0.2	5.0n	2.0p

[Diff Pin]	inv_pin	vdiff	tdelay_typ	tdelay_min	tdelay_max
1	2	200mv	NA	NA	NA

[Model Selector]	two_speed_buffer_D+
USB_FS	Full speed operation of USB
USB_LS	Low speed operation of USB

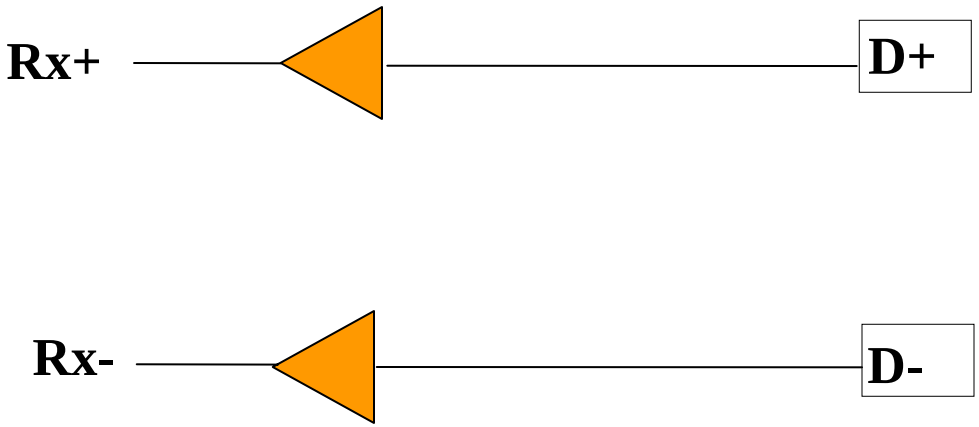
[Model] USB_FS | of usb
Model_type I/O
Polarity Non-Inverting
Enable Active-Low
| Reciever Thresholds
Vinl = 0.8V | USB Specification
Vinh = 2.0V | USB Specification

Driver Operation

- Driver is essentially 2 parallel single ended drivers.
- Extraction of I-V and V-t data can be done individually.
- All the four I-V curves [Gnd Clamp] [Power Clamp] [Pullup] & [Pulldown] are extracted for each pin by considering each one as a separate buffer.
- Similarly V-t curves [Rising Waveform] & [Falling Waveform] can be done. R_fixture has to be 45 ohm as the USB line will be terminated with 45 ohm Single ended .
- Also C_comp can be calculated separately for each pin.

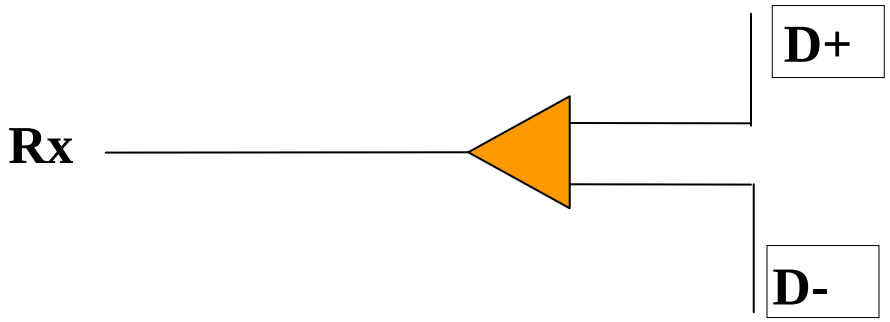
Receiver Operation

Part 1 : Single Ended Receivers



- Signal at Rx+ (Rx-) will be low only when signal at D+ (D-) is below 0.8 V
- Signal at Rx+ (Rx-) will be high only when signal at D+ (D-) is above 2.0 V
- Hysteresis parameters.

Part 2 : Differential Receiver



CMVR=((D+)+(D-))/2	Diff = (D+)-(D-)	Rx
0.8V≤CMVR≤2.5V	Diff ≥200mV	H (core logic HIGH)
0.8V≤CMVR≤2.5V	Diff ≤-200mV	L (core logic LOW)
-	|Diff|<200mV	Undefined
0.8V>CMVR>2.5	-	Undefined

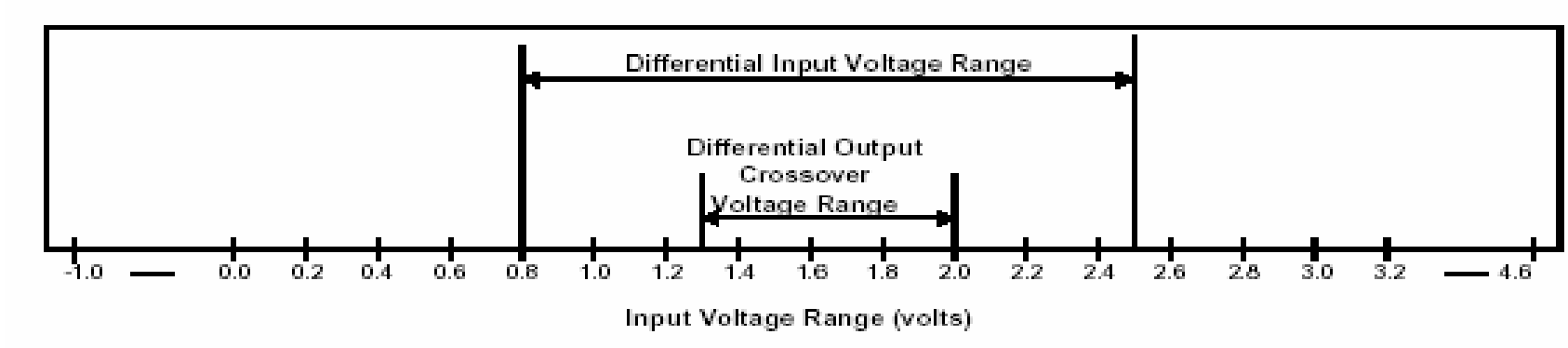
- CMVR = Common Mode Voltage Range
- Diff = Input Sensitivity

Receiver description in IBIS

USB Differential receiver can be correctly modeled only if the values of

- Common Mode Voltage Range (CMVR)
- Input sensitivity (Diff)

  are specified (Section 7.1.4.1 of USB 2.0 Spec document)



In addition Single ended receivers has to be described with

- V_{IL}, V_{IH} values.
- Hystersis parameters.

[Receiver Thresholds]

[Receiver Thresholds] | for a differential receiver **(Rx)**

Vcross_low = 0.8V | USB Spec
Vcross_high = 2.5V | USB Spec

} **CMVR**

Vdiff_ac = +200mV
Vdiff_dc = NA
Tdiffslew_ac = NA

[Receiver Thresholds] | for a single ended receiver **(Rx+, Rx-)**

Vth = 1.4V
Vinh_ac = +0.6V
Vinh_dc = +100mV
Vinl_ac = -0.6V
Vinl_dc = -100mV
Tslew_ac = 1.2ns

Not Possible to define [Receiver Thresholds] for both Single ended and differential receivers in a single model!!!

Issue !!!!

IBIS has to support both Single ended and differential modes for correct modeling of USB.

For Single ended operation : Vinl, Vinh

For Differential mode : Vdiff for Input Sensitivity
Vcross_low and Vcross_high for CMVR

But from the Cookbook…

- For differential Input or I/O model types, the differential input threshold (vdiff) overrides and supersedes the need for Vinh and Vinl.

Solution

- New [Model Type] has to be created in IBIS specification which can handle both single ended and differential ended operation for USB kind of buffers.

Model Contd..

[Model] **USB_FS**

.
.
.

[GND Clamp]
[Power Clamp]
[Pulldown]
[Pullup]
[Ramp]
[Rising Waveform]
[Falling Waveform]

[Model] **USB_LS**

.
.
.

[GND Clamp]
[Power Clamp]
[Pulldown]
[Pullup]

All these 4 tables are same as that of [Model] USB_IOP_FS. Can we avoid this duplication?

[Ramp]
[Rising Waveform]
[Falling Waveform]

Necessity to avoid this duplication

- [GND Clamp], [Power Clamp] , [Pulldown] , [Pullup] - each has 3 tables corresponding to typ, min and max corners.
- So totally 4*3 = 12 simulations required to generate these 4 tables.
- Each simulation may take 1-2 min(approx).
- So if we avoid these simulations it will effectively reduce ~ 30 mins for one model generation.

2 ways to do this..

- Modify IBIS generating tools to intelligently put the same data for the two [Model] ‘s by simulating only once.
- Introduce new IBIS specification which avoids tables in the duplicated model.

2nd method is preferable as it reduces the redundancy of data and thereby the file size.

Proposal to reduce this duplication

By putting model names in front of the curve names.

[Model] **USB_FS**

:

[GND Clamp]
[Power Clamp]
[Pulldown]
[Pullup]
[Ramp]
[Rising Waveform]
[Falling Waveform]

[Model] **USB_LS**

:

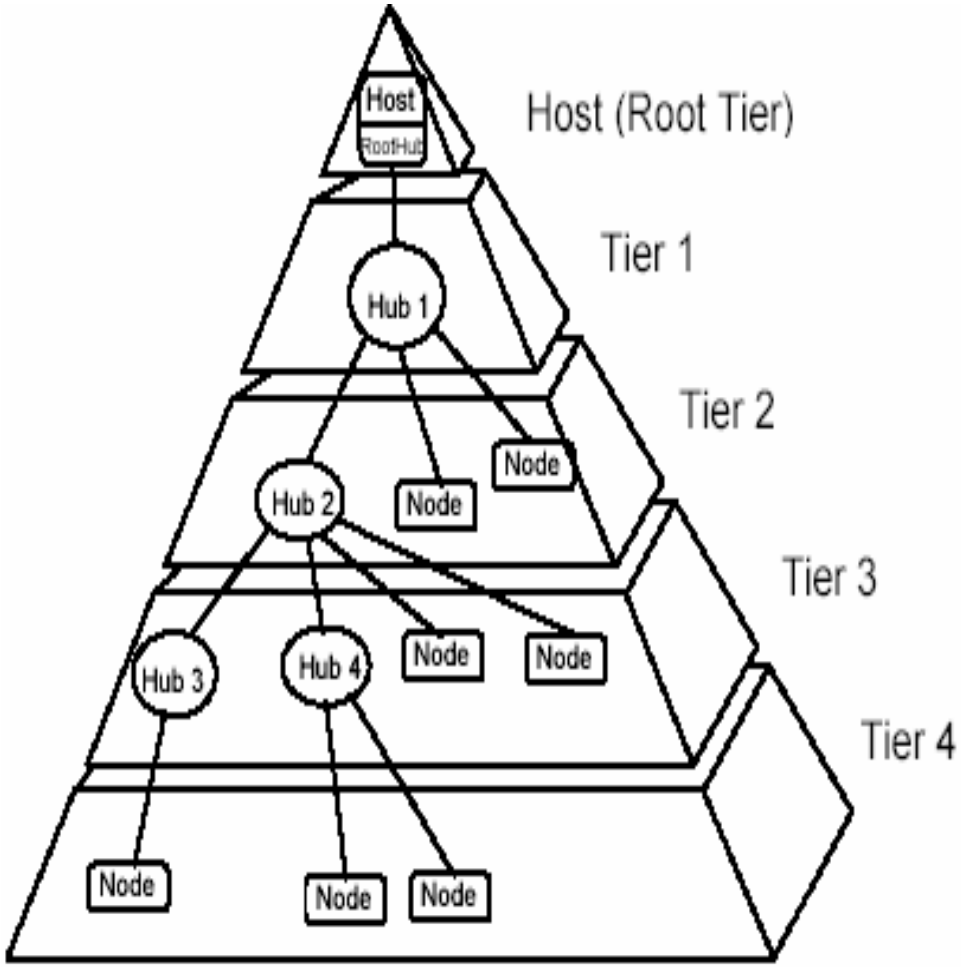
[GND Clamp] USB_FS
[Power Clamp] USB_FS
[Pulldown] USB_FS
[Pullup] USB_FS

[Ramp]
[Rising Waveform]
[Falling Waveform]

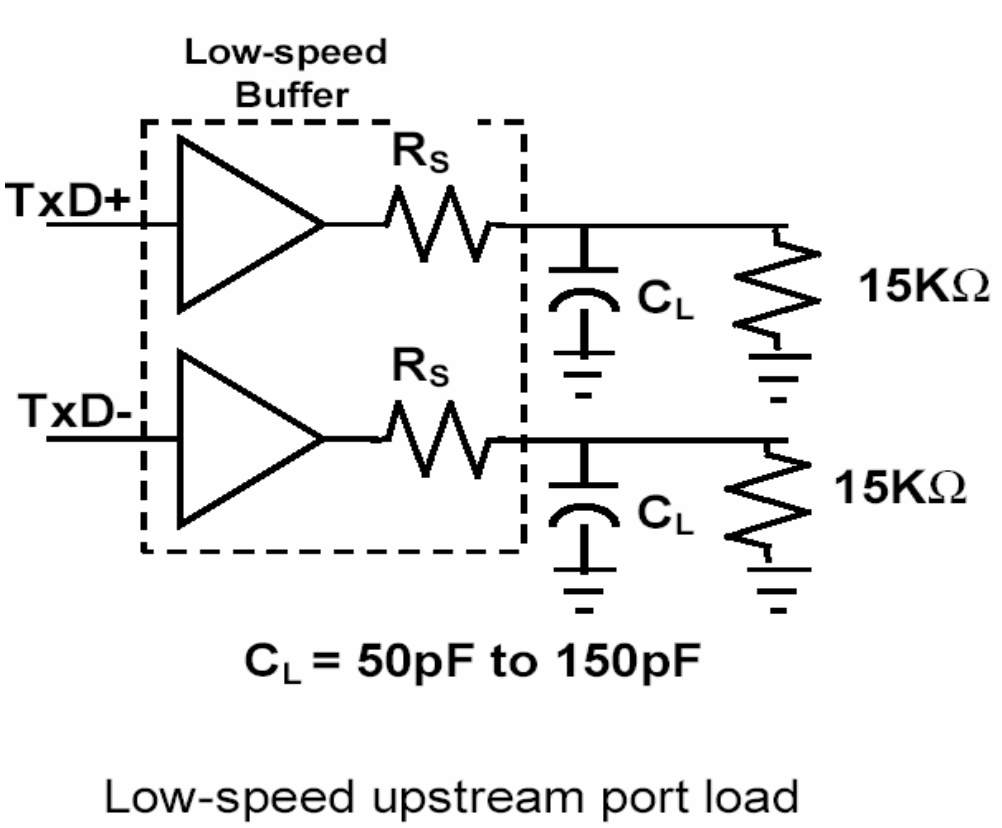
Application of USB

USB Topology

- Upstream Mode
- Downstream Mode



Low Speed USB Model in Upstream Mode.

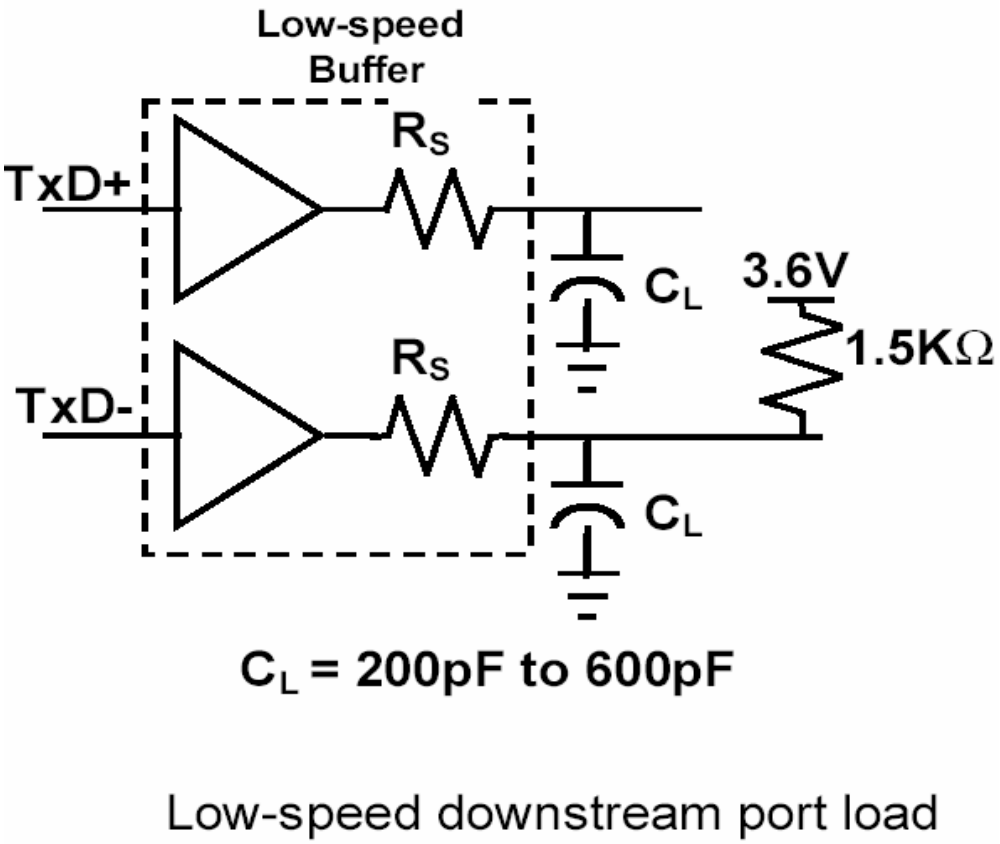


Low-speed upstream port load

AC Test Load Conditions.

- **Rref = 15k**
- **Vref = 0**
- **Cref = 100p**
- Vmeas = 1.65V

Low Speed USB Model in Downstream Mode.



Low-speed downstream port load

AC Test Load Conditions.

- **Rref = 1.5k**
- **Vref = 3.6**
- **Cref = 400p**
- Vmeas = 1.65V

Same Model should work in 2 applications ?

- As the cell is in low speed mode, there will be no difference in I-V or V-t curves between upstream and downstream modes and hence there is only one model defined.
- But the same model has to cater to 2 kinds of applications with varying Vref, Rref and Cref.
- Not possible with the single [Model] !!!
- Copy of same model with different names for upstream and downstream, with models varying in their Vref, Cref, & Rref can be done. But it will result in redundancy of data.
- IBIS community can look into this issue.

Summary

- USB has 2 complementary single ended drivers , 2 complementary single ended receivers and a differential receiver with full swing signaling.
- Not possible to model both single ended and differential receiver in IBIS in a single model.
  - **Proposal : IBIS has to provide new specification to support this type of buffer.**
- As Full speed model and low speed models both have same driver characteristics, simulating the model for these curves **twice** is not required.
  - **Proposal : IBIS can support new specifications as suggested to reduce the time required in model generation.**
- As the same model should cater to 2 kinds of applications with varying Vref, Cref & Rref it is not possible with single IBIS model.
  - **Proposal : There should be an option to override the default values of Rref, Cref and Vref when using IBIS model.**

References

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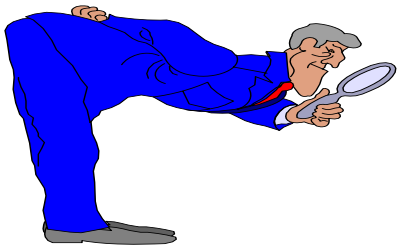
  http://www.usb.org/developers/docs
- Switching in USB Consumer Applications by Eva Murphy & Padraig Fitzgerald , Analog Devices
  http://www.analog.com/library/analogDialogue/archives/40-01/usb_switch.html
- IBIS 4.2 Specification Document
  http://vhdl.org/pub/ibis/ver4.2/ver4_2.pdf
- IBIS Cookbook
  http://www.vhdl.org/pub/ibis/cookbook/cookbook-v4.pdf
- Introduction to IBIS models and IBIS model making by Arpad Muranyi at Intel Corp. Nov. 3 & 4, 2003
- IBIS Modeling for High Speed Designs by Dr. Lynne Green - JEDEX 2004 IBIS Workshop, April 16, 2004
- IBIS Models @ 1.25GHz and Beyond by Bob Haller, Barry Katz, Kevin M. Fisher - DESIGNCON EAST June 23, 2003

- Questions ?

- Comments?



- Suggestions?