DIGITAL WE DAYS 2023

BOARD-TO-BOARD CONNECTORS IN HIGH-SPEED SIGNAL CHAINS

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

TODAY'S SPEAKERS

PRESENTATION
Baptiste Bouix
Product Manager

MODERATION
Markus Eberle
Marketing Department

INFORMATION ABOUT THE WEBINAR

You are muted during the webinar.
However, you can ask us questions using the chat function.

Duration of the presentation	30 Min
Q&A:	10 – 15 Min

Any questions?
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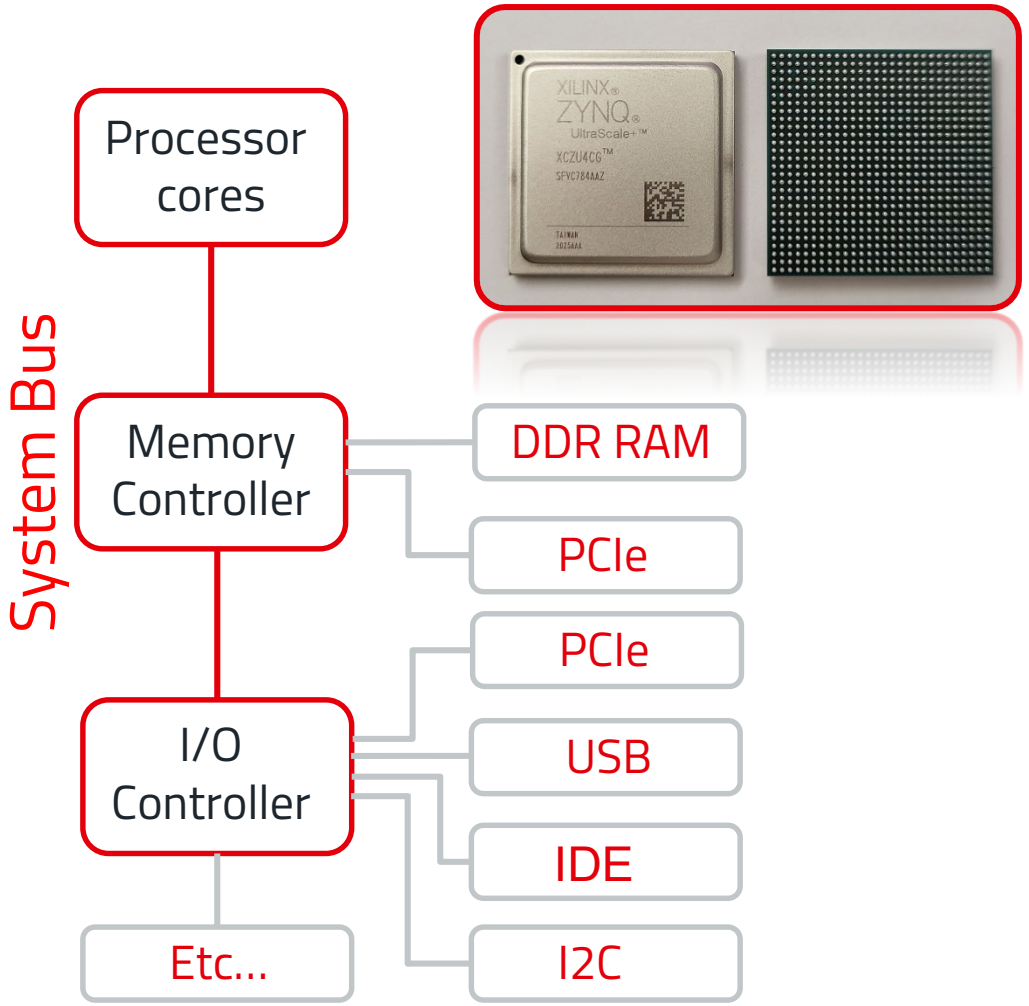
INTRODUCTION

Required concepts for understanding

INTRODUCTION

Electronic System Architecture

- In a electronic system, a computing chip (either a microcontroller, a microprocessor or system-on-chip) will be **processing** what it gets from its system bus.
- The system bus links to the **memory controller**, which handle the system's communication with the memory
- Downstream of the system bus, a **I/O controller** will handle all the inputs and outputs of the system
- **I/O protocols don't necessarily involve an external connector on the device**
- Some protocols can either be on the memory or the I/O controller

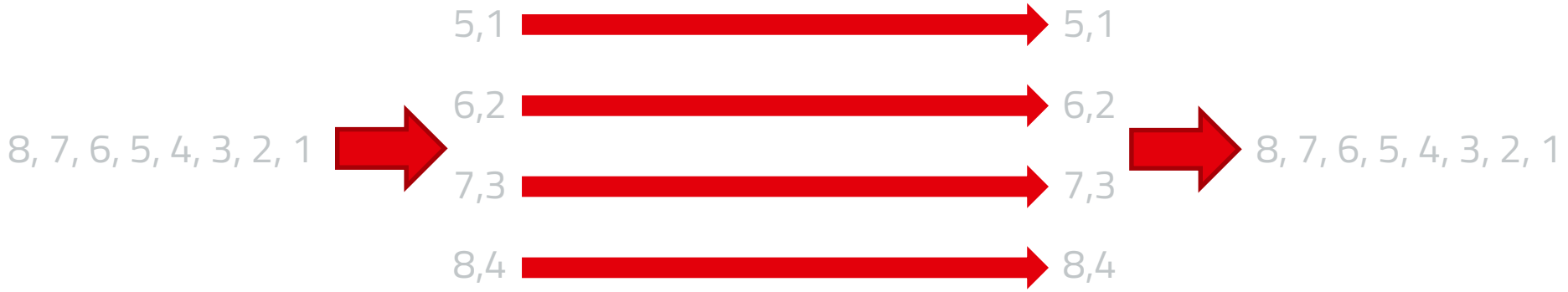


INTRODUCTION

Parallel and Serial Transmission

- **Serial**
  - Symbols are transmitted over 1 channel in sequence

  - 1 channel = 1 or 2 wires
- **Parallel**
  - Symbols are transmitted over n channels, then put again into a sequence
  - The number of channels n is referrend as the « bit width »



INTRODUCTION

Limits of Transmission

- The recieving chip has to be able to read the symbol
  - Symbol = voltage level or transition
- Sample Rate = the frequency of the reading in the recieving device
  - In Transfers/second (T/s)
- Losses are frequency-dependant

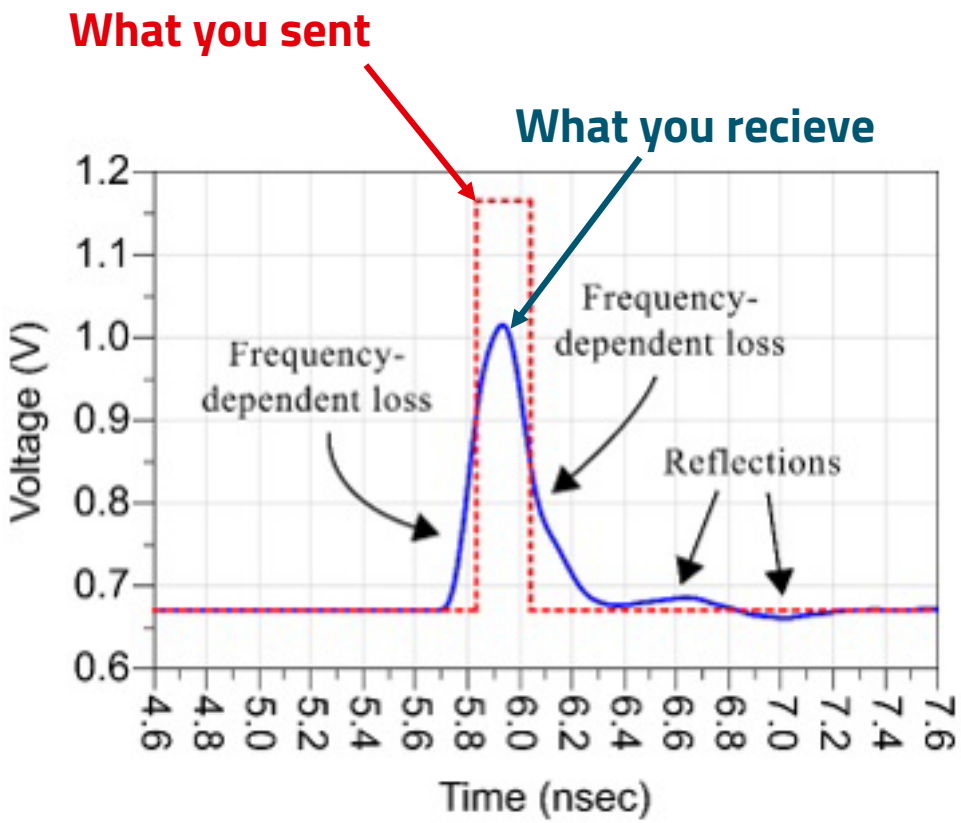


Figure 2. Single pulse response of a DQ line shows both frequency-dependent loss and reflections in a DDR5 channel.

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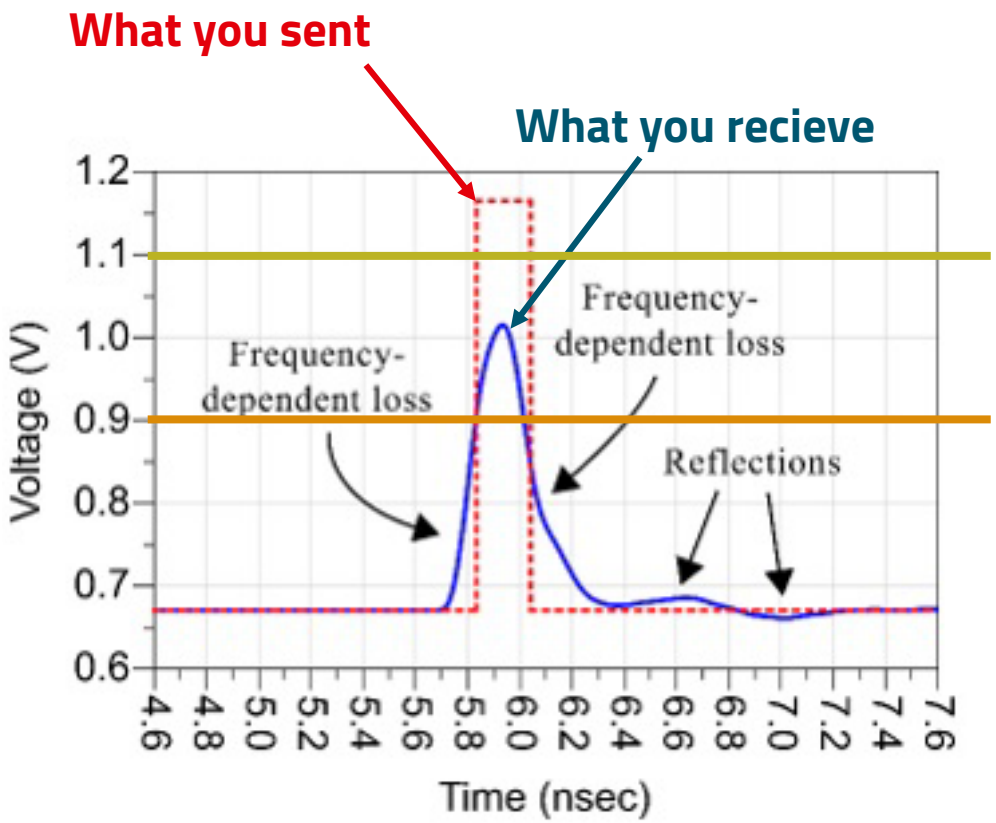


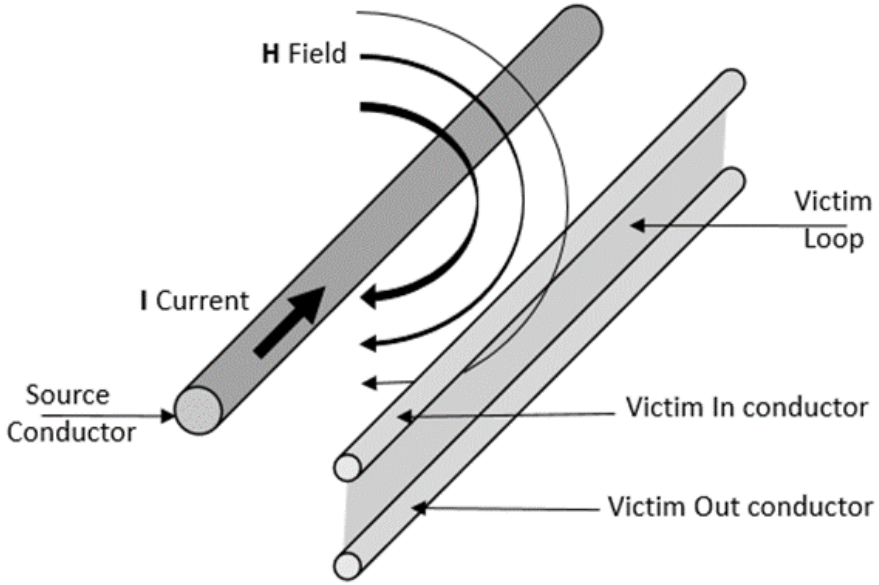
Figure 2. Single pulse response of a DQ line shows both frequency-dependent loss and reflections in a DDR5 channel.

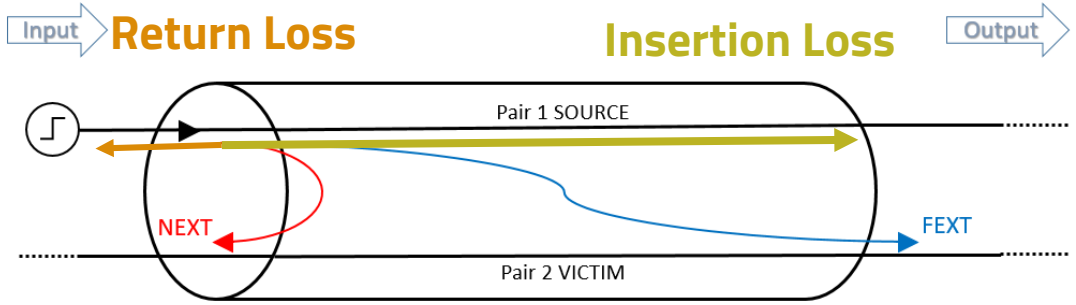
INTRODUCTION

Frequency Channel Losses

- Signal loss at high frequency comes from :
  - Impedance
  - Impedance mismatch
  - Signal going to nearby conductors : Crosstalk

  ➔ **Connectors and cables are a source of high-frequency losses**





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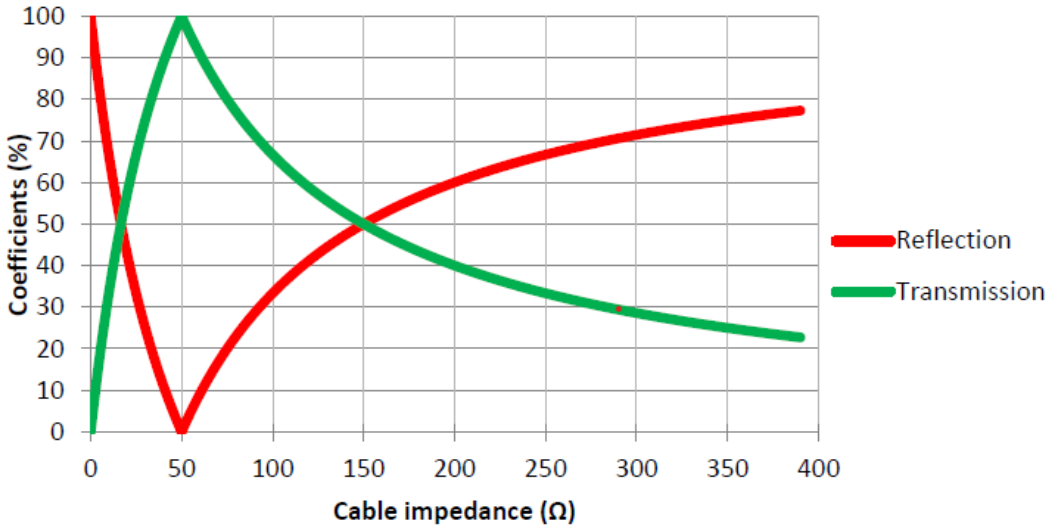
Reflection Coefficient

$$\rho = \frac{Z_{CAB} - Z_S}{Z_{CAB} + Z_S}$$

Transmission Coefficient

$$\tau = 1 - \frac{Z_{CAB} - Z_S}{Z_{CAB} + Z_S}$$



Impedance matching
- Minimizes signal reflections
- Maximizes efficiency

INTRODUCTION

Transmission line in connectors

- To limit losses in connectors, impedance must be matched with PCB
  - Pins on connector ends have a different impedance, it is unadvised to use them for signal
    - It is not always possible (see RJ45)
  - Best performance is reached when signal pins have ground pins around them

- GSG
  - Generic transmission line in connectors

- GSSG
  - Used for Differential Signalling
  - Best performances in higher frequencies and noisy environments

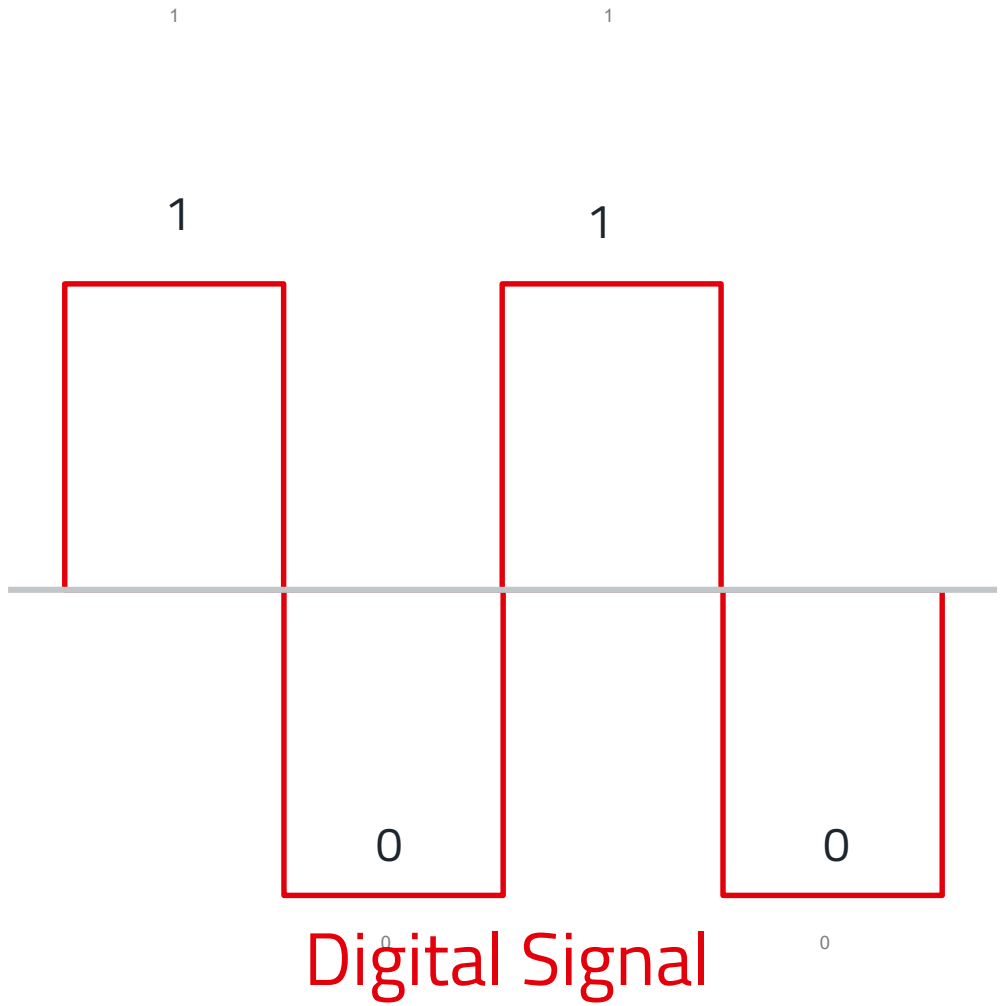
- GSGSG
  - GSG for Differential Signalling
  - Better performance at lower frequencies than GSSG

INTRODUCTION

Nyquist Frequency

- **Shannon's theorem** states that a periodic signal must be sampled at more than **twice the highest frequency** component of the signal to keep information integrity
- $f_{max,signal} = \frac{Sample\ Rate}{2}$
- Protocols can specify a channel loss at $f_{max,signal}$, called the Nyquist Frequency

  ➔ To see if a connector technology, you have to check the allowed Insertion Loss at the $f_{Nyquist}$



Digital Signal

INTRODUCTION

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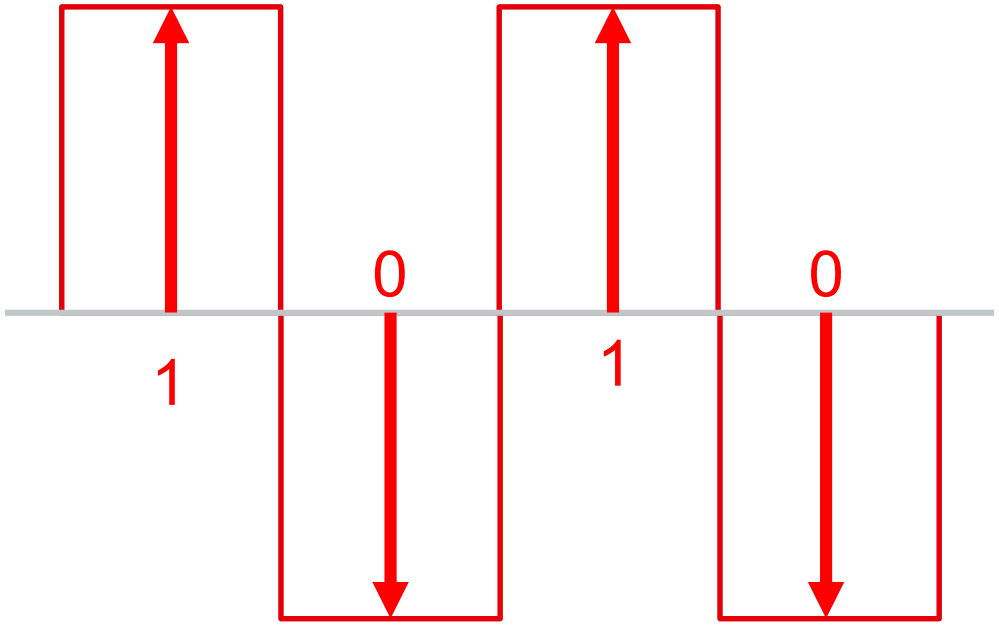

Sampling

INTRODUCTION

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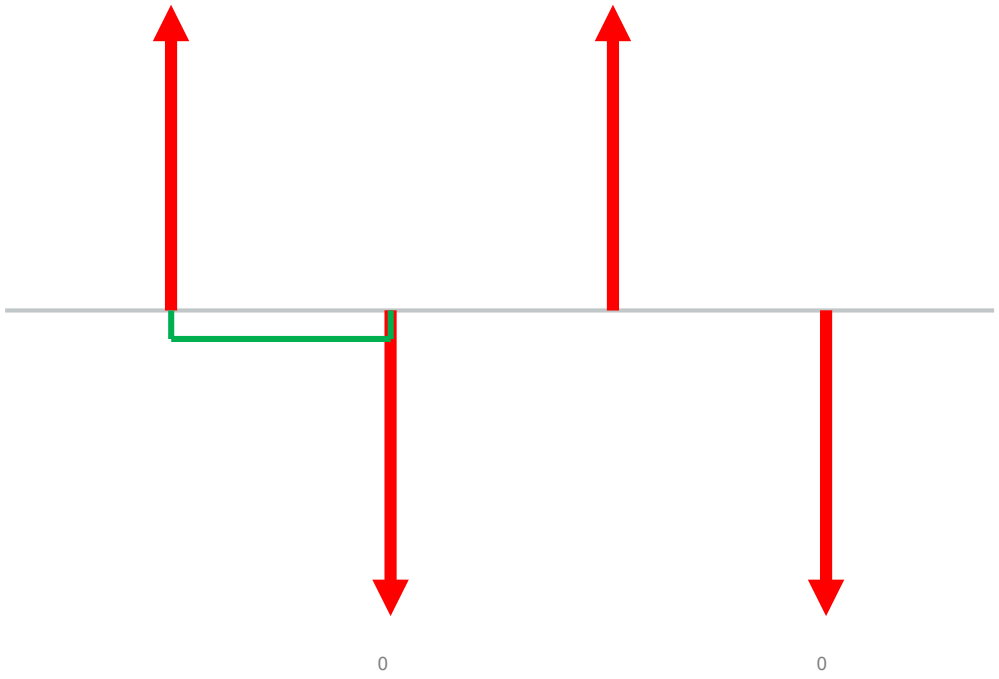

Sample Rate : 1/T

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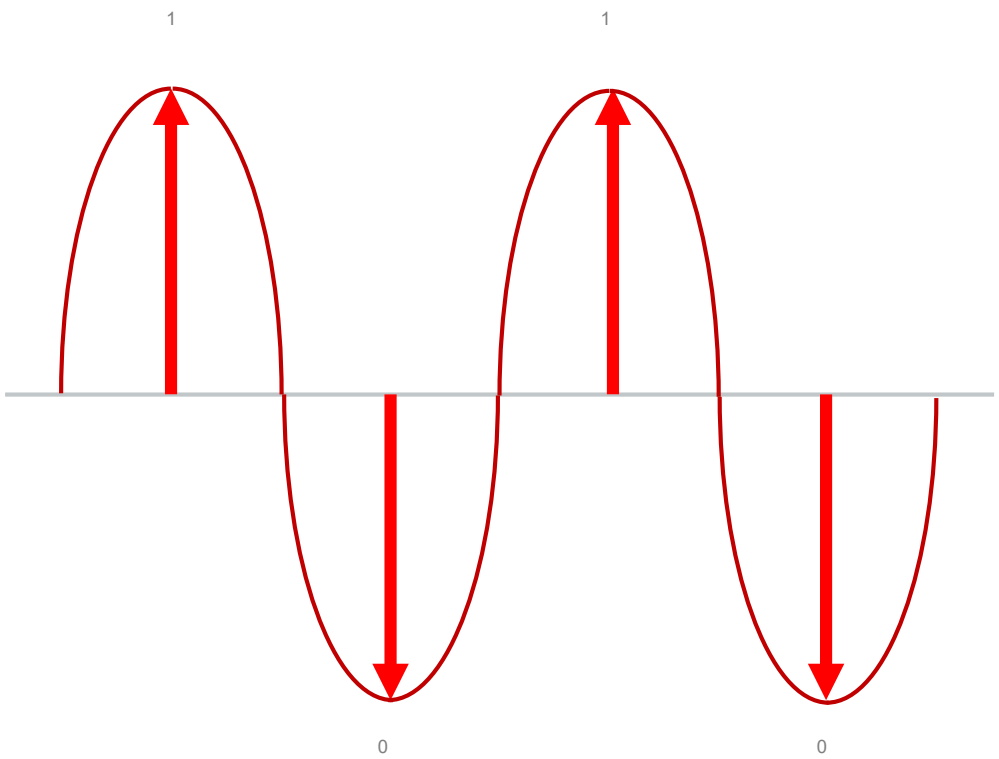

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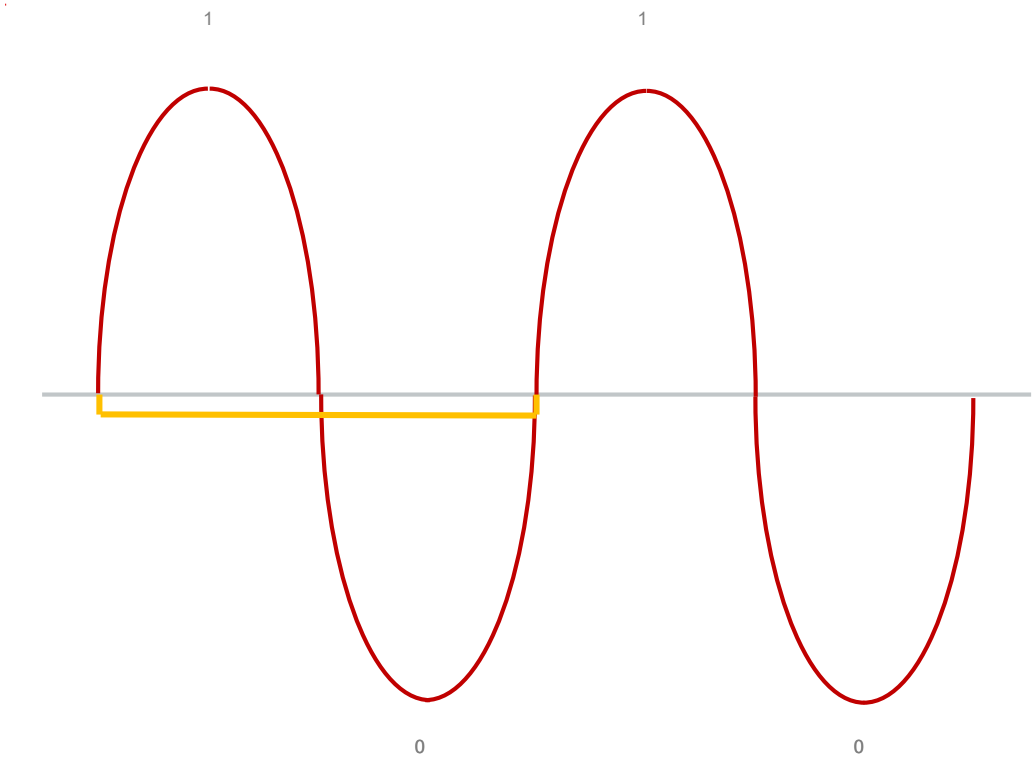


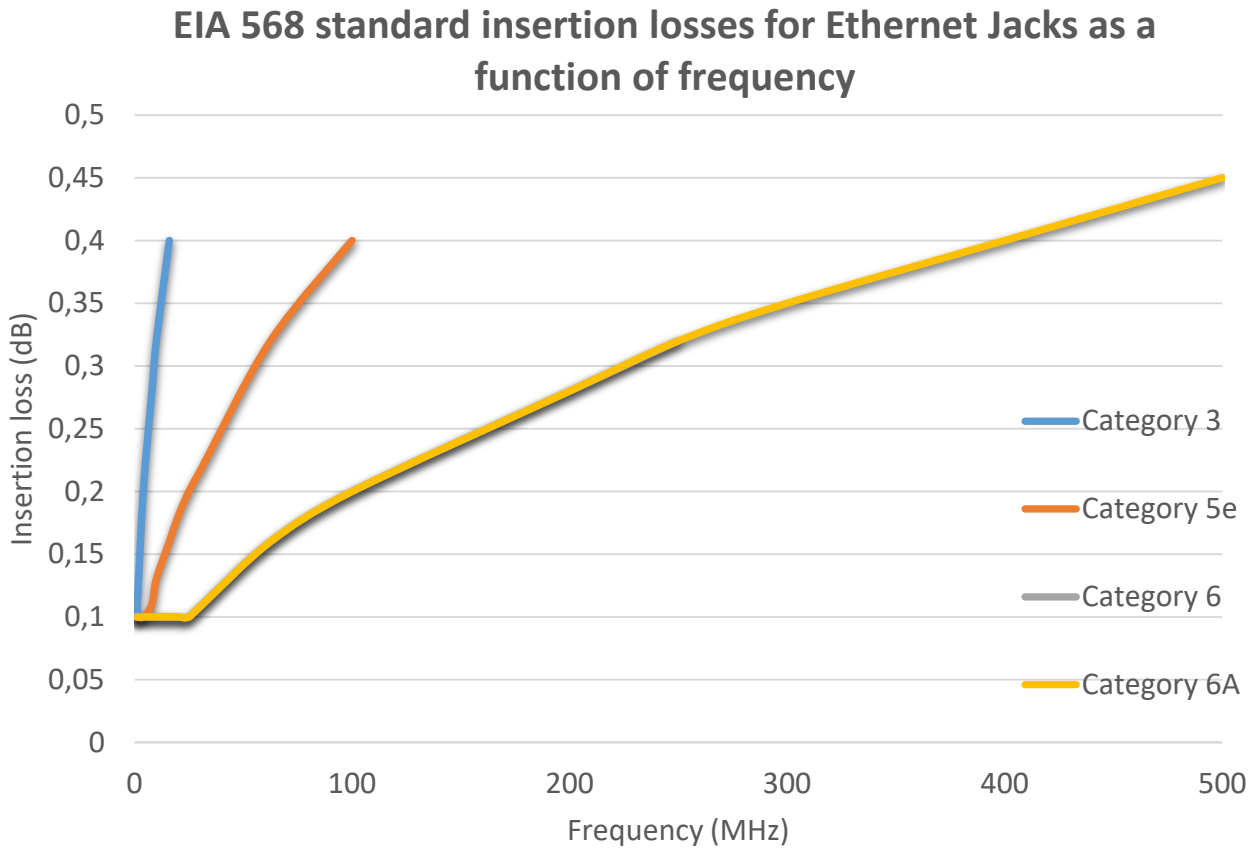
Nyquist Frequency: 1/2T

INTRODUCTION

Example : Category Rating for Ethernet Physical Layer

- Example in the industry : Ethernet cabling
  - Every component (Modular Jacks, Cable…) has an allowed **loss budget in dB**
    - 1,5 dB loss is 29% of the signal lost
    - 3 dB loss is half of the signal lost
  - You can add the losses of the components on the signal chain

➔ **Standards : Physical Layers**



CONNECTORS FOR MEMORY SIGNAL CHAINS

Northbridge/Memory Bus

CONNECTORS FOR MEMORY SIGNAL CHAINS

DRAM Connectors

- Dynamic Random-Access Memory (as opposed to Static RAM embedded in chips)
- Used by systems to store data and programs while in use
- Widespread technology : DDR SDRAM
  - Double Data Rate Synchronous Dynamic Random-Access Memory
  - **Standardized chips** and modules treated like commodities
  - Standard maintained by the **JEDEC**
  - Levels of standard from **DDR (1) to DDR5**
  - Available in higher bandwidth for video memory (GDDR)
- Parallel Transmission (**GSG** configuration)
- Nyquist Frequency from 100MHz (DDR) to 3,6GHz (DDR5)

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Spot | Memory Card | SSD | Contract | Mobile DRAM | eMMC

DRAM Spot Price MORE — Last Update: Sep.28 2023 18:10 (GMT+8) <Price Notice>

Early notice was announced at 17:50. (20 minutes in advance)

Item	Daily High	Daily Low	Session High	Session Low	Session Average	Session Change	History
DDR4 16Gb (1Gx16)3200	3.45	2.68	3.45	2.68	2.996	0.98 %	
DDR4 16Gb (2Gx8)3200	3.35	2.65	3.35	2.65	2.934	0.21 %	
DDR4 8Gb (1Gx8) 3200	1.65	1.37	1.65	1.37	1.450	0.00 %	
DDR4 8Gb (512Mx16) 3200	1.75	1.42	1.75	1.42	1.502	0.00 %	
DDR4 8Gb (1Gx8) eTT	1.27	1.03	1.27	1.03	1.152	0.17 %	
DDR3 4Gb 512Mx8 1600/1866	SK Hynix, Micron, Samsung, Nanya					0.00 %	

Module Spot Price MORE — Last Update:Sep.18 2023 14:40 (GMT+8) <Price Notice>

Item	Weekly High	Weekly Low	Session High	Session Low	Session Average	Average Change	History
DDR4 SODIMM 8GB 2666	15.70	11.60	15.70	11.60	13.856	0.93 %	
DDR4 UDIMM 8GB 2666	15.20	11.60	15.20	11.60	13.684	2.55 %	
DDR4 RDIMM 16GB 3200	38.50	37.00	38.50	37.00	37.500	3.59 %	

Flash Spot Price MORE — Last Update: Sep.28 2023 18:10 (GMT+8) <Price Notice>

Early notice was announced at 17:50. (20 minutes in advance)

Item	Daily High	Daily Low	Session High	Session Low	Session Average	Session Change	History
SLC 2Gb 256MBx8	1.25	0.56	1.25	0.56	0.771	-0.52 %	
SLC 1Gb 128MBx8	1.65	0.52	1.65	0.52	0.812	0.37 %	
MLC 64Gb 8GBx8	4.25	3.40	4.25	3.40	3.867	0.00 %	
MLC 32Gb 4GBx8	3.00	1.90	3.00	1.90	2.063	0.00 %	

GDDR Spot Price MORE — Last Update:Sep.18 2023 14:40 (GMT+8) <Price Notice>

Item	Weekly High	Weekly Low	Session High	Session Low	Session Average	Average Change	History
GDDR5 8Gb	4.20	3.40	4.20	3.40	3.649	4.62 %	
GDDR6 8Gb	3.50	2.10	3.50	2.10	2.957	0.72 %	

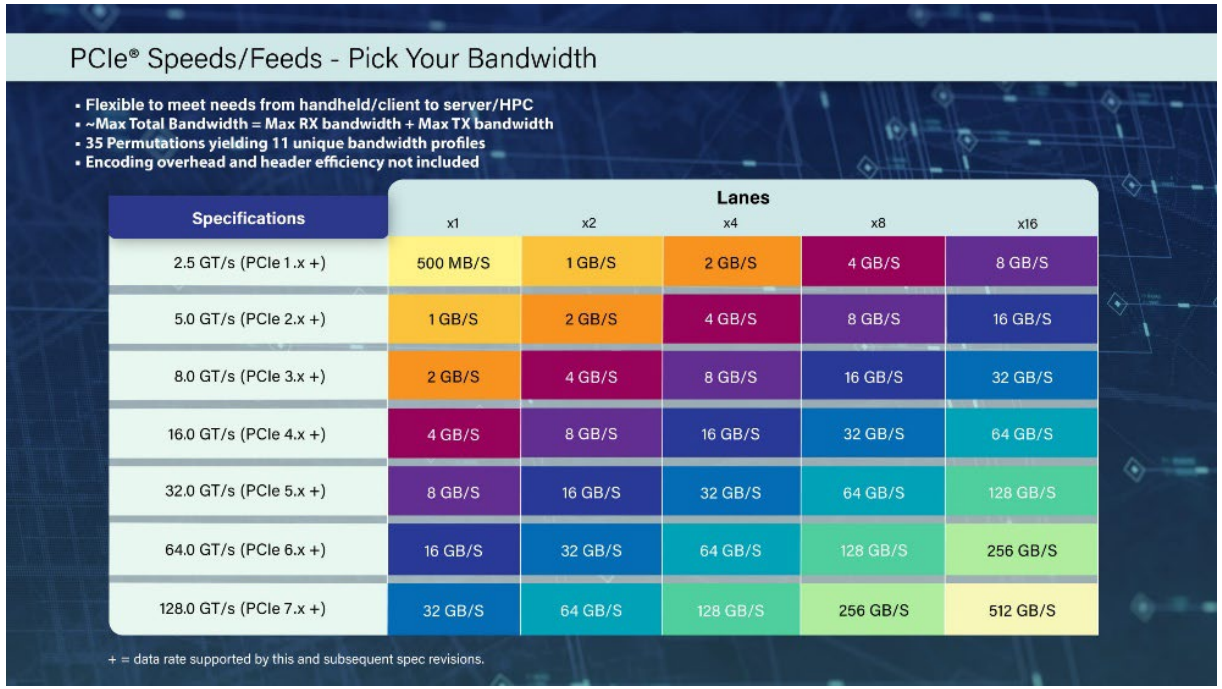
LPDDR Spot Price MORE — Last Update: Sep.18 2023 14:40 (GMT+8) <Price Notice>

LPDDR 3 32Gb	LPDDR 3 16Gb	LPDDR 3 8Gb
LPDDR 4 32Gb	LPDDR 4 16Gb	LPDDR 4 8Gb

CONNECTORS FOR MEMORY SIGNAL CHAINS

PCI Express

- Used for **chip-to-chip** communication at high speed
- Widespread Technology
  - **Power** and **Data delivery** Standard
  - Standard maintained by the **PCI-SIG**
  - Levels of standard available from **PCIe 1 to PCIe 7**
  - Available with **1 to 16 transmission/reception line**
- Serial Transmission in **GSSG** differential configuration
- Nyquist Frequency from 1,2GHz (PCIe 1) to 32GHz (PCIe 7)



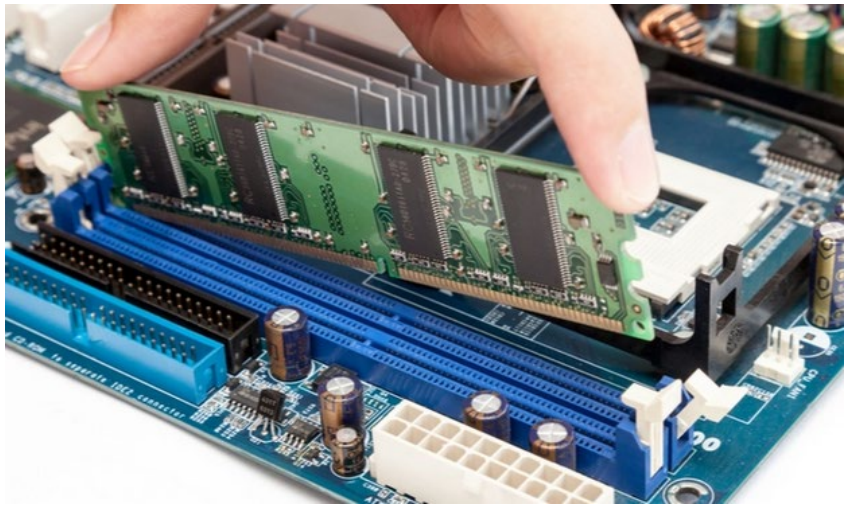
CONNECTORS FOR MEMORY SIGNAL CHAINS

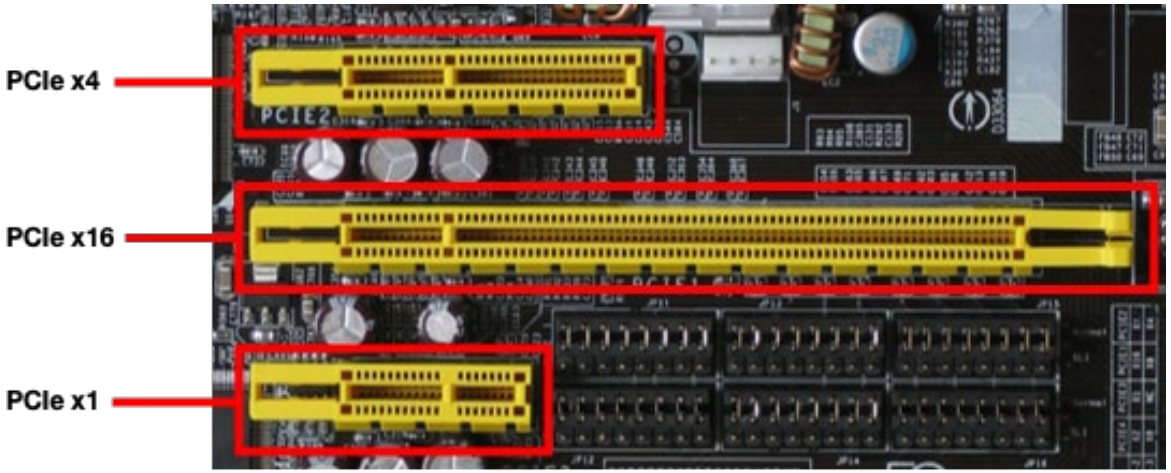
DDR SDRAM and PCI Express Standard Connectors

- **Board Edge** Connector
  - A counterpart PCB makes the connection
  - Very low losses at high frequency
  - Very bulky, only adapted for desktop PC and servers

- DIMM Connector
  - 150-200 contacts
  - DIMM : Dual Inline Memory Module
  - Different variants for each DDR level (notches)

- PCI Express connector
  - 36 contacts for PCIe x1
  - 64 contacts for PCIe x4
  - 98 contacts for PCIe x8
  - 164 contacts for PCIe x16
  - Physically compatible will all levels of PCIe

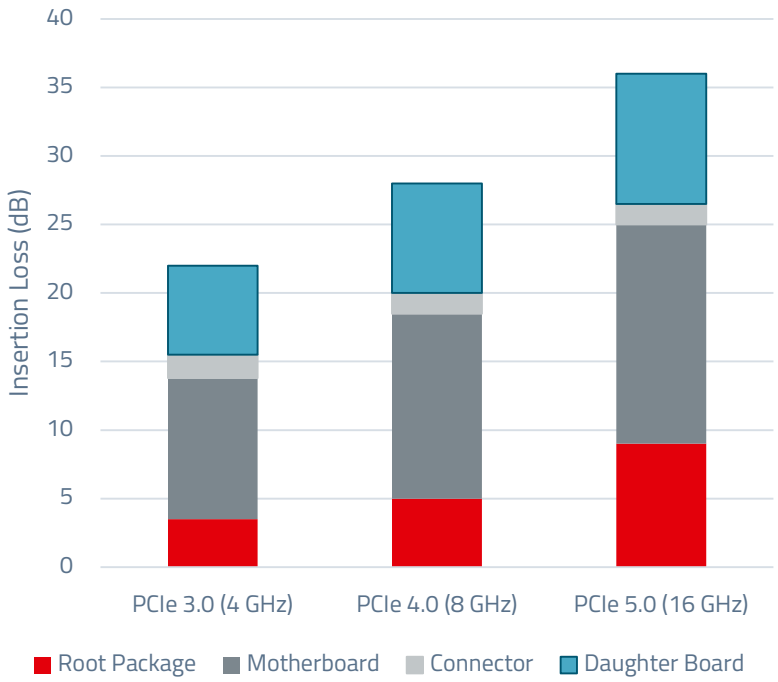


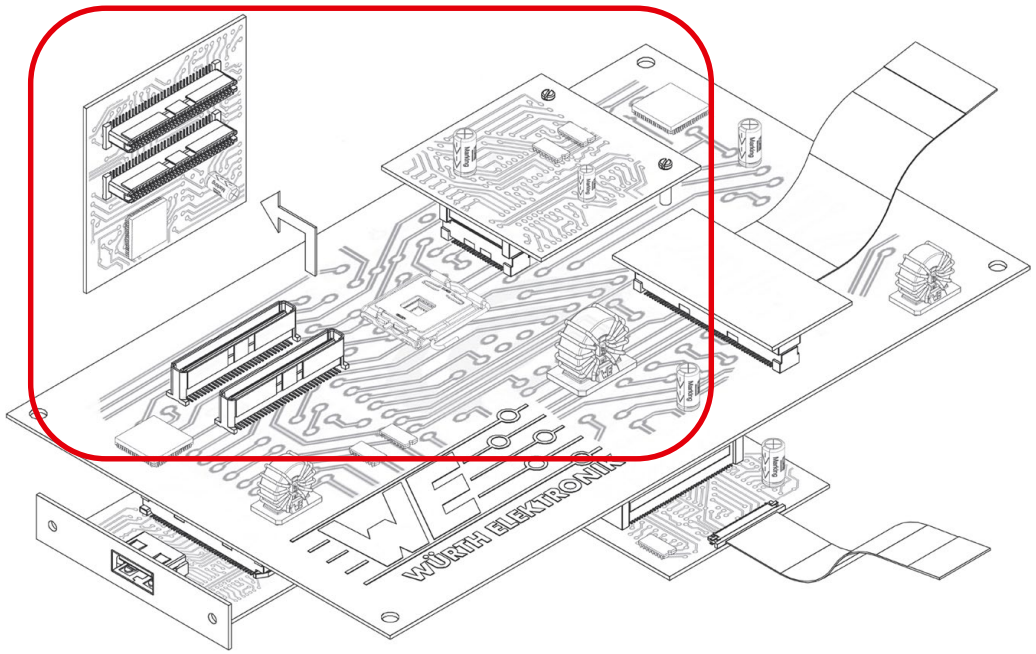


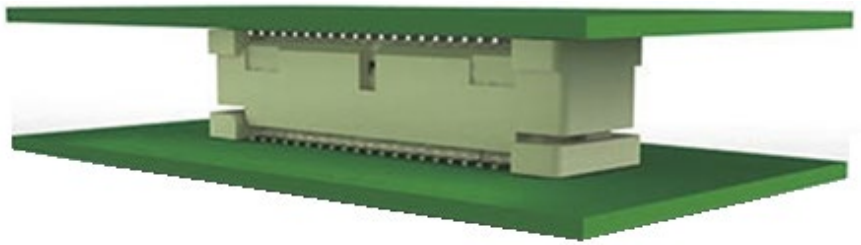
CONNECTORS FOR MEMORY SIGNAL CHAINS

DDR SDRAM and PCIe

- Alternative : Using Mezzanine Board-to-Board Connector is possible, however the standards are very demanding
  - 1,5 dB allowed losses GSSG at Nyquist in PCIe standard





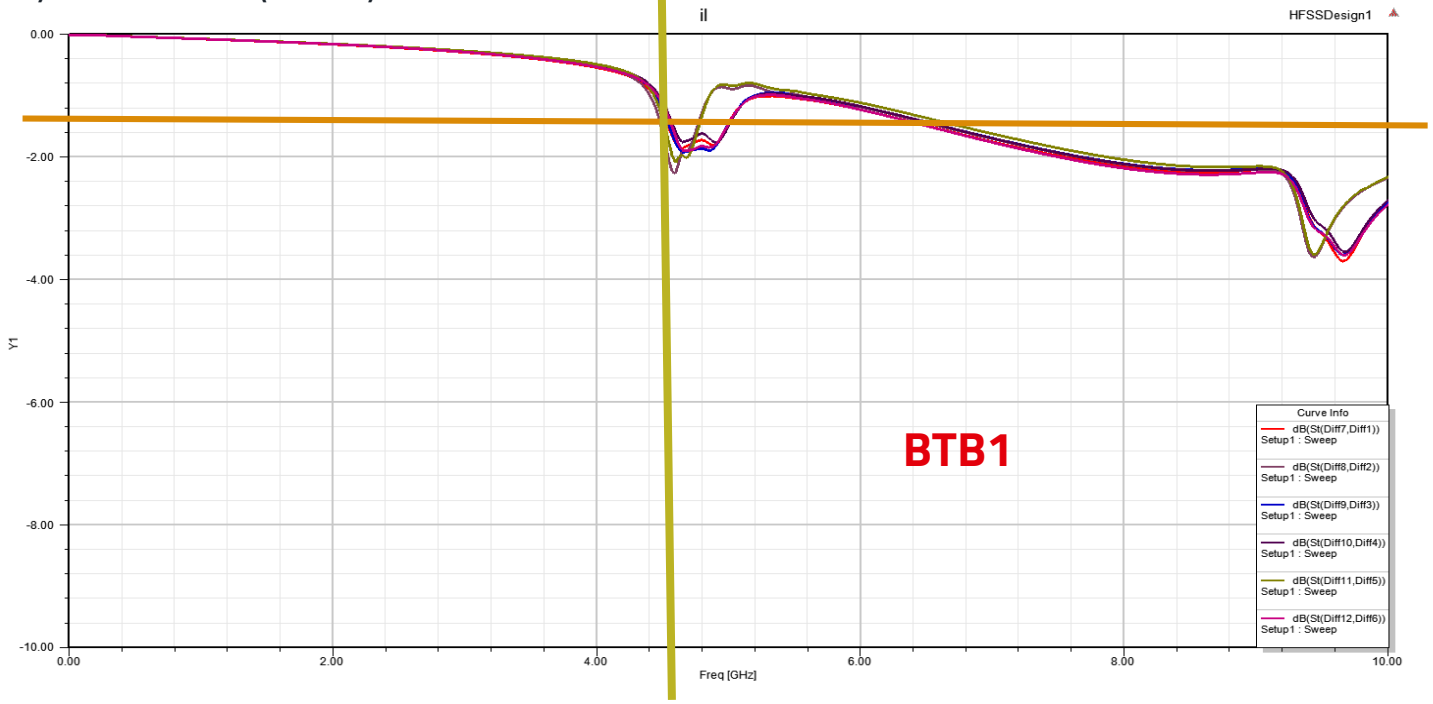


CONNECTORS FOR MEMORY SIGNAL CHAINS

Mezzanine Board-to-Board connectors

- WE **BTB08 and BTB1** series are well-suited for such applications
  - 100 Ohm Differential Impedance (as PCIe)
  - More compact than Board Edge Connectors
  - **Limited** insertion loss in **GSSG configuration**
  - Cross reference with **TE and Amphenol** (BTB08) and **Molex** (BTB1)
- However
  - Non-standard (limits interchangeability)
  - Lower power allowed than Board Edge Connectors

BTB1 : PCIe 3



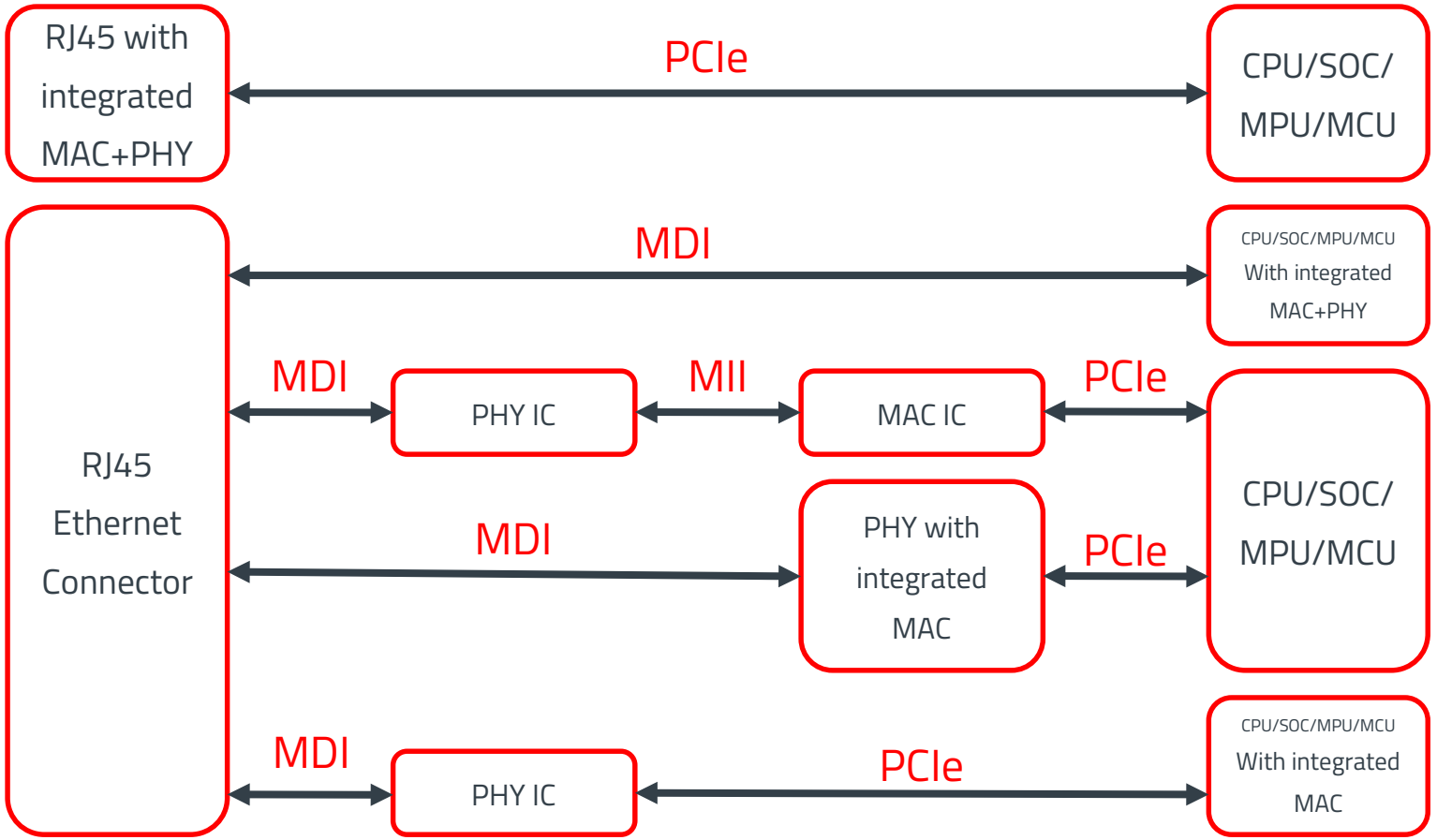
CONNECTORS FOR I/O SIGNAL CHAINS

Southbridge/I/O

CONNECTORS FOR I/O SIGNAL CHAINS

Ethernet Interfaces

- Ethernet has a very complex signal chain
  - An internal interface has to be used to bring signal to the MAC (here, PCIe)
  - **MII** : internal universal interface to link the MAC to the PHY (the PHY can be optical or electrical)
  - **MDI** : external signal that goes in the Modular Jack and cable



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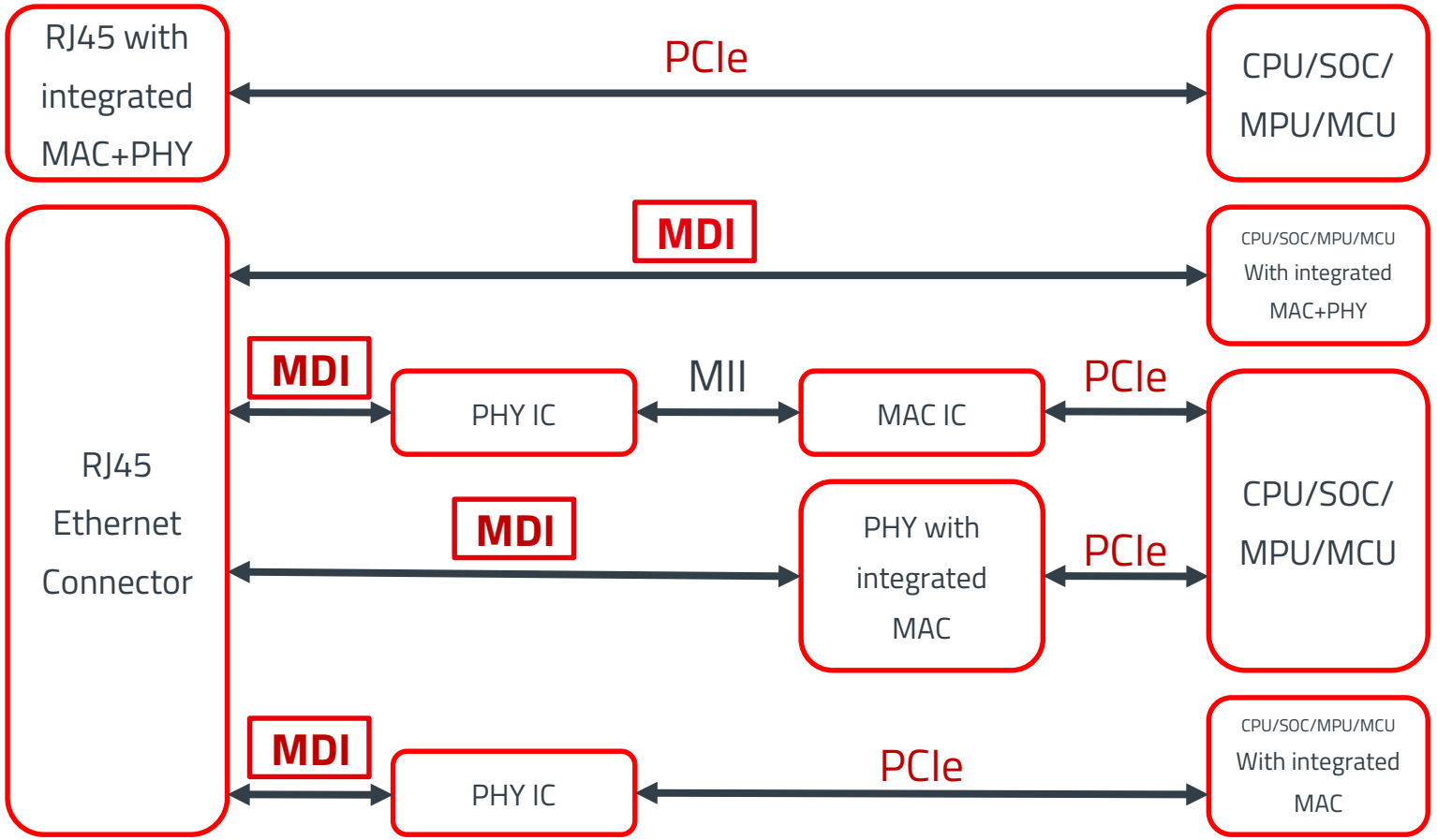


CONNECTORS FOR I/O SIGNAL CHAINS

Ethernet Interfaces

- Ethernet has a very complex signal chain
  - **MDI : external signal that goes in the Modular Jack and cable**

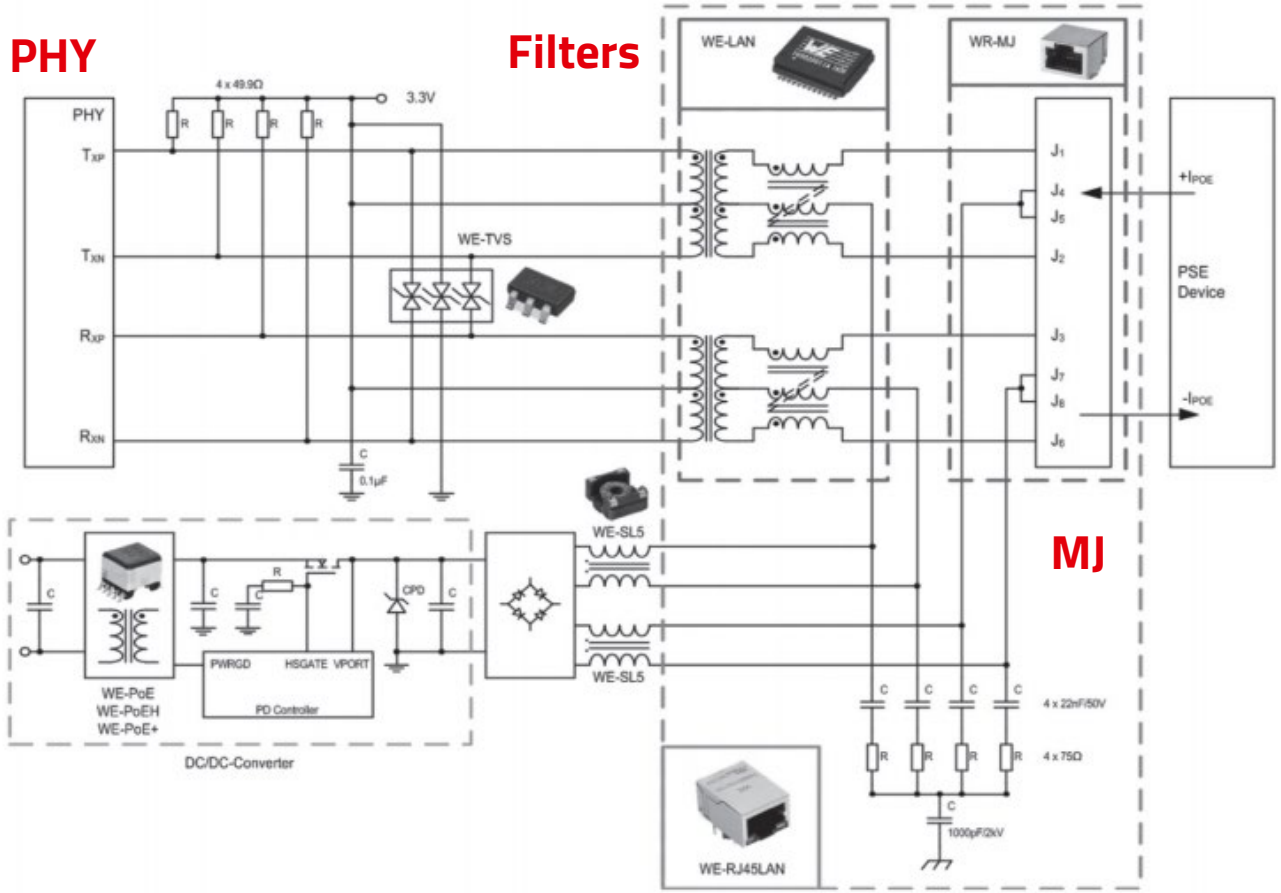
Device 1

- Active PHYciever
- PCB trace
- Passive Filters
- Modular Jack

- Cable with modular plugs

Device 2

- Modular Jack
- Passive Filters
- PCB trace
- Active PHYciever



CONNECTORS FOR I/O SIGNAL CHAINS

Ethernet Interfaces

- Customer example
  - PHY and RJ45 not on the same PCB
  - 100BASE-T (Cat 5)
  - How to link both ?

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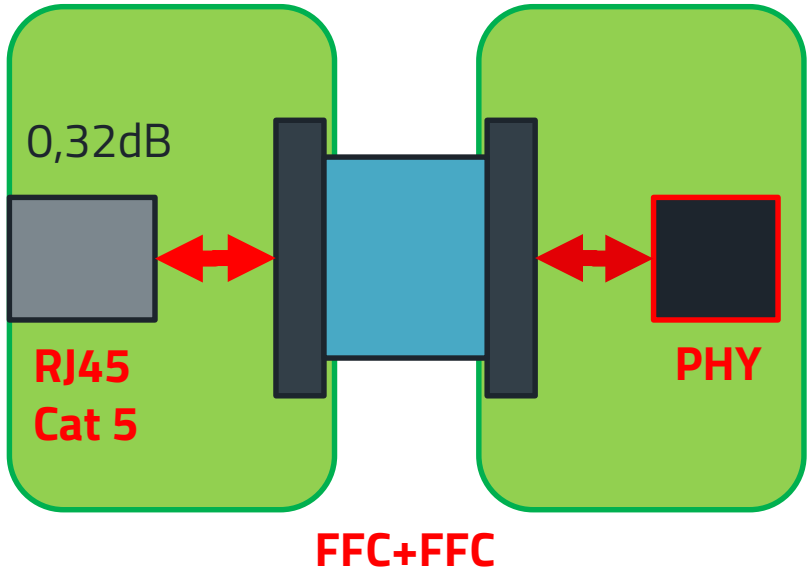
➔ Use a FFC with FPC connectors !

- But how ?



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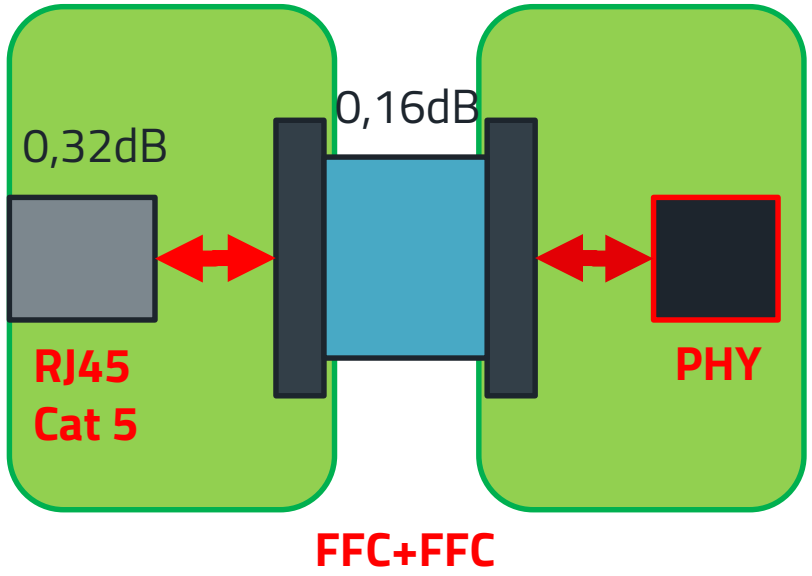
- But how ?
  - Use GSSG configuration
  - At least 13 pins
  - Not over 5-10cm
  - 100Ω differential impedance

- But isn't there a problem with Ethernet standard?



Pin	Signal
1	Ground
2	Line from RJ45 pin 1
3	Line from RJ45 pin 2
4	Ground
5	Line from RJ45 pin 3
6	Line from RJ45 pin 6
7	Ground
8	Line from RJ45 pin 4
9	Line from RJ45 pin 5
10	Ground
11	Line from RJ45 pin 7
12	Line from RJ45 pin 8
13	Ground

CONNECTORS FOR I/O SIGNAL CHAINS

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  - How to link both ?

➔ Use a FFC with FPC connectors !

- But how ?
  - Use GSSG configuration
  - At least 13 pins
  - Not over 5-10cm
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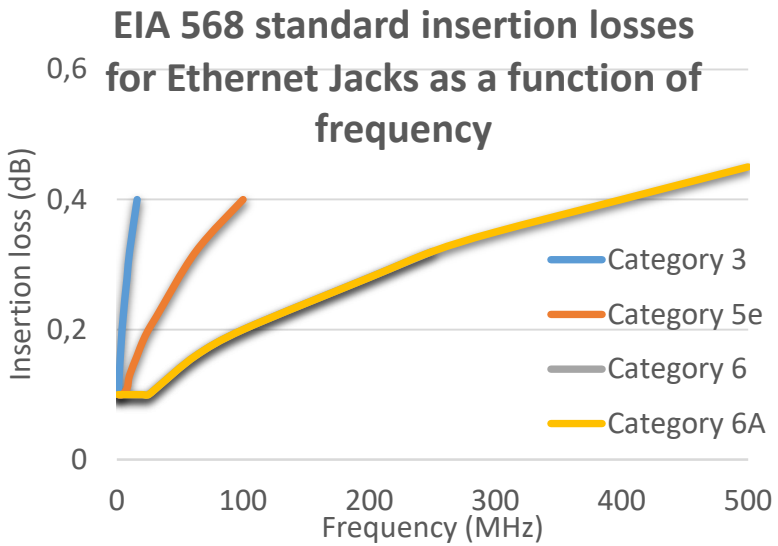
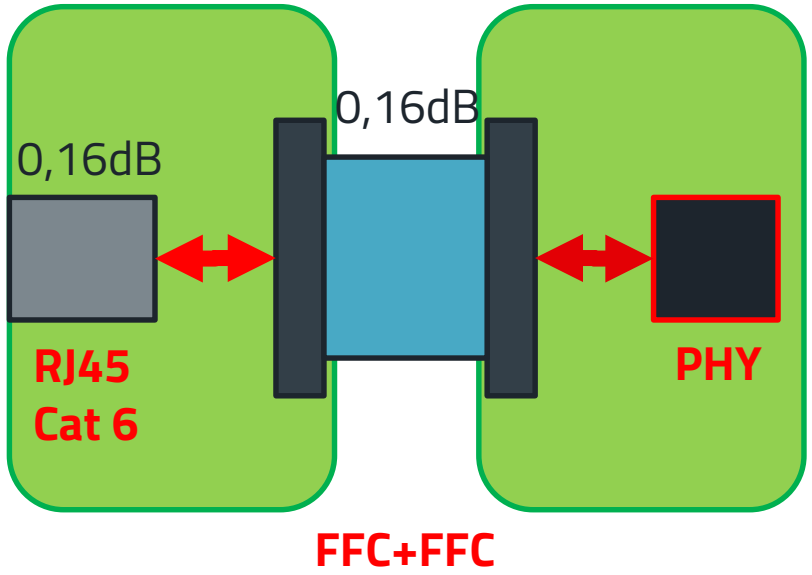
- But isn't there a problem with Ethernet standard?

➔Use a RJ45 one category higher ! (Cat 6)





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6	Line from RJ45 pin 6
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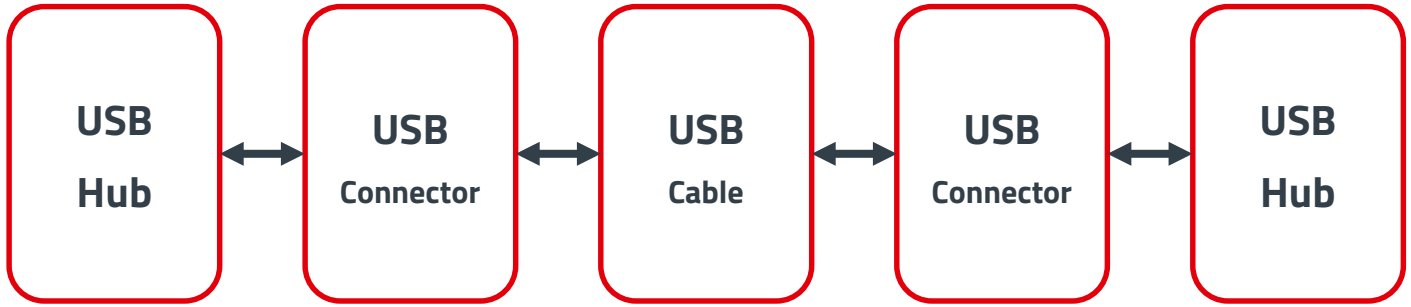
8	Line from RJ45 pin 4
9	Line from RJ45 pin 5
10	Ground
11	Line from RJ45 pin 7
12	Line from RJ45 pin 8
13	Ground

CONNECTORS FOR I/O SIGNAL CHAINS

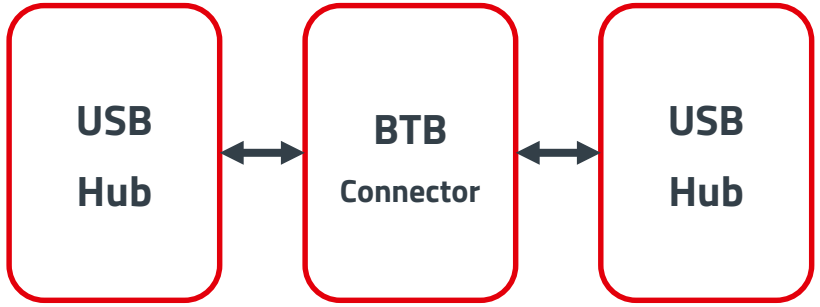
USB HSIC

- **USB** can be used as a serial **Board-to-Board** communication protocol
  - Up to **2 high-speed** lanes for transmission and reception in **GSSG**
  - Nyquist Frequency from 2.5 to 10 GHz for SuperSpeed
  - Total allowed losses : 24,5dB

USB I/O



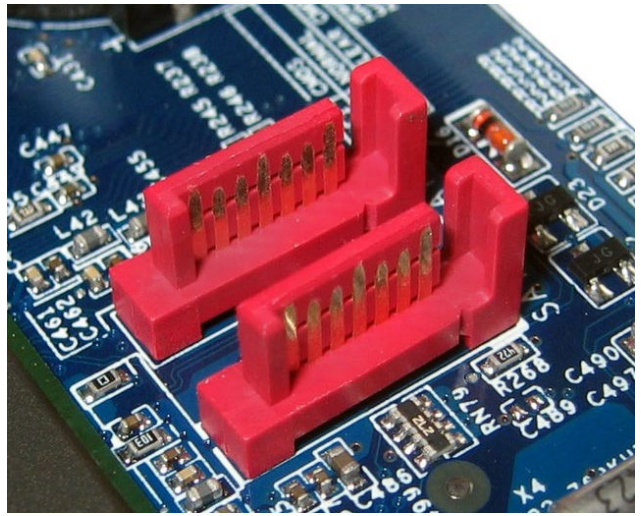
USB HSIC



CONNECTORS FOR I/O SIGNAL CHAINS

Serial I/O Buses

- **Serial bus SATA**
  - Generally for **internal** uses only
  - **One** transmission line, one reception line
  - Flat cable with **GSSG strips**
  - Nyquist Frequency from 1,5 to 6GHz
- High speed serial I/O buses can use **BTB connectors**



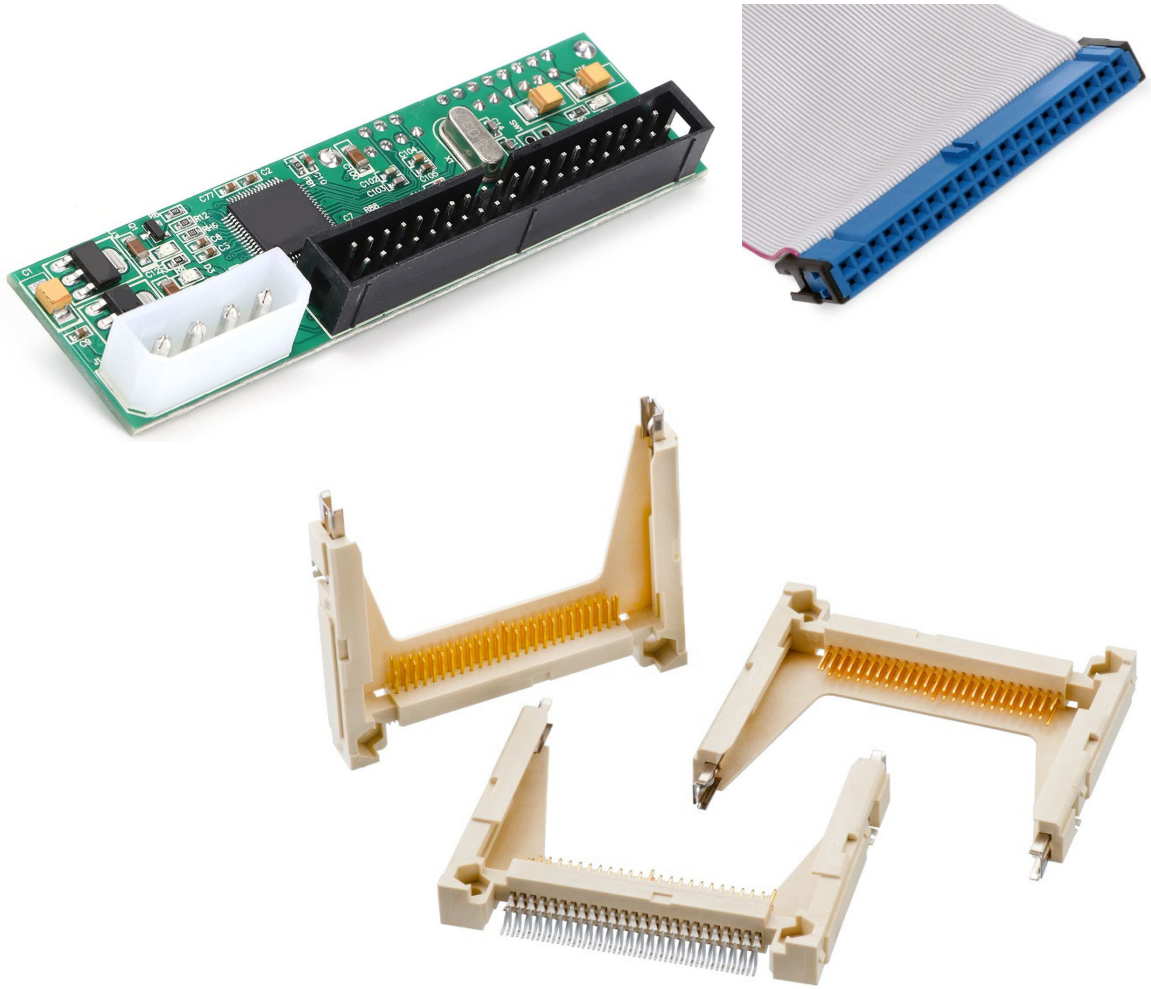
- **I2C**
  - 5 to 2500 kHz Nyquist Frequency
  - Most used :
    - 10kB/s (standard mode)
    - 400kB/s (fast mode)
  - Used in a lot of other protocols for inter-chip communication
    - HDMI VGA, DVI, DIMMs, PCI, PCI Express
- Low-speed serial I/O buses can use pin and socket headers

CONNECTORS FOR I/O SIGNAL CHAINS

Parallel I/O Buses

- **IDE/PATA**
  - 16 bits wide
  - Sample rate 80MT/s max
  - Bandwidth 1Gb/s max
  - 40-wire Ribbon Flat cable with 40-pins Box Headers

- **CompactFlash/PCMCIA**
  - 16 bits wide
  - Sample rate up to 12,5Mt/s (PCMCIA), up to 80MT/s (CF)
  - Bandwidth up to 200Mb/s (PCMCIA), up to 1,3Gb/s (CF)
  - 50-pin or 68-pin Card Connector



CONCLUSION

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- **Signal chain** analysis is going from the **core** of the system and analyzing the **different protocols** in place

- For us, signal chain analysis is :
  - How to find out **which connectors** customer may need to propose **new solutions** to customers.
  - A framework to **adapt our qualification tests** to give the most accurate information to the customers.
  - A good way to integrate work **with our colleagues.**

- It’s always interesting to know and understand the environment in order to propose suitable solutions.

Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

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