

Trends and Technical Challenges for High Speeds Serial Communications

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Presentation Outline



- High Speed Serial Interfaces Applications, Motivation, and Definition
- Copper Media Based Serial Interfaces:
 - Technical challenges for present solutions
 - NRZ vs Amplitude Modulation and Analog vs Digital
 - Trends for copper media based interfaces
- Optical Media Based Interfaces
 - The current applications and solutions
 - Near future evolution
 - Lower costs challenge: The Silicon Photonics
- General Trends and Conclusion

High End Serial Interfaces in Data Centers and High Perf Computing



Serial Interfaces: Enterprise Applications

- High speed interconnection through boards and cables
- Widely used both in Computer and Networking



Serial Interfaces: Consumer Applications

- Large presence and growth in the consumer space too
- HD video and 3D requires high bit rate links
- DVI, HDMI and Display Port are the big runners



Which Standards are or Moved to Serial



Why is the World Going Serial



- There are a number of elements pushing wired communications going Serial:
 - Better exploits the BandWidth of a wired connection
 - Space
 - Weight

 - Miniaturization
 - Simpler connectors
 - Lower energy/bit (cooling)



In the end all translates into lower costs for consumer and better performance for Enterprise.

What do we Define as Serial Interface



- Classically the bits are coded in a two state signal (electrical, optical or whatever) and transmitted sequentially: NRZ data
 - The time base (clock) generating the bits can be transmitted too on a separate channel. So called synchronous interface
- At the receiver side the transmitter clock (frequency and/or phase) and used to sample the incoming bit stream at the right time thus recovering data too (CDR).



Extension of NRZ Serial Interface



 The same concept can be extended to multiple bit transmission at the same time coded as the amplitude value of the transmitted signal: PAM



- An equivalent "parallel" transmission can be done in the optical domain using different polarizations or different wavelengths over the same media.
- These techniques, today split in the different applications segments will contaminate each other in the near future!

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NRZ Data Over Copper Media - Intro

- This is today the largest majority of Serial Links from few centimeters up to several meters distance and up to 15Gb/s;
- The architecture used for Serializing and Deserializing is mixed Analog/Digital and relatively well consolidated.



NRZ Data Over Copper Media - Jitter

- Random jitter → results from the accumulation of random processes, typically electrical noise, following a Gaussian distribution, therefore its contribution to the total jitter is unbounded
 - 14 σ are usually taken, corresponding to 10⁻¹² BER
 - Phase noise of reference clock and PLL
 - Electrical noise in the data path; $J_{rms} = \frac{T_{clk}}{\pi} \cdot \sqrt{\int_{\Delta f = 1/T_f}^{\Delta f = \infty} d\Delta f}$
- Deterministic jitter → results from systematic effects and its contribution to the total jitter is bounded:
 - Periodic jitter (residual clock modulation)

• Duty Cycle Distortion (DCD); $J_{pk-pk} = \frac{2 \cdot T_{clk}}{\pi} \cdot \sqrt{PwrRatio}$



DSc

 This jitter is NOT recoverable and, typically < 1/3 of a Bit Unit Interval is allowed by the standards

NRZ Data Over Copper Media - ISI



 Inter Symbol Interference caused by the attenuation of the lossy media is main design challenge for copper:



ISI can be recovered through Signal Processing !

NRZ Data Over Copper Media - CR

Synchronous clock recovery architectures are the most largely used in High Speed CDR:



- Analog architecture:
 - Requires one vco/data_slice
 - Usual High sensitivity and low portabilty/flexibility of analog ciruity



- i.e. sizing loop gain on transition density
- This is used in all links regarding media length and loss

NRZ Data Over Copper Media - JT

- The Jitter Tolerance of the receiver is directly associated to the performance o the clock recovery loop, particularly for the corner frequency.
- Whatever is the CR architecture, the JT plots qualitatively always look like this:



Datarate; pattern

The jitter frequencies lower than the CDR bandwidth are tracked so that the amplitude tolerated can be higher than the unit interval.

The jitter frequencies higher than the CDR bandwidth are not tracked so that the amplitude tolerated is always lower than the unit interval.

- Out of band JT requirement is ~2/3 of UI.
 - As mentioned 1/3 is left to the TX jitter and the remaining 1/3 is margin left to the channel nise and residual ISI.

Copper Media - Very Short Reach



When connections are short (less than 6dB attenuation @ Nyquist: i.e. a few inches/mts PCB/cable) the transceiver is pretty straightforward: no need of sophisticated equalization techniques



- A GOOD power figure for this class of circuits is ~8mW/Gb/s (8pJ/bit) in the 10÷20Gb/s frequency of operation
 - Power is mainly burnt for clock generation/distribution/recovery

Copper Media - Middle Reach



 When the attenuation @ Nyquist is in the range of 6÷15dB: and some simple TX/RX equalization is needed



- A GOOD power figure for this class of circuits is ~10mW/Gb/s (10pJ/bit) in the 10÷20Gb/s frequency of operation
 - Added power is burnt for TX de-emphasis and RX filtering

Copper Media - Long Reach



 When the attenuation @ Nyquist is in the range of 15÷30dB (i.e. 40" PCB or a few tenths meters cables): and sophisticated TX/RX equalization is mandatory



- A GOOD power figure for this class of circuits is ~15mW/Gb/s (15pJ/bit) in the 10÷20Gb/s frequency of operation
 - Multi TAP TX FIR (up to 7), multi TAP DFE (up to 8) and RX/TX negotiation for best adaptation are added

A little bit more about DFE



- DFE is a non linear filtering based on the bit taken decisions with the purpose to remove the residual ISI
- Compared to a linear filter it is digitally adaptive through an LMS algorithm and it does not boost the noise





 There are several ways to implement a DFE in the A/D mixed mode domain:



Comments on Copper Based Interfaces

- What shown so far is the interface architecture for the largest majority of serial connections in consumer and enterprise
- Compared to others (long Haul, metro, inter-buildings, base stations...) these are quite short range.
- The natural raising question is:

Is there a trend to move away from this interfaces or are they going to stay the same still for long time simply scaling in frequency ?

 My view is that this segment is driven by power and costs and, today, there are no other solutions so cost effective: copper and silicon are by far the cheapest materials

Why Not Going to Digital Transceivers ?

- Even assuming this part of the world stay copper why not moving to digital transceiver ?
 - Signal processing (coding, equalization, FFE, DFE...) are much more natural in the digital domain;
 - DSP is more power and can approach channel max. capacity much more than an analog or mixed architecture which require margin on SNR;
 - Digital is much more flexible and portable, power scales...



- Reason while Digital Transceivers are not very popular is POWER since speed grow too fast:
 - Manufacturers prefer to put effort and money in materials and connectors and to keep high enough SNR and keep NRZ transmission and the transceivers previously shown.

But Digital Transceivers are used too



- An in very popular application like Ethernet BaseT 1Gb/s.
- Because with such a poor media (4 twisted pairs 100mt long) there are no other ways then using all the channel capacity even cancelling echos and Xtalk.
 - Impossible with the shown techniques.



- Simultaneous TX and RX of PAM 5 signals on each pair
- Echo and Near end Xtalk digital cancellation
- Resulting power is high: ~400mW for 1Gb/s link

And keep Evolving...



- Base-T keeps evolving:
 - 10Gb/s links over Cat6 cables are being introduces into serves and data centers and are supposed to take the lergest portion in this area.



- Simultaneous TX and RX of PAM 16 signals on each pair
- Far-End Xtalk digital cancellation added to previous ones
- Resulting power is high: ~3W for 10Gb/s link

Conclusions on Cu - Based Interfaces

- Next generation of short reach ranges (up to 28Gb/s) will scale from presented solutions
- In the same generation PAM serial links will start being standardized and used:
 - They will not be digital solutions, but a mix of what shown in NRZ and PAM: still mixed equalization, feedback from digital on low resolution ADCs... Again to keep power under control.
- This will become the majority of short range when we will go in the 40Gb/s space.
- And purely digital links (Base-T like) are also going to improve:
 - Digital scaling will help
 - Shortening cables (from current 100mt to ~30mt which are the largest majority in DC) or making them more performing (Twinax) going up to 40Gb/s will be possible.

And what about longer distances or higher speed ?

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General Trends and Conclusion

Optical Solutions in HE comms



- Optical links are undisputed since decades for huge distances:
 - Long haul and metro access communications use complex optical modulation to achieve 100Gb/s over a single SMF fiber.



- In this segment cost and power are not the driving factors.
- The key element is squeezing as much as possible of information in the same fiber:
 - Therefore dual polarization, multiple wavelength will keep growing

Current Enterprise Optical Solutions



 Less sophisticated optical communications have largely penetrated the enterprise market too, particularly in the data centers



- Current mainstream transceiver modules are 10Gb/s per fiber (typically there are 4 fibers/link). 25Gb/s/fiber are available too.
- The optical transceiver takes care of electrical-optical conversion using On-Off Keying modulation
 - All the operations of CDR (including SoC to opto-module signal equalization) are done in the electrical domain
- Power for the optical part is few watts, but, thanks to the great quality of the optical channel link it is basically independent on the connection length.
- The cost spans from 100s to a 1000\$ per module.

Is there a way to lower costs ?



- The high costs come from the need to assembly modules coming from different technologies with high mechanical precision
 - The low yield associated to this manufacturing process
- But there ways to put on the same material several optical (components today assembled in a discrete manner) and also the electrical devices to drive them
- The most popular way is Silicon Photonics:



- All basic optical components can be placed directly on the Silicon die:
 - Straight and bended Waveguides
 - Vertical/horizontal Splitters/couplers
 - Mach Zehnder or ring modulators
 - Photodetectors
 - Laser can be mounted on silicon using
- And the great advantage of having these components On-Si is that they can be in on the same die (or within the same package using proven SiP techniques) as the electronics.

Optical backplanes



If optical components are on the die new methods optically connect chip and boards need to be used:



- On board optical waveguides and card/BackPlane connectors are required
- Still required to be industrialized, but it is a very promising solution.

Is this the End of Signal Processing ?

- The important success of optics into lower segments than his traditional Hi-End applications is due to a couple of factors:
 - There is a relevant step in performance vs previous copper technology, particularly in term of bandwidth, SNR.
 - Despite this, actually thanks to this, the same basic concepts widely used so far in serial interfaces, still applies simply changing the domain from electrical to optical.

Does this mean that all the signal processing techniques, analog and digital, will not be any more needed ?

- Of course not: in fact the incredible pressure to reduce costs will rapidly force to use cheap optical components (lasers, fibers, connectors, boards...) requiring compensation through electronics:
 - Let's quickly see an example.

10Gbps: Standard 802.3aq



- 3 different pulses representative of the received signal after 1km of OM1 MMF:
 - Precursor, Symmetric and Postcursor Pulses



MM Fiber Electronic Dispersion Compensation



- EDC: Electronic Dispersion Compensation
- FIR and DFE: Adaptive FIR to track channel variations

Conclusions



- Hi Speed Links is ruled by three main parameters:
 - Power, Distance and Costs
- Today the very low distance space is dominated by NRZ transmission on copper in order to keep both power and costs low.
- The huge distance links are all optical and sophisticated electronic DSP are used to boost performance at the expense of power and costs.
- In the mid range copper and optical co-exists:
 - Copper links are quite cheap at the expense of power efficiency
 - Optical links feature better power at higher costs..
- What's going to happen is that short links will stay as they are, but:
 - Materials will improve
 - Processing techniques today used only in longer reach will enter into this segment
- Mid range will definitely see an increase of optical links:
 - Miniaturization (Si-Pho) will drive the cost reduction
 - The compensation of non-idealities to use cheap techniques will still require the usage of important electronic signal processing.



THANKS!

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