Ethernet Applications & Standard Developments

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2023/05/01


EV6

Outline

- Our daily life
- Ethernet applications
  - data center to automotive
- Ethernet technology - Optical to Electrical
  - Serdes & channel coding
- IEEE standard meeting
- Lessons learned
- Summary

Our Daily Life

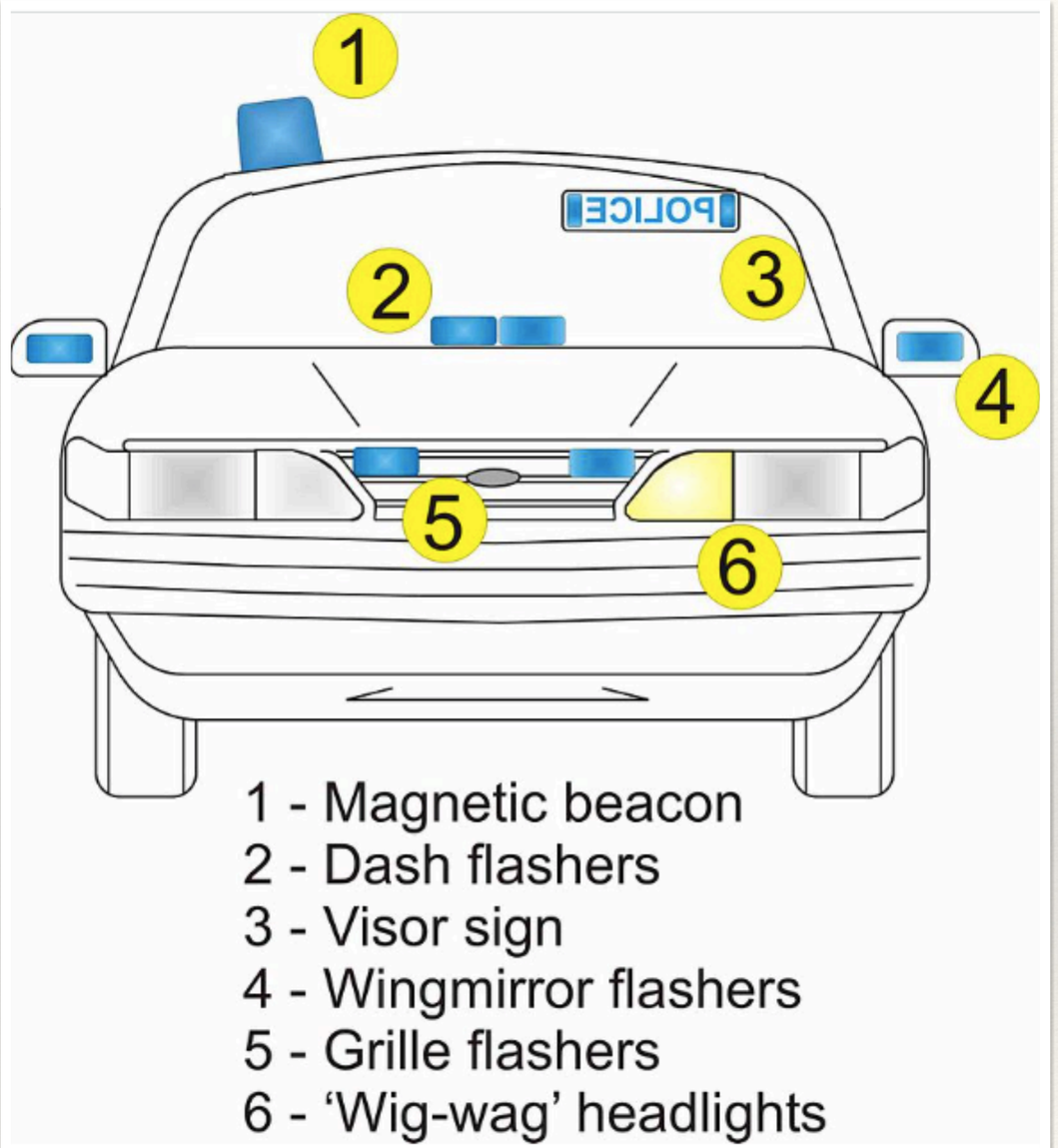
Source: https://en.wikipedia.org/wiki/Smoke_signal

Source: https://guardian.ng/life/the-importance-of-drums-in-african-tradition/

Source: https://zh.wikipedia.org/zh-tw/%E8%A4%92%E5%A7%92

Telecommunication

- Why
  - National security (military)
  - Entertainment
- How
  - Human perception
    - Visual - smoke signals, beacons
    - Audio - drumbeats, horns, whistles
  - Electromagnetic wave



Source: https://en.wikipedia.org/wiki/Telecommunications


健康中街

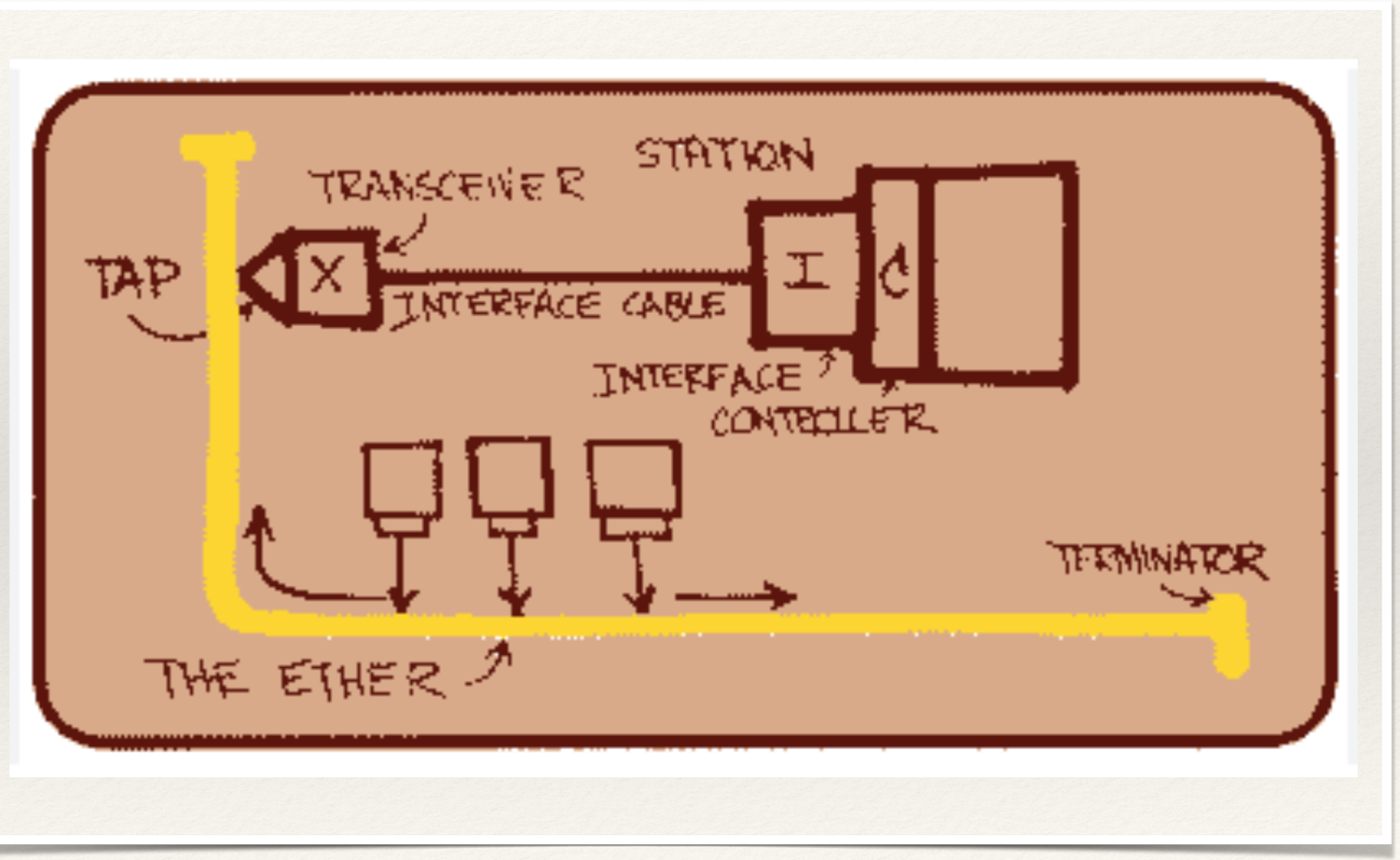

非常律師
禹英禑

Infrastructures Enable What We Enjoy

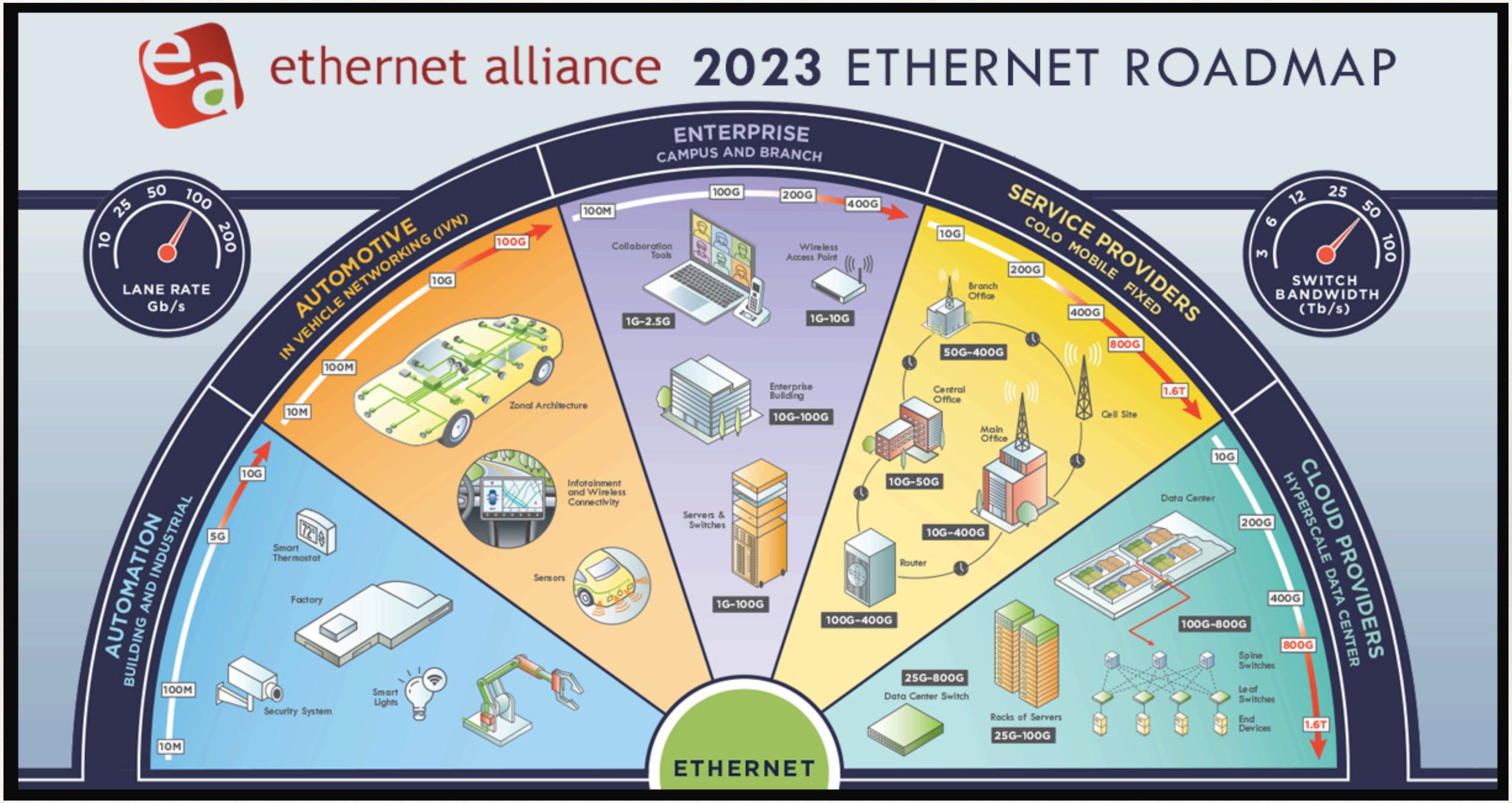
- Data center
- Requirements
  - Power consumption
  - Throughput
  - Reliability - BER
  - Interaction - latency
- Ethernet - Local Area Network

Ethernet (Ether Network)

- Ether - 從“錯誤的理論”到“全球標準”
  - 無所不在
  - 無所不包
- IEEE 802.3 - 50th anniversary
  - 802.3a —> 802.3dj

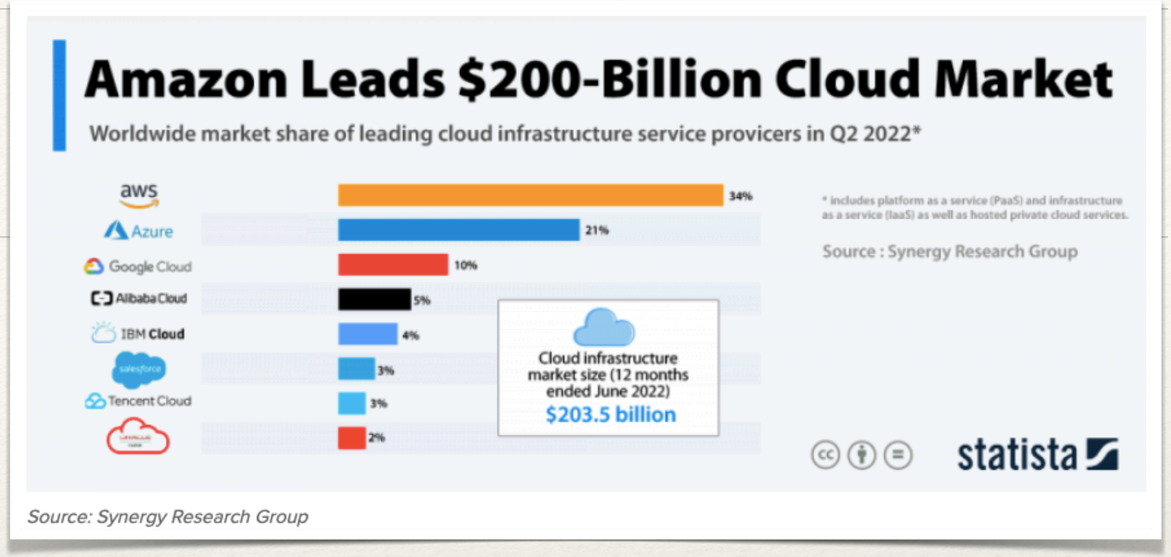


Ethernet Applications

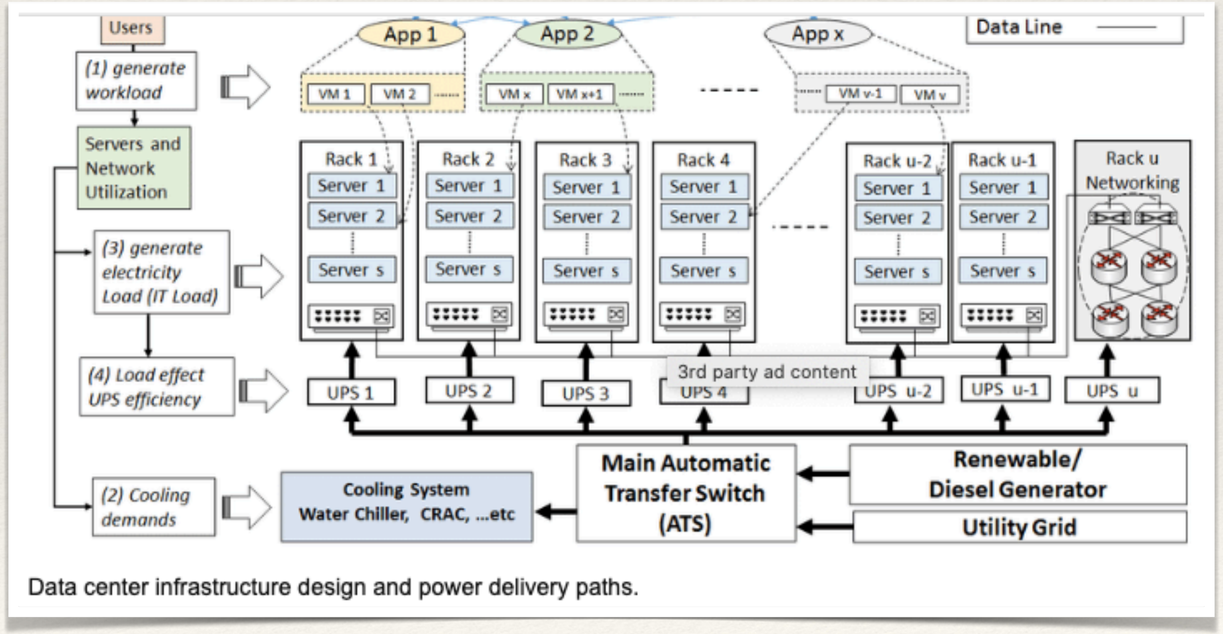

ethernet alliance 2023 ETHERNET ROADMAP
LANE RATE Gb/s
10 25 50 100 200
SWITCH BANDWIDTH (Tb/s)
3 6 12 25 50 100
AUTOMOTIVE
IN VEHICLE NETWORKING (IVN)
10M 100M 10G 100G
Zonal Architecture
Infotainment and Wireless Connectivity
Sensors
ENTERPRISE
CAMPUS AND BRANCH
100M 100G 200G 400G
Collaboration Tools
1G-2.5G
Wireless Access Point
1G-10G
Enterprise Building
10G-100G
Servers & Switches
1G-100G
SERVICE PROVIDERS
COLO MOBILE FIXED
10G 200G 400G 800G 1.6T
Branch Office
50G-400G
Central Office
10G-50G
Main Office
Cell Site
10G-400G
Router
100G-400G
AUTOMATION
BUILDING AND INDUSTRIAL
10M 100M 5G 10G
Smart Thermostat
Factory
Security System
Smart Lights
CLOUD PROVIDERS
HYPERSCALE DATA CENTER
10G 200G 400G 800G 1.6T
Data Center
100G-800G
Spine Switches
Leaf Switches
End Devices
25G-800G
Data Center Switch
Racks of Servers
25G-100G
ETHERNET

Data Center Functions

- Computing
  - Server (Intel, AMD)
  - xPU (nVidia, Google, AMD)
- Memory
  - SSD, DRAM (Samsung, Micron)
- Communication
  - Switch (Cisco, Broadcom, Marvell)



Source: Synergy Research Group



Data center infrastructure design and power delivery paths.

Intel Silicon Photonics SPTSLP2SLCDF 收發器模組 乙太網路 100Gbps 1311nm 3.3V LC 可插...

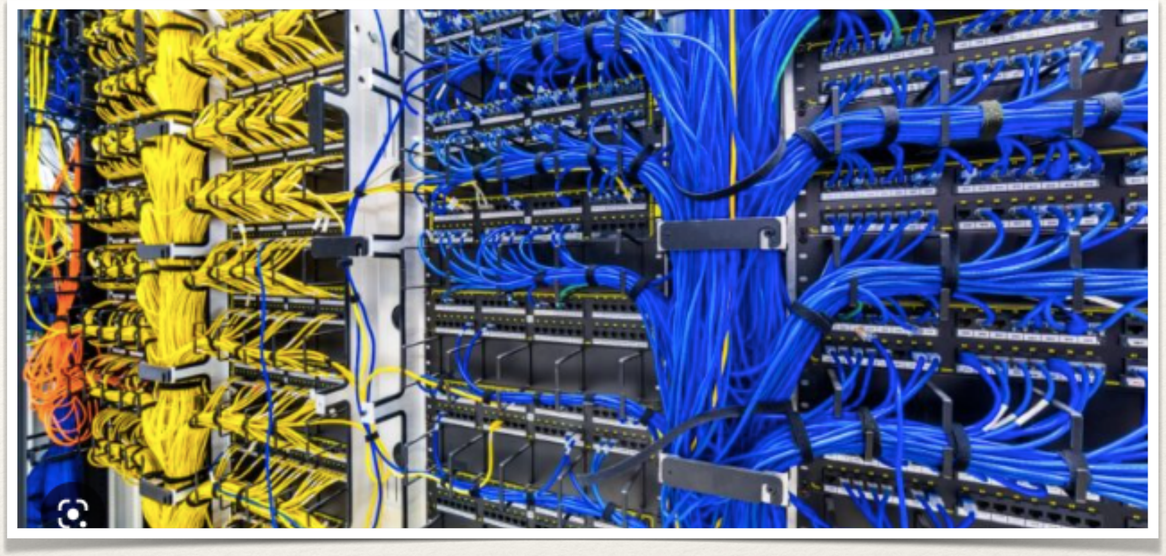
$22,312

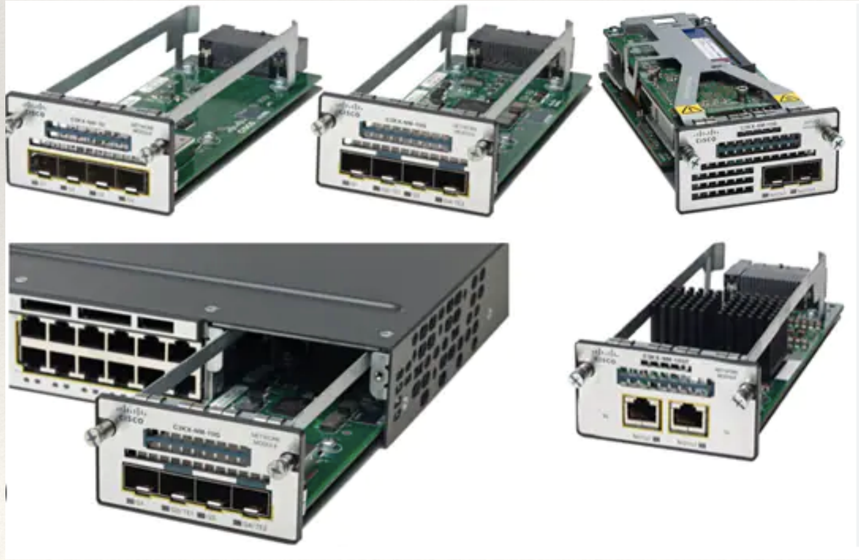
Digi-Key Taiwan

ATGBICS QFX-QSFP-DACBO-15M-AOC-C 位置 QSFP+ 對 SFP+ (4) 插頭對插頭 (4) 49.21'...

$11,606

Digi-Key Taiwan





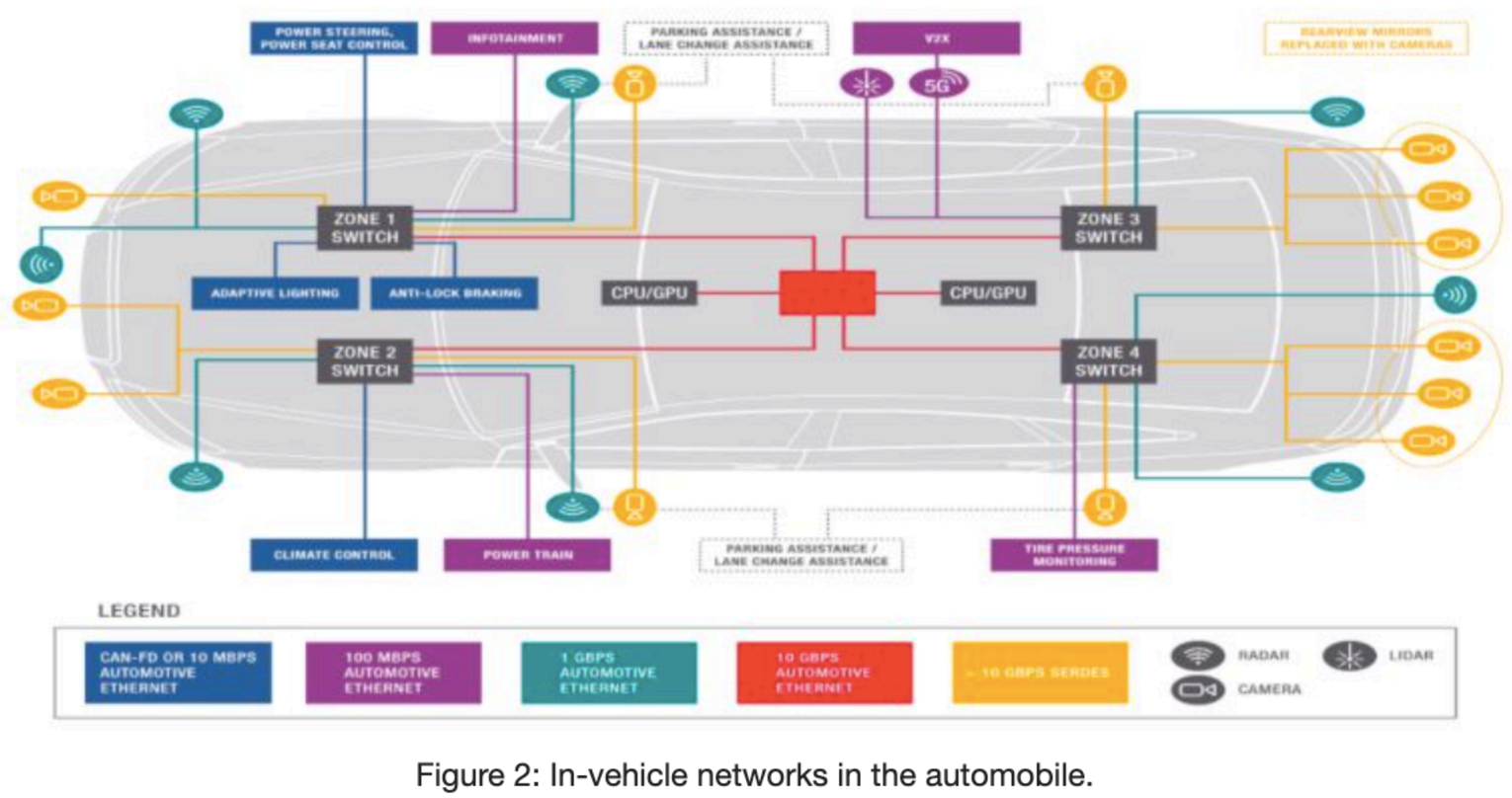
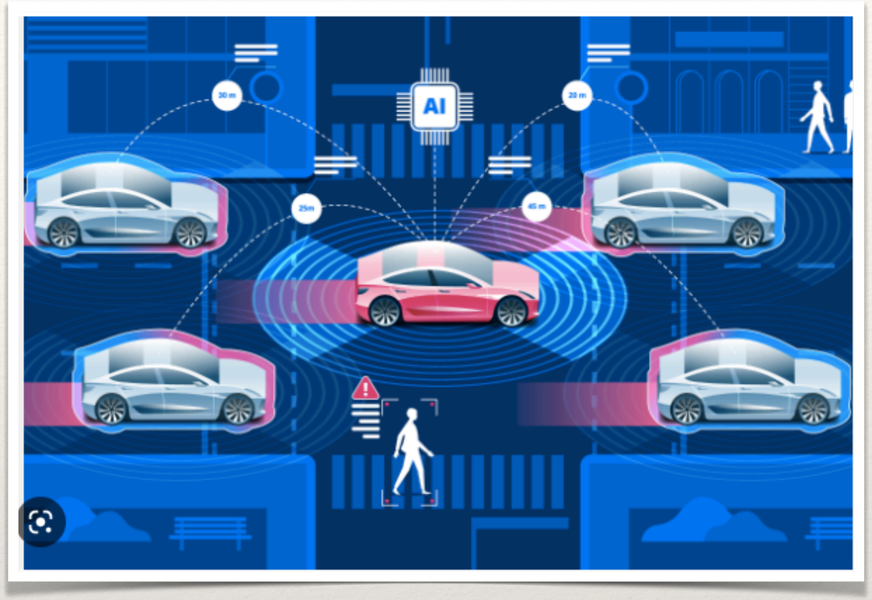
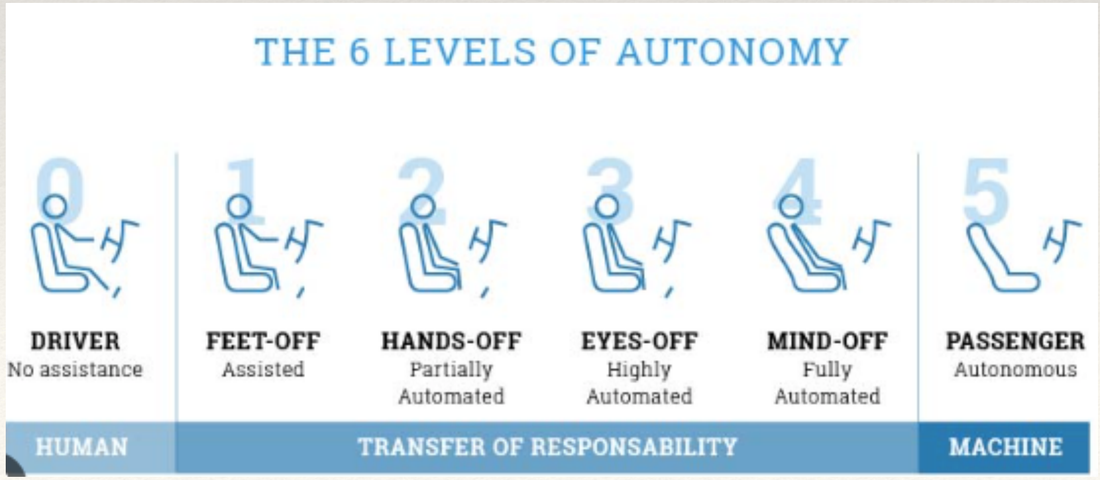


Figure 2: In-vehicle networks in the automobile.

Source: https://www.eetasia.com/automobile-in-vehicle-networks-ethernet-serdes-or-both/

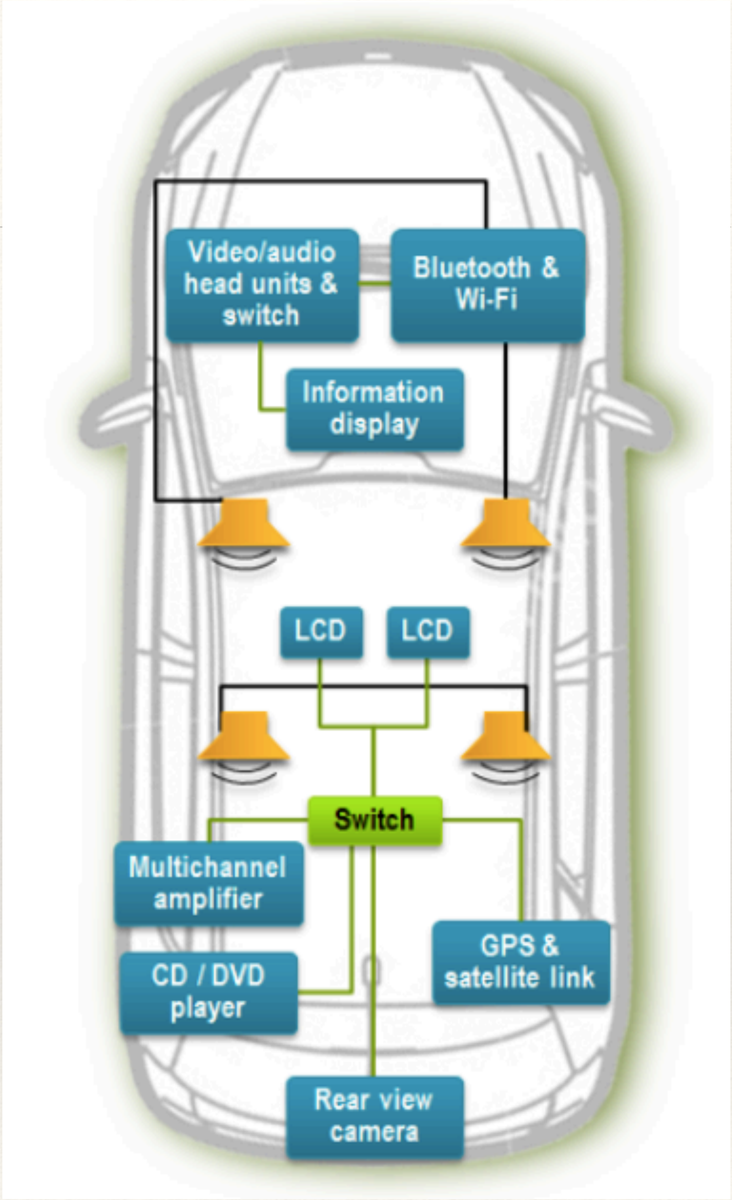




Could self-driving cars make crossings or traffic lights redundant?

Automotive Ethernet PHY

- What's differences in car?
  - A lot of connections
  - Various rates - from <1 Mbps to 10 Gbps
  - Extremely reliability - autonomous driving (human life)
- Challenges for automotive networking
  - Cable weighting
  - Electromagnetic interference



Source: https://www.eeworldonline.com/an-inside-look-at-the-automotive-ethernet-protocol/

Various Ethernet Standards for Automotive

- Reach
  - 15m for passenger car
  - 40m for truck
- Medium
  - Single pair twisted pair cable
  - Plastic optical fiber
- Various standards are competing - Ethernet, MIPI, ASA
  - The winner is …

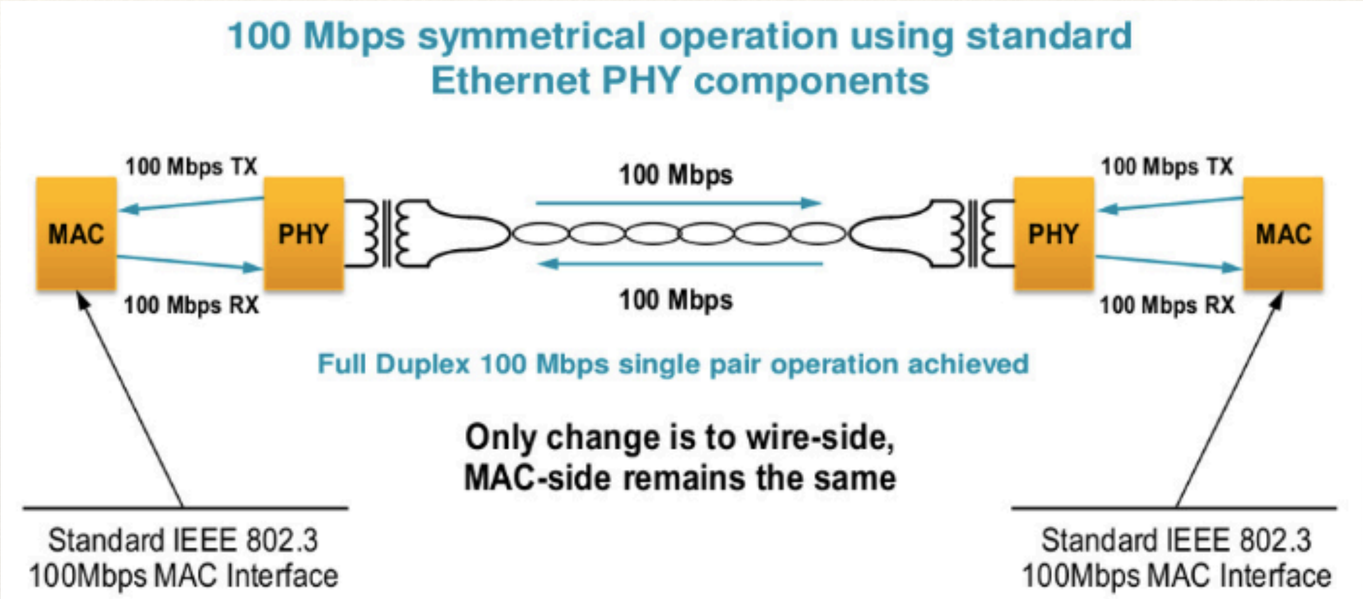


Figure 3: BroadR-Reach differs from IEEE 802.3 Ethernet only from PHY to PHY; they're identical at the MAC level.

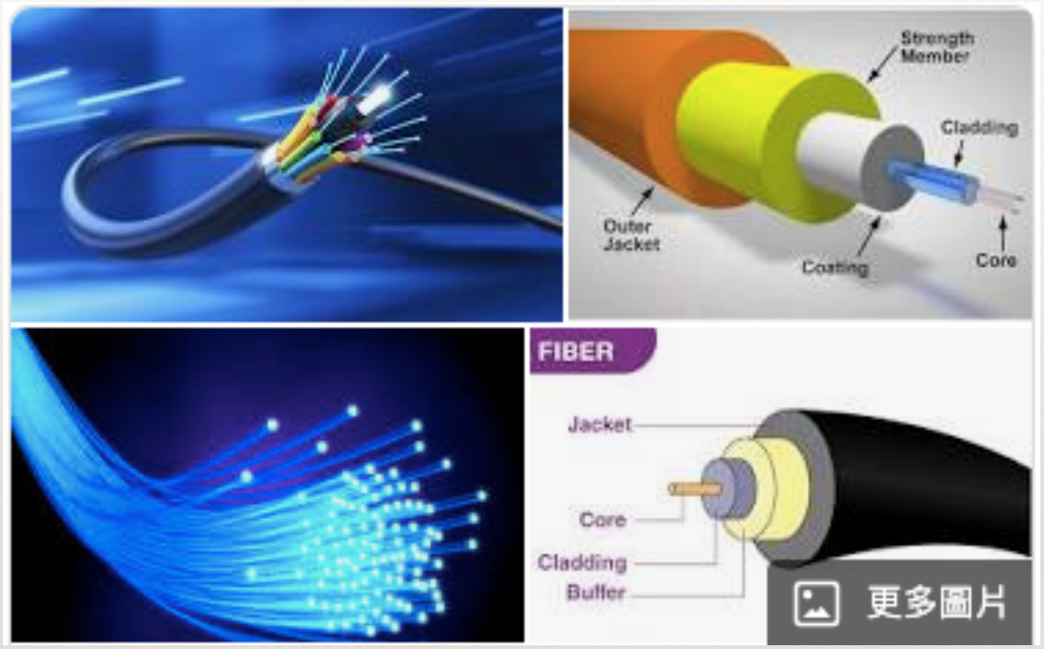
Ethernet Technology

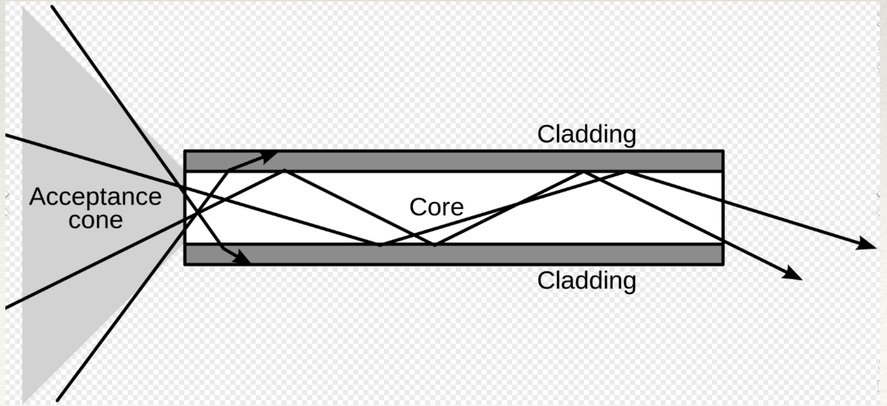
OSI 7 Layers

- For two computer to exchange message (packet)
- Physical (PHY)
  - Medium - cables, fibers, printed circuit board (PCB), inter-die connection
  - Rates - 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps, …, 800 Gbps, 1.6 Tbps
  - BER - 1e-12 ~ 1e-13
  - Latency - 10 ~ 200 ns

Optical Fiber Cable

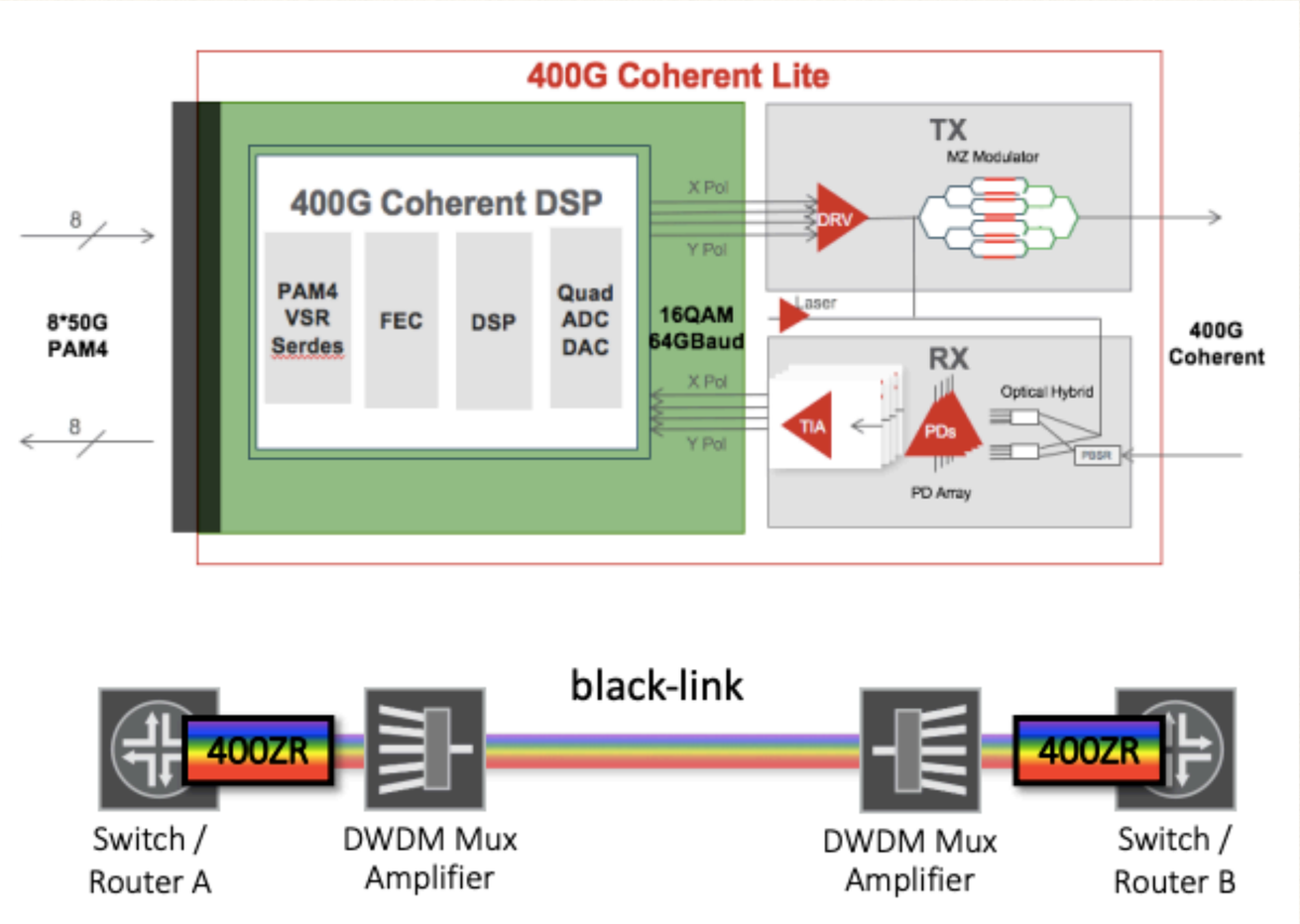
- Long distance
  - Total reflection of laser light in fiber
  - Single Mode Fiber (SMF) & Multi Mode Fiber (MMF)
- High channel BW
  - Limitation at electric-to-optical & optical-to-electric components
- Aging is an issue
- Cost is much higher
  - Silicon photonics is trend





100Gbps/Lane PAM4 Optical PMD - Block Diagram

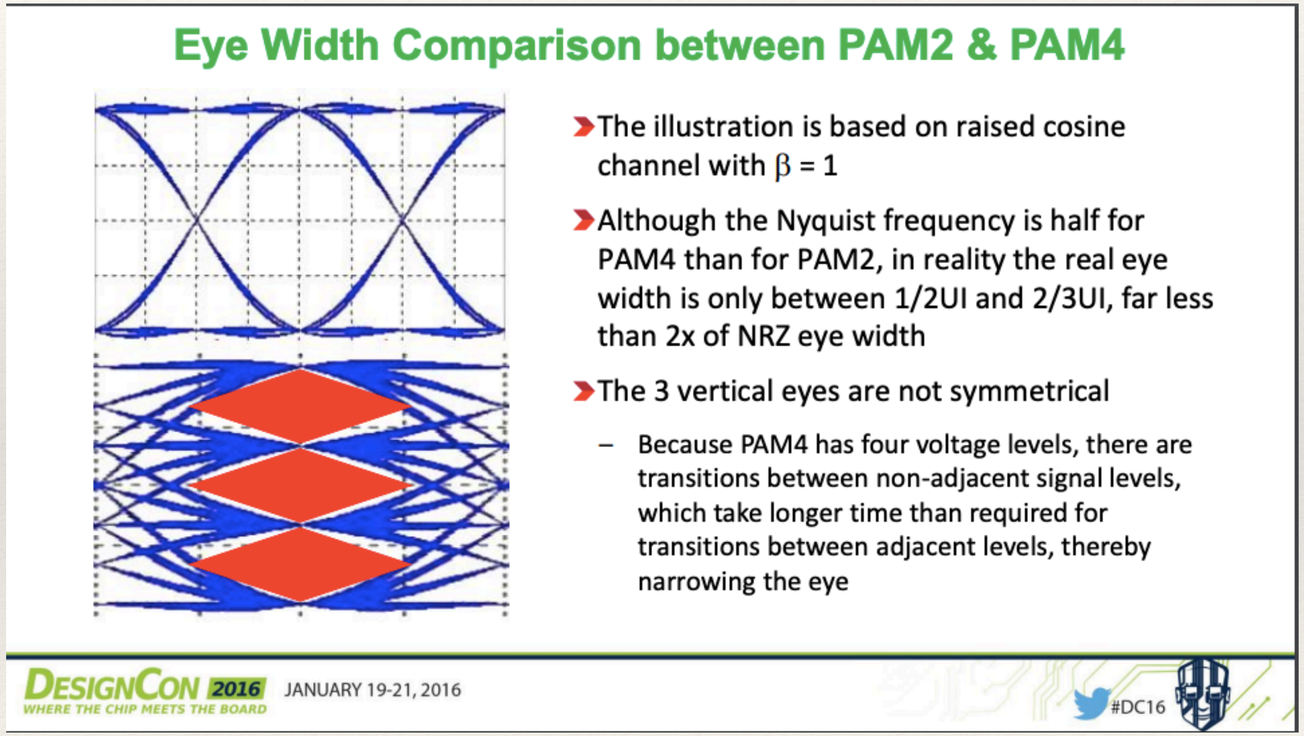
- Serdes - serializer & deserializer
  - High rate, but small pin count
- FEC - forward error correction
  - Channel coding
- DSP - digital signal processing
  - Clock recovery
  - Equalization
- ADC, DAC
  - Analog <—> Digital
- Electrical <—> Optical



Source: https://www.ieee802.org/3/B10K/public/adhoc/18_0508/nicholl_b10k_01a_180508.pdf

How to Achieve Higher & Higher Throughput?

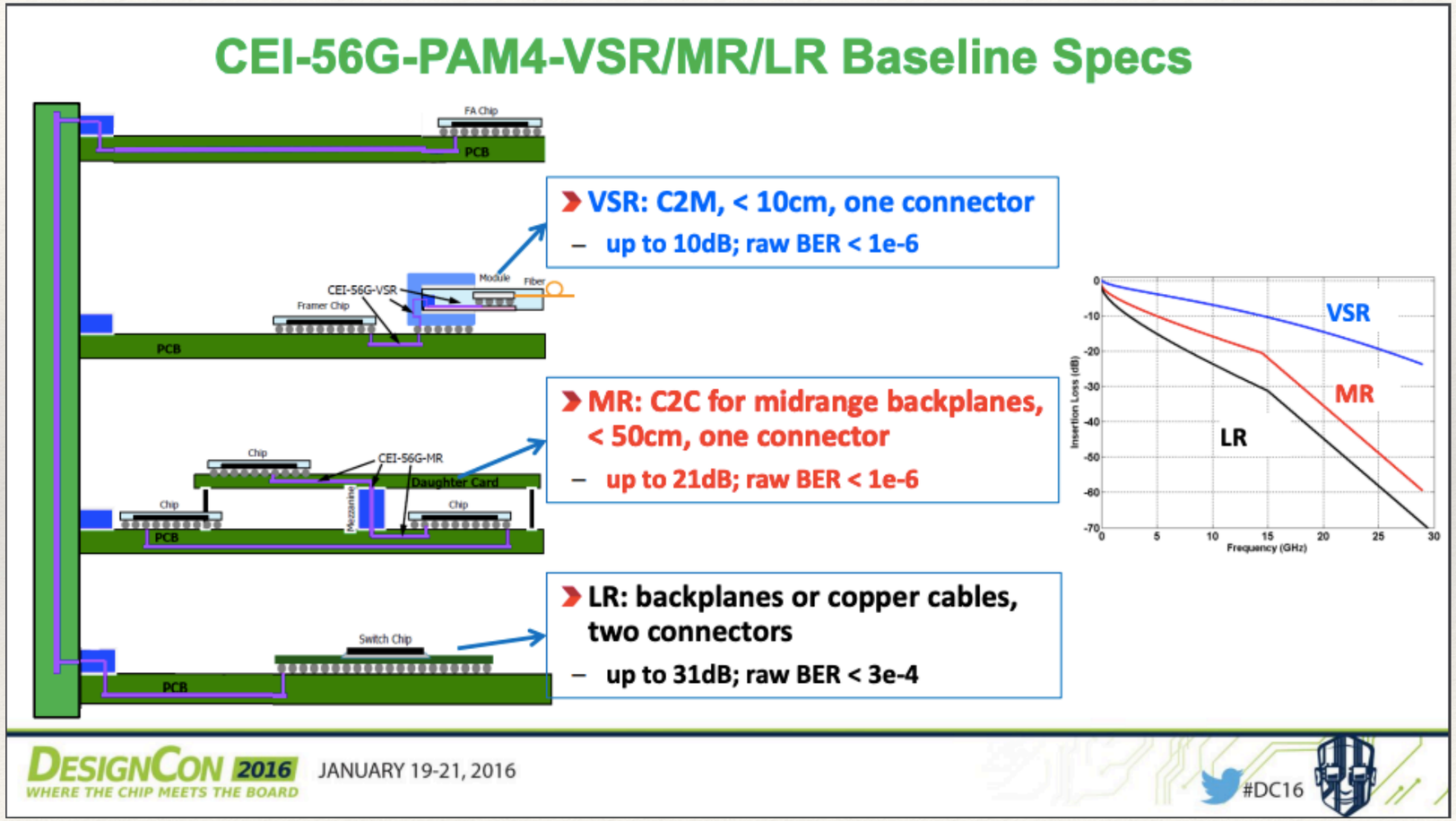
- Increase symbol rate
  - More and more challenging
- Increase modulation order
  - NRZ —> PAM4 —> PAM8 or PAM16
- Stronger channel coding
  - BER before FEC can be relaxed



Source: https://www.xilinx.com/publications/events/designcon/2016/slides-pam4signalingfor56gserial-zhang-designcon.pdf

50Gbps/Lane PAM4 Serdes - Channel

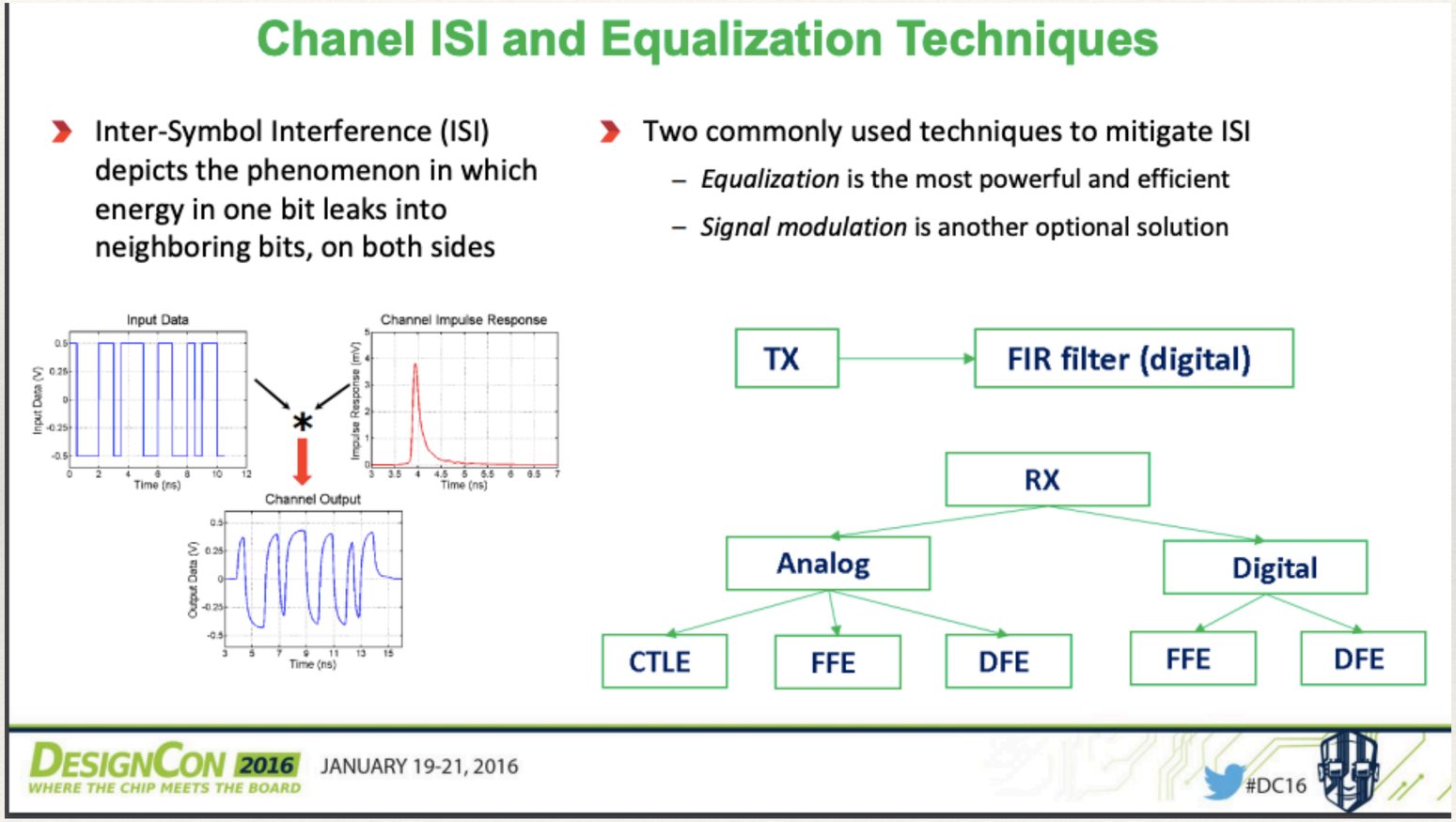
- SNR (signal to noise ratio)
- Signal - louder is better?
- Noise - uncorrelated to signal
  - white vs. narrow-band
- Channel
  - Path loss vs. insertion loss
  - ISI & echo - correlated to signal



Source: https://www.xilinx.com/publications/events/designcon/2016/slides-pam4signalingfor56gserial-zhang-designcon.pdf

50Gbps/Lane PAM4 Serdes - Inter-symbol Interference

- Symbol data rate > Channel BW
  - ISI is correlated signal
  - Compensation of channel —> Equalization
- TX vs. RX
- Inverse matrix vs. by training



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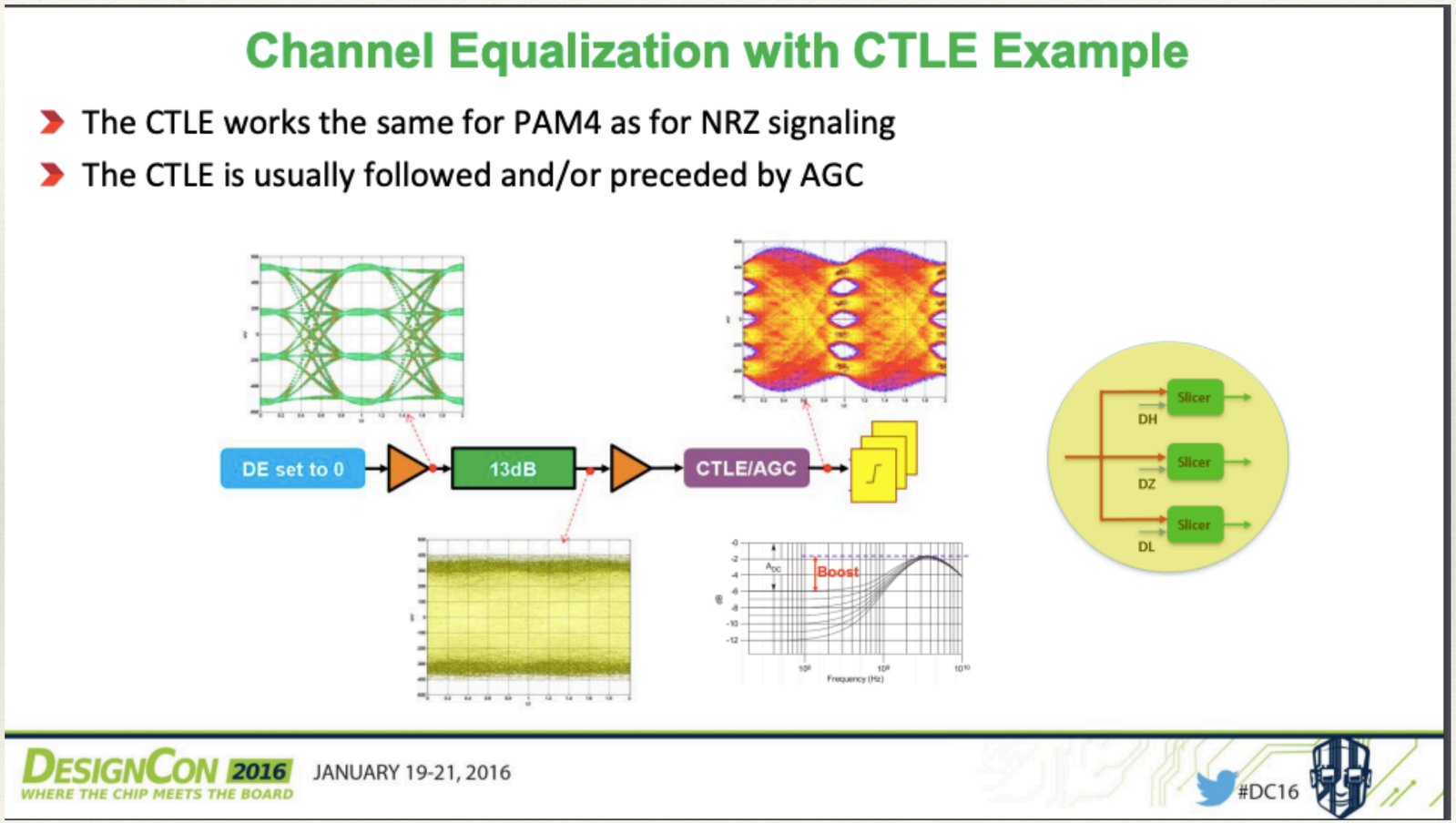
Equalization - RX CTLE

- Continuous-Time Liner Equalizer
  - Low-power
- Noise enhance
- Difficult to have 20+ dB gain & high BW



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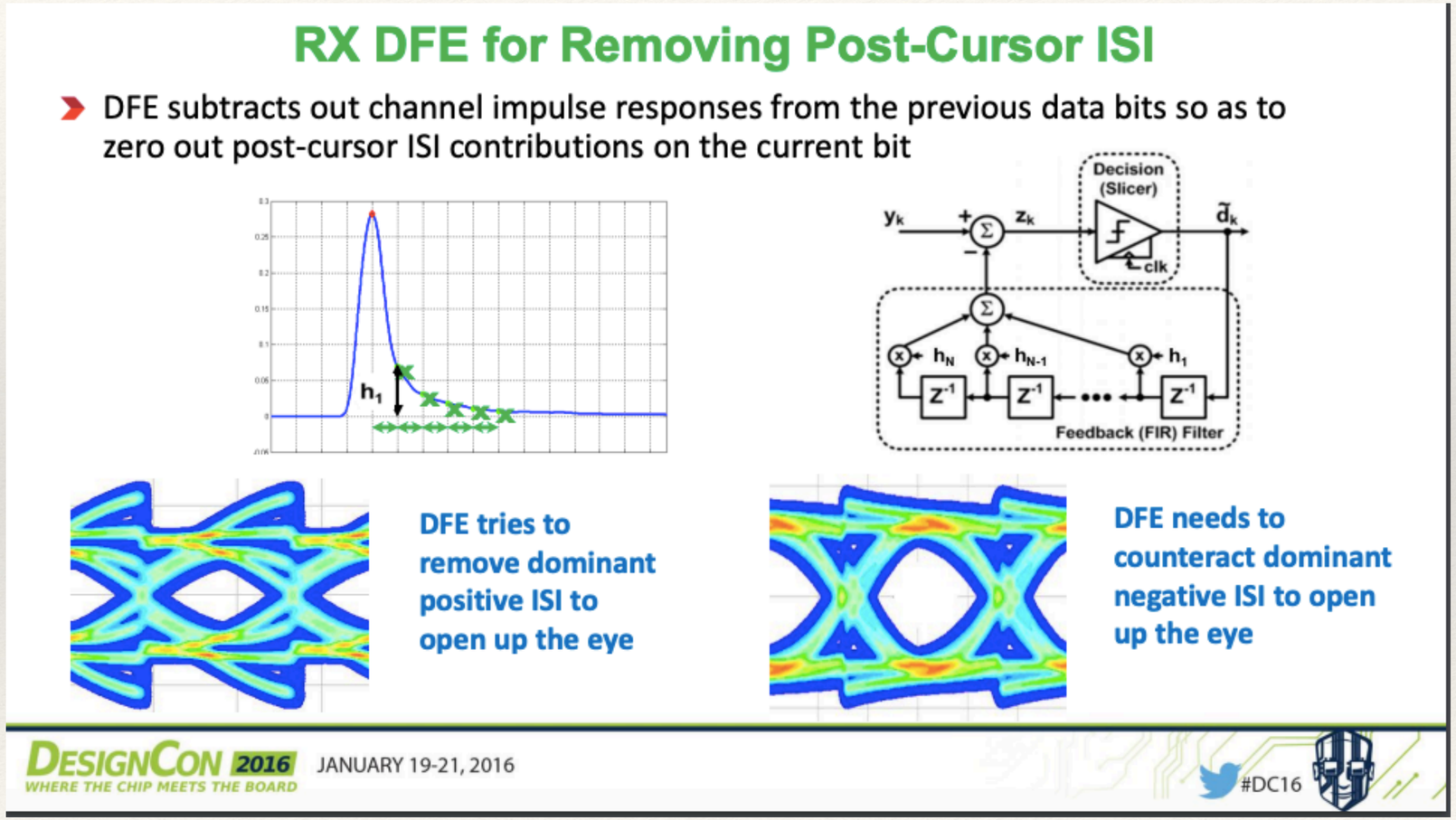
Equalization - RX DFE

- Decision Feedback Equalizer
  - Prone to error propagation
- Challenging for high speed
- Q: Don't cancel ISI? —> Yes. MLSD (Viterbi algorithm)



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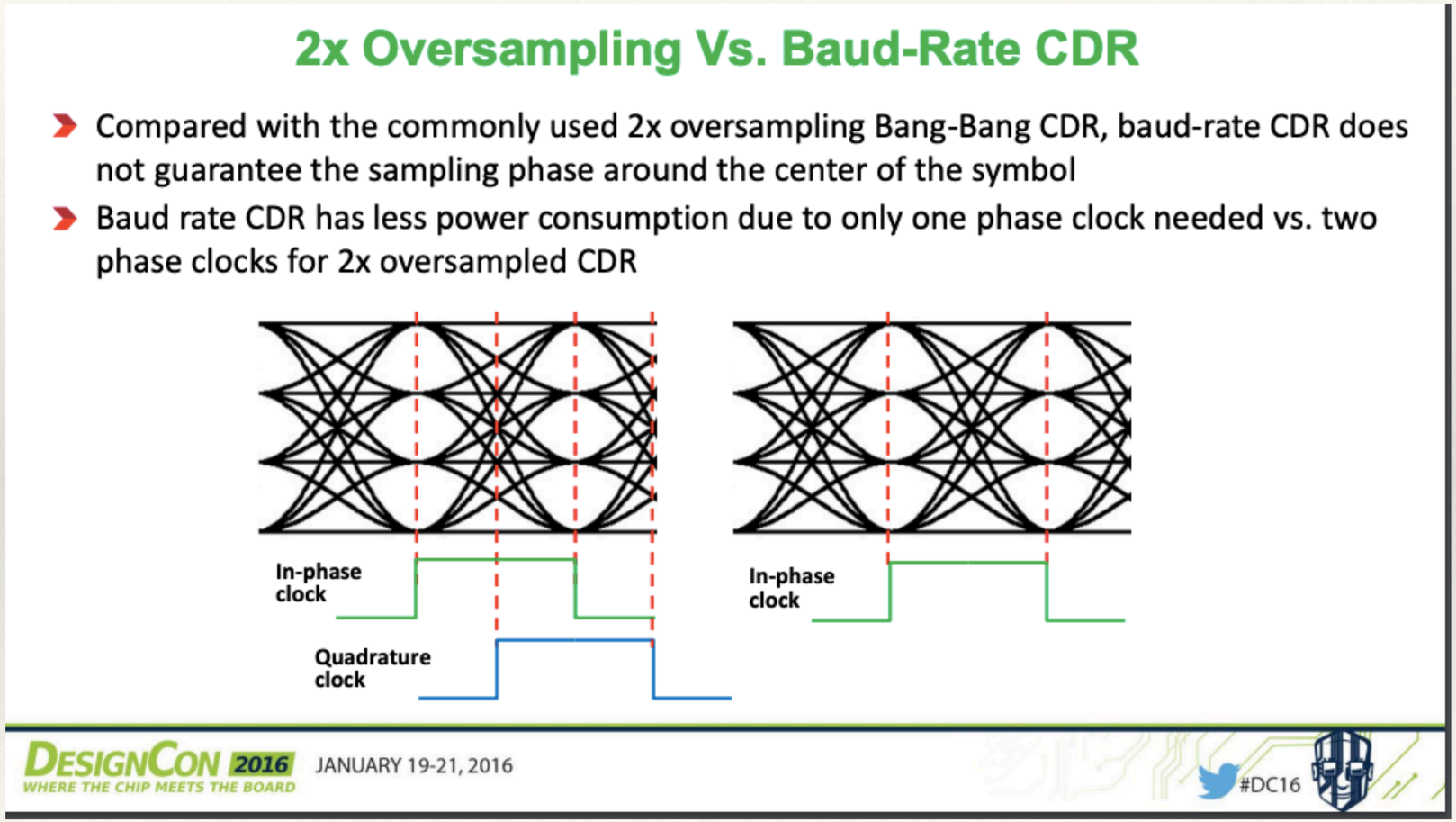
50Gbps/Lane PAM4 Serdes - Clock Recovery

- Timing error —> correct sampling clock
- It's all about jitter
  - PLL
  - Clock recovery
  - Challenging in high clock rate



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50Gbps/Lane Serdes - Are'we Good Enough?

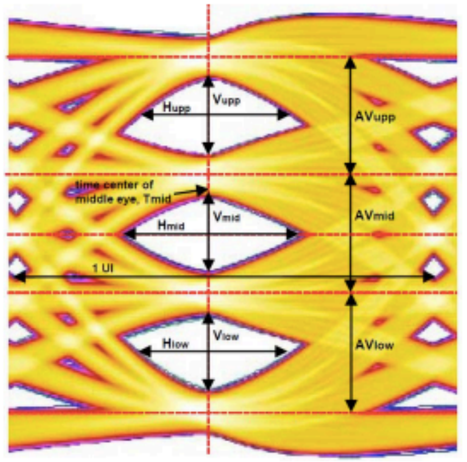
- Eye Height
  - For 1e-6
- Eye Width
  - For 1e-6
- Pre-silicon verification is very challenging

EH6 and EW6

- Since PAM4 is essentially a non-error-free system, eye metrics are defined in the VSR sped at BER = 1e-6
  - EH6 is the vertical distance across the BER = 1e-6 contour
  - EW6 is the horizontal distance across the BER = 1e-6 contour
- Vertical Eye Closure (VEC)

$$VEC = 20 \cdot LOG\left(Min\left(\left(\frac{AVupp}{Vupp}\right), \left(\frac{AVmid}{Vmid}\right), \left(\frac{AVlow}{Vlow}\right)\right)\right)$$

- To support raw BER<1e-6, instead of raw BER<-15
  - The BER is still dominantly affected by deterministic jitter and noise
  - May require redefining link budget to make trade-offs between performance, power consumption, and implementation cost



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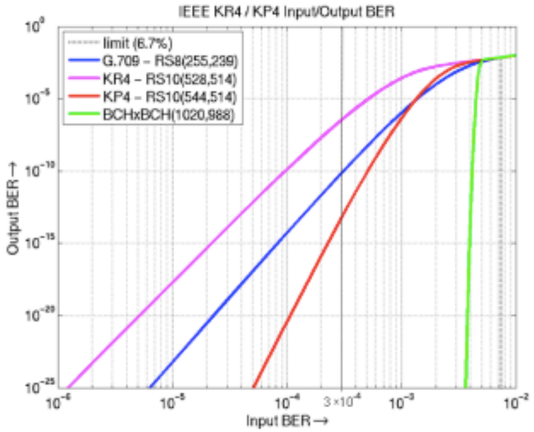
50Gbps/Lane Serdes - Help! Anybody?

- RX complexity vs. Coding
  - Depends on implementation technology
- PAM4 needs help from FEC

FEC Error Correction Capability – Coding Gain

- The coding gain is the reduction in SNR (dB) that can be accommodated while still achieving the desired BER. Under normal link operation conditions, test from system houses showed that
  - RS(528, 514) (KR4 FEC) presents about 5 – 6 dB coding gain
  - RS(544, 514) (KP4 FEC) presents about 7 – 8 dB coding gain



The plot assumes normal, uniform random distribution (Additive White Gaussian Noise)

- Example of Input vs Output BER for several well known FEC codes:
  - G.709: RS8 (255,239) 6.7%
  - IEEE KR4: RS10 (528,514) 3.5%
  - IEEE KP4: RS10 (544, 514) 5.8%
  - BCH-BCH (I.9, G.975.1) : 6.7%
  - Shannon limit for 6.7% OH (G.709 rate)
- Need to keep in mind the over-clocking induced SNR loss when using FEC

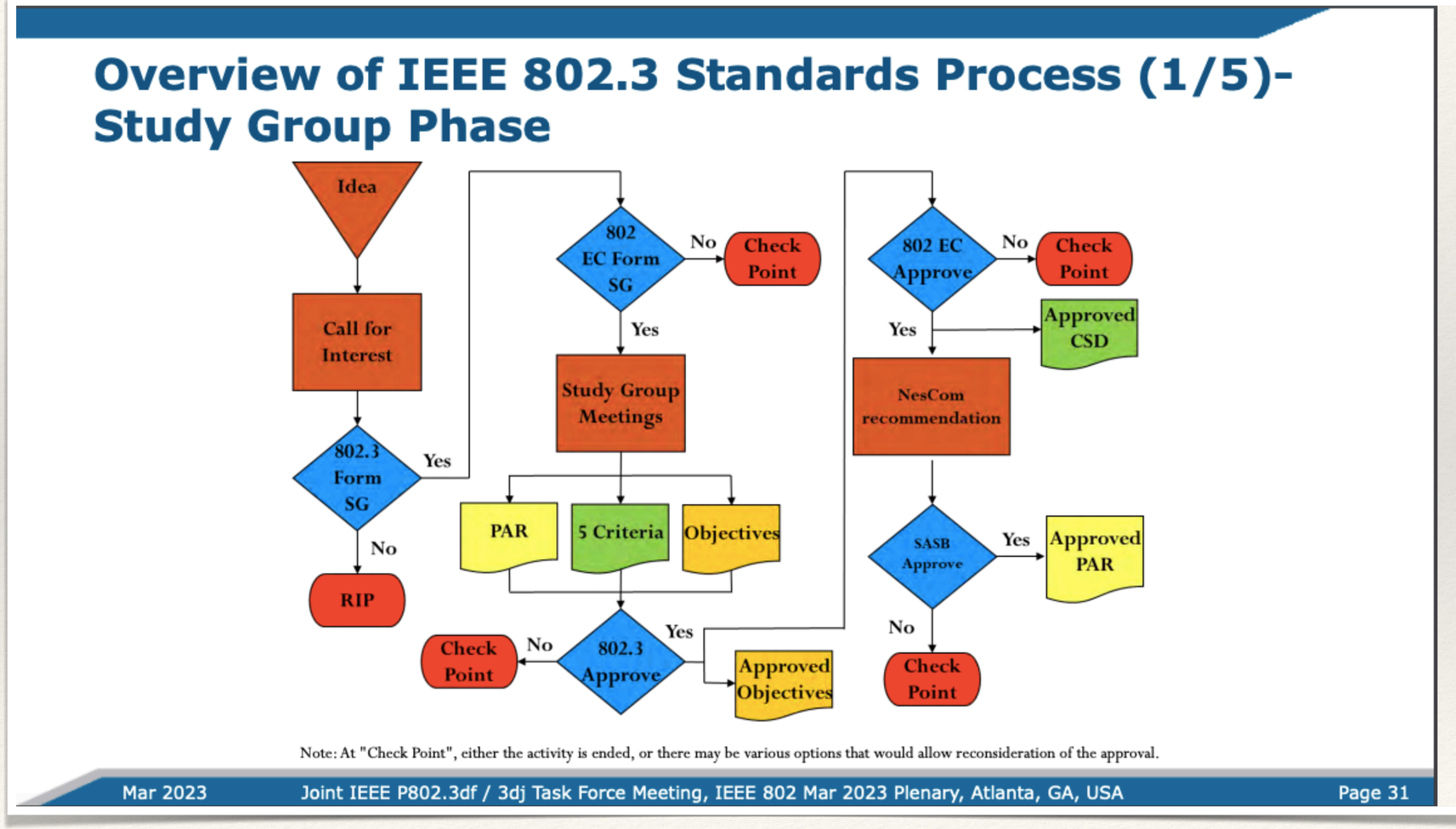
DESIGNCON 2016 WHERE THE CHIP MEETS THE BOARD JANUARY 19-21, 2016 #DC16

Source: https://www.xilinx.com/publications/events/designcon/2016/slides-pam4signalingfor56gserial-zhang-designcon.pdf

IEEE 802.3 Standard Meeting

IEEE 802.3 Standard Flow

- Call for interest
- Study Group
  - Objectives
- Task Force
  - Proposals to D1.0
  - Comments to D2.0
- Working Group
  - Comments to D3.0
- SA Ballot



Source: https://www.ieee802.org/3/dj/public/23_03/agenda_3dfdj_c_2303.pdf

Summary Progress @ End of Meeting

Ethernet Rate	Assumed Signaling Rate	AUI	Cu Cable	SMF 500m	SMF 2km	SMF 10km	SMF 40km
200 Gb/s	200 Gb/s	200GAUI-1 C2C C2M	200GBASE-CR1	200GBASE-DR1	200GBASE-FR1		
400 Gb/s	200 Gb/s	400GAUI-2 C2C C2M	400GBASE-CR2	400GBASE-DR2	400GBASE-DR2-2*		
800 Gb/s	200 Gb/s	800GAUI-4 C2C C2M	800GBASE-CR4	800GBASE-DR4	1. 800GBASE-DR4-2 2. 800GBASE-FR4	800GBASE-LR4*	
	800 Gb/s					800GBASE-LR1*	
	TBD						Over single SMF in each direction IMDD Coherent
1.6 Tb/s	100 Gb/s	1.6TAUI-16 C2C C2M					
	200 Gb/s	1.6TAUI-8 C2C C2M	1.6TBASE-CR8	1.6TBASE-DR8	1.6TBASE-DR8-2		

Adopted baselines | Proposed Baselines | Pending approval of objectives by 802.3WG

Source: https://www.ieee802.org/3/dj/public/23_03/agenda_3dfdj_c_2303.pdf

Stories about Standards

- Bluetooth plugfest - Buletooth vs. WiFi (diligent vs. leverage)
- 必也正名乎
- Uncertainty
- Consensus building
  - Talk to who don’t support you
  - Equally unhappy
- 少數支持卻贏得勝利

Lessons Learned

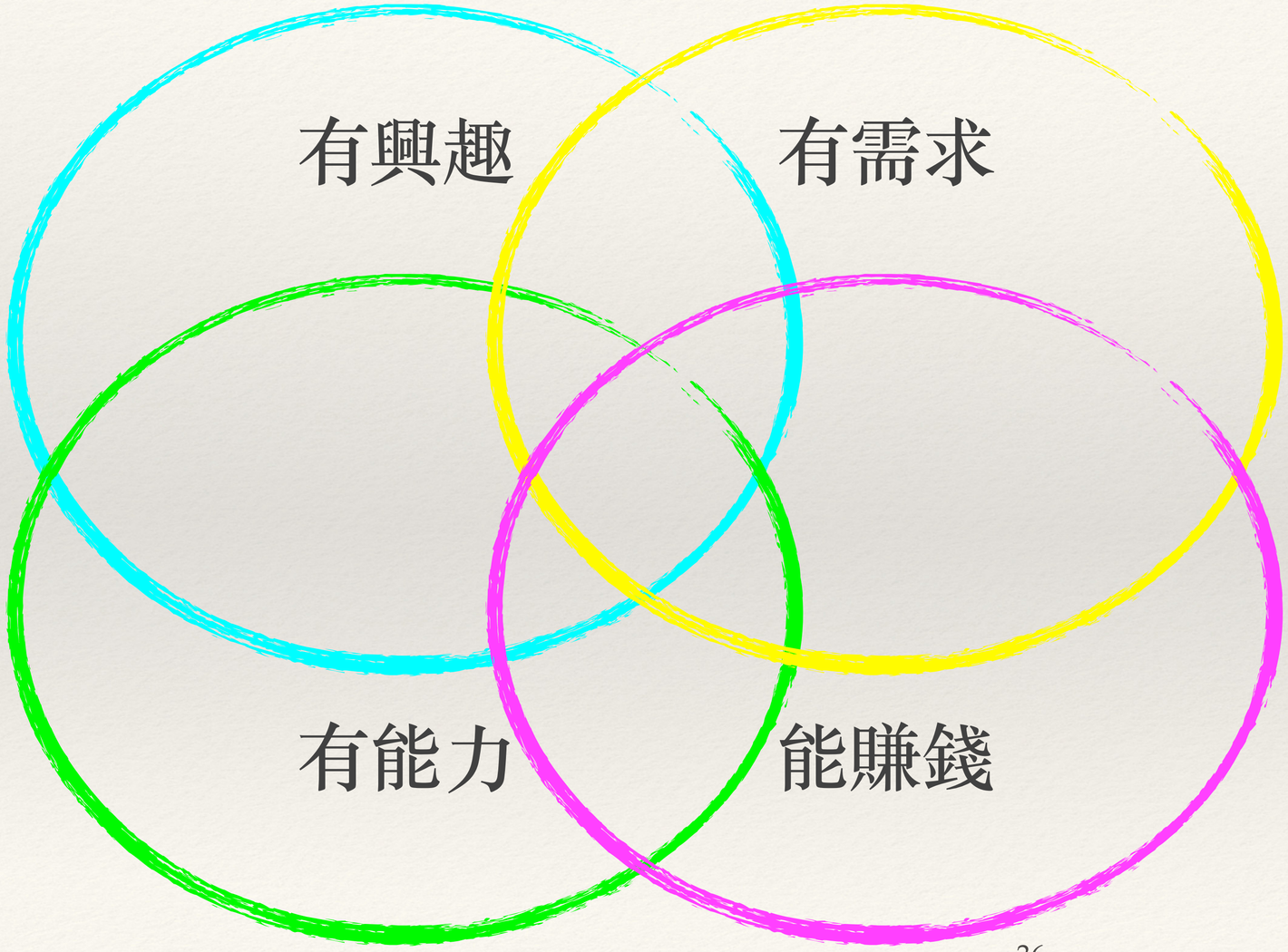
Learning

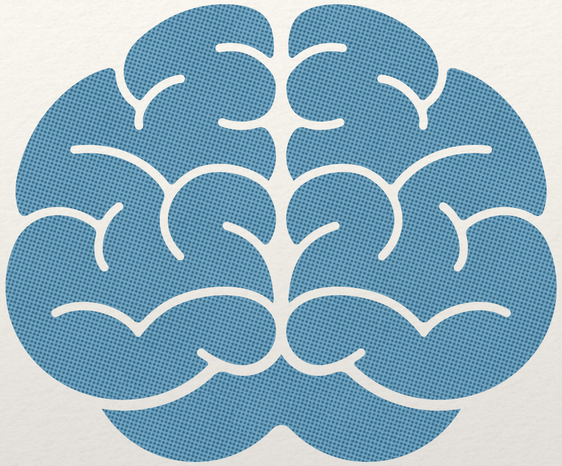
- When you're a student
  - 善加利用學校資源
  - 實體互動的機會 - 教授＆同學
  - 把握"理論"學習的機會 - 別忘了"假設條件"！
- 終身學習
  - 結合你的興趣

能力的培養

- 收集資訊能力是基本，分析判斷才是功夫！
- 我都懂，我只是不太會表達？！
- 深入淺出才是融會貫通
- 無招勝有招

Career





- Curiosity
- Back to Basic
- Think out of the Box

Summary

- Ethernet
  - Everywhere, drive technology to the limit —> innovation —> money
- Think big —> work hard —> dreams come true
- 能力的提升 —> 選擇的自由 —> 快樂的人生