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Abstract: [This document presents PHY considerations for VLC.]

Purpose: [To PAR/5C discussion on the protocol requirements for VLC PHY/MAC]
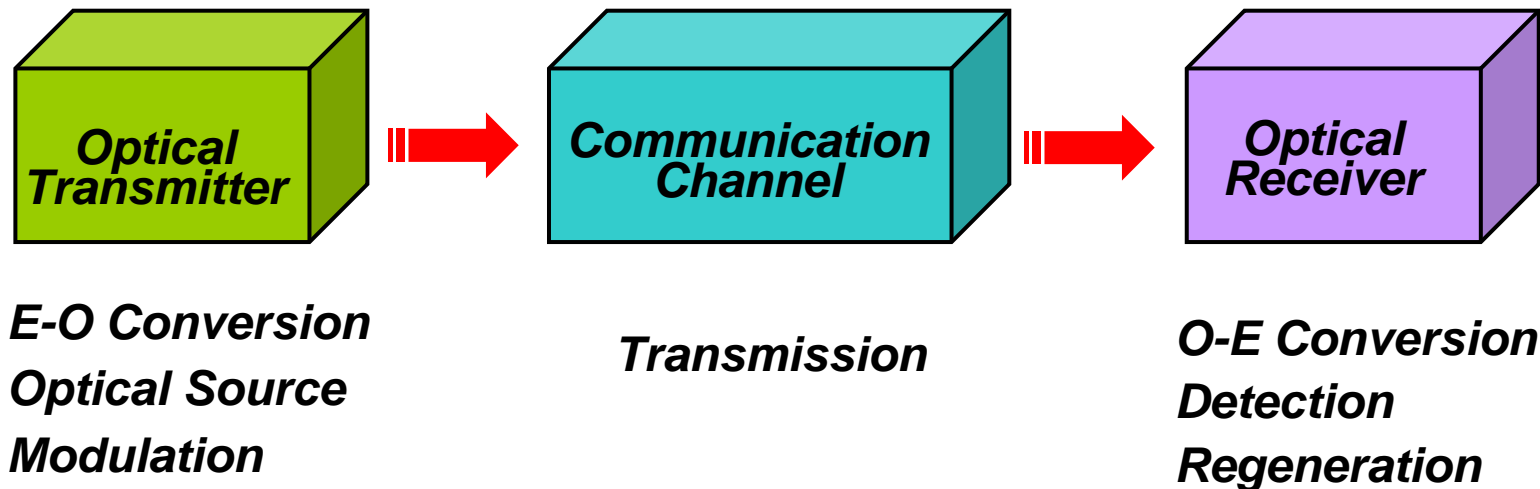
VLC PHY Considerations

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Outline

❑ *Similarities and differences between fiber optic and VLC*

❑ *Overview of fiber optic system*

❑ *PHY considerations for VLC*

Similarities - Fiber Optic and VLC

Optical Transmitter	→	Communication Channel	→	Optical Receiver

E-O Conversion

Optical Source

Modulation

Transmission

O-E Conversion

Detection

Regeneration

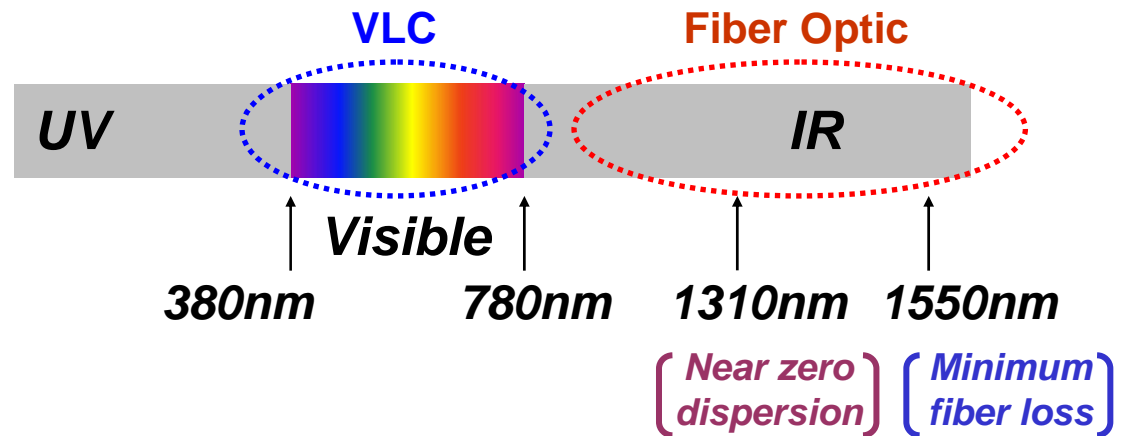❑ ***E-O / O-E conversion***

❑ ***Optical source / detector***

➢ ***LED(Light-Emitting Diode), LD(Laser Diode) / PD(Photodiode)***

■ VLC : Visible Light Communication

■ E-O / O-E : Electrical-to-Optical / Optical-to-Electrical

Differences - Fiber Optic and VLC

❑ *Wavelength*

VLC   **Fiber Optic**

UV   *IR*

Visible

380nm   *780nm*   *1310nm*   *1550nm*

Near zero dispersion   *Minimum fiber loss*

❑ *Medium*

➤ *Optical fiber (Fiber Optic) : Fiber dispersion, Nonlinear effects*

➤ *Air (VLC) : Multipath dispersion, Adjacent channel Interference*

■ UV : Ultraviolet
■ IR : Infrared

Dispersion in Optical Fiber

❑ *Intramodal Dispersion (in Single Mode Fiber)*

> ➢ *Dispersion = Material Dispersion + Waveguide Dispersion*

> ➢ *Spectral components of the optical signal propagate at different group velocities → induce ISI (InterSymbol Interference) between adjacent signals*

> ➢ *Material Dispersion = Chromatic Dispersion*

$\Delta\lambda = 0.5nm$

100ps

L =10km

150ps

Dispersive Medium (D = 10ps/nm.km)

time

time
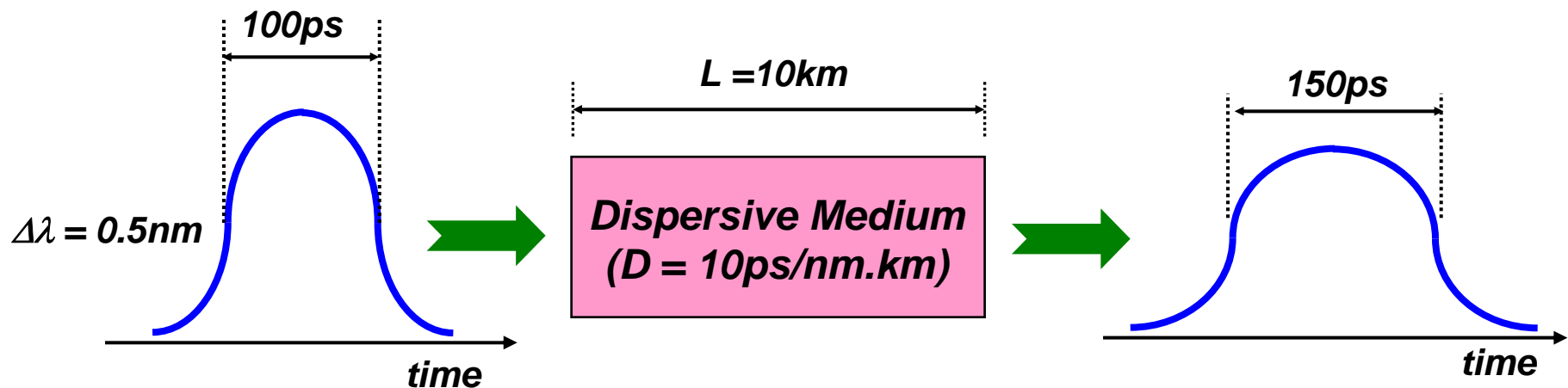
Modulation Schemes in Fiber Optic System

❑ *NRZ modulation scheme : Simple and cheap solution*

Nonlinear sensitive
Dispersion tolerance

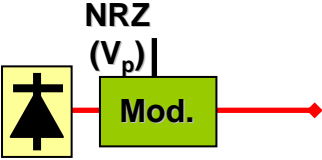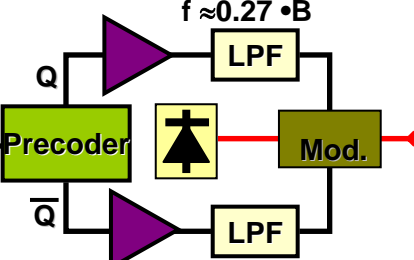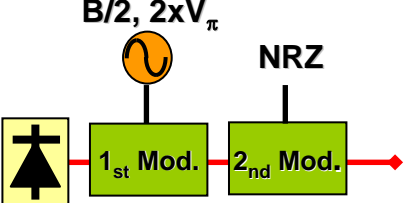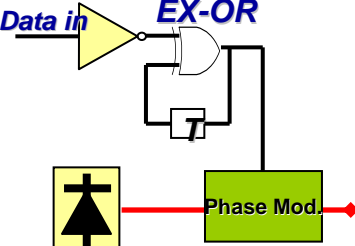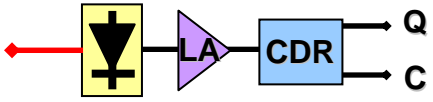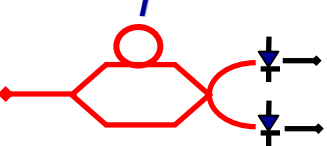*To improve the performance*

➢ *Enhancement of dispersion tolerance (Duobinary, DQPSK)*

➢ *Improvement of OSNR (DPSK, DQPSK)*

➢ *Insensitive to the nonlinear effects (CS-RZ)*

- DQPSK : Differential Quadrature Phase Shift Keying
- OSNR : Optical Signal-to-Noise Ratio
- DPSK : Differential Phase Shift Keying
- CS-RZ : Carrier-Suppressed Return-to-Zero

Summary of Modulation Schemes in Fiber Optic System

NRZ	Duobinary	CS-RZ	DPSK
Simple Cheap **Nonlinear sensitive**	CD tolerance Nonlinear insensitive **Poor sensitivity**	Nonlinear insensitive **Complex Poor CD tolerance Expensive**	3dB OSNR margin Nonlinear insensitive **Complex Poor CD tolerance Expensive**

Fiber Optic Transmitter
– Direct E/O Modulation

Electrical Data

Driver

Optical Source (Laser Diode)

| APC | ATC |

Optical Output

- APC : Auto Power Control
- ATC : Auto Temperature Control

Optical Output

Optical Power

I_{th}

I (mA)

Electrical Input

> *Widely used for < 2.5Gb/s*
> *Low extinction ratio*
> *Transmission distance < 100 km*
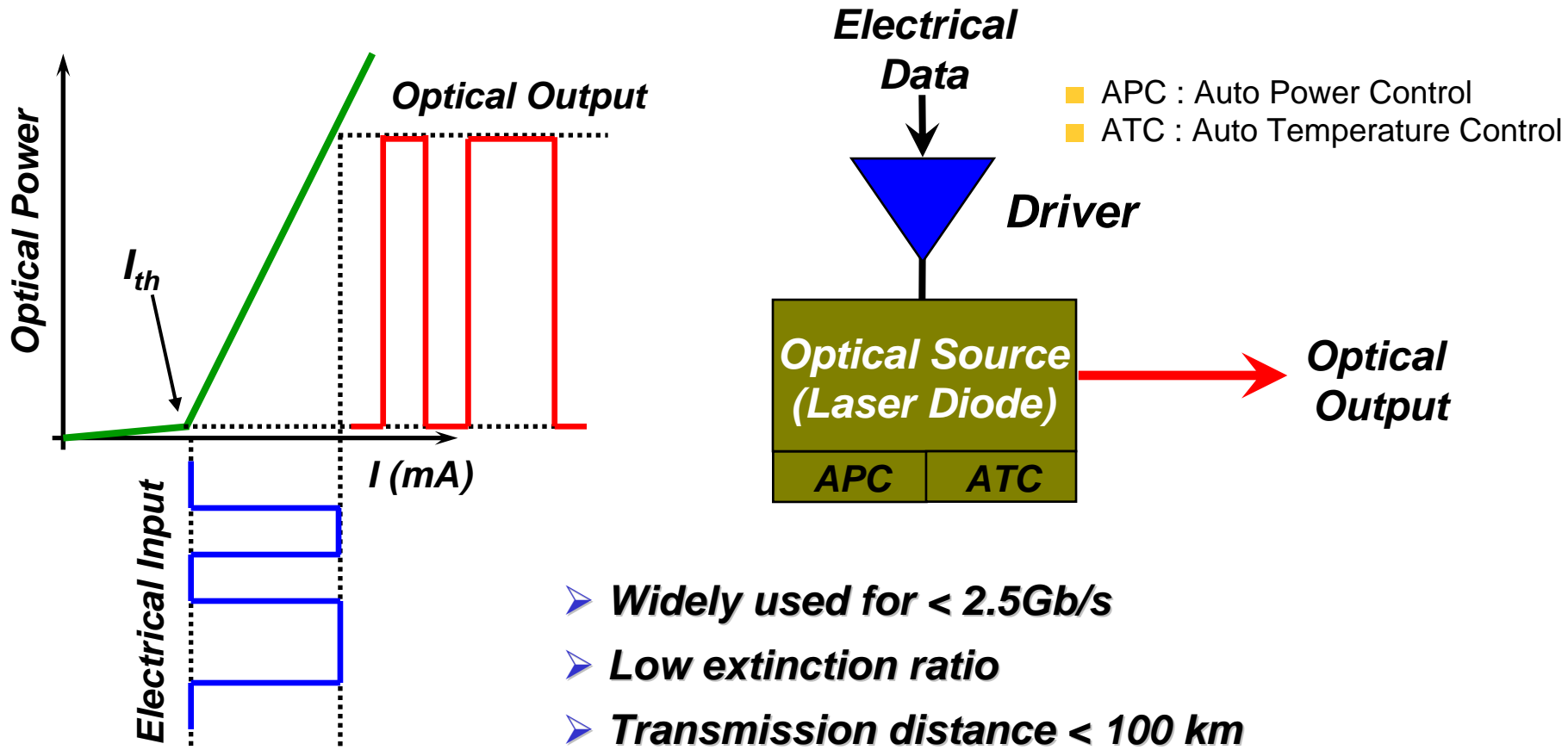
Fiber Optic Transmitter
with External Modulator

Electrical Data

Modulator Driver

Bias point

Optical Output

Modulator Transmittance

Optical Source (Laser Diode)

Modulator

Optical Output

Voltage

| APC | ATC |

Electrical Input
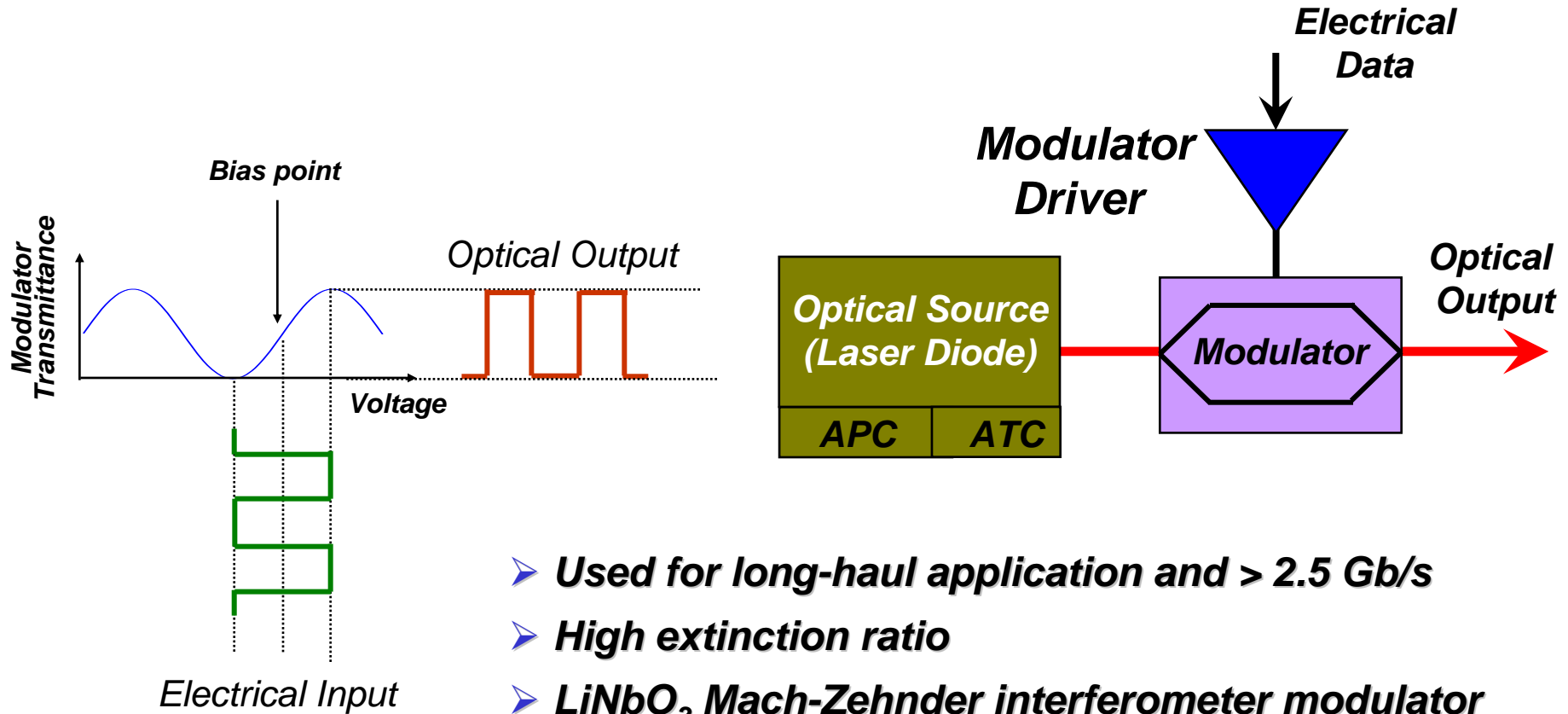
➢ *Used for long-haul application and > 2.5 Gb/s*

➢ *High extinction ratio*

➢ *LiNbO$_3$ Mach-Zehnder interferometer modulator*
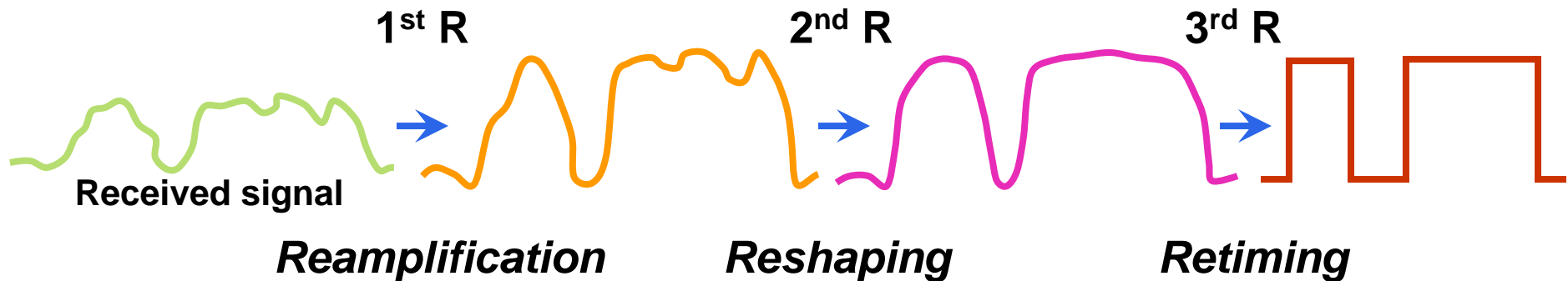
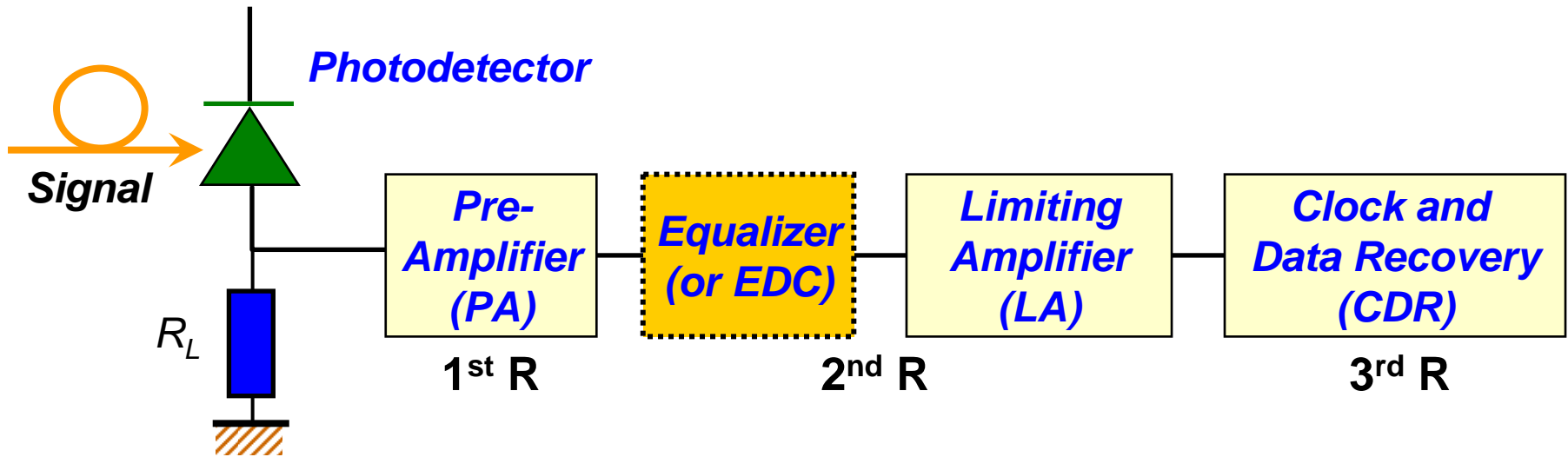➢ *Electro-absorption modulator*

Evaluation of Optical Transmitter
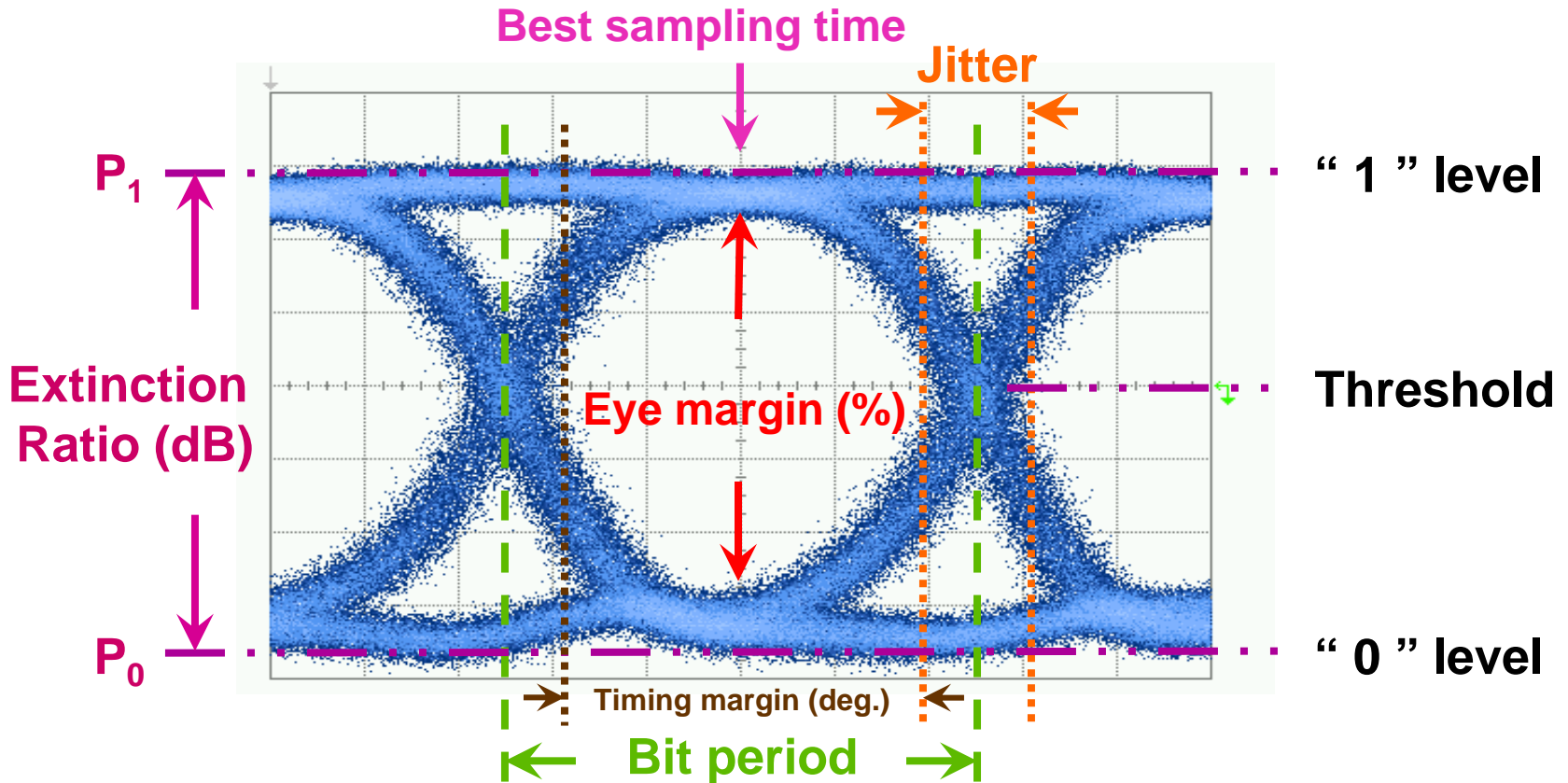
$$Extinction\ Ratio = 10 * log_{10}\ (P_1/P_0)$$

Fiber Optic Receiver – Main Functions

❑ *O/E conversion*

❑ *3R : Reamplification, Reshaping, Retiming*

1ˢᵗ R **2ⁿᵈ R** **3ʳᵈ R**

Received signal

Reamplification *Reshaping* *Retiming*

Fiber Optic Receiver – Building Blocks

Photodetector

Signal

R_L

Pre-Amplifier (PA)	Equalizer (or EDC)	Limiting Amplifier (LA)	Clock and Data Recovery (CDR)
1st R	**2nd R**		**3rd R**

Detector
- **Wavelength**
- **Bandwidth**
- **Quantum efficiency**
- **Noise**
- **Dark current**

PA and LA
- **Circuit Noise**
- **High gain**
- **Bandwidth**
- **Dynamic range**

CDR
- **Clock jitter**
- **Phase margin**

Equalizer in Fiber Optic Systems

Distorted signal

Compensated signal
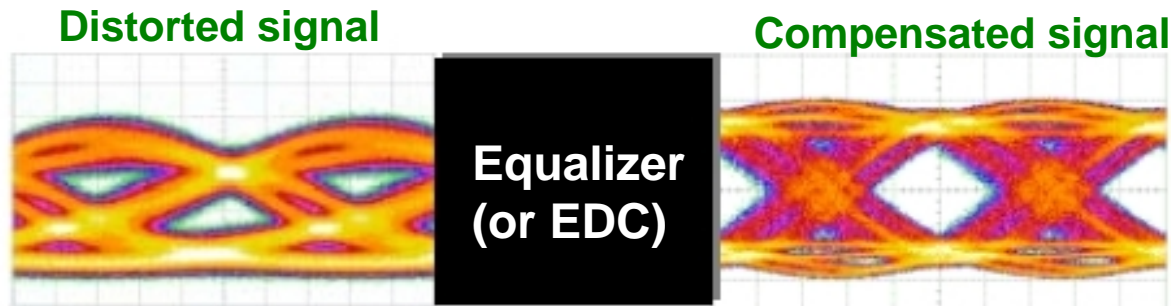
Equalizer (or EDC)

❑ *Main function*

➢ *Equalizer or EDC(Electronic Dispersion Compensator) compensates the signal distortions induced by chromatic dispersion(CD) and polarization mode dispersion(PMD) in fiber.*

❑ *Types*

➢ *Feed-Forward Equalizer (FFE)*

➢ *Decision Feedback Equalizer (DFE)*

➢ *Maximum Likelyhood Sequence Estimator (MLSE)*

Evaluation of Fiber Optic Receiver

❑ *Receiver sensitivity*

- ➢ *Digital receiver* : *Minimum received optical power* satisfying the defined BER(Bit Error Rate).
- ➢ *Analog receiver* : *Minimum received optical power* satisfying the defined SNR(Signal-to-Noise Ratio).

❑ *Dynamic range*

- ➢ *Digital receiver* : *Ratio of the maximum acceptable optical power to the receiver sensitivity* when the given BER are satisfied.
- ➢ *Analog receiver* : *Ratio of the maximum acceptable optical power to the receiver sensitivity* when the given SNR are satisfied.

❑ *Operating bandwidth*

PHY Considerations for VLC (1)

	Fiber Optic	*VLC*
Optical Source	LD / LED	LED Lamp
E/O Modulation	Direct, External modulator	Direct, Compatibility with LED lamp driver
Signal Distortion	By fiber dispersion and adjacent channel Interference in WDM	By multipath dispersion and adjacent channel Interference

PHY Considerations for VLC (2)

	Fiber Optic	*VLC*
Modulation Schemes	To improve fiber dispersion and nonlinear effects	To minimize multipath dispersion and adjacent channel interference
Receiver Functions	3R	2R / 3R
Equalizer	Favorable	Depending on data rates or distance
Transmission Speed Increase	WDM / TDM	WDM