Everything You Need to Know About Fiber Optic Transceivers

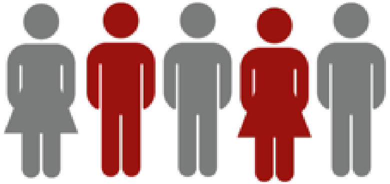
SCTE Webinar
June 26th-28th, 2023

Precision
OPTICAL TRANSCEIVERS

Agenda

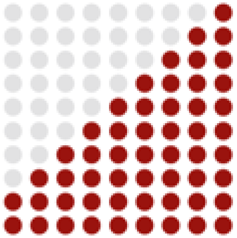
- Introduction to Transceivers
- Inside the Transceiver
- Transceiver Compatibility
- Transceiver Specifications
- Appendix

“Surging demands for capacity/bandwidth are requiring network upgrades.”



120 million households
in the US have internet

Average household
uses 400GB / month



Data usage has grown
1200% since 2000

How do we deliver 48 billion gigs of data per month?
&
How are we going to keep up with usage growth in the future?

The Answer?

<u>Fiber Optic Transceivers</u>

Agenda

- Transceiver Basics
  - What is a Transceiver?
  - Why do Transceivers Exist Today?
  - Evolution of Transceivers
- Transceiver Hardware Overview
  - 1G up to 400G

Introduction to Transceivers – What is a Transceiver?

- Transceiver is an amalgamation of **Transmitter** and **Receiver**
- The specific components and circuitry inside a transceiver can vary depending on the intended application and technology used. However, here are some common elements typically found inside a transceiver.

Basic Components

1. **Metal Casing** – Determines the form factor / size of the transceiver. Heat sink – can be external or internal
2. **Electrical connector** – Board to backplane electrical connector
3. **Microcontroller/DSP** – Provides serial ID and DOM (Diagnostic Optics Monitoring) and signal processing
4. **Laser Driver and TIA** – Laser driver and Transimpedance Amplifier
5. **TOSA** (Transmit Optical Sub Assembly) - Includes the laser and monitor photodiode
6. **ROSA** (Receive Optical Sub Assembly) - Can be comprised of a PIN or APD with a Transimpedance Amplifier (TIA) to convert current to voltage

Transceivers are NOT a one size fits all – There are over 10,000 different types of Transceivers

Transceiver Basics - Why do Transceivers Exist Today?

- Transceivers disaggregate a limiting component of the switch and router
  - **Why?**
    - Port Failures
      - If a port went down, in order to get it back up, you would have to replace the whole switch or router
    - Limited data rate and link budget flexibility
      - Optically locked - would buy the switch with a specific wavelength and link budget and leave no room for design flexibility or adaptability
    - Resulting in limited Architecture Flexibility
      - Transceivers resolve that limitation
  - **So why the shape of a transceiver?**
    - Several years ago when optical transceivers became disaggregated from the switch and router, there were no industry standards, seemingly every company would have its own proprietary form factor.
      - As a result, the primary industry players in this space came together to develop a Multi-Source Agreement (MSA) in order to come to a convention and help develop a product with specific technical and mechanical characteristics that would fit everyone
        - This is why we have SFP, SFP+, QSFP+, QSFP28, CFP etc… available today

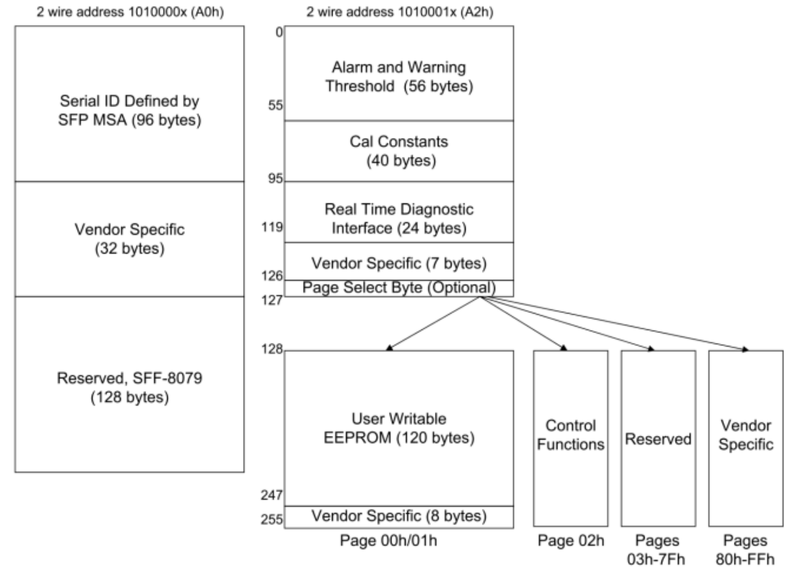
What is an MSA?

MSA = Multi Source Agreement

What does it do?

- Defines the industry standard for the physical, electrical, optical, and memory specifications for a fiber optic transceiver

4.1 Two-wire Interface Fields



Above is a visual summary of the SFP+ EEPROM defined by SFF-8472

Reference SFF-8024 Rev 4.1 r001

- SFF-8083 SFP+ 1X 10 Gb/s Pluggable Transceiver Solution (SFP10)
- SFF-8084 SFP+ 1X 4 Gb/s Pluggable Transceiver Solution
- SFF-8402 SFP+ 1X 28 Gb/s Pluggable Transceiver Solution (SFP28)
- SFF-8418 SFP+ 10 Gb/s Electrical Interface
- SFF-8419 SFP+ Power and Low Speed Interface
- SFF-8432 SFP+ Module and Cage
- SFF-8433 SFP+ Ganged Cage
- SFF-8436 QSFP+ 4X 10 Gb/s Pluggable Transceiver
- INF-8438 QSFP 4X 4 Gb/s Transceiver (Quad SFP)
- SFF-8449 Management Interface for SAS Shielded Cables
- SFF-8472 Management Interface for SFP+
- SFF-8482 Serial Attachment 2X Unshielded Connector
- SFF-8613 Mini Multilane 4/8X Unshielded Connector (HDun)
- SFF-8614 Mini Multilane 4/8X Shielded Cage/Connector (HDsh)
- SFF-8617 Mini Multilane 12X Shielded Cage/Connector (CXP)
- SFF-8630 Serial Attachment 4X 12 Gb/s Unshielded Connector
- SFF-8635 QSFP+ 4X 10 Gb/s Pluggable Transceiver Solution (QSFP10)
- SFF-8636 Management Interface for Cabled Environments
- SFF-8639 Multifunction 6X Unshielded Connector
- SFF-8640 Serial Attachment 4X 24 Gb/s Unshielded Connector
- SFF-8642 Mini Multilane 12X 10 Gb/s Shielded Connector (CXP10)
- SFF-8643 Mini Multilane 4/8X 12 Gb/s Unshielded Connector (HD12un)
- SFF-8644 Mini Multilane 4/8X 12 Gb/s Shielded Cage/Connector (HD12sh)
- SFF-8647 Mini Multilane 12X 14 Gb/s Shielded Cage/Connector (CXP14)
- SFF-8648 Mini Multilane 12X 28 Gb/s Shielded Cage/Connector (CXP28)
- SFF-8661 QSFP+ 4X Pluggable Module
- SFF-8662 QSFP+ 4X Connector (Style A)
- SFF-8663 QSFP+ Cage (Style A)
- SFF-8665 QSFP+ 4X 28 Gb/s Pluggable Transceiver Solution (QSFP28)
- SFF-8672 QSFP+ 4X Connector (Style B)
- SFF-8673 Mini Multilane 4/8X 24 Gb/s Unshielded Connector (HD24un)
- SFF-8674 Mini Multilane 4/8X 24 Gb/s Shielded Cage/Connector (HD24sh)
- SFF-8678 Serial Attachment 2X 6 Gb/s Unshielded Connector
- SFF-8679 QSFP+ 4X Base Electrical Specification
- SFF-8680 Serial Attachment 2X 12 Gb/s Unshielded Connector
- SFF-8681 Serial Attachment 2X 24 Gb/s Unshielded Connector
- SFF-8682 QSFP+ 4X Connector
- SFF-8683 QSFP+ Cage
- SFF-8685 QSFP+ 4X 14 Gb/s Pluggable Transceiver Solution (QSFP14)

Transceiver form factors – From The Outside

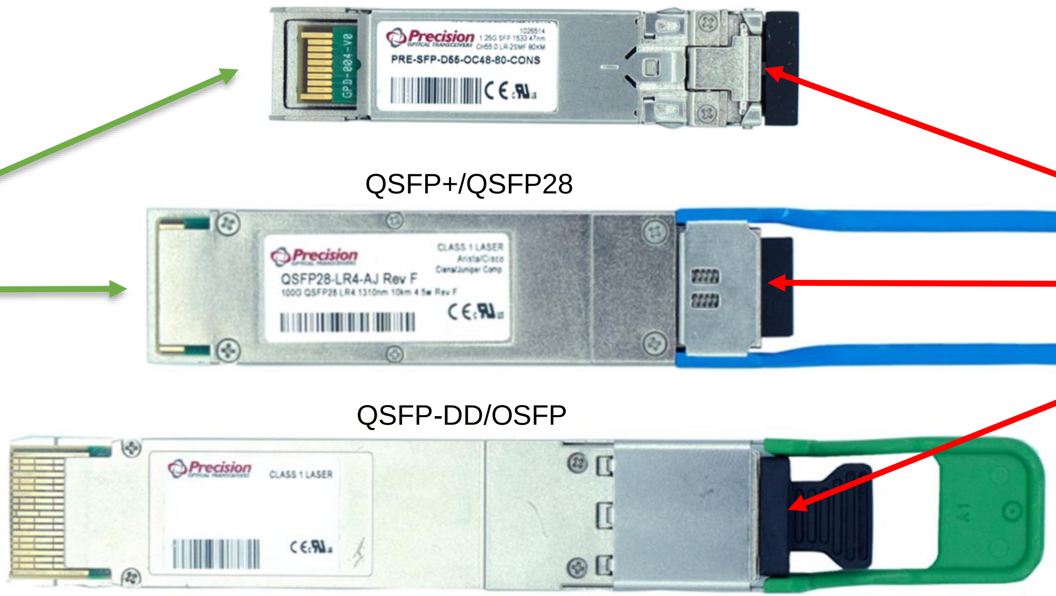
Host Side

SFP/SFP+/SFP28

Media side

QSFP+/QSFP28

QSFP-DD/OSFP



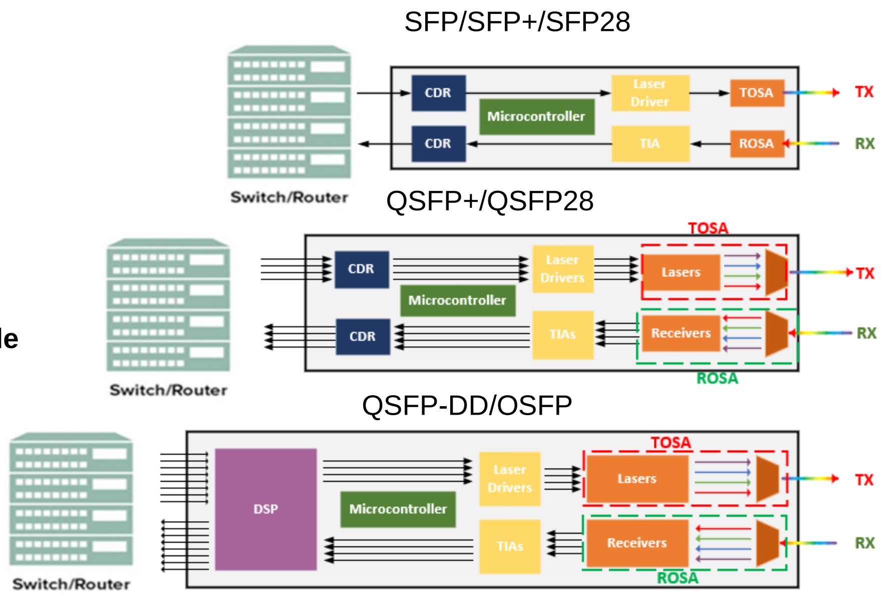
Electrical side
Host connectors

Media Connector
(optical or copper)

Transceiver Components – From Electrical to Optical

Host Side

Electrical Side



Media side

Optical side

Evolution of Transceivers

1999+

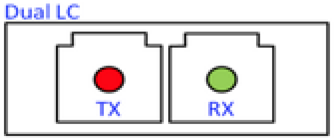
1G Evolution	Optical Characteristics
GBIC	1x1Gbps
SFF	1x1-2.5Gbps
SFP	1x1-2.5Gbps

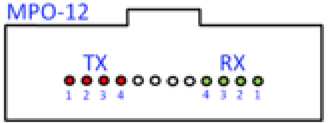
2003+

10G Evolution	Optical Characteristics
Xenpak	4x2.5Gbps
X2/ XPAK	4x2.5Gbps
XFP	1x10Gbps
SFP+	1x10Gbps

2007+

40G Evolution	Optical Characteristics
QSFP/ QSFP+	4x10Gbps





- Evolution of Transceivers is driven by
  - Miniaturization
  - Bandwidth Demands
  - Power Consumption / Heat Dissipation Demands
  - Link Budget Demands

GBIC

X2

Xenpak

XFP

QSFP

Source: *SC462, Introduction to Pluggable Optics, OFC, March 4, 2019*

Evolution of Transceivers Continued

- Evolution of Transceivers is driven by
    - Miniaturization
    - Bandwidth Demands
    - Power Consumption / Heat Dissipation Demands
    - Link Budget Demands

2009+

100G Evolution	Optical Characteristics
CFP	10x10Gbps
CFP2	4x25Gbps
CFP4	4x25Gbps
QSFP28	4x25Gbps
QSFP28	1x100Gbps PAM4

2017+

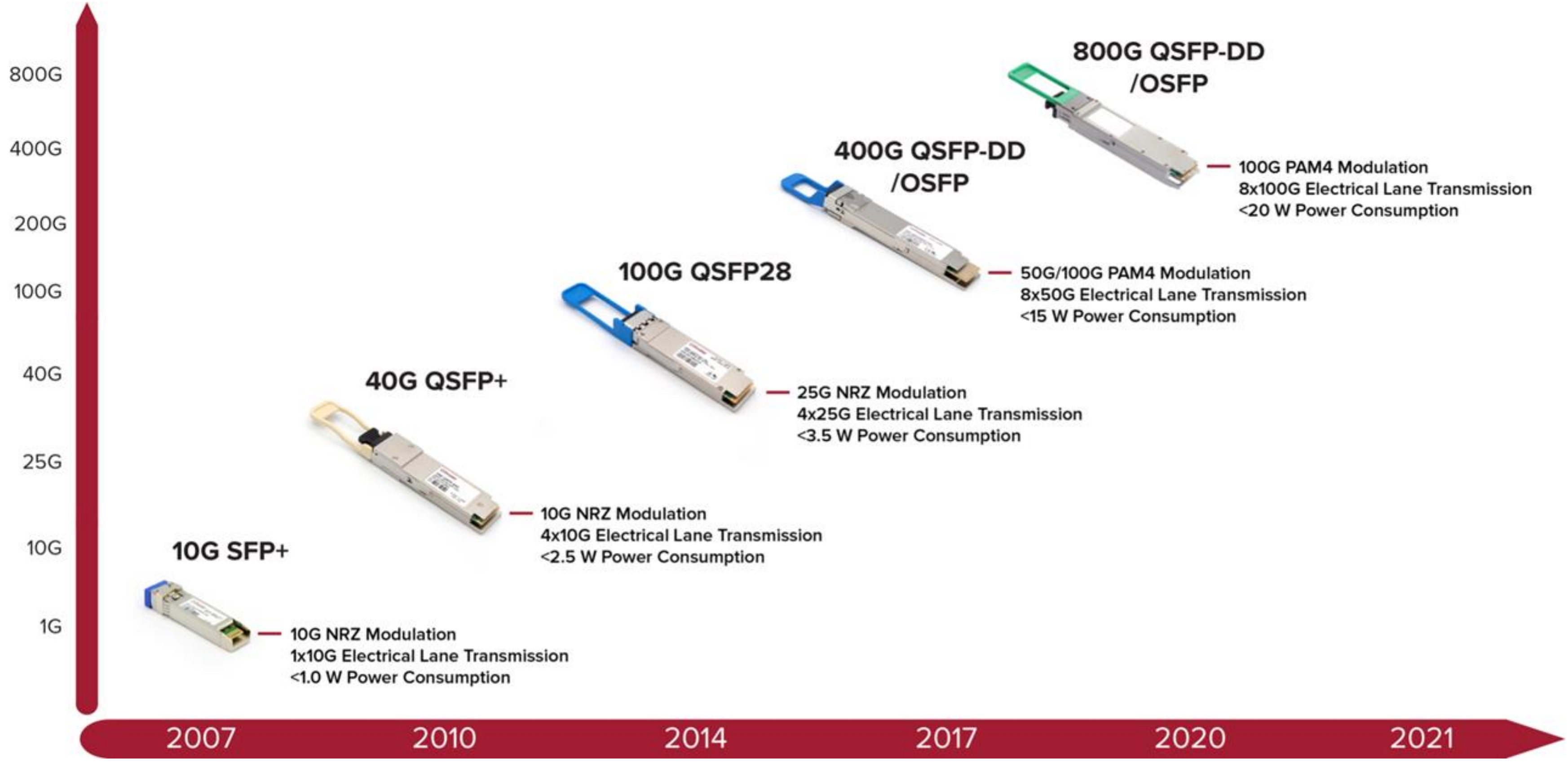
200G Evolution	Optical Characteristics
OSFP	4x50Gbps PAM4 or 8x25Gbps
QSFP28-DD	8X25Gbps
QSFP56	4x50Gbps PAM4

2017+

400G Evolution	Optical Characteristics
QSFP56-DD	4x100Gbps PAM4 or 8x50Gbps

Source: SC462, Introduction to Pluggable Optics, OFC, March 4, 2019

Summary of Evolution



Quick Recap

So far we have reviewed

- What is a transceiver?
- Why do we use transceivers?
- The evolution of transceivers over the past 20+ years

Now we will review:

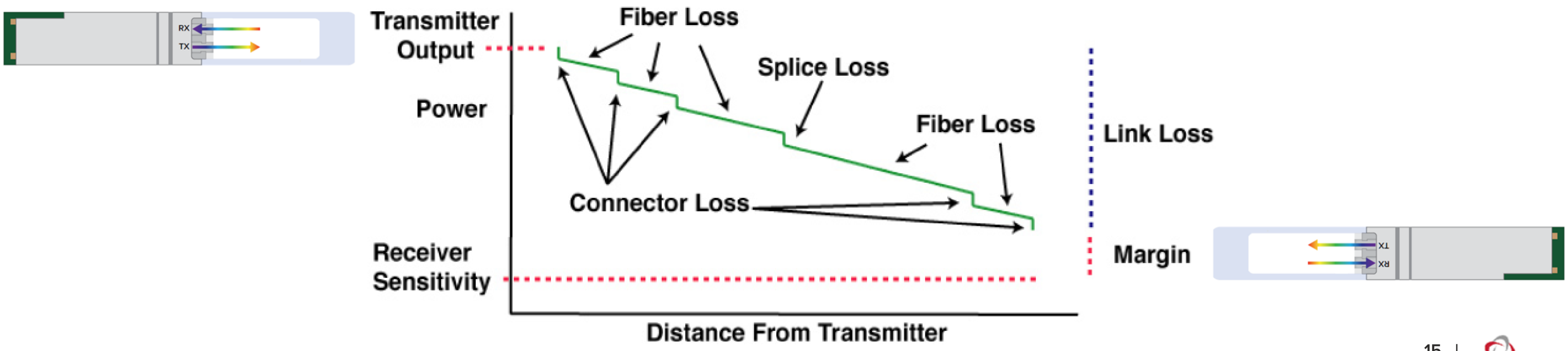
- Questions to Determine which Transceiver to Use
- Transceiver hardware types from 1G to 400G
- Transceiver Optical Port Types
- The 3 main wavelength technologies utilized
- Technical Challenges Developing New Transceivers

Questions to Ask When Deciding Which Transceiver to Use?

1. Host
2. Form Factor
3. Distance/ Loss/ Link Budget
4. Medium - (ie cable type)
5. Fiber Connector Type
6. Temperature Rating

Link Budget

- To plan your optical network, you need a budget.
  - When an optic says "10km", this is only a guideline.
  - Actual distances can be significantly better or worse.
  - It's also smart to leave some margin in your designs.
    - Patch cables get bent and moved around, optic transmitters will cool with age, a fiber cut and repaired will add more loss, etc.



Common Form Factor / Reach Combinations

	SFP	SFP+ I XFP	SFP28	QSFP	SFP56	QSFP28 I CFP I CFP2 I CFP4 I SFP-DD		QSFP-DD I OSFP		
	1G	10G	25G	40G	50G	100G		400G		
	1x1G	1x10G	1x25G	4x10G	1x50G	4x25G	1x100G	8x50G	4x100G	1x400G
100-300m MMF	SX	SR	SR	SR4	SR	SR4		SR8		
500m SMF							DR		DR4	
2km SMF					FR	CWDM4	FR	FR8	FR4 / DR4+	
10km SMF	LX	LR	LR	LR4 / PLR4	LR	LR4 / PLR4	LR	LR8	LR4 / PLR4	
40km SMF	EX	ER	ER	ER4		ER4				
80km SMF	ZX	ZR	ZR			ZR / ZR4				
120km SMF	EZX									ZR / ZRP

The designation for reach often includes a number, which is used to signify the number of optical lanes.

- An FR for example is 1 optical lane whereas an FR4 is 4 optical lanes and an FR8 is 8 optical lanes.
- When deciding on optics for interop, the number of optical lanes must match on each side of the connection.

Legend	
	Form-Factor(s)
	Data-rate
	Optical Lanes x Data-rate (per lane)
	The rest of colors in this table correspond to the pull-tab color for each transceiver.

SFP Hardware Types

Form Factor/Type	Type	Max Distance	Medium	Connector	λ
SFP	Copper	100m	Cat5	RJ45	NA
SFP	Gray SX	500m	MMF	LC Duplex*	850nm
SFP	Gray LX	10km	SMF	LC Duplex	1310nm
SFP	Gray EX	40km	SMF	LC Duplex	1310nm
SFP	Gray ZX	80km	SMF	LC Duplex	1550nm
SFP	Gray ZX+	120km	SMF	LC Duplex	1550nm
SFP	Gray ZX+	160km	SMF	LC Duplex	1550nm
SFP	CWDM EX	40km	SMF	LC Duplex	CWDM
SFP	CWDM ZX	80km	SMF	LC Duplex	CWDM
SFP	CWDM ZX+	120km	SMF	LC Duplex	CWDM
SFP	CWDM ZX+	160km	SMF	LC Duplex	CWDM
SFP	DWDM EX	40km	SMF	LC Duplex	C-Band
SFP	DWDM ZX	80km	SMF	LC Duplex	C-Band
SFP	DWDM ZX+	120km	SMF	LC Duplex	C-Band
SFP	DWDM ZX+	160km	SMF	LC Duplex	C-Band

* All LC Duplex on this slide are LC/UPC

SFP+ Hardware

Form Factor/Type	Type	Max Distance	Medium	Connector	λ
SFP+	Gray SR	300m	MMF	LC/ UPC Duplex	850nm
SFP+	Gray LR	10km	SMF	LC/ UPC Duplex	1310nm
SFP+	Gray ER	40km	SMF	LC/ UPC Duplex	1550nm
SFP+	Gray ZR	80km	SMF	LC/ UPC Duplex	1550nm
SFP+	Gray ZR+	100km	SMF	LC/ UPC Duplex	1550nm
SFP+	CWDM ER	40km	SMF	LC/ UPC Duplex	CWDM
SFP+	CWDM ZR	80km	SMF	LC/ UPC Duplex	CWDM
SFP+	DWDM ER	40km	SMF	LC/ UPC Duplex	C-Band
SFP+	DWDM ZR	80km	SMF	LC/ UPC Duplex	C-Band
SFP+	DWDM Tunable	80km	SMF	LC/ UPC Duplex	C-Band
SFP+	Copper	50m	Cat6A/7	RJ45	N/A
SFP+	DAC	<5m	Cu	N/A	N/A
SFP+	AOC	< 30m	MMF	N/A	850nm

AOC = Active Optical Cable

- Optical cable is embedded into the transceiver hardware on both ends

DAC = Direct Attach Cable

- Copper cable is embedded into the transceiver on both ends

C-band = Wavelengths between 1530 & 1565nm

RX saturation

General transceiver - Too much power into RX – what happens?

Too Much RX? - Datasheet review

PRE-QSFP28-SR4

QSFP28, SR4, 850nm, 100G, 100m, MMF/MPO12

Precision OPTICAL TRANSCEIVERS

Optical Characteristics: Transmitter

Parameter	Min	Typical	Max	Unit
Center Wavelength	840	850	860	nm
Transmit Power per lane (Avg)	-8.4	-	2.4	dBm
Spectral Width	-	-	0.6	nm
Tx Power per lane (OMA)	-6.4	-	3	dBm
Extinction Ratio	2	-	-	dB
Optical Return Loss Tolerance	-	-	12	dB
Transmitter OFF Output Power per lane	-	-	-30	dBm

Optical Characteristics: Receiver

Parameter	Min	Typical	Max	Unit
Receiver Wavelength	840	850	860	nm
Damage Threshold per lane	3.4	-	-	dBm
Rx Power per lane (Avg)	-10.3	-	2.4	dBm
Receive Sensitivity per lane (OMA)			3	dBm
LOS Assert	-30	-	-	dBm
LOS De-Assert	-	-	-10	dBm
LOS Hysteresis	0.5	-	-	dB

- Fiber optic attenuators play a crucial role in controlling the power levels in fiber optic links. They are used to reduce the signal power to an optimal level, preventing overloading of receivers and potential damage to the optical network.

Too Much RX? - Datasheet review

PRE-SFP-Cxx-120(I)
SFP, CWDM, 1470 - 1610nm, 1G, 120km, SMF/LC

Precision
OPTICAL TRANSCEIVERS

Optical Characteristics: Transmitter

Parameter	Min	Typical	Max	Unit
Center Wavelength	λ_c -6.5	-	λ_c +6.5	nm
Transmit Power	0	-	5	dBm
Spectral Width	-	-	1	nm
Side Mode Suppression Ratio	30	-	-	dB
Extinction Ratio	9	-	-	dB
Transmitter OFF Output Power	-	-	-45	dBm

Optical Characteristics: Receiver

Parameter	Min	Typical	Max	Unit
Receiver Wavelength	1270	-	1610	nm
Receiver Damage Threshold	0			dBm
Input Saturation Power	-8	-	-	dBm
Receiver Sensitivity	-	-	-32	dBm
LOS Assert	-45	-	-	dBm
LOS De-Assert	-	-	-33	dBm
LOS Hysteresis	0.5	2	6	dB
LOS Hysteresis	0.5	3	5	dB

- Fiber optic attenuators play a crucial role in controlling the power levels in fiber optic links. They are used to reduce the signal power to an optimal level, preventing overloading of receivers and potential damage to the optical network.

Disaggregated Solution vs. DACs or AOCs

What is an Active Optical Cable (AOC)?

- Optical fiber cable is hardwired into a transceiver on both ends of a link

What is a Direct Attach Cable (DAC)?

- Copper cable is hardwired into a transceiver on both ends of a link

What is a disaggregated solution?

- Transceivers and fiber jumpers are sold and installed separately

Benefits of AOCs & DACs

- Reduced SKUs by kitting transceiver and optical jumper components together

Limitations of AOCs & DACs

- Higher perceived failures on active equipment - a broken fiber takes two transceivers down
- Potential maintenance nightmare not being able to disconnect any jumper cables
- Overall higher cost to spare

Bidirectional Transceivers

What are BiDi's?

- Most transceivers have a Tx & Rx port - BiDi's have the Tx & Rx in the same optical port
  - Instead of the TOSA and ROSA being separate, an SFP BiDi combines the two with a WDM filter to create a BOSA

Benefits?

- Allows for a single fiber solution

What to know?

- Pair required
- 4 different pair types available
  - 1270/1330nm (10G)
  - 1310/1490nm (1G)
  - 1310/1550nm (1G)
  - 1490/1550nm (1G or 10G)
- Can use either a 1270/1330nm or a 1310/1490nm pair in the express port of a DWDM mux

Bidi

Duplex

Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	λ
SFP	BIDI	10km	1G	SMF	LC*	CWDM
SFP	BIDI	40km	1G	SMF	LC	CWDM
SFP	BIDI	80km	1G	SMF	LC	CWDM
SFP	BIDI	120km	1G	SMF	LC	CWDM
SFP	BIDI	160km	1G	SMF	LC	CWDM
SFP+	BIDI	10km	10G	SMF	LC	CWDM
SFP+	BIDI	20km	10G	SMF	LC	CWDM
SFP+	BIDI	40km	10G	SMF	LC	CWDM
SFP+	BIDI	80km	10G	SMF	LC	CWDM
SFP+	BIDI	60km	10G	SMF	LC	CWDM
XFP	BIDI	10km	10G	SMF	LC	CWDM
XFP	BIDI	20km	10G	SMF	LC	CWDM
XFP	BIDI	40km	10G	SMF	LC	CWDM
XFP	BIDI	60km	10G	SMF	LC	CWDM
XFP	BIDI	80km	10G	SMF	LC	CWDM

*All LC connectors require LC/UPC Simplex on this table

SFP28 Hardware Types Available Today

Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	λ
SFP28	SR	100m	25G	MMF	Duplex LC	850nm
SFP28	LR	10km	25G	SMF	Duplex LC	1310nm
SFP28	BIDI	10km	25G	SMF	Simplex LC	C27/C33
SFP28	BIDI	20km	25G	SMF	Simplex LC	C27/C33
SFP28	BIDI	30km	25G	SMF	Simplex LC	C27/C31
SFP28	BIDI	40km	25G	SMF	Simplex LC	C27/C31
SFP28	ER	40km	25G	SMF	Duplex LC	1310nm
SFP28	LRL	300m	25G	SMF	Duplex LC	1310nm
SFP28-Dxx	DWDM	10/12km	25G	SMF	Duplex LC	ITU 18-61
SFP28	DWDM (Tunable)	15km	25G	SMF	Duplex LC	ITU 21-60

Quick Recap

So far we have reviewed

- What is a transceiver?
- Why do we use transceivers?
- The evolution of transceivers over the past 20+ years
- Questions to Determine which Transceiver to Use
- Transceiver hardware types from 1G to 25G
- Chromatic Dispersion

Now we will review:

- Transceiver Optical Port Types
- The 3 main wavelength technologies utilized
    - Wideband, CWDM, DWDM
- Fixed vs Tunable DWDM Hardware
- Techniques for Overcoming Data Rate & Distance Challenges
- Transceiver Hardware overview from 40G to 400G

Wideband (Gray) vs. CWDM vs. DWDM

Technology	Wideband (Gray)	CWDM	DWDM
Wavelengths (nm)	850, 1310, 1550	1430 - 1610	~1520 - 1570
Max Capacity (Single Fiber)	1-3 Channels	16 Channels	160 Channels
Relative Cost	Low	Medium	High
Tunable Availability	N/A	No	Yes
Data Rates Available (Gbps)	1, 10, 25, 40, 100, 200, 400	1, 10, 100*	1, 10, 25**, 100***

* 100G CWDM uses 1271, 1291, 1311, 1331 wavelengths
** 25G DWDM SFPs are new but not widely used because of link budget limitations
*** 100G DWDM is currently only offered in CFP but will eventually be offered in QSFP28

DWDM Transceiver Options

- **Fixed Channel DWDM Optical Transceivers**
  - Fixed-Channel DWDM optics are available in both C-Temp and I-Temp versions
  - Each optic is a fixed wavelength / ITU channel and can be deployed only as such

- **Tunable DWDM Optical Transceivers**
  - Tunable DWDM optics are also available in both C-Temp and I-Temp versions
  - Each optic is tunable within the full ITU spectrum of wavelengths
  - Tune the optic as needed to meet the required wavelength

Are fixed channel and tunable transceivers interoperable and/or interchangeable?

- Fixed Channel and Tunable DWDM transceivers are interoperable assuming the Tunable transceiver is tuned to the same wavelength as the fixed channel transceiver

- Fixed Channel and Tunable DWDM transceivers are also interchangeable, assuming you're using like for like hardware from a link budget perspective and the tunable is properly tuned.

Techniques for Overcoming Data Rate & Distance Challenges

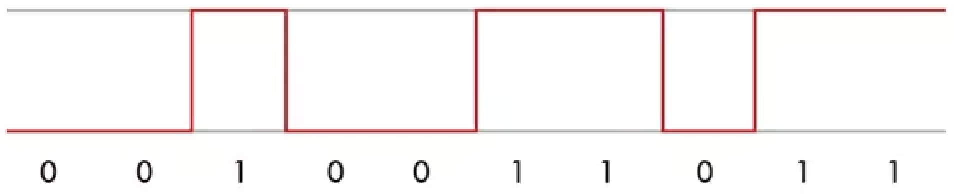
1. Adding Optical Lanes to the same form factor
   - We see this with QSFP/QSFP28s and will only continue to see it more in the future

2. Forward Error Correction
   - A portion of the bandwidth is dedicated to error correcting code meant to assist the receiver with interpreting noisy or unreliable data

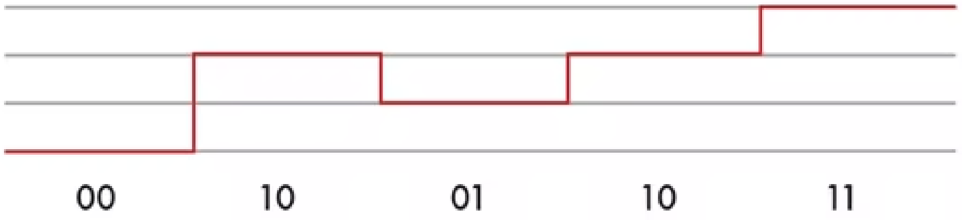
3. PAM4 vs. NRZ

- PAM4 effectively doubles the amount of data sent over the same optical pulse

NRZ = Non Return to Zero, essentially this is binary on/off keying

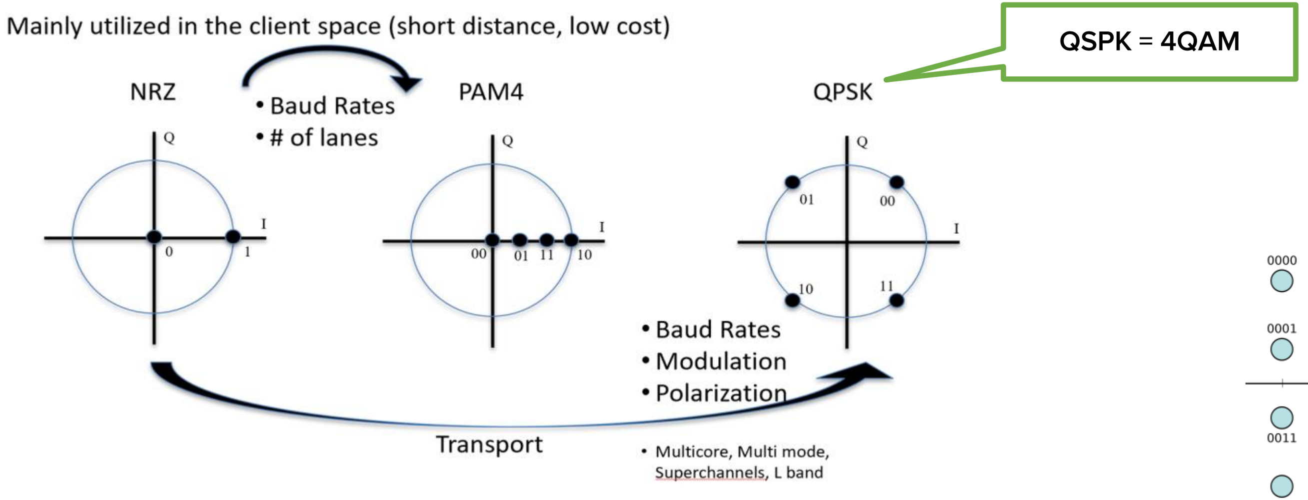


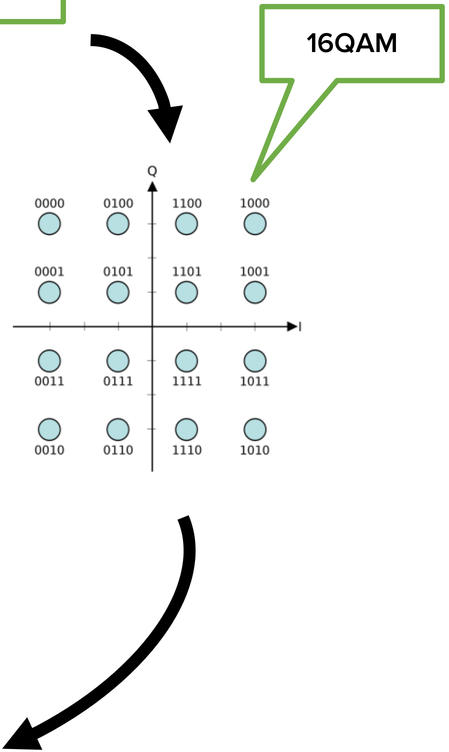
PAM4 = Pulse Amplitude Modulation 4



Source: https://www.electronicdesign.com/technologies/communications/article/21800814/whats-the-difference-between-nrz-and-pam

NRZ vs PAM4 vs Coherent: Real-life examples

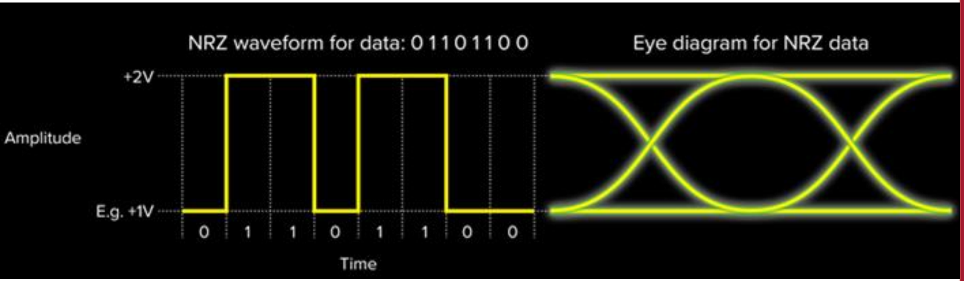




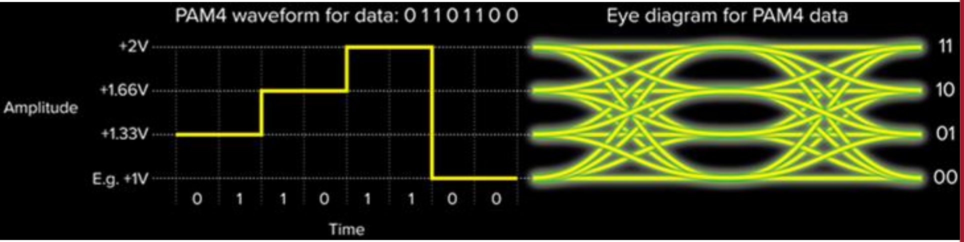
Part Number	Electrical Lanes	Optical Lanes
PRE-QSFP28-SR4/LR4	4 x 28Gbps (28GBd NRZ)	4 x 28Gbps (28GBd NRZ)
PRE-QSFP28-DR/FR/LR	4 x 28Gbps (28GBd NRZ)	1 x 112Gbps (56GBd PAM4)
PRE-QSFP56DD-SR8	8 x 56Gbps (28GBd PAM4)	8 x 56Gbps (28GBd PAM4)
PRE-QSFP56DD-FR4/LR4	8 x 56Gbps (28GBd PAM4)	4 x 112Gbps (56GBd PAM4)
PRE-QSFP56DD-ZR	8 x 56Gbps (28GBd PAM4)	1 x 478.75Gbps (59.84GBd DP-16QAM)

From NRZ to PAM4

NRZ



PAM4



- Baud rate = Symbol rate = symbol/sec
  - **NRZ:** 1 bit per 1 symbol ➔ bit rate = baud rate
  - **PAM4:** 2 bit per 1 symbol ➔ 2x bit rate for the same baud rate

- NRZ (Non-Return to Zero) is the signal modulation scheme that has been used in most of the client optics up to now (up to 25 Gbps per lane).

- Due to signal integrity challenges beyond 25Gbps, Pulse Amplitude Modulation (PAM), specifically PAM-4, has been adopted by the industry to support higher data rates of 50Gbps and beyond.

Staying Within the Lanes for 100G

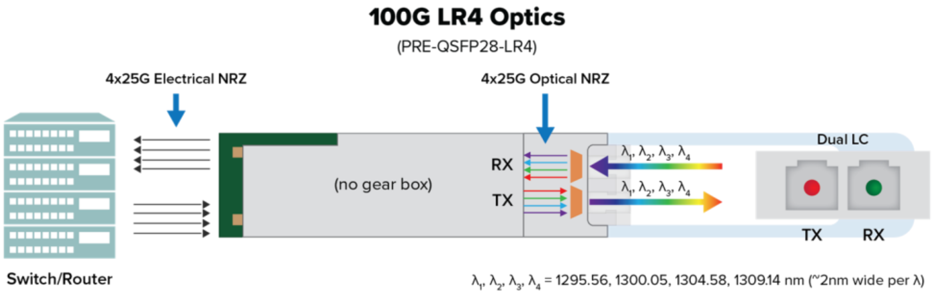
New Modulation/Lane # = No interoperability

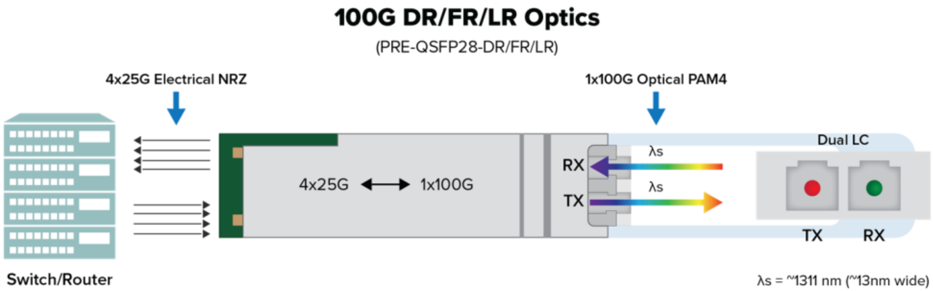
(Legacy) PRE-QSFP28-LR4

- transmit 4x25G lanes/wavelengths with NRZ modulation.

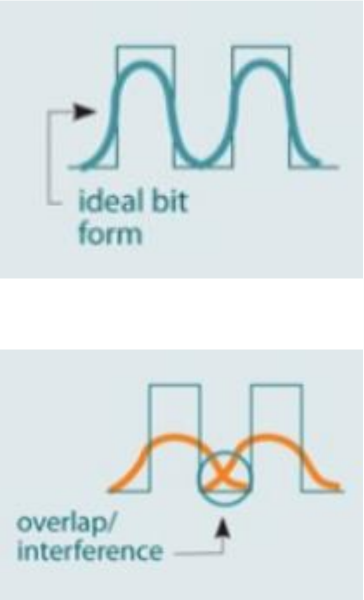
(New) PRE-QSFP28-DR/FR/LR

- transmit 1x100G lanes/wavelengths with PAM4 modulation.

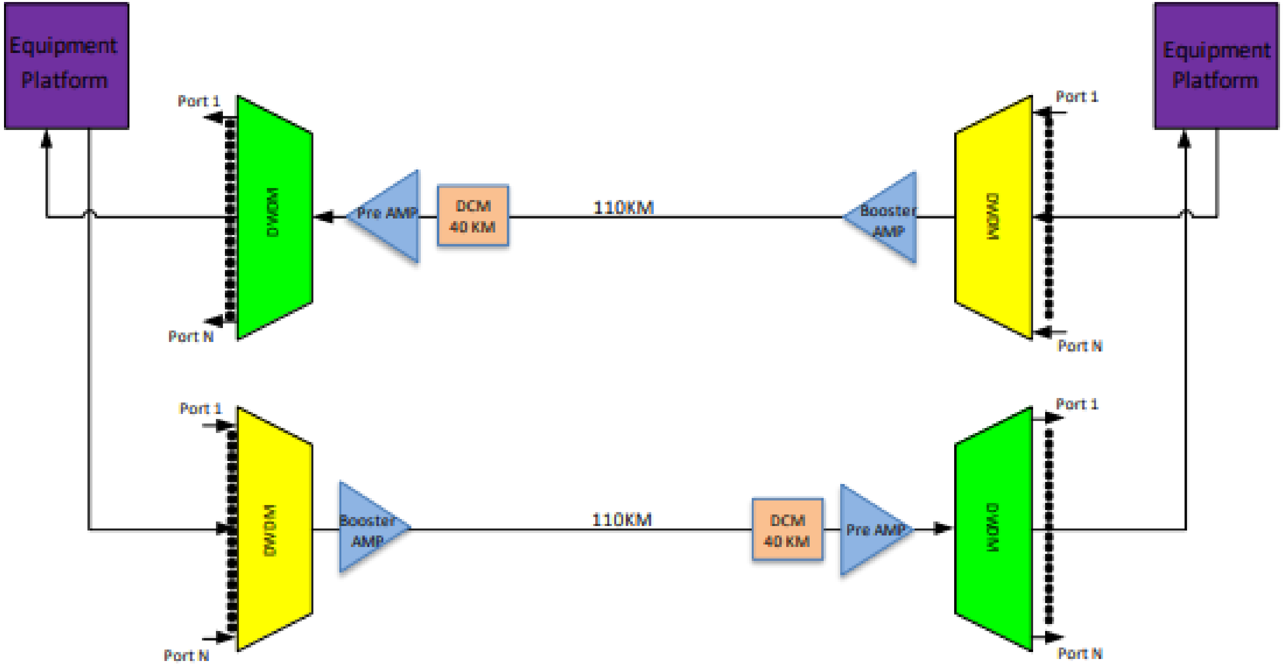




Chromatic Dispersion - Upgrading to 10G & Beyond



This overlap is called Chromatic Dispersion



Chromatic Dispersion is an exponential issue
10G might go 80km but jumping to 25G limits the reach to 15km

Source: *Chromatic Dispersion in 10Gb/s DWDM Systems, White Paper, Precision Optical Transceivers,* www.precisionot.com/white-papers/

Quick Recap

So far we have reviewed

- What is a transceiver?
- Why do we use transceivers?
- The evolution of transceivers over the past 20+ years
- Questions to Determine which Transceiver to Use
- Transceiver hardware types from 1G to 25G
- Transceiver Optical Port Types
- The 3 main wavelength technologies utilized
    - Wideband, CWDM, DWDM
- Fixed vs Tunable DWDM Hardware
- Chromatic Dispersion
- Techniques for Overcoming Data Rate & Distance Challenges

Now we will review:

- Transceiver Hardware overview from 40G to 400G

40G

Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	Electrical Interface	Optical Interface	λ	Breakout to 10G?	FEC?
QSFP	SR4	100m	40G	MMF	Duplex LC	4x10G NRZ	4x10G NRZ	850nm	YES	NO
QSFP	LR4	10km	40G	SMF	Duplex LC	4x10G NRZ	4x10G NRZ	CWDM	NO	NO
QSFP	ER4	40km	40G	SMF	Duplex LC	4x10G NRZ	4x10G NRZ	CWDM	NO	YES
QSFP	LR4L	2km	40G	SMF	Duplex LC	4x10G NRZ	4x10G NRZ	CWDM	NO	NO
QSFP	LX4	.15/2km	40G	MMF/SMF	Duplex LC	4x10G NRZ	4x10G NRZ	CWDM	NO	NO
QSFP	PLR4	10km	40G	SMF	MPO-12	4x10G NRZ	4x10G NRZ	1310nm	YES	NO
QSFP	SR BIDI	150m	40G	MMF	Duplex LC	4x10G NRZ	2x20G PAM4	850/900nm	NO	NO

100G Hardware

Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	Electrical Interface	Optical Interface	λ
QSFP28	SR4	100m	100G	MMF	Duplex LC	4x25G NRZ	4x25G NRZ	850nm
QSFP28	ESR4	300m	100G	MMF	Duplex LC	4x25G NRZ	4x25G NRZ	850nm
QSFP28	LR4	10km	100G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM
QSFP28M	LR4	10km	112G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM
QSFP28	CWDM4	2km	100G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	CWDM
QSFP28	ER4L	30/40km	100G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM
QSFP28M	ER4L	30/40km	112G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM
QSFP28	LR4L	2km	100G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM
QSFP28	PSM4	2km	100G	SMF	MPO-12	4x25G NRZ	4x25G NRZ	1310nm
QSFP28	ZR4	80km	100G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM
QSFP28	CWDM4 BIDI	2km	100G	SMF	Simplex A-LC	4x25G NRZ	4x25G NRZ	C27-C33
QSFP28M	SR4	100m	112G	MMF	MPO-12	4x25G NRZ	4x25G NRZ	850nm
QSFP28	ER4	40km	100G	SMF	Duplex LC	4x25G NRZ	4x25G NRZ	LWDM

100G Hardware (Single Lambda)

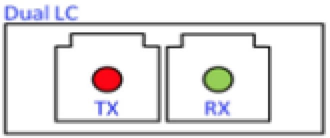
Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	Electrical Interface	Optical Interface	λ
QSFP28	DR1	500m	100G	MMF	Duplex LC	4x25G NRZ	1x100G PAM4	1310nm
QSFP28	FR1	2km	100G	SMF	Duplex LC	4x25G NRZ	1x100G PAM4	1310nm
QSFP28	LR1	10km	100G	SMF	Duplex LC	4x25G NRZ	1x100G PAM4	1310nm
QSFP28	ER1	40km	100G	SMF	Duplex LC	4x25G NRZ	1x100G PAM4	1310nm
QSFP28	DWDM	40km	100G	SMF	Duplex LC	4x25G NRZ	2x50G PAM4	ITU 14-58

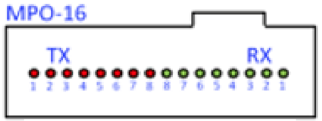
Purpose of single lambda?

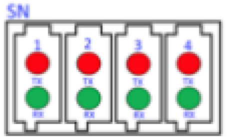
- This will help support some of the transition into 400G
    - 4x 100G connections aggregating into 1x 400G transceiver

400G

Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	Electrical Interface	Optical Interface	λ
QSFP56-DD	DR4	500m	400G	SMF	MPO-12/SN*	8x50G PAM4	4x100G PAM4	1310nm
QSFP56-DD	DR4+	2km	400G	SMF	MPO-12/SN*	8x50G PAM4	4x100G PAM4	1310nm
QSFP56-DD	FR4	2km	400G	SMF	Duplex LC	8x50G PAM4	4x100G PAM4	1310nm
QSFP56-DD	SR8	100m	400G	MMF	MPO-16-APC	8x50G PAM4	8x50G PAM4	850nm
QSFP56-DD	LR4	10km	400G	SMF	Duplex LC	8x50G PAM4	4x100G PAM4	C27-C33







PON Transceiver Hardware

Form Factor/Type	Type	Max Distance	Line Rate	Medium	Connector	Λ (nm)
SFP	GPON	B+	2.5G	SMF	SC Simplex	1490/1310
SFP	GPON	C+	2.5G	SMF	SC Simplex	1490/1310
SFP+	XGSPON	N1	10G	SMF	SC Simplex	1577/1270
SFP+	XGSPON	N2	10G	SMF	SC Simplex	1577/1270
SFP+	XGS/GPON Combo	N1/B+	2.5/10G	SMF	SC Simplex	XGS/GPON
SFP+	XGS/GPON Combo	N2/C+	2.5/10G	SMF	SC Simplex	XGS/GPON
SFP-DD	XGS/GPON Combo	N1/B+	2.5/10G	SMF	SC Simplex	XGS/GPON
SFP-DD	XGS/GPON Combo	N2/C+	2.5/10G	SMF	SC Simplex	XGS/GPON
XFP	XGSPON	N1	10G	SMF	SC Simplex	1577/1270
XFP	XGSPON	N2	10G	SMF	SC Simplex	1577/1270
XFP	EPON	PR30	10G/1G	SMF	SC Simplex	1577/1270*

Max distance for PON is best interpreted by link budget rather than a distance rating

Type	Link Budget
B+	29.5dB
C+	35dB
N1	29dB
N2	31dB
PR30	31.8dB for 1G / 30dB for 10G

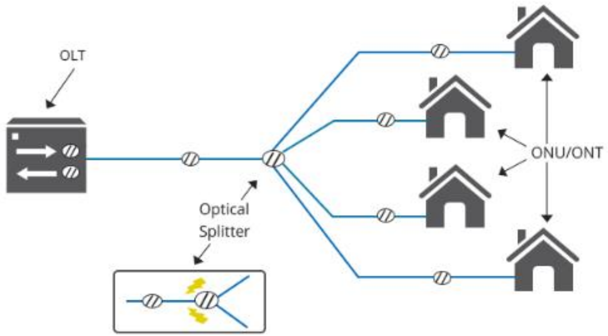
PON and Rural Broadband

Connecting Rural America - Closing The Digital Divide

In today's passive optical networks, fiber optic splitters help deliver affordable, uncapped, ultra-fast broadband services accessible to everyone.

Optical splitters have played an important role in rural passive optical networks (like EPON, GPON, BPON, FTTX, FTTH, etc.) by allowing a single PON interface to be shared among many subscribers.

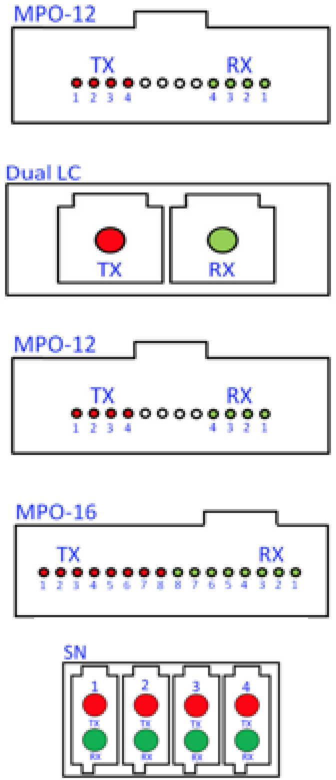
Fiber optic splitters, also referred to as optical splitter or beam splitter, I a passive distribution device that can split a light beam into two or more light beams, and vice versa, containing multiple input and output ends.



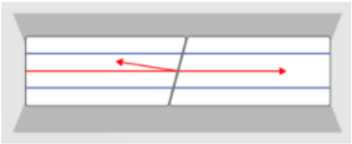
1x16 PLC Rack Mount Splitter

1x128 PLC Pigtail Splitter

Fiber Types & Connector Types



UPC



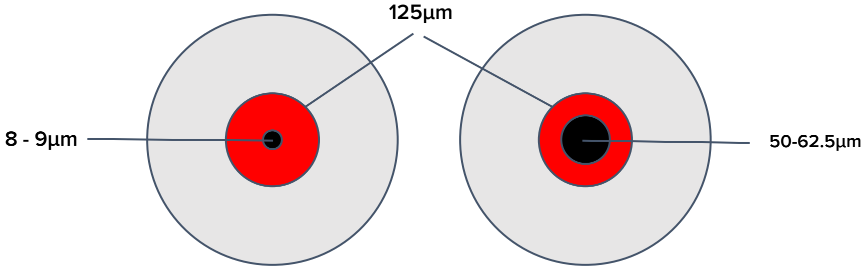
APC

UPC = Ultra Physical Contact
APC = Angle Polished Connector

APC gives better optical return loss which gives a slightly better link budget than UPC

SMF

MMF



Multimode is less expensive to manufacture but at the cost of higher attenuation and refractions

Its possible to use 1310 over multimode, but not recommended

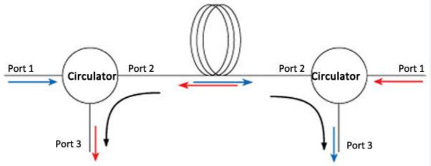
SC connector is similar to an LC connector with the exception of the ferrule being double the diameter (2.5mm vs. 1.25mm)

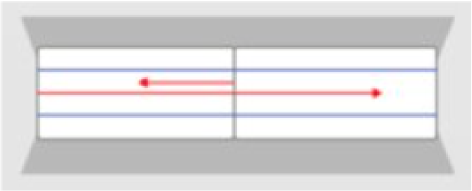
Reflections or "back reflectance"

- **Q: Reflections…how do they impact GigE vs 100/400 GigE?**

  Reflectance often referred to as "back reflection" or optical return loss of a connection is the amount of light that is reflected back up the fiber toward the source by light reflections off the interface of the polished end surface of the mated connectors and air.

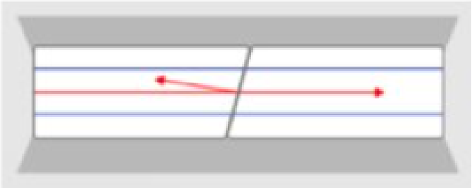
- Reflectance is primarily a problem with connectors but may also affect mechanical splices which contain an index matching gel to prevent reflectance.
  - UPC = MPO MMF and LC connectors
  - APC = MPO SMF
- **Q: How to combat reflections?**
- **Physical contact connectors are purposefully made to reduce the amount of reflections at the contact point by polishing the surface of the connector**
- **Connectors today use finishes that work even better at a slight angle (8°) These connectors are called APC or angled physical contact connectors.**
- Optical Circulators and Isolators are also often used in passive architecture to overcome obstacles in back r





UPC

8 -



APC

UPC = Ultra Physical Contact
APC = Angle Polished Connector

APC gives better optical return loss which gives a slightly better link budget than UPC

Temperature Ratings

For scenarios where network equipment are installed into non-temperature controlled environments, temperature rated optics are often used.

A standard optic is classified as

- **Commercial Temp (C-Temp) -** Commercial Temp 0c to 70c
- **Industrial Temp (I-Temp)** When deploying into a hardened network device / scenario

- **Commercial Temp** (C-Temp)
  - 0 to +70
- **Extended Temp** (E-Temp)*
  - -20 to +85
  - -20 to +70
  - -5 to +85
  - 0 to +85
- **Industrial Temp** (I-Temp)
  - -40 to +85
- **Hardened Temp** (H-Temp)
  - -40 to +92
- **Extended Industrial Temp**
  - -40 to +95

**Extended Temp (E-Temp) is widely defined, depending on vendor. Ranges vary from –20 to +85 down to 0 to +85*

Summary

There are many different types of transceivers with various form factors, data rates, link budgets, and transmit technology types. All of which were developed to help cost optimize a specific application. Although the MSA helped eliminate the headaches of proprietary form factors, newer technical challenges are on the horizon with new techniques and methods invented to overcome those challenges

Any questions, comments, feedback, please feel free to email me at yarik.merkulov@precisionot.com