100GE / 400GE ТРАНСИВЕРЫ

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октябрь 2021 (v01)

JUNIPER NETWORKS | Engineering Simplicity

СОДЕРЖАНИЕ

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- 100G трансиверы
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Введение

ПРОБЛЕМА (ПРАВИЛЬНОГО) ВЫБОРА

- Большая номенклатура трансиверов
- Возможности break-out усложняют картину
- Чтобы ориентироваться и делать правильный выбор, хорошо бы кое-что понимать ☺

QDD-400G-DR4
Part Number: 740-085351
QSFP-DD 400GBASE-DR4/4X100GBASE-DR, SMF 500 m; St
connector
Introduced Release(s): Junos OS Evolved 20.2R1

QDD-400G-FR4
Part Number: 740-085349
QSFP-DD 400G-FR4/400GBASE-FR4, SMF 2 km; Standard Te
Introduced Release(s): Junos OS Evolved 20.2R1

QDD-400G-LR8
Part Number: 740-082823
QSFP-DD 400GBASE-LR8, SMF 10 km; Standard Temperature
Introduced Release(s): Junos OS Evolved 20.2R1

QDD-400G-ZR
Part Number: 740-114884
OIF 400ZR IA compliant 400GE coherent optical module
Caveat: Note: Thermal Restrictions for PTX10001-36MR/Ardbeg • No re
can be placed in lower ports with no temperature restrictions as long as t
should be set to 72% even for idle conditions to prevent optics from turn
Introduced Release(s): Junos OS Evolved 21.3R1

QDD-4X100G-FR
Part Number: 740-085354
QSFP-DD 4x100G-FR, SMF 2 km; Standard Temperature (0 th
Introduced Release(s): Junos OS Evolved 20.2R1

JNP-QSFP-100G-CWDM
Part Number: 740-061408
100G CWDM4 optics
Introduced Release(s): Junos OS Evolved 20.2R1

JNP-QSFP-100G-LR4
Part Number: 740-061409
QSFP28 100GBase-L4 Optics for up to 10km transmission over serial SMF
Introduced Release(s): Junos OS Evolved 20.2R1

JNP-QSFP-100G-PSM4
Part Number: 740-061406
QSFP28 100G base PSM4 optics for up to 500 m transmission over parallel SMF
Introduced Release(s): Junos OS Evolved 20.2R1

JNP-QSFP-100G-SR4
Part Number: 740-061405
QSFP28 100GBase-SR4 Optics for up to 100m transmission over parallel MMF
Introduced Release(s): Junos OS Evolved 20.2R1

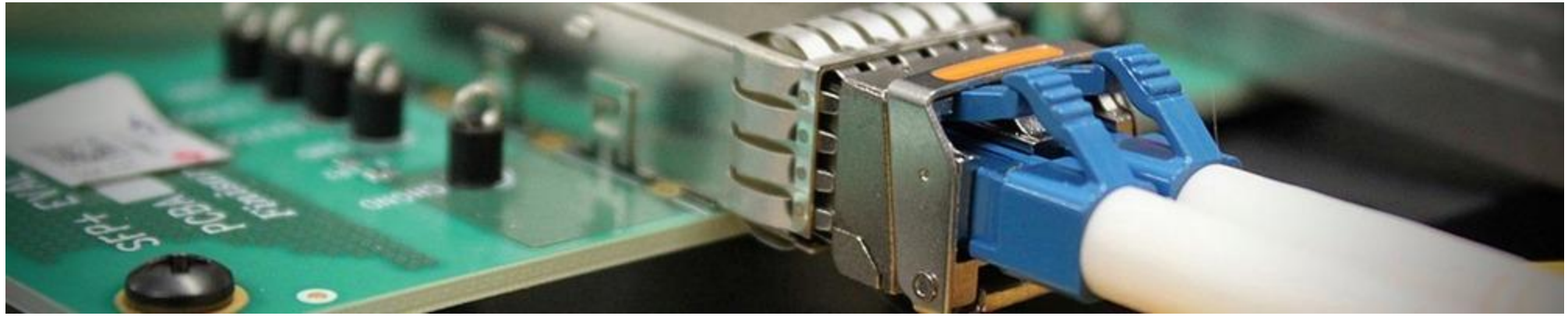
QDD-2X100G-CWDM4
Part Number: 740-077808
QSFP28-DD 2x100G-CWDM4 Standard Temperature (0 through 70°C)
Introduced Release(s): Junos OS Evolved 20.2R1

QDD-2X100G-LR4
Part Number: 740-079871
QSFP28-DD 2x100GBASE-LR4 Standard Temperature (0 through 70°C)
Introduced Release(s): Junos OS Evolved 20.2R1

QSFP-100G-ER4L
Part Number: 740-071175
QSFP28 100G-ER4 Lite Ethernet only module
Introduced Release(s): Junos OS Evolved 20.2R1

ОПТИЧЕСКИЙ (ETHERNET) ТРАНСИВЕР

- Оптический трансивер дуален:
  - дискретная сигнал (двоичные данные) на электрической (внутренней) стороне
  - аналоговый сигнал (световая волна) на оптической (внешней) стороне



СТРУКТУРА ФИЗИЧЕСКОГО УРОВНЯ 40G/100G ETHERNET

- PCS = Physical Coding Sublayer
- FEC = Forward Error Correction
- PMA = Physical Medium Attachment
- PMD = Physical Medium Dependent
- **XL**AUI = 40 Gbps Attachment Unit Interface
- **C**AUI = 100 Gbps Attachment Unit Interface
- 2010 год: **электрический интерфейс** для 100G трансивера определен как **10x10G** (для 40G трансивера как 4x10G)

IEEE Std 802.3ba™-2010

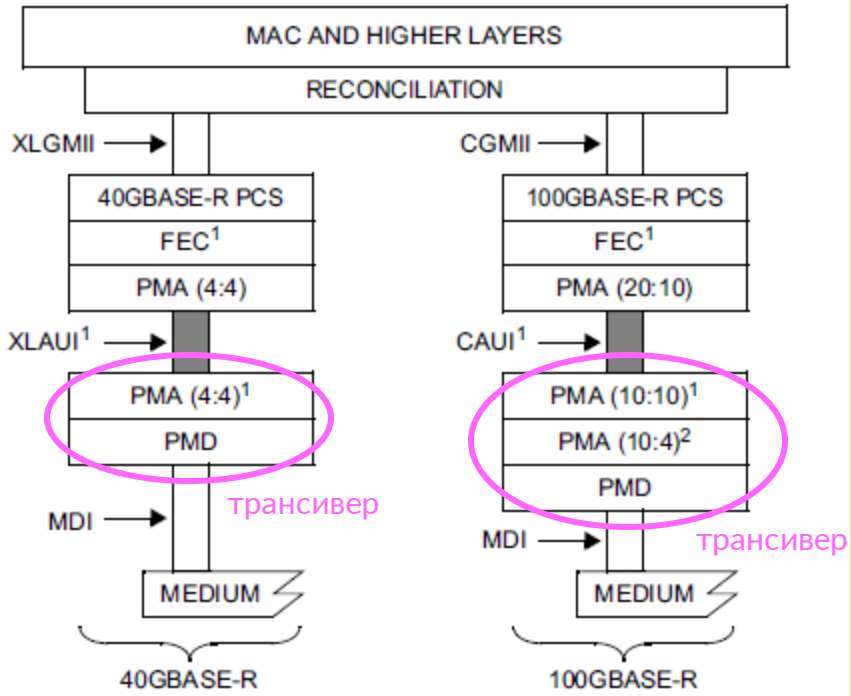


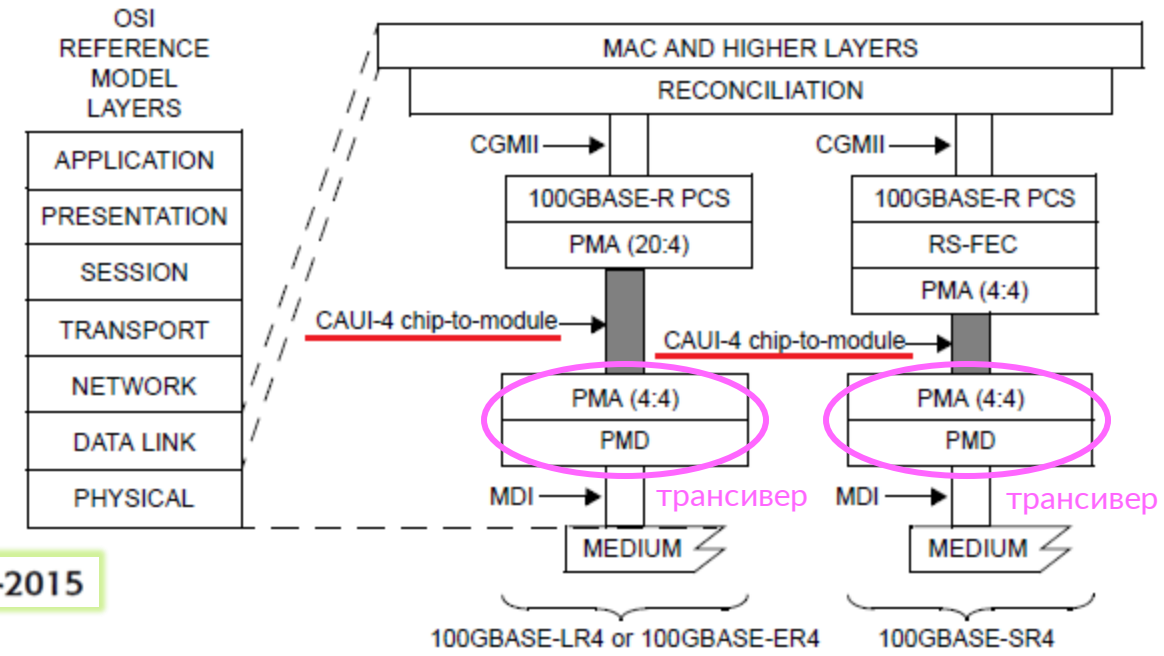
Figure 83A–1—Example relationship of XLAUI and CAUI to IEEE 802.3 CSMA/CD LAN model

83A.1.2 Rate of operation

The XLAUI interface supports the 40 Gb/s data rate and the CAUI interface supports the 100 Gb/s data rate. For 40 Gb/s applications, the data stream shall be presented in four lanes as described in Clause 83. For 100 Gb/s applications, the data stream shall be presented in ten lanes as described in Clause 83. The data is 64B/66B coded. The nominal signaling rate for each lane in both 40 Gb/s and 100 Gb/s applications shall be 10.3125 Gb/s.

CAUI-4 ИНТЕРФЕЙС (CHIP-TO-MODULE, 4X25)

- 2015 год: добавлен **электрический интерфейс 4x25G**
- CAU-4 = 100 Gbps four-lane Attachment Unit Interface
- Что такое 25,78125 GBd ?



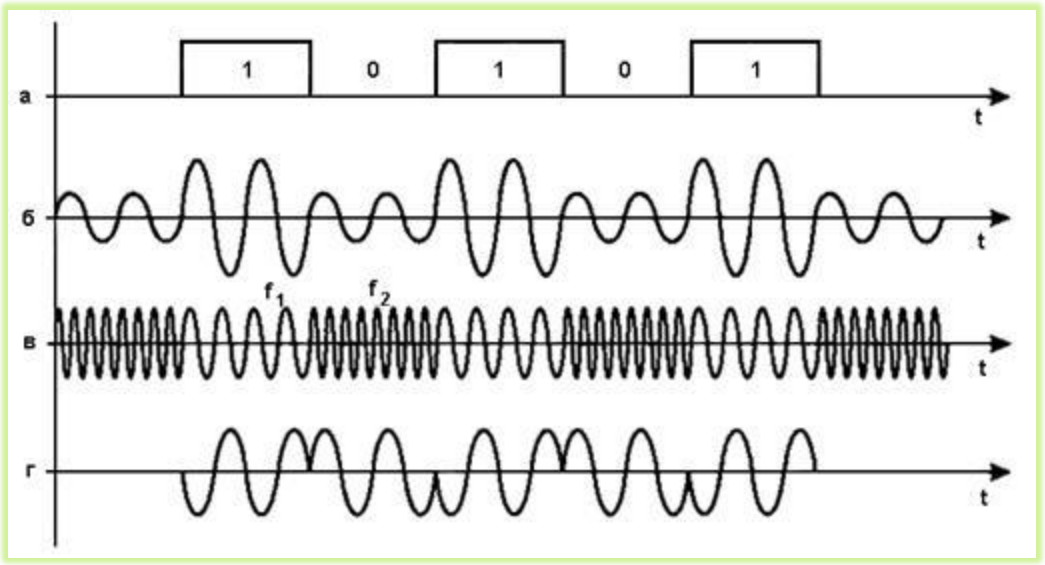
IEEE Std 802.3bm™-2015

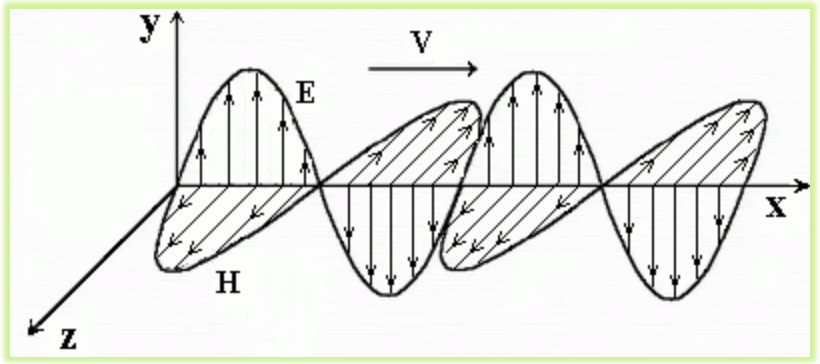
Figure 83E–1—Example CAUI-4 chip-to-module relationship to the ISO/IEC Open System) reference model and the IEEE 802.3 CSMA/CD LAN model

The CAUI-4 link is described in terms of a host CAUI-4 component, a CAUI-4 channel with associated insertion loss, and a module CAUI-4 component. Figure 83E–2 and Equation (83E–1) depict a typical CAUI-4 application and summarize the differential insertion loss budget associated with the chip-to-module application, which is shown in Figure 83E–3. The CAUI-4 chip-to-module interface comprises independent data paths in each direction. Each data path contains four differential lanes, which are AC coupled within the module. The nominal signaling rate for each lane is 25.78125 GBd. The chip-to-module interface is defined using a specification and test methodology that is similar to that used for CEI-28G-VSR defined in OIF-CEI-03.1 [Bx1].

ВСПОМИНАЕМ ТЕОРЕТИЧЕСКИЕ ОСНОВЫ ПЕРЕДАЧИ СИГНАЛОВ

- Сигнальная скорость (=боды в секунду)
- Способ модуляции (=сколько битов передаем за 1 сигнальный такт?)
  - для дискретного электрического сигнала модулируем амплитуду (уровень напряжения)
  - для аналогового светового сигнала можем моделировать амплитуду, частоту, фазу, поляризацию (!)
- Итоговая скорость передачи информации (=биты в секунду) = сигнальная скорость * модуляцию
  - либо мы увеличиваем сигнальную скорость, либо мы используем более сложную модуляцию



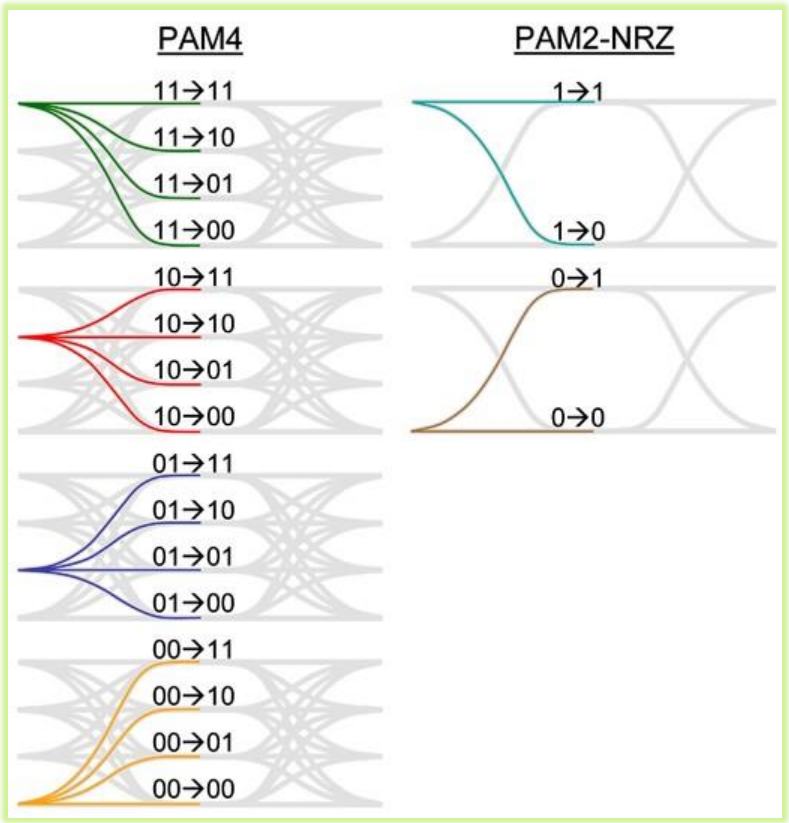


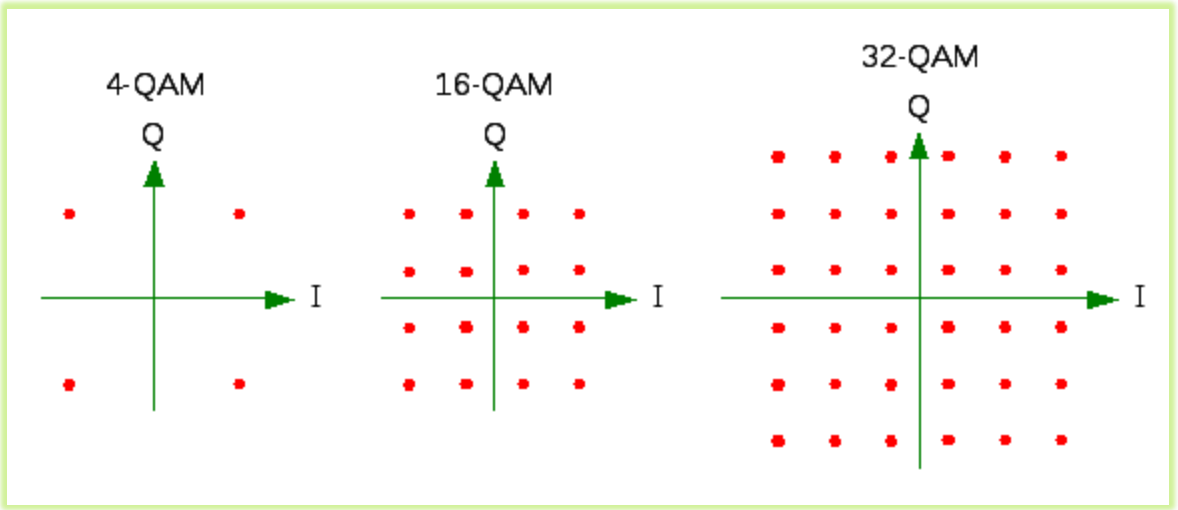
НЕКОТОРЫЕ ПРИМЕРЫ

- Модуляция NRZ (=PAM2): 2 значения амплитуды
  - “0” и “1” (передача **1 бита** за 1 сигнальный такт)
- Модуляция PAM4: 4 значения амплитуды
  - “00”, “01”, “10”, “11” (передача **2-х битов** за 1 сигнальный такт)
- Модуляция 16-QAM: 4 значения амплитуды * 4 значения фазы = 16 разных значений
  - “0000”, “0001”, “0010”, … “1111” (передача **4-х битов** за 1 сигнальный такт)
- Ничего не бывает бесплатно (сигнал/шум, SNR → нужен FEC)

Именно эта модуляция используется в классических 100G стандартах (см. далее)

Эта модуляция появляется в стандартах 400G Ethernet (см. далее)





ПОЧЕМУ 25,78125 GBOD, А НЕ РОВНО 25 GBOD?

- Кодировка “66B/64B”
  - каждые 64 бита передаются как 66 бит (+2 служебных бита)
- Для компенсации нужно увеличить сигнальную скорость: 25 * 66/64 = 25,78125

82.2.3 64B/66B transmission code

The PCS uses a transmission code to improve the transmission characteristics of information to be transferred across the link and to support transmission of control and data characters. The encodings defined by the transmission code ensure that sufficient transitions are present in the PHY bit stream to make clock recovery possible at the receiver. The encoding also preserves the likelihood of detecting any single or multiple bit errors that may occur during transmission and reception of information. In addition, the synchronization headers of the code enable the receiver to achieve block alignment on the incoming PHY bit stream. The 64B/66B transmission code specified for use in this standard is a run-length-limited code.[10]

IEEE Std 802.3ba™-2010

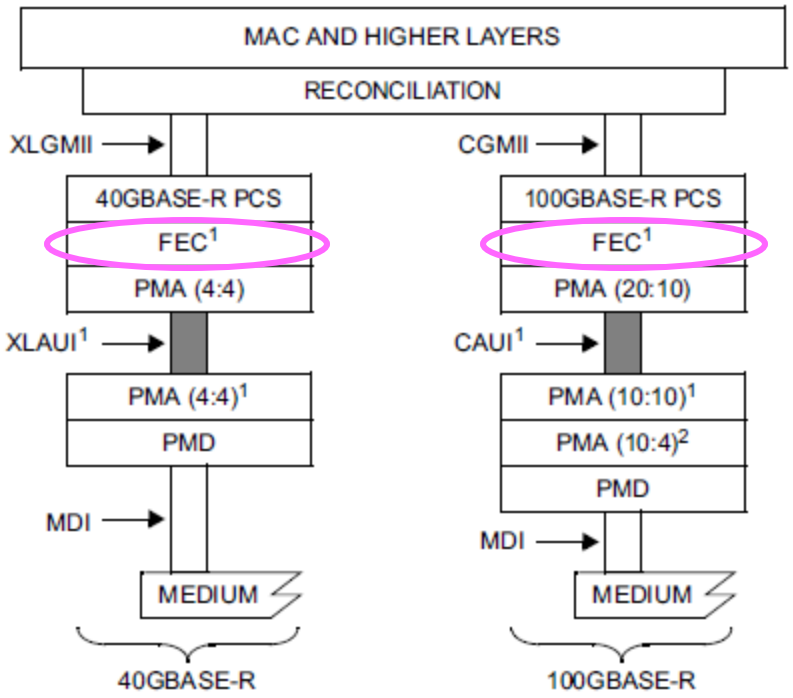
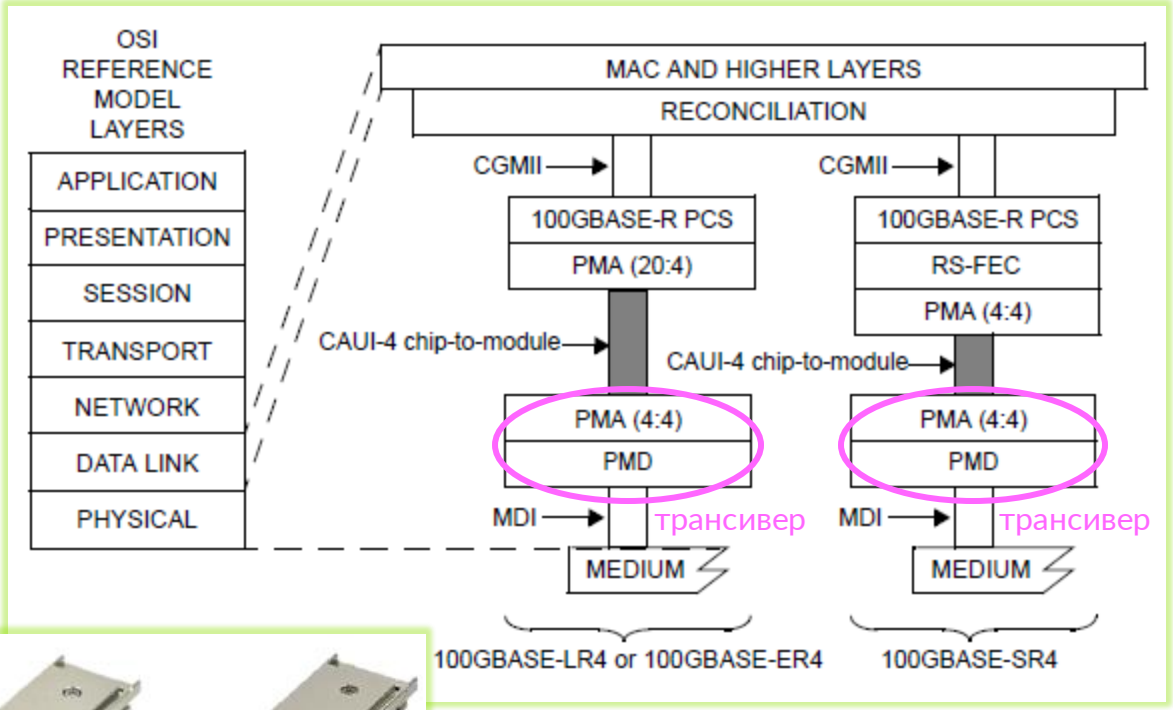


Figure 83A–1—Example relationship of XLAUI and CAUI to IEEE 802.3 CSMA/CD LAN model

QSFP28: ТРАНСИВЕР ДЛЯ 100G ETHERNET

- QSPF28 трансивер реализует CAUI-4 (4x25G) интерфейс на электрической стороне
- Оптическая часть может быть разная (см. далее)
- Спецификация https://www.snia.org
  - SFF-8665
  - SFF-8679
  - и другие составные части стандарта



100G трансиверы

100GBASE-LR4

- https://apps.juniper.net/hct/model/?component=QSFP-100G-LR4-C
  - 25 Gbod * NRZ
  - Single-mode волокно
  - QSFP28 / LC коннектор
  - 4 оптические лямбды в O-band
  - **~10 км**

Standard: 100GBASE-LR4	
Standards compliance	IEEE 802.3ba-2010
Signaling rate, each lane	25.78125 GBd +/- 100 ppm
Transmitter wavelengths (range)	1294.53 nm through 1296.59 nm 1299.02 nm through 1301.09 nm 1303.54 nm through 1305.63 nm 1308.09 nm through 1310.19 nm
Cable type	SMF
Core size/cladding	9/125 µm
Distance	10 km

IEEE Std 802.3ba™-2010

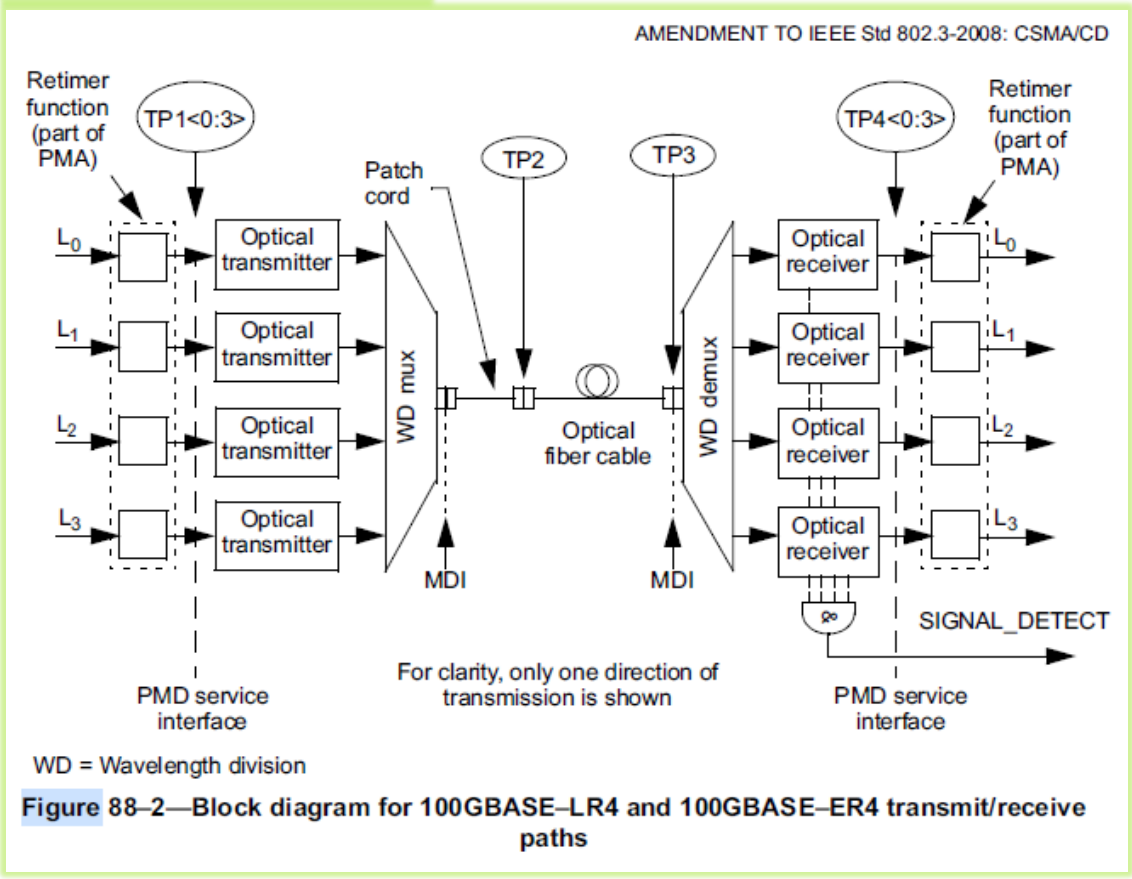


Figure 88–2—Block diagram for 100GBASE–LR4 and 100GBASE–ER4 transmit/receive paths

100GBASE-SR4

- https://apps.juniper.net/hct/model/?component=QSFP-100G-SR4-C
  - 25 Gbod * NRZ
  - Multi-mode волокно
  - QSFP28 / MPO-12 коннектор
  - **~100 м**

Connector	MPO-12
Standard: 100GBASE-SR4	
Standards compliance	IEEE 802.3bm
Diagnostic support	Yes
Signaling rate, each lane	25.78125 GBd +/- 100 ppm
Transmitter wavelengths (range)	840 nm through 860 nm
Receive lane wavelengths (range)	840 nm through 860 nm
Cable type	MMF

IEEE Std 802.3bm™-2015

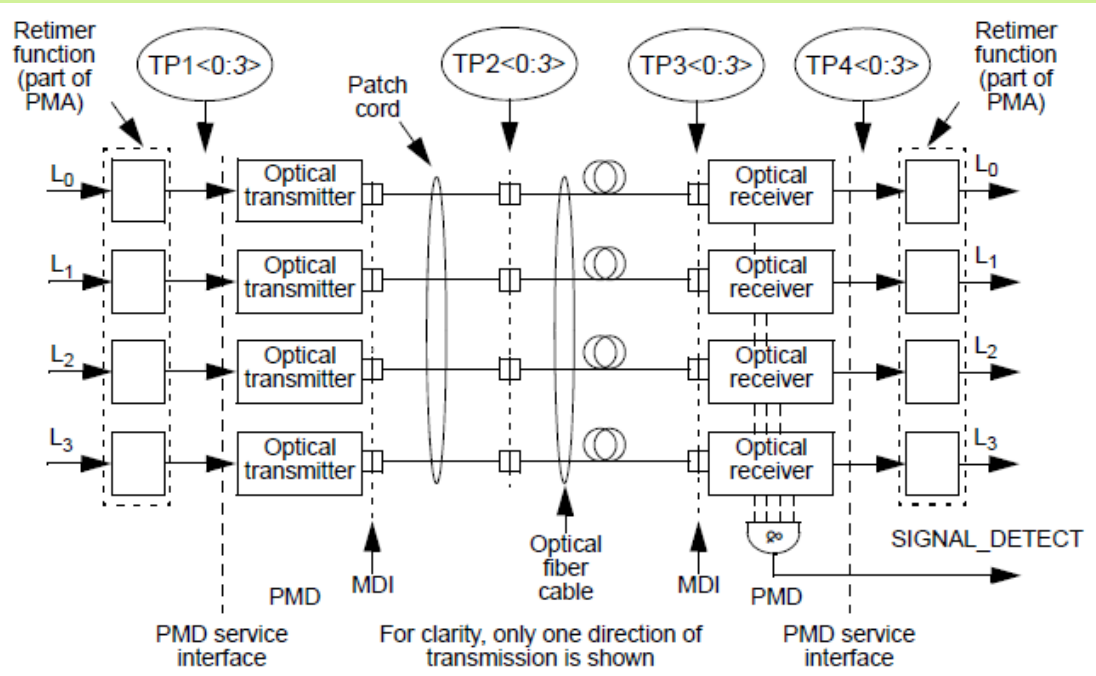


Figure 95–2—Block diagram for 100GBASE-SR4 transmit/receive paths

IEEE Std 802.3bm-2015
AMENDMENT 3 TO IEEE Std 802.3-2012: Ethernet

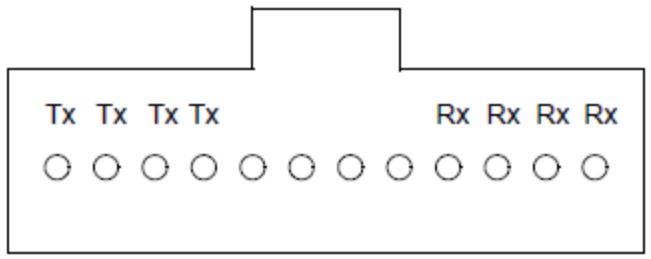


Figure 95–7—100GBASE-SR4 optical lane assignments

100GBASE-CWDM4

- https://apps.juniper.net/hct/model/?component=QSFP-100G-CWDM-C
  - 25 Gbod * NRZ
  - Single-mode волокно
  - QSFP28 / LC коннектор
  - 4 оптические CWDM лямбды
  - **~2 км**

http://www.cwdm4-msa.org/

MSA = Multi-Source Agreement Group

Connector	Duplex LC
Standard: 100GBASE-CWDM4	
MSA compliance (SFF, for e.g. SFF-8665)	100G CWDM4 MSA Technical Specifications 2km Optical Specifications
Diagnostic support	Yes
Signaling rate, each lane	25.78125 ± 100 ppm
Transmitter wavelengths (range)	-1264.5 nm through 1277.5 nm -1284.5 nm through 1297.5 nm -1304.5 nm through 1317.5 nm -1324.5 nm through 1337.5 nm
	SMF

1.1 SCOPE

This Multi-Source Agreement (MSA) defines 4 x 25 Gbps Coarse Wavelength Division Multiplex (CWDM) optical interfaces for 100 Gbit/s optical transceivers for Ethernet applications including 100 GbE. Forward error correction (FEC) is required to be implemented by the host in order to ensure reliable system operation. Two transceivers communicate over single mode fibers (SMF) of length from 2 meters to at least 2 kilometers. The transceiver electrical interface is not specified by this MSA but can have, for example, four lanes in each direction with a nominal signaling rate of 25.78125 Gbps per lane.

100GBASE-PSM4 (PARALLEL SINGLE MODE)

- https://apps.juniper.net/hct/model/?component=JNP-QSFP-100G-PSM4
  - 25 Gbod * NRZ
  - Single-mode волокно
  - QSFP28 / MPO-12 коннектор
  - **~500 м**

http://psm4.org/

Connector	MPO-12 APC
Standard: 100G PSM4 MSA	
Diagnostic support	Yes
Signaling rate, each lane	25.78125 GBd +/- 100 ppm
Transmitter wavelengths (range)	1295 nm through 1325 nm
Cable type	SMF
Core size/cladding	9/125 µm
Distance	500 m

The 100G PSM4 Specification defines requirements for a point-to-point 100 Gb/s link over eight single mode fibers up to at least 500 m. Four identical and independent lanes are used for each signal direction. Table 1 shows the primary attributes of the 100G PSM4 Specification.

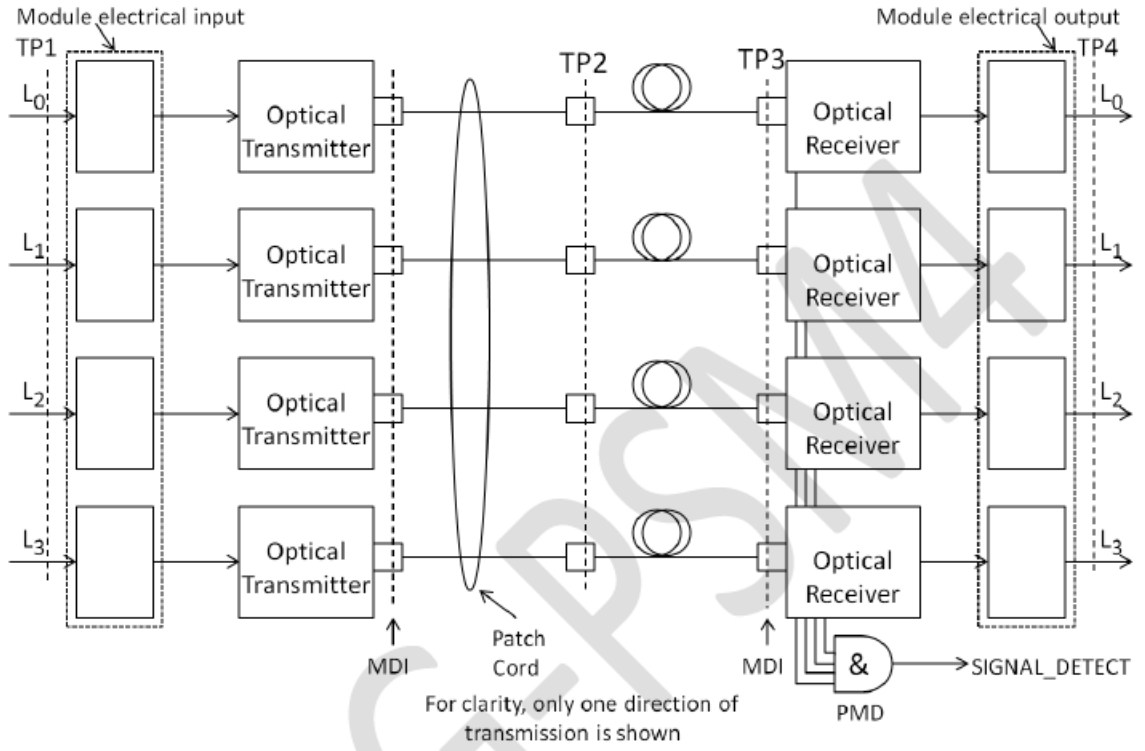


Figure 2: Block diagram for PSM4 transmit/receive path

400G трансиверы (и не только)

ЧТО МЕНЯЕТСЯ НА ЭЛЕКТРИЧЕСКОЙ СТОРОНЕ? (1)

- Вариант 1: 400GAUI-16
  - **16x25Gbod,** кодировка **NRZ** (=25Gbps/lane)
- Точная сигнальная скорость 26,5625 Gbod
  - 25 * (257B/256B) * (544B/514B) = 26,5625

Первая кодировка

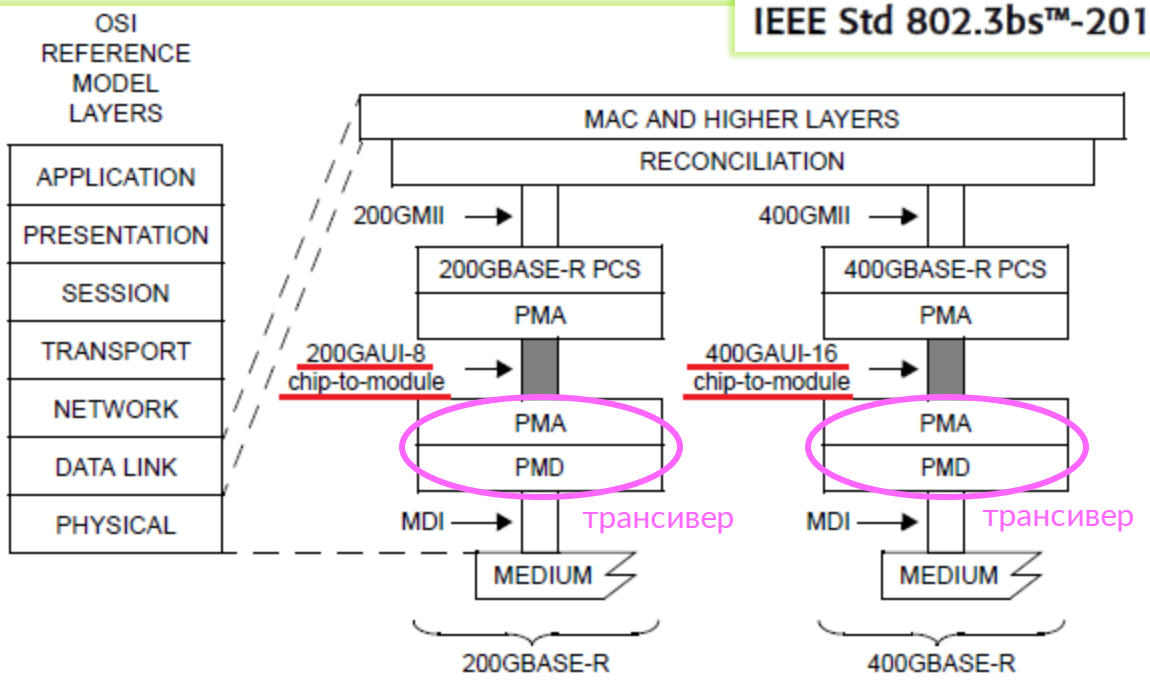
Вторая кодировка (FEC)
код Рида-Соломона

— Annex 120C, which specifies the 200GAUI-8 and 400GAUI-16 interfaces for chip-to-module applications.

— Annex 120E, which specifies the 200GAUI-4 and 400GAUI-8 interfaces for chip-to-module applications.

For 200GAUI-8 or 400GAUI-16, the modulation format is NRZ.
For 200GAUI-4 or 400GAUI-8, the modulation format is PAM4.

IEEE Std 802.3bs™-2017



200GAUI-8 = 200 Gb/s EIGHT-LANE ATTACHMENT UNIT INTERFACE
200GMII = 200 Gb/s MEDIA INDEPENDENT INTERFACE
400GAUI-16 = 400 Gb/s SIXTEEN-LANE ATTACHMENT UNIT INTERFACE
400GMII = 400 Gb/s MEDIA INDEPENDENT INTERFACE
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

Figure 120C–1—Example 200GAUI-8 and 400GAUI-16 chip-to-module relationship to the ISO/IEC Open System Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

ЧТО МЕНЯЕТСЯ НА ЭЛЕКТРИЧЕСКОЙ СТОРОНЕ? (2)

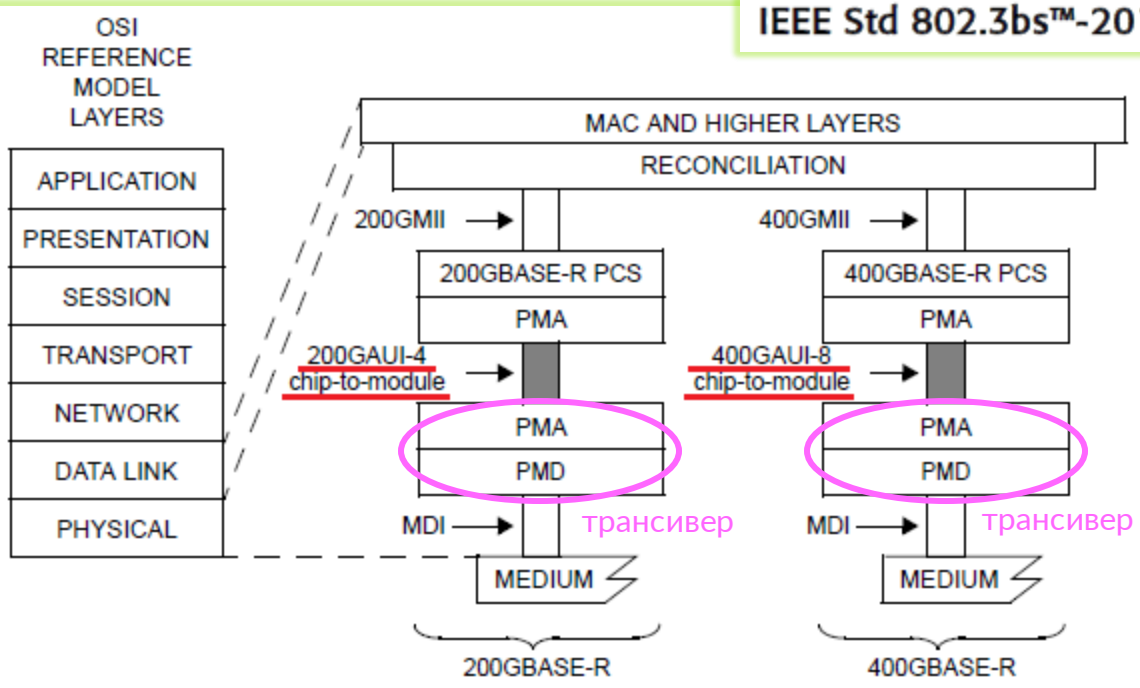
- Вариант 2: 400GAUI-8
  - **8x25Gbod,** кодировка **PAM4** (=50Gbps/lane)
- Точная сигнальная скорость остается 26,5625 Gbod

— Annex 120C, which specifies the 200GAUI-8 and 400GAUI-16 interfaces for chip-to-module applications.

— Annex 120E, which specifies the 200GAUI-4 and 400GAUI-8 interfaces for chip-to-module applications.

For 200GAUI-8 or 400GAUI-16, the modulation format is NRZ.
For 200GAUI-4 or 400GAUI-8, the modulation format is PAM4.

IEEE Std 802.3bs™-2017



200GAUI-4 = 200 Gb/s FOUR-LANE ATTACHMENT UNIT INTERFACE
200GMII = 200 Gb/s MEDIA INDEPENDENT INTERFACE
400GAUI-8 = 400 Gb/s EIGHT-LANE ATTACHMENT UNIT INTERFACE
400GMII = 400 Gb/s MEDIA INDEPENDENT INTERFACE

MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

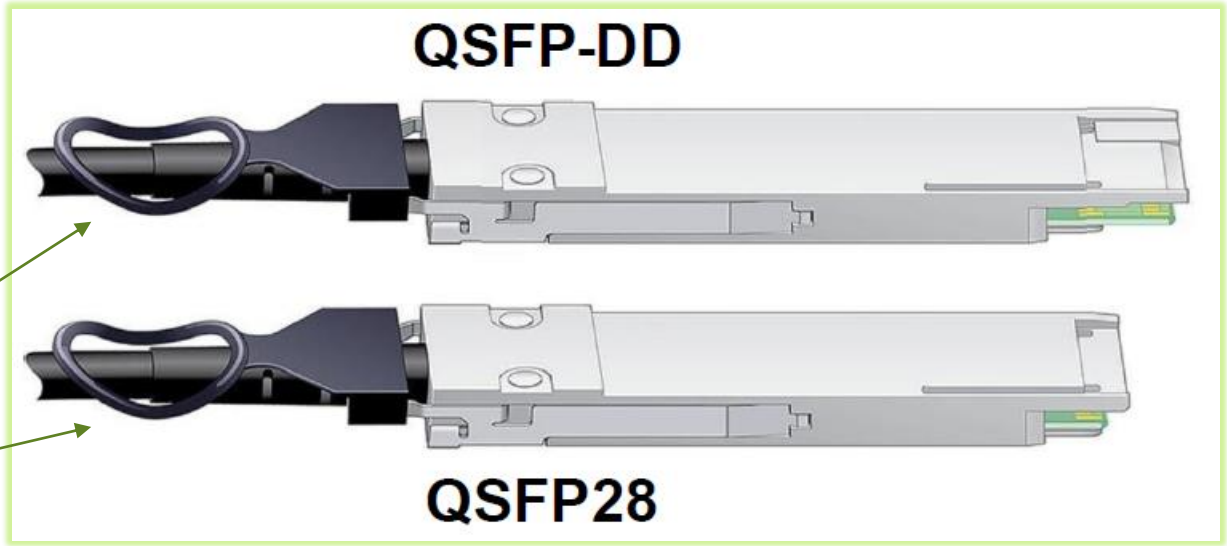
Figure 120E–1—Example 200GAUI-4 and 400GAUI-8 chip-to-module relationship to the ISO/IEC Open System Interconnection (OSI) reference model and the IEEE 802.3 Ethernet model

QSFP-DD: ТРАНСИВЕР ДЛЯ 400G ETHERNET

- QSPF-DD трансивер реализует 400GAUI-8 (8x50G, он же вариант 2) интерфейс на электрической стороне
  - дополнительный/второй ряд контактов
- Также известен как QSFP56-DD (!)
- Оптическая часть может быть разная (см. далее)
- Спецификация: http://www.qsfp-dd.com/

Электрический интерфейс 400GAUI-8 (8x50G)

Электрический интерфейс CAUI-4 (4x25G)



QSFP-DD Hardware Rev 5.1

1 Scope

The scope of this specification is the definition of a high density 8-channel (8x) module, cage and connector system. QSFP-DD supports up to 400 Gb/s in aggregate over an 8 x 50 Gb/s electrical interface. The cage and connector design provides backwards compatibility to QSFP28 modules which can be inserted into a QSFP-DD port and connected to 4 of the 8 electrical channels.

400GBASE-SR16

- Multi-mode волокно (~850 нм)
- MPO-32 коннектор
- 16 * 25Gbod * NRZ в каждую сторону
  - 32 волокна в кабеле (!)
- ~100м
- стандарт есть, реальных трансиверов нет

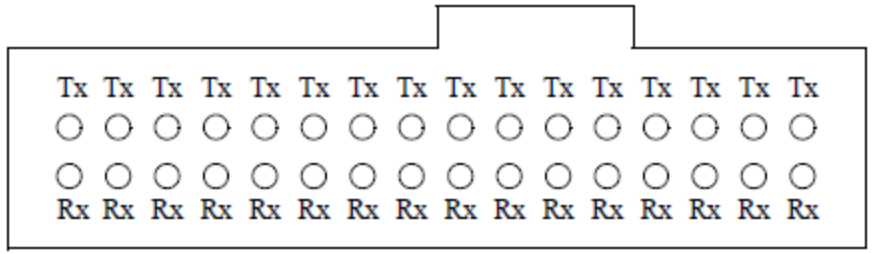


Figure 123–4—400GBASE-SR16 optical lane assignments

IEEE Std 802.3bs™-2017

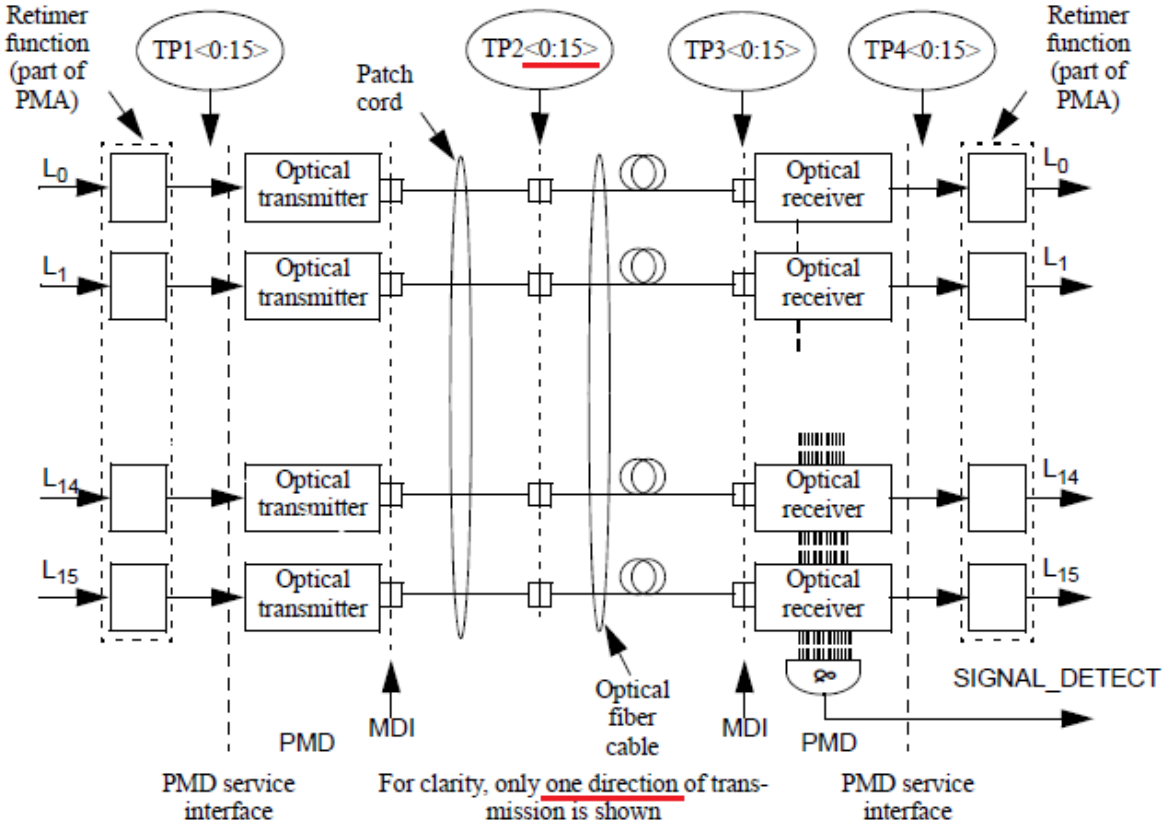


Figure 123–2—Block diagram for 400GBASE-SR16 transmit/receive paths

400GBASE-LR8

- https://apps.juniper.net/hct/model/?component=QDD-400G-LR8
  - **25 Gbod * PAM4** (= 50 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP-DD / LC коннектор
  - 8 лямбд / **~10 км**

IEEE Std 802.3bs™-2017

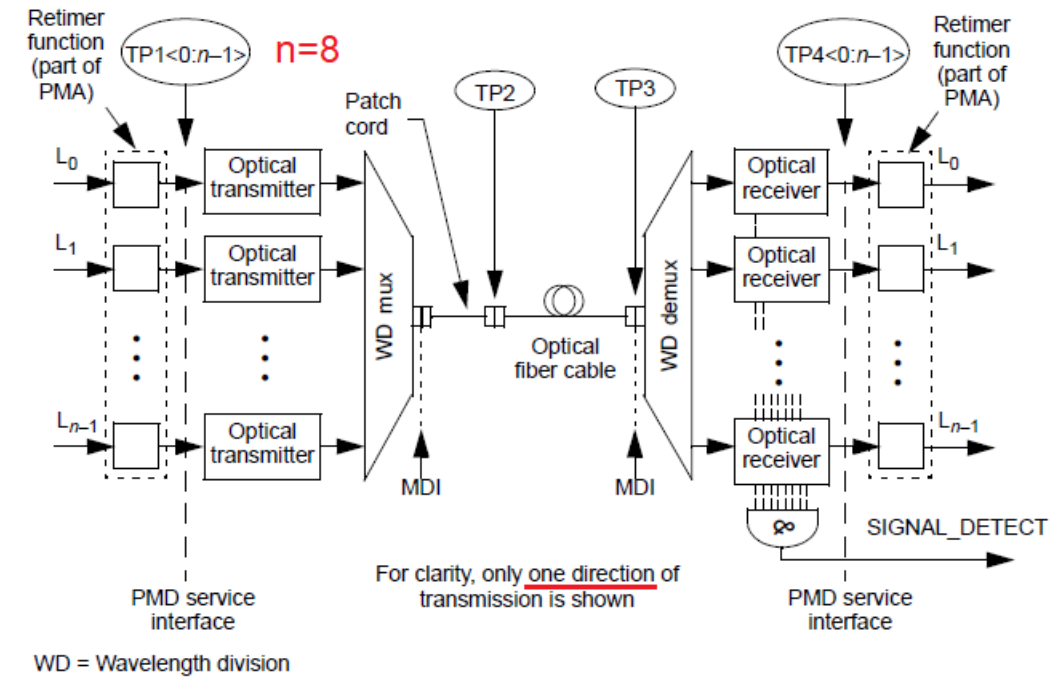


Figure 122–2—Block diagram for 200GBASE-FR4, 200GBASE-LR4, 400GBASE-FR8, and 400GBASE-LR8 transmit/receive paths

Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	Duplex LC
Standard: 400GBASE-LR8	
Signaling rate, each lane	Host lane: PAM4; 26.5625 GBd ± 100 ppm Media lane: PAM4; 26.5625 GBd ± 100 ppm
Transceiver input/output fibers	2
Transmitter wavelengths (range)	1272.55 nm through 1274.54 nm 1276.89 nm through 1278.89 nm 1281.25 nm through 1283.27 nm 1285.65 nm through 1287.68 nm 1294.53 nm through 1296.59 nm 1299.02 nm through 1301.09 nm 1303.54 nm through 1305.63 nm 1308.09 nm through 1310.19 nm

400GBASE-DR4

- https://apps.juniper.net/hct/model/?component=QDD-400G-DR4
  - **50 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP-DD / MPO-12 коннектор
  - **~500 м**

100G на одной длине волны/лямбде (!)

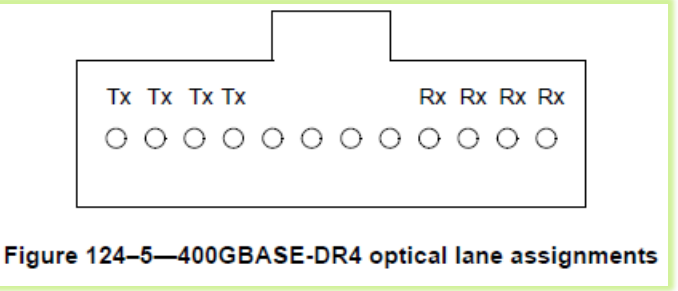


Figure 124–5—400GBASE-DR4 optical lane assignments

IEEE Std 802.3bs™-2017

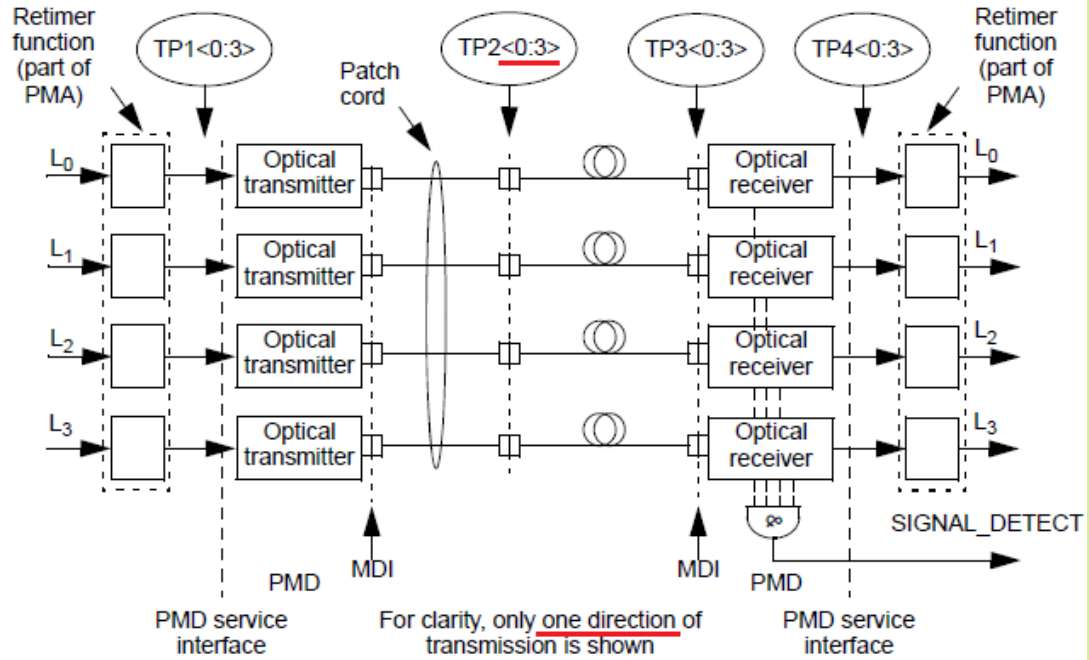


Figure 124–2—Block diagram for 400GBASE-DR4 transmit/receive paths

Speed	400 Gigabit Ethernet
Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	MPO-12
Standard: 400GBASE-DR4	
Signaling rate, each lane	Host lane: 26.5625 GBd PAM4 +/-100 ppm Media lane: 53.125 GBd PAM4 +/-100 ppm
Transmitter fibers	8
Transmitter wavelengths (range)	1304.5 nm to 1317.5 nm
Receive lane wavelengths (range)	1304.5 nm to 1317.5 nm

8 потоков ⇔ 4 потока

100GBASE-DR

- Новые технологические решения для 400G автоматически влекут за собой новые 100G стандарты (!)
- https://apps.juniper.net/hct/model/?component=QSFP-100G-DR
  - **50 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP28 / LC коннектор
  - **~500 м**
- Брейк-аут: QDD-400G-DR4 = 4x QSFP-100G-DR

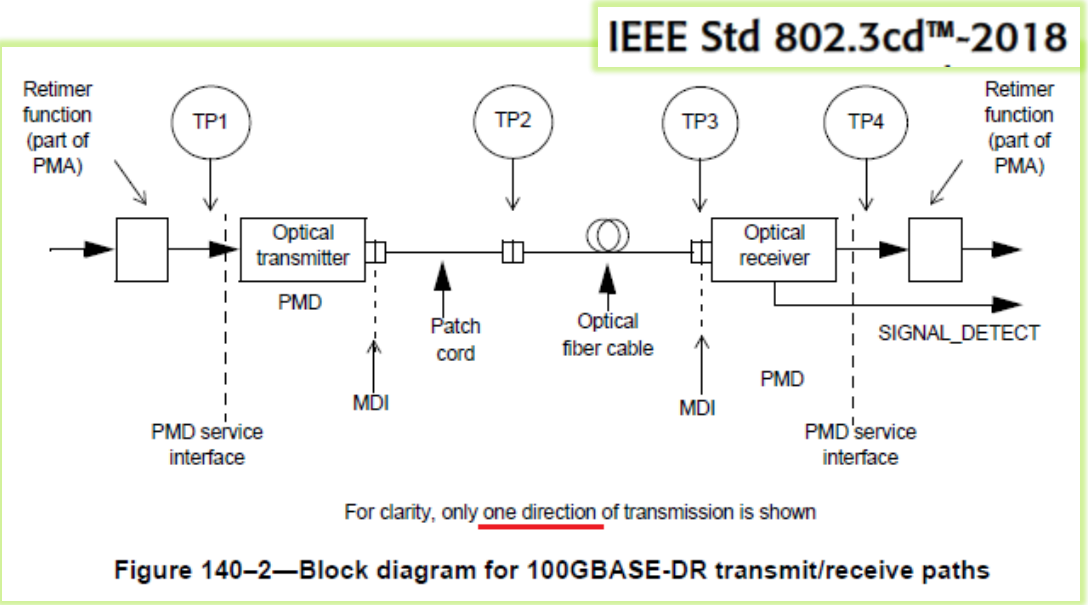


Figure 140–2—Block diagram for 100GBASE-DR transmit/receive paths

Transceiver Type	QSFP28
Product Type	Optical Transceiver
Connector	Duplex LC
Additional Information	These transceivers interoperate with 400-Gbps breakout optics.
Standard: IEEE 100GBASE-DR	
Supported applications	100GBASE-DR (clause 140), CAUI-4 (no FEC)
Signaling rate, each lane	Host lane: NRZ; 25.78125 GBd ± 100 ppm Media lane: PAM4; 53.125 GBd ± 100 ppm
Transmitter fibers	1
Transmitter wavelengths (range)	1304.5 nm to 1317.5 nm
Receive lane wavelengths (range)	1304.5 nm to 1317.5 nm

400GBASE-FR4

- https://apps.juniper.net/hct/model/?component=QDD-400G-FR4
  - **50 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP-DD / LC коннектор
  - 4 оптические CWDM лямбды / **~2 км**

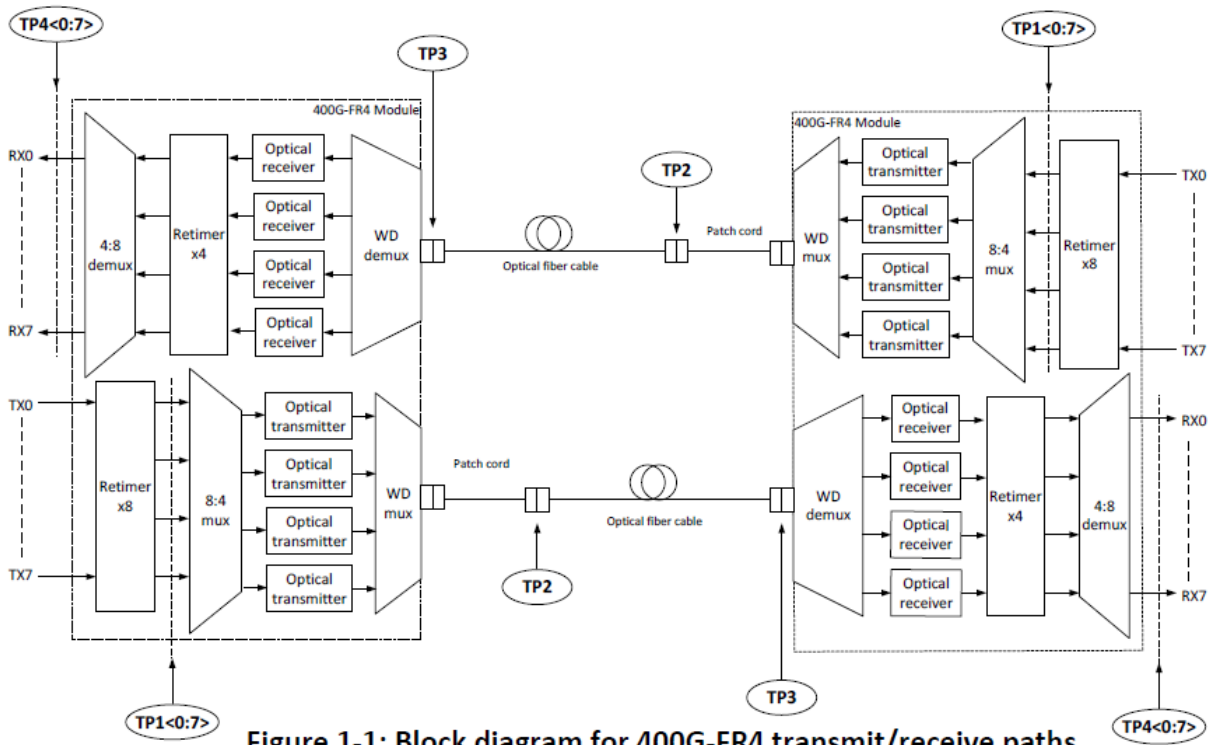


Figure 1-1: Block diagram for 400G-FR4 transmit/receive paths

Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	Duplex LC
Standard: 400G-FR4 and 400GBASE-FR4	
Standards compliance	100G Lambda MSA, 400G-FR4 IEEE P802.3cu, 400GBASE-FR4
Signaling rate, each lane	Host lane: 26.5625 GBd PAM4 +/-100 ppm Media lane: 53.125 GBd PAM4 +/-100 ppm
Transmitter fibers	2
Transmitter wavelengths (range)	1264.5 nm through 1277.5 nm 1284.5 nm through 1297.5 nm 1304.5 nm through 1317.5 nm 1324.5 nm through 1337.5 nm

https://100glambda.com/specifications/send/2-specifications/7-400g-fr4-technical-spec-d2p0

100GBASE-FR1 (И СНОВА НОВЫЙ СТАНДАРТ 100G)

- https://apps.juniper.net/hct/model/?component=QSFP-100G-FR
  - **53 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP28 / LC коннектор
  - **~2 км**

IEEE Std 802.3cu™-2021

Table 140–6—100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 transmit characteristics

Description	~~Value~~ 100GBASE-DR	100GBASE-FR1	100GBASE-LR1	Unit
Signaling rate (range)		53.125 ± 100 ppm		GBd
Modulation format		PAM4		—
Wavelength (range)		1304.5 to 1317.5		nm
Side-mode suppression ratio (SMSR), (min)		30		dB
Average launch power (max)	4	4	4.8	dBm
Average launch power[a] (min)	–2.9	–3.1	–1.9	dBm
Outer Optical Modulation Amplitude (OMA_{outer}) (max)	4.2	4.2	5	dBm
Outer Optical Modulation Amplitude (OMA_{outer}) (min)[b] for TDECQ <1.4 dB for 1.4 dB ≤ TDECQ ≤ 3.4 dB	–0.8 — —	— –0.1 –1.5 + TDECQ	— 1.1 –0.3 + TDECQ	dBm dBm dBm

Transceiver Type	QSFP28
Product Type	Optical Transceiver
Connector	Duplex LC
Standard: 100G Lambda MSA, 100G-FR IEEE P802.3cu, 100GBASE-FR1	
Supported applications	100G-FR or 100GBASE-FR1 (clause 140), CAUI-4 (no FEC)
Signaling rate, each lane	Host lane: NRZ; 25.78125 GBd ± 100 ppm Media lane: PAM4; 53.125 GBd ± 100 ppm
Transmitter fibers	1
Transmitter wavelengths (range)	1304.5 nm to 1317.5 nm
Receive lane wavelengths (range)	1304.5 nm to 1317.5 nm

https://100glambda.com/specifications/send/2-specifications/9-100g-fr-and-100g-lr-technical-specs-rev2-0

QDD-4X100G-FR ТРАНСИВЕР

- https://apps.juniper.net/hct/model/?component=QDD-4X100G-FR
  - **53 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP-DD / MPO-12 коннектор
- Брейк-аут
- Совместимость с:
  - 400GBASE-DR4 **(~500 м)**,
  - 100GBASE-DR **(~500 м)**
  - 100GBASE-FR1 **(~2 км)**

Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	MPO-12 APC
Standard: 100G-FR, 100GBASE-FR1, 100GBASE-DR and 400GBASE-DR4	
Standards compliance	100G Lambda MSA, 100G-FR IEEE P802.3cu, 100GBASE-FR1 IEEE Std 802.3cd-2018, 100GBASE-DR IEEE Std 802.3-2018, 400GBASE-DR4
Supported applications	100G-FR/100GBASE-FR1 (Cl 140), SMF 2 km 100GBASE-DR (Cl 140), SMF 500 m 400GBASE-DR4 (Cl 124), SMF 500 m
Signaling rate, each lane	Host lane: PAM4; 26.5625 GBd ± 100 ppm Media lane: PAM4; 53.125 GBd ± 100 ppm
Transmitter fibers	4
Transmitter wavelengths (range)	1304.5 nm to 1317.5 nm
Receive lane wavelengths (range)	1304.5 nm to 1317.5 nm

400GBASE-LR4-10

- https://apps.juniper.net/hct/model/?component=QDD-400G-LR4-10
  - **50 Gbod * PAM4**
  - Single-mode волокно
  - QSFP-DD / LC коннектор
  - 4 оптические CWDM лямбды
  - **~10 км**

Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	Duplex LC
Monitoring Available	Yes
Digital Optical Monitoring	Yes
Standard: 100G Lambda MSA, 400G-LR4-10, IEEE Std 802.3cu, 400GBASE-LR4-6	
MSA compliance (SFF, for e.g. SFF-8665)	QSFP-DD MSA, QSFP-DD Hardware Specification for QSFP Double Density 8X Pluggable Transceivers, Rev 5.1. Common Management Interface Specification (CMIS), Rev 4.0
Signaling rate, each lane	Host lane: PAM4; 26.5625 GBd ± 100 ppm Media lane: PAM4; 53.125 GBd ± 100 ppm
	1
	1264.5 nm to 1277.5 nm 1284.5 nm to 1297.5 nm 1304.5 nm to 1317.5 nm 1324.5 nm to 1337.5 nm

https://100glambda.com/specifications/send/2-specifications/10-400g-lr4-10-technical-spec-rev1-0

1.1 SCOPE

This Multi-Source Agreement (MSA) defines 4 x 100 Gbps Coarse Wavelength Division Multiplex (CWDM) optical interface for 400 Gbps optical transceivers for Ethernet applications. Forward error correction (FEC) is required to be implemented by the host in order to ensure reliable system operation. Two transceivers communicate over single mode fibers (SMF) of length from 2 meters to at least 10 kilometers (400G-LR4-10). The transceiver electrical interface is not specified by this MSA but can have, for example, eight lanes in each direction with a nominal signaling rate of 53.125 Gbps per lane or four lanes in each direction with a nominal signaling rate of 106.25 Gbps per lane.

Отметим, что MSA не фиксирует электрический интерфейс (!)

100GBASE-LR1 (И СНОВА НОВЫЙ СТАНДАРТ 100G)

- https://apps.juniper.net/hct/model/?component=QSFP-100G-LR
  - **53 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP28 / LC коннектор
  - **~10 км**

Transceiver Type	QSFP28
Product Type	Optical Transceiver
Connector	Duplex LC
Standard: 100G Lambda MSA, 100G-LR IEEE P802.3cu, 100GBASE-LR1	
Supported applications	100G-LR or 100GBASE-LR1 (clause 140), CAUI-4 (no FEC)
Signaling rate, each lane	Host lane: NRZ; 25.78125 GBd ± 100 ppm Media lane: PAM4; 53.125 GBd ± 100 ppm
Transmitter fibers	1
Transmitter wavelengths (range)	1304.5 nm to 1317.5 nm

IEEE Std 802.3cu™-2021

Table 140–6—100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 transmit characteristics

Description	~~Value~~ 100GBASE-DR	100GBASE-FR1	100GBASE-LR1	Unit
Signaling rate (range)		53.125 ± 100 ppm		GBd
Modulation format		PAM4		—
Wavelength (range)		1304.5 to 1317.5		nm
Side-mode suppression ratio (SMSR), (min)		30		dB
Average launch power (max)	4	4	4.8	dBm
Average launch power[a] (min)	–2.9	–3.1	–1.9	dBm
Outer Optical Modulation Amplitude (OMA_{outer}) (max)	4.2	4.2	5	dBm
Outer Optical Modulation Amplitude (OMA_{outer}) (min)[b]	–0.8	—	—	dBm
for TDECQ <1.4 dB	—	–0.1	1.1	dBm
for 1.4 dB ≤ TDECQ ≤ 3.4 dB	—	–1.5 + TDECQ	–0.3 + TDECQ	dBm

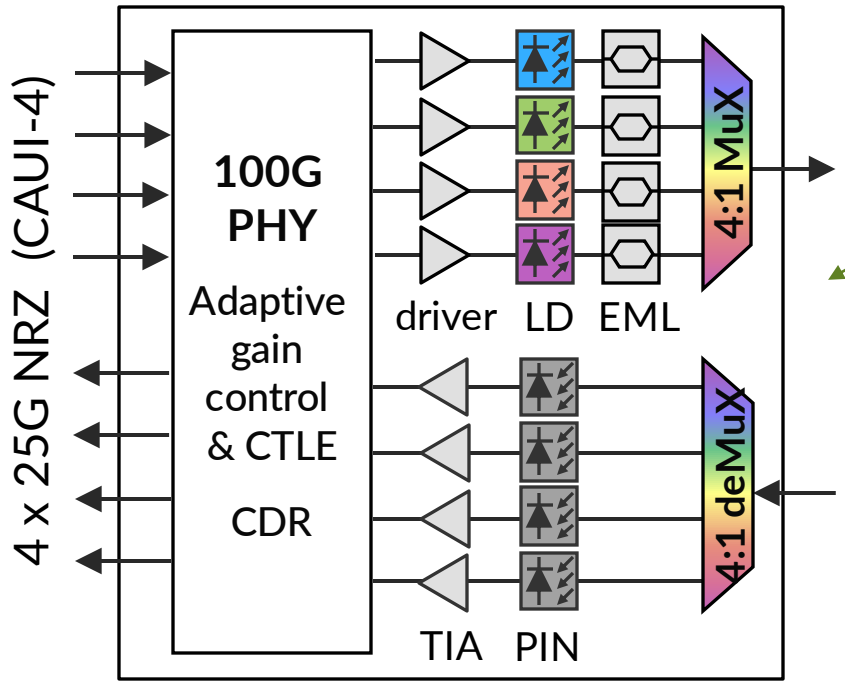
https://100glambda.com/specifications/send/2-specifications/9-100g-fr-and-100g-lr-technical-specs-rev2-0

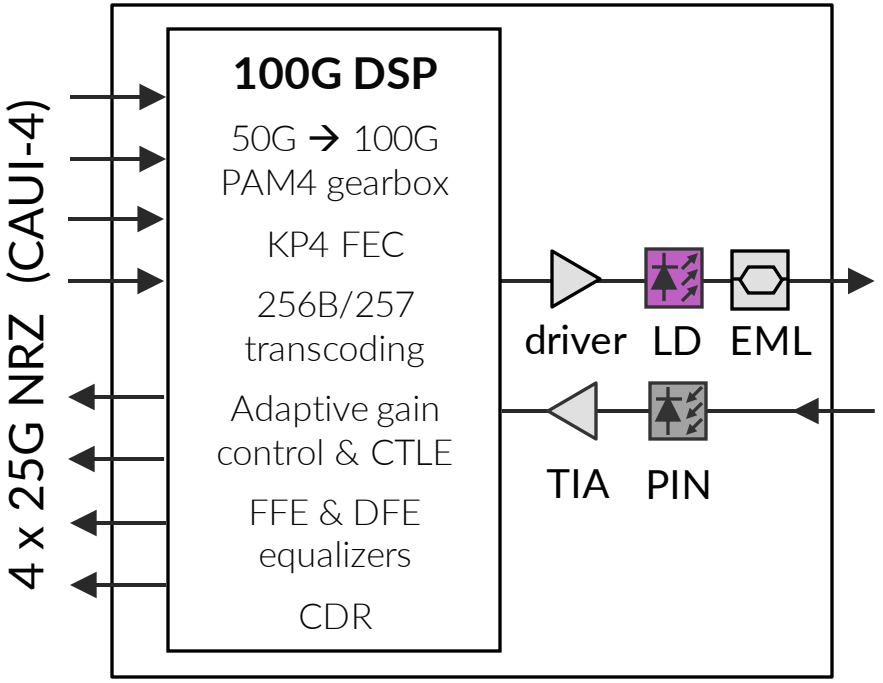
ДВА ПОКОЛЕНИЯ 100G ТРАНСИВЕРОВ

- 1 поколение (4x25G на оптической стороне)
  - 100GBASE-LR4, 100GBASE-SR4, 100GBASE-CWDM4, 100GBASE-PSM4
- 2 поколение (1x100G на оптической стороне)
  - 100GBASE-DR, 100GBASE-FR1, 100GBASE-LR1
- Эти поколения не совместимы друг с другом (!), по очевидной причине

100GBASE-LR4
Сложная оптика (mux/demux)
Мало цифровой обработки

100GBASE-LR1
Простая оптика
Много цифровой обработки
DSP процессор





QDD-4X100G-LR ТРАНСИВЕР

- https://apps.juniper.net/hct/model/?component=QDD-4X100G-LR
  - **53 Gbod * PAM4** (=100 Gbps) на оптической стороне
  - Single-mode волокно
  - QSFP-DD / MPO-12 коннектор
  - **~10 км**
- Брейк-аут
- Совместимость с:
  - 100GBASE-LR1

Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	MPO-12 APC
Standard: 100G Lambda MSA, 100G-LR IEEE P802.3cu, 100GBASE-LR1	
Signaling rate, each lane	Host lane: PAM4; 26.5625 GBd ± 100 ppm Media lane: PAM4; 53.125 GBd ± 100 ppm
Transmitter fibers	4
Transmitter wavelengths (range)	1304.5 nm to 1317.5 nm

400G-ZR (1)

- https://apps.juniper.net/hct/model/?component=QDD-400G-ZR
  - Single-mode волокно
  - QSFP-DD / LC коннектор
  - DWDM сетка частот
  - DP-16QAM (более сложная модуляция)
  - CFEC (более сложный FEC)
  - Спецификация от OIF (Optical Internetworking Forum)

https://www.oiforum.com/wp-content/uploads/OIF-400ZR-01.0_reduced2.pdf

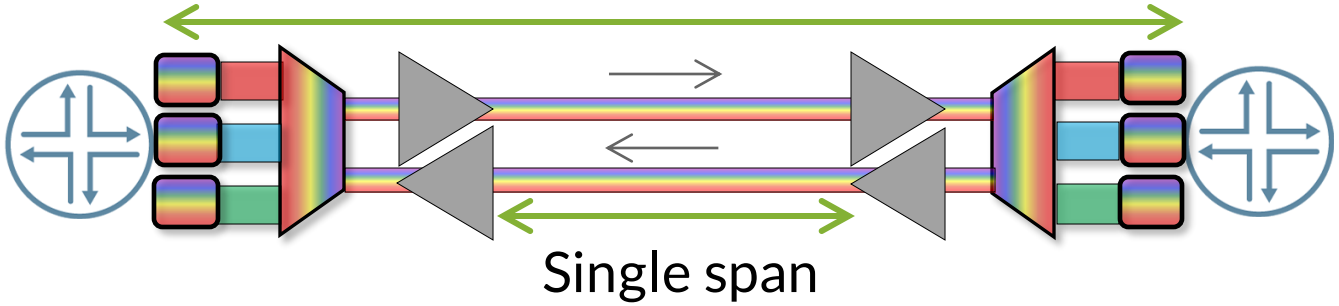
Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	Duplex LC
Additional Information	Thermal Restrictions for PTX10001-36MR/Ardbeg • No restrictions for 400G ZR optics in upper ports • (6) 400G ZR optics can be placed in lower ports wi • Minimum fan speeds for 27C should be set to 72%
Standard: IEEE 802.3-2018	
MSA compliance (SFF, for e.g. SFF-8665)	OIF 400ZR Implementation Agreement (IA)
Signaling rate, each lane	478.750Gbps 59.84375GBd GBd +/- 20 ppm
Modulation format	DP-16QAM
FEC types	Concatenated FEC (CFEC)
Channel plan wavelength range	1567.13 nm through 1528.77 nm
Channel plan frequency range	191.3 THz through 196.1 THz

400GBASE-ZR (2)

- Application Code 0x01
  - через DWDM (с усилением)
  - 48x сетка 100GHz
  - 64x сетка 75GHz
  - **< 120 км**
- Application Code 0x02
  - Темная оптика (без усиления)
  - 1 лямбда (1547.72 нм, 37-ой канал)
  - **< 40 км**

Application Code 0x01

48 or 64 x 400G DWDM over 80 to 120 km



Application Code 0x02

1 x 400G over 40 km

ПРИМЕРЫ 2X100G ТРАНСИВЕРОВ (1): 2X100G-SR4

- QSFP-DD: 8 * 25Gbod * PAM4 = 400 Gbps
- Если переключиться на модуляцию NRZ, мы получим 200 Gbps и возможность организовать 2x 100G интерфейса (!)
- https://apps.juniper.net/hct/model/?component=QDD-2X100G-SR4
  - 25 Gbod * NRZ
  - Multi-mode волокно
  - QSFP-DD
  - MPO-24 (используется 16)
  - **~100 м**

Speed	100 Gigabit Ethernet
Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	MPO-12
Standard: 100GBASE-SR4	
Signaling rate, each lane	25.78125 GBd +/- 100 ppm
Transceiver input/output fibers	16
Transmitter wavelengths (range)	840 nm to 860 nm

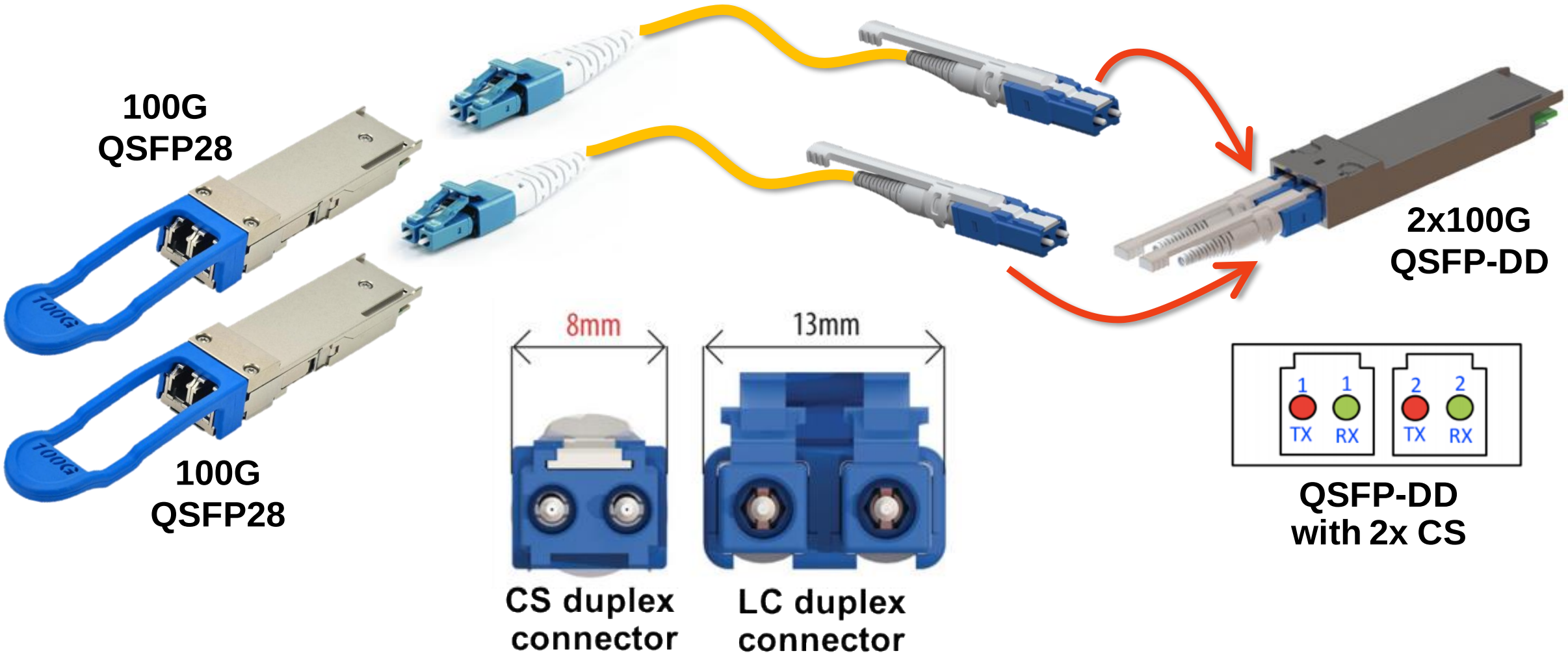
ПРИМЕРЫ 2X100G ТРАНСИВЕРОВ (2): 2X100G-CWDM4

- https://apps.juniper.net/hct/model/?component=QDD-2X100G-CWDM4
  - 25 Gbod * NRZ
  - Single-mode волокно
  - QSFP-DD
  - 4 лямбды
  - CS коннектор
  - **~2 км**

Новый тип коннектора

Speed	100 Gigabit Ethernet
Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	Duplex CS
Standard: 100GBASE-CWDM4	
Signaling rate, each lane	25.78125 GBd +/- 100 ppm
Transceiver input/output fibers	4
Transmitter wavelengths (range)	1264.5 nm to 1277.5 nm 1284.5 nm to 1297.5 nm 1304.5 nm to 1317.5 nm 1324.5 nm to 1337.5 nm

ЧТО ТАКОЕ CS КОННЕКТОР?



ПРИМЕРЫ 2X100G ТРАНСИВЕРОВ (3): 2X100G-LR4

- https://apps.juniper.net/hct/model/?component=QDD-2X100G-LR4
  - 25 Gbod * NRZ
  - Single-mode волокно
  - QSFP-DD
  - 4 лямбды
  - CS коннектор
  - **~10 км**

Speed	100 Gigabit Ethernet
Transceiver Type	QSFP-DD
Product Type	Optical Transceiver
Connector	Duplex CS
Standard: 100GBASE-LR4	
Signaling rate, each lane	25.78125 GBd +/- 100 ppm
Transceiver input/output fibers	4
Transmitter wavelengths (range)	1294.53 nm to 1296.59 nm 1299.02 nm to 1301.09 nm 1303.54 nm to 1305.63 nm 1308.09 nm to 1310.19 nm

ЧТО ПОЧИТАТЬ?


ВОПРОСЫ?
JUNIPER NETWORKS
Engineering
Simplicity

НАШИ КОНТАКТЫ

- Группа FB
  - https://www.facebook.com/groups/Juniper.CIS.SE
- Youtube канал
  - https://www.youtube.com/channel/UCudW8kMjgRE3IIpyzcyS9Iw
- Почта
  - ask-moscow-se@juniper.net