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White Paper

100G beyond 10km
A global study coherent and PAM4 Technology

By Ambroise Thirion

Contents

The common transceivers on the market today are designed to be used in volume and for many access applications, the cost per gigabit and per transceiver unit is key. While the bitrates are today 1Gbits or 10Gbits per line, the jump for 100Gbits is the 25Gbits baud rate (4x 25Gbaud). The technology remains similar, it's a simple modulation called "intensity modulation" (transmitter side) with "direct detection" (receiver side): IM-DD. This technology is also called "on/off keying" (OOK) or "non-return to zero" (NRZ).

This technology has been widely adopted by the market and today used in all networks infrastructures on earth. However, this technology has a main limitation: higher is the bitrate, shorter is the reach.

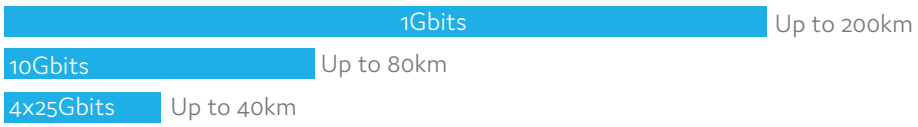


Figure 1 - maximum reach based on bitrates (limitation taken without any amplification, dispersion compensation or any other technology)

This limitation is due by the chromatic dispersion (CD) and the polarization mode dispersion (PMD). It is possible to extend the reach by adding active equipment such as amplifier (EDFA), dispersion compensator (EDC) and forward error correction (FEC).

1. Coherent

The coherent technology has been developed for three decades for copper links (cable television). This technology has been too expensive compared to IM-DD (intensity modulation and direct detection) until the adoption of 100Gbits bitrate. The coherent transmission is a combination of different technologies embed in a single form factor:

- Amplitude and phase modulation

To increase the bandwidth, an advanced amplitude and phase modulation is used, giving the possibility to increase the number of bits per symbol. The modulation is called QPSK.

- Polarization multiplexing

Because light is used for transmission, it is possible to multiplex the signal with two channels by using two polarizations. By combining the QPSK modulation and the polarization multiplexing, the final solution is called PM-QPSK (Polarized-multiplexed + Quadruple phase-shift keying).

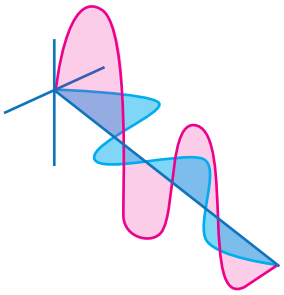


Figure 2: vertical and horizontal polarization

- Coherent detection

The IM-DD technology (regular 1G/10G/25G) is using direct detection with linear or limiting output, proportional to the light intensity.

For Coherent application, a local oscillator (LO) laser is added on the receiver side to extract the two phases channels.

- DSP (Digital Signal Processor) for high-speed analog- to- digital conversion (ADC)

The DSP is an important component of the coherent application as it runs different corrections and optimizations during the optical to electrical conversion:

o Chromatic dispersion compensation
o Polarization mode dispersion compensation
o Intradyne carrier recovery

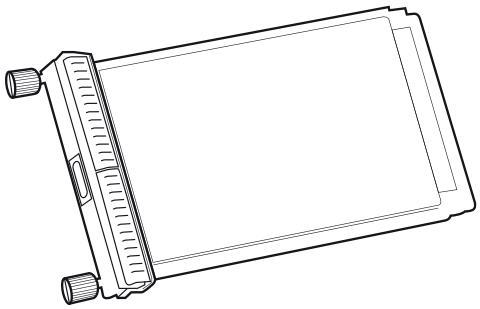
The Coherent technology enables long reach link at high bitrate but requires a pluggable form factor with enough space and enough power. To perform long-haul links, a transport platform is required with short-distance client transceivers (SFP+ 10G, QSFP28) and CFP/CFP2 ports.

The Coherent technology is today available on different pluggable form factors known as CFP and CFP2:

CFP Form Factor

- DCO (Digital Coherent Optics) - DSP included in transceiver

o CFP DCO 100G ZR (up to 80km without amplification)
o CFP DCO 100G DWDM (metro – up to 1200km with amplification).
o CFP DCO 100G DWDM (long-haul – up to 2500km with amplification).



Key information's about Coherent pluggable tranceivers:

- There is no interoperability between DSP from different vendors. A complete optical link must include two Coherent transceivers from the same vendor for CFP-DCO and CFP2-DCO.

Because the DSP is not included in CFP2-ACO, it's the host-board which must be from the same vendor on both sides of the link.

- A CFP-DCO and CFP2-DCO can be plugged in any CFP/CFP2 ports if these are MSA compliant and support CAUI for 100Gbits interface

The CFP2-ACO can only be plugged in a dedicated CFP2 Coherent port as the DSP is on the host-board.

- The CFP is only DCO because it has enough space and power to include the DSP. On CFP2 form factor, an ACO version was initially released by moving the DSP on the host-board as it was too challenging to include it in the form factor.

A CFP2 DCO version has been released in 2017 as technology has been mature enough to include the DSP into a CFP2 form factor.

- The Coherent pluggable transceivers are only available in CFP and CFP2 form factors. There is no availability in CFP4 and QSFP28 form factors because there is not enough power supplied to the components, neither enough space.

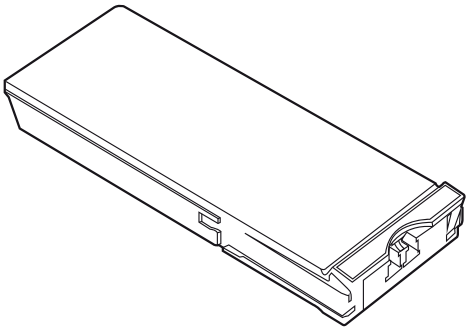
CFP2 Form Factor

- DCO (Digital Coherent Optics) - DSP included in transceiver

o CFP2 DCO 100G (up to 300km without amplification)
o CFP2 DCO 100G DWDM (up to 800km with amplification).
o CFP2 DCO 100G DWDM (up to 2500km with amplification).

- ACO (Analog Coherent Optics) – DSP not included in transceiver but on host-board

o CFP2 ACO 100G DWDM (reach depends of EDC embed in host-board)

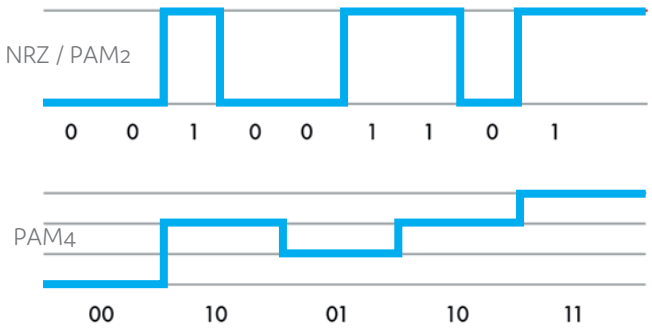


2. PAM4

The IM-DD technology is based on NRZ encoding with 1 bit per symbol. This technology is today largely used but has some limitations and increasing the output bitrates start to be challenging on fibre mainly due to dispersion (chromatic and polarization).

The Coherent technology has adopted more advances modulations such as QPSK, 8QAM or 16QAM enabling to double, triple or quadruple the bitrates. However, this modulation requires an advanced technology which is coherent detection on receiver side and a DSP to correct the dispersion. While the cost per bit remains interesting, the components costs are high, and the pluggable modules require space and enough power; therefore, they are only available on CFP and CFP2 pluggable form factors.

The PAM4 modulation uses multiple levels of pulse-amplitude enabling to carrying 2 bits per symbols, doubling the bitrate:

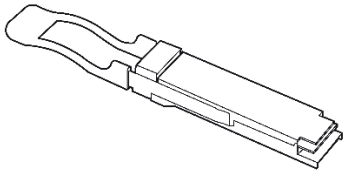


The main advantage of PAM4 is the easiness to use regular electronics and optical components suitable for small form factor such as QSFP28 from factor. The power consumption is drastically reduced and can be used for data centres interconnect application.

The main disadvantage is that PAM4 requires amplification and dispersion compensation system on the optical link for reach longer than 5km at 100Gbits.

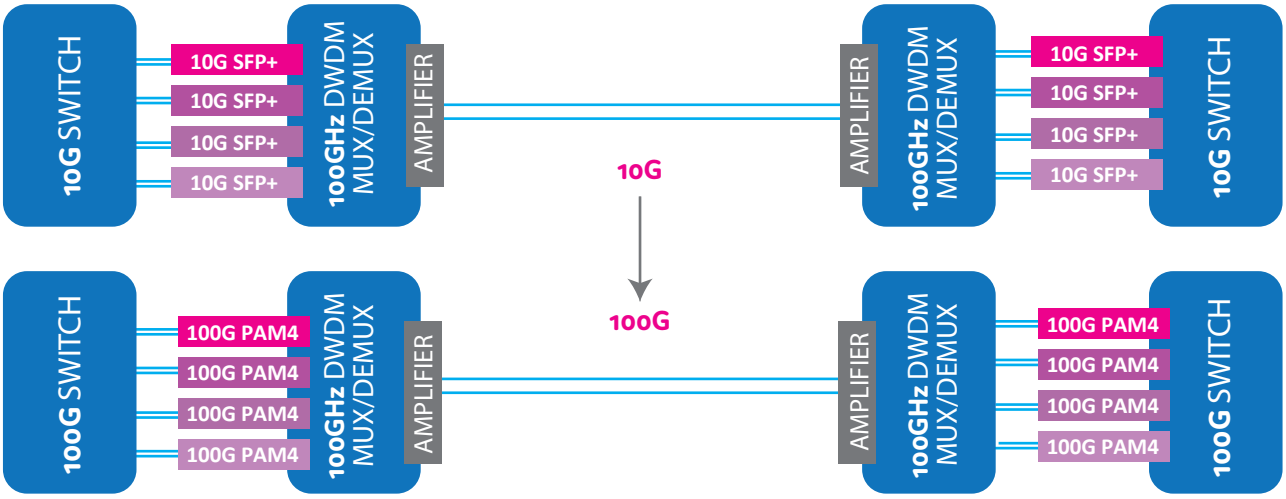
The PAM4 technology is today available on QSFP28 pluggable form factors:

QSFP28 Form Factor



QSFP28 PAM4 80km DWDM 100Ghz "Super Channel" 4.5W (require amplifier).

The QSFP28 PAM4 80km DWDM 100GHz "super-channel" is a combination of two 50GHz carriers also called "dual-carrier". While it is using 2x 50GHz DWDM wavelengths, the main advantage is the compatibility with 100Ghz DWDM single channel enabling direct upgrade from 10G DWDM 100Ghz to 100G DWDM 100GHz:

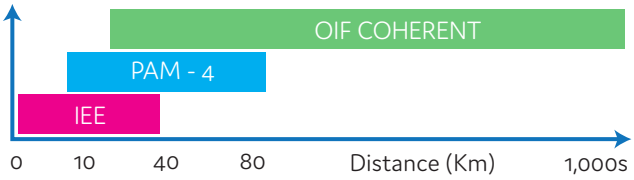


3. Coherent vs PAM4

Figure 3 - 10G to 100G DWDM upgrade (100G PAM4 is on QSFP28 form factor and requires amplification)

	IM-DD (NRZ)	Coherent	PAM4
Components cost	Low	High	Low
Power consumption	Low	High	Low
Density on equipment	High	Low	High
Packaging	CFP/CFP2/CFP4/QSFP28	CFP/CFP2	QSFP28
Laser packaging	External / COB / Silicon	ASIC (including DSP)	Silicon Photonics
DWDM channel space	4x100Ghz (400Ghz)	1x50GHz (50GHz)	2x50Ghz (100Ghz)
Compatibility with 100GHz mux/demux	Yes, 4x channels	Yes, 1x channel	Yes, 1x channel
Compatibility with 50GHz mux/demux	No	Yes, 1x channel	No
Possibility tupgrade from 10Gbps DWDM	No	Yes	Yes
Transmission over long distance	No	Yes - 80km without amplification - >80km with amplification	Yes - 80km with amplification
Transponder platform	Not required	Required	Optional
Application	Intra DC	Metro / Long haul	Inter DC / Metro

In today's market, it is possible to obtain 100G optical transceivers with either PAM-4 or Coherent modulation – the figure below shows the reach available with each type:



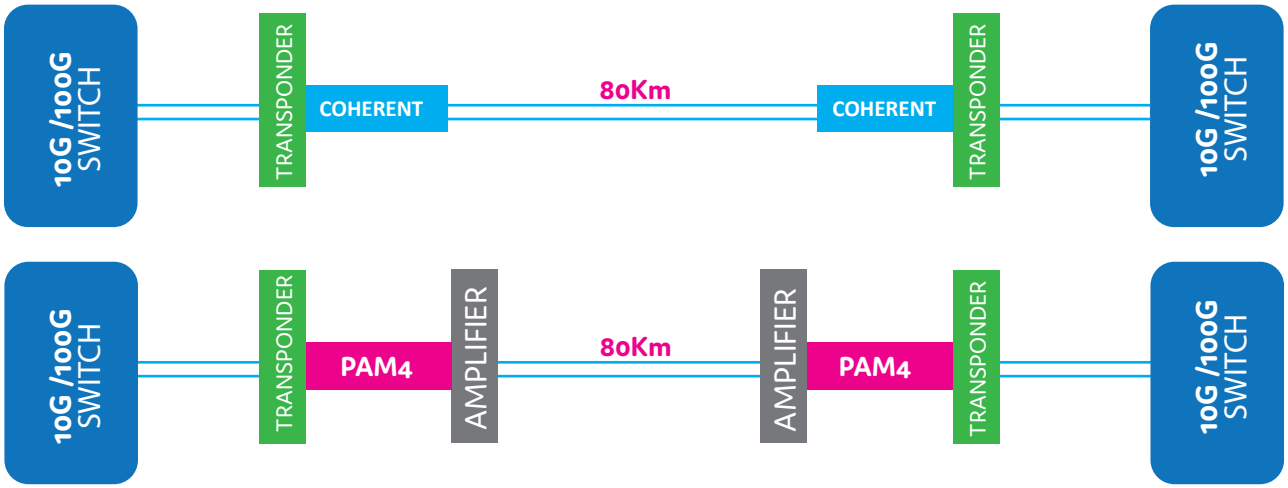
Source: 2016 ACG Research

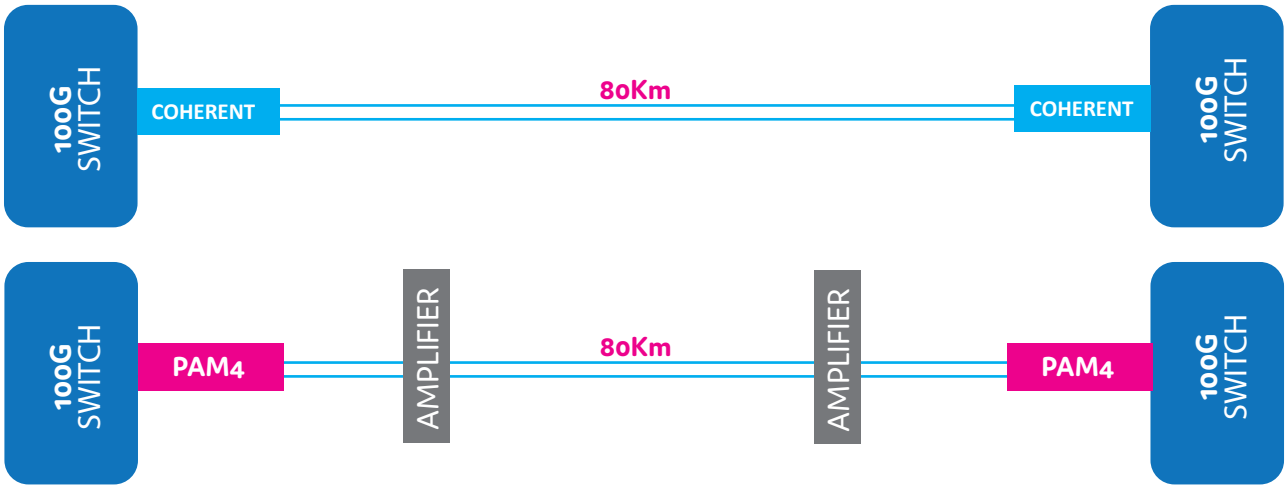
The PAM-4 solution covers a portion of the optical reach needed to interconnect data centers. Below 10km, IEEE 802.3ba 100G pluggable optics are readily available with 100GBASE-LR4 supporting 10km reach in a QSFP28 package. The 100GBASE-ER4 specification for 40km reach has been more challenging for optics suppliers to deliver and remains either in larger packages (example, CFP/CFP2 with SOA or QSFP28 with FEC on host board) or in nonstandard formats, meaning non-interoperable across vendors. So where does the PAM-4 technology fit? In general, its initial fit appears to be in the <40km range as an alternative to existing, pluggable solutions. The solution also plays in the 40–80km range as an alternative to optical DCI/coherent DWDM solutions for some deployment scenarios.

Based solely upon reach, a logical question is how much of the optical DCI/coherent DWDM market is covered by 40–80km? ACG Research recently completed a worldwide survey of data center service providers, including network service providers, cloud service providers, Internet content providers and Internet eXchange providers. One of the questions asked of the service providers was the proportion of optical reach needed to cover their data center interconnections today and in 2019. What was found is that service providers on average believe that 30–80km optical reach is needed for approximately 30% of their data center interconnections.

For 80 km application, different are scenarios are feasible, both with Coherent and PAM4:

With demarcation line

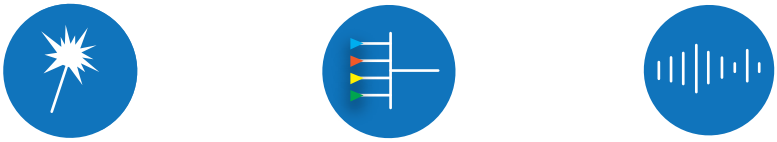




200Gbits and 400Gbits is a straightforward path thanks to Coherent and PAM4 technologies. The 100G is already a combination of 4x25Gbits (IM-DD) with direct detection. To keep a 25/28G baud rate, extra modulations are required combined with other components such as DSP.

Next step is to move with a laser and DSP running at 50/56Gbaud but this technology is not available in volume yet.

1. IM-DD Technology
IM-DD 100Gbits (regular 100G transceivers, max 25km without FEC, 40km with FEC).



25Gbaud laser | 4x DWDM Multiplexing | 100 Gbits bitrate

2. Coherent technology
Coherent 100G DP-QSPK

28Gbaud laser + DSP | x2 QPSK Modulation | x2 Polarization multiplexing | 100 Gbits bitrate

Coherent 200G 16QAM

28Gbaud laser + DSP | x4 16QAM Modulation | x2 Polarization multiplexing | 200 Gbits bitrate

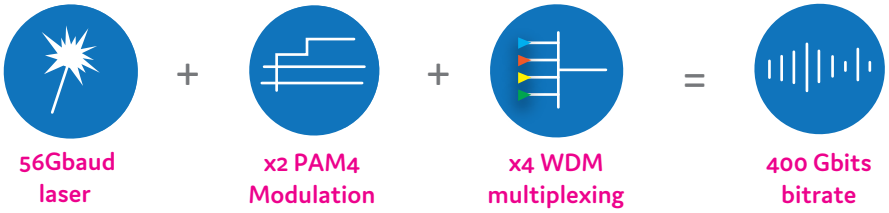
3. PAM4 Technology

PAM4 100G (28Gbaud)

PAM4 200G (28Gbaud)

PAM4 400G (28Gbaud)

PAM4 400G (56Gbaud)



4. Form factors

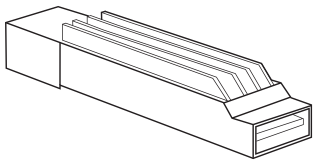
To support these new technologies, a bunch of new form factors are coming on the market*. Some will be popular while some will remain for a niche market.

The QSFP-DD, QSFP-56 and OSFP might be popular with PAM4 technology, while CFP8 might be a good candidate for the Coherent application*.

µQSFP

µQSFP

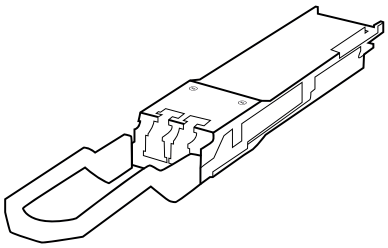
Bitrate:	40G, 100G and 200G
Electrical:	4x25G (NRZ) / 4x50G (PAM4)
Optical:	4x25G (NRZ) / 4x50G (PAM4)
Power diss.:	up to 3.5W
Mgmt proto.:	I2C
Size:	narrow than QSFP, same length as QSFP



QSFP-56

QSFP-56

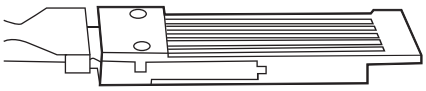
Bitrate:	200G
Electrical:	4x50G (PAM4)
Optical:	4x50G (PAM4)
Power diss.:	up to 3.5W
Mgmt proto.:	I2C
Size:	Same size and shape as QSFP+ and QSFP28



QSFP-DD

QSFP-DD – QSFP Double Density

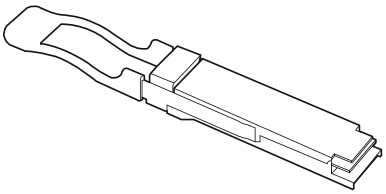
Bitrate:	200G and 400G
Electrical:	8x25G (NRZ) / 8x50G (PAM4)
Optical:	8x25G (NRZ) / 8x50G (PAM4)
Power diss.:	up to 12W
Mgmt proto.:	I2C
Size:	slightly larger than a QSFP+ and QSFP28



OSFP

OSFP – Octal Small Format Pluggable

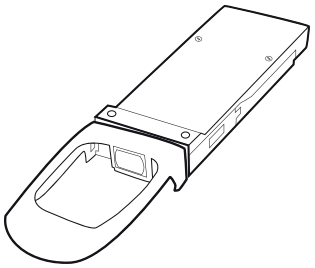
Bitrate:	400G
Electrical:	8x50Gbps (25Gbaud PAM4)
Optical:	8x50Gbps (25Gbaud PAM4)
Power diss.:	7.5W to 15W
Mgmt proto.:	I2C
Size:	slightly larger than a QSFP+ and QSFP28



CFP 8

CFP8

Bitrate:	400G
Electrical:	16x25G (NRZ) / 8x50G (PAM4)
Optical:	16x25G (NRZ) / 8x50G (PAM4) / 4x100G (PAM4)
Power diss.:	4W to 24W
Mgmt proto.:	MDIO
Size:	similar size to a CFP2



***Unavailable in the current market. This is a guide only**

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