

# 40 Gbit/s Small-Form Low-Power Optical Transceiver

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The authors have successfully developed an optical transceiver that complies with Quad Small Form-Factor Pluggable Plus (QSFP+) standard. The optical interface conforms to the 40GBASE-LR4 for 40 gigabit Ethernet over up to 10 km single mode fibers using 1.3  $\mu\text{m}$ -range coarse wavelength division multiplexing (CWDM). The transceiver is designed for high-density application in data center networks, where low power consumption and superior electromagnetic interference (EMI) performance are required. We have achieved less than 2.5 W total power consumption by utilizing the quadrupled shunt-driving technique and very low emission levels. This paper presents the outline of the development and evaluation results.

Keywords: QSFP+, 40GBASE-LR4, CWDM, EMI

## 1. Introduction

Global IP traffic has been increasing at an explosive rate. In recent years, the growth is largely driven by the widespread use of high performance mobile terminals such as smartphones or tablets, as well as newly emerging cloud services. To accommodate these new trends, the importance of data centers has reached an unprecedented level in today's modern infrastructure. Inside data centers, while the networks have traditionally focused on North-South data traffic, East-West traffic has drastically increased with the server virtualization being widely deployed. This has motivated network equipment developers to adopt higher speed optical interfaces to mitigate bandwidth bottleneck. In response, the Institute of Electrical and Electronic Engineers (IEEE) started 40/100 Gigabit Ethernet standards in 2007 and ratified them in June 2010. 40 Gigabit Ethernet is intended for use in data center networks and defined as two optical interfaces: 40GBASE-SR4 for up to 100 meter over multi-mode fibers, and 40GBASE-LR4 for up to 10,000 meters over single-mode fibers.

With increased energy costs and pressure to reduce carbon emissions, low power equipment is imperative in data center networks. The merit of low power optical transceivers is two-fold. First, they reduce operational electricity costs. Second, they can be fit into smaller-sized packages and enable a greater number of optical ports per system, which drives size reduction in networking equipment and improves operational costs associated with colocation space.

This paper outlines the development of a low power optical transceiver that conforms to 40GBASE-LR4 specifications.

## 2. Multi-source Agreement

An optical transceiver sits in networking equipment and converts incoming electrical data streams into optical

signals and vice-versa. The physical form factor, electrical interface, and control/monitor management functions are specified and made public by multi-source agreement (MSA). For 40 Gbit/s, Centum gigabit Form Factor Pluggable (CFP) MSA was defined in 2009, followed by Quad Small Form-Factor Pluggable Plus (QSFP+) MSA. **Table 1** shows the specification difference and **Photo 1** shows a picture of these transceivers.

In many cases, an optical transceiver MSA is optimized for certain applications or markets. CFP is designed for telecom applications and therefore provides a wide range of monitoring and diagnostic functionalities. By integrating the clock and data recovery circuit on both the transmit and receive data paths, it provides superior signal integrity. The flip side is that the transceiver size is relatively large and not very suitable for high-density data center networks. In contrary, the QSFP+ transceiver discussed in this paper has the smallest form factor among 40 Gbit/s MSAs, with lower power consumption, while the diagnostics functions are not as rich as CFP.

**Table 1.** QSFP+ and CFP specifications

MSA		QSFP+	CFP
Size	Length	72.4 mm	144.75 mm
	Width	19.0 mm	82.0 mm
	Height	13.5 mm	14.0 mm
Pin counts		38	148
Optical connectors		LC (SMF) MPO (MMF)	LC or SC (SMF) MPO (MMF)
Power dissipation class		1: 1.5 W 2: 2.0 W 3: 2.5 W 4: 3.5 W	1: 8 W 2: 16 W 3: 24 W 4: 32 W
Max. port count per card		44	8 (Class 1)

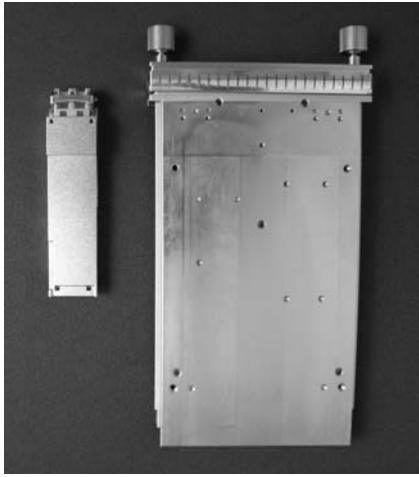


Photo 1. QSFP+ (left) and CFP (right)

### 3. QSFP+ Transceiver Design and Specifications

Figure 1 shows a block diagram of our QSFP+ transceiver. The transmitter block is made of four laser driving circuits and a transmit optical sub-assembly (TOSA). The TOSA consists of four laser diodes, four shunt-drivers, and an optical multiplexer to combine four optical wavelengths into an output port in a hermetic package. Similarly, a receive optical sub-assembly (ROSA) integrates four photo diodes, a quad trans-impedance amplifier, and an optical de-multiplexer. A controller circuit is also prepared to communicate control and monitoring signals with the host systems. All electrical and optical components are contained in a metal housing to suppress electromagnetic interference (EMI).

Miniaturized wavelength division multiplexing TOSA and ROSA are one of the biggest challenges in QSFP+ de-

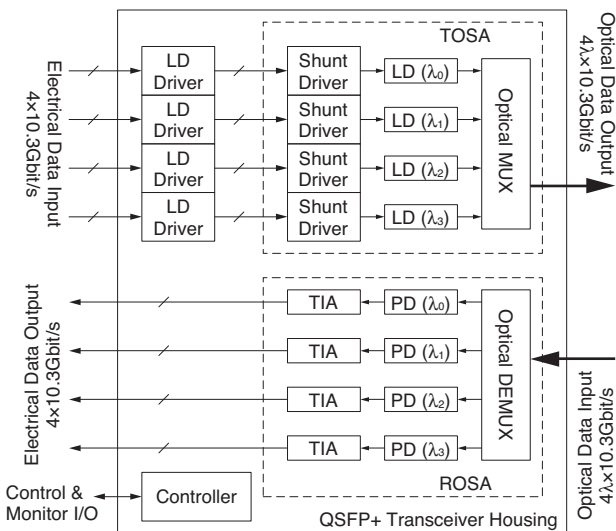


Fig. 1. QSFP+ block diagram

velopment. Taking TOSA as an example, traditionally it was achieved using four individually packaged laser diode modules and a separate optical multiplexing unit. Optical fiber was used to connect these devices together. Since this method requires optical fiber management space, it cannot fit inside the QSFP+ transceiver.

Shunt-driving is a key enabler for reducing overall power consumption. Figure 2 shows the conceptual block diagram of shunt-driving. Switching the FET on and off modulates the current flows through the laser diode and converts electrical signals into optical signals. The shunt driving technique was first introduced in the 10 Gbit/s SFP+ transceiver design. In QSFP+ development, the design was enhanced and quadrupled for 40 Gbit/s capability.

Table 2 provides QSFP+ target specifications. The optical interface in both the transmitter and receiver is to be compliant with the 40GBASE-LR4 standard. Total power

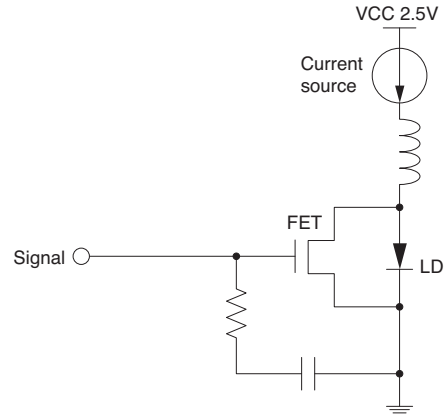


Fig. 2. Shunt-driving block diagram

Table 2. QSFP+ specifications

Parameters	Min	Max	Unit	
Temperature	0	70	°C	
Supply voltage	3.135	3.465	V	
Power consumption	-	2.5	W	
Signaling rate	10.3125		Gbit/s	
Optical transmitter				
Center wavelength	$\lambda_0$	1264.5	1277.5	nm
	$\lambda_1$	1284.5	1297.5	
	$\lambda_2$	1304.5	1317.5	
	$\lambda_3$	1324.5	1337.5	
Optical power in OMA	-4.0	+3.5	dBm	
Extinction ratio	3.5	-	dB	
Eye mask	IEEE 802.3 compliant			
Optical receiver				
Receive sensitivity in OMA	-	-11.5	dBm	
Overload	3.5	-	dBm	

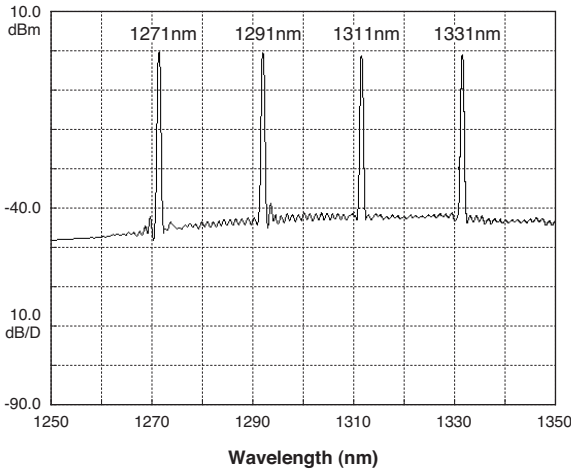
consumption can be as high as 3.5 W (class 4) according to QSFP+ MSA specifications, but our goal is 2.5 W (class 3), which enables increased port density and thus is more suitable for data center networks.

#### 4. Characteristics

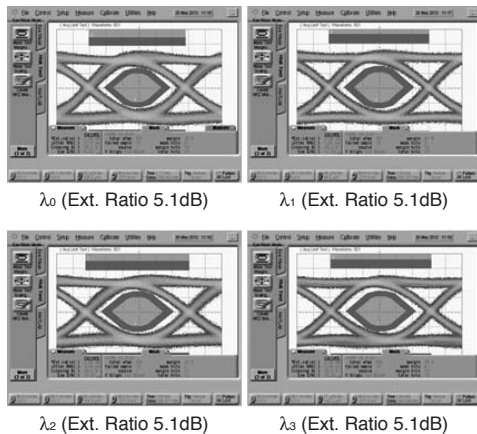
In this section, QSFP+ transceiver characteristics are presented.

##### 4-1 Transmitter characteristics

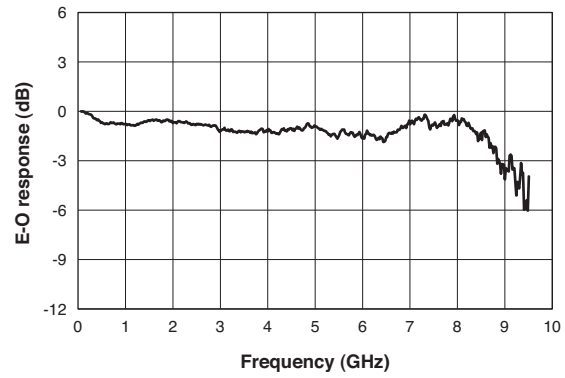
**Figure 3** shows optical spectrum characteristics. The 40GBASE-LR4 uses four wavelengths, namely 1271, 1291, 1311 and 1331 nm. The wavelength of each channel is nearly centered in its wavelength window. Laser diodes are uncooled and therefore the wavelength shifts as the temperature changes. Even after taking that into consideration, the optical spectrum performance meets specifications across 0 to 70°C operating temperature.



**Fig. 3.** Optical spectrum (at 25°C)



**Fig. 4.** Optical waveforms



**Fig. 5.** Transmitter bandwidth

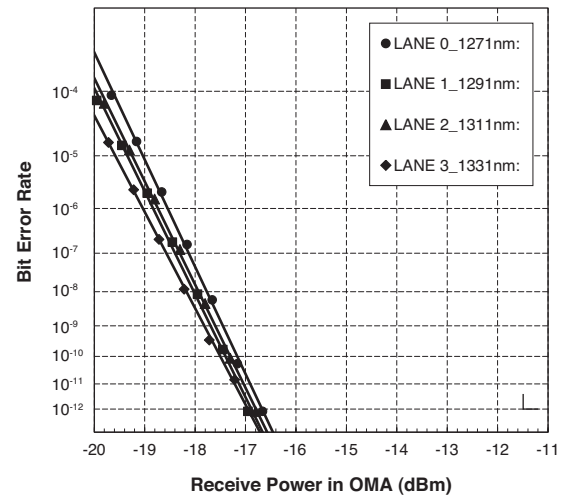
As shown in **Fig. 4**, optical waveforms of all four channels provide good eye opening. The optical eye mask margin is measured at approximately 40% on all channels. As shown in **Fig. 5**, the optical transmitter’s 3 dB-bandwidth is around 9 GHz and sufficient for 10 Gbit/s operation. The extinction ratio is set at 5 dB and provides good margin to the 40GBASE-LR4 requirement of min 3.5 dB.

##### 4-2 Receiver characteristics

**Figure 6** shows bit error rate performance at various optical input power levels to the QSFP+ receiver. The minimum receive sensitivity that corresponds to the  $10^{-12}$  error rate is -16.5 dBm on all channels, which allows for a 5 dB margin to the 40GBASE-LR4 requirement. **Figure 7** shows an electrical 10 Gbit/s output waveform. It provides 30% mask margin.

##### 4-3 Power consumption

**Figure 8** shows the total power consumption over 0 to 70°C. As the temperature rises, the power consumption increases due to increased laser current necessary to maintain optical output power. Even at worst operating conditions (70°C), it still satisfies the class 3 (less than 2.5 W) requirement for QSFP+ MSA with sufficient margin.



**Fig. 6.** Bit error rate

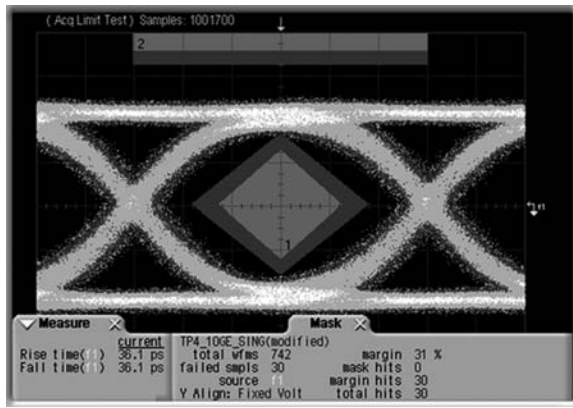


Fig. 7. Electrical waveform

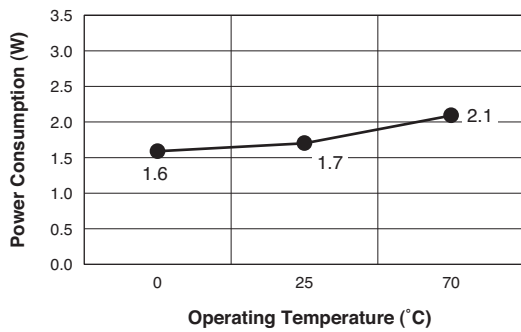


Fig. 8. Power Consumption

#### 4-4 Electro magnetic interference

Figure 9 shows the EMI characteristics. There is no distinguishable emission peak observed in the frequency range from 1 to 26.5 GHz. From the standpoint of signaling bit rate, the most critical frequencies are 2<sup>nd</sup> and 4<sup>th</sup> order harmonic, 10.3125 GHz and 20.625 GHz respectively. Even at these critical frequencies, the emission peak amplitude is very low and is actually buried in the noise floor. This indicates that the newly developed QSFP+ transceiver mechanical housing has a good EMI suppression capability. Shunt driving also helps to suppress emission peaks as it allows the use of a TOSA with 50 ohm input impedance. In the case of using the conventional laser diode driving method, because laser impedance is low, typically 5 to 10 ohm, it is difficult to have good impedance matching with driving circuitry that is normally designed for 25 ohm. Non-optimized impedance matching leads to poor optical waveforms and higher peak emission levels. The networking equipment used in data centers is normally equipped with very high port counts and EMI often becomes a serious issue. The QSFP+ transceiver we have developed is suitable for data center applications, owing to its superior EMI performance.

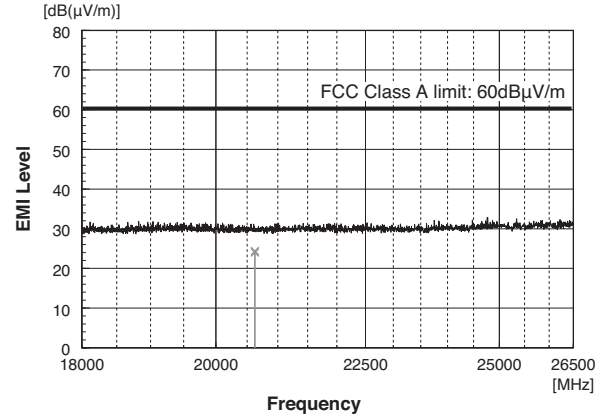
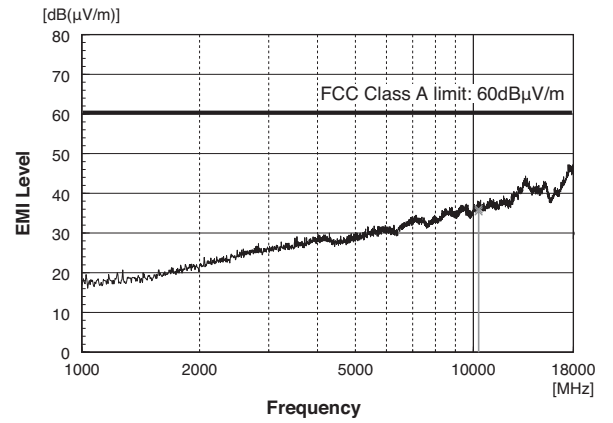


Fig. 9. Electromagnetic interference (top) 1 - 18 GHz, (bottom) 18 - 26.5 GHz

#### 5. Conclusion

We have successfully developed a low power optical transceiver that is compliant with 40 gigabit Ethernet optical interface 40GBASE-LR4 and QSFP+ MSA in electrical and mechanical specifications. The newly developed miniaturized TOSA and ROSA enable drastic size reduction. By utilizing shunt driving, total power consumption of less than 2.5 W at 70°C is achieved. The transceiver housing shows superior shielding capability. We believe that this low power 40 Gbit/s QSFP+ transceiver will contribute to energy efficient data centers.

#### Technical Terms

- \*1 CWDM: Coarse Wavelength Division Multiplexing is a technique for cost-efficiently transporting large amounts of data traffic. CWDM is different from DWDM in that the wavelength spacing is much greater, typically 20 nm.
- \*2 Signal Integrity: The quality of digital signals transmitted over printed circuit boards or electrical cables.

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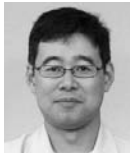
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