

# 100 G Pluggable Optics Drive Testing in New Directions

By Dr. Paul Brooks

With 100 G products now becoming a reality, client interfaces based on c-class form-factor pluggable (CFP) optics are appearing on routers, switches, and transport equipment. Although the technology is maturing, the complexity and performance of pluggable optics remains challenging and is compounded by the relative short supply and high cost of the CFPs.

Traditionally, Ethernet optics have been reliable components, but the increased technical complexity of 100 G optics requires testing and screening them both during the vendor selection and production.

This white paper introduces CFP optics and highlights the tests and measurements required to validate them.

The equipment described in this white paper is currently available from Viavi Solutions. For further details, please visit our website ([www.viavisolutions.com](http://www.viavisolutions.com)), or contact any of our local sales team.

## Transponder Overview

The main transponders used for 40 and 100 Gigabit Ethernet (GE) are listed in the table, and other vendors also may offer transponders as CFPs. Viavi does not endorse or provide support for any particular vendor.

The IEEE 802.3ba defines a system based on four wavelengths for long reach (LR4) at 40 G and 100 G, while NeoPhotonics® offers a 10-lambda-based optic that is not photonically compatible with the LR4 standard but does comply with the CFP Multisource Agreement (MSA).

Note that the nominal cost is only a rough indication of the relative magnitude of costs for the optics and can be subject to change when optics meet maturity and enter mass deployment.

Type	Notes	Reach	Wavelength	Nominal Cost (prices for magnitude comparison)
<b>100 G</b>				
10 x 10 G (SR10)	Uses parallel optics (both CFP and CXP form factor)	~100 m	850 nm x 10	N/10
10 x 10 G	Non-standard NeoPhotonics	10 km+	1550 nm – 10	N
4x25 G (LR4)	IEEE standard, requires a gearbox	10 km	1310 nm – 4	3N
4x25 G (ER4)	IEEE standard, requires a gearbox	40 km	1310 nm – 4	6N
<b>40 G</b>				
4 x 10 G (LR4)	No gearbox required	10 km	1310 nm – 4	N/8
40 G serial (FR)	Requires a SERDES, must be compatible with 40 G 300-pin MSA-based optics	2 km	1550 nm – 1	N/2
40 G (SR4)	CFP and QSFP+ form factor	~100 m	850 nm x 4	N/20

Short reach optics (SR) use multimode fibers and virtual cavity surface-emitting laser (VCSEL) arrays to transmit the 40/100 G signal over parallel fibers. Although the cost of SR optics is much lower (typically <1/10) than the cost of LR optics, concerns exist about parallel optical ribbon cables, such as cost, new infrastructure, inspection, and cleaning of connectors.

The 40 G serial (FR) case is focused on compatibility with legacy 40 G serial 300-pin MSAs (typically used in SONET/SDH deployments). Many large operators like the concept of a universal 40 G port that can support multiple technologies (legacy SONET/SDH/OTN and 40 GE). They have already deployed 40 G based on the 300-pin (fixed optics based on an electrical 17 x 2.5 G interface = 16 + 1 deskew lane). The 40 G serial is still not considered a mainstream, cost-effective technology (despite its introduction in 2000). The upper limit for practical serial transmission (based on integrated circuit [IC] technology and laser physics) is around 28 G. The 40 G serial optics will likely be deployed only in cases where operators have already deployed 40 G serial, as the price of the serial optics will likely remain approximately three times higher than the 40 G parallel.

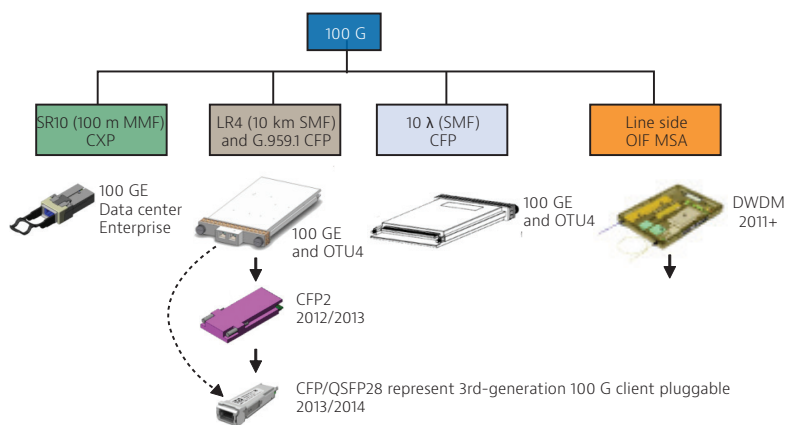


Figure 1. 100 G optics family tree

As you can see, the plan is to migrate away from the CFP form factor. The 100 G technology will take longer as challenges remain over the 25/28 G electrical interface and photonic integration required to support a smaller form factor at that rate. The CXP form factor is already establishing itself as a strong contender in the enterprise space because of its low cost and compact form factor.

Figure 2 shows the internal functions of a 100 G LR4 transponder.

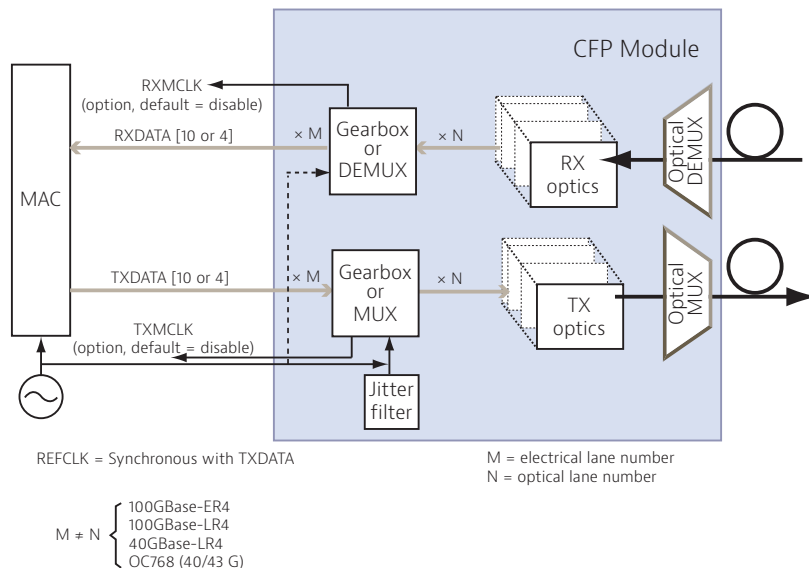


Figure 2. Internal function of a 100 G LR4 transponder

The gearbox IC is a chipset that converts 10 x 10 G electrical lanes into 4 x 25 G lanes and vice-versa for the receiver side. The laser (Tx) optics requires four lasers, each with 5 nm spacing with corresponding modulating and thermal management circuitry.

An optical mux brings together the four separate transmit lambdas onto one single-mode fiber. On the receive side, an optical demux splits the incoming signal into four separate lambdas, which in turn are received by a photodiode and amplifier assembly. A clock data recovery (CDR) will be used on one of the receive channels to provide a recovered clock for the demux gearbox. A 40 GE parallel CFP does not need a gearbox, because it provides a 1:1 correspondence between electrical and optical lanes.

The host (electrical) interface is based on either 10 (100 G) or 4 (40 G) electrical lanes running at ~10.3125 Gbps for Ethernet applications (slightly higher for OTU3/4 rates) and a clock (reference clock, or refclk). Unlike legacy interfaces such as SFI 5.1 that rely on a separate deskew lane, the 40 GE and 100 GE encoding uses embedded deskew information, which has been (re)used for OTU3/4 with the concept of OTL virtual lane rotation, and 40 G SONET can use STL256.4 for backwards compatibility with STM256 serial 40 G.

Module command and control uses a high-speed serial management data input/output (MDIO) bus, which allows monitoring and control of many internal functions such as optical power, temperature, and vendor identification (ID).

The integration of so many complex, high-speed photonics and electronics inside a CFP module remains challenging as do thermal management, stability, performance, and manufacturability.

The gearbox IC requires special attenuation due to the electrical performance of the high-speed interfaces which are extremely demanding, especially the parallel host interface. Managing 10 parallel 10 G electrical signals for individual and relative timing presents significant issues in module integration such as crosstalk, relative dynamic skew, jitter, and eye closure. Note that the top surface is designed to provide good thermal contact with the riding heatsink.

Figure 4 illustrates a comprehensive CFP test system based on the Optical Network Transport (ONT) and Multiple Application Platform (MAP) product lines.

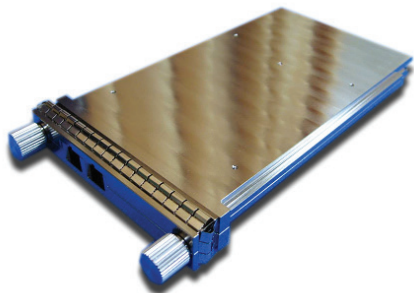


Figure 3. A 100 G CFP module



Figure 4. Comprehensive CFP test system

The top center of the figure shows an ONT 100G system running full rate 100 G Ethernet traffic while simultaneously adding physical layer stresses, such as dynamic skew. The second shelf shows a MAP platform performing the lambda demux/mux function to enable monitoring or attenuating of individual wavelengths (scope on right shows individual 25 G eye). A T-BERD<sup>®</sup>/MTS-8000 shows the complete optical spectrum. Figure 5 shows the electrical interface side.



Figure 5. CFP LR4 module inserted in ONT tester

The high-speed electrical interface uses parallel 10 G lanes (either 4 or 10), each running as a differential signal (receive [Rx] and transmit [Tx]). Various clock signals are also running at subrates of the data lines (typically 1/16 lane speed or approximately 644 MHz) as well as control pins (dedicated and MDIO) and power.

The bulk of the test validation should focus on the functionality and signal integrity of the high-speed parallel data bus, but it is also important to validate the control pin functionality, especially the MDIO bus.

## Unframed PRBS and Digital Word

An unframed pseudorandom bit sequence (PRBS) and digital word provides the basis of first-pass testing for hardware, especially transponders. Normally a basic 10 x 10 G PRBS/digital word can be used to validate continuity but a 10 G per lane pattern is not transparent to a 10:4 gearbox. The mux/demux process can scramble the bit order leading to an invalid pattern. Therefore, one should have a gearbox-transparent (10 x [2 x 5 G]) pattern generator that is 20 logical lanes each with a 5 G PRBS (or digital word) bit-sequence muxed onto 10 physical lanes. However, the 40 G (4 x 10 G) does not require this.

The test should start with a short PRBS (2<sup>7</sup>-1) and move to a longer pattern if everything runs well. The ONT test set reports both errored zeros and errored ones as well as the conventional error count. This capability is useful for determining error bias, which can be an indication with some photonic automatic gain control (AGC) circuits. Longer patterns and digital words can also be used to stress clock recovery and direct current (DC) balance aspects of the circuitry. The ONT also allows for offsetting the PRBS patterns (per lane) to remove any bit-wise correlation between lanes that could mask any potential crosstalk issues.

Lambda mapping is another unique and powerful tool that the ONT provides that allows mapping of individual 5 G PRBS to the 25 G lambda that carries it (via the gearbox). This mapping is random at start up and can change on the Rx or Tx upon loss of clock signal; therefore, users cannot predetermine it. However, the ONT has a patented algorithm that can determine it, allowing the end user to determine if errors are correlated with a 10 G lane (electrical issue) or a 25 G lambda (photonic issue). See Figure 6 for a screen illustrating the lambda mapping BERT screen.

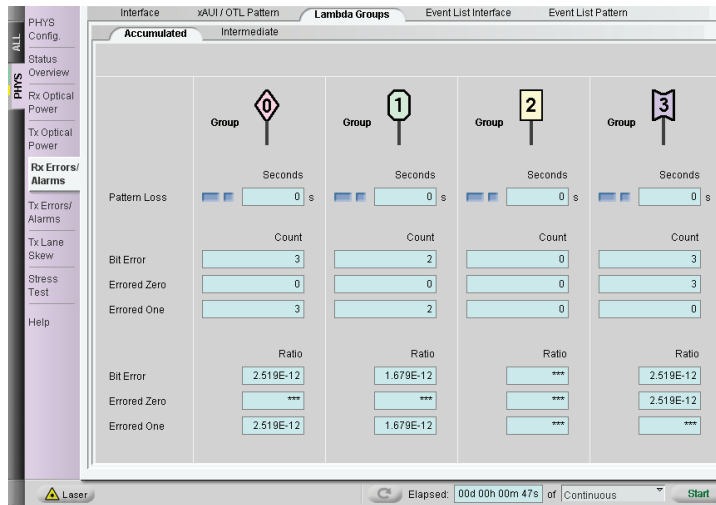


Figure 6. The lambda groups mapping BERT screen

## Voltage Swing and Pre-Emphasis Margin

Control over the voltage swing can allow margin testing on the electrical interface as well as the use of the ONT electrical CFP adapter to drive longer electrical cables. With this combination, the 100 G attachment unit interface (CAUI) (or 40 G AU [XLAUI]) electrical reference plan can be extended out (by up to 1 m), which places the CFP under test in a climatic chamber while conducting the full range of tests to allow testing over the full range of nominal operating temperature. Full and precise control over voltage swing and pre-emphasis allows use of the electrical adapter to its full advantage, as Figure 7 illustrates.



Figure 7. The CFP electrical adapter maintains electrical access to all high-speed CAUI/XLAUI signals

## Dynamic Skew

Skew (timing variation) between lanes can become an issue with any parallel data bus. At 10 G per lane, only 100 ps exists per UI, so even a small change in timing per lane may represent a significant part of the whole UI. The ONT allows for controlling two types of skew variation. The first is controlling a variation on the whole UI on a per-lane basis, which is the standard static skew approach. The first skew variation provides a useful indication (at the PCS layer) of the performance of the per lane first-in/first-out (FIFO) buffer depth. More critical is the performance of the receiver tolerance to dynamic skew variation. If a link has been established, then the 10(4) individual lanes must continue to track correctly despite skew changes across a range of  $\pm 2$  UI. This dynamic skew tolerance ensures that any propagation delay variation in individual 10 G output buffers will not cause bit errors in the line receivers.

During the initial enabling of the dynamic skew mode in the ONT, the instrument performs an internal de-skew process. This de-skew will also occur if the skewing lane(s) are reassigned. During the de-skew process, permutations in both pattern and clocking may occur on the interface. It is recommended that a FIFO reset is performed after de-skew has occurred. The FIFO reset could be manually executed in the case of an individual component evaluation or automatically executed in the case of a module or system. It is important to note that measurement results during a de-skew may not be valid.

Figure 8 shows the control screen for the dynamic skew variation test that allows individual lanes to be subject to dynamic skew variation (in steps of 25 mUI out to  $\pm 32$  UI). Compensation for the variation in the skew of the transmitted lanes is provided by the receiver FIFO/data link layer (DLL) circuitry. If the variation is too large, the receiver slip causes a burst of bit errors and, most likely, loss of pattern synchronization. The dynamic skew test is a mandatory test called out in IEEE 803.3ba. It is designed to show the interface tolerance to skew changes typically caused by thermal effects. The standard does not specifically call out a skew rate but typically 10 mUI/s is a typical value.

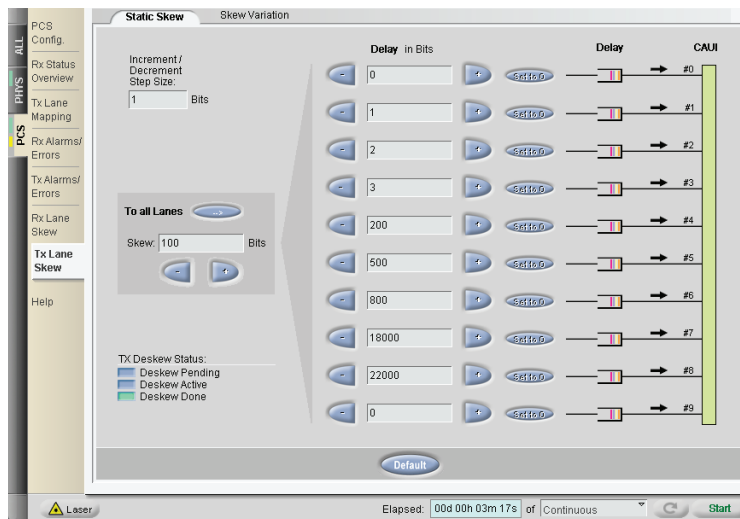


Figure 8. Dynamic Static Skew control screen—individual lanes can be varied in 25 mUI steps

Skew Tolerance Skew Point	Maximum Skew	Maximum Skew Variation
SP1	29 ns (~150 UI)	0.2 ns (~ 2 UI)
SP2	43 ns (~222 UI)	0.4 ns (~ 4 UI)
SP3	54 ns (~278 UI)	0.6 ns (~ 6 UI)
SP4	134 ns (~691 UI)	134 ns (~691 UI)
SP5	145 ns (~748 UI)	3.6 ns (~ 37 UI)
SP6	160 ns (~824 UI)	3.8 ns (~ 39 UI)
At PCS RX	180 ns (~928 UI ~928 bits)	4 ns (~ 41 UI 41 bits)

SP points are shown in Figure 9.

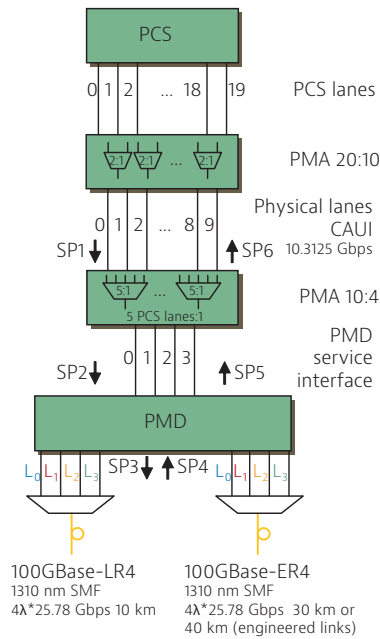


Figure 9. Multilane model

## MDIO Compliance

The MDIO serial control also demands attention (as Figure 10 shows), because the in-depth features it supports require validation for performance over a range of operating conditions. Some implementations of MDIO based on slower microcontrollers within the CFP may struggle to keep up with features such as auto-increment address. It is also important that parameters such as optical power, temperature, voltage, and vendor ID are correctly identified. The ONT offers a suite of MDIO debug applications and includes several MDIO operating modes that allow control over a CFP even with MDIO issues. The static control and monitoring lines should also be checked for operation, because the programmable control lines are often used by CFP vendors for special functions specific to their CFP.

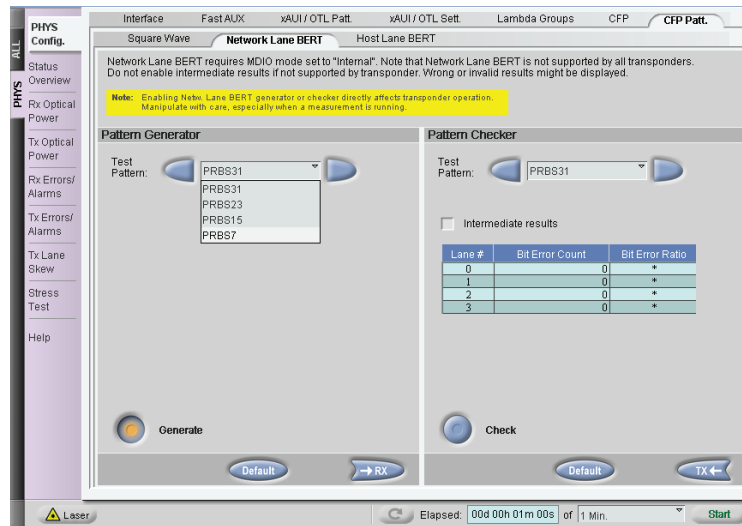


Figure 10. MDIO serial control demanding attention

## Stress Testing

The ability to fully stress test the range of parameters such as dynamic skew and clock pulling range automatically is extremely valuable in screening components for production; such an automated test can be used together with climatic chambers to give complete confidence in module performance. As Figure 11 shows, the ONT is unique in that it offers a fully automatic “canned” stress test for CFPs.

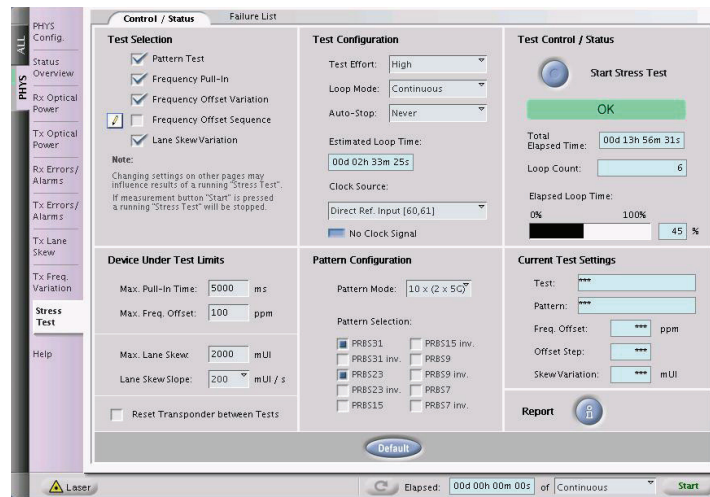


Figure 11. Automatic stress tests for CFPs

## Summary

CFPs remain the critical path for cost-effective and reliable 100 GE deployment; and as dual rate (100 GE and OTU4/111.8 Gbps) CFPs are developed, they will also require extensive testing and characterization. They are complex and involve interaction between fast photonics, parallel electronics, and firmware.

It is prudent to validate all aspects of CFP performance, not just the classic link BER. The parallel data means inter-lane timing, pattern sensitivity, and crosstalk must all be thoroughly stressed before deployment. Having breadth and depth of test coverage for CFPs coupled with applications that quickly help highlight and troubleshoot issues is mandatory for quick and cost-effective product release. The Viavi ONT offers complete coverage from the physical layer through the photonics and PCS/Ethernet traffic into deep OTN analysis with many unique and valuable features, such as dynamic skew. An investment in test equipment that can cover all 40/100 GE and OTU3/4 needs, from component and IP selection, through optics validation and into system test and deployment makes more sense than ever.



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