Application Note

Advancing beyond

Evaluating Co-Packaged Optics (CPO) Performance

Signal Quality Analyzer-R	MP1900A
BERTWave	MP2110A
Optical Spectrum Analyzer	MS9740B
Network Master Pro	MT1040A

Table of Contents

1. Introduction

Hyperscale data centers currently being deployed are focusing on changing the optical interface to facilitate the "Beyond 400G" revolution. To increase data transmission speeds even further, pluggable optical transceivers for data centers are starting to transition to 800 GbE and 1.6 TbE QSFP-DD/OSFP modules.

At the same time, to achieve larger capacity and higher integration, development of optical interfaces using Co-Packaged Optics (CPO) technology, which are fundamentally different form to current optical transceiver interfaces, is in progress. The CPO is a package in which an optical module and a Switch ASIC using silicon photonics (SiP) technology are mounted on a board with the minimum required area. The standardization is being handled by the Optical Internetworking Forum (OIF) Co-Packaging Framework Implementation Agreement (IA), the Consortium for On-Board Optics (COBO) Co-Packaged Optics Working Group, etc. The OIF aims to implement 51.2 Tbps Ethernet switches using 16 optical engines each of 3.2 Tbps (8 × 400 GbE) surrounding a Switch ASIC, as illustrated in Figure 1. The Ethernet switches are expected as a new solution for achieving large-capacity transmissions while solving the issue of rising power consumption of data centers.

This Application Note introduces how to test for each CPO characteristics.

2. CPO Outline

The growing demand for new applications using machine learning and AI requires higher speed communications. Current data center Ethernet switches using pluggable optical transceivers are transitioning to faster 800 GbE. For 800 GbE, the electrical connection between the internal Switch ASIC and optical transceiver requires the transmission of PAM4 signals with 53 Gbaud. The necessity to improve digital correction to compensate for increasing loss when transmitting high-speed signals over long distances incurs high power consumption and cooling costs. In addition, limited space both inside and outside the switch causes issues with implementing future high-speed 1.6 TbE.

CPO is one of the packaging methods for solving the above issues. Mounting both the optical transceivers and ASIC in proximity on the same board not only shortens the electrical path to cut power consumption and cooling costs but also facilitates higher bandwidth. This is not a new concept and is also used in the On-Board Optics (OBO) business. Advances in component integration using SiP technology are attracting renewed interest in CPO as a high-density implementation technology facilitating combination of multiple components, including switch ASICs, optical engines, laser light sources, and optical fibers.

Figure 1 illustrates the evolution from pluggable optical transceivers to CPO. Currently, the CPO with an ASIC surrounded by optical engines is under investigation and a concept model is being announced. In addition, a Near Package Optics (NPO) design with improved maintenance using an external light source and connector is being discussed as a practical CPO implementation. Future higher integration combining the optical engines, laser source, and ASIC in a single chip is under consideration.

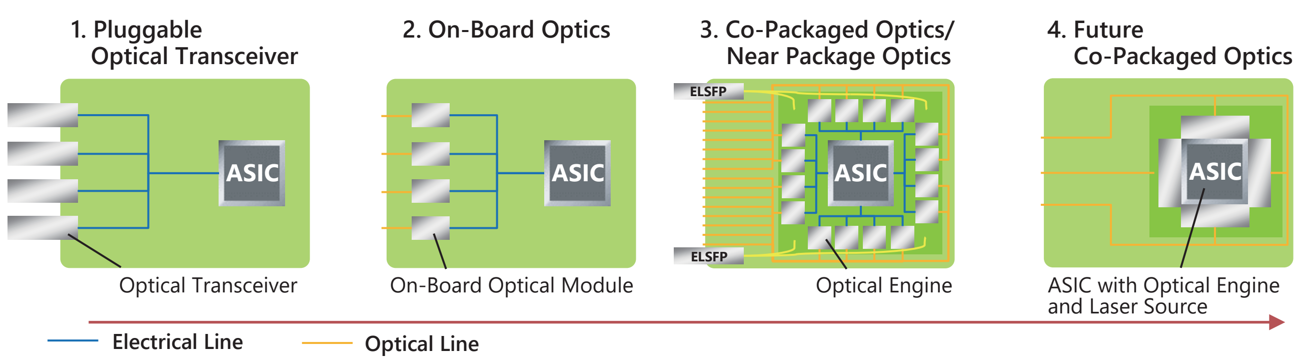

Figure 1 Evolution of Optical Transceivers.

3. CPO Module Test Points

Figure 2 shows the test points for the CPO/NPO (item 3) shown in Figure 1. The main three test points are listed as follows:

- Switch ASIC electrical signal test.
- Optical engine optical signal test.
- CPO switch Ethernet signal test.

Electrical and optical signals on the Switch ASIC and the optical engine use a standardized interface. Tests to assure that this standard is met are key to guaranteeing that the entire system is operating correctly.

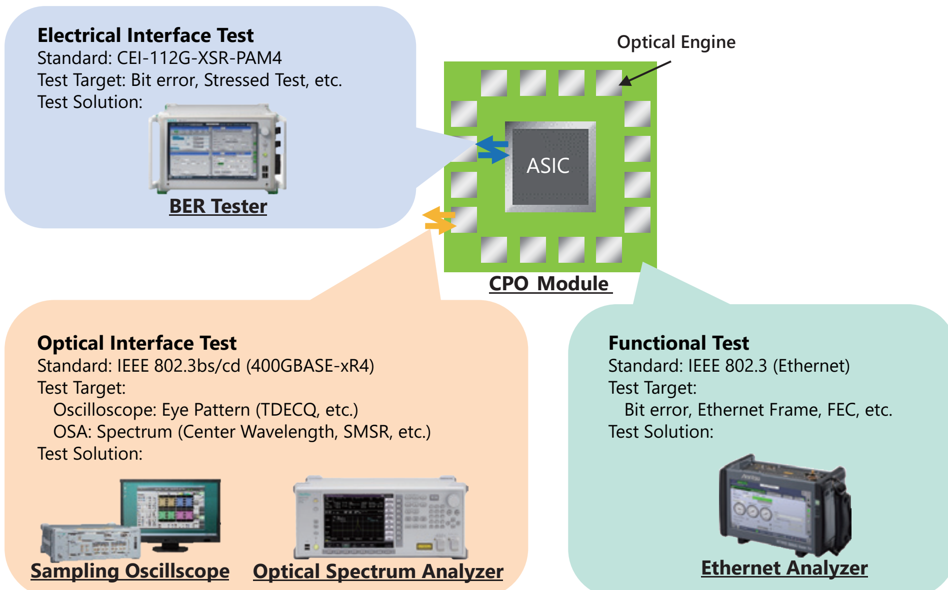

Figure 2 CPO Module Test Points.

4. Electrical Signal Test for Switch ASIC

The Switch ASIC electrical signal is affected by various important properties, such as external effects, stress, transmission channel. These properties degrade the signal integrity and prevent equipment interoperability. Consequently, this performance test is important for assuring interoperability. The CPO electrical interface uses the CEI-112G-XSR-PAM4 standard. In addition, support for CEI-112G-XSR+-PAM4 is being discussed to support the NPO application.

Bit errors can be evaluated using the Signal Quality Analyzer-R MP1900A. This modular 8-slot test equipment executes the high-speed electrical signaling tests required by a DUT supporting NRZ/PAM4 signal modulation. It supports 32 and 64 Gbaud per channel.

Figure 3 shows an example of a Switch ASIC electrical signal stress test setup. With PAM4 PPG/ED, synthesizer, jitter, and noise modules, the all-in-one MP1900A simulates external stress to simplify this test. The reference clock is output from the synthesizer module for input to the jitter module generating jitter stress, such as SJ, RJ, BUJ, etc. The jittered clock signal is used by the PPG module generating the test pattern output signal. The output signal is sent to the noise module where noise is added. The stressed signal with this added jitter and noise is supplied to the Switch ASIC. The signal output from the Switch ASIC receiving the stressed signal is sent to the ED where the BER is evaluated by comparison with the original signal.

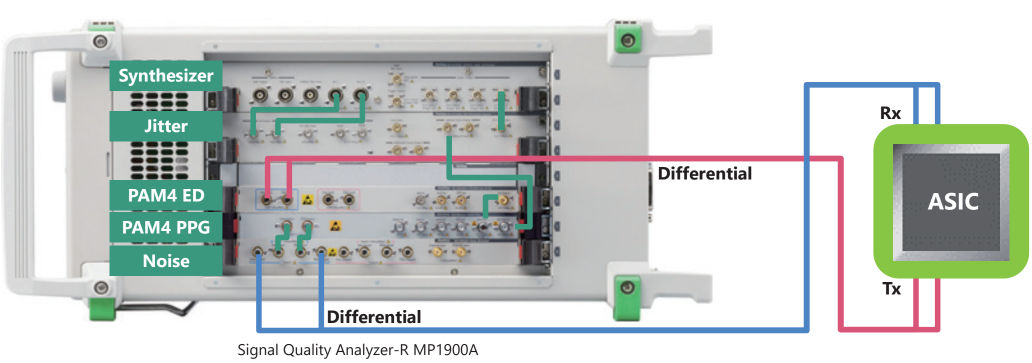

Figure 3 Switch ASIC Stress Test.

5. Optical Signal Test for Optical Engine

5.1. Waveform Evaluation using Sampling Oscilloscope

Evaluating the optical digital signal quality observed from the Eye pattern waveform is necessary for the optical engine. The optical signal of the optical engine is based on the same 400GBASE standard as pluggable optical transceivers with the PAM4 modulation technology. Transmitter and Dispersion Eye Closure for PAM4 (TDECQ) is used as the PAM4 waveform evaluation index.

Eye pattern waveform can be evaluated using the BERTWave MP2110A, which is an ideal all-in-one test solution for measuring 10 G to 800 G optical transceivers and analyzing NRZ/PAM4 Eye patterns.

Figures 4 and 5 show the test setup using the sampling oscilloscope. The optical output signal from the optical engine is input to each channel of the MP2110A. A breakout cable with a multi-core connector, such as an MPO, is used for 400GBASE-DR4 to input the signals to the oscilloscope. 400GBASE-FR4 uses a DEMUX to split the signal to the oscilloscope because the optical wavelengths are multiplexed using Wavelength Division Multiplexing (WDM).

The sampling oscilloscope requires a trigger signal to synchronize with the data signal. In many cases, the optical engine does not output a separate trigger signal. In this case, using a Clock Recovery Unit (CRU) supports optical engine testing without an external trigger signal because the trigger signal can be recovered directly from the optical input signal. The signal input to the MP2110A CRU is split by the built-in splitter and one signal is used for clock recovery while the other is output externally to the oscilloscope to evaluate up to four signal channels including the input to the CRU.

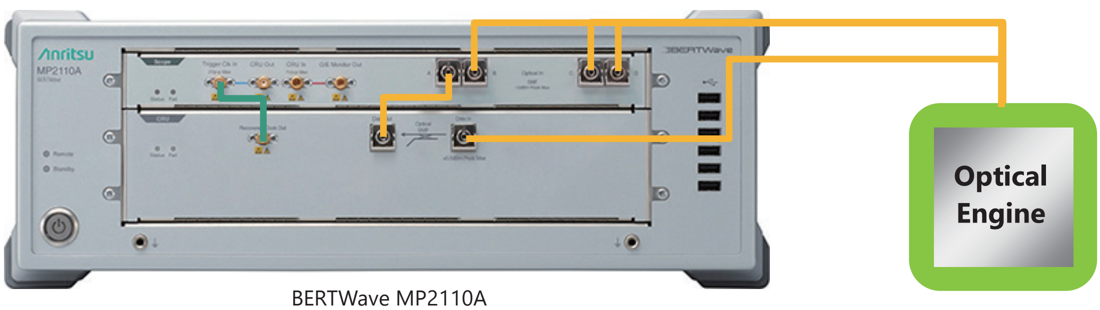

Figure 4 Optical Engine Optical Signal Test (400GBASE-DR4).

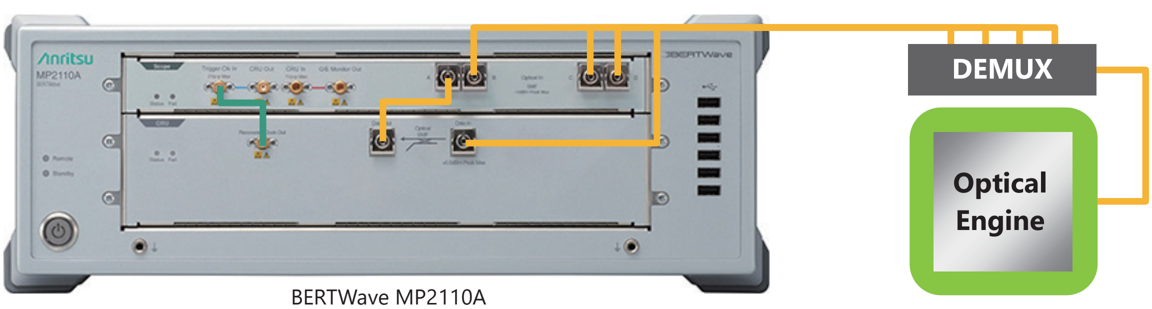

Figure 5 Optical Engine Optical Signal Test (400GBASE-FR4).

Thirty-two lanes must be tested for an OIF-defined 3.2 Tbps optical engine using 400GBASE × 8. Since conventional pluggable optical transceivers use four to eight lanes, the large increase in the number of CPO lanes causes new challenges. The test methods in this case are either parallel measurement using multiple test instruments, or measurement using an optical switch. Although 32 lanes can be evaluated quickly in parallel using multiple MP2110A units, the equipment capital cost is high. Alternative use of an optical switch cuts this cost, but the test time is longer because only four lanes can be evaluated at one time. There is a tradeoff between this equipment capital cost and test time. Therefore, users need to choose the optimum solution according to the relative importance of capital cost or test time.

5.2. Spectrum Evaluation using OSA

An optical spectrum analyzer (OSA) can evaluate the characteristics of optical signals such as center wavelength, spectrum width, side mode suppression ratio (SMSR). Usually, the characteristics such as center wavelength, spectrum width, and SMSR fluctuate. If these properties exceed the permitted values, the transceiver is evaluated as failing the test.

Some CPO designs use a light source that is external to the optical engine. Light sources generally suffered from high failure rates and there are problems with reliability in high-temperature environments. As a countermeasure to this reliability issue, OIF defines an easily changeable external light source as an External Laser Small Form-factor Pluggable (ELSFP) light source. The ELSFP optical output power per channel is extremely high at +20 dBm. As a result, unlike general pluggable optical transceivers, the ELSFP generally uses the blind-mating method outputting the optical power at the connector side. Consequently, the users can change the ELSFP in complete safety without exposure to the high-output laser.

Figure 6 shows a test example using the OSA MS9740B. As described previously, Since the ELSFP outputs the optical signal at the connector side, capturing the optical signal is difficult. Consequently, evaluating a standalone ELSFP requires an evaluation board to capture the optical signal. Alternatively, the optical spectrum of the signal output from the optical engine can be evaluated while the optical engine and ELSFP are coupled.

Care must be taken at the test due to the high optical output power of the ELSFP. If the maximum optical input power of the test instrument might be exceeded, an optical attenuator must be inserted between the ELSFP and the OSA. With its built-in settable optical attenuator, the MS9740B can measures optical powers up to +23 dBm.

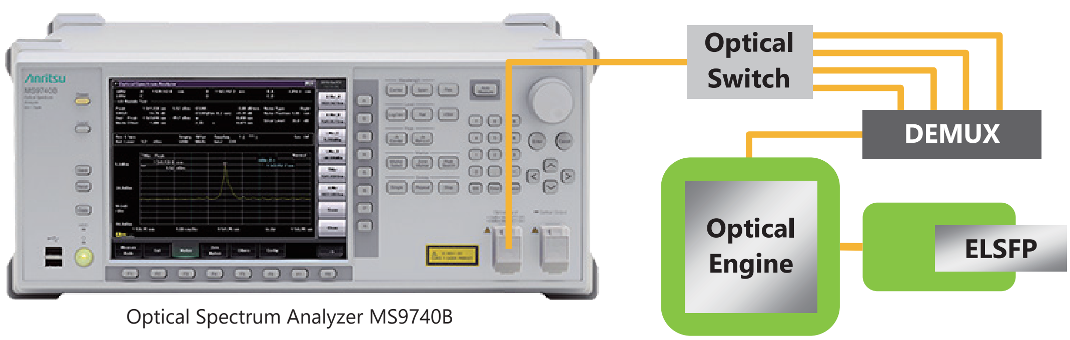

Figure 6 Optical Engine Optical Spectrum Test (400GBASE-FR4).

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n addition, as shown in Figure 7, when combined with evaluation using the sampling oscilloscope described in section 4.1, both the optical signal waveform and spectrum can be tested, enabling evaluation of all required parameters for optical engine.

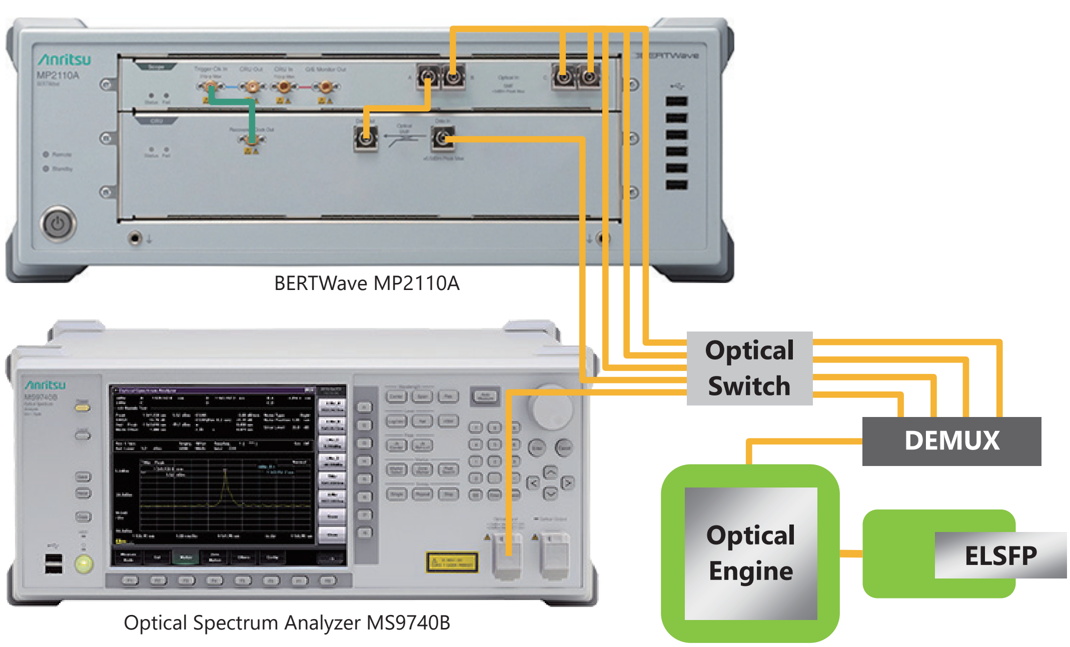

Figure 7 Optical Engine Optical Signal Test (400GBASE-FR4).

6. Ethernet Signal Test for CPO Switch

CPO switch testing requires both physical-layer and higher layer, which can be performed using an Ethernet tester.

The CPO switch uses PAM4 modulation and 400GBASE optical signals to increase transmission efficiency. The high-speed transmission may result in an increase in the probability of signal errors because of the drop of the amplitude level. As a result, IEEE-specified Forward Error Correction (FEC) is used to correct any errors occurring during signal transmission and assure high-reliability communications. Unfortunately, FEC has some limitations and an excessive number of contiguous errors in the signal cannot be corrected by the FEC algorithm, causing a large decrease in transmission quality.

The Network Master Pro MT1040A Ethernet tester can evaluate both error-free data transmissions and the number of errors which is within the correction range of the FEC algorithm. As shown in Figure 8, the MT1040A displays the optical transceiver FEC distribution characteristics in an actual Ethernet Frame TRx environment.

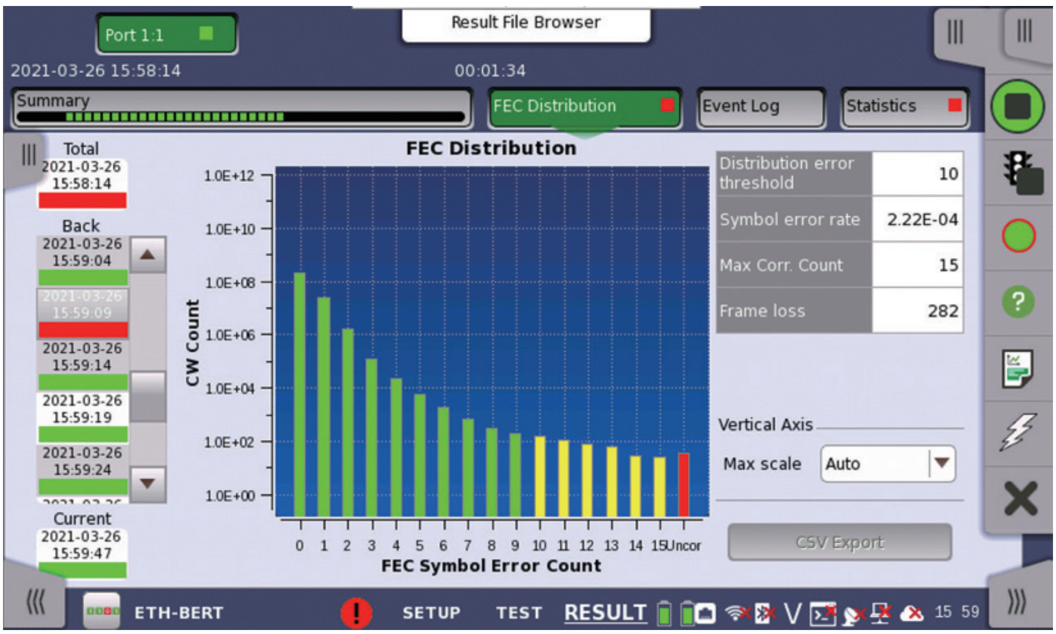

Figure 8 FEC Distribution Characteristics.

Figure 9 shows the Ethernet test setup for a dual-port CPO switch using the MT1040A with two installed 400G optical modules to evaluate two 400G ports. Inputting the optical signal output from one port of the CPO switch while inputting the optical signal output from DUT #2 receiving this input to the other port of the CPO switch supports switch performance evaluation, such as the Frame Loss, Error Frame, and Latency tests. Additionally, FEC codeword (CW) errors can be identified to evaluate the distribution of all received FEC CW. As shown in Figure 8, users can observe test results in real-time as well as set threshold levels for any symbol error to easily grasp the green, yellow, and red color-coded results.

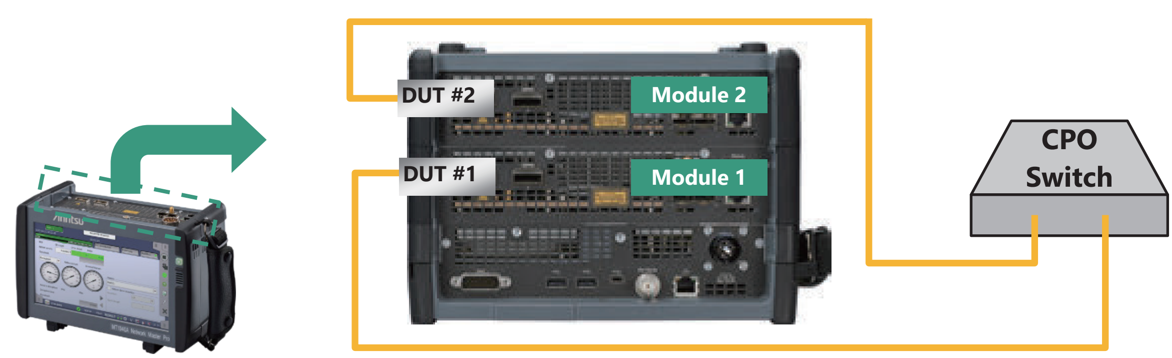

Figure 9 CPO Switch Ethernet Test.

7. Conclusion

This Application Note has explained the three types of CPO tests for the Switch ASIC electrical signal, optical engine optical signal, and CPO switch Ethernet signal tests. Interoperability testing and evaluation are important as CPO integration progresses.

Anritsu has a wide range of test solutions including BERT, sampling oscilloscopes, optical spectrum analyzer, Ethernet testers, etc., offering ideal solutions. For evaluating CPO performance, Anritsu supports electrical and optical test solutions for CPO performance and compatibility requirements.

Anritsu continues to deliver new test solutions for customers requiring network equipment and services with assured quality.

Advancing beyond

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