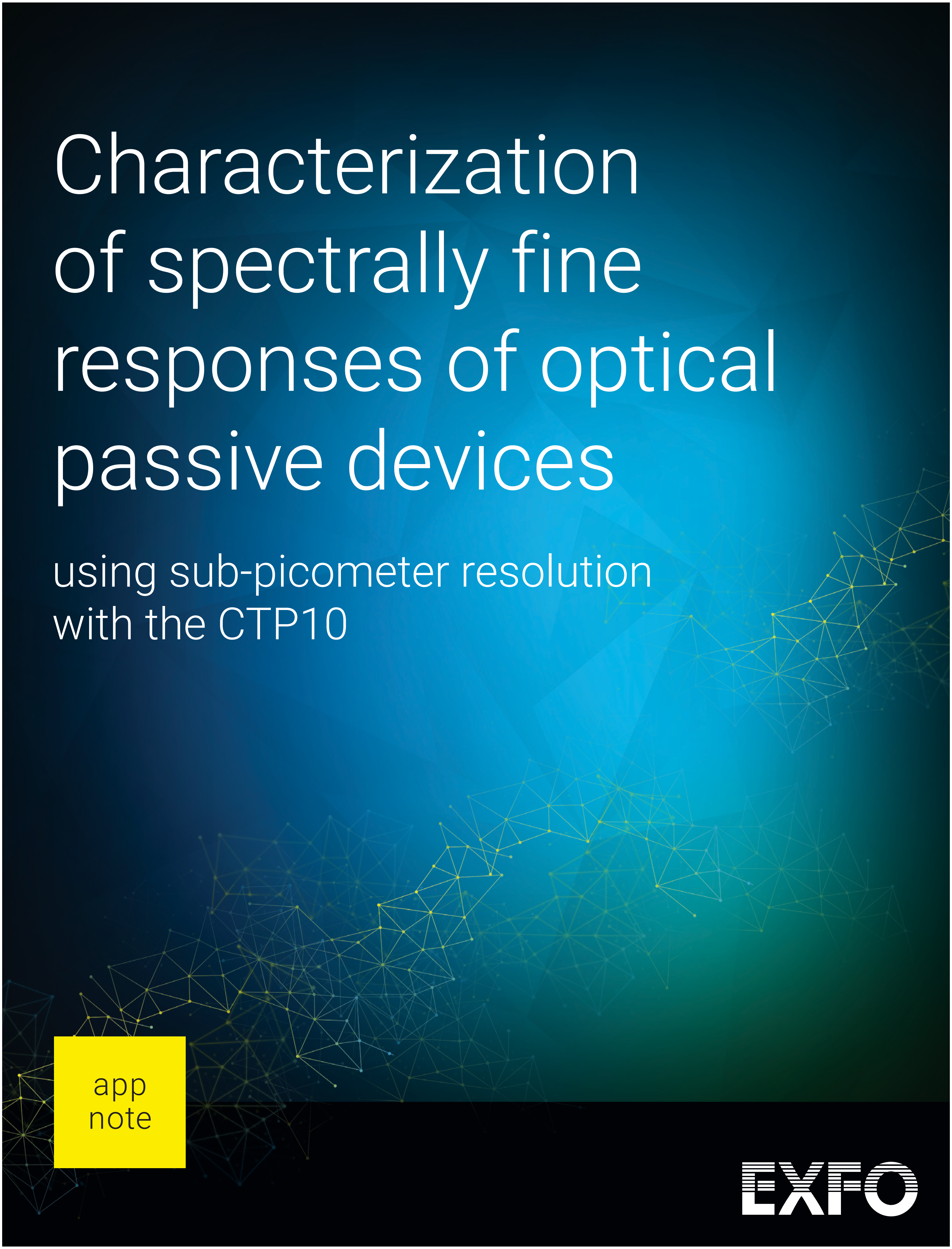

Characterization of spectrally fine responses of optical passive devices

using sub-picometer resolution with the CTP10

app
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EXFO

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Introduction

This application note describes how the CTP10 platform performs spectral measurements in the sub-picometer wavelength-resolution regime using the built-in high-resolution functionality.

The CTP10 is a modular high-performance multiport detection system for optical passive component testing that operates with EXFO's series of continuously swept tunable lasers. Within the selection of modules of the CTP10 platform, the IL RL OPM2, IL PDL OPM2 and SCAN SYNC modules offer a comprehensive and integrated solution to perform swept insertion loss (IL), polarization dependent loss (PDL) and return loss (RL) measurements with excellent wavelength resolution down to 20 fm (femtometers) while maintaining high performance.

Using the standard wavelength detection mode in the CTP10, the best achievable resolution (i.e., the wavelength spacing between two data points) is 1 pm (picometer) which covers most current needs in R&D and manufacturing. Nowadays, there are many new applications for photonic integrated circuits (PIC) devices—such as high-Q factor ring-resonators and ultra-fine spectral-response components. Therefore, sub-picometer resolution is required for an accurate spectral characterization of these devices motivating the introduction of the high-resolution special wavelength detection-mode in the CTP10.

With such high-resolution in spectral acquisition, it is possible to perform more advanced measurements such as sweep-wavelength interferometry (SWI), homodyne-detection of laser sources and optical frequency domain reflectometry (OFDR). The first two applications are presented in this application note through proof-of-concept experiments. The possibilities offered by the CTP10 for OFDR measurements are detailed in another application note available on EXFO.com.

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Setting up high-resolution measurements in the CTP10

IL measurements in the CTP10 require either the IL RL OPM2 or IL PDL OPM2 modules operating with the SCAN SYNC module, as shown in the figure below.

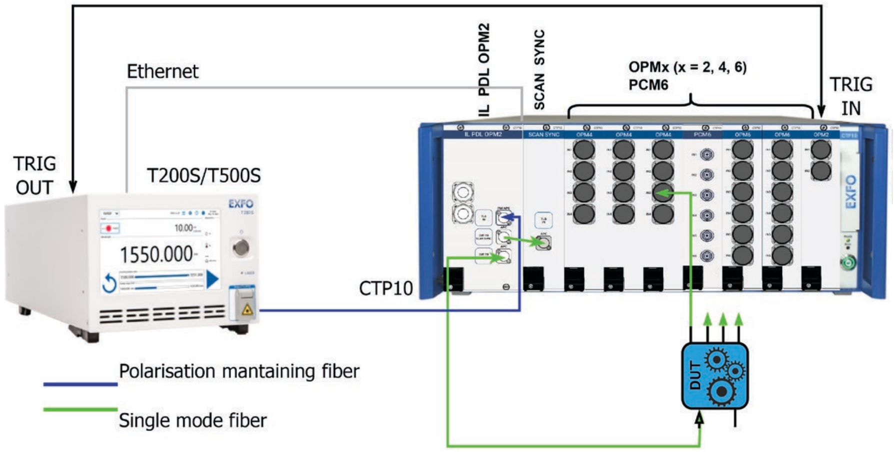


Figure 1. Physical connections for swept IL measurements with sub-pm resolution on the CTP10 using the IL PDL OPM2, SCAN SYNC, OPM (optical power meter) and PCM (photocurrent meter) modules.

The example configuration shown in Figure 1 presents the schematics of a typical CTP10 configuration setup for IL and PDL measurements.

- A continuously tunable laser is connected to the CTP10 mainframe using an Ethernet cable, allowing full control of the laser sweep from the CTP10 interface.
- The IL PDL OPM2 module monitors and compensate, in real time, the laser power variations during the wavelength sweep. From the IL PDL OPM2 module, a portion of the light is sent to the device under test (DUT) and another portion to the SCAN SYNC module.
- The SCAN SYNC module enables dynamic wavelength measurement with sub-picometer resolution.
- The various output ports of the optical component being tested are connected to power meters in the OPMx modules.

Pertaining specifically to the high-resolution mode, an electrical BNC connection going from the TRIG OUT port on the laser side to the TRIG IN port at the back of the CTP10 is necessary to ensure synchronization during the laser sweep.

> The capability of realizing measurements in the sub-pm regime opens the door to new applications where the CTP10 can be of great help.

High-resolution configuration in the CTP10 interface

The sub-picometer configuration must also be set up in the CTP10 graphical user interface (GUI). Once again, the only difference with a typical CTP10 configuration is the addition of a virtual link between the TRIG OUT port from the laser to the TRIG INx port of the CTP10 in the subsystem tab of the GUI (see the bottom left of Figure 2 – TRIG IN 1). The selected TRIG INx port, where x goes from 1 to 8, must correspond to the physical connection at the back of the CTP10.

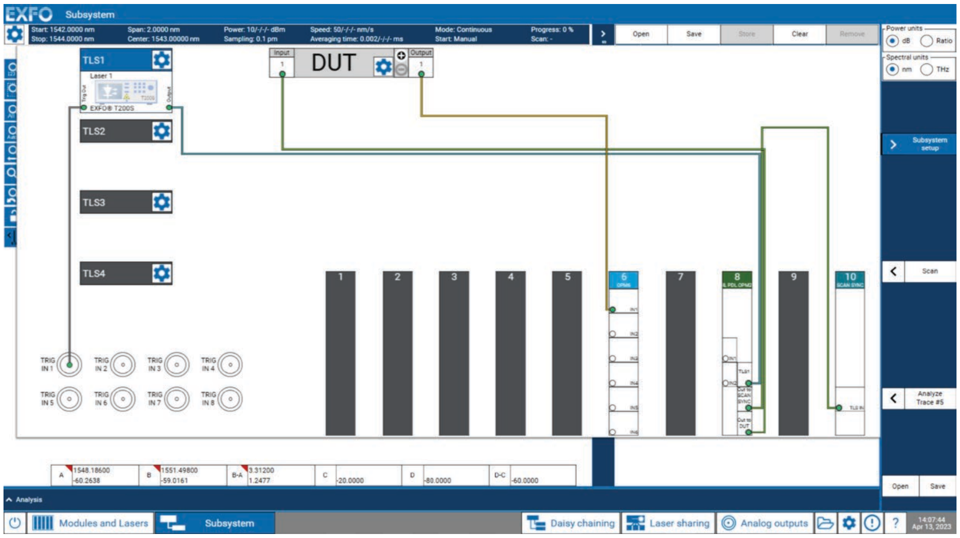


Figure 2. Configuration of the high-resolution mode in the CTP10 GUI. The CTP10 subsystem consist of an IL PDL OPM2, SCAN SYNC and OPM6 modules. The TRIG INx port in the CTP10 can be selected at the bottom left of the subsystem tab in the CTP10 GUI.

Once the virtual connection is made, the high-resolution sampling mode on the Scan tab of the GUI is ready for use as shown in Figure 3. One can observe that the High-Resolution menu allows the selection of up to five choices from 0.5 pm down to 0.02 pm (i.e., from 500 fm to 20 fm). Upon selection of the required wavelength resolution and proper referencing of the detectors at the corresponding resolution, the system is ready to perform a measurement.

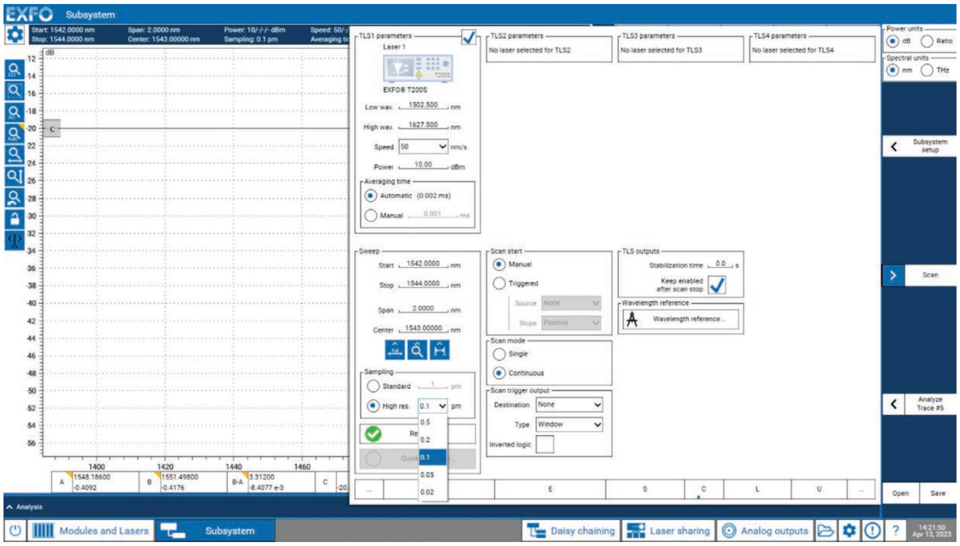


Figure 3. Selection of a sampling resolution in the high-resolution mode in the Scan tab of the CTP10 GUI.

Applications

The capability of realizing measurements in the sub-pm regime opens the door to new applications where the CTP10 can be of great help. For instance, a 10-fold improvement in spectral resolution results in a 10-fold enhancement of the measurement reach of an Optical Frequency Domain Reflectometry setup.

Below are some use cases where sub-picometer resolution is essential for the characterization of the devices being tested.

Use case 1 – Measurement of ultra-fine responses of integrated photonic ring-resonators.

The use of a higher resolution in IL measurements provides remarkable advantages on the spectral characterization of high-Q ring-resonator devices. For instance, Figure 4 shows a comparison of the spectral response of a ring resonator with a Q factor of the order of 6 million using 1 pm and 20 fm resolutions at 1550.000 nm. Using a resolution of 20 fm reveals the Lorentzian shape of the absorption line of this device while at a resolution of 1 pm it is difficult to evaluate the shape and the maximum loss featured by the peak.

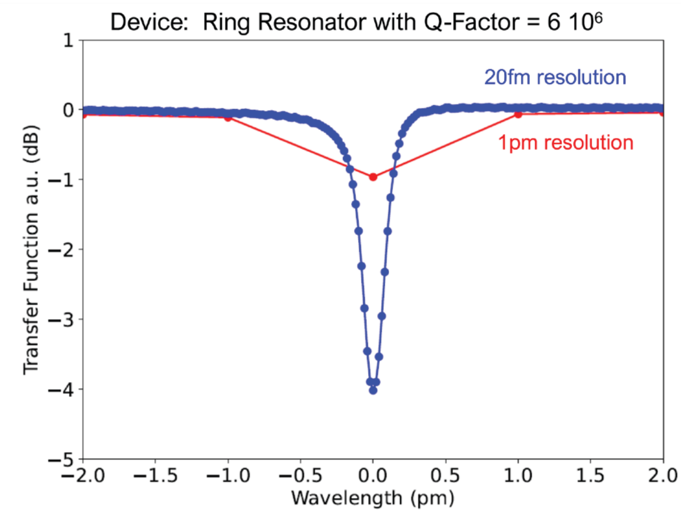


Figure 4. Spectral response of a high Q-factor ring resonator using rezsolutions of 1pm (red) and 20 fm (blue) measured with the CTP10. Device courtesy of CEA-leti.

When it comes to PIC characterization of spectrally fine devices, the CTP10's sub-picometer built-in functionality adds on to the other key advantages of the instrument. Indeed, even in high-resolution mode, wavelength accuracy, repeatability, optical power dynamic range and power change tracking are maintained, outperforming other swept laser solutions. Scanning speed follows the resolution, e.g., spectral characterization at a resolution of 0.1 pm is performed at a sweep speed of 100 nm/s.

> A sampling resolution from 500 pm down to 20 fm while maintaining wavelength accuracy, repeatability, optical power dynamic range and power change tracking.

Figure 5 shows the spectral characterization of another high-Q ring-resonator using a resolution of 0.1 pm with a scanning speed of 100 nm/s. The CTP10 measurement exhibits the Lorentzian shape feature of the ring-resonator absorption line with maintained performance on wavelength repeatability and dynamic range.

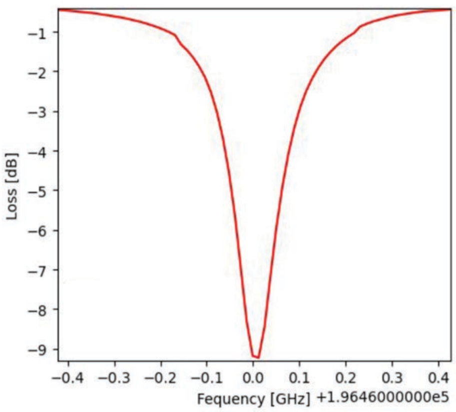


Figure 5. Spectral response of a high-Q ring-resonator using a resolution of 0.1 pm. CTP10 response, at a scanning speed of 100 nm/s exhibits expected Lorentzian shape of absorption line.

Use case 2 – Swept-wavelength interferometry (SWI)

SWI is a frequency-based domain interferometric technique for single-scan and high-resolution spectral measurements of the transfer function (TF) of an optical component. Accurate spectral amplitude and phase measurements can be extracted in the form of polarization-averaged group-delay, chromatic-dispersion and other linear parameters. In the scope of this application note, we only determine the path-length difference of a Mach-Zehnder interferometer from the interferogram measured by the CTP10.

The figure below shows the experimental setup used to record the interferogram of a fiber-based Mach-Zehnder interferometer. The path-length difference of the interferometer corresponds to a time delay τ_0 producing an interferogram with an FSR equal to $1/\tau_0$, which means that for the CTP10 to measure it correctly, it is necessary that its sampling resolution be of the order of $1/(2\tau_0)$, based on the Nyquist-Shannon sampling theorem. For the resolution setting of 0.02 pm, we find the sampling frequency to be of the order of 2.56 MHz enabling a measurement range of up to 40 m.

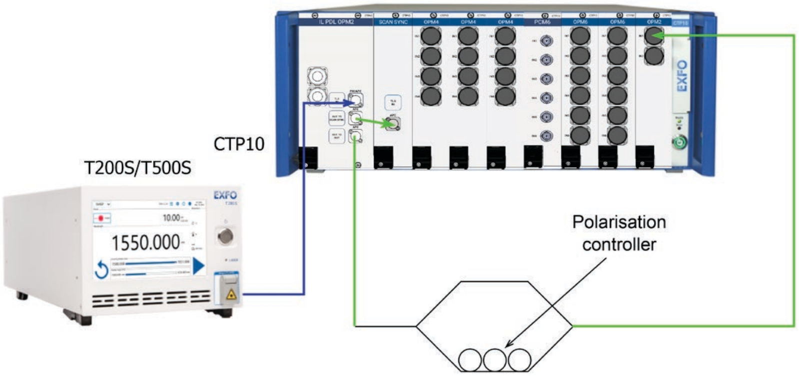
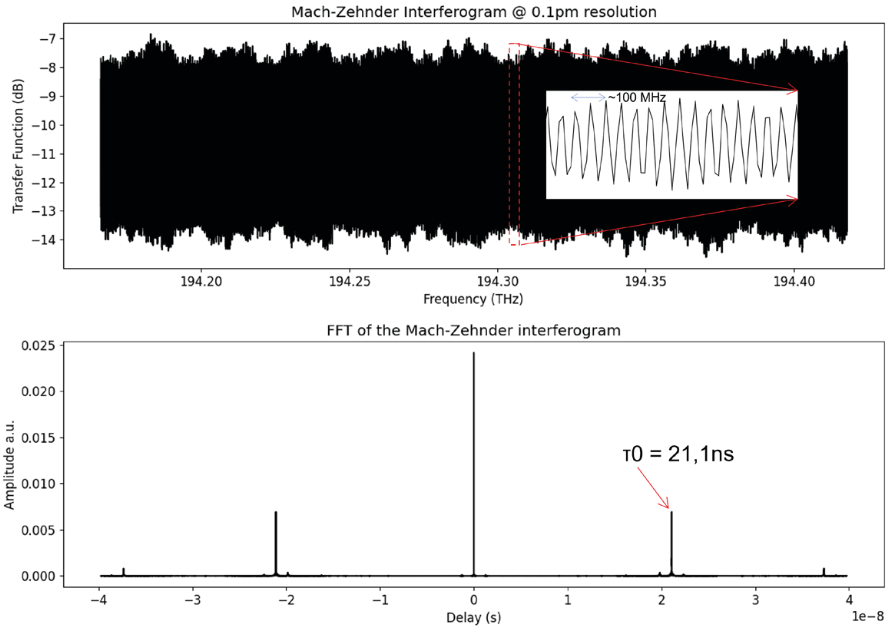


Figure 6. Experimental setup used to record the interferogram of a fiber-based Mach-Zehnder interferometer. A polarization controller is necessary to optimize visibility of interference fringes.

We can determine accurately the path-length difference of the interferometer by applying a fast Fourier transform (FFT) on the frequency-domain interferogram (see Figure 7). For this interferometer the time-delay τ_0 is of 21.1 ns corresponding to a path-length difference L of approximately 4.3 m ($L = \tau_0 * c/n$, where c is the speed of light and n the index of refraction, n =1.469 for optical fiber).


Mach-Zehnder Interferogram @ 0.1pm resolution

FFT of the Mach-Zehnder interferogram

Figure 7. Interferogram of a fiber-based Mach-Zehnder interferometer and determination of its path-length difference using FFT. Top - The interferogram is plotted in the frequency domain. The FSR of the interferogram is aprox. 50 MHz. Bottom - Fourier spectrum of interferogram in time domain reveals peak associated to periodicity in interferogram.

Use case 3 – Homodyne detection: wavemeter emulation.

An extremely accurate source wavelength measurement can be achieved using the homodyne detection technique that consist of combining or mixing a source under test (SUT): laser-type and fixed wavelength, with a continuously swept tunable laser on a photodetector. This produces an interference pattern when both sources are spectrally identical. The measurement of this interference pattern allows to determine the SUT’s emission wavelength.

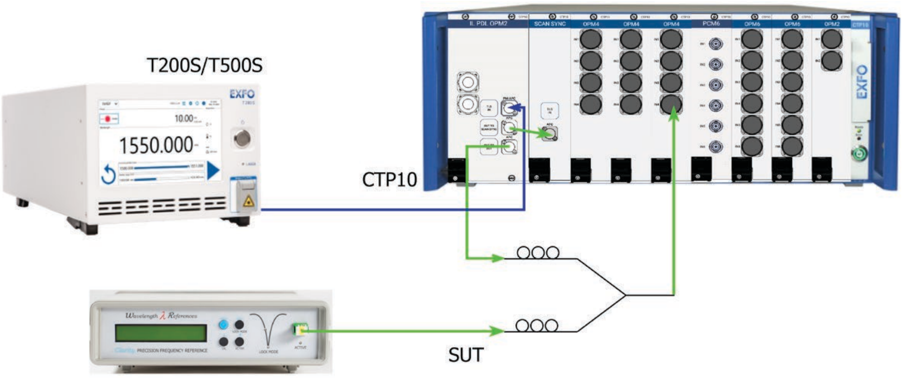


Figure 8. Homodyne detection technique implemented in the CTP10. Combining or mixing SUT and swept-tunable laser in a photodetector produces interferogram when both sources are spectrally identical. Its measurement allows to determine SUT's emission wavelength.

In the framework of the CTP10, homodyne detection provides the value of the SUT's peak wavelength that the swept laser scanned across. As the swept laser wavelength approaches the peak wavelength of the SUT, interference fringes are generated featuring a highest peak at the nominal wavelength to be determined. The experimental setup used for wavelength measurement is shown in Figure 8. It consists of a 2 x 1 optical coupler, where the SUT and the T200S swept tunable laser are combined. The output of the coupler is connected to one of the detectors in the CTP10, whose optical power is limited to +10 dBm. In order to observe optimal interference, care must be taken to launch the same polarization and equal optical power in both SUT and swept laser branches of the optical coupler. Also, a high sampling-resolution of 20 fm was set to resolve the interference fringes.

To enhance the accuracy of the wavelength measurement, an optical wavelength reference was performed using a C2H2 gas cell on the CTP10. Such process is built in the CTP10 GUI and only requires a few seconds to perform.

In the figure below we have plotted ten measurements of the spectral line of a phase-locked DFB laser from Wavelength References at 1530.3686 nm. The set of these ten measurements defines a FWHM of 0.5 pm where the center wavelength is located; in this case 1530.3685 nm. The location of the main peak differs between measurements since the optical phases of the SUT and the swept tunable laser are not locked with each other. Also, the limited number of visible fringes is due to the available detection-bandwidth which is in the order of 10 MHz.

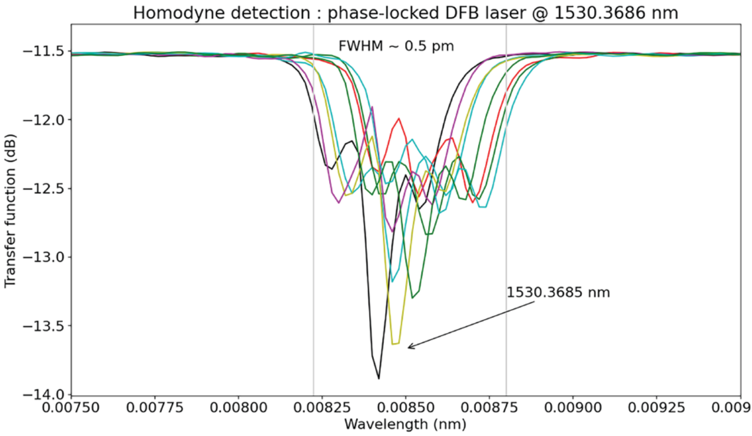


Figure 9. Ten measurements of the spectral line of a phase-locked DFB laser from wavelength references at 1530.3686 nm

Additional references

Reference
www.exfo.com

Important info
www.exfo.com

Conclusion

Spectral measurements at high-resolution enable multiple applications where the CTP10 can be of great help in providing a sampling resolution from 500 fm down to 20 fm while maintaining wavelength accuracy, repeatability, optical power dynamic range and power change tracking. High-resolution spectral measurements can be achieved with the help of a **CTP10** component test platform and EXFO's series of continuously tunable swept lasers, the **T200S** and **T500S**.