# Zentralisierte, pilotton-basierte Wellenlängenstabilisierung für WDM-PON mit 1GbE Datenrate

# Centralized, Pilot-Tone-Based Wavelength-Locking for WDM-PON with 1 GbE Data Rate

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## Kurzfassung

In diesem Beitrag wird erstmals eine Kundenanschlusseinheit (Optical Network Unit, ONU) im laufenden Datenbetrieb mit einem abstimmbaren Laser demonstriert, der ohne thermo-elektrisches Kühlelement (thermoelectric cooler, TEC) und ohne integrierte Wellenlängenreferenz (Etalon) arbeitet. Stattdessen wird ein zentralisiertes Wellenlängenabstimmsystem verwendet, das ein von allen ONUs gemeinsam genutztes Etalon in der Vermittlungsstelle verwendet. Einzelne Wellenlängen können dort durch verschiedene Pilottonfrequenzen unterschieden werden. Die Informationen über die Wellenlängengenauigkeit werden durch einen eingebetteten Kommunikationskanal von der Vermittlungsstelle (Optical Line Terminal, OLT) zurück zur ONU übertragen. Die Nutzdatenrate in dem untersuchten System beträgt 1,25 Gb/s (1 GbE). In einem Laborexperiment konnte gezeigt werden, dass sich die ONU selbstständig auf die gewünschte Wellenlänge einstellt und diese auch bei Änderungen der Temperatur in einem geringen Toleranzbereich halten kann.

## Abstract

In this article an optical network unit (ONU) has been demonstrated with real-time data traffic based on a tunable laser operating without a thermo-electric cooler (TEC) and without an integrated wavelength reference (etalon). Instead a centralized wavelength control system has been deployed, which uses only one shared etalon at the optical line terminal (OLT) to transmit wavelength locking information to all attached ONUs. Different wavelengths can be distinguished in this scheme by different pilot-tones. The control information on wavelength accuracy is provided back to the ONU through an embedded communication channel (ECC). The data rate of the upstream traffic has been set to 1.25 Gb/s (1 GbE). We have shown in a laboratory experiment that the ONU can tune automatically to the desired wavelength and can keep this wavelength within a small tolerance region even when the temperature is changing.

## 1 Introduction

The rapid development of the Internet and of broadband services (e.g. video-on-demand) can also be seen by an exponential growth of the data traffic being transported in access networks. Currently, the annual growth rate of the data volume is in the range of 30 - 60%. It is not expected that this rapid growth will flatten in the near future [1][2].

To cope with the expected bandwidth demand in the next 5 to 10 years and to offer line rates of 1 Gb/s or higher, new access concepts will be required. One candidate for next generation access (NGA) is a wavelength-division multiplex passive optical network (WDM-PON) [3]. NGA solutions should ideally have a long reach, be bandwidth- and energy-efficient, and as well they should be offered at a low cost. To achieve these goals and to provide a plug & play solution for new subscribers the optical network unit (ONU) will have to be colorless and at the same time inexpensive. For bit rates of ≥ 1 Gb/s and a desired

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reach in excess of 40 km, tunable lasers are favorable compared to reflective approaches. To enable low cost and low energy-consumption such a tunable laser should be realized without a thermo-electric cooler (TEC) and also without a wavelength locker (etalon). Instead a scheme with a centralized wavelength locker inside of the optical line terminal (OLT) could be used, which provides a (wavelength) reference to all attached ONUs [4].

In this paper we report on a recent laboratory experiment, which shows for the first time to our knowledge, an uncooled low-cost tunable ONU with running high-speed data transmission and centralized wavelength locking provided by the OLT.

The paper is organized as follows. In the next paragraph the laboratory setup and the centralized wavelength locking principle are outlined. Afterwards the wavelength control algorithm is explained and measurement results are presented. Finally conclusions are drawn.

## 2 Lab setup of WDM-PON system

The general setup of a WDM-PON system is shown in **Fig. 2** consisting of an OLT, a remote node (RN) and one or several ONUs. The L-band is used in downstream and the C-band in upstream directions permitting a single-fiber solution. The ONUs are equipped with tunable lasers. These lasers can be realized as e.g. digital super-mode distributed Bragg reflector (DS-DBR) devices.

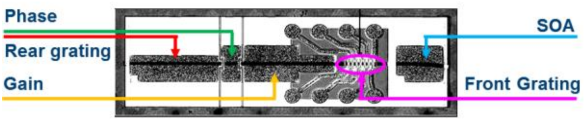


**Fig. 1** Digital super-mode DBR laser [4]

The DBR laser used in our experiments consists of 5 sections (**Fig. 1**): a multi-contact front grating section, a gain section, a phase section, a rear grating section, and a semiconductor optical amplifier (SOA). This laser is normally operated in a temperature range of 15° - 65° C with a TEC. In the experiments we turned off the TEC (which was built-in to the device we used), which in turn requires control of the currents of the different laser sections to maintain the desired wavelength (more details are presented in Section 3). Mode-hops are avoided by delicately controlling the gain and phase currents except when it needs to reset the currents or switch between super-modes.

The detailed setup of the laboratory experiment is depicted in **Fig. 5**. In that configuration an AM pilot-tone has been added to the upstream channel to identify the specific WDM channel at the centralized etalon. Afterwards an external Mach-Zehnder modulator (MZM) is used to imprint a 1.25 Gb/s data signal (PRBS length $2^{31}$-1). This signal is consecutively transmitted over a 40 km long standard single mode fiber (SSMF). At the OLT part of the signal is tapped out and fed to an etalon and reference photodiode. Both signals are digitized and afterwards transferred to the frequency domain by FFT. This allows to distinguish between different WDM channels due to different pilot tone frequencies and to determine the power level and wavelength deviation of each individual channel. This information is conveyed back to the ONU embedded in an Ethernet frame (and using an electrical Ethernet connection) to simplify the laboratory experiments. In a real system configuration the embedded communication channel (ECC) will be provided by modulating the downstream pilot tones with a low data rate signal. After reception and deframing the control information is passed to a microcontroller on which the tuning algorithm is implemented to control the different sections of the DS-DBR laser. In this configuration the TEC of the laser is not used (s. above). It may, however, be utilized to deliberately set the laser to different operating temperatures and in this way to emulate the effect of varying ambient temperatures. Apart from the control path described above upstream data is passed to a bit error rate tester (BERT) through an arrayed waveguide grating (AWG) for demultiplexing purposes.

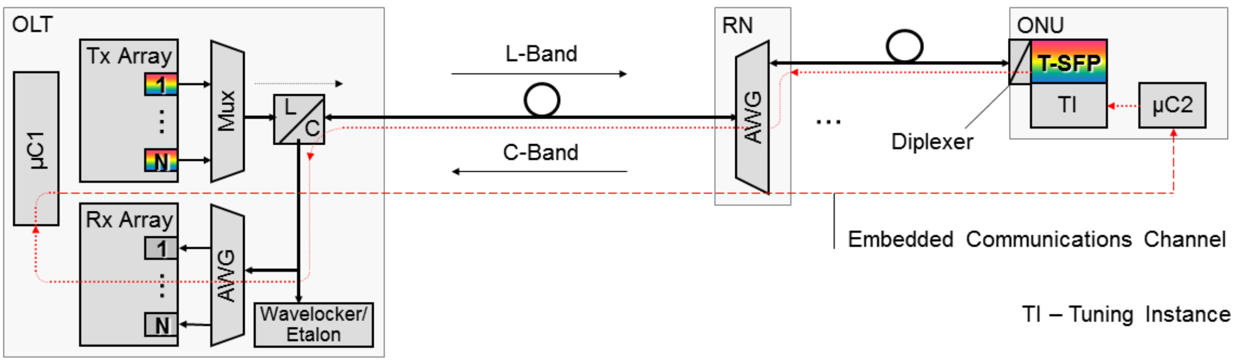


**Fig. 2** Setup of a WDM-PON system with centralized wavelength locker. OLT: optical line terminal, RN: remote node, ONU: optical network unit, µC: micro controller.

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# 3 Wavelength control algorithm

The laser control algorithm is used for two different objectives. First it allows plug & play configuration of the ONU by tuning it automatically to the right frequency (i.e. AWG port it is attached to). Furthermore, it will keep this frequency even when the ambient temperature of the laser is changing.
For this purpose on power-up of the ONU a frequency sweep is initiated with a step-width of approximately 0.3 nm to find the AWG slot it is attached to. In this phase only the received power level is used as feedback criterion (**Fig. 3, top**) until a pre-defined threshold of the received signal power is exceeded. This indicates that the current laser frequency is lying in the desired AWG pass-band slot.

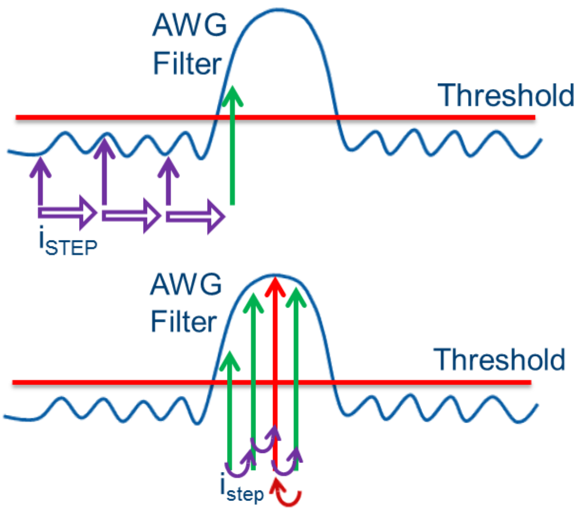


**Fig. 3 Top:** Frequency sweep on power-up (plug & play configuration); **Bottom:** Fine-tuning of the wavelength during regular operation

As soon as the received pilot tone's power is above this threshold the sweep step width is reduced, and the maximum transmission power level is determined through an optimization process. In a second phase, the control information from the centralized etalon is used to fine tune the laser wavelength (**Fig. 3, bottom**). Eventually, the wavelength deviation will be oscillating slightly around the desired center frequency (compare also Fig. 6). If anytime the power is below the threshold, a re-sweep within the vicinity range will be triggered (e.g. because the ONU has been switched-off in the meantime).

# 4 Measurement results

During the laboratory experiments different tests have been conducted to proof the initial tuning on power-up of the ONU (plug & play phase) and to monitor the long-term behavior (regular operation phase). The initial wavelength calibration phase is depicted in **Fig. 4**. It can be observed that the laser starts tuning at the lowest possible frequency and reaches the desired channel in less than a minute. This time is only needed during first power-up of the ONU.

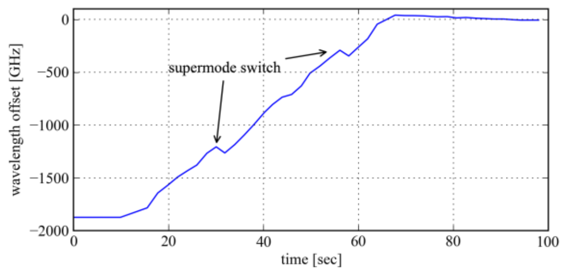


**Fig. 4** Initial wavelength search after power-up of the ONU

The initial tuning time is dominated by the delay in the control loop, where the measurement is done at the OLT and the control information needs to be conveyed back to the ONU. As can be seen in Fig. 4 the

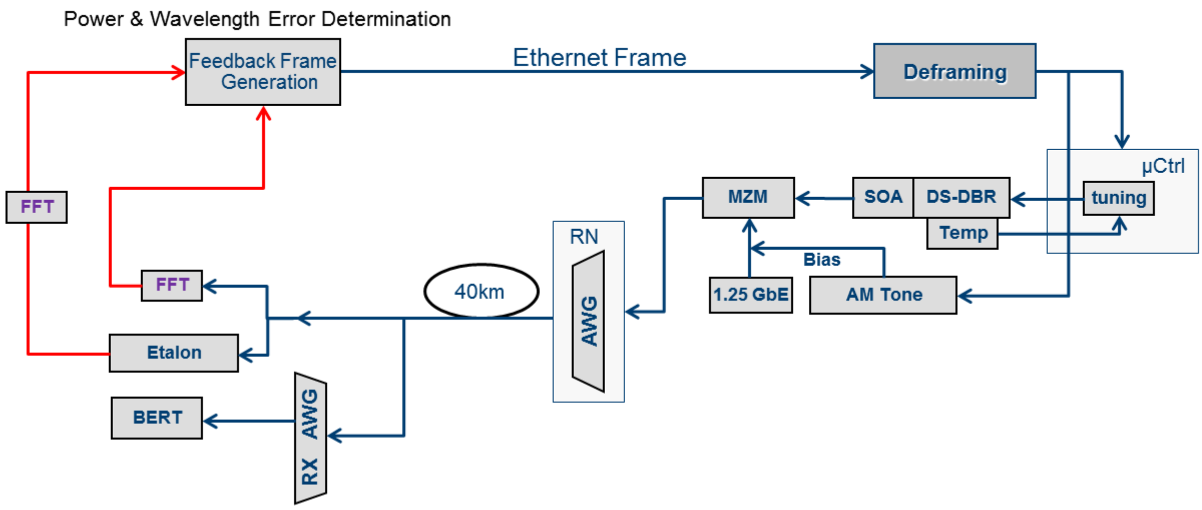


**Fig. 5** System diagram and control flow

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initial tuning speed is roughly 2 THz/min. As the entire C-band used for upstream transmission has a width of approximately 4 THz the initial tuning phase is thus finished in less than 2 minutes. Initially only the front and rear grating currents are changed. The wavelength control is improved afterwards by taking into account also phase and gain sections. When the phase current reaches its maximum limit, it must be reset to zero and a longitudinal mode hop occurs (compare **Fig. 4**).

After the desired upstream frequency has been found (i.e. the AWG port the ONU is attached to), the control algorithm is switching to the fine tuning phase. In this mode long term frequency stability within a range of ± 4 GHz can be achieved (**Fig. 6**). During a long term performance measurement of approximately three hours the laser frequency remained well inside the desired range. The temperature varied arbitrarily during that measurement between 29.5 and 31.5° C. The measured BER remained below $10^{-9}$. Other system tests have shown that the laser operates error free even when the temperature is varied from 15° C to 70° C [6]. It is furthermore possible to decrease the frequency of longitudinal mode hops from approximately 4° C to more than 25° C [7].

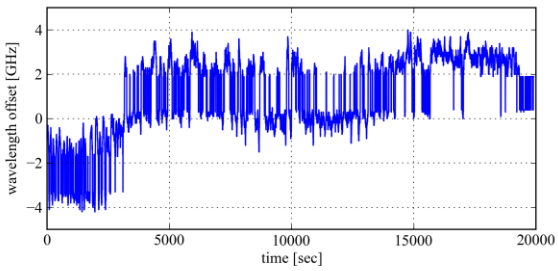


**Fig. 6** Long-term frequency stability

# 5 Conclusion

We have shown a laboratory experiment of a next generation access system based on a wavelength-division multiplexing passive optical network (WDM-PON). We demonstrated that a new low-cost tunable laser can be realized without TEC and wavelength locker, which will lead to a much lower price as well as better energy efficiency. This device relies on feedback from a centralized etalon inside the OLT. We have shown that the ONU can automatically tune to the desired frequency and keep it within a frequency range of ± 4 GHz. The control algorithms have been implemented in a microprocessor and operated in real-time.

# Acknowledgement

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