Performance evaluation of low-cost pluggable WDM-PON transceivers

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The next generation passive optical networks have the option to employ the wavelength domain to provide bandwidth and flexibility to the users. Each user will be addressed with a specific wavelength from the central office. These specific wavelength transceivers will give a serious inventory management problem to the PON operators. A possible solution is to create transceivers consisting of two parts: colorless and colorful. The colorless part which is wavelength-independent in a small form-factor pluggable is connected externally to a wavelength-selective module. Full characterization of such devices is presented here in order to evaluate their suitability for WDM-PON.

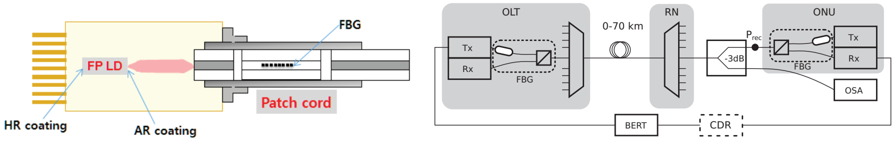
Introduction

Fiber-to-the-Home (FTTH) has been adopted as the most future-proof access network solution. Historically, the majority of FTTH connections in Europe are point-to-point based [1]. In view of cost reduction operators are looking into options for central office (CO) consolidation, i.e. moving the CO towards the metro network. This will only be feasible if fiber sharing can be used. WDM-PON allows for fiber sharing, without the performance degradation due to bandwidth aggregation typical for TDM-PONs. WDM-PON provides increased bandwidth and a virtual Point-to-Point link for each user [2]. Each user will be addressed with a specific wavelength from the CO. However, these specific wavelength transceivers will give a serious inventory management problem to the PON operators. As these transceivers can only operate at a specific wavelength, the operator needs to keep track of the wavelengths of each user. Moreover, the operator also needs to keep sufficient stock of many different transceivers.

A possible solution is to create transceivers consisting of two parts: colorless and colorful. The colorless part which is wavelength-independent in a small form-factor pluggable (SFP) is connected externally to a wavelength-selective patch cord. This can be a lower-cost solution compared to a fully-flexible setup with tunable filters. In this paper characterizations will be presented of these wavelength-selective pluggable WDM-PON transceivers.

Wavelength-Selective Pluggable WDM-PON

The distinctive part of the Pluggable WDM-PON system are the transceivers. They consist of two parts, a colorless SFP module and a colorful fiber patch cord, as shown in Fig. 1a. The optical transmitter components in the SFP module consist of a gain section and a HR coated wavelength-independent rear facet. The gain medium has a broad spectrum over either the entire C or L band. The front reflector of the laser is located in the



(a) (b)

Fig. 1. (a) Schematic representation of the transmitter. Picture courtesy of MEL Telecom. (b) Schematic representation of the experimental setup. BERT denotes the bit error rate tester, CDR the clock-data recovery if present, FBG the pluggable patch cord including a fiber Bragg grating and C/L band splitter.

fiber connector of the patch cord in the form of a fiber Bragg grating (FBG). Due to the small wavelength range where the FBG reflects, the transmitter lases at the wavelength of choice. This particular structure allows us to select the desired output wavelength by plugging in the appropriate patch cord, utilizing the same SFP module. The receiver has a reported operating wavelength from 1260 to 1620 nm, allowing broadband operation.

The system as a whole comprehends mainly the structure of a typical WDM-PON system with bidirectional communication, typically the L band is used for downstream transmission and the C band for upstream. In total 40 wavelength pairs are available, placed on the 100 GHz ITU-T WDM grid. In the Optical Line Terminal (OLT) at the CO side the pluggable patch cord incorporates a C/L band split filter. A 40 channel cyclic AWG combines multiple wavelengths in a feeder fiber connecting the OLT to a Remote Node (RN). In the RN another AWG splits the wavelengths over multiple distribution fibers towards the Optical Network Units (ONU) at the users' premises. Here the same pluggable structure as in the OLT can be used. Alternatively, it is possible to incorporate a passband filter additional to a C/L band splitter at the receiver in the ONU. This would allow the use of a power splitter at the RN, at the cost of an increased split loss compared to an AWG. This would make it possible to use WDM-PON over a standard TDM-PON network without altering the optical distribution network (ODN).

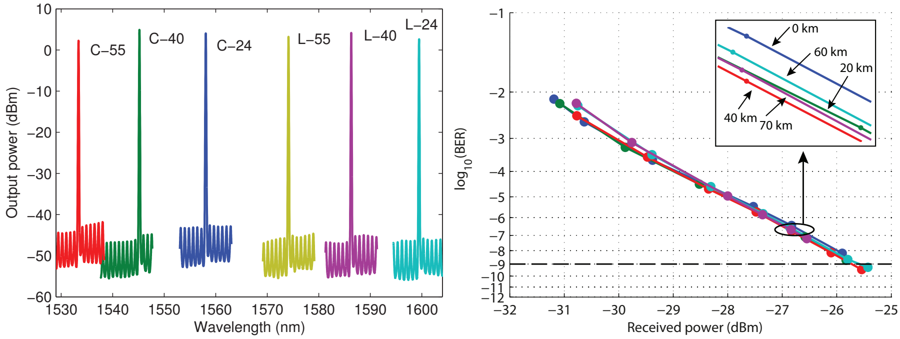
Experimental setup

The experimental setup, as depicted in Fig. 1b, is used to characterize the transceivers. A transceiver, consisting of a SFP module and a pluggable patch cord with incorporated C/L splitter connects to the appropriate port on a 32 channel cyclic AWG. The signal is transported through a fiber spool. After a second AWG, a 3 dB power splitter feeds the signal to both the ONU and an optical spectrum analyzer (OSA).

Data transmission results presented in this paper are under bidirectional operation of the system. Back reflections are considered in a worst-case scenario, i.e. a CW beam is transmitted from the ONU side of the system when data is transferred from the OLT to the ONU side. A power penalty for the receiver sensitivity at BER $= 10^{-9}$, compared to uni-directional data transfer of approximately 3.5 dB is observed if 2.5 Gbps data is transferred. This induced penalty is attributed predominantly to electronic noise in the SFP module, as the penalty remains similar if the transmitted signal from the ONU side is blocked before it enters the patch cord.

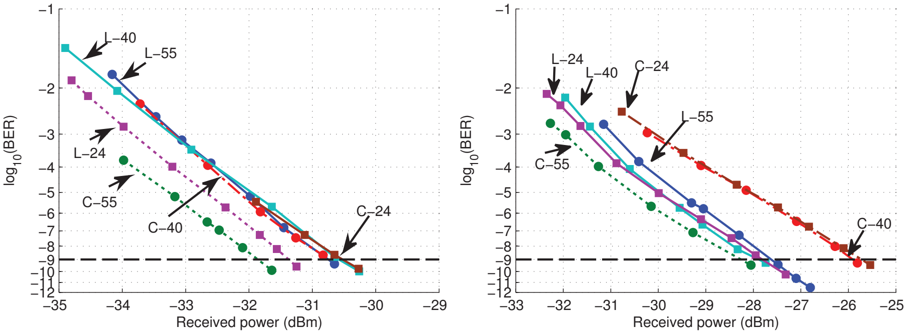
Experimental Results

A combination of two SFPs, one for the C band and one for the L band, and six wavelength filters, ITU-T WDM channels 24, 40 and 55 in the C and L band, have been



(a) (b)

Fig. 2. (a) Spectrum of the six characterized transmitter combinations in ITU-T bands 24, 40 and 55 in the C and L bands, (b) BER curve of 2.5 Gbps data transfer over distances ranging from 0 to 70 km for channel C-24.



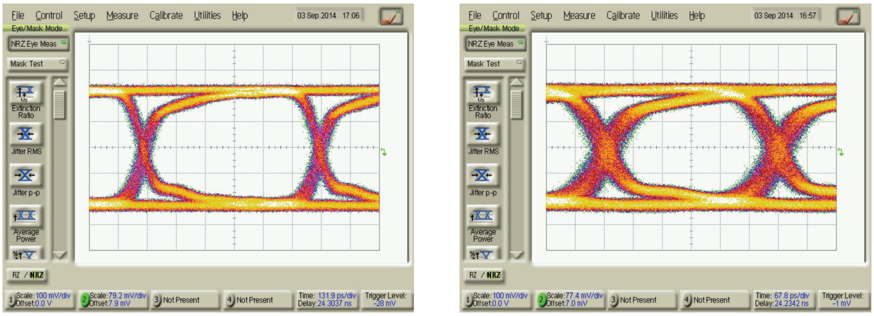
(a) (b)

Fig. 3. BER curve of: (a) 1.25 Gbps data transfer back-to-back for six wavelength channels (b) 2.5 Gbps data transfer over 40 km of fiber for six wavelength channels

investigated. The corresponding wavelengths are 1558.17, 1545.32, and 1533.47 nm for the C band. For the L band the accompanying wavelengths are 1599.50, 1586.31, and 1574.15 nm. Fig. 2a shows the spectrum emitted by the six possible combinations. It can be seen that the peak to sidelobe ratio of the output is larger than 45 dB for all channels. The measured output power of the channels varies between 2.2 and 4.9 dBm among the channels, measurements have been done while a continuous alternating bit sequence was transmitted.

In Fig. 2b BER characterization curves are shown for 2.5 Gbps data transfer in the C-24 wavelength channel at 1558.17 nm for fiber lengths ranging from 0 to 70 km. No power penalty for fiber lengths up to 70 km can be observed as the curves are < 0.3 dB apart and not uniformly decreasing in sensitivity for increasing fiber length. Error free operation at $\text{BER} = 10^{-9}$ was observed for distances up to 60 km. For longer fiber lengths the power budget was insufficient, due to excess losses in our experimental setup.

In Fig. 3a BER curves are shown for 1.25 Gbps over 0 km fiber (B2B), for six different wavelength channels. It should be noted that due to the available clock data recovery equipment, for the 1.25 Gbps case the clock has been transferred electronically B2B,



(a) (b)

Fig. 4. Eye diagrams of: (a) 1.25 Gbps transfer over 20 km of fiber (b) 2.5 Gbps transfer over 40 km of fiber

whereas for the 2.5 Gbps cases presented elsewhere the transmission is with CDR at the receiver end. Similar, in Fig. 3b are BER curves shown for 2.5 Gbps over 40 km fiber for the same six wavelength channels. It is observed that replugging the Rx fiber connector in the transceiver can vary the required power for a certain BER by up to 2 dB. Therefore, it is believed that the difference in performance between the different wavelength channels is not due to different performance of the SFP modules or FBG filters, but due to the necessary replugging of the fiber connectors. Error-free operation at 2.5 Gbps is observed for all channels at power levels > -25.5 dBm. Therefore, for 60 km operation a worst-case power budget of 27.7 dB is available. After allocating 9 dB for two AWGs and 0.25 dB/km$\times$60 km $=$ 15 dB for fiber losses, 3.7 dB is available for connector and excessive losses.

The eye diagrams of both 1.25 and 2.5 Gbps over 20 and 40 km respectively are shown for completeness in Fig. 4a and Fig. 4b respectively.

Conclusion

We presented characterizations of pluggable WDM-PON transceivers, to be used in WDM-PON scenarios where a low-cost solution to the inventory problems of operators is required. Up to 60 km error free operation at 2.5 Gbps is demonstrated. At operation over a distance of 60 km, a power budget margin of 3.7 dB is available. With appropriate filtering in the pluggable patch cord, WDM-PON can be used on a standard TDM-PON network without altering the ODN.

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