Up to 10 Gbit/s transmission in WDM-PON architecture using External Cavity Laser based on Self-Tuning ONU

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Abstract: An external cavity laser is demonstrated with a RSOA at ONU and a mirror at the RN which can be 5km away. A record transmission of 10Gbits/s is shown and compared with performance at 1.25, 2.5, 5Gbit/s.

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1. Introduction

WDM-PON is a candidate technology to provide high bit rate for the Next Generation Passive Optical Networks (NG-PON). Nevertheless, network architecture and technologies used at the ONUs (Optical Network Unit) need to remain cost-effective and prove a possible co-existence with existing access networks. Fig.1 shows a WDM-PON overlay on existing GPON scenario, where a WDM OLT service co-exists with GPON OLT service board in local exchange. An AWG (Arrayed Waveguide Grating) is connected to one of the dark distribution or drop fibers in RN (Remote Node) reusing distribution fiber. One of the major technologies permitting practical implementation of WDM PON system is the optical components development, especially the upstream ONU transmitters. Having advantages of identical functioning, flexibility, simplicity for all the users, and permitting mass of production and deployment, colorless ONU’s transmitters represent major low-cost components for WDM-PON application. Up to now proposed solutions such as tunable laser, remotely-injected devices such as RSOA or FP-LD (Fabry-Perot Laser Diode) which require one or more external active seeding sources at the OLT, prove to be unsatisfactory. Self-seeding of RSOA solutions obviate external active broadband light source. Using a reflection-type FBG (Fiber Bragg Grating) to reflect light for self-injection locking was proposed in [1], to obtain colorless ONU. In this case, a tunable FBGs technology would be required, while the stability versus temperature is a critical issue. Another RSOA self-seeding solution by using a passive reflective path at RN such as BPF (Band Pass Filter) in [2], explores a weak-feedback regime, in which it is impossible to take advantage of the deeply saturated regime of RSOA. Recently a seamless solution based on a FRM (Faraday Rotating Mirror) has been proposed to realize an embedded self-tuning laser cavity as colorless ONU transmitter [3], while the up-stream modulation capacity is still limited at 1,25Gb/s per user. With these prior states of art in mind, we evaluate for the first time a very long self-tuning cavity based on a commercial RSOA and standard mirror up to 5km drop fiber away and we show up to 10Gbit/s up-stream transmission performance.

2. Experimental Setup

Figure 2 depicts an upstream transmission experimental set-up with a self-seeded ONU. The ONU contains only the RSOA which is directly modulated with a Pulse Pattern Generator (PPG). The laser cavity consists of the reflective facet of RSOA and an 80% reflective FM (Fiber Mirror) which is connected to the AWG via a 30/70 splitter at the RN (see fig.2 represented in red). Here the AWG acts as wavelength multiplexer and demultiplexer and the self-tuning element. Thus, the ONU operating wavelength is chosen by the AWG channel. In our experience, we used two different 8-channels AWG in the C band. The first device is DWDM device with 100GHz bandwidth at -3dB with an IL (Insertion Loss) of 1.3dB. The second one has a bandwidth of 200GHz at -3dB with the same IL of 1.3dB. The total length of the cavity varies from few meters to 5km. Also, 2dB of extra losses are added inside the cavity to account for last distribution fiber connection losses. At the OLT, transmitted signals are received after several kilometers of feeder fiber by an APD (Avalanche Photo-Diode) and a CDR (Clock and Data Recovery). An error...
free transmission is considered for BER (Bit Error Ratio) lower than $10^{-3}$ when a FEC (Forward Error Code) is used. Such an experimental set-up can be equally used for a downstream transmission with a RSOA at OLT to realize a symmetrical WDM-PON architecture.

3. Laser characterizations

Several characteristics are evaluated in terms of spectrum with and without the mirror (cf. vignette Fig. 2), RIN (Relative Intensity Noise) (cf. Fig. 3 and Fig. 4) and chirp parameter (cf. Fig. 5). The laser emission wavelength is centered at 1554nm. For a 1km long cavity self-tuning laser, a high RIN level is measured at low frequency and can be optimized from -85dBc/Hz to around -115dBc/Hz by increasing the biased current of RSOA. A higher RIN level is observed when the cavity length is increased up to 5km for the same biased current (see in Fig. 4). The chirp parameter is then measured applying the fiber transfer function method originally proposed by F. Devaux in [4]. Fig. 5 shows the measured AM frequency response through 90km SMF (in blue) and model according (in red). A first analysis shows two contributions of the phase and amplitude coupling: one coming from the gain section of the RSOA (estimated to $\alpha=7$ based on the model), and a second expresses itself through the large oscillation.

4. Transmission results and discussions

We firstly evaluate the lower speed modulation performance at 1.25Gb/s and 2.5Gb/s for different cavity length. The RSOA is biased at a current of 100mA and modulated by non return to zero PRBS (Pseudo Random Bit Sequence) data with a length of $2^{31}-1$.

![Graphs showing BER measurements for back-to-back and after 10km/20km SMF link at 1.25Gb/s and 2.5Gb/s for 1km long cavity and 5km long cavity.](image1)

![Graphs showing AM frequency response through 90km SMF, measured in blue, model according to Devaux in red.](image2)

Fig. 6 and Fig.7 represent BER measurements versus received power for 1km and 5km long laser cavities with an extra optical attenuation of 2dB inside the cavity. In the former case, the laser output power is around -2dBm with an Extinction Ratio around 4.5dB (cf. vignettes Fig 6-7). The Back-to-Back (BTB) sensitivity at 1.25Gbps and 2.5Gbps for achieving a $10^{-3}$ BER is about -35dBm and -33dBm respectively, which means that an OB (Optical Budget) of 33dB and 31dB between OLT and laser can be tolerated. Both of two results prove the possibility of co-existence with B+ class GPON of standard at 1.25Gb/s and 2.5Gb/s. The power penalties after 20km of SMF (in the feeder) are less than 0.5dB at 1.25Gbps and 3dB at 2.5Gb/s.
In case of 5km-cavity, despite the higher RIN level and higher cavity total round trip losses, which lead an error floor appears in BTB case at 2.5GB/s and after fiber transmission case. We can still obtain an OB which is 32dB at 1.25Gb/s and 29.5dB at 2.5Gb/s respectively with a laser output power of around -3dBm. Results prove equally the possibility of co-existence with B+ class GPON of standard with such a long cavity. The power penalties after 20km of SMF are less than 1dB at 1.25Gb/s and 6.5dB at 2.5Gb/s.

As described previously, for higher bit rate modulation at 5Gb/s and 10Gb/s, an AWG with larger bandwidth and lower IL is required to reduce the cavity total round trip losses. The extra distribution losses of 2dB are equally removed to minimize cavity losses. Due to the optical bandwidth limitation of RSOA component and higher frequency loss at high bit rate transmission, we use for the first time a pre-emphasis technology to maintain eyes opening by correcting waveform amplitude to optimize transmission performance. As signal source, the PPG generate a NRZ data PRBS with a length of $2^{31}-1$ and the clock is sent into a 4-tap Emphasis which generate an emphasis data to modulate our RSOA-based laser. Evaluation of 1km-cavity was done at a bit rate of 5Gb/s with the RSOA current biased at 150mA, which resulted in an output power of about 1.5dBm with 2.8dB of ER. To achieve a $10^{-3}$ BER in B2B, the required power is about -22dBm permitting an OB of 23.5dB. After 5km of SMF (cf. Fig. 8), the power penalty is less than 0.5dB at a BER of $10^{-3}$. When we increase the bit rate up to 10Gb/s, in case of 10m-cavity, we successfully obtained 1.6dB of ER and BTB curves with a sensitivity of -20.5dBm for a BER at $10^{-3}$, which means an OB of 22.3dB can be tolerated. It is possible to realize a 1km-transmission in the feeder with a penalty of 5.5dB at the considered BER. The cavity length can also be increased up to 500m to keep the same transmission performance. BER measurement for 1km-cavity is also performed at 10Gb/s. After propagation through 1 km of feeder fiber, the BER obtained was $4.10^{-3}$.

4. Conclusion

This paper shows for the first time an extra-long self-tuning cavity laser based on a commercial RSOA and standard mirror up to 5km distribution fiber long at 1.25 and 2.5Gb/s. This performance shows the feasibility of convergence with existing GPON architecture. Transmission up to 5Gb/s and 10Gb/s is also realized by applying a simple pre-emphasis treatment. The cavity length can be attained up to 1km at 5Gb/s and 500m at 10Gb/s respectively for achieving a $10^{-3}$ BER with low penalty after propagation through certain reach of SMF link. The experimental results show the possibility to achieve 10Gbit/s bit rate by using colorless self-tuning extra-long ONU transmitter.

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6. References