Applications of Injection Locked FP Laser in WDM Networks

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Abstract: *We discuss here the use of injection-locked FP laser in a variety of applications including as a potentially low cost modulator in WDM access network, for wavelength switching at the WDM transport layer, and for wavelength conversion in a reconfigurable wavelength routing network.*

Data Remodulation in WDM Access Networks

The deployment of WDM technology in access and distribution layer requires the introduction of much lower cost version of those components used in the transport layer, but probably with less stringent requirements on performances and reliability. A key high cost element in WDM system implementation is the stocking and footprint problem associated with the laser sources of various wavelengths. A possible, yet expensive, solution is to use a wavelength-tunable laser. Other approaches include the use of a centralized light source [1-5] where all the wavelength channels are distributed to add-drop nodes or optical network units (ONU) from the Central Office (CO). The CO may send data packets with some blank time slots to each assigned ONUs, where the blank time slots will be used for upstream data through modulation by a local modulator [1-3]. However, this time-slot sharing scheme has the disadvantage of low throughput and imposes stringent requirements on timing if high-speed data are transmitted. In [4], multi-frequency laser is used for the downstream and spectral-sliced LED is used for the upstream, resulting in a limited upstream data rate. FP lasers injection-locked by a CW signal from a centralized spectral-slicing source are demonstrated for a WDM upstream transmitter in [5]. Our approach is to employ injection locking of FP laser by the downstream signals denoted by a particular wavelength, and the upstream data are imprinted on the injection-locked signal through direct modulation on the FP laser diode [6]. Several downstream modulation formats, including OOK, BPSK and analog, were demonstrated with OOK remodulation to carry the upstream data.

Fig.1 shows the experimental set up, which simulates the add-drop function of an ONU. The laser diode used is a commercial diode with standard cavity length (longitudinal cavity mode spacing ~1.3 nm) and air-facet reflectivity. We found that for injection locking, the input injection power (measured at the fiber input) has to maintain above −15 dBm, resulting in a side mode suppression ratio of ~30 dB. Once injection locked, the output power from the FP laser diode is clamped irrespective to the power and modulation speed of the injected signal. We have evaluated the injection locking based remodulation schemes over several modulation formats including (1) 10-Gb/s NRZ OOK data as downstream signal and 1-Gb/s NRZ OOK upstream data with FP laser diode biased at threshold current [6]; (2) 2.5-Gb/s BPSK downstream data with 1.25-Gb/s OOK upstream data; and (3) subcarrier multiplexed downstream analog channels (20 and 40 channels with channel spacing 6 MHz, ranging from 50 MHz to 600 MHz) with 1-Gb/s OOK upstream data. For the OOK to OOK remodulation case, both the downstream and the remodulated upstream signals are measured after propagating over 50 km of single mode fiber to simulate the network distance. The bit error rate performances are shown respectively for the three cases in Fig. 2(a)-(c), suggesting the least power penalty (~0.5 dB) arising in the BPSK-downstream-OOK-upstream data scheme. It should be noted that there exists an optimal extinction ratio (~8 dB) in the downstream data for the OOK-downstream-OOK-upstream scheme (see Fig. 3) due to the trade-off between the downstream power penalty arising from a degraded extinction ratio [7], and better injection locking for the upstream data with a poor extinction ratio in the downstream. In addition, the wavelength operation range of these remodulation schemes almost covers the entire semiconductor gain spectrum, supporting the whole C-band.

All-Optically Controlled Wavelength Switching

All-optically controlled fast wavelength switching can be achieved through dual wavelength injection locking of FP laser diode [8]. The proposed scheme is illustrated in Fig. 4, showing the wavelength switching between λ_1 and λ_2 by injection of a third control signal λ_C. The mechanism is based on the absorption characteristics of the higher-order transverse modes (subsidiary modes) in the FP-LD. The absorption has a 3-dB bandwidth of 0.08 nm, and a band rejection ratio of over 12 dB (Fig.5). It should be noted that this absorption is polarization dependent; the polarization of the injected signal should be aligned with that of the subsidiary mode. Through injection locking, the FP mode comb is red shifted, thus switching can be achieved between two wavelengths separated by the shift. Fig.6 shows the experimental setup. The 10-Gb/s channels are separated from each other by 0.3 nm. The results are shown in Fig. 7. The switching time is observed to be less than 500 ps. The wavelength detuning (red shift) can be controlled by the control signal power. In our experiment, a 0.6-nm red shift can be obtained by an injected power of 0 dBm.

Dynamically reconfigurable Wavelength Routing

In optical routing network, the routing path can be dynamically reconfigured if wavelength converter is employed. Wavelength conversion can be achieved through injection locking [9]. Fig. 8 depicts the experimental setup, demonstrating dynamically reconfigurable routing. By simultaneously injecting a dropped signal and a signal from tunable laser into the FP-LD, the dropped signal at λ_i will then be wavelength converted into λ_k under dual-wavelength injection locking [9]. The wavelength-converted signals will eventually be routed to different destination by a waveguide grating router. The routing information is encoded by a subcarrier tone superimposed on the data. Different tone frequency denotes routing to different output port. In the experiment, a 2.5-Gb/s 1546.1-nm signal with a tone of 10 GHz or 12 GHz is generated via two modulators, one for tone addition and the other for data modulation. With a tone of 10 GHz or 12 GHz, the signal will be converted to wavelength 1541.7 nm or 1554.6 nm, respectively. Fig. 9 depicts the spectrum for the dual wavelength injection-locked FP-LD. In the proposed experimental setup, the wavelength converted signal is filtered by passing an isolator and fiber-Bragg grating (FBG) with reflection at the drop wavelength such that no fast tuning bandpass filter is required. Fig.10 shows the BER performance for the wavelength converted signals with wavelengths of 1554.6 nm (up-converted) or 1541.7 nm (down-converted) for the 2.5-Gb/s 1546.1 nm input signal encoded with 10-GHz or 12-GHz tone, respectively. The signals are measured after wavelength routing by the WGR at channel 4 and channel 16. The corresponding eye diagrams for error-free measurement are shown in the insets of Fig.10. The power penalty difference between the two different converted signals is smaller than 0.5 dB, mainly due to the asymmetric gain-profile of the FP-LD as well as the difference in wavelength detuning from the converted wavelength to the FP modes. On the other hand, since the extinction ratio of the wavelength converted signal is decreased after injection-locking, a 0.8-dB power penalty is observed between the wavelength converted signals and the original input signal. The power measured for the input signal and the probe signals are -12.6 dBm and -7.25 dBm, respectively. Any longitudinal modes of the FP-LD can be used for the converted wavelength, therefore over 30-nm spectral range for discrete wavelength conversion can be demonstrated [9]. Thus a low cost, low power consumption all-optical wavelength converter is successfully demonstrated for reconfigurable wavelength routing networks.

References

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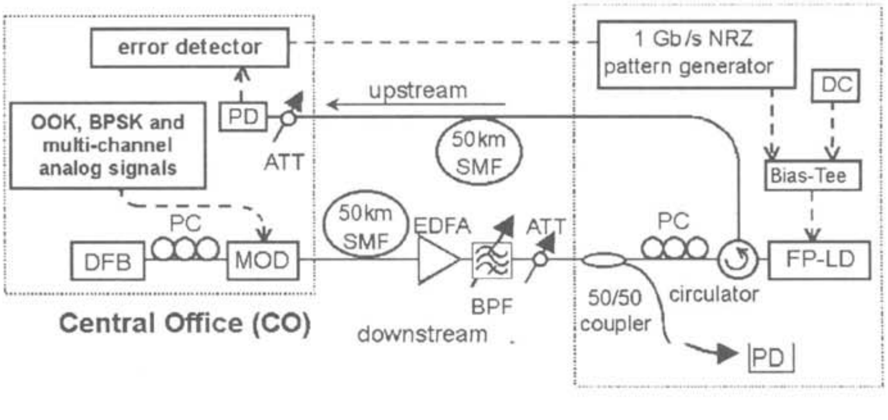

Fig. 1 Experimental setup for upstream data remodulation using injection locking.

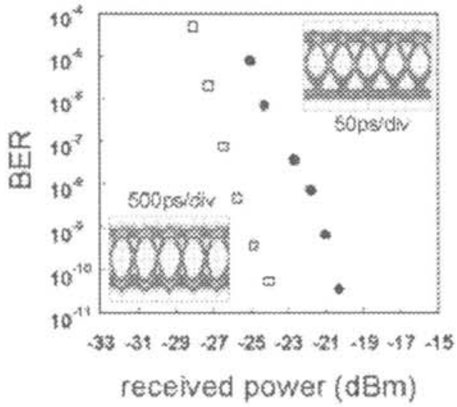

Fig. 2(a) BER performance for (•) 10Gb/s OOK downstream signal; and (□) 1 Gb/s OOK-downstream-OOK upstream remodulated.

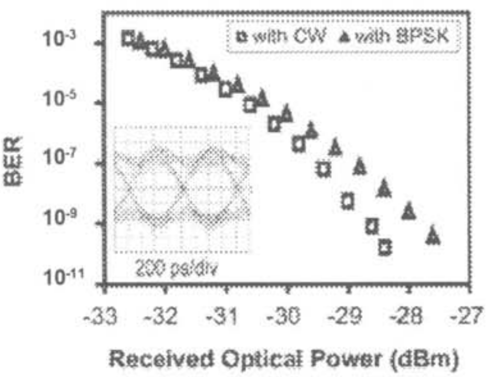

Fig. 2(b) Upstream BER performance for BPSK to OOK remodulation scheme. Downstream data at 2.5 Gb/s and upstream data at 1.25 Gb/s.

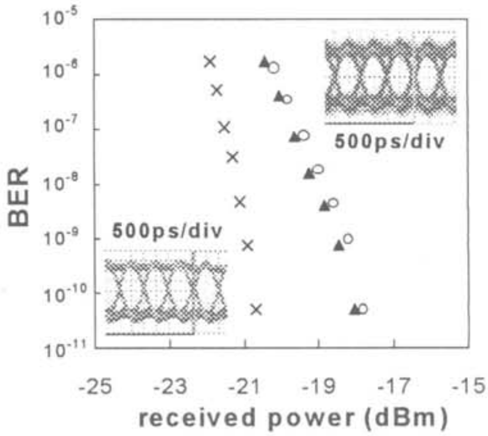

Fig. 2(c) Upstream BER performance for analog-downstream OOK-upstream remodulation. (x) downstream is cw; (σ) 20-channels and (o) 40-channel analog downstream channel.

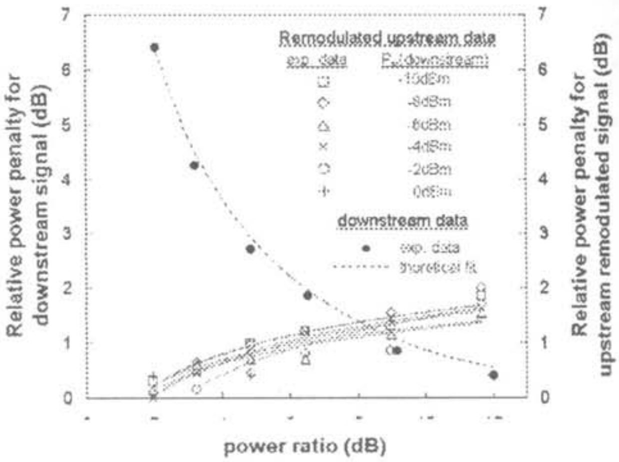

Fig. 3 Relative power penalties for the upstream and downstream signals with different extinction ratios of downstream data.

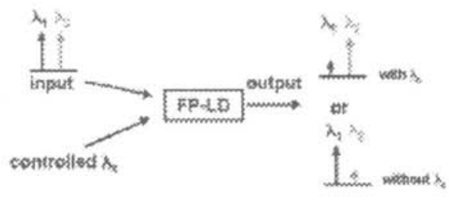

Fig.4 The proposed wavelength switching scheme using injection-locked FP-LD which can be opticall) controlled by another injected signal in λ_c

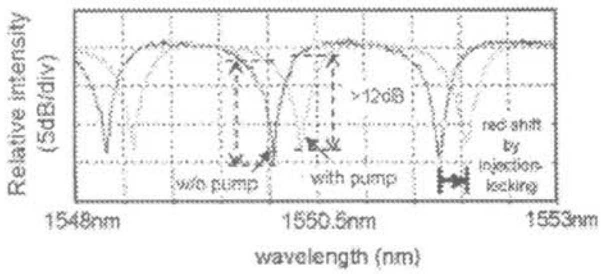

Fig. 5 The absorption spectra for the subsidiary modes with and without optical pumping (Note the red shift of the absorption null due to injection locking)

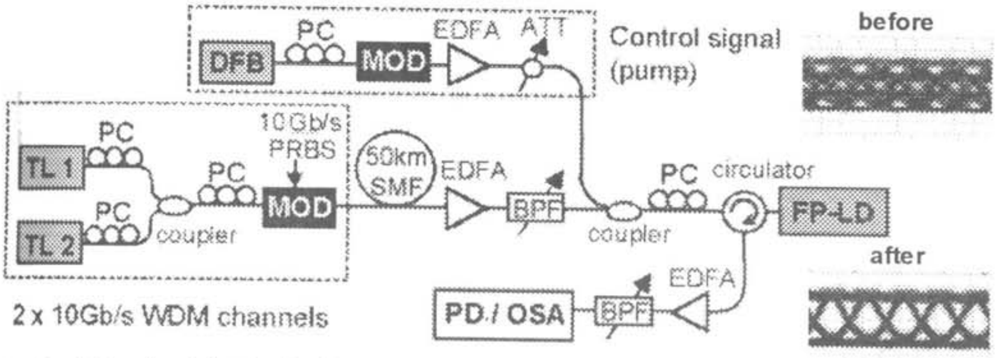

Fig. 6 Experimental setup for the wavelength switching scheme by using injection-locked FP-LD. Insets show the eye diagrams before and after passing through the FP-LD.

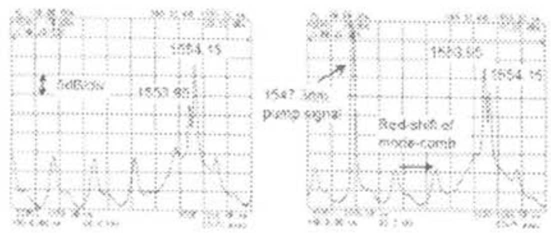

Fig.7 Spectra show (left) a 10dB suppression of 1553.95nm signal by the subsidiary mode; and (right) the absorption wavelength switched to the 1554.15nm signal after injection-locking.

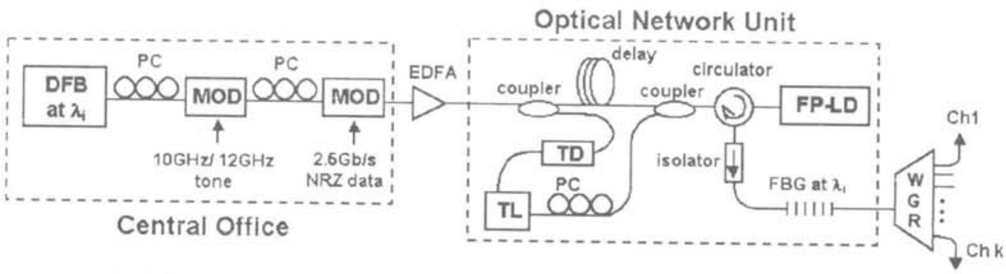

Fig.8 The experimental setup for the 2.5Gb/s wavelength conversion and routing using injection-locked FP-LD

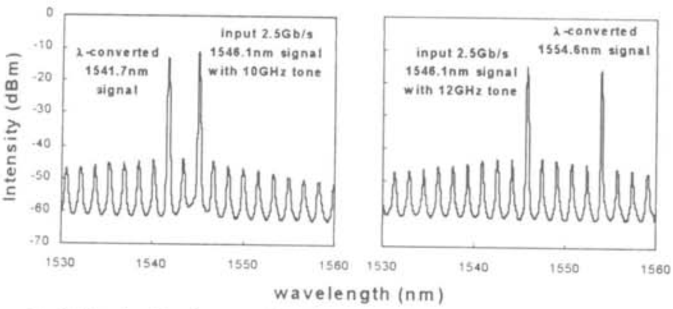

Fig.9 Spectra for the wavelength conversion of the 2.5Gb/s 1546.1nm signal under dual wavelength injection-locking, (left) down-convert to 1541.7nm and (right) up-convert to 1554.6nm.

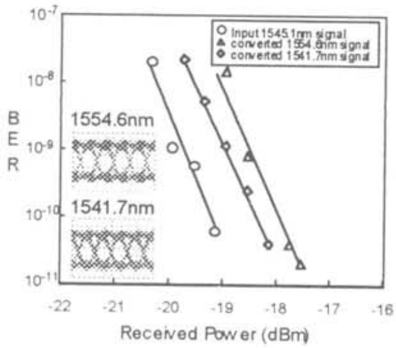

Fig.10 BER performance for the wavelength converted signals measured after routing by the WGR. The 2.5Gb/s 1546.1nm signal with tones of 12GHz and 10GHz were wavelength converted to 1554.6nm and 1541.7nm respectively. (insets: eye-diagrams with 200ps/div)