Cross-Channel Interference Due to Wavelength Drift of Tunable Lasers in DWDM Networks

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***Abstract*—The authors present an investigation of the wavelength stability of a tunable laser (TL) transmitter and its impact on the performance of a 2.5-Gb/s dense wavelength-division-multiplexed (DWDM) system. Performance of a DWDM system, employing such a TL, is characterized by examining the cross-channel interference caused by this drift when the channel spacing is set to 12.5 and 25 GHz. Results obtained show that the wavelength drift affects the system performance by introducing an error floor in the case of 12.5-GHz spacing. This error floor can be mitigated by increasing the blanking time of the TL during the channel transition, in order to reduce the wavelength drift.**

***Index Terms*—Sampled-grating distributed Bragg reflector, tunable lasers (TLs), ultradense wavelength-division multiplexing (UDWDM), wavelength drift measurement.**

I. INTRODUCTION

THE USE of tunable lasers (TLs) in wavelength-division-multiplexed (WDM) networks for optical switching, routing, and networking has gained a lot of interest in recent years. Employment of TLs as tunable transmitters in wavelength packet switched (WPS) networks is one of the possible applications of these devices [1]–[3]. In the above-mentioned systems, the transmitted information could be encoded onto a destination dependent wavelength and the routing of traffic could be performed on a packet-by-packet basis. The performance requirements for the devices will strictly depend on the architecture and parameters of the network such as channel spacing, packet length, number of wavelengths used, etc. As the demand for broadband connectivity increases, it may be expected that TLs will be employed in metro and access networks within ultradense wavelength-division-multiplexed (UDWDM) systems that have many channels with spacing <50 GHz. Such systems would be able to provide significant capacity in order to maximize users. This reduction in channel spacing, however, puts more stringent requirements on the devices used in the system. In terms of the transmitter, the wavelength stability becomes very important, since even a small drift could cause serious cross-channel interference.

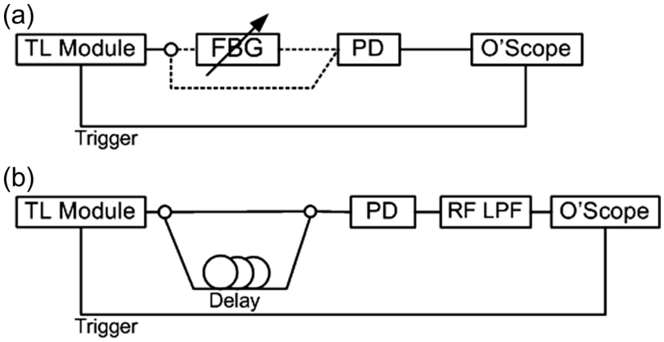

Fig. 1. Frequency drift measurement setup to measure the magnitude and duration of the frequency drift after the TL comes out of blanking: (a) FBG method; (b) self-heterodyning method.

In this letter, we investigated the possibilities of using TLs in UDWDM WPS networks. In our experiments, we used a TL module employing distributed Bragg reflector technology that can access 80 wavelength channels in the conventional C-band with channel spacing of 50 GHz. In order to minimize interference due to spurious output from the switching process, the laser output is blanked for the first 60 ns after a transition between wavelengths is initiated [4]. After blanking, the currents are set to give an output within 15 GHz of the target wavelength channel. A wavelength locker then locks the laser to the target wavelength. The wavelength locker comprises an etalon filter for wavelength monitoring followed by a servo-loop controller. Other locking mechanisms exist [5] that can better reduce the magnitude of wavelength drift, however, these are more complex and costly. The focus of this letter is to examine the drift associated with an existing, practical locking mechanism that is likely to be used in initial systems using TLs. We first measured the instantaneous frequency drift of a TL after the blanking time, and then examined the impact that such a drift would have on a neighboring data channel in a two-channel pseudo-UDWDM network when the channel spacing was set to 12.5 and 25 GHz. We also investigated how increasing the blanking time reduces the frequency drift and improves system performance.

II. FREQUENCY DRIFT MEASUREMENT

The frequency drift of the TL, after the blanking time, was measured using a tunable fiber Bragg grating (FBG) [6] with a 3-dB bandwidth of 27.5 GHz, using the experimental setup shown in Fig. 1(a). We were able to obtain oscilloscope (O'scope) traces of the variation of optical power through the optical filter as a function of time due to the frequency drift of the laser. This was carried out with the TL settling into a target wavelength that was set to two different positions [shown on Fig. 2(a)] on the bandpass characteristic of the FBG (by tuning

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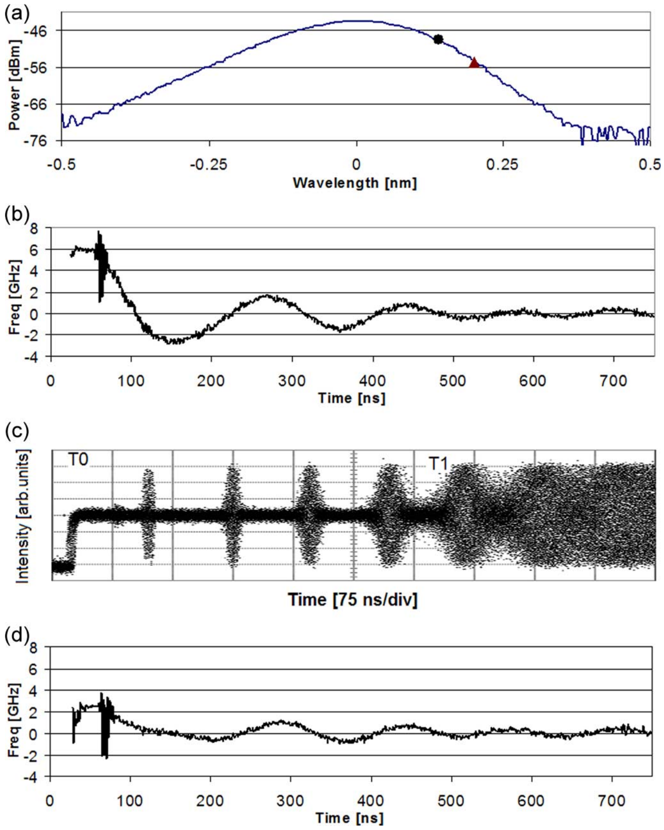

Fig. 2. (a) Frequency response of the FBG showing the placement of the TL target wavelength; (b) measured frequency drift for TL switching from Channel 42 to Channel 52 using FBG method; (c) corresponding drift measured using self-heterodyne method; (d) drift measured using an extended blanking of 200 ns.

the central bandpass wavelength of the FBG). We operate at these points, as it gives us an extended range over which to measure the full wavelength drift. However, this is at the expense of a lower signal-to-noise ratio and a more complex nonlinear wavelength drift to power transmission mapping. The frequency drift measurement was performed for numerous channel transitions. We present the result for transition between Channel 42 (1548.915 nm) and Channel 52 (1544.924 nm). This transition was found to have one of the larger drifts.

From the filter profile, we know the wavelength or frequency difference between the steady state levels of the measured traces, and we know how power variation relates to the frequency variation, so we can accurately determine the frequency drift of the TL after the blanking time. This calculated frequency drift is presented in Fig. 2(b). As the TL emerges from blanking, it is ~6 GHz from the target channel. The wavelength locker can be seen to turn on ~30 ns after the TL comes out of blanking. The locker causes a fast fluctuation in output wavelength for a small period of time (~15 ns), after which the wavelength drift is characterized by a damped oscillation.

The result presented in Fig. 2(b) is consistent with a temporal frequency measurement technique presented in [7]. Using the setup shown in Fig. 1(b), an optical self-heterodyne system was set up where the delayed signal from the tuning TL was mixed with itself when already tuned to its target wavelength. The beating between the outputs from both fibers (on the photodiode) generates an electrical signal, whose frequency corresponds to a difference in frequencies between the two signals. The detected photocurrent after passing through a low-pass filter with a 3-dB bandwidth of 117 MHz was sent to an oscilloscope. The tuning cycle after the blanking time is shown in Fig. 2(c). At the beginning of the transition (T0), the heterodyne signal was of a frequency greater than 117 MHz, therefore, it was filtered out and no signal was observed on the oscilloscope. As the laser settles to its target wavelength, the frequency of the heterodyne signal decreases and the filter passes the signal, finally settling to its target at time T1.

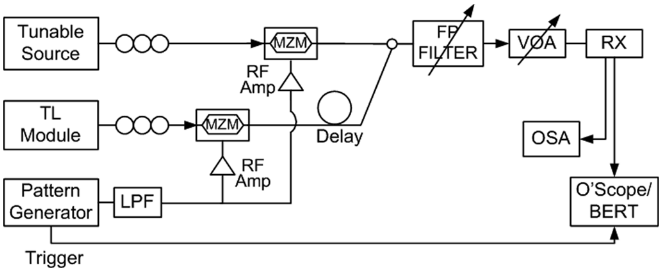

Fig. 3. Setup used to investigate the effect of the measured wavelength drift in a DWDM network.

III. IMPACT OF DRIFT ON DWDM NETWORK

A. 25-GHz Channel Spacing

The setup shown in Fig. 3 was used to investigate the effect of the measured wavelength drift in a DWDM network. First, a two-transmitter DWDM system with channel spacing of 25 GHz was investigated. The TL was set to switch into and out of Channel 52. A fixed laser was used as a second transmitter operating 25 GHz away from the TL target channel at 1544.724 nm. Each channel was externally modulated with a 2.5-Gb/s nonreturn-to-zero pseudorandom bit sequence with a pattern length of $2^7 - 1$. The same data was used for both lasers, therefore, it was necessary to decorrelate the information carried in each channel. This was achieved by passing one of the channels through an appropriate length of fiber of 3 m. The two channels were then combined together and the fixed channel was filtered out using a Fabry–Pérot (FP) tunable filter with a 3-dB bandwidth of 6 GHz. The demultiplexed channel then passed through a variable optical attenuator before entering the receiver stage which consisted of an erbium-doped fiber amplifier, an optical filter, a photodiode, and an electrical amplifier. The signal spectrum, eye diagram, and the bit-error rate (BER) of the detected channel were examined.

The BER of the filtered channel was measured as a function of the received optical power for various TL configurations—when the interfering TL was 1) set to Channel 42 (>500 GHz away from filtered channel), 2) set to Channel 52 (25 GHz from filtered channel), and 3) switching from Channel 42 to Channel 52. The TL was set to switch at a rate of 5 kHz.

There was a minimal power penalty (<0.1 dB) when the TL was static at Channel 52 (i.e., 25 GHz from the fixed channel) compared to when the TL was static at Channel 42. When the TL was switching, there was no additional power penalty or degradation in system performance. This is expected as at a channel separation of 25 GHz the measured drift of the TL as it comes

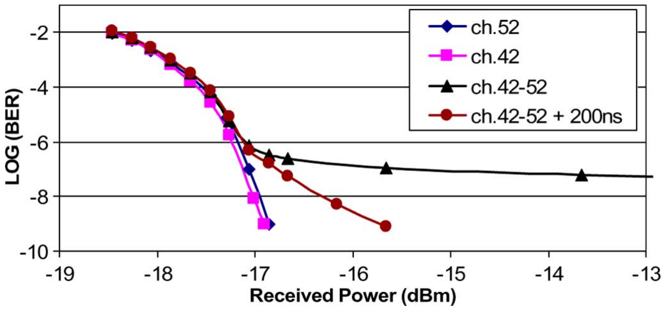

Fig. 4. BER measurements for 12.5-GHz channel spacing with default blanking time (▲), and for 12.5-GHz channel spacing using an extended blanking time of 260 ns (●).

out of blanking is too small to fall within the passband of the filtered channel.

B. 12.5-GHz Channel Spacing

To investigate the effect of the frequency drift on a 12.5-GHz channel spaced system, the wavelength of the fixed channel was tuned to 1544.824 nm. The center wavelength of the FP filter was also tuned accordingly. The BER measurements of the filtered channel versus received optical power were repeated using the same TL configurations as for the 25-GHz channel spacing, and are presented in Fig. 4. When the TL switches between Channels 42 and 52, the wavelength drift, after blanking, degrades the system performance and introduces an error floor at a BER of 10^{-7}. This BER is the average number of errors on the fixed channel over 1) the time at the beginning of the data transmission when the TL is settling into Channel 52, 2) the time when the TL is settled into Channel 52, 3) the time when the TL is at Channel 42, and 4) the time when the TL is blanked. The switching TL causes a burst of errors only at the beginning of the data stream, as it emerges from blanking and begins to settle into Channel 52. At this time, the drift is large enough such that it enters the filter passband of the fixed channel. As the TL approaches its target wavelength, the errors reduce [8], eventually giving no errors when the TL is within $\sim$3 GHz of its target wavelength. Thus, if the TL can be locked with less drift, then the interference can be reduced.

IV. EXTENDED BLANKING TIME

The laser blanking time after the wavelength transition is initiated was subsequently increased from the default value of 60 to 260 ns. This was done in anticipation that the laser wavelength would be closer to the target wavelength once the blanking time ends; however, this would also result in a corresponding increase in the effective TL switching time, thereby reducing network throughput. The drift of the TL as it comes out of blanking was measured again for the channel transition 42 to 52 as in Section II. The frequency drift measured using the tunable FBG filter is presented in Fig. 2(d). It can be seen that increasing the blanking time resulted in the expected reduction in the frequency drift of the laser output in comparison with Fig. 2(b).

The same experimental setup and method used in Section III was also used to investigate if this reduction in drift improves the system BER performance. The results are presented in Fig. 4. With the extended blanking time, the system performs with a residual power penalty of $\sim$1.1 dB (relative to the case when the TL laser is static) at a reference BER of 10^{-9} due to interference from the adjacent TL channel. This power penalty could not be reduced by further increasing the blanking time as we believe it is primarily due to the frequency drift induced by the locking mechanism.

V. CONCLUSION

The magnitude and duration of the TL wavelength drift, as it emerges from the blanking and locks into its target wavelength, has been investigated. The measured drift (>7.5 GHz) is small enough not to cause problems for 25-GHz channel-spaced WDM networks. However, we have shown that as channel spacing decreases this issue becomes more important, resulting in critical error floors at 12.5-GHz spacing. In order to avoid this interference, it is necessary to decrease the wavelength drift of the TL. In this case, this was achieved by increasing the blanking time of the TL which ensures that the TL output is sufficiently close to its target wavelength to prevent cross-channel interference. This will, however, reduce the throughput of the network. Other solutions may be to use a narrower optical filter to select out the target channel, or to investigate how the tuning characteristics of the laser maybe improved.

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