Cross-Channel Interference Due to Wavelength Switching Events in Wavelength Packed Switched WDM Networks

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Abstract: An important characteristic of tunable lasers, that may affect system performance, is that they can generate light at various wavelengths as they tune between different wavelength channels. These spurious components could cause severe cross-channel interference if the tunable laser is used in a WDM network. In this paper we investigate the effect of such interfering signals, generated by up to three tunable lasers during a switching event, on the BER of a data channel transmitted on the same wavelength as the spurious components. The results show that it is vital to attenuate the output of tunable lasers during their wavelength transition in order to prevent system performance degradation.

Keywords: Optical networks, tunable lasers, wavelength division multiplexing, cross-channel interference

Introduction

The use of Tunable Lasers (TLs) in WDM networks has gained a lot of interest in recent years. They lend themselves to many applications in WDM networks, the simplest of such being back-up transmitters [1]. The use of these lasers for optical switching, routing and networking poses a bigger and more challenging task. In such a case, the information transmitted over the network could be encoded onto different wavelengths depending on the destination. Routing of traffic could be performed on a packet-by-packet basis. A TL transmitter could be used to generate a desired wavelength for each packet to be transmitted [2- 6].

The main characteristics of a TL that need to be taken into account, when used in the above-described networks, would be wavelength tuning range, output power, switching time, channel stability and Side Mode Suppression Ratio (SMSR) [7]. One of the most suitable types of tunable transmitter that exhibits a wide tuning range (excess of 60 nm) and a substantial SMSR (> 40 dB) is the Sampled Grating Distributed Bragg Reflector (SG-DBR) [1, 8]. However, one of the difficulties in employing this type of laser in a WDM system is that when the laser is tuned between wavelengths it can generate spurious components [9]; these in turn would interfere with other channels in use. In previous work [10], we presented the characterisation of cross-channel interference from a single TL that was switched between two wavelengths. The spurious components generated during the switching event placed an error floor on the BER of a channel transmitted at the same wavelength as the spurious components. It was also proven that in order to achieve an acceptable BER the output of the TL must be attenuated by a certain level during the transition.

DBR based nanosecond wavelength switched lasers are used in this work. These lasers can be switched between any set of 50 GHz spaced ITU channels within the C-band with a maximum switching time of 200ns, after which the laser output is guaranteed to be within +/-2.5 Ghz of the intended frequency. Depending on the particular channel transition the time taken to be within +/-15 GHz of the final frequency is typically in the order of 20-50 ns, during this 20-50 ns period spurious output wavelength may be generated by the TL. The main difference in comparison to the TL module used in [10] is a Semiconductor Optical Amplifier (SOA) placed at the output of the tunable laser. The SOA can be turned off to blank the laser output for a period of 50 ns starting from the moment the laser tuning (to a different wavelength) is initialised. This attenuates the spurious components that are generated during the switching event. In this paper the effectiveness of this method of reducing the cross-channel interference caused by multiple TLs in future wavelength packet-switched WDM networks is verified.

Experimental Setup and Results

The experimental set-up used is shown in Fig.1. It consists of three computer controlled TLs. Each TL is switched between two wavelengths. A Pattern Generator (PG) is used to generate a Pseudo Random Bit Sequence (PRBS) at 2.5 Gbit/s, which is then externally modulated onto an optical carrier generated by a Continuous Wave (CW) Laser. The combined output power of the three TLs is adjusted using a Variable Optical Attenuator (VOA) before being coupled with the data channel. This ensures that the powers of the four lasers (from the three TLs and the externally modulated CW laser) are equalised. The receiver consists of an Erbium Doped Fibre Amplifier (EDFA), an Optical Band Pass Filter (OBPF) – to filter out the data channel, a VOA to vary the optical power falling on the detector, a photodiode, an electrical amplifier and a low pass filter. An error analyser is used to measure the BER of the recovered data channel.

In order to characterise the cross channel interference, the TLs are switched continuously between different pairs of wavelengths: TL1 between 1531.5 and 1554.5 nm, TL2 between 1542.9 and 1560.6 nm and TL3 between 1544.9 and 1555.3 nm. Using these particular transitions it is found that significant spurious modes are generated around the same wavelength, 1548.04 nm (within a window of 0.16 nm). As it would be in an actual system the three TL modules switch independently of each other. In order to verify how these undesired modes would influence the performance of a WDM system, the wavelength of the data channel is set in the middle of this window at 1548.04 nm. The optical spectrum of the TL outputs with blanking disabled is shown in Fig. 2. From the figure it can be seen that the TLs produce a series of spurious components during the transition between wavelengths – especially at the location where the data channel is to be multiplexed in. The optical spectrum of the TLs with the blanking enabled is presented in Fig.3. In this case the spurious components are attenuated since the SOAs at the output of the TLs are momentarily switched off (for a period of ~50 ns from the moment the lasers begin to tune).

In order to verify the impact of the spurious components generated by the TLs on the data channel, the BER of the latter is measured as function of the received optical power for various TL switching configurations (with blanking enabled and disabled). Fig. 4 presents the results when the blanking is disabled for: (i) the average BER of the data channel multiplexed with one TL switching, (ii) the average BER of the data channel multiplexed with two TLs switching, and (iii) the BER when the TLs are on but not switching. The effect of multiplexing the switching TLs with the data channel is to place an error floor on the performance of the monitored data channel. The average error floor for one TL switching is 7.5×10^{-3}. This increases to 1.5×10^{-2} when a second TL is added. The BER of the data channel multiplexed with the three TLs switching can not be measured due to such a high level of noise. The eye diagrams of the received data signals, when the data channel is multiplexed with the three TLs before being filtered out, for the case when the TLs are on but not switching and for the case when they are switching, between different pairs of wavelengths, are shown in Fig. 5(a) and Fig. 5(b) respectively. It can clearly be seen that the optical filter selects out both the data channel and the spurious emissions generated within the filter window by the switching TLs. These spurious emissions cause errors on the data channel during the switching time of the TLs.

Switching the SOA off for 50 ns from the moment that the transition is initiated reduces the interference from the TL as the laser is guaranteed to be within +/- 15 GHz of the final wavelength when it emerges from the blanking. This can be seen in Fig. 6 which presents the results when the blanking is enabled for: (i) the BER of the data channel when the TLs are on but not switching (ii) the average BER of the data channel with one TL switching, (iii) the average BER of the data channel with two TLs switching and (iv) the BER of the data channel with the three TLs switching. However, it can also be seen that for such a scenario there is a slight power penalty incurred due to coupling the data channel with the output of the TLs that are switching, even though blanking is enabled for 50 ns after the switching begins. This gets progressively worse with the addition of more TLs, giving a penalty of ~0.4 dB for coupling with the three TLs switching. This may be due to the attenuation blanking level of the SOA not being high enough. The power penalty may also be attributed to not all the spurious modes being blanked as the TL blanking may not continue long enough after the switch occurs. This subject will be investigated in detail in future work using TL modules which have variable blanking times and levels.

In order to characterise how the switching interval time (i.e. the time TL remains tuned to a particular wavelength before switching) impacts the performance of the system the BER of the data channel as a function of the switching interval time for one TL switching with blanking disabled is measured. The results acquired are plotted in Fig. 7. The BER improves as the switching interval time is increased. This is due to the fact that the spurious components, which degrade the quality of the data signal, are generated less often as the TL remains tuned to one wavelength for a longer time. As expected, the degradation in performance of a wavelength packet-switched WDM system, due to the spurious wavelengths emitted from the TL, will be determined by how often the TL switches. This in turn will be strongly dependent on the packet length used in such systems.

Conclusions

Wavelength tunable lasers are becoming more and more important for the development of future WDM wavelength switched networks. In this paper it has been shown that one of the main problems associated with these devices is the generation of undesired spectral components during the switching event. This issue becomes more important as the switching interval time is reduced. It has been demonstrated that the solution to this problem is to use an SOA at the output of the TL. The SOA effectively blanks the output during the transition to attenuate the spurious components that may be generated during that time. However, if a large number of TL’s are employed in a network, then the system penalties due to this effect maybe non-negligible, as shown in our work with three TLs. In WDM networks employing a large number of TLs it may be necessary to increase blanking levels to prevent performance degradation due to wavelength switching events.

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Figure Captions

Fig. 1 Experimental configuration to determine how the spurious wavelength signals emitted during switching of the TL modules affect a multiplexed data channel lying between the TLs' output wavelengths.

Fig. 2 Optical Spectrum of TLs switching with blanking disabled.

Fig. 3 Optical Spectrum of TLs switching with blanking enabled.

Fig. 4 Average BER vs. received optical power measurements for the case when the data channel is multiplexed with the combined TL module output with blanking disabled (i) when one TL Module is switching, (ii) when two TL Modules are switching, and (iii) when no TLs are switching.

Fig. 5 Eye diagrams of the received data signals, when the data channel is multiplexed with the three TLs before being filtered out, for (a) the case when the TLs are on but not switching, and (b) for the case when the TLs are switching between different pairs of wavelengths.

Fig. 6 Average BER vs. received optical power measurements for the case when the data channel is multiplexed with the combined TL module output with blanking enabled (i) when no TLs are switching, (ii) when one TL Module is switching, (iii) when two TL Modules are switching, and (iv) when the three TL Modules are switching,.

Fig. 7 BER of the data channel vs. the switching interval time of a TL module.

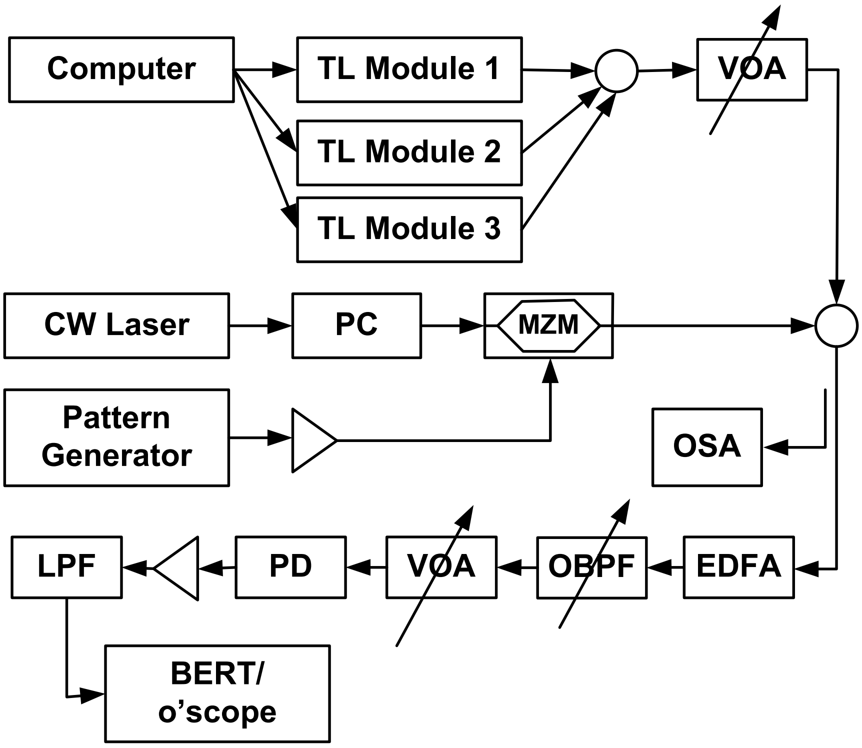

FIGURE 1

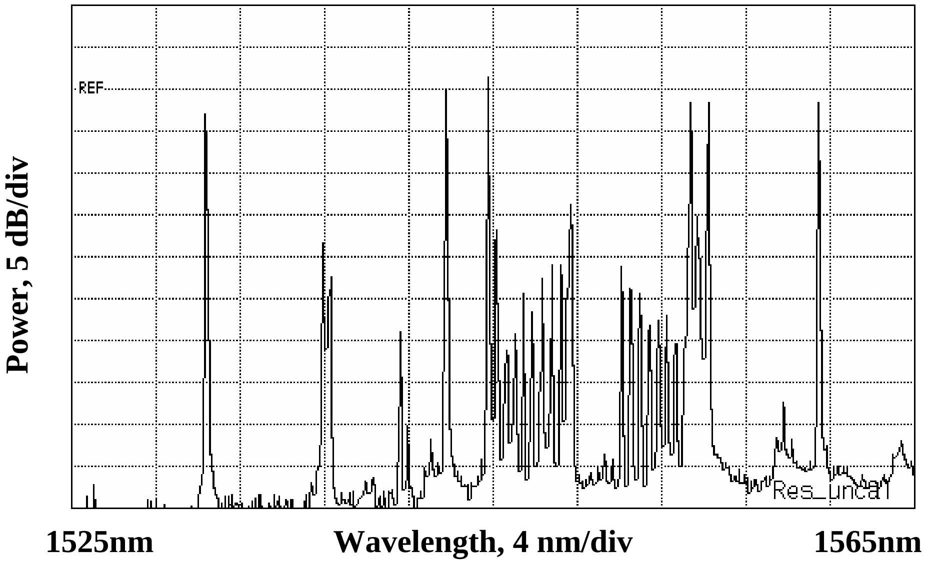

FIGURE 2

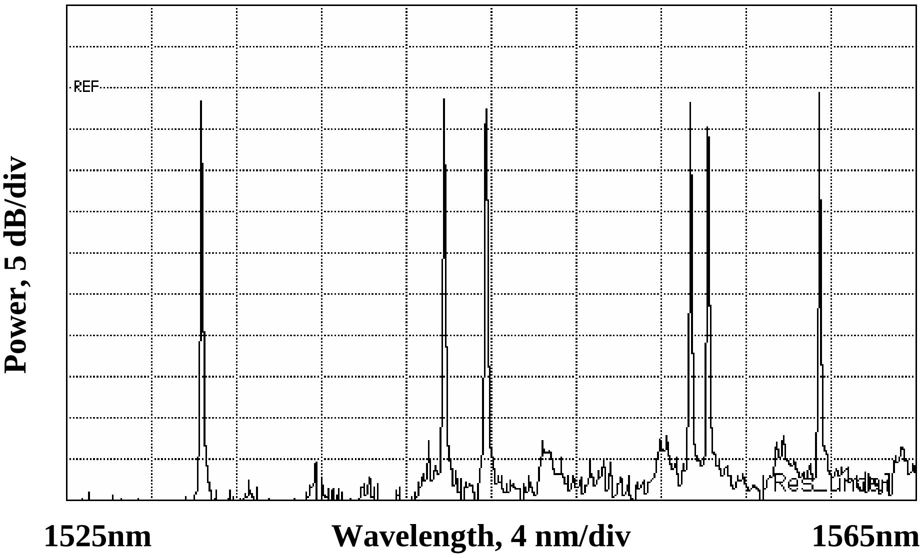

FIGURE 3

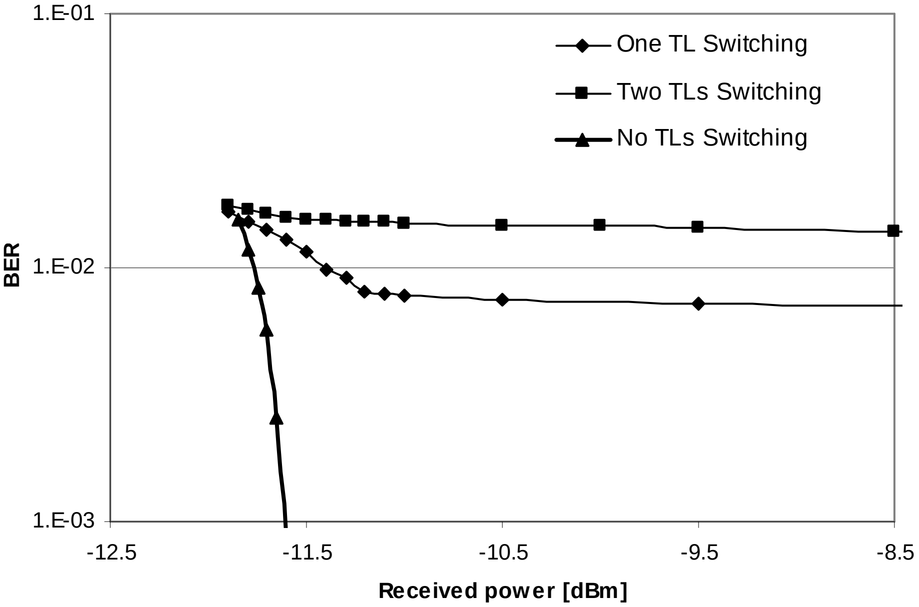

FIGURE 4

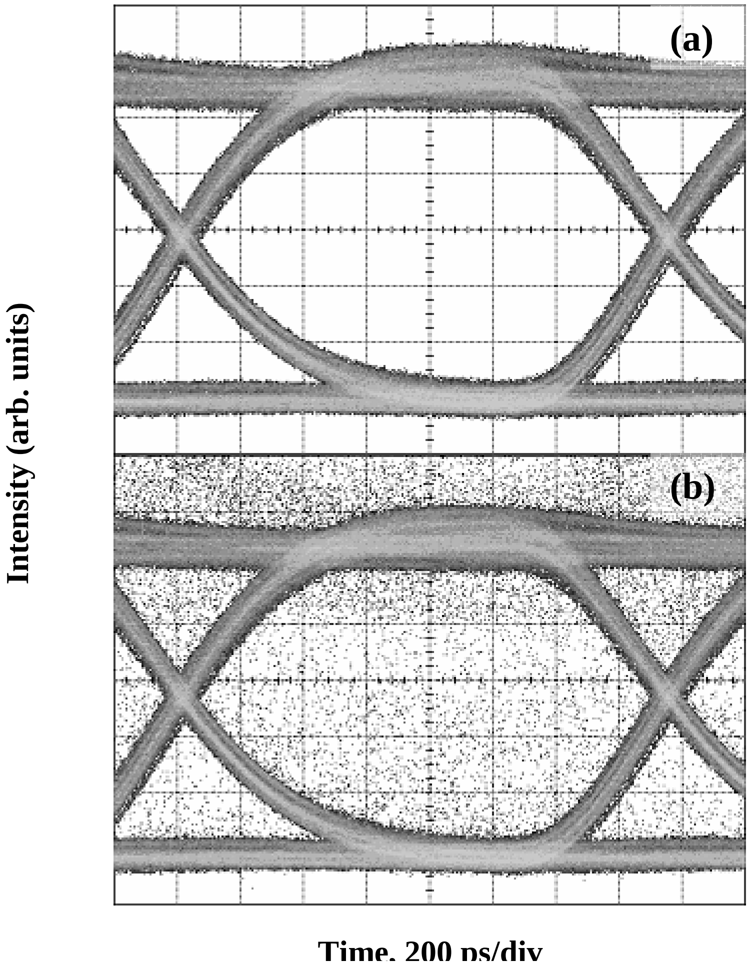

FIGURE 5

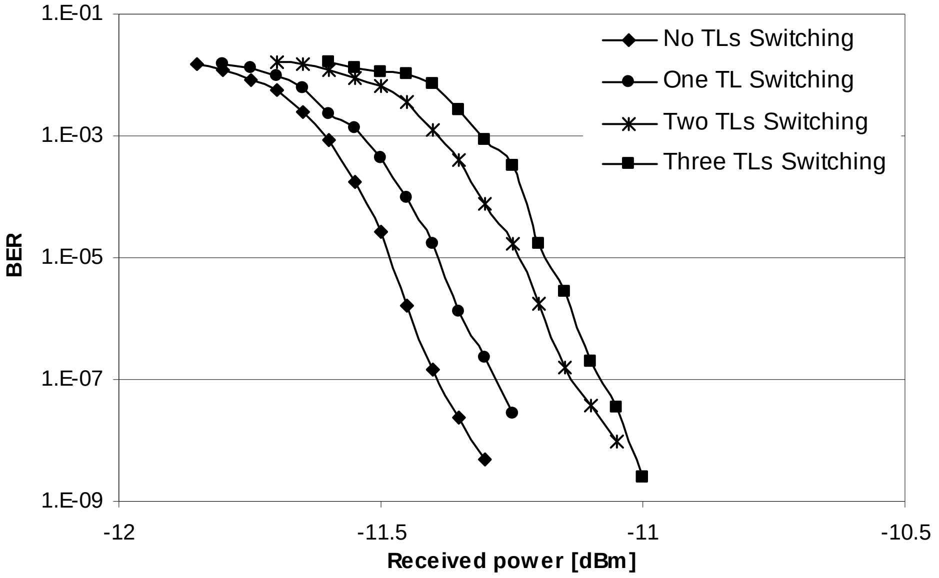

FIGURE 6

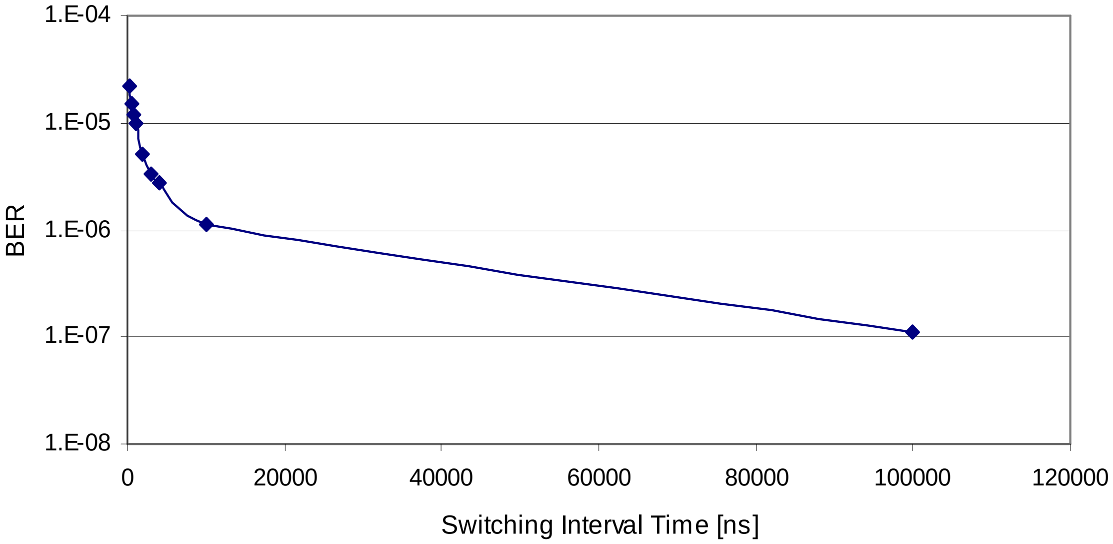

FIGURE 7