# Semiconductor Laser White Noise Suppression by Optical Filtering with Ultra-Narrowband FBG

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**Abstract:** The white frequency noise of semiconductor lasers is attenuated significantly by optical filtering with an ultra-narrowband fiber Bragg grating. This noise reduction will improve carrier phase estimation in coherent receivers of multi-symbol signals.

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## 1. Introduction

Multi-symbol modulation is considered to increase spectral efficiency in future coherent networks. Denser symbol constellations translate into a more stringent phase estimation requirement and a decrease in acceptable laser linewidth [1,2]. The phase of transmitter and local oscillator lasers must remain stable during the time span over which phase estimation is carried out. At 10 and 25 Gbaud, white frequency noise is mostly of concern. The strong white frequency noise of semiconductor lasers (SCLs) is expected to be a limiting factor for high-order multi-symbol modulation.

White frequency noise affects only the wings of the optical spectrum of a narrow-linewidth SCL. It can be attenuated markedly by optical filtering of these wings. A fibre interferometer made of two fibre Bragg gratings (FBGs) can be used to this end. Such filter is short, rugged, and can be easily packaged [3]. It can produce a narrow transmission peak a few tens of MHz wide, while providing strong attenuation up to tens of GHz away from this peak. It can be tuned to maintain spectral alignment between its transmittance peak and an optical carrier.

Experiments were performed with such a filter providing a single transmittance peak. A multi-peak filter can be fabricated as well for filtering an ITLA tuneable over the C-band.

## 2. Experimental Setup

The experimental setup is illustrated in Fig. 1. The injection current of a SCL is modulated at 890 Hz for frequency locking to an all-fibre narrowband filter composed of two FBGs separated by 4 mm in the same fiber. Each grating is 15 mm long, for a filter total length of 34 mm, which could be reduced significantly [3]. The relative phase of the gratings determines the location of a transmission peak within the reflection spectrum. It is centered in the middle when the phase shift is $\pi$. Peaks as narrow as 10 MHz have been so obtained, whereas that used in the current experiment had a 40 MHz FWHM bandwidth.

The laser signal propagates through polarization maintaining (PM) fibre, a polarizing isolator, a circulator, and on to the optical filter. Light reflected by the filter is detected and sent to a lock-in amplifier that compares the phase of the modulation on the detected signal with that of the modulation sent to the laser and produces an error signal. This error signal is sent to a proportional–integral–derivative controller (PID) that controls a TEC driver to shift thermally the filter transmission peak and frequency lock it to the laser signal. The laser optical carrier is thus transmitted by the filter while fast frequency fluctuations falling outside of the transmission peak are suppressed.

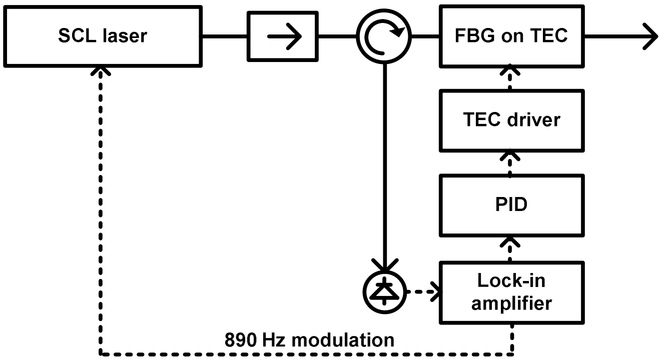

Fig. 1: Experimental Setup.

## 3. Experimental Results

The measured filter transmission spectrum is shown in Fig. 2. The narrow notch transmission maximum is underestimated on this figure because of the number of measurement samples. Insertion loss at the transmission peak was measured to be -0.3 dB. The gratings being written in a PM fibre, the rejection was limited by the polarization extinction ratio (PER) of light, which was measured to vary between 20 and 23 dB versus time. This explains the measured filter rejection of 20 dB, while it should exceed 35 dB in theory. The maximum measured optical power transmitted by the filter was 13 dBm.

Measured power spectral densities of frequency noise (PSDFN) are shown in Fig. 3. The frequency noise measurement setup comprised an interferometer with a free spectral range of 819 MHz that was kept in quadrature by a heating wire. The interferometer is used as a frequency discriminator that translates frequency fluctuations into intensity fluctuations [4]. Both outputs of the interferometer were sent to a balanced detector to suppress RIN from the measurement and measure only frequency noise. The bottom curve shows a noise floor due to photodetector thermal noise, which limits the range of meaningful measurements to frequencies below 600 MHz. The laser used for these measurements was a low-noise, high-power commercial DFB laser. The upper curve shows the PSDFN of the free-running laser without noise filtering, showing clearly a white frequency noise floor of $10^4$ $Hz^2/Hz$. Optical filtering attenuated this noise by more than 20 dB at frequencies above 300 MHz, as expected from the measured transmittance of the filter.

Optical filtering degrades the laser RIN by about 40 dB from -160 to -120 dBc/Hz in the optical filter bandwidth, i.e. up to about 40 MHz. Frequency noise is translated into intensity noise by the optical filter acting as a frequency discriminator, an effect probably enhanced by the 890 Hz modulation of the laser injection current. This modulation causes an optical frequency excursion of a few tens of MHz bringing laser emission on the side of the transmission peak, where frequency discrimination is maximized. If so, this RIN degradation should be avoided by increasing the modulation frequency so that modulation sidebands fall outside of the transmission peak, as the Pound-Drever-Hall technique suggests [5]. In any case, these intensity fluctuations are slow compared to the symbol rates in coherent systems and should be taken care of by balanced detection and DSP algorithms.

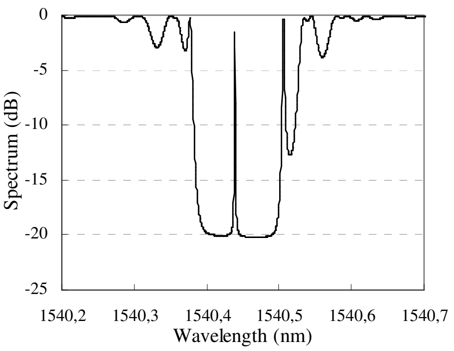

Fig. 2: Measured optical filter transmission spectrum.

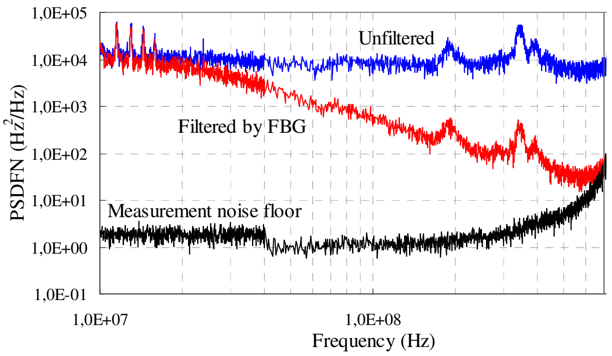

Fig. 3: PSDFN measured on a DFB SCL.

## 4. Tuneability and integrability

In the context of telecommunications, two important features for a laser source are tuneability over the whole C-band, which removes the need to have a different laser for each channel, and a form factor compatible with integration into line cards. To obtain full C-band tuneability with the proposed optical filtering scheme, a multi-channel filter can be designed. Multi-channel filters can be produced by adding a periodic modulation to the phase of an underlying FBG structure, a process known as phase sampling [6]. For example, a FBG providing 40 MHz (FWHM) transmission peaks over 51 channels was designed. A Gaussian apodisation profile was chosen in order to avoid channel spectral overlap. A 1014-µm periodic phase sampling cell was added to the grating phase to produce replicas of the spectral response at 100 GHz intervals. The maximum index change of $1.5\times10^{-3}$ is compatible with manufacturing. The transmission spectrum is shown in Fig. 4 together with a zoom over 3 channels. By thermally tuning a multi-channel FBG, a transmission notch can be centered on any wavelength within the C band. Thus, using a multi-channel FBG, the proposed filtering approach can be applied to a tuneable laser such as the ITLA standard for telecommunications.

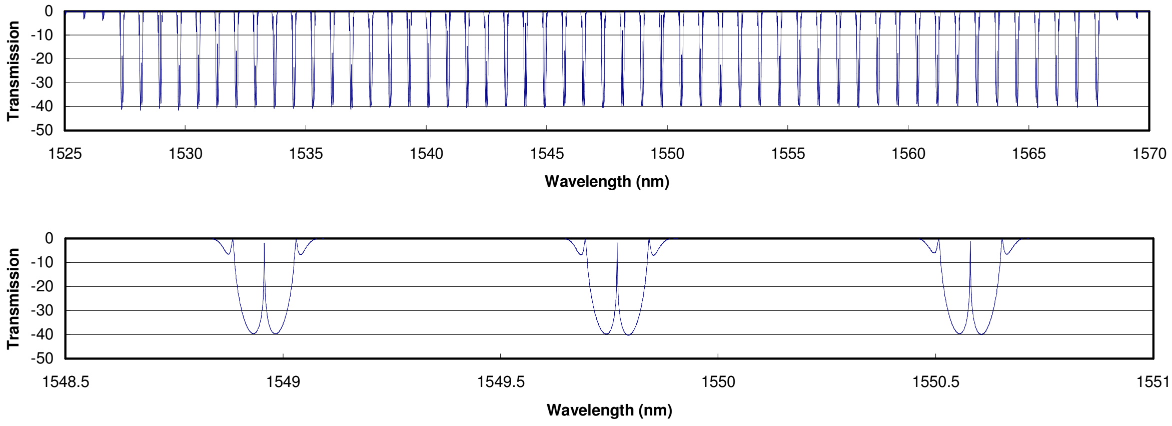

Fig. 4: Multi-channel optical filter transmission spectrum.

The experiment of the previous section was repeated with an ITLA having a linewidth of 100kHz. Fig. 5 shows a reduction in white frequency noise by optical filtering similar to that observed with the DFB laser, even though the noise floor prevents meaningful results above about 200 MHz.

The optical filters considered here are of the same type as FBG filters used for optical dispersion compensation in direct detection links. Tuneable dispersion compensators of the sort have found widespread commercial acceptance and are integrated into line cards. The optical filters discussed here are much shorter and thus even better adapted for integration.

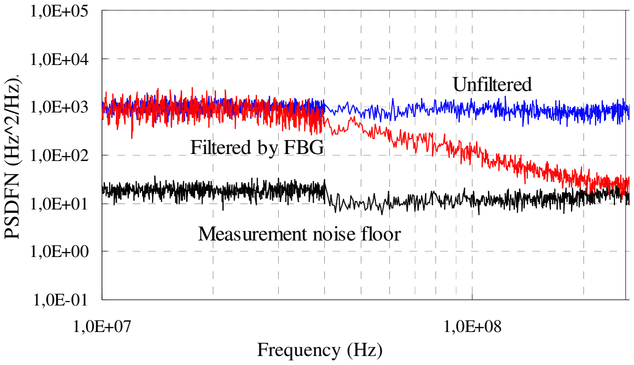

Fig. 5: PSDFN measured on an ITLA.

## 5. Conclusion

A practical solution for reducing the white frequency noise of DFB SCL and ITLA lasers has been demonstrated. White frequency noise attenuation has been realized by optical filtering with a FBG-based Fabry-Perot interferometer, which displays a transmission peak a few tens of MHz wide centered in a multi-GHz reflection bandgap. This optical filter is short, rugged and easily tuned for locking to a laser signal. Phase sampling can be used to produce a multiplicity of transmission peaks uniformly distributed over the whole C-band, allowing reduction of the white frequency noise in a tuneable laser. The small form factor of this optical filter is compatible with integration into line cards.

## 6. References

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