Biasing a Diode Laser at the Self-Mixing Crossover Improves Immunity to Backreflection

Silvano Donati, Enrico Randone
Dipartimento di Elettronica, Università di Pavia, Via Ferrata 1, I-27100 Pavia, Italy
e–mail silvano.donati@unipv.it

Abstract: The adverse effects of back-reflected waves on a diode laser used as a transmitter can be substantially mitigated if the current biasing is set at a specific value, the self-mixing crossover which can be found by a simple setup. A de-sesitization of the reflection effects by a factor of 25 dB has been observed.

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1. Introduction

As it is well known, retro-reflected waves affect the operation of a single-mode laser used as a transmitter, impairing both line width and phase noise. Insertion of an optical isolator is mandatory between the source and the line. On the other hand, reflected waves are used to advantage in the self–mixing interferometer (SMI). In the SMI, light from a single-mode laser diode is focused on the remote target, and a fraction of the back–scattered light re–enters the laser cavity, where it is coherently mixed with the lasing field. This induces a modulation of the emitted power in form of an interferometer signal with the phase information of path length traveled by the field from the laser cavity to the target and back [1,2]. The signal is detected by the monitor photodiode usually provided in the laser package. Of course, the difference between the two cases above is that back reflection is not under a good control for the transmitter laser, whereas it is a slow-varying and coming from a well defined distance in the latter case.

Recently, we have carried out an analysis [3] to compare the different signals available in a SMI (Fig.1): S_1 exiting from rear-mirror, S_2 from the front mirror on the same side of the remote target, and V_{ak} across the junction. Analyzing these signals, we find that the front mirror S_2 changes from in-phase to a phase-opposition respect to S_1 and V_{ak}, as bias current is increased. This is because the field reflected at the front mirror (folded arrow in Fig.1) is added to the field leaving the laser whereas it is missing from the rear-mirror. Denoting with $m_1= \Delta S_1/S_1$ the modulation index of the self-mixing signal ΔS_1 superposed on a dc component S_1, and similarly for $m_2=\Delta S_2/S_2$, the analysis according to the scheme of Fig.1 provides the following results [3]:

$$m_1 = (- T_1/\sqrt{R_1}) \sqrt{A} \cos 2ks \; [(2\gamma L \ln R_1R_2)-1] \qquad (1)$$

$$m_2 = (- T_1/\sqrt{R_1}) \sqrt{A} \cos 2ks \; [(2\gamma L \ln R_1R_2)-1 - R_1/T_1] \qquad (2)$$

Here T, R are the (power) transmission and reflection of mirrors, A is the attenuation in propagation up to target at distance s and back, and $2\gamma L$ is the gain per pass of the laser. Term $-R_1/T_1$ at the right hand side of Eq.2 is the contribution reflected from the front output mirror. The minus sign is due to a double passage of this contribution in reflection respect to the other in transmission, resulting in a cumulative $2(\pi/2)=\pi$ phase difference.

Examples of waveforms ΔS_1 and ΔS_2 measured with the self-mixing interferometer are shown in Figs. 2 and 3. In the setup, we used an 825-nm laser diode from Hitachi (ML8325) and a collimator lens to focus the spot on the target, a piece of white paper glued on a loudspeaker. The loudspeaker was driven by a sine wave at audio frequency, with a few wavelengths of amplitude swing. In addition, writing the gain per unit length as [3]:

$$\gamma = A\, I_{bias} - B \qquad (3)$$

where I_{bias} is the current fed to the laser diode, and A, B are constants, we can express Eqs.1 and 2 in term of the bias I_{bias} and be able to calculate the ratio m_1/m_2 of modulation index, as plotted in the diagram of Fig.4. Here, the experimental points come from measurements of waveforms like those in Fig.3, at different currents.

From the above discussion, it is clear that the disturbance due to reflected wave is ideally canceled out in the front output S_2 at the crossover point $I_{bias}= I_{CO}$. To evaluate in a practical case the cancellation, we may define a back-reflection suppression ratio BSR as the reduction (in dB) of the spurious components added to the signal spectrum. If the spurious component of S_1 is taken as the reference, then the suppression ratio easily follows as BSR= 10 $\mathrm{Log}_{10}[m_1/m_2]$. In Fig.5 we plot the experimental frequency spectrum measured at crossover and at high current (where $m_1/m_2 \approx -1.2$). The peak corresponding to the fundamental frequency content of the self-mixing signal (waveform of Fig.2) is reduced of about 25 dB by working at a bias near the crossover.

References

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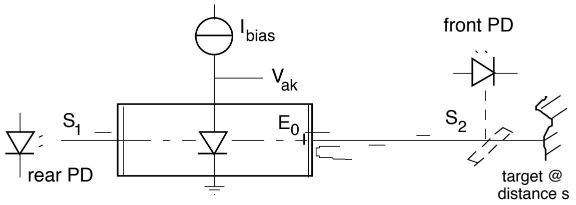

Fig. 1. Signals available in a self-mixing interferometer: S_1 is taken at the rear-mirror output (usually by the monitor photodiode); S_2 is the output from the front mirror, and V_{ak} is the voltage across the laser diode junction. Analyzing these signals one can find that S_2 has a crossover (vanishes) at a certain bias current, whereas S_1 and V_{ak} increase monotonically with I_{bias}.

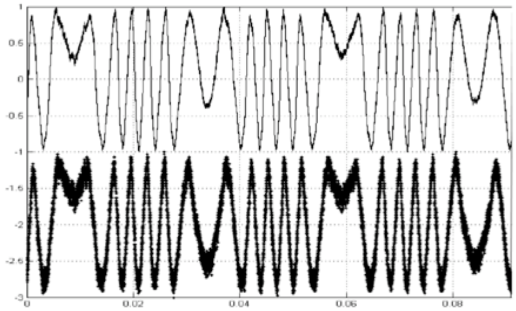

Fig. 2. Rear (top) and front (bottom) output signals, S_1 and S_2, taken moderate bias I_{bias}=50 mA where they are in-phase. The target is a loudspeaker driven at audio frequency with a sine wave at ≈4 μm peak-to-peak amplitude.

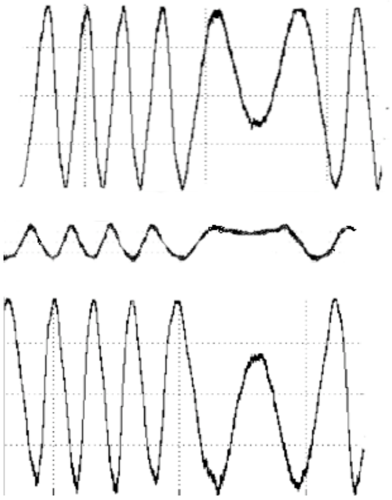

Fig. 3. Self-mix signal S_2 at different bias currents. Top: I_{bias}=50 mA, moderately above threshold; middle: I_{bias}=58 mA, about the crossover; bottom: well above threshold, at I_{bias}=80 mA where the self-mixing signal S_2 has changed polarity respect to S_1.

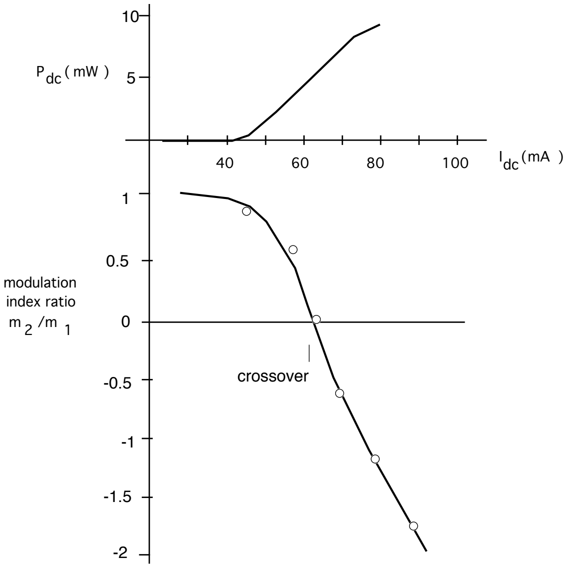

Fig. 4. Power-current diagram (top) and the ratio of modulation index m_2/m_1 versus bias current. Threshold is at 45 mA and the crossover of S_2 signal at a bias of about I_{bias}=63 mA. Dots are experimental points.

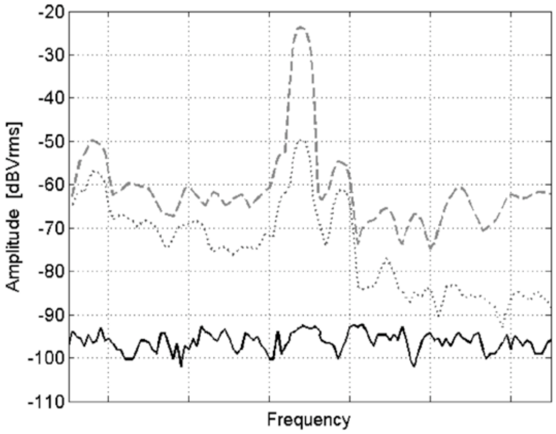

Fig. 5 The frequency spectrum of signal S_2 for I_{bias}=80 mA (at which m_2/m_1=-1.2), top trace, and at I_{bias}= I_{CO}= 60 mA (at which m_2/m_1≈0), middle trace; noise floor is the bottom trace. No optical isolator is used. The peak corresponds to the fundamental frequency contained in the signals of Fig.2. The disturbance is reduced, comparing the top and middle traces, of a factor BSR ≈ 25 dB.