RELATIVE INTENSITY NOISE FOR MODE-LOCKED HYBRID SOLITON PULSE SOURCE

Nuran Dogru — *e-mail:dogru@gantep.edu.tr*
M. Sadettin Ozyazici — *e-mail:sadi@gantep.edu.tr*
Gaziantep University, Faculty of Engineering, Department of Electrical & Electronics Engineering, Gaziantep, Turkey

Key words: Mode-locked laser, fiber Bragg grating

ABSTRACT

In this study the effect of spontaneous emission noise on mode-locked Hybrid Soliton Pulse Source (HSPS) utilizing uniform fiber Bragg grating is investigeted and the relative intensity noise (RIN) is calculated using a numerical solution of couple mode equations. It is found that high feedback cause additional noise peaks in the RIN spectrum .

I. INTRODUCTION

Laser diodes are intrinsically noisy devices because of the quantum nature of the light. Spontaneous emission is the main source of noise and it alters the phase and amplitude of the laser. Spontaneous emission events instantaneously add incriments to the laser field each increment having a magnitude of unity and a random phase angle.

In this work semiconductor laser noise is presented when it operates single mode and when it is mode-locked. The effect of noise on HSPS utilizing uniform fiber Bragg grating is investigated and RIN spectrum is obtained. HSPS is a strong external feedback device providing stable and single mode operation [1] and it consists of mainly three sections as shown the Fig.1; Multi-Quantum Well laser diode, lensed fiber and fiber Bragg grating. One facet of the diode is high reflectivity (HR) coated and the other antireflection (AR) coated.

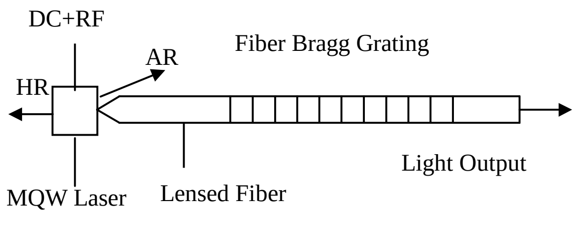

Figure 1. Schamatic of HSPS

HSPS is modeled by using couple-mode equations. These equations are solved numerically and then further processed in order to obtain the RIN spectrum.

In this analysis, we show that high feedback cause additional noise peaks in the RIN spectrum.

II. MODELLING OF HSPS

Couple-mode equations can be used to model the electric field traveling in both directions inside a grating, and a coupled cavity laser such as Distributed Feedback Laser (DFB) or Distributed Bragg Reflector Laser (DBR). Although the solution of these equations are obtained for planer wavequide [2], it has been shown that they are also valid for the fiber Bragg gratings having cylindrical core [3].

Assume that the refractive index of the uniform fiber core varies along the propogation direction as

$$n(z) = n_{co} + \delta n \cos(2\beta_o z) \tag{1}$$

where n_{co} is the refractive index of the unmodified fiber core (usually taken as 1.46), δn is the peak of the index variation ($\delta n << n_{co}$). β_o is the Bragg propagation constant given by

$$\beta_o = \frac{M_B \pi}{\Lambda} = \frac{2\pi}{\lambda_o} n_{co} \tag{2}$$

where Λ is the periodic strucure, λ_o is the Bragg wavelength and M_B stands for the order of the grating. In practice M_B=1 and M_B=2 are commonly used, and M_B=1 is considered in this work.

Starting from these equations and using Maxwell equations and some assumptions [2,4], we obtain

$$-F' - j\delta F = j\kappa R \tag{3}$$

$$R' - j\delta R = j\kappa F \tag{4}$$

In these equations F is the forward-propogation field $F(t,z)$ (+z direction) and R is the reverse-propagating field $R(t,z)$, (-z direction), F' and R' are the derivatives with respect to time, κ is the coupling factor ($\kappa=\pi\delta n_{co}/\lambda$), δ is the deviation from real part of propagation constant β ($\beta=\beta_o+\delta$).

After some algebraic operations on Equations (3) and (4), the coupled-mode pair can be reduced to a set of second order differential equations with constant coefficients such that

$$F''-\gamma^2 F=0 \tag{5}$$

$$R''-\gamma^2 R=0 \tag{6}$$

where ($\gamma^2=\kappa^2-\delta^2$).

Solutions of these equations assuming that the fields at z=0 are known can be written as

$$F=\left[\cosh(\gamma z)-j\frac{\delta}{\gamma}\sinh(\gamma z)\right]F_o-\left[j\frac{\kappa}{\gamma}\sinh(\gamma z)\right]R_o \tag{7}$$

$$R=\left[\cosh(\gamma z)+j\frac{\delta}{\gamma}\sinh(\gamma z)\right]R_o+\left[j\frac{\kappa}{\gamma}\sinh(\gamma z)\right]F_o \tag{8}$$

In order to calculate the progressive fields, either F_o and R or R_o and F are assumed to be known. Also, these equations must be modified in such a way that they include gain, loss and spontaneous emission noise in the laser. Let us assume F_o and R are known, and write R_o and F in terms of these known fields:

$$\begin{bmatrix} F \\ R_o \end{bmatrix}=\frac{1}{\gamma\cosh(\gamma z)-(g_{net}-j\delta)\sinh(\gamma z)} \cdot\begin{bmatrix} \gamma & -j\kappa\sinh(\gamma z) \\ -j\kappa\sinh(\gamma z) & \gamma \end{bmatrix}\begin{bmatrix} F_o \\ R \end{bmatrix}+\begin{bmatrix} s_f \\ s_r \end{bmatrix} \tag{9}$$

Here g_{net} is the net field gain in the laser diode when the loss is subtracted from the gain. s_f and s_r are the spontaneous noise coupled to the forward and reverse waves, respectively. They are assumed to have equal amplitudes [5], e.g.,

$$s\ (z,t)=s_f(z,t)=s_r(z,t) \tag{10}$$

Spontaneous emission is assumed to have a Gaussian distribution and to satisfy the correlation:

$$<s(z,t)s^*(z',t')>=\beta_{sp}\frac{R_{sp}}{v_g}\delta(t-t')\delta(z-z')$$
and (11)
$$<s(z,t)s(z',t')>=0$$

Here, $R_{sp}=BN^2/L_l$ is the electron-hole recombination rate per unit lenght contributed to the spontaneous emission. Here, B is the radiative (or bimolecular) recombination coefficient, L_l is the length of the lasing section, N is the carrier density, β_{sp} is the spontaneous coupling factor, and v_g is the group velocity of light in the cavity.

III. RELATIVE INTENSITY NOISE

The intensity noises are characterized by the relative intensity noise (RIN) and they lead to a limited signal-to-noise ratio. The RIN of a laser diode as the ratio of the mean square intensity fluctuations to the mean intensity squared of the laser output as shown the equation (13).

Since the emitted optical power P of a laser exhibit noise which causes it to fluctuate around its steady-state value, it can be written as

$$P(t)=<P>+\delta P(t) \tag{12}$$

where $<P>$ is the mean power. The RIN relates the noise of the optical power $\delta P(t)$ to $<P>$ and it is defined as

$$RIN=\frac{<\delta P^2(t)>}{<P>^2}=\frac{<P(t)^2>}{<P>^2}-1 \tag{13}$$

The noise processes are considered to be stationary and ergodic, so that the symbol <> denotes either the ensemble or the time averages.

The values of RIN is calculated using expression (13) and then fast Fourier transform (FFT) is applied.

IV. RESULTS

In this analysis, the wavelength is 1.55 µm, mode-locking frequecy is 2.5 GHz, DC and RF currents applied both the laser diode are 6 and 20 mA, respectively. Grating and laser lengths are taken 4 cm and 250 µm.

Figure. 2 and 3 show the reflection spectrum of a uniform grating with 0.99 and 0.5 peak reflectivity. There are many side-lobes at the long- and short-wavelenght sides of the main lobe. These lobes are the results of the Fabry-Perot effect employed by the grating edges that behave as partially reflecting mirrors [3]. Figure. 4 and 5 show the RIN spectrum of the HSPS with 0.99 and 0.5 peak reflectivity.

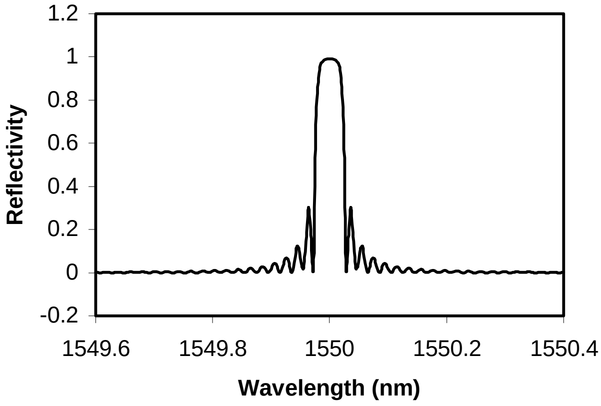

Figure 2. Reflectivity of uniform grating

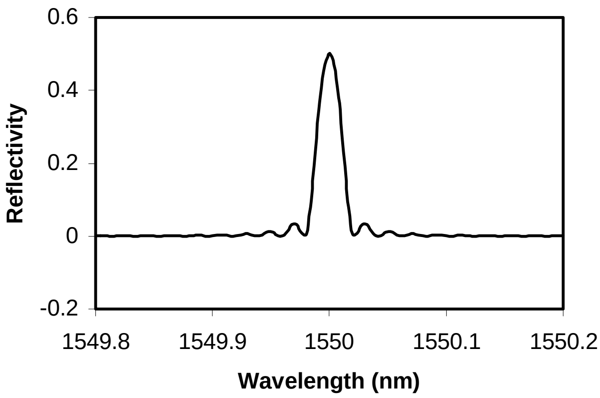

Figure 3. Reflectivity of uniform grating

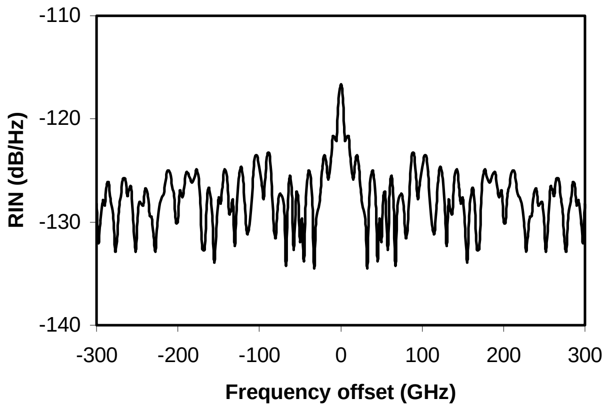

Figure 4. RIN spectrum of the HSPS

As seen the Fig. 2 amplitude of the side-lobes increases as expected because of high feedback. Increasing of these lobes cause additional peaks within the center of the RIN spectrum as shown Fig. 4. Again in this figure RIN level is suppressed in the vicinity of the peak due to high feedback. RIN is concentrated at the center frequency with feedback as seen the Fig. 4 and 5 but supression is not observed with 0.5 peak reflectivity.

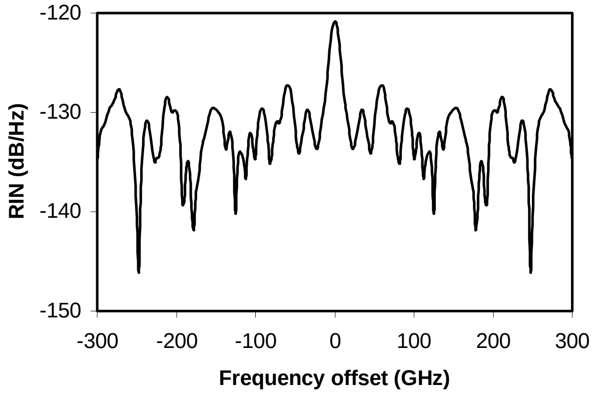

Figure 5. RIN spectrum of the HSPS

As seen the figures RIN value is approximately 120 dB/Hz and this shows the very high noise level of the device. These results indicate that RIN is not sufficiently low for practical purposes (e.g., 150 dB/Hz).

V. CONCLUSION

In this study, it is expected that high strong feedback cause increasing amplitude of side-lobes in the reflection spectrum and multi-pulse output from the HSPS. This multi-pulse cause additional noise peaks in the center of the RIN spectrum.

Also, it has been shown that our model can describe a laser with strong optical feedback leading to stable, single mode operation.

REFERENCES

1. P.A. Morton, V. Mizrahi, P. A. Andrekson, T. Tanbun-Ek, R. A. Logan, P. Lemaire, D. L. Coblentz, A. M. Sergent, K. W. Wecht, and JR. P.F Sciortino, Mode-Locked Hybrid Soliton Pulse Source with Extremely Wide Operating Frequency Range, IEEE Photon. Technol. Lett., Vol. 5, no. 1, pp. 28-31, 1993.
2. H. Kogelnik, and C. V. Shank, Coupled- Wave Theory of Distribured Feedback Lasers, J. Appl. Phys., Vol. 43, no. 5, pp. 2327-2335, 1972.
3. T. Erdogan, Fiber Grating Spectra, J. Lightwave Technol., Vol. 15, pp. 1277-1294, 1997.
4. J. Buus, Single Frequency Semiconductor Laser, SPIE Optical Engineering Press, (Washington, 1991).
5. L. M. Zhang, S. F. YU, M. C. Nowell, D. D. Marcenac, J. E. Carrol and R. G. S. Plumb, Dynamic Analysis of Radiation and Side-Mode Supression in a second-Order DFB Lasers Using Time-Domain Large-Signal Traveling Wave Model, IEEE J. Quantum Electron, Vol. 30, no.6, pp. 1389-1395, 1994.
6. K. I. Kallimani and M. J. O' Mahony, Relative Intensity Noise for Laser Diode with Arbitrary

Amounts of Optical Feedback, IEEE J. Quantum Electron, Vol.34, no. 8, pp. 1438-1446, 1998.