IMPROVEMENT OF SIGNAL-TO-NOISE RATIO IN A BISTABLE VERTICAL CAVITY LASER: COMPARATIVE STUDY OF VIBRATIONAL AND STOCHASTIC RESONANCE

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In the last years, in the context of stochastic resonance *(SR),* large efforts have been devoted for the improvement of detectability of weak noisy signals. This subject is a matter of great interest in different fields and it is not a trivial problem. As a rule, the quality in the detection of periodic signals can be evaluated using the signal-to-noise ratio *(SNR).* A theoretical treatment using the concept of SR has revealed that a *SNR* gain (that is, the output SNR_{out} is higher than the input SNR_{in}) can be achieved in level crossing detectors [1], nondynamical threshold systems with a static nonlinearity [2], in bistable dynamical systems for a periodic sequence of alternating rectangular pulses with a small duty cycle and near-threshold amplitudes [3].

Recently, the phenomenon of vibrational resonance (VR) has been theoretically predicted by Landa and McClintock [4]. The phenomenon shows up in a bistable system as a resonance-like behaviour at the low frequency (LF) depending on the amplitude or frequency of an additional high-frequency (HF) modulation. An experimental evidence of VR has been demonstrated in analog circuits [5] and in a bistable vertical cavity laser (VCSEL) [6]. The mechanism underlying VR can be associated with a parametric amplification near the onset of bistability controlled by the HF modulation.

Here we present the results of theoretical and experimental investigations of the effect of additive noise on VR in VCSEL operating in the regime of the polarization bistability. Our theoretical consideration is based on the application of the effective potential to the theoretical results developed for studying the phenomenon of SR. Due to the difference in time scales associated with LF and HF modulations, a rapidly oscillating double-well potential can be transformed into an effective potential with a parametric dependence on the amplitude and frequency of the HF modulation. Making use of such an approach, we find analytically scaling laws which relate the gain factor and the *SNR* for the LF signal due to VR with the strength of added noise, which are in good agreement with the numerical and experimental results in the limit of weak LF signals. We also demonstrate that the gain factor *(G)* and *SNR* in VR for LF signals are always higher than the ones which could be obtained in the same conditions using conventional SR. Besides, we present the experimental and numerical evidence that the relationship $SNR_{out}>>SNR_{in}$ can be achieved for rectangular periodic LF signals with weak subthreshold amplitudes in a broad range of the level of initial noise coming together with the signal.

Theoretically, the dynamics of the polarization switchings induced by noise and a deterministic modulation in the bistability domain in a VCSEL can be described in the framework of a Langevin equation with a two-well potential. Therefore, we consider the phenomenon of VR in the presence of noise using the model of an overdamped bistable oscillator. The system is being excited by LF and HF periodic signals with amplitudes A_L and A_H at frequencies Q_l and Q_H, respectively, such that Q_H >> and by a white, Gaussian noise £(t) with <£(t)£(t')>=2D5(t - t') and mean <^(t)> = 0 . In such conditions we found that the maximum of the gain factor *(G_{max})* and the maximum of SNR (SNR_{max}) obey the following scaling laws, respectively:

$$Gmax \sim D^m, \qquad (1)$$

$$SNRmax \sim (AL)^2 D''\backslash \qquad (2)$$

The gain factor G defined here as $G = R_L/R_0$, where R_L and R_0 are spectral responses at the frequency Q_L in the presence and in the absence of the HF modulation, respectively. In more details, theoretical results will be presented elsewhere [7].

The experimental setup was essentially the same as in our previous investigations [6]. We studied VR in the laser intensity after polarization selection when two sinusoidal signals at the frequencies Q_L = 1 kHz and Q_H = 100 kHz with amplitudes A_L and A_H, respectively, and noise with amplitudes z_N were applied to the injection current. In what follows we use the normalized amplitudes of the LF and HF signals defined as e = A_L/^_L and £ = A_H/^_H, where and $ц_H$ are the switching thresholds at the frequencies Q_L and Q_H, respectively. The normalized amplitude of the HF signal £ is the control parameter. We define the noise strength as $D = o_N^n$. The injection current was chosen in order that the laser operates in the regime of polarization bistability, where switching between two states could be induced by applying the deterministic modulation and noise. The laser responses were detected with a fast photodetector and recorded by a digital oscilloscope coupled with a computer to store and process the data. Every time series contained $5*10^4$ sampling points with 20 periods of the LF signal. Each point of G_{VR} and *SNR* was obtained by averaging over 10 time series. For an illustration of the effect of noise on VR, the experimentally measured gain factor G_{VR} for a weak LF signal (e = 0.028) versus £ is shown in Fig. 1 for different values of the noise intensity.

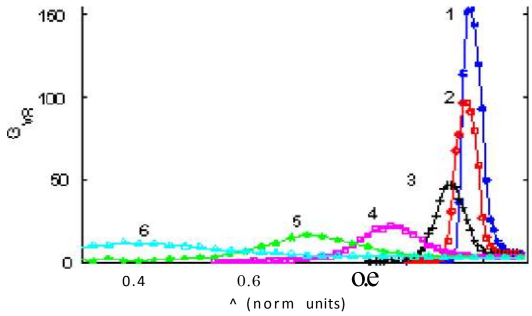

Fig. 1. The gain factor *G* versus the normalized amplitude for different values of the noise level ON = 7 (1), 14 (2), 30 (3), 65 (4), 110 (5), 250 (6) (mVrms) (e = 0.028)

One can see that an addition of noise results in a diminution of the gain, the shift of its maximum and broadening the response curve as the noise intensity *D* increases. These experimentally observed features are in a good qualitative agreement with the theoretical results. We found that in this case $G_{max} \sim D^{-047}$ in agreement with theoretical prediction (1).

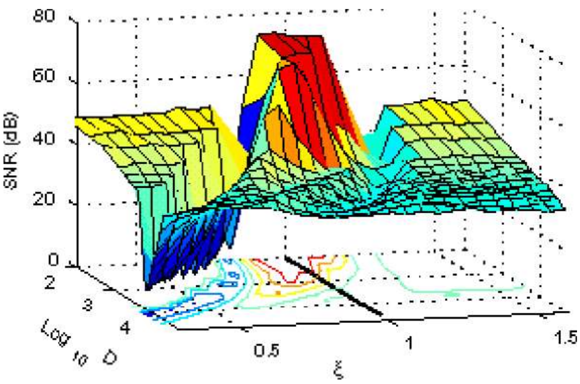

Fig. 2. The SNR for the square-wave LF signal as a function of and *D* (e = 0.2)

In Fig. 2, experimentally measured SNR for the weak square-wave LF signal (e = 0.2) with increasing the level of noise is shown. One can note a strong increase of SNR with respect to SNR_{in}. This rise takes place near the onset of bistability controlled by the HF modulation. A further increase of *D* (for a moderate level of noise) leads to a degradation of SNR. One can note also the broadening of the curves and the shift of the optimal values of the HF modulation corresponding to SNR_{max}.

2. *Loerincz K., Gingl. Z., Kiss L. B.* // Phys. Lett. A. 1996. V. 224, № 1. P. 63-69.
3. *Chapeau-BlondeauF.,* Phys. Lett. A. 1997. V. 232, № 1. P. 41-48.
4. *Casado-Pascual J., Gomez-Ordonez J., Morillo M., Hanggi P.* // PRL. 2003. V. 91, № 22. P. 220601-4.
5. *LandaP. S., McClintockP. V. E.* // J. Phys.A: Math. Gen. 2000. V. 33. P. L433-L438.
6. *Baltanas J. P., LopezL., Blechman 1.1. et all.* // PRE. 2003. V. 67, № 6. P. 066119-7.
7. *Chizhevsky V. N., SmeuE., Giacomelli G.* // PRL. 2003. V. 91, № 22. P. 220602-4.