IF-WE-58

A new approach for RIN peak and phase noise suppression in microchip lasers

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Abstract **This paper is concerned with the suppression of the relative intensity noise (RIN) peak and phase noise of a diode pumped Neodymium-doped Lithium Niobate ($Nd:LiNbO_3$) microchip laser. Relaxation oscillations result in about 15-20 dB noise peak above the flat noise at 350 kHz offset frequency. In case of high quality requirements this noise peak is significantly disturbing. In this paper a new approach is presented for the suppression of the RIN peak and phase noise in microchip lasers.**

I. INTRODUCTION

The laser noise is a crucial parameter in many applications, like optically controlled phased array antennas, optically fed mobile radio base stations, high speed optical links, etc. Therefore significant effort is done to reduce the noise of lasers. The microchip laser exhibits a very low phase noise. However, it suffers from the relaxation resonance as every laser. At the relaxation resonance the noise has a high peak, 15-20 dB higher than that outside of the resonance region.

There have recently been a number of publications on the design and analysis of fiber radio systems using solid state microchip lasers. Herczfeld [1], Jemison et al. [2] have examined the applications of a $Nd:LiNbO_3$ mode locked laser in an LMDS system. Because of the good phase noise characteristics the optical generation of the local oscillator signal is feasible. However, the suppression of the close to carrier relaxation oscillations can improve the quality of the whole system. A number of feedback loops for different types of lasers have been evaluated and their corresponding advantages discussed. Kane [3] and Harb [4] have designed an electronic feedback for the reduction of intensity noise in a diode pumped Nd:YAG laser. Similarly, Geronimo [5] and Taccheo [6] have investigated the intensity noise reduction in an ytterbium-codoped erbium glass laser. In addition, the noise suppression with an external feedback was studied by Tsang-Der Ni [7].

However, the known methodes did not produce a significant reduction in the phase noise. In this paper a new approach is presented for the suppression of the RIN peak and phase noise in microchip lasers. The structure of the paper is the following. Section II presents the theory of the suppression and the computer simulation results. Section III outlines the feedback loop electronics. Section IV exhibits the measurement results of the noise suppression. Section V summarizes the results of the paper and the further possible efforts in this field.

II. THEORY AND SIMULATION

The block diagram of the feedback loop for noise suppression is depicted in Fig. 1. A fraction of the laser output signal is detected, differentiated, phase shifted, amplified and fed back to the pump laser DC supply.

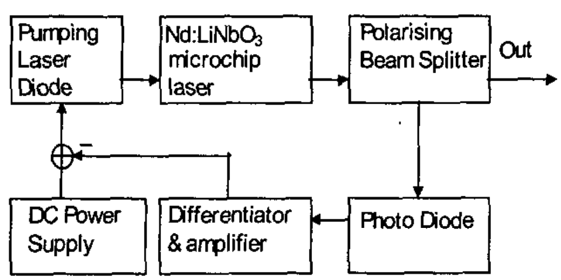

Fig. 1. Block diagram of the feedback loop to suppress the RIN peak and phase noise. A fraction of the diode-pumped output signal was detected, differentiated, phase shifted, amplified and added as correction signal to the bias current of the laser diode.

A. Loop Transfer Function

The noise peak at 350kHz is reduced by using negative feedback. Because the transfer function of the laser transmitter has a phase shift of almost -180° near the frequency where the gain of the open loop goes below unity, we have to realize positive phase shift in the amplifier following the low noise photodiode. To increase the phase noise sensitivity of the loop we use a differentiator circuit (phase shift +90°) with a zero near to the relaxation oscillation frequency and a pole at f=10MHz. The zero of the differentiator in the feedback circuit can compensate the effect of the complex conjugate poles of the microchip laser transfer function, which are responsible for the high noise peak. The additional pole at a higher frequency (10MHz) is only needed because of the stability of the differentiator circuit and does not have any effect in the frequency range of the peak. After the differentiation the phase shifted and amplified signal is added to the bias current of the pump diode.

B. Simulation

During the computer simulations the RIN peak of the solid state laser was modeled by the simple transfer function G(s);

$$G(s)=\frac{1}{1+2dTs+T^2s^2}=\frac{1}{1+2\cdot 10^{-8}s+2.06116\cdot 10^{-13}s^2} \quad (1)$$

where d defines (2) the value of the complex conjugate poles and so the height of the noise peak, and T gives the frequency of the resonance.

$$d=\frac{R}{2}\sqrt{\frac{C}{L}} \qquad T=\sqrt{LC} \qquad (2)$$

Fig.2. shows the Bode diagram of the transfer function G(s) which was used to simulate the RIN peak of the microchip laser.

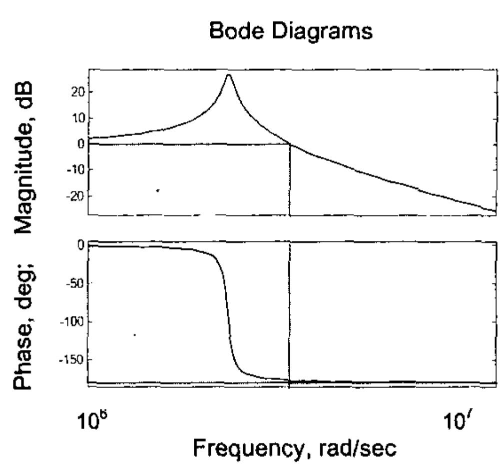

Fig. 2. Bode diagram of the transfer function G(s) of the RIN model. Because of the very small phase margin we have to use a differentiator circuit in the feedback loop.

The transfer function of the closed loop is shown in (3), where G(s) is the transfer function of the RIN model and β(s) is the transfer function of the feedback system.

$$F(s)=\frac{G(s)}{1+G(s)\beta(s)} \qquad (3)$$

If the optical and electrical delay is taken into account the above expression should be changed to the form of (4).

$$F(s)=\frac{G(s)}{1+G(s)\beta(s)e^{-s\tau}} \qquad (4)$$

The time delay could cause instability so it should be kept as low as possible.

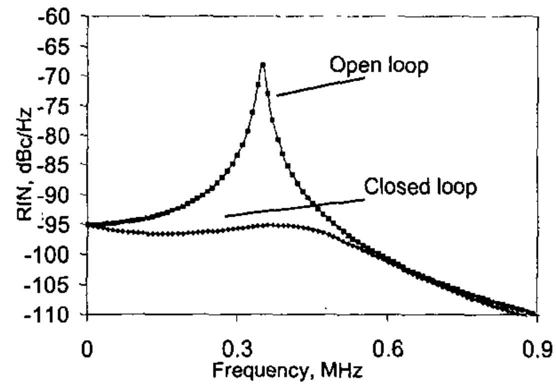

Fig.3. Simulation results on RIN suppression, for both free-running laser and with operating feedback control. The relative intensity noise spectrum of the solid state laser was modeled with the transfer function G(s),(1).

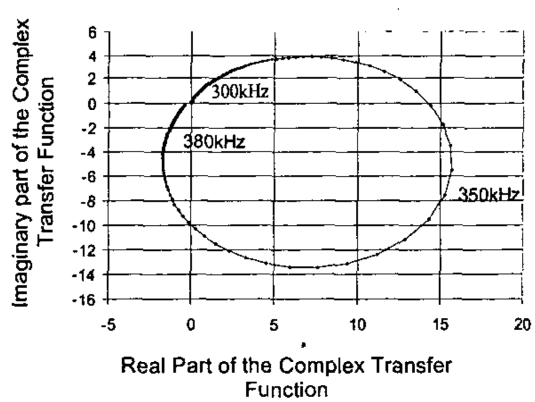

Fig. 4. The Nyquist diagram of the control loop. Maximum is at 350kHz in the pos.-neg. quadrant of the diagram. The instability point is not encompassed by the curve, hence the loop is stable.

The results of the computer simulations are shown in Fig. 3. The real disturbing resonance term (open loop) is standing out by 15-20 dB from the outside region [1].

The simulation results show an intensity noise suppression of ~20dB and a slight increase of noise at higher frequencies. Resetting the phase shift and the gain of the differentiator circuit in the feedback loop this small (~1dB) increase in the noise can be shifted to lower or higher frequencies according to the application requirements.

The Nyquist diagram of the simulated control loop is shown in Fig. 4. The instability point (-1,0) is not encompassed by the loop, so the loop is stable and has a maximum suppression at the relaxation oscillation frequency.

III. FEEDBACK LOOP ELECTRONICS

The 1084 nm optical power of the $Nd:LiNbO_3$ laser directed by the optical beam splitter to the photodiode was 1mW, and the generated DC photocurrent had the value of 0.8mA. The low noise transimpedance amplifier was built with ultra low noise and low cost Linear Technology LT1028 (Voltage Noise 1.1nV/√Hz Max. at 1kHz, GBWP=50MHz) type operational amplifier. The gain of the differentiator circuit is a 6 dB/octave rising function of frequency between 10Hz and 1MHz and the circuit has a phase shift of -90°. Because of the negative phase shift the control current can be added to the biasing current of the pump diode to realize the negative feedback. The laser driver circuit, which supplies the DC power for the pump diode and modulates it with the feedback signal, was built with LT1028 operational amplifiers, too, because of the noise requirements. The pump was a semiconductor laser diode operating at 814nm with an output power of 280mW. The loop electronics is shown in Fig. 5. To avoid instability the loop delay was kept at minimum.

IV. MEASUREMENT RESULTS

Fig. 6. shows the measured relative intensity noise spectrum with and without the feedback loop. The laser signal was measured after the polarizing beam splitter at the Laser Out in Fig. 5. by a photodiode. The results were recorded by a HP8593E Spectrum Analyzer. Fig. 6. shows both the open and the closed loop relative intensity noise of the microchip laser. The noise peak is reduced by 13 dB due to the feedback loop.

The noise level of the microchip laser can be further reduced, it is only limited by the noise of the measuring photo receiver. Using low noise photodiodes the suppression at the relaxation oscillatons can be increased.

The RIN suppression can be employed in case of other lasers too, such as pump laser diodes in Erbium-Doped Fiber Amplifiers (EDFA), in optical transmitters or in optical local oscillators.

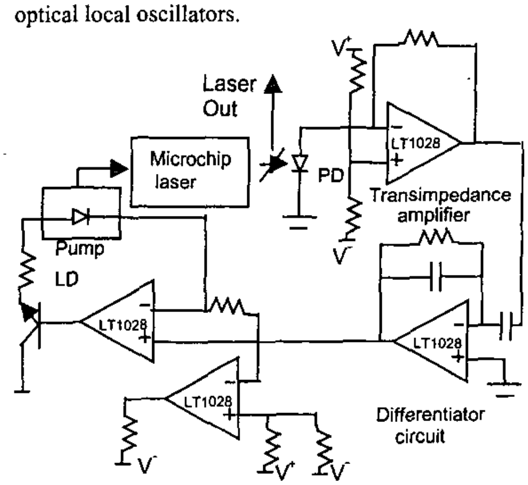

Fig. 5. Schematic diagram of the control loop electronics and the laser transmitter subsystem. The main components are the diode pump laser, the $Nd:LiNbO_3$ microchip laser, the low noise transimpedance amplifier, the differentiator circuit and the pump laser driver to add the correction current to the current of the diode laser.

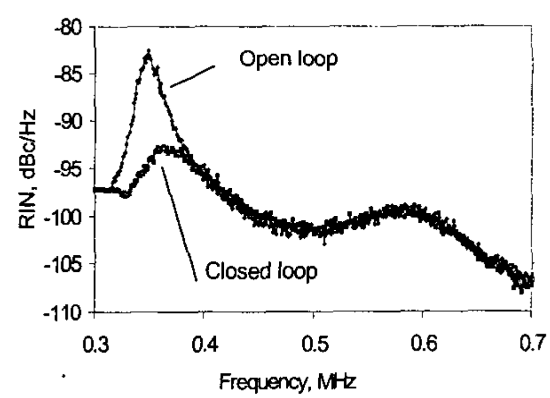

Fig. 6. Experimental RIN spectrum of the $Nd:LiNbO_3$ microchip laser in the free-running regime, and with using of the feedback control loop to suppress the intnsity noise. The input pump power to the laser crystal is 280mW, and the laser output power is 50mW. The reduction in intensity noiese at the relaxation oscillation frequency of 350kHz is ~15dB.

V. CONCLUSIONS

A system with capabilities both suppressing the relative intensity noise peak and reducing the phase noise of a Nd:$LiNbO_3$ microchip laser was demonstrated.

That approach applied a special feedback loop sensitive to the phase noise. First computer simulations were carried out. They provided very good results. According to them 15-20dB suppression was expected. Then experiments were performed. Their results proved the theoretical expectations. The RIN peak was suppressed by ~15dB.

This work illustrates the suitability of the Nd:$LiNbO_3$ microchip laser as the main component in high quality optical communication systems. In LMDS and fiber radio systems or in case of optically fed phased array antennas this laser is found to be as a good solution because of its excellent phase noise characteristics. Suppressing the low frequency relative intensity noise peak, a mode locked Nd:$LiNbO_3$ crystal can match the requirements of high quality and low cost Local Multipoint Distribuition Systems. By mode locking it is possible the further suppression of the phase noise and to transmit simultaneously two high quality optical signals and so to cancel the expensive local oscillators in the base stations.

ACKNOWLEDGEMENT

The authors at the Budapest University of Technology and Economics and at the Drexel University, Philadelphia, would like to acknowledge the Grant of Office of Naval Research No. 00014-01-1-0680 and to the National Research Foundation (OTKA) No. T0630148.

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