Frequency Control of Microchip Lasers

Arkadiusz J. Antonczak *, Krzysztof M. Abramski

Laser & Fibre Electronics Group,
Institute of Telecommunications and Acoustic
Wroclaw University of Technology, 50–370 Wroclaw, POLAND
Tel: +48 (71) 320-40-79, Fax: +48 (71) 320-31-89,

** mailto: arkadiusz.antonczak@.pwr.wroc.pl*

The idea of coherent optical FDM (Frequency Division Multiplexing) gives larger possibilities and new qualities compare to IM-DD (*Intensity Modulation – Direct Detection*) systems. These optical FM systems require stable and controllable offset lasers.

1 Introduction

Considering FDM there are additional problems with mutual overlapping signal spectra from different transmitter, causing inter-channel crosstalk [1]. In this cases it is necessary to applied efficient control offset-frequency stabilisation systems and prevents high spectral purity radiation of both lasers. Considering above, it seems that solid state diode pumped microlasers have big advantage on laser diode. They have much narrowed spectral lines (~ kHz), they operate in single mode frequency and have very good beam quality [2]. The control systems of laser frequency stabilization use a few mechanisms of tuning: thermal, piezoelectric and electrooptic. Thermal tuning is a very slow process but it enables to tune the resonator laser even over few tens of microns. Piezoelectric tuning is usually limited to a few of microns and in the frequency band of tens of Hz. The electrooptic phase modulator inserted inside a laser resonator gives the fastest tuning in the band of few tens of kHz. Two kinds of microchip lasers Nd: YVO_4 and Nd:YAG with $LiNbO_3$ modulators are presented.

2 Laser with electrooptical modulator

The laser system with internal electrooptical tuneability uses simple dependence of refractive index changes Δn (optical length $L_0\Delta n$) due to voltage put to the modulator. The change of laser frequency due to electrooptical tuning can be written as:

$$\Delta\nu(t) = -\frac{c}{2\cdot(n_1 l_1 + n_2 l_2)}\cdot\frac{\Delta U(t)}{U_{\lambda/2}} = \nu_q\,\frac{\Delta U(t)}{U_{\lambda/2}}$$

where: c – light speed, n_1 – refractive index of the active medium, l_1 – geometrical length of the active medium, n_2 – refractive index of the modulator, l_2 – geometrical length of the modulator, $\Delta U(t)$ – applied tuneable voltage, $U_{\lambda/2}$ – half-wave voltage, ν_q – free spectral range frequency of the laser.

From above one can see that tuning sensitivity of laser with internal electrooptical modulator is proportional to the free spectral range frequency – ν_q and inversely proportional to the half-wave voltage – $U_{\lambda/2}$. Optimisation of sensitivity can be obtained by using laser with short active length. This requirement is well fulfilled by microchip laser. For example, let take in account microchip laser Nd:YAG with the length l_1 = 5 mm and $LiNbO_3$ crystal with dimension d = 2 mm, l_2 = 10 mm. The tuning sensitivity calculated is: $\Delta\nu/\Delta U \cong 7$ MHz/V.

3 Experimental setup

In order to stabilise the offset frequency in the heterodyne of Nd:YAG laser we used the system of PLL with double feedback branch [3] presented in Fig 1 & 2. Using PLL system (TLC2932 Texas Instruments circuit), two chains of servo loops were designed: one slow loop operated with thermoelectric cooler stabilisation system. The second loop was connected to the $LiNbO_3$ phase modulator.

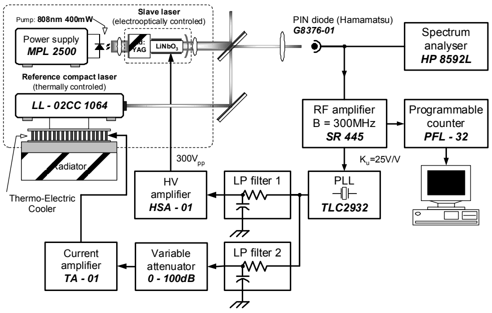


***Fig. 1** The block diagram of the phase locked microchip lasers with electrooptical frequency control*

To get stable work of optical phase loop it is necessary to settle its frequency response. From one side the minimal value of natural frequency of the loop is determined by passive stability of heterodyne system [4]. From the other side, this frequency has to be less then resonance frequency of controlling element. These above conditions can be written as:

$$\omega_{kr}\gamma > \omega_n > \sqrt{\Delta f_H / \Delta t}$$

where: ω_{kr} – critical (resonance) frequency of controlling element, $\gamma < 0$ – safety coefficient with typical value: 0.1 ÷ 0.5, $\Delta f_H/\Delta t$ – maximal speed of frequency fluctuations (established on the base of passive stability of stabilised system).

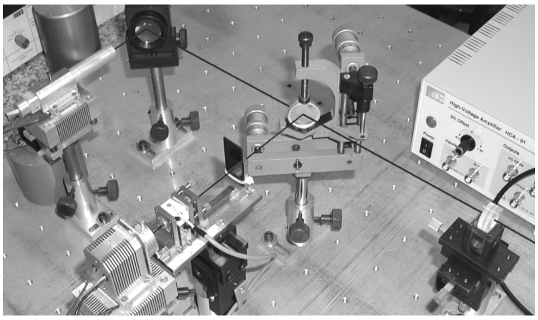


***Fig. 2** The setup of microchip Nd:YVO$_4$/LiNbO$_3$ laser*

The statistic measure of frequency stability is the variance of frequency fluctuation analysed in the standard procedure, so called Allan variance. Especially programmable counter PFL-32 (Fig 1) measured Allan variance of offset frequency fluctuation for free running case and for stabilisation. Some results presenting intermediate frequency stability of two Nd:YAG microchip lasers, are shown in Fig 3.

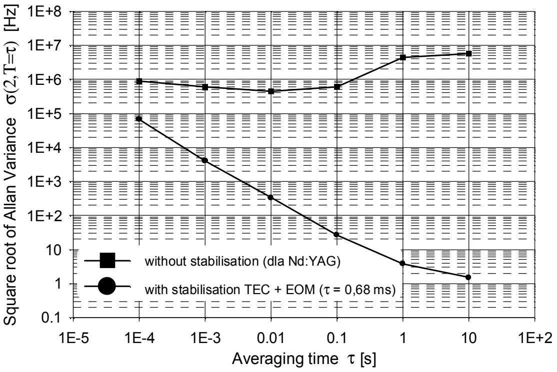


***Fig. 3** Offset frequency stabilization effect (Allan variance) of built Nd:YAG lasers*

Analysed beat frequency between both laser without and with stabilization in time domain presents Fig 4.

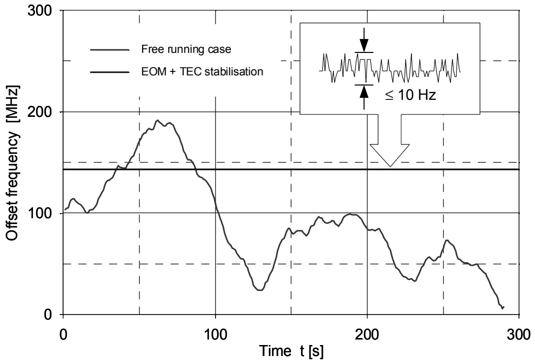
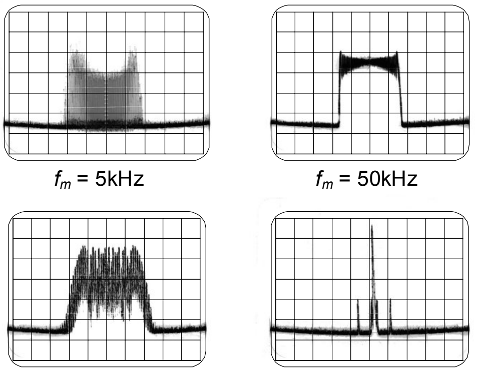


***Fig. 4** Beat frequency between two microchip lasers without and with stabilisation*

Such stable offset system allows getting frequency modulation quite easy. We modulated in frequency one of the used lasers. Fig 5 presents spectral analyses of frequency modulation of the microchip laser for four differential frequency deviations.



f_m = 5kHz f_m = 50kHz

f_m = 500kHz f_m = 5MHz

***Fig. 5** Spectral analysis (optical FM) of modulated Nd:YVO$_4$/LiNbO$_3$ microchip lasers (X: 5MHz/div, Y:10dB/div, Ref: -20dBm, U_{LiNbO3} = 10 V_{pp})*

4 Conclusions

- ✓ Performed measurements show that combining both mechanism of tuning: thermal and electrooptical allows stabilising fast and small and slow and large frequency deviations.
- ✓ Using these two mechanisms we ware able to improve the offset frequency stability by one to six orders.
- ✓ Presented system of stabilisation of Nd:YAG lasers for the offset frequency f_H = 143.2 MHz enabled as to get stability δ = 1.5 Hz at averaging time τ = 10 s.

References

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