Circuits for Optical Frequency Stabilization of Metrological Lasers

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Abstract. *Nowadays, the Slovak National Length Standard is based on the HeNe laser. Its optical frequency is stabilized by the saturated absorption method in* $^{127}I_2$ *iodine molecules with relative uncertainty* 10^{-11}*. This solution is dominant in majority of metrological institutes of the world so far [1]. The ground of long time laser stability is in its thermally stable mechanical construction. Optoelectronic feedback allows stabilizing the laser frequency precisely at wavelength causing the saturated absorption in iodine vapour. This feedback is controlled by signal of photodiode and action control element is the piezo carrying the laser mirror. The operation principle and the arrangement of diode laser differ from that of HeNe laser and therefore the application of method mentioned above must be adapted to new conditions. This contribution is aimed for design of electronic circuits providing for this new approach.*

Keywords: optical feedback, tuning frequency generator, saw tooth voltage generator

1. Introduction

The long-time stability of laser frequency is determined by the length of its resonator. Providing a small frequency sweep by signal led to piezo-element stabilizes the laser at wavelength corresponding with some saturated absorption region of iodine. There will appear a specific signal in saturated absorption region at photodetector, which is phase detected and returns back on the control element as a correction of the resonator length; e.g. the piezoelectric mounting on one resonator mirror of HeNe laser or diffraction grating of ECDL in Littrow configuration or reflective mirror in Littman [2] configuration (Fig. 1).

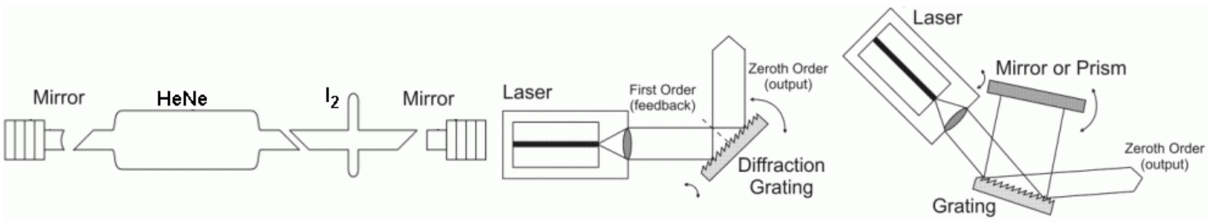

Fig. 1. Optical scheme of $HeNe/I_2$ laser and ECDL in Littrow and Littman arrangement.

Whilst HeNe lasers are typical for their intra-cavity cell arrangement, in the case of diode lasers we put the cell outside the resonator. Improved stability is reached when the laser beam, or part of it, passes through an external cell with gaseous iodine with resonant absorption lines. The amplitude changes of laser beam caused by the iodine cell are used to control the resonator length. The portion of laser output is detected by photodetector (PIN D). The output of PIN D is processed by a phase detector, which compares its amplitude and phase with the 3*f* (3234 Hz) generator signal. The phase detector output is imposed on the piezoelectric element as part of its dc bias after filtration. When the resonator length is proper, the laser frequency corresponds with the centre of the gain profile, or with one of the spectral lines of iodine molecule [3]. In our contribution we concentrate our effort to solution of the electronic circuits, which we realized.

2. External Iodine Cell and its Function

The conception of electronics follows the application of microcomputer ADuC 841 and also the possibility of hooking up the device to PC, which enables so-called service operation mode. The key electronic circuits needed for application of external cell are: thermo controller of iodine cell cold finger (TCP), reference 3*f* and 1*f* generator of precise frequency (3*f*), synchrodetector with filtration (FD), generator of tuning frequency and microcontroller ADuC 841.

The first assumption of laser frequency stabilisation by saturated absorption method is the laser beam of sufficient intensity passing through the iodine cell (Fig. 2). Several absorbing lines of iodine $^{127}I_2$ hyperfine spectral structure fit within ECDL emission line near the wavelength of 632.99 nm. These lines have precisely defined frequencies [4]. PIN D together with phase detector records the absorption peaks during the laser is tuned across its power curve. The feedback loop is open during this process. After switching on the feedback in a proper moment, the laser frequency is locked at given absorption line and it is possible to obtain the optical frequency with relatively small uncertainty. To reach suitable frequency stability, appropriate pressure of iodine vapour in the cell, i.e. 17.29 Pa, as given, must be kept. This pressure will be achieved if the temperature of the cold finger is (15.0 ± 0.2)°C. Thermo controller (TCP) consists of small platinum resistor (Pt 100), electronic circuit and Peltier element (PE), which keeps the cold finger temperature at 15°C. Temperature of the cell walls is about (25 ± 5)°C.

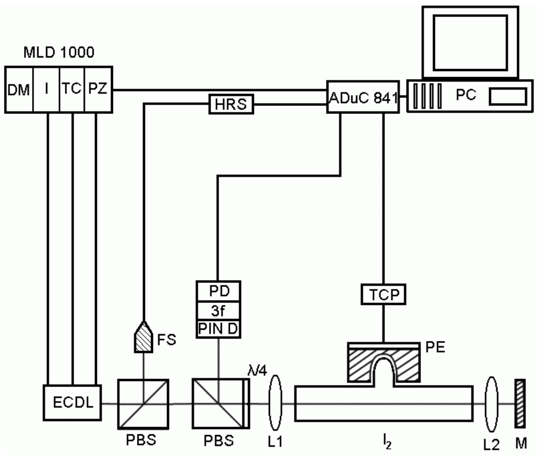

Fig. 2. The arrangement of ECDL/I_2 Stabilization System. ECDL laser head, MLD 1000 electronic of Sacher Laser GmbH, (DM display module, I source of the stabilised injection current, TC diode temperature controller, PZ piezo controller), M mirrors, $\lambda/4$ phase retardation plate, PBS polarizing beam splitter, FS, HRS fibre spectrometer, L1, L2 lenses, I_2 iodine cell, PE Peltier element, TCP Peltier thermocontroller, PIN D pin photodiode, 3f frequency generator, PD phase detector, ADuC 841 microconroller, PC personal computer.

3. Electronic Circuits

If the laser resonant frequency and the frequency of some iodine spectral line are identical the effect of saturated absorption of iodine molecules will arise.

When the laser beam passing through the iodine cell excites all molecules of given velocity [1] the beam reflected off the back mirror (M) cannot be absorbed and the medium of gaseous iodine becomes almost transparent for specific frequency. The output signal from

PIN D (Fig. 2) is led to the input of phase detector (PD) during tuning and after low-pass filtration is led to input of A/D converter of microcontroller. This allows finding saturated absorption region and locking here the laser automatically. The analogue signal can also be observed on the oscilloscope. In service operation mode is via RS 232 plugged also PC.

4. Reference 1*f* and 3*f* generator of precise frequency (1078 Hz and 3234 Hz)

Generator of 1078 Hz is the source of reference frequency of the phase locking loop. The sine-shaped signal from generator is led to PZT, which tilts the mirror of ECDL optical resonator. This signal wobbles the basic optical frequency of 474 THz laser with frequency swing of 6 MHz. The frequency modulation is changed to the amplitude modulation under the influence of the iodine cell. Modulated signal is demodulated in PIN D. The signal contains also higher harmonics and for the improvement of the sensitivity the third harmonic is usually used. Third harmonic together with triple of 3*f*-generator frequency 3*f* is led on the synchronous detector. During the phase locking both signals are in the phase coincidence. 3*f* signal generates stronger slope of detected signal and therefore is of higher sensitivity of phase detector. It also eliminates possible disturbance of 1*f* signal as well. The block scheme of 1*f* and 3*f* generator is represented on Fig. 3.

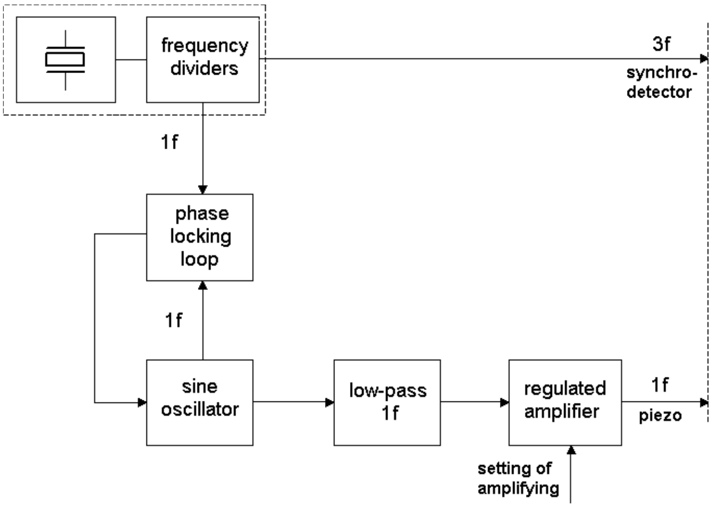

Fig. 3. Block scheme of 1*f* and 3*f* generator.

5. Synchrodetector and filtration

The ground of the phase detector is the analogue multiplier with low-pass frequency filtration (LP). Many new circuits were commercially produced in last two decades, like the phase locking loop, synthesizers and phase detectors. These circuits work in the frequency region of hundreds of MHz or units of GHz. This segment was developed on the basis of CMOS 4046 circuit. Further filtration of the signal determines dynamic features of the phase locking loop. Block scheme of the phase detector and LP filter is pictured on Fig. 4.

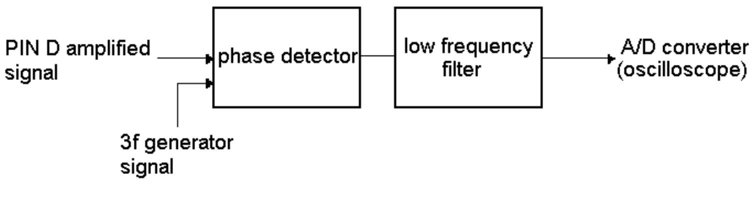

Fig. 4. Block scheme of the phase detector and LP filter.

The output signal from PIN D is led to A/D converter of microcontroller and its value is transferred via RS 232 to PC. PC will be used for automatic phase locking on absorption peaks of iodine hyperfine structure.

6. Microcontroller and circuits for connection with surroundings

The microcontroller serves for the following functions:

- by the assistance of D/A converter generates the saw-tooth course voltage of PZT for tilting of ECDL tuning mirror (the change of laser resonant frequency),
- the transport of the signal from the synchronous detector, A/D transformer and RS 232 boundary to the superior PC,
- monitoring and control of the temperature stabilization of the cold finger,
- monitoring of laser output power by use of the signal from PIN D,
- communication with superior PC through RS 232 bus, recording and distribution of measured data.

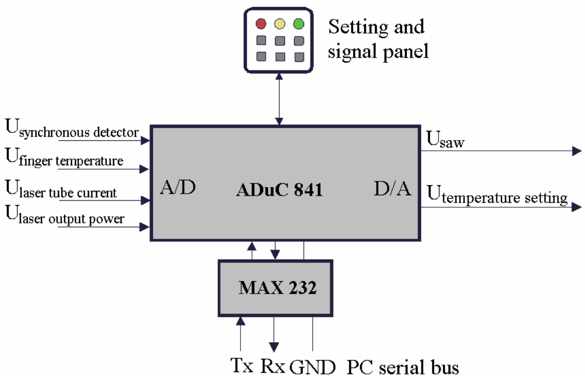

Fig. 5 Block scheme of microcontroller.

The microcontroller board had been designed and realised on the basis of ADuC 841 circuit by Analog Devices Company. It is based on 8-bit microprocessor, 8-chanel 12-bit A/D converter, two 12-bit D/A converters with internal voltage reference, 16-bit counter/timer, 52 kB electrically erasable Flash type ROM memory for storing the data and with 2 kB RAM memory. Communication with superior PC is secured via the MAX 232 circuit (Fig. 5).

7. Conclusion

As mentioned, frequency stabilization of diode lasers requires different conception of feedback installation from HeNe lasers. It was also the aim of this contribution to point out the complexity of electronic circuits solution in this application.

Acknowledgements

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References

[1] Fíra R., Navrátil V.: Stabilization of Laser’s Frequency for Metrological Purposes by Use of Saturated Absorption (In Slovak). *Metrológia a skúšobníctvo*, 1999, 4 (1-2): 20-24

[2] Hecht J.: Tuning in to Tunable Lasers. *WDM Solutions*, 2002, 4 (3): 119-122

[3] Bartl J., Fíra R., Jacko V.: Tuning of the Laser Diode. *Measurement Science Review,* 2002, 2 (3): 9-15

[4] Quinn T. J.: Practical Realization of the Definition of the Metre Including Recommended Radiations of other Optical Frequency Standards, *Metrologia*, 2003, 40: 103-133