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A technique for frequency stabilization of an internal mirror He–Ne laser

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Abstract. A technique for frequency stabilization of an internal mirror He–Ne laser using phase sensitive detection without cavity length modulation is suggested. The orthogonally plane polarized modes are separated and then convered into two photoelectric signals using two photodetectors. The photoelectric signals are switched alternately so as to generate a square wave, whose amplitude is proportional to the intensity difference between the two orthogonal polarizations. A lock-in amplifier is used to detect this square wave, with the switching frequency as reference. The phase detected signal is used for thermal stabilization of the laser. The frequency stability of 5×10^{-9} was obtained with an integration time of 1 s.

Keywords. Laser; frequency stabilization; electronic switching; phase sensitive detection.

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1. Introduction

The frequency stabilized internal mirror He–Ne lasers operating at 633 nm are widely used for various metrological applications. A number of methods (Balhorn *et al* 1972; Bennett *et al* 1973; Desai *et al* 1979 and Puntambekar *et al* 1982) are available for the frequency stabilization of two-mode lasers. In most of the methods, the orthogonally plane polarized modes are separated and their intensities are converted into electrical signals using two photodetectors. The difference between them is obtained through a difference amplifier and the differential signal is used for thermal stabilization of the laser frequency.

As in single-mode laser, some authors (Desai *et al* 1979; Seta and Iwasaki 1985 and Puntambekar *et al* 1987) used phase sensitive detection for two-mode lasers so as to improve their stability. Desai *et al* (1979) used mechanical chopping of the orthogonally plane polarized laser beams and detected the chopped signal by a lock-in amplifier. Seta and Iwasaki (1985) modulated the laser cavity using a thin film coated heater and detected the frequency modulated photoelectric signal with a lock-in amplifier. Recently a new technique of frequency stabilization (Puntambekar *et al* 1987) based on polarization modulation and phase sensitive detection has been developed in our laboratory. However the last two techniques give rise to modulated laser beams which are undesirable for some applications such as ultra high resolution laser spectroscopy, small phase variation measurement, long distance interferometry, etc.

In the present technique, the orthogonally plane polarized modes are separated and their intensities are converted into corresponding photoelectric outputs. These photoelectric outputs are switched alternately using an electronic switch. The electronic switching of the photoelectric outputs is much convenient than mechanical chopping of the laser beams. The output of the electronic switch is a square wave whose amplitude is proportional to the intensity difference between the two modes. The amplitude modulated square wave is detected by a lock-in amplifier. The phase detected output can be used for thermal stabilization of the laser. The technique can be used even if the laser is oscillating in more than two modes and the modes can be tuned over the laser gain curve within a limited region. The main advantage of the technique is stabilization of laser using phase sensitive detection, even without cavity length modulation.

2. Experimental apparatus

The block diagram of the experimental apparatus is shown in figure 1. The two orthogonally plane polarized modes are separated by properly oriented Wollaston prism and are received by two photodetectors D_1 and D_2. The outputs of these two photodetectors are switched at some suitable frequency by an electronic analog switch. The switched output is a square wave whose amplitude is proportional to the difference in intensities of the two modes. The signal vanishes when the two modes are symmetrical with respect to gain curve peak. In the present experiment a switching frequency of 400 Hz was used from an external pulse generator.

The output signal from the switching IC is synchronously detected by a lock-in amplifier. The lock-in amplifier output is amplified, integrated and then passed through a heating coil of about 8 ohms resistance, modifying the quiescent current flowing through it. The laser gets stabilized at a point when the intensities of the two modes are equal and the square wave output becomes zero. The laser can be tuned over the gain curve by introducing intentional imbalance with the help of a rotatable analyser.

In order to determine the frequency stability, one of the modes from the back-beam of the laser is selected using a polarizer "P". This is mixed with the beam from a Zeeman split frequency stabilized laser (HP make) using a beam splitter (BS), and the mirror M as shown in figure 1. The stability of this Zeeman split laser is 1 in 10^9

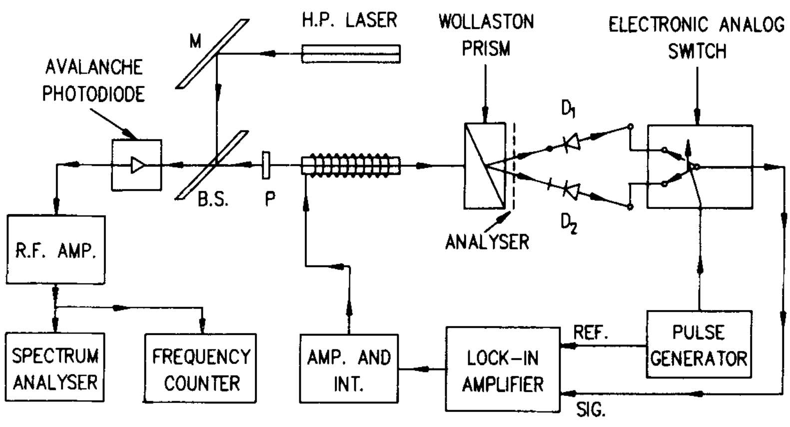

Figure 1. Schematic diagram of the frequency stabilized internal mirror He–Ne laser using switching technique.

with 1 s integration time. The two beams are combined on the avalanche photodiode so as to give a beat frequency signal. This signal after amplification is monitored on a spectrum analyser. The beat frequency is measured using a frequency counter. The variation in beat frequency is analysed for the estimation of the stability.

3. Discussion

Figure 2 shows the switching pulses and the resulting alternately switched output of the switching IC. For ease of recording a very low pulse frequency of 20 pulse/min was used. The upper level and lower level of the square wave of the switched output correspond to the intensities of the two modes of the laser. As the cavity length varies and symmetrical position is approached the two intensity levels tend to be equal. At point 'Q' they are exactly equal. On the other side of this point, the intensity levels of the two modes are interchanged. Thus the square wave on the right hand side of point Q is 180° out of phase with the square wave on left hand side. The error signal on either side of point 'Q' is used to modify the current flowing through the heating coil, so as to lock the laser cavity at point 'Q'. At this point the error signal is zero. Thus the laser is stabilized with the two modes locked at the symmetrical position with respect to the peak of the gain curve. It can also be locked at any other point by tuning it with the help of the rotatable analyser. The analyser rotation causes the intensity change which compensates for the change in intensity due to asymmetry.

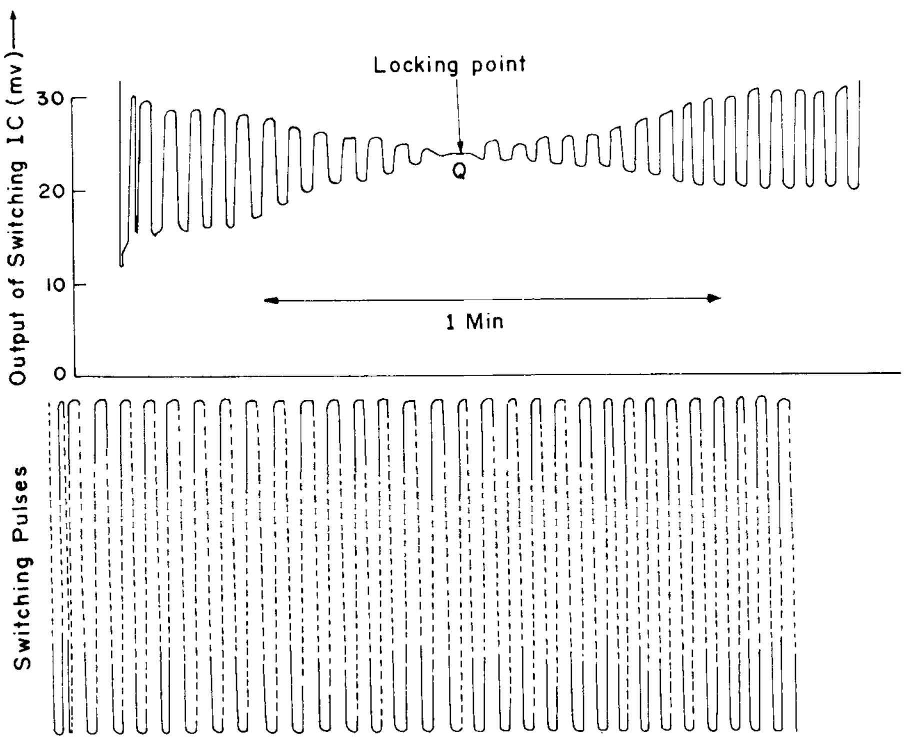

Figure 2. Square wave with amplitude proportional to intensity difference along with the switching pulses.

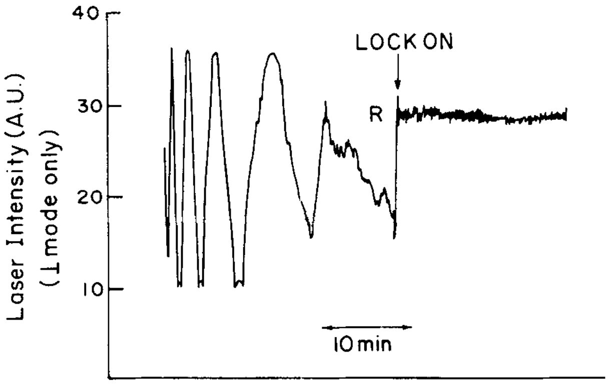

Figure 3. Demonstraton of intensity stabilization. The frequency stability after locking at point R is 5×10^{-9}.

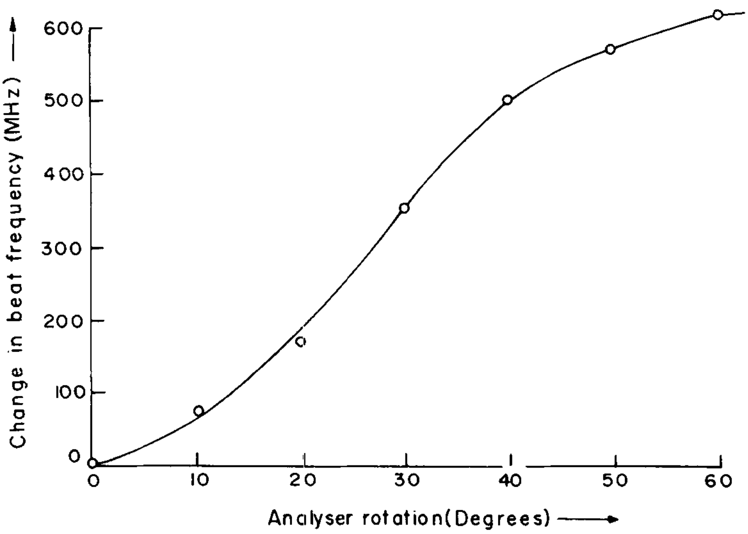

Figure 4. Tunability of the two mode laser after frequency stabilization. The tuning range is 600 MHz corresponding to 60° rotation of the analyser.

Figure 3 demonstrates the intensity stabilization of the laser. Before locking, the control is switched on so as to apply the error signal to the heating coil. The laser gets stabilized immediately, as the variations in intensity are drastically reduced.

The beat frequency was monitored and the Allan variance was calculated. The stability was found to be 5×10^{-9} for 1 s integration time.

The tunability of the laser is demonstrated in figure 4. The analyser rotation is plotted on X-axis and the beat frequency is plotted on Y-axis. Figure 4 shows that the laser can be tuned within a bandwidth of 600 MHz by rotating the analyser in steps. The corresponding change in analyser rotation was about 60°.

4. Conclusion

A technique of stabilization of an internal mirror He–Ne laser without cavity length modulation has been developed using electronic switching and phase sensitive detection. The stability was found to be about 5×10^{-9} for 1 s integration time. The laser could be tuned by rotating the analyser. The tuning range was found to be about 600 MHz.

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