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Frequency Stablization of of He-Ne lasers

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FREQUENCY STABILIZATION OF He-Ne LASERS

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Abstract

For many applications, stability of a free running laser is not adequate and some type of external control over the oscillation frequency is required. Elaborate schemes have been designed to achieve various degrees of stabilization. However, it has been shown that stability of the order of about 1 part in 10^8 can be achieved in a relatively simple manner for a commercial internal mirror He-Ne laser of Spectra Physics Model 138-01. The principle of the method is to thermally control the laser cavity length. Error signal in the form of a heating current in a coil wound around the laser is derived by comparing intensities of adjacent orthogonally polarized axial modes of a laser of proper cavity length (mode spacing $\simeq$ 600 MHz).

We have used a scheme which depends upon the same principle as described by S.J.Bennet, R.E.Ward and D.C.Wilson, Appl. Opt., 12, 1406 (1972) but differs in certain design details such that it offers advantages of simpler optical

layout, greater freedom from drift, and does not require aligning laser mode polarization directions to that of the external optical elements. In our scheme, the output beam of the laser passes through a rotating polarizer and is then received on a photoresistor. Modulated part of the photoresistor signal is phase sensitively rectified and then amplified to get a d.c. error signal voltage. A voltage to current converter converts the error signal voltage to a proportional current through a 12 Ω heater coil. This coil is wound round the laser plasma tube and serves to actively control the resonator length.

Detailed circuitry and other design details are given and the performance is discussed. The degree of stability achieved is inferred from the fluctuations of the error signal voltage and is better than 2 parts in 10^8.

I. Introduction:

For certain applications the frequency stability of a free running He-Ne laser is not adequate and it is necessary to have some external control over the oscillation frequency. In most of the schemes used to achieve the desired degree of frequency stabilization, the resonator cavity length is servo-controlled with reference to an error signal derived by comparing its frequency with some reference frequency such as Lamb dip or an atomic absorption[1]. In recent years it has been shown, however, that it is possible to achieve a stability of about 1 part in 10^8 for commercial fixed mirror He-Ne lasers by a thermal control of the cavity length. Schemes working on this principle have been used by Balhorn[2]; Bennet et al.[3] and Gordon et al.[4]. In brief, a TEM_{00} mode laser is selected with adjacent axial mode spacing of about 600 MHz, so that normally, two axial modes which are polarized mutually orthogonally, are substained. The output beam is then passed through a polarizing beam splitter or a wollaston prism and the two orthogonally polarized beams are received on two photocells. Output of the photocells are difference amplified and the resulting signal is fed back as a heating current through a coil wound around the laser tube. This current thermally controls the resonator length and locks the laser frequencies of the two polarizedbeams symmetrically on either side of the gain profile.

We have used a modification of this scheme, which has several advantages discussed later.

II. Method:

In our method, schematically shown in Fig.1 the output beam is passed through a rotating polaroid and is then received as a photosensor. Modulated part of the photosensor response is phase sensitively rectified and then amplified, the phase reference being obtained by chopping a reference beam falling on a photo transistor. Excursion of this basic error signal is kept normally between +4V to -4V, its value being zero when the two polarized beams are equal in intensity - a condition to which the servo error signal locks the cavity length under frequency stabilized condition.

Fig.2 shows the electronic circuit used for generating the error signal. It essentially consists of two channels. Signal channel and Reference channel.

Signal channel:

The laser beam after getting intensity modulated by a rotating polarizer falls on a photoresistor. A.C. part of the output signal of the photoresistor is amplified by a bootstrapped a.c. amplifier with a variable gain of 1 to 10. The output of the a.c. amplifier is fed as a common input to a synchronous switch whose switching input pulse of +12V to -12V is derived from the reference signal. The synchronous switch output is a full wave rectified output and it is fed to a low pass filter for filtering the a.c. part. The d.c. output of the low pass filter is further amplified by a d.c. amplifier of variable gain from 1 to 10.

Reference channel:

Reference source is a lamp whose light intensity is chopped by the rotating chopper which rotates alongwith the polaroid as depicted in Fig.1. The chopped beam is sensed by a photo-transistor to get the switching reference pulse. This switching reference pulse is passed through a tuned amplifier which is tuned to chopper frequency. The sine wave output of the tuned amplifier is fed to a phase shifter consisting of two sections as 0° to 180° and 180° to 360° phase shift variations. These phase shifters are useful during experiment to adjust the phase of the reference switching pulse properly with the phase of the polarized laser beam signal for proper stabilization. The final output of the phase shifter is fed to a squarer which is a zero crossing comparator. The squarer output switches from +12V to -12V square pulses and it is fed as a switching reference pulse input for the FET switch incorporated in the synchronous switch of the signal channel. The wave forms shown in Fig.3, which schematically illustrates the generation of the error voltage signal; when laser frequency is drifting. It may be noted that, whatever be the directions of the two principle polarization modes of the laser, proper phase relation with the synchronous switch can be adjusted with the help of the phase shifting network provided that these direction are stable and that the rotation frequency also does not vary much.

III. Servo stabilization of laser frequency:

Frequency stabilization of laser can be achieved by servo adjustment of the cavity dimension. One possibility is to use the d.c. error signal as a voltage to piezo electric tube, on one face of which one of the end mirrors of the laser tube is mounted. This however needs a laser tube with external mirrors. For the sake of ruggedness and convenience of field operation we have preferred to use an internal mirror system in which the cavity length is thermally controlled. The initial response is slower and the system takes about an hour before stable frequency output is achieved.

The d.c. error signal voltage varying from +4V to -4V (Vmax $\simeq$ 12V) is converted into a current variation which varies from 600 mA to 200 mA, by a voltage-current converter as shown in Fig.4. This current is then sent through a coil of 12 ohms resistance which is wound around the laser tube as shown in Fig.1. Thus a heating servo loop is created which controlls the cavity dimension and achieves stable frequency operation within one hour.

The voltage to current converter shown in Fig.4 basically consists of two divisions such as summing amplifier and a non-inverting voltage to current converter of floating load type. The summing amplifier sums the two inputs such as the d.c. output coming from the synchronous detector and a reference d.c. voltage derived from a d.c. voltage source which can be adjusted by a 100 K potentiometer as shown in Fig.4. The idea behind the summing amplifier is to convert the -12V to +12V variation of d.c. voltage to 0V to +12V or any other low value linearly, which can easily be converted by a standard voltage to current converter of floating load type from 200 to 600 mA. When the d.c. input signal for the voltage to current converter is zero, the current is around 400 mA which is the mean stabilizing current persisting continuously around the laser beam tube. Once the tube is stabilized, this mean current can be adjusted either low or high for proper stabilization around zero error voltage by adjusting the summing amplifier reference d.c. voltage input using a 100 K potentiometer.

The heater coil is wound around the laser tube and the entire assembly is placed within an outer housing with a controlled wall temperature. The temperature control of the outer housing wall is simply a heater coil, relay and a sensing thermistor set to close the relay at a nominal temperature of 40°C. The control of the outer housing wall temperature was found necessary to prevent drifts due to sudden changes in the ambient temperatures.

IV. Performance:

On switching on the entire system, initially the error voltage fluctuates fairly rapidly from +4V to -4V. The fluctuations subsided after an hour and the error signal voltage remained near zero for several hours. Over a period of 6 hours the typical variations of error signal were ± 0.2V about a mean value which was near zero (but not necessarily equal to zero).

V. Estimation of the frequency stability:

In absence of a very high resolution Fabry-Perot of necessary resolution and stability, or a spectrum analyser to check the relative stability by monitoring the beat frequency obtained by mixing signals with another similarly stabilized laser, we have estimated theoretically the stability by monitoring the error voltage excursions.

Let I_a and I_b be the intensities of the two orthogonally polarized axial modes at any time t, after passing through the rotating polaroid. We can write

$$I_a = a^2 \text{Cos}^2 (\omega t + \phi)$$

$$I_b = b^2 \text{Sin}^2 (\omega t + \phi)$$

where $\frac{\omega}{2\pi}$ = f = Chopper frequency

ϕ = Initial phase

Net intensity incident on photo resistor:

$$I = I_a + I_b$$

Taking $a = b + \delta$ we have

$$I = b^2 + \underbrace{\delta\,\frac{(\delta + 2b)}{2}}_{\text{DC}} + \underbrace{\delta\,\frac{(\delta + 2b)}{2}}_{\text{AC}}\ \text{Cos.}2\ (\omega t + \phi)$$

Under conditions close to stabilization

$$\delta << a \text{ or } b$$

and $\frac{\text{AC}}{\text{DC}} \sim \delta/_b$ ... (1)

To a first approximation as given by Stephen Jacobs et al.[5] the output intensity of the laser due to one mode can be written as

$$I\ (\nu)\ 0 = A \exp\left[-4\ln^2\left(\frac{\Delta\nu}{\Delta\nu_D}\right)^2\right] - B\ .$$

where ν = Frequency within the Doppler profile at which the mode oscillates.

$\Delta\nu = \nu - \nu_o$; ν_o being line centre frequency.

$\Delta\nu_D$ = Doppler line width (FWHH) (typically 1.5 GHz)

$$B = A \exp\left[-4\ln^2\left(\frac{\Delta\nu_t}{\Delta\nu_D}\right)^2\right]$$

$\Delta\nu_t = \nu_t - \nu_o$; ν_t = threshold frequency at which lasing is just possible.

Taking $I(\nu_1) = a^2$

$I(\nu_2) = b^2$

$a = b + \delta$, $\delta \ll a$ ..... quasi stabilization condition.

We have

$$\ln\left[\frac{I(\nu_1) + B}{I(\nu_2) + B}\right] = -4\ln 2\left[\frac{(\Delta\nu_1)^2 - (\Delta\nu_2)^2}{(\Delta\nu_D)^2}\right]$$

Now

$$(\Delta\nu_1)^2 - (\Delta\nu_2)^2 = (\nu_1 - \nu_o)^2 - (\nu_o - \nu_2)^2$$

$$= (\nu_1 - \nu_2)(\nu_1 + \nu_2 - 2\nu_o).$$

If ν_1° and ν_2° are frequencies symmetrically situated with respect to line centre and if 'L' represents the cavity length such that

$$\nu_1^\circ + \nu_2^\circ = 2\,\nu_o$$

and $\nu_1^\circ - \nu_2^\circ$ = Inter mode spacing = $C/_{2L} = \nu_1 - \nu_2$

then we can write

$$\nu_1 = \nu_1^\circ + \Delta$$

$$\nu_2 = \nu_2^\circ + \Delta$$

Here Δ represents the maximum departure from stability position during an experiment.

$$\therefore\ (\Delta\nu_1)^2 - (\Delta\nu_2)^2 = \frac{C}{2L}\ 2\Delta .$$

$$\frac{I(\nu_1) + B}{I(\nu_2) + B} \sim \frac{2\delta}{b(1 + B/_{b}2)} \sim 2 .\ \frac{AC}{DC} \cdot \frac{1}{(1 + B/_{b}2)}$$

Thus under quasi stabilization conditions.

$$\frac{\Delta}{\nu_o} = \frac{AC}{DC} \cdot \frac{1}{(1 + B/_{b}2)} \cdot \frac{2L}{C} \left(\frac{D}{o}\right)^2 \cdot \frac{1}{4\ \ln 2}$$

Taking $\Delta\nu_t = \nu_t - \nu_o = 500$ MHz

$$C/_{2L} = 641 \text{ MHz}$$

$$\Delta\nu_D = 1.5 \text{ GHz}$$

$$\nu_o = 474\ \overset{\text{THz}}{\cancel{\text{GHz}}}$$

$$b^2 \sim I\,(\nu_1^{o} \quad)$$

Observed : $\frac{AC}{DC} \sim \frac{1}{65}$

We get

$$\frac{\Delta}{\nu_o} \sim 2 \times 10^{-8}$$

The estimate indicates that for an observed $AC/_{DC}$ value of $1/_{65}$ the frequency stability is about 2 parts in 10^8.

VI. Conclusion:

In conclusion, we point out the following advantages of the present scheme over the earlier schemes.

1) No polarizing beam splitters are needed so that optical layout is simpler.

2) The scheme uses a single photosensor which minimizes the drift problems.

3) No adjustments are needed to orient the directions of laser beam polarization axes

with respect to that of the polarizing beam splitters.

The present equipment is developed for servo-control of path difference for a high resolution astronomical Fourier Transform Spectrometer now under fabrication at our laboratory.

Acknowledgements:

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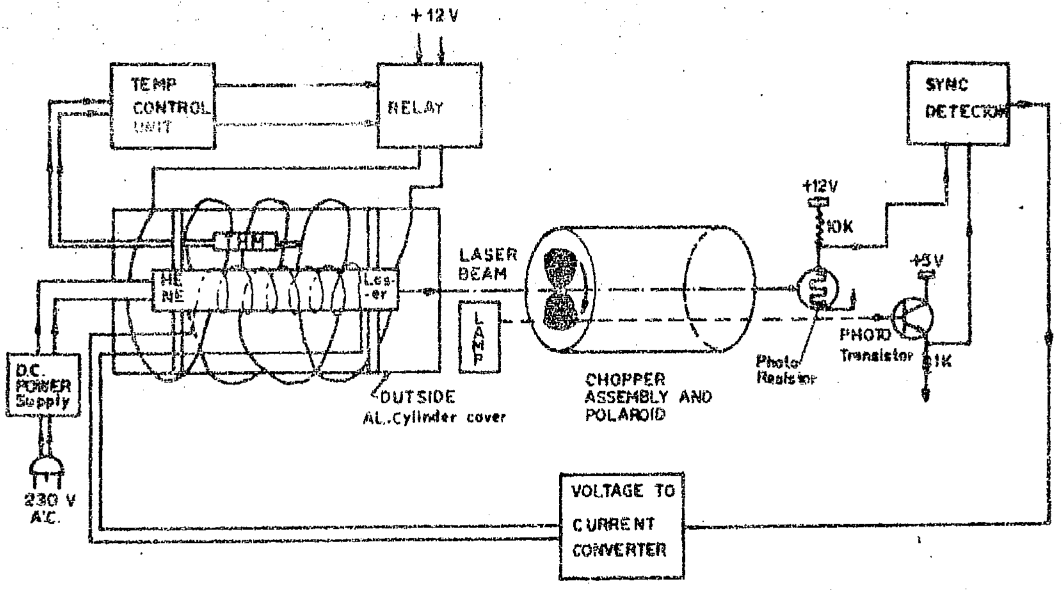

FIG. 1 SCHEMATIC DIAGRAM OF THE LASER BEAM STABILIZER SYSTEM.

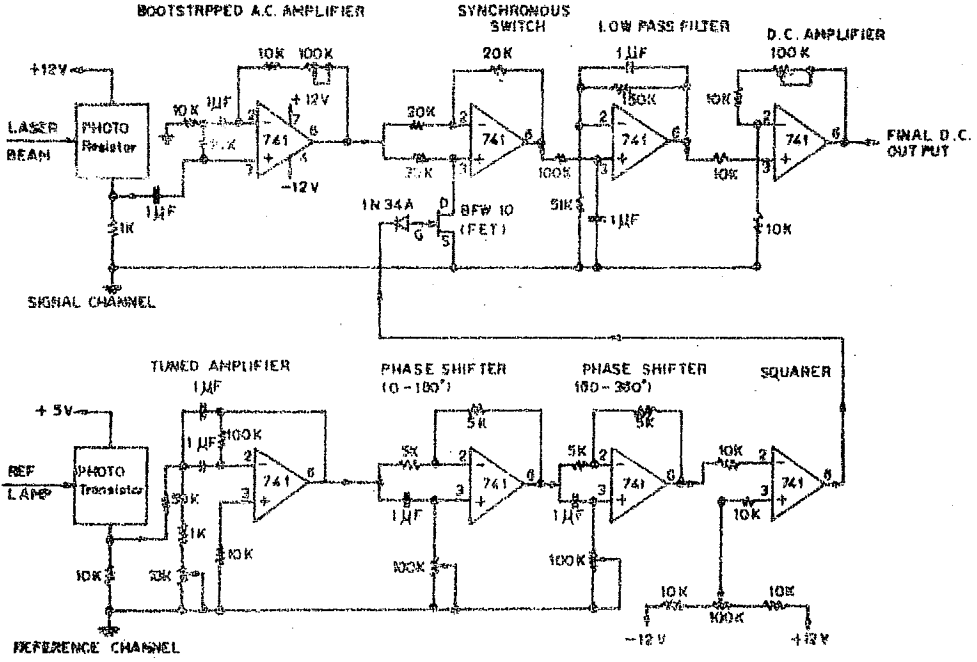

FIG. 2 SYNCHRONOUS DETECTOR

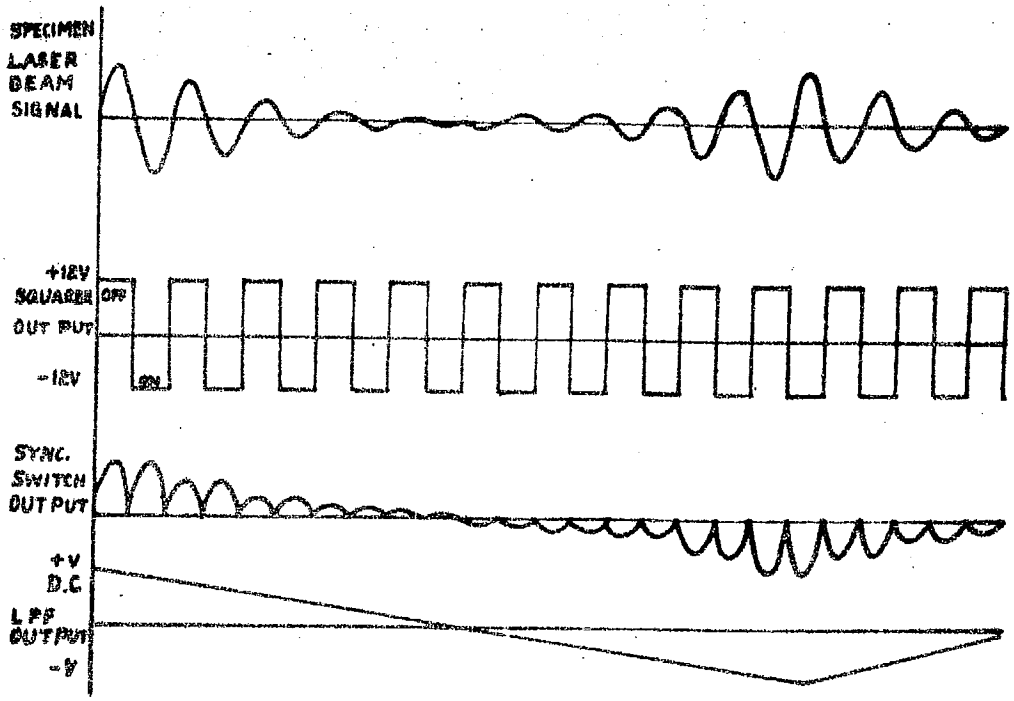

FIG.No. 5 WAVE FORMS OF SYNCHRONOUS DETECTOR

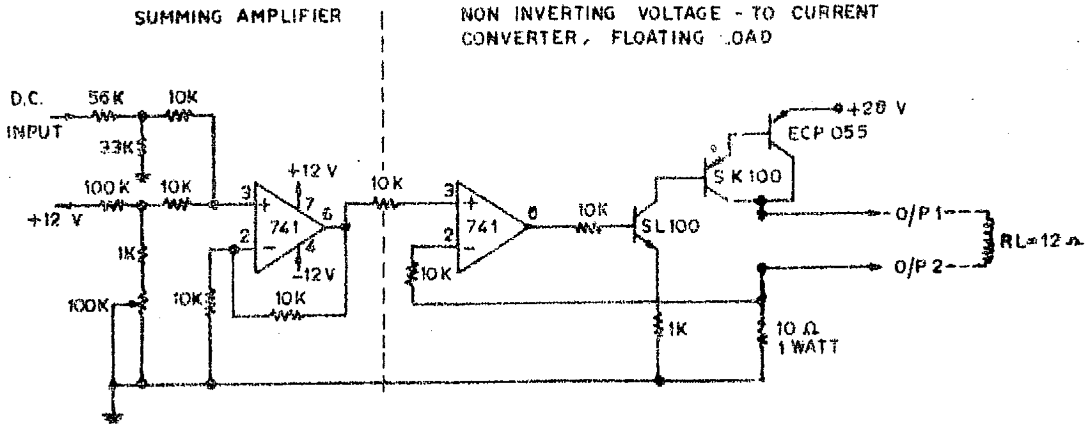

FIG 4 VOLTAGE TO CURRENT CONVERTER