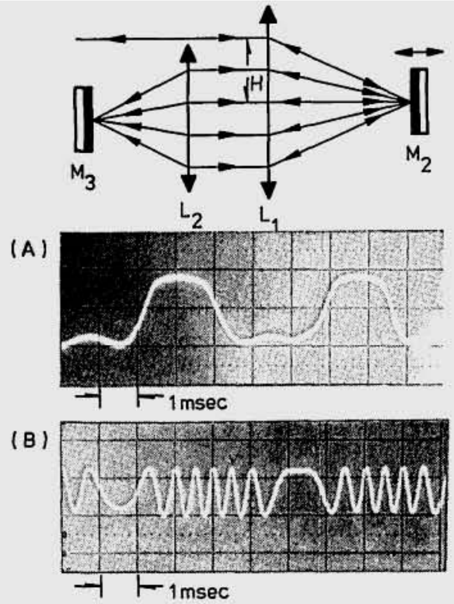

Fig. 3. Trace A shows the beat signal for an oscillatory mirror M_2 movement in the SMI ($N = 1$). For the same movement of M_2 the trace B shows the beat signal in the MRLDI ($N = 5$, $H = 2.2$ cm, $f_1 = 19$ cm, and $f_2 = 7$ cm).

M_2. To ensure that the incident probe beam returns back ward along the same path, a relation of $D = H/(N - 1)$ must be satisfied, where H is the initial incident height of the probe beam to lens L_1, and N is the reflecting number of the probe beam on the moving mirror.

Defining the displacement sensitivity S as the ratio of the number of beat signals N generated by the MRLDI to the number of beat signals N_0 obtained by the SMI for the same time interval and conditions, we have $S = N/N_0$. The geometric considerations give the general equation of S as

$$\left.\begin{aligned} S_{\text{odd}} &= 1 + 2\sum_{i=1}^{(N-1)/2} \cos\theta_i; \qquad N = \text{odd}, \\ S_{\text{even}} &= 2\sum_{i=1}^{N/2} \cos\theta_i; \qquad N = \text{even}, \end{aligned}\right\} \tag{1}$$

where the incident angle $\theta_i = \tan^{-1}[(N - 2i + 1)H/(N - 1)f_1]$, and f_1 is the focal length of the lens L_1. Figure 2 is a graph of S vs f_1 when H is 3 cm and shows that $S \approx N$ in the region of $f_1 > 15$ cm. That is, it is effective to use a lens L_1 with $f_1 > 5H$ in the MRLDI.

In this experiment a He–Ne laser is used as the light source, and two lenses (L_1:$f_1 = 19$ cm and L_2:$f_2 = 7$ cm) are used. A mirror M_2 is attached to the center of a speaker and vibrated with 100 Hz. Figure 3 shows the beat signals obtained by the SMI(A) and the MRLDI(B) in the same conditions, where $N = 5$ and $H = 2.2$ cm. The theoretical value of S_5 is 5.0 in the experimental conditions, and the experimental value of S_5 is 5.1 ± 0.3, so that two values are in good agreement within the error limit of 10%. This experiment was done to $N = 20$. When a rectangular prism replaced the mirror M_3 and the lens L_2, the same results were obtained.

This MRLDI has a disadvantage in that an additional mirror M_3 must be kept still during measurements because any motion of the mirror adds noise to the signal. But the detected area and the error made by the angular motions can be mimimized by using the lens system (M_3, L_1, and L_2) in the MRLDI.[3] This MRLDI will be used to measure laser damage thresholds of optical glasses, and this technique may be used in methods to delay the optical path length.

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Sensitivity of frequency stability of two-mode internal-mirror He–Ne lasers to misalignment of polarizing optics

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Commercially available internal-mirror He–Ne lasers oscillating in two axial modes can be conveniently frequency-stabilized by the so-called two-mode method.[1–5] In this method, the difference in intensities of the two orthogonally polarized modes ΔI is used as the error signal and fedback as a heater current through a coil wound around the laser tube. By maintaining ΔI a constant, one can stabilize the laser cavity length and hence its frequency.

It has not been pointed out explicitly in the earlier works,[1–3] however, that lasers stabilized by this method could be sensitive to the angular misalignment of the laser with respect to the polarizing optics. More recently, Yoshino[4] stated that exact alignment is mandatory, while Ciddor and Duffy[5] commented briefly that the accuracy required is quite low ($\theta \simeq 10$–$20°$), where θ is the angle between the azimuths of polarization of the laser axial modes and the polarizing axes of the beam splitter. In this Letter, we clarify this point and show that the reduction in sensitivity due to misalignment error can be compensated by proper system design.

It can be readily shown that

$$\Delta I'(\theta) = \Delta I \cos 2\theta. \tag{1}$$

That is, the sensitivity of the control system decreases by a factor $\cos 2\theta^5$ when misaligned; $\Delta I'(\theta)$ is the actual error signal used in the servo. This angular dependence is illustrated in Fig. 1 with data for our test laser, a Spectra-Physics model 155. The frequency variation of the laser Δf, which is assumed to be proportional to ΔI in this method, is given by

$$\Delta f = k/\cos 2\theta, \tag{2}$$

where k is related to system parameters and can be regarded as a constant for practical purposes in a particular system.

The reduction in sensitivity and consequent degradation in frequency stability due to misalignment can be minimized, however, by proper design of the control system. In particular, a phase compensation network in the controller is required. To demonstrate this, we present data for two servo systems. Both systems A and B utilize a pulse width modulation (PWM) type power converter which modulates the on/off time of the heater. In system B, a compensation net-

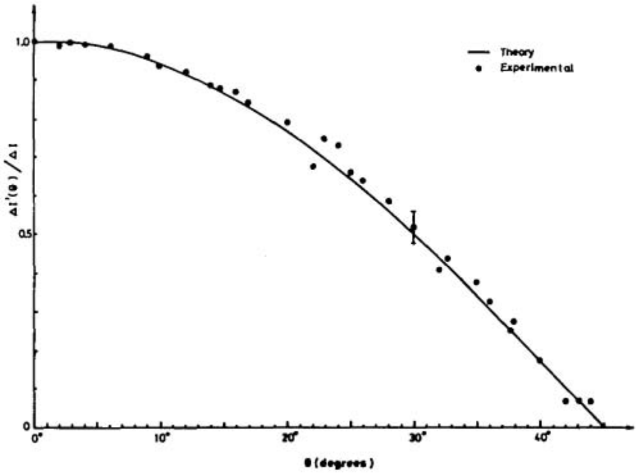

Fig. 1. $\Delta I'(\theta)/\Delta I$ as a function of angle of misalignment.

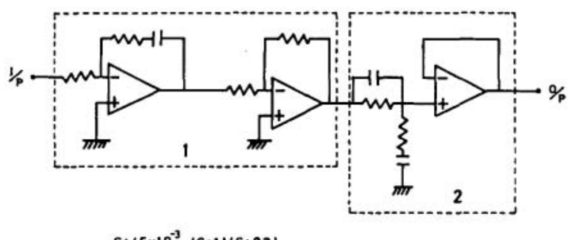

Fig. 2. Compensation network for control system B. $H(s)$ is the transfer function of the compensation network.

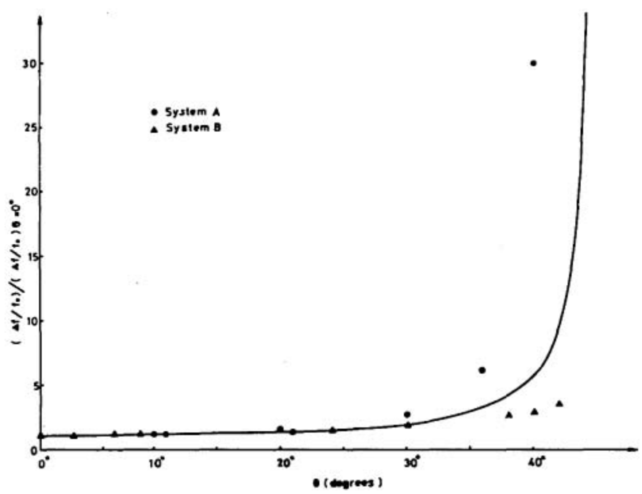

Fig. 3. Relative laser frequency stability as a function of angle of misalignment for control systems A and B.

work is employed as shown in Fig. 2. It contains an integrater for zero cavity length error to step impulse and a zero to cancel a main pole very close to zero of the heat transfer function of the laser system (box 1 in Fig. 2). This is followed by a lead–lag network (box 2 in Fig. 2) to increase both the gain margin and phase margin of the controller. With system B, we can readily achieve a long-term frequency stability of ($\leq\pm 5 \times 10^{-9}$). Figure 3 shows relative laser frequency stability as a function of the angle of misalignment. The solid curve is plotted using Eq. (2) and normalized to $(\Delta f/f_0)_{\theta=0°}$, f_0 being the center frequency of the laser. In these measurements, the control system parameters were optimized for $\theta = 0°$ and not adjusted up to $\theta = 30°$. For $\theta > 30°$, the loop gain was slightly increased (<6 dB). Examining Fig. 3, one finds the degradation in frequency stability is minimal for $\theta \leq 30°$ and at most a factor of 4 worse at $\theta = 40°$) when system B was employed. While for system A, which does not incorporate a compensation network, $(\Delta f/f_0)_{\theta=40°} \simeq 30(\Delta f/f_0)_{\theta=0°}$. Thus system B is relatively insensitive to angular misalignment because of its larger gain and phase margin. In terms of Eq. (2), this means the factor k for system B is such that the factor $\cos 2\theta$ due to misalignment has little effect on the stabilized value of Δf.

To summarize: we have examined the effect of misalignment of polarization optics on laser frequency stability by the two-mode method. Angular misalignment is shown to reduce the error signal ΔI by a factor $\cos 2\theta$. When properly designed (e.g., by incorporating a compensation network as illustrated in Fig. 2), however, laser frequency stability can be maintained even for large misalignment angles.

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Asymmetric optical logic gate

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In 1969 Szöke *et al.*[1] published the ingenious idea of combining nonlinearity with the resonance properties of a Fabry-Perot interferometer. A series of beautiful experiments showed that this idea of optical bistability really works.[2–5] McCall *et al.*[2] discovered that the idea had to be refined substituting nonlinear absorption by nonlinear refraction.[6] Seaton *et al.*[7] used a nonlinear Fabry-Perot device to demonstrate optical AND/OR and NAND/NOR logic gates, which opened the way to think of optical computers.[8]

In the present Letter we point out one more curious aspect of nonlinear Fabry-Perot devices. Imagine a Fabry-Perot interferometer with a nonlinear medium between its mirrors. However, let us assume that, in contrast to the usual case, the two mirrors have different reflectivities, $R_1 < R_2$. The minimal power P of an incident beam that is just enough to switch the device into a high transmission state will then depend on