

## 8. Quantum Optics and Photonics

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### 8.1 Measurement of Fresnel–Drag in Moving Media Using a Ring Resonator Technique

*U.S. Air Force Geophysics Laboratory (Contract F19628-70-C-0082)*

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It has been known for many years that the observed velocity of light in a moving medium differs from that in a stationary medium. This effect, namely the Fresnel–drag, was explained by the special theory of relativity. While special relativity has been very accurately tested, no tests of comparable precision can be claimed regarding the theory's predictions for light propagation in moving media.

We have performed careful measurements of the Fresnel–drag in various moving glass media and tested the dependence of the drag coefficient on refractive index and dispersion. A solid medium was used in our experiments to provide a precisely known velocity and index.

Our technique is based on moving a glass plate of known index and dispersion back and forth inside a ring resonator. In this way, any nonreciprocal phase shift induced by the motion of the glass manifests itself as a difference in the resonance frequencies of the cavity for oppositely propagating field directions. The precision measurement of small resonance frequency differences in a ring cavity is described in detail elsewhere in connection with the measurement of nonreciprocal phase shift due to the Sagnac effect.<sup>1</sup>

In order to distinguish the drag effect from various sources of noise, the glass plate was moved sinusoidally at a rate of 5 Hz to enable the use of AC detection techniques. To avoid the effects of multiple reflections inside the glass, the normal of the glass sample was tilted by an angle  $\Theta$  with respect to the optical axis of the cavity. In addition the glass plate was anti–reflection coated to reduce cavity losses. The velocity of the glass was determined interferometrically using a stabilized HeNe laser.

Measurements of the Fresnel–drag were repeated for glass samples of different index  $n$  and

dispersion  $\partial n/\partial \lambda$ . In addition, the dependence of the drag on the glass thickness  $\ell$ , the velocity  $\vec{v}$ , and  $\Theta$  was also measured. Variations of the above parameters provided for fifteen different sets of measurements of the effective Fresnel-drag coefficient  $\alpha$ . In each case, the experimental drag coefficient  $\alpha_e$  was compared to that predicted by theory  $\alpha_{th}$ . Weighting each measurement by its respective error bar gave an average agreement with theory for the fifteen measurements of

$$\frac{\alpha_e - \alpha_{th}}{\alpha_{th}} = 6 \times 10^{-5} + 2.4 \times 10^{-4},$$

which constitutes the most accurate verification of the Fresnel-drag effect thus far.<sup>2</sup> In addition, the confidence of including the dispersion dependence of the drag was improved to approximately 1 part in 130.

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## 8.2 Observation of Lineshape Distortion by Raman Induced Focusing

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*Robert E. Tench, Shaoul Ezekiel*

We have observed strong, spatially dependent lineshape distortion while studying the interaction of two copropagating monochromatic laser fields with a folded, Doppler broadened three level system in  $I_2$  vapor. In our experiment, the pump field is generated by a single mode CW argon laser operating at 5145 Å and the probe field at 5828 Å is generated by a single mode CW dye laser. The pump is resonant with a hyperfine component of the B-X, 43-0 R(15) transition in  $I_2$ , while the probe is resonant with the corresponding hyperfine component of the B-X, 43-11 R(15) transition. Copropagating pump and probe fields are ensured by coupling both the pump and the probe beams into a single mode fiber. The combined beams which emerge from the fiber are collimated before passing through a cell containing a few mTorr of  $I_2$  vapor. After the cell, the pump and probe beams are separated by a dielectric filter. Raman induced gain at the probe frequency is measured by amplitude modulating the pump field and synchronously demodulating the detected probe beam. Lineshapes are recorded by holding the pump frequency fixed and scanning the probe frequency.

Figure 8-1(a) shows the observed probe lineshape for a strong pump field ( $4 \text{ W/cm}^2$ ) and for a detector size that is large compared to the probe beam diameter. However, when the detector is apertured so that only part of the probe is detected, an asymmetric lineshape is observed; the magnitude and sign of the asymmetry depend on the spatial position of the detector. We attribute this

lineshape distortion to the focusing of the probe beam induced by the nonlinear refractive index generated by the Gaussian pump field in the  $I_2$  vapor. Preliminary calculations are in reasonable agreement with the data.

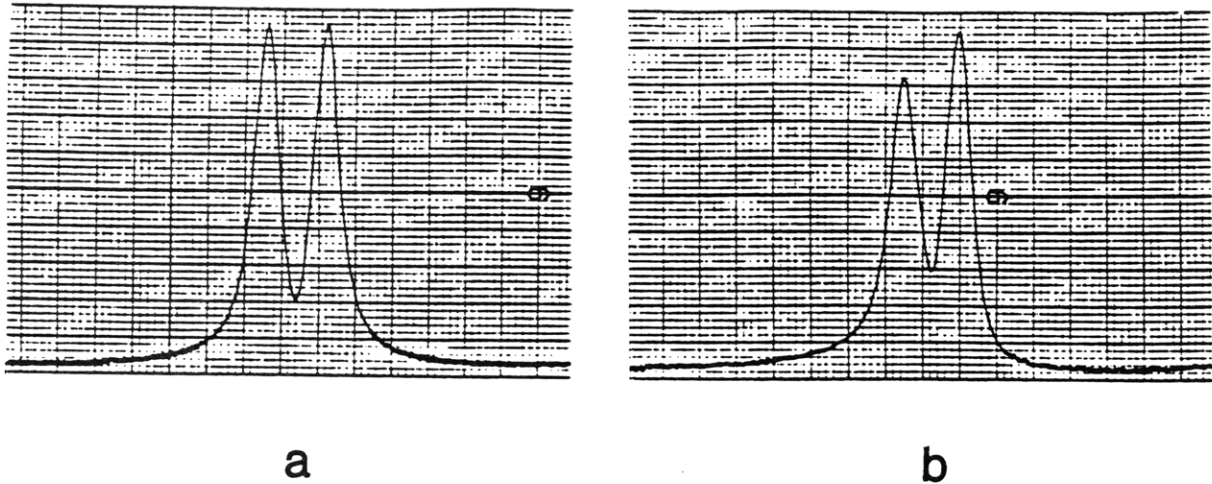


Figure 8-1: Probe Lineshape as a Function of Frequency for a Pump Intensity of  $4 \text{ W/cm}^2$ :

- (a) detector size large than probe beam diameter
- (b) detector size smaller than probe beam diameter

Frequency Scale: 560 kHz per large box

This lineshape asymmetry can be eliminated by using a large detector with uniform sensitivity over the detector surface; a highly symmetric laser beam profile; and a uniform number density. In practice, however, it is difficult to satisfy the above conditions, particularly with regard to detector uniformity. Therefore, such lineshape distortion must be considered in precision studies and applications of resonance Raman interactions.

### 8.3 Performance of a Microwave Clock Based on a Laser Induced Stimulated Raman Interaction

*U.S. Air Force - Rome Air Development Center (in collaboration with C.C. Leiby, Jr.)*

*U.S. Air Force - Rome Air Development Center (Contract F19628-80-C-0077)*

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Recent experimental work<sup>1-4</sup> has demonstrated that a microwave oscillator can be stabilized using a

stimulated resonance Raman transition in a sodium atomic beam. This Raman technique is of interest because optical lasers rather than microwaves are used in the interaction and, aside from fundamental interest, the greater flexibility of optical systems may make it possible to eventually develop more stable and more portable atomic clocks.

The experimental setup consists primarily of a single mode dye laser, an acousto optic frequency shifter and a sodium atomic beam. The dye laser is used to generate the pump laser field and is locked to the sodium  $3^2S_{1/2}(F=1) \leftrightarrow 3^2P_{1/2}(F=2)$  transition, near 5896 Å, via fluorescence induced in the atomic beam. The probe laser field is obtained by shifting a portion of the dye laser output by 1772 MHz using an acousto optic frequency shifter driven with a quartz controlled microwave oscillator. This technique reduces the effects of laser jitter by generating one laser frequency directly from the other so as to correlate the jitters in the two laser fields. To reduce transit time linewidth, Ramsey's method of separated oscillatory fields is employed with interaction region separations up to  $L = 30$  cm producing Ramsey fringes as narrow as 1.3 kHz (FWHM).

To demonstrate the applicability of the stimulated resonance Raman technique to clock development, a microwave oscillator at 1772 MHz was stabilized using a Ramsey fringe of width 2.6 kHz (FWHM), corresponding to  $L = 15$  cm. The measured short term stability of  $5.6 \times 10^{-11}$  for  $\tau = 100$  sec compared well with conventional microwave  $C_s$  clocks when differences in transition frequency and transit time were taken into consideration.

Present research is concerned primarily with an experimental as well as a theoretical study of error sources and level shifts in this Raman stabilization scheme. An extension of the Raman region to 150 cm will be incorporated in the near future.

In addition, we are setting up a Raman clock based on a simple beam of Cesium and employing semiconductor lasers and fiber optics technology. Such a Cesium clock may provide a low cost alternative to the present portable cesium clocks using microwave cavities and magnetic state selectors.

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## 8.4 Fiberoptic Ring Resonator "Gyroscope"

*U.S. Air Force - Office of Scientific Research (Contract F49620-82-C-0091)*

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We are investigating the use of an all-fiber ring resonator as a sensor of absolute rotation. The principle here is similar to that of the discrete mirror resonator method that has been under development in our laboratory for several years. In brief, the mirror resonator is simply replaced with a single mode fiber resonator and the input-output coupling is accomplished by means of a fused evanescent wave fiber coupler.<sup>1-2</sup> At present the finesse of the 3 meter fiber resonator is 140. Preliminary data on short-term noise is about  $0.5^\circ/\text{hr}$  ( $\tau = 1$  second) (rms) which is 10 times greater than the shot noise limit in our present setup.

There are a number of problems that are being investigated. These include the backscattering in the fiber, the stability of the polarization alignment and nonlinear phenomena such as the optical Kerr effect.

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## 8.5 Precision Atomic Beam Studies of Atom-Field Interactions

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*Bruce W. Peuse, Mara G. Prentiss, Shaoul Ezekiel*

The interaction of radiation with two and three level quantum mechanical systems is of much interest because it involves basic processes. So far we have studied the interaction of 2-level and 3-level sodium atoms with one and also with two monochromatic fields provided by stable, single frequency dye lasers. One laser acts as the pump and interacts primarily with two of the levels. The second laser then probes the absorption between either one of these levels to a third level. In this way we have studied a cascade system, a Vee system, and also an inverted Vee system. In the case of a weak pump field, our probe data was in very good agreement with theoretical calculations. However, when the pump was made very intense the probe data could not be explained by the a.c. stark effect alone. Atomic recoil had to be included in the calculations in order to explain the peculiarities observed.<sup>1-6</sup>

The research at present is primarily concerned with reducing atomic recoil effects and the study of atom-field interaction in non-uniform fields.

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## 8.6 Fiber Interferometer "Gyroscope"

*U.S. Air Force - Office of Scientific Research (Contract F49620-82-C-0091)*

*Joint Services Electronics Program (Contract DAAG29-83-K-0003)*

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The fiberoptic gyroscope has been receiving considerable attention for the past several years. A number of different approaches have been studied, and as these studies progress a number of problems were uncovered.

Our approach employs a 200 m long fiber wound around a 19 cm diameter spool and operated in a closed loop mode. Our measurement technique is based on the use of two acousto-optic frequency shifters placed within the fiber interferometer for providing nonreciprocal phase modulation as well as nonreciprocal frequency offsets needed in closed loop operation. Short-term random drift is about  $0.03^\circ/\text{hr}$  for averaging times of 30 seconds which is close to that predicted by the photon shot noise limit in our setup. The long-term performance departs from the photon noise limit and considerable effort is at present directed into the sources of long-term drift. In this connection, we have predicted and observed an intensity-induced nonreciprocity in the fiberoptic gyro. We found that a nonreciprocal phase shift of  $1.4 \times 10^{-6}$  radians can be generated by a one microwatt power difference between the oppositely propagating light beams. Our fiber is 200 m long with a core diameter of 4.5 microns, and wound on a 19 cm diameter spool. The intensity dependent nonreciprocal phase shift, which is attributed to a four wave mixing process in the quartz medium, is equivalent to a rotation rate of  $0.2^\circ/\text{hr}$  in the present geometry, and therefore stresses the need for a strict intensity control in precision fiber rotation sensors.<sup>1-3</sup>

Our present effort is in the study of noise sources in a 1 km long interferometer gyro setup that employs evanescent wave fiber couplers. In addition, we are developing techniques of light frequency shifting that would be suitable for fiber gyro application.

#### References

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## 8.7 Long Term Frequency Stabilization of Semiconductor Lasers

*U.S. Air Force - Rome Air Development Center (Contract F19628-80-C-0077)*

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We are interested in developing techniques for the long term frequency stabilization of semiconductor lasers. This area of research is becoming very important for communication, frequency standards, as well as for sensor applications. We are considering both narrow band and broadband lasers in the wavelength range  $0.8 \mu-1.5 \mu$ .

