

8. Photonics

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8.1 Ultrahigh-Resolution Spectroscopy and Frequency Standards in the Microwave and MM Wave Regions Using Optical Lasers

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U.S. Air Force - Rome Air Development Center (Contract F19628-80-C-0077)
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In this program we are considering an attractive possibility for obtaining ultrahigh resolution in the microwave and mm regions using optically induced Raman transitions in atomic beams. The research is centered around the interaction of two laser fields with a three level system in an atomic beam. Of particular interest is the basic study of coherent two-photon excitations in a folded three level system in which exceedingly narrow resonances can be obtained when the initial and final levels are long lived states. As is well known, the linewidth is determined only by the initial and final level decay rates for a Doppler Free system such as an atomic beam.

In order to achieve such narrow linewidths, laser frequency jitter must be eliminated and the time the atom spends in the excitation field must be made as long as possible to reduce the transit time linewidth. We eliminate laser jitter by correlating the jitter in the two lasers since the transition frequency of interest depends on the difference in the laser frequencies. In summary, we are able to make a transition from the first level to the final level indirectly via the intermediate level and achieve a linewidth equivalent to that obtained by a direct transition from the first to the final level using a microwave or mm wave source.

Our initial experiments have been conducted with an atomic beam of sodium and dye lasers. In this case the difference in the laser frequencies is 1772 MHz. Laser jitter in each beam was correlated by simply deriving one laser frequency from the other by an acousto-optic frequency shifter driven at 1772 MHz. A linewidth of 650 Hz was achieved by using Ramsey's separated oscillator method with a 30 cm separation between the interaction regions. We have also stabilized the 1772 MHz oscillator to

the Ramsey resonance and achieved a stability of 5.6×10^{-11} for an averaging time of 100 seconds.

Future work is concerned with the study of level shifts in the resonance Raman scheme which influence the ultimate performance of such a stabilization system. In addition we are considering various techniques for cooling the Na Beam so as to achieve narrower transit time linewidths.

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8.2 Resonant Light Diffraction by an Atomic Beam

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We have observed resonant light diffraction by an atomic beam of 2-level sodium atoms. This grew out of an effort to develop new techniques of performing absorption spectroscopy in low density atomic beams, that are capable of achieving quantum noise limited sensitivity. As a result of using such techniques, we found that the absorption lineshape exhibited an asymmetry even for weak fields and the magnitude of this asymmetry depended on the position and size of the detector. In contrast, the lineshape determined by collecting the fluorescence for the same atoms did not exhibit any asymmetry. Moreover, we measure the on-resonance and also the off-resonance absorption as a function of detector position.

We explain the observed distortion in the absorption lineshape and the spatial absorption behavior as a manifestation of the interference between light scattered by the atoms with the excitation beam at a given position of the detection plane. In other words, we have observed a diffraction-like pattern due to the laser beam propagating across a thin atomic beam. The difference between on-resonance and off-resonance behavior is explained by the dependence of the phase of the scattered field on frequency. Our calculations are in good agreement with the experimental data.

The above diffraction phenomena along with the resulting lineshape distortion can be eliminated by placing the detector very close to the interaction region, but this is clearly not feasible. However, it is

possible to achieve the same results by imaging the fields in the interaction region at the detection plane. In our experiment this was accomplished by placing two lenses of equal focal length f in the laser beam after the interaction region. In this way, the fields in the interaction region are faithfully reproduced at the image or detection plane. When the apertured detector is scanned along the image plane while the laser is held on resonance, the spatial pattern that results no longer shows any diffraction behavior. Moreover, the lineshape distortion was also eliminated by using this imaging technique.

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8.3 Precision Atomic Beam Studies of Atom-Field Interactions

National Science Foundation (Grant PHY79-09739)

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

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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.

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8.4 Measurement of Natural Predissociation Effects in Iodine Molecules

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

National Science Foundation (Grant PHY79-09739)

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In our continuing study of the interaction of two monochromatic fields with folded 3-level systems in vapors, we have performed extremely high resolution measurements of Doppler free resonances in I_2 . With weak copropagating pump and probe fields we have observed linewidths as narrow as 50 kHz, vapors, we have performed extremely high resolution measurements of Doppler free resonances in I_2 . With weak copropagating pump and probe fields we have observed linewidths as narrow as 50 kHz, determined, in principle, by the relaxation rates of the first and final levels with a small contribution from the relaxation rate of the intermediate level. For counterpropagating fields we have observed a probe linewidth of about 150 kHz that is determined primarily by twice the relaxation rate of the intermediate level. We are using this doubling of the intermediate level relaxation rate to perform precision measurements of the nature linewidths of the many hyperfine transitions in the P(13) 43-0 and R(15) 43-0, B-X transitions at 5145 Å. Because of natural predissociation effects in the I_2 molecule, the natural width of each hyperfine component will be different. Our precision measurements will therefore enable us to study in more detail such predissociation phenomena.

Since molecular iodine is being considered as a reference molecule in the visible region of the spectrum, precision linewidth and lineshape measurements of individual hyperfine components as well as the spacing between components is of much interest.

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8.5 Passive Ring Resonator Method for Sensitive Inertial Rotation Measurements in Geophysics and Relativity

U.S. Air Force Geophysics Laboratory (Contract F19628-79-C-0082)

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Precision measurement of inertial rotation is of much interest in a number of areas, such as navigation, geophysics, and relativity. The geophysical applications include the measurement of the

various effects that cause fluctuations in the earth's rotation rate Ω_E , ranging from 10^{-7} to $10^{-9}\Omega_E$, for example, nutation, precession, wobble, and tidal-friction effects. The relativistic effects range in sensitivity from 10^{-9} to $10^{-11}\Omega_E$ and include measurements of the preferred frame and the drag parameters.

The advent of the laser in 1960 rekindled the interest in the use of the Sagnac effect for sensing inertial rotation by optical means. Several approaches to implementing the Sagnac effect have been under investigation. These include active techniques, such as the ring laser gyro, and passive techniques employing passive ring resonators or multiturn fiber-optic interferometers. In all these approaches, the measurement sensitivity scales with the area enclosed by the light path. Typically, to reach the sensitivity needed to measure the geophysical and relativistic effects mentioned previously, it is necessary to consider areas between 10^2 and 10^4 m².

Our research effort centers around the passive resonator technique. Our present setup is a square cavity, 70 cm on a side, mounted on a super invar table. The difference between the resonance frequencies of the cavity for clockwise (cw) and counterclockwise (ccw) propagation induced by inertial rotation is measured by a 1/2-mW He-Ne laser, mounted external to the cavity. We have reduced the short-term random drift to about $3 \times 10^{-4}\Omega_E$ (where Ω_E is earth rotation rate) in an averaging time of 30 seconds which is close to the photon shot noise limit in our setup. The study of long-term drift is in progress.

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8.6 Closed Loop, Low Noise Fiberoptic Rotation Sensor

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

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

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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 present approach employs a 200 m long fiber wound around a 19 cm diameter spool and operated in a closed loop mode. Our measurement approach 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 1.4×10^{-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.

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8.7 Fiberoptic Ring Resonator Gyroscope

U.S. Air Force Geophysics Laboratory (Contract F19628-79-C-0082)

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

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In addition to the fiber interferometer method described in the previous section we are also 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. 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.

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