mance are important. Some different 2-D scanners are compared on a common specification of a total resolution of 6.25 million pixels. According to our analyses, the polygon-mirror system offers the best straightness but is the most sensitive to mechanical wobble and eccentricity.[1] Different holographic 2-D scanners are also investigated, and their performances depends strongly on design parameters and on the configurations. The scan line straightness of the grating scanner's system is comparable with that of a polygon mirror.[2] The scan line linearity of the scanner with an auxiliary reflector[3] is the best one. The simplicity and therefore the expected reliability of holographic scanners may influence people to prefer holographic scanners. However many technical problems remain to be solved before holographic scanners can be widely used. **(12 min)**

1. R. Hradaynath and A. K. Jaiswal, "Distortion in a 2-D Scan Pattern Generated by Combining a Plane Mirror and a Regular Polygon Scanner," Appl. Opt. **22**, 615 (1983).
2. C. J. Kramer, "Holographic Laser Scanners for Nonimpact Printing," Laser Focus **16**, 333 (1975).
3. C. S. Ih, "Design Considerations of 2-D Holographic Scanners," Appl. Opt. **17**, 748 (1978).

Tuesday **AFTERNOON**
15 October 1985 **TUP**
LINCOLN EAST

1:30 PM Dye Lasers and Frequency Stabilized Lasers

Robert W. Gammon, Presider

TUP1 Narrowband picosecond cascade-pumped dye laser

S. C. HSU, P. H. CHIU, and H. S. KWOK, SUNY at Buffalo, Electrical & Computer Engineering Department, Amherst, NY 14260.

Recently, the Roess-Lin scheme for the generation of picosecond dye laser pulses has been demonstrated in cascade.[1] This cascade-pumped dye laser (CDL) was shown to produce dye laser pulses of 10-ps duration starting with 350-ps nitrogen laser pump pulses. The bandwidth was also measured to be $\gtrsim 100$ Å. For the CDL system to be more useful, the pulse duration stability has to be characterized and the bandwidth has to be narrowed. Because of the nature of the Roess-Lin scheme, intensity variations in the pump pulse translate into fluctuations in the duration of the output pulse. We have completely redesigned the CDL laser by replacing the first stage with a side-pumped dye laser. The thickness of the second stage was also decreased to produce a shorter cavity lifetime and wider mode spacing. By using a spectrometer to pass only one longitudinal mode, it was found that the bandwidth was 0.5 Å. Using a 2-ps streak camera to monitor 100 laser pulses, it was found that the average duration was 7.6 ps with a standard deviation of 0.7 ps. These near transform-limited ultrashort pulses can be amplified to high energy for further pulse compression or for performing nonlinear optics experiments. **(12 min)**

1. P. H. Chiu, S. C. Hsu, S. J. Box, and H. S. Kwok, IEEE J. Quantum Electron. **QE-20**, 652 (1984).

TUP2 Self-modulation of propagation direction of a ring dye laser

STEVE CHAKMAKJIAN and CARLOS R. STROUD, JR., U. Rochester, Institute of Optics, Rochester, NY 14627.

Observations are reported of a sinusoidal oscillation of the direction of operation of a cw-pumped ring dye laser. The dye laser cavity contains two solid glass etalons and a prism but not a unidirectional device. The etalons are chosen such that the laser operates in two longitudinal modes separated by 10–30 GHz. In these conditions the laser breaks into self-oscillation in which the total amplitude and spectrum of the output of the laser is constant, but the amplitudes of the clockwise and counterclockwise propagating components of the field are each 100% amplitude modulated. The frequency of the modulation can be varied from 10 to 300 kHz by tilting the etalons but is essentially independent of the pumping intensity. The observations are related to a theory of mode competition in the dye jet and to other observations of instabilities in homogeneously broadened lasers. **(12min)**

TUP3 Paper withdrawn

TUP4 Precise frequency synthesizer scanning of a single tunable laser using electrooptic modulation techniques

M. D. RAYMAN and J. L. HALL, Joint Institute for Laboratory Astrophysics, Boulder, CO 80309; C. G. AMINOFF, Helsinki U. Technology, Espoo 15, 02150 Finland.

We have developed a new single-laser/rf sideband technique to provide accurate frequency guiding of a tunable cw dye laser. A high efficiency, broadband electrooptic modulator produces rf sidebands on a portion of the laser output. One filtered sideband is presented and locked to the resonance of a stable optical reference cavity using the output error signal to servo control the laser frequency. Thus computer-programmed changes of the rf source frequency are directly transferred onto the laser's carrier frequency. Drifts in the cavity are measured (and corrected) when scanning the laser over an atomic resonance by periodically relocating the center of the atomic line relative to the cavity. Computer-feedforward tuning of the laser and on/off switching of the servo locks allow frequency jumping to another resonance, perhaps many reference cavity orders away. (The FSR itself can be measured very accurately with rf sideband techniques.) We measured isotope shifts and hyperfine splittings in the Hg (6^3P_2–7^3S_1) transition at 546.2 nm. These frequency intervals (from 850 MHz to 32 GHz) were measured with 2×10^{-3} linewidth accuracy, e.g., ~50 kHz for adjacent isotopes. **(12 min)**

TUP5 Paper withdrawn

Tuesday **AFTERNOON**
15 October 1985 **TUQ**
MONROE WEST

1:30 PM Raman Processes

William K. Bischel, Presider

TUQ1 Cross-correlation measurements between the pump and Stokes intensities in stimulated Raman scattering

L. A. WESTLING and M. G. RAYMER, U. Rochester, Rochester, NY 14627.

The cross-correlation function between the pump and Stokes intensities in stimulated Raman scattering has been measured. It has previously been conjectured[1] and theoretically shown[2] that the Stokes light generated in the presence of a multimode or broadband pump is generated with mode amplitudes and phases in perfect correlation with those of the pump. We present here experimental evidence of such cross correlations for scattering in hydrogen gas. The measurement technique used is the same as that previously used for measuring the intensity autocorrelation function of a multimode dye laser.[3] This technique is based on detecting the frequency doubled light from a nonlinear crystal as a function of time delay between the pump and Stokes beams. We have performed cross-correlation measurements using as a pump the light from a multimode dye laser which is operated in two different cavity configurations: one in which the mode spacing $\Delta\nu$ is large compared with the spontaneous linewidth of the Raman transition Γ, $\Delta\nu > \Gamma$; and one in which the mode spacing is small, $\Delta\nu < \Gamma$. **(12 min)**

1. D. Eimerl, International Conference on Lasers (1978), p. 333.
2. M. G. Raymer and L. A. Westling, to be published in J. Opt. Soc. Am. B.
3. L. A. Westling and M. G. Raymer, to be published.

TUQ2 Generation of frequency correlated laser beams via optical means

PREM KUMAR AND SENG-TIONG HO, MIT Research Laboratory of Electronics, Cambridge, MA 02139.

Generation of frequency correlated laser beams is of importance in various applications, in particular, for extending the frequency of the laser Raman microwave clock[1] into the millimeter region where acoustooptic methods are not available. We propose and demonstrate an all-optical technique for such a purpose. The technique is based on the recently observed Raman-shifted oscillation[2] that occurs when a three-level atomic system of Λ type is optically pumped and placed in a ring cavity. Our initial experiments are performed in sodium vapor pumped by a cw ring dye laser. Raman-shifted oscillation, detuned from the pump laser by 1.772 GHz which is the ground state hyperfine splitting of sodium, occurs in the wings of the Doppler broadened D_1 line. This Raman-shifted oscillation is demonstrated to be highly frequency correlated with the pumping laser when the two are heterodyned on a fast photodetector. In our experiments the heterodyne beat signal at 1.772 GHz had a linewidth as low as 17 kHz, whereas the pumping laser has a rms frequency fluctuation of 300 kHz. The beat signal stays narrowband when the pumping laser is unlocked from the reference cavity increasing its rms frequency fluctation to ~10 MHz. **(12 min)**

1. P. R. Hemmer, S. Ezekiel, and C. C. Leiby, Jr., Opt. Lett. **8**, 440 (1983).
2. P. Kumar and J. H. Shapiro, Opt. Lett. **10**, 226 (1985).

TUQ3 Raman beam combination in multiline and broadband operation

SHIRLEY J. PFEIFER, TRW Optical Sciences Department, Redondo Beach, CA 90278.

Efficient conversion in Raman beam combination systems with preservation of the Stokes seed phase front and temporal coherence is dependent on pumping geometry, mode spectrum, and relative intensities of lines in multiwavelength operation. Beam cleanup with highly aberrated narrowline single-wavelength pump beams is shown to be a function of injection angle, Fresnel number, and gain saturation. In multimode operation, however, the loss of correlation between pump and Stokes beams during amplification as well as the influence of injection angle in establishing and maintaining a phase-locking condition will affect efficiency. Nonlinear dispersion, four-wave mixing of pump/Stokes modes, and mixing of lines at phase-matching angles in multiline conversion will be factors affecting the beam quality of the output Stokes and the generation of higher orders. Analytical and numerical results for conversion of single-line and two-line XeF in H_2 are given for both narrowband and broadband operation. Results are presented on the use of phase conjugation to correct for component and distributed medium aberrations in a Raman amplifier used in beam combining applications as a function of pump beam aberration, degree of Raman medium aberration, phase conjugator reflectivity, injection angle, and Fresnel number. **(12 min)**

TUQ4 Molecular cooperation in the transient regime of stimulated Raman scattering

M. G. RAYMER and I. A. WALMSLEY, U. Rochester, Institute of Optics, Rochester, NY 14627.

The nonlinear regime of stimulated Raman scattering (SRS) may be reached in two ways. The best known is that of depletion of the pump laser as a large number of photons are scattered into the Stokes field. There is, however, another way in which gain saturation can occur, that is, by depletion of the atomic population while the laser remains undepleted. The equations which describe SRS, including damping and population inversion,[1] are remarkably similar to those of well-known theories of two-level superfluorescence, and it is possible by analogy to define a delay time τ_D for cooperative Raman scattering (CRS). This delay time is inversely proportional to the spontaneous scattering rate, which depends on the pump laser intensity. A sufficient condition for CRS is that the spontaneous Stokes linewidth Γ is very much greater than τ_D^{-1}. The only other requirement is that there be more laser photons than scatterers, so that τ_D is independent of the number of scatterers. The $S(1)$ transition in molecular hydrogen, when excited by a short ($\cong$100-ps) laser pulse, provides a possible system for observing pure CRS. Similar studies have been carried out previously[2] for $\Gamma \cong \tau_D^{-1}$. **(12 min)**

1. Y. Takahashi, T. Tan-no, K. Yokoto, Opt. Commun. **22**, 127 (1977).
2. V. S. Pivtsov, S. G. Rautian, V. P. Safanov, K. G. Folin, and B. M. Chernobrod, Sov. Phys. JETP **54**, 250 (1981).

TUQ5 Density and temperature dependence of the rotational Raman gain in N_2

G. C. HERRING, MARK J. DYER and WILLIAM K. BISCHEL, SRI International, Chemical Physics Laboratory, Menlo Park, CA 94025.

Rotational stimulated Raman scattering in N_2 was recently observed[1] at Lawrence Livermore National Laboratory when the Nova beam was propagated through 100 m of air. Stimulated Raman scattering in N_2 will limit the maximum intensity that can be transmitted by air if the frequency and divergence of the laser are to remain unchanged. Modeling of this process requires knowledge of the Raman gain as a function of density and temperature for the N_2 Raman lines. Using stimulated Raman gain spectroscopy, we have measured the temperature dependence of the density broadening coefficient for the Stokes branch rotational lines of N_2. At 295 K, our experimental broadening coefficients are in agreement with the corrected *ab initio* theory.[2] The absolute value of the $S(10)$ gain coefficient was determined by ratioing the N_2 gain to that observed for the $S(0)$ transition in H_2. From these data, we have calculated the temperature, wavelength, and J dependence of the Raman gain coefficient in the high density limit, which is in agreement with the value derived from the Livermore experiments. **(12 min)**

1. J. Murray, private communication.
2. C. G. Gray and J. Van Kranendonk, Can. J. Phys. **44**, 2411 (1966).

TUQ6 Raman scattering or four-wave mixing

JOHN G. KEPROS, Lockheed Missiles & Space Co., P.O. Box 504, Sunnyvale, CA 94086.

An attempt was made to prove the identity of the set of equations describing the Raman phenomenon with the set describing four-wave mixing. The result is a classic proof by contradiction: for the two phenomena to be the same, 1 would have to equal 3/2, 1 would have to equal 5/2. The Raman phenomenon is described by Hertzberg as the vibronic coupling of monochromatic light with the quantized vibrational states of a molecule, producing sidebands from integral quanta. This process is considered one of the initial proofs of quantum mechanics. Four-wave mixing is the optical application of a radar model: two signals of frequency f_1 and f_2 are transmitted through a radar amplifier with four (or more) waves emitted, of the form f_1, f_2, $jf_1, + kf_2$, and $jf_1 - kf_2$. When the Raman equations are equated with the CARS, HORSES, SCISSORS. . .equations[2]

$$f_0 + jf_r = (j + 1)f_1 - jf_2,$$

$$f_0 - jf_r = (j + 1)f_2 - jf_1,$$

where $j = 1,2,3 \ldots$ and f_2 is greater than f_1, the result is inconsistent with logic. Thus, one is led to the conclusion that the Raman effect and the collection of acronyms do not describe the same effect. It is recommended that the Optical Society of America take the editorial position that submissions which label their topic contrary to the proposed definitions be returned to the author for revision. **(12 min)**

1. J. G. Kepros, J. Opt. Soc. Am. A **1**, 1252 (1984).

Tuesday **AFTERNOON**
15 October 1985 **TUR**
MONROE EAST

1:30 PM **Image Understanding and Machine Vision: 2**

Robert J. Woodham, Presider

TUR1 Measurement of orientation and image velocity through hierarchical processing

DAVID J. FLEET and ALLAN D. JEPSON, U. Toronto, Computer Science Department, Toronto M5S 1A4, Canada.

This paper concerns the first functional level of visual processing in which basic image properties are measured and made available for later interpretation. We constrain this level to be a blind process, that is, an image-independent process which involves no previous or concurrent interpretation. Interpretation is postponed until a rich description of the image, including at least orientation and velocity information, is available. The simultaneous use of such different types of visual information will facilitate most subsequent tasks. For example, in the human visual system, primitive motion and depth information contribute significantly to early form interpretation. The velocity selective mechanisms we propose correspond to short-range motion processing in the human system and require no previous spatial interpretation. By contrast, current approaches to the determination of optic flow in machine vision rely on some degree of spatial interpretation (such as contour estimation, peak finding, or more elaborate spatial analysis). Here, we show the extraction of orientation and 2-D normal velocity based on layers of explicit (bottom-up) and implicit (lateral interactions) spatiotemporal processing. The hierarchy allows a very simple and efficient construction of mechanisms that are well localized in space–time and tuned to narrow ranges of orientation and speed. The degree of specificity can be altered by varying the number of layers in the cascade and the form of processing in each layer. **(12 min)**

TUR2 Shape representation using scale-space

ERIC SAUND, MIT Psychology Department, Cambridge, MA 02139.

A major goal of shape analysis is to derive discrete qualitative descriptions of binary data which may assume a continuum of distributions in space—witness the range of 2-D silhouettes that may be called hammer. We address the question, when during information processing should a representation proceed from a continuous, iconic data structure (i.e., in the format of the image array) to more abstract, discrete symbolic descriptors? Conventional approaches to shape representation immediately describe shape in terms of the spatial relationships among instantiations of a small number of shape primitives. Depending on the primitives chosen and the rules for assigning primitives to portions of the image, this strategy can lead to unnatural and unstable descriptions. We argue that at an early level of shape analysis the quantity of interest is the continuous-valued location and density of matter in space, across all scales of resolution. A natural data structure is scale-space, the original signal smoothed at all scales.[1] Shape information is manipulated via operations for moving matter around in the scale-space im-