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S.S. Thattey, A.S. Dongare, B.M. Suri and L.G. Nair*
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BHABHA ATOMIC RESEARCH CENTRE
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21 Affiliation of author(s) : 1) Multi Disciplinary Research Section, Bhabha Atomic Research Centre, Bombay; 2) Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Bombay

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60 Abstract : Pulsed tunable dye lasers are being used extensively for spectroscopic and photo-chemical experiments, and a system for acquisition and spectral analysis of a volume of data generated will be quite useful. In this report we describe the development of a system for wavelength tuning and control of tunable dye lasers and an acquisition system for spectral data generated in experiments with these lasers. With this system, it is possible to control the tuning of three lasers, and acquire data in four channels, simultaneously. It is possible to arrive at the desired dye laser wavelength with a reproducibility of $\pm$ 0.012 cm^{-1}, which is within the absorption width (atomic interaction) caused by pulsed dye lasers of linewidth 0.08 cm^{-1}. The spectroscopic data generated can be analyzed for spectral identification within absolute accuracy $\pm$ 0.012 cm^{-1}.

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CONTENTS

COMPUTER CONTROL OF PULSED TUNABLE DYE LASERS

1. Introduction : Tunable dye lasers [1],[2] find their application in a number of spectroscopic and photochemical experiments, due to their tunability over a wide range (~ a few tens of nanometers) with a single dye, low linewidths (less than 0.05 cm^{-1}, for pulsed, and , few MHz for cw lasers), and high pulse powers (~ MW or more).

Laser wavelength needs to be calibrated both in the relative and absolute sense. For relative calibration with reference to the wavelength of a known spectral line, a Fabry-Perot interferometer can be used conveniently and fringes recorded photo-electrically. The Fabry-Perot interferometer used should cover the desired spectral range and have a suitable free spectral range and finesse. For absolute wavelength calibration a suitable spectroscopic source has to be chosen as reference. Such a source should be able to offer a reasonable number of sharp and adequately dispersed spectroscopic features over a wide wavelength region. We have tried in our laboratory as reference spectra absorption and fluorescence spectra from a room temperature iodine cell and opto-galvanic spectrum of a neon cell and a uranium-neon hollow cathode discharge. The ro-vibrational features of the B-X band of iodine have Doppler widths of ~ 250 MHz, and there is a very large density of spectral features in the wavelength region 490-630 nm [3] . Thus it would be more appropriate to use such a source for calibration of narrow band single mode CW and pulsed dye lasers in this spectral region. The easily available neon lamp gives rise to some very large opto-galvanic signals in a limited wavelength region. However, the density of spectral features is very low. Also the absorption widths of neon lines are relatively large (~ 0.2 to 0.3 cm^{-1}). Uranium-neon hollow cathode lamp gives rise to a rich opto-galvanic spectrum which covers a very wide wavelength region from 290 to 800 nm [4]. The Doppler widths of the O.G features are ~ 0.05 cm^{-1} (without any cooling). The most interesting aspect is the density of spectral features is neither too large (to complicate recognition), nor too small (to cause interpolation errors). The recognition of spectrum is further facilitated by the availability of detailed uranium-neon hollow cathode discharge O.G. spectral charts with wavelength of features marked [5,6].

A system that can monitor and control the dye laser wavelength, and acquire the experimental data at different dye laser wavelengths will be extremely useful in accurate and fast analysis of the spectroscopic and photochemical experiments. We have developed such a system at B.A.R.C. The system can be used to tune to required wavelengths up to three dye lasers simultaneously. The tuning speed can be selected continuously from 0.05 cm^{-1}/sec to 21 cm^{-1}/sec. The reproducibility of arriving at a desired wavelength is ± 0.012 cm^{-1}.

2. <u>System Description</u> : The system uses Opto Galvanic (O.G.) signal from either a Uranium Hollow Cathode Discharge Lamp (H.C.D.L.) or a Neon Discharge Lamp to determine the absolute wavelength of the dye laser output. Any change in the dye laser output wavelength is monitored using the fringes from a Fabry-Perot interferometer.

The schematics of the dye laser tuning control operation is shown in Fig. 1 . A small fraction (~ 4 %) of the dye laser output

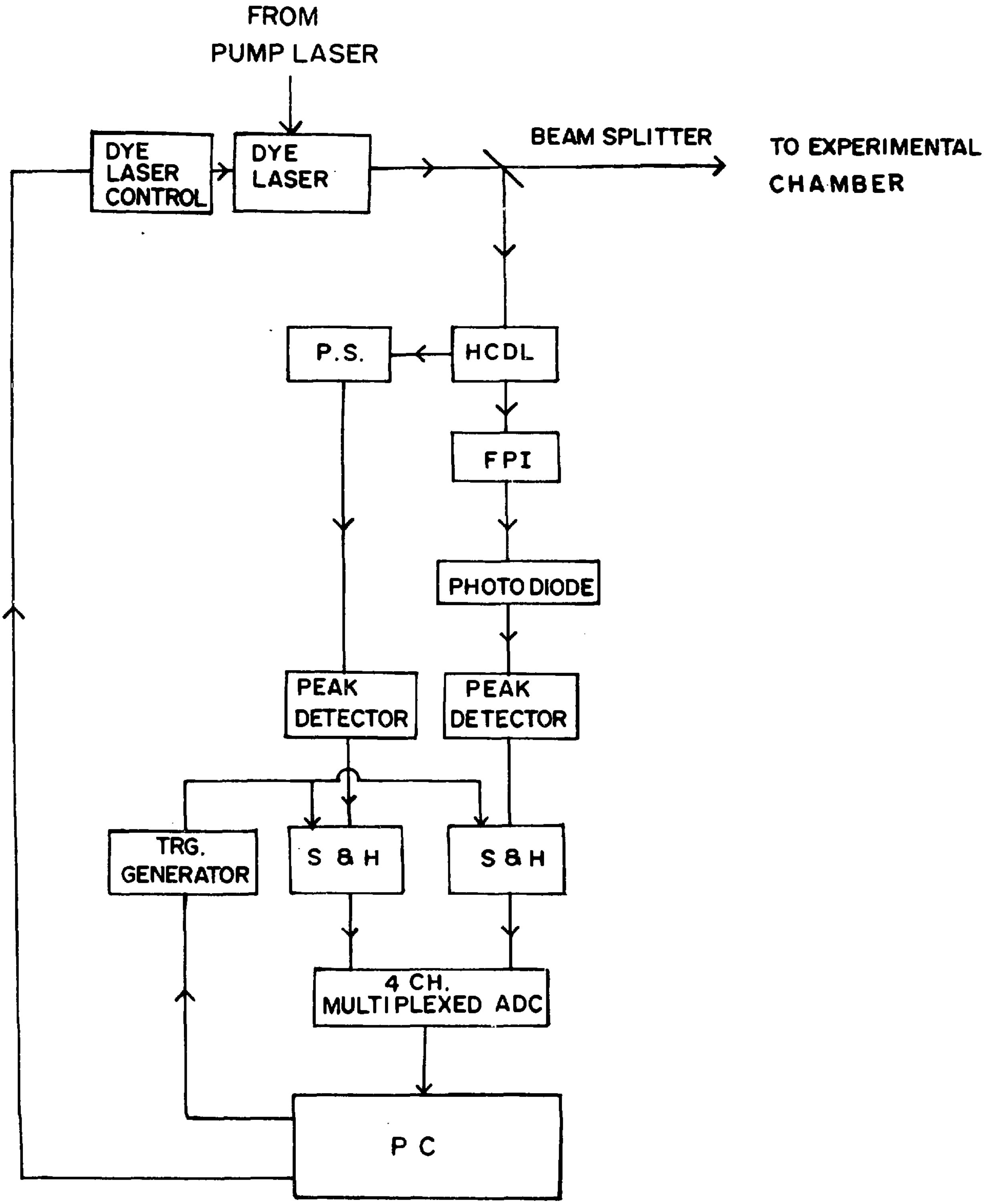


FIG. 1 SCHEMATIC OF CLOSED LOOP DYE LASER TUNNING CONTROL OPERATION.

beam is directed, using a beam splitter, towards the system. This fraction passes through either a Uranium Hollow Cathode Discharge Lamp or a Neon Discharge Lamp. The Opto Galvanic signal from the Discharge Lamp is in the form of short duration pulses, and is sent to one of the channels of the Data Acquisition System. The corresponding D.C. signal is given as the input to one channel of the four channel multiplexed Analog to Digital Converter. The digitized value of the signal is stored in the computer memory for reconstructing the O.G. spectrum and identifying the initialization peak.

Another small fraction of the beam goes to a Fabry-Perot interferometer. One of the fringes formed is focused on a photo-diode. The signal from the photo-diode is also in the form of short duration pulses, which are sent to another channel of the Data Acquisition System. The corresponding D.C. signal is also given as the input to another channel of the Analog to Digital Converter. The digitized value of the signal is stored in the computer memory for fringe counting.

The dye laser is tuned using a DC motor as shown in fig. 2. If $\bar{\nu}_i$ is the initial wavenumber as obtained from an initialization peak, if FSR is the free spectral range of the Fabry-Perot interferometer, and if n is the differential fringe count, then the current wavenumber $\bar{\nu}$ is given by,

$$\bar{\nu} = \bar{\nu}_i + n * FSR \qquad \ldots[1]$$

The remaining two channels of the Data Acquisition System are connected to signals coming from two other parts of the experimental assembly for digitization.

3. Electronics of Signal Acquisition System :

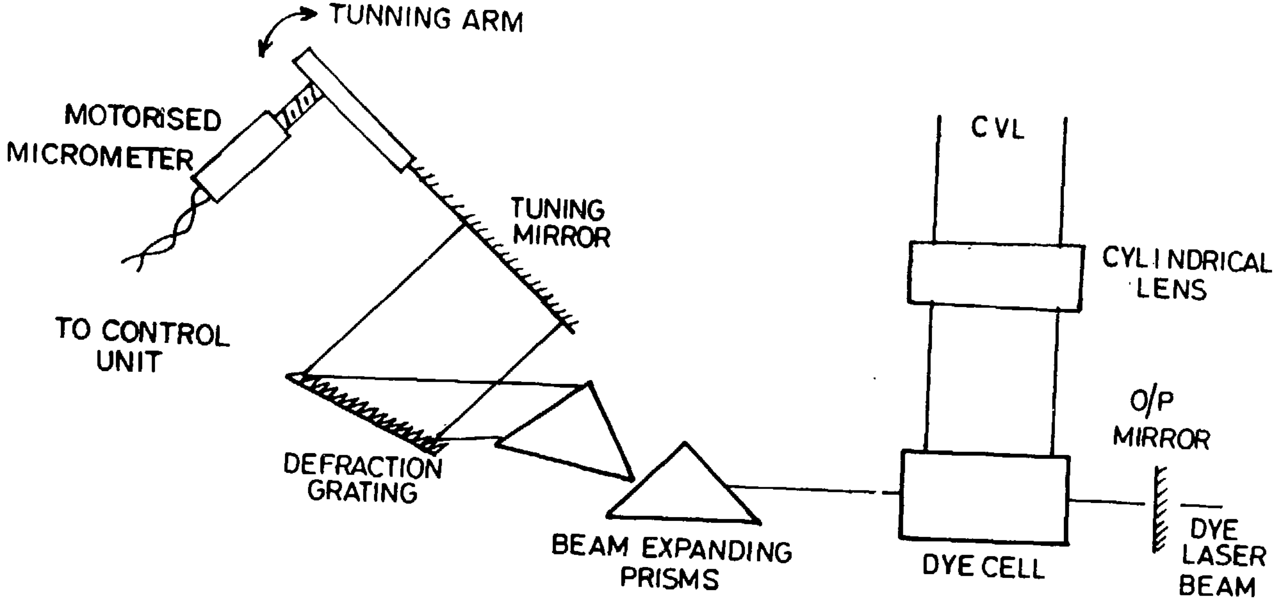


FIG. 2 DYE LASER TUNING SCHEMATICS.

3.1. Signal Pick up System :

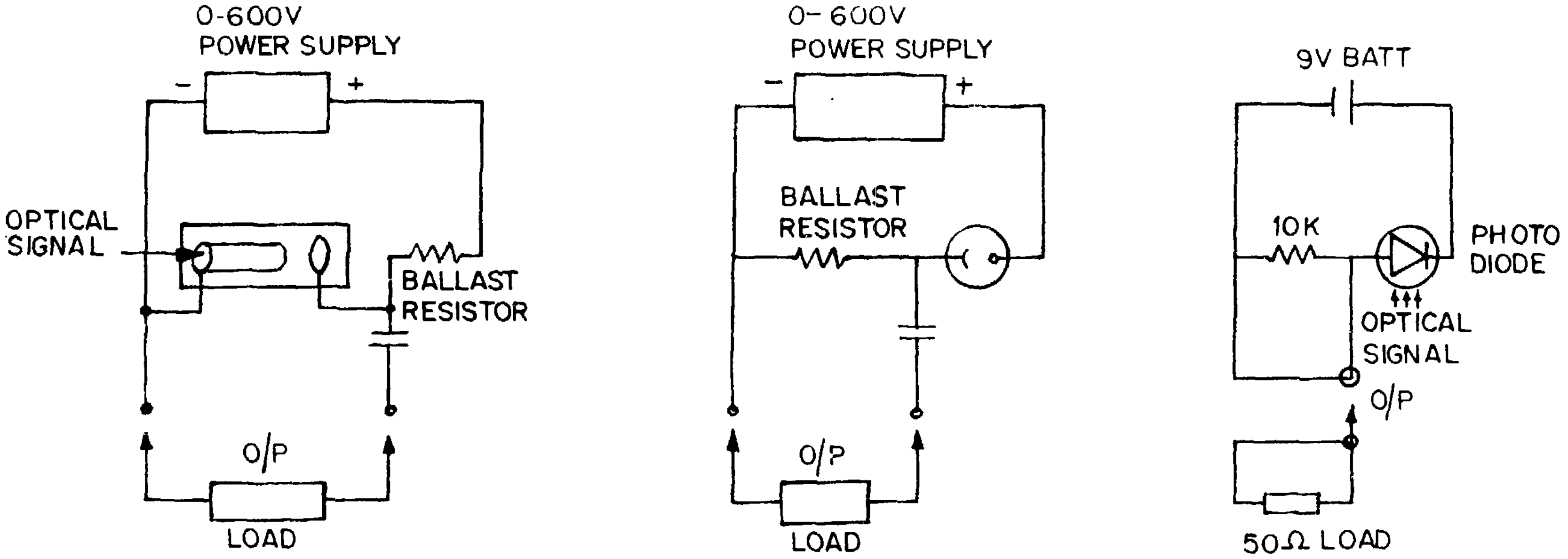
The discharge lamp kept in the path of the Pulsed Dye Laser beam is powered by a 600 volts d.c. power supply. A ballast resistor is used to limit the discharge current. A change in discharge current gives a voltage signal output. The signal output is taken through a coupling capacitor as shown in fig. 3[a], and 3[b].

A photo-diode (see fig. 3[c]) monitors the dark and bright bands of Fabry-Perot fringes. The reverse biased photo-diode current depends on the intensity of the incident light. A change in current produces a voltage signal across a 50 Ω resister.

A preamplifier (see fig. 4) receives the signal from signal pick-up system. The Neon discharge lamp gives a positive polarity signal and the uranium hollow cathode discharge lamp a negative polarity signal. The signals are amplified in the preamplifier and with the help of the polarity selector, the positive amplified signal is given to a peak detector.

The peak detector detects the peak voltage and averages it over 50 or 300 samples. This averaged voltage is given as output to a sample-and-hold amplifier as shown in fig 5. The sampling and holding pulses are obtained from the sample and hold trigger generator circuit, shown in fig. 6. The sampled signal is given as an input to a gain selectable amplifier. The gain is selected so as to avail the maximum resolution of a 12 bit ADC.

A synchronizing pulse of 10 ms duration is obtained from the computer and using three monostables, three additional channel scanning pulses of 10 ms duration each are generated sequentially, as shown in fig. 7. When the sample-and-hold amplifier receives a



URANIUM HOLLOW CATHODE
DISCHARGE LAMP
CIRCUIT
(a)

NEON DISCHARGE
LAMP CIRCUIT
(b)

PHOTO DETECTOR CIRCUIT
(c)

FIG. 3 SIGNAL PICK-UP SYSTEMS

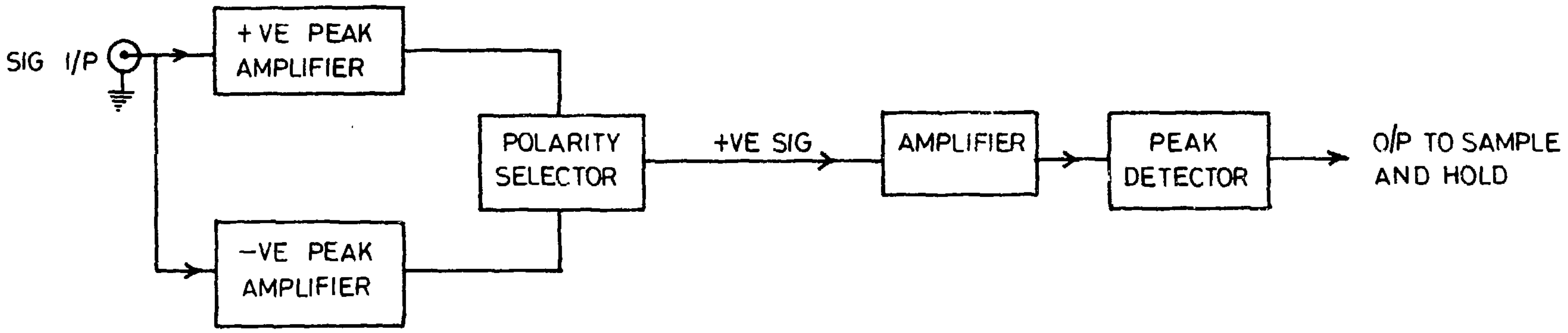


FIG. 4 PREAMPLIFIER AND PEAK DETECTOR CIRCUIT.

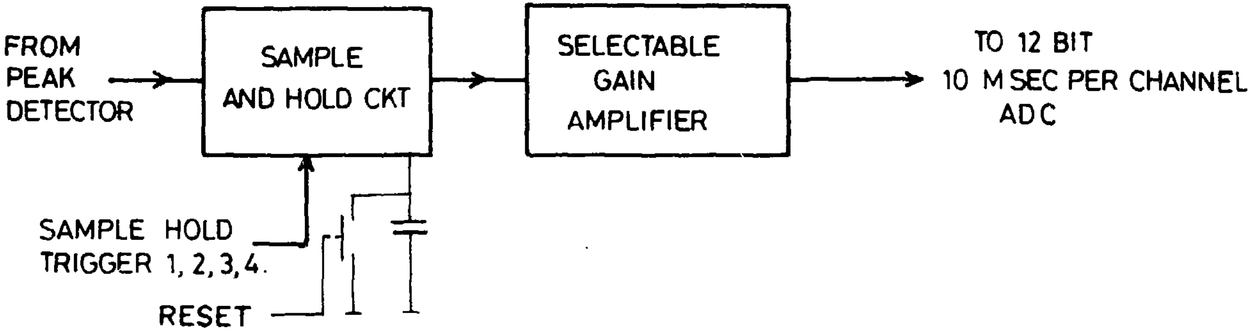


FIG.5 SAMPLE-AND-HOLD AND GAIN SELECTOR CIRCUIT.

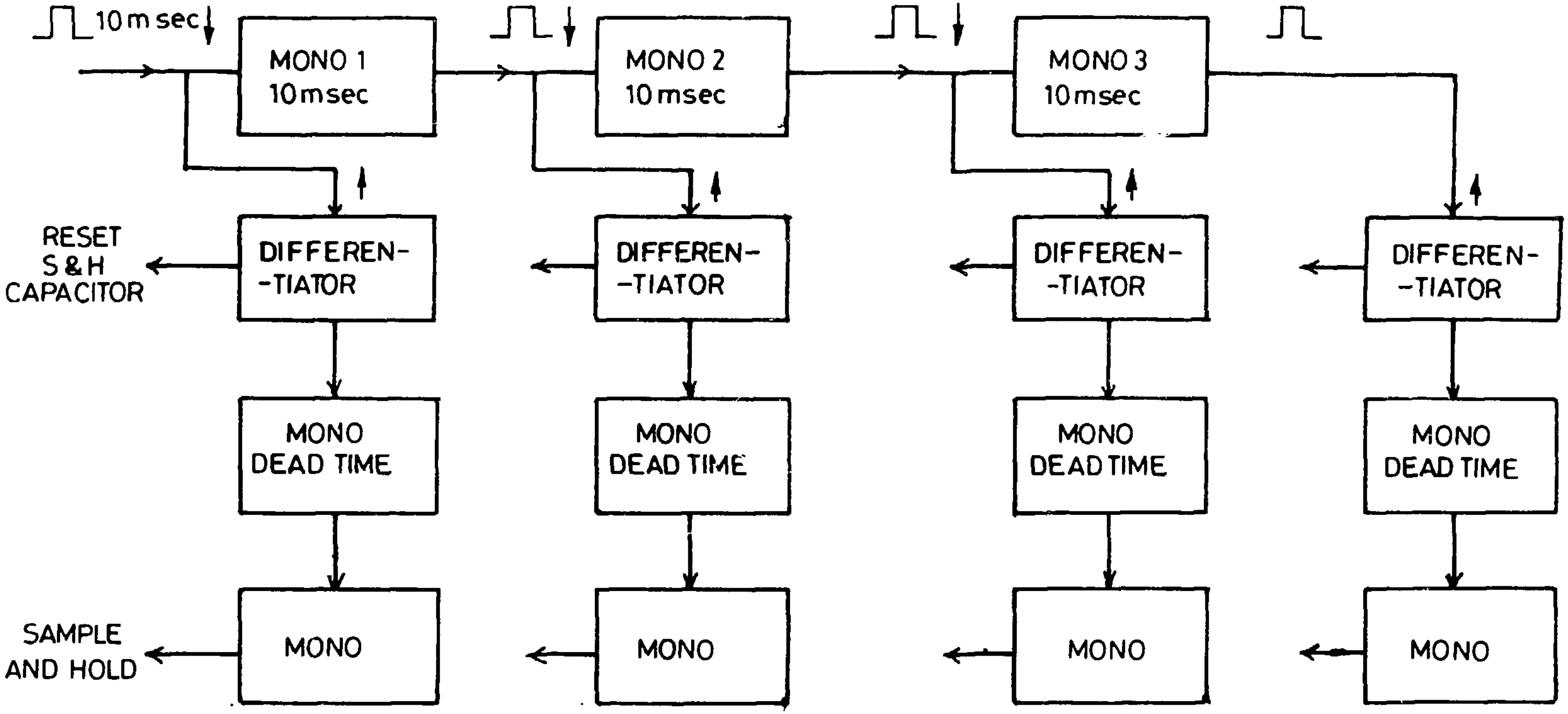


FIG. 6 SAMPLE AND HOLD TRIGGER GENERATOR CIRCUIT.

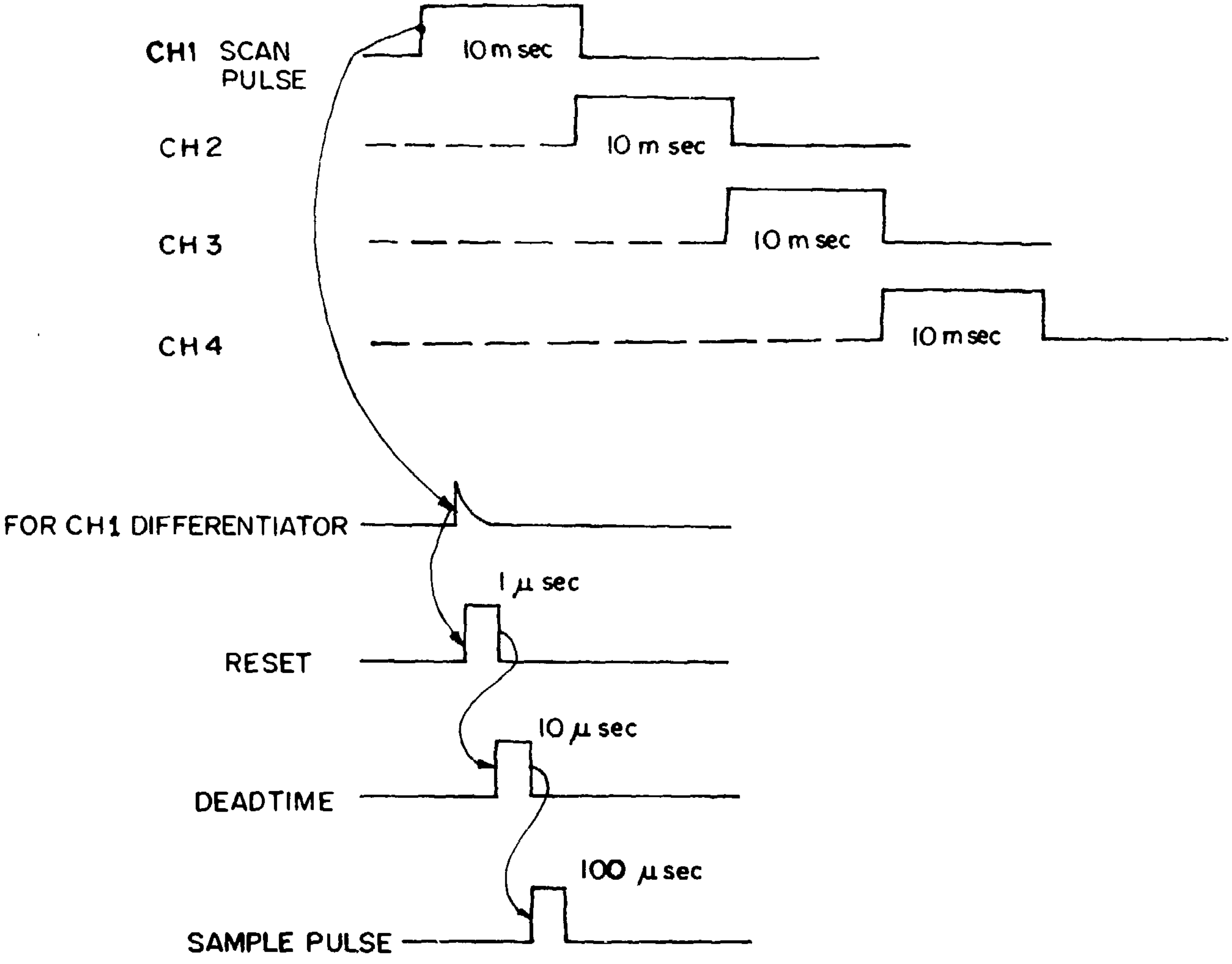


FIG. 7 TRIGGER TIMING DIAGRAM OF ONE CHANNEL.

rising edge of channel scanning pulse as shown in fig 7, a 1 μs reset pulse discharges the sampling capacitor through a solid state switch. The dead time (~ 10 μs) is introduced to avoid overlapping of the sample and reset pulse. The sample pulse samples the signal for about 10 μs by closing the sampling switch, the voltage on the capacitor is held constant, within droop rate, (<0.1%) for the rest of the period till the next channel sampling pulse is received. All these signals are generated in the interface module shown in fig. 8.

3.2. Interface Module :

The interface module shown in fig. 8 receives 8 bit control signals from the computer output port. Out of the eight bits, bits 0, 1, and 2 are used for On-Off control of the DC motor. The transistors-relay circuit is used to interface the bits and motor driving voltage. The schematic is shown in fig 8. Bit 3 is not used. The bits 4, 5, and 6 are used for controlling the direction of motion of the DC motors. Bit 7 is used for command start-channel-scanning. This 10 ms pulse is used for scanning the first channel, other three subsequent pulses are generated as described above.

4. Program logic :

4.1. Arriving at the Desired Wavenumber :

The wavenumber $\bar{\nu}$ of the dye laser is governed by the Grating equation,

$$\bar{\nu} = \frac{1}{d_g * (\sin\theta + \sin\phi)}$$

where, d_g is the grating constant, θ is the angle of incidence, and ϕ is the angle of diffraction. For the dye laser used in the

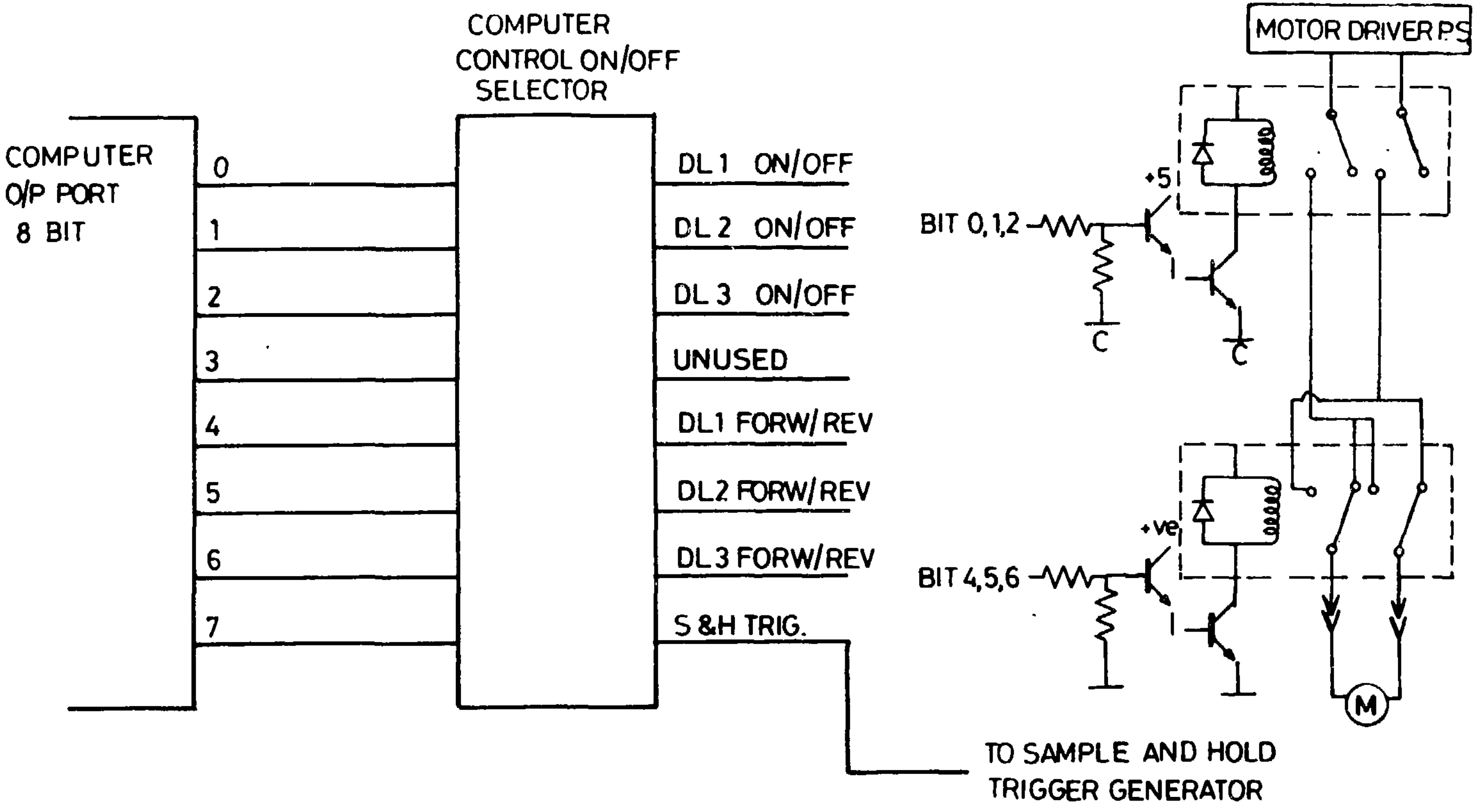


FIG. 8 COMPUTER INTERFACE AND MOTOR CONTROL CIRCUIT.

experiment, $d_g = \frac{1}{24*10^3}$ cm, $\vartheta = 81^\circ$ and $\phi = 23.1^\circ$ for 575 nm, and $\phi = 26.9^\circ$ for $\lambda = 600$ nm.

The angle of diffraction ϕ is changed in order to tune the dye laser. If $\Delta\bar{\nu}$ is the desired change in the wavenumber then,

$$\Delta\bar{\nu} = \frac{-\cos\phi}{d_g * (\sin\vartheta + \sin\phi)^2} * \Delta\phi$$

The change in the angle ϕ is given by, $\Delta\phi = \Delta x/R$, where, Δx is the displacement of the lead screw of the D.C. motor, and R is the length of the tuning arm. Thus,

$$\Delta\bar{\nu} = \frac{-\cos\phi}{d_g * (\sin\vartheta + \sin\phi)^2} * \frac{\Delta x}{R}$$

The current wavenumber $\bar{\nu}$ is given by,

$$\bar{\nu} = \bar{\nu}_i + \Delta\bar{\nu}$$

where, $\bar{\nu}_i$ is initial wavelength, confirmed using an opto-galvanic peak of uranium HCDL. The change $\Delta\bar{\nu}$ can be computed using the number of Fabry-Perot fringes as counted using the photo-diode detector. If $FSR(\bar{\nu})$ is the free spectral range of the Fabry-Perot interferometer used, and n is the number of fringes crossing the detector, then, $\Delta\bar{\nu} = n * FSR(\bar{\nu})$, where n can be split into integer part N, and fractional part ΔN, that is, $n = N + \Delta N$. The fringe signal peaks obtained from the detector give the integer part N. The fractional part ΔN is computed, as described below.

Let t_p be the time that elapses between appearance of two consecutive fringe peaks. If t_e is the time that has elapsed since appearance of previous peak, then, $\Delta N = \frac{t_e}{t_p}$. If $FSR(\bar{\nu})$ is the free spectral range of the Fabry-Perot interferometer at $\bar{\nu}$. Then, the wavenumber $\bar{\nu}$ is given by,

$$\nu = \bar{\nu}_i + FSR_c * N + FSR(\bar{\nu}) * \frac{t_e}{t_p} \qquad [2]$$

The suffix c is put to indicate that for a large change in wavenumber, FSR has to be duly corrected for its variation due to the changing wavenumber.

4.2. Determining Time Elapsed between two Fringe Peaks :

The optical power of the dye laser output varies with time. This leads to a change in peak heights of the fringe signals coming from the photo-diode. The RF noise pulses from the CVL pumping the dye laser distort the signal from the photo-diode. Thus, the simple method of using derivative of the signal to find its peak position cannot be used. Instead peaks were located using threshold crossing method.

Fig. 9 shows two consecutive fringe peaks. Their peak heights are different, and their maxima positions are also shifted in time due to distortion. Instead of monitoring the time at which the peak occurred, we monitor the time at which the signal crosses a particular threshold value. This threshold value is so chosen that, it is large as compared to the noise, but is lower than the smallest value of the peak signal. The threshold value is shown by a horizontal line in fig. 9. When the fringe signal crosses the threshold, the time is registered as t_u. Similarly, when signal goes below the threshold value, the time is noted as t_d. For each peak these times are registered. Then t_p is given by

$$t_p = \frac{(t_{2d} - t_{2u}) - (t_{1d} - t_{1u})}{2},$$

where symbols t_{2d}, t_{2u}, t_{1d}, t_{1u} have their meanings as shown in fig. 9. It can be verified readily, that above definition of t_p gives correct value of time that elapses between crossing of

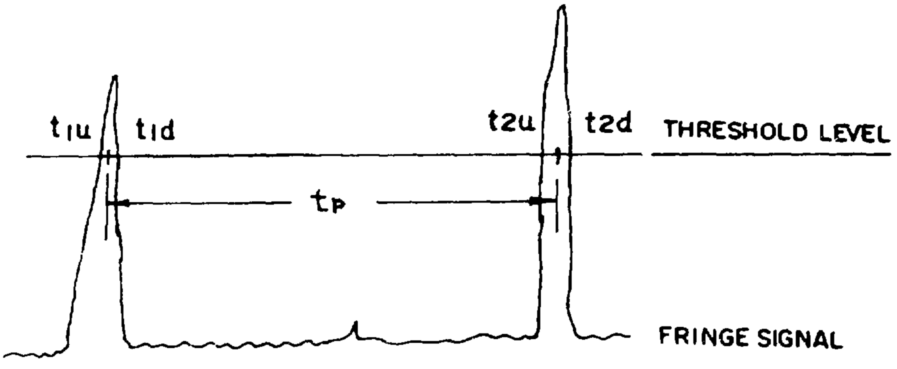


FIG. 9 FRINGE PEAKS AND DIFFERENT TIME REFERENCES.

consecutive fringes even when the fringes are asymmetric about the fringe peak.

5. Error Analysis :

5.1. Systematic Error :

Dye laser output wavenumber $\bar{\nu}$ is given by $\bar{\nu} = \bar{\nu}_i + \Delta\bar{\nu}$, from which it can be shown that, $\frac{\delta\bar{\nu}}{\bar{\nu}} = \frac{\delta\bar{\nu} + \delta\,\Delta\bar{\nu}}{\bar{\nu}_i + \Delta\bar{\nu}}$, where δ stands for modulus of the error in the quantity that follows. Expanding denominator of R.H.S. in the powers of $\frac{\delta\bar{\nu}}{\bar{\nu}_i}$, we get,

$$\frac{\delta\bar{\nu}}{\bar{\nu}} = \left[\frac{\delta\bar{\nu}_i}{\bar{\nu}_i} + \frac{\delta\,\Delta\bar{\nu}}{\bar{\nu}_i} \right] * \left[1 - \frac{\Delta\bar{\nu}}{\bar{\nu}_i} + \text{higher order terms in } \frac{\Delta\bar{\nu}}{\bar{\nu}_i} \right]$$

FSR of the Fabry-Perot interferometer used ~ 0.48 cm^{-1}, and typically $\Delta\bar{\nu}$ ~ few FSRs, and $\bar{\nu}_i$ ~ 17000 cm^{-1}. Hence $\frac{\Delta\bar{\nu}}{\bar{\nu}_i}$ and its higher powers can be neglected in comparison to 1, and we can write,

$$\frac{\delta\bar{\nu}}{\bar{\nu}} = \frac{\delta\bar{\nu}_i}{\bar{\nu}_i} + \frac{\delta\,\Delta\bar{\nu}}{\bar{\nu}_i} = \frac{\delta\bar{\nu}_i}{\bar{\nu}_i} + \frac{\Delta\bar{\nu}}{\bar{\nu}_i} + \frac{\delta\,\Delta\bar{\nu}}{\Delta\bar{\nu}}$$

Which can be written using equation [2], as

$$\frac{\delta\bar{\nu}}{\bar{\nu}} = \frac{\delta\bar{\nu}_i}{\bar{\nu}_i} + \frac{\Delta\bar{\nu}}{\bar{\nu}_i} * \left[\frac{\delta t_p}{t_p} + \frac{\delta t_e}{t_e} \right]$$

From the atlas of HCDL lines, the wave number of the initial line can be found sufficiently accurately, so that, $\frac{\delta\bar{\nu}_i}{\bar{\nu}_i}$ can be neglected. The error in measurement of time i.e. δt_p and δt_e ~ ± 5 ms. The typical values of t_p and t_e are of the order of few 100 ms to few seconds. Thus, we can estimate $\frac{\delta\bar{\nu}}{\bar{\nu}}$ to be of the order of few parts in 10^7.

5.2. Other Errors :

The backlash of the lead screw is specified to be ~ 0.6 μm, which corresponds to a backlash in the dye laser tuning of ~ 0.08 cm^{-1}, which is comparable to the fractional change, ΔN * FSR($\bar{\nu}$) in the dye laser wavelength. Hence to avoid effects of the backlash it is necessary to tune the dye laser in unidirectional mode.

6. Testing & Results :

6.1. Tuning speed and Tuning Range :

The tuning speed of the DC motor was determined by measuring time it requires to shift between two known wavenumbers. The maximum tuning speed is ~ 21 cm^{-1}/s and minimum tuning speed is ~ 0.05 cm^{-1}/s. The displacement range of the lead screw is 50 mm. It is found to be more than sufficient to cover full tuning range of any dye used. For example, tuning the Rhodamine 6G dye from one end of its tuning range to the other (approximately, from 16750 to 17750 cm^{-1}) requires a displacement of the lead screw by approximately 9 mm only.

6.2. Reproducibility of the tuning :

The system was tested on a CVL pumped dye laser. Fig. 10 shows the schematics. A monochromator was used to monitor the wavelength. The output of a uranium HCDL was fed as an input to a boxcar averager, and the output of the boxcar was used as an input to a chart-recorder. The output of photodiode was also recorded simultaneously. The plots provided confirmation of the desired wavelength change.

The dye laser was initialized by tuning it to the peak of

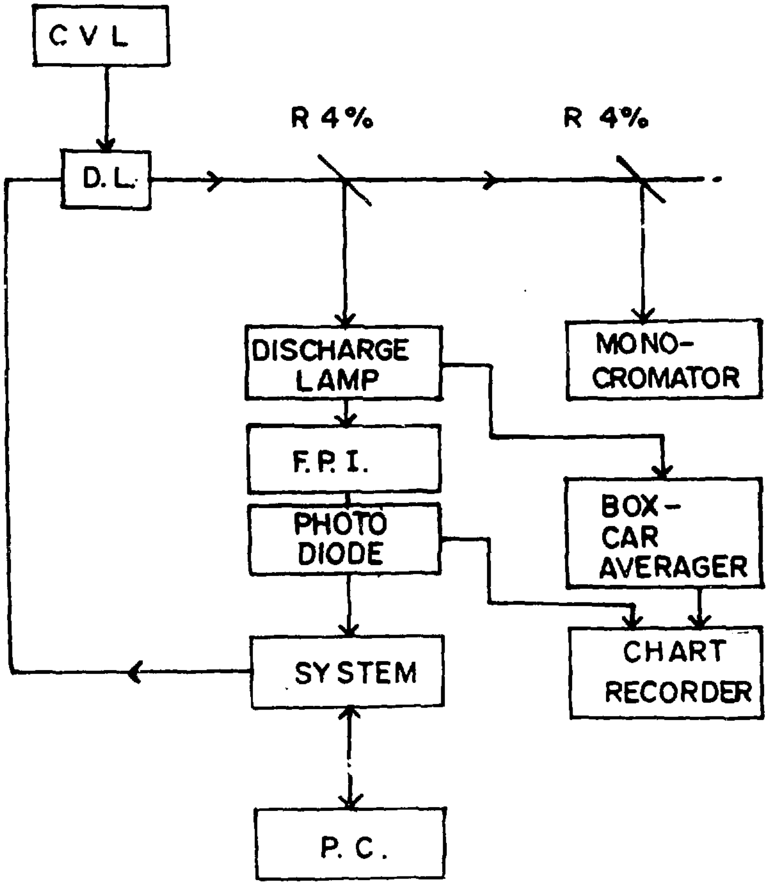


FIG.10 TESTING ARRANGEMENT

Uranium O G line at 17287.8482 cm^{-1} (578.28062 nm). The wavenumber difference between this line and an adjacent line at 17273.5536 cm^{-1} (578.75918 nm) was given as an input to the computer. The dye laser output wavelength changed under computer control to the new value, which was confirmed by the uranium HCDL spectral plot and the fringe plot. (See fig. 11). The dye laser landed at the desired peak. The procedure was repeated several times either by increasing or decreasing λ. The Fabry-Perot interferometer used had a FSR of 0.48 cm^{-1} . The reproducibility of the system was tested. The deviation from the desired value was ± 0.012 cm^{-1} .

7. Conclusion :

In this report we describe the development of a system for wavelength tuning and control of tunable dye lasers and an acquisition system for spectral data generated in experiments with these lasers. With this system, it is possible to control the tuning of three lasers, and acquire data in four channels. It is possible to arrive at the desired dye laser wavelength with a reproducibility of ± 0.012 cm^{-1}, which is within the absorption width (atomic interaction) caused by pulsed dye lasers of linewidth 0.08cm^{-1}. The spectroscopic data generated can be analyzed for spectral identification within absolute accuracy ±0.012 cm^{-1}.

With increasing use of pulsed dye lasers for spectroscopic and photochemical experiments it is imperative to have data acquisition and spectral analysis of a volume of data generated. Such a system will find varied applications. For example, studies on LIDAR, or detection of polluting species in industrial

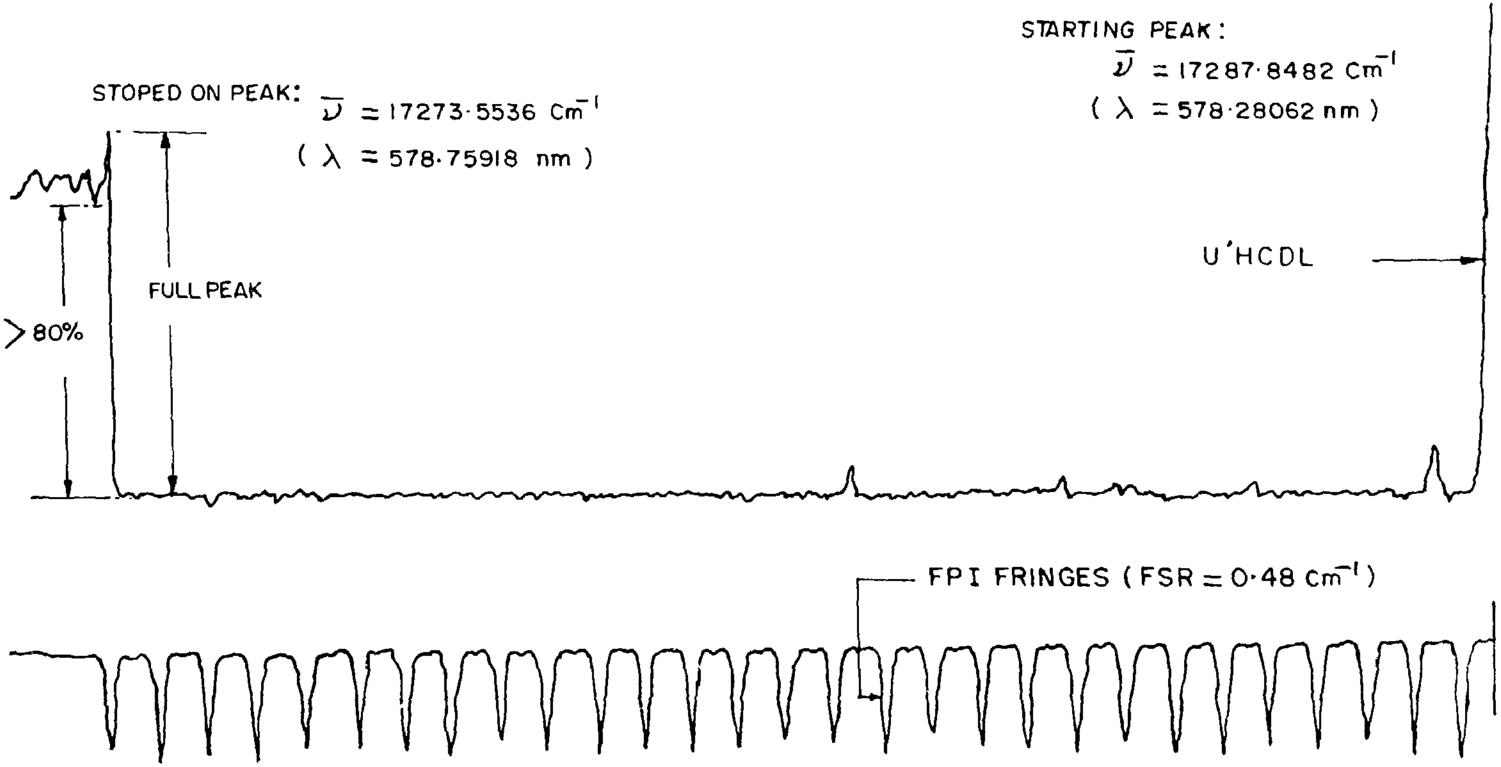


FIG. 11 ACQUISITION OF AN OPTO-GALVANIC PEAK USING THE SYSTEM.

environments or upper atmosphere, using lasers in air-borne and other vehicles will be facilitated by such a data acquisition system. For studies involving molecular species absorbing in ultraviolet region, the hollow cathode discharge lamp may be replaced by a reference absorption cell of certain molecular gases.

This system can be upgraded by the use of a fast photo-diode array for acquisition of fringes from a Fabry-Perot interferometer. This will enable on-line wavelength information as the dye laser is scanned.

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