A NEW SINGLE MODE TUNABLE TEA LASER

by

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ABSTRACT

A simple and inexpensive technique for producing a single mode TEA CO_2 laser is explored. The method involves the use of an intracavity selective absorber. A large laser system used in the early research was observed to yield 1.1 J single longitudinal mode pulses. This amounted to 73% of the multimode pulse energy. This encouraging result led to the design of a stabilized, tunable laser system. The laser frequency is smoothly tunable over some tens of megahertz, and stepwise tunable across the entire gain bandwidth of any particular line. The system includes a frequency reference laser so that precise knowledge of the TEA laser frequency with respect to line center is possible. Both lasers are grating tunable to any of the CO_2 rotational transitions in the 9 to 11 micron region. The TEA laser exhibits an output energy of 200 millijoules in a single mode pulse, the absolute frequency of which is known within 5 MHz.

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CHAPTER I

INTRODUCTION

Carbon Dioxide Lasers

Carbon dioxide (CO_2) lasers are widely used in industry and research because of high power capabilities and tunability from 9 to 11 microns. In particular, pulsed transversely excited atmospheric pressure (TEA) versions of the laser are capable of peak power in excess of megawatts. However, the power is generally spread over a spectral range of .5 GHz due to pressure broadening of the gain spectrum which allows oscillation on many longitudinal and transverse modes of the laser cavity. Many applications of lasers require high spectral brightness. Spectral brightness can be defined as the ratio of intensity to laser bandwidth. The purpose of the research described in this thesis is to increase the spectral brightness of the powerful TEA CO_2 laser by selecting a single mode of the laser cavity. The frequency of this single mode should be tunable across the gain bandwidth of a rotational transition in order to match frequencies with a feature one wishes to interact with.

Several methods of forcing a laser into single mode operation have been published. This thesis presents an innovative technique using selective absorber gases which is simpler, less expensive to implement, has been found to give superior results, and allows tuning over a large portion of the laser gain curve.

Modes of a CO_2 Laser

A TEA CO_2 laser operating on a single rotational transition has a gain bandwidth of 3 to 4 GHz. The laser does not, however, lase at all frequencies inside this envelope, but instead lases at discrete points in the frequency spectrum associated with each of the individual modes of the laser cavity. Furthermore, competition effects between the laser modes generally limit the actual lasing bandwidth to approximately .5 GHz. (Figure 1)

Longitudinal modes arise from a requirement that an integral number of half-wavelengths of the infrared radiation lie between the mirrors of the laser cavity. The longitudinal mode spacing is given by $c/2L$ where c is the speed of light, and L is the distance between the laser reflectors. Typically the longitudinal mode frequency spacing will be on the order of 100 MHz. The transverse modes create intensity variations in the plane perpendicular to the cavity axis and are separated in frequency by[1]

$$\Delta f = \cos^{-1}\left[\left(1-\frac{L}{r_1}\right)^{\frac{1}{2}}\left(1-\frac{L}{r_2}\right)^{\frac{1}{2}}\right]\cdot\frac{c}{2\pi L}$$

where r_1 and r_2 are the radius of curvature of the cavity reflectors. Typically the transverse mode spacing will be

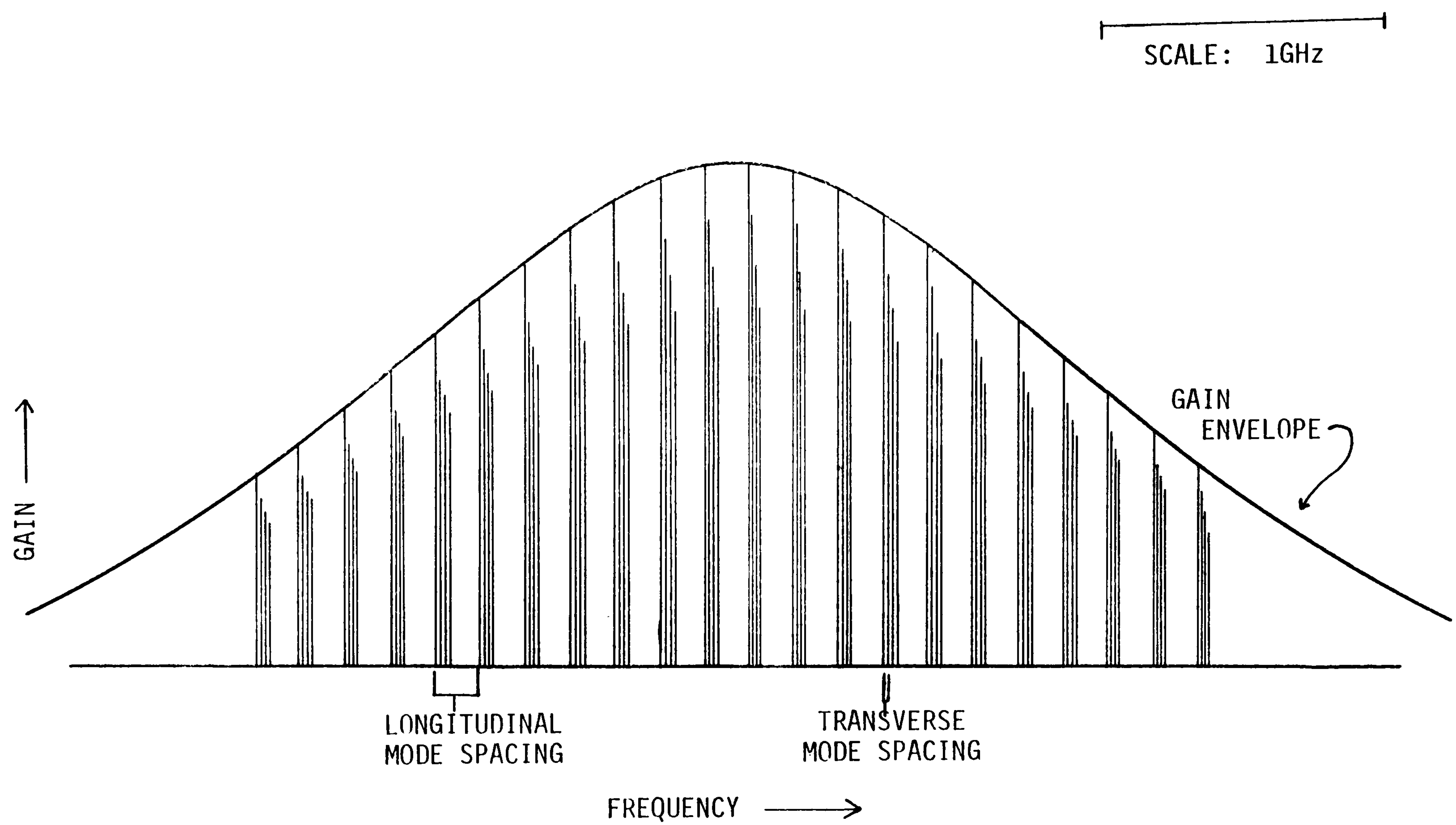


Figure 1. Frequency Spectrum of TEA CO_2 Laser Modes

around 10 MHz.

It is a simple matter to select the fundamental transverse mode and eliminate all other transverse modes by placing in the optical cavity an aperture to control the beam diameter. The fundamental mode has the smallest diameter and has a gaussian distribution of intensity in the plane transverse to the direction of propagation. With only one transverse mode of the laser oscillating the frequency spectrum of the emitted light is simplified as shown in Figure 2, and the spectral brightness is enhanced. The spectral brightness is further increased by selectively limiting oscillation to only one of the possible longitudinal modes of the cavity, while not significantly decreasing the total energy output. With only one mode of the laser oscillating the frequency spectrum obtained is shown in Figure 3. The spectral brightness is maximized, as all of the energy is now concentrated in a narrow frequency spike of bandwidth $1/2\Pi T$ where T is the photon decay time in the passive resonator. Tunability of this single mode frequency is required in order to interact with a feature at some frequency inside the laser gain bandwidth as shown in Figure 4.

Previous Work on Mode Selection

Much work has been done in the past to mode-control a CO_2 laser. Most of the techniques have serious drawbacks as will be detailed shortly.

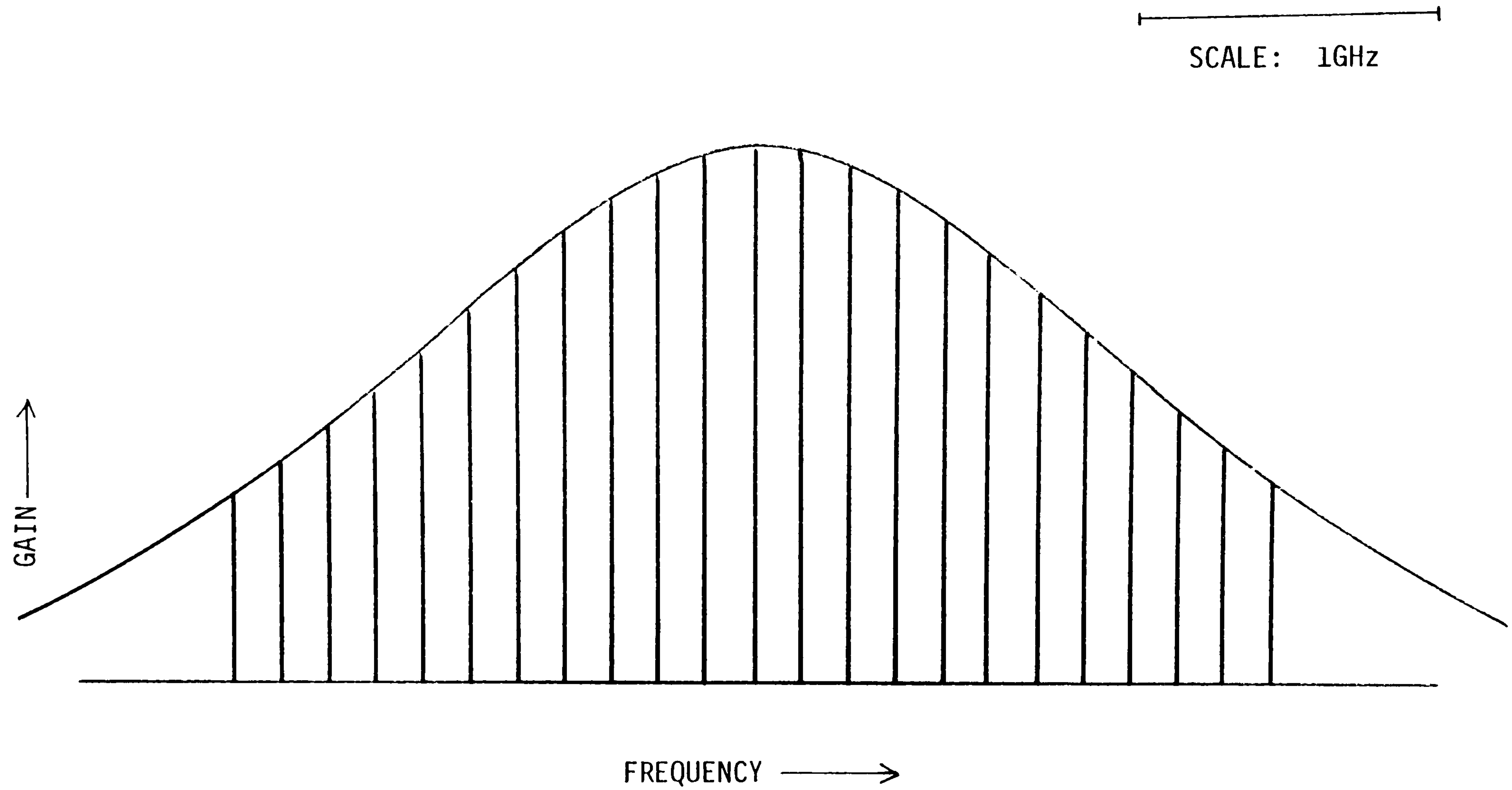


Figure 2. Frequency Spectrum of Laser: Single Transverse Mode Operation (multiple longitudinal mode)

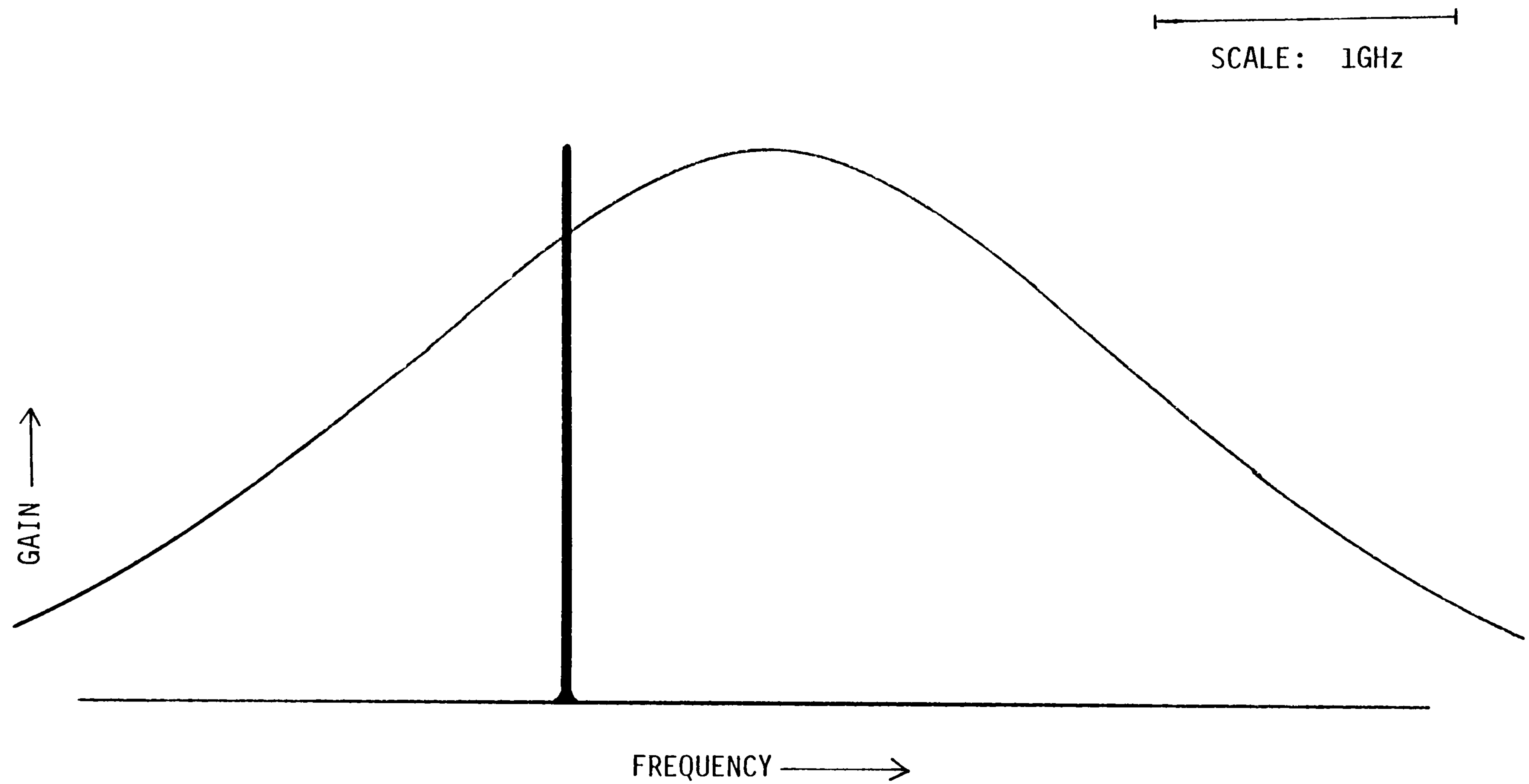


Figure 3. Frequency Spectrum of Laser: Single Mode
(single transverse _and_ single longitudinal mode)

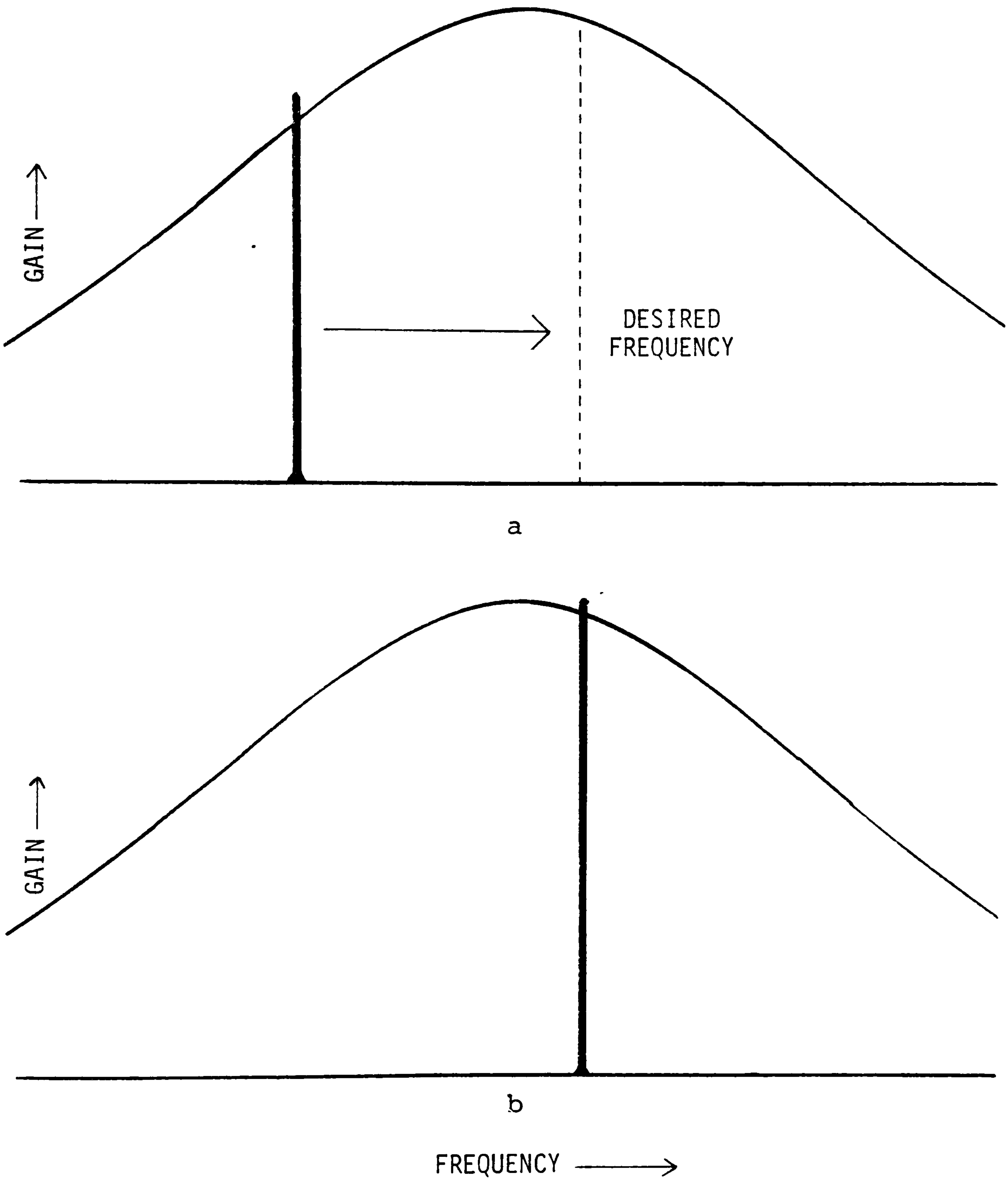


Figure 4. Tunability of Single Mode Frequency: (a) Laser is not at desired frequency of operation. (b) Laser is tuned to desired frequency.

A relatively simple method to mode-control a CO_2 laser depends upon the fact that a laser operating at low pressure will have a narrow pressure-broadened gain bandwidth. One can insert into the optical cavity of the TEA laser a cell with electrodes and low pressure CO_2 gas mix[2]. A quasi-continuous electrical discharge through the cell causes an enhancement in gain near line center. Oscillation intensity is an exponential function of gain so the TEA laser runs predominantly on the mode with the most gain, that is the mode nearest line center.

A somewhat similar technique is injection locking[3]. The beam of an independent low power laser is injected into the cavity of the TEA laser to introduce "seed" radiation. The TEA laser will lase predominantly on the mode closest to the frequency of the injection laser.

A third approach is to include in the laser cavity an etalon, a sort of Fabry-Perot filter[4]. The etalon for such an application will generally be a solid piece of ZnSe or Ge coated for high reflectivity. The etalon will allow the laser to have a net gain only within a narrow frequency band, so that only one mode can oscillate.

Each of the mode-controlling techniques discussed thus far has shortcomings. The simplest, the gain cell, leaves no provision for tuning the laser more than approximately 20 MHz from line center. The output frequency is essentially fixed. The injection laser technique involves complex problems of mode matching and triggering. Additionally, more equipment is needed since the technique uses two lasers. The etalon as a mode selection device is very susceptible to damage from the high peak powers of the TEA laser, and is quite expensive. The etalon is also susceptible to frequency shifts as thermal effects change the dimensions of the crystal. Although the etalon cannot generally be used in high power lasers, it has shown some promise controlling the frequency of a small laser which is then used to injection lock a TEA laser[5].

The method of mode-control described in this thesis is perhaps the best for a number of reasons. It is simpler to implement than a gain cell, it is self-healing and therefor not susceptible to catastrophic failure due to high peak powers, and it is insensitive to minor variations in temperature. The technique involves nothing more than inserting into the laser cavity a cell filled with a suitably chosen gas which absorbs strongly in the region of the CO_2 laser transition.

CHAPTER II

THE SELECTIVE ABSORBER AS A MODE CONTROLLING ELEMENT

Theory of Selective Absorber Mode-control

Single longitudinal mode (SLM) operation of a CO_2 laser with an intracavity absorber was first reported by Nurmikko, DeTemple, and Schwarz[6]. They originally suggested three possible mechanisms for the single moding effect: 1) The absorber is bleached only at the frequency of a single mode. 2) The absorber causes the pulse to be amplified a greater number of times, and hence the spectrum is narrowed. 3) Nonlinear polarizations which act to mode-lock longitudinal modes under some conditions may reverse in sign under other conditions so that one mode acts to suppress others. Of these three they proposed that a combination of the first and third was most likely. Subsequently Nurmikko and DeTemple suggested a fourth and possibly simpler explanation[7] which is supported by the work done here.

The present theory for the single moding effect relies on the requirement that for oscillation to occur the net loop gain must exceed the losses. The net gain is the difference between the laser gain curve, and the loss curve. The loss curve is a sum of several individual components due to partial reflectors, window losses, and absorption gas losses. Losses due to reflectors and windows are essentially constant over the gain bandwidth of the CO_2 laser. The losses due to the absorber gas are highly varying over the CO_2 gain bandwidth. When the components of gain and loss (Figure 5a) are added together one arrives at the net gain curve in Figure 5b. Now it is readily seen that one mode of the laser will have a net gain much greater than the others. The mode with the most gain will oscillate preferentially to the rest and will predominate in the laser spectrum.

Assuming then that the single moding effect is due to the fine structure in the spectrum of the absorber gas it can be anticipated that a basic requirement of the selective absorber is that it have a spectrum sufficiently complex to cause large absorption variations within the CO_2 laser gain bandwidth. Also, the gas must have very strong features at the general position of the CO_2 line so that at very low pressure it can have a significant effect on the laser. The absorption gas pressure must be limited to a few torr or less to prevent pressure broadening of the absorption features which would smooth over the fine cracks through which the laser oscillation occurs.

Experimental Work

The laser selected as the best candidate for absorption mode control was a resistive-pin transversely excited

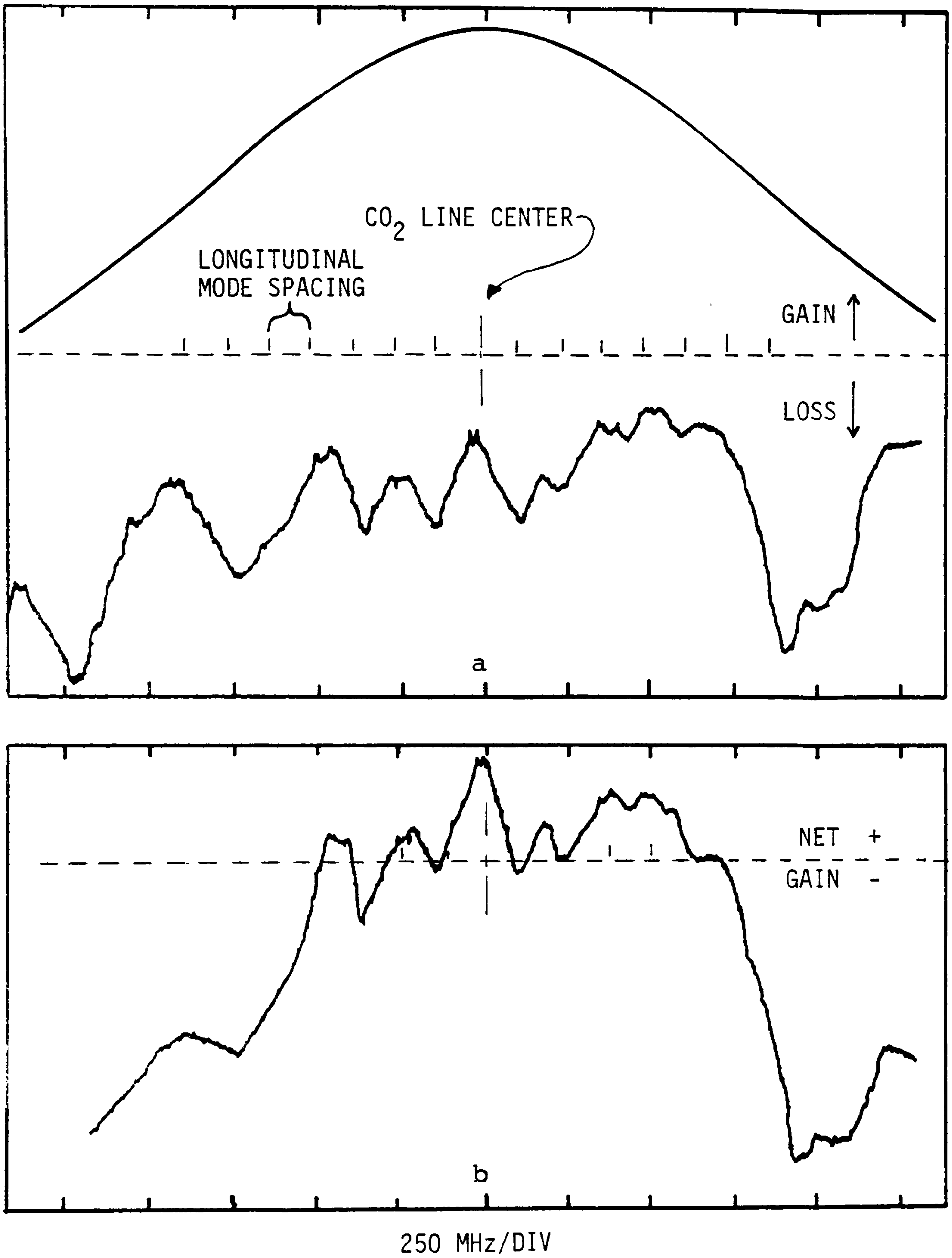


Figure 5. Gain Profile of Laser with Intracavity Absorber: (a) Gain of active region and loss of absorber. (b) Net gain.

(TE) laser capable of operating at any pressure from 200 torr to 500 torr. A sub-atmospheric pressure laser was chosen because at lower pressures the laser has a narrower gain bandwidth, and so fewer longitudinal modes are competing in the selection process. The cavity length was kept as short as was practical to keep the modes as widely spaced as possible. The 230 cm long optical cavity was bounded on one end by a grating for line tuning and on the other by a 10 m radius 80% reflective mirror for output coupling. The gain region was 120 cm long and the laser exhibited an output energy of 10-30 mJ per pulse on the 9R14 and 9R18 transitions. Most of the early work was done on these transitions which lie near 9.3 microns. Apertures were placed in the cavity to limit lasing to the fundamental transverse mode. Initially absorption cells of various lengths were tried, ranging from 9 cm to 60 cm. A 700 MHz pyroelectric detector coupled to a 400 MHz storage oscilloscope was used to monitor the temporal shape of the laser pulse. A schematic of the equipment is shown in Figure 6.

With the absorption cell evacuated the laser pulse was heavily modulated, showing frequency components at multiples of the longitudinal mode spacing. Computer simulated signals are shown in Figure 7. The modulation is due to the beating of the infrared frequency electric fields of each of the modes in the detector element. The difference frequency of the several longitudinal modes is the output of

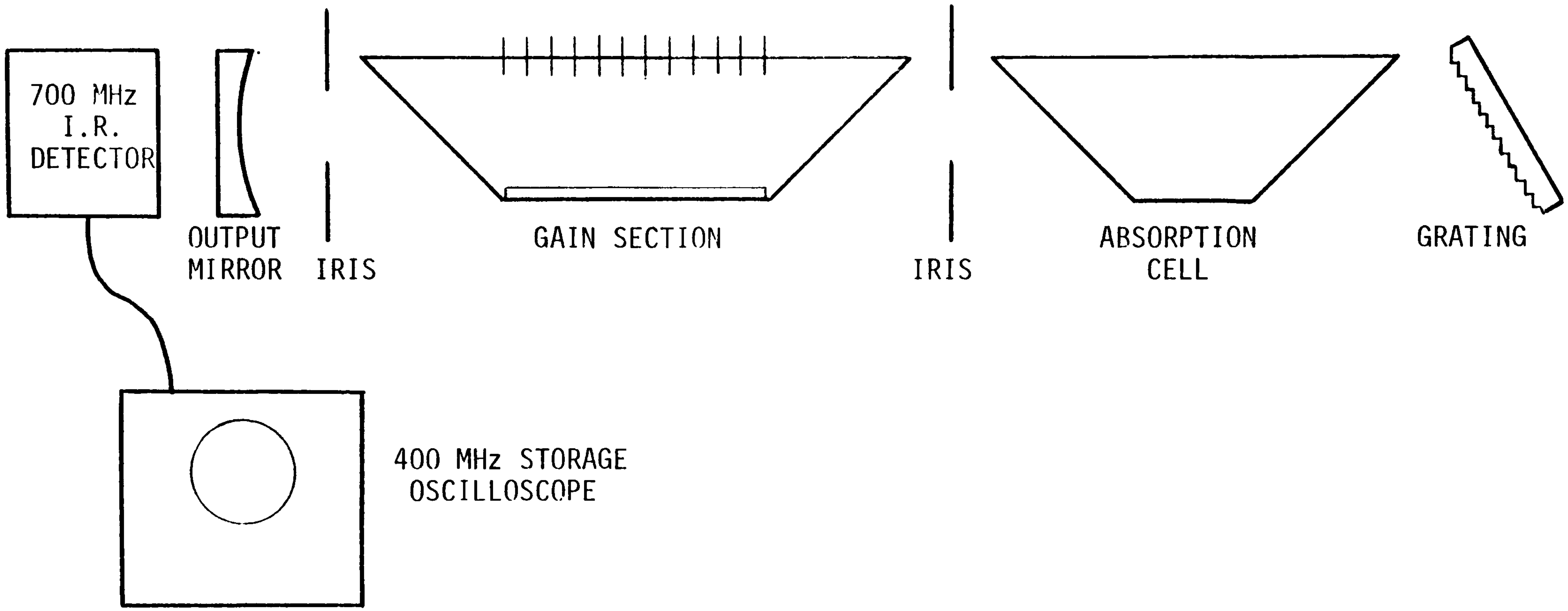


Figure 6. Schematic of Equipment

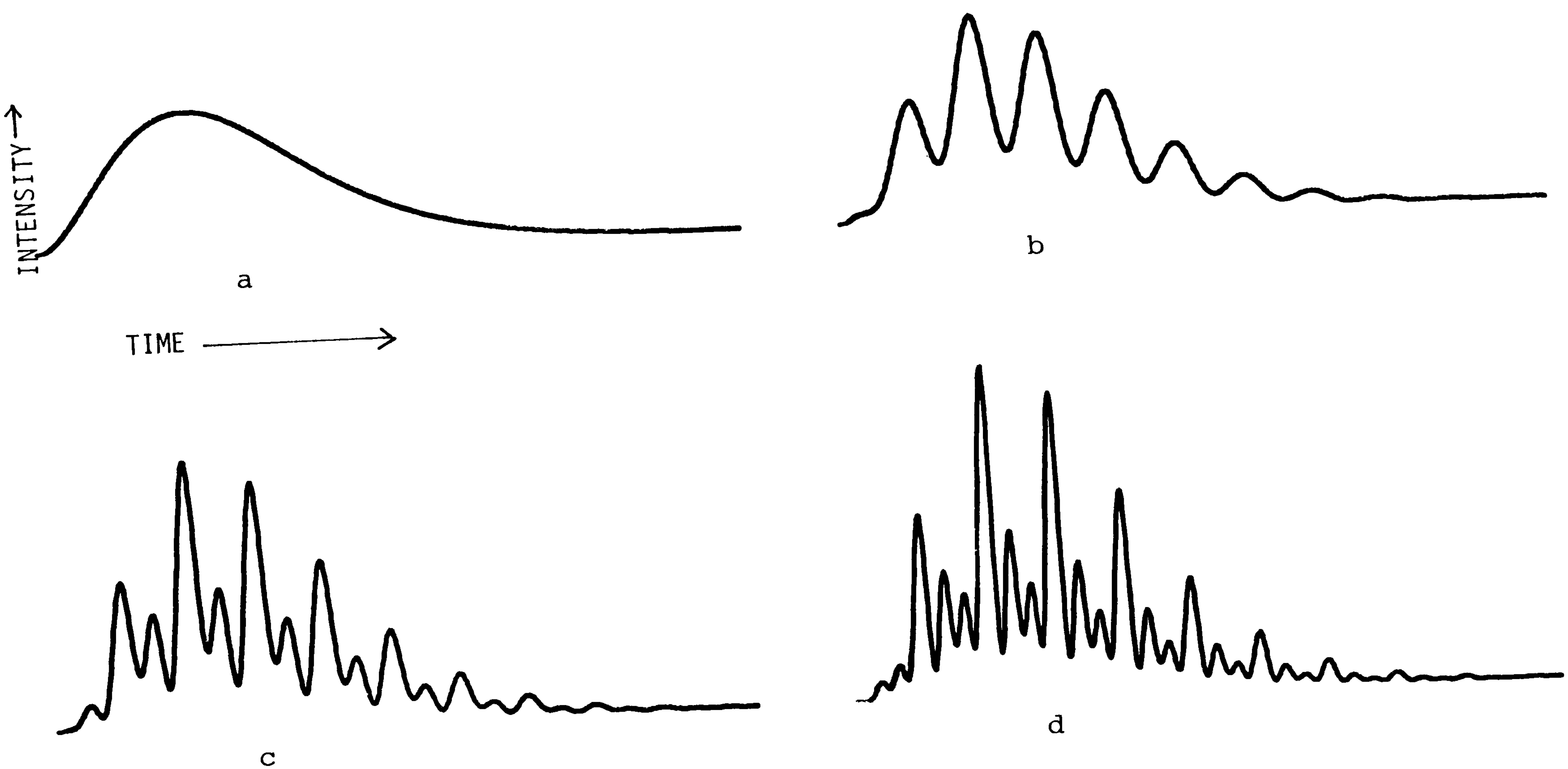


Figure 7. Computer Simulation of Temporal Behavior of Multiple Longitudinal Mode Pulses: (a) Single mode. (b) Two modes. (c) Three modes. (d) Four modes.

the detector which is displayed on the oscilloscope.

The absorption gases were chosen on the basis of an absorption in the 9.3 micron region, and were selected to represent a broad cross section of absorption strengths in this region. An absorption gas was slowly introduced into the cell and the effect on the temporal shape of the pulse noted. Some gases appeared to allow only two modes to oscillate, as evidenced by only a single beat frequency in the output pulse. Others produced a smooth pulse, indicative of single mode operation, as shown in Figure 8. Occasionally at higher pressures a gas would mode-lock the laser. A few gases had no effect on the laser pulse shape. All gases did have the effect of lengthening the oscillation buildup time, resulting in a delay in the light pulse and increased jitter. The delay was typically 1-3 microseconds and the jitter increased to .5-1 microsecond. However, both jitter and delay were expected to improve in a laser with higher gain. An increase or decrease in the TE laser gas pressure broadened or reduced the gain bandwidth of the laser, and consequently some gases caused single mode operation at low pressure and multimode operation at a higher laser pressure. As absorption cell pressure increased the lasing power decreased. A chart of the preliminary results appears as Table I. It was apparent quite early that a long absorption cell worked much better than a short one so all the subsequent data was taken with a 60 cm cell.

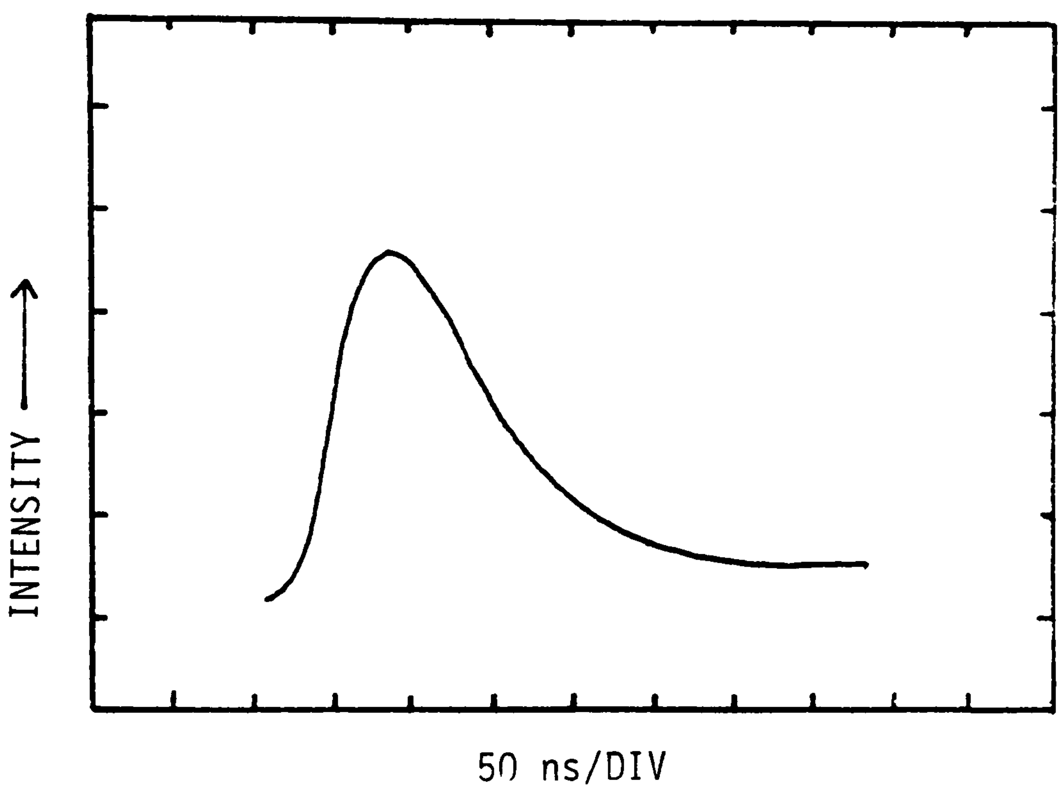


Figure 8. Oscilloscope Trace of Temporal Behavior of Single Mode Pulse

TABLE I

Preliminary Results with Selective Absorbers

ABSORBING GAS	RELATIVE STRENGTH OF ABSORPTION	CELL PRESSURE 60 cm LENGTH (TORR)	LASER PRESSURE (TORR)	MODE STRUCTURE	CO_2 LINE
HCOOH	30	2.0	200	TWO	9R14
		5.0	200	MODE-LOCKED	14
		2.5	400	TWO	18
CH_3OH	30	3.0	380	TWO	14
		6.0	200	MODE-LOCKED	14
		4.0	400	SINGLE	18
CCl_2F_2	50	3.5	200	SINGLE	14
		1.2	500	SINGLE	14
		1.5	400	TWO	18
CCl_3F	500	.15	350	SINGLE	14
		.10	350	SINGLE	18
CB_rF_3	500	.20	350	SINGLE	14
		.10	350	SINGLE	18
CH_3Cl	1	10	350	MANY	14
		10	350	MANY	18
CH_3I	1	10	350	MANY	14
		10	350	MANY	18

Inspection of Table I reveals that gases with strong absorption features worked much better than those gases with only moderate or weak features. For example, $CHCl_2F$ caused good SLM operation and CH_3Cl did not. All of these results were basically as expected.

Many features are apparent in the fine spectrum of the gases that could be causing the SLM operation, and it is important to know the exact lasing frequency so that a correlation between the spectral data and the SLM frequency can be made. If the lasing frequency is at the frequency of an absorption minimum the proposed theory of operation would be substantiated. To this end an experiment was developed which would measure the frequency of the TE laser with respect to line center of the CO_2 line.

A low pressure (10-30 torr), pulsed, longitudinal discharge CO_2 laser with an invar stabilized frame for frequency stability over long periods of time was set up as a local oscillator with which the TE laser could be heterodyned. The frequency reference laser was known to oscillate on a single longitudinal mode within 20 MHz of line center due to its low operating pressure and short length. An internal iris eliminated higher order transverse modes. The output from the TE laser and the reference laser was incident colinearly on a fast (200 MHz) photovoltaic detector where heterodyning occured. The beat frequency of the two beams was displayed on an oscilloscope. A typical waveform of the beat frequency can be seen in Figure 9.

The beat frequency is the absolute value of the frequency offset from line center of the TE laser. To determine the sign of the frequency shift it was noted that increasing the voltage applied to the piezoelectric translator (PZT) on which the output coupling mirror of the reference laser was mounted shortened the cavity and therefore raised the laser frequency. If the beat frequency increased as the PZT voltage was increased it implied that the TE laser was operating to the low frequency side of line center. Conversely, if the beat frequency decreased the TE laser must be lasing to the high frequency side of line center.

The next refinement was to add a PZT to the output coupler of the TE laser in an attempt to vary its frequency over the width of the transmission feature in the selective absorber. It was found that some modes could be tuned almost a complete free spectral range of the cavity. The series of heterodyne signals in Figure 10 exhibits clearly the tunability of the laser over a range of 30 MHz. Table II lists laser operating conditions and tuning ranges observed with the various selective absorbers.

At this point a correlation can be made between the absorption spectra of the gases and the SLM frequencies selected by the gases. For example, CCl_2F_2 showed evidence

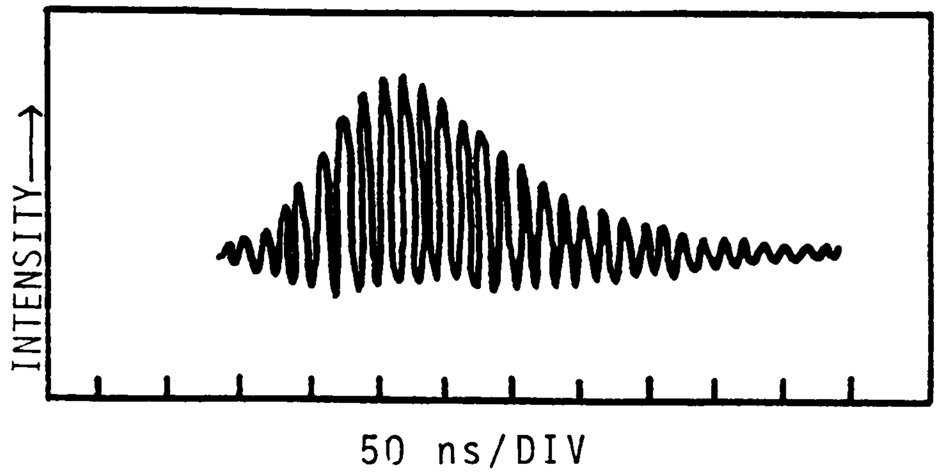


Figure 9. Oscilloscope Trace Showing Frequency Beating Between SLM Laser and Reference Laser

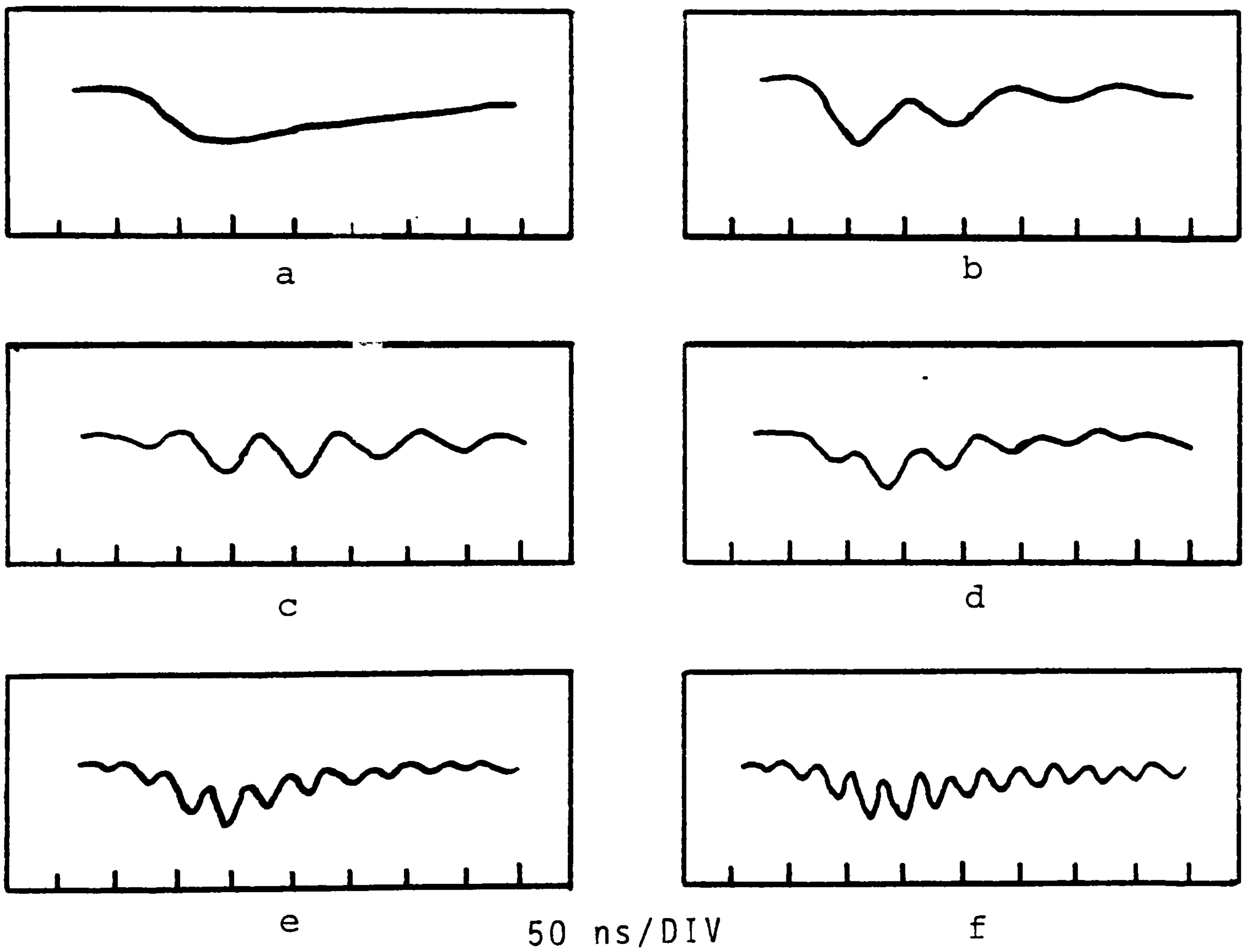


Figure 10. Heterodyne Signals Exhibiting Tunability of SLM Laser

TABLE II

Selective Absorber Gases and Tuning Ranges of SLM Laser

GAS	CELL PRESSURE (TORR)	TE LASER PRESSURE (TORR)	FREQUENCY OFFSET (MHz) 9R14	9R18
CCl_3F	.1	350	+50-100	+110-120
	.1	350		-150-200
	.1	250		180
	.1	110		6-23
$CHCl_2F$	.1	350	+55-85	
	.3	350		-125-160
$CBrF_3$	.2	350	-20-50	
	.2	350	+250-300	
	.1	350		+150-185
CCl_2F_2	2	350	200	
	2	350	-0-55	
$C_2H_3Cl_3$	2	350	-45-100	
CH_3OCH_3	5	350	+30-50	
CH_3OH	3	350	-140-160	
	1.5	350		+200-220
C_2H_5OH	.3	350		-10-+10
	.6	350		+220-250
	.6	250		-45-60

of two transmission peaks in its spectra[8] close to line center of the 9R14 CO_2 laser line, one about 25 MHz below line center, and the other 250 MHz above. See Figure 11. The observed TE laser frequency offset was near 20 MHz under some conditions, and near 200 MHz at other times. Apparently the 200 MHz feature was narrow, and only wide enough for the laser to lase at that frequency when the PZT had tuned the cavity exactly to it. Typically the laser prefered the feature closer to line center where laser gain was higher. These results reinforce the argument in favor of the proposed theory of SLM operation, and further, suggest that one may actually predict the SLM frequency of a laser by studying the absorption spectrum of the mode controlling gas.

The practicality of the selective absorber method of mode control of a TE laser depends heavily on the ability to adapt it to lasers of higher power. A technique which works well on a 20 mJ laser may not work well on a 1 J laser. Additionally, it was questionable whether a higher powered laser with a longer cavity length could be forced into SLM operation by this technique because the modes are much more closely spaced, and therefore the mode discrimination must be higher. Also, an increase in absorption cell pressure might be called for, which would pressure broaden the absorption features and render the technique useless.

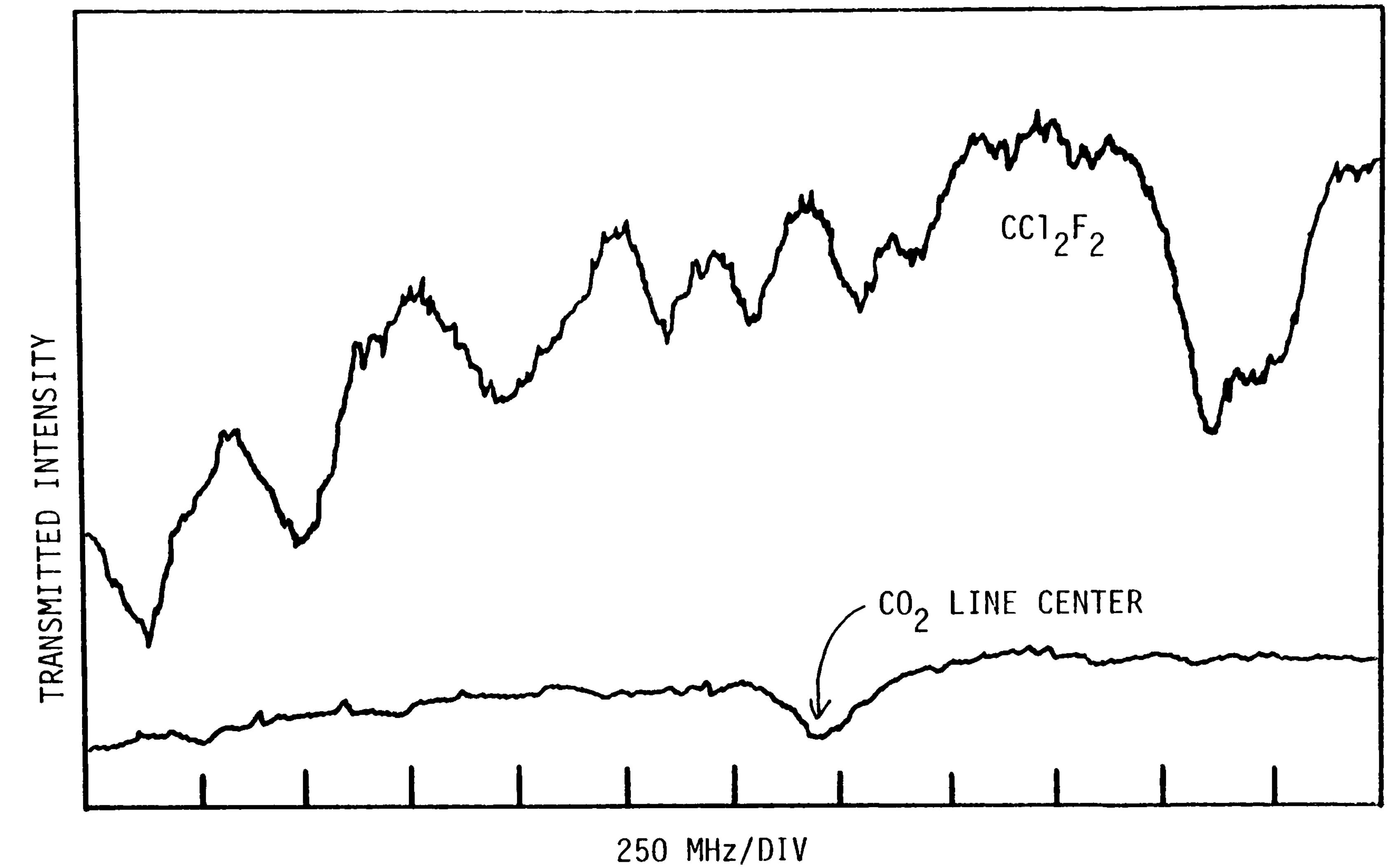


Figure 11. High Resolution Spectrum of CCl_2F_2

To investigate the feasibility of selective absorber mode-control on a high powered laser a Lumonics model 103 TEA laser was modified to accept a 45 cm long absorption cell. The laser cavity was 3.5 m long, yielding a mode spacing of 43 MHz. The laser lased with an output energy of 1.5 J on the fundamental transverse mode, but with multiple longitudinal modes. Addition of the gas to the absorption cell caused SLM operation for some of the gases tried, but not all of those which worked for the low powered laser worked for the larger TEA laser. Only those gases with the strongest absorption features near 9.3 microns were effective. Table III lists the gases that were effective for the TEA laser and the frequencies at which SLM operation occured. The laser power was not reduced significantly by the addition of the absorption gas. The typical SLM energy was 1.1 J, 73% of the multimode energy. This appears to be one of the highest reported for a single stage SLM TEA laser. The high efficiency may indicate that once laser oscillation on a single mode is achieved the absorption gas "bleaches" and is no longer a significant loss. Additionally, as predicted, the oscillation buildup time was shortened and jitter greatly reduced.

The successful single mode operation of the TEA laser was an important development because it indicated that a narrow bandwidth research tool with useful energy levels could be built fairly easily. Since the laser was a single

TABLE III

Selective Absorber Gases and Tuning Ranges of High Power SLM TEA Laser

GAS	CELL PRESSURE (TORR)	FREQUENCY OFFSET (MHz)	
		9R14	9R18
CCl_3F	1.5	310	
	1.5		-200-220
$CHCl_2F$	1.0	+60-70	
$CBrF_3$	.6	285	
	1.0		+115-135
	1.0		600

stage device the problems of interfacing with other equipment would be minimized. The next natural step to take was stabilization of the single mode frequency over extended periods of operation.

CHAPTER III

DEVELOPMENT OF A STABLE SINGLE MODE LASER TOOL

Design

Research was directed towards development of a single mode TEA laser which could be expected to maintain a constant output frequency over long periods of operation. Since the device would be considered a tool for future experiments any features which might be convenient to the operator in the course of an experiment were considered worthwhile to include. A brief introduction to the CO_2 laser system is presented before discussing the particulars of the design.

The laser system (Figure 12) incorporates two laser cavities within the same structure. One, the TEA laser, provides the intense SLM infrared beam used for laser research. The second, included only as a convenience, is a small longitudinal discharge CO_2 laser used as a reference to measure frequency displacement of the high power laser from line center using heterodyne techniques. This allows precise knowledge of the SLM TEA laser frequency. Both cavities are grating tunable over the various CO_2 rotational transitions. Provision is made for monitoring the laser frequency without interfering with the main beam so that the TEA laser offset may be continually monitored during

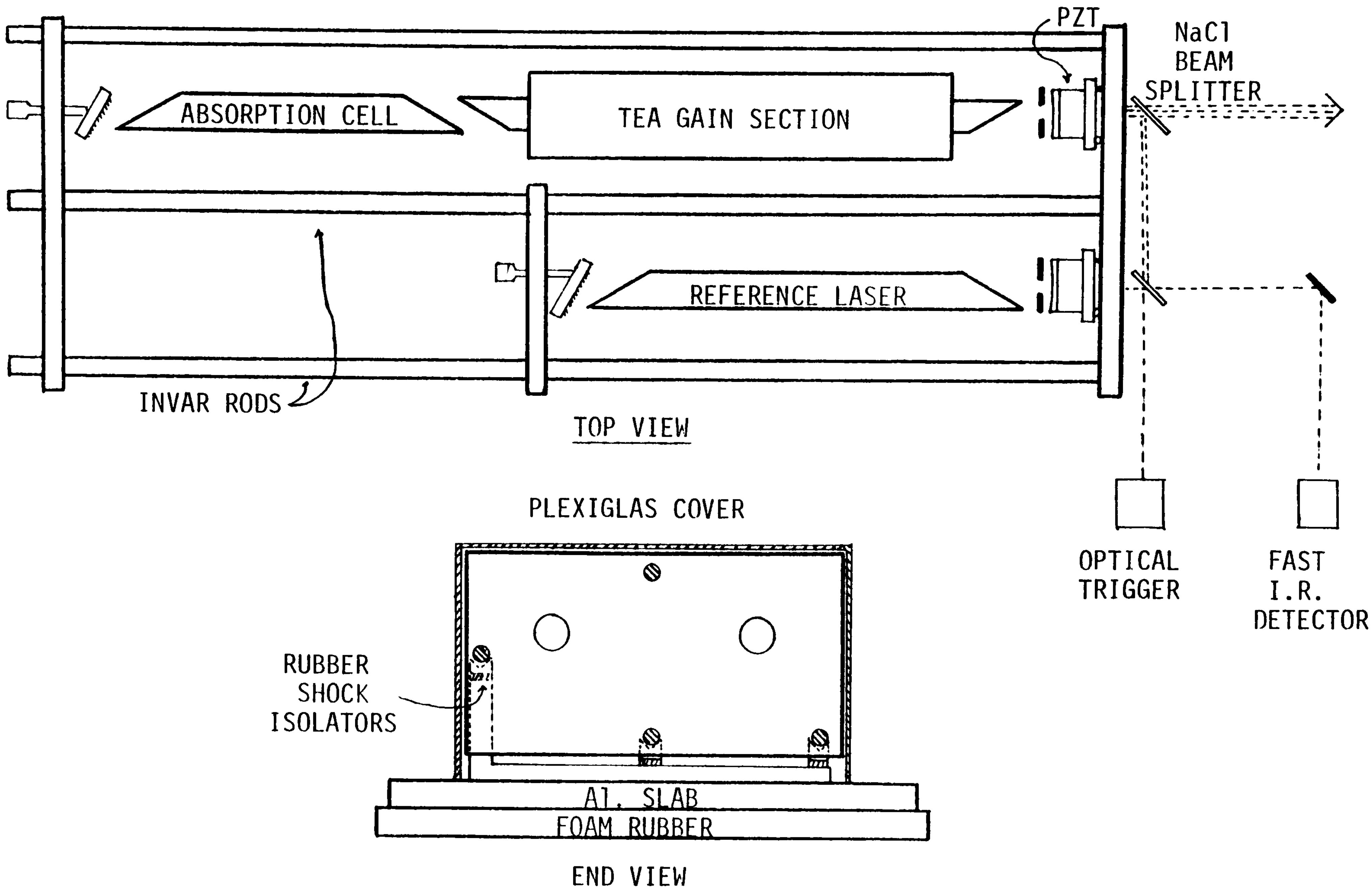


Figure 12. Stable Single Mode Laser System

an experiment.

Thermal and mechanical stability of the optical mounts are important factors in determining the ultimate frequency stability of the laser. An invar frame has been incorporated into the laser system to reduce drift of the laser frequency as a result of expansion of the optical cavity due to room temperature variations. Additionally, temperature compensation is provided by counter-expanding aluminum optical mounts. The entire structure is enclosed in plexiglass to eliminate air currents and the four invar rods are covered with urethane foam and wrapped in aluminum foil to further desensitize the system to thermal variations. The one-inch invar rods are positioned so as to provide the most rigid optical support structure possible, while not interfering with proper placement of other components. The entire optical system is mounted on three brackets each containing rubber insulators of 3 mm thickness to reduce transmission of vibrations to the structure. In addition, the entire laser system rests on an aluminum slab 50 mm thick, which is further isolated from the table by 50 mm of foam rubber. Mechanical rigidity and shock isolation are important to eliminate pulse to pulse jitter in the laser frequency due to vibrations.

The plates on which the optics are mounted are constructed of one-inch aluminum. Three plates are used, one apiece to mount the gratings for the two lasers, and one to which the two output couplers are mounted. The two plates to which the gratings are mounted may be moved longitudinally to select an optimum cavity length under various conditions, such as substitution of a different absorption cell. Generally, the shortest cavity length possible is best as it provides maximal longitudinal mode spacing. The reference laser cavity is 80 cm long, and the TEA laser cavity is typically 150 cm long.

The gain medium of the TEA laser is produced by a Lumonics 101 kit with a 50 cm long active region. Brewster windows on both ends seal the gain section. The absorption cell used for mode selection is 50 cm long and is similarly sealed with Brewster windows. The cell is equipped with one port to which a low pressure gas handling system is attached.

The low pressure reference laser is constructed of a 7 mm ID pyrex tube 65 cm long, with nickel pin-type electrodes and gas ports on each end. The pulsed electrical discharge is supplied by a 9 nF capacitor charged to 18 kV and switched through a spark gap. The Brewster windows are mounted to the tube via ground glass couplings to minimize maintenence problems (Figure 13).

The rear reflector of each of the laser cavities is a grating. The grating for the TEA laser is a 100 groove per mm gold-coated master, blazed at 10 microns. A master grating is necessary for the high power laser to suppress

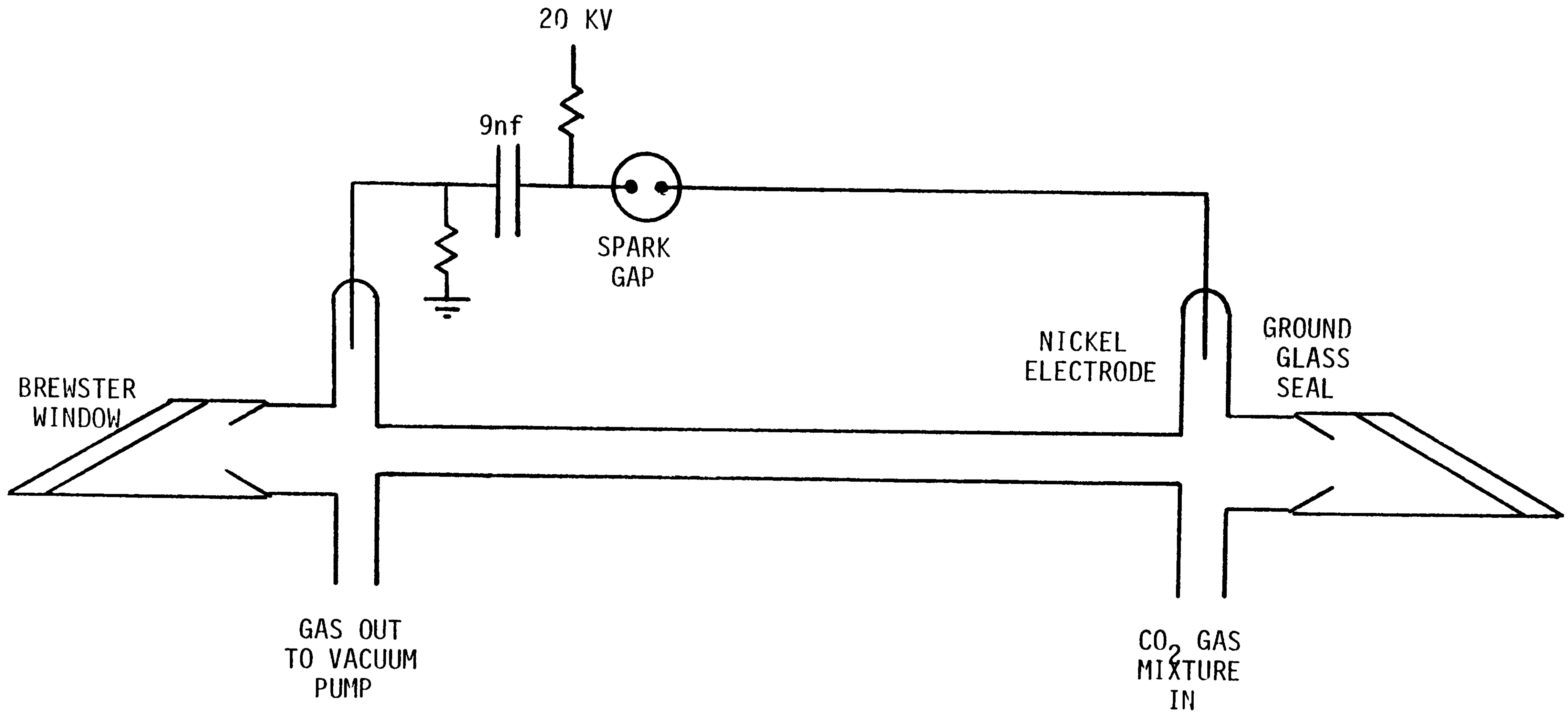


Figure 13. Reference Laser

grating damage from high flux densities. The low pressure reference laser is tuned with a 150 groove per mm gold-coated replica grating blazed at 9 microns. The higher groove density is necessary for proper operation in the shorter cavity. Both gratings are mounted in adjustable fixtures directly to the 1-inch aluminum plates.

The front reflectors for the two cavities are mounted to the forward plate via an adjustment mechanism for cavity alignment. In addition, between the mirror and the adjusting mechanism is a PZT for adjustment of the cavity length over a distance of 10 microns. Inside each of the two laser cavities is an adjustable aperture to eliminate multiple transverse mode operation. Two NaCl windows are mounted on the outside of the endplate which holds the output couplers. These salt windows provide the capability of splitting off a small portion of the TEA laser beam and mixing it colinearly with the reference laser beam so that the beat frequency can be monitored with a fast HgCdTe detector.

An electronic control unit was designed and built to supply the trigger signal to the lasers and to control the PZT voltages. The unit contains a master trigger section with variable rate which supplies a pulse every .2 to 20 seconds to the four channel delay section. Variable amplitude pulses (0-40 v into 50Ω) of 5 microsecond duration can be individually delayed from zero to 100 microseconds to synchronize the TEA laser output pulse with the reference laser. Two extra channels are provided for synchronization of other equipment such as oscilloscopes or other lasers. Also included in the unit are two variable power supplies of zero to 1.2 kV range for operation of the PZTs. Digital display of the PZT voltage is provided. A simplified circuit schematic is shown in Figure 14.

Operation of the Laser System

The TEA laser operates with a flowing gas mixture of 8:1:1 (He, CO_2, N_2) at local atmospheric pressure of about 680 torr. The reference laser is operated on a flowing gas premix of 5:1:1 at a pressure of 10-20 torr. Generally the system is set up for operation by tuning the two lasers to the desired rotational transition with the gratings, then introducing into the evacuated absorption cell enough of the selective absorber gas to quench lasing. Then the gas is evacuated slowly until the laser is lasing with moderate power. At this point the TEA laser pulse shape should be checked with a fast detector to ensure that SLM operation has been achieved. SLM operation is evidenced by a smooth pulse with no modulation.

The reference laser will generally need to be peaked by adjusting the cavity length with the PZT since the gain bandwidth at low pressure is less than the cavity mode spacing. By carefully watching for peak amplitude of the

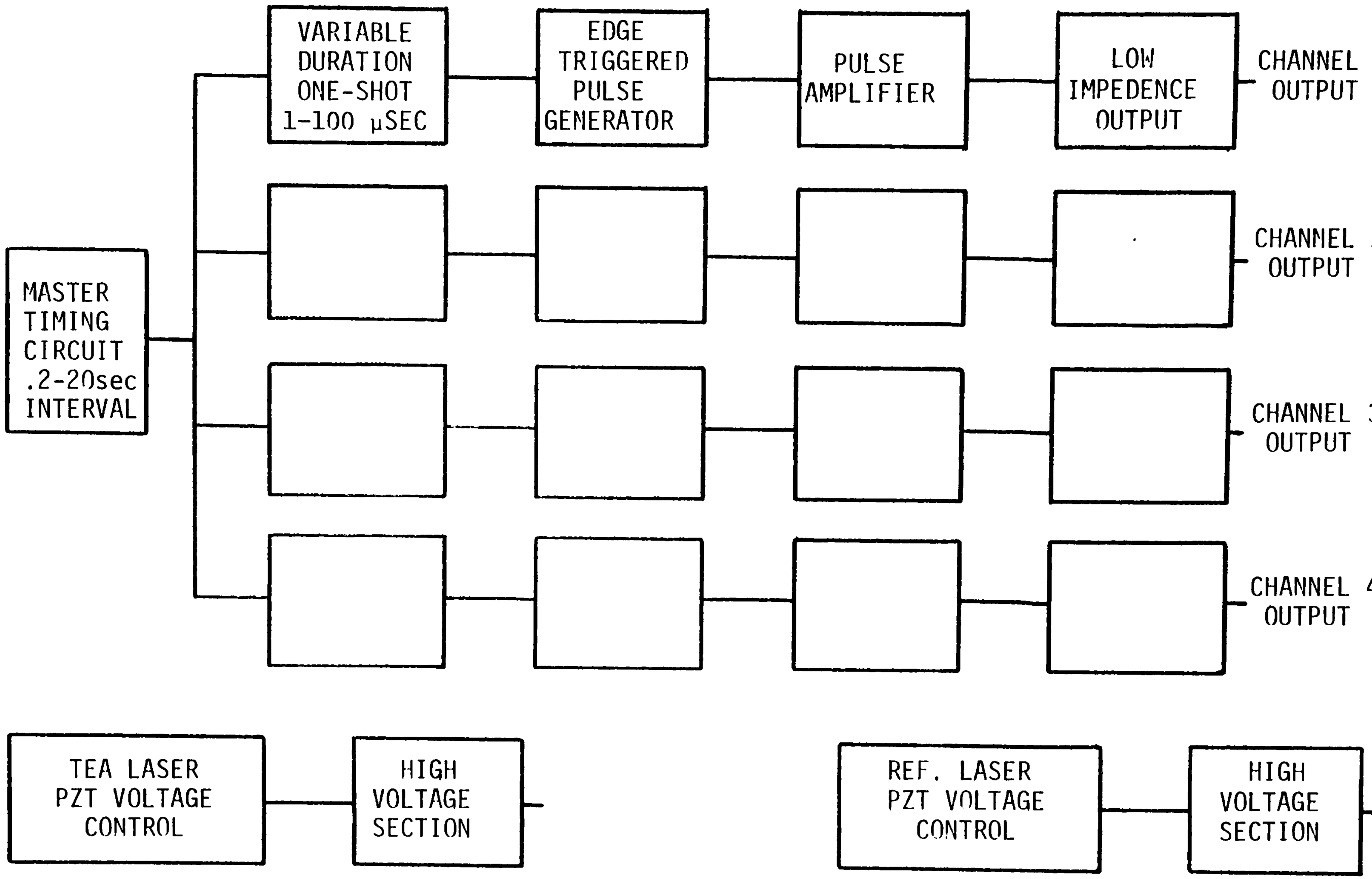
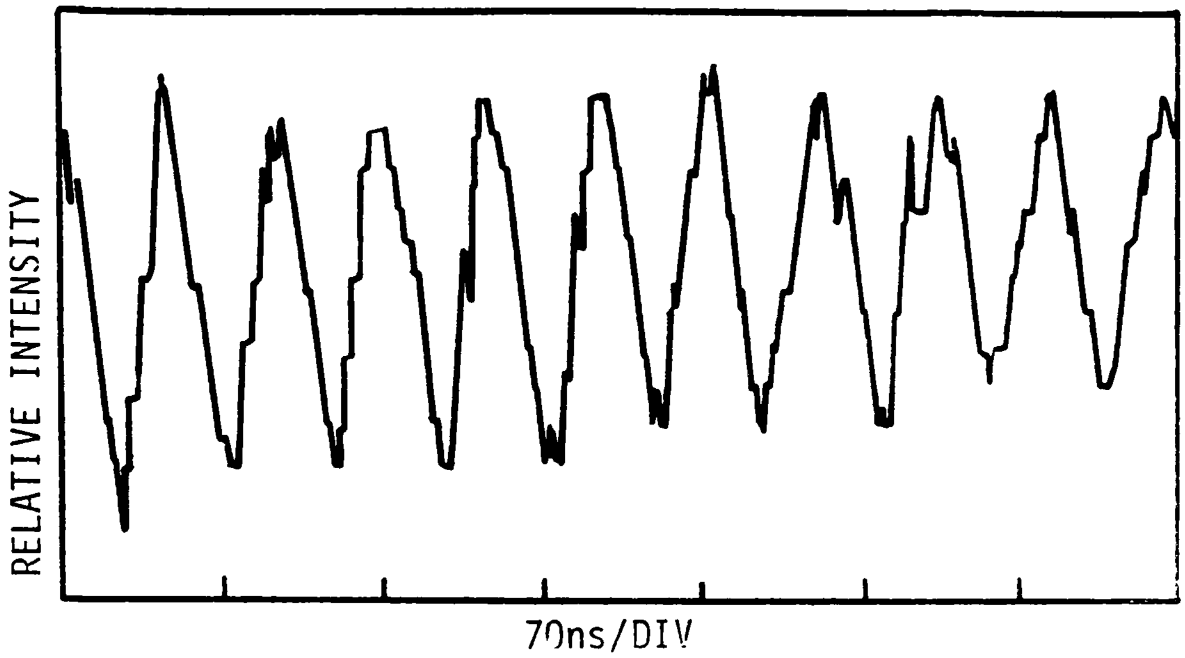


Figure 14. Simplified Circuit Schematic of Control Unit

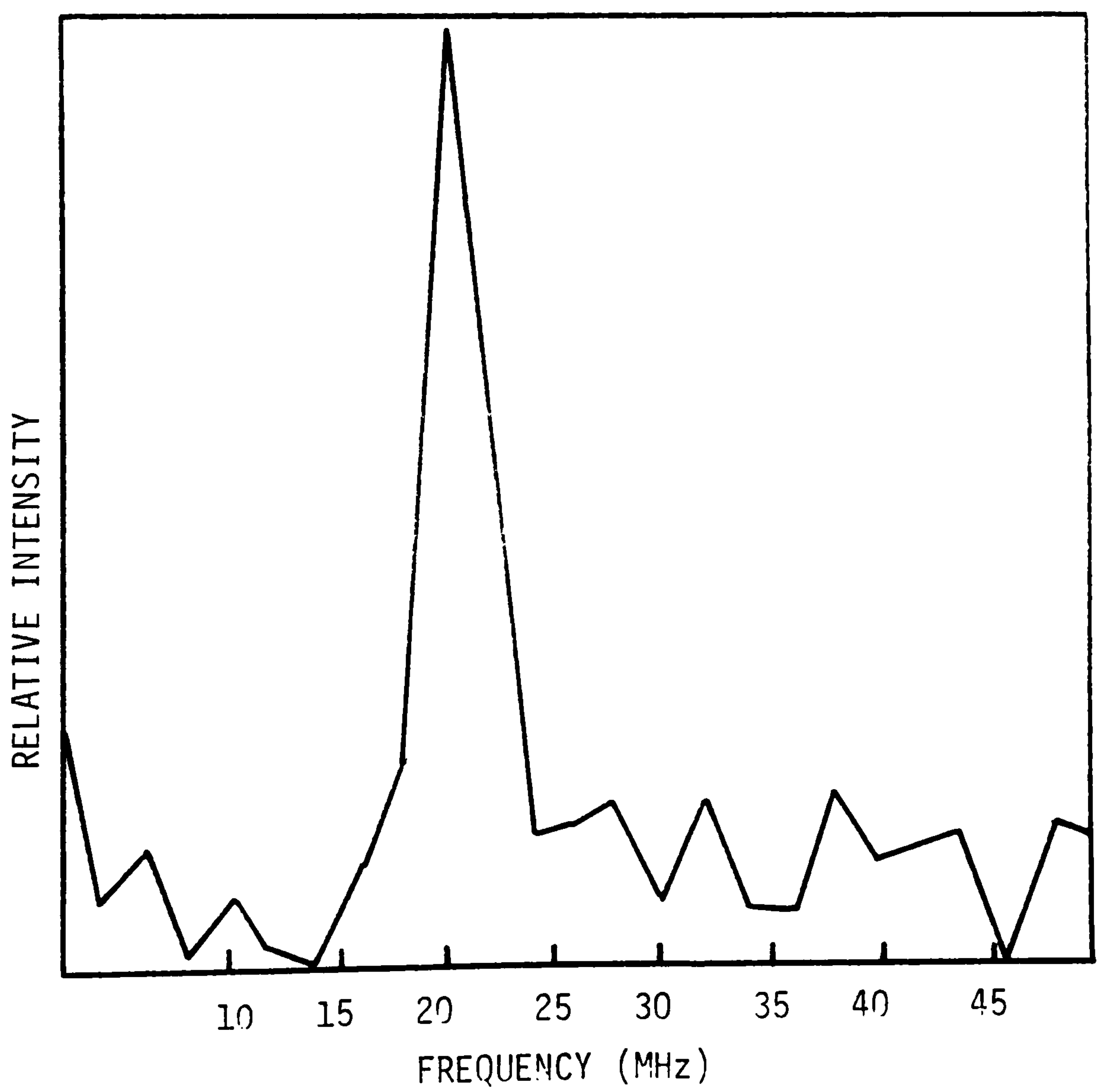
lasing it is possible to ascertain the position of line center. Allowing both laser beams to strike the detector simultaneously and colinearly produces a beat frequency signal from the detector which indicates the precise frequency offset from line center at which the TEA laser is oscillating. Figure 15a is a digitized picture of the beat frequency of the two lasers, and 15b is the fourier transform which clearly shows the frequency offset from line center. Adjustment of the PZT on the TEA laser output coupler can yield a tuning range nearly equal to the mode spacing of the cavity, although it is dependant on the particular selective absorber gas used. Shifting the frequency beyond the tuning range of the laser with a particular absorber gas in the cell requires using another gas with different absorption characteristics.

The laser has been observed for periods of 20 minutes to be stable within a range of 15 MHz. Pulse to pulse frequency jitter is around 3 MHz. Single mode energy per pulse is 60% that of the laser operating multiple longitudinal mode, and typical pulse energy is 200 mJ.

The laser system has been very reliable and easy to operate. A great deal of the ease of operation is attributable to the static gas charge in the cell which provides mode control. However, it has been found that over a period of several hundred laser shots the effectiveness of the absorber begins to decrease. This is apparently due to



a



b

Figure 15. Computer Digitized Picture of Beat Signal (a) and its Fourier Transform (b)

decomposition of the absorber gas by the laser beam. This observation is supported by the appearance of a haze on the cell window inner surface, apparently caused by the action of free fluorine atoms which are released from the freon type gases frequently used in the system. If a system is to be used for extended periods of time or at high repetition rates it might be advisable to flow the absorber gas. Another potential problem is that the jitter in the system increases when the absorption gas is introduced into the cell. This is due to the longer build-up time caused by the lowered gain. An optical trigger off the TEA laser light pulse has proven a suitable solution to the problem.

CHAPTER IV

CONCLUSION

A theory of operation for selective absorber mode control of a CO_2 laser has been proposed, and in fact, substantiated by research findings. The fact that the laser SLM frequency was found to lie within the region of a local transmission maxima indicates that the fine structure of the absorption gas dictates the SLM frequency. The mode of the laser with the most net gain, that is one at an absorption minima, is the mode which oscillates preferentially to the rest. The single moding is not due to the gross absorption as was first implied by Nurmikko et. al. which would eliminate any hope of tunability.

Having found that the selective absorber technique for mode control worked well, and was generally applicable to any CO_2 laser transition, a program to develop a single longitudinal mode TEA laser to be used as a research tool was initiated. This program culminated in the construction of a laser system, complete with gas handling apparatus and electronic controls, which is reliable and easy to use.

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