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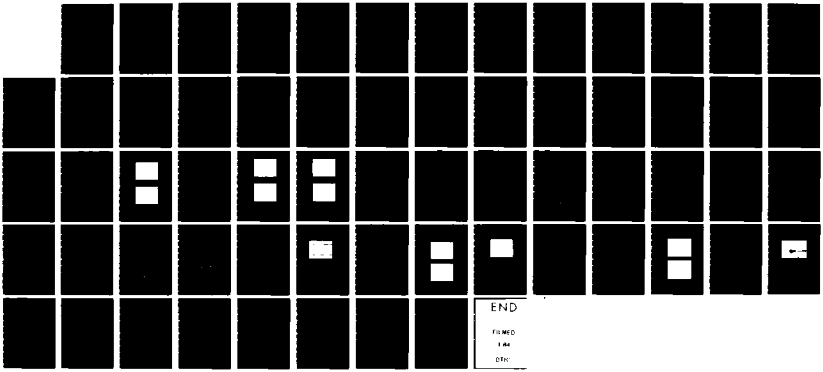

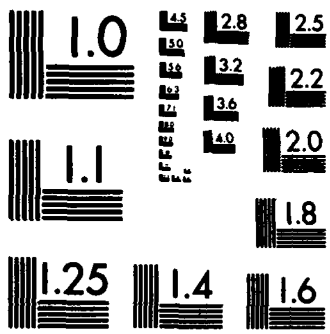

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PULSED HETERODYNE CO_2 LASER/SCANNER SYSTEM
Volume II - Operating Instructions

G.B. Jacobs

General Electric Co.
Electronics Laboratory
Syracuse, New York 13221

Final Report
September 1980 - June 1983

June 1983

Approved for public release; distribution unlimted

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

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The operation volume of a two volume report is intended to aid the government in assembling and operating the long pulse laser radar built and delivered on this contract. The equipment is intended for operation in a trailer to be supplied by the government. It incorporates a high pulse repetition frequency, high power electron beam injection CO_2 laser developed by the General Electric Co. and a hemispherical scanner with a laser beam of less than 2×10^{-3} degrees beamwidth.

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1 INTRODUCTION

1.1 SUMMARY

Ten-micron heterodyne laser radar offers a new type of remote sensor that can add significantly to our characterization and understanding of the atmosphere. For example, accurate range-resolved measurements of air velocity via the Doppler of aerosol backscatter -- to distances of tens of kilometers -- will yield a better understanding of wind shear. This report describes the operation of the laser radar built by General Electric for the Air Force Geophysics Laboratory (AFGL) under Contract F19628-80-C-0184. This report is the second of a two-volume series. The first describes the procedure for assembling this equipment.

The system incorporates a high pulse repetition frequency (PRF), high-power electron-beam injection CO_2 laser developed earlier by the General Electric Company. The system is intended to be assembled in a trailer to be supplied by the government and will permit hemispherical scanning with a laser beam of less than 2×10^{-3} degrees beamwidth.

This report is augmented by several others published earlier on the contract. The 2nd scientific report was a design evaluation report, as was the first and contains design descriptions of most of the system.

For the purpose of convenience, we list in exhibit A, the contract specifications that our design is to meet. To date, we have set up a breadboard of the heterodyne laser radar facility and have tested the critical techniques to be used. In addition, we have completed the engineering design and shop work in all major areas of construction (laser, scanner, electronics, and optics). The TEA laser and its power and control electronics have been set up and tested and results are described in this report. A small portion of the electronics subsystem remains to be wired.

CAUTION

The electrical system is the source of a number of high voltage hazards. The sustainer capacitor box is particularly dangerous. In setting up and operating this system all possible safety precautions should be observed with diligence. All metal parts that may be touched should be solidly and permanently grounded with heavy copper braid. Permanent grounds should be provided for cable connectors that may be unlatched during operation (such as oscilloscope leads). A grounding stick should be handy and always used whenever a high voltage circuit box is opened.

Section 6 discusses this and other safety hazards, such as x-rays, ozone and laser emission. Anyone who contemplates working on or operating the system should first become thoroughly familiar with the precautions delineated in this section.

EXHIBIT A

Attachment 2

Engineering Desription for a Pulsed Heterodyne CO_2 Laser/Scanner System (Full Hemispheric Scanning)

1.0 Introduction

1.1 This specification describes requirements for the development of a moderate high energy, high prf, pulsed doppler CO_2 laser/scanner system. The system will be used for experimental studies in remote sensing of atmospheric wind patterns and aircraft wake vortices. The system will operate on the principle of heterodyne detection of the frequency shifted signal received from atmospheric particulate backscatter. A nominal range of 20 km is the design goal with a minimum range of approximately 1 km.

1.2 System power levels, frequency stability, optical configuration, and sensitivity shall be such as to provide a radial wind measurement over the velocity range of ±50 meters/sec full scale. Transmitted signal pulse length shall be selectable to provide a 2 meter/sec velocity resolution at long pulse and a 5 meter/sec resolution at short pulse.

1.3 The laser beam shall scan in azimuth and elevation under remote operator control.

2.0 Specifications

2.1 The laser shall produce plateaus of 5 microsecond pulse duration at a 1-Joule energy level and of 1 microsecond pulse duration at an 0.2-Joule energy level. The energy shall be single wavelength, single transverse mode, and single longitudinal mode.

2.2 The gain switch spike to plateau ratio shall be reduced to a practical minimum, and not to exceed 3 to 1.

2.3 Provisions for control of radio frequency interference and acoustical noise shall be included in the design.

2.4 The pulse repetition frequency shall be 50 pps or greater for automatic frequency control (AFC) and to permit data signal averaging for enhanced signal to noise ratio.

2.5 The system shall provide separate intermediate frequency (IF) amplifier/discriminator channels for optical system AFC loops and as a data output discriminator to interface with existing government-owned signal processing and display systems. The data IF/discriminator shall provide a 70 MHz center frequency with linear bandwidth sufficient to provide ±50 m/sec full scale radial wind speed data with a resolution of 1 m/sec at a 5 microsecond pulse duration and a resolution of 5 m/sec at a 1 microsecond pulse duration.

2.6 Frequency chirp during the pulse shall be controlled to 0.2 MHz p-p, for compatibility with requirement 2.5.

2.7 The receiver infrared (IR) detector shall be a wideband (Hg, Cd, Te) unit cooled with a liquid nitrogen dewar of at least four hour hold time. Alternate cooling methods of equivalent performance may be proposed. Detectivity of at least $D^* = 5 \times 10^9$ cm $Hz^{1/2}/w$ and a quantum efficiency of at least 40% shall be provided. Additional pyroelectric or other IR detectors shall be incorporated as needed for AEC control and for establishing and monitoring system alignment and performance. Means shall be provided for continuous wideband monitoring of the transmitted signal waveform and power level. Efforts shall be made to provide optimum phase matching of the signal and local oscillator beams and sufficient stable local oscillator power to maximize the system heterodyne detection efficiency.

2.8 The laser small-optics configuration will be mounted on a suitable optical bench for contractor installation in a government-furnished trailer located at the AFGL Weather Radar Facility, Sudbury, MA. An 8-foot by 32-foot equipment trailer has been requested for use with this system. Mechanical modifications of the trailer will be provided by the government in accordance with acceptable contractor specified requirements for system housing and stability. Of the space available, no more than 8 feet × 24 feet shall be required for the laser system. Provision shall be made for necessary equipment access for alignment and maintenance within this space. Prime power (3ϕ and 1ϕ) and water for heat exchanger cooling will be provided by the government.

2.9 The laser system shall meet the requirements of these specifications over an ambient temperature range from 18°C (64°F) to 24°C (75°F).

2.10 The optical system shall include a beam-expander telescope of approximately 30 cm diameter and the necessary components and mounts to provide azimuth and elevation scan capability. An overall optical system efficiency of at least 10% is required. It is necessary that the scanner be capable of operation roof mounted on top of the trailer.

2.10.1 The scanner shall provide full hemispheric elevation and azimuth beam pointing under remote servo loop or stepping motor control.

2.10.2 The contractor will provide remote positioning controls, azimuth and elevation indicators, and data readout electrical signals for installation in the trailer. Angle resolution and repeatability for this application shall be 0.25 deg or better. Holding stability of 1 milliradian or better is expected for 10 knot winds. A scanning rate selectable up to two rpm is desired. A practicable degree of adverse weather prctection shall be provided for the external optical system.

2.10.3 Optical components shall be included in the system suitable for visual examination of targets and checking of system alignment.

2.11 The system design shall attempt to minimize the required fresh gas mixture make-up rate.

1.2 SYSTEM CONCEPT

The basic functional diagram of the system is shown in Figure 1. The TEA laser transmitter beam is expanded by the 12" diameter telescope and aimed by computer directed control of the scanner to the area of the atmosphere to be studied. The doppler shifted aerosol backscatter return is collected, concentrically, by the same scanner/telescope system and imposed on the heterodyne detector. Here, this signal beats with the optical local oscillator to produce an intermediate frequency which is amplified in the usual superheterodyne signal processor. Two heterodyne receivers are used, one at 40 MHz to control the TEA laser frequency and one at 70 MHz for the customer computer input.

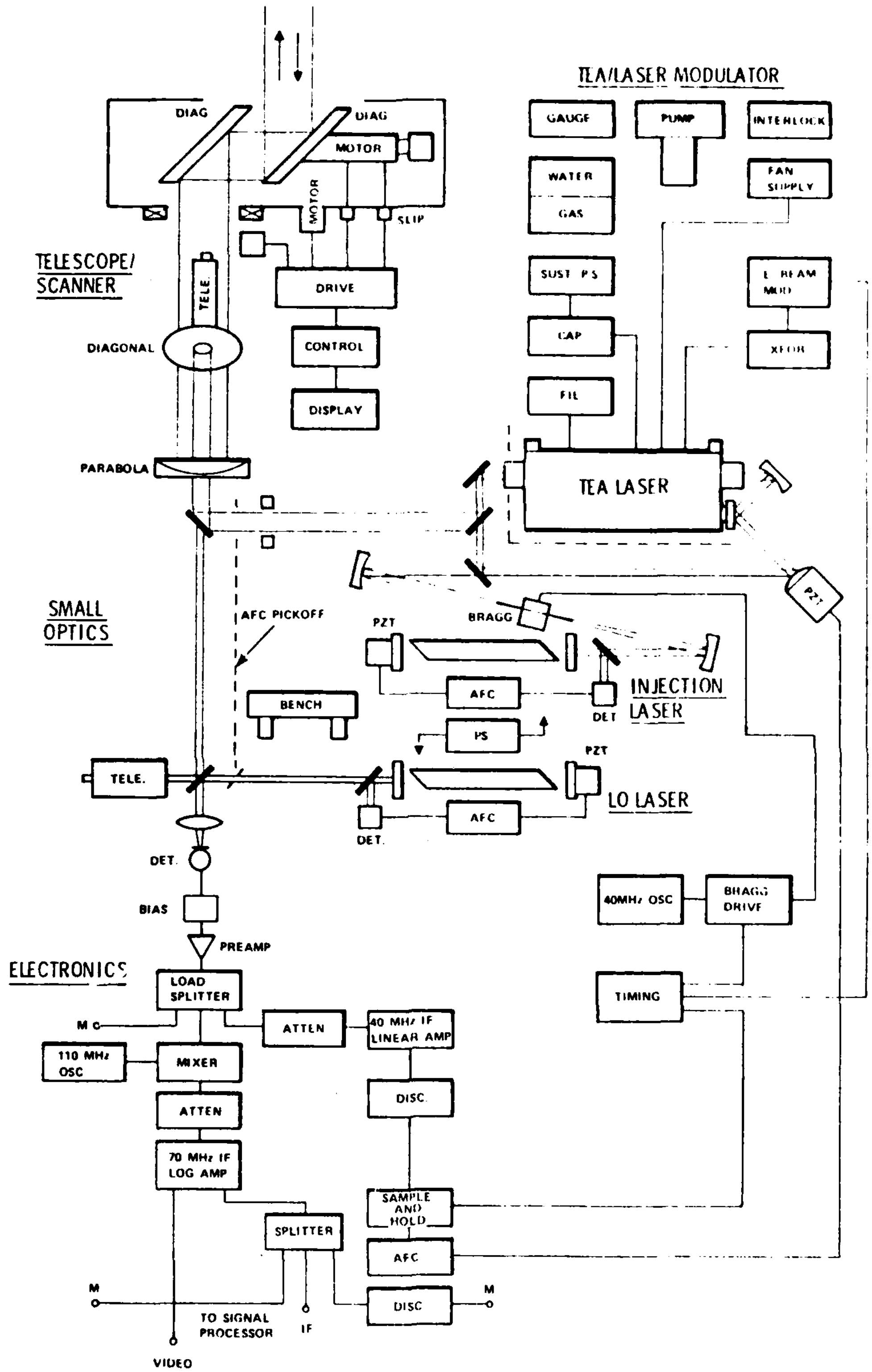


Figure 1. Basic Laser Heterodyne Radar System

The TEA laser mode and "J value" are controlled by injecting into its cavity a "seed" pulse, of the correct frequency just before the laser would oscillate by itself. The injection laser frequency and the local oscillator laser frequency are self-controlled (dither AFC) to the center of the desired CO_2 laser wavelength. The TEA laser is then corrected for any frequency errors measured by the TEA AFC IF discriminator. The frequencies of all three lasers are controlled by changes in their cavity length obtained by a piezoelectric transducer support of one of the cavity mirrors.

To generate the basic 40 MHz IF the injection laser output is shifted 40 MHz by a Bragg (acoustic) modulator before it is injected into the TEA cavity, thereby shifting the TEA laser frequency by the same amount.

An unusual feature of the system is the use of a 120 kV 15 ampere beam of electrons injected into the TEA laser CO_2 gas to generate the ions and plasma that creates the lasing inversion. This plasma is increased to about 500 amperes by the action of a 20 kV DC discharge across the sustainer electrodes in the same region. The 500 ampere discharge is just below avalanche and thus is easily controlled, on and off, by the smaller electron beam injection current. The lack of avalanche conditions in the plasma permits a laser pulse of lengths particularly suited for accurate range gated doppler measurements.

1.3 REPORT OUTLINE

It is apparent from the functional diagram that to get this system into operation a number of subsystems must be operational first. And that to provide these conditions in some cases adjacent subsystems must be set up and tested first. Thus the outline of this report is based on the unique sequence necessary to successively enlarge the subsystem operation to full scale. Section 2 describes five basic electronic subsystems and is followed in Sections 3 and 4 with the alignment procedures for 8 key optical subsystems. Section 5 describes operation of the full system.

1.4 SUBSYSTEM NUMBERING SYSTEM

To simplify system discussion we have separated Figure 1 down into an electrical system and an optical system. However many subsystems or components have a dual nature. The Bragg modulator for example is both an electrical component and an optical component. To avoid confusion we have labeled each of the major components with both an electrical (EL) number and an optical (SO) number.

Figure 2 shows the optical bench and the relative location of all the optical components and their "SO" numbers. Figures 3 and 4 show the relative location of the electrical components and their "EL" number. A discussion of the function, location, assembly and cabling of all 78 items is provided in Volume I. We are concerned here with their use in operating the system as a whole.

The Assembly Report, Volume I, should be consulted with respect to circuits, switches and controls referred to in the following text.

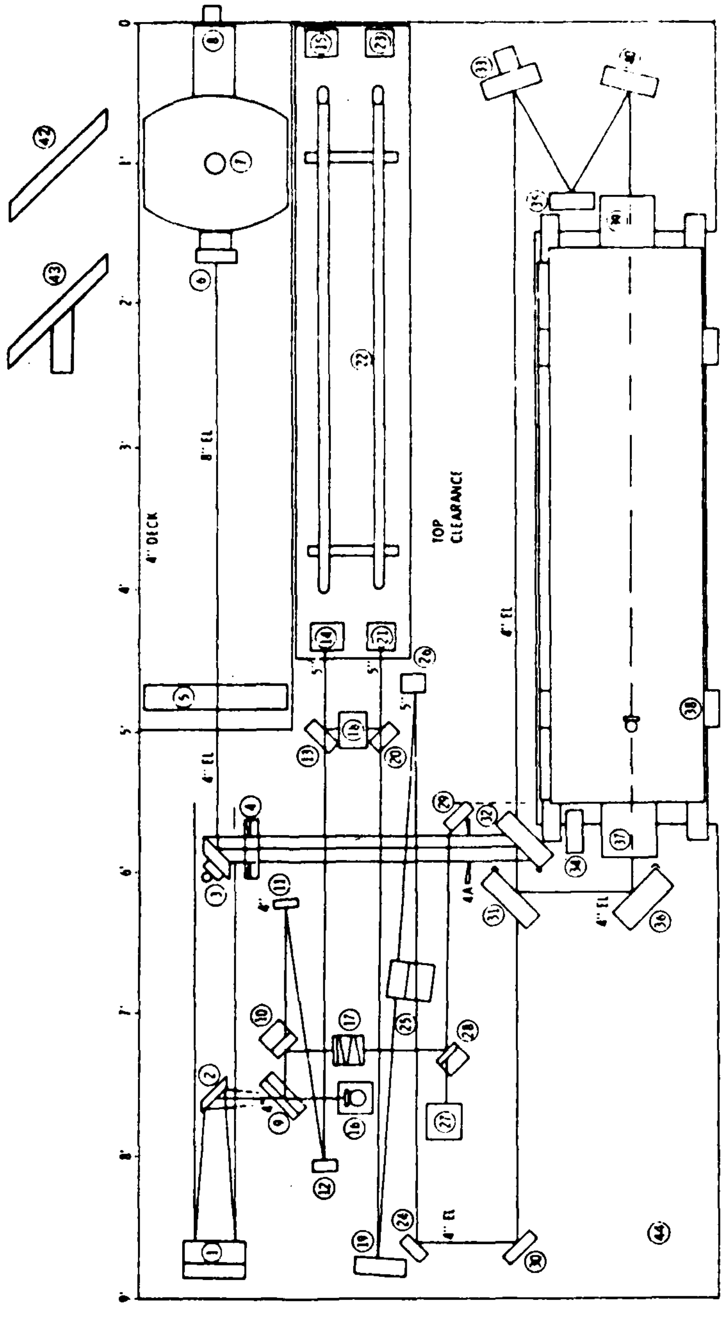


Figure 2. Optical System

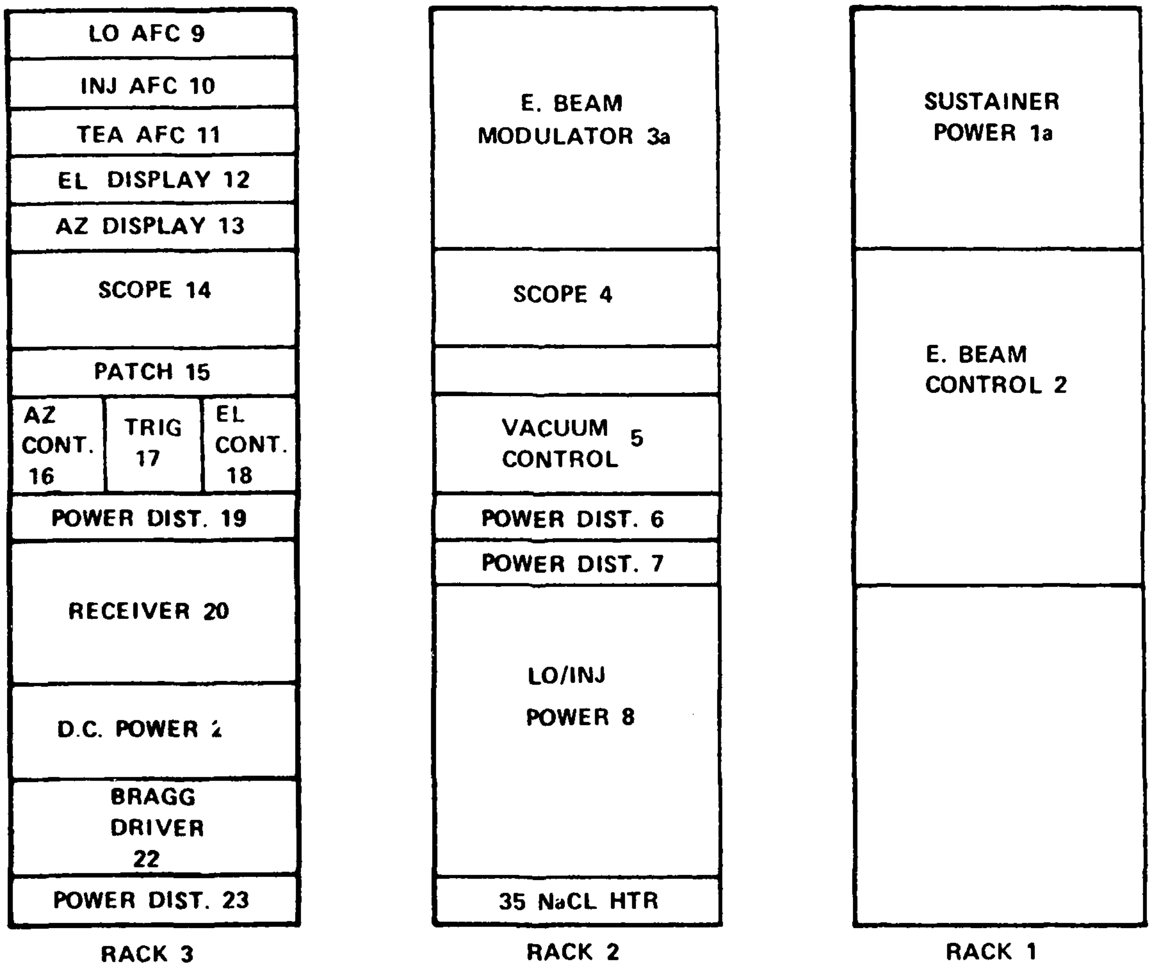


Figure 3. Electrical System, Racks

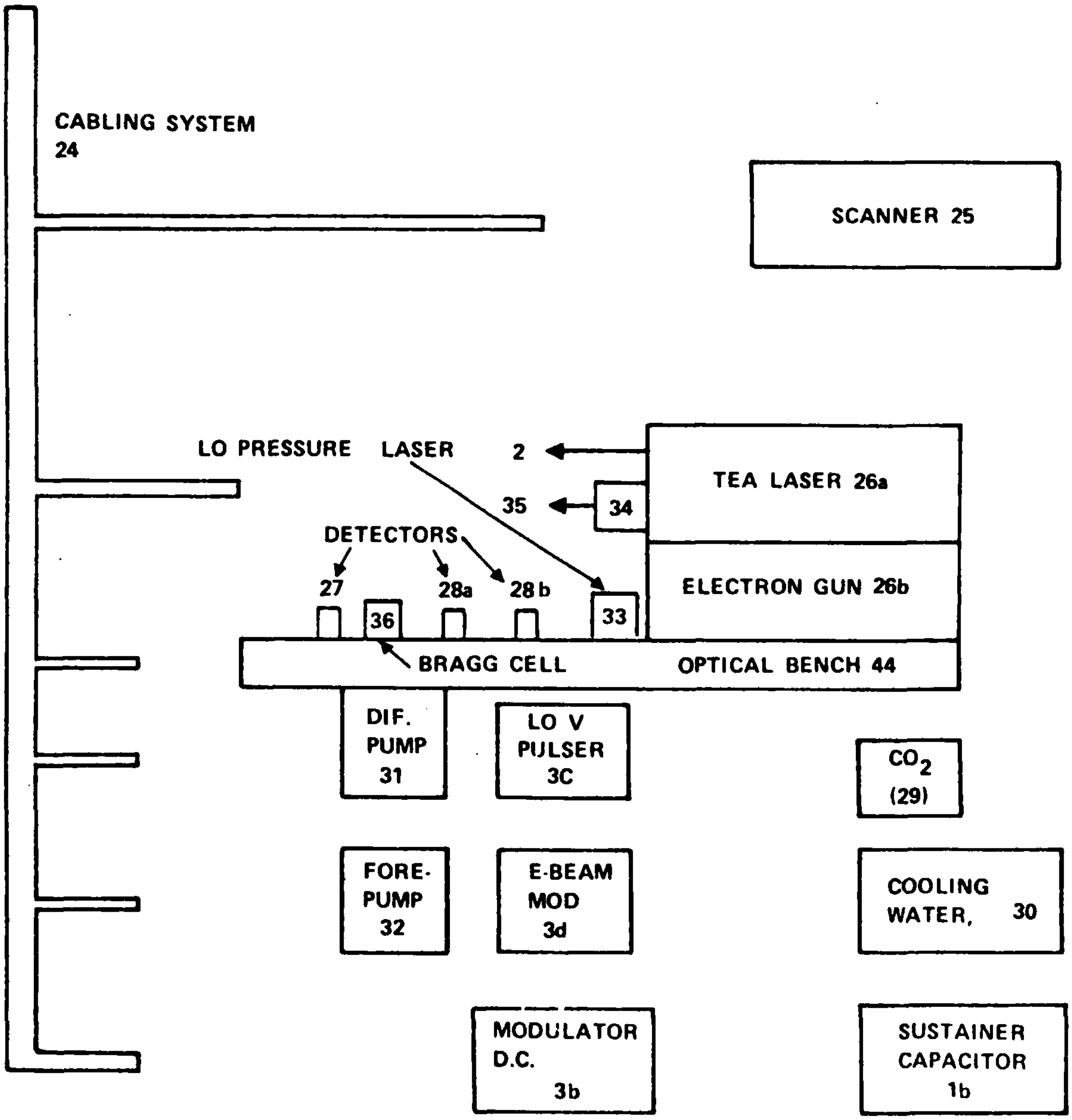


Figure 4. Electronic Subsystem, Optical Bench

2 ELECTRONIC SUBSYSTEMS OPERATION

Prerequisite to operation of the laser radar is operation and test of five major electronic subsystems: Timing (EL #17, 22), receiver (EL #20), scanner (EL #12, #13, #16, #18, and #25), electron gun (2, 5, 31, 32, 26b) and electron gun modulator (EL #3a,b,c, and d). Other electrical systems such as LO, Inj and TEA AFC, sustainer power etc., can only be operated (to any significant degree) in conjunction with the optics and are discussed in Section 3. And some of the adjustments described below will have to be peaked again later when more of the system is in operation.

2.1 TIMING SYSTEM

The timing system controls the pulse sequence in the TEA laser, Bragg modulator and AFC system. The system, in chassis EL #17, is shown functionally in Figure 5. It starts with the pulse repetition oscillator which is to be set at about 50 Hz. The earliest output pulse should be the scope trigger so the scopes can display the leading edge of all the others. The next pulse should be the Bragg modulator driver (see Figure 6) gate pulse which should be about 40 ma into the quad diode switch of the Bragg driver chassis, EL #22. The on-time should permit adequate injection laser buildup in the TEA laser cavity before the TEA laser excitation starts. The Bragg gate pulse off-time is critical. Injection gating must continue long enough to control the TEA laser buildup wavelength but must be shut off soon enough to prevent feedback from the TEA laser into the injection laser. This would be about 1 μs before the TEA laser output starts at about 4 μs after the electron beam pulse has started.

The last pulse is the TEA AFC sample and hold trigger which should start about 0.5 μs after the TEA laser output starts. This will typically be 5.5 μs after the E-beam modulator pulse starts. The intention here is to trigger the sample and hold so that the bipolar AFC pulses from the TEA AFC discriminator will be converted to bipolar DC representing the TEA laser frequency error but without errors due to RFI or FM noise. Most of the RFI noise is due to firing of the E-beam modulator thyratrons. Between-pulse FM noise may be caused by too much gain in the AFC IF. This pulse timing will accommodate both the long pulse (5 μs) and short pulse (1 μs) TEA laser modes and pulse jitter which is about ±.25 μs. However, the timing may have to be changed when the TEA laser excitation power (buildup time) is changed.

2.2 RECEIVER

The heterodyne receiver is chassis EL #20, (see Figure 6). The receiver should be readjusted after the system is in operation. Initial adjustment should be based on the signal levels shown in Figure 6. To set the TEA AFC receiver put a -53 dBm signal of 40 MHz into the detector preamplifier. (Note the HgCdTe cryogenic detector can be easily damaged by bias coupling transients and RF as well as excessive IR power (>25w/cm^2) (see NERC manual). The AFC IF gain control should be set for about -8 dBm

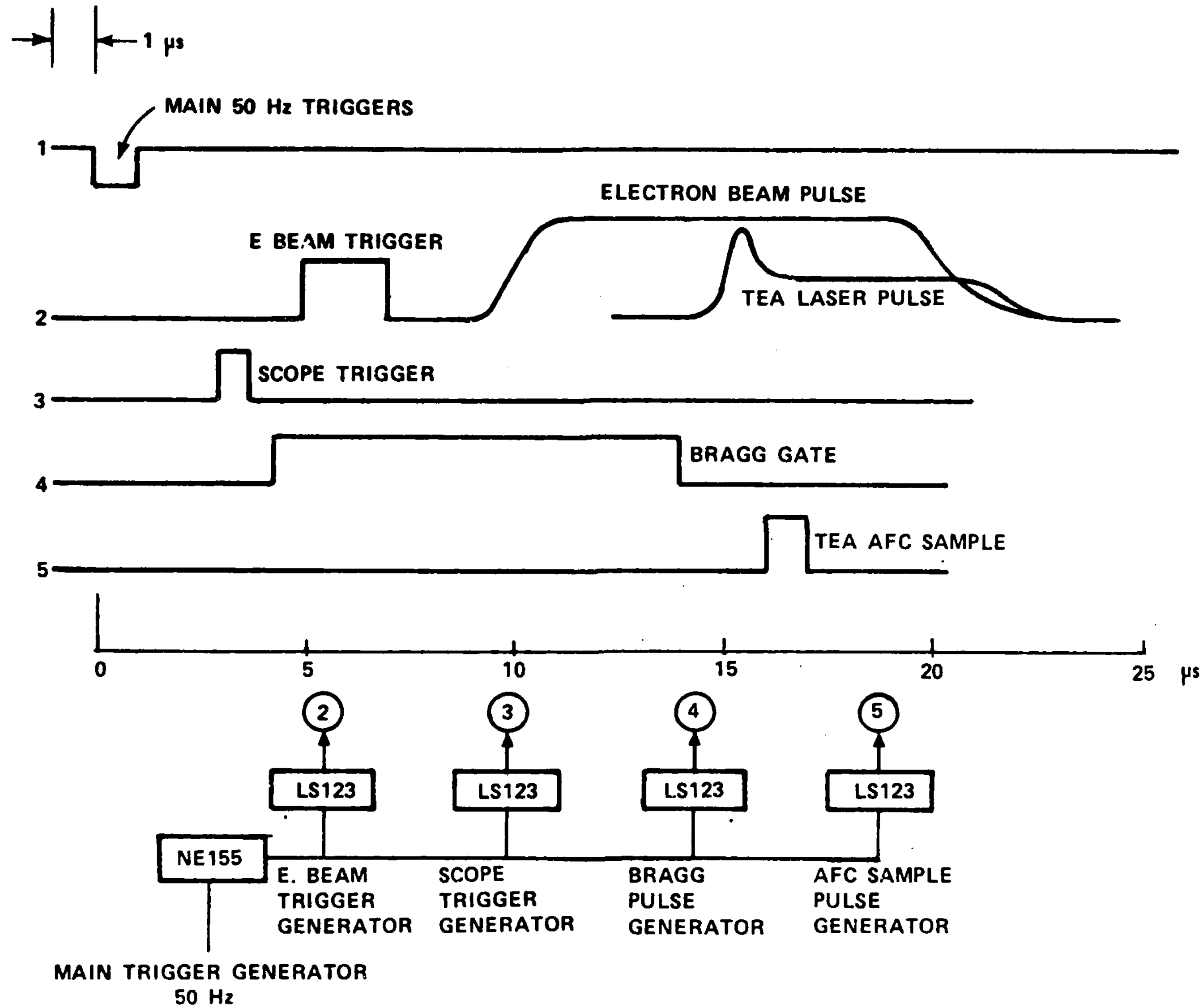


Figure 5. Pulse Trigger Timing

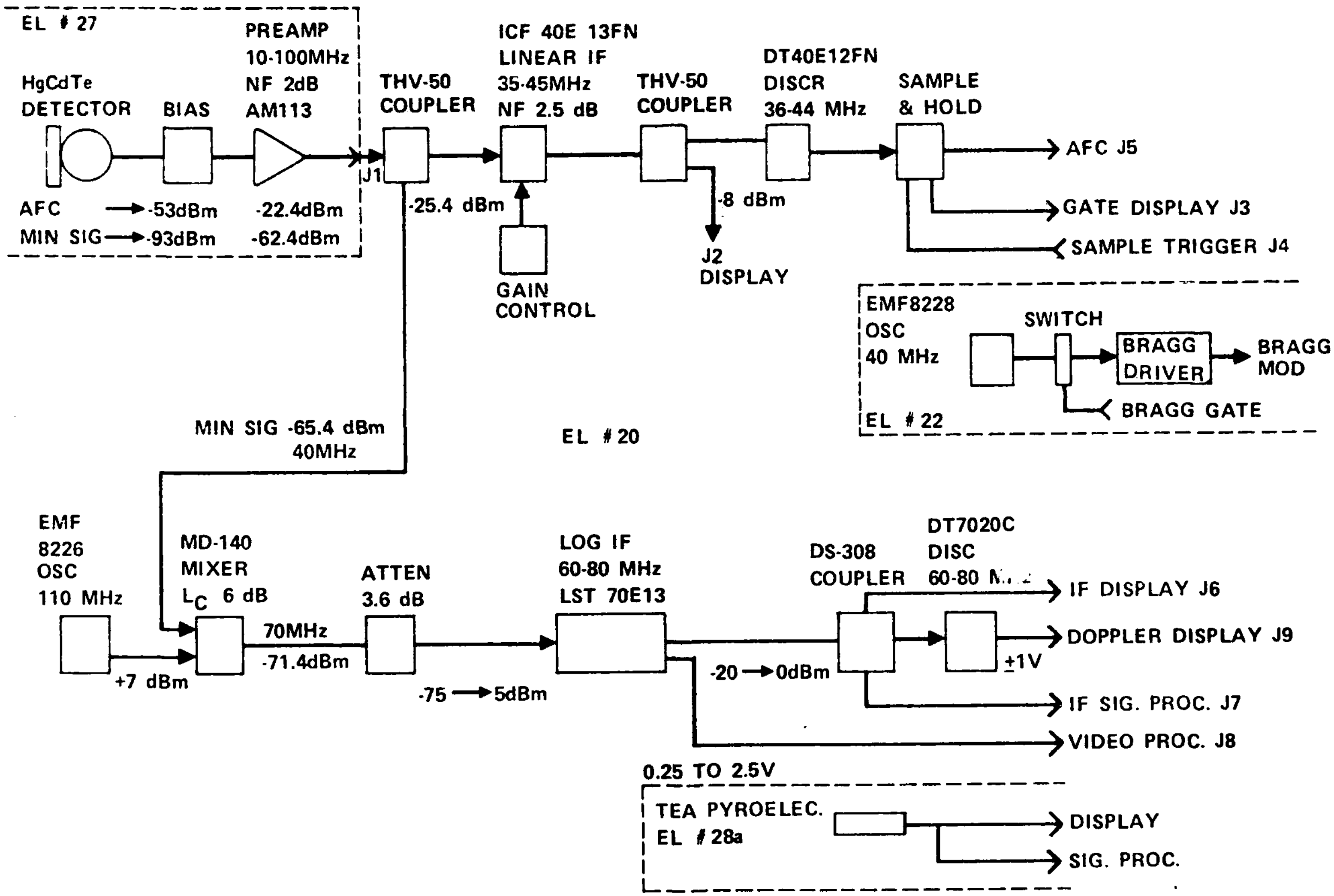


Figure 6. Receiver Electronics, EL #20

which will put the discriminator near the center of its dynamic range. The TEA AFC discriminator output should be about 2.5v/MHz and independent of input signal amplitude.

Set the preamplifier input signal at 40 MHz and -93 dBm. Tune the EMF 8226 oscillator to center the 70 MHz IF band. At +7 dBm LO signal level the output signal to noise ratio should be about unity and the discriminator input should be about -20 dBm. The discriminator output should be 0.1 V/MHz.

The EMF 8228 Bragg drive oscillator is located in the Bragg drive chassis EL #22. With the quad diode temporarily bypassed the level of the oscillator should be set to give about 12 watts out of the ENI driver when the latter is connected to the Bragg modulator. The level can be adjusted again later (with the diode switch in place) to slightly higher levels but will saturate at about 15 watts peak. The 8228 frequency should be adjusted for 40 MHz.

2.3 SCANNER

Figure 7 shows the mechanical components of the scanner. The physical position of the scanner should be exactly above the optical coupler mirror SO #7. The alignment techniques are discussed under small optics.

The chain belts on the scanner axes are tensioned by adjusting the mount springs. The azimuth motor should be set for about 35 pounds tension on the belt and the *elevation drive* should be tensioned at about 15 pounds. The two synchro belts should be set for about 5 pounds. Brushes, on the slip rings, should be set for 6 oz. pressure. The preloading on the elevation and azimuth bearings has been set, with shims, in the GE shop.

Figure 8 shows the electronics components of the azimuth and elevation scanner system. With the connector from the azimuth control chassis (EL #16) going to J2 on the azimuth display EL #12 and the connector from the elevation control (EL #18) connected to the elevation display EL #13 the system can be exercised and adjusted manually, without commands from a computer. With the manual/auto switch set on "auto" and the manual binary input set on say 90° (in binary) the servo gain control should be adjusted for critical damping when a position change is made. The azimuth and elevation displays should read 90° in decimal. The azimuth and elevation synchros can now be turned slowly in their mounts until the scanner mirrors are pointed East and Zenith respectively. When S15 is put on "manual" the velocity pot should allow continuous scanning up to 2 rpm.

2.4 ELECTRON GUN

Testing the TEA laser electron gun subsystem, EL #26b requires the operation of the E-beam control EL #2, the vacuum gauges and vacuum pumps, EL #5, 31 and 32. Figure 9 shows the elements of the control panel.

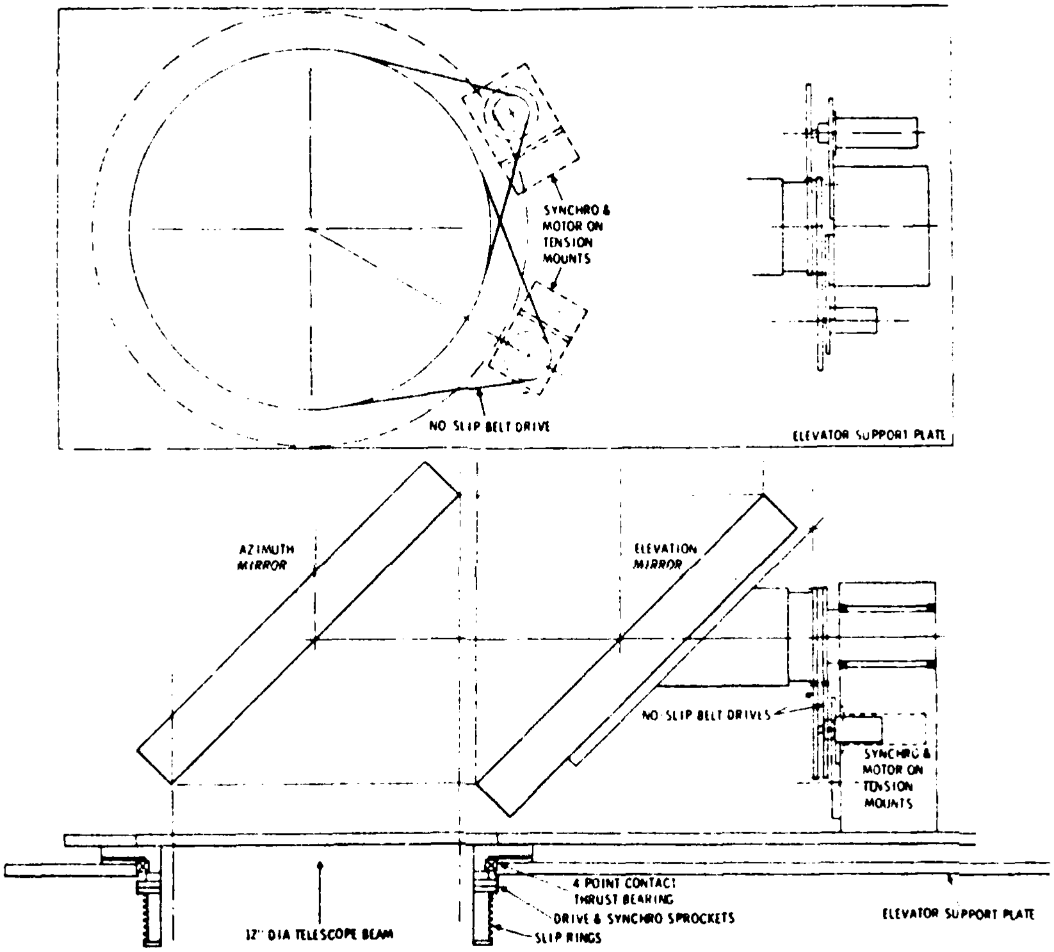


Figure 7. Scanner Bearing Detail

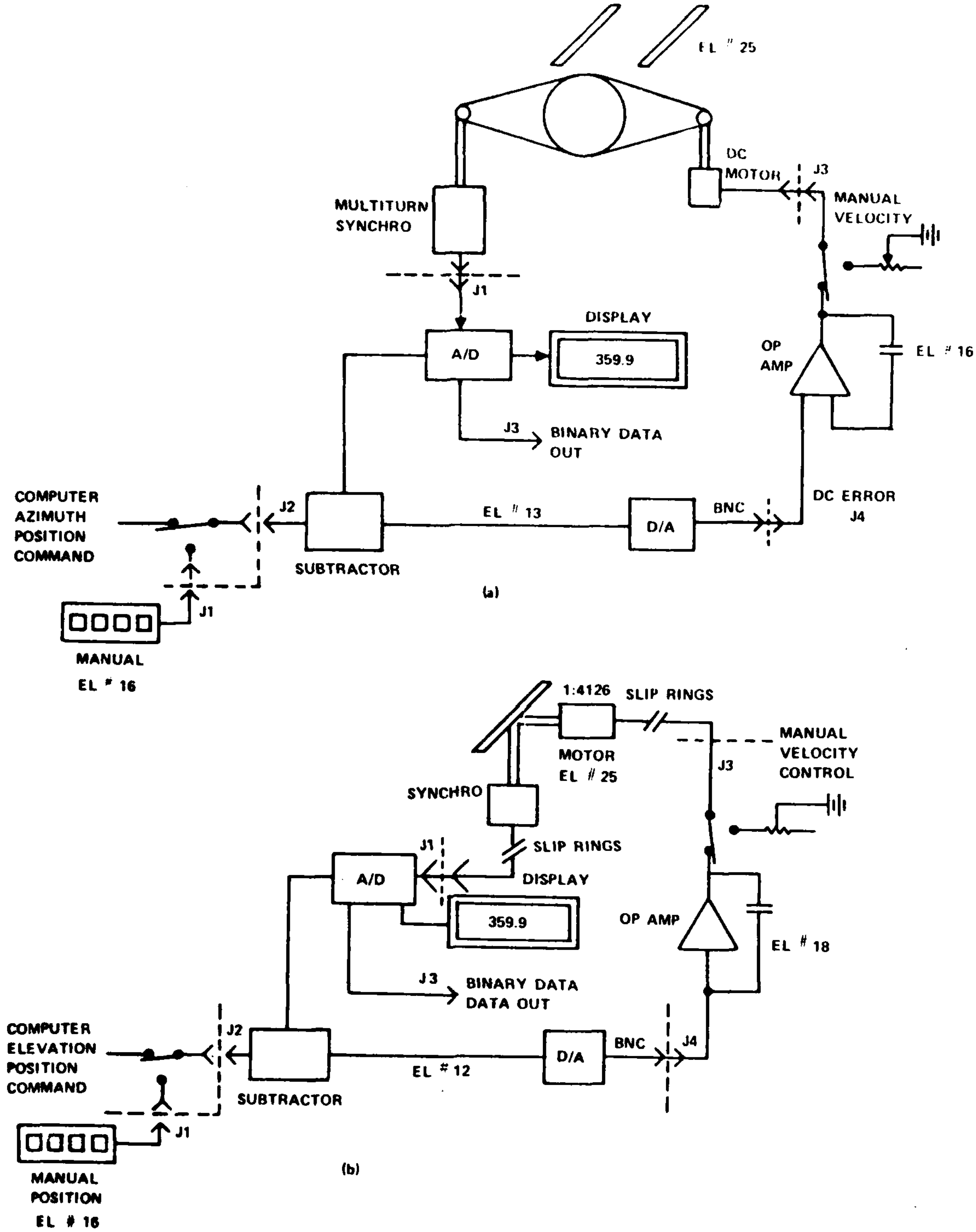


Figure 8. Digital Position Command Servo
a) azimuth, b) elevation

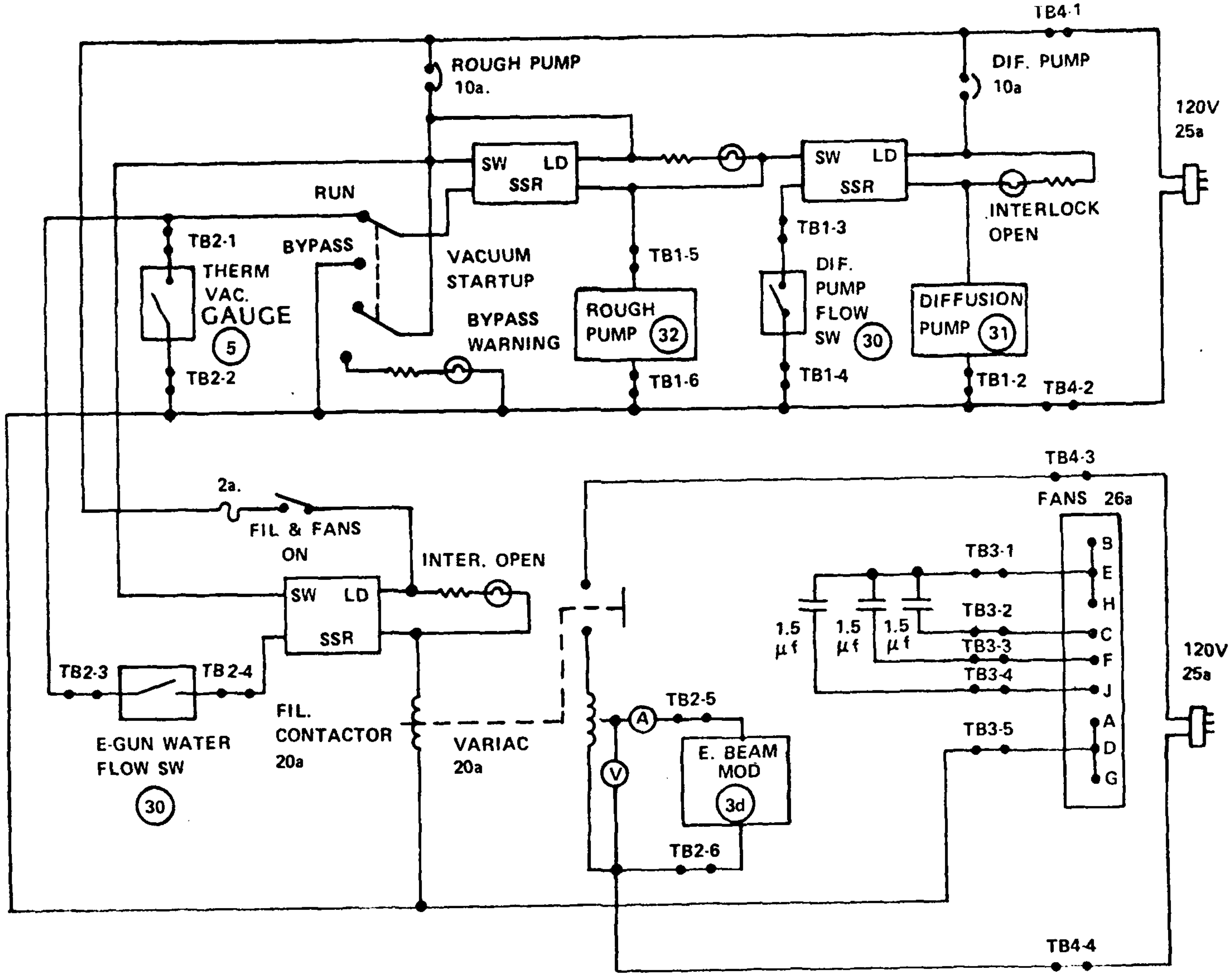


Figure 9. E-Beam Control Panel, EL #2

To start the electron gun system the vacuum startup switch must be on "bypass" and the roughing pump circuit breaker closed. When the pressure has dropped below the interlock setting (100 millitorr) on the thermocouple gauge the startup switch should be returned to "run." This should take no more than a few minutes. When the pressure has dropped to about 5 millitorr the diffusion pump cooling water should be adjusted for about 0.4 GPM and the diffusion pump circuit breaker closed. After about one hour, the vacuum should reach at least 10^{-5} torr.

The next step is to set the electron gun water flow for about 0.6 GPM (evenly divided between foil plate and gun box as noted in Volume I). After double checking that the filament variac is on zero close the "filament on" switch. This will also turn on the foil cooling fans. Bringing up the filament current to a dull red, as observed (with a mirror) looking in the electron gun window, will start the outgassing processes of the gun. Increase filament current in small steps, so the pressure does not drop below say 10^{-4} torr. This will take about 1/2 hour with a new filament.

Figure 10 show the relationship between the AC filament rectifier current and the actual DC filament current. Normally the filament current should not be increased beyond 8.0 amperes (DC) based on the AC meter because of calibration uncertainty. Final current adjustment should be made using the electron beam current as a measure of filament temperature. Above about 20 kV pulse voltage the electron beam current will be emission limited. A nominal maximum, 9 ampere DC, filament current will be that which allows about 15 amperes pulse current. As the filament ages (evaporates) less filament current will be required to obtain the same temperature.

With the E-beam modulator pulsing at 15a, 50 pps the vacuum should be better than 5×10^{-5} torr. Without pulse voltage or filament current a well-outgassed gun should have a vacuum of better than 5×10^{-6} torr unless there is a pinhole in the foil. To test for a leak paint the foil area with a small brush dipped in acetone. When the acetone passes over the leak the gauge pressure will drop suddenly and significantly.

In shutting down the system, the roughing pump should not be turned off and its vacuum should not be released until the diffusion pump has cooled. Indeed, since the foil life is reduced by cycling of foil-stretch over the edges of the foil windows, the roughing pump should be left on continuously.

2.5 ELECTRON BEAM MODULATOR

The modulator is relatively small for its power rating. It has many unique design features some of which are discussed in our earlier report on this contract, Scientific Report #2. For example a bias winding on the core of the high voltage pulse transformer allows a greater pulse flux change without saturation of the iron by biasing the flux in the opposite direction from the peak. And the bifilar secondary is split into two sections on each leg of the core to allow 400 volt filament rectifier power and thus smaller wire on the secondary.

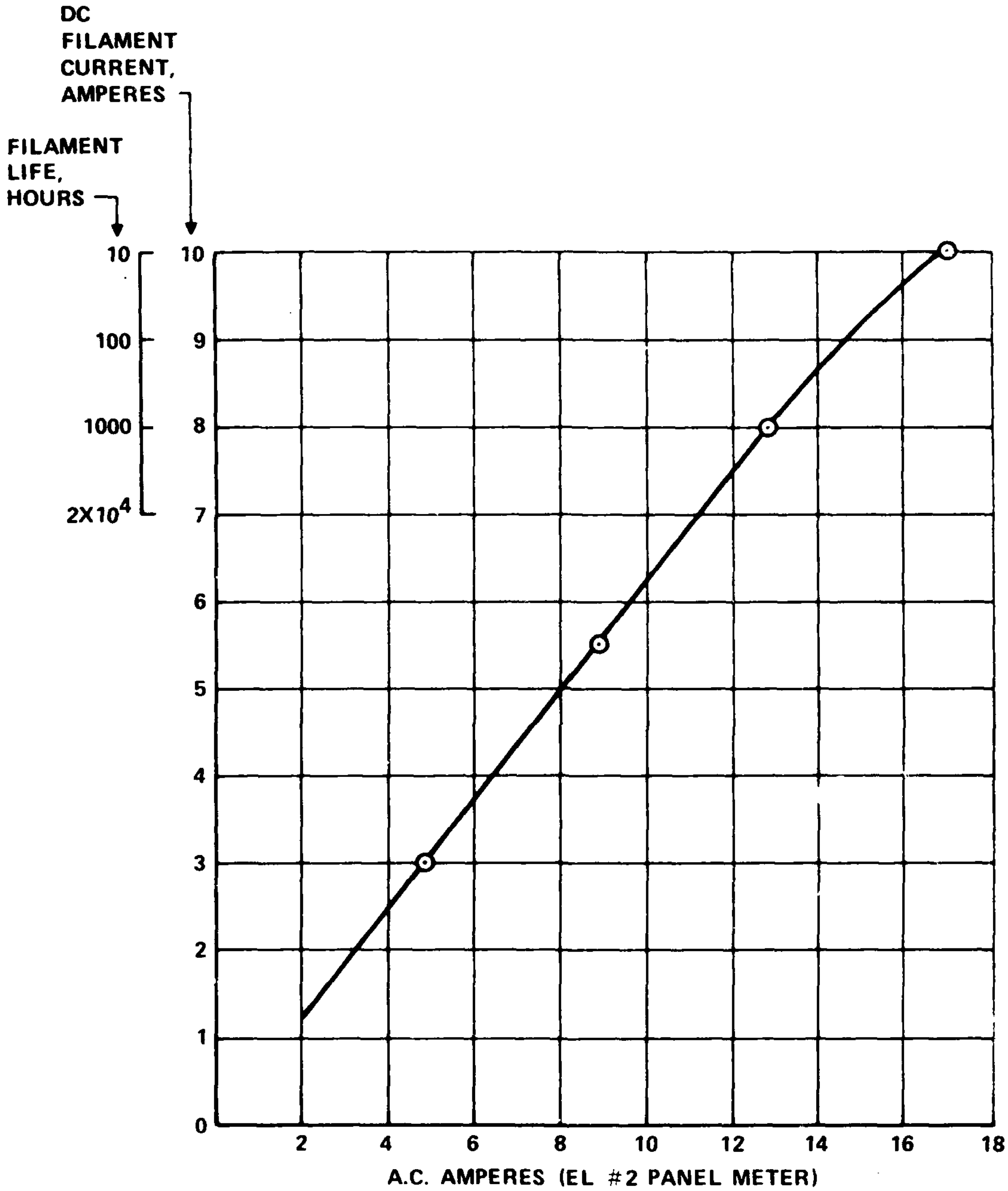


Figure 10. A.C. Filament Current Meter Calculation

The electron beam modulator (see Figure 11) consists of 4 sections. The control unit, EL #3a, the high voltage rectifier EL #3b, the low voltage pulser EL #3c, and the high voltage pulser EL #3d. The first is located in the center rack and the last three under the optical bench. The high voltage pulser is to deliver 120 kV 15 ampere 5 or 10 microsecond pulses (and 1 kW DC) to the cathode of the electron gun EL #26b. At the time of this writing the modulator had only been tested to 100 kV.

The low voltage pulser is turned on at EL #7 and the high voltage is turned on by the three breakers on EL #3a. The time delay relay, TDR1 will prevent the "on" button on the control unit from becoming effective until the thyratrons heat up, in 15 minutes. The pulse length selection control will not change the pulse length (via relay K1) unless (1) the time delay has expired, and (2) the high voltage power supply is off. To change the pulse length again the low voltage pulser has to be turned off momentarily, thus recycling the 15 minute delay. The system also requires the +24 volt power supply, EL #21, (relay power) and the trigger generator, EL #17, to be on. To continue further into operation requires that we monitor the E-beam current and voltage.

In order to monitor functions of the E-beam modulator one oscilloscope should be operating with patch panel connection to scope trigger, E-beam voltage, and E-beam current. Additional waveforms readily obtainable are I_{pri} and V_{drive}. The primary current on the pulse transformer can be monitored from the test point J5. The drive voltage to the grid of V_1 can be monitored using a high voltage probe (3 KV) at the N connector in the center of the top deck of the low voltage pulser.

The monitor point calibrations are: 20 kV/V for secondary voltage, 2 a/v for secondary current and 15.6 a/v (nominal 20 a/v) for primary current as shown in Figure 11. These calibrations assume 50 ohm load.

In addition to V_{sec}, I_{sec}, V_{drive} monitoring described above there are other points useful for performance analysis. The secondary current can be measured with the Pearson current transformer (normally connected to monitor sustainer capacitor current) which we call I_{load}. The voltage on the anode of the 7890 thyratron, V_{anode}, and the voltage on the primary of the output pulse transformer, V_{pri}, can be measured by removing part of the oil and the cover of the modulator and connecting to the appropriate point using a high voltage probe (40 kV Tektronix P60 15). The data below shows what these waveforms should look like.

Figure 12 upper shows the anode voltage with 10 kV DC from the main power supply. Note the doubling action of the resonant charging reactor brings the voltage to 20 kV in about 10 milliseconds and holds it there with little drop until the thyratron fires. The anode drop is difficult to read but can only be a hundred volts or so if the tube fires at all. Figure 12 lower shows the current into an 8000 ohm (120 kV 15 amperes) linear (resistive) load, I_{load}, to be 12 amperes for 10 μs when using 20 kV DC from the

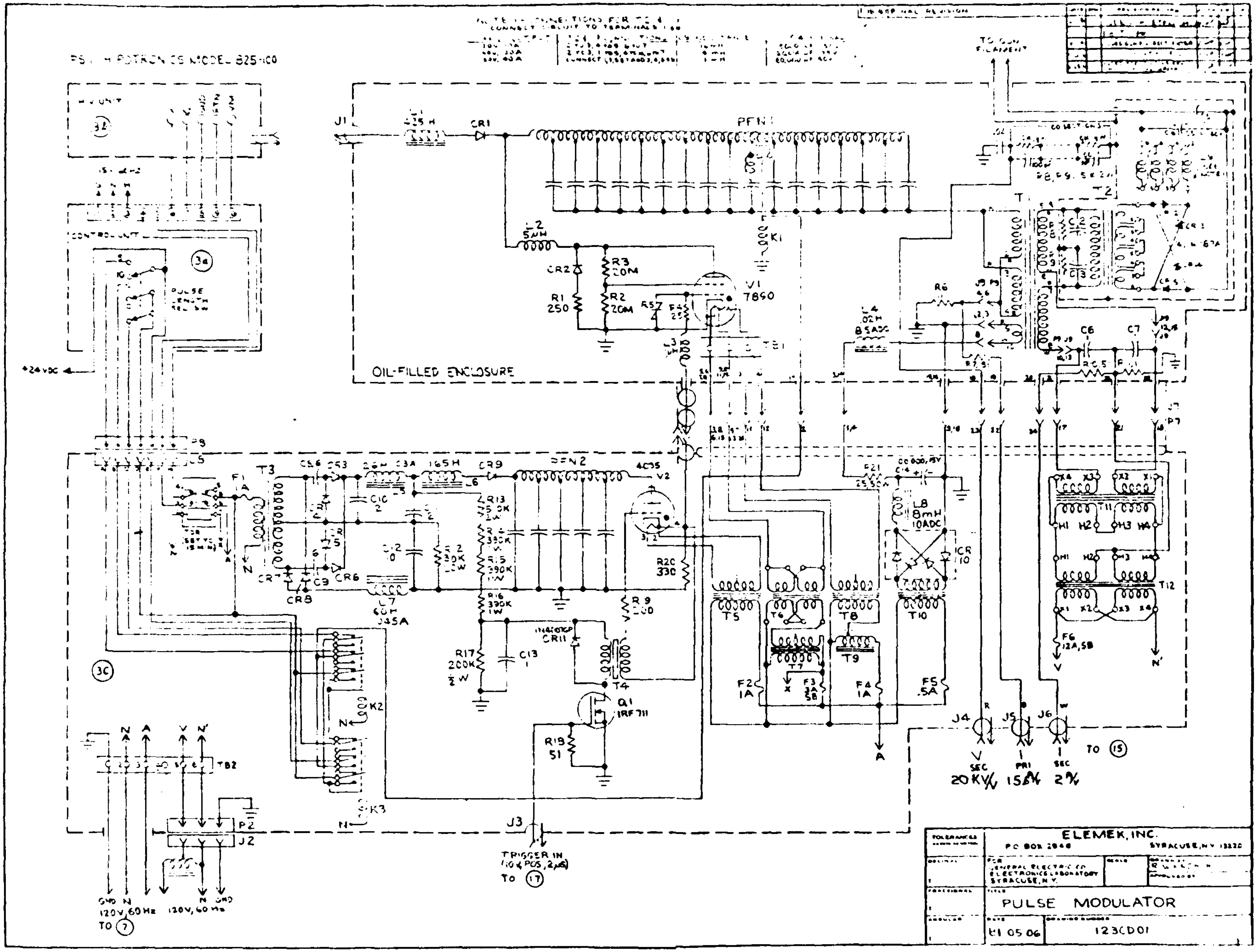
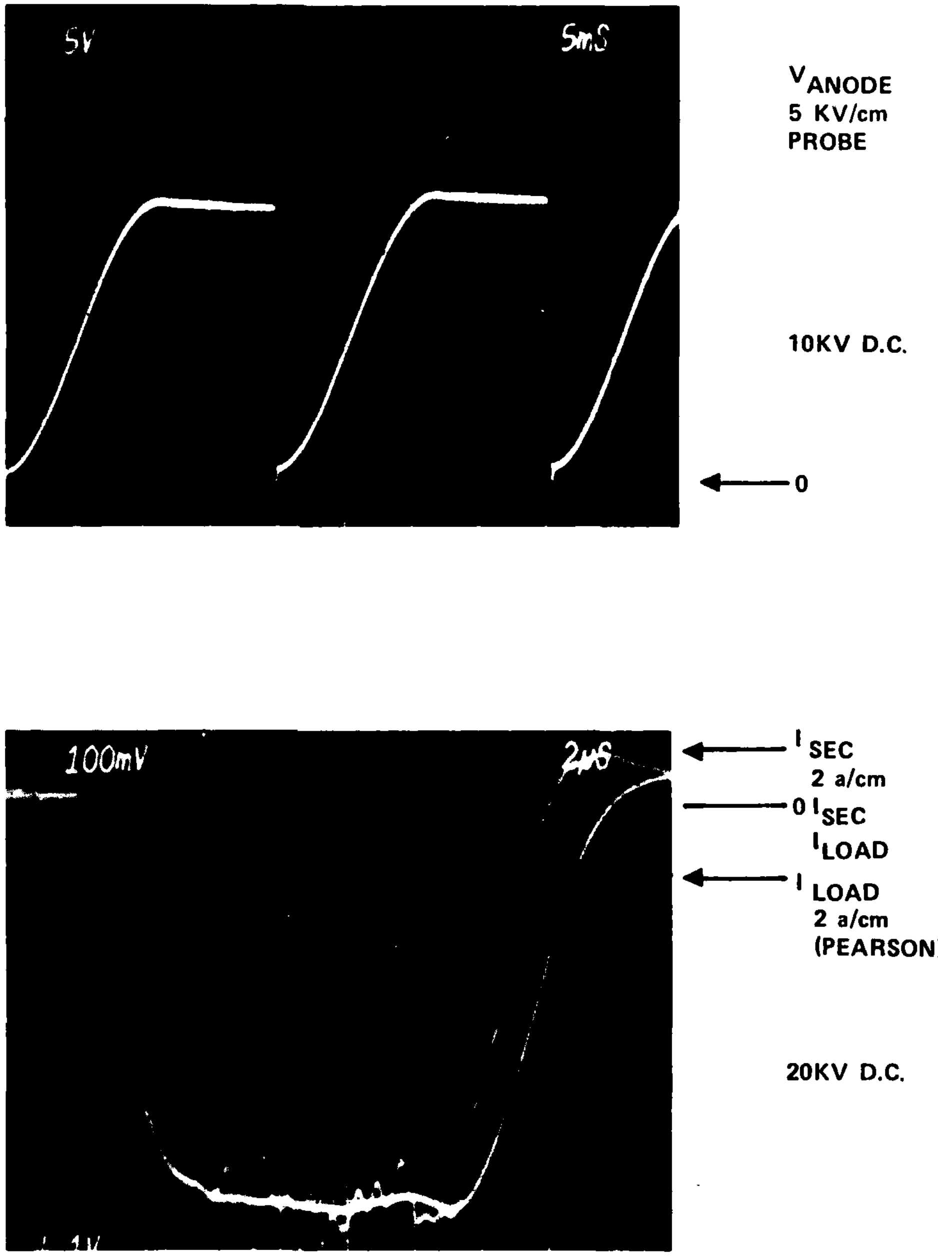


Figure 11. Test Points of the E-Beam Modulator



ELECTRON BEAM MODULATOR
10µs PFN
50 PPS
3/17/83

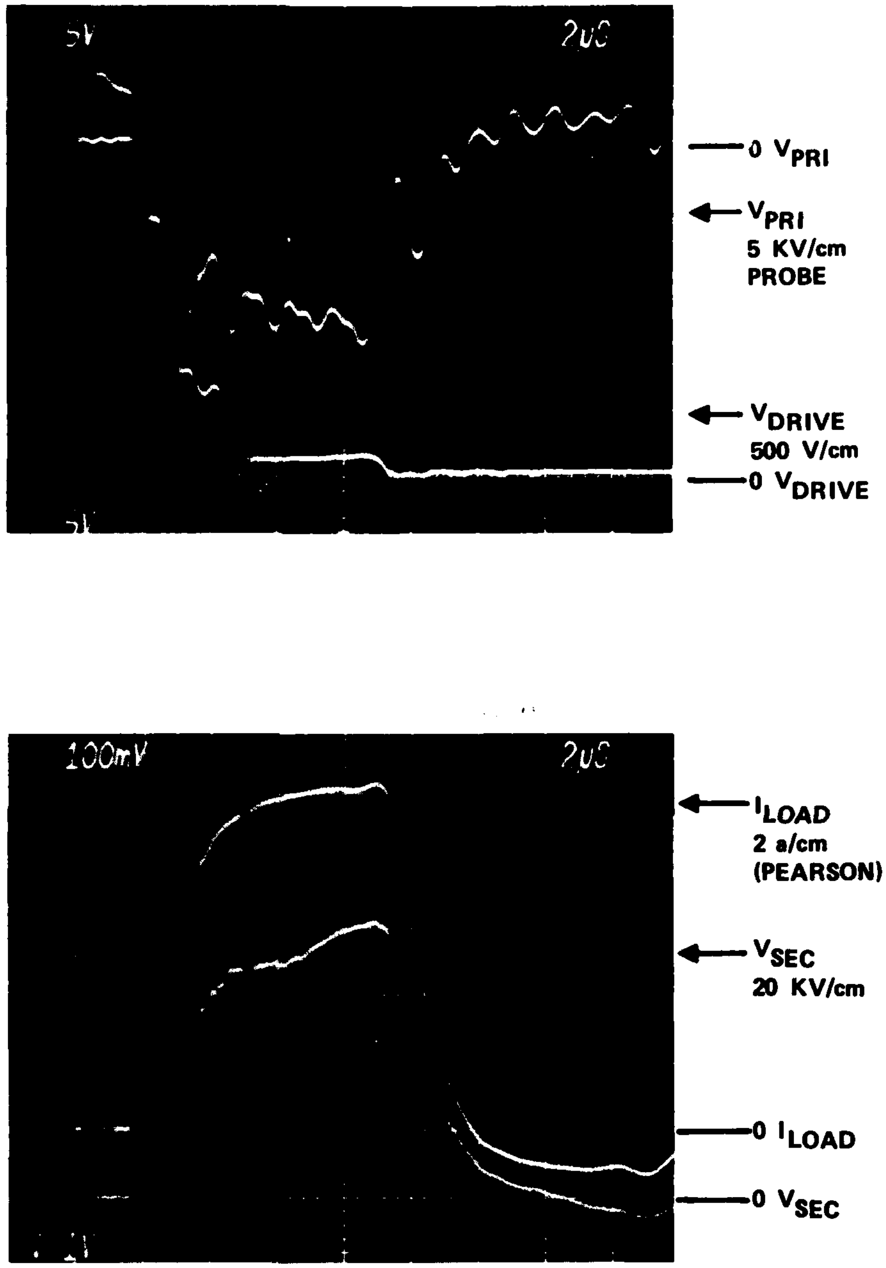
Figure 12. Modulator Waveforms

power supply. The 8000 ohm load should have a 12 × 8000 = 90 kV drop. I_{sec} measured at the Elemek pickoff gives the same 12 amperes but shows a lot of high frequency, (1.5 MHz), noise. This noise is almost certainly the result of pickup (RFI) due to lack of a good common ground for the scope allowing pickup of thyratron transients.

Figure 13 shows the system using the short pulse PFN length. Figure 13 upper shows the 3 kV pulse from the low voltage pulser, V_{drive}. This pulse would normally be 2-1/2 μs but the effect of the 7890 firing at 2 μs pulls the grid voltage to about 2 kV briefly when the latter fires. With 16 kV DC the voltage on the primary of the transformer should be less than the PFN voltage (32 kV) depending upon the impedances. The impedance of the main PFN is 250 ohms and the pulse transformer turns ratio is six. The 8000 ohm load reflected into the primary is 8000/36 = 220 ohms. The small mismatch causes the PFN voltage to be reduced to $[220/(250 + 220)] \times 16000 \times 2 = 15$ kV. The 6:1 turns ratio should bring this to 90 kV. Figure 13 upper shows that V_{pri} is about 15 kV but noise pickup prevents an accurate measurement. Figure 13 lower shows the secondary voltage to be 80 kV (10 amperes × 8000 ohms). The 10 kV loss is due to leakage reactance. The trace V_{sec} also shows 80 kV with some kind of transient reducing the apparent voltage to 70 kV in the early part of the pulse.

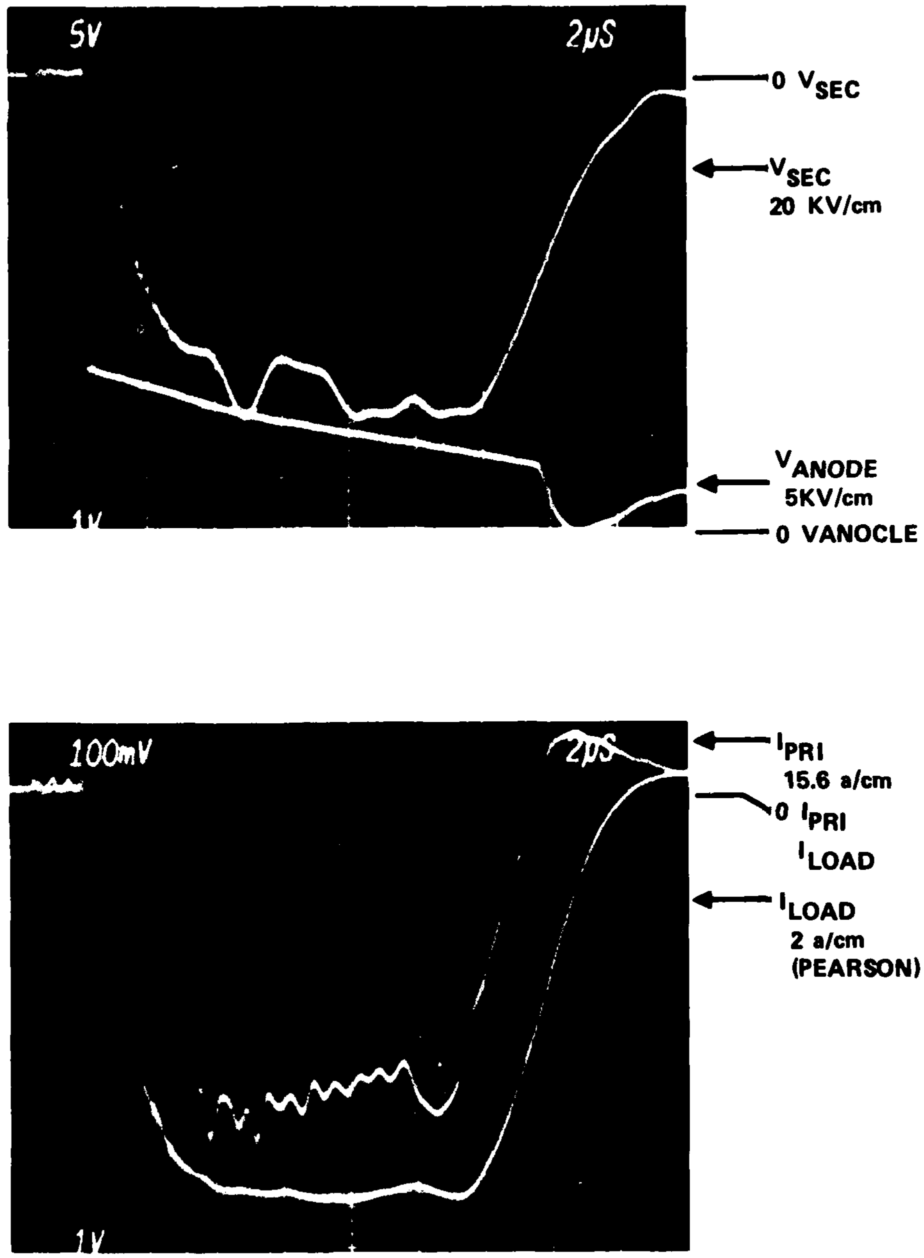
Figure 14 shows the long PFN pulse with 20 kV DC from the power supply. The lower photo shows I_{load}, secondary current of 12 amperes corresponding to 100 kV. The primary current is about 70 amperes which is about 6 times the secondary current. Notice the large initial peak in the primary current which is the charging current to the stray capacitance of the transformer winding. In the upper photo V_{sec} agrees with the 100 kV using I_{load} but again shows pickup noise. The V_{anode} probe is picking up the equivalent of a 12 kV charge (that slowly decays over about 20 microseconds) due to its proximity to either the thyratron or the PFN. The tube drop cannot possibly be more than about 200 volts. But the reverse pulse of the PFN at about 14 μs due to the intentional impedance mismatch shuts the tube off with about a 5 kV negative transient.

In operation the modulator is turned on for the 15 minute warmup and the filament current load is increased slowly up to about 8 amperes DC using the variac on the E-beam control panel, EL #2. Note that the foil cooling fans are automatically on at this point. The DC voltage on the modulator is then turned on and increased to about 8 kV DC. (Any D.C. load current at this point will indicate leakage or misfiring in the thyratron circuit.) Then the trigger can be turned on at the required PRF, and the pulse current noted. The thyratron grid may be damaged if the trigger pulse is applied with less than 8 kV DC on the anode. At this point the filament current can be raised slowly until the E-gun current (I_{sec}) is near the desired level for lasing, say 10 amperes. Then the secondary voltage and secondary current can be raised alternately to the final operating point without the tendency for arc-over due to no load operation of the modulator. Shutdown should be in the reverse order, to prevent operating the pulse transformer at full voltage with no load.



ELECTRON BEAM MODULATOR
5μs PFN
50 PPS
16 KV D.C.
2/3/83

Figure 13. Modulator Waveforms



ELECTRON BEAM MODULATOR

10μs PFN
20KV DC
50 PPS
3/17/83

Figure 14. Modulator Waveforms

When the TEA laser itself is turned on (see Section 4), the sustainer voltage should be raised to near the avalanche level which is about 15 kV (for the 48/40/12 He/N_2/CO_2 mix). At this level a decrease in E-beam current will cause a reduction in the IR drop of the sustainer ballast and thus possible arc-over of the sustainer electrodes. Thus to shut down the sequence should be (1) reduce sustainer voltage to zero, (2) reduce the E-beam voltage reduced to 8 kV, (3) remove the pulse trigger, (4) reduce the E-beam voltage to zero, and, finally, (5) turn the filament variac to zero.

3 OPTICAL SUBSYSTEMS OPERATION

The next step in operating the laser radar is alignment of the optical system. This is done first by alignment and operation of the three major optical subsystems: (1) TEA laser optics, (2) local oscillator optics, and (3) injection optics. Secondly, by co-alignment among these in five steps: (4) Injection/LO laser heterodyne, (5) telescope/scanner alignment, (6) detector/target alignment, (7) TEA laser/target alignment, and (8) target/LO/Inj. heterodyne. We note here the steps for individual alignment of each of the eight subsystems but it will also be necessary to iterate several times since each subsystem has some effect on the others.

3.1 TEA CAVITY SUBSYSTEM

The TEA laser cavity is a confocal, positive branch unstable cavity of magnification 1.33. The radius of mirror SO #33 is -298 cm and the radius of SO #40 is 400 cm. The mirrors should be separated optically (via SO #35) 51 centimeters. The alignment technique is to send a small collimated He/Ne laser beam along the injection laser path, using two mirrors (a) and (b), into the TEA cavity as shown in Figure 15. When the He/Ne beam passes through the first NaCl window the forward scatter from the window will cause the scraper mirror, SO #32, to be illuminated sufficient to trace the entire beam path down to the telescope secondary. Alignment of the cavity will appear as superposition of spots of the He/Ne beam on the mirror centers for several round trips. The technique is extremely accurate and will permit lasing as soon as the TEA excitation is on (even without injection from the injection laser). Later, (see Section 4), TEA cavity alignment is peaked with the TEA laser power on and tuning the cavity mirror #31 for a bright uniform annulus on a carbon block placed at the output of the scraper mirror.

Initial alignment of the duplexer system can also be done with the He/Ne beam. The large forward scatter beam will illuminate the sides of the scraper mirror, #32, and the sides of the confinement carbons #4 and #4a. Mirrors #3 and #6 should then be positioned exactly in the center of the resulting annulus such as to minimize back scatter into the detector.

At this time the TEA AFC path can be prealigned by aligning the pickoff of AFC mirror #SO 29 to 27 and 28 to 17 to 10 to 9 to the center of the cryogenic detector window 16. This alignment is not exact and will have to be improved later.

3.2 LOCAL OSCILLATOR SUBSYSTEM

Alignment of the local oscillator laser system using an He/Ne laser is shown in Figure 16 where SO #11 is replaced temporarily by a flat mirror. The laser beam should follow the center of the mirrors and plasma tube all the way to grating, SO #15. Since all the 10μ optics are transparent at 6328Å the injection laser itself can be lined up using the reflections from 14 and 15. The reflection from 14 back toward the He/Ne laser will also permit the

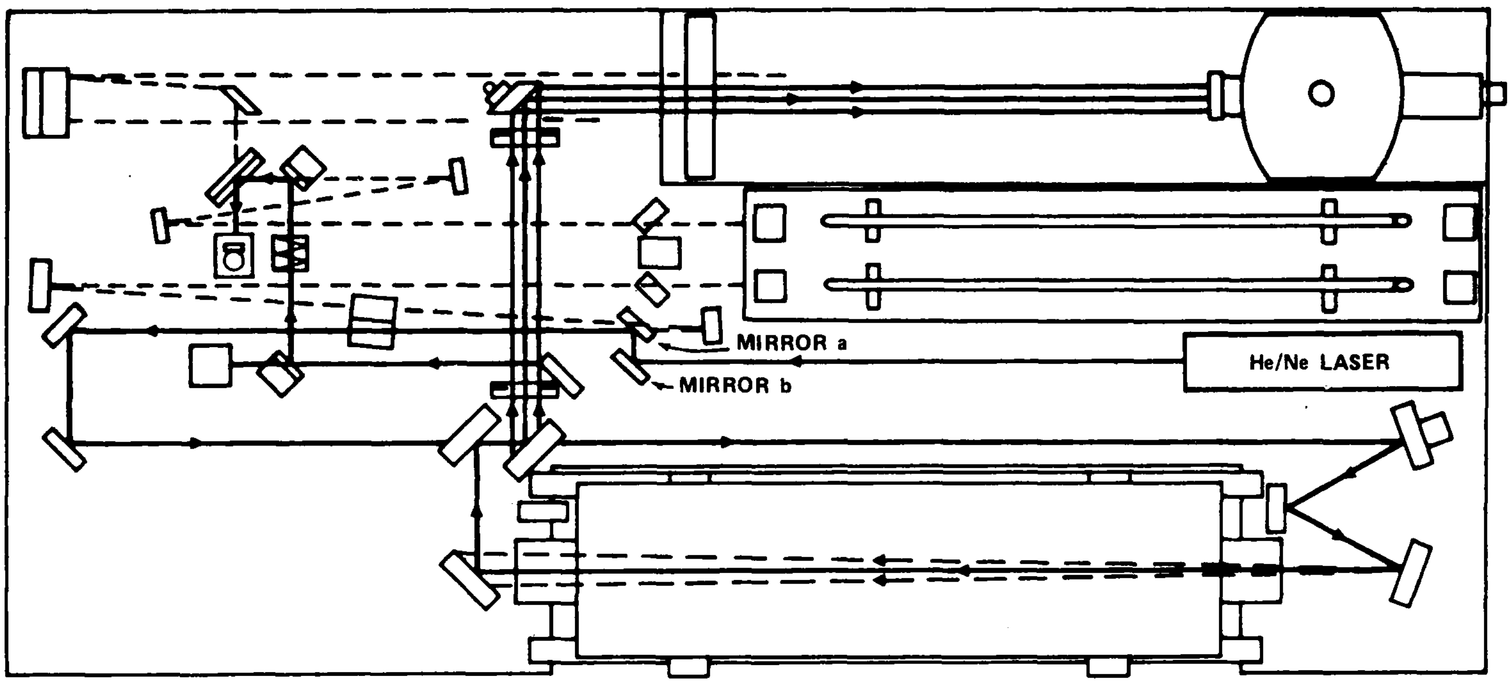


Figure 15. Alignment of TEA Laser Optics

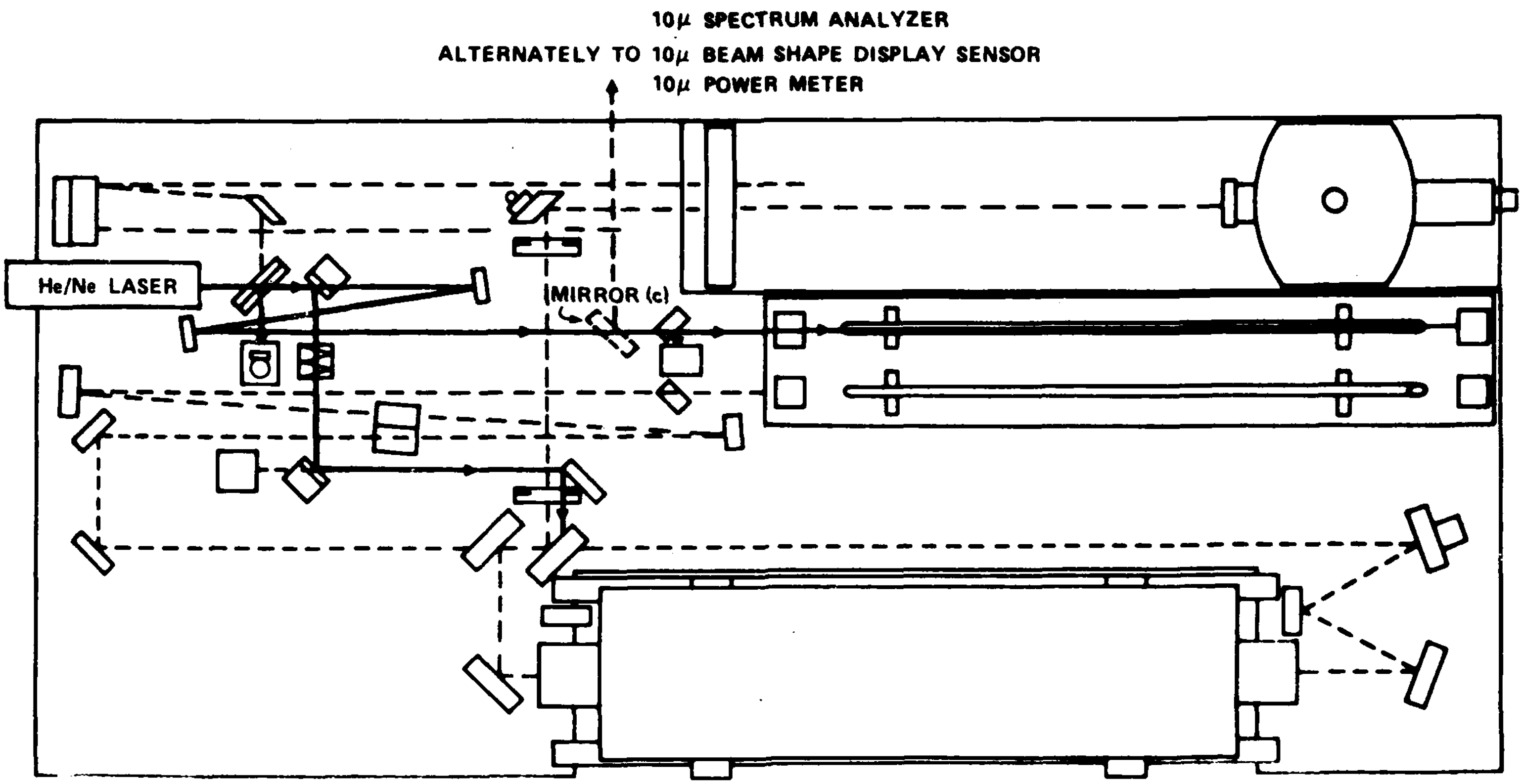


FIGURE 16. ALIGNMENT OF LOCAL OSCILLATOR OPTICS

adjustment of beamsplitter 13 into the dither detector 18 and beamsplitter 9 into the approximate center of the heterodyne detector window, 16. The forward ray from the He/Ne laser can also be used to improve previous TEA AFC optic path from 10, to 17 to 28 to 29 to 32.

Be sure the HgCdTe detector is covered any time there is undetermined 10 μ energy being used such as when the LO laser is being adjusted.

The local oscillator cavity must be peaked and tuned using the LO laser at 10 microns and mirror C. Set the CO_2 gas flow needle valve for a pressure of about 15 torr and bring the DC up to about 5 milliamperes. The recommended laser gas mixture is 75/15/10 of $He/N_2/CO_2$. The LO laser is tuned for peak power using the 10μ power meter shown. The AFC system can now be set up using the procedure outlined in Volume I and the Lansing Manual. The wavelength is adjusted to the P-20 line using the ten-micron spectrometer recommended in Volume I. When concave mirror, 11, is replaced it must be positioned to focus the LO laser output on the detector, 16.

At this point it is necessary to make an approximate calculation of the total laser power necessary (about 1 watt) to obtain the desired local oscillator current (see Scientific Report #2 of this contract, pg. 43). The current and gas pressure can then be adjusted for this power as long as the output is single mode. If the beam shape display shows multiple angular modes it will be necessary to insert apertures at each end of the cavity.

The last adjustment is to modulate the 10μ beam using a chopper. By measuring the DC level of the HgCdTe detector output the final local oscillator beam path to the detector can be peaked and the level of the signal adjusted to give the desired LO current, about 1 ma.

3.3 INJECTION LASER SYSTEM

Aligning the injection laser cavity itself is done as described above for the local oscillator laser. A He/Ne beam is introduced at 19 for initial alignment of the cavity. Then the laser, operated at 10μ, is aligned for maximum single mode power on the P-20 line with the dither AFC system EL #10 operating. At this point the injection laser can be aligned with the Bragg modulator and the TEA cavity for its main function of injection. (See Figure 17.) The goal is to get as much power as possible into the normal mode of the TEA laser cavity.

Injection alignment requires a pyroelectric detector in the TEA cavity as shown in Figure 17. The mirrors 19 and 26 are positioned about 120 cm apart with their common focus in the active region of the Bragg modulator. (The injection beam is focused again at the 4 mm diameter injection hole in 26.) Operating the Bragg modulator requires the timing (EL #17) and Bragg driver (EL #22) be in operation. With the Bragg modulator on CW, the focal point of 19 and the two emerging beams of the Bragg modulator can be found with thermofax paper. With the Bragg modulator on pulse and the pyroelectric detector output displayed on the oscilloscope the beam can be

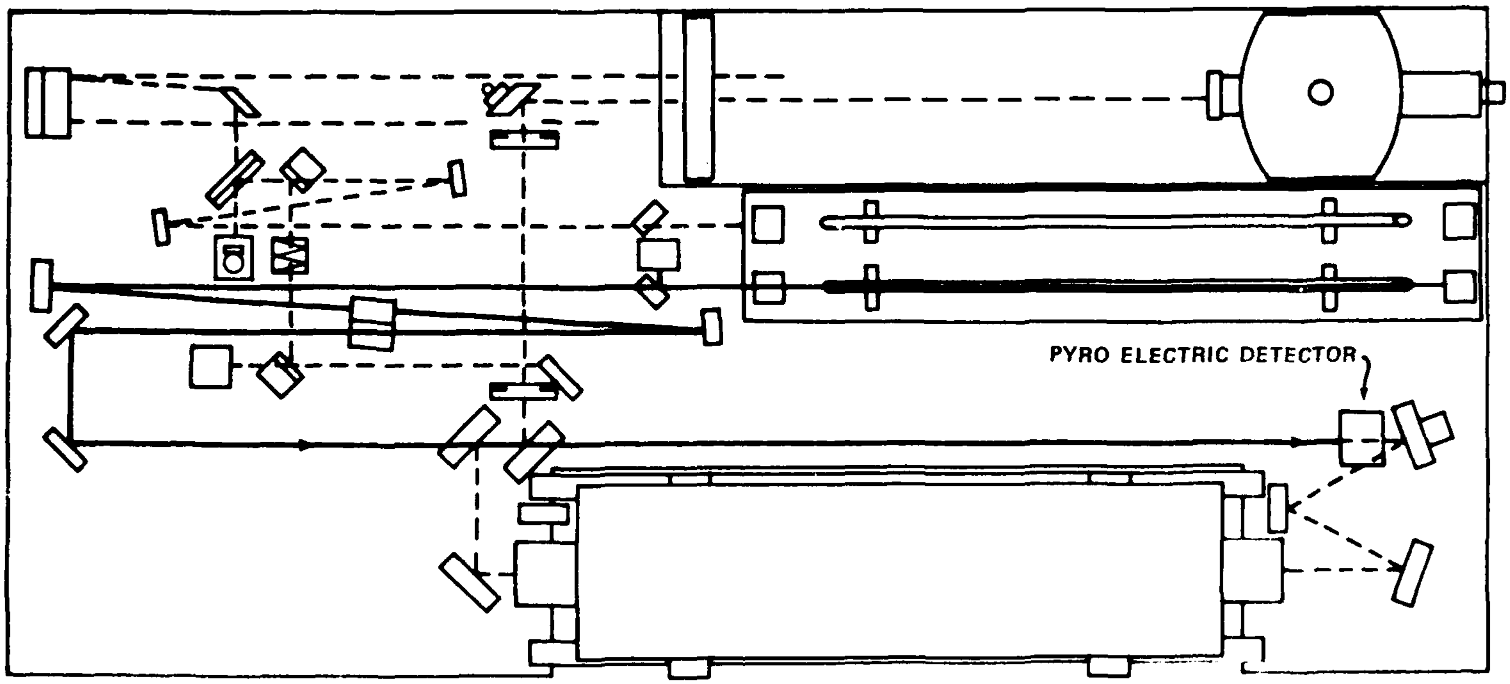


FIGURE 17. ALIGNMENT OF INJECTION LASER OPTICS

traced and made coaxial with the TEA laser cavity. Although the injection beam will be only about 1 cm diameter at 33, and diverging, the injection power into the TEA cavity mode is about as high as can be obtained with other mode matching arrangements.

3.4 LOCAL OSCILLATOR - INJECTION HETERODYNE SYSTEM

At this point we can make a phase front alignment and a frequency and frequency stability measurement of the injection laser-local oscillator system. (See Figure 18.)

If the attenuation at 17 is removed a heterodyne beat between the LO and a weak but usable injection laser signal via the TEA laser pickoff, 29 can be obtained.

The two lasers are operated as noted above, single mode, P-20, and at the center of the P-20 line as maintained by the two dither AFC systems. The LO and injection paths should be aligned to be coaxial in the region 10-9-16 as much as possible. The TEA cavity pickoff signal will be the vector sum of several round trips of course. Thus the TEA AFC driver EL #11 should be turned on, (open loop), and the PZT bias voltage adjusted for the maximum heterodyne signal.

The frequency and frequency stability of the LO and injection laser AFCs can now be checked by operating the full dual receiver system shown in Figure 6. If the frequencies of the electronic oscillators EMF8228 and EMF8226 have been set at 40 MHz and 110 MHz (respectively) as described in Section 2.2 (and the two discriminators have been tuned at the factory accurately for their center frequencies of 40 and 70 MHz). The discriminator outputs observed on the oscilloscope should, on the average, show a zero AFC error. There will, of course, be a pulse-to-pulse jitter of the bipolar pulse AFC error amplitude due to unsynchronized dither and room vibration of the two cavities. We have found this to be typically a large fraction of a megaHertz. We have found that occasionally there will be a steady or slowly drifting error equivalent to one or two megaHertz if the two lasers are not treated identically with respect to the physics of the dither AFC. These are due to plasma current, plasma temperature or angular cavity frequency pulling differences between the two lasers.

3.5 TELESCOPE/SCANNER OPTICS

At this point the telescope primary and secondary (SO #5 and #6) should be aligned and the combination aligned on the reticle of the boresight telescope SO #8, using some remote target such as a white card at say 500 meters. Figure 19 shows two positions for the observer's eye, at the boresight telescope EL #8 and at the telescope secondary. Alignment of the scanner and reticle of the boresight telescope on the target is obtained by manual scan control using the elevation and azimuth servo EL #12, 13, 16, and 18. The telescope (5 and 6) should now be adjusted so the observer, at position #1 sees the target, in the center of the frame of concentric circles generated

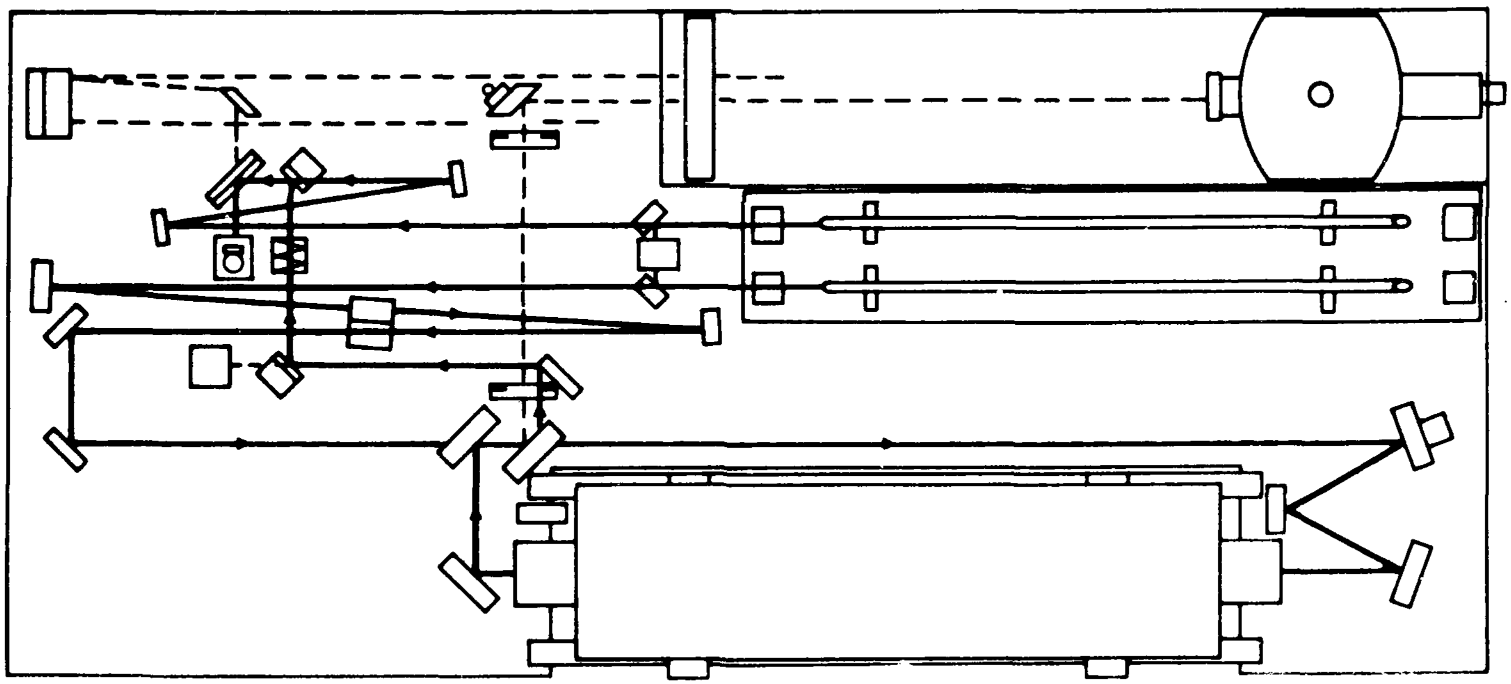


FIGURE 18. ALIGNMENT OF LOCAL OSCILLATOR HETERODYNE OPTICS

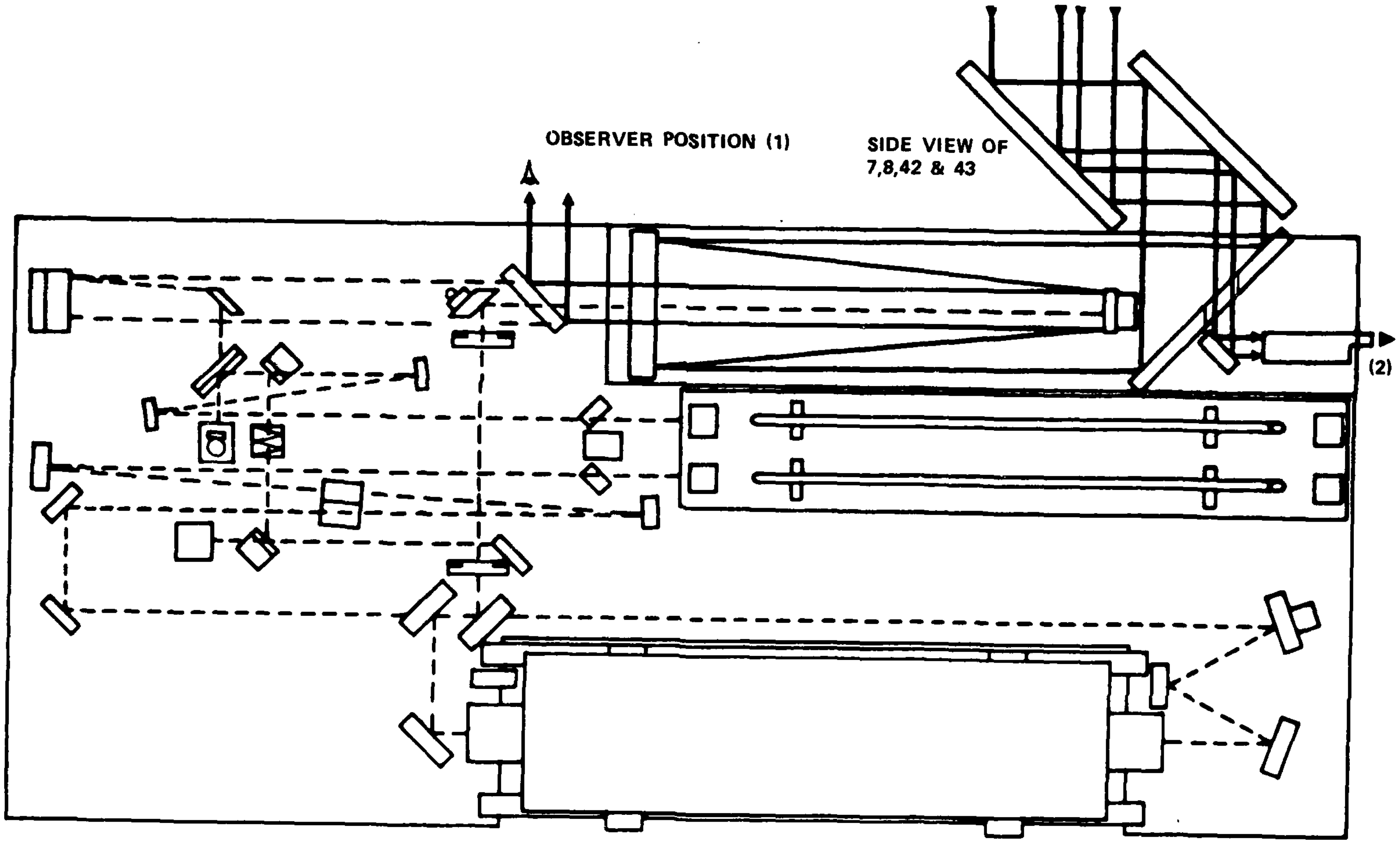


FIGURE 19. TELESCOPE/SCANNER OPTICS

by (1) the perforation of the primary, (2) the perimeter of the secondary, (3) the perimeter of the primary and (4) the perimeter of the two scanner mirrors. Since this alignment includes both angular and translational positioning of the secondary this procedure will require considerable iteration. The telescope should be focused by setting the secondary for a collimated beam from mirror (a) when the scanner is aimed at a source in the far field. The alignment of mirrors 5 and 7 is done with shims between their mounts and the optical bench.

3.6 DETECTOR/TARGET OPTICS

Figure 20 shows the position of the observer's eye (or eye and telescope) for aligning the target-scanner all the way to the detector. The exact position of the eye should be such that the center of beamsplitter 9, and the center of the LO laser should appear superimposed. Coarse alignment of the scanner/target then occurs when the target appears in the center of the beamsplitter 9, by adjusting 1 and 2. Mirrors 1 and 2 should also be adjusted such that the perimeters of mirrors 1, 2, 3, and 6 appear concentric.

To aid in final alignment record how much the gimbals of #1 must be turned to scan the target area.

3.7 TEA CAVITY/TARGET OPTICS

The next step, coarse alignment of the TEA cavity on the target (white card at 500 meters), is shown in Figure 21. If the alignment of the TEA laser optics, Figure 15, and alignment of the target/detector, Figure 20, have been completed correctly, this adjustment is redundant. The image of the target in the telescope is difficult to see but should appear concentric to the annulus of the telescope and telescope perforation. The chief value of this adjustment is to gauge the amount and direction by which 3 and 6 should be scanned when searching for the target in the final alignment.

3.8 INITIAL HETERODYNE SYSTEM ADJUSTMENTS

In this step we align the receiver/telescope/target heterodyne optics using the injection laser, only, as transmitter. This alignment of the full heterodyne optics uses the injection laser pulsed as in procedure 3.4 above using the Bragg modulator. Since the injection beam is diverging it acts as a relatively broad beam transmitter thus simplifying the search for simultaneous alignment of heterodyne receiver and transmitter to the scanner boresight telescope.

The supplied corner reflector at say 100 meters will serve as the target initially. The scanner boresight telescope reticle is positioned on this new target using the manual scanner controls.

The two dither AFC systems, trigger, Bragg modulator and the log IF receiver should be operating with the oscilloscope display on IF. It may help to have the TEA AFC receiver operating as well (as in test 3.4) as a check on the AFC and cryogenic detector.

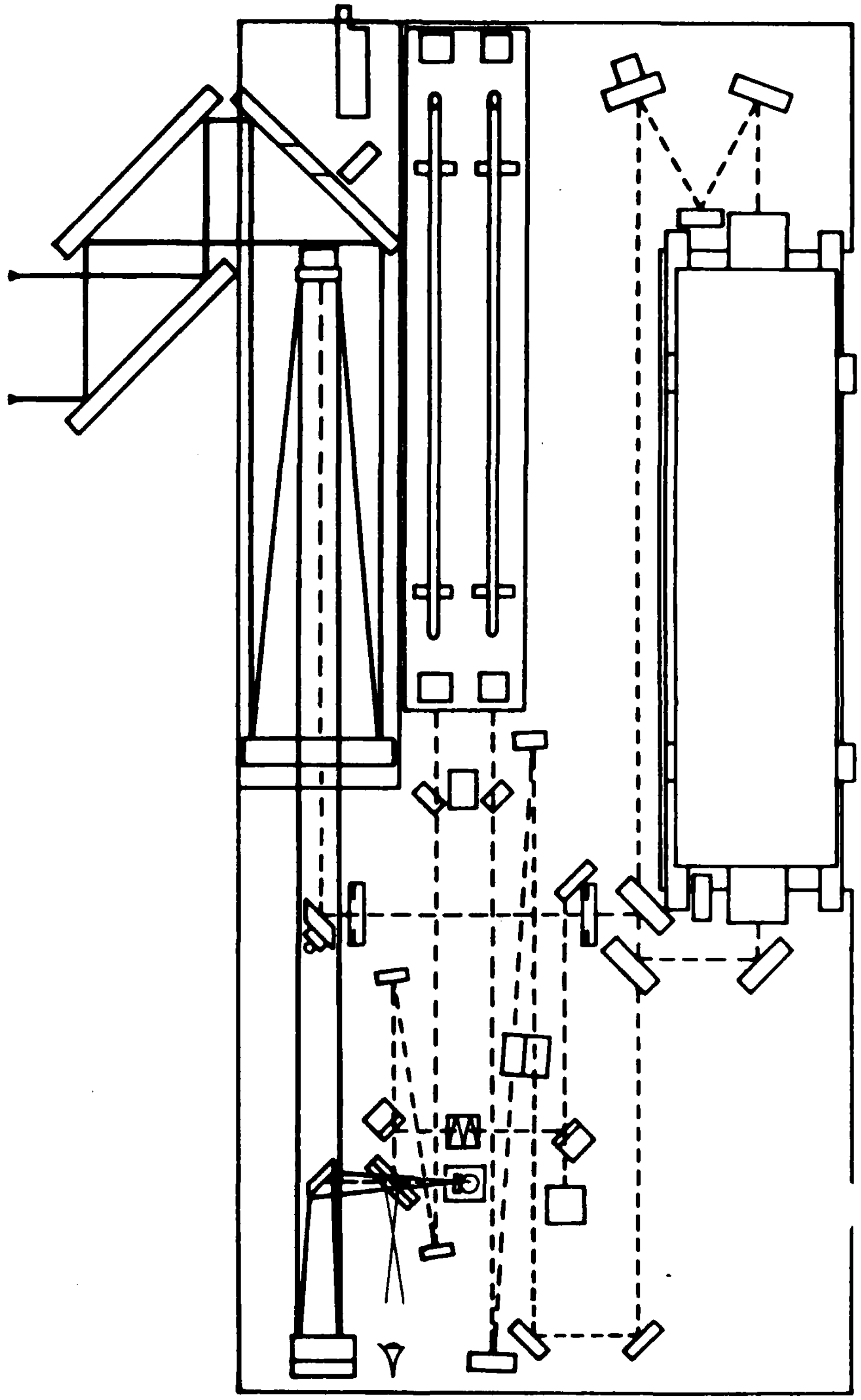


FIGURE 20. DETECTOR/TARGET OPTICS

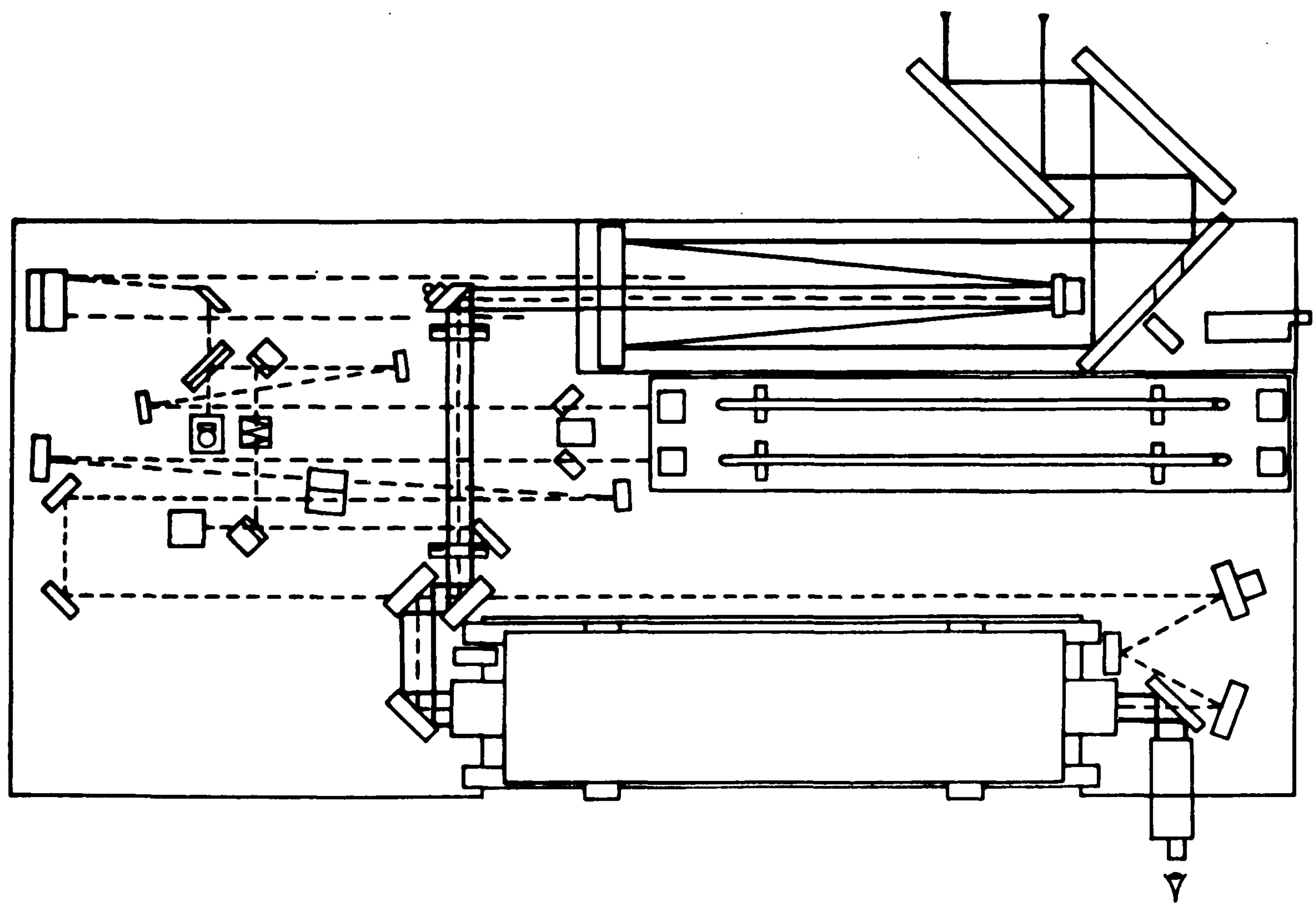


FIGURE 21. ALIGNMENT OF TEA CAVITY ON TARGET.

In this test one should leave the scanner boresight reticle on the target and scan for maximum target IF signal using first the receiver angle control (mirror #1) and then (if necessary) the injection laser transmitter angle control, mirror #3. When the received signal has been peaked by these angle adjustments the retro reflector can be moved farther out and realigned on the boresight telescope crosshairs using the manual scan control. The receiver beam alignment, mirror #1, is then peaked at successively greater distance until the signal is very weak.

Figure 22 shows the heterodyne signals from this system using 8" optics. The upper trace is the output of the detector preamp. The IF beat at T = 0 is less than the noise level. The lower trace is the output of the linear IF amplifier (30 MHz in this setup). Note the strong signal from a corner reflector at 1 km even though the injection beam is highly divergent. This exposure shows about 3 successive pulses. Note the large pulse-to-pulse amplitude fluctuation due to atmospheric effects.

The next step in the alignment process is with the TEA laser as transmitter. (See Section 5.) Consider first however the operation of the TEA laser alone in Section 4.

At this point attenuator 17 should be replaced and "safety" attenuators placed over the detector until there is clearly no danger to the detector.

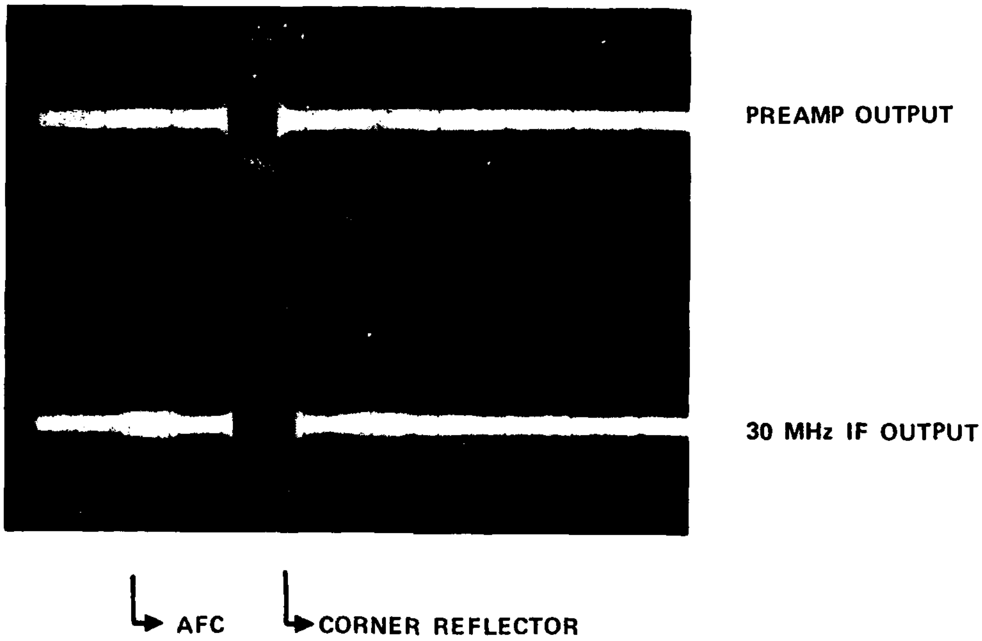


Figure 22. Heterodyne Signals Using Injection Laser Only

4 TEA LASER OPERATION

This section concerns operation of the TEA laser alone. We resume discussions of system heterodyning in Section 5.

4.1 TEA LASER WITH NO INJECTION

To operate the TEA laser alone we need only the trigger system, EL #17, the E-beam modulator, EL #3, the electron-gun control EL #2, and the sustainer power, EL #1. We bring the modulator up to about 15 amperes pulse as noted in Section 2.5 then increase the sustainer voltage until lasing commences. With the initial He/Ne alignment described in Section 3.1 lasing should start at about 15 kV and 400 amperes sustainer voltage and current, even without injection. Peaking the TEA laser alignment (with SO #31) for maximum power will allow reduced E-beam current to maximize filament life. Next the TEA cavity alignment should be refined by adjusting 31 to obtain a symmetrical incandescent annulus on a carbon target. The sustainer electrodes may arc if the sustainer field is increased above 15 kV for the usual 4 cm spacing and the 48/40/12 He/N_2/CO_2 mix supplied. Maximum sustainer current will be about 500 amperes.

Figure 23 shows the waveforms to be expected from the E-beam modulator when connected to the electron gun. These early photos are at reduced voltage from the power supply EL #3a and at filament temperatures causing reduced load currents. At 18.5 kV DC the pulser output is 80 kV for 8 μs when delivering an eleven ampere pulse. The voltage will, of course, increase considerably at reduced beam current. Figure 24 shows the sustainer current with 15 kV DC from EL #1a and filament current reduced slightly to I_{sec} of 9.5 amperes. In these tests the laser power was well over the required 1.0 joules. Final system tests are reported elsewhere.

If cavity adjustment is correct the annulus produced on a carbon block will show concentric rings, which are the effects of diffraction in the near field, and a more intense field on the top which is due to secondary emission of the anode. Angle modes cannot be recognized by eye and are only perceived by extra beats (around 2 MHz in the heterodyne receiver).

Since there is, at this point, no injection, there will be strong counterclockwise emission as shown by incandescence of the CCW absorber SO #34. Beating of the longitudinal modes of the TEA laser cavity will show as 50 and 100 MHz beats in a wideband detector at position #27.

We can now improve the alignment of the duplexer. Any incandescence on the inside of the carbon rings SO #4 and 4a should be uniform and the annulus should be concentric to the perimeter of SO #3 and 6. This can be checked by a carbon-coated paper behind the mirrors. The goal is to assure there is no spillover or illumination of the edges of the diagonal mirror that can diffract or reflect back to the detector.

I_{sec}
2 a/cm

V_{sec}
20 kv/cm

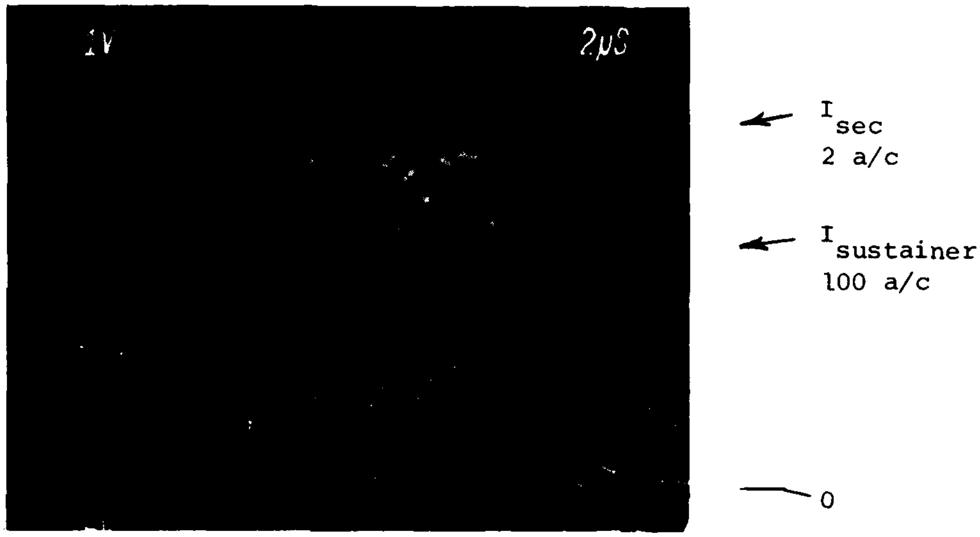
V_{DC} = 17.4 kv
I_f = 13.9 a. (ac)

I_{sec}
2 a/cm

V_{sec}
20 kv/cm

V_{DC} = 18.5 kv
I_f = 13.9 a. (ac)

Figure 23. E-Beam Modulator with Diode Load



V_{DC} - 18 kv

I_{DC} - 90 ma

V_{sec} - 92 kv

I_{sec} - 9.5 a

PRF - 25 pps

Gas Mix - 48/40/12

Gas Flow - 5 CFM STP

$V_{sustainer}$ - 15 kv

Wattmeter - 2 watts

Power Slot - .31"

Multiplying Factor - 14

ccw Power - 28w

ccw/cw Ratio - .7 est

Joules/pulse - 1.6

Figure 24. TEA Laser System Test 5/4/83

4.2 TEA LASER WITH MANUAL INJECTION

With no injection, or injection of the wrong frequency the TEA laser pulse will start about 5-1/2 microseconds after the start of the sustainer current pulse. The output will include several longitudinal modes, and several wavelengths other than the P-20 line and will contain a strong CCW emission.

To start the injection process, the injection laser should be on, with its AFC operating as described in Section 3.3. Timing of the injection pulse (Bragg gate) should encompass the TEA laser buildup period as described in Section 2.1.

With the TEA laser operating the enhancement effects of injection will be observed when the TEA cavity is manually tuned through the center of the P-20 line. This is done by manually "tuning" the TEA PZT voltage using EL #11 set for manual bias voltage control. When the critical coincidence of injection and TEA frequencies occurs it will be very evident in the earlier onset of the TEA pulse, the disappearance of mode beats, an increase in total TEA laser pulse power, a disappearance of the CCW mode and a decrease of the spike to pedestal ratio.

If, however, the Bragg gate pulse timing is such as to keep the Bragg gate open during the full power of the TEA pulse the feedback into the injection cavity will cause the injection laser AFC to jitter wildly. Timing must be adjusted such that the gate is closed about 1/2 μs before the injection locked TEA pulse starts.

At this point, if the TEA AFC were ready to operate, one could close the TEA AFC loop and the TEA frequency would be locked to that of the injection laser.

4.3 TEA LASER WITH AFC

To operate the TEA AFC the full heterodyne receiver must be operating. This requires the LO laser to be operating as in 3.2 and the LO/injection laser heterodyne system be operating as in 3.4. It is of course essential that the AFC pickoff, SO #29, provide the detector with a TEA signal but that the attenuator, position 17, be sufficient to prevent damage to the cryogenic detector.

At this point the manual adjustment of the TEA cavity, as described above (3.2), should be adjusted for zero TEA AFC servo error (at least momentarily) and the loop closed. This is done by moving the "FUNCTION SWITCH" of EL #11 from "SET" to "STABILIZE", and adjusting AFC servo loop gain (on EL #20) for best stability. The loop will now hold the TEA laser to within one or two MHz of the LO laser as observed by the oscilloscope display of the AFC discriminator.

Figure 25 shows typical AFC signals. The upper traces of both photos shows two successive pulses. Although the average AFC error may be zero the pulse to pulse jitter will be about 1 MHz. Note that the discriminator output is quite flat, showing less than 200 kHz chirp over the entire 4-1/2 μs pulse. Also shown are the wideband waveform of the TEA laser photon drag detector output and the narrowband IF output. Pulse to pulse timing jitter is about 0.5 μs and is caused by many factors including injection frequency jitter.

These photos were taken from an earlier AFC system in which the injection laser used heterodyne AFC too. The lower trace of each photo shows the IF output of the injection AFC.

Best operation assumes that the AFC gate (sample and hold) be set to sample the TEA pulse at a point where any RFI is at a minimum. The TEA pickoff attenuator should be such that the detector signal is strong enough to override time-zero RFI yet not be near the damage point of the detector, say -53 dBm. Figure 6 shows the signal levels corresponding to this.

If the TEA cavity is misaligned the TEA laser output will contain off-axis modes whose frequencies are a few MHz away from the zero order mode and will cause the AFC to lose lock. The mode beats can be observed in either the preamp output or the IF output.

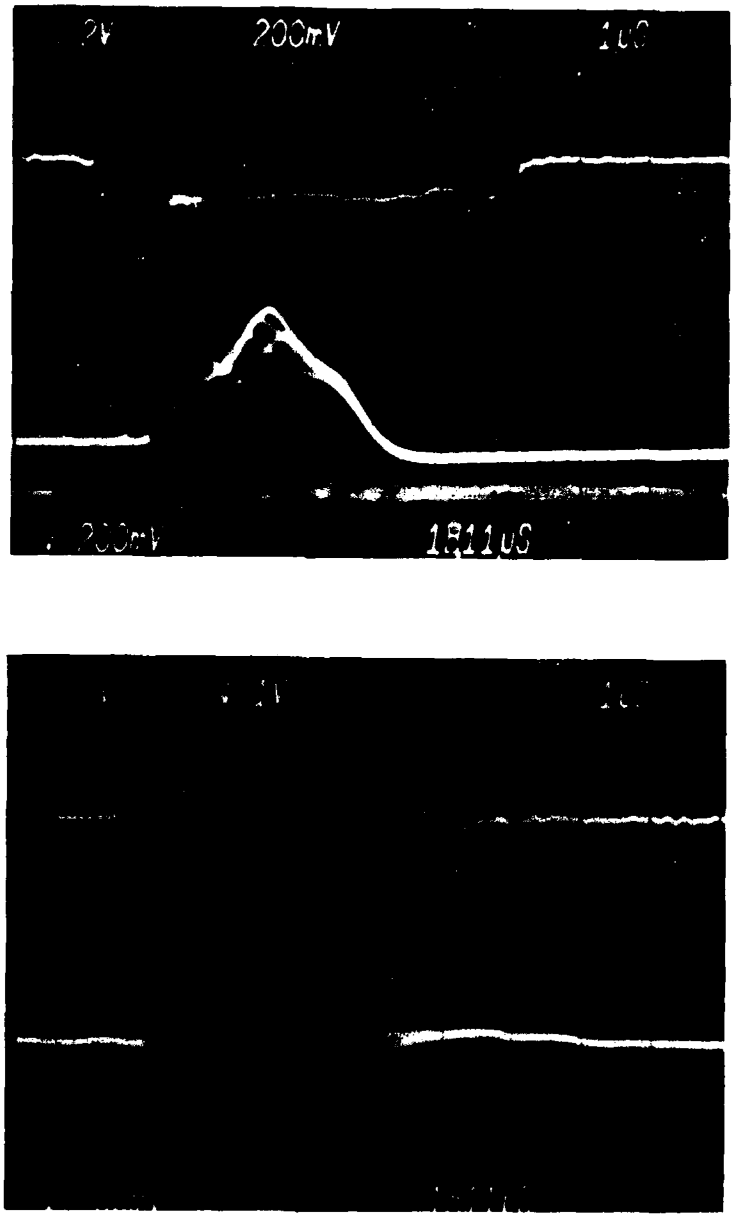


Figure 25. TEA Laser Frequency Chirp

5 SYSTEM OPERATION

At this point we have all subsystems in operating condition. We need only align the operating TEA laser on the boresighted target to become fully operational.

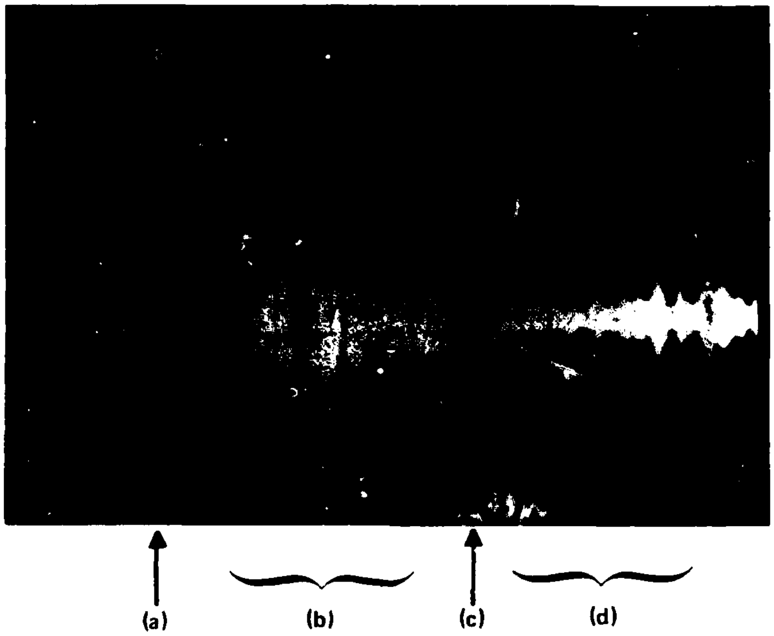
The heterodyne receiver/telescope/scanner has been aligned on the remote corner reflector, Section 3.6, using the injection laser as transmitter. The TEA laser has been approximately aligned with the duplexer using the He/Ne laser (3.1) and more carefully with the TEA laser operating 4.1. Thus illuminating the target with the TEA laser at this point requires only a slight readjustment at the TEA laser output angle, using mirror SO #3. Since the received signal from the corner reflector may damage the detector, this step should proceed cautiously with a series of successively smaller attenuators between mirrors #2 and #9.

The received log IF signal from the corner reflector is peaked using SO #3, then the scanners (boresight crosshairs) are set on a more distant, diffuse target and the receiver attenuators removed. If the diffuse target is smaller than the transmitted and receive beams, final peaking of the optics is obtained by peaking the IF signal with both mirrors, 1 and 3, using the reticle of the boresight telescope as reference.

Using an eight-inch diameter receiver parabola and transmitting the 4 cm diameter laser beam coaxially but without magnification we made some propagation measurements of the breadboard model of this system. (See Figure 26.)

The figure shows an extremely strong signal return from a water tower about a mile away, a strong backscatter from a roof top periscope mirror (our system was in the basement) and moderate aerosol backscatter signals out as far as the water tower. Note that even in the shadow of the tower there is some target continuum caused either by sidelobes of the main beam or ground backscatter from the tower reflection.

Note the characteristic speckle pattern of the aerosol return. The IF bandwidth was about 4 MHz; thus the coherence length of the aerosol backscatter was about .25 μs. Adjacent range cells of the diffuse aerosol return have a random speckled amplitude analogous to the way in which adjacent diffraction limited angle cells of the eye show random speckle amplitude to diffuse laser reflection.



(a) AFC

(b) AEROSOLS

(c) WATER TOWER

(d) MULTIPLE SCATTER

Figure 26. Single Pulse Heterodyne Signals Using Full TEA Laser Transmitter (2/10/81)

6 SAFETY PRECAUTIONS FOR THE PULSED HETERODYNE CO_2 LASER/SCANNER SYSTEM

The following precautions pertain to the high power CO_2 laser radar system (Contract F19628-80-C-0184) which is the subject of this document. This unit is sent by General Electric disassembled to the Air Force at Hanscom AFB, MA., where it will be reassembled in a trailer by the customer. If assembled and/or operated improperly, operating personnel or bystanders can be injured or killed. The purpose of this section is to list some of these hazards and indicate how they may be minimized.

Laser radar is an advanced technology and utilizes techniques requiring knowledgeable and thoroughly trained scientists for its assembly and operation. It is essential that proper procedures and effective and conspicuous warning signs be used to discourage operation by unqualified personnel.

Although there are many potential sources of injury in any high power electro-optical equipment, the chief sources of hazard of this apparatus are:

(1) Ozone

(2) High Voltage

(3) Laser Radiation

(4) X-Radiation

This section presents details of these hazards and how they should be handled. While the procedures are generally known to technicians qualified to assemble and operate this equipment, this section is included for emphasis and as a reminder. To apprise operating personnel of these hazards, we have prepared warning signs and urge the Air Force to attach these in conspicuous places on the final installation.

The major safety assurance is training. We request the Air Force to conduct periodic training programs for all personnel having access to this equipment. The General Electric Company stands ready to prepare and conduct such programs on request from the Air Force.

The four dominant safety hazards for this equipment are:

(1) Gas poisoning of personnel in the operating building due to ozone generated by high voltage discharge.

(2) Electrical shock due to high continuous and pulse voltages generated and delivered among the several units of the equipment.

(3) Eye and skin damage due to the high power radiation from the several lasers used in the system.

(4) Ionizing radiation in the form of x-rays from the high voltage electron gun used in the transmitter laser.

Other hazards exist such as eventual damage to hearing (due to acoustic pulses generated by the transmitter laser) or fire hazards (due to oil filled electrical equipments). This section, however, addresses only the four main hazards.

Ozone

The atmospheric pressure (TEA) CO_2 laser and the two low pressure CO_2 lasers in this system use less than 10 CFH STP gas mixture of about 10% CO_2. Although exact fractions are unknown, if 1% of this were continuously converted to ozone the laser would generate ozone at a rate of 0.1 cubic feet per hour. In an unventilated trailer laboratory of 3000 cubic feet this would cause a dangerous level (0.1 ppm) in about two minutes. When installed in a large well-ventilated laboratory, we have found the ozone buildup to be negligible but clearly in the special case of this installation special precautions are necessary. Fortunately, the precautionary technique is simple. The exhaust of the three lasers is merely directed out the ceiling of the trailer. The TEA laser exhaust is a small 1/8" pipe fitting on the top of the laser. The low pressure laser exhaust is the high pressure side of the roughing pump.

Proper ventilation of the exhaust of the CO_2 lasers is essential to the safe operation of this system.

High Voltage

The system consists of 40 separate electrical chassis or boxes, described elsewhere in the assembly and operating instructions. Nearly every unit contains a variety of voltages including the usual 120V, 60 Hz domestic power. In addition, several commercial units are used that contain high voltages such as two oscilloscopes and a vacuum gauge which, like a home television set, are clearly marked, carefully housed and technically described in their own manuals. We discuss here the three special high voltage subsystems whose conditions of operation require special attention. These are:

(1) Low pressure CO_2 Laser, EL#33

(2) Electron Beam Modulator, EL#3

(3) TEA Laser EL#1, EL#26

As in any high power electrical system, the first general precautions are (a) all conducting components a person might touch should be solidly and permanently grounded, (b) a convenient grounding stick should be provided to remove the temptation of touching apparatus after only the power itself is turned off, and (c) equipment should not be repaired or adjusted by a lone operator.

(1) Low Pressure CO_2 Laser

This system uses a 20 kv power supply, EL #8, delivered through ballast (current limiting) resistors located in Rack #2 and transmitted by a cable to the 4 electrodes of the two low pressure lasers. The danger points are the electrodes and windows of the laser and the ballast resistors. The hazard can be reduced by mechanical shields over all three and by interlocking the power supply to the door of Rack #2.

(2) Electron Beam Modulator

This unit consists of four chassis containing high voltages, EL #3a, 3b, 3c, and 3d. EL #3b is the 25 kv power supply whose voltage is controlled by EL #3a. EL #3c is a 3 kv pulse generator that drives the high voltage (120 kv) electron beam modulator, 3d. All units contain or are cabled to high voltages that are shielded according to customary engineering practice. Because of technical requirements, the high voltage output of EL #3d is partially exposed. It is connected to the electron gun of the TEA laser under the optical bench and partially shielded by the table and the skirts of the electron gun. Nevertheless it should be shielded by other barriers and marked clearly with signs to prevent someone from coming within one foot of the high voltage bushing.

(3) TEA Laser

The TEA laser uses 20 kv power from the sustainer capacitor box EL #1b. This capacitor is charged from the commercial power supply EL #1a. The door to the power supply is interlocked, the 20 kv DC to the sustainer capacitor box is carried by shielded cable and passed into the box by shielded connectors. The capacitor's energy is passed out of the box by shielded leads and connectors and attached to a bushing on the laser whose connection is covered with rubber potting compound. The exposed metal fasteners of the box are connected together for grounding. Holes in this box are provided for cooling air. Energy stored in this capacitor is extremely large. All exposed metal should be solidly grounded, with heavy copper braid. The time constant of the capacitor and the bleeder, in EL #1a, is about 30 minutes. If an individual removes the input connectors before this time after shut-off or reached into the connector's sheaths, he could receive a lethal shock. To avoid these hazards, the grounding stick should be permanently applied to all metallic components whenever the equipment is disconnected or opened for adjustment.

Laser Radiation

To set up this system a commercial Helium-Neon (Red) laser is used to align the mirrors and other optical components. The danger is damage of the retina due to the red beam. The usual precaution with these low power lasers should be followed: avoid looking directly into the beam of the laser and use protective goggles when possible.

The laser radar operates at far-IR wavelength, 10μ, at which wavelength the eye is opaque. The danger is thus due to burning of the skin or eye not damage to the retina. The New York State CO_2 Laser Safety Standard is 10^{-2} joules per cm^2 for pulsed lasers and 10^{-2} w/cm^2 for CW lasers. The TEA laser beam has an intensity of up to 1.0 joules/cm^2 (5 joules/pulse) and the low pressure CO_2 lasers put out up to 10 watt/cm^2 and higher at points in the system where the beam is focused. Although these beams are confined to the optical system and normally exist only from component to component on the optical bench, one could get his eye into these beams by bending over or inadvertent movement of a beam. To avoid this, a shield or cage should be lowered over the table once the alignment and operating conditions have been set.

The normal power out of the TEA laser is no more than 1 joule per pulse and when expanded to the 20 cm output beam diameter has an intensity of less than about .004 joules/cm^2. Thus even for a bystander directly outside the trailer house the power on the eye would normally be less than prevailing standards. However, to avoid any possible danger under any circumstances of power or optical focusing, we recommend that the scanner not be allowed to point at anyone, however far away.

X-Radiation

The attached figures show the TEA laser, some preliminary x-ray levels and the location of some temporary, lead shielding installed to supplement the 1/2" lead shielding. The latter is permanently attached to the laser and electron gun and hidden from view by the aluminum housing. The temporary shielding plus the permanent shielding is adequate if the operator is exposed below the levels described in the following paragraphs. If exposure beyond these levels is contemplated, several areas should be shielded more heavily depending upon the number of hours an operator will be exposed. These areas are (1) the foil plate that lies between the gun and the laser, (2) the two laser windows from which the laser beam emerges, (3) the underside of the electron-gun, (4) the high voltage bushing blister which has only 1/16" shielding on the operator side and none on the table side, and (5) the rim of the laser end plate.

We have made measurements of the TEA laser x-ray levels in millirems per hour which unit expresses the fact that a given radiation level is dangerous depending upon the time of cumulative exposure. Federal standards call for no greater than 2 1/2 millirems per hour if the operator will be exposed 40 hours per week, 50 weeks per year. Thus a year's cumulative exposure should be less than 5 rems. It calls for no greater than 100 mr/h for any given week of 40 hours. These levels are for the more vulnerable parts of the body rather than say the fingers or feet.

In respect to higher exposure levels for short exposure periods and lower exposure levels for pregnant women the US Nuclear Regulatory Commission (NRC) regulations and applicable State Regulations should be consulted. The US NRC and some state regulations recommend that during the entire 39 consecutive week gestation period the maximum permissible dose equivalent to the fetus from occupational exposure of the expectant mother should not exceed 0.5 Rem.

Figures 27 and 28 show that at electron beam current levels somewhat less than maximum power (95 kv, 11a, 10 μs, 50 pulses per second). The x-ray levels impinging above knee level are in the range of 2 to 50 millirems per hour on the operator side and 12" away from the laser. At five feet away these levels would be 0.1 to 2 millirems/hour (if the source is small compared to its distance). At ankle height, 12" away, the radiation is coming from nearly overhead and thus it too would be the 2 millirem range at 5 feet.

Thus it is clear that while, in the lightly augmented shielded system, there is an x-ray hazard, it becomes negligible for an operator who stays five feet away from the system or approaches closely for only brief periods.

Further shielding is easily added. Figure 29 shows the shielding delivered with the system and designed in particular to cover major leaks in the initial shielding system of Figures 27 and 28.

General Electric Company urges the Air Force to train its operating personnel to limit their distance and exposure time according to the Federal and/or State standards and to use all the temporary shielding GE has supplied whenever the system is used.

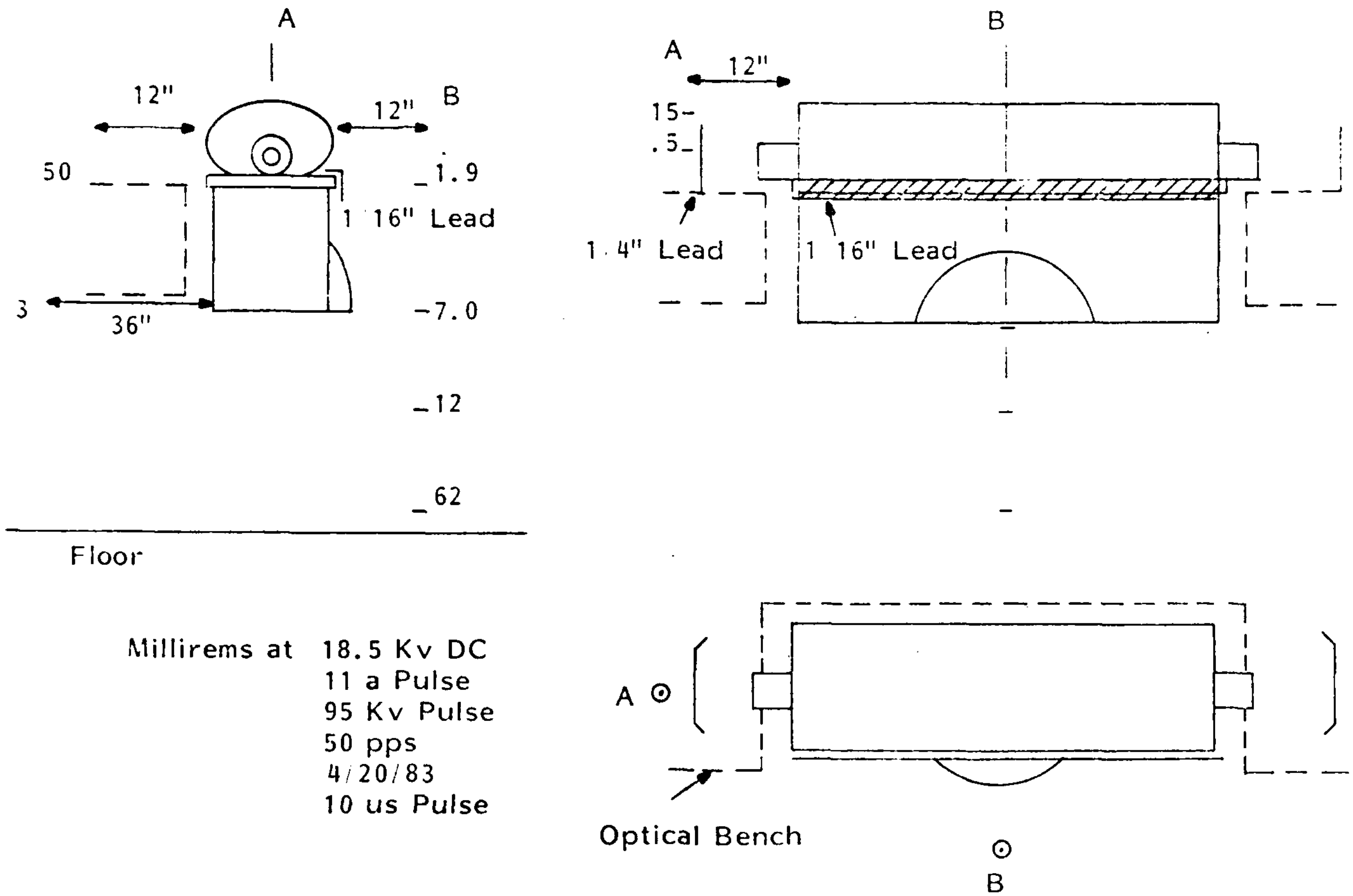


Figure 27. TEA Laser X-ray Levels, Axes A & B

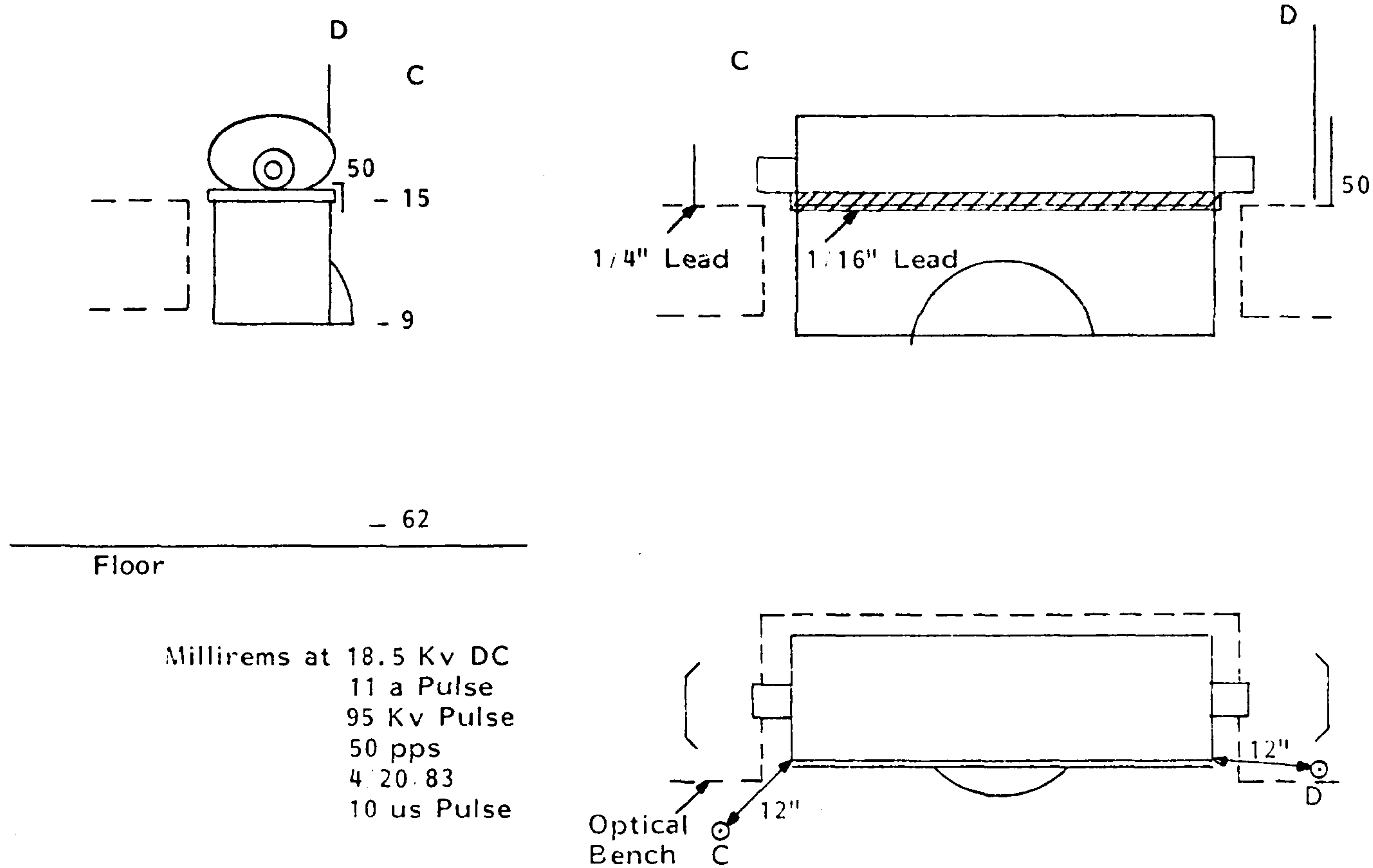


Figure 28. TEA Laser X-ray Levels, Axes C & D

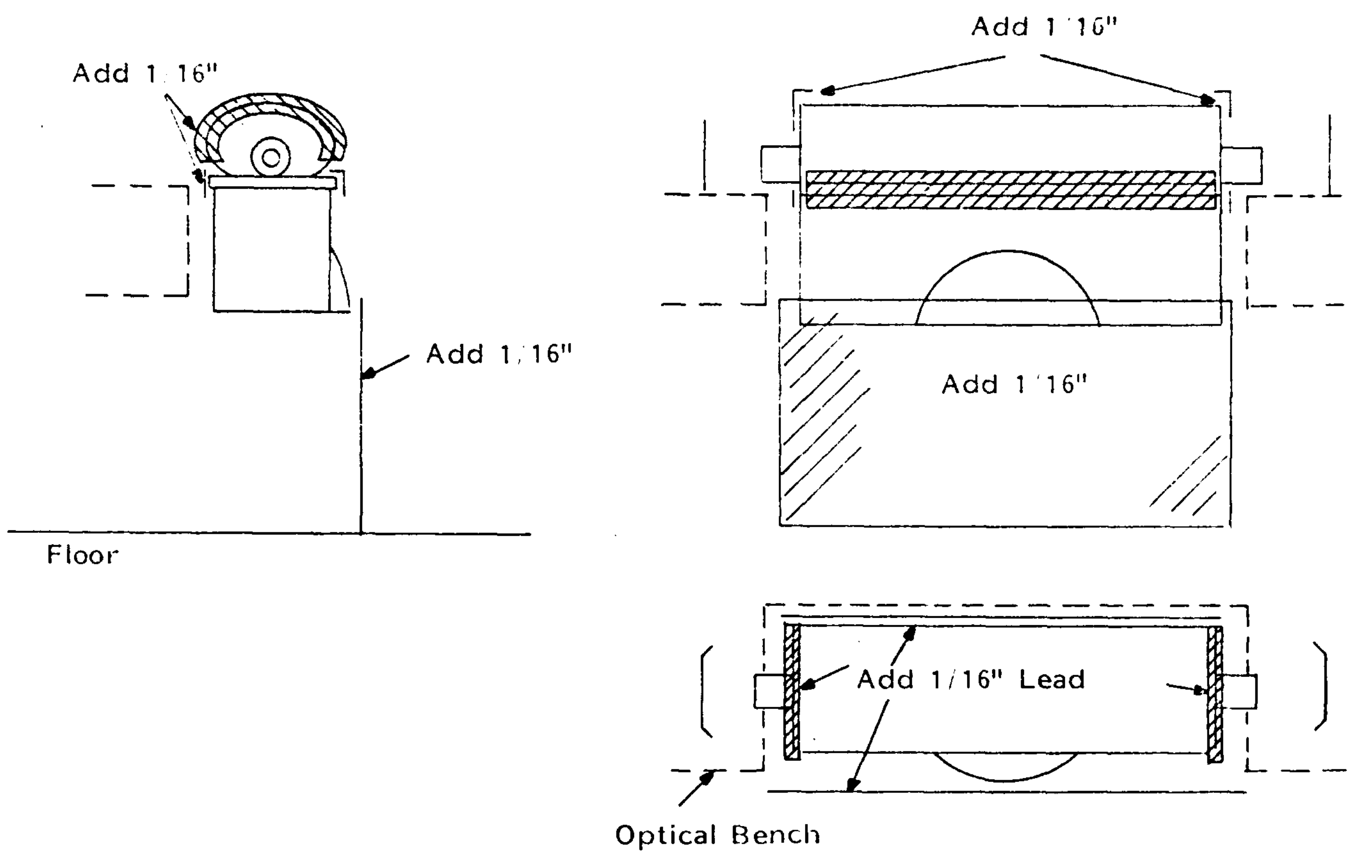


Figure 29. TEA Laser Additional X-ray Shielding