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MANUFACTURING METHODS AND TECHNOLOGY (MM&T) PROGRAM.

10.6 MICROMETER CARBON DIOXIDE TEA LASERS

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10.6 Micrometer Carbon Dioxide TEA Lasers

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ABSTRACT

This report documents the efforts of Raytheon Company to conduct a manufacturing methods and technology (MM&T) program for 10.6 micrometer carbon dioxide TEA lasers. A set of laser parameters is given and a conforming tube design is described. Results of thermal and mechanical stress analyses are detailed along with a procedure for assembling and testing the laser tube. Also provided are purchase specifications for optics and process specifications for some of the essential operations.

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PURPOSE

The purpose of Contract DAAK70-81-C-0048 was to have the contractor furnish all engineering, labor, tools, equipment, materials, supplies and services necessary to establish production techniques in accordance with Electronic Research and Development Command Industrial Preparedness Procurement Requirements (ERADCIPPR) No. 15 dated March 1978 for 10.6 Micrometer Carbon Dioxide TEA Lasers meeting Purchase Description MM&T H803031 dated 15 January 1980, and Section C of the contract document.

The primary objective was to establish the manufacturing methods and technology necessary to fabricate 10.6 micrometer carbon dioxide TEA lasers. It was to establish the manufacturing procedures and processes, test procedures, and a pilot production line to both produce these lasers in volume and to increase the manufacturing yield of acceptable lasers and to sharply reduce the cost involved in manufacturing these lasers utilizing R&D procedures.

GLOSSARY

ERROR BUDGET:

In mechanical construction, the tolerance is first established on a critical component relationship. Then all the items which connect the two critically spaced components are listed along with the tolerance on each.

The sum must be less than or equal to the allowed critical tolerance. Such a budget will show those items which must be super toleranced. It will also suggest those items which could be by-passed to reduce the total error budget.

FABRY-PEROT INTERFEROMETER:

A device for examining interference effects in light beams. This type consists of two accurately flat and parallel mirrors which face each other. If the spacing is adjusted slowly, a reflected beam of monochromatic light goes in and out of phase with the primary beam. This results in transmission peaks and valleys. A laser resonator is a modified form of Fabry-Perot interferometer.

FLEXURE PIVOT:

A special use pivot made by reducing the cross section of a piece of metal to cause all flexing to occur in the neck. Work hardening will occur but is not serious if the degree of flexure is kept small and the number of cycles also kept small.

GAS CHROMATOGRAPH:

This is an analytical instrument to detect and evaluate quantitatively the presence of a selected set of gaseous molecules. The instrument is always calibrated by a standardizing sample of the molecules expected and is in a sense a comparator.

Its name derives from the paper chromatograph used, for example, to analyze a complex dye solution. The different molecules of the dye soak into the paper different amounts. The resultant colored bands can be cut apart for independent analysis.

In the gas chromatograph the time from injection at one end of a pipe or column which contains special materials, such as silica, for each species of molecule to be carried through by the carrier gas to the detector is unique to the molecule. The size of the detected signal depends on the concentration of that molecule in the injected sample.

The gas chromatograph instrument includes precision flow rate control of the carrier gas, thermostatic control of the column temperature and a balanced detector to reduce zero drift. The Perkin-Elmer instrument at Raytheon includes microprocessor control of both the analog chromatograph and a data print-out facility.

G.C.: Abbreviation for Gas Chromatograph (see above).

GEN TEC:

The Gen Tec is an energy detector which produces an output voltage pulse proportional to the integral of the power vs. time input pulse. It is a calorimetric device for short pulses; it does not store and accumulate energy.

GETTERING:

Vacuum tube technology, meaning to absorb gases to enhance the vacuum within a sealed enclosure. The silvery coating on the inner wall of vacuum radio tubes was barium metal which served as a "getter" by combining with water vapor or CO_2 or O_2.

GIMBAL:

In laser technology, a mirror controlling device which permits independent angular adjustment in two orthogonal axes. Used to align one laser mirror with the other. Requires fine resolution control for this purpose.

GREENWARE:

Technical ceramics are formed by hydrostatically pressing high alumina powder in a form. The unfired shape which results is called "greenware." It is soft and brittle. It must be fired to become hard and tough. Firing results in about 8-12% linear shrinking and some minor distortion.

MONOLITHIC:

Literally, one stone. Refers to a mechanical assembly which remains dimensionally stable, as adjusted, throughout the range of environmental conditions.

PFN:

Pulse Forming Network, after radar technology. It is the electrical driving circuit, combined with mechanical holding and locating functions, which drives the pulsed laser. Electrically, the PFN includes capacitors and a triggered high-voltage switch to apply the charge to the laser.

PHOTON DRAG DETECTOR:

A high-speed detector used for recording the power vs. time output wave shape of a pulsed laser. Light enters and passes through a bar of doped germanium crystal. Photons in the beam transfer their momentum to free carriers in the germanium. This creates a voltage gradient which is fed to the output terminal. Photon drag devices are made by Rofin Ltd., Winslade House, Egham, Surrey, G.B.

PLANIMETER:

In comparing measured total energy with an oscilloscope trace (Rofin detector) of power vs. time, scope photographs are made and the area under the curve measured with a planimeter. This requires manually guiding a stylus around the area to be measured. The area is proportional to the reading taken from a numbered roller on the mechanism.

ROFIN (DETECTOR)

See Photon Drag Detector.

ZYGO:

A precision Fizeau-type interferometer operating at 6328 A.U., the wavelength of the helium-neon laser. The Zygo has the built-in capability of making Polaroid photographic records of interferograms of test optical elements.

INTRODUCTION/SUMMARY

In April 1981, Raytheon was awarded a Manufacturing Methods and Techniques (MM&T) contract (DAAK70-81-C-0048) for the design and development of a manufacturable Transversely Excited Atmospheric (TEA) pressure carbon dioxide (CO_2) laser for rangefinder applications. During the performance of the contract, problems were encountered in meeting the two (2) million shot lifetime with the required energy and power output. As such, the program was not fully completed and this report reflects the activities and accomplishments of the programs that were developed up to the limitation of funding.

In addition, an added scope proposal was submitted to NVEOL reflecting their desire to incorporate a Brewster Angle Polarizer into the laser tube. This modification was desired in order to maximize rangefinder performance due to the limiting aperture available in the existing M-1 vehicle. The Government elected not to fund this proposal and the program proceeded up to the expenditure of the available funding.

This report has been assembled into three sections. Section 1 describes TEA CO_2 laser design, the experimental and development programs and the design features of the laser tube for which a complete set of manufacturing drawings was prepared. A listing of the drawings along with the generation breakdown is contained in Appendix K. Section 2 is a process specification defining the steps necessary for the manufacture of the laser tube defined by the drawing set of Appendix K. Section 3 describes the quality controls as far as they were developed for the manufacture and testing of the laser. In the appendices to this report, electrode geometrics are considered; process specifications, as far as they were developed, are given, and circuit diagrams of the special apparatus used for life testing of pulsed TEA CO_2 lasers are also given.

It is fitting to recognize the assistance of Mr. Frederick Cunningham in performing the experimental work of this program. Dr. Richard Eng assisted in the writing of certain subsections of this report, as well as the performance of parts in the experimental program. Mr. Peter Laurendeau of the Microwave and Power Tube Division contributed much in the manufacture of ceramic components and the high temperature brazing of certain structures. Mr. Eberhard Praeger developed the sputter metalization and infrared soldering techniques for the output cooler.

The TEA CO_2 laser developed under the MM&T contract produces high peak power pulses of radiation at a wavelength of 10.6 microns. The radiation is a consequence of the electrical excitation of gaseous carbon dioxide in a mixture with nitrogen, carbon monoxide and helium. Dissociation of the carbon dioxide molecules, limiting the life expectancy, occurs as a result of the high electric field used to excite the gas. Due to the high peak power within the resonator of the laser (1/4 megawatt or more), mirror damage is also a potential life-expectancy-limiting process. Overcoming these and other problems concerned with electrode and mirror alignment constituted the main experimental activity to create a design capable of over two million pulses.

The external dimensions of the laser were determined by the packaging requirements of the rangefinder being built for the M-1 tank. Because of the need to hard-mount the rangefinder rigidly to the sight in the turret, the laser is subjected directly to the treaded armored vehicle shock and vibration spectrum which includes large bore weapon firing impulses. At the inception of the program, Raytheon had already developed a ceramic version of the TEA CO_2 laser which would operate satisfactorily in the tank environment, albeit with a constantly renewed gas supply. This laser also used a rigid flashboard preionizer developed to overcome the vibration damage experienced by wire preionizers.

The laser for the M-1 built similar to microwave tubes employs a high alumina, high density ceramic envelope manufactured by Raytheon's Microwave and Power Tube Division. Components of the envelope are joined together by high temperature brazing preceded by metalization of the appropriate contact areas.

An exception to microwave tube technology is the output coupler, made of optically finished zinc selenide supporting a multi-layer dielectric coating to provide the correct reflectivity for the laser resonator. The coupler cannot be furnaced at high temperatures without damage. Consequently, a sputter metalizing technique has been developed to create a bonding surface which is later soldered in vacuo with a tin-silver low temperature soldering alloy.

The fully-assembled tube is evacuated and baked at a moderately elevated temperature to drive off unwanted volatiles. After completion of bakeout, the tube is back-filled with the appropriate gas mixture. Since the electric discharge needed to excite the gas also tends to destroy it, measures to conserve or restore the composition are necessary. A very effective arrangement is to replace part of the nitrogen with carbon monoxide to shift the equilibrium toward carbon dioxide.

If the starting mixture is limited to 15% carbon dioxide, the rate of decomposition is small enough and the restoration rate great enough so that the net decomposition at 1 Hz is effectively zero. Greater than 15% carbon dioxide and the mixture cannot restore itself. Flowing gas experiments have shown much higher peak power with less afterpulsing can be obtained with higher percentage CO_2 mixtures, but higher percentage mixtures fail rather quickly in sealed tubes. This suggests a catalyst technique might be used to aid the restoration of carbon dioxide. Because of its rather critical power requirements, heated platinum is not feasible for portable equipment. However, other catalysts show considerable promise for future development.

Another limitation, imposed by the rangefinder packaging requirements, is the overall length of the laser tube. Even though peak power density had to be reduced to assure mirror life, the mirror spacing had to be kept constant. This led to a very long radius-of-curvature rear mirror. The longer the radius, the tighter the alignment tolerance and the more rigid the structure has to remain over the environmental range. The rear mirror alignment must be within 36 microradians. A detailed computer simulation analysis determined how well this alignment would be maintained over the environmental extremes of -25°F to +125°F. The analysis predicted a worse case change in alignment of 43 microradians. Misalignments this small will not cause changes in mode structure of the output beam, only a slight skewness and a slight reduction in output.

The Raytheon production design includes innovative solutions to critical alignment problems. These are designed to result as much as possible in correct alignment within tolerances automatically. An example is the use of electrical discharge machining (EDM) to face-off the internal supports for the main discharge electrodes to very close tolerances relative to the exterior edge which defines the direction of the output beam. This special internal machining process is essential because the inner walls of the ceramic envelope do not have adequate planar reference surfaces after high temperature firing.

Another example, also involved with main electrode support, is concerned with lengthwise differences in expansion of the copper electrodes and the ceramic walls. One of the two supports permits flexing in the longitudinal direction. Yet it is adjusted to provide enough tension to prevent transverse motion under the extremes of the shock and vibration spectrum.

It is not found possible to assemble the rear mirror in precise alignment with the output coupling mirror. The required adjusting mechanism is closed in by a heliarc-welded metal cover after experimentally determining the correct alignment to preserve gas-tight integrity.

A TEA CO_2 laser requires conditioning the gas mixture prior to the application of high voltage to the main electrodes. In very early TEA CO_2 lasers, this was accomplished by field emission and/or corona from fine wires stretched parallel to the axis on either side of the main electrodes. Taut wires form acoustic resonators and shock and vibration tests showed them susceptible to stretching and breaking. Raytheon developed a flat ceramic version of the sliding arc preionizer to replace the fine wires. This preionizer was used successfully in the high survivability test vehicle infrared sight where firing on the move with the 75-mm high velocity automatic weapon was accomplished using the Raytheon laser rangefinder. Therefore, this sliding arc technique was proposed for the manufacturable laser program.

Sixty nanoseconds are required for the 13-electrode double-ended preionizer. This is too long for adequate conditioning in the single spark gap shunt triggered circuit. To demonstrate this, Raytheon built a double spark circuit to operate the laser with independent control of the time interval between flashboard firing and the application of peak voltage to the main gap. A technique for triggering two or more spark gaps at predetermined time intervals with jitter less than 2 nanoseconds was devised. The time interval could be set by using different lengths of coaxial cable as an adjustable delay line. In particular, shot-to-shot reproducibility was significantly improved by optimizing the time delay.

The optimum time delay was longer than 60 nanoseconds less than the time to peak voltage in the single spark gap circuit. Either the circuit had to be modified or the flashboard modified to lengthen the net time to the peak voltage. Both techniques were investigated in the laboratory.

The advantage of the series arrangement, called the sliding arc preionizer, is that there are only three terminals to the device. A parallel version having the same number of arcs would have 13 terminals to pass through the gas-tight wall. Twelve resistors are used, one for each electrode to decouple it from the others so the first one to fire would not steal all the energy. An experimental version with 12 fixed resistors inside the envelope of a flowing gas laser had extremely good shot-to-shot reproducibility but the decoupling resistor problem was not solved. These resistors inside the tube cavity would contaminate the gas in a sealed tube configuration unless a resistor development was achieved. This decoupling resistor approach was not further developed on the MM&T program.

The use of nonlinear conducting material, a form of semiconductor, could be the way to decouple one preionizer ultraviolet source from another. In fact, if this can be done on a bulk basis, the number of arcs would be infinite. A rugged, refractory nonlinear conductor which should be considered for use in the manufacture of laser tubes in the near future is silicon carbide which, when coupled with the catalyst, should form the ideal tube of the future. Details of the work accomplished and the technology achievements are contained in the following sections.

PREFACE

A laser rangefinder to be used in an armored vehicle should be covert and eyesafe, as well as capable of range penetration in typical battlefield obscurants. Raytheon developed and demonstrated the feasibility of the eye-safe 10.6-micron length laser rangefinder in the light high performance test vehicle (HSTV-L) built by AAI of Cockeysville, MD. The ruggedness to perform while undergoing firing-on-the-move trials with the 75-mm high velocity weapon was demonstrated on the Wilcox range, Fort Knox, Kentucky.

Current Government vehicles utilize neodymium (YAG:Nd) solid-state laser rangefinders. To achieve a 3-5 km range, the laser is Q-switched, producing an extreme eye hazard since the 1.06-micron YAG:Nd wavelength is transmitted by the cornea, the eye lens, and ordinary glass lenses, such as those used in binoculars. Scattering by atmospheric particles also makes the beam detectable with simple night vision scopes and photoelectric devices using S-1 cathodes.

Raytheon was awarded a manufacturing methods and technology (MM&T) program to determine techniques for the manufacture of a two-million shot sealed carbon dioxide (CO_2) infrared laser. The laser requirements implied a co-axial optical system for the rangefinder and did not include a polarization requirement. In order to reach the performance goals with a 3-inch aperture which exists on current Government vehicles, the laser requirement to have linear polarization of its output was indicated because of the need to use the full aperture for both transmitting and receiving. This technique has been extensively used in homodyne laser systems.

The contract for the MM&T program was not modified to reflect this change before the funding limitation was reached. However, much valuable technology was learned and accomplishments achieved.

A complete set of engineering drawings was prepared for a laser using microwave tube construction techniques for the main parts of the envelope. The background experiments and developments leading to the structural choices and innovations on the drawings are described. Special techniques proposed for assembling the laser are given. Laser testing specifications and optical component purchasing specifications are furnished. The appendix includes the MIL-490D process specifications developed for cleaning, plating and other operations for the laser components. These do not include all of the processes which will be required because they were not prepared before the funding limitation was reached.

The appendices also include a discussion on an easily-manufactured electrode contour using standard cutting tools as well as circuits for life test monitoring equipments. In addition, a glossary is included.

SECTION 1
LASER TUBE DEVELOPMENT

The purpose of this program is to design a laser transmitter tube for armored vehicle infrared rangefinding equipment. The transmitter tube design shall be capable of reliable quantity production by a suitably qualified facility. A design study has been completed and a complete drawing set prepared. This report describes this design study effort and the features of the ruggedized ceramic laser tube which could be built from the drawing set.

The laser tube, in conjunction with appropriate electrical driving circuitry, is an infrared transmitter which emits a short high peak power pulse of 10.6-micron radiation. The laser uses carbon dioxide as the active medium which is Transversely Excited at Atmospheric pressure inside the closed volume of the device, hence it is called a TEA CO_2 laser. The high peak power output pulse is transmitted toward a selected target. The target scatters the beam and the echo pulse is detected by a mercury-cadmium-telluride detector cooled to 77°K. The bandwidth of this typical detector matches the pulse width of this laser. These two components are the basic elements of a direct detection infrared rangefinder/fire control system.

1.1 DESCRIPTION OF LASER TUBE

The laser tube has a maximum overall length of 7.25 inches, set by M-1 laser rangefinder (LRF) requirements, and a cross section of 2.25 inches high by 1.88 inches wide. Terminals and pinched-off gas filling tubes protrude through the surface. Laser output is emitted through a dielectric-coated zinc selenide optical flat at one end. The far end is closed off with a metal protective cap. The main structural body of the tube is fabricated from a high density, high alumina ceramic blank. Parts are attached to the ceramic by high temperature, reducing atmosphere furnace brazing. A ruggedized, sealed-off laser tube should employ ceramic/metal microwave tube technology as much as possible. The similarity to microwave tube technology includes the need for ultra-cleanliness, obtained by careful parts cleaning and vacuum bakeout. Three technical areas are different from tube technology, however. One, the output window, which is a partially reflecting mirror of zinc selenide, requires a low temperature-sealing technique. The second is that the laser tube is filled with a noninert gas mixture at a pressure of about one atmosphere rather than high vacuum. Third is that, although free oxygen is undesirable in the laser, it must not be removed by a "getter" as used in the vacuum tube, because the oxygen which does occur must be combined with CO to reform the all-essential CO_2. Gettering the oxygen would have the effect of removing CO_2.

Special facilities needed to manufacture the tube include high temperature, reducing atmosphere furnaces for firing ceramic greenware, metalizing the ceramic and finally brazing the components together in appropriately designed fixtures. Low temperature cleaning facilities which include plasma ashing are needed before attaching the zinc selenide output coupler. Sputter metalization is performed on the zinc selenide optic to permit tin-silver-alloy soldering to be done in a vacuum.

Optical alignment and performance testing requires calibrated pulse energy and fast response power detectors to evaluate the laser output. The circuit in which the laser is mounted provides energy storage and high-speed switching to fire the laser. A rugged life test circuit is described in this report. However, smaller compact components would be used for operating the tube as a rangefinder transmitter.

1.2 OPERATION OF THE TEA CO_2 LASER

In Figure 1 the capacitor, PFN-2, is charged by drawing current through current-limiting resistor, PFN-4, from a high voltage power supply. The other side of the capacitor, PFN-2, is connected to ground through resistor PFN-5. The total resistance is adjusted to accomplish full charge to the supply voltage within one second. The resistor PFN-5 keeps both sides of the laser at close-to-ground potential during charging.

Initially the thyratron, PFN-1, is not conducting. Its heater and reservoir have been warmed up for several minutes. Application of a trigger pulse to the grid terminal will cause the thyratron to conduct strongly, lowering the right-hand terminal of the capacitor, PFN-2, to ground. Thus the full potential across the capacitor begins to appear across the contacts of the laser. Both

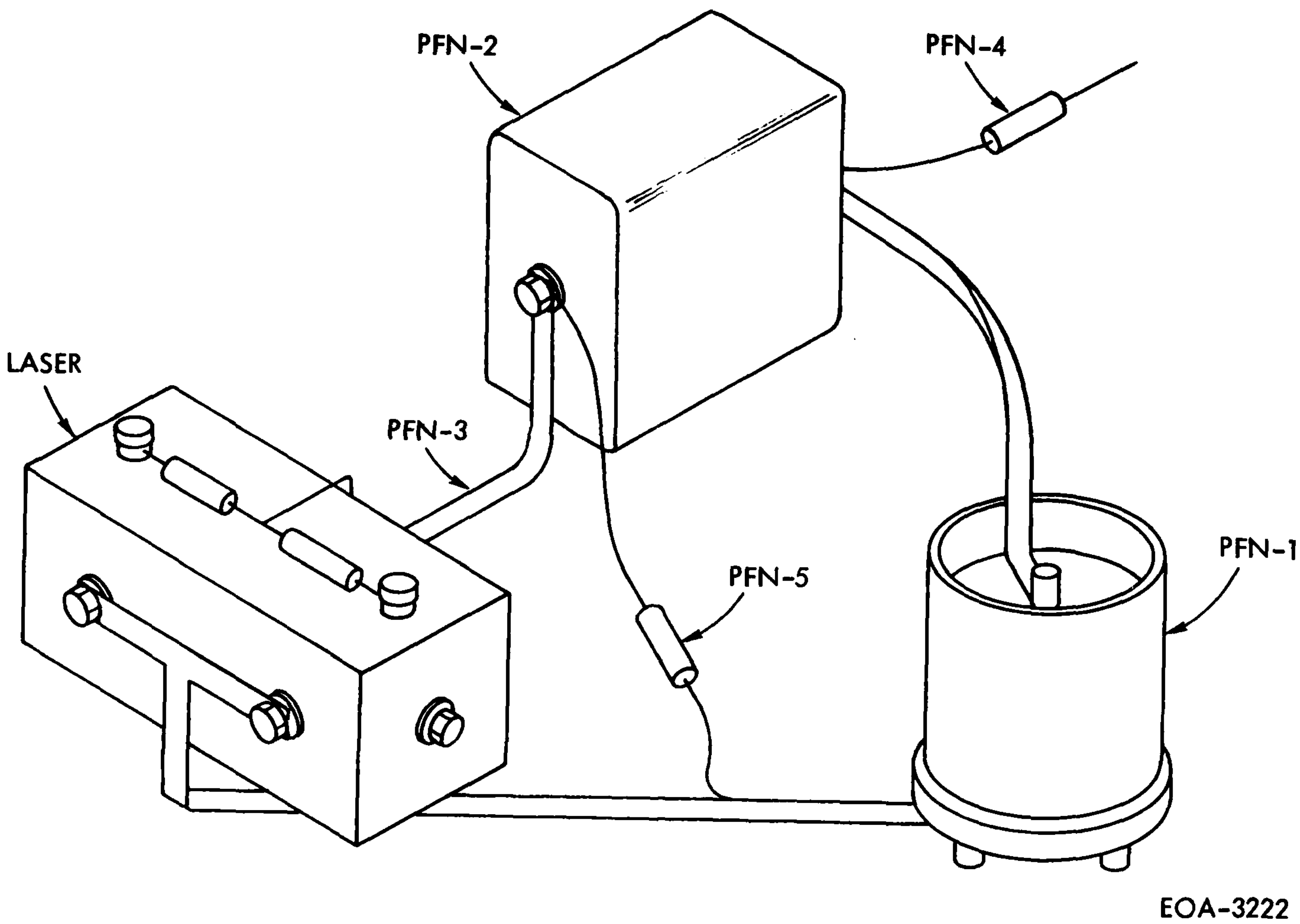


Figure 1. Laser in Simple PFN Using Thyratron

resistors, PFN-4 and -5, are large compared to the series resistance of the heavy leads and the conducting thyratron.

The voltage on the laser terminals rises in a steep ramp. The flashboard in the laser begins to fire first, gap by gap. Refer now to Figure 2, which is the laser tube itself. Inside the body, 1, of the tube are two electrodes, 4, accurately located parallel to each other. The flashboard, 5, is also parallel to the electrodes off to the side irradiating the electrodes, 4, and the volume between. The 13 buttons, 5a, having 12 gaps which arc, constitute a line of UV sources. The current through the flashboard is limited by the resistors on top of the unit. It is not desirable to continue operation of the preionizer after sufficient conditioning of the gas has been reached.

Since the net impedance of the flashboard and its current-limiting resistors are high compared to the thyratron plus lead impedance, the operation of the flashboard does not affect the voltage ramp on the main electrodes, 4. After a short time, the discharge voltage across the main electrodes, 4, is reached. This short time is important for the conditioning of the gas in the interaction space. If the time is too short or too long, filamentary discharge may occur, wasting energy and resulting in poor shot-to-shot reproducibility. If the preionization is inadequate, a full high current arc may occur, damaging the electrodes and producing no laser output.

The discharge between the main electrodes, 4, deposits energy in the gas. The upper laser level in the CO_2 molecule is excited, partly directly by electron impact and partly by resonant energy transfer from the metastable N_2.

Downward transitions radiate energy and upward transitions absorb energy. If the number capable of radiating exceeds the number capable of absorbing, there will be a net gain or amplification for radiation of the correct wavelength.

1.2.1 LASER RESONATOR

In the laser, there are two mirrors, 3a and 6a, located beyond the ends of the region between the electrodes, 4, which contain the excited gas. These mirrors are aligned so that radiation traveling nearly parallel to the axis of

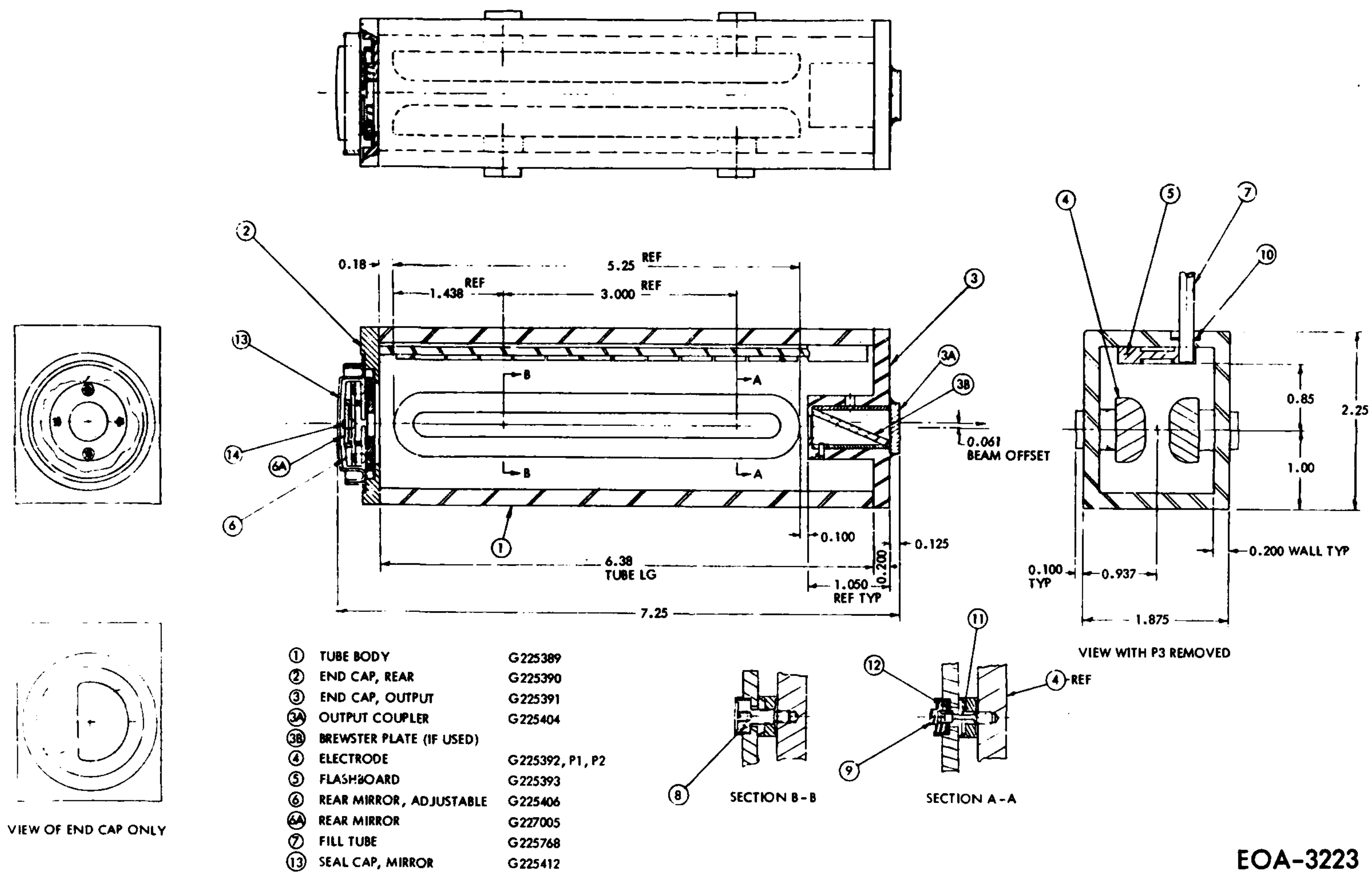


Figure 2. TEA Laser Tube Assembly

the tube will be reflected into the excited medium. The initial radiation comes from a spontaneous transition. The excited medium amplifies this radiation by stimulated emission. The mirrors direct the radiation through the excited medium where amplification occurs again and again in an avalanching process. As a result, a very high peak power pulse of several hundred kilowatts is reached before using up the stored energy. The remaining long-lived metastable nitrogen molecules can now give up their energy by repumping the relaxed CO_2 molecules. This gives rise to afterpulsing.

The mirror, 3a, designated as the output coupler is made partially transmitting. A fraction of the radiation falling on it passes through as the output beam.

The other mirror, 6a, is a concave mirror of long radius of curvature. The mirrors in conjunction with the aperture, 3d, are chosen and arranged to produce single-mode output, approximately TEM_{00}. This mode results in the smallest beam divergence for the best usage of the excited medium.

1.2.2 ACHIEVING LINEAR POLARIZATION

If it is necessary to have a polarized output beam, a thin plate of zinc selenide would be installed at Brewster's angle which transmits one plane (p) of polarization with almost no loss. Hence, the output oscillates in the p plane.

The Brewster plate would be held in place between two wedge-cut pieces of ceramic tubing. These hold the Brewster plate in a cylinder which locates inside the cylindrical aperture support, part of the output end cap, 3.

1.3 STATE OF THE ART, 1979 - 1980

Prior to the beginning of this program, a flowing gas TEA CO_2 laser using MACOR, a machinable ceramic material, was developed by Raytheon for military rangefinding applications. Two rangefinders using this laser design were built: one was installed in the high survivability test vehicle light HSTV(L); the other, among other things, was field tested in Germany by Raytheon on the Gepard vehicle. These units operated at 5 Hz repetition rate and used a 46% CO_2 mixture. It was demonstrated during the development program that afterpulsing was capable of producing false target information in the last pulse logic mode. Last pulse logic means that the counter keeps running until the gate for the maximum range is reached and the digital range word for each target echo returned is put into a shift register which is updated by each return. Thus, the last pulse within the range gate setting is considered the target.

At the inception of Raytheon laser rangefinder investigations, the TEA lasers then in use had wire preionizers. A thin tungsten wire was stretched along each side of the main electrode gap. These wires sprayed electrons into the gap to condition the gas.

The mechanical resonance of these wires was below the maximum safe frequency of vibration for treaded armored vehicles. Vibration tests showed them to be prone to damage. The Raytheon Research Division was asked to investigate a rigid preionization scheme for these miniature lasers. They developed a simple sliding arc preionizer.

Imagine an output pulse which has a secondary pulse 100 nanoseconds past the main pulses. The main pulse starts the clock but the last pulse will always be the secondary pulse, indicating a range 46 feet after the true target.

In first pulse logic where the main pulse only produces a range indication, this problem does not arise. This first return is stored by the shift register but the range counter is stopped and the presence or absence of secondary pulses is of no consequence as far as the rangefinder is concerned. However, secondary pulsing and energy in the tail is wasted. The useless radiation stresses the optics needlessly. Narcissus will keep the detector "hung up" longer which effectively increases the closest range which can be precisely measured.

During the Raytheon laser development program, it was discovered that the ratio of the main spike energy to the energy in the tail increased as the concentration of CO_2 increased. On the other hand, the shot-to-shot reproducibility deteriorated as the CO_2 percentage was increased. An effective compromise was reached at 46% CO_2.

A systematic method for selecting a mixture was developed.* By plotting contours of equal laser performance on a map of helium concentration vs CO_2 concentration coordinates for different laser electrode spacings, a method for selecting the best match for the laser and the gas became available for a particular electrical driving circuit. The driving circuit used then, shown in Figure 3, depended on the race between the flashboard firing and the application of high voltage to the main gap.

In this driving circuit, firing the spark gap produces a voltage rate of change across the main gap and the flashboard. The series button flashboard, an equivalent circuit of which is shown in Figure 4, fires gap by gap, step by step and thus requires some time interval to radiate UV fully from all gaps.

The breakdown voltage per gap is a function of helium concentration. The more helium, the lower the voltage and the sooner the flashboard generates UV before the main gap breaks down. More helium means less CO_2. Conversely, high CO_2 concentrations lead to poor shot-to-shot reproducibility and eventually arc over becomes too frequent. Recall that all this experimentation was performed with the circuit of Figure 3. When the driving circuit is modified to increase the time delay between preionization and application of main gap voltage, the shot-to-shot reproducibility improves.

Another method of improving the timing which was investigated places all the flashboard electrodes in parallel, discharging to a common electrode as shown in Figure 5. Decoupling resistors are needed to prevent the first arc from discharging all the stored energy. An experimental laser using this arrangement exhibited very good shot-to-shot reproducibility. The concept was not actively pursued because outgassing of resistors was anticipated to be a contaminating factor in sealed-off tube operation.

*W.M. Lipchak and C.F. Luck, Rev. Sci. Instrum., November 1982, p. 1785.

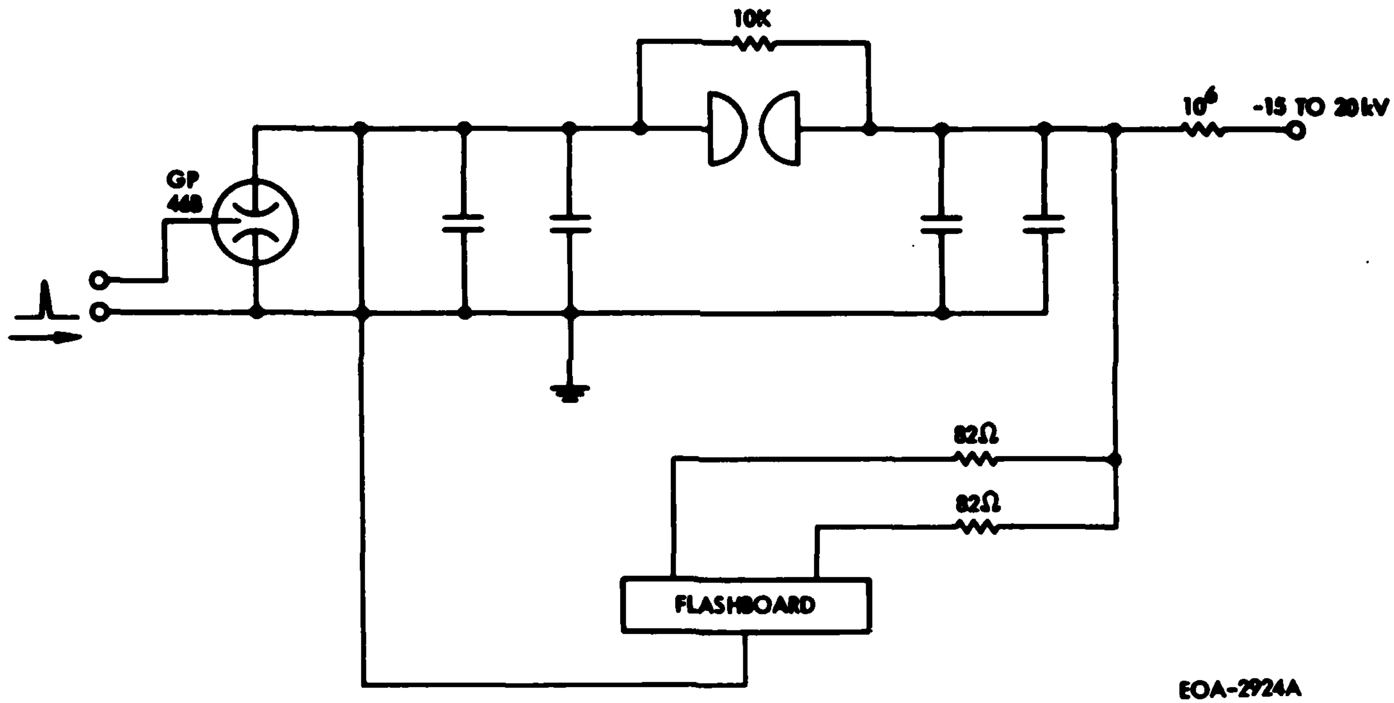


Figure 3. Early PFN

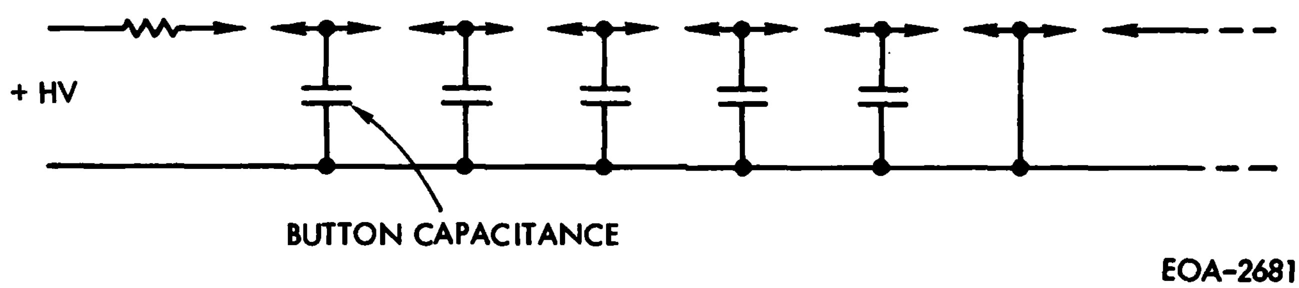


Figure 4. Equivalent Circuit of Flashboard

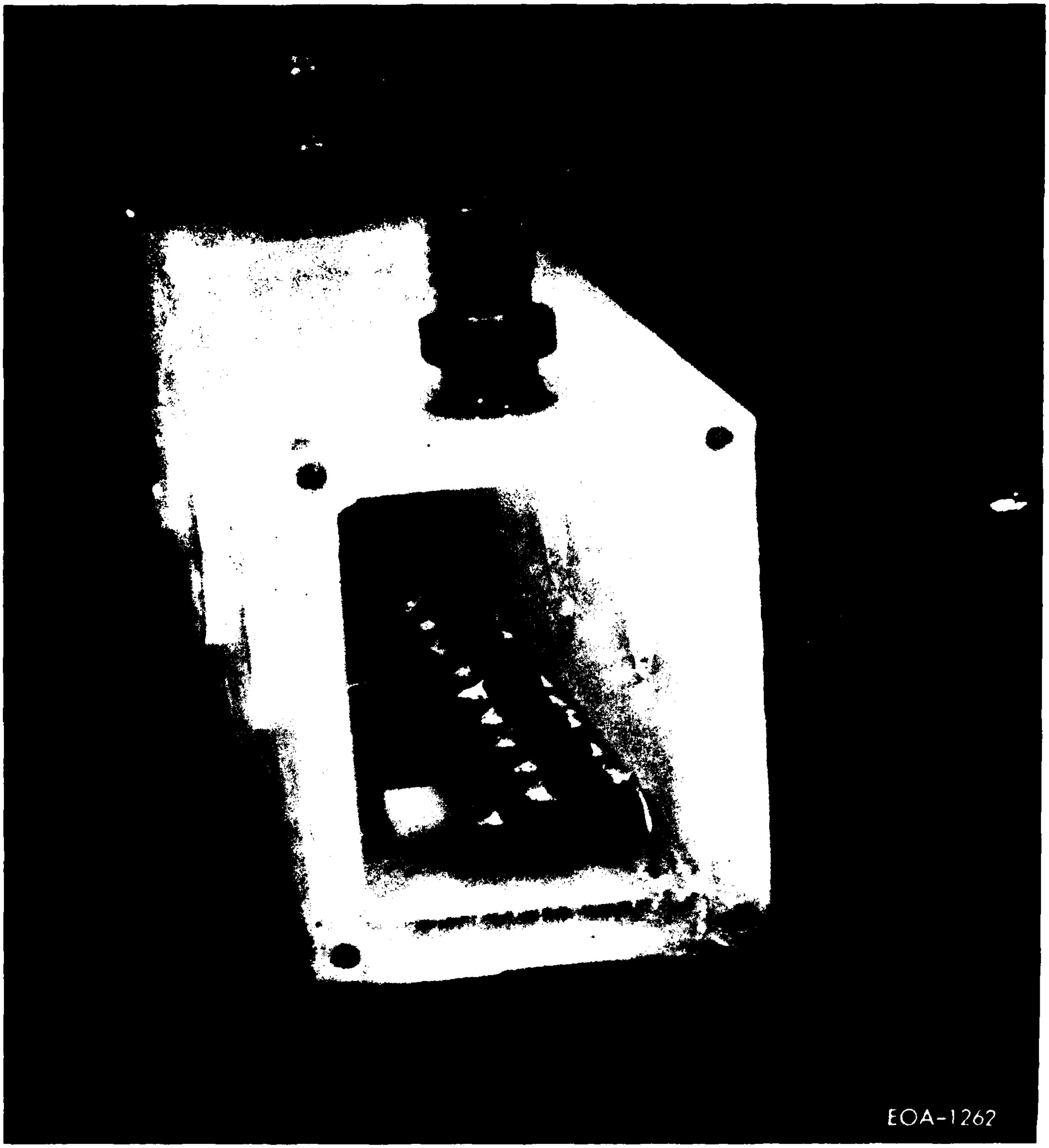


Figure 5. Parallel Flashboard Installed in a Demountable Tube

1.4 TEA CO_2 LASER RESEARCH

The Raytheon Research Division investigated TEA CO_2 laser designs using series flashboards with glass dielectric substrates. These lasers used rectangular cross-section Pyrex glass for their body structures. Assembled with epoxy adhesives, Brewster-angled windows were used at the ends and the mirrors were both external to the laser envelope. In this way, the research effort was directed toward gas composition effects isolated from the mirror damage aspect of life expectancy.,

They found that CO_2 decomposition occurred as expected. They also found a material, developed for gas masks, which seemed to work as a catalyst to combine the O_2 and CO formed by the electric discharge. Unfortunately their work was masked by their use of epoxy. These adhesives use various amines as hardeners. The amines have been shown to assist laser operation but they also form carbonaceous decomposition products leading to contamination within the tube. There were indications that the catalyst should be very effective. Indeed, it is very useful in extending the life of CW waveguide lasers.

1.5 THE RAYTHEON PROPOSAL

The TEA CO_2 laser tube proposed in response to the RFP for the MM&T program was a synthesis of the Research Division life test experience and the tank rangefinder machinable ceramic laser tube experience. Figure 6 is a drawing of the laser as proposed by Raytheon which was responsive to the RFP. Due to packaging constraints previously unrecognized, the rangefinder manufacturer required some reduction in dimensions for the laser to fit the housing. The allowed overall length was reduced from 8.00 to 7.323 inches. The allowed cross section was reduced from 2.38 X 2.50 to 2.01 X 2.36 (inches by inches). These reductions occurred in the contract. The RFP had the larger dimensions.

As it turned out, the reduction in length was a serious problem. To achieve the energy in a TEM_{00} mode distribution, the mode volume must be as large as possible. This means the use of a long radius-of-curvature rear mirror. This in turn results in extremely tight alignment tolerances. The thick mode must fit very closely and symmetrically within the main electrodes requiring great precision in the electrode mounting structures.

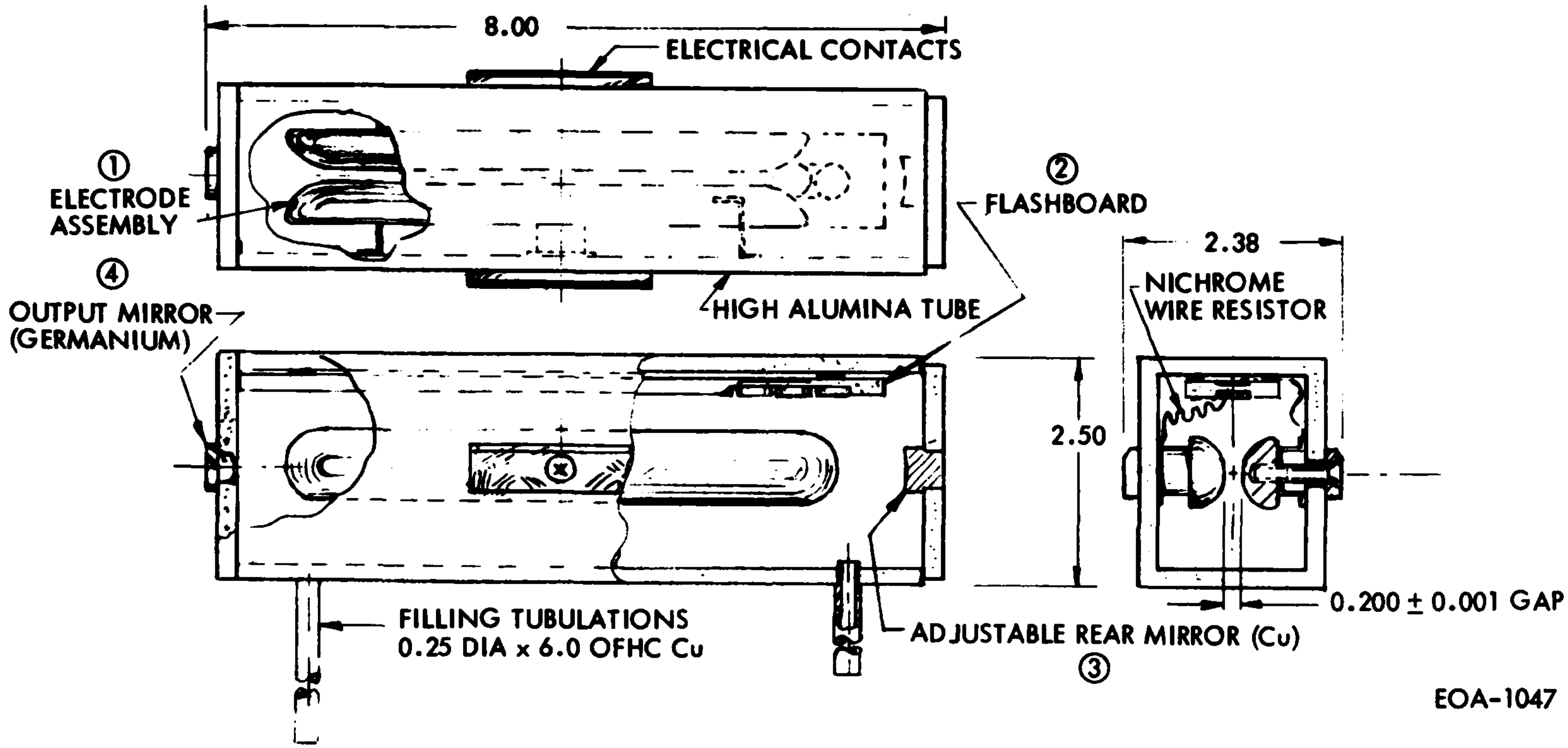


Figure 6. Permanent Seal Laser

1.6 POLARIZATION

Another prospective change required by the rangefinder manufacturer was polarization. This requirement did not receive official status during the program. This would have the effects of introducing a small amount of loss because of the extra optical component in the resonator and the shortening of the length of the excited volume available.

1.7 PROBLEMS ENCOUNTERED

The first sealable ceramic laser built using high alumina ceramic and an all-brazed structure, with the exception of the output coupler, used a 46% CO_2 mixture. It began to arc and had a very poor shot-to-shot reproducibility within a few thousand shots. The gas composition was altered by the electrical discharge. There was some recovery overnight, but not enough to declare this tube a success. Making the tube relatively clean with a minimum of exposed epoxy was not the answer.

1.7.1 GAS DECOMPOSITION

In order to investigate gas decomposition, an analytic instrument to test gas samples is required. The laboratory was already equipped with a Liebold-Heraeus mass spectrometer coupled to an Inficon data display. The mass spectrometer measures the mass of atomic species. It does so by ionizing the gas under test and then allowing the ions to pass through an orifice into the spectrometer. Consider the CO_2 decomposition equation:

$$2\ CO_2 \rightarrow 2\ CO + O_2$$

The mass spectrometer would detect both CO and the gas ever present in these laser mixtures, N_2 (both mass 28) the same. Yet this reaction is probably the one most responsible for sealed laser failures due to arcing.*

An instrument which can detect different molecular species and quantify them in a mixture is a gas chromatograph. This is a comparison instrument requiring calibration standards.

*Shields, H., Smith, A.L.S., and Norris, B. J. Phys D,9 (1976).

1.7.1.1 Gas Chromatography

The gas chromatograph works by measuring the travel time of the components of a gas sample through a "column" which is actually a length of metal tubing filled with a material such as silica gel which acts as a labyrinth having different flow rates for different molecules. The gas mixture is introduced into a constant flow rate of a carrier gas, typically an inert gas such as helium. At the exit end a detector measures some property which differs from the carrier gas for each species to be detected. Thermal conductivity is a convenient property to instrument. Thus the chromatograph plots the thermal conductivity of the effluent gas as a function of time after injecting the sample.

Raytheon acquired a Perkin-Elmer Sigma 115 gas chromatographic system to use for laser gas measurement. This instrument has a microprocessor and printer to plot the chromatographic peaks and valleys. It also relates this to percentage composition. Correction factors based on calibration samples can be incorporated as well. Different column filling materials have different calibration factors so the columns must be chosen to enhance the contrast of the expected molecular species.

1.7.1.2 Sampling Technique

A sample for the gas chromatograph is obtained by inserting the needle of a gas sampling syringe into a soft rubber septum in the gas line attached to the laser. Pulling back the plunger extracts a small sample of gas. The septum reseals after withdrawal of the needle. The needle is then inserted into another septum located at the entrance to the column on the chromatograph. Pushing the plunger "in" firmly starts the sample through the column.

During the course of many test runs, the septum on the laser was found to leak occasionally. Therefore, a diaphragm valve was installed between the septum and the laser. The volume which communicates with the septum was evacuated through another diaphragm valve before sampling. The laser-side valve was opened briefly after closing the evacuation valve. Gas expands into the septum chamber. Closing the laser-side valve again permits syringe sampling of the gas without risking leakage to the air. Figure 7 is a diagram of the laser plumbing. The second tube into the laser body permits flowing gas testing to

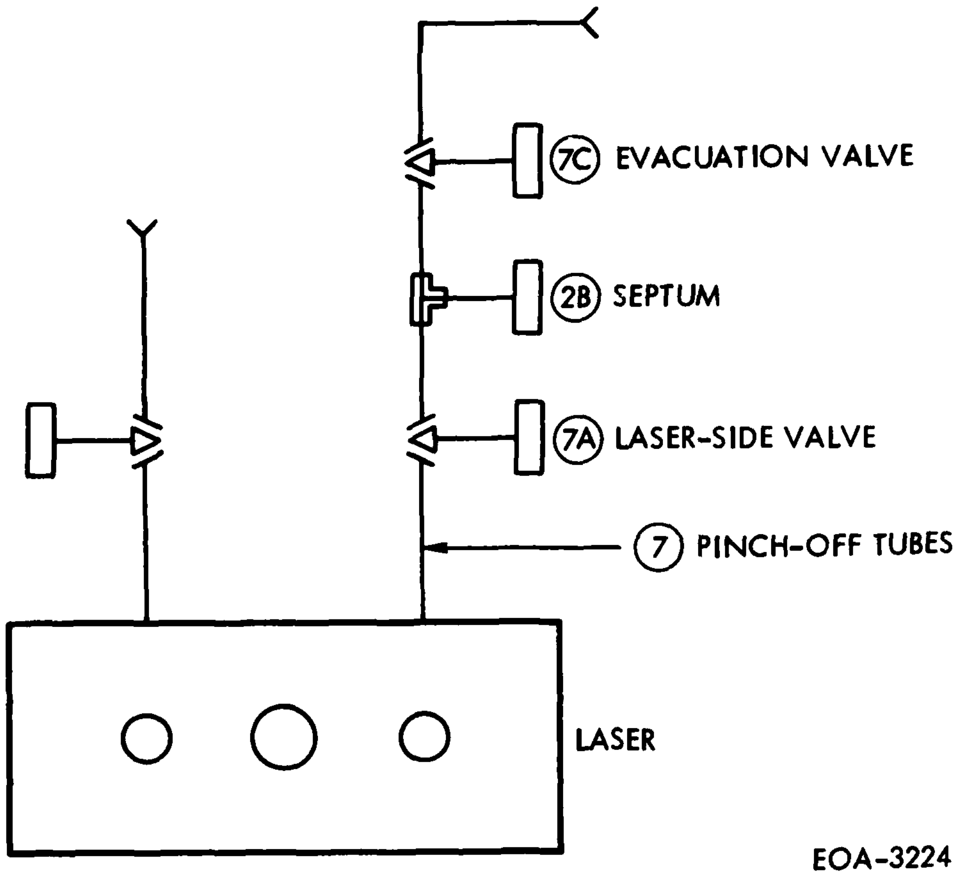


Figure 7. Laser Plumbing

be done. In a suitable fabricated laser, the tubes would be pinched off close to the laser. The valves and septum are for gas mixture investigation only.

1.7.2 CHOICE OF GAS MIXTURE

Assuming a gas-tight envelope, there can be no loss of helium. The carbon dioxide content can change however by decomposition of the CO_2 molecule due to electronic excitation. Oxygen appears as O, O_2, and O_3. Atomic oxygen and ozone are extremely reactive and may combine with metals in the tube structure. The oxide film may alter tube behavior. Aluminum main electrodes formed a non-conducting oxide layer which adversely affected the discharge. Of course, the concentration of CO_2 in the gas mixture decreased. The presence of gaseous oxygen tends to promote arcs by capturing electrons defeating the preionization.

There is a dilemma; removing the oxygen helps the arc problem but prevents recombination with CO to reform CO_2 and the oxide layer may alter the discharge conditions. Apparently, some recombination does occur. Replacing some of the nitrogen with CO so there is an excess of CO on the right side of the equation helps the recombination. But nitrogen is needed to help UV generation in the flashboard so that a compromise between CO and N_2 must be reached. Recombination is also assisted by a fraction of a percent of hydrogen according to the reaction:

$$CO^* + OH \rightarrow CO_2^* + H$$

A mixture of 15% CO_2 will recombine rapidly enough to allow continuous pulsing at a 1-Hz repetition rate without deteriorating and hence spoiling the laser operation. The gas mixture arrived at is: 15% CO_2, 11% N_2, 4% CO, 0.7% H_2, balance helium.* More than 15% CO_2, shot-to-shot reproducibility rapidly degrades. Life expectancy testing proceeded with this mixture as a standard.

1.7.3 MIRROR LIFE EXPECTANCY

The next serious life-limiting problem was mirror damage. Enlarging the beam diameter made it possible for mirrors to survive but at the expense of

*Paul W. Pace and Marc LaCombe, "A Sealed High-Repetition-Rate TEA CO_2 Laser," IEEE J. Quantum Electron, QE-14, 263 (1978).

much more stringent alignment specifications. Of course extreme cleanliness is required to avoid contamination of mirror surfaces. Copper flashboard buttons, for example, sputtered copper onto the mirror, inducing coating damage. Tungsten buttons also produced particles which lead to mirror coating damage.

Electron microscopy and electron spectroscopy for chemical analysis techniques were used to analyze surface films for contaminating species. Molybdenum has emerged as the best flashboard button material tried.

1.8 EXPERIMENTAL LASERS

Lasers for test were built with parts along the lines of Figure 8. The diaphragm valves and the septum are shown at the top. The body of rectangular ceramic tubing is shown in the middle with the end caps, rear mirror and output coupler assemblies at the ends. The copper main electrodes and their mounting hardware are also shown. Note the "D" hole in the rear ceramic part which prevents arc-over between the rear mirror structure and one end of a main electrode.

At the left of the rear end cap, the ceramic rear aperture, the flexure pivot gimbal and the special screws for adjustment, although sealed, are shown.

At the right-hand end, the output coupler mount is shown beyond the ceramic end cap. It was observed previously that some output coupler distortion occurred with direct epoxy attachment of the coupler to the end cap.

Between the output end cap and the body tube is a ceramic block with a mode control aperture machined in place.

Lasers built with these components have been tested. To overcome problems assumed to be due to the "O" ring seals around the rear mirror screws, short screws were used on another laser which was then closed with a one-piece rear mirror cover. This prevented rear mirror adjustment after sealing, a crude simulation of the eventual production model. Testing of this laser revealed thermal drift of the alignment probably due to dimensional change of the epoxy films used to fasten the mirror holder parts together.

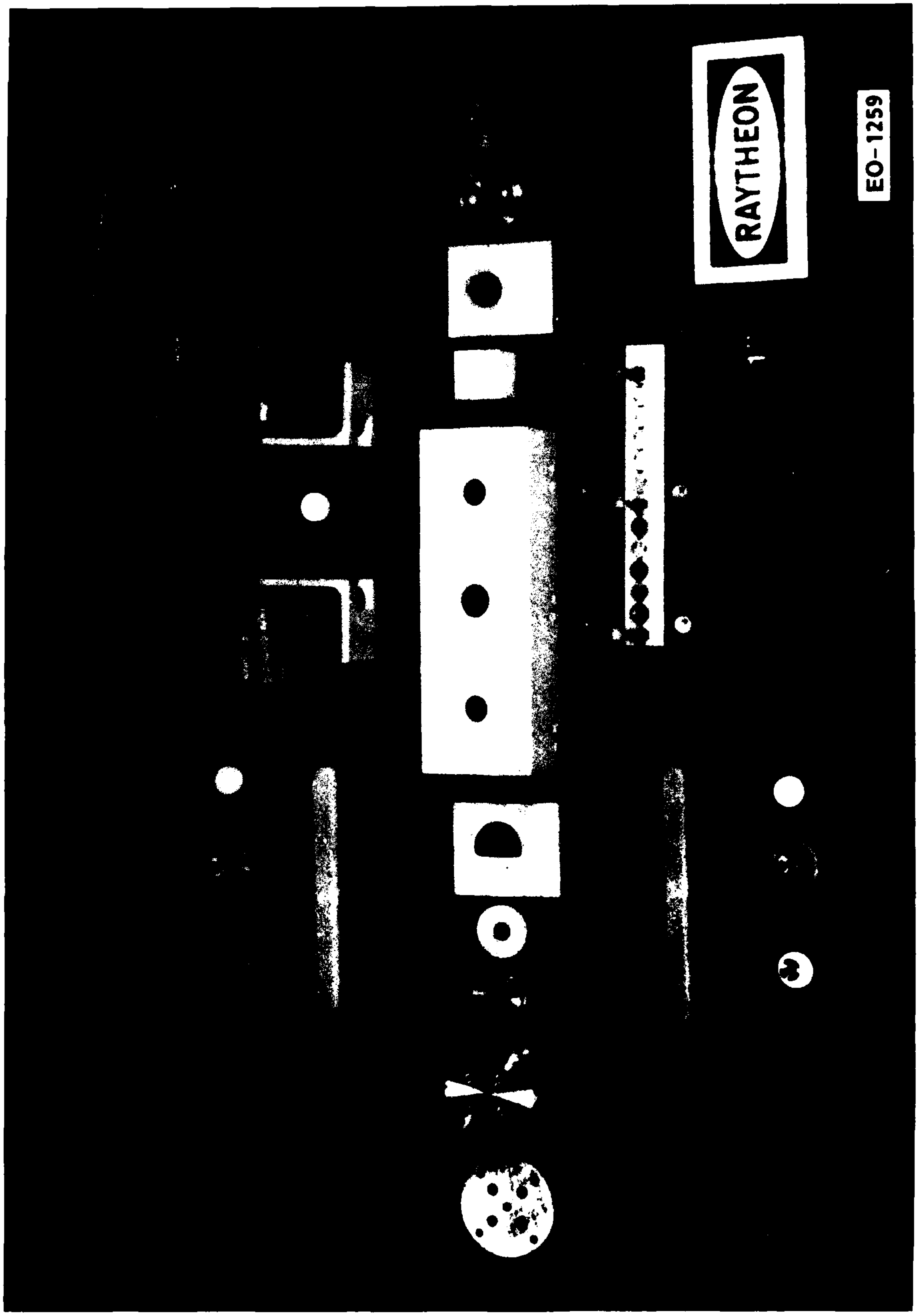


Figure 8. Experimental Laser

1.8.1 DETAILED EXPERIMENTAL FINDINGS, PROBLEMS AND SOLUTIONS

To investigate several new design and construction concepts for lasers, two experimental laser tubes were built. The concepts to be investigated are:

- An adjustable mirror mount for the internal rear mirror,
- Mirror alignment procedure using an autocollimator.

These were the last two laser tubes constructed under this contract. There was no modification to the design concepts because of time and funding limitations.

1.8.1.1 Tube Construction

Figure 8 shows an exploded view of the first of these two experimental tubes. The body is rectangular, made of dense alumina ceramic. With the exception of the flashboard assembly, none of the parts in this tube were metalized or brazed and E-7 epoxy was used extensively for fastening and envelope sealing operations. The use of epoxy allows critical evaluations of the above design concepts without much loss of time. The tube design and construction concepts have been approached with the understanding that, even though these tubes were fabricated for the most part using epoxy, an eventual switch to hard-sealing techniques, such as high temperature brazing for all tube parts other than the output coupler, and rear mirror is feasible.

Two Rogowski-like electrodes of oxygen-free copper with spacers were fastened to the inside surfaces of the tube body using stainless steel screws and hole covers; small metal shims were used to achieve correct electrode spacing and parallelism.* On the inside bottom side of the tube body, three similar but smaller hole covers and screws were used to hold down a sliding-arc preionizer (flashboard) consisting of two linear arrays of molybdenum buttons. Hoke brand bellows valves epoxied to the top side of the tube were used for exhaust and gas filling.

*The inner walls of the ceramic body are not flat and parallel enough to use as reference surfaces for electrode alignment.

1.8.1.1.1 Optical Axis Alignment

With the aid of a cathetometer, the discharge axis of the laser tube, defined as the axially directed line through the center of the discharge space between the main electrodes, was located and marked with thin cross wires at each open end of the tube body.

The axis of an autocollimating telescope was then adjusted until it coincided with the discharge axis. An end-plate assembly consisting of a ceramic end plate was inserted into the laser tube body. With the discharge axis oriented vertically, the center of the mode-limiting aperture was made to coincide with the cross hair in the autocollimator by adjusting the end-plate assembly as a whole. This assembly was epoxied to the tube body.

Next, a ZnSe output coupler was placed on top of the stainless steel coupler holder which had previously been epoxied to the ceramic end plate. The output coupler was then viewed through the autocollimator and a small thin shim was used to tilt the output coupler for retroreflection to within 20 seconds. The output coupler was then epoxied to the stainless steel holder (Note: Figure 8 shows that the coupler holder has an "O" ring which was not used in the second of the two laser tubes under consideration.)

Finally, a rear mirror assembly, adhered with epoxy, consisted of a ceramic end plate with a D-shaped hole, rear aperture ceramic wafer, rear mirror mount and BeCu mirror, was epoxied to the rear end face of the tube. With the aid of a Fizeau-type unequal path interferometer, Zygo Model GH, the tilt of the rear concave mirror was then adjusted until the interference fringes were concentric with the image of this mode-limiting aperture. The rear mirror mount permits tilt adjustment.

1.8.1.1.2 Rear Mirror Mount

Figure 9 shows the design of the rear mirror mount which is made of one piece of Kovar. There are three layers or disks, each with a central hole, and the middle disk is connected to the two outer disks. One of the outside disks holds the mirror and the other disk is connected to the rear aperture wafer. Small altitude and azimuth angular motions can be performed by adjusting four

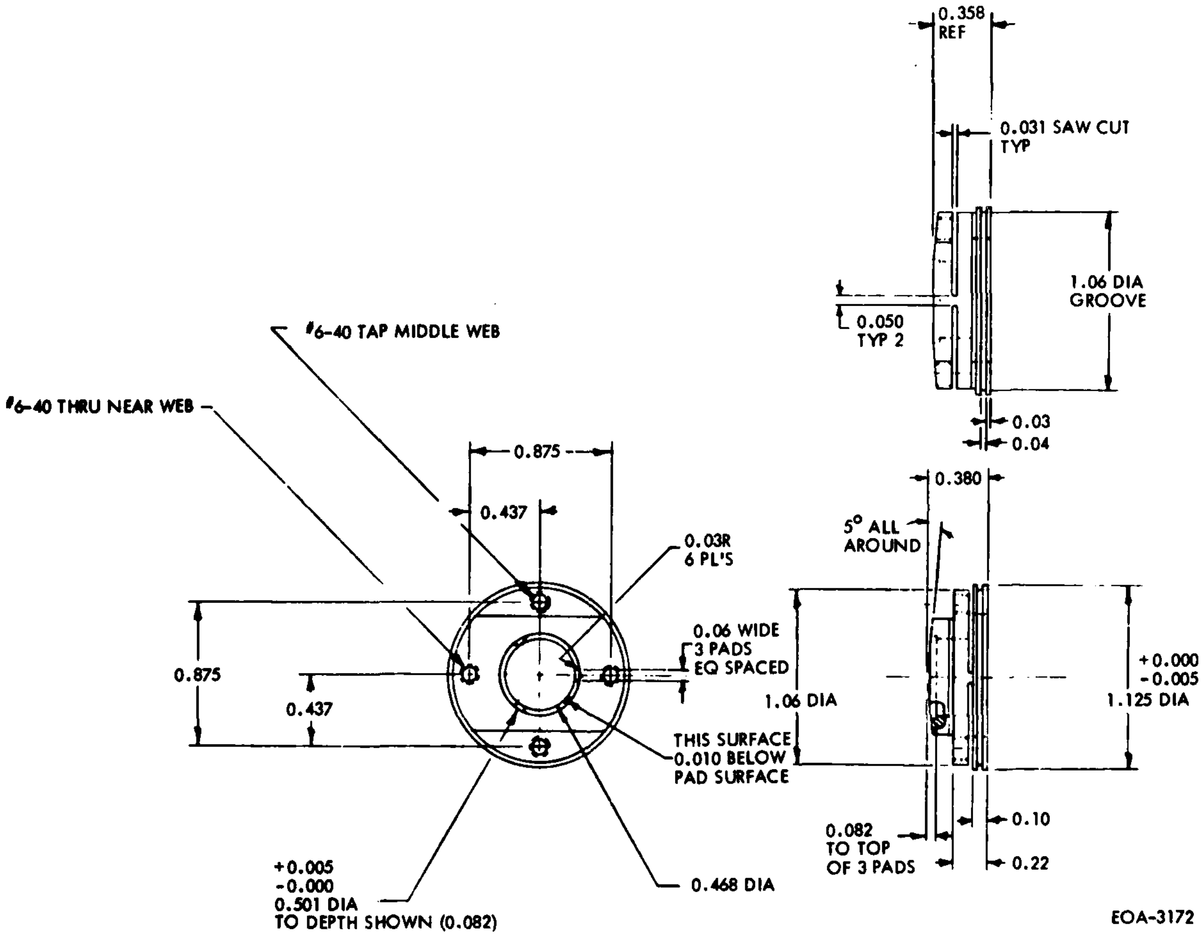


Figure 9. Rear Mirror Mount

fine-threaded screws which are equally spaced on a 0.875-inch diameter circle. This comes about because the advance motion of the screw tips causes a slight bending motion of the webs connecting the disks relative to one another. In particular, for the 6-40 screws used, a fine adjustment of about 15 seconds of arc in the mirror tilt requires that the angular rotation of the screws be as small as 1°. Since no lubricant was permitted on the screw thread, fine adjustment of the screws was an exacting task.

1.8.2 EXPERIMENTAL TEST AND MEASUREMENT SETUP

The experimental setup for energy and power measurement and the life test of the TEA CO_2 lasers is described. Figure 10 is a schematic diagram of the experimental setup. The laser is placed in a pulse-forming network (PFN) which uses a hydrogen thyratron for high voltage and high current switching. A peaking capacitor is used across the main electrodes to effect a proper time delay between the firing of the preionizer and the main electrodes for optimum TEA CO_2 laser operation. Figure 11 is a photograph of the TEA CO_2 laser and its associated pulse-forming network; a more detailed description of both the PFN and its operating characteristics will be presented in Section 1.13 of this report. The main energy storage device was a large polypropylene capacitor, while the remaining capacitors were the doorknob-type with barium titanate dielectric.

For energy measurements, a GenTec Model ED200 pyroelectric detector was used and was periodically calibrated with a Scientech Model 38-0102 joulemeter. To measure the laser peak power and pulse shape, a Rofin Model 7441 photon drag detector was used. A storage oscilloscope, Tektronix Model 7834 with a 350 MHz bandwidth plug-in unit, was used for the pulse shape measurement.

For continuous life test at 1 Hz, a "laser minder" circuit was used. This device counted the number of laser output pulses and provided an emergency shut-off of the high voltage power supply in case of premature laser failure causing at least five consecutive laser output pulses to fall below a preset energy level.

1.8.3 ENERGY AND POWER MEASUREMENTS

After the laser was aligned with the Zygo Model GH interferometer, it was placed in the test setup. Using flowing premixed gas of 15:15:70::CO_2: N_2:He,

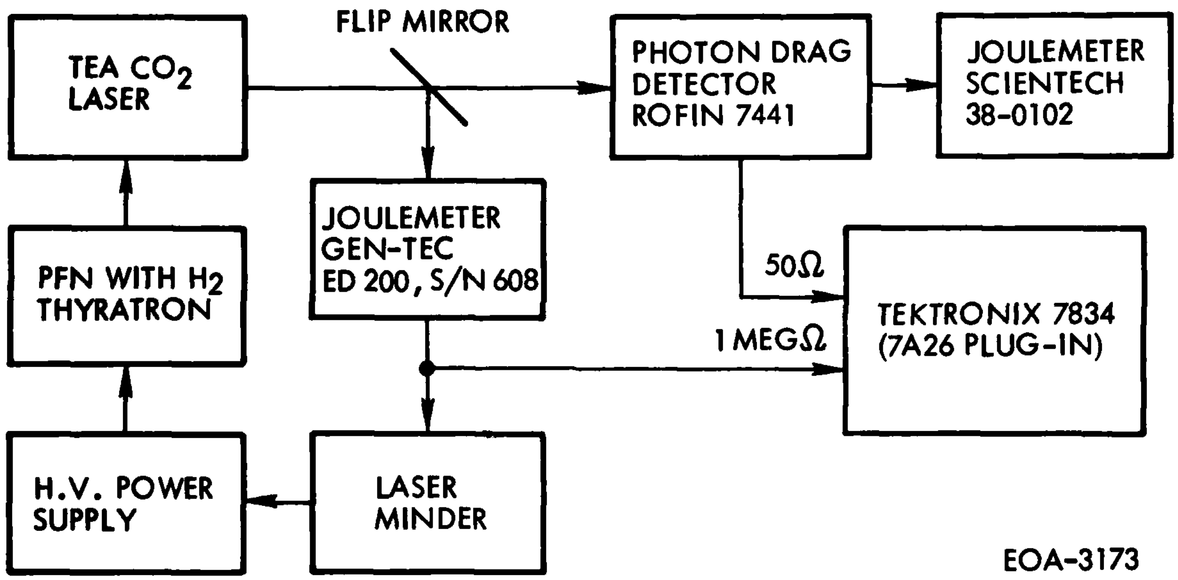
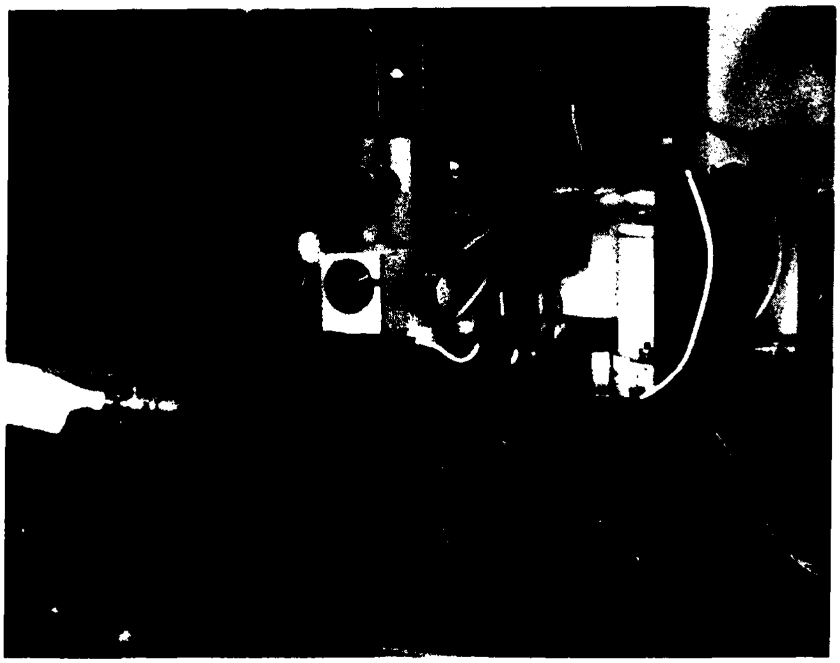


Figure 10. Schematic Diagram of Experimental Setup - TEA CO_2 Laser



EO-1423

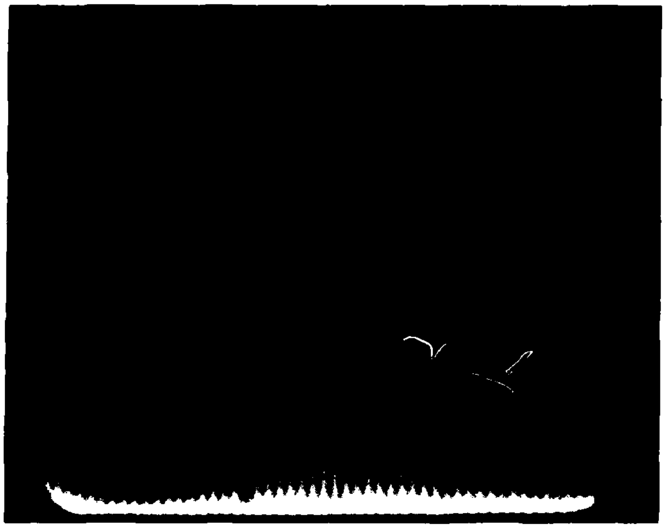
Figure 11. TEA CO_2 Laser with PFN in Measurement Setup

the energy output was measured to be about 42 mJ at a charging voltage of 15 kV for the 15 nF main capacitor. This was purposely done to determine the feasibility of using the Zygo interferometer for accurate prealignment. Subsequent fine-tuning of the laser rear mirror by lightly adjusting the 6-40 screws resulted in an increase in the output energy to about 53 mJ with a corresponding peak power of about 250 kW. Figure 12 shows the shot-to-shot energy output variation and Figure 13 shows the pulse shape recorded using the photon drag detector. It can be seen from Figure 12 that the energy output variation does not exceed $\pm 3\%$. Because of the slightly higher percentage of nitrogen used in the flowing gas mixture, the laser has a relatively large tail.

After this initial adjustment of the rear mirror with the laser operating, the vacuum cover which normally seals the rear mirror mount assembly is epoxied on the end plate. To reduce curing time, the joint was heated to 90°C for 2 hours with a heat lamp. After this curing, and after the temperature returned to room level, the energy and power using the same flowing gas mixture were found to be only about 44 mJ and 180 kW.

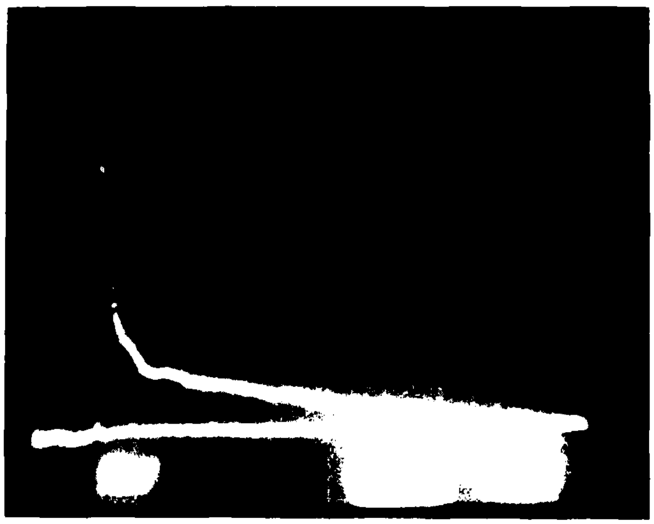
The mirror alignment was suspected to be off perhaps due to heating of the mirror mount or the epoxy which held the mirror to the Kovar holder, or to some slight loosening of the adjustment screws. Therefore, the cover over the mirror mount was removed and the tube was realigned using a flowing gas mixture. The energy and power returned to the same original values. To be a little more cautious, the adjustment screws were tightened with a slightly higher torque to assure positive seating in this last alignment.

After the above procedure, the laser end cover was sealed; using a heat lamp, the tube was baked at about 70°C for about 8 hours. The laser was then filled with a long-life gas mixture of 15:11:4:0.7:69.3::CO_2:N_2:C:H_2:He. Energy in the initial sealed-off operation was 12 mJ. After excluding the possibility of error in the gas filling procedure through gas chromatographic analysis of the gas in the laser, and by operating the laser with a flowing gas mixture, we concluded that the mirror alignment was out again perhaps due to the 70°C bakeout and the 90°C epoxy curing.



EO-1424

Figure 12. Energy Output Flowing Gas Mix



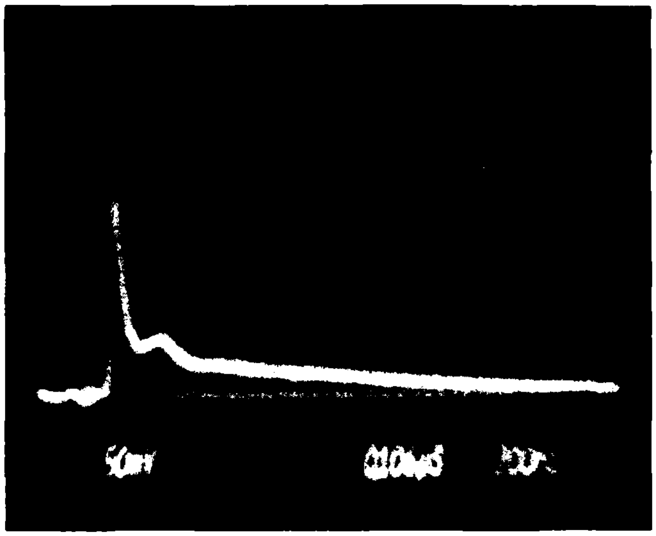
EO-1425

Figure 13. Power Output Flowing Gas Mix

The mirror cover was removed and the laser mirror was realigned using a flowing gas mixture. The energy and power were now slightly lower, 51 mJ and 225 kW, respectively, after the bakeout. Based on the above observation, it became obvious that either the present mirror mount design was not adequate and/or epoxy could not be used for fastening critical parts. For this reason, it was decided to bake the laser with flowing heated helium gas at 60°C for about 4 hours. After this was carried out, the laser power was found to be about 180 kW at 48 mJ using a flowing gas mixture. The mirror was next aligned to yield energy to 50 mJ and peak power to about 220 kW.

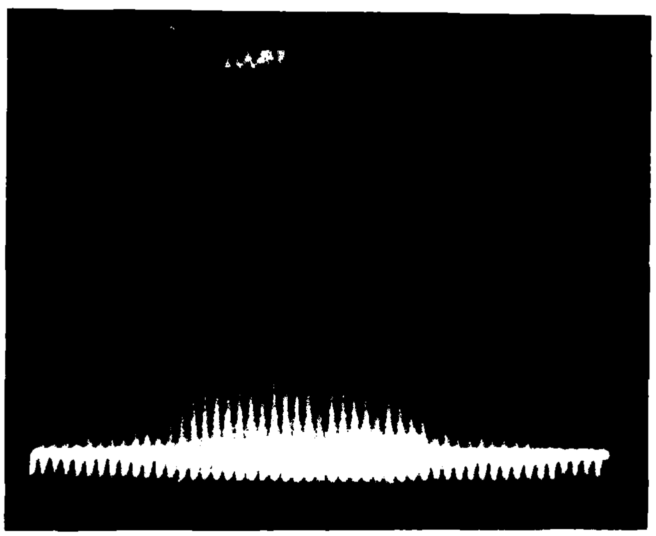
After performing some additional experiments which included running the laser sealed off at 1.2 atm with a long-life mixture containing 15% CO_2, we were ready to run the life test, and about 300,000 laser shots had already been accumulated. As a result, when the laser was filled to 1 atm with the long-life mix and the life test was started, the initial energy and peak power immediately after seal-off were 44 mJ and 180 kW respectively. Figures 14 and 15 show the energy and pulse shape near the start of the laser life test. Both the power and energy decayed rather rapidly near the start of the test but were stabilized after about 100,000 shots. Between 100,000 shots and 400,000 shots, the output levels remained relatively constant. Beyond 400,000 shots, the output decayed steadily. At 1.2 X 10^6 shots, the power and energy fell below one-half of the original values and the life test was terminated. Figures 16 and 17 show the power and energy output characteristics just before the laser life test was terminated. Throughout the life test, no missing pulses were noted and the pulse-to-pulse energy reproducibility was excellent. Figures 18 and 19 are plots of the laser energy and power vs the number of laser shots. At the end of the life test operation, the energy was only 19 mJ and the power was just about 80 kW. The laser gas was then analyzed using a gas chromatograph, Perkin-Elmer Model 115. Table 1 shows the gas analysis results. It shows that the CO_2 content had decreased from 15% to about 12.2%. There was very little O_2 and H_2O. The 0.23% O_2 presence was sufficiently low to not contribute to arcing in the discharge. In addition, the final gas pressure was found to be about 750 Torr indicating no loss of gas.

To determine the causes of the laser output degradation, several tests were performed after the life test was terminated at 1.2 X 10^6 shots.



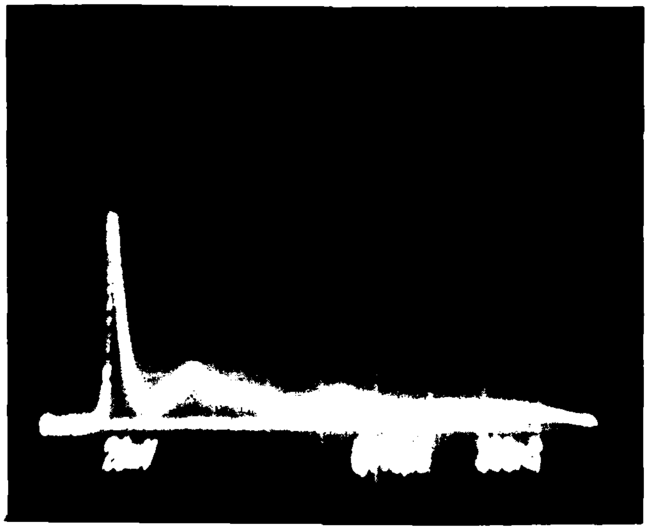
EO-1426

Figure 14. Power Output Initial Seal Off



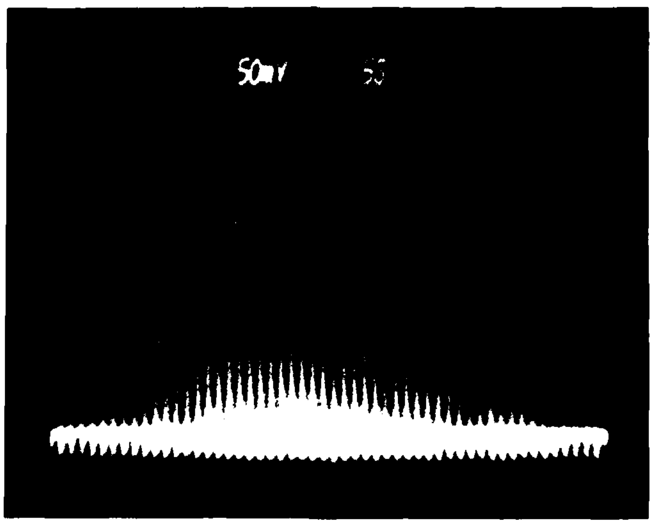
EO-1427

Figure 15. Energy Output Initial Seal Off



EO-1428

Figure 16. Power Output Final Seal Off



EO-1429

Figure 17. Energy Output Final Seal Off

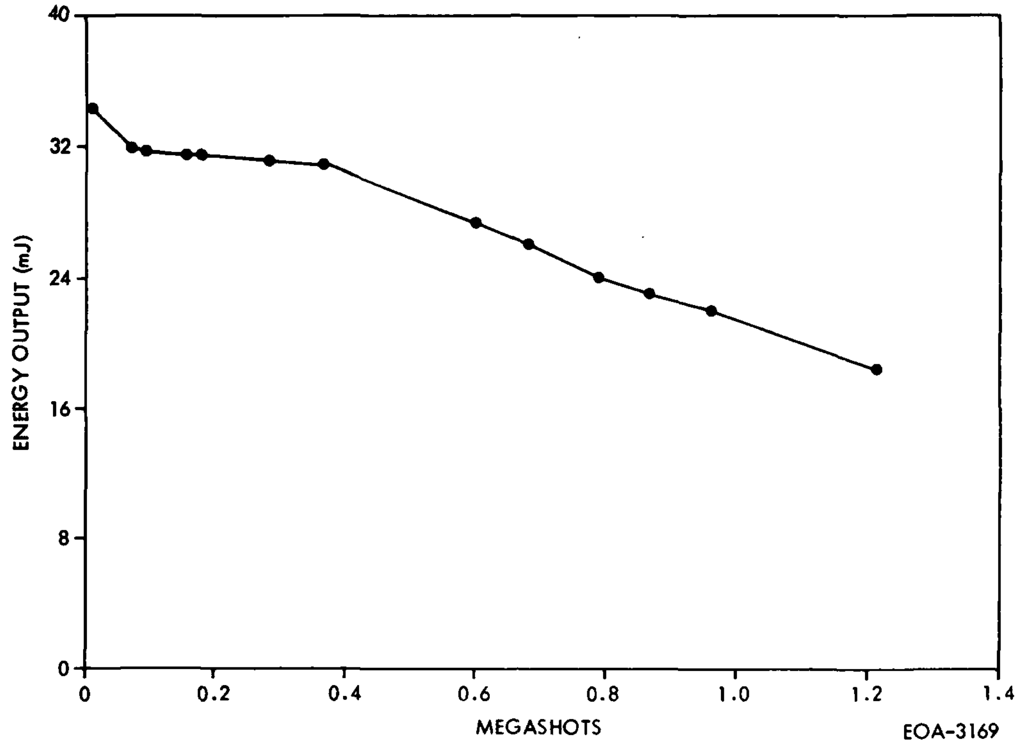


Figure 18. Energy Output vs Number of Laser Shots

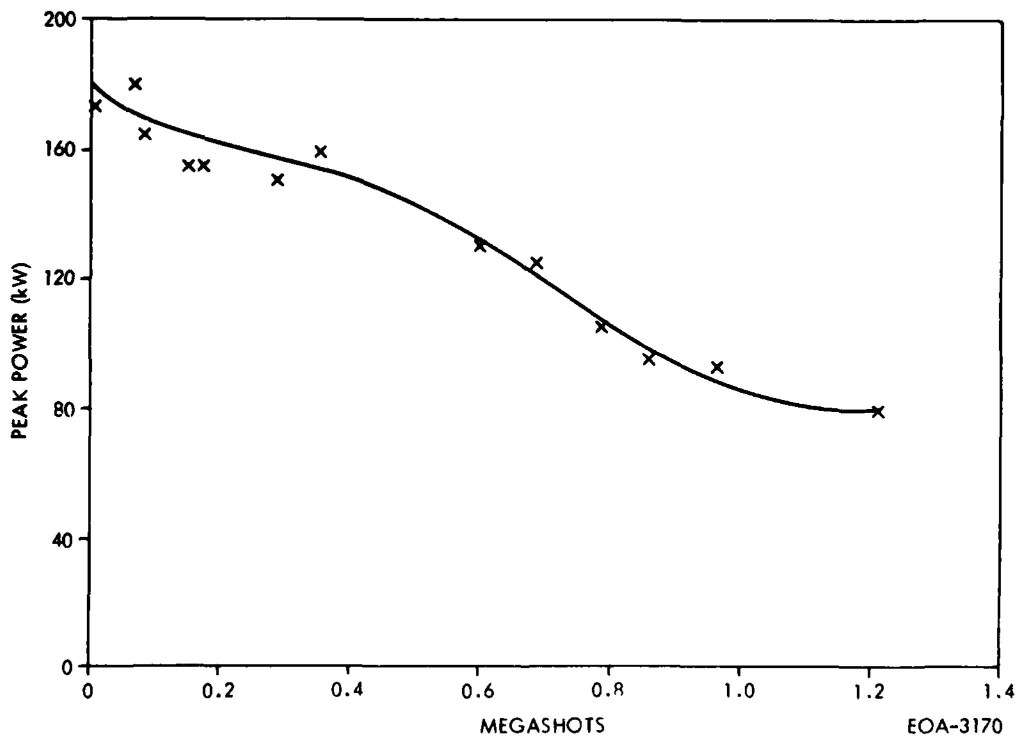


Figure 19. Peak Power Output vs Number of Laser Shots

TABLE 1. GAS CHROMATOGRAPHIC ANALYSIS OF LASER GAS MIXTURE

	Quantity in Percent	
Gas Component	After 1.2 X 10^6 Shots	Start
H_2	0.0044*	0.7
O_2	0.24	0
N_2	11.0	11.0
CO	7.2	4.0
CO_2	12.2	15.0
He	69.3**	69.3

*Detection sensitivity questionable.
**The 69.3% He content is assumed to remain constant.

a. The PFN was found to be in good working condition by testing it with a known laser in good working order.

b. After life test, the laser was run with the same flowing gas mixture; the energy and power were 34 mJ and 150 kW respectively.

c. The rear mirror was removed and the mirror surface was examined using electron spectroscopy for chemical analysis (ESCA). In particular, molybdenum was found. Molybdenum apparently evaporated from the preionizer buttons during normal tube operation.

1.8.4 RESULTS OF NEW CONCEPT INVESTIGATION

Of the new design concepts investigated, the mirror alignment procedure using an autocollimator appeared to be successful because we were able to obtain a very good laser output mode with high output power. The adjustable mirror mount used for holding the internal rear mirror did not appear to have sufficient stability under moderate thermal cycling such as occurred in the bakeout, although part of the loss of alignment could have been caused by creeping epoxy as it gradually cured.

After examining all of our data on the lasers, the following conclusion can be drawn.

The decrease in the laser energy and power can be accounted for as follows:

a. 20% caused by CO_2 dissociation

b. 5% caused by mirror misalignment through continuous normal laser operation

c. 5 to 10% caused by electrode and preionizer deterioration

d. 15 to 20% caused by optical damage to the optics.

Among the above items, only the first is backed by good experimental evidence. The laser degradation in item b. can be minimized using high temperature brazed joints rather than epoxy. Better choices of materials such as nickel for the electrode and smoothly finished tungsten for the preionizer buttons could reduce the laser degradation rate in item c.

A better shielding around the preionizer could be effective in reducing the surface contamination problem mentioned in item d. above; in this regard, the preionizer discharge current should be set as low as possible, contrary to the mode of operation used in these experiments.

1.9 TUBE REQUIREMENTS

The temperature, shock and vibration environments which the tube will be subjected to are summarized in Table 2. The laser structure was designed to meet these environments with a comfortable margin.

Previous development of experimental lasers has provided a set of conditions which the laser must also meet to operate for the 2 X 10^6 shot-life expectancy required. The recipe, given in Table 3, is not necessarily the optimum but it is workable and will produce long-lived tubes.

The design problem is to produce a tube which holds together under mechanical and thermal environmental and internal stress. The optics form a Fabry-Perot interferometer with one shallow curved mirror. Periodically an electrical storm is unleashed within the interferometer. When the laser operates, a strong shock wave also occurs which adds to the storm effect. The flashboard produces ultraviolet radiation. Thus, inside the tube is a hostile environment as well.

TABLE 2. TEMPERATURE, SHOCK AND VIBRATION ENVIRONMENT

ENVIRONMENTAL CONDITIONS

Air Pressure:

a. The laser shall operate within specified performance requirements over a range of atmospheric pressure from 19.5 inches of mercury to 33.00 inches of mercury.

b. The laser shall not be damaged nor shall its subsequent performance be impaired after being exposed to an atmospheric pressure of 2.96 inches of mercury for a period of four hours.

High Temperature:

a. The laser shall operate at temperatures from +32° to +125°F.

b. The laser shall operate after a storage at +160°F.

Low Temperature:

a. The laser shall operate at all temperatures from +32° to -25°F.

b. The laser shall not be damaged by exposure to temperatures down to -70°F.

Temperature Shock:

a. The laser shall not be damaged by exposure to the following thermal shocks:

   (1) From a stabilized temperature of +70° to -20°F within 5 minutes.

   (2) From a stabilized temperature of -20° to +70°F within 5 minutes.

EXTRANATURAL PHENOMENA (DYNAMIC-SERVICE ENVIRONMENT)

Vibration with Laser Mounted in Holding Fixture:

a. Ambient. Damage shall not result from exposure to sinusoidal vibration input load as follows: 1-inch double amplitude displacement from 5 to 9 Hz and 4.0g's from 9 to 500 Hz.

b. Temperature. Damage shall not result from exposure to vibration as specified above combined with the high and low operating tempertures.

Shock with Laser Mounted in Holding Fixture:

a. Basic Design 40 g's; 18 ms; 1/2 sine. Three shocks along three orthogonal axes in both directions, 18 shocks total.

b. High Intensity. 100 g's; 2 ms; 1/2 sine. Three shocks along three orthogonal axes in both directions, 18 shocks total.

TABLE 3. RECIPE FOR LONG LIVED TUBE

<u>Electrodes</u>:
OFHC copper sandblasted spaced 0.315 ± 0.005 inch, parallelism within 0.002 inch, cant angle (to compensate electric field for flashboard asymmetry) 2 minutes of arc.
<u>Flashboard</u>:
13 molybdenum buttons on 0.100-inch thick Al_2O_3 substrate spaced 0.030 inch, tapered to force arcs to occur above surface of substrate.
<u>Optics</u>:
Output coupler ZnSe flat 79%R. Rear mirror, 20-meter radius of curvature concave, aperture, 0.285-inch diameter of Al_2O_3 ceramic, optical alignment within 36 μrad.
<u>Gas Fill</u>:
15% CO_2, 11% N_2, 4% CO, 0.7% H_2, balance helium.
<u>Processing</u>:
Solvent/methanol, ultrasonic cleaning, plasma ashing, vacuum bakeout (10^{-7} mm Hg), back fill and seal.
<u>Structure</u>:
High alumina Raytheon ceramic and molytitanium metalization for furnace brazing using gold-silver alloy and nickel-gold alloy, etc., permitting step brazing. Output coupler soldered by special vacuum technique. Room temperature sealing with heliarc welding.

Many experimental tubes were built and tested to define the recipe for laser components which survive the assaults, both internal and external.

Appendix J lists the experimental tubes and their parameters from which the recipe was drawn.

1.10 SUMMARY OF LIFE TEST REQUIREMENTS

The following steps are quoted or derived from the indicated paragraphs of the contract. They may be assembled in a time line, since the 2 X 10^6 shots are performed at the rate of one shot/second, the specified pulse repetition rate (Paragraph 3.5.10).

Step	Ref. Paragraph	Test
1	3.5.1	1000-shot full input burn-in.
2	-	Start counting toward 2 X 10^6 shots.
3	3.5.5	Peak pulse output to be no less than 200 kW in a 5-mrad cone.
	3.5.6	Energy in first 100 ns in a 5-mrad cone to be no less than 12 mJ.
4	3.5.8	Within 20,000 shots (after burn-in) during a 1000-shot sample, the peak power in a 5-mrad cone shall not vary more than ±10%. Misfires shall not occur more than 2% of the pulse attempts - a misfire is defined as a drop below the 200 kW spec.
5	3.5.8	Within the last 20,000 shots of a 2 X 10^6 shot test, ±10% of the mean peak power is a 5-mrad cone is the reproducibility and a misfire is defined as a shot below 150 kW peak pulse power in a 5-mrad cone.
6	3.6	After the 2 X10^6 shots plus burn-in, peak optical power shall be no less than 150 kW in a 5-mrad cone and the energy in the first 100 ns of the pulse shall be no less than 9 mJ.
6a	3.6	The laser shall be designed for a shelf life of at least ten years.

To meet the requirements, performance objectives may be stated as follows: after 1000-shot burn-in, the peak power must be 200 kW or better. After 2 X 10^6 shots, the peak power must be 150 kW or better. Shot-to-shot reproducibility shall be better than $\pm 10\%$ (peak power). There shall be no more than 2% of the pulses less than the values specified.

1.11 LASER DESIGN

The mechanical design of the laser tube was finalized and documented as a formal drawing set. Questions of design details were resolved by experimental tests and by thermal structural analyses. The driving design parameters resulted in more closely spaced components at the rear of the laser. This geometry was checked experimentally to find out whether or not arcing to the rear mirror structure would occur.

Thermal structural analysis was performed to make sure the design would remain in alignment over the full range of operating environments and would return to the required alignment after exposure to specified environmental extremes beyond the operating limits. It was assumed that laser operation would not be required coincident with the 100g shocks, but that the tube would survive to operate immediately after the shock. During this period, the design goals were achieved by integration of the efforts of the environmental stress analysis group and the laser laboratory with the mechanical design facility. Figure 20 is the assembly drawing of the laser.

1.12 TUBE DESIGN FEATURES

The laser tube can be divided into a number of separate design problems which are connected by the rectangular ceramic body which is the high voltage insulator as well as the gas-tight wall. The ceramic body with the end caps sealed in place and with the mirrors installed becomes a (modified) Fabry-Perot interferometer. Environmentally induced tilting of the mirrors must be examined and the design developed to keep the misalignment within tolerance. There is a pair of relatively massive copper electrodes coupled to the body tube. Because the flashboard on one side requires these electrodes to be offset to the other side of the center plane to avoid arcing, there is an asymmetric stress in the body assembly which leads to tilt at the temperature extremes but not greater than the tolerances allow.

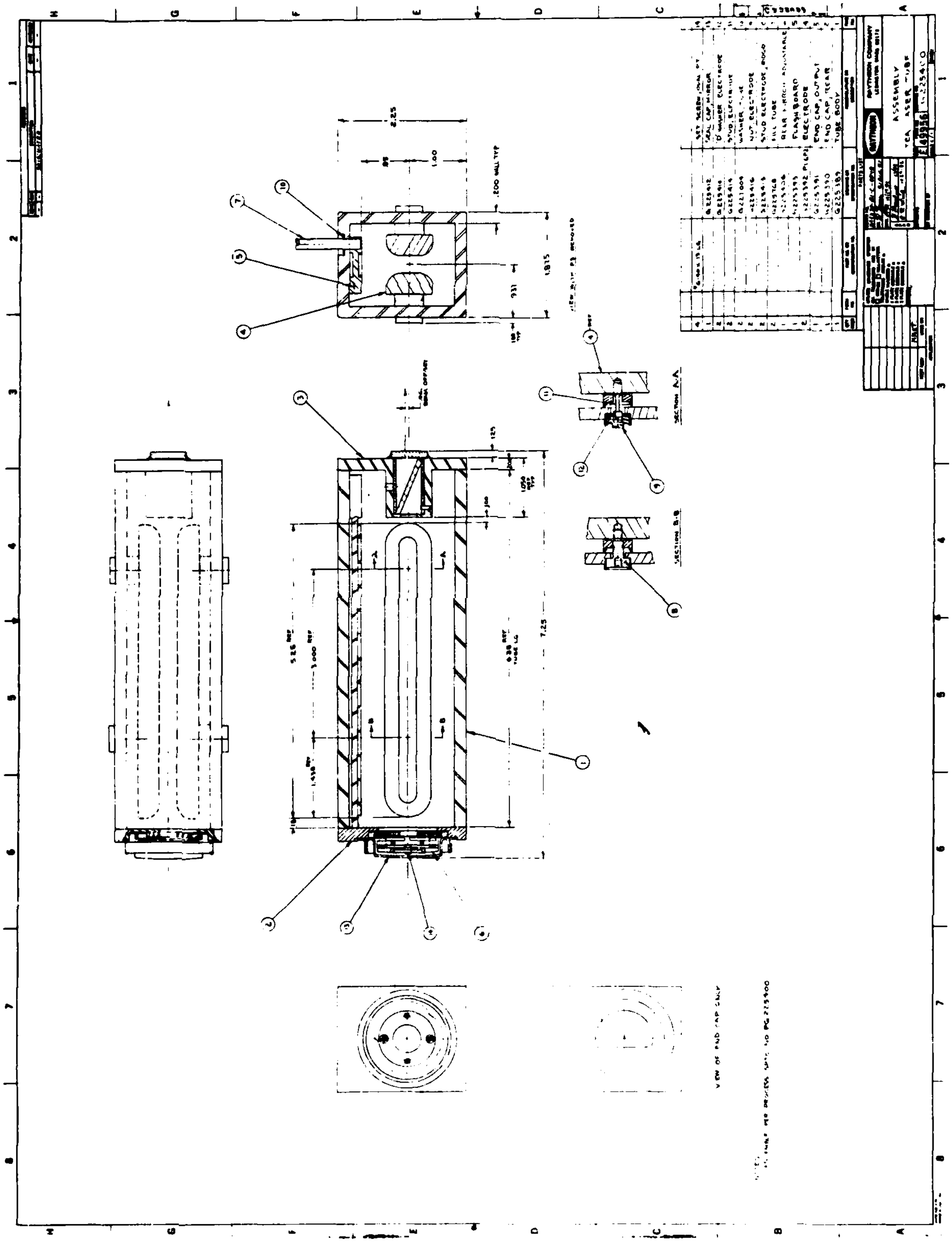


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Figure 20. Assembly Drawing

Aside from the dimensional tolerancing to make sure the device is aligned properly, it is also necessary to consider the manufacturability of the laser tube. The guiding principle is to establish an error budget. This technique allows assignment of the coarsest tolerances to the components most difficult to manufacture.

Throughout the design effort, the principles of ceramic microwave tube assembly were observed. What is required is a rigid, vacuum tight, very low vapor pressure, precision aligned assembly. The only concession to infrared technology is the sealing of the output coupler in place. There are no materials commonly used in microwave tube construction which are transparent to the 10.6-micron laser radiation. In the past, infrared windows were made of sodium chloride, a hygroscopic, frangible, and soft material. Such materials were deemed out of the question for ruggedized hardware. Now there are two materials worthy of consideration, zinc selenide and germanium. Zinc selenide was chosen because this material permits visual examination of the interior of the tube. This allows preliminary optical alignment using a helium-neon laser and optical measuring instruments such as the Zygo* interferometer. Since it is difficult to assemble the laser in an adequately aligned condition, the rear mirror is adjustable to achieve precision optical alignment. A gas-tight cap is then sealed over the adjustable mount by heliarc welding after proper alignment with the output coupler.

The entire tube envelope, prior to installing the output coupler, is assembled like a microwave tube. A special low temperature, vacuum soldering technique is then used to attach the output coupler. By performing this operation "invacuo," no flux is needed, obviating contamination.

1.12.1 MIRROR MOUNT DESIGN

1.12.1.1 Requirements

The rear mirror mounting is required to have sufficient adjustment range to compensate for assembly tolerance build-up and to have fine enough resolution so that alignment to a few microradians is not difficult for a skilled,

*Zygo is a precision alignment aid using the principles of interferometry, see Glossary.

trained operator. It must be stable over the environmental range, producing no distortion of the relatively soft copper mirror. It must be capable of sealing after adjustments are completed. It must be made of materials compatible with high temperature brazing to ceramics. These requirements are tabulated below.

Adjustment Range	±1.5 milliradians
Resolution	36 microradians
Braze compatibility,	
mirror	BeCu
mount	Kovar
Clear Aperture	0.300 inch

1.12.1.2 Possible Configurations

Initially, a permanently deformable partition was considered for the rear mirror adjustment. A removable fixture could be used to deform the assembly into alignment. The stability of this arrangement was questionable, however.

Next a large radius dish-like seat for the mirror was considered. The dish converts lateral motion into tilt. The frictional forces involved would lead to jumpiness in alignment. The lateral motion required for the adjustment range must be small enough so that the mirror mount remains within the boarders of the rear end cap of the laser. Analysis performed on this configuration showed that, although these conditions could be met, this configuration was rejected mainly on experience factors which favored the flexure pivot gimbal.

A flexure pivot is a narrowed part of an assembly where the small cross section causes almost all of the relative rotation to occur about the narrowed part. Such pivots are extremely strong and backlash free. Failure only occurs after repeated cycling causing work hardening and fatigue. When the device is cycled back and forth only a few times before locking (in the alignment), fatigue is not a problem.

Two versions of the flexure pivot gimbal were considered. One uses a thin-walled drawn corrugated cup to vacuum seal the mirror proper to the envelope. The gimbal grabs the mirror outside the cup. This version is highly asymmetric and more susceptible to misalignment during temperature variation.

The version finally adopted is symmetric about the center line. When its adjusting screws are tightened, it is effectively monolithic, and angular shifts due to temperature changes cannot occur. Sealing is accomplished by welding a cover over the assembly.

1.12.1.3 Rear Mirror Mount Configuration

Figures 21 and 22 show details of the mirror alignment component. Sealing is accomplished after adjustment by heliarc welding a cap over the outside as shown in Figure 20, the assembly drawing. By using "welding lips," the cap can be removed readily for readjustment. Enough metal would be still available for rewelding, a valuable feature for reclaiming misaligned tubes.

The prototype has number 6-40 screws. Only a small fraction of a turn is needed to finely adjust the screw. The moment arm is 0.438 inch, hence the mirror would tilt 57 mrad per turn or 0.018 turns per mrad. This would be quite coarse if it were not for the screw symmetrically placed on the other side of the center line. The pair can be used to strain the mirror carrier into alignment. Within limits, this technique works to achieve a vernier effect, and at the same time, the longitudinal force locks the threads against vibration. The concept performs well and has been used in the past for mirror mounts on Raytheon argon ion lasers and for the electro-optical equipment in the more recent ATH Program.

In order to avoid distortion of the mirror, even though the gimbal may be distorted, the mirror is fitted into a semikinematic nest. There are only three contact spots. Heliarc welding at points above the contact pads only will be used to hold the mirror.

The gimbal is provided with a ceramic disk which has a 0.300-diameter centered hole which is intended to reduce ion bombardment and dust contamination on the mirror. The ceramic rear end cap has a D-shaped hole to act as an arc preventer and the efficacy of the "D" hole has been validated in the laboratory.

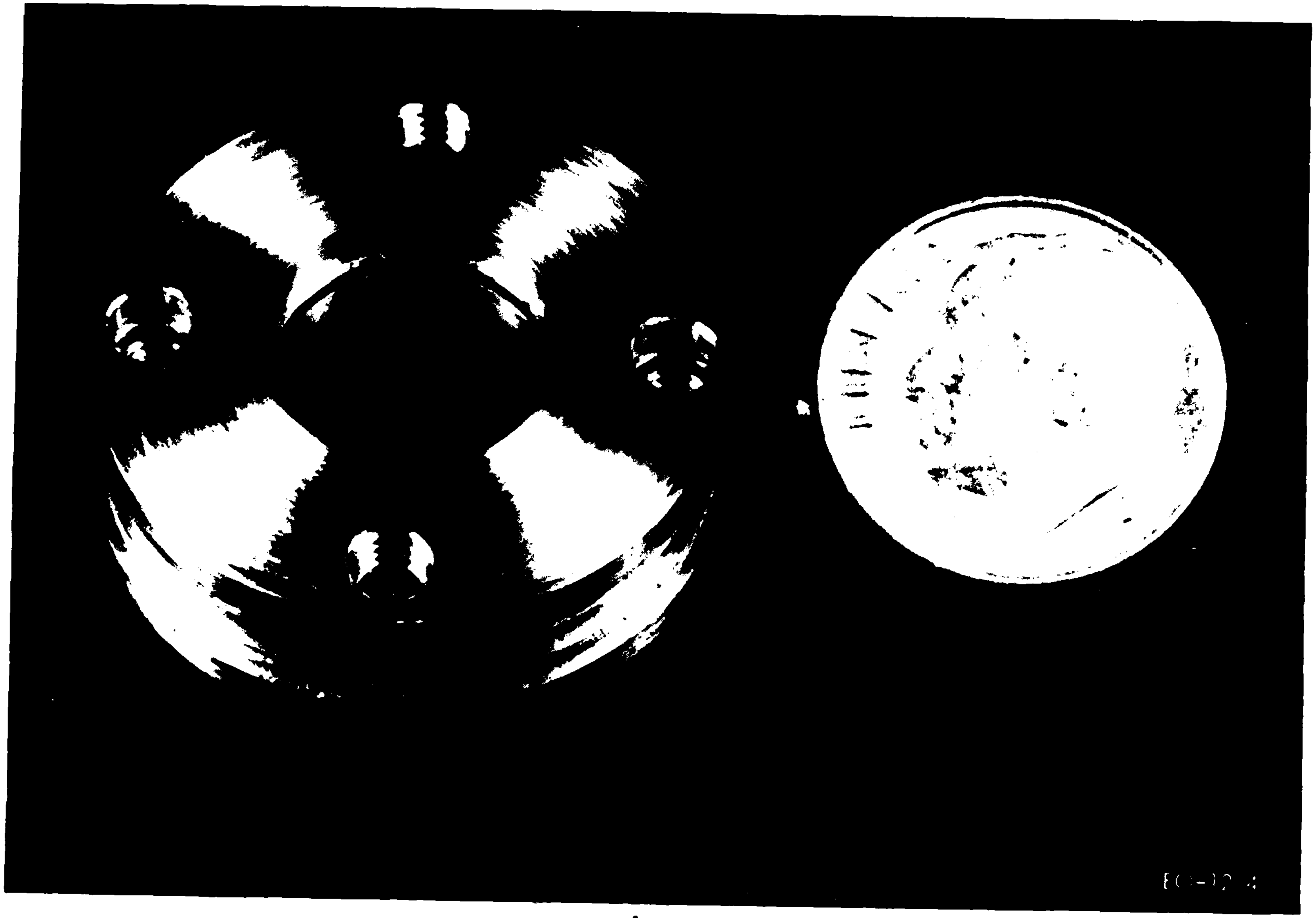


Figure 21. TEA Laser Mirror Mount

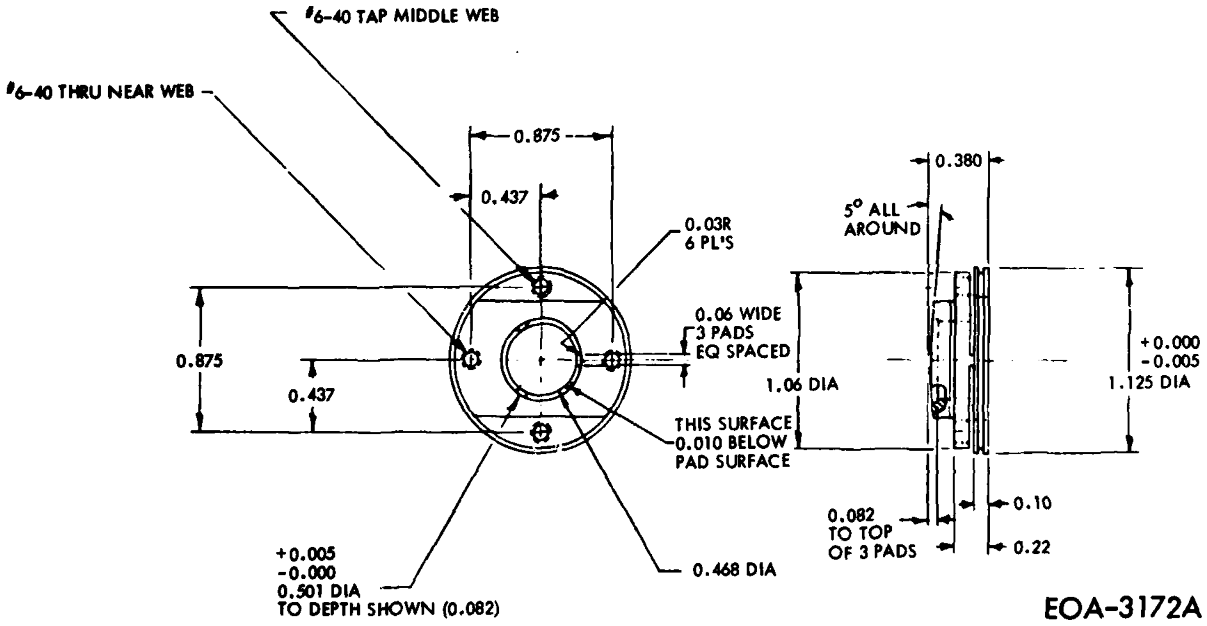


Figure 22. Flexure Pivot Gimbal

1.12.2 FLASHBOARD DESIGN

1.12.2.1 Requirements

The basic requirement is to supply a string of ultraviolet-emitting arcs. These should produce the radiation with a minimum of contamination. The arcs should be uniform in intensity and equally spaced. The end-most arcs should be aligned with the effective ends of the main electrode. Electrical connections shall be made between the ends and the copper filling tubes. The center will be internally connected to the main grounded electrode. The assembly shall pass a high voltage test to make sure there is no substrate breakdown. The buttons shall be molybdenum metal.

1.12.2.2 Design

Figure 23 shows the flashboard assembly. One of the features here is the use of fixturing to accurately locate the buttons. Previously, braze material or metalizing material has sometimes been noted protruding beyond the edge of the molybdenum. This has resulted in arcs at substrate level between the relatively volatile deposits of brazing materials. Not only does this result in partially shaded illumination, but also produces contamination which could lead to mirror damage.

The filling tubes which are made of soft copper for "pinching off" capabilities do not hold the flashboard in place. It was considered undesirable to attempt a solid connection because of the expansion differences. Hence there is a relief built into the inner ends of the tubing to make them compliant, yet capable of handling the flashboard current. The flashboard will be brazed to the body tube via several metalized pads.

The chief advantage of this method of assembly is the elimination of several seals through the envelope. Each seal is a potential source of leakage, and therefore, the fewer the number of seals, the better. The flashboard will not be easy to replace, requiring critical inspection beforehand.

1.12.3 MAIN ELECTRODES

1.12.3.1 Requirements

The function of the main electrodes is to couple the energy stored in the PFN to the upper laser level in the CO_2 molecules. The mechanism has been

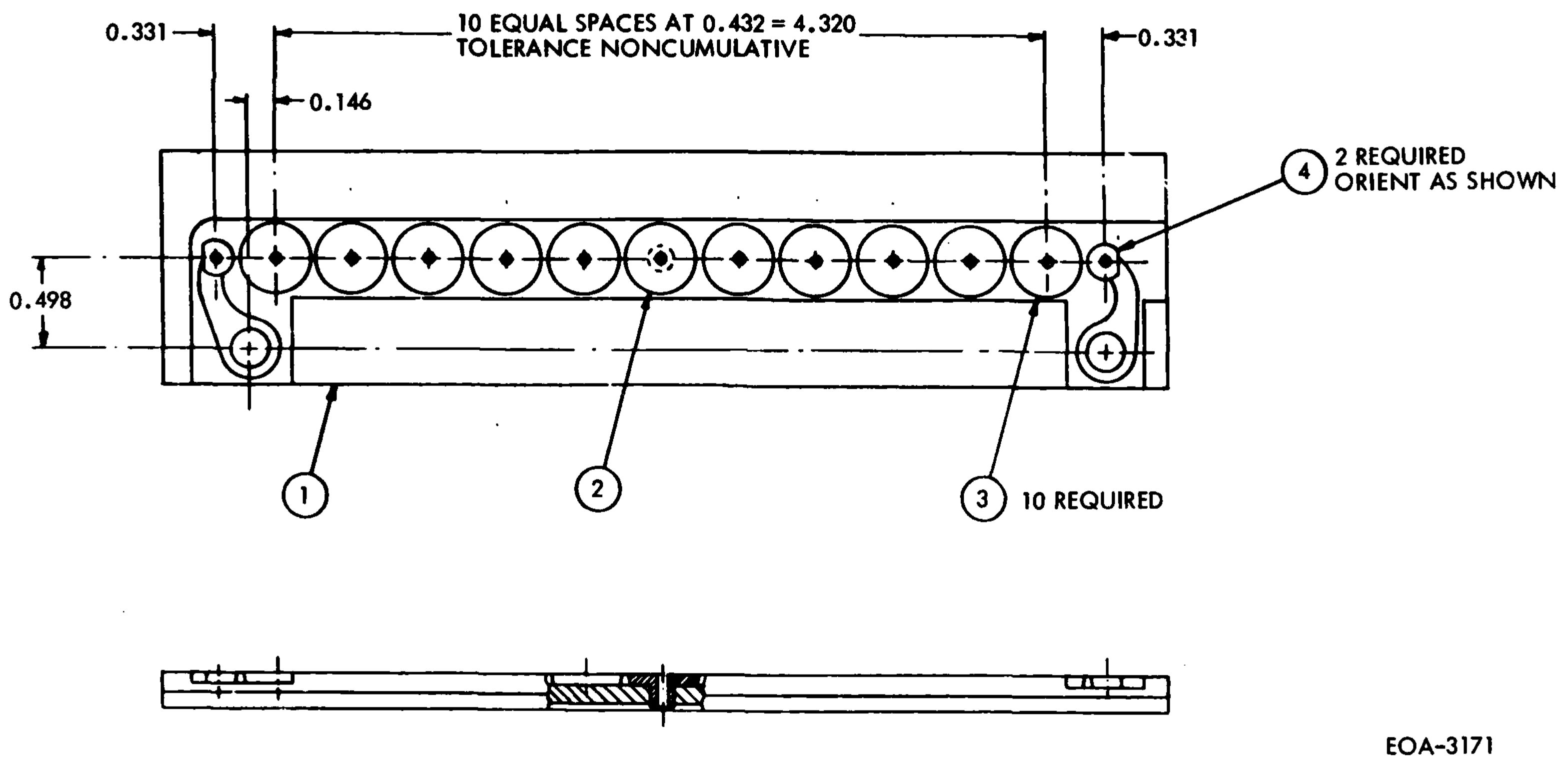


Figure 23. Flashboard Assembly

discussed in the scientific literature. The requirement on the electrode pair is that the electric field in the interaction space be uniform, with no concentration at the edges or ends. Accidental arcing shall not produce field concentration resulting in further arcing.

The flashboard located to one side illuminates the nearest edge of the cathode more than the farthest. This results in increased excitation in the region of the gap nearest the flashboard. It has been shown experimentally that a very slight spreading of the gap edge resulting from canting of the electrodes will compensate and produce a uniform glow.

The material used to make the electrodes should not adversely affect the gas chemistry over the 2×10^6 shot-life expectancy. The cathode surface must remain a photoelectric emitter in spite of oxide or nitride build-up over the same period.

The requirements discussed above are summarized below:

Spacing	0.315 ± 0.005 inch
Parallelism	within 0.002 inch
Cant Angle	$20^{\pm 5}$ minutes of arc total included angle
Material	Pure copper

1.12.3.2 Design of the Electrodes

The reasons for the chosen electrode contour are discussed in Appendix A. Figure 24 shows the dimensions and tolerancing required to manufacture the electrodes. The thickness and parallelism tolerances are required in order to achieve the gap dimensions tabulated above.

The material chosen is OFHC (Oxygen Free High Conductivity) copper. The experimental evidence indicated that aluminum oxidized, resulting in (1) a poorly conductive surface, and (2) the trapping of oxygen which therefore could not recombine with CO resulting in a loss of CO_2 population. Copper also oxidizes but the surface film remains adquately conductive. The amount of oxygen removed by copper does not appear to be important. Copper is a good photocathode even when oxidized.

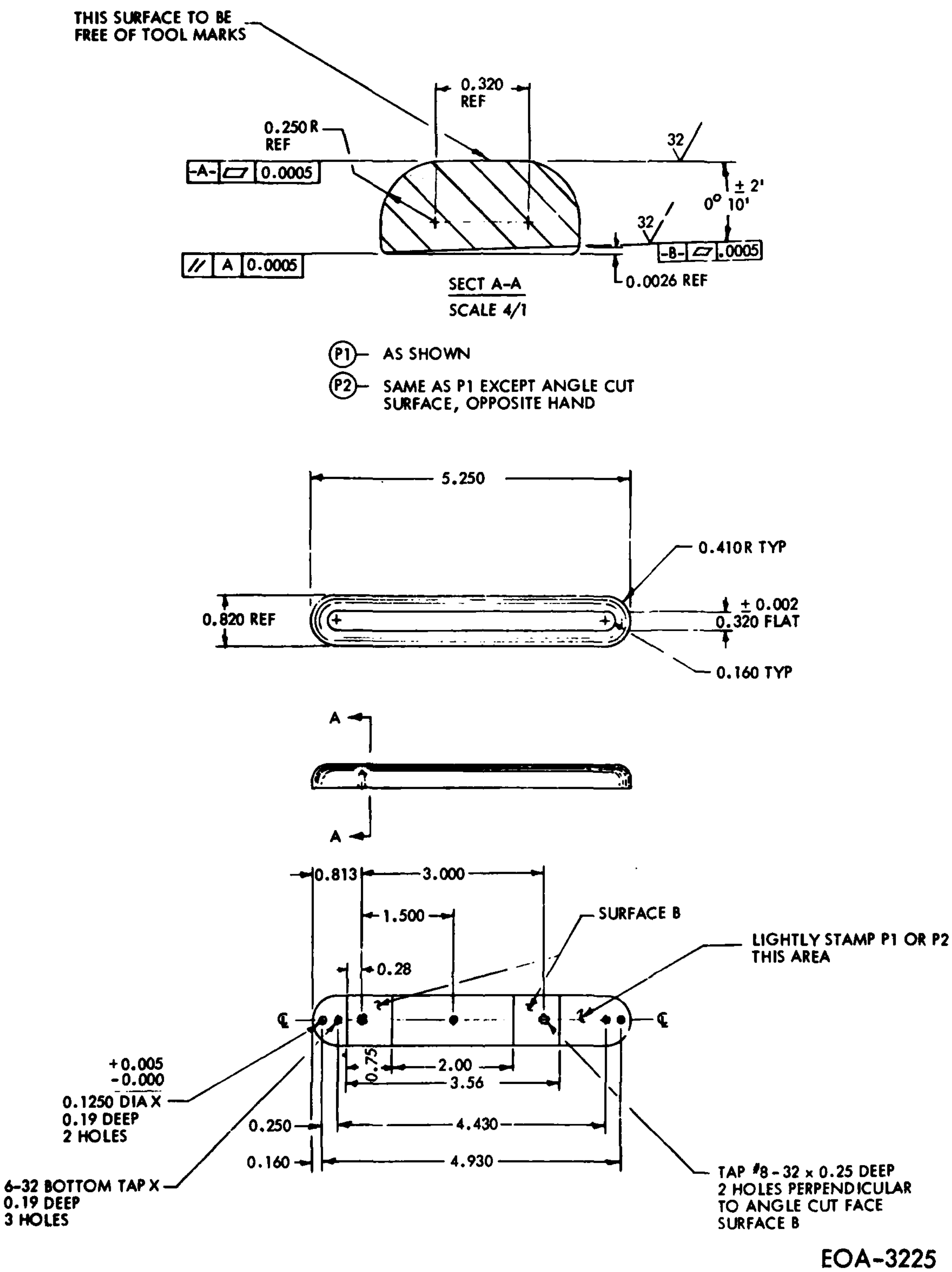


Figure 24. Main Electrodes

1.12.3.3 Mounting

The electrodes are fastened to support structures brazed to the ceramic tube body of the laser. The inner surfaces of the body tube are not flat or parallel. They are the result of shrinking during firing of the hydrostatically pressed greenware. Therefore, these surfaces are not suitable for references if the dimensional requirements are to be met.

The outer surfaces of the ceramic body tube are precision ground. Figure 25 shows the critical dimensions to which the machining of the electrode supports is referenced.

The electrode supports, (1) in the figure, are high temperature brazed to the inner surfaces of the tube body. They are oversized to protrude into the space inside the laser body. The next step is to machine them internally to the dimensions shown in the figure. This is accomplished by electrical discharge machining (EDM). Two local vendors and Raytheon, Bedford, MA, have the capability for performing this operation within the specified tolerances.

At the same time the internal supports are brazed in place, exterior fittings, item (2) in the figure, are also brazed in place. The function of these parts is to provide welding lips for sealing after assembly. These seals could be machined away and dissassembly permitted to repair defective tubes. There would be enough lip remaining for careful rewelding.

The copper electrode forms a strong heavy beam which will expand more than the ceramic body as the temperature is raised above the assembly temperature. Likewise, the electrodes contract more as the temperature is depressed. The electrode cannot be rigidly fastened to the ceramic in more than one place without either distorting the electrode or overstressing and fracturing the brittle ceramic. Nevertheless, the electrode must be held in more than one place to survive shock and vibration and maintain electrode alignment. The solution is to allow one of the supports to slip in the direction of the length of the electrode. This is done by a modification of the flexure pivot concept. Figure 26 shows both the rigid electrode mounting post and the flexible or sliding mounting post. Item 8 in the figure is a Kovar screw with a tapped hole for

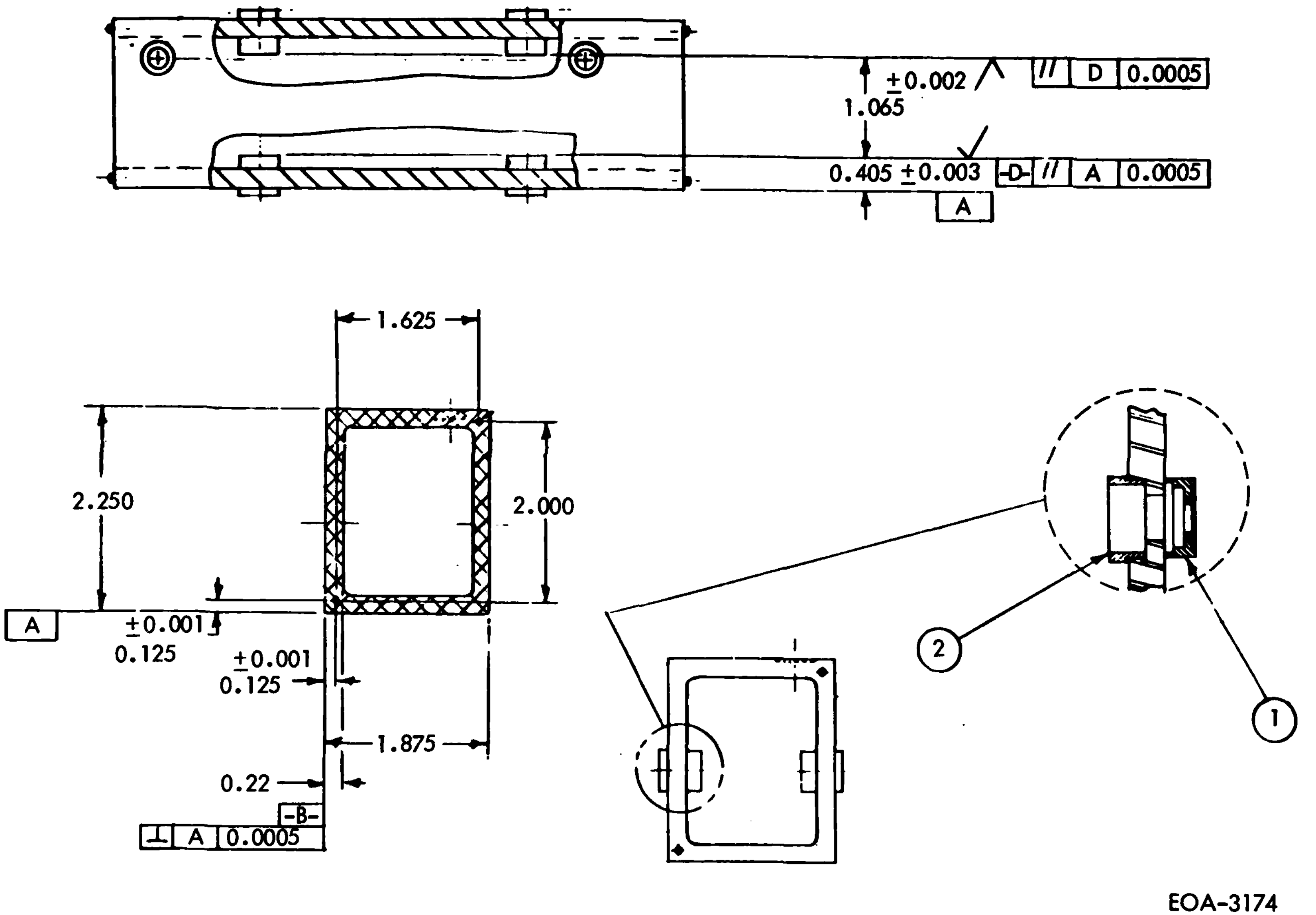
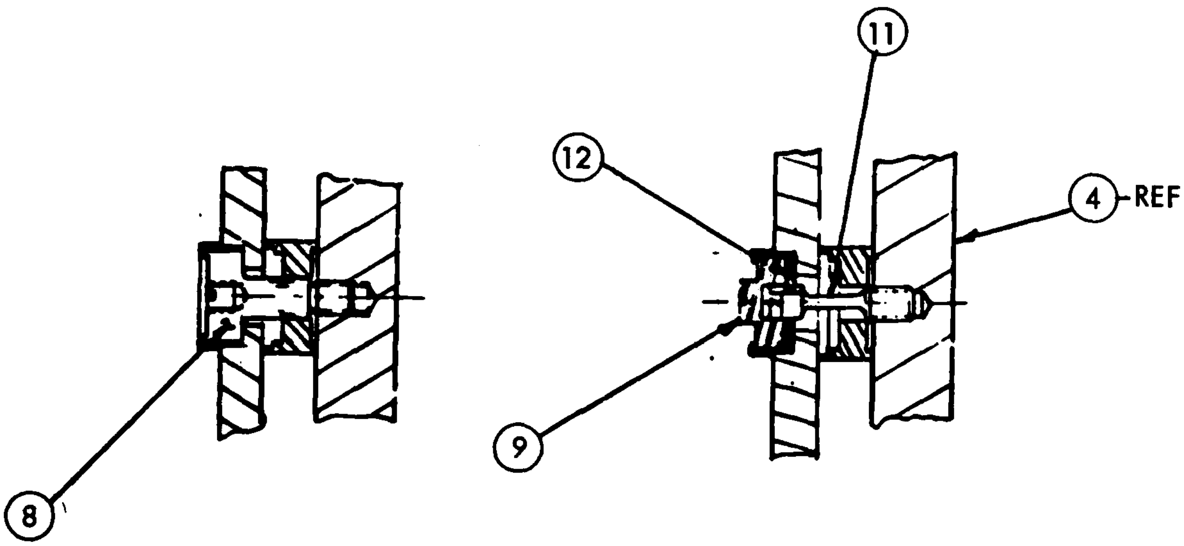


Figure 25. Machining of Electrode Supports



a. FIXED LEG

b. "SLIDING" LEG

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Figure 26. Main Electrode Support Structures

external electrical connections. The rim of the head of the screw is sealed by heliarc welding to the Kovar lip previously brazed to the ceramic body. Item 11 is the flexible screw which permits longitudinal sliding of the electrode but no transverse deflection because of its bladelike cross section. The electrode itself (item 4) slides on the machined supporting surface as it expands. The tension of the blade is adjusted to 50 lbs. Calculation shows this to be adequate for 100 g shocks, without the support spacer digging in to the electrode. Stick-slip will occur to some extent but not enough to cause deflection of the electrode.

Item 12 is a key pin washer which determines the rotational alignment of screw 11. Special nut, part 9, is used over the keyed washer to adjust the tension of screw 11. Part 9 is also welded to lips brazed to the ceramic for sealing purposes. The electrodes are thus assembled in place at room temperature. Correct alignment can be checked through the rear mirror opening before the rear mirror is installed. The electrodes are inserted through the "D" hole mentioned above.

Alignment tests could also be made by operating the discharge using flowing laser gas and a glass window held over the rear mirror hole. The cant angle and the parallelism requirements specified will assure an arc-free uniform discharge in the active region. This quality of the discharge is achieved by a minimal build-up of tolerances resulting from EDM of the support spacers.

1.12.4 FRONT MIRROR

The output coupler or front mirror is low temperature soldered to a precision ground metal pad brazed to the output end of the laser body. Number 45 alloy* has been adopted as the best candidate for this metal pad, in the light of experimental temperature cycling, which revealed leaks due to the Kovar washer previously used. Number 45 alloy matches the zinc selenide coupler more closely without stressing the ceramic.

*Carpenter Low Expansion 45 Alloy is manufactured by Carpenter Steel, P.O. Box 662, Reading, PA 19603.

The solder was changed from InPbAg to SnAg. The indium-based solders remain plastic at all temperatures which could lead to creep and mirror misalignment particularly when there is a positive pressure difference. The harder solder is safer too, considering the hammering effect of the shock wave in the gas produced when the laser is fired.

1.13 EXPERIMENTAL PROGRAM

Experiments were performed with a plastic demountable laser and with a ceramic-bodied version somewhat like tube Serial No. 0006 previously reported. Tendencies to arc were investigated because the new geometry resulted in decreased spacing at the rear mirror mounting. The electrode geometry and the effectiveness of the cant angle requirement (discussed previously) were investigated by visually inspecting the glow discharge. The measurement of the operating E/N and the relative efficiency of this laser were investigated. The Zygo interferometer alignment technique was investigated. Results indicate optimum Zygo alignment may not be the optimum laser alignment.

The main electrodes used in an earlier experimental tube which failed during life test were discovered to have colored deposits on their surfaces. The nature of these deposits was examined by Electron Spectroscopy for Chemical Analysis (ESCA). Auger Electron Spectroscopy (AES) was used to investigate deposits on a flashboard used in life tests.

1.13.1 E/N AND LASER EFFICIENCY

One way of characterizing the TEA laser operation is to determine E/N, the operating electric field to neutral particle density ratio. Nighan* has shown that the efficiency of population inversion generation depends on the E/N ratio.

The PFN used to perform this experiment is an optimized version of the single capacitor thyratron-switched circuit, diagrammed in Figure 27. The "T" network and peaking capacitor serve to delay the application of voltage to the main discharge until preionization has begun.

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*W.L. Nighan, Phys. Rev. A2, 1989 (1970).

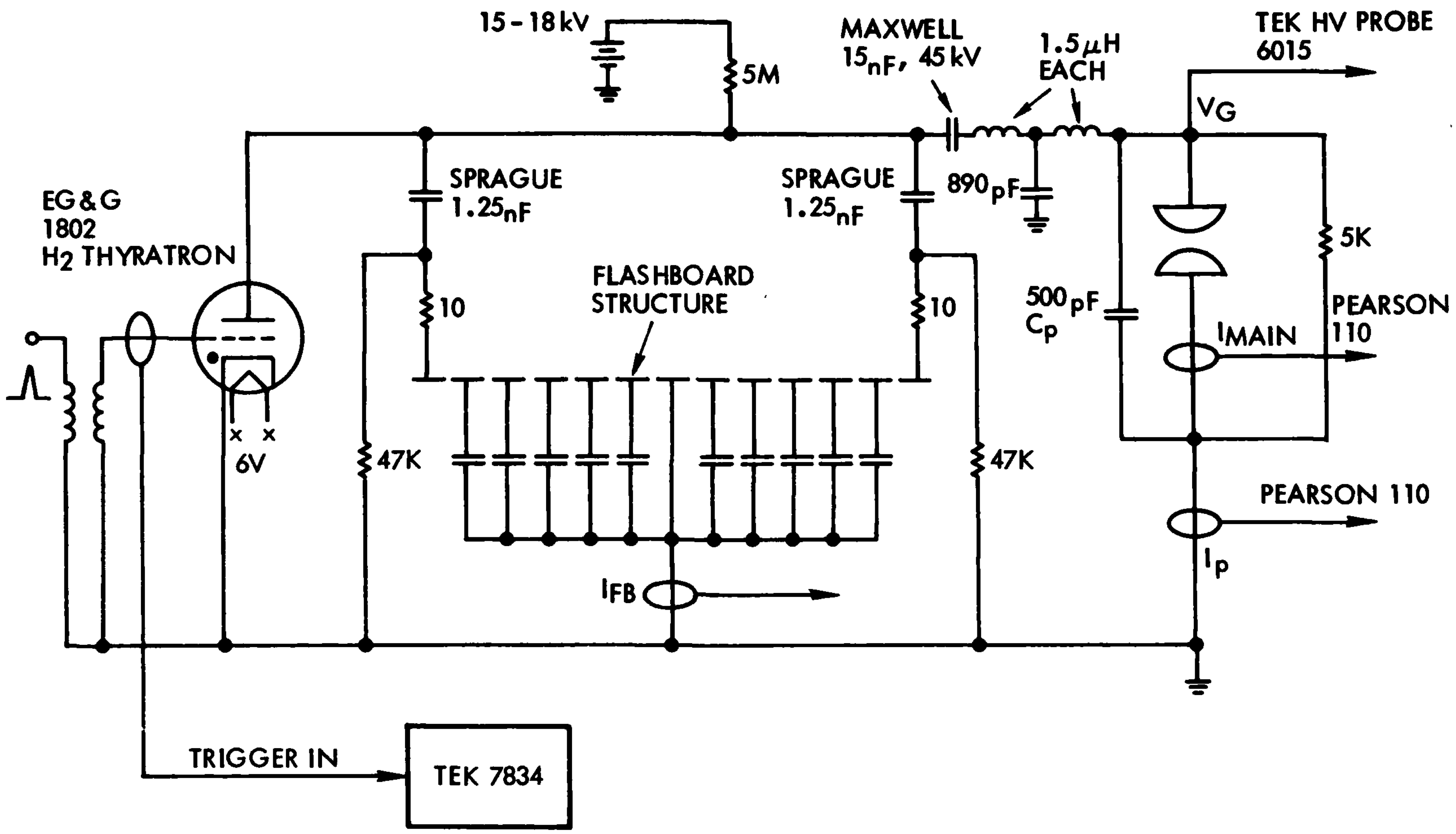

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Figure 27. PFN with One Main Electrode at Ground Potential

The laser was built in a demountable plastic housing and the 15% CO_2 "long life" gas mix was used. The voltage across and current through the main gap were measured as a function of time. Energy deposited is determined by summing the I-V products for all the time intervals considered. All the energy deposited was 0.569 joules. The electrodes were 5.75 inches long, 0.310-inch gap so the discharge volume is about 7.6 cm^3. This corresponds to an energy of 75 J/liter.

Since the mode control aperture is 0.285 inch in diameter, the mode volume usage factor is 61% (0.61 X 0.569) so 347 mJ is available for laser excitation. At 44 mJ, the energy output was 12.7% of that available. This is respectably high, attributable to the relatively low value of E/N

$$2.65 \pm 1.33 \times 10^6 \text{ volt cm}^2.$$

This value of E/N is lower than those reported by Cridland and Howells* in their paper relating laser performance to PFN configuration. Their laser used a smaller aperture (<0.25 inch) and a longer spacing (13.8 inches) between the mirrors.

According to Nighan, for the E/N ratio obtained, nitrogen molecule excitation is purely vibrational. CO_2 molecule excitation, also vibrational, but divided between the upper and lower laser levels, is in a ratio of 1.5 to 1.0, which probably accounts for the long flux build-up time. The observed delay between the emitted pulse and the leading edge of the current pulse is 600 ns.

The laser output pulse shape shows less than 250-kW peak power. Much of the total energy is in the tail. The possible relation between this and the input pulse was due to the rather long duration of the input pump pulse which stretches for 400 ns.

To explore the possible benefits of short input pulses, the two spark gap PFN was used. Here, the flashboard is fired separately with precision timing relative to the main gap. Fifty-two millijoules were obtained and a peak power of over 250 kW at 18-kV input.

*Cridland and Howells, J. Appl Phys 53, 4016, 1982.

The measured full width at half maximum of the current pulse was 130 ns. Although the current peak was sharper and stronger, neither the output energy nor the peak power increased by corresponding amounts. One advantage observed was that virtually no filaments occurred in the discharge. It does not appear that sharpening up the input pulse will alter the output pulse in any significant way.

1.13.2 CONTAMINATION ANALYSIS

1.13.2.1 Aluminum Main Electrodes

A laser operated in a life test failed. The electrodes were aluminum and had black and yellow deposits on their surfaces. The deposits were investigated and the findings indicate that aluminum getters oxygen from the discharge, changing the proportions of the gas mix.

ESCA techniques were used to obtain the following results:

RELATIVE ATOMIC CONCENTRATION

As-Received Surfaces

	Concentration					
	Al	O	C	Mo	Fe	N
Electrode No. 1:						
Black Area	29.0	46.5	20.8	2.0	1.8	-
Yellow Area	28.7	34.6	21.3	3.0	3.8	8.5
Electrode No. 2:						
Black Area	28.0	43.3	32.0	1.2	1.6	-

Examination of the electron spectra reveals the aluminum is composed solely of aluminum oxide on the surface. The carbon is present mainly in low molecular weight hydrocarbons. Breakdown of this carbon by the plasma would result in graphitic carbon mixed into the alumina (Al_2O_3) on the surface.

1.13.2.2 Flashboard Contamination

It was observed that some flashboard buttons were not properly centered over their braze pads. When operated in a transparent plastic laser body, the spark was seen traveling along the substrate in some cases of decentered button brazing. A blackish deposit was noted on the substrate between such buttons.

Two flashboard buttons were removed and examined by Auger Electron Spectroscopy (AES) giving the following results:

RELATIVE ATOMIC CONCENTRATIONS

	M_o	C_u	N_i	C	O	Al	S_i	N
Button No. 1:								
As-received	1.3	1.3	-	56.8	16.6	2.0	20.6	1.4
~150 A° Removed	16.0	3.8	2.1	32.7	19.8	8.8	11.5	5.2
Button No. 2:								
As-received	1.7	0.6	-	39.1	25.9	2.3	27.1	3.3
~150 A° Removed	26.5	0.4	0.2	10.5	38.5	5.0	8.6	10.2

As indicated in the design of the flashboard, the buttons will be fixtured in place during brazing. The metalization pads will also be located more precisely than in the previous laser constructions.

1.13.3 LASER ALIGNMENT

The radius of curvature of the rear mirror is long compared to the mirror spacing. Thus the TEM mode radius is very large. In order not to vignette, the center of curvature of the rear mirror must lie on a line perpendicular to the inner surface of the output coupler intersecting the plane of the aperture at its center. A maximum of 10% offset may be allowed. This is 36 μrad of angular misalignment which is the desired limit of resolution of the rear mirror alignment device. An experiment to check the order of magnitude was performed on a plastic demountable laser. Seventy-five microradians produced a misalignment which reduced the output energy by 3%. From this it seems reasonable to accept 36 μrad as an alignment resolution.

1.13.4 TEMPERATURE SURVIVAL

The environmental conditions specified state that the tube shall operate from -25°F to +125°F. The tube shall survive storage temperatures from -70°F to +160°F. The method for sealing the zinc selenide output coupler into place uses a reflow solder technique. A solder, rich in indium to lower the melting point and to retain ductility over a large temperature range was used to test the output coupler seal. Engineering Sample 0001 was utilized to perform environmental tests. The following paragraphs describe thermal tests, results and analyses of the possible mechanisms of seal failure.

1.13.4.1 Thermal Test

Step 1 The laser tube temperature was brought from room temperature to 125°F in approximately half an hour and then cooled in air to room temperature. The ZnSe output coupler was tested with a Zygo interferometer and leak checked. No optical deformation nor vacuum leak was found. The front AR-coated surface of the output coupler was found to be flat, while the high reflectance surface was convex with a radius of curvature about 10m. Surfaces of the coupler were supposedly flat and convex (but not Zygo tested) before soldering.

Step 2 Step 1 was repeated except the temperature range was from room temperature to 160°F. It stayed at 160°F for about two hours. Again, the coupler seal and other seals passed the test.

Step 3 The tube was then brought down to -70°F from room temperature in about 36 minutes and then brought back up to room temperature in about 30 minutes after it had stayed at -70°F for about 2 hours. Again the Zygo picture showed no optical distortion. However, leaks developed at the ZnSe to $IN_{.80}Pb_{.15}Ag_{.05}$ (fraction by weight) solder joint (see Figure 28), at the large Kovar flange-to-ceramic seal at the end plate (see Figure 29) and at one of the center ceramic-to-Kovar seals through which the main electrodes were held in place by a heliarc-welded sleeve.

1.13.4.2 Thermal Stress Analysis for ZnSe-to-Kovar Seal

Figure 30 shows how the ZnSe window is soldered in place. The Kovar-to-ceramic seal is a brazed seal, while the ZnSe-to-Kovar seal is a "soft solder" seal. The $In_{.80}Pb_{.15}Ag_{.05}$ solder has a tensile strength of 2550 psi. The thermal coefficients of expansion are given below. Neglecting the radius-of-curvature effect on the cylindrical surface of the ZnSe, the stress due to a temperature change from the melting point of the solder -70°F (equal to -55°C) is calculated as follows:

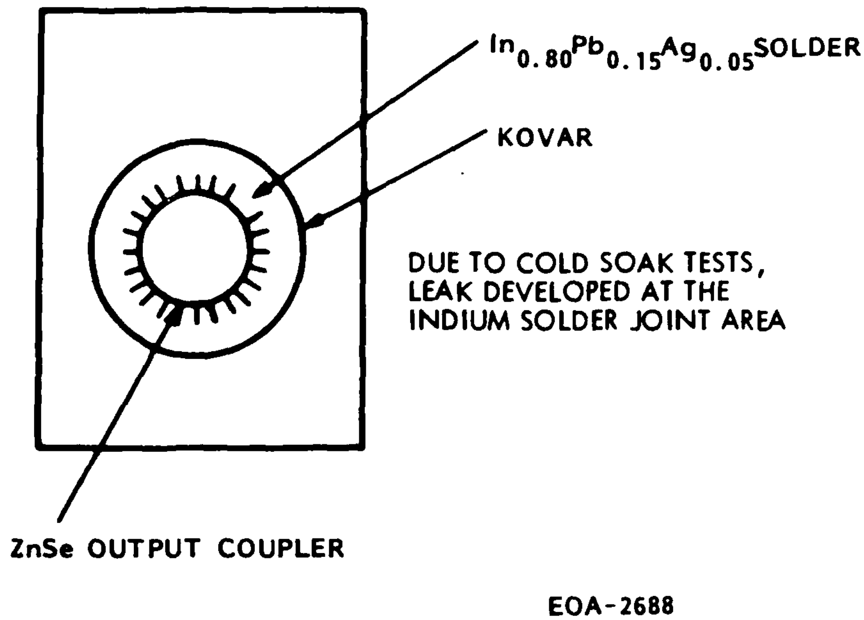


Figure 28. Engineering Sample 0001 (End View)

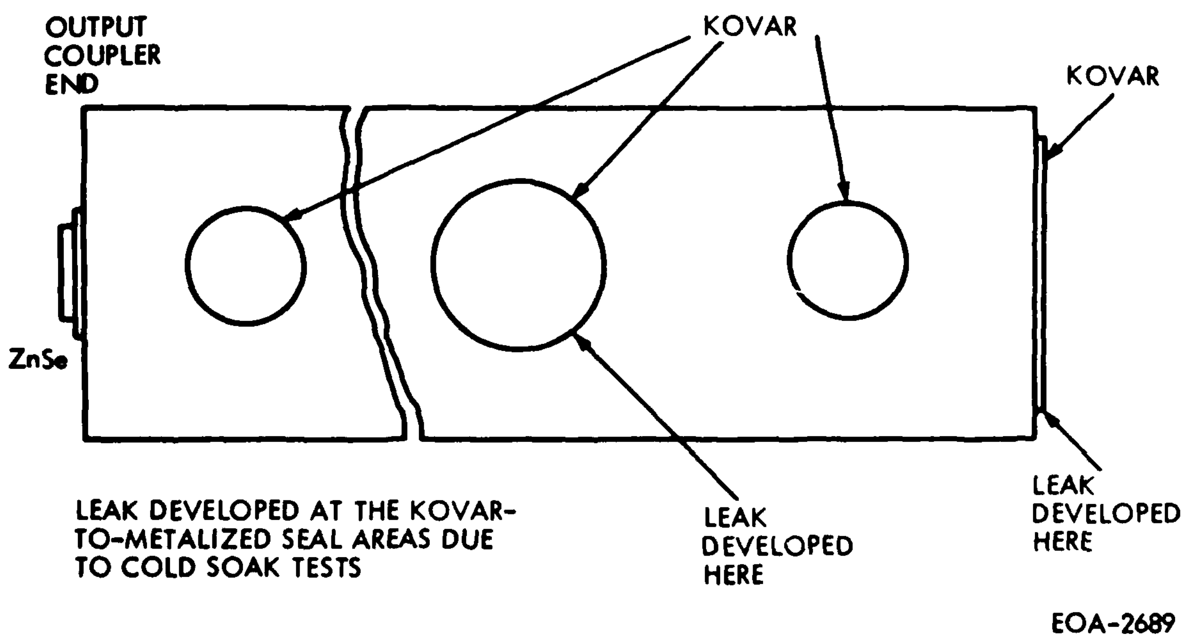


Figure 29. Engineering Sample 0001 (Side View)

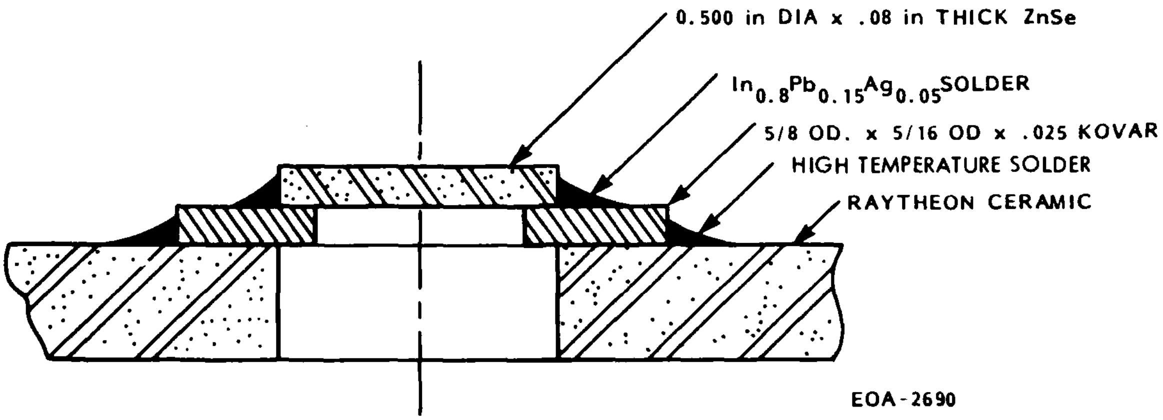


Figure 30. Output Coupler-to-Kovar-to-Tube Assembly

$$\Delta t = 149 - (-55) = 204°C$$

$$\Delta\alpha = \alpha_{Kovar} - \alpha_{ZnSe} = - Z \times 10^{-6} \text{ in in}^{-1} \, °C^{-1}$$

The stress on the solder is independent of the diameter of the window and is given by:

$$S_{solder} = -E \, \Delta\alpha\Delta T$$

The stress of the solder was in tension for the cooling test and was in compression in the heating test

$$S_{solder} = -653 \text{ psi}$$

for a value of $E = 1.6 \times 10^6$ psi.

The above value of E is for pure indium at 0°C. At room temperature, E for pure indium is 1.57×10^6. Therefore, for pure indium, the value of E at -55°C is still less than 2 and the value of E for the $In_{.80}Pb_{.15}Ag_{.05}$ solder we used is not much higher than 2, so that the stress at the solder was still less than 1000 psi, which is below 2550 psi listed by the manufacturer for the 80% In solder.

Because of the above finding, the remaining possible source of seal failure is at the sputtered film of chromium-nickel-gold (CrNiAu) on the ZnSe cylindrical surface (to isolate the leak carefully, black Glyptal was painted over the brazed joint at the ceramic-to-Kovar seal and it was verified that the ZnSe-Kovar seal was not vacuum tight).

It is intended to isolate the solder failure from the sputtered film failure by using a material which has about the same thermal coefficient as ZnSe and can also be soldered with the $In_{.80}Pb_{.15}Ag_{.05}$ solder, and to utilize a metal or alloy that has a thermal coefficient of expansion that is better matched to ZnSe than Kovar. For example, a nickel-iron alloy (45) containing 43.6% Ni matches the expansion coefficient of ZnSe very well.

COEFFICIENT OF THERMAL EXPANSION

Material	Coefficient of Thermal Expansion		
ZnSe	7.5×10^{-6}	in. in.$^{-1}$ C°$^{-1}$	(20 to 170°C) range
Kovar	5.86×10^{-6}	in. in.$^{-1}$ C°$^{-1}$	(25 to 100°C)
	5.2×10^{-6}	in. in.$^{-1}$ C°$^{+1}$	(25 to 200°C)
Raytheon Ceramic	9.2×10^{-6}	in. in.$^{-1}$ C°$^{-1}$	
NiFe alloy	6.9 to 7.1×10^{-6}	in. in.$^{-1}$ C°$^{-1}$	(25 to -80°C)
#45 alloy	7.3×10^{-6}	in. in.$^{-1}$ C°$^{-1}$	(25 to 100°C)

1.14 STRUCTURAL ANALYSIS

This section summarizes the structural analysis performed on the TEA laser tube assembly. Deformation and stresses due to thermal, pressure, shock and vibration loadings were examined. This section is based on a Raytheon Company memo dated 10 December 1982, describing work performed by the Analysis and Antenna Design facility.

1.14.1 DISCUSSION

Finite element mathematical models of the tube assemblies were generated for use with the NASTRAN structural analysis computer program. The models were used to obtain stresses and deflections due to environmental loads. The assemblies were checked for deflections over a temperature range of -25°F to 125°F, with a vibrational input of 4 g's (9 to 500 Hz), and for a positive internal pressure equivalent to a tube pressurized to 1.4 atm exposed to a 0.645 atm ambient pressure.

The assembly was checked for survival over a temperature range of -70°F to 160°F, the above-mentioned vibration, 100g 2 ms 1/2 sin shock pulse, and a pressure load of 1.3 atm equivalent to a tube pressurized to 1.4 atm exposed to a 0.1 atm environment. The shock and vibration inputs were applied along the longitudinal, lateral and vertical axes.

Geometry checkplots of the mathematical models used are shown in Figures 31 through 33.

*See paragraph 1.12.4 above.

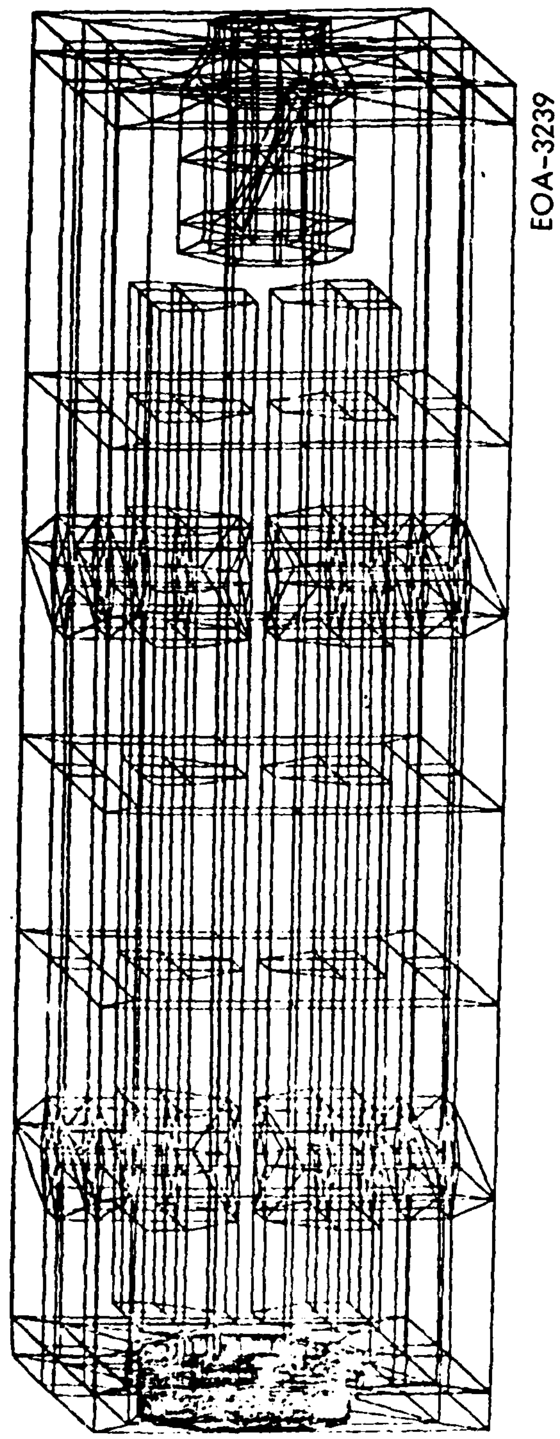
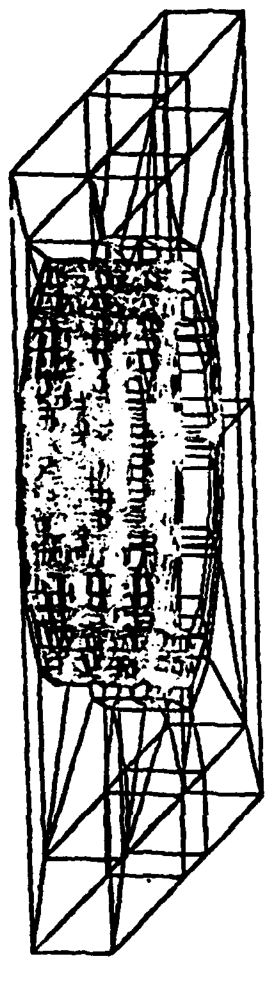


Figure 31. TEA CO_2 Laser, Electrode Thermal Distortion Model



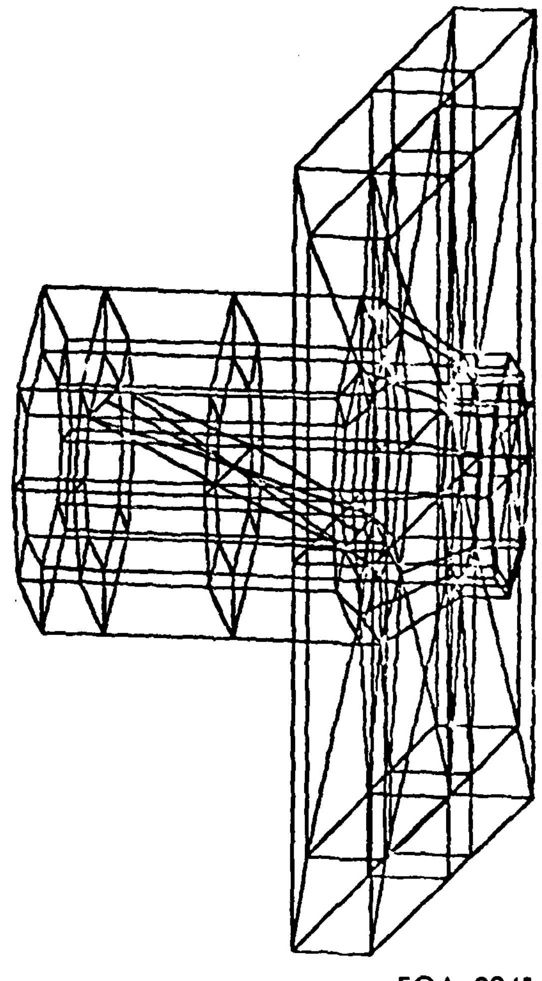


Figure 32. Adjustable Mirror

Figure 33. Output Coupler

Of primary concern in the analysis was a comparison of operating misalignment error with the error budget outlined by Electro-Optics Systems Laboratory (EOSL). The maximum allowable deviation from parallel of the two electrode surfaces was 0.5 mil, due to operating environments. The combined rotations of the rear mirror assembly, polarizing elements to be inserted later and the output coupler were required to be within a 36-microradian tolerance for the operating environments.*

A separate model of the output coupler and end cap assembly was generated to obtain stresses in the InPbAg** solder due to temperature extremes. An axisymmetric model of this assembly is shown in Figure 34.

The tube assembly has simply supported ends. The material properties are shown in Table 4. These properties were assumed to be linear elastic over the environmental ranges in the analysis.

1.14.2 RESULTS

The minimum natural frequency of the assembly was computed at 3150 Hz. The magnitude of the frequency assures that there will be no absorption of the shock and vibration inputs as the frequency of these loads is an order of magnitude smaller. Using this information, a maximum survival shock load of 100 g's along each axis was obtained.

Electrode deflections are summarized in Table 5. For the analysis, a slip joint at one of the electrode posts was assumed to exist after a 50-lb friction force was overcome between the electrode and the Kovar washer/spacer. Deformed geometry plots of one electrode are shown in Figures 35 and 36.

Figure 37 shows the rotations of the rear mirror due to various loading conditions. Figure 38 shows the rotations of the output coupler assembly.

---

*When setting up the highly complex computer model of the laser tube, it was deemed advisable to include the possibility of adding a Brewster-angled polarizer of zinc selenide.

**The solder for the output coupler will probably be SnAg for the reasons outlined elsewhere.

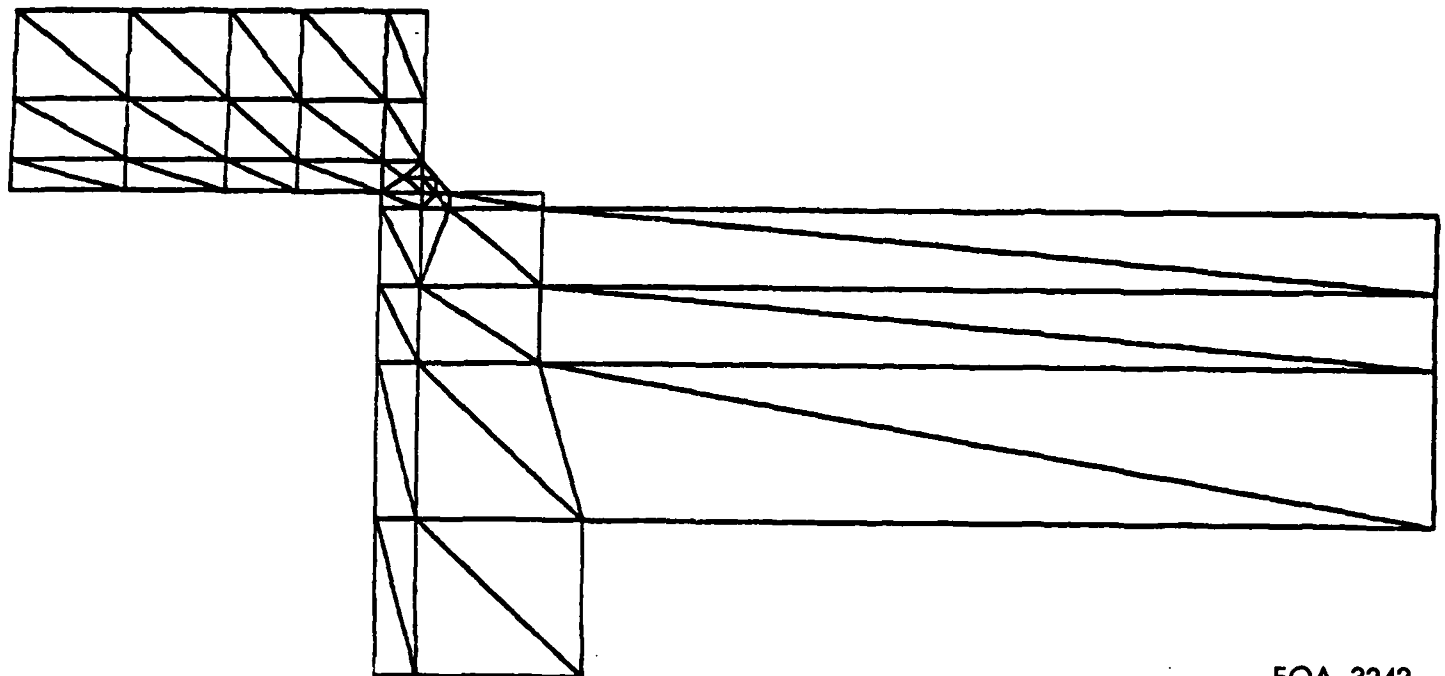


Figure 34. ZnSe Output Coupler

TABLE 4. MATERIAL PROPERTIES

Material	Young's Modulus (psi)	Poisson's Ratio	Density (#/IN^3)	Thermal Coefficient of Expansion (IN/IN°F)
OFHC Copper (Annealed)	17.5 (+6)	0.33	0.323	0.3 (-6)
Alumina (Raytheon R-95)	47.0 (+6)	0.22	0.134	4.2 (-6)
Solder In(80%)Pb(15%)Ag(5%)	1.6 (+6)	0.33	-	18.3 (-6)
Kovar	20.0 (+6)	0.317	0.302	3.3 (-6)
Zinc Selenide (RAYTRAN)	9.75 (+6)	0.28	0.190	4.2 (-6)

TABLE 5. ELECTRODE VERTICAL DISPLACEMENTS* (MIL)

Loading Condition	Rear	Middle	Front (Output End)	Max Deviation from Parallelism
Thermal Distortion 70°F -25°F (W̄ Slip Joint)	-0.75	-0.80	-0.61	0.38
Thermal Distortion 70°F 125°F (W̄ Slip Joint)	0.37	0.45	0.28	0.34
Thermal Distortion 70°F -25°F (W/O Slip Joint)	0.12	-1.55	0.70	4.5
Thermal Distortion 70°F 125°F (W/O Slip Joint)	-0.06	0.84	-0.38	2.4
Pressure Loading (11.0 psig)	-0.004	-0.005	-0.006	
4.0 g Vibration Longitudinal Axis	0.0006	0.0007	-0.0008	
4.0 g Vibration Lateral Axis	0.0002	0.0002	0.0003	
4.0 g Vibration Vertical Axis	0.0008	0.0027	0.0039	

*All displacements are measured from undeformed positions using bottom face of tube as datum.

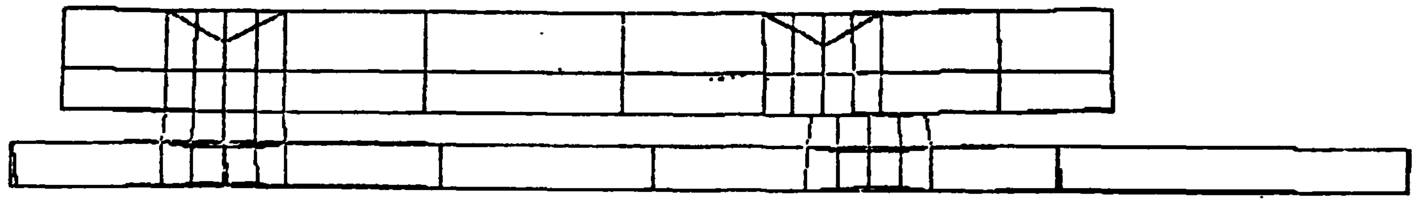


Figure 35. TEA CO_2 Laser, Electrode Thermal Distortion Model
70°F to 32°F, Copper Electrode
Static Defor. Subcase 11, Load 0

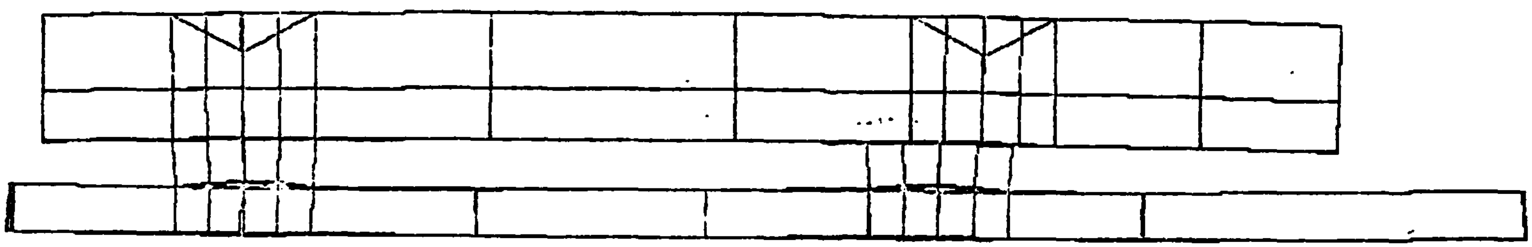
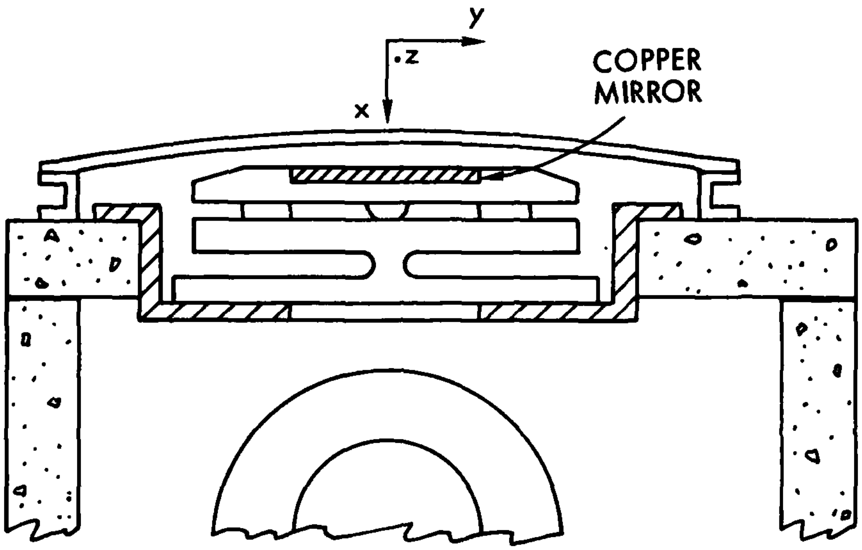


Figure 36. TEA CO_2 Laser, Electrode Thermal Distortion Model
70°F to 125°F, Copper Electrode
Static Defor. Subcase 12, Load 0



LOADING CONDITION	ADJUSTABLE MIRROR ROTATIONS (μrad)
TEMPERATURE DROP 70°F ⟶ -25°F	30.4
4g x-DIRECTION	0.32
4g y-DIRECTION	0.24
4g z-DIRECTION	0.15
10 lb NORMAL FORCE ON 1 UPPER SCREW	9.3
10 lb NORMAL FORCE ON 1 LOWER SCREW	11.6

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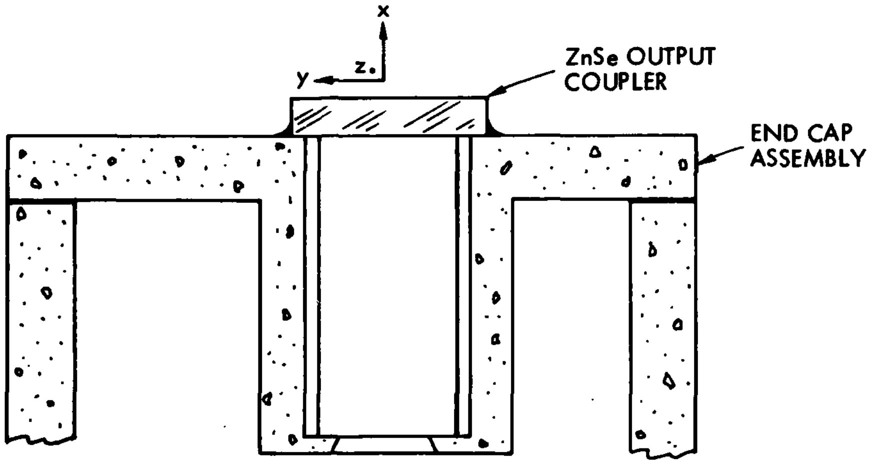
Figure 37. Rotations of the Rear Mirror



LOADING CONDITION	OUTPUT COUPLER ROTATIONS (μrad)
TEMPERATURE DROP -10°F → -25°F	12.80
TEMPERATURE RISE 70°F → 125°F	7.41
4g x-DIRECTION	0.02
4g y-DIRECTION	0.12
4g z-DIRECTION	0.06

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Figure 38. Rotations of the Output Coupler Assembly

A linear addition of these rotations shows a total misalignment of 43-microradians which is out of spec, but within a reasonable limit considering the accuracy of the analysis.

The stress summary (Table 6) shows that none of the materials should exceed their elastic limits. Stresses in the solder joint between the output coupler and the Kovar washer show a principal stress of 1510 psi opposed to an advertised tensile strength of 2550 psi. This could be of concern for continued cycling between room temperature (70°F) and the low storage temperature (-70°F) as solder is very fatigue sensitive. Further analysis, using more detail and optimizing solder fillet geometry, could be performed if deemed appropriate. The anticipated change to SnAg solder should result in no fatigue problems.

TABLE 6. STRESS SUMMARY

All Stresses in psi

Material	Allowable	Maximum Principle Stress	Loading Case
OFHC Copper	6500. Yield	6900.*	70° → -70°
Alumina	25000.	16700.	100 g Z
Kovar	-	1230.	70° → -70°
Zinc Selenide	7500.	1260.	100 g X
InPbAg Solder	2550.	1510.	70° → -70°

*Maximum copper stress occurs in electrode if slip joint does not function. Copper stresses decrease by an order of magnitude if joint slips at 50 lb longitudinal force.

1.14.3 CONCLUSIONS

The analysis shows that the tube assembly should be structurally adequate to operate over the specified environmental range and survive the design limit loads.

For the thermal cycling, the results assume that a slip joint at one electrode can be made to work. Table 5 shows that without slip the electrodes do not meet the required parallelism specification, and Table 6 shows that, at the low storage temperature, the yield stress for annealed OFHC is exceeded. More detailed analysis and physical testing of this area of the assembly should be performed to prove out the slip joint method used.

1.15 OPTICS

The optical elements within the laser tube are chosen to form an optical resonator. They are also required to survive the special soldering and brazing during assembly. Furthermore, they must withstand extremely high peak power infrared radiation generated within the resonator. They must also withstand ultraviolet radiation generated by the flashboard.

1.16 RESONATOR CONDITIONS

The optical resonator is chosen to be "stable" on the usual stability plot of $g_1 = 1 - d/R_1$ and $g_2 = 1 - d/R_2$. *The stability criterion is that:*

$$0 \leq g_1 g_2 \leq 1$$

Stability can be achieved anywhere between the axes and the hyperbola whose limbs are in the first and third quadrants, Figure 39.

An additional boundary condition governing the TEA laser resonator is that the output beam must have minimum beam divergence, which implies a flat phase front at the output coupler. This in turn means the output coupler has an infinite radius, $R_2 = \infty$ and therefore $g_2 = 1$. The rear mirror radius can range from $R_1 = d$, the spacing, to R_1 approaching ∞, producing a flat-flat resonator. The beam divergence is largest at the short end of the range.

It is also necessary that the portion of the beam included within the electrodes of the laser be as large as possible to maximize electrical transfer of energy. Furthermore, there should be no focusing on or within the resonator.

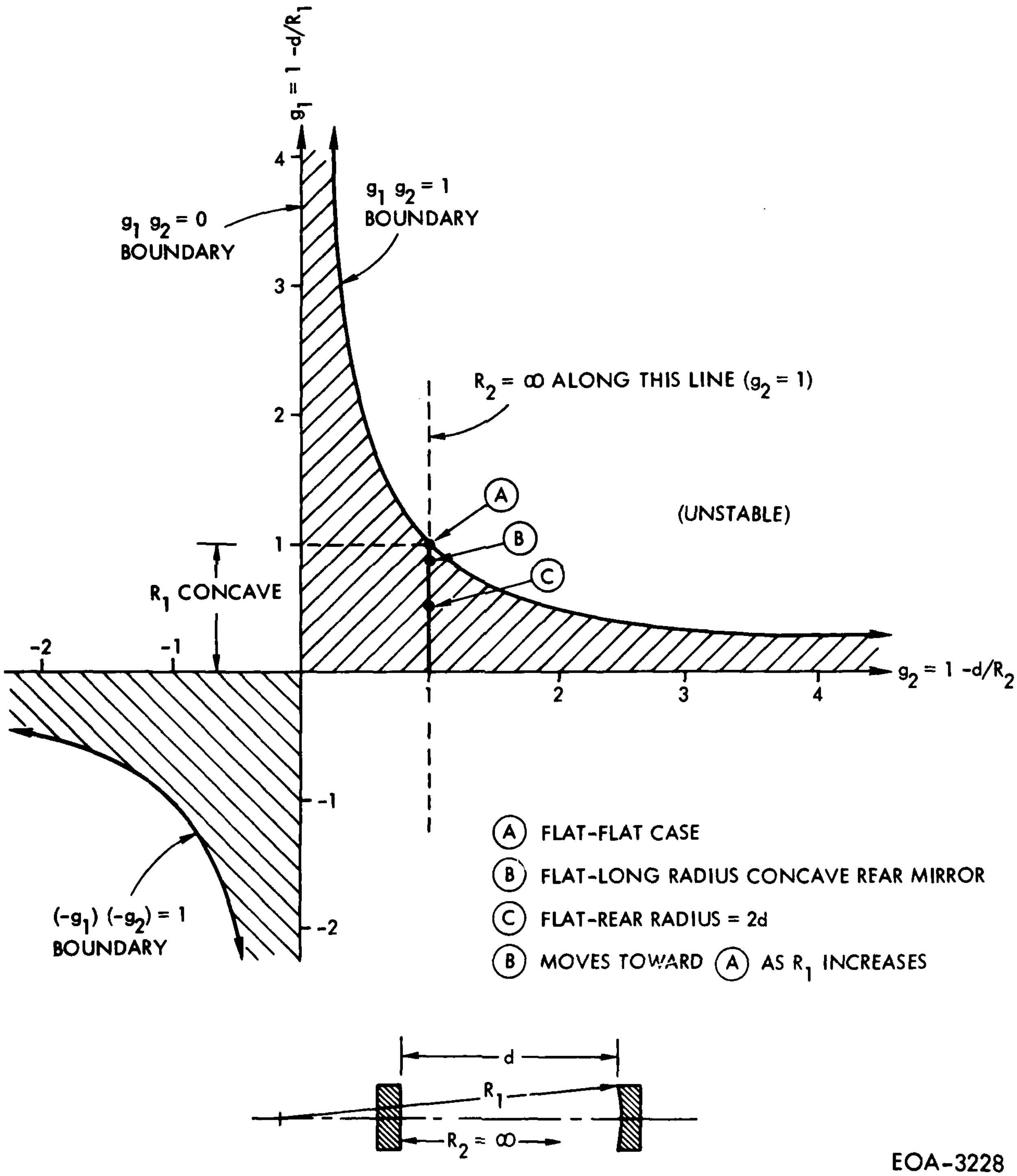


Figure 39. Stability Diagram
Stability Condition: $0 \leq g_1 g_2 \leq 1$

1.17 DESCRIPTION OF THE OPTICAL RESONATOR

The optical resonator is comprised of a concave rear mirror, a flat output coupler and an aperture close to the front mirror. If a polarizer were to be added, it would go between the aperture and the output coupler. The relative alignment of these components is shown in Figure 40. The optical axis is perpendicular to the output coupler which passes through the center of the aperture.

The rear mirror is a section of a large diameter sphere with a definite center of curvature. The mirror is aligned by tilting it until the center of curvature falls on the optical axis defined by the center of the mode-limiting aperture and a normal to the output coupler.

In addition to the constraints outlined above, the volume defined by a circular cylinder whose cross section coincides with the aperture and whose axis is the optical axis, must be contained within the rectangular parallelopiped bounded by the main electrodes. The aperture diameter must be less than the main electrode spacing but not too much. If the aperture is very small, the excited volume to utilized mode volume ratio is unfavorable.

The choice of rear mirror radius of curvature is based on the requirement to generate a quasi TEM_{00} or Gaussian output beam. The aperture truncates the Gaussian beam. The object is to obtain a far-field beam divergence which is as small as possible. The important parameter here is the beam waist radius, w_0.

Leaving out the aperture for the moment, the mode waist radius can be calculated from the separation, d, and the rear mirror radius of curvature, R:

$$w_0 = \sqrt{\frac{\lambda d}{\pi}} \left(\frac{g}{1 - g}\right)^{1/4}$$

where g = 1 - d/R. Now the full width beam divergence, α (to $1/e^2$), is given by:

$$\alpha = \frac{D\lambda}{\pi w_0^2} \text{ if } w_0 < D/2$$

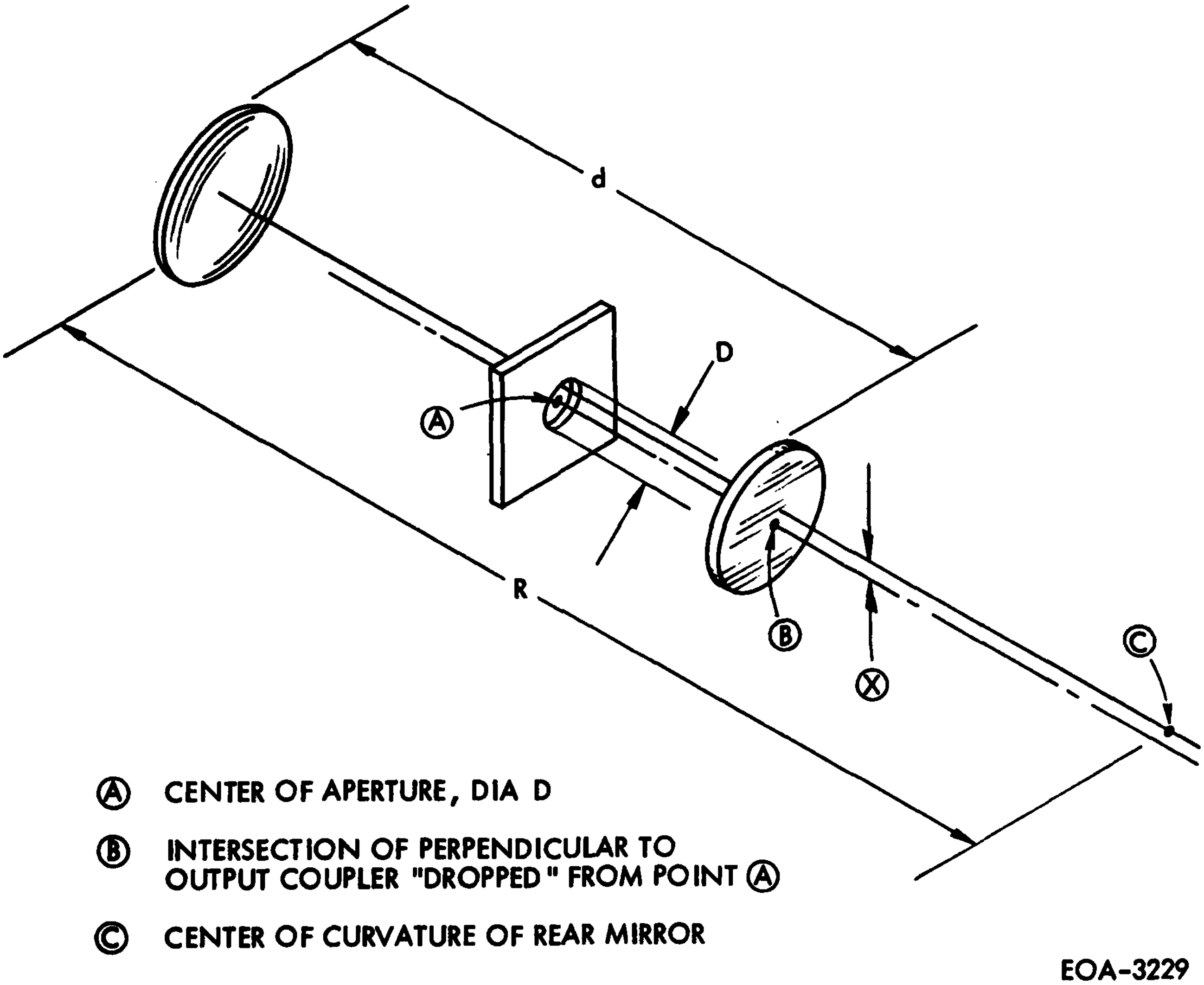


Figure 40. Optical Resonator

where D is the aperture diameter. Substituting resonator geometry parameters for w_0:

$$\alpha = \frac{D}{d}\left(\frac{1-g}{g}\right)^{1/2}$$

This equation predicts a divergence of 3.8 mrad. The parameters are tabulated below:

D	= 0.285 inch	= 0.724 cm
d	= 7.25 inches	= 18.42 cm
R	= 20m	= 2000 cm
w_0	= 0.101 inch	= 0.256 cm
D/d	= 0.039	
g	= 0.991	

From the equation for α, it would seem that increasing D is the wrong direction, but D must be large enough to prevent excessive attenuation of the edges of the quasi TEM_{00} mode. On the other hand, D must be small enough to deliberately attenuate the next higher order modes. Mode waist diameters for the first three orders are: $2w_0(0) = 0.202$, $2w_0(1) = 0.350$, $2w_0(2) = 0.452$ and so D = 0.285 is seen to be a good choice.

The spacing, d, can be beneficially increased, but d is limited by the package length restrictions.

The radius of curvature of the rear mirror will also reduce the divergence if increased. The calculated divergence would become 2.7 mrad if this radius were increased to 40m. The attenuation of the TEM_{00} mode increases as well. The magnitude of the angular alignment tolerance decreases with increased radius. Recalling the alignment requirements above, the displacement of the center of curvature from the line through the center of the aperture perpendicular to the output coupler must be small compared to the aperture diameter. The angular misalignment is then displacement divided by the radius of curvature. Suppose 10% of the diameter is allowable. The angular alignment, $\Delta\theta$, required is then:

$$\Delta\theta = \frac{0.10D}{R} = \frac{0.072}{R} \text{ radians}$$

where R is expressed in cm. Some radii and the tolerance are given as follows:

R	$\Delta\theta$
20m	36 μrad
40m	18 μrad
200m	3.6 μrad

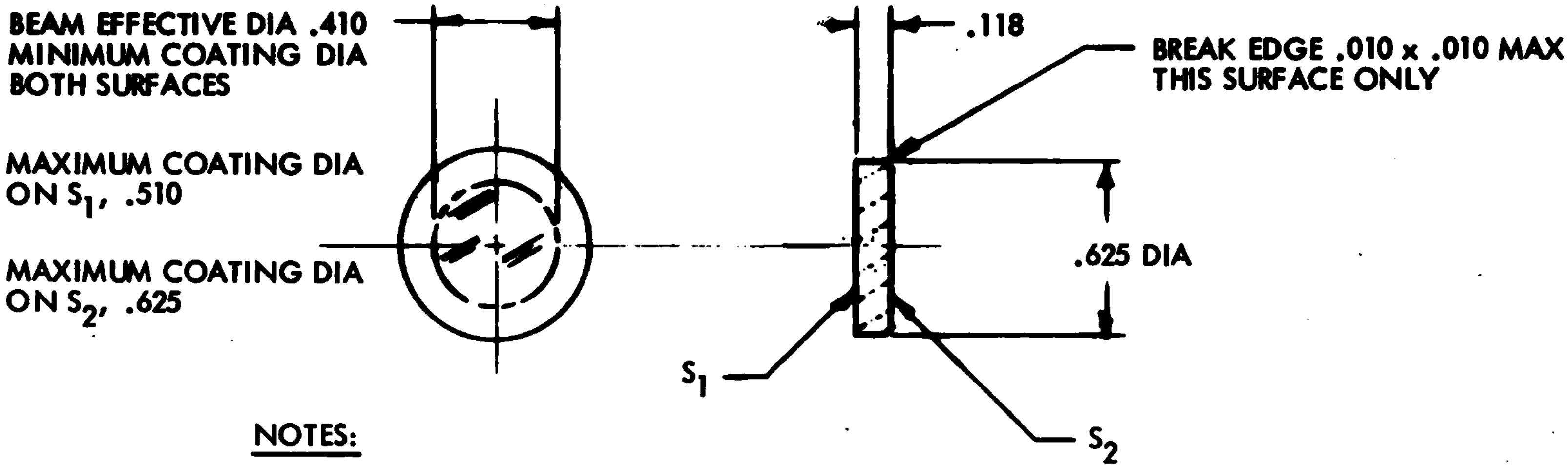
These calculations assume the internal gas is at rest and optically homogeneous. Such is not the case. There is a strong shock wave generated during the excitation pulse. The turbulence remaining at the time of the laser pulse would tend to defeat efforts to narrow the beam divergence. It does not seem that a mechanically aligned gas laser tube to be quantity produced could reliably achieve rear mirror alignment closer than 36 μrad.

1.18 SPECIFICATION OF OPTICAL ELEMENTS

The optical components which make up the resonator must be carefully specified to assure surface quality and durability. The spectral requirements must be met after environmental and durability testing. A military specification which closely matches the TEA laser requirements is MIL-F-48616 (29 July 1977). It is intended to control coated infrared filter optical elements. However, there are additional requirements for the TEA laser optics. A set of Raytheon specifications has been drawn up for TEA laser optics. The Raytheon document which specializes MIL-F-48616 to the particular requirements of the TEA CO_2 laser transmitter is included as Appendix B of this report.

The specification is made a part of the purchase agreement with optical component vendors by incorporating imperative references in the notes accompanying each relevant shop drawing. Figures 41 and 42 are examples.

Three terms are used in the specification which should be clarified here. The Beam Effective Aperture Diameter (BEAD) defines the minimum diameter which must be properly finished and coated to guarantee the laser beam will properly intersect the element regardless of the orientation of installation. It is neither necessary nor desirable to finish off the entire optic, but on the other hand, finishing off a spot only the size of the beam places unnecessary constraints on the installation of the part.



NOTES:

1. OPTICAL COMPONENT PROCUREMENT SPEC: G227206
2. MATERIAL: LASER GRADE HIGH PEAK POWER LEVEL ZINC SELENIDE
3. FLATNESS, BOTH SURFACES: $\lambda/10$ AT 6328 Å
4. PARALLELISM OR WEDGE: INCLUDED ANGLE MUST BE LESS THAN 100 ARC SECONDS
5. SCRATCH AND DIG: GRADE A-A WITHIN BEAM EFFECTIVE DIA.
   5.1 NO VISIBLE DEFECTS WHEN OBSERVED WITH THE UNAIDED EYE
6. COATINGS:
   6.1 INNER SURFACE S_1 = 79% $\pm$ 1% PEAK REFLECTANCE AT 10.6 MICRONS
   6.2 OUTER SURFACE S_2 = ANTI-REFLECTIVE, LESS THAN 0.1% AT 10.6 MICRONS
7. RECOMMENDED VENDOR: II-VI INCORPORATED
   SAXONBURG BLVD
   SAXONBURG, PA 16056
   TEL. (412) 352-1504

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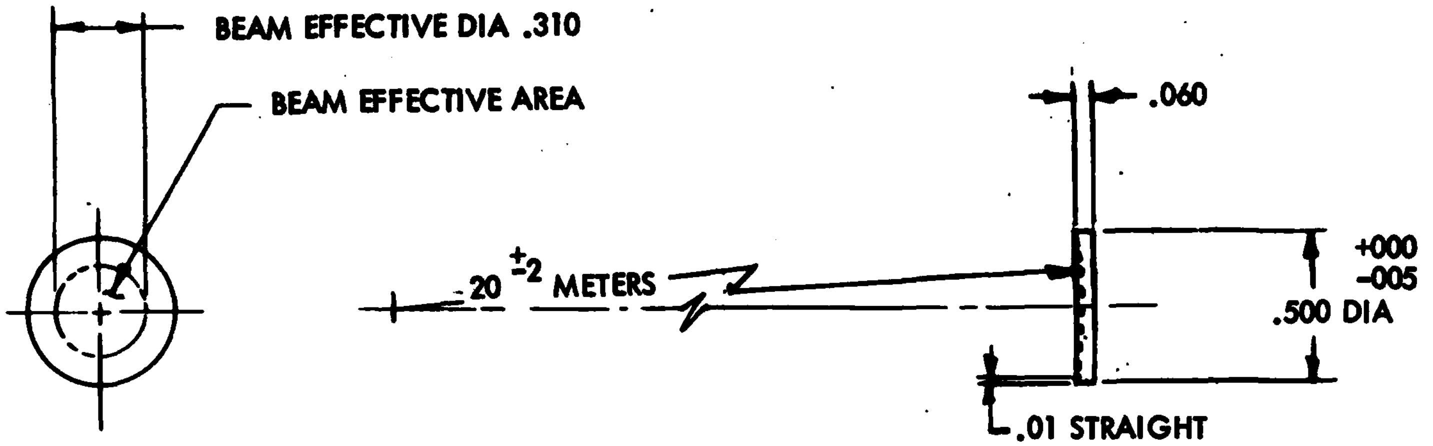
Figure 41. Output Coupler



NOTES:

1. PURCHASE SPECIFICATIONS: G227206 (PARA. 3.4 CONCERNING THIN FILM COATING DOES NOT APPLY)
2. MATERIAL: BERYLLIUM COPPER ALLOY
3. SURFACE FIGURE: 1 FRINGE AT 6328 Å
4. PARALLELISM OR WEDGE: NOT APPLICABLE
5. SCRATCH 8 DIG: A-A WITHIN B.E.A.
   5.1 NO VISIBLE DEFECTS WHEN OBSERVED WITH THE UNAIDED EYE
6. COATINGS: NOT APPLICABLE
7. SUGGESTED VENDOR: P.T.R. OPTICS CORP.
   145 NEWTON ST.
   WALTHAM, MA 02154
   TEL. (617) 891-6000

EOA-3231

Figure 42. Rear Mirror

"Sealing area" is defined as the region(s) on an optical component used as environmental window which must not be coated to provide for sealing processes. The sealing area must not intersect the BEAD. In the case of the TEA laser described in this report, the output coupler of zinc selenide has a sealing area. This area will be sputter-metalized with chromium, nickel and finally gold. Low temperature soldering in vacuo will then seal the coupler to the laser body. The reflective coating within the BEAD must not be disturbed by the sputter-metalizing process or the vacuum-soldering process.

The Beam Effective Area (BEA) is delineated by a circle of the BEAD for circular beam cross sections. If the beam is not circular, the boundary of the BEA must be indicated on the part drawing. A Brewster-angled plate, if used, is an example of such a part.

The BEA is defined by an ellipse which should be indicated on the component drawing. Within the BEA, the highest level of surface quality required is specified. Surface finish may be much poorer outside the margin of the BEA without degrading laser performance. The BEA must not overlap the sealing area on optical elements which are used as environmental windows.

1.19 ELECTRICAL DRIVING CIRCUITS

The purpose of the electrical driver is to transfer energy to the laser gas. This means, ideally, the entire CO_2 population would be elevated to the upper laser energy level. A very short time interval after the transfer of energy ceases, the gain resulting from the energy stored in the interaction space, being very high, is converted into 10.6-micron wavelength radiation to result in a several hundred kilowatt output pulse.

The electrical driving circuit, often called a pulse-forming network or PFN, is the electro-mechanical part of the complete laser which accumulates, stores and releases the input energy into the laser tube. Accumulation of energy is usually accomplished by drawing current from a high voltage power supply during the interpulse period. The charge is accumulated in a capacitor bank. The energy stored is then released on demand into the gas mixture in the laser tube.

Actually, there are three steps to the process. First, a fraction of the available energy is used to precondition the gas in the discharge region so that it will absorb energy uniformly without arcing. Second, energy is transferred to the gas. Third, the discharge extinguishes. The time between the conditioning pulse and the energy absorption pulse is critical. The conduction switch-off is also essential to prevent arcing after the main energy absorption.

The components which make up a PFN include capacitors for energy storage, leads to carry the current and high voltage switches which initiate the process on command.

1.19.1 CAPACITORS

The capacitors must be rated for the input voltage, have low inductance, and very low ohmic loss. They must be capable of being short circuited without peak current damage to the lead structure. In the ultimate end use, compactness is important and the high dielectric constant of barium titanate has been useful in producing compact PFN's. Such capacitors are made by Sprague and Murata-Erie. This "ferroelectric" material exhibits a decrease in dielectric constant with applied field, however. Aging has also been observed in which the energy stored decreases strongly as a function of numbers of shots.

Another type of capacitor is the mica paper and foil as developed by Tobe Deutschmann. Rolls of this sandwich are compressed and impregnated with a resin-type dielectric and then potted in a G-10 epoxy-filled fiberglass box. Their energy storage density is about the same as new barium titanate units.

For high reliability and constancy of capacitance, the Maxwell polypropylene capacitors, although physically large, are best for life testing the laser. They do not appear to have voltage or age-dependent coefficients.

Barium titanate units are made in the form of squat cylinders. The mica foil capacitors can be made in any reasonable parallelopiped shape, thus they have the better packing fraction for ultracompact rangefinder installations. Maxwell polypropylene capacitors are too large for portable equipment.

1.19.2 SWITCHES

Application of the high voltage to the main electrodes results in high current flow on the order of 1400 amps peak. In addition to passing this current, the special switch must hold off the peak-applied voltage, up to 25 kV. Switches capable of this performance include triggerable spark gaps and hydrogen thyratrons.

1.19.2.1 Spark Gaps

Spark gaps are relatively compact and convenient to use since they require no power prior to activation. They do wear out, however, and require replacement in less than a million shots in this application.

The triggered spark gap is fired by a high voltage pulse applied to the trigger electrode. This electrode is a thin wire concentric with a ceramic bushing which is in turn flush with the surface of one of the main spark gap electrodes. The manufacturer, EG&G of Cambridge, MA, also markets trigger transformers such as the TR180B. A two-microfarad capacitor, charged to 200V, is switched across the primary by an SCR (silicon control rectifier) to generate the trigger pulse. Due to the large inductance of the many turn secondary, the voltage rise is relatively slow and the circuit rings.

1.19.2.1.1 Spark Gap Firing Jitter

The slow rise of trigger voltage results in considerable time jitter between spark gap firing and the SCR gate trigger. This effect also requires a laser output sample detector to furnish a start pulse signal for range counting circuits rather than use the input fire command pulse. Similar difficulties with jitter are experienced when a two-spark-gap PFN is used with two TR180B's.

To overcome the jitter, the rise time of the trigger pulse must be cut down. Jitter can be reduced to less than 5 ns by the following techniques.

Use a ferrite core few-turn step-up transformer. The first spark gap to be fired is triggered conventionally, but the series current is passed through the primary of the small ferrite transformer. The secondary pulse is applied to the second gap to be fired. The jitter between the two is remarkably small.

By incorporating a coaxial cable as a distributed delay line between the spark gaps, the so-called dual spark gap PFN was developed. The purpose was to control the relative firing time between the flashboard and the main gap. The most important result from this was the nearly perfect shot-to-shot reproducibility which occurred with nearly any laser tested if the right time was allowed between the flashboard and the main gap.

Most single-gap PFNs merely start a race between the flashboard and the main gap. Various start-up uncertainties produce a variable, from shot-to-shot delay between the two. Thus, there is considerable jitter on the degree of preionization and hence some instabilities appear in the main discharge. Sometimes a fully developed arc occurs. These instabilities result in lessened excitation, less energy stored in the gas, so that the laser output varies considerably from shot to shot.

Although a ferrite transformer can be made compact and the extra volume for a second spark gap is not great, the extra components can create reliability problems. The Government thus decided to forego the advantages of a dual spark gap PFN for the increased reliability of a single spark gap PFN.

1.19.2.2 Thyratrons

Hydrogen thyratrons are much larger than spark gaps of equivalent current rating and require tens of watts of steady heater power. They will last for many millions of shots and are therefore useful for life testing in the laboratory as noted previously. Exceeding the current rating results in destruction of the thyratron in a few shots. As long as the current rating is not exceeded, the thyratron characteristics do not change noticeably during the course of many 2×10^6 shot life tests.

An EG&G Type 1802 thyratron was connected to a heater and reservoir supply capable of 18 amps at 6.3 volts. The 1802 thyratron is brought up to temperature gradually and allowed to approach equilibrium for five minutes before turning on the high voltage.

Triggering requires a strong pulse which is derived from a small capacitor charged through a decoupling current-limiting resistor which derives its voltage from the common high voltage supply. The charge is switched through a ferrite core transformer by a lightly loaded spark gap. The spark gap is triggered by the EG&G trigger supply modified to have an internal pulse source at 1 Hz. No lifetime problems have been experienced with this lightly loaded spark gap.

1.19.3 LIFE TEST PFN

This test PFN was built initially with the Tobe Deutschmann mica paper capacitors. They did not have enough capacitance and so another Murata barium-titanate unit was added in parallel. The thyratron-controlled PFN, as described, can be readily protected by the previously developed "laser minder" circuitry which shuts off all high voltage supplies if the laser fails to pulse.

For life testing, the mica paper capacitor was then replaced with the Maxwell polypropylene unit. This PFN, as used for life expectancy testing, has previously been discussed in Section 1.13.1.

1.19.4 SUGGESTED PRACTICAL PFN

A PFN which could be used for an armored vehicle rangefinder might have the same circuit, but a spark gap, such as the EG&G Model SG20B, substituted for the thyratron. To replace the large, bulky capacitor, a Tobe Deutschmann mica paper capacitor of the correct capacitance encased in G-10 glass-filled epoxy box would be suitable. All other components are small enough.

An advantage of this circuit is that one side of the laser being grounded simplifies packaging into a close-fitting shielded metal box. There are fundamentally three different two-terminal devices to be connected in series. It is more advantageous mechanically to connect one side of the laser to ground. Then, only the capacitor is completely off ground which is convenient because it can be manufactured completely within an insulating case without adding size or weight.

1.19.5 INSTRUMENTED PFN EXPERIMENT

High voltage probes and Pearson current transformers can be used to monitor voltage and current waveforms. An example of an instrumented PFN experiment is shown in Figure 43. This experiment was performed to determine the energy partition. The current and voltage waveforms are shown in Figure 44.

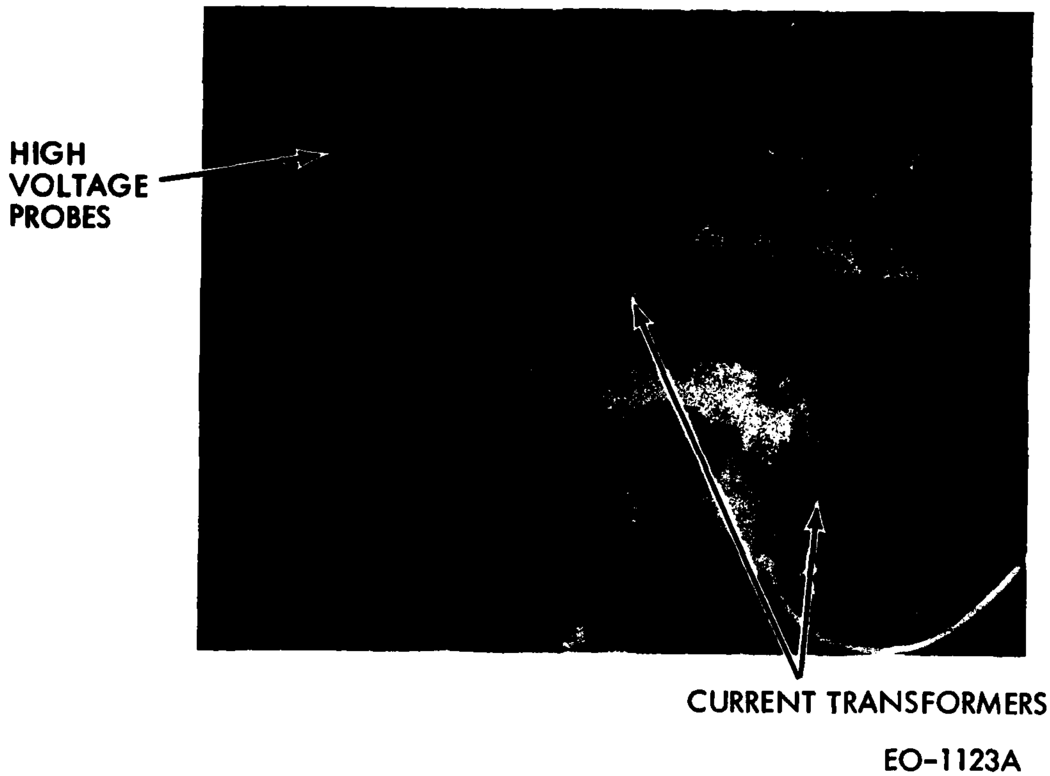


Figure 43. Instrumented PFN

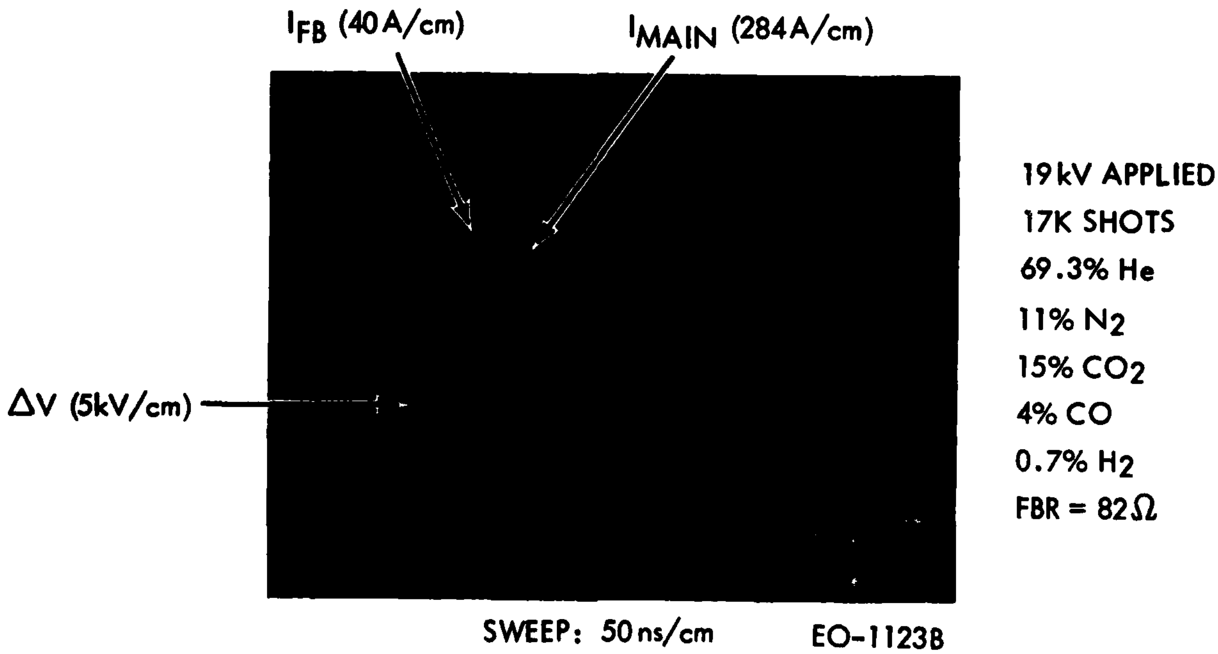


Figure 44. Instrumented PFN Current and Voltage Waveforms

A ceramic laser tube having 0.300-inch gap, 85% reflective ZnSe output coupler and a gas fill of 69.3% He, 11% N_2, 15% CO_2, 4% CO, and 0.7% H_2 was run to 17,000 shots. The PFN containing 10,000 pF total was altered to include two Pearson current transformers, one to measure the main discharge current only and the other to measure 1/2 the total flashboard current only. Also measured was ΔV. The input voltage was 19 kV.

The current and voltage were calculated for points 50 ns apart for both the main gap and the flashboard. The peak current pulse for each was very high, leading to the deposition of energy in the first 100 ns or so of each. The flashboard current begins 60 ns after spark gap trigger. The main gap current begins 30 ns thereafter.

	Peak Current	Peak Power	Avg Z	Energy
Main Gap	1340A	6700 kW	3.7 ohms	0.6J
Flashboard	177A (X2)	2700 kW (X2)	60 ohms	0.36J

The total input energy was 1.75J. Therefore, 29% is in the main gap and 21% is in the flashboard. The balance, 0.89 joules, is partially spent in the spark gap circuit and partially left in the PFN.

1.20 CONCLUSION

The goal of the program was to develop a manufacturable TEA CO_2 laser which would produce 200 kW peak power at a repetition rate of 1 Hz for 2×10^6 shots. The recipe for this laser was developed. A mechanical design which would keep the critical specification of the recipe over the full environmental and dynamic service ranges has been analyzed. A complete print set has been created which includes innovative methods for obtaining the critical tolerances.

A factor in meeting the 2×10^6 shot-life requirement is gas composition. If the initial composition within the laser does not exceed 15% CO_2 the life expectancy can be reached. There is some energy in the pulse tail which need not lead to difficulties if the rangefinder is suitably programmed. For example, a time-programmed gain circuit following the detector preamplifier can be used to prevent blocking of the subsequent stages due to the late departure of the energy in the tail. This sets a limit on the nearest range which can be measured, but with modern high velocity weapons, a minimum range of 500 to 1000m is acceptable.

If the target is one of several objects in line, spillover would provide returns from each. During the HSTV(L) program,* last pulse logic was provided. This, along with a maximum range gate, was then used to try to determine which return was the real target. This required some deductive skills on the part of the gunner and many laser shots. The afterpulsing seen with 15% CO_2 lasers would provide multiple echoes from a single target which would confuse a gunner trying to isolate the true return.

The use of last pulse logic and selective range gating is a sophisticated technique not likely to be a realistic mode of operation for the tank corps. Furthermore, the many shots required are more apt to be detected by an enemy than a single shot. Therefore, it seems logical to eliminate the last pulse logic mode and to limit the number of shots.

The new scenario is one laser shot, one gun shot, one kill. In fact, the gunner does not need to know the laser rangefinder is in use. The gunner lines up the selected target with an electronic reticle on the TV monitor. He pulls the trigger. The rangefinder fires and ranges, the anemometer reads the wind direction, the fire control computer solves the ballistic equation. The turret rotates and the gun elevates for the proper windage and range. Then the gun fires. All of this should occur in less than half a second and the electronic reticle stays locked on the target image.

Thus, it does not seem that it will be important from the rangefinder point of view when the laser pulse is followed by smaller afterpulses. It is more

*The HSTV(L) Program was the High Survivability Test Vehicle, Light, an experimental high speed, high maneuverability three-man tank with a 75-mm-high velocity armor piercing weapon. It was equipped with a digital fire-control computer, hydraulic gun laying servos, a gas turbine propulsion system and a sight which provided infrared viewing and rangefinding. Raytheon designed and built the 10.6-micron laser rangefinder.

important to have reliability which comes from long life testing periods than to have last pulse logic capability. The 15% CO_2 mixtures are acceptable for rangefinding on the first pulse logic basis. To squeeze some of the afterpulse energy into the first spike would be more efficient.

In the future, when tactial electro-optic systems spawn countermeasures, excess radiation must be avoided. Any emission beyond the pulse required for adequate S/N ratio at the detector increases the chances of detection by enemy laser warning systems. The longer the excess radiates, the finer the angular resolution for the device pointing at the laser, increasing the enemy's chances of retaliation.

The ultimate solution is to develop a laser which only emits the main spike. This may require an intracavity modulator which inserts loss in the resonator greater than the output coupling loss 100 ns after the main spike begins to rise.

The effect is to spread out the relaxation of the remaining nitrogen metastables over a longer time, reducing the power in the afterpulsing to benign levels. It could be almost completely eliminated by using an electro-optic shutter exterior of electro-optic modulators capable of surviving very high peak power in the transmissive mode and yet having adequate loss in the blocking mode.

The laser, as developed, meets the performance requirements for first pulse logic with a 500 to 1000m minimum range.

A set of manufacturing drawings has been created from which a reliable laser tube can be built. Structural innovations designed to solve problems resulting from environmental temperature excursions have been analyzed by a computer-aided design program called NASTRAN. Analytically, the critical dimensions, the mirror alignment and the electrode spacing and parallelism remain within specification.

Details of some of the processes which are used to prepare the materials remain to be developed. Most assuredly, some aspect of the laser will not function properly and further development may be needed. As much as could be foreseen has been taken care of. Any changes which might be required will have to be life tested to guarantee that they do not upset the chemical system. If an optimized high performance laser is desired, any changes in component chemistry will have to be life tested again.

For many applications, more peak power is required. If the size must remain the same, increasing CO_2 percentage will require a catalyst. A new catalyst, tin oxide, with palladium seems most promising. It is a passive agent, not requiring power. Further development is needed to fully realize the benefits of this material.

There are other methods of UV preionization. Some such as Pace's Carborundum preionizer and Kaminski's surface corona preionizer appear to have performance advantages. They are essentially parallel high-speed systems. The current-limiting impedances are intrinsic and in-built. They would have to be life expectancy tested in this tube to make sure they are compatible with the other factors in the 2×10^6 shot laser tube. Such development is certainly recommended.

The preionizer depends on high current density arcs. The short rise time of the current means elevated temperatures are reached by the surfaces of the preionizer electrodes. Evaporation of the preionizer electrode material is inevitable. This was observed when copper electrodes were used with flowing gas. A deposit of copper carbonate formed inside the tube. Moly electrodes have also produced contamination but only after many more shots. Although moly was a definite improvement, a better material would be desirable.

What is needed is a less volatile material with higher thermal conductivity and better electrical conductivity. A composite material of copper and tungsten may be suitable. Previous experiments with pure tungsten showed mirror damage due to tungsten particles. In this case, the buttons were not well finished having ragged edges. Smoother finish and the addition of copper to improve conductivity should overcome the contamination problem. Such a composite is made by sintering copper and the tungsten particles together. It is used for some spark gap electrode designs and for spot-welding electrodes.

The timing of the preionizer relative to the onset of high potential on the main electrodes has been demonstrated repeatedly to be critical. If the time interval is too long or the time for fully developed operation of the flashboard is too long, filamentary arcing occurs, leading to poor shot-to-shot reproducibility, a symptom of inadequate preionization.

A method of experimentally demonstrating the effect of varying the timing was developed. These experiments showed that appropriate timing could always be achieved by the use of more than one spark gap and high speed ferrite trigger transformers. This extra equipment is not desirable from portability and reliability points of view.

An alternative approach would be a high speed preionizer, i.e., simultaneous arcs. This could be achieved by a parallel arrangement rather than buttons in series. If there were N arcs in series, the time for N parallel arcs should be 1/N as long. Now if the N arcs produced enough preionization, doubling the number should require half as much input per arc. Eventually, by doubling again and again, the energy per arc can be reduced dramatically. In the limit, of an infinite number of arcs, the result is remarkably like a corona preionizer.

Corona preionization is similar to the surface-guided arc.* This serves to lower the energy required and may involve the substrate spectroscopically. Choice of substrate can affect the emission spectrum. But substrate involvement may result in contamination problems. Material may be deposited on the mirrors. Life testing of this device must be accomplished before the corona preionizer can be actively supported. This could be done with a special chamber, closed at the ends with flat glass windows to collect any material released by the preionization processes. By operating the test chamber sealed, periodic gas chromatography analysis can be done to track the gas condition as a function of time.

The closeness of the corona preionizer to the main discharge should reduce CO_2 absorption of the UV and the inverse square-law fall-off is less. On the other hand, the dielectric substrate blocks free motion of the gas transverse

*R.E. Beverly, "Surface Guided Arcs," Progress in Optics Vol XVI pp 357-441, to the discharge. This could retard the usefulness of the catalyst presently under consideration. Higher repetition rates may also be difficult to achieve because of local heating of the entrapped gas.

When increasing the repetition rate becomes important and when high peak power becomes important, a form of high speed preionization which does not restrict gas flow for cooling and for catalytic interaction becomes imperative. The developments which may be considered are:

- Locating the preionizer within the anode
- Locating the catalyst within the anode but using the wraparound corona preionizer
- Use a finite arc parallel flashboard
- Use one corona-type preionizer on one side; catalyst on the other

The electrode shape designed for ease of manufacture may not ultimately be the best compromise; more energy could be deposited in the gas with the profile of Chang,* for example.

A forthcoming paper to be published in Rev. Sci. Instrum, by P.W. Pace, J.M. Cruickshank, and P. Mathieu will describe a simple laser using the corona preionizer on one side and Chang-contoured electrodes. The PFN consists of a capacitor and a vacuum switch which connects the capacitor across the laser tube. It is their intention to attempt sealed-off operation, using a tin oxide and palladium catalyst. Although these test results were for an unapertured tube operating with flowing gas, the impressive peak power of over two megawatts would not be achieved under TEM_{00} sealed conditions but would probably not degrade to less than 50%. Materials such as silicon carbide have not been thoroughly tested for life expectancy; hence, this tube concept should be pursued to investigate its life potential.

The mirror alignment problem stems from the short, large diameter resonator which must produce "TEM_{00}-like" mode operation. Polarizing the laser by the addition of an internal Brewster angle plate shortens the space available for

*Chang, T.Y., Rev. Sci. Instrum, 44, 405 (1982).

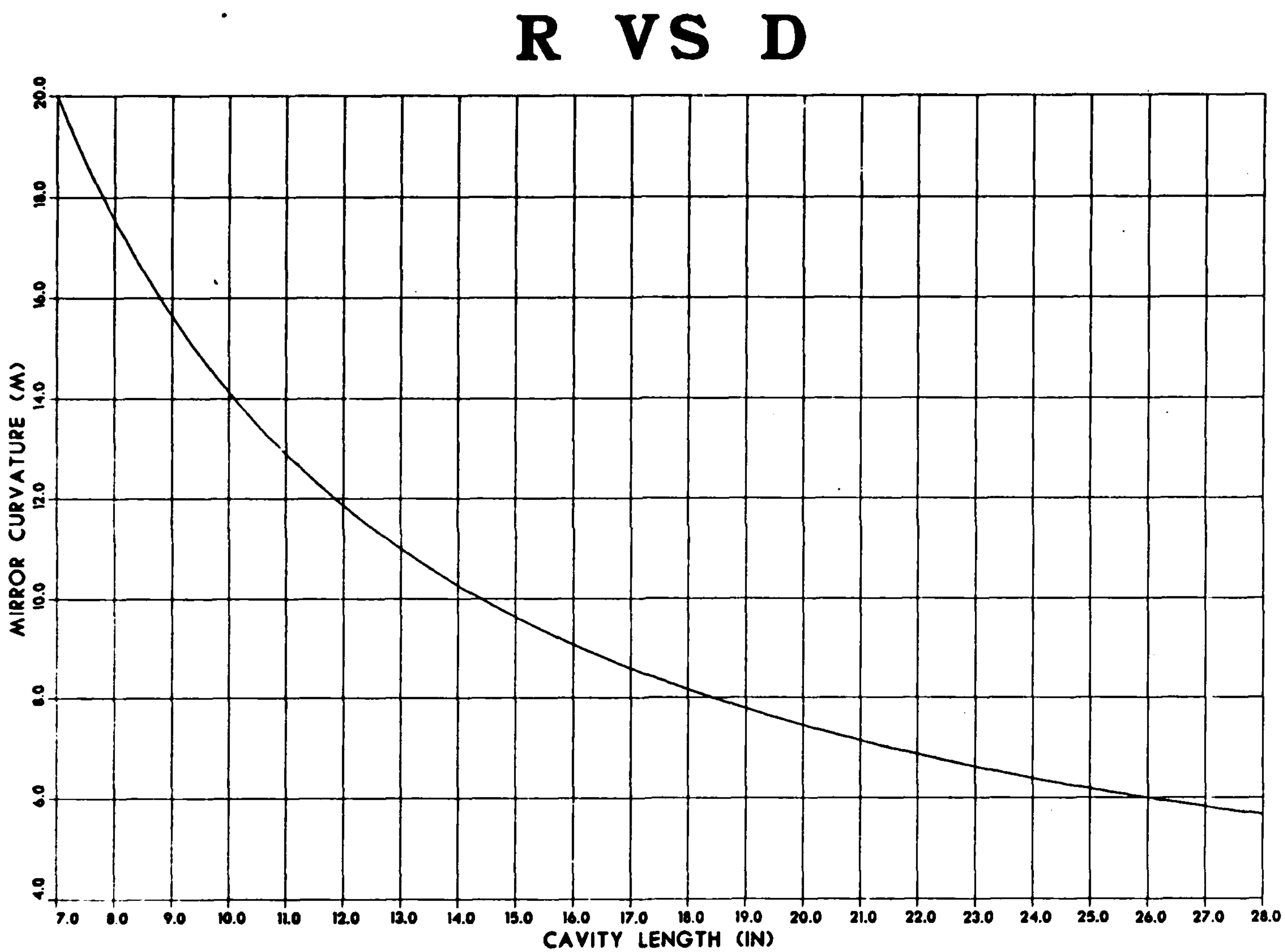
excitation. In order to fill the aperture with the waist of the mode volume, the rear mirror radius of curvature must be large; 20 meters was selected as the maximum practical length which could still be maintained in alignment. But this alignment is not easily achieved with a hermetic structure.

Assuming the mode waist is kept constant, i.e., the beam divergence remains constant, Figure 45 shows how the mirror radius of curvature varies with resonator length. It is a hyperbolic relation. The alignment tolerance varies inversely with the length of the radius. The longer the resonator, the easier it is to keep it aligned. In the future, laser transmitter packaging should make the laser the driving force and not a retrofit from some other completely different technology.

The several possibilities here include:

a. Lengthening the resonator
   - Fold the tube, doubling the resonator length
b. Constructing a prealigned resonator which is then sealed within the gas-tight envelope
c. Using an unstable resonator configuration
d. Using Brewster-angled windows at both ends of the sealed envelope with external mirrors; this does not overcome the need for maintaining precise alignment, but the mirrors can be readjusted without opening the seals.

A sealed external mirror tube with valved gas tubes, rather than pinched-off seals, could be refurbished by refilling the gas supply, and, when required, by replacing optics damaged by high peak power. Preionizer erosion and contamination on the inner surfaces of the Brewster-angled windows would then be the irreparable life-limiting processes. It should be clear that preionizer erosion is a principal cause of Brewster window contamination. A solution to the preionizer problem must include erosion and contamination reduction, i.e., copper and tungsten as described above.



EOA-3233

Figure 45. Rear Mirror Radius as a Function of Cavity Length for Constant Beam Waist Diameter

SECTION 2

PROCESS SPECIFICATION

MANUFACTURE OF A CERAMIC TEA CO_2 LASER TUBE

2.1 SCOPE

The purpose of this specification is to outline the steps necessary in the manufacture of a ceramic TEA CO_2 laser tube. The tube, when coupled to an appropriate electrical driving circuit, is intended for use in 10.6-micron wavelength pulsed laser rangefinders, specifically the rangefinder for the M-1 tank.

2.2 APPLICABLE DOCUMENTS

2.2.1 DRAWINGS

The parts, subassemblies and assemblies necessary for the manufacture of the tube are fully described in the following set of drawings*:

DRAWING LIST

Drawing Title	Size	Drawing No.
Assembly, TEA Laser Tube	E	G225400
Tube Body	D	G225389 (2 Sheets)
Spacer, Electrode	B	G225403
Seal Ring Stud	B	G225415
Washer, Tube	B	G227004
End Cap Assembly, Rear	C	G225390
End Cap, Rear	C	G225396
Flange, Rear Seal Cap	B	G225411
Flange, Rear End Cap, Adj Mirror Mtg	B	G225407
Rear Mirror Mount and Aperture Assembly	C	G225406
Rear Mirror Mount Adj	D	G225408
Aperture Shield	C	G225397
Mirror, Rear	B	G227005

* The drawing numbers assigned are Raytheon Company drawings. The FSCM number is 49956.

Drawing Title	Size	Drawing No.
End Cap Assembly, Output	D	G225391
Output Coupler	B	G225404
Washer, Output Coupler	B	G225405
End Cap, Output	D	G225399
Washer, Thrust	B	G225409
Holder, Upper and Lower	D	G225395 Pin, Alignment
Pin, Alignment	B	G225398
Electrode	D	G225392 (P1 and P2)
Stud, Electrode, Rigid	B	G225413
Stud, Electrode	B	G225414
"D" Washer Electrode	B	G225410
Nut, Electrode	B	G225416
Flashboard Assembly	D	G225393
Ground Button	B	G225770
Flashboard Button	B	G225401
High Voltage Button	B	G225769
Flashboard	D	G225402
Artwork, Ground Line*	C	G225773
Artwork, HV Line, LH*	B	G225772
Artwork, HV Line, RH*	B	G225771
Fill Tube	B	G225768
Seal Cap, Mirror	C	G225412

2.2.2 APPLICABLE PROCESS SPECIFICATIONS

The following is a list of applicable process specifications. Additional specifications will be required as development proceeds.

a. Ultrasonic Cleaning (Appendix C)

b. Ultrasonic Cleaning, Non-Ionic Detergent (Appendix D)

c. Firing of Metalization (Appendix E)

d. Cleaning Parts before Plating (Appendix F)

e. Rinse of Plated Ceramics (Appendix G)

* Artwork defines shape of metalized areas on the ceramic substrate. May be used to make dies for cutting the Vitta metalizing tape, for example.

2.2.3 OTHER SPECIFICATIONS

A purchase specification for the special optical components used in this laser tube is referenced in Section 3, Quality Control Manual. "Laser Output Measurement" is also referenced as a specification in Section 3 as well as circuit diagrams and descriptions of the special instrumentation developed for monitoring life testing. The referenced specifications and diagrams are included in the Appendices to this report.

2.3 REQUIREMENTS

2.3.1 EQUIPMENT

2.3.1.1 Component Manufacturing

Equipment typical of the manufacture of metal/ceramic high vacuum microwave tubes is required. These facilities include:

a. High temperature reducing atmosphere furnace
b. Hydraulic press
c. TIG or heliarc welding equipment
d. Stamping and drawing presses
e. Ball mill for metalizing material
f. Electroplating baths, agitators, power supplies and waste disposal systems
g. Ultrasonic cleaning equipment
h. Precision ceramic grinding equipment

2.3.1.2 Assembly Operations

Certain assembly processes require special equipment including:

a. Electrical discharge machine (EDM)
b. High vacuum infrared soldering equipment
c. Sputter metalizing equipment
d. Plasma ashing equipment

2.3.1.3 Laser Assembly Equipment

Optical alignment and gas filling equipments which are peculiar to the laser technology include:

a. Zygo interferometer
b. Evacuation, bakeout and back-fill station
c. Helium-mass spectrometer leak detector

2.4 MATERIALS

The materials required are specified on the detail drawings.

2.5 REQUIRED PROCEDURES

The processes for building a laser tube consist of firing greenware to performance testing of the finished product. The steps proposed for the construction of laser tubes from parts manufactured according to the drawing set are listed in Table 7. In addition to the main steps indicated, cleaning and other forms of surface preparation are required. It is assumed that these steps have been performed prior to the putting together of the components. Each of the major steps is described following Table 7.

TABLE 7. STEPS IN LASER MANUFACTURING

	Operation	Item	Subassembly	Reference
1.	Hydrostatic Press	Greenware blank		
2.	Fire in HT Furnace	Greenware blank		
3.	Precision Grind	Ceramic body		
4.	Metalize			2.5.1
	4a. Apply 4b. Fire 4c. Electroplate	Ceramic body and metalizing preforms		
5.	Furnace Braze	Electrode supports, weld lips, Flashboard to ceramic body	Flashboard	2.5.2
6.	EDM	Electrode supports on ceramic body		2.5.3
7.	Furnace Braze	Front end cap, Rear end cap to ceramic body	Front end cap Rear end cap	2.5.2
8.	Machine	Output coupler mounting pad, perpendicular to reference axis on ceramic body		
9.	Install	Main electrodes in ceramic body		
10.	Heliarc weld	Main electrode screws		2.5.6
11.	(Vacuum) sputter metalize	Output coupler and pad on ceramic body		2.5.4
12.	Vacuum solder	Output coupler in place on ceramic body	Sputter metalized output coupler	2.5.5
13.	Heliarc weld	Rear mirror assembly "in place"	Rear mirror assembly	2.5.6
14.	Align and test	Laser with flowing gas (PFN assembly)		Section 3
15.	Heliarc weld	Rear mirror screws		2.5.6
16.	Test	Laser performance		Section 3
17.	Heliarc weld	Rear end cover		2.5.6
18.	Vacuum and bakeout	Complete laser		
19.	Vacuum and backfill			2.5.7
20.	Test	Laser		2.5.8
21.	Pinch-off	Laser tube		2.5.9
22.	Test and evaluate sealed laser performance	Laser tube, PFN assembly and high voltage power supply		Section 3

2.5.1 METALIZING

By these processes, the surface of a ceramic tube component is prepared for a solid vacuum-tight bond to a metal component or to another ceramic component. There are two principal methods in use in the microwave tube industry: the active metal hydride - metalize and braze in one step in a vacuum, and the molybdenum titanium - metalize, fire in hydrogen, plate and braze in a hydrogen atmosphere. The second type is better adapted to the multiple steps required for laser tube fabrication.

The moly-titanium process begins by ball-milling ultrafine powders of the two metals in a jar with a nitrocellulose lacquer binder. The metalizing mixture is then painted on the ceramic in the places where braze joints are to be made. The metalizing application must be accurately done because, in later brazing, the braze filler metal will flow wherever the ceramic has been metalized.

2.5.1.1 Tape Metalizing

There is an alternative method of application. This involves a self-adhesive tape manufactured by Vitta Corporation, 382 Danbury Road, Wilton, CT. The tape is cut to the shape desired and applied to the ceramic. When fired, the tape disappears and a metalized pad is produced just as if the metalizing had been applied with a brush. The best tape found is 97 percent molybdenum and 3 percent titanium and, on Raytheon R-95 ceramic, it is fired at a peak temperature of 1600°C.

2.5.1.2 Plating

After the metalization has been fired in the hydrogen atmosphere, the metalized areas must be electroplated to accept the brazing operation. Nickel is typically used for this and fired again at 1000°C in hydrogen. The ceramic part is then ready for brazing.

2.5.2 BRAZING

The term generally refers to a method of joining metals or metallic surfaces, in which another filler metal having a melting point lower than that of either metal to be joined is fused by being elevated to a temperature above the fusion temperature of the solder. High temperature brazing is usually performed with solders which do not contain lead, tin or zinc and have substantially higher melting points. A reducing atmosphere acts as a flux.

2.5.2.1 Serial Brazing

Serial brazing enables assemblies to be built up with several furnacings at slightly lower temperatures each time. Precision temperature control is needed to avoid accidental melting of previously brazed parts. Table 8 is a very brief selection of brazing metals.

TABLE 8. BRAZING METALS*

Liquid (°C)	Solid (°C)	Composition	Application
1083	1083	Copper	Kovar
1075	965	Nickel-gold (35, 65)**	
1065	1002	Palladium-silver (10, 90)	Nickel
1063	1063	Gold	Copper, moly
1060	1000	Silver-copper (5, 95)	Copper
1035	1015	Gold-copper (30, 70)	Copper, iron, Kovar
1030	975	Nickel-gold-copper (3.35 bal)	Copper, Kovar, moly, nickel
1020	1000	Gold-copper (35, 65)	Copper, Kovar, nickel
975	950	Copper-gold (50, 50)	Copper, Kovar, nickel
9605	960.5	Silver	
950	950	Nickel-gold (18, 82)	Copper, Kovar, moly, nickel
910	779	Silver-copper (40, 60)	Ferrous and nonferrous alloys
779	779	Copper-silver (Eutectic) (28, 72)	Copper, Kovar

* Selected from Fred Roseberry, "Handbook of Electron Tube and Vacuum Techniques," Addison-Wesley, Reading, MA, pp 176-187

** Percentage by weight

2.5.3 EDM (ELECTRICAL DISCHARGE MACHINING)

The principle of operation is based on erosion of metals by spark discharges. The spark is an electrical discharge between two electrodes, one of which is the workpiece and the other, the tool. The discharge occurs when the potential difference between the electrodes is great enough to cause a breakdown of the dielectric material between the electrodes. The dielectric medium is usually a hydrocarbon. It also serves to cool the electrodes and to carry off the particles removed by the discharge.

The process finds application in precision machining within cavities or in the production of special shapes in otherwise difficult materials. The hardness and conventional machinability has only slight impact on the rate of removal by EDM. Rates of removal can be as high as 0.2 in^3 per minute, but for better surface quality, the rate should be 0.06 in^3 per minute or less to achieve 25μ in finishing cuts. Vigorous cleaning is required before subsequent assembly can proceed.

The tool is typically made of brass, sintered material or graphite. The tool wear depends on the workpiece. The tool feed is servomotor controlled and the tool wear can be programmed into the control systems electronics. Tolerances can be as fine as 0.0005 inch.

2.5.4 SPUTTER METALIZING

As noted previously, one way the TEA laser tube differs from the typical microwave tube is the output window which is made of a relatively delicate material, zinc selenide. The zinc selenide cannot be elevated in temperature to the extent required for furnace brazing discussed above. "O" ring seals and epoxy seals have been ruled out, primarily because of the extended shelf life goals. It is also imperative that the output window, which as a partially reflecting mirror and is the output coupler of the laser, must not be distorted over the operational environmental range.

Sputter metalizing is a technique which applies specific metallic coatings to the sealing coupler without the use of fluxes or high temperatures. Similar coatings are applied to the 45-alloy pad part no. G225405 on the output end of the body assembly after the pad is precision ground perpendicular to the long axis of the laser body tube.

Sputter metalizing is performed in high vacuum. A plate of the metal is used as a cathode; positive ions bombard the cathode, knocking out metal ions which condense on the workpiece. Extreme cleanliness is required for proper adhesion of the sputtered metal; 500Å-thick chromium is applied first, then 25,000Å nickel and finally 7000Å gold. To prevent unwanted deposits on exposed areas, the workpiece must be masked.

2.5.5 VACUUM SOLDERING

The output coupler in particular is sealed to the pad on the laser body assembly by soldering in a vacuum. The parts are fixtured together and a solder preform installed around the output coupler. Focused infrared lamps heat the interface after the chamber is evacuated. The solder melts and flows between the coupler and the seat by capillary action. Care must be taken to heat uniformly and to avoid overheating of the zinc selenide which would turn black.

In the earlier experimental work, InPbAg solder was used, and after problems at the lower temperature limits, the solder of choice was changed to SnAg. Prior to this change, a structural and thermal analysis was prepared.

2.5.6 HELIARC WELDING

This process is also called tungsten inert gas (TIG) welding. It produces high quality welds between nickel and copper alloys and in stainless steel. The tungsten electrode is not consumed and the fusion is made between metals of the two welded parts. The shielding gas is usually helium or argon. Because of the shielding and because no metal passes through the arc plasma, there is no spatter.

Parts to be welded in the laser tube are usually formed with lips of equal size which are fused together by the welding process. The lips are usually made long enough so that the fused portion could be machined away and the parts disassembled for repairs. The remaining lips can be welded again. An important design principle followed in this laser tube is that the TIG-welded lips should not bear major structural loads. They instead serve mainly as vacuum seals.

2.5.7 VACUUM BAKEOUT

High alumina ceramic is a ready adsorber for atmospheric water vapor. It is not desirable to seal this trapped vapor within the tube. It is therefore necessary to pump the tube with a high vacuum turbo molecular pump. Heat is applied to further accelerate the removal of the water vapor. Before pumping down, however, the tube should be checked to be sure it is leak tight. Experiments have been performed on the time and temperature requirements. The experiments also determined that the impurity was indeed water vapor.

The previous work was limited to 62°C because of the presence of E-7 epoxy within the tube. The design developed in the drawing set described herein does not require epoxy. Consequently, higher bakeout may be permissible, greatly improving the rate of water removal. The temperature cannot be indefinitely raised, however, due to the zinc selenide output coupler and its attachment. Adequate bakeout can be assessed by noting the pressure drop which occurs after a number of hours while the tube is still hot.

After the pressure drop (to 10^{-7} Torr or less), the tube may be allowed to return to room temperature. The high vacuum system continues to pump. Next, the pump valve is closed and premixed laser gas is allowed to back-fill into the system to the desired pressure (between 1.0 and 1.4 atmospheres). The laser fill tubes are then pinched off (see Section 2.5.9).

2.5.8 BACK-FILL

Back-filling is the process of introducing a precise gas mixture into a vessel which has been evacuated and preferably vacuum baked out to rid outgassable contaminants.

2.5.9 PINCH-OFF

During the furnace brazing operations, the gas filling tubes, which are made of copper, become annealed. In this soft state, they can be made to cold flow and fusion weld. These two effects are utilized in a pinching-off operation which seals the tube with the requisite gas fill inside.

After the bakeout and subsequent final back-fill of laser gas, the tube is ready for pinching off. Two polished steel jaws are moved parallel to each other to squeeze the copper tubing. The metal extrudes above and below and cold welds along the contacting internal surfaces. After a successful pinch-off, the sharp edge of extruded copper should be protected by a thin application of epoxy. Later, the two pinched-off stubs can be enclosed in plastic caps.

2.6 QUALITY ASSURANCE PROVISIONS

This section is not applicable to this specification. Refer to Section 3, Quality Control Manual.

2.7 PREPARATION FOR DELIVERY

This section is not applicable to this specification.

2.8 NOTES

2.8.1 INTENDED USE

This specification outlines the steps required to assemble a TEA CO_2 laser using the parts defined by the drawing set referenced in Section 2.2.1. The purpose of the rugged TEA CO_2 laser is to provide high peak power pulses of 10.6-micron wavelength radiation in a well-collimated beam. This beam is used in a rangefinder. The rangefinder measures the round-trip time for the laser pulse to return scattered from a selected target. This measurement provides data for the fire control system in the armored vehicle. Specifically, this laser tube is for use in the M-1 laser rangefinder.

SECTION 3
QUALITY CONTROL MANUAL

3.1 SCOPE

The purpose of this section of the final report is to outline those quality control measures documented so far in the TEA CO_2 laser tube development program.

3.2 APPLICABLE DOCUMENTS

3.2.1 PURCHASE SPECIFICATIONS

a. Optical Component Procurement Specification (Appendix B)

b. Military Specification MIL-F-48616, 29 July 1977

3.2.2 LASER TESTING SPECIFICATIONS

a. Laser Output Measurement (Appendix H)

b. Table 2, Section 1, Part A, Environmental Conditions, Part B, Extranatural Phenomena

c. Summary of Life Test Requirements Subsection 1.10, Section 1

d. Electrical Equipment for conducting pulsed-laser life testing (Appendix I)

3.3 REQUIREMENTS

3.3.1 EQUIPMENT

The requisite instrumentation is described in the appropriate documents. In addition, a life test electrical driving circuit or PFN is required.

3.3.1.1 Life Test PFN

The PFN shall be sturdily built according to the circuit of Figure 46.

3.3.1.2 Laser Trigger

The laser shall be triggered by an EG&G TM-11A trigger circuit as modified to include a repetition rate clock, see Appendix I.

3.3.1.3 Laser Minder

The laser minder circuit, also Appendix I, should be connected between the line and the HV power supply. A GenTec energy monitor is placed in the beam.

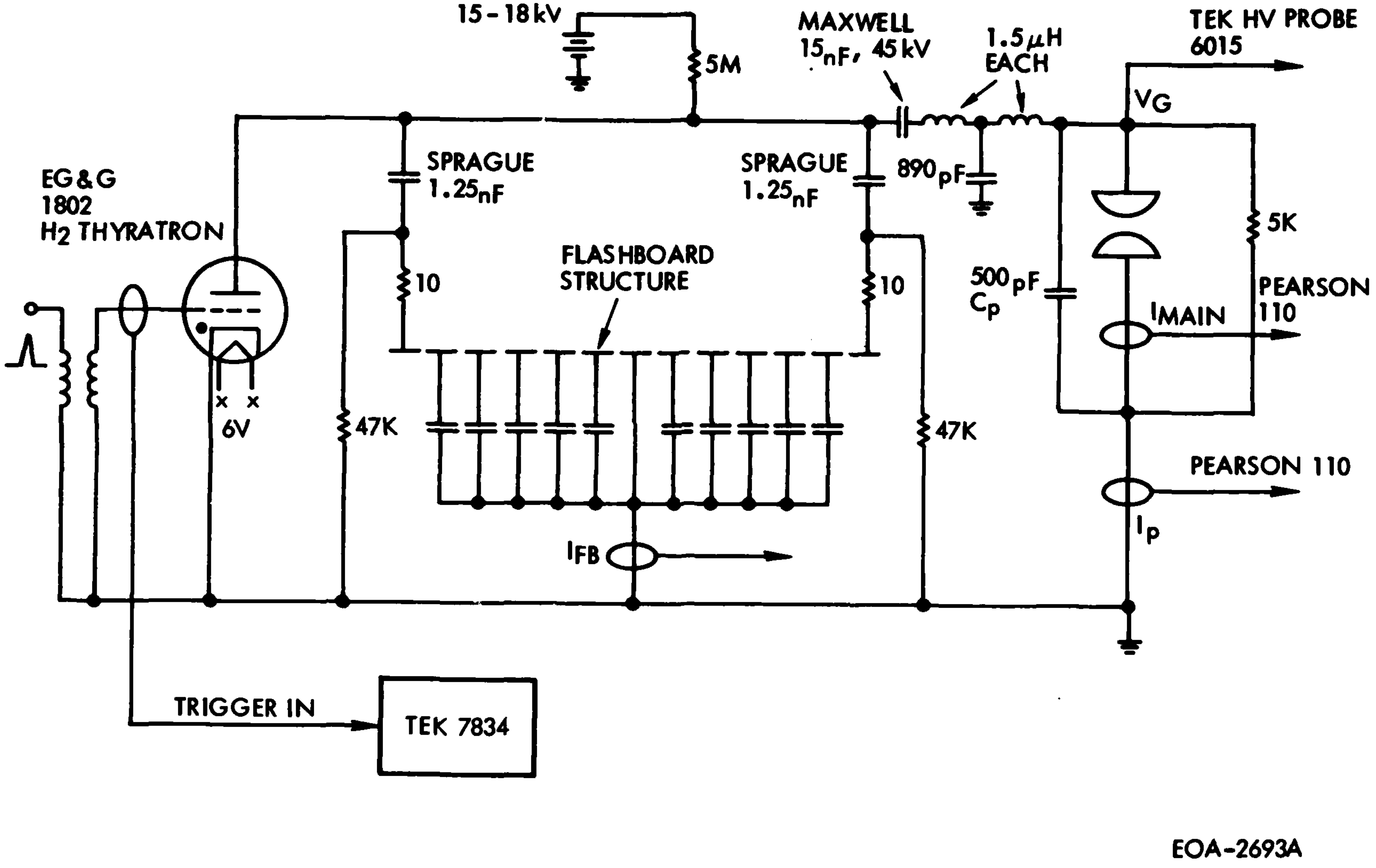


Figure 46. Life Test PFN

Insufficient energy shuts off the high voltage power supply protecting the laser and/or PFN from damage until the dropouts can be corrected.

3.3.1.4 Shots Accumulated

The shot counter should be connected to the laser minder to total the actual number of shots accumulated (Appendix I).

3.3.2 MATERIALS

Only record-keeping supplies are needed.

3.3.3 REQUIRED PROCEDURES

3.3.3.1 Optical Procurement

3.3.3.1.1 Components Applicable

Three optical components are used in the laser as follows:

a. Rear mirror, Drawing No. G227005

b. Output coupler, Drawing No. G225404

c. Brewster plate which would be required for linearly polarized output.

3.3.3.1.2 Procurement Specification

The relevant purchase information is contained in the notes on each drawing which include reference to the "Optical Component Procurement Specification for TEA CO_2 Lasers" G227206 reproduced herein as Appendix B.

3.3.3.2 Laser Output Measurement

Laser performance shall be measured according to the test procedure, "Laser Output Measurement," see Appendix H. The performance required is listed in Section 1 of this final report. The life test schedule describes when and what to measure.

3.3.3.3 Laser Life Testing

Laser life tests shall be run in the standard life test PFN, Subsection 3.3.1.1 above. The trigger, laser minder and shot counter shall be as specified. Life testing shall be monitored periodically as indicated.

3.4 QUALITY ASSURANCE PROVISIONS

The Optical Procurement Specification cites tests and measurements which may be set up for assuring the adherence to specification of vendor-supplied optical components.

3.5 PREPARATION FOR DELIVERY

This section is not applicable to this specification.

3.6 NOTES

3.6.1 INTENDED USE

The laser tested by the procedures outlined in this specification is for use in a rangefinder, part of the fire control systems in armored vehicles.

APPENDIX A
ELECTRODE CONTOUR

The main discharge electrode contour must be designed to minimize electric field concentration which would result in frequent arcing. Approaches to this problem include the work of W. Rogowski and the use of network relaxation solutions to Laplace's equation to test arbitrary electrode shapes. A criterion of considerable importance in choosing a contour is reasonable manufacturability.

Programming the Maxwell equations for the semi-infinite strip electrode equipotentials provides plots which demonstrate the nature of Rogowski electrodes. It becomes clear all too soon that there is a problem with a finite strip whose width is not much greater than the gap between the strip and the ground plane. The $\pi/2$ equipotential is gently curving for quite a distance into the space between the electrodes.

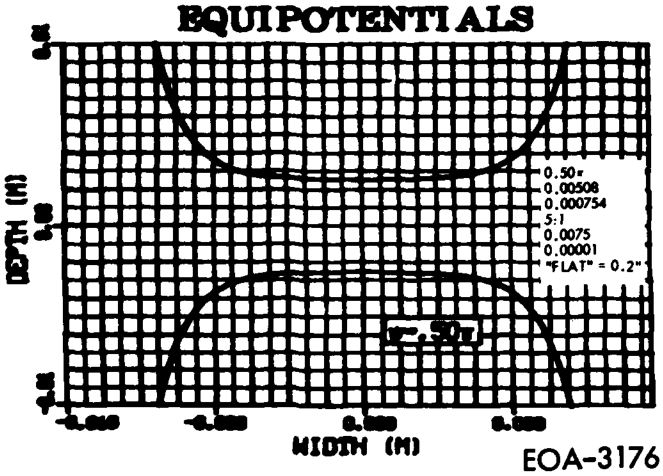
According to Rogowski's extension* of Maxwell's analysis of the electrostatic field due to a finite plane parallel to an infinite plane, the equipotentials are labeled $\psi = (v/V)\ \pi$.

In this equation, V is the potential across the plates and v is the potential of the equipotential surface under consideration. The Rogowski electrode matches the contour of $\psi = .50\pi$ or greater.

An approximation must be made to fit two oppositely directed curves together in the gap space. The acceptable tolerance on "flatness" determines the degree of the approximation. A program which produces a plot of the cross-section of a pair of electrodes, with provision for input parameters of spacing, width of flat portion, electrode thickness, tolerance on the flat portion, and magnification of the plot expressed in meters, generated the plots in Figure A-1, A-2, and A-3.

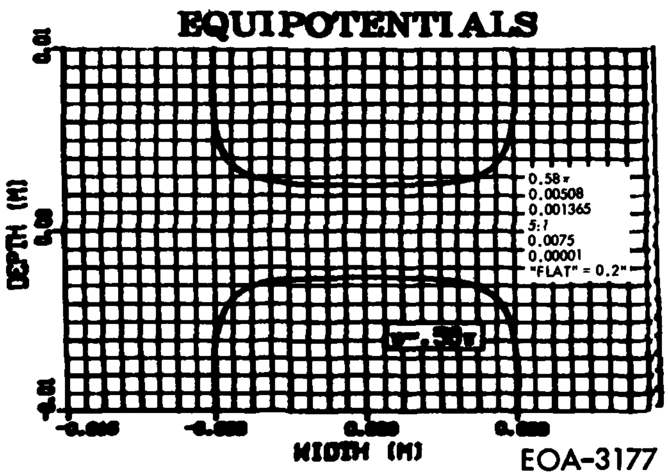
In Figure A-1 on the axis, a ridge will be noted. For a square excited volume where the beam mode diameter is only slightly less than the side of the

*Cobine, "Gaseous Conductors," p. 177, 1958 Dover Publications, New York City.



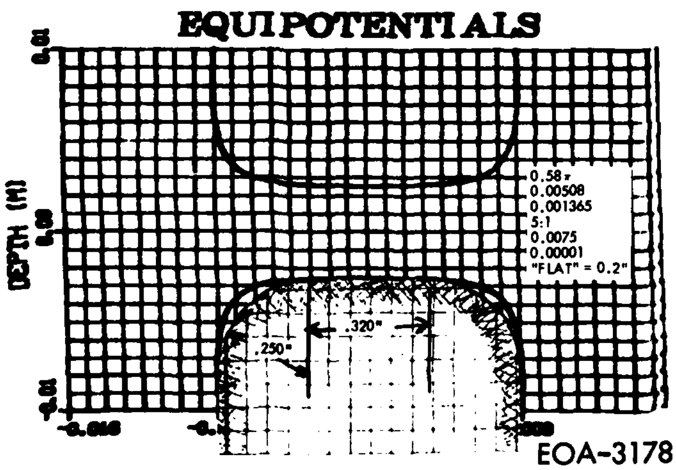
EOA-3176

Figure A-1. Computer Plot of Electrode Cross Section (ψ = .50 π)



EOA-3177

Figure A-2. Computer Plot of Electrode Cross Section (ψ = .58 π)



EOA-3178

Figure A-3. Computer Plot of Electrode Cross Section with Circular Approximation Superimposed square, this ridge would cause enough field concentration to arc. To remove the ridge by hand-blending is to invite a unique personality to invade each pair of electrodes. It is not likely that a hand-controlled operation would have sufficient reproducibility for the degree of uniformity desired. Furthermore, experience with a contoured tool for making electrodes has revealed loss of contour as a result of frequent hand-sharpening the edges. It was therefore decided to attempt to manufacture electrodes using a commercially available milling cutter which could be scrapped when the edge became dull. What has been considered a reasonably close approximation to the families of Rogowski contours is a pair of circular radii tangent to a short straight line. It is easy to "blend" the three line segments when the electrode is sand blasted. Figure A-2 shows Rogowski profiles for the 0.58π equipotential.

A corner-rounding end mill of the type is the Weldon CR8-3 high speed steel 1/4-inch radius tool. The tool is used in the Raytheon numerical control milling machine. The cutter is moved along one side, around the end, back along the other side and around the other end. The work is held in a suitable fixture. Locating pins are used to prevent slippage. This contour, adjusted for scale, is shown superimposed on the 0.58π contour in Figure A-3.

Other electrode contours which may offer longer life without arcing seem to be more difficult to manufacture. If a good master could be contour milled, various replicating techniques could be employed. Deep drawing or other forms of presswork could be considered. However, in an MM&T program manufacturability is most important. Improved contours which may be more difficult to manufacture precisely are not justified if the performance can be obtained without them.

For the purpose of designing shapes for resistance to high-voltage breakdown, Raytheon has a program which plots equipotentials for arbitrary models. This program has been applied to the MM&T laser cross section.

The presence of the flashboard distorts the potential distribution in an asymmetrical manner. There is compression toward the flashboard.

The equipotential plot shown in Figure A-4 is a steady-state solution. In the laser, the electrode potentials change within 50 ns. Furthermore, the dielectric constant is not unity when the plasma is formed.

In consideration of all of the above factors, the manufacturability of the electrodes seems to take on a more important role in choosing the contour. Experimental results with the flat circular arc contour have been satisfactory. Other factors, such as preionizer timing, have a greater effect on the elimination of filamentary discharges and arcing.

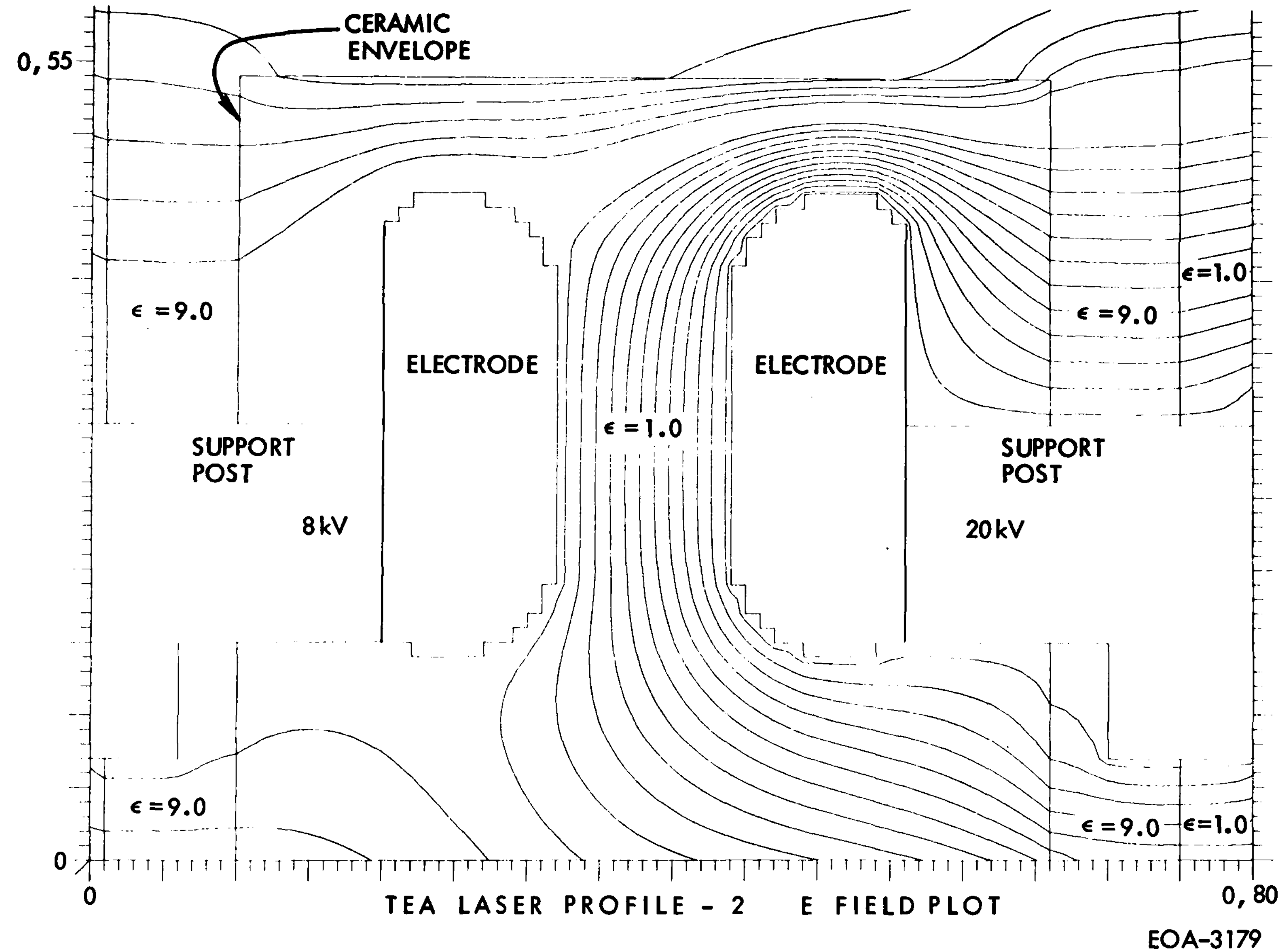


Figure A-4. Free Space Model Showing Extreme Compression

APPENDIX B

OPTICAL COMPONENT PROCUREMENT SPECIFICATION FOR TEA CO_2 LASERS

B.1 SCOPE

This specification establishes performance and durability requirements for optical elements and thin film coatings which are used in 10.6-micron TEA lasers (see Section B.6.1).

B.2 APPLICABLE DOCUMENTS

Military Specification MIL-P-48616, 29 July 1977.

B.3 REQUIREMENTS

B.3.1 SPECIFICATION APPLICABILITY

This specification information applies to the component which references this specification. All paragraphs apply unless express exception is indicated.

B.3.2 SPECTRAL

This part shall meet the spectral requirements after environmental and durability testing.

B.3.3 SUBSTRATE MATERIAL

As specified on the drawing.

B.3.3.1 Internal Defects (For Substrates Transparent to Visible Radiation)

Prior to coating, if coatings are required, substrate materials which are transparent or semitransparent to visible radiation shall be evaluated for internal defects, such as bubbles and other defects which are essentially round in nature. These defects shall not exceed the dig requirements specified for surface defects in Subsection B.3.4.1.3. The substrate materials shall also be evaluated for other internal defects such as striae, fractures, inclusions, etc.

B.3.3.2 Surface Defects

Surface defects on the substrate shall be such that the finished component (whether coated or uncoated) does not have defects in excess of the surface quality requirements of Subsection B.3.4.1.2 and B.3.4.1.3.

B.3.3.3 Dimensions

The substrate shall meet the dimensional requirements of the applicable part drawing.

B.3.4 COATED COMPONENTS

As a minimum, a component which requires coating shall meet the following requirements.

B.3.4.1 Surface Quality

B.3.4.1.1 Coating

The coating shall show no evidence of flaking, peeling, cracking, fingerprints, brush marks, outgassing, blistering, back-coating, crazing, etc. Spatter and holes on or in the coating shall be considered as a dig and shall not exceed the allowable dig size and quantity.

B.3.4.1.2 Scratches

Surface scratches (coating and substrate) shall not be in excess of the values specified. Scratches are permissible provided the width does not exceed that specified by the scratch letter (see Subsection B.6.2.4). The accumulated length of all maximum scratches shall not exceed 1/4 of the average diameter of the beam effective aperture (BEAD).

B.3.4.1.3 Digs

Surface digs (coating and substrate) shall not be in excess of the values specified on the component drawing or procurement document. Digs are permissible on a surface provided the average diameter does not exceed that specified by the dig letter (see Subsection B.6.2.4) and no more than (1) maximum-size dig occurs in any 20-mm (0.80 inch) diameter circle on the substrate. If the substrate is less than 20-mm diameter, (1) maximum size dig can occur if it is outside the BEAD as specified on the part drawing.

B.3.4.1.4 Cosmetic

No blemishes (coating and substrate) such as streaks, smears, stains, blotchiness, discoloration, etc., shall be permitted on an optical component lying in a focal plane. Unless otherwise specified, blemishes on a component which lie outside the BEAD shall be acceptable when it can be shown that these blemishes do not impair the spectral performance, durability and sealing requirements.

B.3.4.1.5 Coated Area

Optical components shall, when coating is required, be coated over the entire beam effective area (BEA) plus an adequate margin to assure uniformity of the coating within the BEAD. Coatings shall not be applied in areas specified for sealing of the component or on areas outside a maximum specified boundary.

B.3.4.2 SURFACE DURABILITY (COATING AND SUBSTRATE)

B.3.4.2.1 Environmental and Physical Durability

The coated optical surface shall meet the following service conditions in the order specified.

B.3.4.2.1.1 Adhesion

The coated optical surface shall show no evidence of coating removal when cellophane tape is pressed firmly against the coated surface and quickly removed at an angle normal to the coated surface.

B.3.4.2.1.2 Humidity

After exposure in an atmosphere at 12 ± 4°F (40°C) and 95 to 100% relative humidity, the coated optical surface shall meet the requirements of Subsection B.3.4.1.1 and B.3.4.1.4.

B.3.4.2.1.3 Moderate Abrasion

The coated optical surface shall show no signs of deterioration such as streaks or scratches when abraded with a dry, clean cheesecloth pad.

B.3.4.2.2 Thermal and Cleaning Durability

The coated optical surface shall meet the following conditions.

B.3.4.2.2.1 Temperature

The coated optical surface shall be exposed to temperatures of -80°F and +160°F (26°C and 71°C) for 2 hours at each temperature. The rate of temperature change shall not exceed 4°F (2°C) per minute. Subsequent to these exposures, the coated optical surface shall meet the requirements of Subsection B.3.4.1.1 and B.3.4.2.1.1.

B.3.4.2.2.2 Solubility and Cleanability

After immersion in trichloroethylene, acetone and ethyl alcohol and wiping with cheesecloths, the coated optical surface shall show no evidence of coating removal or scratches and shall meet the requirements of Subsections B.3.4.1.1 and B.3.4.1.4.

B.4 QUALITY ASSURANCE PROVISIONS

B.4.1 RESPONSIBILITY FOR INSPECTION

Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other facilities suitable for the performance of the inspection requirements specified herein.

B.4.1.1 General Provisions

Definitions of inspection terms shall be as listed in MIL-STD-109.

B.4.1.2 Witness Piece

Unless otherwise specified, witness pieces representing the actual coated component may be used for spectral and environmental testing. The witness pieces shall be positioned in the coating chamber such that they represent the whole evaporation lot. The purchaser reserves the right to test the actual coated component. Should a component fail, even though the representative witness pieces pass the test, the lot shall be rejected. Witness pieces are not required for visible opaque uncoated optical elements.

B.4.1.3 Characteristic of the Witness Piece

The witness piece shall be of the same material and have a surface finish similar to that of the component to be coated. The witness piece shall be such that it presents no difficulty in measuring and testing the spectral requirements of the coating. Spectral performance of coating applied to small, thick, or curved components may be verified on convenient sized flat, thin (approximately 1.0 mm or, 0.40 inch) witness piece.

B.5 PREPARATION FOR DELIVERY

B.5.1 PACKAGING AND PACKING

In the absence of specified packaging data in the contract, or purchase order, each optical element shall be individually wrapped in a chemically inert paper that will not scratch, leave a residue or corrode the element. The wrapped coated or uncoated element shall be immobilized in a unit container that provides adequate protection during handling and shipment. The optic shall be clean and free of residue or corrosive material prior to wrapping.

B.5.2 MARKING

Each packaging and shipping container shall be marked to show the following:

- a. Lot or batch number
- b. Contract or purchase order number
- c. Part or drawing number
- d. Quantity of parts in container
- e. Manufacturer's name or trademark
- f. Optics coated both sides shall be marked to identify the characteristic of the coating on each side, clearly and unambiguously
- g. Spectral response curves or facsimile thereof, if measured as part of the inspection of the optical element, shall be included with the shipment.

B.5.3 SHIPPING CONTAINER

Shipping containers shall be marked with words "DELICATE OPTICAL COMPONENTS REQUIRING SPECIAL HANDLING." The appropriate side of the container shall be clearly marked to indicate "TOP" or "OPEN THIS SIDE."

B.6 NOTES

B.6.1 INTENDED USE

The optical components governed by this specification are intended for high peak power carbon dioxide laser use. Certain components are contained completely within the laser envelope and are therefore exposed to an atmosphere comprised of a mixture of carbon dioxide, nitrogen, helium, carbon monoxide and hydrogen, as well as decomposition products. Certain specified components are sealed to the envelope walls providing a gas-tight window.

B.6.2 DEFINITIONS

B.6.2.1 Beam Effective Aperture Diameter

The beam effective aperture diameter (BEAD) is the minimum diameter which could be applied to the part and used by the laser beam if the optic were installed in any orientation. This diameter is determined by twice the sum of the beam radius and the beam offset. If there is no offset, the bead equals the beam diameter.

B.6.2.2 Sealing Area

Optical components forming a gas-tight window in the laser envelope shall have an uncoated annulus on their inner surfaces of a diameter required for the implementation of a sealed fastening. The sealed area shall not intersect the BEAD.

B.6.2.3 Beam Effective Area (BEA)

The area on a surface through which the laser beam may pass is the beam effective area (BEA). It is delineated by the beam effective aperture diameter where the beam is circular in cross section. The edge or margin of the BEA on components located where the beam is not circular in cross section shall have the margin delineated on the part drawing. The BEA is important because it requires the highest level of specification to reduce scattering losses, prevents beam divergence increases, etc. Larger digs and scratches may be allowed outside the margin because they will not affect the laser performance.

B.6.2.4 Scratch and Dig Sizes (Reference MIL-F-48616)

B.6.2.4.1 Scratch

Scratch Letter	Scratch Width Millimeters	Scratch Width Inches	Disregard Scratch Widths less than Millimeters	Disregard Scratch Widths less than Inches
A	0.005	0.00020	0.0010	0.00004
B	0.010	0.00039	0.0025	0.00010
C	0.020	0.00079	0.0050	0.00020
D	0.040	0.00157	0.0100	0.00039
E	0.060	0.00236	0.0100	0.00039
F	0.030	0.00315	0.0200	0.00079
G	0.120	0.00472	0.0200	0.00079

B.6.2.4.2 Dig

Dig Letter	Average Dig Diameter Millimeters	Average Dig Diameter Inches	Disregard Digs Smaller Than Millimeters	Disregard Digs Smaller Than Inches
A	0.05	0.0020	0.010	0.0004
B	0.10	0.0039	0.025	0.0010
C	0.20	0.0079	0.050	0.0019
D	0.30	0.0118	0.050	0.0019
E	0.40	0.0157	0.100	0.0039
F	0.50	0.0197	0.100	0.0039
G	0.70	0.0276	0.200	0.0079
H	1.00	0.0394	0.250	0.0099

APPENDIX C
ULTRASONIC CLEANING PROCESS SPECIFICATION

C.1 SCOPE

This specification defines the materials and equipment required and describes the procedures to be followed in ultrasonically cleaning or rinsing parts prior to use, or for rinsing immediately after plating or cleaning parts.

C.2 APPLICABLE DOCUMENTS

None.

C.3 REQUIREMENTS

C.3.1 MATERIALS

The materials to be used in this process shall be as follows:

(a) Tap water - hot and cold
(b) Water softener - Alconox, Personic or equivalent
(c) Cleaning solutions as required
(d) Clean white nylon gloves
(e) Lint-free paper
(f) Plastic bags

C.3.2 EQUIPMENT

The equipment required for this process shall include:

(a) Generator - Ultrasonic with tank
(b) Transducer - Ultrasonic, capable of producing 100 Cavin units in hot water with wetting agent
(c) Exhaust hood
(d) Containers - glass or stainless steel, suitable for cleaning solutions
(e) Baskets, racks, etc. - for holding parts
(f) Tank heaters - immersible or built in (optional)

C.3.3 START-UP PROCEDURE

The equipment shall be activated and maintained in the following manner:

(a) Fill tank with hot water (135°F - 165°F) to operating level (over half full).

(b) If using an immersible-type transducer, place it at bottom of the tank in position directly under area where parts are to be cleaned.

(c) Turn on tank heater if unit is so equipped and set temperature regulator at 160°F if hot water is to be used in the procedure.

(d) Add appropriate water softener (approximately 1 tablespoon per gallon of water).

(e) Turn main power on and regulate generator according to manufacturer's instructions; allow water to de-aerate for 10-15 minutes.

C.3.4 CLEANING

Parts shall be cleaned in the following manner:

(a) Immerse parts to be cleaned or rinse in solution as specified on Chemical Parts Processing Card or Operation Sheet.

(b) Indirect cleaning agitation may be obtained by placing the desired cleaning solution in a glass or metal container and immersing it in the ultrasonic cleaning tank solution.

(c) For operations requiring a continuous-flow rinsing, the incoming rinse water shall be maintained at a flow rate of 1-3% of the total tank volume per minute in order to provide a sufficiently de-aerated rinse solution.

C.4 QUALITY ASSURANCE

This section is not applicable to this specification.

C.5 PREPARATION FOR DELIVERY

C.5.1 PRESERVATION AND PACKAGING

(a) Package parts in lint-free or plastic bags.

(b) Parts shall be handled with clean white nylon gloves when so specified.

C.6 NOTES

(a) The method detailed in Para C.3.4(b) is advantageous for cleaning small or intricate parts, or for using chemical solutions which may attack the stainless steel cleaning tank.

(b) Operator should check each time parts are immersed for audible sound of cavitation and visually observable surface ripples on the liquid in the ultrasonic tank.

(c) Ultrasonic tank should be drained and cleaned at the end of each work shift.

(d) Containers or glass blocks must never rest on the bottom of the tank.

(e) Power must never be turned on without water in the cleaning tank.

(f) This process specification derived from Raytheon 11841.

APPENDIX D

ULTRASONIC CLEANING, NONIONIC DETERGENT PROCESS SPECIFICATION

D.1 SCOPE

This specification defines the material and equipment to be used and the procedure to be followed in the ultrasonic cleaning of parts to remove physical and water soluble contaminants.

D.2 APPLICABLE DOCUMENTS

None.

D.3 REQUIREMENTS

D.3.1 MATERIAL

The material used in this process shall be as follows:

(a) Igepal CA630 - General Dyestuffs, Incorporated

(b) Water per current specification for deionized water

(c) Tap water, running hot and cold

D.3.2 EQUIPMENT

The equipment required for this process shall include:

(a) Tank, stainless steel, cold water

(b) Tank, stainless steel, hot water

(c) Generator and transducer, ultrasonic, 25-30 kc, in stainless steel tank capable of heating solution to 45-55°C

(d) Tank, cascading rinse, 3 compartment, 302 or 316 stainless steel

(e) Racks or baskets, stainless steel, for holding parts

D.3.3 PREPARATION OF SOLUTION

Igepal solution shall be prepared by mixing 0.3 parts Igepal with 1000 parts water (Para. D.6(a)).

D.3.4 CLEANING

Parts shall be cleaned in the following manner.

(a) Place parts in appropriate rack or basket.

(b) Immerse parts slowly in tank containing cold overflowing tap water to dislodge any loosely bound contaminants.

(c) Hold under water until the surface water has been replaced in order to prevent floating contaminants from being redeposited.

(d) Transfer wet parts to ultrasonic Igepal tank.

(e) Clean parts ultrasonically for two minutes minimum (Para. D.6(b)).

(f) Rinse parts in hot overflowing tap water for 1 to 2 minutes (Para. D.6(b)).

(g) Rinse parts in deionized water for minimum of 3 minutes.

(h) Repeat D.3.4(g) two times, rinsing in the next cleanest tank each time.

D.4 QUALITY ASSURANCE

This section is not applicable to this specification.

D.5 PREPARATION FOR DELIVERY

Process immediately per next process.

D.6 NOTES

(a) Igepal solution shall be changed weekly.

(b) Solution shall be maintained at a temperature of 45-55°C.

(c) Overflowing hot tap water shall be maintained at a temperature of 50-59°C.

(d) This process specification is derived from Raytheon Process Specification No. 637262.

APPENDIX E
FIRING OF METALIZATION PROCESS SPECIFICATION

E.1 SCOPE

This specification defines the method and materials used to fire a properly applied metalization paint or tape on high alumina ceramic. This process establishes the bond between the metalization and the ceramic.

E.2 APPLICABLE DOCUMENTS

None.

E.3 REQUIREMENTS

E.3.1 MATERIALS

The materials used in this process are as follows:

(a) Molybdenum boats

(b) Molybdenum rods

(c) Dissociated ammonia gas

E.3.2 EQUIPMENT

The equipment required is as follows:

(a) Furnace - 4 inch I.D. tube furnace capable of 1620°C with controlled vertical opening doors at each end for atmosphere exclusion

(b) Gas Control - Regulator and flow meter to be sure dissociated ammonia flow is 12 liters/minute

E.3.3 PROCEDURE

E.3.3.1 Preloading Checkout

(a) Check temperature - steady 1620°C.

(b) Check gas flow at 12 liters/minute.

(c) Check to see pilot lights are ignited.

E.3.3.2 Loading

(a) Slowly open entrance door approximately 1/2-inch high and wait for escaping hydrogen to ignite.

(b) Open door fully.

(c) Place loaded boat in entrance tube and push clear of door.

(d) Close door and wait some time before pushing boat further. Time depends on mass of objects in boat.

(e) At intervals, open door 1/2 inch, wait for escaping hydrogen to ignite, then push boat a short distance in the furnace, close door.

(f) Repeat E.3.3.2(e) until boat is centered in hot zone of the furnace.

(g) Allow boat to remain in hot zone for specified length of time.

E.3.3.3 Unloading

(a) After prescribed "soak" period in hot zone, slowly open exit door 1/2 inch and wait for escaping hydrogen to ignite. Hook molybdenum rod on boat and withdraw short distance into exit tube, disengage rod and close door.

(b) After the prescribed intervals, repeat E.3.3.3(a) until boat is just inside the exit door.

(c) Slowly open door, making sure the hydrogen ignites and remove boat using tongs. Close the door, protect the boat and its contents from dust and dirt until cool.

E.3.3.4 Cautioning Remarks

(a) Do not open both ends of furnace at the same time.

(b) A boat can be loaded while another is inside provided E.3.3.4(a) is observed.

(c) A boat can be removed while another is inside provided E.3.3.4(a) is observed.

(d) Flow rate specified of the strong reducer such as hydrogen must be maintained even when one or the other door is opened.

(e) No "volatile" materials may be introduced into the furnace under any circumstances. Volatile means having an appreciable vapor pressure at 1620°C. Solder, tin, lead, zinc, and brass are examples of materials which are absolutely forbidden in the furnace. They would evaporate, contaminating the ceramic tube of the furnace rendering it unsuited for future use for manufacturing vacuum electronic devices.

E.4 QUALITY ASSURANCE PROVISIONS

No inspection procedures for metalized but unplated ceramic components have been established as yet.

E.5 PREPARATION FOR DELIVERY

Not applicable.

E.6 NOTES

E.6.1 INTENDED USE

(a) This specification covers the procedure for firing ceramic parts which have been sprayed, painted or taped with metalization material, such as molybdenum-titanium to drive off the vehicle and create a bond to the ceramic. Subsequent plating steps are required before the parts can be used.

(b) This specification is based on Raytheon Process Specification 11720.

APPENDIX F

CLEANING PARTS BEFORE PLATING PROCESS SPECIFICATION

F.1 SCOPE

The purpose of this specification is to detail the equipment and materials to be used and the procedure to be followed in cleaning parts before plating.

F.2 APPLICABLE DOCUMENTS

None.

F.3 REQUIREMENTS

F.3.1 MATERIALS

The materials used for this process shall include:

(a) Anode 61X (MacDermid Co., Waterbury, Connecticut)

(b) Metalex "W" Special (MacDermid Co., Waterbury, Connecticut)

(c) Cyanegg or Cyanabrick (DuPont Co., Inc., Wilmington, Delaware)

(d) Hydrochloric Acid, Concentrated, C.P.

(e) Hot and cold running water

F.3.2 EQUIPMENT

The equipment required for this process shall be as follows:

(a) Degreaser unit

(b) Stainless steel or glass tanks and crocks

(c) Steam heat or electrical immersion heaters

(d) Exhaust vents over all cleaning tanks

(e) Stainless steel baskets, barrels, plating racks and wire

(f) Continuous filtration (Sethco or equivalent)

F.3.3 PREPARATION OF SOLUTION

(a) Tank for electrolytic cleaning: Dissolve the appropriate amount of Anodex 61X powder in hot water to yield a concentration of 8($\pm$1) oz/gal. Maintain a bath temperature of 180° to 200°F. (Note: Manufacturer recommends 8-12 oz/gal for steel, and 6-8 oz/gal for copper.)

(b) Tank for soak cleaning: Dissolve the appropriate amount of Metalex special powder in hot water to yield a concentration of 8-12 oz/gal. Maintain a bath temperature of 180° to 200°F.

(c) Tank for 4% sodium cyanide solution: Dissolve Cyanegg or Cyanabrick in cold water to yield a concentration of 4.8 - 5.9 oz/gal. Continuous filtration is optional. Operate at room temperature.

(d) Tank for 50% hydrochloric acid solution: Add 1 part of concentrated hydrochloric acid to 1 part cold water. Operate at room temperature.

(e) Hot water rinse after Metalex is maintained at temperature of 135°F to 155°F.

(f) Cold water rinses are run continuously.

F.3.4 OPERATIONAL PROCEDURE

(a) Degrease parts, if specified, according to Chemical Processing Specification indicated.

(b) Parts that are specified for electrolytic cleaning are immersed in the Anodex 61X solution in either basket, rack or wire and cleaned anodically or cathodically as specified. Current density should be 50 - 125 amperes/ft^2. Follow with water rinse 90 to 95 seconds.

(c) Immerse parts in Metalex "W" Special for 1-3 minutes or as specified. Periodic agitation is desirable.

(d) Rinse parts in hot running water (135°-155°F) with occasional agitation for 1-3 minutes.

(e) Rinse parts in cold running water with occasional agitation for 1-2 minutes.

(f) Immerse parts in 50% (±5%) HCl acid tank and agitate 5-15 seconds unless otherwise specified.

(g) Rinse in cold running water with occasional agitation for 1-2 minutes.

(h) If electroplate is to be nickel or rhodium, proceed directly to paragrph F.3.4(k).

(i) If electroplate is to be copper, gold, silver, cadmium or bright alloy, immerse parts in 4% sodium cyanide solution for 15-30 seconds.

(j) Rinse parts in cold water for 20-30 seconds.

(k) Plate parts as specified.

(l) Handle parts with clean cloth gloves or finger cots and store as specified.

(m) Parts to be plated immediately need not be rinsed in hot water (after HCL or cyanide). If parts are to be dried in methanol, they should first be rinsed in hot (110°-130°F) water.

F.4 QUALITY ASSURANCE PROVISIONS

Inspecting procedures have not been defined at this time.

F.5 PREPARATION FOR DELIVERY

Not applicable.

F.6 NOTES

F.6.1 INTENDED USE

(a) Machined parts and metalized ceramic parts are to be assembled, and for the most part, brazed. Machining and handling before brazing can introduce contamination which must be removed before plating.

(b) Cyanide compounds and many other materials listed in this specification are toxic and must be teated accordingly.

(c) This specification is derived from Raytheon Process Specification 11436.

APPENDIX G

RINSE OF PLATED CERAMICS PROCESS SPECIFICATION

G.1 SCOPE

This specification outlines the equipment and material needed and the procedure to be followed to rinse plated ceramics.

G.2 APPLICABLE DOCUMENTS

None.

G.3 REQUIREMENTS

G.3.1 EQUIPMENT

(a) Ultrasonic generator and transducer - 25-30 kc

(b) Oven-nitrogen fed at 110°C - explosion proof

(c) Stainless steel tanks - #302, #304 or #316 stainless steel

G.3.2 MATERIAL

(a) Water purity to be specified

(b) Methyl alcohol (methanol) per specification

(c) Nitrogen prepurified. Filtered at point of use.

G.3.3 REQUIRED PROCEDURE

(a) After plating, rinse parts in cold overflowing tap water (reference paragraph G.3.1(c).

(b) Rinse parts ultrasonically in room temperature water for one minute.

(c) Repeat paragraph G.3.3(b) in clean water or until the resistance of water is 2.5 meg/cm min.

(d) Rinse parts ultrasonically in methyl alcohol for one minute.

(e) Blow parts dry with nitrogen.

(f) Dry parts in nitrogen-fed oven for 10-12 minutes at 105-115°C.

(g) Store parts in clean containers.

G.4 QUALITY ASSURANCE PROVISIONS

Plated areas shall not exhibit discoloration or mottling after long periods of storage (visual inspection). Ceramic shall appear white.

G.5 PREPARATION FOR DELIVERY

Not applicable.

G.6 NOTES

G.6.1 INTENDED USE

Parts are now ready for assembly after the performance of this specification.

APPENDIX H

LASER OUTPUT MEASUREMENT PROCESS SPECIFICATION

H.1 SCOPE

This specification covers the laboratory procedures used to measure laser output energy per pulse and the waveform as a power vs. time scope trace photograph. By these two measurements, the power in terms of watts can be determined. This procedure may be incorporated in laser test reports by reference.

H.1.1 CLASSIFICATION

This procedure is classified as a Type D-Process Specification.

H.2 APPLICABLE DOCUMENTS

Applicable documents include the specification sheets and manuals associated with the referenced equipment.

H.3 REQUIREMENTS

H.3.1 EQUIPMENT

H.3.1.1 Oscilloscope

To record the rapidly changing waveforms, a very high-speed storage oscilloscope is required. The vertical writing speed may be so high that suitable exposures are impossible without the storage feature. The Tektronix Model 466 has been selected as first choice for standardized measurements because all the circuitry is built in. Additional specifications are not required. A 50-ohm termination must be used at the input when the Rofin power detector is used.

However, the Tektronix Model 7834 with preamps 7A19, 7A26 and time bases 7B85, 7B70 will also function very well. Note that the 50-ohm input impedance preamplifier can be used directly with the Rofin power detector which requires such a termination.

H.3.1.2 Energy Detector

Of the energy detectors which could be used, the Scientech is preferred. It can be used to calibrate the Gen Tec.

H.3.1.2.1 Scientech Model 362 with 380102 Power Head

This instrument is a long time-constant dc calibratable calorimeter having a D'Arsonval panel meter read-out. It integrates pulses to determine their energy content.

The detector can be calibrated with a known direct current passed through a built-in heater coil. In this way this instrument is calibrated in terms of easily measured dc quantities. It can be used to calibrate the Gen Tec units.

H.3.1.2.2 Gen Tec Model ED 200

The Gen Tec Model ED 200 energy monitor is used with the 1-MΩ input impedance oscilloscope front end. RG223 double-shielded cable of length between 6 ft and 8 ft is used. The output energy incident on the Gen Tec produces a voltage peak proportional to the integrated output wave shape. The calibration may be done as outlined in H.3.4 below.

H.3.1.3 Power Detector

The Rofin Model 7441 photon drag detector coupled to the Rofin Model 7401 10X amplifier through the Rofin 7405 adapter is used to develop a voltage proportional to the instantaneous power in the laser output waveform. The voltage waveform is pictured on the oscilloscope for a camera to record.

The sensitivity of the Rofin detector appears to vary with the exact location of the center of the beam as well as the laser to Rofin distance. Therefore these causes of variation shall be standardized. The nominal calibration of the Rofin as stated by the manufacturer is not sufficiently precise and so the Rofin is calibrated against the energy meter by measuring the area under the photographed curve of power vs. time.

H.3.1.4 Planimeter

Areas under curves or within borders of a given closed curved line can be measured with a planimeter. The chief source of error with a well-made planimeter is in the operator's ability to define the line forming the boundary of the area to be measured. In the case of TEA laser pulses, another source of error is the long tail of the pulse. The output seems to approach zero asymptotically and thus a determination of the end of the pulse is required.

H.3.1.5 Optical Bench

The spacing and alignment of the energy and power detectors with respect to each other and with the laser must be preserved to utilize a calibration factor as worked via the planimeter method for more than one reading of the peak power. A Ziess-type optical rail and bases and columns, etc., attaching the laser at one end and the two detectors some distance along on another rail, may be used. The spacings required are discussed in paragraph H.3.3.1.

H.3.2 MATERIALS

The only materials required are Polaroid scope camera film and data recording materials. Replacement batteries may be required for the Rofin power detector amplifier (Union Carbide Type 522 or equivalent).

H.3.3 REQUIRED PROCEDURES

H.3.3.1 Initial Setup

The PFN and cradle for carrying the laser shall be rigidly coupled to the optical rail with the posts adjusted for a convenient optical axis height. The Scientech energy detector is located at the opposite end of the bench.

The Rofin power detector must be mounted on an insulating support post rather than the normally used metal post. This is important for the reduction of unwanted electrical noise.

The spacing between the Rofin power detector and the laser output coupler must be approximately 30 ft. The spacing between the Scientech energy detector and the laser must be 30 ft. The spacing between the Gen Tec energy detector, if used, and the laser may be any short convenient distance.

H.3.3.1.1 Electrical Connection

The double-shielded RG223 coaxial cable must be used between the output connector of the Rofin power detector amplifier and the 50-ohm input of the oscilloscope.

H.3.3.1.2 Rofin Amplifier Batteries

Note the Rofin amplifier contains two 9V batteries. These must be replaced frequently and will be ruined if left "on" overnight. Be sure the Rofin amplifier is switched "off" when not in use. Typically, a pair of batteries will last 10 hours. Use Union Carbide type 522 batteries.

H.3.3.1.3 Marking the Rail

The optical rails should be marked to show the location of the measuring components. The post heights should also be marked.

H.3.3.2 Energy Reading

After beginning operation of the laser under test, the energy can be determined by using the Scientech instrument. It will be necessary to temporarily remove the Rofin detector from the rail.

Block the laser output from entering the detector head. Zero the meter. Remove the block allowing one pulse to enter the detector head. Replace the block after one pulse. The meter pointer will come to rest at the energy value measured. Record the data including the laser input conditions.

H.3.3.2.1 Alternative Technique

If the shot-to-shot reproducibility of the laser output is poor so that one shot may not be representative, an average of the accumulated energy of a number of shots may be used.

The Gen Tec energy monitor may be connected to the oscilloscope with the sweep rate set as slow as possible. A series of vertical spikes will appear on the scope trace. If they are all of the same height, the shot-to-shot reproducibility is nearly perfect. If not all alike, a measure of the lack of reproducibility can be taken by noting the difference between the maximum and the minimum and then comparing this difference to the mean.

If the shot-to-shot reproducibility is poorer than 5%, the Scientech energy measurement for a single shot has roughly the same percentage uncertainty. In such cases it is recommended that N shots be counted off while the beam block is clear exposing the detector. Then the meter reading divided by N will yield a fairer representation of the average shot. N should be at least 10.

The Rofin power detector signal will also vary from shot to shot. If the variation is considerable, it may be advisable to use the monitor feature of this model Rofin and detect the energy passed through the Rofin. Although the manufacturer claims 25% absorption by the Rofin, the exact value should be measured.

H.3.3.2.1.1 Rofin Detector Transmission Measurement

The Rofin detector absorbs a nominal 25%. It is useful to know the exact value of transmission in a precise dedicated measurement configuration.

In order to overcome variation in laser output from shot to shot, the averages of large numbers of shots taken with the Gen Tec energy detector, both with and without the Rofin detector in place, are compared.

$$\% \text{ Transmission} = 100 \times \left[\frac{\text{Avg. with Rofin}}{\text{Avg. w/o Rofin}} \right]$$

hence the true energy for a given shot will be:

$$E_{true} = \frac{100 \times E \text{ (measured with Rofin in place)}}{\% \text{ Transmission}}$$

The averages are obtained by photographing a very slow scope sweep trace which shows M number of shots. M should be the same for both measurements. The units are not important. Millivolts scope deflection may be used. The calibration of the Gen Tec is not required. It is important, however, that the beam be reasonably centered on the Gen Tec sensitive surface. It is also important not to exceed the linear safe range of the Gen Tec, about 0.5 joules per square centimeter. The laser pulse width should not exceed 1 millisecond.

H.3.3.2.2 Scope Trace Photography

To record the power vs. time behavior of the laser pulse, the Rofin power detector is used with a 50-ohm terminated transmission line.

Typical oscilloscope settings are:

vertical	50 mV/div
horizontal	200 ns/div

The single shot storage mode is used. A trace which is too wide will be difficult to measure accurately. Be sure focus and astigmatism are adjusted for minimum trace width.

H.3.3.3 Determination of Power in the Pulse

The Rofin power detector scope trace photograph is a plot of instantaneous vertical deflection (in millivolts) as a function of time. The vertical deflection is proportional to the instantaneous power in watts. Since the area under a curve of power vs. time is proportional to the energy expended, to know the energy is to calibrate the measurement. The energy is determined by the Scientech energy meter reading divided by the Rofin transmission factor.

The photograph made of the same pulse as the pulse recorded by the Scientech is used with the planimeter to determine the power scale and the peak power in the leading spike.

H.3.3.3.1 Energy in First 100 ns

After the total area has been measured with the planimeter (H.3.3.3), the area in the first 100 ns must also be determined. The following calculations must then be made:

$$\text{Energy in first 100 ns} = \frac{\text{area in first 100 ns}}{\text{total area}} \times \text{total energy}$$

This measurement is to be made in accordance with contractual requirement, Section 3.5.6, of the contract, the energy in the gain switch spike which is defined as that portion of the pulse which occurs in the first 100 ns after initiation.

The rise time, and the pulse width can be measured from the Rofin detector scope trace photograph. For this reason, it is important to choose and record the sweep speed carefully. Typically, 50 or 100 ns/division are used for these requirements.

H.3.3.3.2 Scope Trace Thickness

It will be observed that the scope trace is actually made of a moving beam of circular cross section. The slower it moves, the wider the trace. However, the actual center of the trace is the value to measure, not the leading edge or the trailing edge. It is thus very important to adjust astigmatism controls to give a circular beam cross section. The planimeter tracings should also be made to the center of the trace pattern.

H.3.4 RECOMMENDED PROCEDURES

For quick tests of laser performance, the Gen Tec is recommended. It is useful for adjusting lasers because it gives a voltage peak for each input pulse. This is not so for the Scientech instrument.

Each Gen Tec detector needs its own calibration. These should be revised with the aid of the Scientech by using a laser with a very good shot-to-shot repeatability. The Scientech is used as described above to measure a single pulse in terms of the dc calibration.

H.3.5 Certification

The procedures described above in Section H.3.3 depend on the dc calibration of the Scientech instrument. Thus these calibration measurements are as good as the fundamental current and voltage readings. These are measured by instruments periodically checked by Raytheon Company's instrument test, repair and calibration departments.

H.4 QUALITY ASSURANCE PROVISION

The measurements described in this specification are performed by engineering laboratory facilities. Quality assurance is not involved.

H.5 PREPARATION FOR DELIVERY

Not applicable.

H.6 NOTES

H.6.1 INTENDED USE

The purpose of this specification is to standardize the measurement procedures used to determine the output characteristics of the engineering and confirmatory samples. A less general, more concise specification would be required for a pilot production run.

H.6.2 GENERAL INFORMATION

Vendor addresses and telephone numbers are as follows:

Gen Tec, Inc. 2625 Dalton St., Ste-Foy, Quebec, Canada (418) 651-8000
Rofin, Inc., 910 Boston Post Road, Marlboro, MA 01752 (617) 481-7822
Scientech, Inc., 5649 Arapahoe Ave., Boulder, CO 80303 (303) 444-1361
Tektronix, Inc., PO Box 1700, Beaverton, OR 97075 (800) 547-1512

H.6.3 DEFINITIONS

H.6.3.1 The Laser

The particular sample under test. This specification is concerned with TEA CO_2 lasers to be used for rangefinder transmitters. The peak power is of the order of 200 kW, the total energy 30-50 mJ and the repetition rate 1 Hz or less. The overall length of the device is 7.25 inches.

H.6.3.2 The Contract

The reference contract is DAAK70-80-C-0048.

H.6.3.3 Calibration

Comparison of a measurement standard or instrument of known accuracy with another standard or instrument to detect, correlate, report or eliminate by adjustment, any variation in the accuracy of the item being compared.

H.6.3.4 Measuring and Test Equipment

All devices used to measure, gauge, test, inspect, or otherwise examine items to determine compliance with specifications.

H.6.3.5 Measurement Standard (Reference)

Standard of the highest accuracy order in a calibration system which establishes the basic accuracy values for that system.

H.6.3.6 Measurement Standard (Transfer)

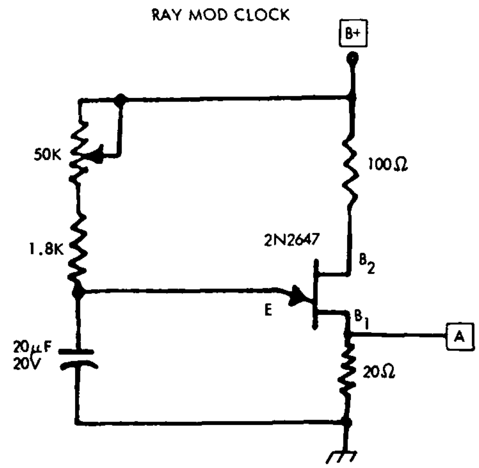
Designated measuring equipment used in a calibration system as a medium for transferring the basic value of reference standards to lower echelon transfer standards or measuring and test equipment.

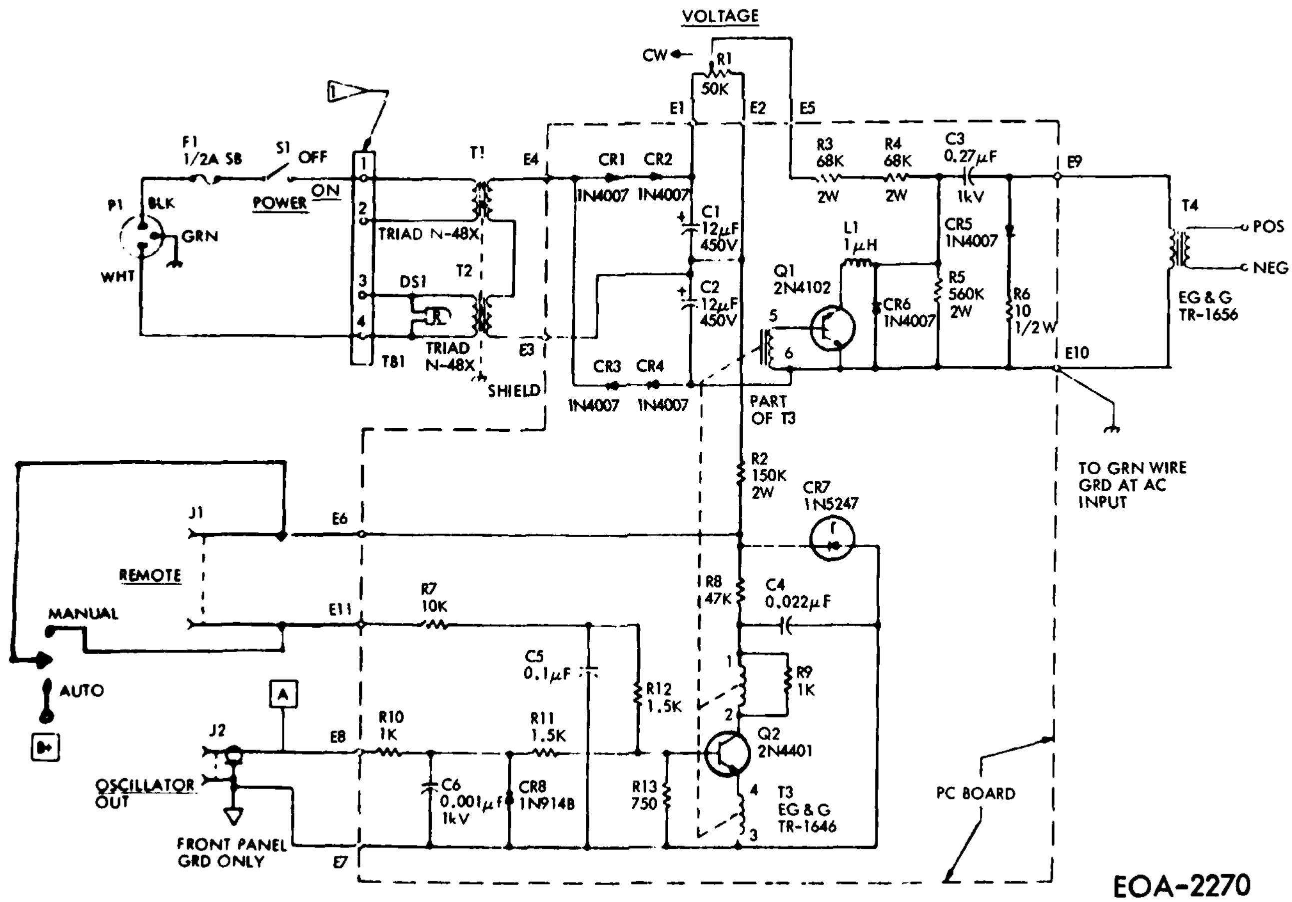
H.6.3.7 Interim Standard

An instrument used as a standard until an authorized standard is established.

APPENDIX I

ELECTRICAL EQUIPMENT FOR LIFE TESTS





EOA-2270

Figure I-1. TM-11A Trigger Module Schematic

Figure I-2. Life Test Monitor

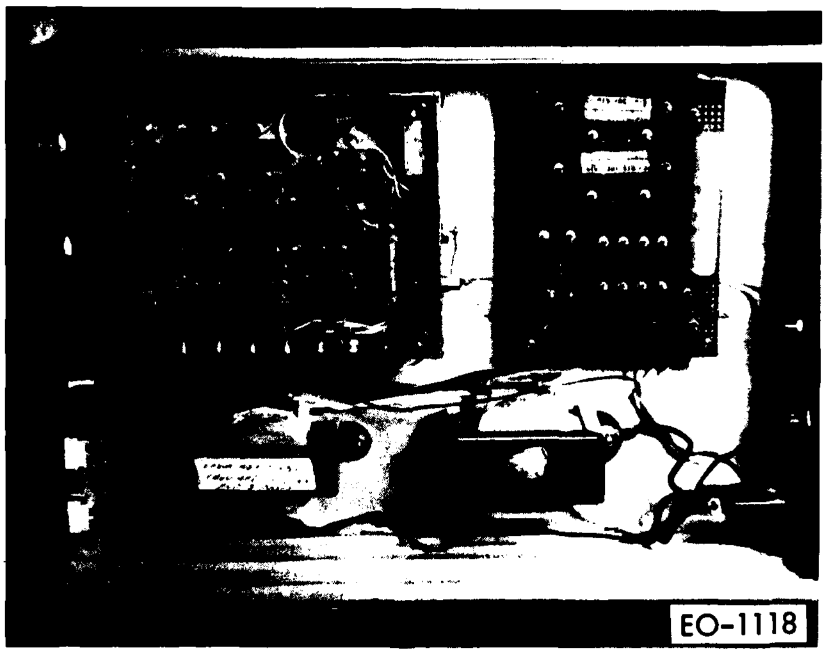


Figure I-3. Internal View of Life Test Monitor

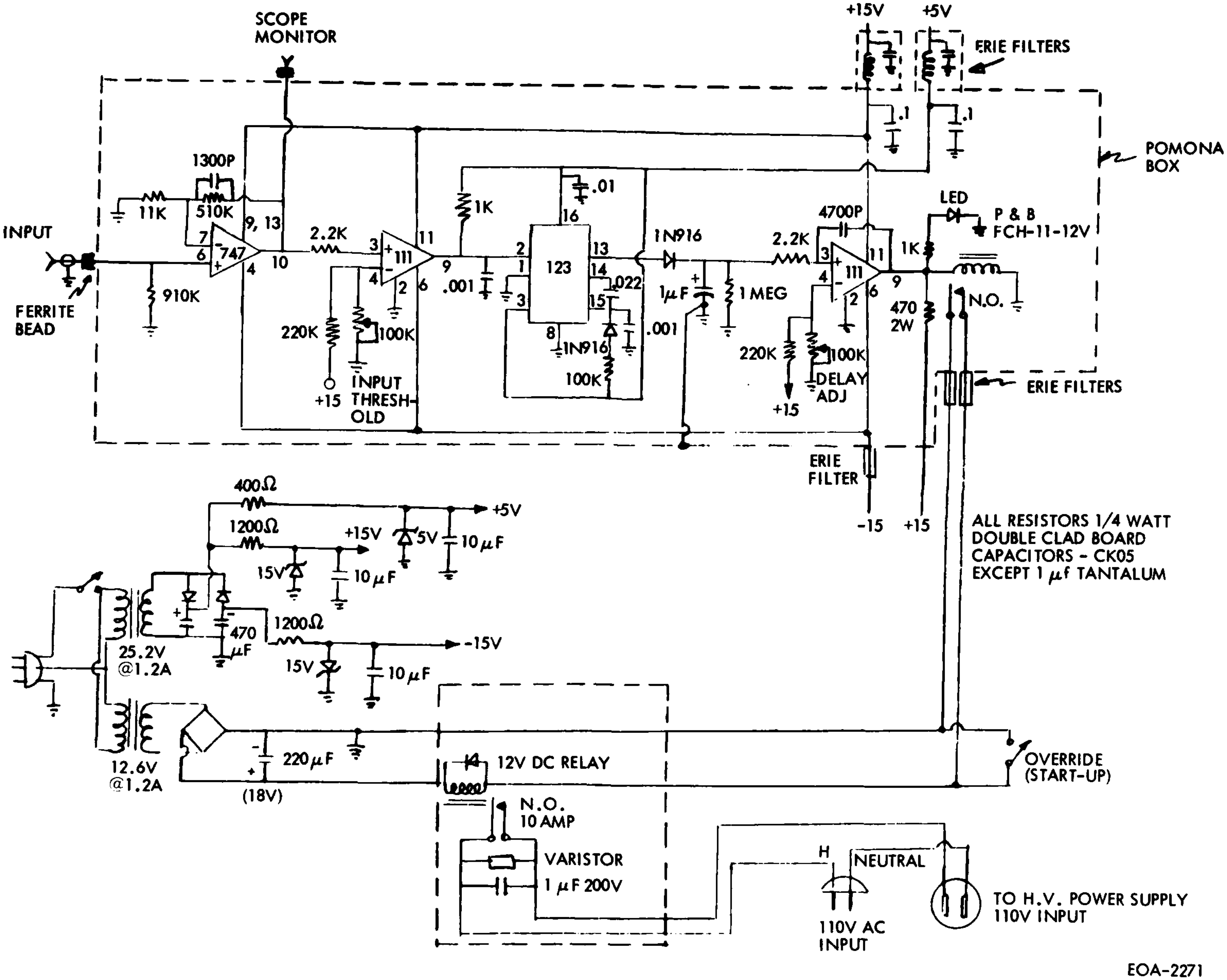


Figure I-4. Circuit for Protecting Life Test Equipment

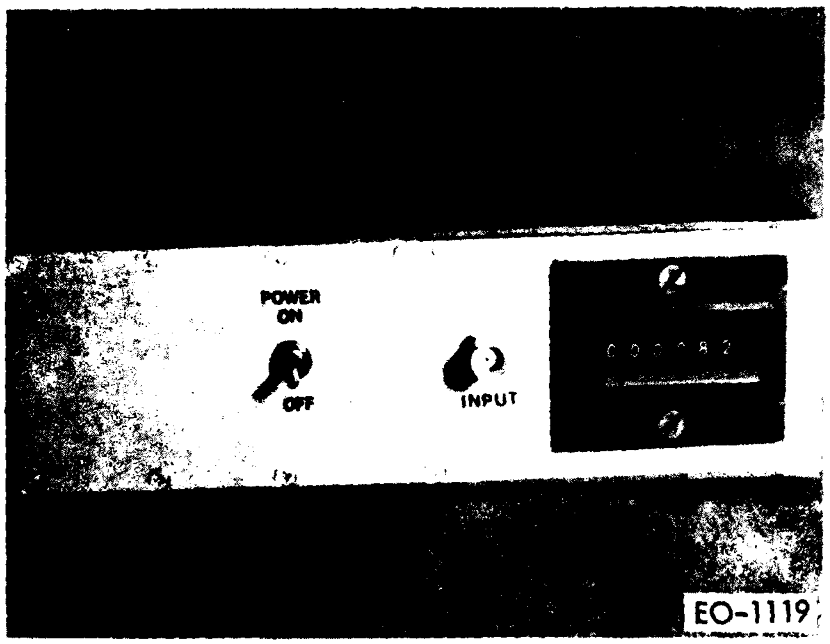


Figure I-5. Output Pulse Counter

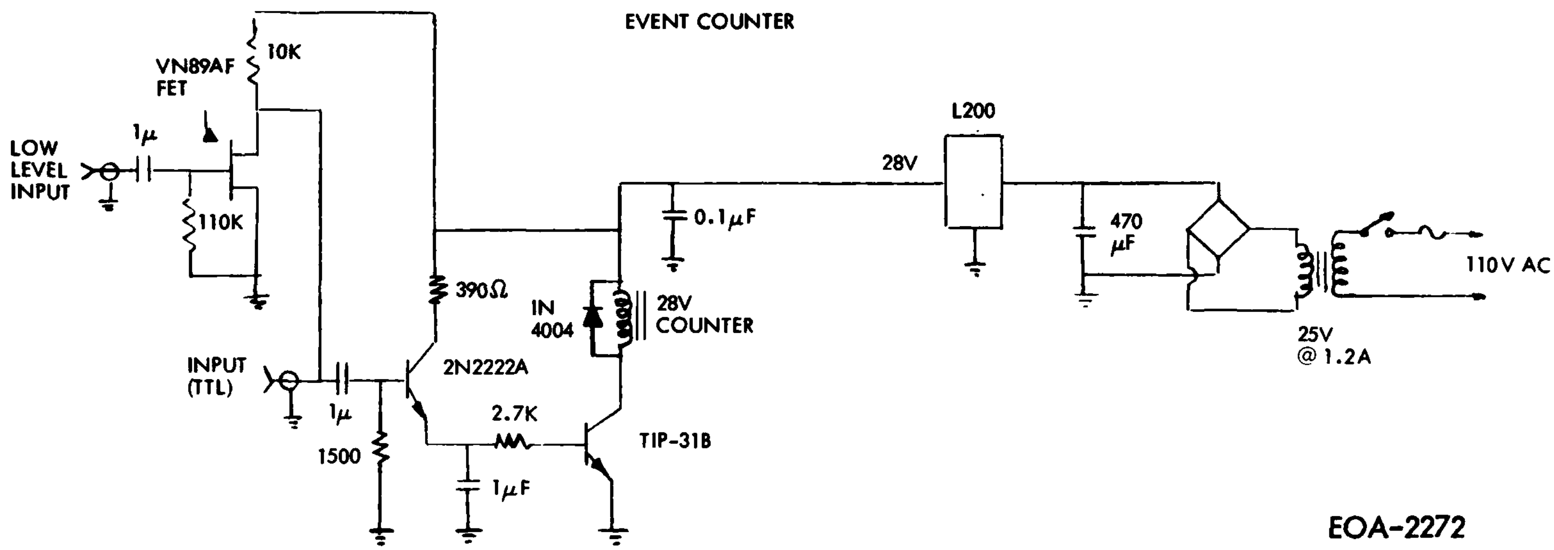


Figure I-6. Circuit to Operate Shot Counter for Life Test Equipment

APPENDIX J

SEALED CO_2 LASER TUBE TEST SUMMARY

This chart lists the tubes built, their parameters and the life test results.

TUBE NO. QKL2049-	BODY	ELECTRODES	ELECTRODE SPACING	FLASHBOARD	FLASHBOARD RESISTOR	BREWSTER WINDOWS	REAR MIRROR	OUTPUT MIRROR	GAS MIX	LC INVERSION GEN. CAPACITANCE	NO. OF SHOTS LIFETIME	COMMENTS
X-1 INITIAL OUTPUT 25 mJ APERTURE .188"	1 PC MOLDED PER ARMY SPEC (ALUMINA)	SMALL AL	.200"	TUNGSTEN BUTTONS BRAZED ON ALUMINA, OFF CENTER, ARC ABOVE SURFACE	82 Ω	NONE	99% 4 MR	85% FLAT E-7 EPOXY	He - 33% N_2 - 21% CO_2 - 46%	10 nF/SIDE	1000	DELIVERED TO ARMY
0001 INITIAL OUTPUT 24 mJ 1/2 LIFE 8 mJ APERTURE .188"	SAME AS X-1	SMALL AL	.200"	SAME AS X-1	47 Ω	NONE	SAME AS X-1	SAME AS X-1	SAME AS X-1	10 nF/SIDE	63K	FAILURE DUE TO LOSS OF GAS NOTE NUMEROUS GAS FILL COMBINATIONS WERE TRIED WITH THIS TUBE INCLUDING REBUILDING
0002 INITIAL OUTPUT 25 mJ APERTURE .188"	SAME AS X-1	SMALL AL	.200"	COPPER BUTTONS BRAZED ON ALUMINA, OFF CENTER, ARC ABOVE SURFACE	36 Ω	NONE	SAME AS X-1	SAME AS X-1	He - 33% N_2 - 20% CO_2 - 33% CO - 14%	10 nF/SIDE	750K	FAILURE MECHANISMS, LOSS OF GAS, MIRROR DAMAGE, CATALYST CHAMBER CONTAINED AN EPOXY BUTTON NOTE A NUMBER OF DIFFERENT GAS MIXES WERE TRIED
0002 INITIAL OUTPUT 25 mJ APERTURE .188"	SAME AS X-1	SMALL AL	.200"	COPPER BUTTONS BRAZED ON ALUMINA, OFF CENTER, ARC ABOVE SURFACE	39 Ω	NONE	SAME AS X-1	SAME AS X-1	He - 33% N_2 - 20% CO_2 - 33% CO - 14%	10 nF/SIDE	390K	TRIED SEED GAS TRIMETHYLAMINE .2 TORR LASER OUTPUT UNSTABLE
0003 APERTURE .188"	SAME AS X-1	SMALL Cu PREOXIDIZED	.200"	COPPER BUTTONS BRAZED ON ALUMINA, CENTERED, ARC ABOVE SURFACE	39 Ω	NONE	SAME AS X-1	SAME AS X-1	He - 33% N_2 - 21% CO_2 - 46%	10 nF/SIDE	--	OPERATED FLOWING ONLY. DISCHARGE QUALITY POOR
0004 INITIAL OUTPUT 1/2 LIFE 12 mJ APERTURE .250" BOTH MIRRORS BAFFLED	SAME AS X-1	LARGE Cu	.300"	COPPER BUTTONS EPOXIED ON GLASS WITH TORR SEAL, ARC CENTERED, AND ABOVE SURFACE	82 Ω	1 BREWSTER INTERNAL ON 100% REFLECTOR SIDE	100% BeCu 20 MR EXTERNAL TO CAVITY	SAME AS X-1	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	5 nF/SIDE	2.25×10^6	PRIOR TO THIS SUCCESS, TUBE WAS TESTED WITH VARIOUS GAS COMBINATIONS. TUBE BAKED 250°C 15 HRS
RES INITIAL OUTPUT 44 mJ 1/2 LIFE 2? mJ NO APERTURE	1 PC MOLDED PER ARMY SPEC	LARGE Cu	.300"	COPPER BUTTONS EPOXIED ON GLASS WITH TORR SEAL, ARC CENTERED, AND ABOVE SURFACE	82 Ω	2 EXTERNAL BREWSTERS	100% Cu 1.5 MR EXTERNAL TO CAVITY	85% FLAT	He - 33% N_2 - 20% CO_2 - 33% CO - 14%	5 nF/SIDE	300K	TUBE FAILED WHEN FLASHBOARD CURRENT LIMITING RESISTOR FAILED
RES INITIAL OUTPUT 20 mJ NO APERTURE	1 PC MOLDED PER ARMY SPEC	LARGE Cu	.300"	COPPER BUTTONS EPOXIED ON CERAMIC WITH TORR SEAL, ARC CENTERED, AND ABOVE SURFACE	82 Ω	2 EXTERNAL BREWSTERS	100% Cu 1.5 MR EXTERNAL TO CAVITY	85% FLAT	He - 33% N_2 - 20% CO_2 - 33% CO - 14%	5 nF/SIDE	1 - 5K	LASER OUTPUT ERRATIC WHEN OPERATED EITHER SEALED OR IN THE FLOWING GAS MODE
RES INITIAL OUTPUT 20 mJ NO APERTURE	1 PC MOLDED PER ARMY SPEC	LARGE Cu	.300"	COPPER BUTTONS EPOXIED ON GLASS WITH CERAMIC EPOXY, ARC CENTERED, AND ABOVE SURFACE	82 Ω VARIED THE VALUE OF THIS RESISTOR	2 EXTERNAL BREWSTERS	100% Cu 1.5 MR EXTERNAL TO CAVITY	85% FLAT	He - 33% N_2 - 20% CO_2 - 33% CO - 14%	5 nF/SIDE	1 - 5K	LASER OUTPUT ERRATIC WHEN OPERATED EITHER SEALED OR IN THE FLOWING GAS MODE NOTE FOUND MAIN ELECTRODE TO BE OUT OF GAP SPACING SPEC
0005 INITIAL OUTPUT 10 mJ APERTURE .260"	1 PC MOLDED PER ARMY SPEC	LARGE Cu	.300"	COPPER BUTTONS EPOXIED ON GLASS WITH TORR SEAL, ARC CENTERED, AND ABOVE SURFACE	82 Ω	NONE	100% BeCu 20 MR ATTACHED TO LASER BODY VIA AN O-RING	85% FLAT	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	5 nF/SIDE	1 - 5K	LASER OUTPUT FLOWING MODE 30 mJ
0005	1 PC MOLDED PER ARMY SPEC	LARGE Cu 5.275"	.280"	COPPER BUTTONS EPOXIED ON GLASS	82 Ω	ONE KCl AT REAR HOLDING PRESSURE	EXTERNAL	85% FLAT	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	5 nF/SIDE	300K	18 mJ WHEN TERMINATED AT 300K SHOTS TUBE HEATED BUT NOT BAKED
0005	1 PC MOLDED PER ARMY SPEC	LARGE Cu 5.275"	.280"	COPPER BUTTONS EPOXIED ON GLASS	82 Ω	ONE KCl AT REAR HOLDING PRESSURE	EXTERNAL	85% FLAT	He - 69.3% N_2 - 7.5% CO_2 - 15.0% CO - 7.5% H_2 - 0.7%	5 nF/SIDE	2.2 MILLION	10 mJ OUTPUT WHEN TERMINATED TUBE BAKED AT 60°C 15 HRS
0006	1 PC MOLDED PER ARMY SPEC	LARGE Cu 5.275"	.300	MOLY BRAZED TO ALUMINA	82 Ω	ONE ZnSe EXTERNAL AT FRONT HOLDING PRESSURE	100% Be-Cu 20 mR	85% FLAT	He - 39.3% N_2 - 15.0% CO_2 - 30.0% CO - 15.0% H_2 - 0.7%	5 nF/SIDE	7K	HIGH CO_2 MIX ARCING AT 7K SHOTS
0006A	1 PC MOLDED PER ARMY SPEC	LARGE Cu 5.275"	.300"	MOLY BRAZED TO ALUMINA	82 Ω	ONE ZnSe EXTERNAL AT FRONT HOLDING PRESSURE	100% Be-Cu 20 mR	75%	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	TIME DELAY PFN	2 MILLION	170 kW AT 2 MILLION SHOTS LINEARLY POLARIZED 1 ATM PRESSURE TUBE BAKED AT 62°C 40 HRS
0006B	1 PC MOLDED PER ARMY SPEC	LARGE Cu 5.275"	.300"	MOLY BRAZED TO ALUMINA	82 Ω	ONE ZnSe EXTERNAL AT FRONT HOLDING PRESSURE	100% Be-Cu 20 mR	75%	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	TIME DELAY PFN	1.2 MILLION	230 kW AT 1.2 MILLION SHOTS LINEARLY POLARIZED 1.2 ATM PRESSURE REFILLED NOT OPENED TO AMBIENT
0007A	1 PC MOLDED PER ARMY SPEC	SHORT ALUMINUM ELECTRODE .400" WIDE	.340"	12 MOLY AND 1 Cu BUTTONS BRAZED TO ALUMINA	82	NO BREWSTER BUT SPACE AVAILABLE	100% Be-Cu 20 mR	80%	He - 63.3% N_2 - 13% CO_2 - 18% CO - 5% O_2 - 0.7%	TIME DELAY PFN	600K	200 kW AT START 110 kW AT 600K SHOTS 1 ATM PRESSURE BAKED 62°C 16 HRS
0007B	1 PC MOLDED PER ARMY SPEC	SHORT ALUMINUM ELECTRODE .400" WIDE	.340"	12 MOLY AND 1 Cu BUTTONS BRAZED TO ALUMINA	82	NO BREWSTER BUT SPACE AVAILABLE	100% Be-Cu 20 mR	80%	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	TIME DELAY PFN	500K	210 kW AT START 125 kW AT 500K SHOTS 1.2 ATM PRESSURE
0007C	1 PC MOLDED PER ARMY SPEC	SHORT ALUMINUM ELECTRODE .400" WIDE	.340"	12 MOLY AND 1 Cu BUTTONS BRAZED TO ALUMINA	82	NO BREWSTER BUT SPACE AVAILABLE	100% Be-Cu 20 mR	75%	He - 69.3% N_2 - 11.0% CO_2 - 15.0% CO - 4.0% H_2 - 0.7%	TIME DELAY PFN	380K	290 kW AT START 110 kW AT 380K SHOTS 1.2 ATM PRESSURE MIRROR DAMAGE
0008	1 PC MOLDED PER ARMY SPEC	COPPER	.325"	12 MOLY BRAZED TO ALUMINA	10 Ω FOR EACH OF 2 SECTIONS	YES	20m BeCu 100%	79.5%	LONG LIFE MIX 1 atm	THYRATRON, SINGLE ENDED, 15 nF	$\cdot 1.2 \times 10^6$	180 kW AT START, 250 kW FLOWING 80 kW AT 1.2×10^6 SHOTS

Rev 1 2/24/82
Rev 2 9/15/82
Rev 3 9/30/82
Rev 4 10/1/82
Rev 5 2/1/83

EOA-3234

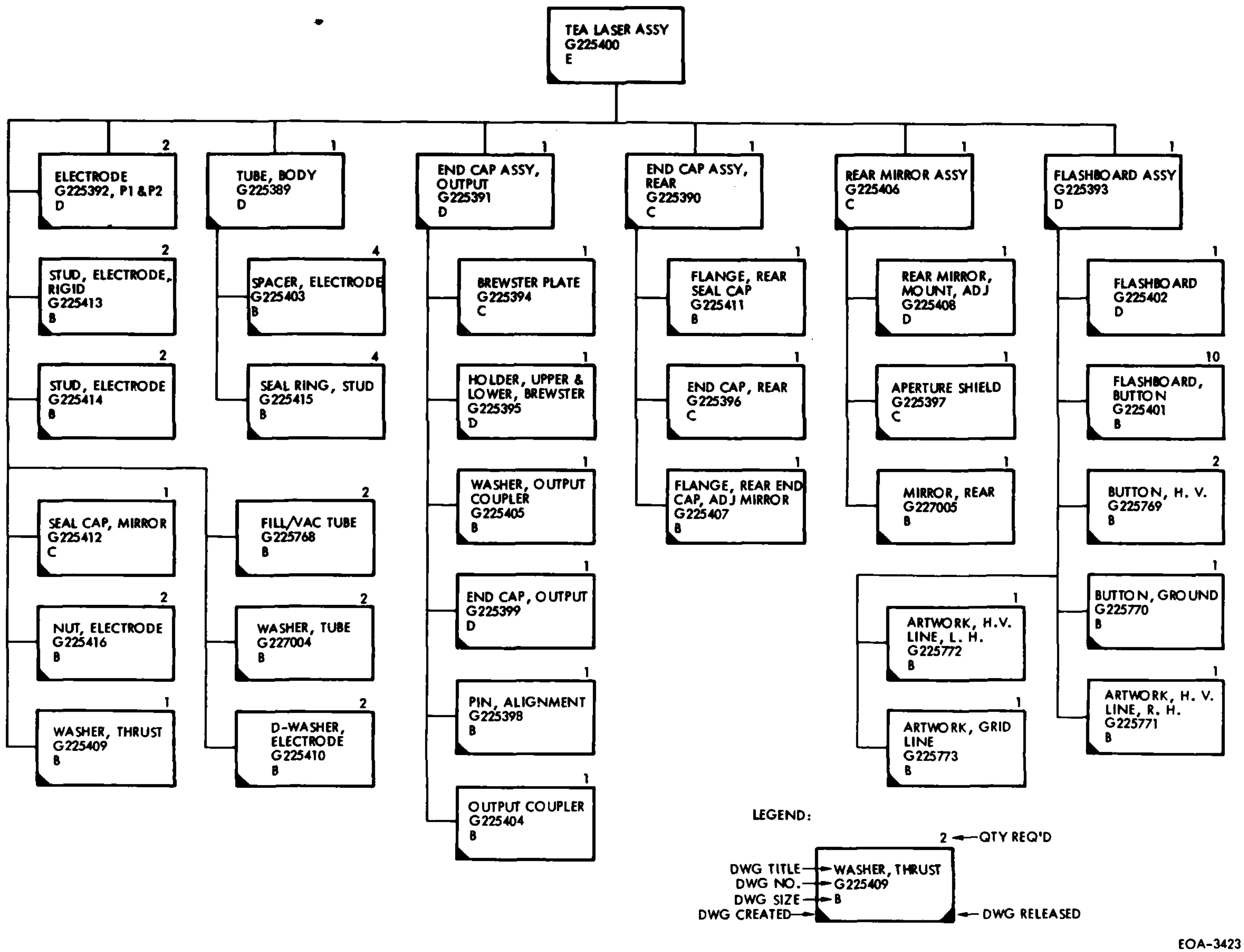
APPENDIX K

MM&T GENERATION BREAKDOWN

A complete print set has been generated for the fabrication of the CO_2 TEA Laser for the MM&T Program. This print set contains innovative methods for obtaining the critical tolerances required for the proper operation of the CO_2 TEA Laser Tube. A generation breakdown (family-tree) listing these drawings is contained in the following table, K-1.

TABLE K-1

MM&T DRAWINGS BREAKDOWN



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