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**INTRODUCTION OF LASER INITIATION
FOR THE 48-INCH ADVANCED SOLID ROCKET
MOTOR (ASRM) TEST MOTORS AT MARSHALL
SPACE FLIGHT CENTER (MSFC)**

**C.J. Zimmerman
Aerojet-ASRM Division**

**G.E. Litzinger
Aerojet-APD Division**

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I. Pyrotechnic Ignition System

The Advanced Solid Rocket Motor is a new design for the Space Shuttle Solid Rocket Boosters. The new design will provide more thrust and thus more payload capability, as well as incorporating many design improvements in all facets of the design and manufacturing process. A 48-inch (diameter) test motor program is part of the ASRM development program. This program has multiple purposes for testing of propellant, insulation, nozzle characteristics, etc. Ignition of this motor is the subject of this paper.

This paper overviews the evolution of the 48-Inch ASRM test motor ignition system which culminated with the implementation of a laser ignition system. The laser system requirements, development, and operational configuration will be reviewed in detail.

The igniter for the 48-inch test motor is a fairly simplistic style of design, known in the ignitor field as a "Bag Igniter". The bag connotation refers to arrangement of propellant in a loosely controlled structure and contained in a flexible and/or consumable container. The objective of this style of igniter is to provide a specific energy flux or pulse without controlling the direction of the energy output.

Figure 1 depicts the original design for the bag igniter. The design is as follows:

- 1) An ignition cord (ITLX) is looped inside a velostat bag which encases Boron Potassium Nitrate (BPN) granules.
- 2) The components of #1 are encased in a second velostat bag which contains BPN pellets.
- 3) The components of #2 are encased in a third velostat bag which contains propellant.

Figure 2 is a schematic of the ignition train. The ignition sequence begins with the Safe and Arm which initiates the nonel shock cord. The shock cord transfers pyrotechnic energy to the ignition cord. The ignition cord ignites the granules, which ignites the pellets, which ignites the propellant.

Initial development testing revealed that energy transfer to the ignition cord was not reliable. The design was revised that which is depicted in figure 3. The ignition cord was removed. A cellulose acetate tube was added and inserted into the bag of BPN granules. BPN powder (IP-10) was added into the tube and the nonel shock cord was inserted into the powder. This system was tested several times without failure. A demonstration of the igniter initiating a test motor was successfully performed at MSFC.

After the successful firing of the test motor at MSFC, production of 2 lots of igniters was commenced. During this build it was discovered that the revised ignition system output was not 100% reproducible. It was then decided to completely redesign the ignition system. A laser ignition system was chosen as the best option to interface into the complete system requirements of the 48-inch test motor. The laser ignition option met safety and remote operation requirements, fulfilled pyrotechnic output requirements, and easily integrated into the sequencing operations of the test control facility at MSFC.

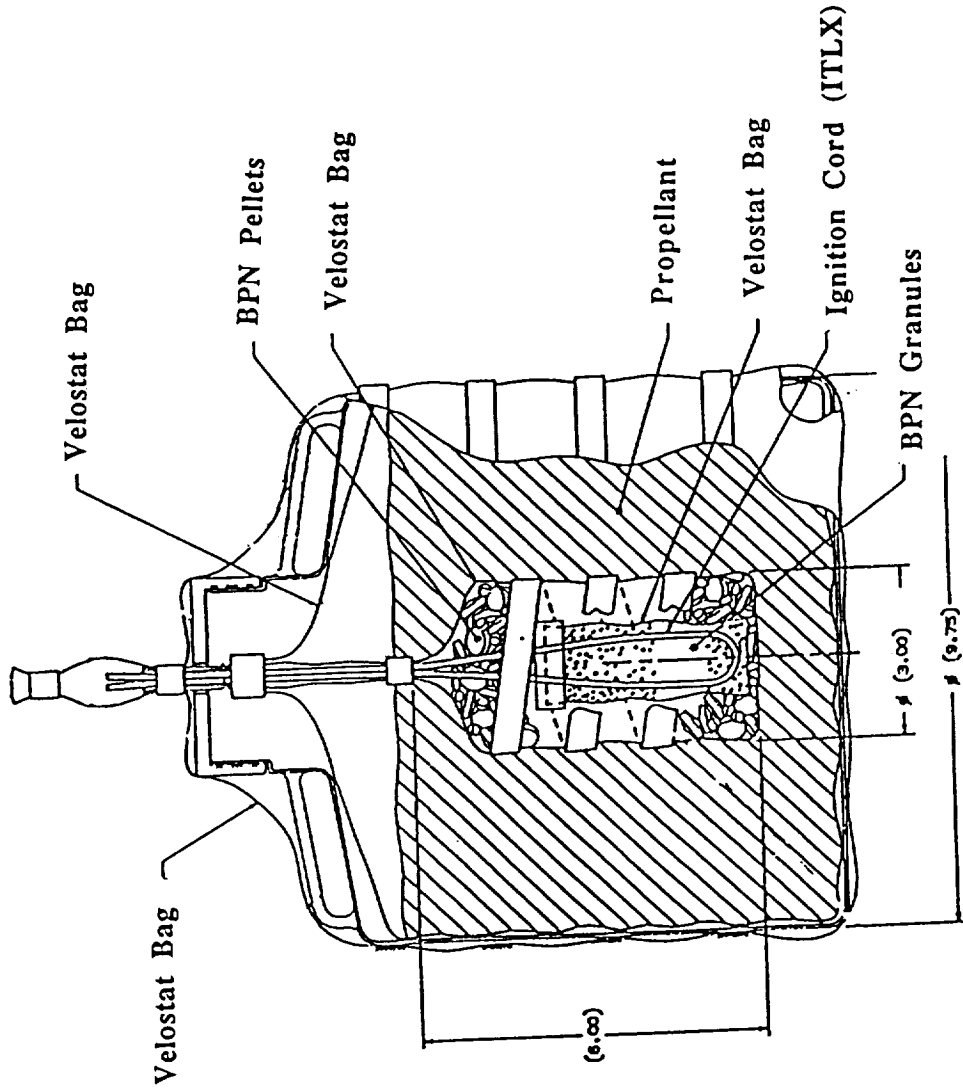
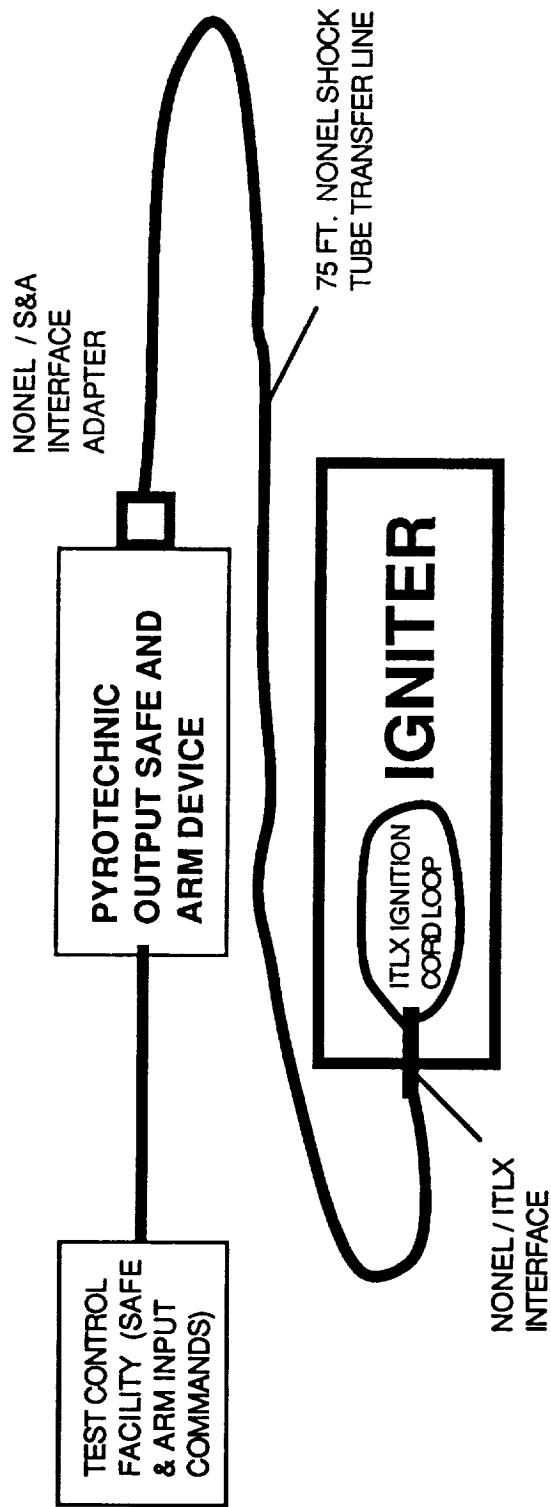


Figure 1
Original Design



- PYROTECHNIC OUTPUT FROM SAFE AND ARM DEVICE
- PYROTECHNIC NONEL SHOCK TUBE TRANSFER LINE
- NONEL SHOCK TUBE TRANSFER TO ITLX IGNITION CORD WHICH INITIATES THE IGNITER BAG CONSISTING OF BPN GRANUALS AND BPN PELLETS

FIGURE 2: ORIGINAL PYROTECHNIC INITIATION SYSTEM

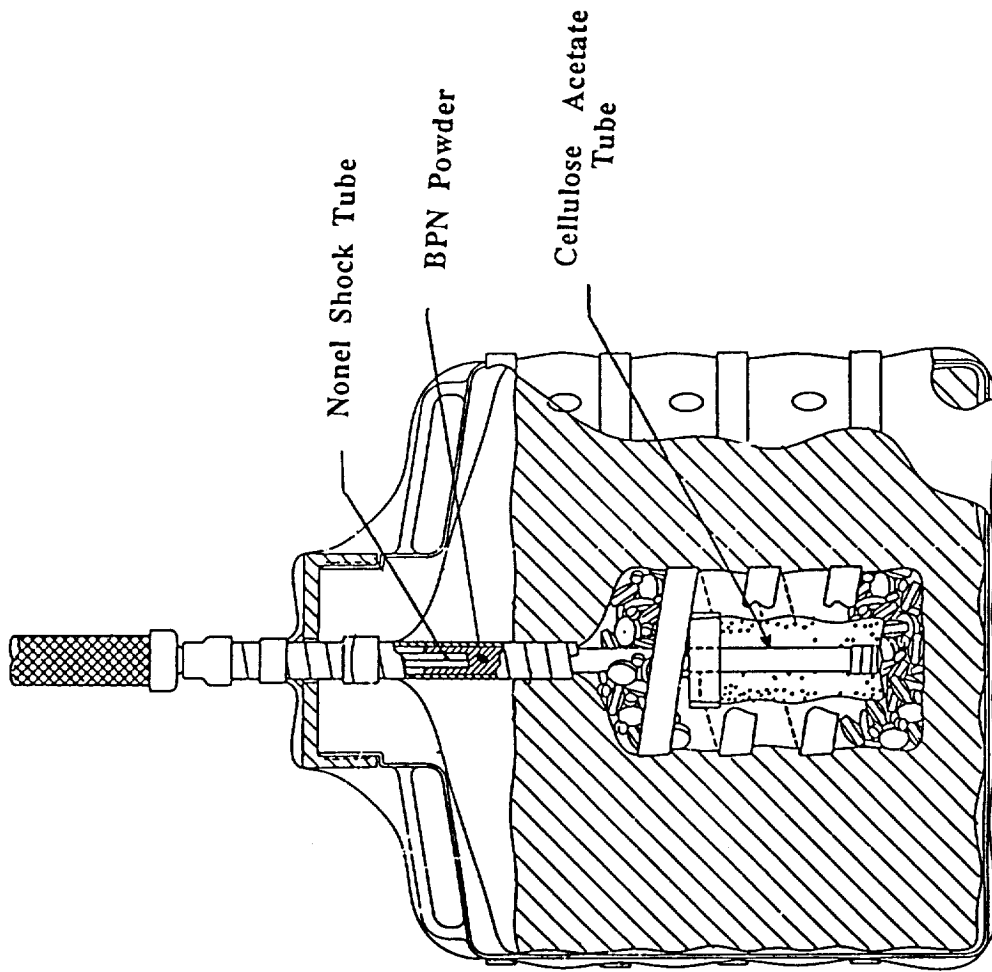


Figure 3
Modified Original Design

II. Laser Initiated Ordnance System.(LIOS)

The LIOS consists of a remotely operated portable laser diode firing unit, fiber optic cables with optical connectors, and a laser initiated squib. Additionally, a laser energy sensor meter is used for laser system checkout prior to connection of the pyrotechnics. This system is designed and manufactured to comply with all CDHR (United States Department of Health, Education, and Welfare Center for Devices and Radiological Health) requirements. Figures 4 & 5 show schematics of the laser system, and the test facility schematic. Figure 6 lists the test facility requirements on the system.

Portable Laser Diode Firing Unit. (PLDFU)

System Overview

The PLDFU is designed to operate in a remote mode only. The user has control of the Arm & Fire commands from a remote location. A local and remote voltage feedback is provided to monitor the capacitor network internal to the unit. The front panel power indicator will function in remote mode and is also useful for voltage monitoring purposes.

PLDFU Front Panel

The PLDFU front panel contains a key switch interlock, interlocking remote power and an LED indicator to identify PLDFU power. The front panel is described below. Refer to Figure 7 for reference.

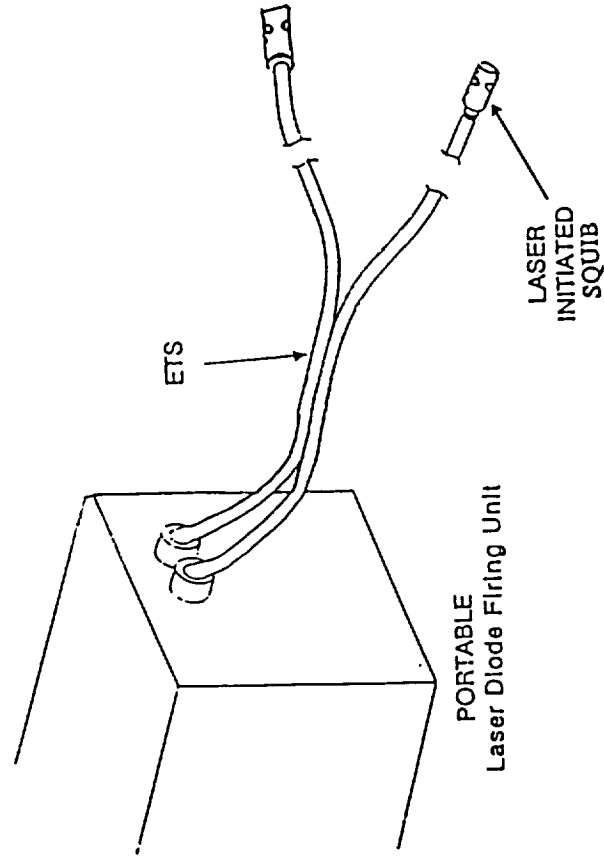
Enable Key Switch -- The enable key switch is used to control external primary DC power to the PLDFU. Two positions are available: OFF and ON. In the OFF position (vertical), external DC power is disconnected from internal circuitry. In the ON position (horizontal), DC power is enabled. The ON position is the normal position when the system is in operation. In preparation to turning the system ON, the user must turn the key switch from the OFF position to the ON position. The correct method of powering down the system is to turn the key switch from the ON position to the OFF position. The key can only be removed in the OFF position.

Power Lamp -- The power lamp will illuminate when external power has been provided and the interlock key switch is in the on position.

PLDFU Back Panel

The PLDFU back panel contains dual laser diode outputs, a power connector, voltage monitor output and remote interface connector. Refer to figure 7 for reference.

J2, Power Input -- External power must be provided to this input. The required level is +24VDC +/- 2VDC. Also provided on this connector is voltage feedback used for remote voltage monitoring.



ASRM SYSTEM

Figure 4

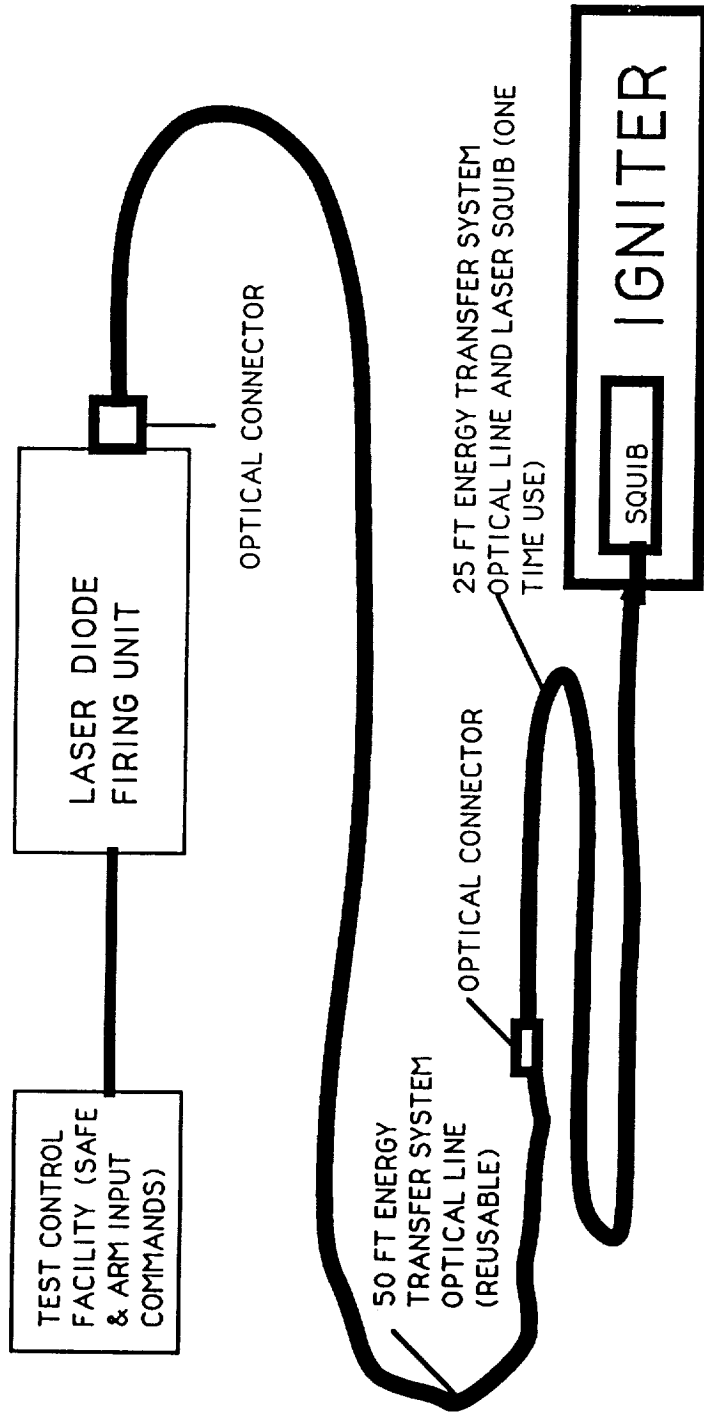
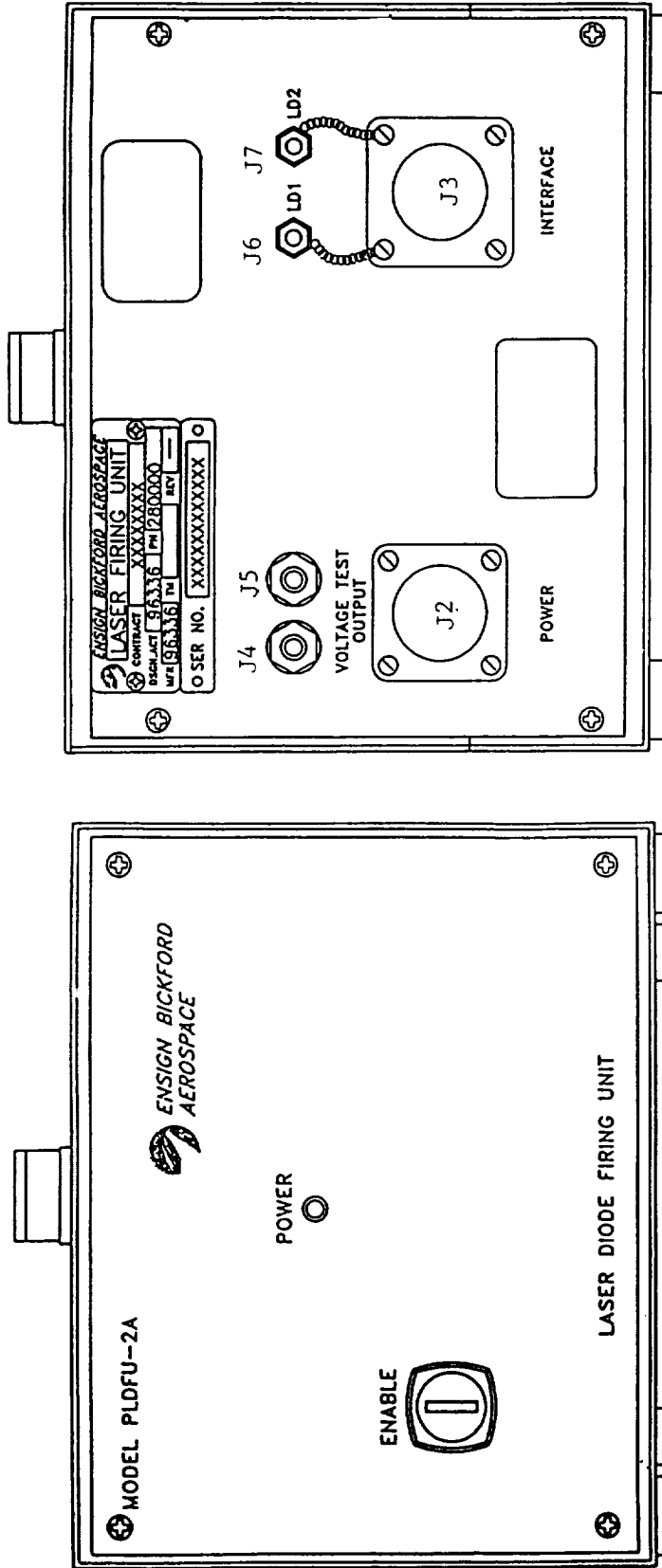


Figure 5: Test Facility Schematic

- REMOTE POWER SUPPLIED BY TEST FACILITY
 - STRAY VOLTAGE VERIFICATION INCORPORATED INTO DESIGN
- REMOTE MONITORING OF TRIGGER CIRCUIT
 - EVALUATE TIME PROFILE FROM FIRE COMMAND TO MOTOR IGNITION
- REMOTE ARM STATUS MONITORING
- REMOTE FIRE STATUS MONITORING
- COMPLETE VERIFICATION OF UNIT ACCOMPLISHED OFF-LINE, PRIOR TO MOTOR FIRING TEST SET-UP
 - STRAY VOLTAGE TEST
 - TEST FIRING OF LASER DIODES (LASER ENERGY METER)
 - VERIFICATION OF "SAFE" CONDITION PRIOR TO HOOK UP

Figure 6: Test Facility Requirements



PLDFU FRONT PANEL

PLDFU BACK PANEL

Figure 7

J3, Remote Interface Connector -- The remote interface enables the user to control PLDFU's arming and firing in remote locations. Also, discrete outputs are available to inform the user of armed and firing status and trigger output. The trigger output is an electrical output enabling the user to monitor the actual internal fire pulse generated by the PLDFU. It can be used as a trigger source when measuring system delay times.

J4,5, Local Voltage Feedback -- The internal capacitor bank voltage is provided at these connectors.

J6, Laser Diode Output 1, LD1 -- Laser diode output 1 provides the laser output used for event initiation. The Energy Transfer System (ETS) connects to this output.

J7, Laser Diode Output 2, LD2 -- Laser diode output 2 provides the laser output used for event initiation. The Energy Transfer System (ETS) connects to this output.

Energy Transfer System. (ETS)

The ETS is an optical harness that transfers laser power from the PLDFU to the igniter squib. The components of the ETS are:

- 1) Reinforced fiber optic lines
- 2) PLDFU and squib harness optic connectors

The ETS interfaces to the PLDFU with a MIL -C-38999 Series IV connector. The squib is assembled directly to the reinforced fiber optic lines as a subassembly.

Fiber Optic Connectors

The fiber optic connector is a MIL -C-38999 Series IV connector that utilizes fiber optic contacts. The contact used to terminate the fiber optic core is based on 16 gauge electrical contact. The fiber optic contact, like its electrical counterpart, is removable from the rear of the connector. The fiber optic core is assembled into the connector using a crimp, epoxy

and polish process that holds the optic losses to less than 1dB per interface. The fiber optic contact can be placed in any standard insert that accepts 16 gauge electrical contacts. Figure 8 is a schematic of a fiber optic connector.

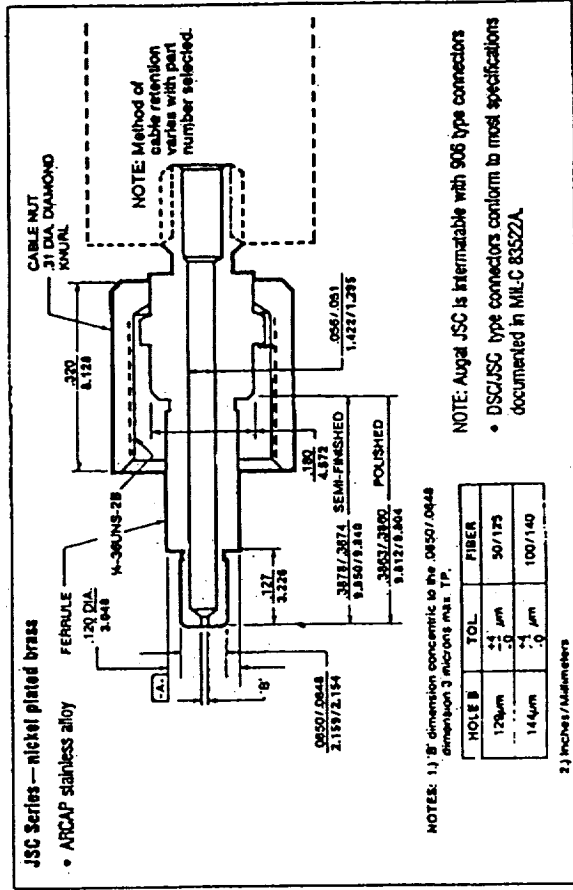


Figure 8

Fiber Optic Connector

Fiber Optic Line

The fiber optic line (see figure 9) is a 400 um HCS fiber manufactured by the Ensign Bickford Optics Company. The fiber has a core of high purity silica, and a hard polymer outer cladding. The hard cladding is a hydrophobic material which offers high resistance to moisture penetration. The hard clad is applied during manufacture to the pristine surface of the core just after the drawing operation. It provides an intimate protective coating by chemically bonding to the silica, and increases the tensile strength of the fiber to in excess of 750,000 psi. The structure of the fiber optics line includes an extrusion of Tefzel over the cladding, a Kevlar reinforcement layer over the Tefzel, and a final polyurethane jacket. The fiber optic line weighs less than 2.5 grains per foot and the energy loss is less than 6 dB per kilometer at 800 nm wavelength.

Laser Initiated Squib. (LIS)

The LIS assembly is shown in Figure 10. The initiator body is 0.25 inches in diameter and 1.25 inches long. The body material is polycarbonate. Two 0.35 inch diameter bushings and bonded to the body to center it within the tube in the igniter assembly. The body is configured with four equally spaced holes to provide radial pyrotechnic output. A polycarbonate plug is threaded into the end of the body to prevent axial pyrotechnic output. The body contains a cavity for two pyrotechnic charges- 25 milligrams of boron/red lead as the first fire mix and 45 milligrams of zirconium/potassium perchlorate as the output mix. The first fire mix is pressed directly against the face of the 400 micron diameter optical fiber which is secured within a polycarbonate fiber ferrule threaded and epoxied into the initiator body. The output mix is pressed directly on top of the first fire charge. The optical fiber pigtail is 25 feet long and is terminated on the input end by a SMA-type optical fiber connector.

III. Laser Initiator Development

The initiator was designed to interface with the Aerojet P/N 3802019 Igniter Assembly - 48 Inch Motor. All major components of the initiator are machined from polycarbonate to ensure their consumption during the motor firing. The initiator was designed to be functioned by a Laser Diode Firing Unit and has .999/95% all-fire and no-fire powers of 472 and 145 milliwatts respectively. Adequate system margin is assured as the anticipated power received from the Laser Diode Firing Unit will be approximately 2.5 times the all-fire.

Fiber Optic Schematic

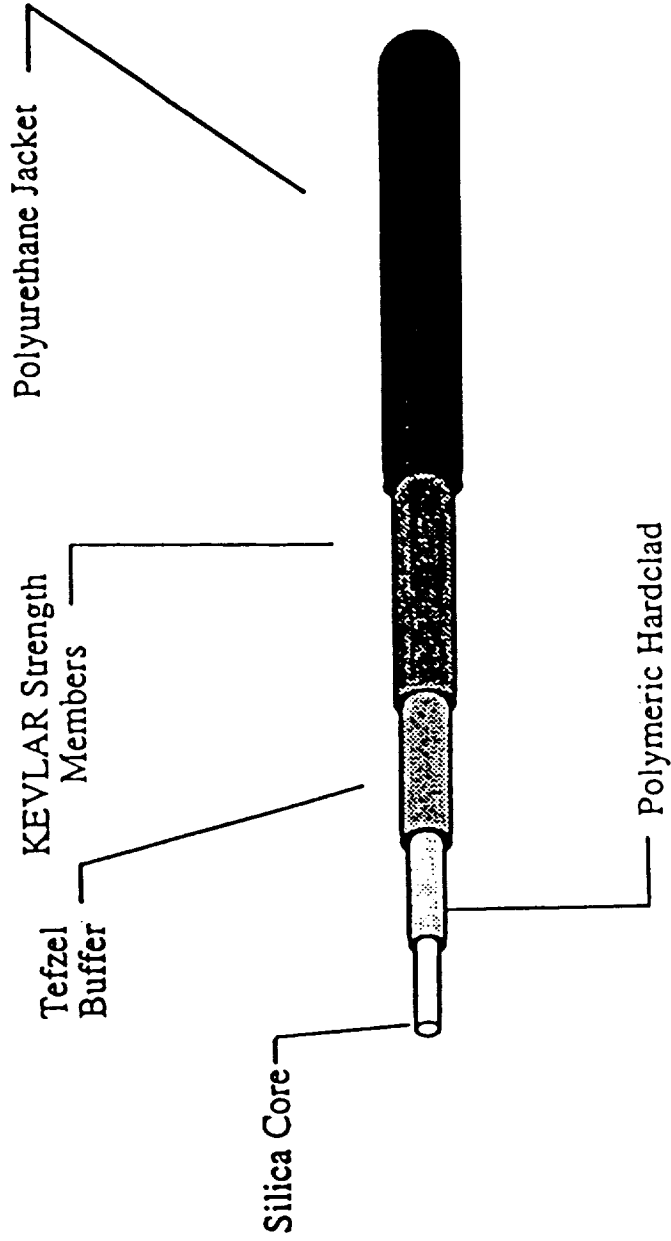


Figure 9

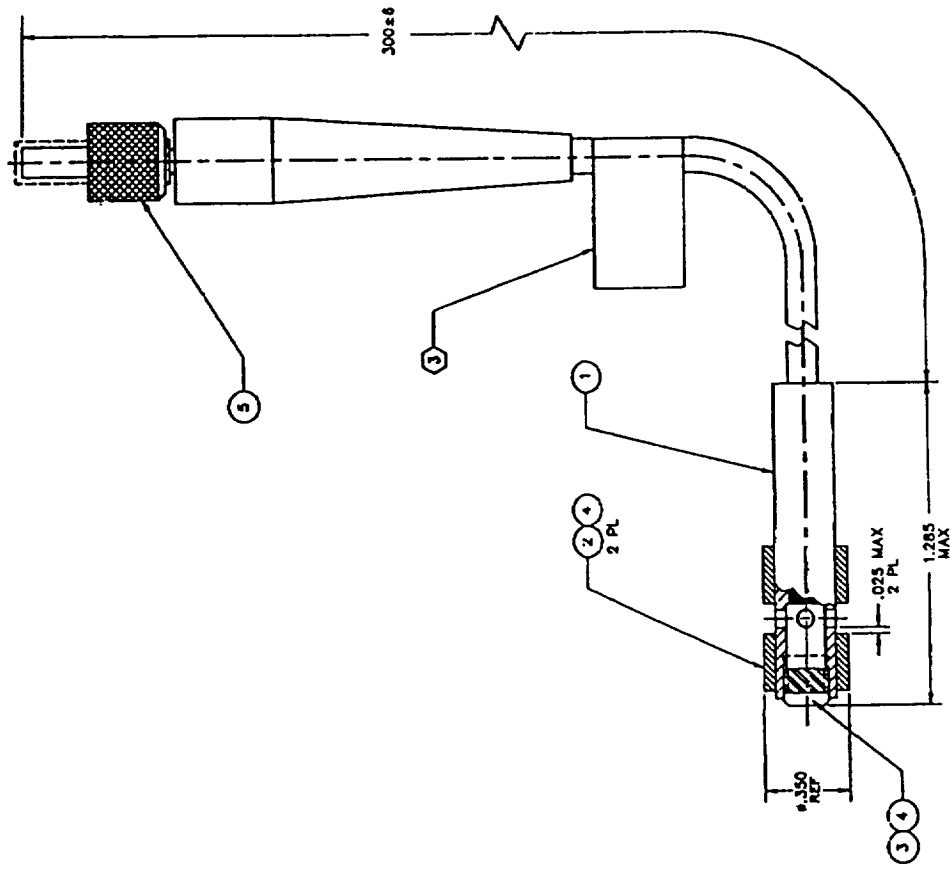


Figure 10

Laser Initiator

Test Summary

The Laser Initiator design was based upon two devices that were developed for similar applications. Boron/red lead was evaluated several years ago as a first fire mix for a diode initiated squib. The zirconium/potassium perchlorate output mix has been used in a variety of squibs and the selected charge weight of 45 mg was used in a prior design to initiate boron/potassium nitrate pellets in a solid rocket motor igniter.

However, as these baseline devices utilized 200 micron diameter optical fiber, development testing had to be conducted with this new device to determine its all-fire and no-fire power and thus ensure that there was sufficient power margin in the system for reliable functioning.

Two series of six firings each were conducted with generic design plastic housings to obtain baseline data on the all-fire power of boron/red lead when mated to a 400 micron fiber. Results of this limited testing indicated that the 50% power (1/2 fire, 1/2 no-fire) was in the area of 400 milliwatts. As improvement on this number was expected when the actual hardware was utilized and more data was generated in a formal test, work proceeded on the basic design.

A prototype lot of fifteen initiators was manufactured to preliminary processing documentation. The purpose of this lot was twofold. It served to provide units for formal development testing and also checked out the preliminary manufacturing and inspection procedures. Ten assemblies were expended in a formal Langlie analysis for all-fire and no-fire powder level determination. The raw test data is shown in figure 11. With a normal distribution assumed, the calculated all-fire power at .999 reliability and 95% confidence was 472 milliwatts. The calculated no-fire power at identical reliability and confidence levels was 145 milliwatts. Radial output was achieved in all instances and no fragmenting of the initiator occurred. The function time curve of Figure 12 is based upon limited timing data that was obtained during the Langlie test. At the anticipate system power input, a function time of under 4 milliseconds should be achieved.

One assembly from this lot was rejected on x-ray and was functioned in a test to demonstrate the radial output. In this firing, the initiator was centered within a 1 inch diameter cardboard tube. When fired with a laser diode, the initiator's radial output left four equally spaced signatures on the inside diameter of the tube.

One assembly from this lot was fired to determine if its output was sufficient to rupture the cellulose acetate buterate tube in the P/N 3802019 igniter. When this requirement became known, the initiator design was modified to incorporate the two bushings on the outside of the body to both center it within the tube and to direct and confine the radial output against the tube wall. When functioned in this test, the initiator output was sufficient to rupture the wall of the tube.

Test	Test S/N	Calculated Energy Level (mw)	Actual Energy Level (mw)	Result X=Fire 0=No Fire	Function Time (ms)	Destruct Energy Level (mw)	Destruct function Time (ms)	Desired Current (amps)	Actual Current (amps)
1	2	375	376	X				1.31	1.27
2	15	188	187	0		675	4.44	0.81	0.80
3	1	281	279	0		-	48.07	1.05	1.02
4	3	516	519	X	5.7			1.65	1.588
5	4	399	401	X	10.7			1.36	1.314
6	5	293	292	X	17.7			1.08	1.054
7	6	146	145	0		675	3.02	0.72	0.714
8	7	220	221	0		675	2.54	0.90	0.882
9	9	309	310	0		675	6.39	1.12	1.090
10	10	413	414	X	14.0			1.39	1.340

FIGURE 11. Laser Initiator Development Test Raw Data

FUNCTION TIME VS LASER DIODE INPUT POWER
P/N 239141 LASER INITIATOR

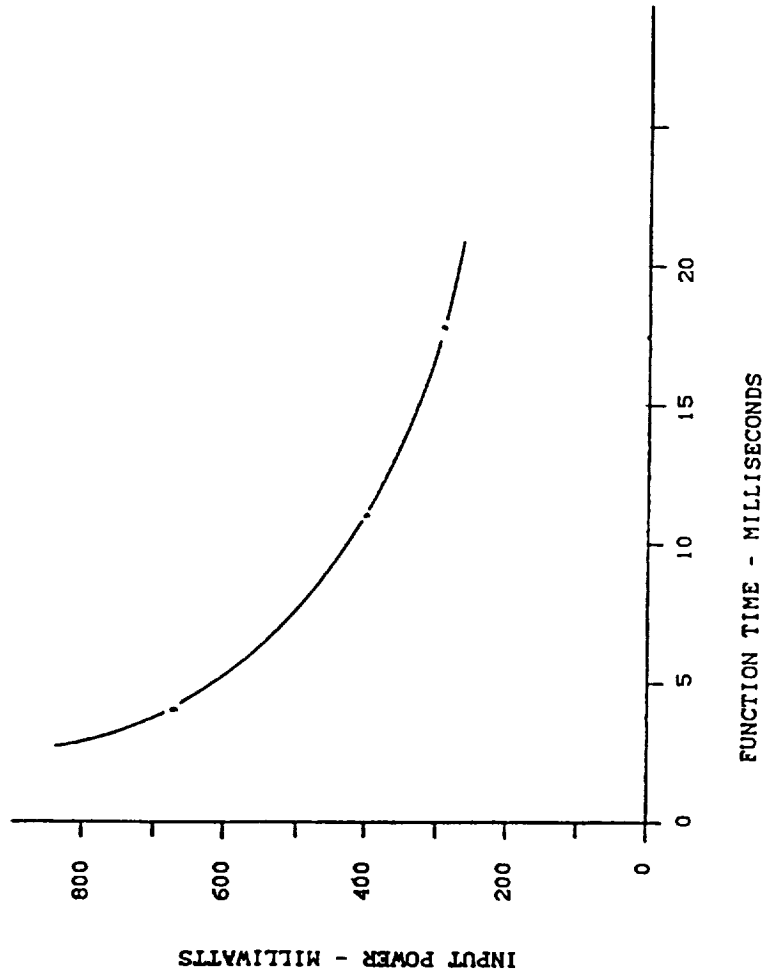


Figure 12

Two initiators were functioned to demonstrate that they could directly initiate boron/potassium nitrate (BPN) granules. The set-up was similar to that to be employed in the P/N 3802019 Igniter except that only 5 grams of BPN granules were loaded into the velostat bag. The functional set-up comprised a laser diode firing unit, a fifty foot optical fiber trunkline, and the igniter subassembly with its twenty-five foot fiber pigtail. The firing unit provided 690 milliwatts of power at the output of the fifty foot trunkline. Testing was conducted at an outdoor test site; the ambient temperature was approximately 20 degrees Fahrenheit. The laser initiator in the first set-up failed to function when the diode powder was applied. This initiator was replaced with a spare and was subsequently successfully functioned as was the second igniter set-up. In both instances the initiator ignited the BPN pellets through the cellulose acetate buterate tubing.

Failure Analysis

The following preliminary failure modes were established at the time of the functional failure:

- 1) Insufficient or no output from the firing unit
- 2) Frozen condensation at the optical fiber interface resulting in high loss and insufficient power to the initiator
- 3) Initiator defect (broken fiber, foreign material at fiber/pyrotechnic interface)

The firing unit was checked out immediately following the failure and prior to resuming testing. The output was found to be at the required level. Subsequent examination revealed no defects in the firing unit, i.e., loose wires, etc. The firing unit was eliminated as the cause of the failure.

In the first test, the optical fiber connection between the initiator and trunkline was made outdoors. In addition, the connector ends were cleaned with methanol outdoors immediately before the connection was made. It was thought that water in the methanol might have frozen in the cold temperature and subsequently attenuated the power at the connector interface. Examination of the methanol used showed that less than 0.05% water was present. This was eliminated as a failure cause.

As further test of the above two failure modes, the failed initiator was set up for firing under controlled laboratory conditions. It again failed to fire.

The failed initiator was re-x-rayed to determine if any internal defects were present. None were found. It was then subjected to a teardown analysis. The body was cut at the radial output holes to expose the inner seal over the powder charge. The rear bushing was then removed. Both charges could be seen through the clear body and had been loaded in the correct locations. The output end of the body was soaked in acetone to soften it and the epoxy seal. The seal was then removed, exposing the output charge. Both charges were then removed via an ultrasonically-activated water soak; all residual material was saved. When all pyrotechnic was removed, the optical fiber was checked for loss. Originally at 0.45 Db, it was found to be at 0.59 dB which showed it to be intact. This minor increase is reasonable as no attempt at special cleaning was made to remove any residue. It should be noted that the acceptance criteria was 0.7 dB maximum. A broken fiber was thus eliminated as a cause of the failure. The residual material from the cleaning operation was then examined. Foreign material was found. This object, 388 microns in diameter, appeared to be either a thin film of epoxy or flake of polycarbonate with boron/red lead

embedded on its surface. Either could have been present with the epoxy coming from the gluing of the fiber ferrule to the body and the polycarbonate from the body machining operation. With this lot of assemblies, the fiber face was not examined just prior to loading, so it is not possible to prove/disprove this theory. Loss testing with a thin film of epoxy over the fiber face showed an increase from 0.54 dB to 2.16 dB on a sample fiber; this would have brought the power at the fiber/pyrotechnic interface to 80% of the all-fire level. A higher loss would be anticipated with a flake of polycarbonate at that interface.

During the manufacture of the deliverable units, operators noticed that flakes of polycarbonate were present within the initiator body and in fact were adhering to the fiber ferrule when it was inserted. These flakes were due to the machining operation and had not been removed by two water washes.

It was concluded that the most likely cause of failure was the presence of a polycarbonate shaving at the fiber/pyrotechnic interface which prevented full power from reaching the first fire charge. The following corrective actions were instituted for the manufacture of the deliverable units;

- 1) All plastic parts were cleaned with compressed air to remove residual plastic shavings.
- 2) A QC visual inspection point was added to the manufacturing lot traveler to check for contamination at the fiber face just prior to loading.
- 3) A second fiber loss check was included at the subassembly level after the housing and fiber ferrule were mated.

IV. Laser Initiation Of the 48-Inch Test Motor

Laser Initiator Demonstration at Igniter Production facility.

The laser initiators were next integrated into the 48-inch motor test program. First it was demonstrated that the system worked by firing 1 squib by itself at the igniter production facility. The Bag Igniter was redesigned to accommodate the laser initiator as depicted in figure 13. Laser initiation of the bag igniter was demonstrated in an R&D firing. With the successful demonstration of the squibs and the bag igniter, full confidence in the system had been achieved and lot production of the igniter assemblies was reinstated. Two lots of Igniter assemblies with laser initiators were built and successfully completed Lot Acceptance Testing (LAT), including 4 igniter firings.

Laser Initiator System Checkout / First Firing at Test Facility (MSFC).

Detailed sequencing procedures for testing checkout and live operation at the test facility were prepared and reviewed. When the procedures were approved the PLDFU and ETS was installed at the test facility. The laser energy sensor meter was attached to the ETS. Full motor firing sequencing was demonstrated and verification of the laser system operation was accounted for by registering laser energy on the laser energy sensor meter. When proper set up and system operation had been verified, actual pyrotechnic operation was demonstrated by firing 3 laser initiators. Each firing was performed using full rocket motor firing procedures. On April 10, 1991 the first 48-inch rocket motor initiated by a laser ignition system was fired. This firing also has the distinction of being the first laser initiated large rocket motor firing at Marshall Space Flight Center.

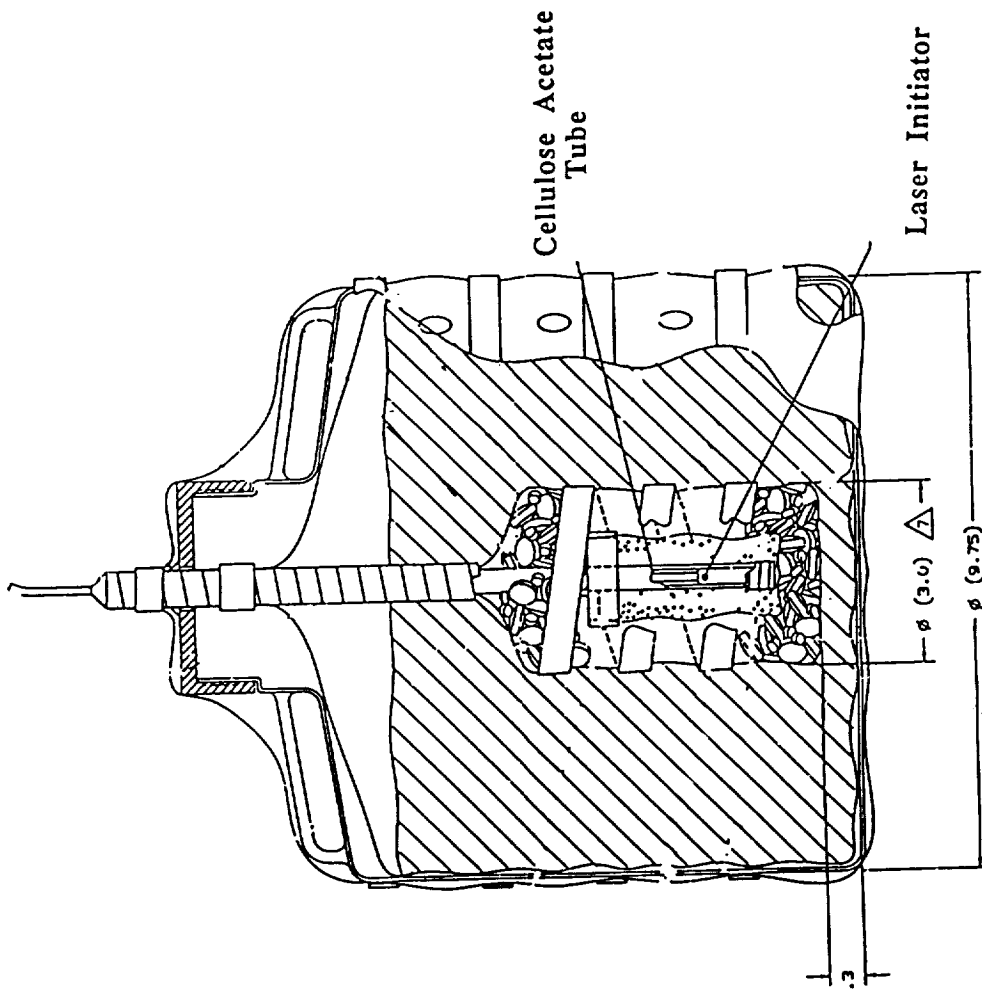


Figure 13
Laser Initiated Design

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