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EXPLORATORY DEVELOPMENT ON AN ELECTRONIC SAFING AND ARMING DEVICE FOR ORDNANCE FUZING

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Prepared by

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20. ABSTRACT (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

The objective of the program was to explore a concept for a safe, reliable, general purpose, low cost, electronic, safing and arming (S&A) system for use in projectiles, mortars, rockets, and other muniton fuzes. Specific tasks included: requirements definition, system analysis, and design, fabrication and testing of breadboard model hardware of the electronic S&A device.

The electronic S&A device consists of an explosive barrier module (EBM) explosive train element based on a concept patented by HDL, environmental sensor elements, and an interconnecting processing electronics element. The electronic S&A will remain safe prior to launch of the munition, thereafter it will sense the launch environments, delay the arming to safe separation from the launcher and sequentially energize the EBM to move the explosive train into the armed position.

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The resultant electronic S&A is deemed to be a feasible approach to a general purpose method of safing and arming electronic fuzes of the future. However, much development work remains to be done to perfect various elements of the design.

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1. INTRODUCTION

This report describes the work performed under Contract DAAG39-78C-0084 with the Harry Diamond Laboratories (HDL), beginning in July 1978 and completed in August 1981. The program objective can be summarized as three primary tasks:

- Design an Explosive Barrier Module (EBM) element based on U.S. Patent No. 3,760,726. Fabricate and test models to demonstrate out-of-line safety, reliability, and operation under specific environmental conditions.

- Design a general-purpose safing and arming (S&A) electronic circuit to drive the EBM which accepts various power supply voltages and inputs from two independent environmental sensors, provides an arming delay for safe separation from the launcher, and provides the firing circuit for the four pyrotechnic devices in the EBM.

- Study various concepts for solid state electronic environmental sensors that would be compatible with the EBM and the S&A electronic circuit.

Included in the report is a chronological discussion of the specific tasks performed, and an analysis of the results, including test data as appropriate. Conclusions and recommendations for improving performance of the specific items and proposals for reducing costs are included in the appropriate discussion within the text while over-all recommendations for further study for the entire program conclude this document.

The project engineer at Honeywell was Dean Anderson in 1978-1979 and Edwin Stryker in 1980-1981.

Technical support was provided by David Overman and John Carpenter from HDL. Subcontractor and vendor support was supplied by ICI Americas, Valley Forge, Pennsylvania, and Stresau Laboratories, Spooner, Wisconsin.

The EBM S&A device and test fuze assemblies were designed based on the requirements given below.

a. The EBM should be producible at minimum cost whether assembled by hand line or automatic techniques. A cost goal per million units was less than $0.50 each in 1978 dollars.

b. The EBM should be no larger than 33mm in diameter and 15mm high including electrical interconnections. A smaller size is preferred.

c. The EBM should incorporate three movable members (bolts) mechanically interlocked so they can move in only one given sequence. The last bolt to move shall align a transfer explosive element (relay) on the EBM centerline. The bolts can move by translating, rotating, or a combination of both motions. They shall be moved by the forces produced by the individual explosive/pyrotechnic element (motors or EEDs) made integral with the EBM. They shall not move under any expected environmental influences, except when the motors are initiated in the proper sequence. (For the remainder of this report, these will be referred to as EEDs.)

d. Molded plastic, sintered or cast metal should be among the low cost fabrication techniques considered for the basic construction of the EBM. Models built may be machined.

e. The EBM should be designed so it will fail safe if the EEDs are initiated out of the proper sequence. The relay should not initiate and there should be no burning or charring of the lead charge if a fourth, centrally located EED (initiator) functions with the third bolt in its out-of-line or safe position. The fourth EED should have the same design as the three motor EEDs.

f. The EBM should be designed so that the functioning of one motor will not initiate another motor nor affect the reliability of initiation of another motor.

g. The M55 detonator (MIL-D-14978) should be used for the relay charge. The lead charge shall contain 90 mg minimum and 160 mg maximum of a secondary explosive per MIL-STD-1316. Functioning of this lead charge by the M55 in the EBM shall produce a 0.040 inch minimum depth dent in a 2024-T4 aluminum witness block. An RDX base explosive is preferred, but not required for the lead charge.

h. The EBM should be designed so that the third bolt positively detents in the armed position. Functioning and detenting of any of the three bolts shall not require the presence of spin forces and shall not be degraded by spin forces of up to 20,000 g.

i. The EBM design should take into account appropriate venting or relief of gas pressures created by the moving bolts and by firing the EEDs in both the proper and improper sequences.

j. When designing the EEDs for the EBM, the electro-explosive bridging techniques of welded wire, etched metal, deposited film, and conductive explosive mixture should be considered. The explosive/pyrotechnic motors should be designed to be sealed against moisture so the EBM will pass Test 108, Waterproofness, of MIL-STD-331.

k. The explosive materials, bridge and substrate materials, sealant materials, and other structural materials of the EBM should be chemically compatible to the extent that performance will not be degraded over storage periods of at least 10 years.

l. The EBM motors and electro-explosive bridges should be designed to all-fire with an energy input of approximately 500 ergs. For test purposes, all developmental motors shall be fired using a 2.2 ± 10% MFD tantalum capacitor charged to 7 ± 10% volts and discharged through a mechanical switch having mercury wetted contacts.

m. The EBM should be designed with plug-in type interconnections to mate with other parts of the S&A device. (For purposes of this contract, it was preferred that the female portion of the contact be contained within the EBM.)

n. The EBM should be designed to be reliable (goal of at least 99.5%) and rugged enough to withstand the following environmental conditions:

Setback to 30,000 g/ΔV of 3,000 fps

Spin to 30,000 RPM

Side shocks of 20,000 g peak/approximate ΔV of 30 fps

1.5 Meter Drop: MIL-STD 331, Test 111.1

Jolt: MIL-STD 331, Test 101.1

Jumble: MIL-STD 331, Test 102.1

Transportation Vibration: MIL-STD 331, Test 119 Procedure I

Waterproofness: MIL-STD 331, Test 108

Thermal Shock: MIL-STD 331, Test 113

2. EXPLOSIVE BARRIER MODULE MECHANICAL ELEMENT

The mechanical element for the EBM of this S&A device provides out-of-line explosive train interruption. It incorporates three movable members (bolts), mechanically interlocked so they can move in only one predetermined sequence. Movement of the third member arms the device; see figures 1 and 2. Electrically initiated propellant charges provide the force to move the bolts into the armed position and to initiate the detonator. The initiation of these propellant charges is controlled by the electronic circuit, which will be discussed later. Of the 24 possible combinations for firing these four propellant devices, only one will initiate the detonator and lead charge. This mechanical logic device protects against certain types of electronic failures that could otherwise bypass the fuze safety system.

Safety during prelaunch handling is achieved by a mechanical interlock of each movable bolt to the other and to the EBM housing. The housing interlock consists of a shear pin on each bolt. The bolt is confined within the housing assembly. The pin must be sheared to move the bolt from the safe position. The shear pin is designed to maintain the bolt in the safe position under inertial loads of at least 20,000 g.

The arming cycle is accomplished by reaction to three sequential electric signals received from the electronic element. Each electric signal will initiate a propellant charge which provides the force to shear the pin and move the respective bolt. Movement of the third bolt arms the device by positioning an M55 stab detonator between a fourth propellant charge and a lead charge. The bolts are designed to positively lock in the armed position. A firing pin rides with the third bolt and is positioned above the sensitive end of the M55

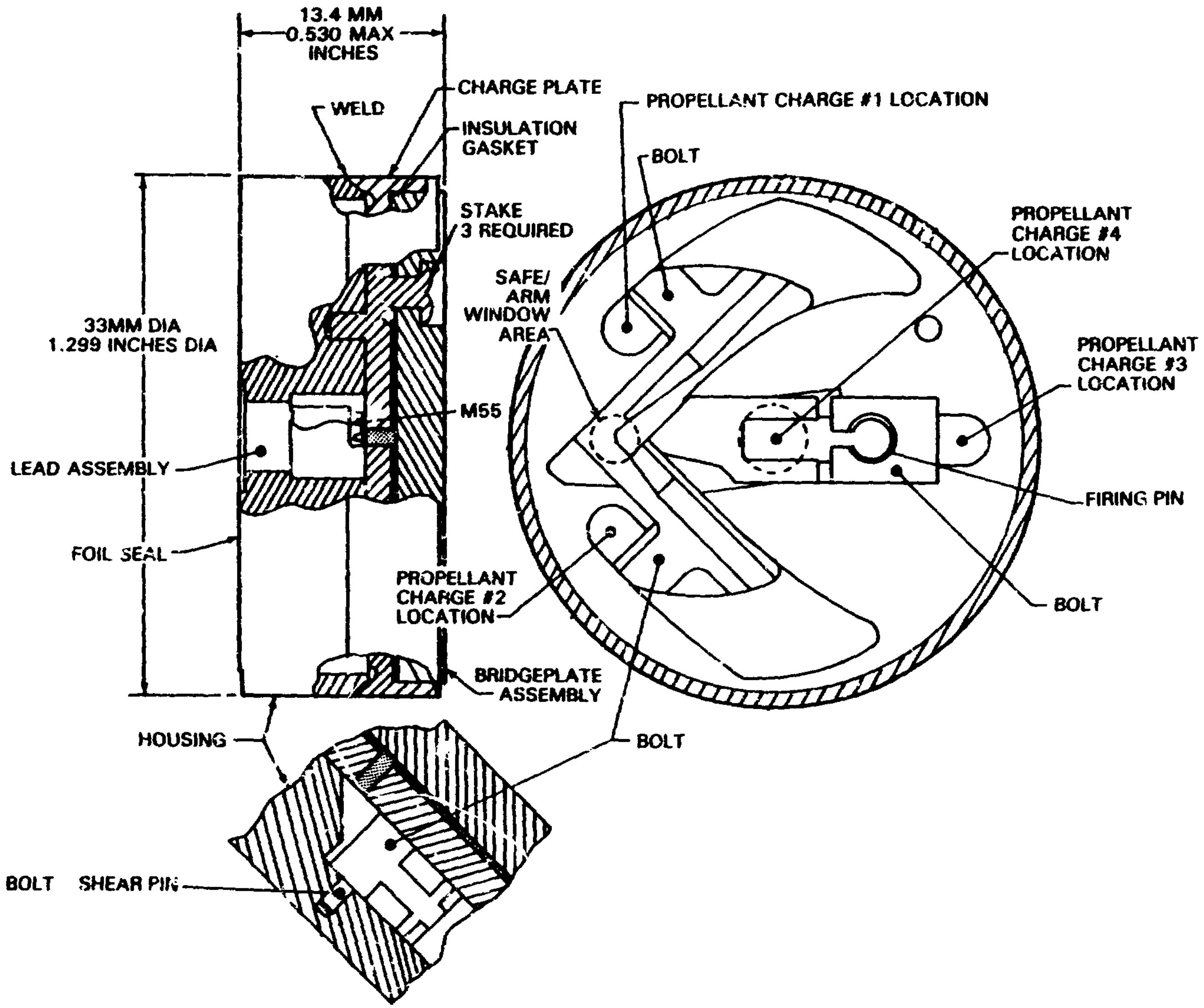


Figure 1. Explosive Barrier Module (EBM)
Assembly - Safe Condition

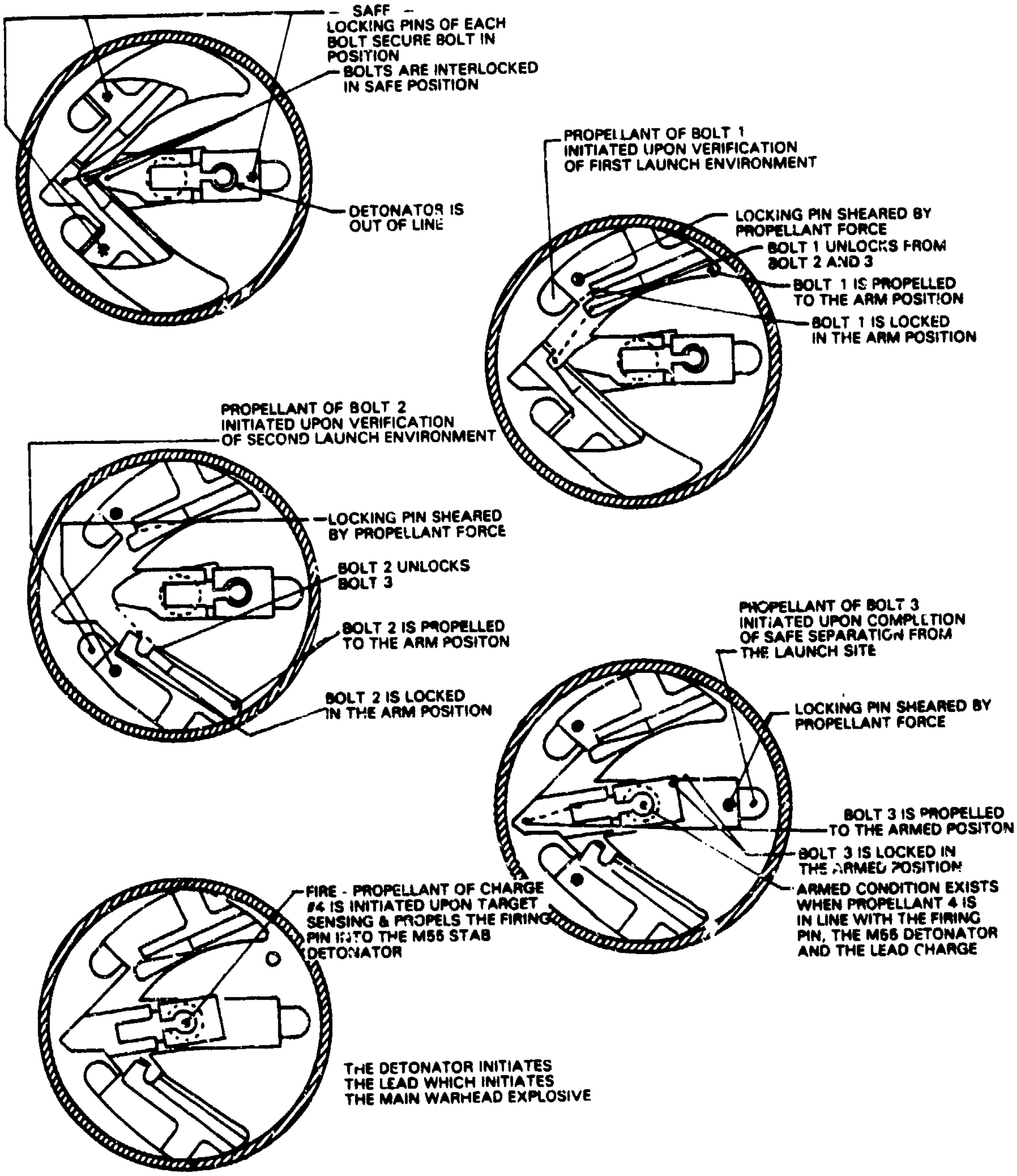


Figure 2. EBM Operating Sequence

stab detonator. The firing pin is driven by the fourth pyrotechnic propellant charge to reliably initiate the stab detonator which initiates the explosive train.

2.1 Requirements

Using details provided in the contract statement of work, a preliminary design specification was prepared and approved to define the critical design parameters. A layout drawing was prepared to determine the dimensional characteristics required for the EBM piece parts.

After the basic configurations of EBM piece parts were determined, we conducted detailed analysis and testing of critical components and interfaces. The design in each of these critical areas is described in the following subsections.

2.1.1 Bolt/Propellant Interface Development — A bolt driven by propellant was designed to shear a pin at the initial peak pressure of the propellant charge. Expansion of the propellant gases moved the bolt. In this design, the propellant output is deflected 90° to apply the force to the bolt. Leakage of the propellant pressure is limited by close tolerances.

The bolt must have adequate strength and impact resistance to avoid being shattered during propellant function and be light in weight so the forces produced during 20,000 g side loading can be minimized. The bolt material selected was acetal plastic, which exhibits the desirable properties of dimensional stability, lubricity, adequate mechanical strength, impact resistance, and injection moldability.

A shear pin capable of withstanding 20,000 g side loading was incorporated in the bolt/housing interface. Provisions were made to vent air from the front of the bolt as it moved forward so that entrapped air would not restrict bolt movement. A locking method capable of positively locking the bolt in the armed position was required. The locking method uses the plastic spring flexure of the bolt as it passes to the armed position.

2.1.2 Bolt 1 and 2 Design — Test bolt assemblies were used to determine a suitable bolt design and to evaluate the pyrotechnic charge. The test bolt assembly consisted of a single bolt, a housing and a cover. The assembly, while not suitable for evaluation of the interaction between the three EBM bolts and four pyrotechnic charges, was effective for preliminary design evaluation and was significantly less costly to machine than an entire EBM assembly.

The first generation test bolt assembly is shown in figure 3. One assembly of this configuration was fabricated. The design incorporated locking/sealing lips on the top and bottom of the bolt which fit into two sets of grooves in the housing and cover. The design intent was that the lips would hold the bolt in the safe position, bend inward as the bolt was propelled providing a tight gas seal on the top and bottom of the bolt and lock the bolt in the armed position at the end of its stroke. The design proved unsatisfactory in the following ways:

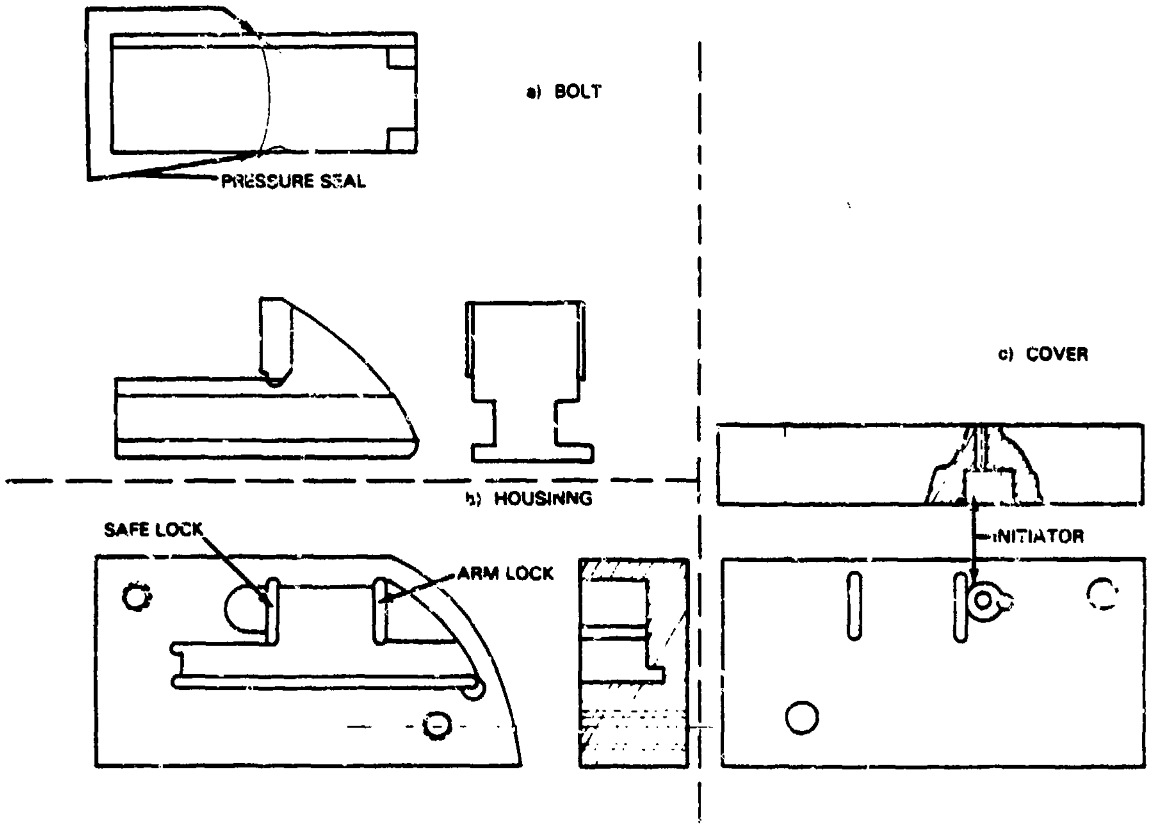


Figure 3. Initial Configuration, Bolt 1 & 2

- The locking lips could not be made sufficiently strong to retain the bolt under 20,000 g side loading.

- The lips had a tendency to yield during bolt function and did not properly lock the bolt in the armed position.

- The bolt lip feature would require a complex mold with inserts to form the lips.

Evaluation of the first design was concluded after static laboratory tests. No propellant functioning tests were conducted.

A second generation test bolt assembly was designed as shown in figure 4. The locking device consisted of a spring integral to the bolt. In the safe position the spring is in a relaxed position. As the bolt moves forward, the spring-end rides up a ramp and falls into a groove in the base to lock the bolt at the termination of its stroke. Because the locking mechanism left an area of the bolt unsupported by the cavity sidewall, a guide rail was provided on the bolt bottom.

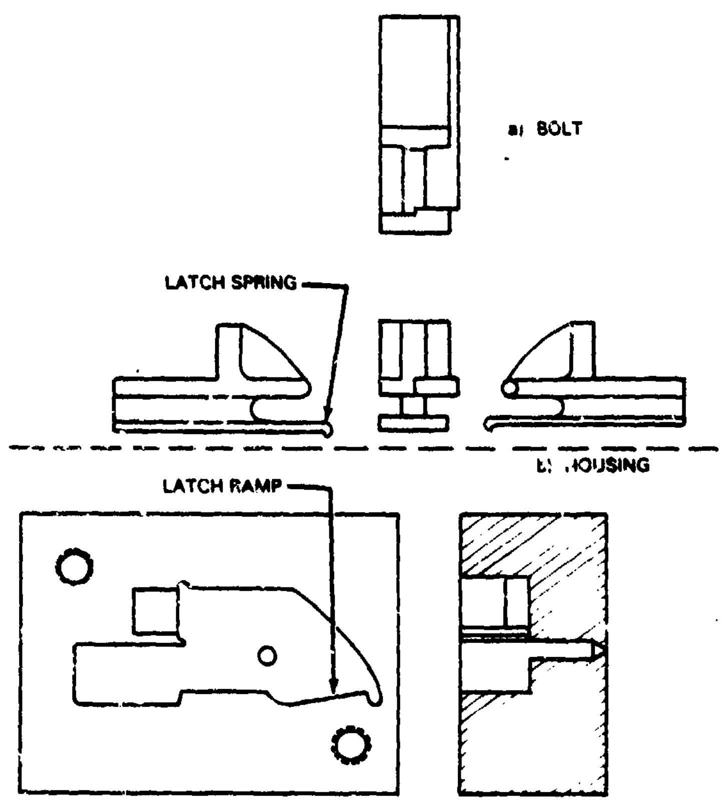


Figure 4. Integral Spring Configuration, Bolt 1 & 2

Bolt weight was minimized by removing material at low stress areas, forming an I-beam type configuration. In addition to reducing bolt weight, the slots produced by removing bolt material provided a venting path for air contained in the bolt cavity. A shear pin was located at the front of the bolt to restrain the bolt during 20,000 g side loading. (The shear pin was fabricated separately from the bolt to allow reuse of the bolt during testing, but in production the pin would be an integral part of the bolt.)

The free air volume in the cavity under the EED propellant charge was minimized by changing from a simple flat-bottom hole in the first design to an angled, ramp-type cavity.

Twenty of the second generation test bolt assemblies were fabricated at Spooner Machine Shop in Spooner, Wisconsin. These assemblies were then explosively loaded and tested at R. Stresau Laboratory, Inc, Star Route, Spooner, Wisconsin. Macro-detonator (U.S. Air Force Dwg. 66A11302-microdet) headers with chromium thin film bridges were used to initiate the pyrotechnic charge. The headers were mounted in the cover and loaded as shown in figure 5. The headers were used in the tests because bridges fabricated directly on the cover were not available.

A summary of the testing conducted with the second generation assemblies is shown in table I. The explosive utilized in these tests was normal lead styphnate. Nine tests in addition to those listed in table I were conducted with higher charge weights during the initial determination of charge volume. The larger charges resulted in bolt shattering.

Strength of shear pin was calculated as follows:

At 70°F, Acetal shear strength = 9,500 psi

Force required to shear 0.044 in. dia. pin at 70°F =

$(9500) (\frac{\pi}{4}) (0.044)^2 = 14.4$ lb.

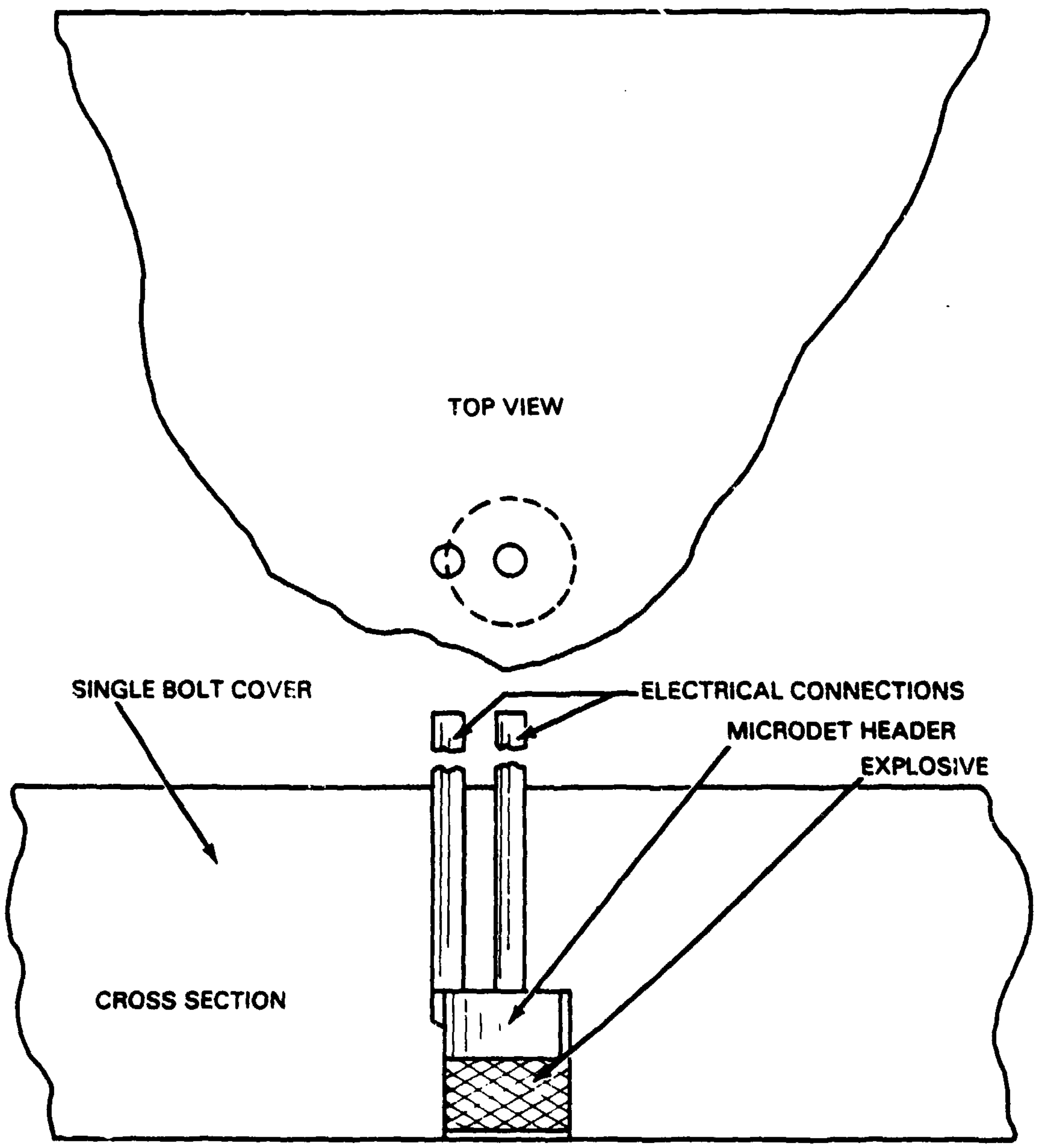


Figure 5. Microdet Header in Test Bolt Cover

TABLE I. TEST DATA ON SECOND GENERATION BOLT ASSEMBLIES

TEMPERATURE (°F)	3 MG CHARGE			4.5 MG CHARGE		
	DID NOT SHEAR PIN	SHEARED PIN (ONLY)	SHEARED PIN & BOLT	DID NOT SHEAR PIN	SHEARED PIN (ONLY)	SHEARED PIN & BOLT
Room	1	1	0	0	1	2
-65	1	0	0	0	1	1
+170	0	0	2	0	0	1

NOTE: In no case did the bolt lock in armed position

During testing the bolt was found to fracture. The fracture was due to a sharp corner that created a high stress area. Stress relief was provided by adding a 0.020 radius at point A, figure 6. to reduce the stress effect, and the guide rail was eliminated. Based on knowledge gained from the first two bolt designs, a third generation bolt was designed as shown in figure 7. This is a much simplified design, much less intricate. Locking is performed by the "tail" of the bolt itself. As the bolt is pushed along a curved path, the bolt flexes until it clears the notch in the sidewall and then snaps back to the unflexed position to lock behind the notch as shown. The shear pin was moved from the front of the bolt to the "pad" area of the bolt.

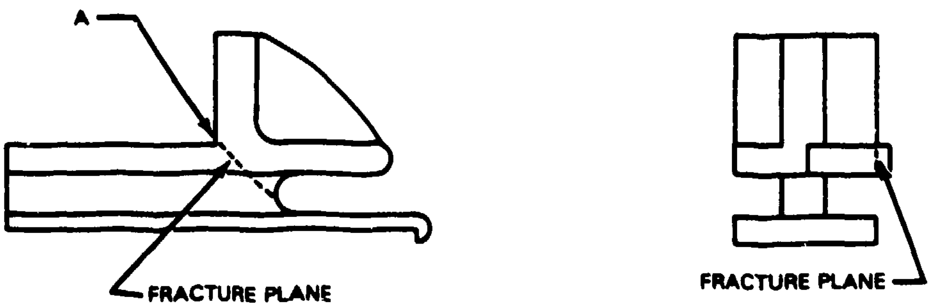


Figure 6. Integral Spring Bolt Fracture due to Propellent Force

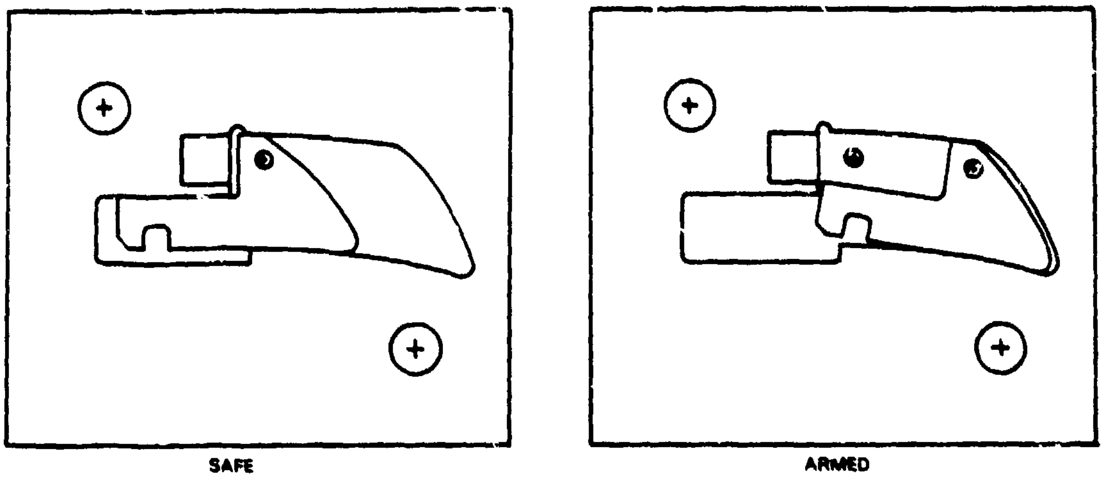


Figure 7. Test Configuration, Bolt 1 & 2

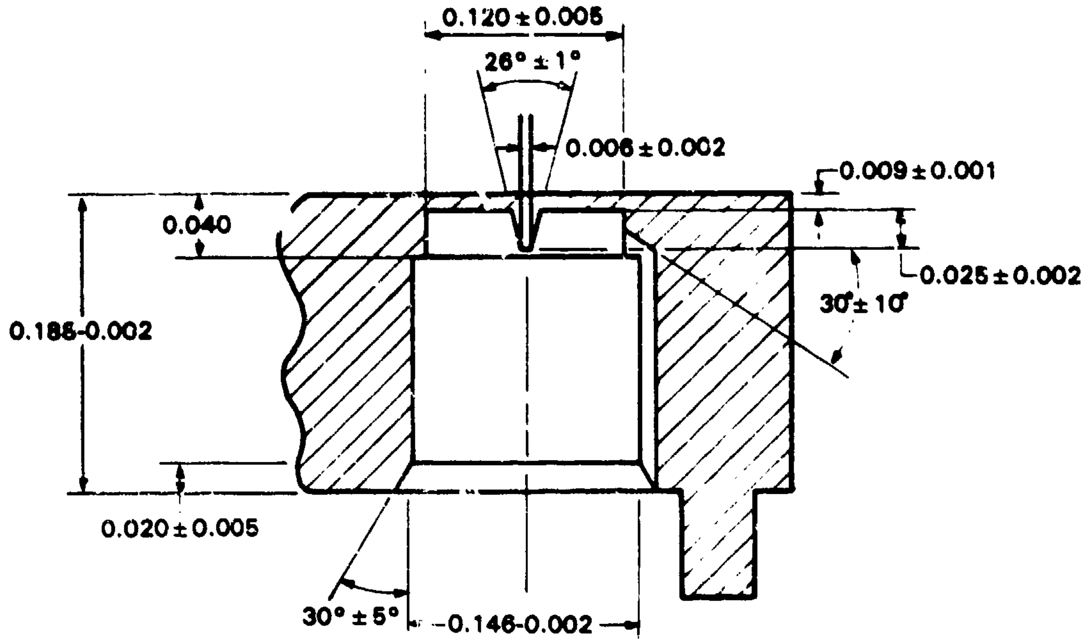
One test bolt assembly of the third design was fabricated at Honeywell.

Initial testing of this assembly at R. Stresau Labs resulted in successful pin shear, bolt movement and bolt locking at -45°F, 70°F, and 145°F with a charge of approximately three milligrams of normal lead styphnate.

The final bolt configuration is molded from Delrin™ 100 acetal plastic to ride in the molded housing of polycarbonate plastic. Bolt color was added to bolt 1 and 2 to provide a visual indicator color of green for safe and red to bolt 3 for armed when viewed through a hole in the housing cover area as shown in figure 2.

2.1.3 <u>Bolt 3 Design</u> — The center EBM bolt or bolt 3 which contains an M55 detonator could not be of the same design as bolts 1 and 2. Therefore, it was necessary to develop and test a center bolt design. The bolt design is restrained in the safe position by a shear pin. The bolt movement is mechanically sequenced as travel is prevented unless bolts 1 and 2 have moved.

Initial designs assumed the #4 propellant charge would initiate the M55 detonator directly. The inital design was modified when tests demonstrated the initiation of the M55 by direct propellant blast was unreliable. The M55 stab detonator will fire in the most reliable manner when a stab firing pin having a 0.005 inch diameter tip is used. A plastic firing pin was fabricated, molded as a thin disk in the hole over the M55 detonator with a 0.015 inch high cone pointed in the direction of the M55, see figure 8. Inspection



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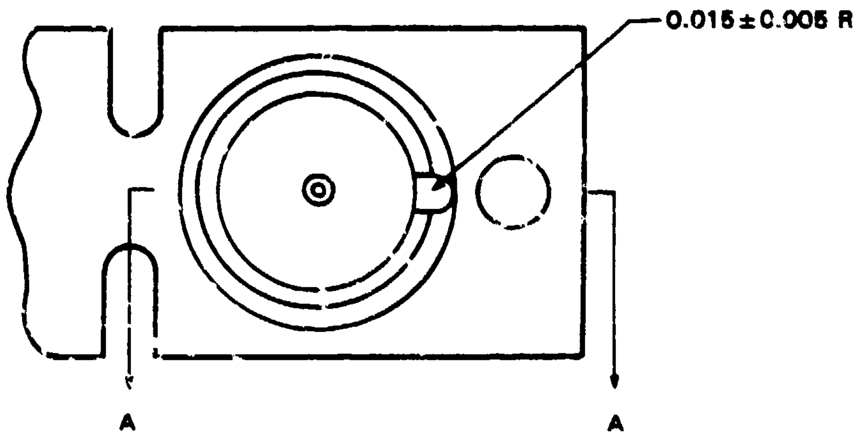


Figure 8. Bolt 3, Injection Molded Firing Pin Design

revealed that the plastic does not injection mold to a point as fine as 0.005 inch diameter, and tests showed that the molded point was not sufficiently sharp or strong enough to reliably initiate the M55.

The mold was revised to use a metal, chemically machined, firing pin (figure 9) which is very reliable. The tail of the firing pin is depressed in a cavity in the bolt to prevent hangup of the bolt during travel from the safe to the armed position.

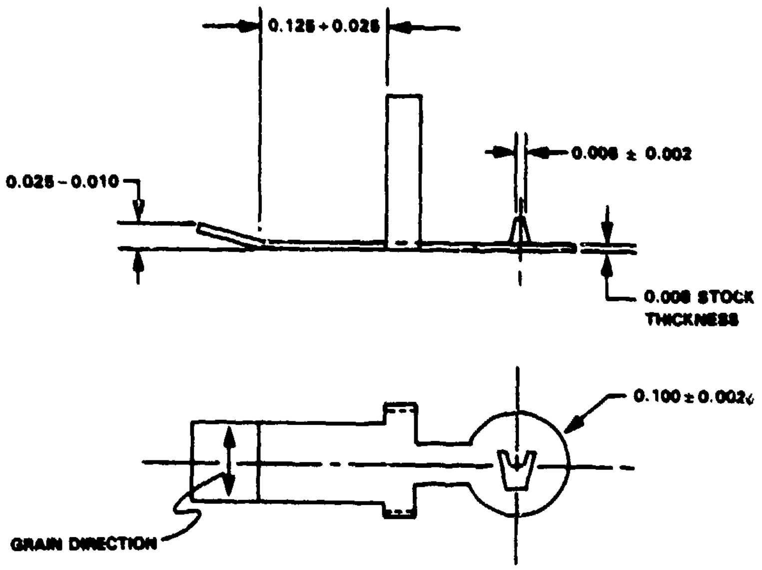


Figure 9. Firing Pin, Metal

The addition of a separate firing pin adds cost to the EBM assembly and the possibility of modifying the #4 charge assembly to fire the M55 directly should be investigated as a potential cost-savings feature.

The bolt and cavity design are shown with the locking action of the bolt as depicted in figure 10. When the bolt 3 propellant charge is initiated, pressure rises at the rear of the bolt until sufficient force is developed to shear the safe lock shear pin. The bolt then slides forward causing the "nose" of the bolt to contact the ramp near the end of the bolt cavity. This ramp causes the bolt to bend as it completes its stroke until the "tail" of the bolt clears the locking recess in the cavity side wall and snaps into the locked (armed) position.

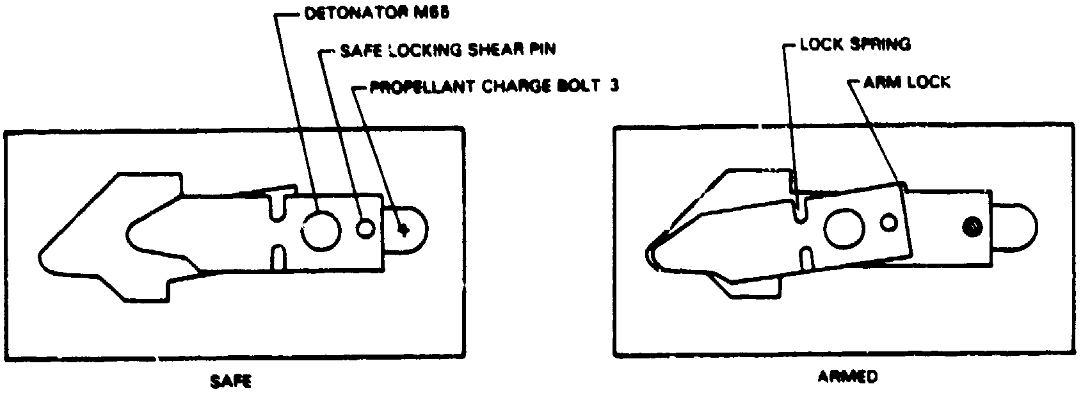


Figure 10. Bolt 3 Configuration

One bolt 3 assembly was fabricated and tested. Test results are shown in table II. The tests resulted in the successful demonstration of the bolt 3 concept.

TABLE II. BOLT 3 TEST RESULTS

TEST NO.	CHARGE QUANTITY MG	DETONATOR TYPE	RESULTS
1	3	Inert M55	Proper pin shear & bolt lock
2	3	Inert M55	Proper pin shear & bolt lock
3	6	Inert M55	Proper pin shear & bolt lock
4	6	Inert M55	Proper pin shear & bolt lock
5	9	Inert M55	Bolt fractured at hinge point
6	6	Live M55	Proper pin shear, bolt lock and no sympathetic detonation of M55 detonator

NOTE: All tests conducted at room ambient.

2.2 Initial EBM Mechanical Element Tests

Molds were fabricated so that all plastic EBM piece parts could be injection molded. Two molds were fabricated, one to produce the three acetal bolts and the other to produce three polycarbonate parts, Housing, Bridge Plate, and Charge Plate.

Five EBM's were built with the molded plastic parts: 1) four microdet headers installed in the Bridge Plate as depicted in figure 5 were used to initiate the explosives, 2) the Charge and Bridge Plate Assembly were attached to the Housing with screws, 3) the Bridge Plate was attached to the Charge Plate using double faced adhesive tape, and 4) no output lead was installed in the EBM.

These five prototype EBM's were test fired at ambient temperature. The test results indicated the following:

- o 4 mg of normal lead styphnate was adequate to propel the bolts to the armed position.
- o Sympathetic initiation or crosstalk between EEDs will occur if the EED output ends are exposed.
- o A mylar tape disk placed between the Charge and Bridge Plate Assembly will prevent crosstalk when the assembly is bolted together.
- o 4 mg of lead styphnate will not directly initiate the M55 detonator.

As a result of these initial EBM tests, modifications were incorporated to the EBM as follows:

- o Enlarged charge plate holes to contain enough lead styphnate (4.5 milligrams).
- o The output of each charge was coated with a thin film of RTV in place of the combustible laquer coating.

- The double faced adhesive tape seal between the Charge and Bridgeplate assembly was replaced with a silicone rubber gasket.

- A firing pin for the #4 charge was added to improve initiation of the M55 detonator.

These improvements were incorporated in the field test projectiles described in detail in the field test section of the report.

2.3 Bridgeplate - Propellant Development

Thin film bridge electric initiators were investigated as a low cost highly producible system for initiating pyrotechnic charges. Significant research activity was expended in gathering data on processes utilized and possible problem areas in metallization of plastic substrates. Photoetching of thin films, sputtering, and thermal deposition of metal films through masks were the fabrication techniques investigated.

Comparisons were made using glass and polycarbonate substrates with a wide variety of metal film materials. These were compared for line definition, length, width, thickness, uniformity, and resistance as related to the EBM explosive bridge geometry.

2.3.1 **Initial Thin Film Bridge Deposition Work** — Bridge deposition work was initially conducted at Koral Labs, Inc., Minneapolis, Minnesota, a subcontractor of R. Stresau Labs. Delays in bridge deposition progress occurred due to vendor equipment malfunctions. The first attempt at bridge deposition failed because the solvent employed to remove the photoresist from the bridge disolved the polycarbonate substrate. Through conversations with William Isler at the HDL thin film laboratory, an alternate method of removing the photoresist from the bridge was found, which was to expose the resist to light and redevelop, then wash the photoresist away. Testing indicated that the developer chemicals do not attack polycarbonate.

Subsequent attempts at bridge deposition resulted in unsatisfactory films believed to have been caused by excessive substrate heating during processing. Subsequent cooling caused separations due to differences in coefficient of expansion of polycarbonate and metal film.

2.3.2 Additional Film Bridge Deposition Work -- As a result of the above problems, the feasibility of fabricating thin film on polycarbonate bridges was continued in the Honeywell thin film laboratory. Our laboratory tried both photo etching and sputtering techniques. A summary of this effort follows.

Typical thin film on glass/ceramic explosive bridge geometry is several mils wide and 5 to 20 mils long. For the photoetching process, a test pattern was made by cut and strip/photoreduction procedures having 11 bridges on a 1 x 3 inch substrate. Various metal films were deposited on glass and polycarbonate panels. The panels were then photopatterned using Shipley AZ1350 positive photoresist. Excellent bridge definition was possible on glass substrates using standard chemical etchants, developers, and removers. With polycarbonate substrates, definition was poor due to interaction of the photochemicals with the polycarbonate. The attack by the remover was especially pronounced. The interaction of the polycarbonate with the developer and etchants was not as pronounced, but in most cases film adhesion was reduced.

For investigation of the sputter deposition technique, several fine line metal masks were obtained from the Honeywell Chemical Process Group for trial. Sputter deposition through the metal mask was not satisfactory because of poor line definition. Intimate contact between mask and substrate cannot be attained and maintained in the sputtering environment. However, thermal evaporation deposition through the metal masks did give good line definition. A mask set was fabricated to fit the molded polycarbonate bridge plates. One mask provided four lines three mils wide (0.003 inch) for the resistive bridges. A second mask provided a conductor pattern that overlapped the bridge lines and defined the bridge length to five mils (0.005 inch). A locating pin was provided to assure registration. Depositions by thermal evaporation, both filament and e-beam, proved very satisfactory. Metal masks are recommended for any additional bridge development work. A test pattern containing an assortment of bridge lengths and widths rather than one of fixed geometry would be preferred.

The first depositions onto glass and polycarbonate test panels were made by radiofrequency (rf) sputtering techniques. There were two reasons for trying sputtering. First, sputtered films tend to have better adhesion than thermally evaporated films. Second, a wide variety of metals was readily available in the form of six inch diameter sputtering targets. Eight different metals were deposited in a total of 30 depositions. The most promising resistive materials were chromium, palladium, platinum, tantalum and nickel. The most promising conductive material was aluminum.

With the switch to metal masks, thermal evaporation was tried with aluminum and nickel from tungsten filaments. Aluminum readily evaporated from filaments and provided good definition, adequate thickness and tolerable substrate heating. Nickel alloyed with the tungsten and would not provide adequate deposition thickness before burning out the filament. A boat deposition source gave similar results. A switch to aluminum coated tungsten boats prevented nickel-tungsten alloy formation, but the poor thermal contact between the boat and nickel charge resulted in excessive substrate heating.

An electron beam system was also used for bridge depositions. Aluminum e-beam deposits worked very well with good definition, thickness uniformity, and a minimum of substrate heating. Chromium deposits very well with good definition, thickness uniformity, and low substrate heating, but the films are of such high stress that film crazing occurs before adequate thickness can be attained. Nickel e-beam depositions were also made.

Both aluminum and nickel exhibit crazing when deposited onto polycarbonate to the thickness required for resistive bridge fabrication. Coatings of like thickness of nickel on glass do not craze and have sheet resistances in the desired 2 to 5 ohm/square mil range. Continuous films on the polycarbonate usually have resistances 10 to 30 percent higher than the source film on glass, so it is believed that had the nickel been continuous on polycarbonate, the resistance would have been acceptable. A photograph of the nickel bridge is shown in figure 11.

Figure 11. E-Beam Evaporated Nickel Bridge on
Polycarbonate (80X)

We were not able to attain resistivity in the 2 to 5 ohms/square resistance range with evaporated chromium on either polycarbonate or glass without crazing.

Film adhesion was fair to good with most materials tested. Substrate roughening improves adhesion, but care must be taken not to create steep-walled scratches that would result in film discontinuity.

E-beam nickel was evaporated at a fast and at a slow rate to resistivity, approximately 2 to 3 ohms/square. The substrates were polycarbonate having an abrasion resistant coating. Both methods result in a crazed film. The craze density is much lower than on bare polycarbonate, but it is quite distinct and uniform over the entire substrate.

Thirty RF sputter depositions, 14 thermal filament and bond depositions, and 7 thermal e-beam depositions were made (51 total depositions).

Resistance monitoring was added to the e-beam deposition system. The fixture used was fairly makeshift, but it did prove the feasibility of resistance monitoring. An improved monitor coupled with quartz crystal monitoring for rate and back-up thickness determination will give adequate deposition control.

Based on data gathered, the sputter deposition bridge fabrication technique was selected for initial evaluation. A photomask was used to form the bridge configuration shown in figure 12. This design is a 3 mil x 5 mil chromium bridge with gold over chromium electrodes. Bridge thickness is varied to arrive at the proper bridge resistance.

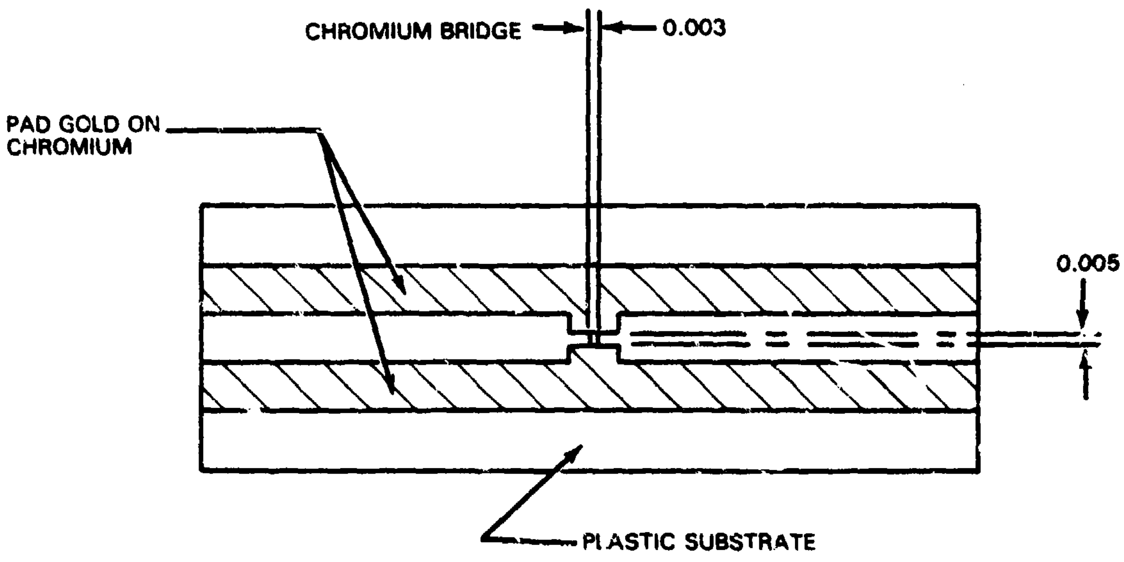


Figure 12. Thin Film Bridge Configuration

Other bridge concepts were reviewed for incorporation into the EBM. Thin film bridge used in the microdet (M100) detonator appeared feasible and could be a low cost bridge fabrication process. In the microdetonator, thin film on glass microelectronics process techniques are used for deposition of a highly reproducible resistance element. The microdetonator withstands the high setback and spin forces encountered in modern fuzes as well as the chemical and long-term storage environments typical of fuze requirements. It has a further advantage of being amenable to a solder/weld sealing process without degradation and to a nondestructive sorting technique for inspection without actual functioning of the unit. Microdetonator headers were procured and used in interim bolt evaluation tests and the field fired EBM tests. The molding of separate glass headers into a bridge assembly was not considered to be a cost effective approach for the EBM and was rejected.

2.3.3 Bridge Testing — Selected deposited bridge configurations were sent to R. Stresau Laboratory, Inc., for loading and initiation test. These were:

One Bridge Plate with evaporated bridge network
Two Charge and Bridge Plate assemblies
Two Polycarbonate Plates with 11 sputtered gold bridges.

The Bridge Plate had nickel bridges about 5 mil wide by 3 mil long with aluminum leads for electrical connection. Bridge resistance was as follows:

Bolt 1	38.3 ohms
Bolt 2	36.9 ohms
Bolt 3	infinite
M55 EED	44.3 ohms

The two Charge and Bridge Plate assemblies had the resistance shown in Table III, measured through pins pressed into the conductive elastomer as shown in figure 13.

TABLE III. CHARGE AND BRIDGE PLATE RESISTANCE

ASSEMBLY	RESISTANCE IN OHMS	
	PLATE C	PLATE D
Bolt 1	37.5	26.8
Bolt 2	40.7	103.0
Bolt 3	51.2	27.1
M55 EED	82.2	166.7

The resistance of the gold bridges averaged about 15 ohms.

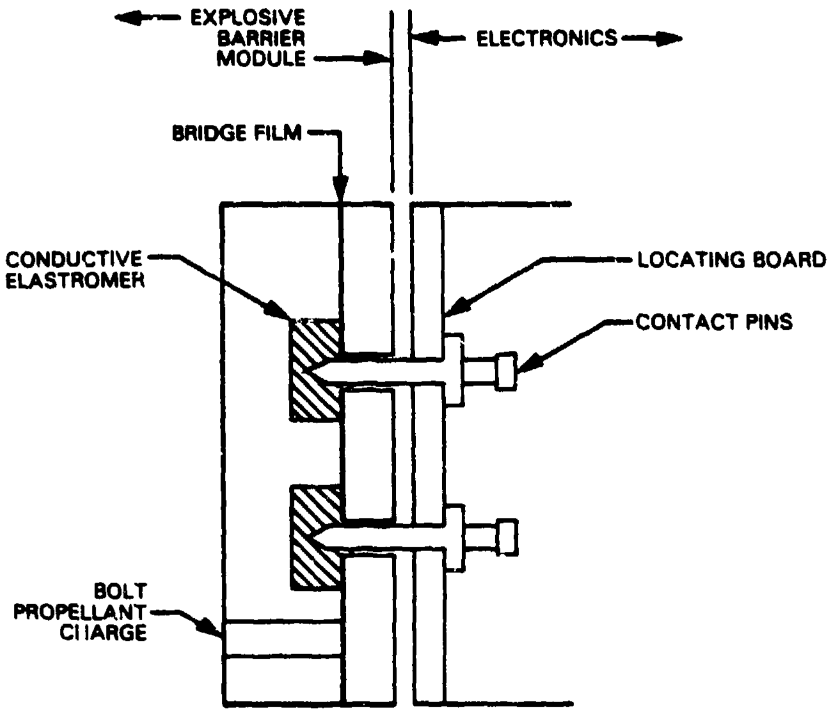


Figure 13. EBM Electronics Conductive Elastomer Connector

A dry-milled normal lead styphnate was pressed directly onto the bridge at 10,000 psi and tested as shown in table IV.

TABLE IV. BRIDGE SENSITIVITY

Dry-Milled Normal Lead Styphnate Pressed to 10,000 PSI

Bridge Resistance before Loading (ohms)	Bridge Resistance after Loading (ohms)	Test Voltage on 2.2 mFD Capacitor	Bridge Resistance After Testing (ohms)
7 to 12	19.6	7.9	16.6
		11.4	27.7
		15.2	bridge open
7 to 12	34.3	18.9	43.4
		23.9	30.0
		28.8	bridge open
7 to 12	22.3	36.8	20.3
		45.0	fired
7 to 12	22.4	36.8	14.0
		44.8	bridge open

The conclusion from these tests was that loading affected the bridges, therefore, initiation sensitivity data is inconclusive.

A second group was tested using a reduced propellant loading pressure of less than 1000 psi. The bridge sensitivity is shown in Table V. Bridge resistances changed less than 10 percent due to loading.

TABLE V. BRIDGE SENSITIVITY

Dry-Milled Normal Lead Styphnate Pressed to 1000 PSI

Bridge Resistance before Loading (ohms)	Bridge Resistance after Loading (ohms)	Test Voltage on 2.2 mFD Capacitor	Bridge Resistance After Testing (ohms)
7 to 12	7.9	7.9	6.8
		9.7	6.8
		13.4	6.8
		15.3	6.8
		19.0	6.1
		20.8	6.0
		24.4	bridge open
7 to 12	10.2	32.2	fired
7 to 12	11.0	16.3	fired
7 to 12	9.4	11.5	10.3
		15.3	bridge open
7 to 12	16.6	14.0	bridge open

The conclusion from these tests was that the sensitivity is not significantly different from that when the Normal Lead Styphnate spotting mix is applied directly to the bridge, and the reduced loading pressure does not affect the bridge resistance. Comparison of the sensitivity of the two bridge charging tests indicates there is not a spotting charge problem. The sensitivity is approximately 3000 ergs.

2.3.4 <u>Bridge Plate Redesign</u> — The initial bridge plate design was a Lexan polycarbonate plastic upon which printed wiring and a bridge would be applied through a vacuum deposition process. The bridge cross sectional area required to assure increase in temperature to the pyrotechnic ignition point using 500 ergs or less of energy resulted in a bridge so narrow and thin that it could not survive the stress of temperature changes due to the difference in coefficient of expansion of the bridge and the Lexan polycarbonate. This fabrication technique had been preferred as a low cost method. However, due to all the problems above, a more costly but functional method was selected using a g-10 glass epoxy printed wiring board and welded bridges.

ICI Americas provided Honeywell with a list of metals suitable for use with the capacitor discharge spot-welding process. After reviewing the ICI list of recommended materials, Type 301 stainless-steel was selected as the EBM weld pad material (see figure 14). Weldable bridge materials of Moleculoy wire (0.000295 inch diameter) and #851 platinum wire were considered compatible with printed wiring board conductor pattern spacing. Either of these bridge wires can be used to achieve the sensitivities required for 500 ergs initiation. The bridgewire length estimate for the selected wire (Moleculoy) was 0.006 inch. This was the minimum gap between conductor welding pads. Added length for the weld gave an effective wire length of 0.008 inches.

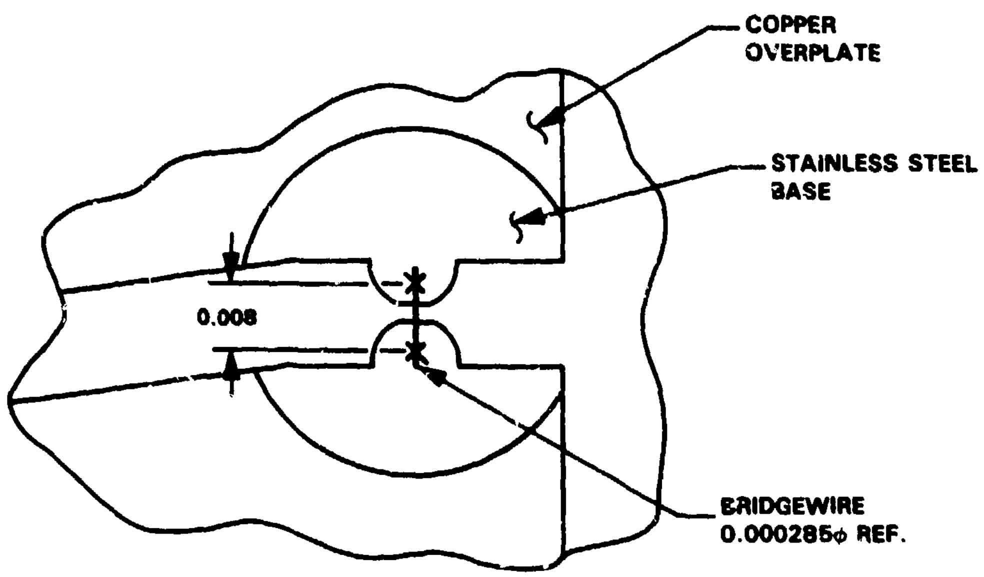


Figure 14. Circuit Board Bridgwire Design

An initial group of boards was fabricated in the Honeywell Printed Wiring Laboratory and sent to ICI for bridge welding. This task required that ICI weld four bridge wires on each of the thirty boards. Each weld area had the 301 stainless-steel pads etched in the four bridge wire circuit areas to span a 0.006 inch gap.

The welding was tedious and the weld quality which resulted was poor for two reasons.

- ICI employed a welding technique and used a fixture so each of the four individual circuits had a common welding ground. Contact to ground was made through the Augat Holtite pin connector in each section. As a result, the 0.0015 inch thick 301 stainless-steel foil presented a resistance path to ground which varied with each weld. This affected the weld energy and made it difficult to get uniform welding energy to each weld.

- There was a tendency to deform the stainless steel pad during the weld cycle. This caused an increase in the effective wire lengths and contributed to the poor weld quality. Due to these welding difficulties, the effective length of the wire was actually closer to 0.015 inch, and the average resistance was approximately 10 ohms after welding, rather than the desired goal of 6.0 ohms. The major cause for the problem seemed related to the thickness of the stainless-steel pad and its support on the phenolic board. The adhesive material directly under the steel seemed to melt at the weld, except at the minimum weld energy. This further affected the ability to make good welds of uniform quality.

These problems were solved by increasing the stainless-steel to 0.003 inch thick, firmly pressing the stainless-steel to the board to assure a flat area in which to weld, and applying a copper/solder overlay plating to within 0.1 inch of each bridge weld to conduct the weld energy uniformly to each weld. Welds were consistent thereafter, considering a single station laboratory process was used. Less than 10 of the welded bridges failed during loading, transportation, or subsequent ultrasonic staking or welding of the EBM.

2.3.5 <u>Propellant Charge Selection</u> -- Stresau Laboratory was contracted to do the initial explosive work. They suggested that the feasibility of using other, more generally available propellants be one of the first experimental efforts undertaken. Lead styphnate (both normal and basic) is widely used in ordnance and has many desirable properties. It had been suggested that lead styphnate might be too "brisant" for use as a propellant in this application. On the other hand, the brisance of lead styphnate is a function of particle size and loading density and thus is subject to control over a wide range by means of preparation and loading procedures. Barium styphnate, which is much less brisant, has been demonstrated to be suitable as a propellant in actuator applications. The need, regardless of the propellant to be used, is to acquire some first hand experience in the design, fabrication, loading, and testing of single bolt modules before the effort is expanded to complete modules. The evaluation of lead styphnates (or mixtures containing them) as propellants will require little effort if this commonly available material proves satisfactory. This would save both time and expense in demonstrating a workable module. Explosive compatibility testing between lead styphnate and polycarbonate and acetal plastics was evaluated by HDL and they were found compatible.

2.3.6 <u>Preliminary Propellant and Igniter Tests</u> -- A test circuit to discharge a 2.2 mf capacitor through a mercury switch into an explosive buttered header was set up in the Stresau Explosives Laboratory. The following explosive mixes were used:

- o Barium styphnate
- o Normal lead styphnate
- o Colloidol lead azide

The explosives were tested on the following type headers:

- o Microdet header with chromium bridge
- o Manganin bridge on Mylar film
- o Chromium bridge on header of size similar to MK71
- o Alfenol bridge on header of size similar to MK71

While none met the 500 erg all-fire conditions for the program, the microdet headers with normal lead styphnate were the closest to the requirements. These were used for additional testing involving single bolts.

Single bolt test assemblies were loaded and fired using the microdet headers bridged with chromium to further investigate the bolt propellant. A number of units were fired with the following highlights:

1. A unit with an additional charge of normal lead styphnate placed in a shallow hole in the cover plate near the interlock end of the bolt was functioned without initiation of the second charge (no crosstalk). This test was at -65°F. A similar test at +170°F resulted in undesirable initiation of the second charge (crosstalk). Visual examination of the test assemblies from these and other tests reported below found no charring, etc., outside the bolt cavity.

2. Results of preliminary testing of propellant quantity using normal lead styphnate are shown in table VI.

3. The locking mechanism did not lock the bolt in any of the tests.

4. A machined plastic shear pin was static tested in a bolt and it sheared at 15-16 lbs.

TABLE VI. PROPELLANT CHARGE

Temp. (°F)	3 mg Charge				4.5 mg Charge			
	Number of Bolts Tested	Did Not Shear Pin	Sheared Safe Pin	Sheared Pin and Bolt Moved	Number of Bolts Tested	Did Not Shear Pin	Sheared Safe Pin	Sheared Pin and Bolt Moved
Room	2	1	1	0	3	0	3	2
-65	1	1	0	0	2	0	2	1
+170	2	0	2	2	1	0	1	1

2.4 Electrical Connections

The initial design of the electrical connections integral to the EBM is that shown on figure 13. A conductive silver-filled silicone elastomer material manufactured by Chomerics, Inc., Woburn, Massachusetts, is compressed between the charge plate and the cover making contact with the thin film bridge electrode. Contact pins protruding from the S&A electronics connector circuit board will fit into holes on the EBM cover and contact the elastomer pads.

A fixture for evaluating the contact design was fabricated and tests were conducted. The contact test results showed continuity of 0.01 ohms or less over the temperature range of -65°F to +160°F. However, when the decision was made to use a printed wiring board instead of a sputtered conductor on plastic, the contact between the EBM side of the board and the pin side of the elastomer raised a question of reliability. The pin contact is pressing the elastomer away from the printed wiring conductor. HDL provided information on a small contact made by Augat Datex Inc. that can be automatically inserted into plated through-holes in a printed wiring board and a decision was made to use this contact. Board thickness of 0.125 inch was selected to use contacts in plated through-holes. The socket (female connector) is in the EBM and the pin (male connector) is in the mating electronics. The pin and socket provided the advantages of a proven design, spring pressure contact, a suitable method for high volume production, and gold to gold contact for good energy transfer to the bridge wire.

2.5 EBM Housing

The EBM Housing is designed to guide the pyrotechnic pressure output to the bolts by a fixed air volume. The fixed volume constrains the propellant charge output until the pressure on the bolt exceeds the shear strength of the bolt safe locking pin. At shear, the pressure is required to be in excess of 500 psi.

The housing is injection molded from polycarbonate acetal plastic. Wall thickness uniformity provides dimensional control, therefore, void areas are distributed to control thickness. The orientation to the charge plate is controlled by a single pin and the outer weld diameter of the housing. The weld area is designed to be flush on the internal mating surface of the charge plate interface. There is a no-flash groove around the periphery of the charge plate.

Welding is performed using a horn and ultrasonic energy. The weld horn cylinder directs the ultrasonic energy to the outer ring of the housing for welding. Mating of the interface surface between the charge plate and housing is critical because it must restrict gas leakage from the propellant charge during the bolt transfer process. Experiments show a gap of 0.012 inch can leak enough of the pressure to prevent the bolt pins from shearing. The weld area is designed to support a tensile load of 417 lbs.

The final water seal of the housing is made by pressing in the Lead Cup Assembly and covering with aluminum tape. The tape has a 0.125 inch diameter hole at the position where bolts 1 and 2 interlock. When locked in the safe condition, green shows through this hole. When bolt 3, which is red, has transferred into this area, the EBM is armed and shows through the hole.

2.6 Lead Charge Design

2.6.1 Lead Cup Assembly Testing -- The lead cup assembly contains PBXN-5 pressed into an aluminum cup. The output end of the lead was sealed with aluminum tape. The lead is required to be reliably initiated by the M55 detonator and provide an output dent of 0.040 inch deep minimum in a 2024-T4 aluminum witness block. Six reliability test assemblies per figure 15 were fabricated by Honeywell and were loaded and tested by Stresau Laboratories. All six assemblies were identical and had a propellant charge consisting of a normal lead styphnate "spotting" charge on the bridge wire followed by a "butterable" mixture of 75 percent by weight of colloidal lead azide and 25 percent aluminum powder (MIL-A-512 A, Type III, Grade F, Class 6). The 0.060 diameter by 0.080 inch deep charge hole was filled with the mixture.

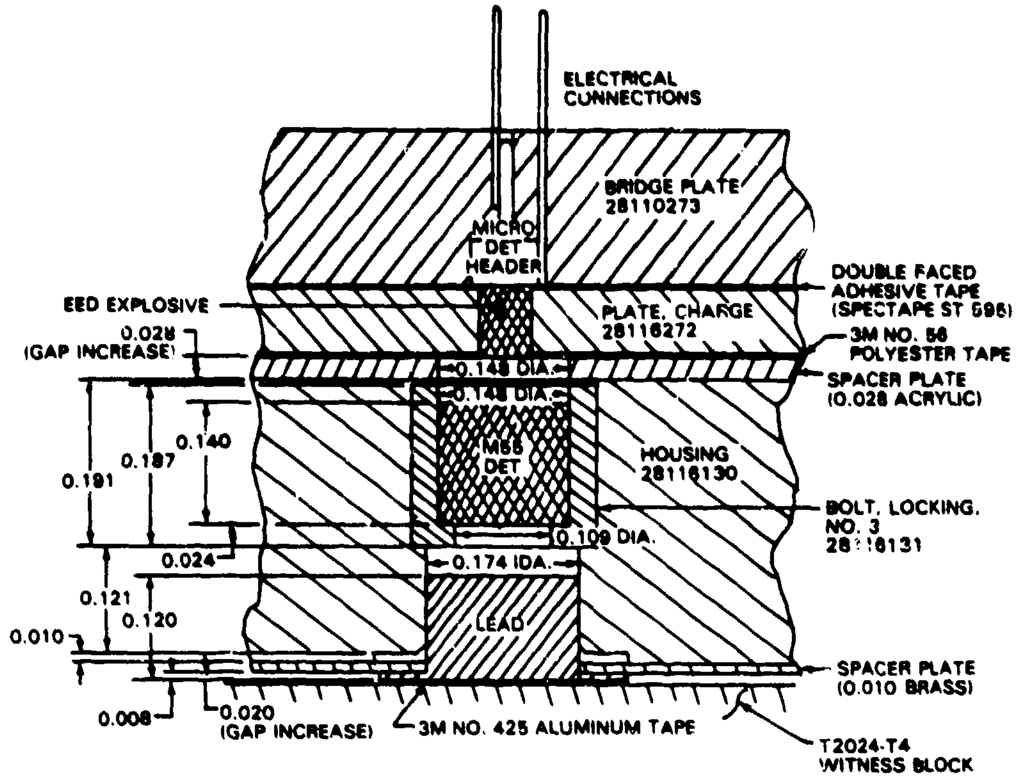


Figure 15. Explosive Output Reliability Test Assembly

The analysis which determined the configuration of the spacer plates is as follows:

EED to M55 nominal air gap

$= 0.191 - 0.024 - 0.140 = 0.027$ inch

Nominal EED output air volume

$$= \pi \frac{(0.148)^2}{4}(0.027) = 4.64 \times 10^{-4} \text{ cubic inch}$$

To double the air volume, an 0.027 inch thick spacer plate with a hole in the plate of 0.148 inch diameter was inserted.

To increase the air gap by 50 percent, the lead must be spaced an additional 0.017 inch minimum from the M55 detonator for a total of 0.050 inch.

Nominal M55 output air volume

$$= \frac{\pi}{4} (0.109)^2 + \frac{\pi}{4} (0.174)^2 (0.121 + 0.0[illegible] + 0.008 - 0.120)$$

$$= 9.13 \times 10^{-4} \text{ cu inch}$$

To double the air volume and maintain the 0.174 diameter lead hole, the lead must be spaced an additional $\frac{(9.13 \times 10^{-4})(4)}{(0.174)^2} = 0.038$ inches from the M55 Det.

The test procedure was as follows: The EBM test units with 2024-T4 aluminum witness block and a steel heat sink block approximately 3-inch diameter by 1.5 inch thick were placed in an environmental chamber at $-65^{\circ}\ ^{+0^{\circ}}_{-5^{\circ}}$F for a minimum of two hours. As a group, all items were removed from the environmental chamber and moved to a suitable firing chamber. Within 60 seconds of opening the environmental chamber, the propellant charge was initiated with a mercury switch and a 2.2 microfarad capacitor charged to 30 $\pm$ 10 volts. The depth of the dent in the witness block due to the explosive output was measured and recorded.

Six reliability test units were fired at -65°F. Four units propagated from the propellant to the leads with resultant witness block dents of 0.035 to 0.039 inch. Two failures occurred in the EED to M55 interface, indicating the need for an improved method of initiating the M55 Detonator other than direct charge.

Three lead cups loaded with PBXN-5 were fired into 2024-T4 aluminum witness blocks using an M55 detonator for initiation. Dents were 0.040 inch to 0.044 inch deep. Testing was at room temperature. These tests of the lead assembly demonstrated design requirements are met.

2.6.2 <u>Out of Line Safety Tests</u> — Tests were conducted using the test setup shown in figure 16. The objective of the test was to demonstrate that the out-of-line condition of the explosive train is safe and does not initiate the lead assembly. Offset distance of 0.050 inch did not initiate the lead or detonator when the propellant charge was initiated. The test also demonstrated the cantilever of the firing pin must be under the direct force of the pyrotechnic to initiate the M55 detonator.

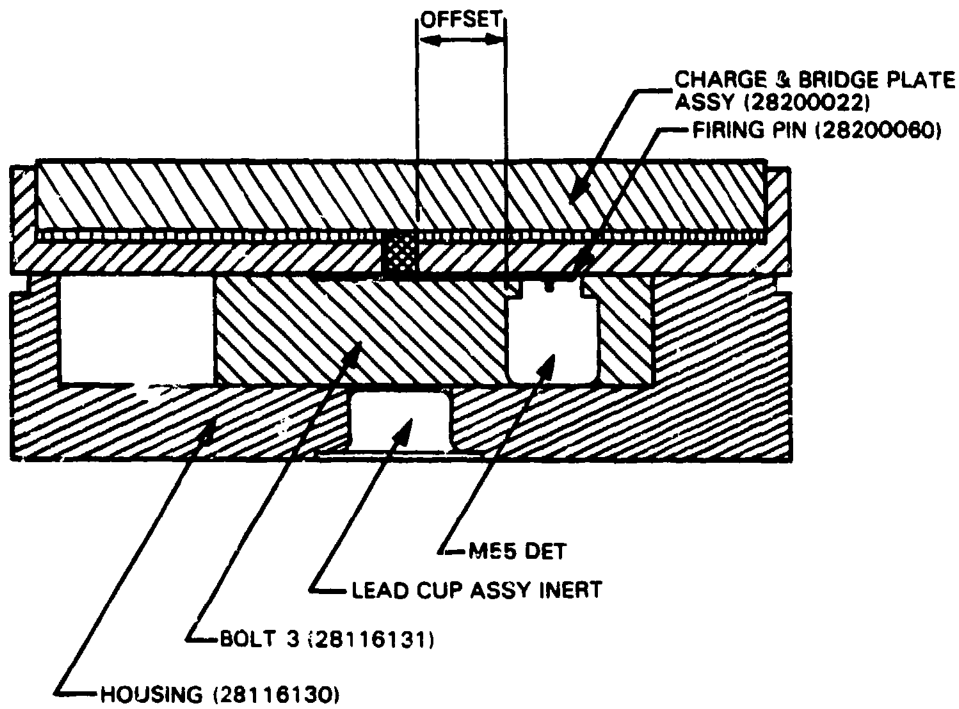


Figure 16. Sympathetic Detonation Test Setup,
Propellant to Detonator to Lead

2.7 Initial EBM Sequence Tests

Three units were fabricated for initial tests of the EBM firing sequence. Units contained 4.5 mg colloidal lead azide in the center charge and 4.5 mg of normal lead styphnate for the three bolt charges. All charge output holes were covered with 3 mil aluminum tape and tested at room temperature.

Unit #1
- Bolt 1 fired and locked
- Bolt 2 fired and locked
- Bolt 3 fired and locked
- Charge 4 had open bridge wire but fired with 1000 volt supply and initiated M55 detonator

Unit #2
- Bolt 1 fired and locked
- Bolt 2 fired but did not lock (locked manually to continue test)

Bolt 3 fired and locked
Charge 4 fired and initiated M55 detonator

Unit #5 Bolt 1 fired and locked
Bolt 2 fired and locked
Bolt 3 fired and locked
Charge 4 bridge still intact but no charge (believe charge fired due to crosstalk from firing charge #2)

The Mylar sheet used as an insulating gasket between the charge plate and the bridge plate does not provide a water tight seal and does not conform to prevent the explosive of one charge to the others. To effectively seal along the printed wiring edges, a silicone rubber gasket was designed to replace the Mylar sheet. The initial gaskets fabricated were about 55 durometer and, as tested in the Phase I, permitted explosive to crosstalk. It appeared the crosstalk could propagate along the edge of the printed wiring where the gasket did not adequately form into a seal, as shown in figure 17. The gasket was then fabricated using about 28 durometer silicone rubber and it did not completely resolve the problem. An alternate solution must be designed to resolve this problem. Molding the charge plate directly to the bridge plate may provide isolation and the seal.

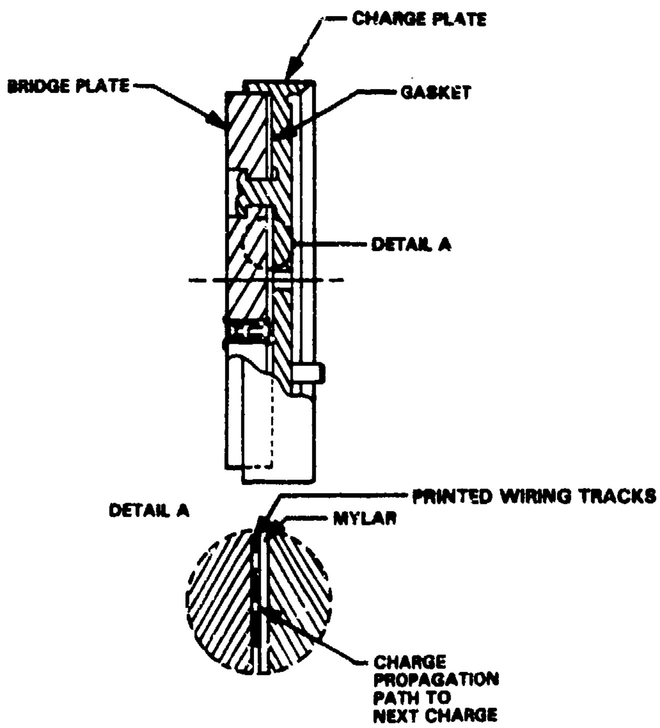


Figure 17. Charge Propagation Path

2.7.1 Phase I EBM Fabrication -- In April of 1980, the design of the EBM components was frozen so a group of EBMs could be fabricated and tested to determine if any design deficiency existed. These deficiencies could then be corrected prior to assembly of a larger quantity for Phase II which would be fabricated and tested.

Phase I construction included the 0.001 inch thick 301 stainless-steel welded bridge wire pads fabricated in the Honeywell Printed Wiring Lab. Contact pins were added by manually inserting into the plated through-holes provided. Normal lead styphnate was loaded into the holes provided in the charge plate.

Honeywell molded the sealing gaskets in the plastics laboratory and assembled the gasket, bridge plate, and charge plate using a single point ultrasonic welding process to stake the polycarbonate weld pins.

ICI Americas was subcontracted to weld bridge wires to the bridge plate. The 0.060 inch diameter charge plate hole volume was calculated to contain 4 to 4.5 milligrams of normal lead styphnate propellant when filled. The charge estimates were based on calculations from the spot charge applied to the microdet headers in previous tests which appeared to have the proper output. The dimensions and weight of spot charges of five samples of both lead styphnate and KDNBF drops are shown in table VII.

TABLE VII. SPOT CHARGE WEIGHT AND DIMENSIONS FOR FIVE SAMPLES

	Normal Lead Styphnate					KDNBF*				
Sample	1	2	3	4	5	1	2	3	4	5
Weight (grams)	4.5	4.4	3.5	4.5	4.2	2.0	1.7	2.2	1.7	1.8
Height (in.)	0.028	0.030	0.018	0.022	0.019	0.021	0.023	0.023	0.018	0.020
Diameter (in.)	0.140	0.130	0.130	0.130	0.120	0.120	0.125	0.130	0.120	0.125

*KDNBF drops are a slurry mix with 4 percent nitrocellulose lacquer. KDNF is an alternate propellant material.

The spot is assumed to be a segment of a sphere in which the height and diameter are known and the volume is computed. On this basis, an 0.060 inch diameter charge hole in the charge plate gives 4.2 milligrams of normal lead styphnate charge.

The amount of charge added to the EBM charge plate assembly at loading could not be measured by the usual means of weighing. This could be a problem as far as uniformity of weight was concerned. We were unable to make any tare weighing checks to determine the exact spot weight because the boards would not reach a constant weight at the temperatures used to cure the drops.

Apparently, there is a combination of effects here. Moisture pick-up is certainly a factor, and the materials of adhesion and the board materials themselves may lose weight independent of moisture absorption, through out-gassing of the plastics.

If variable drop sizes significantly affect output tests, more accurate spot weight checks can be run by drilling flat bottom holes in aluminum which are the same size as the charge plate hole sizes. These can then be precisely tare weighed.

The 0.060 inch diameter hole in the charge plate will be difficult to drop-load with a dispenser. If the hole is opened to 0.020 inch minimum diameter, it can then be made shallower to compensate for volume and should be easier to drop-load.

2.7.2 Phase I Tests — The Phase I test units included 30 EBMs loaded with normal lead styphnate and 5 EBM loaded with KDNBF. Of the 30 EBMs loaded with lead styphnate, satisfactory performance was demonstrated by 12 of 19 units tested. Four (4) of the 5 KDNBF units worked without crosstalk but with insufficient energy to lock the bolts.

Initial testing of ultrasonically welded units revealed that the explosive charges were breaking up and simultaneous initiation was occuring between the various EEDs. Eleven units of the original thirty were expended in determining a solution to this problem. Solutions investigated included: reduced weld duration, reversed weld direction, adding Mylar tape over the output ends of the EEDs, removing the silicone gasket between the charge and bridge plates and replacing it with an epoxy laminate, deleting the weld operation, and conformal coating (RTV 732 diluted with Hexane) of the EEDs. Of these techniques, the last two were selected for the actual test series.

One unit was subjected to high-speed (6000 ft/sec) photographic analysis. Data were taken on only two of the three bolts due to simultaneous initiation caused by insufficient compression loading of the silicone gasket between the bridge and charge plates. Data analysis of the films taken revealed that bolt 1 moved to the armed position in less than 0.340 msec and bolt 3 to its armed position in less than 0.333 msec. It was concluded that the various bolts would move to their armed position in less than 0.500 milliseconds.

Due to crosstalk, various degrees of arming existed on units 12A, 16A, 5A, and 7A. On unit 12A, the detonator was partially in line and capable of firing the lead. However, propellant charge 4 did not press the firing pin and initiate the detonator. On unit 5A, which did not contain a detonator, charges 2, 3, and 4 initiated simultaneously, but the unit remained in a safe condition. Unit 7A moved to a partially armed position because charges 1, 2, and 3 initiated simultaneously or with enough delay to shear and lock bolt 1, shear and move bolt 2, and shear and partially move bolt 3. With bolt 3 free to move due to spin, vibration, etc., the S&A could be armed by the first environment.

Of the numerous problems which surfaced during these tests, the most prominent was simultaneous initiation of the various EEDs, failure of the device in the fail-safe mode (firing out of sequence), bolt breakage and fracture of the EBM housing. All of these appear to be related to the high energy output from the EED; 4.5 mg of Stresau normal lead styphnate (which transferred the bolt properly in previous tests) does not have the energy of 4.5 mg of ICI normal lead styphnate which shattered the bolt. The charge must be specified by output so the manufacturer will adjust the grain size and mix to meet the proper output.

Most of these problems were not evident on the five EBMs loaded with the KDNBF. The KDNBF charge was about 2 mg as compared to the normal lead styphnate charge of 4.5 mg. The 2 mg of KDNBF would not transfer and lock the bolts at low temperature, but did at room and high temperature. Therefore, increasing the KDNBF charge or decreasing the normal lead styphnate to some value slightly above that of the KDNBF units would greatly enhance the performance of the EBM.

The detailed report of bridge resistances discussed in subsection 2.3 and individual EBM Phase I tests were sent to HDL. Evaluation of the test results showed several problem areas in which the design must be improved before building and testing of the next lot. These areas were as follows:

- If normal lead styphnate is used, the energy in each of the three charges which are used to drive the bolts into the armed and locked position must be reduced to prevent crosstalk, to prevent shearing of bolt interlocks, and to prevent damage to the housing. The KDNBF charged EBMs did not have these problems as the energy was much lower (too low, as all bolts did not lock in the armed position). The calculations on the weight of the charge, as recommended by the Stresau Labs report, checked very close to the 4.2 milligrams of lead styphnate. A task to "zero in" on the proper charge and establish an output test for verification must be included in the next build.

- Lacquer MIL-L-1028 type 1 was specified to seal the output end of the charge. The output from the first EED fired propagated across the charge plate and housing interface to all other charges. The lacquer is combustible and seems easily ignited.

- Ultrasonic welding of polycarbonate plastic applies a severe stress to the bridge wires and charge material. With good welded bridge wires there was no problem and the ultrasonic stress may be a good test to assure proper welds. A reduction of energy level and change in direction of the energy application along with a reduced time cycle resulted in good plastic flow and reduction in stress to the bridges.

Two units were subjected to MIL-STD-331, Test 101, Jolt. The EBMs were placed in the S&A cavity of an M739 fuze body for this test. Analysis of the units following the test revealed no breakup of the explosive charges, no movement of the bolts and no changes in the bridge wires. Both units were subsequently tested at +145°F. The results show no compromise in safety due to Jolt testing. One unit functioned successfully. One unit with KDNBF charges functioned successfully, except the bolts 2 and 3 did not lock and the M55 did not fire.

2.7.3 **Phase IA EBM Fabrication and Test** -- Phase IA was an additional group of EBM units tested because of the poor results of the Phase I tests. The EBM configuration for Phase IA was adjusted to prevent problem areas exposed in Phase I.

The charge material was changed to KDNBF. The charge plate hole diameter was increased from 0.060 to 0.091 inch; an increase in KDNBF by a factor of 2.2 when filled.

The lower density of the KDNBF compared with lead styphnate permits the hole to be filled and thereby prevents overcharge error. Tolerances are easier to control on the larger volume. Once the proper charge weight is established, mixes of other primer materials can be utilized as alternatives. Calculations of internal output pressure and loading on the bridge plate are shown in table VIII. These are based on ICI output pressure data of 750 psi into a volume of 0.25 cubic inch for a 4.5 milligram charge of KDNBF.

ICI computer program modeling for KDNBF shows 0.005 milliseconds to bring the 0.000285 inch diameter bridge wire to 775.1°F (initiation temperature) using the discharge of a 2.2 mf capacitor charged to 6.5 Vdc. Under the same conditions, the lead styphnate will require 0.015 milliseconds to reach 1069°F (initiation temperature). KDNBF has a MIL-P-50486 specification. However, most manufacturers take exception to it because of the length of testing involved to prove it to be an acceptable material. This makes the material proprietary to ICI.

Loading of the charge into a fixed volume provides some control of the charge energy. A variable which is not controlled is the charge density. The print should specify both minimum and maximum output energy as determined by test into a fixed volume and also specify peak pressure. Considerable testing should be done to establish the correct values required for a consistent and reliable source of energy to transfer the bolts. The charges may not be the same for bolts 1, 2, and 3 because the mass of the bolts and leakage around each is different.

Thirteen units were fabricated for testing to evaluate changes made to eliminate problems exposed in Phase I tests. These changes included:

- The pyrotechnic charge was changed to the less dense KDNBF.

TABLE VIII. CALCULATED OUTPUT PRESSURE

Concept	Volume (cu. in.)			Prorated Pressure PSI/0.025 (cu. in.)	Calculated Peak PSI	Bridge Plate Area (sq. in.)	Bridge Plate Load (lb.)
	KDNBF	Void	Total				
Present 0.090 inch dia/charge	0.00038	0.00177	0.00215	750	8720	0.00638	55.6
50/50 mix KDNBF/inert	0.00019	0.00177	0.00196	375	4783	0.00638	30.5
0.076 inch dia hole/charge	0.000272	0.00177	0.00204	469	5744	0.004533	26
Fill Present hole half full KDNBF	0.00019	0.00196	0.00215	375	4360	0.00638	27.8
Taper hole 0.060 inch at Bridge to 0.090 inch at output	0.000272	0.00177	0.00204	375	5744	0.002833	16.3

- Charge weight was increased (4.5 to 5.0 milligrams) and measurements showed that a 0.091 inch diameter hole will contain this new charge weight.

- Printed wiring board stainless steel cladding was increased from 0.001 to 0.003 inch thick for better welding electrode support. Copper plating covered with solder to within 0.1 inch of the weld was added to improve energy delivered to the weld area. The ground bus was routed to provide a barrier between charges by changing from separate ground for each bridge to common ground for all bridges. Two ground electrical connector pins were removed.

- The three-eared ultrasonic horn was used to stake the charge plate to the bridge plate assembly.

- The ultrasonic welder was used to weld the housing to the charge plate.

- The insulating gasket was modified to put a 0.004 inch thick raised ring around each of the charges.

- A thin coating of silicone rubber was applied to the charge output side to retain the charge material, eliminate crosstalk in the bolt area and not interfere with bolt action.

2.7.4 Phase IA Test Results -- The results of the Phase IA test units are discussed below:

The charges crosstalked along the gasket at -45°F in all cases except one, which had two screws added to clamp the bridge plate to the housing. This indicated the charge was too large for the free volume involved. Internal pressures were calculated to be greater than 8000 psi behind the bolt. The force separating the bridge plate from the charge plate was calculated to be 55.6 pounds. It is believed housing expansion due to the internal pressure caused the crosstalk. Calculation shows that the unsupported case will not stand the internal pressure and must be clamped with a force of approximately 50 pounds for testing. Push-off force for the three-stake weld of the bridge plate to the charge plate was measured on the Tinius and Olson tensile strength machine and was found to be insufficient to prevent separation of the charge plate and bridge plate with one 4.5-milligram pyrotechnic initiation.

Welding of the housing to the charge plate was controlled by setting the final height after welding to be equal to 0.504 to 0.508 inch. Practice weld units with final weld height of 0.515 had too much gas leakage across the interface between the housing and charge plate. The leakage does not permit the pressure against the bolt to shear the bolt pin or move the bolt to the armed position. Figure 18 shows screw clamping method, epoxy added to reinforce stake pin heads, and slot-modified gaskets used for venting over-pressure during the test of three additional units. One of three functioned properly when tested at room temperature with the clamping force and a vented gasket. New charge plates with 0.090 diameter charge holes were fabricated. Eleven EBMs were fired in the charge evaluation tests. The results show the following areas which, if incorporated, should improve the performance.

1. The 4.5 to 5.0 milligram charge as measured by ICI is too large. Pressures due to the large charge cannot be contained to prevent crosstalk. Pressure calculations for various possible charges are based on ICI data of 750 psi and a volume of 0.025 cubic inches, see table VIII.

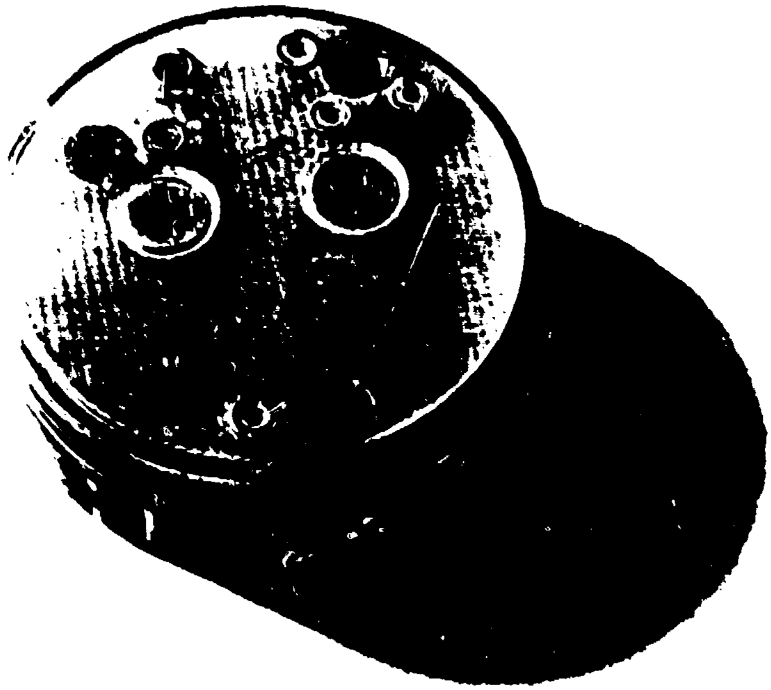
2. Staking the three pins on the charge plate requires a pushoff load of 54 pounds to separate bridge plate and charge plate. Calculated loads due to pressure of ignited propellant are shown in table VIII.

3. Set charge and bridge plate assembly weld to housing at 0.503 to 0.508 inch as measured from charge plate collar to housing bottom to minimize gas leakage at the interface. Dimensions greater than 0.514 inches will prevent bolt pin shear and bolt transfer with 4.5 to 5.0 milligrams of charge.

4. Set the staking height of the charge and bridge plate to 0.206 to 0.208 inch (as held by the fixture clamp) between the bridge plate epoxy glass surface and the charge plate output surface. Stake in position. This provides a good compression of the rubber gasket seal.

5. Test EBM units with 50 pounds compressional load to prevent expansion of the case during test.

a)



b)

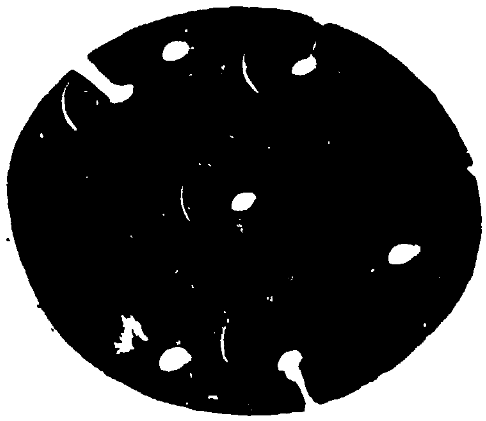


Figure 18. Screws Added (a) and Slotted Gasket (b) to Reduce Crosstalk

Applying these as guidelines, seven EBMs were loaded with a charge of 3.22 milligrams of KDNBF. The charge hole was adjusted to 0.071 inches diameter from the previous 0.090 inch diameter. These seven EBM units were tested to verify that the guidelines and reduced charge would assure bolt transfer without crosstalk. They were fired from a power supply at room temperature in the arming sequence of bolt 1, bolt 2, bolt 3 then charge 4. All charges in units 17A and 19A ignited when ultrasonic welding energy was applied. The friction of the ultrasonic scrubbing apparently ignited the charges. This was the first occurrence of this type of failure. At least 12 units were welded previously without ignition of the charge.

When the charge is loaded (by dropping) the excess is removed, using a squeegee, from the charge plate surface and the surface rinsed with alcohol. These units apparently were not sufficiently cleaned, especially in the corner where the weld energy takes place. A second cleaning with alcohol is done before sealing the charges with RTV. Even after sealing there must have been tracks of charge material leading from charge to charge under the seal as some crosstalk still occurred after a third cleaning was done with a cotton swab. Even after this third cleaning, the swab turned yellow, showing that charge material was still present on the charge plate surface.

The third unit fired (18A) ignited charge 1 and charge 2 at the same time, due to a wiring error. Bolt 1 sheared the lock pin, transferred to the armed position, and locked there. Bolt 2 was removed, the shear pin was cut off and the bolt set into the armed position. Charge 3 was initiated and charge 4 fired as a result of crosstalk. Charge 4 did not bend the firing pin and showed evidence of firing out of line, which it should do in this condition. Bolt 3 sheared the locking pin and transferred to the armed position.

A cotton swab and alcohol was used for an additional cleaning on remaining units to remove charge residue from the charge plate surface. A 3 mil Mylar tape was cut to fit the charge plate area which mated with the housing and was applied to the charge plate in an attempt to interrupt the crosstalk propagation along the charge plate surface.

The fourth unit fired (21A) failed to ignite charge 1 when 15 volts direct from the power supply was applied. The bridge plate burned open without ignition of the propellant charge. Bolt 1 was then manually moved to its armed position. Similarly, bolt 2 failed to ignite the charge, but the bridge burned open. Bolt 2 was manually moved to the armed position. Power supply voltage was increased to 40 volts. Charge 3 initiated and transferred bolt 3 to the armed and locked position. Charge 4 initiated properly, driving the firing pin in its proper sequence.

It should be pointed out that adding the 50 pounds compressional load will further compress the silicone rubber gasket between the charge plate and bridge plate. This can squeeze gasket material into the bridge wire area and may break or partially separate the weld between the bridge wire and the bridge plate. This can also disturb the intimate contact between the bridgewire and the charge material.

The fifth unit (22A) fired in sequence successfully even though bridgewire 4 had increased resistance from 11.7 ohms to 3000 ohms. In the sixth unit (23A), bolt 1 fired, sheared and moved to the armed position. Charge 2 ignition also fired 3 and 4 (crosstalk) under the Mylar tape, which stretched and bubbled. Bolt 2 sheared and moved to the armed position. Bolt 3 did not shear or move, and charge 4 fired out of line as it should do under this condition. The seventh unit (24A) was modified by making several holes 0.020 to 0.030 inch diameter in the Mylar tape at the charge locations. This was to further prevent crosstalk. The unit was fired successfully in sequence with no crosstalk. The resistance measurements made on the bridges are recorded in table IX.

2.8 EBM Assembly Process and Cost Estimate by Design Engineering

The assembly process for the EBM is depicted by the "gozinto" chart shown in figure 19. Cost estimates assume a fabrication rate of 10,000/month.

Bridge plate assembly is fabricated by normal printed wiring process. Care is necessary in not over etching the 0.006 inch gap for the bridge wire weld pressure support and in control of the connector spring contact plated through-holes. Connector spring contacts are automatically inserted by machine. Bridge wire welding is also automated. Estimated cost $1.33/PWB + $0.18 contacts + $0.35 bridges + $0.21 labor and inspection = $2.07.

The insulation gasket, charge plate, and bridge plate are automatically assembled and ultrasonic staked. Cost Estimated - Charge plate $0.05 + gasket $0.10 + $0.05 labor and inspection = $0.20.

TABLE IX. BRIDGE RESISTANCE HISTORY DATA

Serial #	BRIDGE RESISTANCE															
	After Welding				After Staking				After Dropping				At Start of Test			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
17A	9.0	10.3	10.3	11.6	9.1	10.3	10.3	11.7	9.1	10.3	10.3	11.7	9.8	Broken Bridge	Broken Bridge	12.8
18A	12.0	12.0	11.2	12.1	12.1	12.3	11.7	12.1	12.1	13.7	11.6	12.1	12.2	14.0	11.8	12.3
19A	10.8	9.6	11.7	9.8	10.9	12.9	12.3	9.9	10.7	13.0	Broken Bridge	9.9	Broken Bridge	14.7	Broken Bridge	10.6
21A	10.9	12.0	10.3	11.1	11.0	12.2	10.5	11.3	11.0	12.2	10.6	11.7	11.1	12.4	10.7	11.8
22A	9.6	11.3	11.0	9.1	9.6	11.4	11.2	9.2	9.6	11.4	11.2	9.1	9.7	11.6	11.3	9.3
23A	9.5	9.4	9.9	10.0	9.6	9.5	10.0	10.0	9.5	9.5	10.4	9.9	9.7	9.6	10.5	10.1
24A	10.8	10.6	11.8	9.6	10.9	10.7	11.9	9.7	10.9	10.7	11.9	9.7	11.0	10.8	12.0	9.7

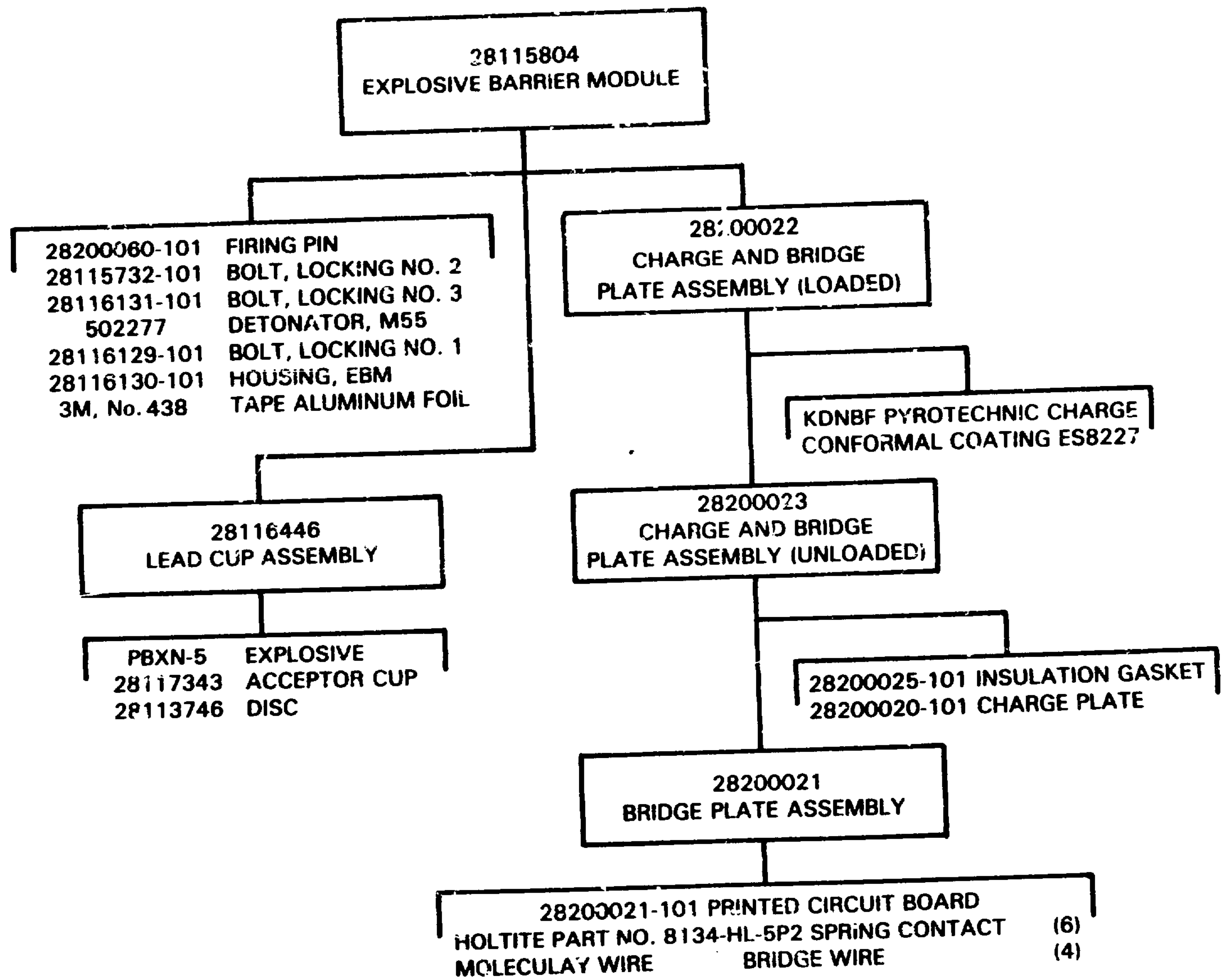


Figure 19. Fabrication Gozinto Chart

Add propellant charges by automatic dropping, cure and seal with coating and cure. Cost estimated $0.20 charges + $0.10 seal + $0.05 labor and inspect = $0.35. Charge and bridge plate assembly is completed.

Put stamped disk automatically into drawn acceptor cup and dispense PBXN-5 and press to fabricate lead cup assembly. Estimated cost disk $0.02 + acceptor cup $0.03 + PBXN-5 $0.10 + $0.03 labor and inspection = $0.18.

Injection mold bolts 1, 2, and 3. Injection mold housing, procure M55 detonators, and chemically machine (etch) firing pin. Assemble det into bolt 3 and into housing automatically with bolt 1 and 2. Bend and add firing pin. Estimated cost -- housing $0.07 + bolt 1 $0.02 + bolt 2 $0.02 + bolt 3 $0.03 + detonator $0.07 + firing pin $0.10 + $0.07 assembly and inspection = $0.38.

Weld charge and bridge plate assembly to loaded housing by ultrasonic weld. Press in lead cup assembly. Stamp aluminum foil tape roll, apply tape to housing bottom. Mark and identify. Estimate cost -- aluminum tape material $0.02 + ink $0.01 + $0.09 labor and inspection = $0.12.

Engineer estimate of EBM cost $3.30 for labor and material.

2.9 Recommended Improvements

1. Charge energy - must be further evaluated on the basis of:

   a. Increasing the volume at each bolt to adjust the energy - pressure levels.

   b. Adjusting the charge volume for each bolt using the charge plate hole size and shape of material.

2. Bridge wire cost - may be adjusted (decreased) by development of a uniform conductive mix which will contact the conductors on the bridge plate and become initiated due to its conductivity.

3. Make flatter parts to prevent gas leakage between the charge plate and housing, or redesign housing to make the charge plate and housing one part, then add a bottom cover.

4. Make the charge hole tapered to reduce the separation force between the bridge plate and charge plate with the small end of taper at the bridge wire and large end of taper at the output part. Since the charge tapers aft in the projectile, some method to retain the charge during setback must be implemented.

5. To add structural support to the center area of the bridge plate, add two stake pins from the housing through the charge plate, gasket and bridge plate. Stake the bridge plate end as the final assembly operation.

6. The polycarbonate stake pins lose strength rapidly as the temperature is increased. A material which will more nearly match the expansion of polycarbonate should be used for the bridge plate other than g-10 epoxy glass board.

7. Several EBM units that fired simultaneously or with very little time between charges were very close to an armed condition. A longer delay in unlocking the lock between bolts could be accomplished and prevent the condition. This could be done by adding extensions to the length of interlock so that bolt 1 would have to travel 0.1 inches before it unlocked bolt 2 (presently 0.02 inches are required). Then an extension could be added to bolt 2 to add an equivalent delay with bolt 3. The problem can also be addressed by making the pressure pulse shorter in duration by incorporating a blow out cavity or by using a different propellant.

3. ELECTRONIC CIRCUIT ELEMENT

The objective of this portion of the program was to design, build, and test a breadboard circuit that could be used to accept inputs from a power supply and environmental sensors, to provide safe separation delay time, and to fire the propellant charge initiators in the EBM element.

The circuit which was breadboarded and tested is shown in schematic diagram, figure 20. The electronic S&A system is shown in the block diagram of figure 21. Portions not

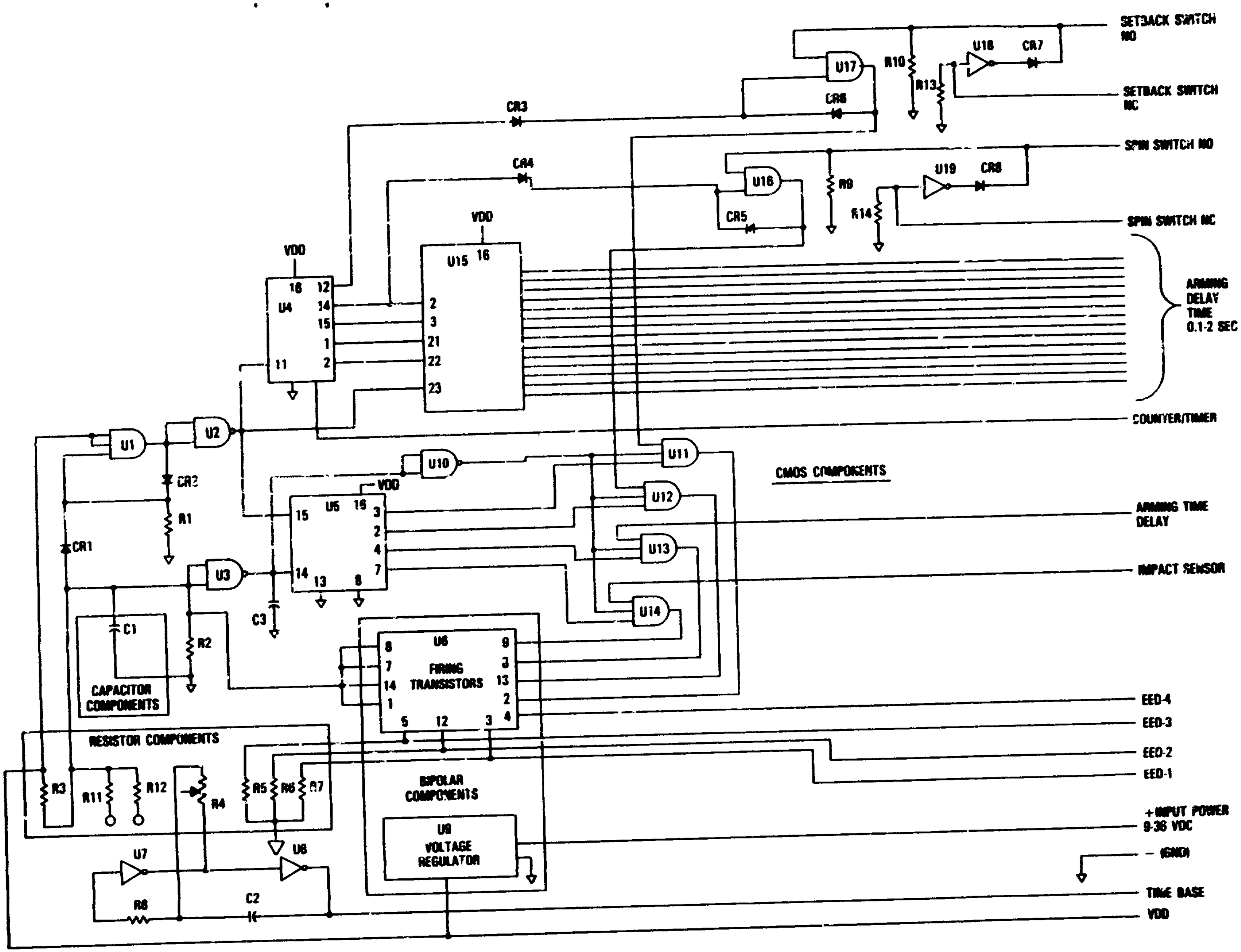


Figure 20. EBM Electronics Schematic Diagram

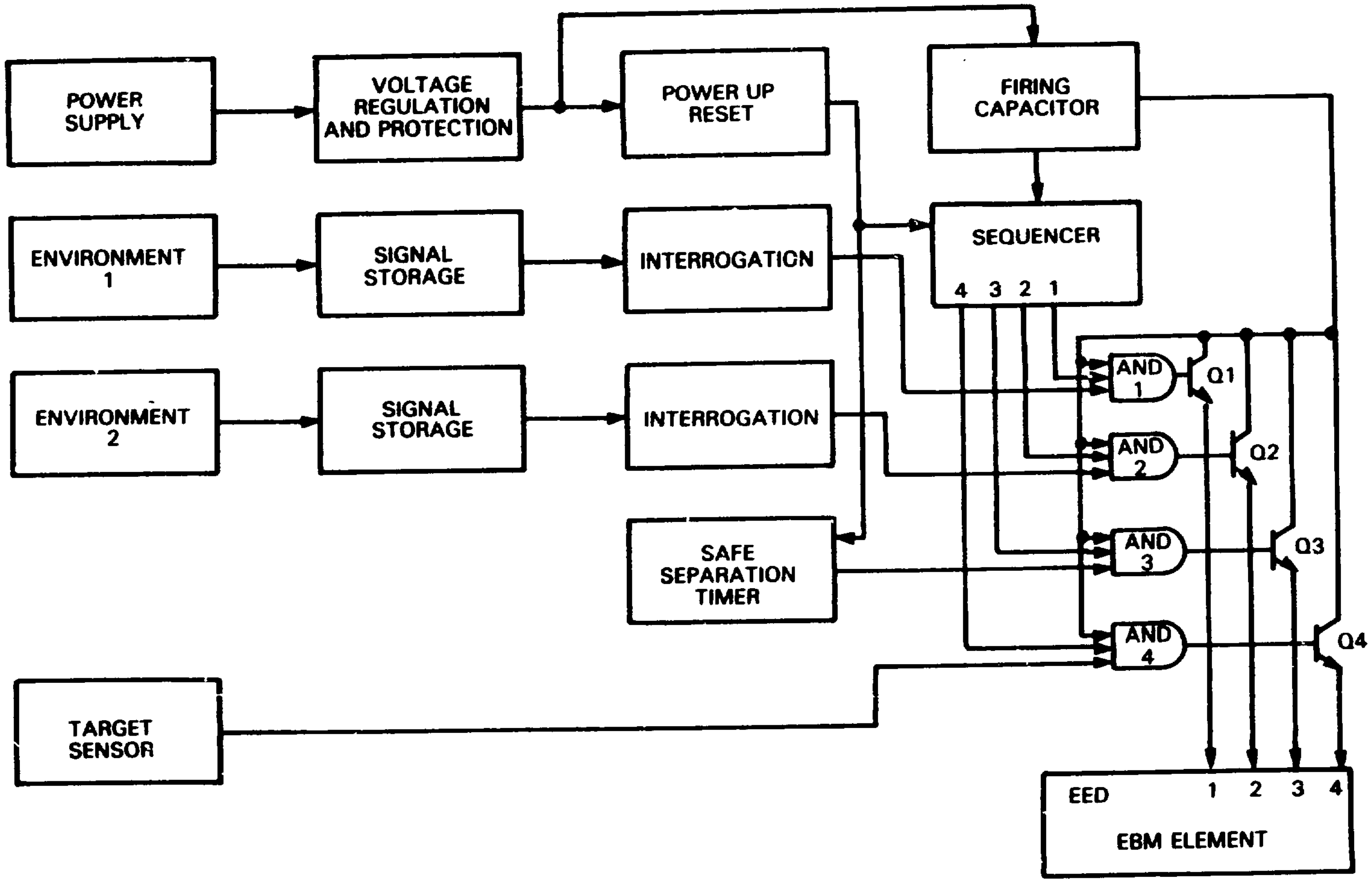


Figure 21. Electronic S&A Functional Block Diagram

included in the circuit diagram are the power supply, environment 1, environment 2, the two signal storages, target sensor and the EBM element. The remaining blocks are those included in the circuit.

3.1 Requirements for Electronic Circuit

The requirements for the electronic S&A circuit element were detailed in the specification. The principal requirements are summarized below:

1. The electronics must operate with a multitude of power supplies from 7 to 36 volts with activation time from 0 to 55 milliseconds delay.

2. The electronics should accept either switching high or switching low signals from a multitude of environment sensor types.

3. The electronics should not be affected by the known fuzing requirements for temperature, shock, storage, etc.

4. The electronics should be simple to assemble and contain four components or less within a small volume.

5. The electronics should be designed to fail in a safe condition and contain no single point failure modes.

6. Integrated-circuit digital technology that is of low cost and can be mass produced was the preferred design goal.

7. Application to a multitude of fuze systems was desirable, and a minimal interconnect change to modify to a new fuze application was required. Printed wire interconnect change was preferred; IC masking interconnect change was second preference and IC layout interconnect change was third choice.

8. To meet and adapt to a wide variety of fuze applications, the electronics should provide 0.2 to 2.0 seconds arming time in 0.1 second increments minimum.

9. The circuit should provide 3000 ergs initiation energy to fire EBM explosive energy devices in only one controlled sequence.

10. The electronics should be capable of being packaged within the diameter of the EBM and have a minimum thickness.

3.2 Operating Sequence

The sequence of operation is described with reference to figure 17 in terms of an electronic artillery projectile fuze. The power supply is a battery which is activated by setback forces of launch and completes activation in 50 milliseconds after setback. The first environment is an acceleration level and duration sensor. The second environment is a spin switch which closes at 1000 revolutions per minute and a launch safe separation time of one second provides launch safety. The target sensor is an impact switch. The events are listed in sequence as follows:

a. Setback acceleration initiates the power supply. It drives an acceleration sensor at a minimum of 600 g's for 4 milliseconds, after which environment 1 is completed.

b. Environment 1 signal is stored.

c. Spin velocity reaches 1000 revolutions per minute.

d. Environment 2 signal is stored.

e. At 50 milliseconds, battery voltage is available and is regulated.

f. At 50 milliseconds power reset occurs; starts the oscillator time base; starts the safe separation delay timer; sets sequence to 1 and places a high input to AND 1 of the sequencer.

g. From 50 milliseconds, interrogation of environment 1 signal is processed.

h. From 50 milliseconds, interrogation of environment 2 signal is processed.

i. At 60 milliseconds firing capacitor is charged to firing energy level and applies a 1 to AND 1 input.

j. At t_1 ($t_1 > 60$ milliseconds) from oscillator timer and satisfactory sensing of environment 1, the first two inputs are present at AND 1. Then the third AND 1 input turns on Q1, discharges firing capacitor into the EBM 1 EED, transfers bolt 1 from safe to the ARM position.

k. Discharge of the firing capacitor clocks the sequencer from 1 to 2, turns off AND 1, Q1 and provides the sequence input to AND 2.

l. With Q1 off, the firing capacitor charges to full energy level and provides an input to AND 2.

m. At time t_2 ($t_2 > 60$ ms + capacitor charge time) from the oscillator time and satisfactory sensing of environment 2, the first two inputs are present at AND 2. Then the third input to AND 2 turns on Q2, discharges firing capacitor into EBM 2 EED, transfers bolt 2 from safe to the arm position.

n. Discharge of the firing capacitor clocks the sequencer from 2 to 3, turns off AND 2, Q2, and provides the sequence input to AND 3.

o. With Q2 off, the firing capacitor charges to full energy level and provides an input to AND 3.

p. At one second safe separation time delay, the third input to AND 3 is high, turns on Q3, discharges firing capacitor into EBM 3 EED, transfers bolt 3 from safe to arm (placing detonator in-line with explosive train) and locked position.

q. Discharge of the firing capacitor clocks the sequencer from 3 to 4, turns off AND 3, Q3, and provides the sequence input to AND 4.

r. With Q3 off the firing capacitor charges to full energy level and provides an input to AND 4.

s. At target impact, the target sensor makes the third input high to AND 4, turns on Q4, discharges the firing capacitor into EBM 4 EED, drives the firing pin into the M55 detonator initiating the M55 detonator, initiating the lead explosive and initiating the warhead explosives.

The requirements for a single positive sequence of operation are commanded by the logic AND gates 1, 2, 3, and 4. First, the sequence is commanded to position 1 by the power-up reset. There must be a proper energy level available on the firing capacitor to fire the EBM EED and the environmental sensor must be satisfied before the first step in arming can be accomplished. Each step of the arming cycle checks to be certain the three elements are satisfied.

A functional flow diagram of the system is also shown in figure 22, which may be an aid to understanding the function of the EBM system.

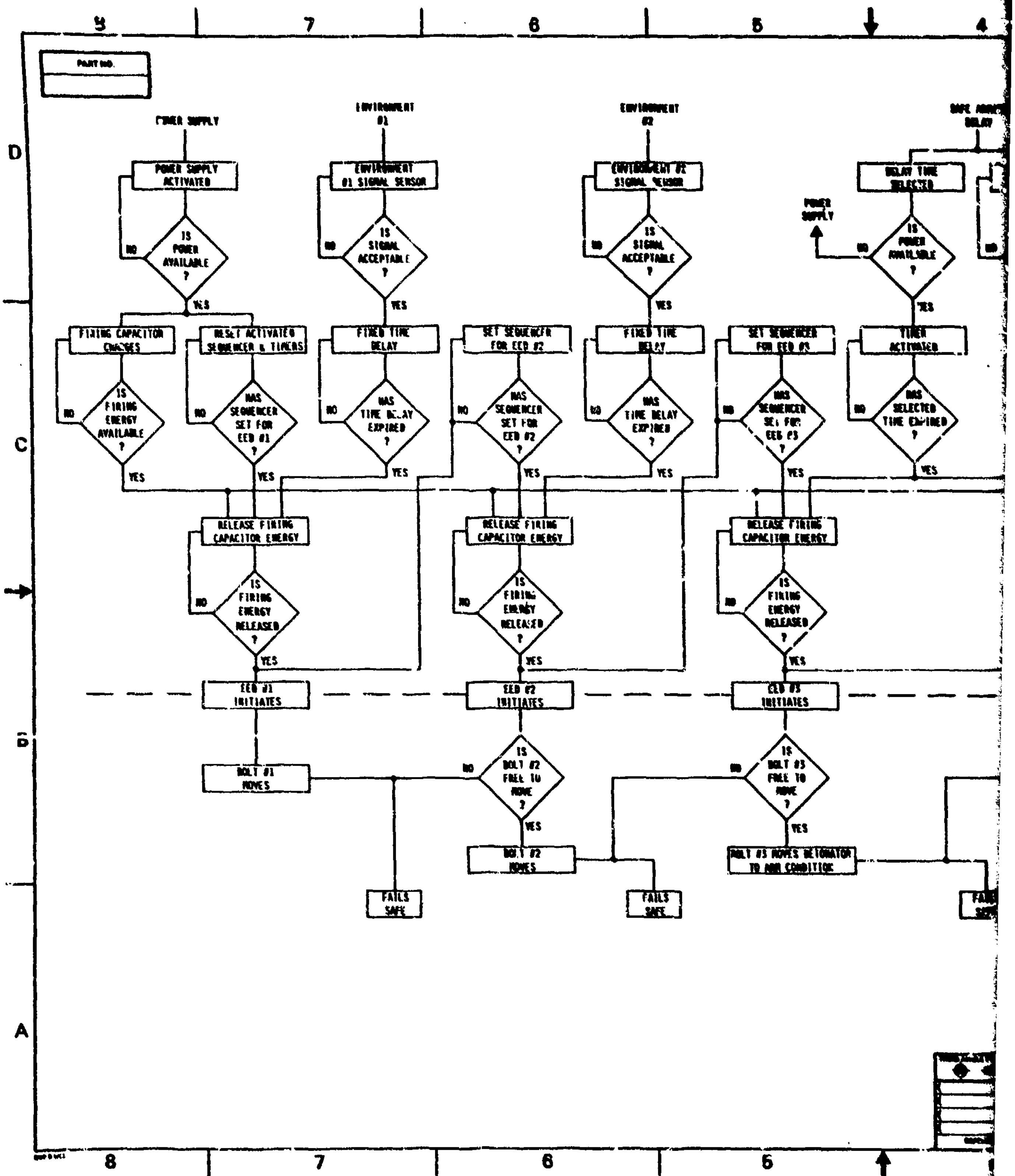
3.3 Breadboard Design

The S&A system consists of the EBM, the Electronic Circuit, and Sensors.

This section describes the breadboard electronic S&A circuit designed in accordance with the contract requirements. The discussion provides the circuit diagram, component partitioning and technology suitable for future preparation of a preliminary specification of a custom integrated circuit. Components of known technology were breadboarded and successfully tested through the functional requirements of sequence and temperature. The basic parameters of these discrete components can be combined to provide the preliminary requirements for the custom integrated circuit design. The conversion to an integrated circuit custom chip for future procurement can be accomplished from the schematic diagram.

A principal objective of the electronic S&A device is to achieve a wide application on various munition types. The EBM, as configured, could be electrically adapted to many fuzes. Physical limitations must be further examined.

Packaging concept is also included in this discussion. Packaging concepts to meet the 30,000 g requirement require not only solid state circuitry, but near solid packaging, with



PART NO.
POWER SUPPLY
POWER SUPPLY ACTIVATED
IS POWER AVAILABLE ?
NO
YES
FIRING CAPACITOR CHARGES
IS FIRING ENERGY AVAILABLE ?
RESET ACTIVATED SEQUENCER & TIMERS
HAS SEQUENCER SET FOR EED #1 ?
ENVIRONMENT #1
ENVIRONMENT #1 SIGNAL SENSOR
IS SIGNAL ACCEPTABLE ?
FIXED TIME DELAY
HAS TIME DELAY EXPIRED ?
SET SEQUENCER FOR EED #2
HAS SEQUENCER SET FOR EED #2 ?
ENVIRONMENT #2
ENVIRONMENT #2 SIGNAL SENSOR
SET SEQUENCER FOR EED #3
HAS SEQUENCER SET FOR EED #3 ?
POWER SUPPLY
DELAY TIME SELECTED
TIMER ACTIVATED
HAS SELECTED TIME EXPIRED ?
RELEASE FIRING CAPACITOR ENERGY
IS FIRING ENERGY RELEASED ?
EED #1 INITIATES
EED #2 INITIATES
EED #3 INITIATES
BOLT #1 MOVES
IS BOLT #2 FREE TO MOVE ?
BOLT #2 MOVES
IS BOLT #3 FREE TO MOVE ?
BOLT #3 MOVES DETONATOR TO ARM CONDITION
FAILS SAFE
D
C
B
A
8
7
6
5
4

The rev

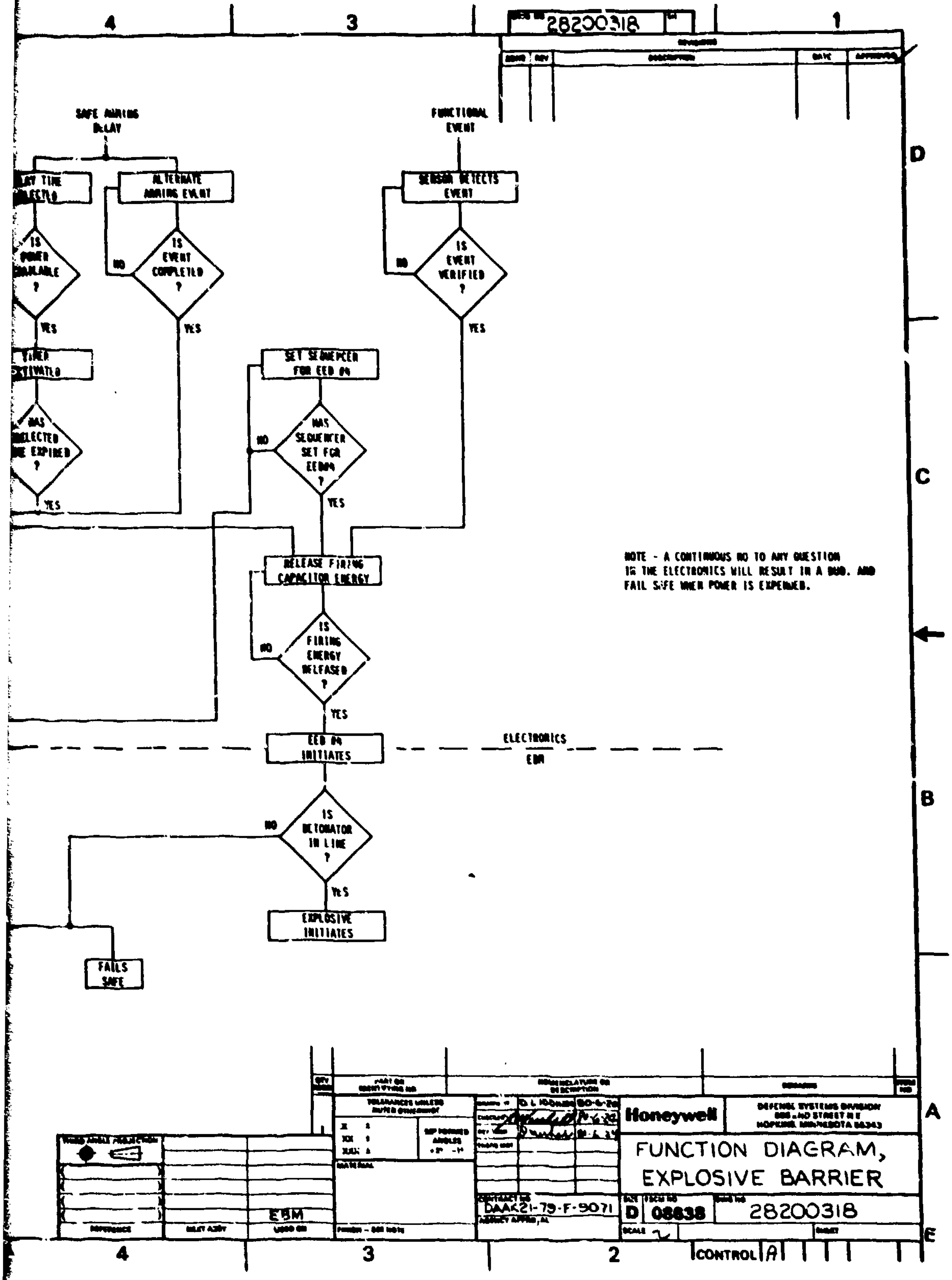


Figure 22. Functional Flow Diagra

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near uniform thermal coefficients of expansion of the materials involved. Solid state sensor elements are also required. However, not all applications will require the 30,000 g capability; therefore, only the S&A electronics should provide this feature to improve the potential for low cost for all possible applications.

3.3.1 Reliability and Safety -- The reliability of electronic timers and sequencers has improved with industry experience obtained using them in watches, calculators, and TV games. The electronic watch, for example, is virtually unaffected by everyday environments when worn or stored. When batteries are replaced, a single reset establishes the basic function and the accuracy is very good. These electronic watch features apply to the electronic S&A in both reliability and safety. They can be tested without wear or significant change in characteristic. The electronic S&A circuit in a discrete component assembly is expected to provide 99.99 percent reliability at 90 percent confidence and when integrated it should be greater.

Because the sequencing of the electronic S&A's three bolts is a predominant feature for assurance of safety, the criteria applicable to reliability also applies to safety. The single point failure mode problem does not exist because of the mechanical logic associated with the EBM. A three-way combination of firing energy, electronic sequencing, and EBM bolt sequencing also eliminates any possible dual failure mode. The use of shielded low power circuits and noise tolerant technology prevents the probability of the mythological spurious pulse causing a safety problem in the electronic S&A.

3.3.2 Packaging for Low Cost -- The circuit "design to cost" must include a relationship between the size, applicability, or usage, and the assembly technology available. No specific size requirements were applied to the contract; however, small size is interpreted to be equal to or less than the EBM element.

Discrete packaging of the available components, by automatic component insertion, into rigid printing wiring boards with wave soldering is the most cost-effective assembly method today. Size is the limitation in this technique and would not meet the requirements of this program. Shock requirements can also prevent the use of discrete component packages. One of the main cost reduction concepts is to minimize the component count.

Hybrid assembly places all components, complimentary metal oxide semiconductor (CMOS) chip, bipolar chip, and resistor network into one package. The capacitor could be in or out of the hybrid package, depending upon the volume available. The hybrid could be wire bonded for interconnection and provide opportunity for changes in different applications. The package is filled with a damping material for shock protection. The package is then connected by external means to the sensors, power or external selector switches by a convenient means. This method of assembly eliminates packaging cost of each individual discrete component and could meet the EBM requirements. The hybrid package increases the cost because it is not an automated assembly technique.

The third packaging method provides for integrated circuits with applied solder or gold bumps at the pad locations. The bumps are aligned to a flexible printed wiring film such as 70mm Kapton tape on reels. The integrated circuit chip is optically aligned and thermal-compression bonded to the printed wiring film at a rate in excess of 600 chips per hour. The bump location mask or the printed wire termination can be used to alter the function for each fuze application.

The assembled chips are encapsulated and film tabs are used to interconnect to the sensors and EBM. This technology is in use today and would be the preferred technology for low cost packaging.

3.3.3 <u>Power Supply Input</u> — The circuit is designed to include a bipolar regulator for power supply inputs up to 36 volts. The regulator limits the voltage on the circuit to 15 volts. The logic CMOS chip, which is powered by the regulated voltage, has failure modes which are predominantly due to insulation layer breakdown above 20 volts. The "B" (buffered) type CMOS is typically rated at 20 volts. The CMOS chip is analogous to the discrete components used and was of the "B" type CMOS. For voltages below 15 Vdc, the regulator is bypassed to conserve power. The breadboard circuit, as shown in figure 20, is functional to 6 Vdc and can be adjusted for operation to lower voltage, possibly 3 Vdc. The circuit, as designed, meets the contractual guideline of 9 to 18 Vdc with 20 percent undervoltage and overvoltage to 36 Vdc. Power up delay of 50 milliseconds does not cause a safety or reliability effect. It does add to the delay in arming, as 50 milliseconds is added to the first charge time of the firing capacitor.

3.3.4 Environmental Sensor Input — The electronic S&A is designed to receive two independent environmental input signals such as setback and spin, as shown in figure 20. The inputs are provided for signals which increase to the Vdd voltage or decrease from the Vdd voltage to ground when proper environments are sensed. Short-duration signals are stored in capacitors and maintain the signal level for a period until the electronics interrogates the sensor circuit. Thereafter, the sensor circuit may discharge or be removed. The sensor signals may be continuous and may be low power because the input circuits are high impedance. The electronic design is capable of input from any sensor provided the electrical signal requirements are met. The sensor must establish if the environment sensed is proper for safety or arming, and the electronics will process the signal to function the EBM accordingly. This is contrary to the contract guidelines, which recommend that the electronics be capable of distinguishing between the arm and safe sensor signal. A survey of fuzes shows a wide variety of sensor discrimination requirements. A trade-off study of the integrated CMOS component increased chip size, added pin outs, and chip testing costs versus the added discrimination features should be made. Several extra NAND gates would be helpful for uses such as frequency discrimination. However, discrimination techniques should be at the option of the particular fuze designer for his application and therefore be included as a part of the particular environmental sensor used.

Environmental signal "time windows" (t_1 and t_2) are automatically applied by the environmental sensor interrogation method. Environment 1 is interrogated at $t_1 = 50$ milliseconds after power-up reset. If the environment has occurred, EED 1 fires at t_1. If the environment 1 signal is input between 50 and 100 milliseconds, then EED 1 fires at the time of environment 1 signal input. If the environment 1 is input at 125 milliseconds, then EED 1 will fire at 150 milliseconds or the start of the next window. Of course, EED 2 cannot fire until EED 1 has sequenced by discharging the firing capacitor. A delay in arming occurs but no compromise of safety. The same interrogation window applies to EED 2, except the window is wider. However, the environment signal for EED 2 should be a continuous signal such as RPM spin or continuous frequency. Delay of environment 1 and 2 does not add to the arming delay because the arming delay is a decoded selected time period for a particular munition fuze.

3.3.5 Arming Delay — The electronic S&A provides a factory-settable, or the option of field setting of a fixed time delay between 0.2 and 2.0 seconds in 0.1 second increments for safe separation from the launcher. The timer times from the reset of the circuit at battery rise in voltage. The timer consists of a time base of a resistor and capacitor coupled to two CMOS inverters then connected to the digital binary counter, decoded to provide the time options. The time can be readily increased or decreased by changing the R in the circuit. A change of 10:1 in resistance to decrease time base frequency can be accomplished without a serious change in accuracy to yield a 2 to 20 second selection for arm delay. Actually, a thick film trim resistor could adjust the range in between in proportional increments.

A constant arming distance from launch can be achieved by the use of a revolution (spin) sensor. The revolution sensor is used in place of the time base. As the coil picks up the earth's magnetic field, a positive and a negative signal are generated for each revolution. A full wave rectifier provides two counts/revolution to the counter. The decode of the binary counter can be used to select the number of revolutions to environment 1, environment 2, or the safe arm distance in revolutions.

The arming delay output is used to initiate the EED 3 and place the detonator in line.

3.3.6 Firing Circuits — The electronic S&A provides power to fire each of the four EEDs in the EBM element. The four EEDs are fired in only one sequence using one firing capacitor controlled by four transistors. A circuit using one firing capacitor and one transistor was considered and rejected. A means of switching the energy through the sequence of the four EEDs was not feasible. The four transistors are integratable in a single bipolar chip, are easily controlled in both the "on" and "off" state by CMOS logic and have good energy transfer characteristics. A single capacitor is used to save space and lower component count.

3.3.7 Circuit Partitioning — Several parameters were considered in partitioning the electronic circuit into specific components. These are discussed in the following partitioning considerations:

a. **Three-Component Integration** - A maximum integration partitioning of the S&A electronics shown in figure 20 was discussed with CMOS chip designers at Honeywell. The level of integration into a three-component concept using CMOS at a high risk factor would divide into one capacitor component, one select resistor, and one CMOS mediumscale integrated circuit (MSI) measuring 0.1 x 0.1 inch. The high risk area is the regulator for the voltage above 18 volts. Typical CMOS oxide layers are limited to 20 volts without reliability breakdown; therefore, a special oxide layer for 36 volts is required. Firing transistors would be CMOS devices which require large area on the chip, and special design features must be applied to produce these large devices.

The three-component design was rejected because the maximum application voltage supply would be limited to 18 volts, and the firing transistors in CMOS technology were a high risk and high cost concept.

b. **Four Component Integration** - Partitioning of the EBM electronics shown in figure 20 was sorted into optimal components for breadboarding. The risk factor was minimal since each component group is in the discrete technology form. The four components, as shown in figure 23, are: (1) one capacitor component, (2) one thick film resistor component, (3) one bipolar integrated circuit component, and (4) one CMOS-MSI component.

This partitioning presents certain features which improve the fuze concept for a multi-application design. The capacitor component can be tailored to the energy needs, which depend on the minimum arming time, the power supply, and the final EBM energy needs. A reduction in size, both physical and capacitance, can be achieved at nigher voltage levels available on some applications. This also presents the opportunity to readily reduce the time of initiation between bolts because a smaller capacitor will charge faster with the same input resistor and thereby reduce the power supply peak load requirements. Optimum input voltage of a power supply would be just below the 15 volt level. At this condition, the regulator is still in the off state and will not require a regulation current bias. The 15 volts will permit the lowest capacitance and smallest size capacitor component.

The desired all-fire energy specified for each bridge wire is 500 ergs. The desired safety margin for the firing pulse is 3000 ergs. The overkill of 3000 ergs when 500 may do the job may not be cost effective. The transistors require larger silicon areas which directly affect cost and yield. The power supply peak currents are required to be higher to supply the higher energy, and the capacitor physical size increases as shown in table X.

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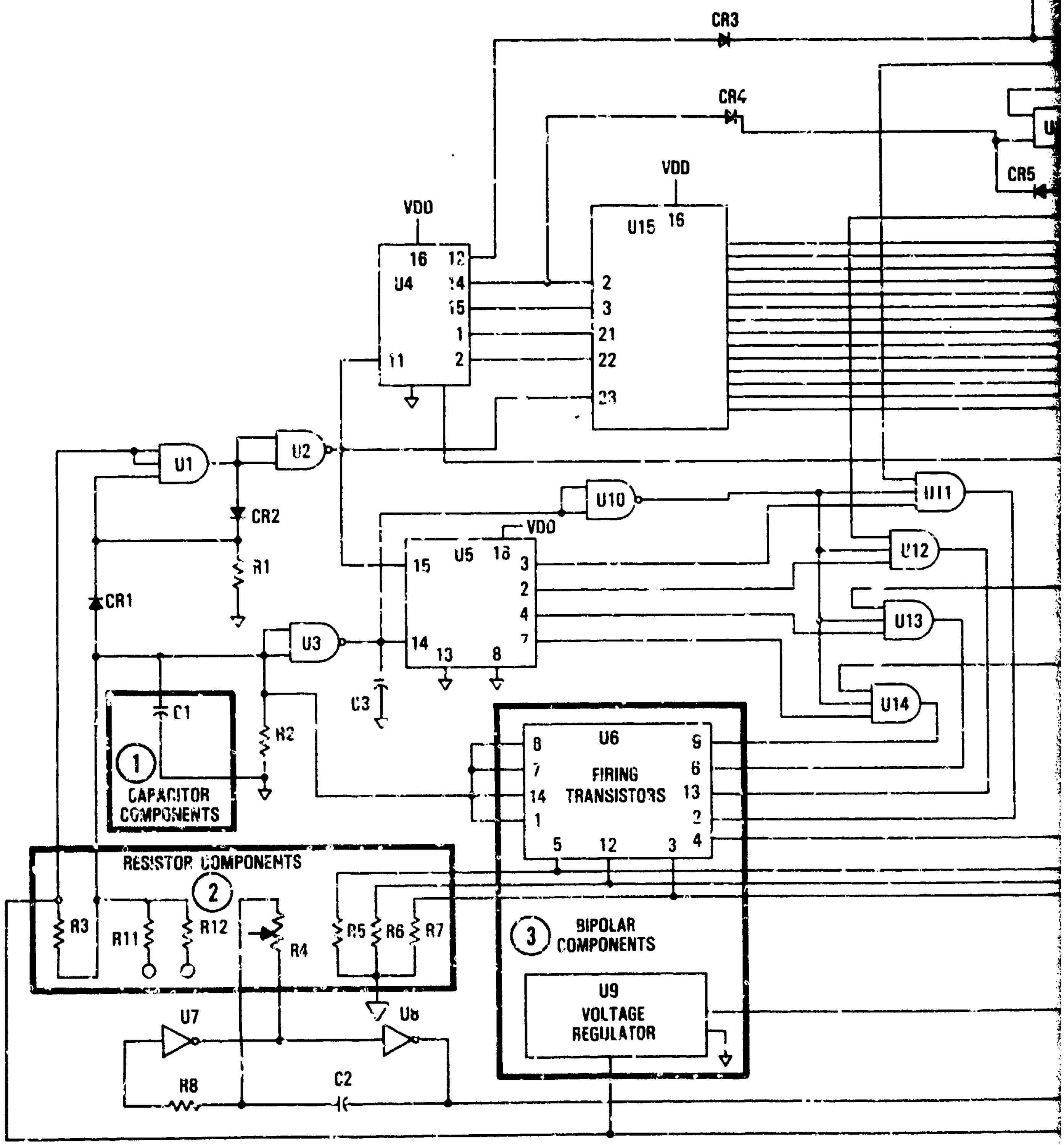

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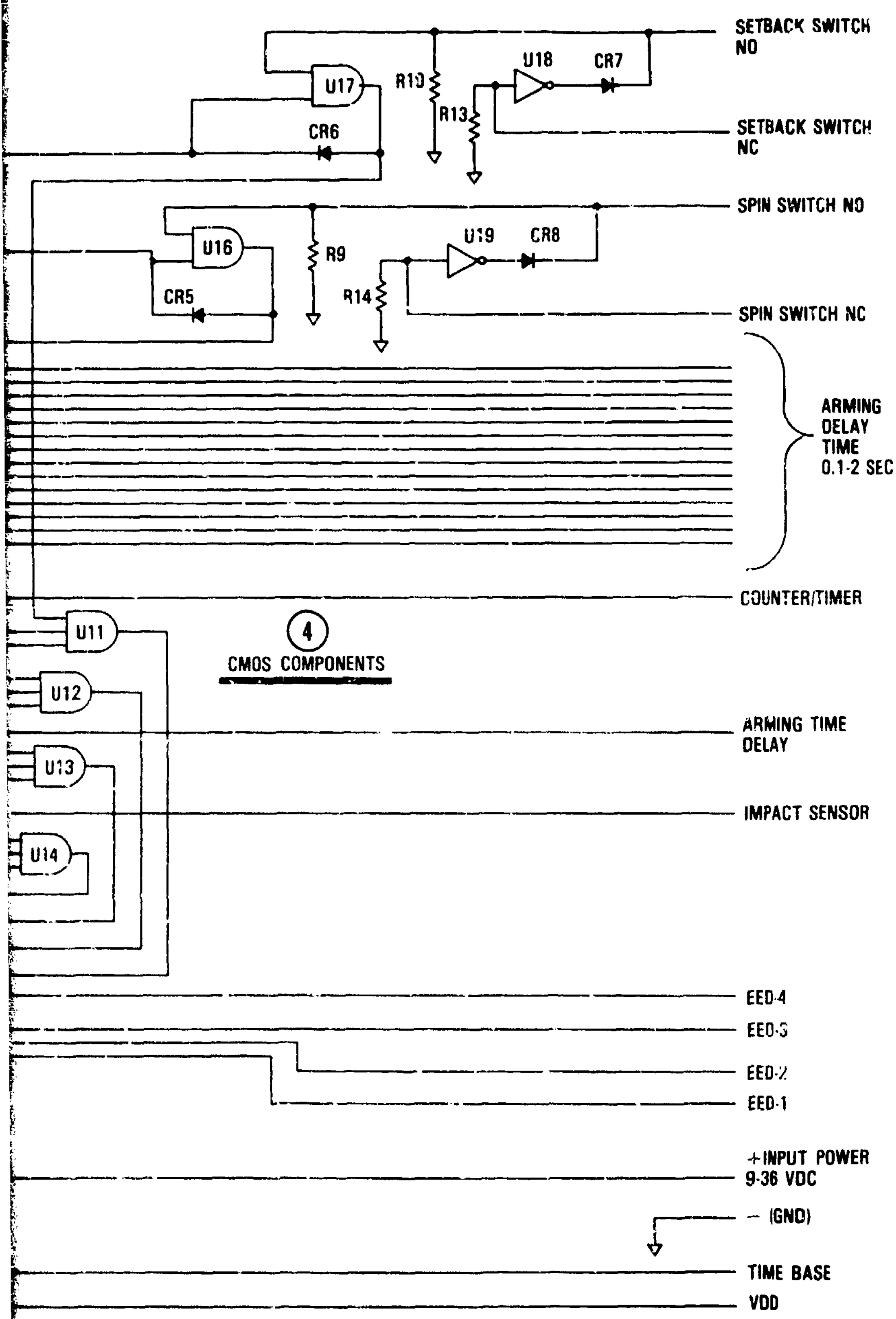

Figure 23. Partitioning for Four Component Assembly

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EBM energy all-fire	=	500 ergs
dissipated energy firing transistor	=	500 ergs
total switch + EBM	=	1000 ergs
leadwire + contacts	=	1000 ergs
total capacitor energy	=	2000 ergs

$$\text{Energy} = Q = \tfrac{1}{2}CV^2 \times 10^7 \text{ (ergs)}$$

$$\frac{2000 \times 2}{V^2 \times 10} = C \text{ in mf}$$

TABLE X. CAPACITOR SIZE FOR 500 ERG DETONATOR

Supply Voltage	Capacitance Req'd.	Case Size	MIL-C-39003-01
15 V	1.8 mf	B	-2361
10 V	4 mf	A	-2508
8 V	6 mf	B	-2303

Using the same logic with 3000 ergs required at the bridge wire, the increase in capacitor size is shown in table XI.

EBM energy all fire	=	3,000 ergs
Dissipated energy firing transistor	=	3,000 ergs
total switch + EBM	=	6,000 ergs
leadwire and contacts proportional to I	=	6,000 ergs
total capacitor energy	=	12,000 ergs

$$\text{Energy} = Q = \tfrac{1}{2}CV^2 \times 10^7 \text{ (ergs)}$$

$$\frac{12{,}000 \times 2}{V^2 \times 10} = C \text{ in mf}$$

TABLE XI. CAPACITOR SIZE FOR 3000 ERG DETONATOR

Supply Voltage	Capacitance Required	Case Size	M39003/01
15 V	10.6 mf	B	-2526
10 V	24 mf	B	-2511
8 V	37.5 mf	C	-2532

Reliability of initiation must be addressed with energy levels when the EBM bridge wire and electrical connection designs are completed, particularly if the lowest cost is to be achieved. The design of the transistor can be unique to yield high gain with fast turn on to take advantage of peak currents to the bridge wire for fast heating of the ignition charge. It is rare that a transistor is specifically designed to initiate propellant on capacitor discharge. Transistors are usually selected from the catalogue to obtain the best parameters available in package size.

3.3.8 <u>Application Adaptation</u> — Design of a specific fuze for a specific munition requires making some modification and/or selections. The first check requires physical size to be compatible with EBM and electronics. Only one size EBM was designed and packaged for exploratory development. The power supply must have available energy compatible with the electronic needs for life, activation time, safe separation delay, and internal impedance compatible with safe separation time.

The capacitor element and charging resistor is selected to provide the energy at the bolt firing sequence required for safe separation. One must determine safe separation time or the time to add to power up reset (time 0) and make the required mask change to bring out specific fixed time or, if selectable, bring out selected times to pin-outs. The oscillator or time base frequency must also be fixed at this time.

3.3.9 <u>Interconnections</u> — To fabricate a fuze, the assembly can be automated to prevent mal-assembly of component parts. Interconnections to the electronics and other components are discussed below.

The EBM circuit assembly operation begins in the factory where interconnections must be made for the particular fuze requirements and the environment sensed for safe launching and arming of the munition. The SETBACK SWITCH or first environment sensor connection for normally opening (NO) power or normally closing (NC) shall be made to the printed wiring. The SPIN SWITCH or second environment sensor connection for normally opening (NO) power or normally closing (NC) shall be made to the printed wiring board. Connect TIME BASE, a fixed period oscillator, to the COUNTER/TIMER and connect the ARMING DELAY TIME 0.1 to 2 sec time desired to the ARMING TIME DELAY.

The IMPACT SENSOR is connected to the circuit. This connection can be made to any function such as proximity sensor, time sensor, altimeter, impact sensor, or other electrical function which is desired to initiate the munition explosive train.

The five electrical connections are made to the EBM EED's 1 through 4 and a common ground return. These connections are part of the printed wiring board to prevent interchanging EEDs and possible alteration of the sequence by wiring errors.

Power supply connections are made at the factory and can be connected to the + INPUT POWER 9 to 36 Vdc which will regulate the input to 15 Vdc and the minus or ground connection. The ground connection is provided for all sensor circuits as well as the power supply. The regulator can be bypassed if a dc voltage power source is 3 to 15 Vdc by connecting to Vdd and ground. The Vdd terminal is available for sensor switching or to power other inputs of the logic circuit. Total loads should be kept below 100 milliamperes dc. Other high logic signals from outside sensors must be between 70 percent and 100 percent of Vdd. The low logic signals must be between 20 percent of Vdd max and -0.5 Vdc min.

3.3.10 Bipolar Integrated Circuit Component -- The construction of the bipolar integrated circuit is a single bipolar chip composed of four NPN firing transistors and the voltage regulator. A 14 pin-out chip would be adequate with firing transistor interconnections made on the chip. Resistance to limit CMOS base drive current is incorporated in the CMOS chip but must be a trade off with transistor gain. The transistor should be optimized for conducting the energy of the capacitor to the EED efficiently.

Flip chip process for connecting die to spider are recommended for mass production. Interconnections from the die to the spider are made using 1.5 mil aluminum wire. Aluminum wire provides good current carrying capability, strength and light weight to withstand high acceleration shock load. Double stitch bonding to the pads and spider are preferred. A ceramic DIP provides protection from moisture. Two pins of the 14 lead DIP can be used to conduct heat from the die to the copper on the printed wiring board. This is important for the cooling of the voltage regulator transistor.

3.3.11 Resistor Component — The resistor component is a thick or thin film resistor network with as few as 5 resistors, two of which are trimmable. One resistor will trim for time base frequency and one will trim to obtain EED/capacitor maximum initiation rate for close-in arming when necessary. The remaining three resistors at 100 ohm ± 30 percent are not critical; therefore, thick film is the preferred technology for lower cost. The resistors should be glass frit covered after trimming and packaged similar to the bipolar package to withstand acceleration shock and encapsulation for moisture protection.

3.3.12 Capacitor Component — The capacitor component is a discrete tantalum capacitor. Orange dipped epoxy coated capacitor is the preferred type for 30,000 g shock; however, these require hand insertion at assembly. Chip tantalum capacitors are available in the smaller capacitance values. These can be soldered directly to printed wiring paths.

3.3.13 CMOS Integrated Circuit Component — The CMOS component is a single MSI circuit die packaged similar to the bipolar chip. The base die size is estimated to be 100 x 100 mils. The die is packaged in a 36 pin package to make all connections available outside the package and at the printed wiring board. The package size is greatly reduced by connecting internal bonding pads for the particular munition design and reducing the pin count to a standard 16. This would provide for the optimum trade off of a standard die manufacture and test with maximum function selectability done in the packaging of the die.

3.4 Functional Safety Diagram

A functional and safety diagram was prepared using the electronic logic sequencing and the interlocking of the EBM bolts shown in figure 22. Safety numbers or reliability numbers have not been assigned to each function. The precise sequence of the electronics in itself will demonstrate a very safe fuze. The mechanical bolt interlock and the lock of each bolt with the safety pins add to the safety of the system. An additional sequence command, which has not been added, would require that each subsequent sequence could not operate unless environment 1 logic is satisfied, i.e., power to the environment 2 is provided by the output from environment 1. Safe separation logic is enabled by the output from environment 2.

Single point safety failure modes do not exist in the system. Activation of the power supply is essential to function and results in fail safe. Without the power supply, thermal ignition temperature of the EEDs is greater than 700^{o}F and is a very remote possibility. Friction due to vibration might cause ignition of the EED if the parts were not properly secured, but this has not been observed with regular detonators. The EEDs firing due to friction in the proper sequence is very remote; however, firing all EEDs at once requires very little delay to unlock the bolts in sequence since the charges move the bolt only 0.020 inch to uncouple the mechanical bolt 1 and bolt 2 interlock. An extension of the mechanical interlock between the bolts will reduce the probability of sequencing due to EED initiation simultaneously. Shorter pressure pulses will also minimize this potential problem.

3.5 Reliability

A specific reliability analysis was not conducted. The electronics portion in a single or multiple chip configuration can be tested and retested during assembly to assure high reliability and confidence.

Testing would be automated to reduce cost. The interconnection method using solder and printed wire would be a reliable economic method. The points which are least reliable in the system are considered the initiation of the EEDs and interconnection of the integrated circuit to the electrical circuit. This must be carefully considered due to the large number of connections.

Initiation of the EEDs using a heated bridge wire has been reliably accomplished in many fuze designs. Initiation of consecutive EEDs, each being exposed to the shock of the previous charge, may pose a problem in reliability. Stresses on the bridge wire and bridge wire weld are high. The bond between the bridge wire and charge must be retained.

The problems associated with crosstalk must be considered reliability problem areas. The EED charge volume, void volume, pressure and leakage around the bolt are interrelated with crosstalk. Solution to a combination of these concerns may result in a reliable transfer of the EBM bolts in sequence from safe to armed condition without detrimental effects.

4. TEST FUZE ASSEMBLY

The purpose of the test fuze assembly was to act as an EBM carrier vehicle during gunfire tests. The design of the test fuze was based on the structural hardware from the XM587E2 electronic time fuze. Contained within the XM587E2 structure was the EBM and the electronic element, and the environmental sensors. The EBM element was improvised with microdetonator headers in place of EEDs built onto the circuit board which were not yet designed or available.

4.1 Test Fuze Configuration

Several components of the XM587E2 fuze were modified for use in the test fuze. An identification of the modified components and a description of the changes is as follows:

Cup, Orientation and Cover, Electronics — A 30° slot was cut into each of these components to provide an opening for the eight wires which connect the S&A circuitry to the EBM.

Nose Plug, Electronics — Four through holes were added so that two wires could be looped from the circuitry, out the nose and back into the circuitry. One of these wires (black) provides a short across the spin switch so the circuit can be tested after potting.

The black wire is cut after final testing prior to gun firing. The other wire (red) connects the electronic S&A firing circuit to the power supply. When the red wire is cut, the power supply is disconnected from the fire circuit rendering the fuze safe for ordnance disposal.

Sleeve -- A 30° by 0.06 inch deep by 1.33 inch long slot was machined into the 1.507 inch ID to provide clearance around the battery for the 8 wires connecting the EBM element to the electronic S&A element. Also, a 1.37 inch diameter threaded hole was made in the sleeve base to allow access to the EBM after the test fuze is assembled.

In addition to the modification of XM587E2 fuze hardware, several new parts were fabricated including the following:

Cap, End — A 1.37 inch diamter x 0.225 inch thick threaded cap was fabricated to mate with the threaded hole in the sleeve base. The cap retains the fuze explosive output lead and has two 0.01 inch diameter holes which allow use of spanner wrench in torqueing the cap to the sleeve.

Bushing, Locating -- A 1.40 inch OD by 1.30 inch ID by 0.50 inch long bushing was fabricated to reduce the ID of the sleeve to that of the EBM element.

Tape, Foam. — Two double faced foam disks for each fuze were fabricated. One disk is applied to each end of the battery. The disks are compressed during fuze assembly to eliminate any possible "slop" in the assembly and to restrict the battery from spinning inside the fuze under gun launch environments.

4.2 Testing

Three partial fuze assemblies were fabricated for static tests. One test fuze assembly was subjected to Jolt, one unit to Jumble and one to 1.5m drop of the MIL-STD tests specified in section 3.1.1 of the Test Plan for EBM test fuze assembly. Following the MIL-STD tests the units were conditioned at +145°F and subjected to fail safe tests. The exact testing sequence and results are shown in table XII. The EBM EEDs were initiated

TABLE XII. TEST RESULTS FOR TEST FUZE ASSEMBLIES WITH EXTERNAL CONNECTIONS

JOLT UNIT

Firing Sequence (Note 1)	M55's EED 4	EED 1	EED 3	
Post Jolt EED Res. (ohms)	5.8	7.0	5.7	
Fire Time from Power On (milliseconds)	235	812	Note 2	

TEST RESULTS: No M55 initiation. No burning or charring of lead. M55's EED functioned. EED 1 functioned moving Bolt 1 to locked armed position. EED 2 did not function and Bolt 2 remained in safe position. EED 3 functioned and Bolt 3 moved 0.02 in. and sheared its retaining pin prior to being stopped by Bolt 2 interlock.

NOTE 1: EED 2 was intentionally not fired

NOTE 2: The electrical wiring to EED 3 became disconnected prior to firing so that EED 3 was not initially fired. EED 3 was subsequently fired several minutes after EED 1.

JUMBLE UNIT

Firing Sequence	EED 3	EED 1	EED 2	M55's EED 4
Post Jumble EED Res. (ohms)	6.3	5.5	5.4	5.4
Fire Time from Power on (milliseconds)	234	812	1234	1781

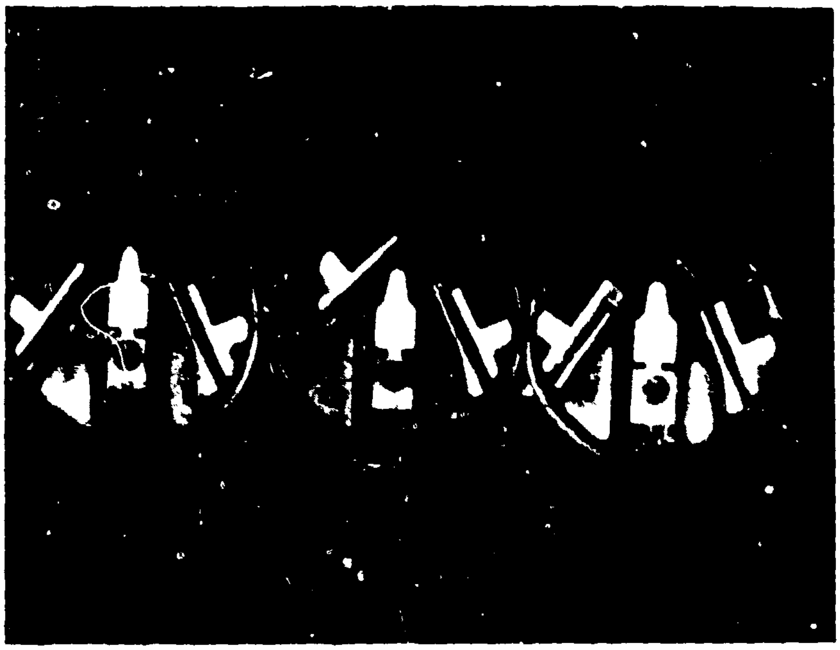
TEST RESULTS: No M55 initiation. No burning or charring of lead. EED 3 functioned. Bolt 3 retaining pin sheared and the bolt moved 0.08 in. but not into fully locked in armed position. EED 1 functioned and moved Bolt 1 to locked armed position. EED 2 functioned and moved Bolt 2 to locked armed position. The M55's EED 4 functioned and did not initiate the M55 detonator.

1.5m DROP UNIT

Firing Sequence	EED 2	EED 1	M55's EED 4
Post 1.5m Drop EED Res. (ohms)	6.0	6.2	6.0
Fire Time from Power On (milliseconds)	233	811	1246

TEST RESULTS: No M55 initiation. No burning or charring of lead. EED 2 functioned. Bolt 2 broke Bolt 1 interlock section and moved to locked armed position. EED 1 functioned and moved Bolt 1 to the locked armed position. The M55's EED 4 functioned and did not initiate the M55 detonator.

with the electronic S&A circuit. Figure 24 is a photograph taken of the 3 units immediately after test completion.



#6 JUMBLE #4 JOLT #1 1.5M

Figure 24. Post Test EBM Bolt Position

Several conclusions can be drawn from the test results shown in table XII.

1. Exposure of the test fuze assemblies to Jolt, Jumble and 1.5m drop environments prior to firing produced no functional or safety problems.

2. No "crosstalk" or sympathetic initiation between the EBM EEDs occurred. This indicated that the crosstalk problem experienced in early testing was solved by placing Mylar tape over the output ends of the EEDs.

3. No M55 initiation or burning of the EBM lead occurred. This indicates that the EBM remained out-of-line safe during the tests. It should be noted, however, that prior reliability testing without the firing pin has shown that the M55's EED has marginal M55 propagation characteristics, especially at low temperature. Therefore,

interpretation of the results of the out-of-line tests reported here will depend upon the final design of the M55's EED. A firing pin was not used in this early design.

4. The bolt interlock configuration is inadequate to retain the bolts in certain out of sequence firings. In the case of the Jolt unit, bolt 3 remained safe even though it moved slightly and sheared the bolt 3 pin because bolt 2 remained intact restraining bolt 3. The interlock between bolt 1 and 2 was too weak and the shear pin for bolt 3 should not shear when fired with bolt 1 and 2 in the safe position.

4.3 Fuze - Electronic S&A Device

A series of field tests were conducted to demonstrate that an electronic S&A device can be assembled, launched from a 105mm Howitzer and function the explosive barrier module to arm and fire a flash charge.

Six of ten test fuze assemblies having electronic circuits and environmental sensors were selected for field firing tests. Three of the six fired properly. Analysis of the failed units show anomalies in the improvised EBM. Three of the six units were recovered. Two of these had functioned properly. One which had been exposed to thermal shock before launch, failed. Epoxy had leaked into the EBM and prevented bolt 2 from moving. Of the three units which were not recovered, all had flash charges, and one flash charge was seen. Test conclusions were that the EBM concept appears feasible for use in artillery projectiles.

The test fuze assembly was designed to utilize the existing power supply from the XM587 fuze.

4.4 Test Fuze - Electronics Circuit Element

The safing and arming electronics concept for the test fuze was based on the block diagram shown in figure 25. The setback launch environment initiates the power supply. The power supply output is time integrated for 200 milliseconds to initiate EED 1 of the EBM. The power supply output is time integrated for 600 milliseconds and is ANDED with the Environment 2 spin RPM switch, then EED 2 of the EBM is initiated. The power

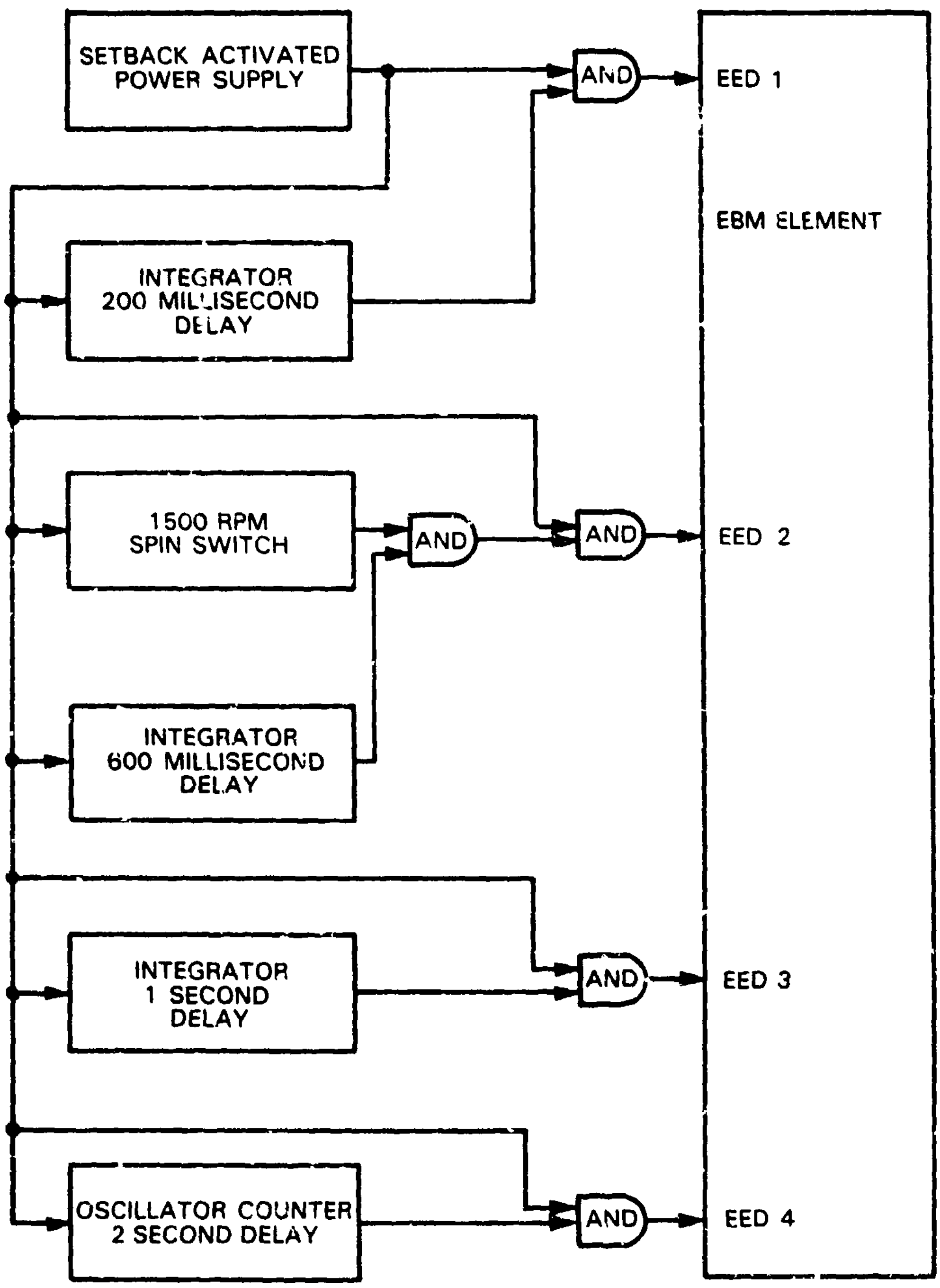


Figure 25. Test Fuze - Electronic S&A Device Block Diagram

supply output is time integrated for 1000 milliseconds for safe separation delay to initiate EED 3 of the EBM. The fuze is in the armed condition. The power supply is used to drive an oscillator time base which is counted to accumulate a period of two seconds to simulate an impact to initiate EED 4 of the EBM and the flash charge.

Implementation of the electronics to function the EBM is shown in the schematic diagram figure 26. The electronic S&A was demonstrated in the XM87E2 hardware, therefore, the battery and power supply printed wiring board assembly were utilized with only minor modification. The modification included a 10 volt regulator and inversion from negative to a positive output voltage. A test point is provided external to the fuze nose which can be used to power the electronics externally and monitor the EBM EED contacts without initiating the battery and firing the EBM EEDs. This wire is also used to provide a safe means of disconnecting the environmental power supply from the explosive components. Cutting the red wire will provide a safe explosive ordnance disposal method.

The timers for arming are one shot resistor/capacitor integrating type. The time of integration is added to the battery activation time to achieve a timed sequence to the EBM element. The firing capacitors are charged at minimum rates to minimize the load on the power supply. The firing capacitor charging circuit is controlled by resistors R5, R7, R8 and R11, as shown in schematic diagram, figure 26. Firing transistors Q1 through Q4 are base current limited to minimize power supply load current. Diodes CR9 through CR12 isolate the ground return paths and prevent crosstalk between the bolt driver firing circuits. Unused portions of the CMOS IC's are electrically connected to ground to eliminate power supply drain due to floating gates.

The electronic S&A presented in the test fuze is one method of testing the EBM component in a fuze. This early design for the test fuze should not be construed as an optimum electronic S&A designed for highest reliability, safety, performance and minimal cost.

4.5 Breadboard Electronics for Test Fuze Assembly

One complete breadboard was assembled and tested using the printed wiring boards. The breadboard was assembled on these specific configurations to verify the electrical layout,

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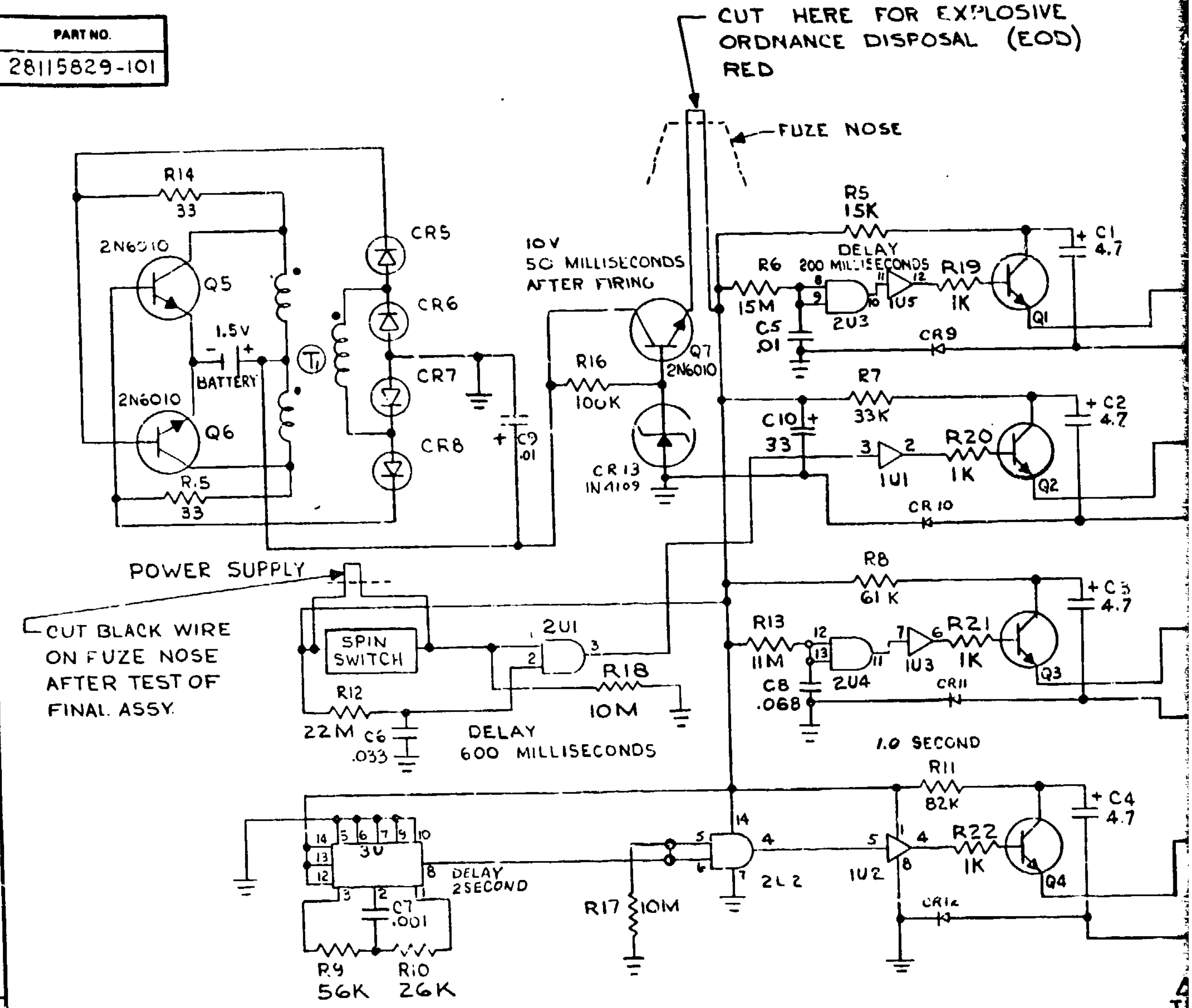
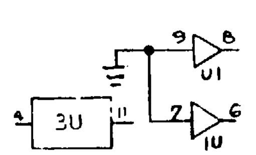
28115829-101



∠- NO'S REFER TO PIN & WIRE NO'S ON 28116424, CONN BD ASSY

UNUSED I.C.s



REF	TYPE
1U	CD4050BE
2U	CD4081BE
3U	MC14541 BAP
CR1 CR12	1N645-1
Q1-Q4	JAN2N2222A

QTY REQD	PART OR IDENTIFYING NO

THIRD ANGLE PROJECTION

TOLERANCES UNLESS NOTED OTHERWISE: X ± XX ± XXX ±

MATERIAL

FINISH — SEE NOTE

REFERENCE	NEXT ASSY	USED ON
28116391	—	EBM

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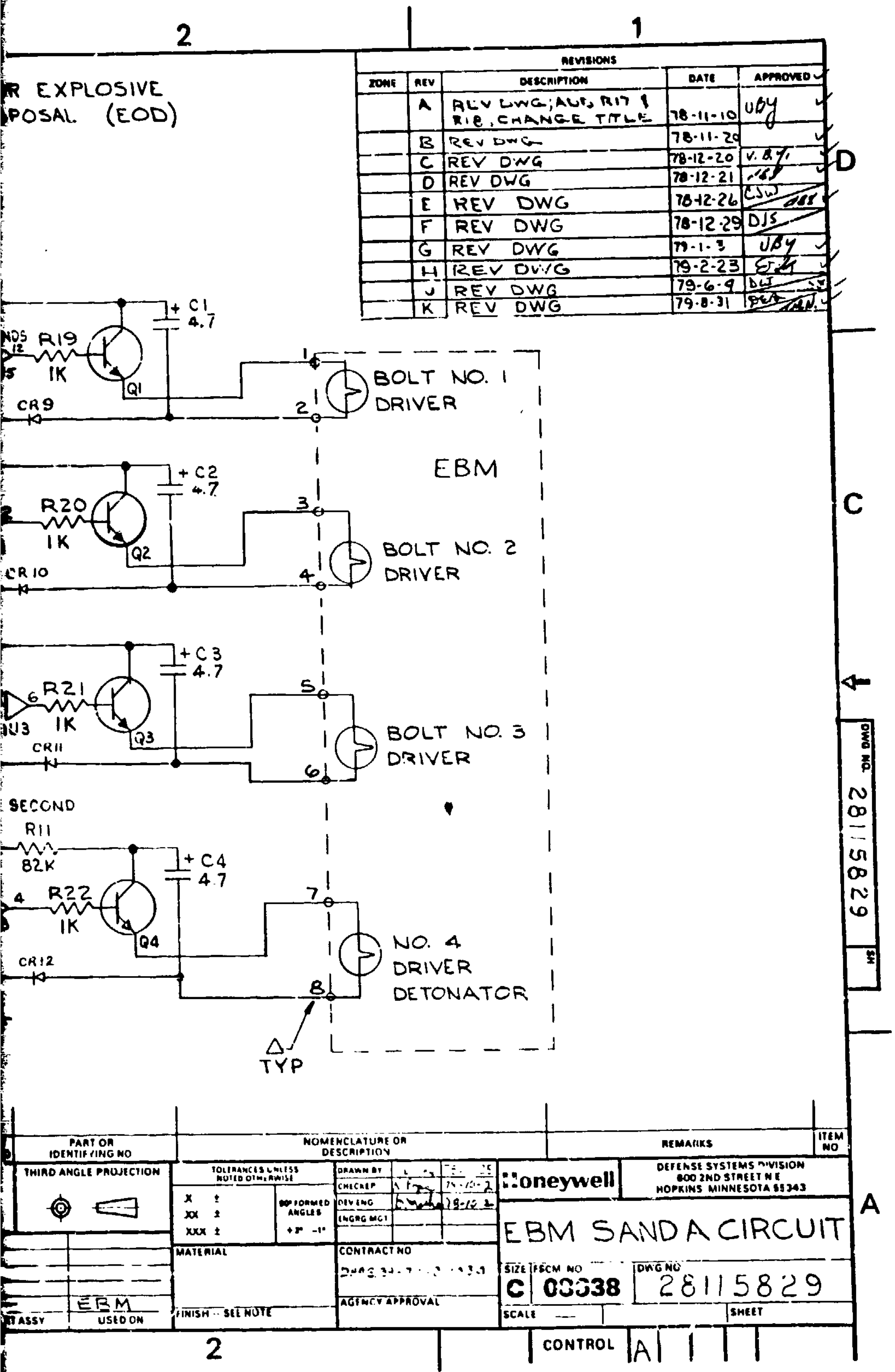

Figure 26. Electronic S&A Device Schematic

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the parts mount on the boards and that the function of the circuit was as designed. The data recorded is as follows:

Power is obtained from a 1.5Vdc power supply in lieu of the battery.

- Output voltage at the regulator 9 volts
- Input current at minimum load 300 ma
- Input current at max load 500 ma
- DC to DC converter frequency 50 KHz

The power was switched directly with no rise time. The battery rise time will be from 10 to 50 milliseconds and is added to the function time of EED signal output time out. The data for each EED is:

EED 1 - 195 ms output with 8.5V peak voltage
EED 2 - 550 ms output with 8.0V peak voltage
EED 3 - 1010 ms output with 8.0V peak voltage
EED 4 - 1950 ms output with 8.0V peak voltage
The 2 second time base frequency was 17,241 Hz.

Test fuze assembly electronics were fabricated and tested with battery power supplies. Timing of the sequence was tested and data was taken twice on each assembly shown in Table XIII.

The peak output voltage was measured across a 10 ohm resistor used in place of the EEDs. The final electronic S&A device assemblies were tested for firing energy using micro-detonators in place of the EBM element. Three units were tested, one each at -45°F, +145°F and ambient temperature using XM587 fuze batteries. The voltage regulator was changed to provide 14 volts from the original breadboard of 8.5 volts to increase the energy of the firing circuit as follows:

Ergs of Energy $E = \frac{1}{2} CV^2 \times 10^7$ $C = 4.7 \times 10^{-6}$ Farads

at 8.5 V $E = 1697.9$ ergs

at 14 V $E = 4606$ ergs

TABLE XIII. ELECTRONICS TIMING DATA

Identity of Board 28115948 /28115949 /28116119	Battery Current in ma.	Time Delay (msec)			
		EED 1	EED 2	EED 3	EED 4
4/4/14	270	174	570	1014	1782
	270	190	627	1205	1781
10/10/20	280	215	646	1293	1792
	280	212	639	1273	1793
9/9/19	280	221	712	1384	1775
	280	220	706	1339	1768
8/8/18	300	189	635	1212	1778
	300	190	637	1222	1777
7/7/17	300	211	647	1262	1756
	300	211	647	1239	1754
6/6/16	300	208	699	1332	1804
	300	206	692	1276	1804
5/3/15	270	210	631	1224	1754
	270	211	635	1203	1754
3/3/13	270	209	634	1202	1782
	270	206	626	1178	1780
2/2/12	270	211	709	1289	1780
	270	208	692	1240	1780

4.6 Environment Sensors for Test Fuze Assembly

The battery initiation and power up are used to detect the first environment of launch acceleration. The second environment of minimum spin RPM was detected using a spin switch. The spin switch selected is one readily available from Accudyne which was tested on the Tactical Munition Dispenser (TMD). The switch was mounted at a 0.6 inch radius. The switch was procured as a 500 RPM ± 5 percent at a radius of 6.0 inches. Recalculating to 0.6 inch radius of the spin axis, the spin limit will be 1581 ± 5% RPM or 26.35 revolutions per second. These switches were tested on the TMD program for accuracy, therefore, no further testing was done. Mounting of the switch is with the housing leadwire forward to provide support against the setback load during launch.

The assembled electronics components were conformally coated with RTV to a coat 0.002 to 0.015 inches thick and encapsulated into the nose cone using a silicon filled epoxy.

4.7 Problem Areas - Test Fuze Assembly

One problem area in the original breadboard was in providing sufficient energy to the EEDs through the leadwires and connectors to the explosive chamber. The 2N2222A transistor was temporarily replaced with a MPS-14 Darlington transistor. The Darlington, even though the gain rating was very high (15,000 to 20,000) was found to turn on very slowly. The slow turn-on reduced the peak current during capacitor discharge to a very low level and failed to initiate the EEDs. The 2N2222A transistor was then reinstalled and the voltage regulator supply was increased from 8 to 14 volts.

4.8 Test Results

The ten test fuze assemblies were tested at temperature extremes using a circuit to simulate voltage rise time of a battery and microdetonators in place of EEDs in the EBM. Table XIV describes the tests and results. The results of these tests verified the test fuze would function if fired in the 105mm projectile with a flight time of 2.5 seconds.

Six units were selected from these 10 to conduct the field tests described earlier in this report.

TABLE XIV. FUNCTIONAL TEST FUZE RESULTS USING MICRODETONATORS IN PLACE OF EBM AND THE ELECTRONIC S&A ASSEMBLY WITH SIMULATED BATTERY RISE TIME

Unit SN	Temp (F^{0})	Power Supply Rise Time Regulator		Resistance Bolts Microdet (Ohms)				Function Time (Milliseconds)				Results
		MS	Volts	#1	#2	#3	#4	#1	#2	#3	#4	
1	+145	32	14.4	6.2	5.7	6.2	5.0	228	786	1296	--	*Failed
2	+145	28	14.1	5.3	5.7	6.3	5.0	206	808	1132	1796	OK
3	Amb.	30	14.0	6.4	6.7	6.0	6.7	224	806	1038	1758	OK
4	-45	42	13.0	5.2	5.6	5.4	4.9	236	980	1646	1760	OK
6	Amb.	30	13.8	5.7	6.1	5.1	5.2	224	858	1188	1798	OK
7	-45	37	13.1	5.6	6.1	5.6	5.5	237	980	1584	1784	OK
8	+145	34	14.4	5.5	5.7	5.0	5.9	214	818	1166	1800	OK
9	Amb.	34	13.7	6.4	5.5	5.9	5.8	-	668	904	1754	*Failed
10	-45	37	12.8	6.3	5.2	5.7	7.0	246	998	1588	1947	OK

* Failure due to broken wires and were repaired.

5. SYSTEM APPLICATIONS

The electronic S&A device is designed to accommodate a large variety of sensor inputs and power supplies. The sensor study and application of the electronic circuit to real fuze requirements was requested by HDL for four existing fuzes in the concept form of schematic diagrams. These fuzes were:

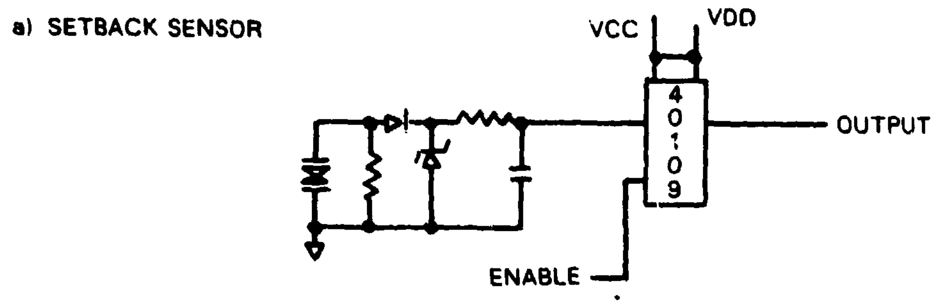
- o 724, 732, 739 type
- o 734 type
- o SMAW or MAW
- o 120mm Guided Projectile.

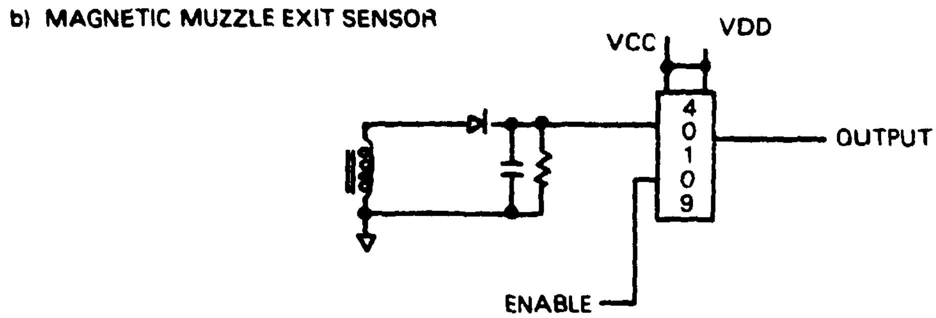
These fuze groups included interconnection for intent to launch signals, air flight frequency signals, safe separation delay distance signals, setback sensor signals, muzzle exit magnetic sensor signals, muzzle exit with minimum velocity signals, safe separation arming delay signals, and impact signals. Schematic diagrams documenting these concepts of sensor versatility with the EBM electronics are shown in figures 27, 28, 29, 30, 31, and 32.

6. SENSOR STUDY

The Electronic S&A Device will be applicable to many munition fuzes. Miniature sensors compatible with both the munition and the Electronic S&A Device are needed to fit these applications for fuzing. The sensor study was used to analyze the environments which are selected for arming the fuze in present-day fuze applications. This data was used to select sensors for miniaturization in the sensor design phase of the program.

A compendium of 23 fuzes is presented in table XV which lists the first and second environments used for arming, the safe separation criteria for arming, the power or energy source and the warhead function criteria. The fuze environments are summarized in table XVI. Setback is the most used first environment with spin as second environment used most.





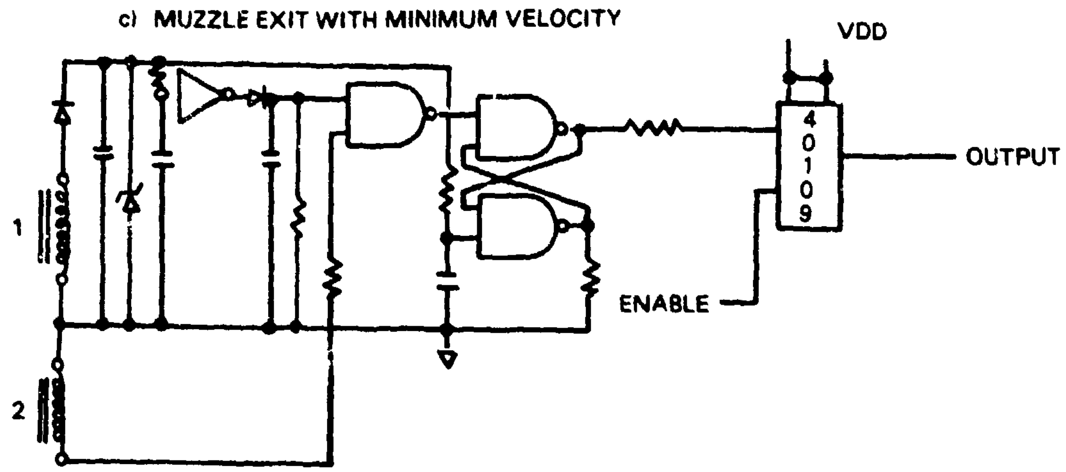


Figure 27. Environmental Sensor Electronics (ESE) for Setback, Magnetic Muzzle Exit and Muzzle Exit with Minimum Velocity.

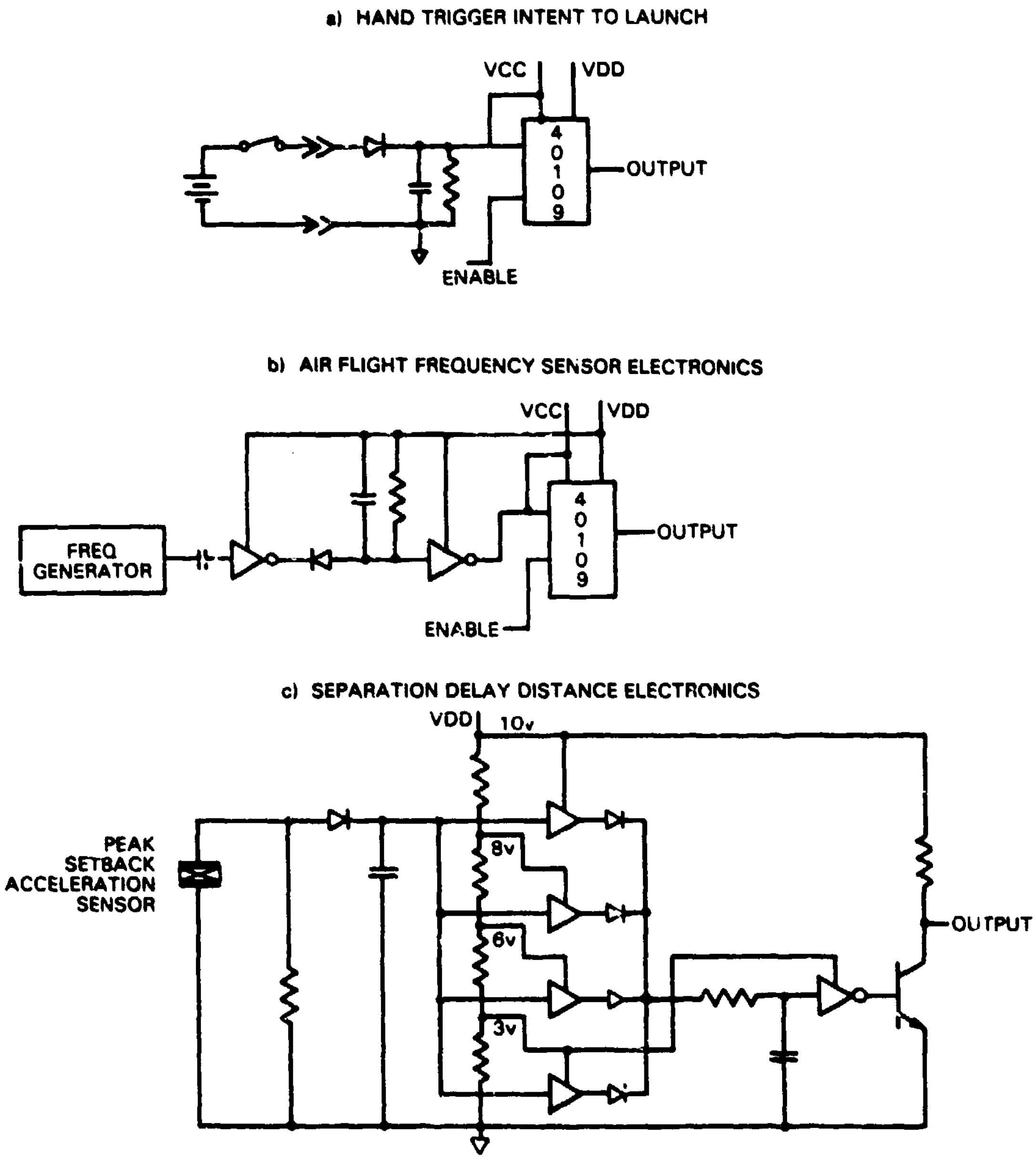


Figure 28. ESE for Hand Trigger Intent to Launch, Airflight and Separation Delay Distance

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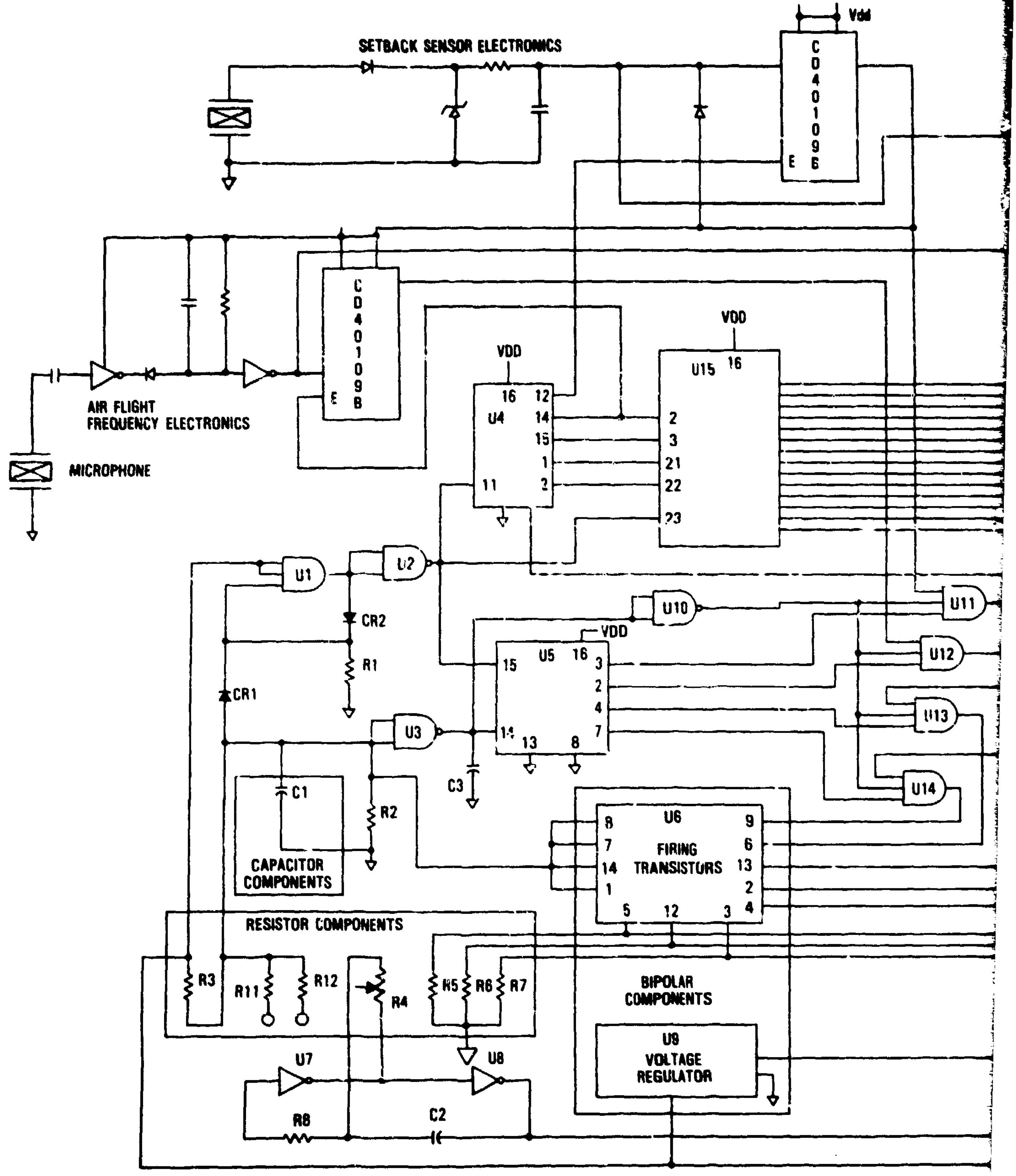

SETBACK SENSOR ELECTRONICS
Vdd
CD40109B
E
AIR FLIGHT
FREQUENCY ELECTRONICS
MICROPHONE
VDD
U4
U15
U1
U2
U3
U5
U6
U7
U8
U10
U11
U12
U13
U14
CR1
CR2
R1
R2
R3
R4
R5
R6
R7
R8
R11
R12
C1
C2
C3
CAPACITOR
COMPONENTS
RESISTOR COMPONENTS
FIRING
TRANSISTORS
BIPOLAR
COMPONENTS
U9
VOLTAGE
REGULATOR

The revers

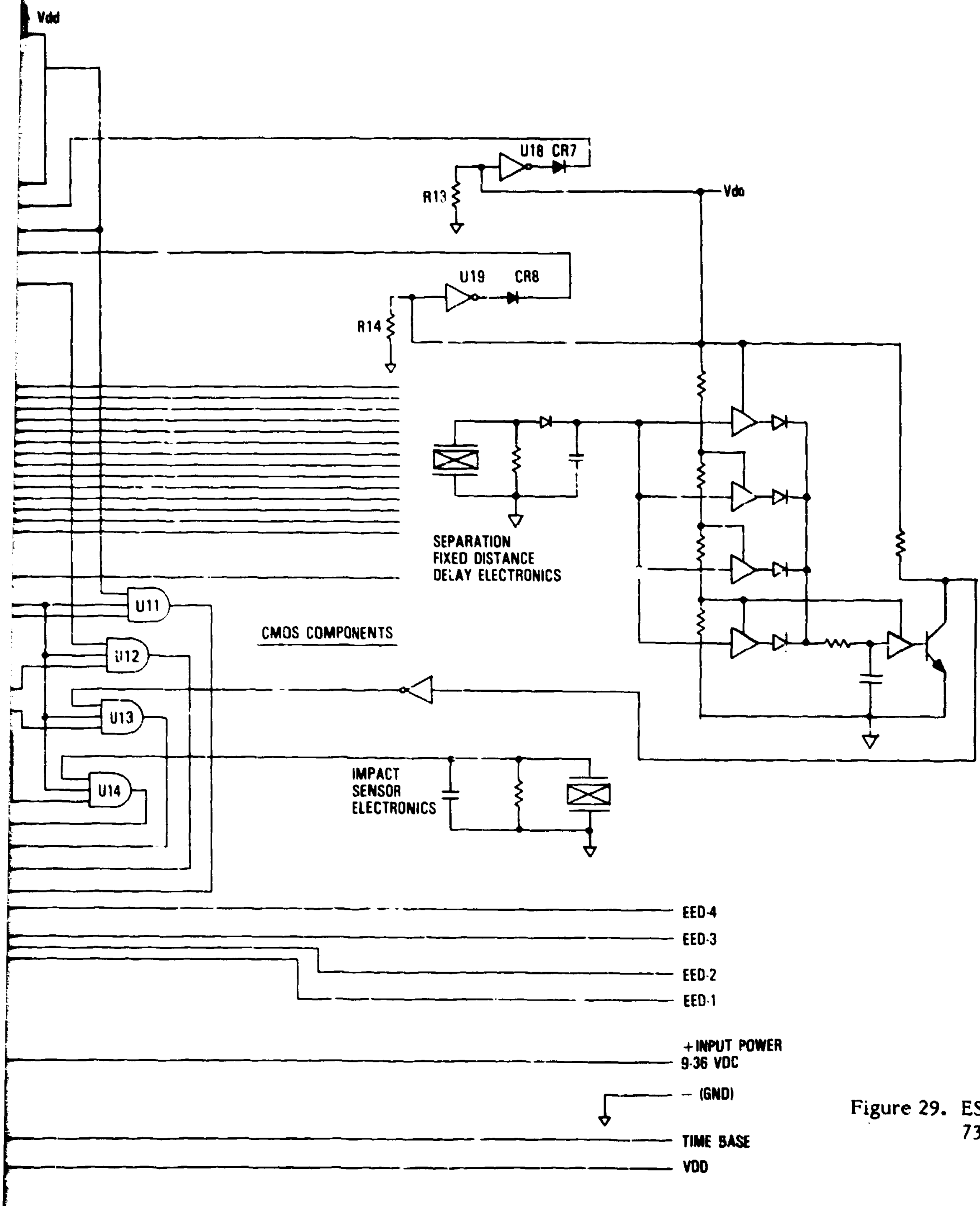
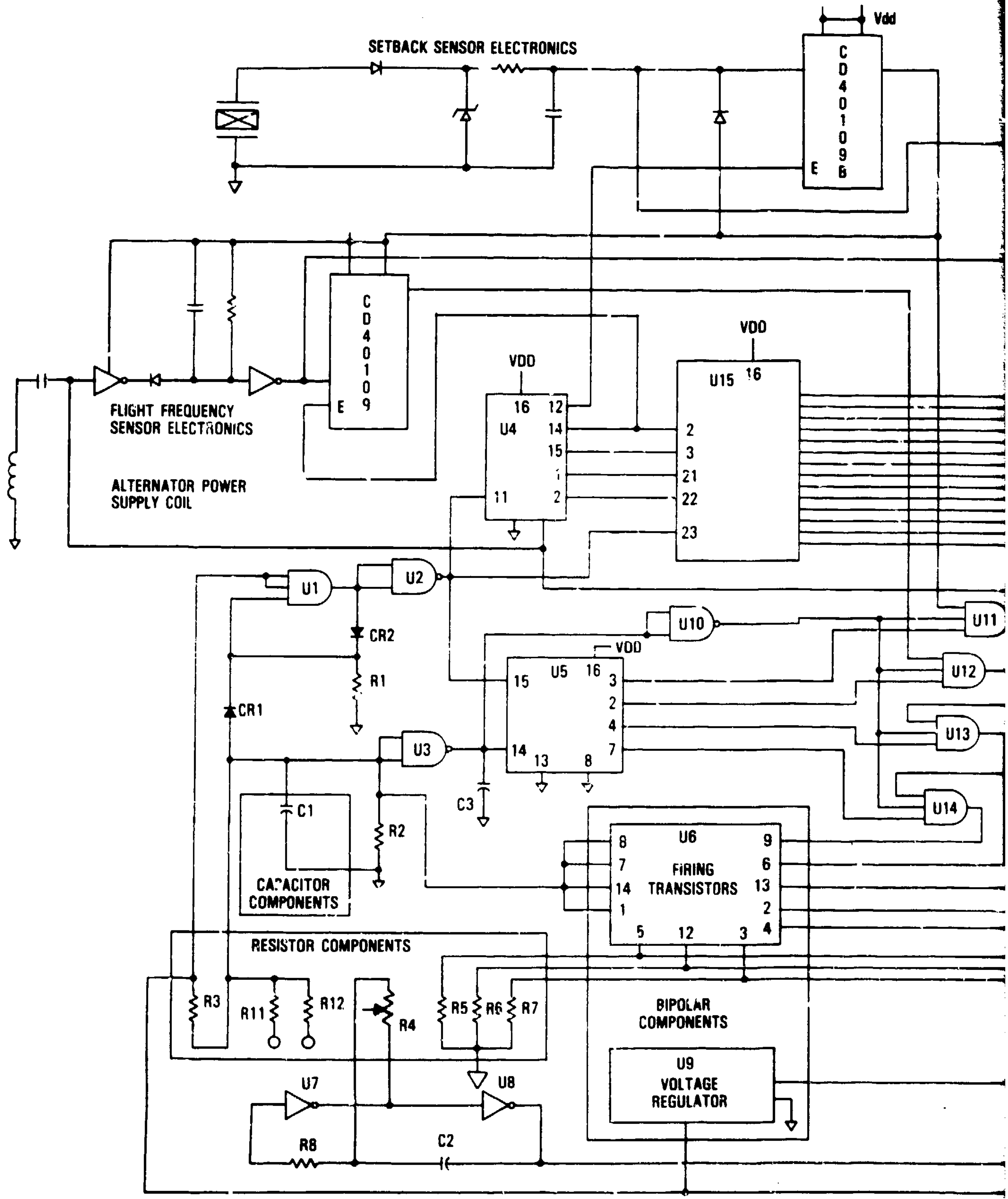


Figure 29. ESE Implementation for 732, 739 or 724 Fuzes



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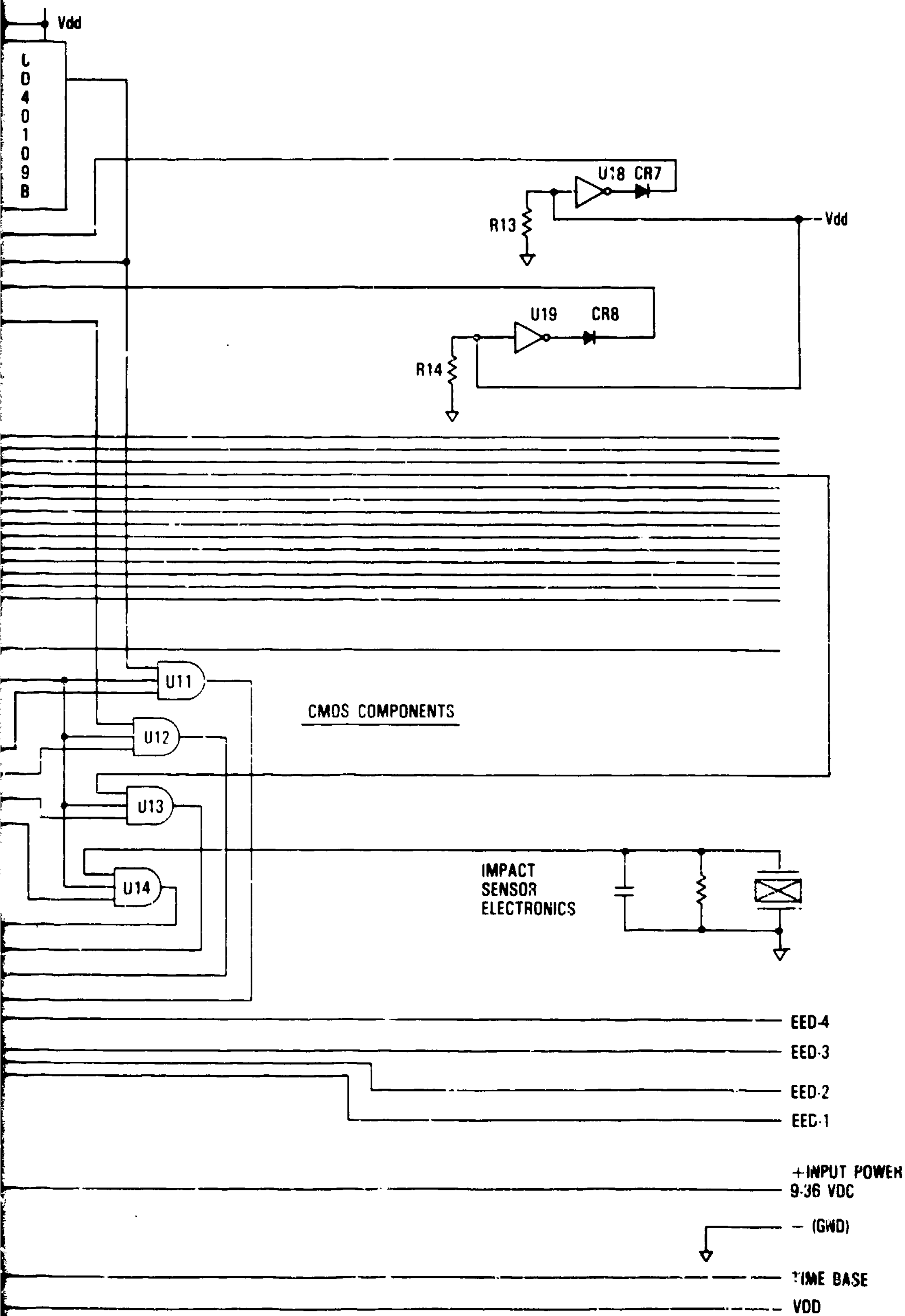

Figure 30. ESE Implementation for 734 Fuze

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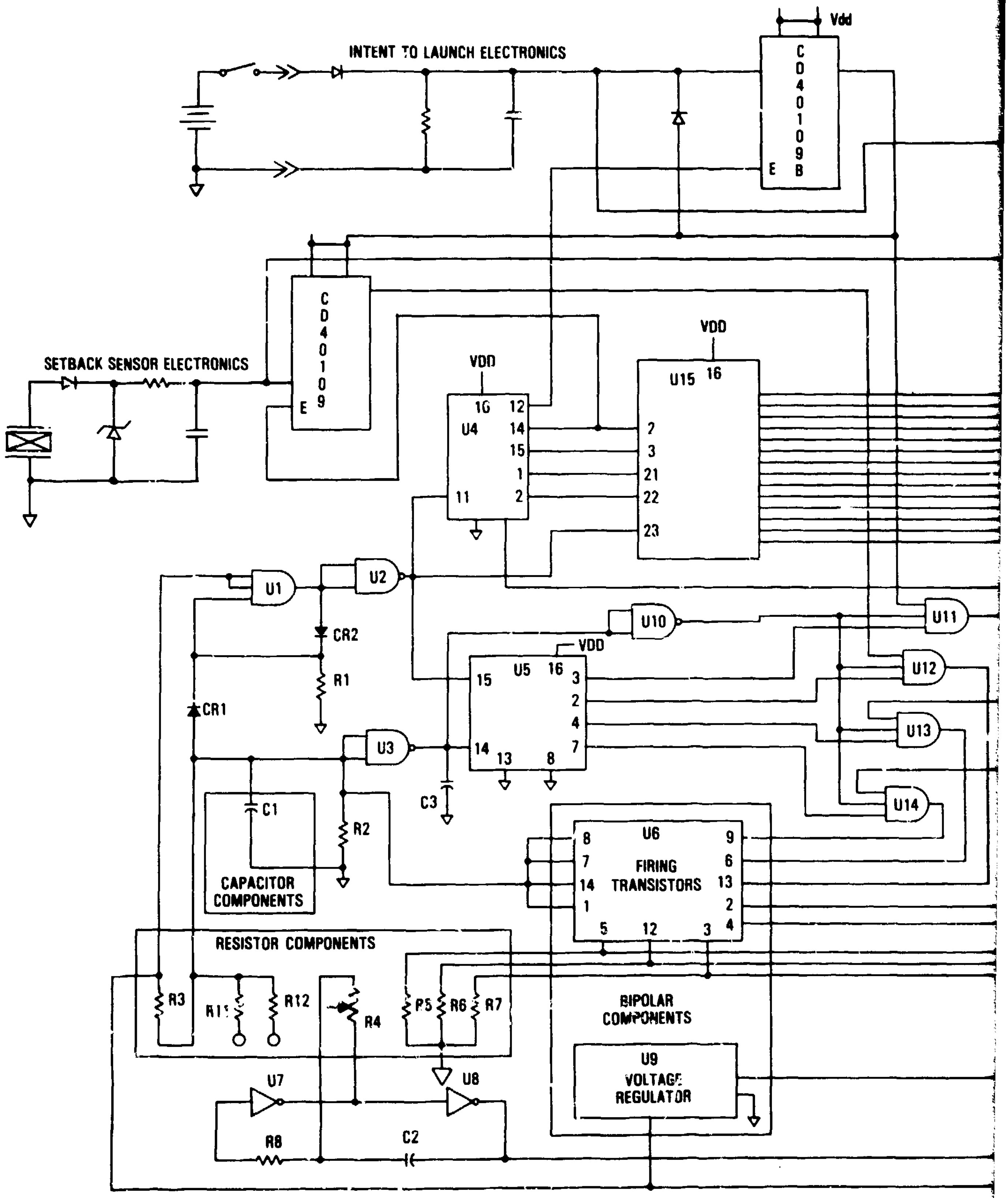

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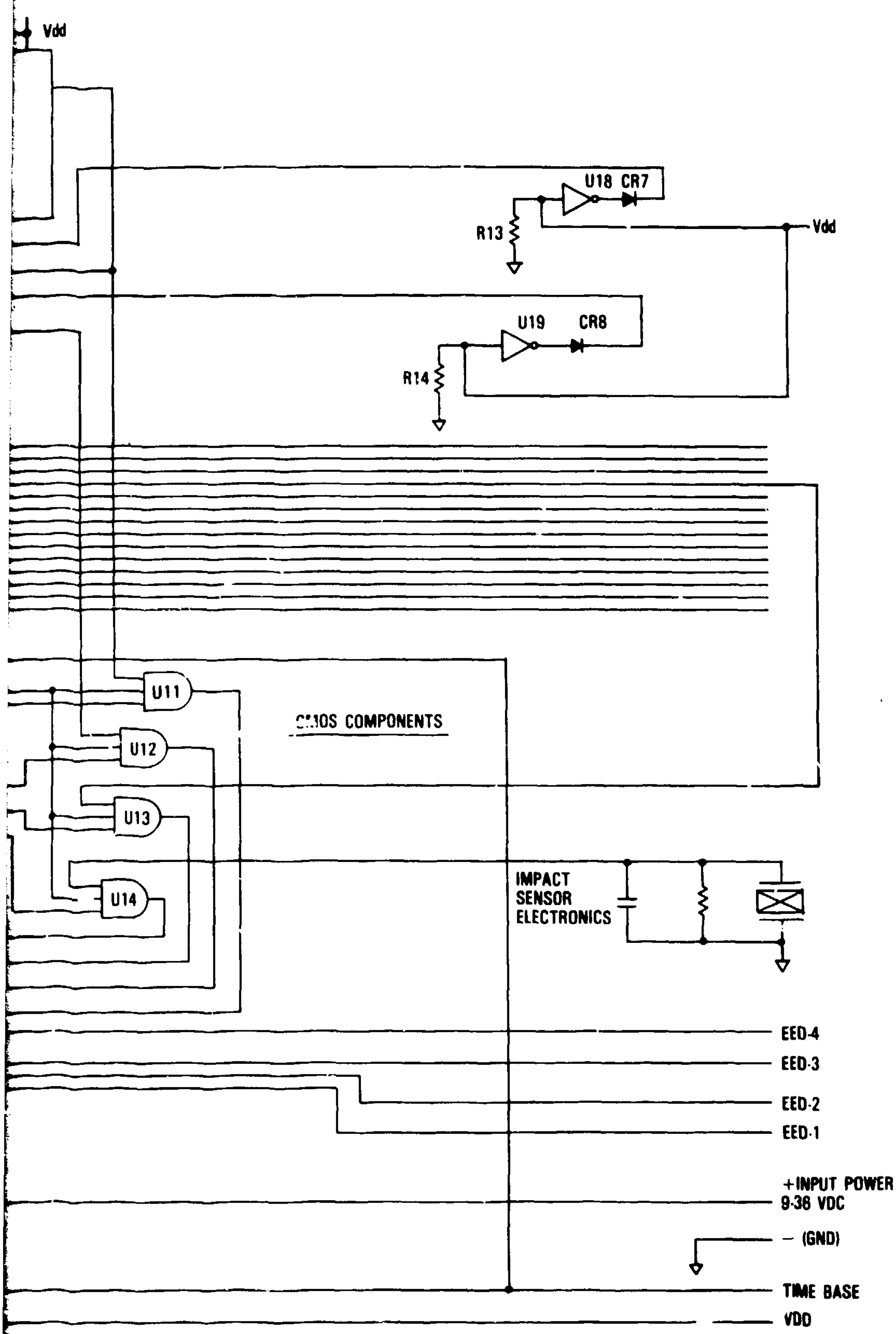

Figure 31. ESE Implementation for SHAWL or SMAW

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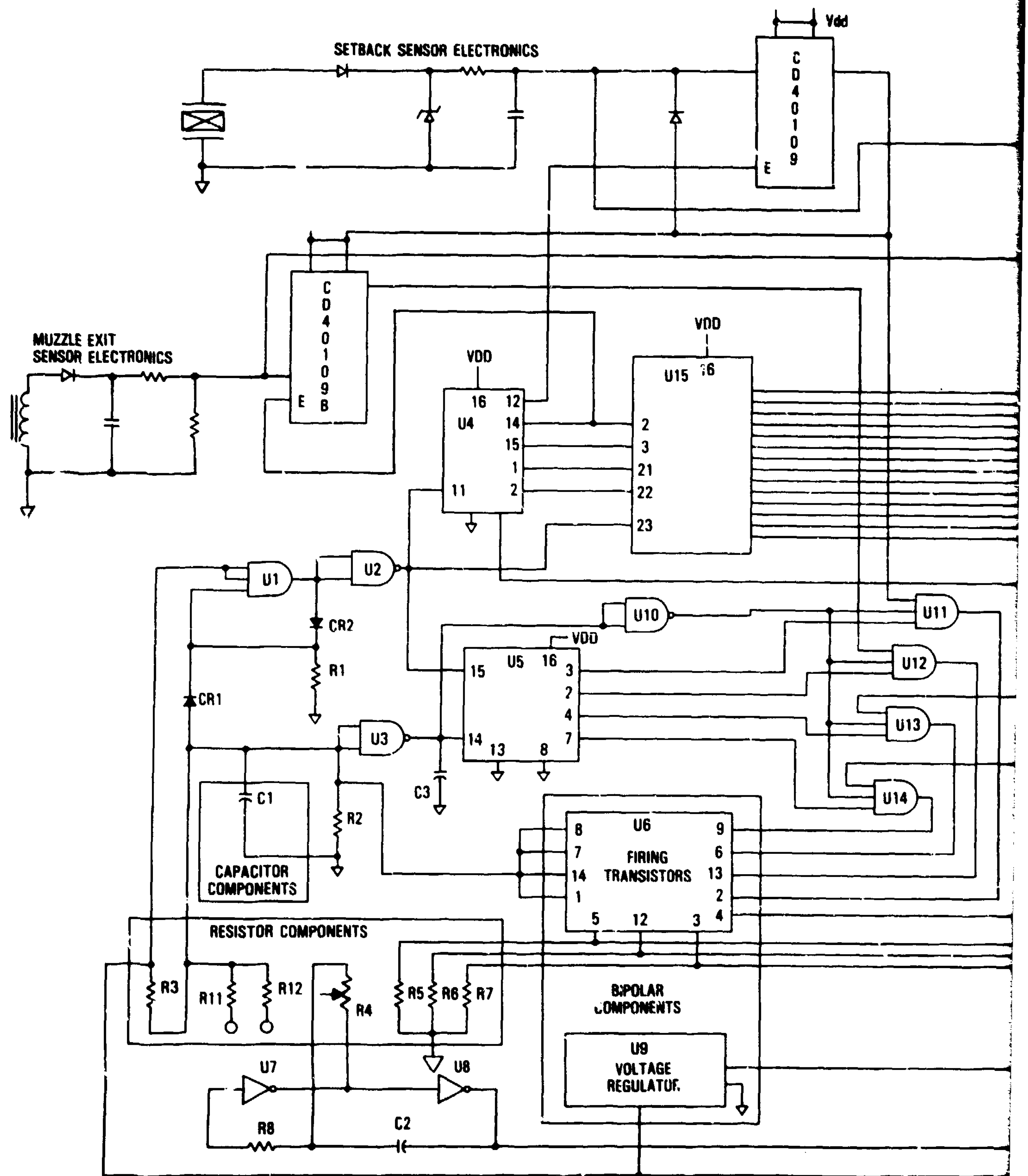
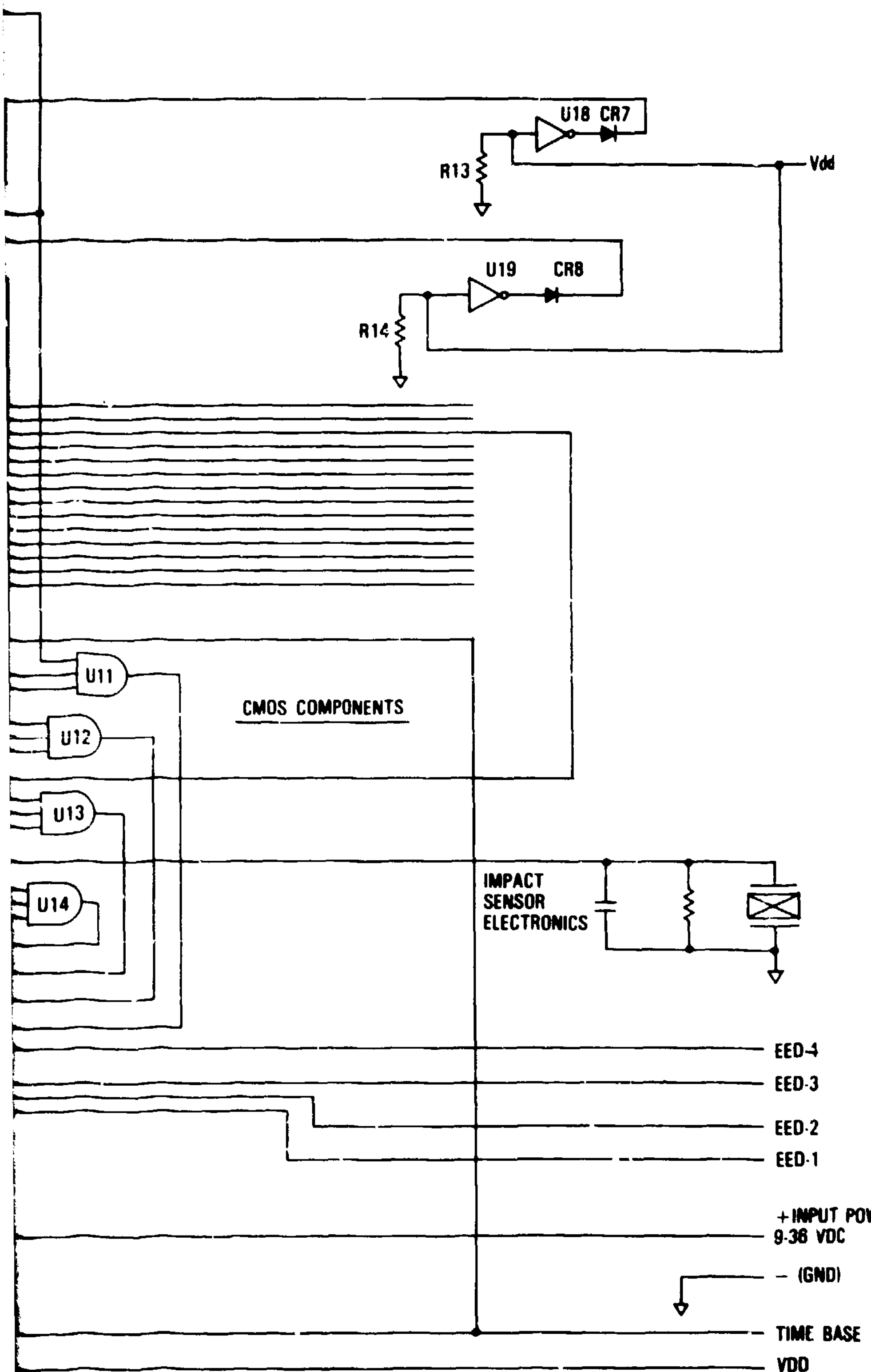


The reverse of



TYPICAL PARAMETERS

COMPONENTS

R1	100K
R2	1.4M
R3	120
R4	270K
R5	100
R6	100
R7	100
R8	510K
C1	12µF
C2	100pf
C3	0.47µF

CLOCK FREQ. 16.8kHz

EVENT TIMING

EED1	3.8 MSEC
EED2	7.6 MSEC
EED3	11.4 MSEC

Figure 32. ESE Implementation for 120mm Guided Projectile

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TABLE XV. FUZE COMPENDIUM

	Fuze ID	Environment to Arm: First	Environment to Arm: Second	Safe Separation Criteria	Type of Power Supply	Function Criteria
1	M734	Setback	Amplitude and Minimum Frequency	Cycle Counter	Wina Driven Alternator	Proximity Mortar
2	M732	Setback	Spin	Turns Counter	Battery	Proximity Artillery
3	Navy 5" ASD	Setback	Muzzle Exit Magnetic	Fixed Delay 0.6 - 1.0 sec.		Impact
4	GSRS (MLRS)	Setback	Frequency Minimum	Cycle Counter	Vibrating Reed Magnetic (Oscillator)	Electronic Time
5	M587	Setback	Spin	Turns Counter	1.5V Floraboric Battery + Converter	Electronic Time
6	SMAW	Launch Signal	Setback	Fixed Delay		Impact
7	SHAWL	Launch Signal	Setback	Fixed Delay		Impact
8	SEAGNAT	Launch Signal	Accel/Window	Fixed Delay	Thermal Battery	Electronic Time
9	120mm Viper German Mod	Setback 1800	Drag (25g)	11-18 Meter 9-16 sec. Fixed Delay	Piezoelectric Charge .068 F to 114V	Impact
10	M739	Setback	Spin	Turns Counter		Detonator Stab
11	M616	Manual	Timer/Window	30 Minute Timer	Non-Reserve Battery	Magnetic Prox
12	TMD	Lanyard	Air Velocity/ Pressure	C.61 sec to 4.2 sec Select Delay	+16V Reserve Battery	Time/RPM

TABLE XV. FUZE COMPENDIUM (Concluded)

	Fuze ID	Environment to Arm: First	Environment to Arm: Second	Safe Separation Criteria	Type of Power Supply	Function Criteria
13	CLGP	Setback	Min. Velocity Magnetic (Stored)	Fixed Delay Mech. 1.5 sec. Target Acquisition	+15V Reserve +28V Reserve	Impact
14	Modified Viper 120mm	Setback Min. 12,000G	Drag 25G Min.	Fixed Mech. Delay 12 msec.	0.56 F Magnetic	Impact
15	ACM	Bore Rider	Parachute Open Drag	Select Delay 4 Settings	None (Piezoelectric at Impact)	Impact
16	RAAM	Setback	Spin	Set Forward Ejection	Battery Initiated at Ejection	Target Locator
17	JAN PD	Setback	Spin	Revolution Count (Fixed)	Magnetic at Setback	Impact Fixed-Delay Auto-Delay
18	FAE II	Lanyard	Air Velocity/ Pressure	Fixed Mechanical 3.4 sec. Electrical 3.5 sec.	+15V Reserve	Altitude Timed
19	ERAM	Bore Rider Starts Arm Delay	Parachute Open Drag	Fixed Time	S&A Initiated Battery	Impact
20	ADAM (WEDGE)	Battery Activation	Shorting Strap Severed	Fixed Delay	G2514 Amonia Battery 3.5V	Tripline Low Voltage
21	Rockeye	Air Velocity	Air Stream Pressure	Rev. Counter Wind Driven Gear Train	Piezoelectric at Impact (M55 Stab Energized)	Impact Force
22	2.75" Rocket	Setback	Maintain Continuous Thrust	Fixed Delay 1.5-2.5 sec.	Reserved Battery S&A Initiated	Proximity
23	Torpedo	Pressure (Depth)	Min. Velocity (Digital)	Fixed Delay 10 sec.	Battery and Alternator	Contact Proximity

TABLE XVI. FUZE COMPENDIUM SUMMARY

Environment		Arming Delay	Warhead First	Function Alternate
First	Second			
12 Setback	5 Spin	10 Fixed Time (2) Selected	12 Impact	1 Delay
6 Mechanical	4 Air Velocity Pressure	(2) + Alternate 5 Distance	5 Timed	1 Prox
3 Launch Signal	4 Drag	5 Rev. Count	4 Prox.	1 RPM
2 Pressure	2 Setback	2 Freq. Count (Wind Driven)	1 Target Detect	1 Low Voltage
	2 Muzzle Exit Vel.	1 Set Forward (Deceleration)	1 Tripline	
	3 Frequency Count		1 Altitude + Time	
	2 Accel.			
	1 Battery Voltage			

Power Supplies
12 Reserve Battery
2 Wind Driven
3 Setback Charge Capacitor (2) Magnetic (1) Piezoelectric
2 Piezoelectric at Impact
3 None
3 Unknown

6.1 Unique Launch Environments for Fuzing

Unique environments which can be selected for arming are listed in table XVII.

TABLE XVII. UNIQUE ENVIRONMENTS

Environment		
Characteristic	Use	
setback acceleration		1
spin acceleration	2	1
spin velocity		2
linear velocity		2
muzzle flash		1
chamber pressure		1
top of trajectory		3
terminal velocity		3
guntube	2	1
chamber temperature		1

Environment		
Characteristic	Use	
ionization		1
aerodynamic pressures		2
time	3	2
revolutions	2	3
proximity		3
power up electrical	1	2
target acquisition		3
air drag		2
air flight		2

Notes on Use:

1 Environments which can be selected for the 1st sensing of launch.

2 Environment of proper sequence which can be selected for the 2nd sensing of launch.

3 Types of sensing which can be selected for safe separation delay.

Environment selection must be determined for each particular munition; however, environments selected for non-spin munitions would be generally applicable to spin stabilized munitions but the reverse is not necessarily true. Selection is based on those events which can consistantly provide a signal to noise ratio of 10:1. The noise involved is the environment selected signal during any handling, shipping or other occurrence which can cause the signal without intentional launch of the munition. Improvements can be made in reducing noise environments by combining environments selected. This is done to limit noise and improve the ratio.

The environment selected must operate a sensing device and manipulate the environment sensed into an electrical signal in the 10:1 ratio. Environments which require sensors that alter flight characteristics and firing tables must be avoided as the cost of verifying characteristics and adjusting tables is very high.

6.2 Environment Sensor Characteristics

Sensors for determining that the munition is launched by the intended means must pick two unique environments from the launch or post launch. The sensors should be solid state, small in size, not exposed to damage on an external mounting, resetable/testable without destruction or disassembly, and retain the necessary information for the minimum time required for sequencing during the interrogation period. Comparison of some sensors with the environments to be sensed are as follows:

6.2.1 Setback Acceleration -- Requirement is established by go/no go launch for a projectile fuze at zone 1. Worst case can be 400 g not arm, 600 g to arm. The sensor must always provide arming signal by the voltage level established, above 600 g and conversely shall never provide for arming below 400 g. Duration of the acceleration is more unique than the amplitude. The amplitude can be easily accomplished by dropping the round. A zone 1 acceleration will rise from minimum g to peak g in about 1/4 launch tube length. Knowing the muzzle exit velocity from the firing tables one can approximate the time of acceleration.

Several sensors which will provide the amplitude (minimum) and duration of the launch acceleration and meet the configuration requirements are discussed. The sensor output is integrated to differentiate a short duration acceleration from the launch acceleration which represents a large change in velocity.

6.2.1.1 Piezoelectric Acceleration Sensor -- Three basic equations are manipulated to provide a piezoelectric acceleration sensor suitable for cannon launched projectiles. The sensor sensitivity is established by selecting a piezoelectric material which will provide a charge Q when the minimum launch acceleration is applied to the projectile. The force applied to the crystal at this minimum applied acceleration is determined by the size and weight of the mass selected. The charge produced Q when the mass is pressed against the piezoelectric crystal by the acceleration will produce voltage in proportion to the crystal and integrator capacitance. The three equations are:

$$d_{33} \text{ sensitivity of the crystal} = \frac{Q \text{ charge in Coulombs}}{\text{Force in Newtons}} \qquad 1)$$

$$\text{Force in Newtons} = M_{mass} \quad a_{acceleration\ in\ g} \qquad 2)$$

$$V_{volts} = \frac{Q \text{ Charge in Coulombs}}{C \text{ Capacitance in Farads}} \qquad 3)$$

The integrator, capacitor and resistor are used to determine the duration of the acceleration pulse. The integrator will not provide proper discrimination if the voltage is permitted to follow the peak acceleration, so a zener diode is used to clip the voltage at the 600 g level. Only the positive signal acceleration from 0 to peak is accepted as a signature for the minimum acceleration because, as the acceleration decreases from peak, the voltage applied to the integrator will not be sufficient to increase the charge level to the threshold.

The low acceleration at the low zones of firing is applied for the longest duration and can be accurately set to reach a threshold between the 400 and 600 g limits. As the accelerations of launch are increased, the voltage is applied more rapidly as the rise time of the leading edge reaches the 600 g zener clip. At the maximum acceleration, the voltage applied to the integrator becomes very nearly a square wave and a square wave input is used to calibrate the integrator for accept and reject signatures.

The response time is excellent in tracking increasing acceleration force. The acceleration time is measured accurately and can be used to discriminate between a drop impact acceleration, which is of short duration, and a launch which is of long duration. High acceleration greater than 400 g's of a dropped projectile impact while electrical power is applied is expected to be less than 100 microsecond, whereas the launch acceleration is greater than 2 millisecond which provides a favorable 20/1 signal to noise ratio. The mass must be free to apply force to the crystal, but does not require separation so as to impact the crystal. Using high impedance discrimination circuits, the sensor output is expected to dissipate in less than 0.5 seconds. The setback is interrogated by the Electronic S&A electronics between 50 ms (battery power up) and 250 milliseconds.

6.2.1.2 Mechanical Switch -- Several types of switch closure methods have been examined. Two areas of calibration are critical to meet with a single design. One is to accept 600g and reject 400g and the other is to accept the maximum cannon launch which is quite short in duration, and reject the drop impact. Mechanical design could be made of two or more sensors rather than attempt to cover the range in a single component.

The mechanical zig-zag appears to be a logical approach to a fixed acceleration spinning projectile where a limited acceleration range is expected. Or if electrical power is available during setback, the projectile without spin could be accommodated.

6.2.1.3 Spin Acceleration Sensor (Piezoelectric) -- Spin acceleration is a unique environment for Spinning Projectiles. The spin sensing is accomplished using a matched pair of sensors located at 180 degrees around the longitudinal axis of the fuze. The output of the sensors will subtract their respective signals on accidental acceleration due to dropping the projectile. The signals are additive to provide the detection of the rotational acceleration in the gun tube. Piezoelectric sensors can be used to detect the acceleration which is a very short duration signal. The change in spin acceleration in most cannon launched spinning projectiles is large compared to noise such as rolling across a floor. The level of the additive minimum signal can be used as a threshold. The sensor is adequate to detect gun firings to the maximum zone. The signal of spin acceleration is completed by the end of the gun tube and must be stored until circuit power is available. Interrogation by the Electronic S&A electronics can be accomplished in 400 milliseconds. The signal can be dissipated in 600 milliseconds. Spin acceleration can be used as a first environment or second environment on a spinning projectile fuze.

6.2.1.4 Breech Environment Sensing -- Chamber temperature, ionization or flash and chamber pressure would be suitable environments for base mounted fuzes. Base mounted fuzing systems are common with the shaped charge armor piercing munitions. Thermal sensors are usually slow. Sensors mounted at the base are difficult to seal against high pressure propellant gases. For these reasons, they are not considered candidates for development or investigation.

6.2.2 Second Environment Sensors — Second environment sensors which are considered for further study are discussed in the following paragraphs. The electrical power up of a setback generated power source can be used if the environment used to create the energy is unique and different from the first environment. Electrical power must be available to operate the electronics. The sensor is essentially free, for the system used to activate the electrical power must be incorporated for the system power.

6.2.2.1 Pressure Sensing — Aerodynamic pressure can be sensed directly by pitot tube and a solid state pressure sensor. One drawback is that the tube can easily plug. Fluctuations in the pressure surrounding the fuze during flight are normally audible as the projectile flies by. It is logical that the sound generated by the projectile flight is present within the projectile as well as transmitted through the air. The projectile is the sound source, therefore, the signal is maximum at the projectile. A microphone could be used to pick up the flight sound or pressure modulation. If the sound is present at the time of interrogation of the second environment, the sensor would be required to monitor the pressure modulating signal for a specific time period.

If more precise projectile pressure modulation is required, a deformation or protrusion on the fuze could be used to create a specific frequency or tone in flight.

6.2.2.2 Velocity Sensor — A minimum linear velocity was determined by a timer between two magnetic sensors and gun tube in the Copperhead munition second environment sensing system. Separation of the projectile from the gun tube was magnetically detected by two sensors and the time between signals measured linear velocity. The Copperhead projectile provided the opportunity to place the magnetic sensors at the caliber diameter to obtain coupling to the gun bore. This provided the opportunity to obtain power for the timing circuit. Nose fuzes do not provide this opportunity and may not be suitable for detecting the gun tube magnetically unless electrical power is available at setback.

6.2.2.3 Fixed Arming Distance — Peak acceleration has been measured by piezoelectric sensors on launch. The level of the acceleration signal was used to shorten the arming delay in accordance with the higher levels of launch acceleration. This signal processing will provide a minimal error to a fixed arming distance regardless of the zone of charge used to fire the projectile.

Spin velocity can be detected or sensed very accurately if used in conjunction with a revolution counter. At short arming distances, it would not be too practical, but a count of 5 revolutions in a period of 200 milliseconds would be reasonable. Revolution counting on a spinning projectile was proposed and demonstrated for the Electronic Joint Arming Navy point detonating fuze. The sensor, a loop of wire to pick up the earth's magnetic field, is predicated on exposure to the magnetic field and not surrounded by any magnetic material. An integrated circuit magnetometer is in development which can be used in this application, therefore, no effort was expended in this program on this sensor concept.

6.3 Micro-Miniature Sensor Concepts

6.3.1 Silicon Accelerometers -- Piezoelectric strain gauge is fabricated at the cantilever bend where the cantilever is an etched-through portion of the silicon integrated circuit chip. The cantilever beam measures 2 x 3 millimeters with a weight of approximately 0.02 grams. A typical device measures acceleration from 0.01 to 100g and has a resonant frequency of 1000 Hz. The sensing level is low for projectile application, but is suitable for rocket acceleration or other low g arming systems. The cost is high, primarily due to etching of the silicon to form the cantilever beam.

6.3.2 Velocity Sensors -- Velocity can be detected and measured by air flowing over a heated surface. The rate of flow will create a temperature difference between two temperature sensors, one placed down stream of the other. Heat is applied between the balanced chip sensors. When air flow is applied, the chip sensor side toward the air source is cooled and the chip sensor down-wind of the heat source is heated. The differential can detect the velocity. The chip, being very small, can respond quite rapidly. Exposure to the air source usually requires external surface mounted chips which are delicate.

6.3.3 Pressure Sensors -- The pressure transducer consisting of piezoresistive strain gauges have been deposited on silicon and interconnected to integrated electronics on the silicon integrated circuit chip. Pressure sensors are difficult to apply to projectiles for several reasons: a) They require openings to the atmosphere, b) they are usually fragile and will not withstand rough handling, c) they are usually distorted by rain or snow, and d) they usually require a stabilized pressure volume for comparison and compensation for attitude, and temperature is very difficult especially when the volume is limited.

6.3.4 Revolution Counter Integrated Circuit -- The magnetoresistive bridge magnetometer (MRB) is a new device manufactured by Honeywell Solid State Electronics Center. The major advantage of this sensor is its small size and process compatibility with large scale integrated circuit technology. The MRB and signal processing electronics are fabricated on a common silicon substrate resulting in a low cost large scale integrated circuits.

The disadvantage of the MRB is that it requires a bias current of approximately 100 micro amperes, so it is not well suited for extremely low power systems.

6.4 Sensor Concepts

During the sensor study, several concepts were generated which may be feasible for future development. These concepts are recorded in the following paragraphs.

6.4.1 Spin Sensor -- Figure 33 shows a small mass (0.125 inch steel ball bearing) resting against a conductive silicone foam element. The element has a free standing resistance R. If interrogated to detect spin, and spin g forces are not present, the conductive foam element is not compressed. The resistance will cause an oscillator to oscillate at a frequency f. The demodulator input from this low frequency f is calibrated to run free. If spin is present, the foam element (spring) is compressed, reducing the resistance value to R/2. The oscillator frequency will increase to 2f. When interrogated for spin and spin is present, the demodulator will latch as the frequency has doubled. This sensor can be economical and is compatible with the CMOS logic used in the EBM. Precise calibration of the resistance is not required as a frequency shift of 2/1 should be easily attained.

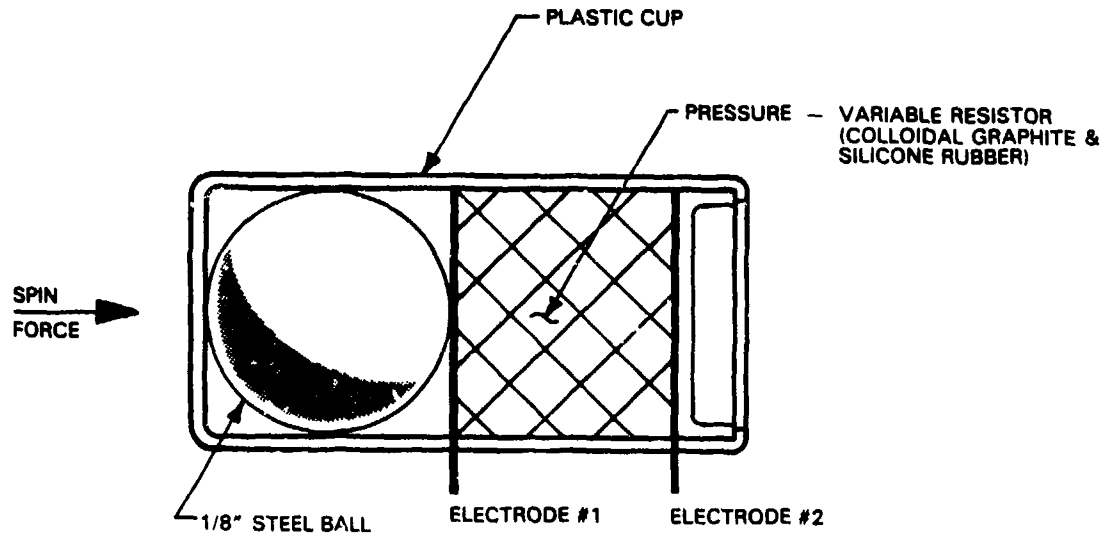

Figure 33. Spin Sensor

6.4.2 Setback & Spin Combination Sensor -- The concept is an alteration of the zig-zag setback/spin mechanical switch and is shown in figure 34. The cantilevered beam, a fiber optic strand, is a lightweight stable material and will bend in proportion to setback and rotate into a latch on spin. Photo-detectors are positioned at the fiber end at each latch position. On setback, the fiber is deflected in proportion to the g level and on spin is thrust into the aligned notch. As setback terminates, the fiber is retained in the notch.

The setback acceleration is divided into a number of g-brackets by the notches. The setback acceleration is determined and interrogated by lighting a LED and the detector receiving the light through the fiber will register the condition at launch. This system eliminates the problem of contact resistance present in contact switches and can provide a positive not-armed signal when the fiber has not latched because no spin is present. Balloting loads may cause the fiber to be ejected from the notch.

6.4.3 Piezoelectric Setback Sensor Exploratory Development -- A minor effort of the contract was to develop and fabricate a breadboard model of a piezoelectric setback sensor for use in artillery projectiles. The sensor must be small size and compatible with the Electronic S&A device.

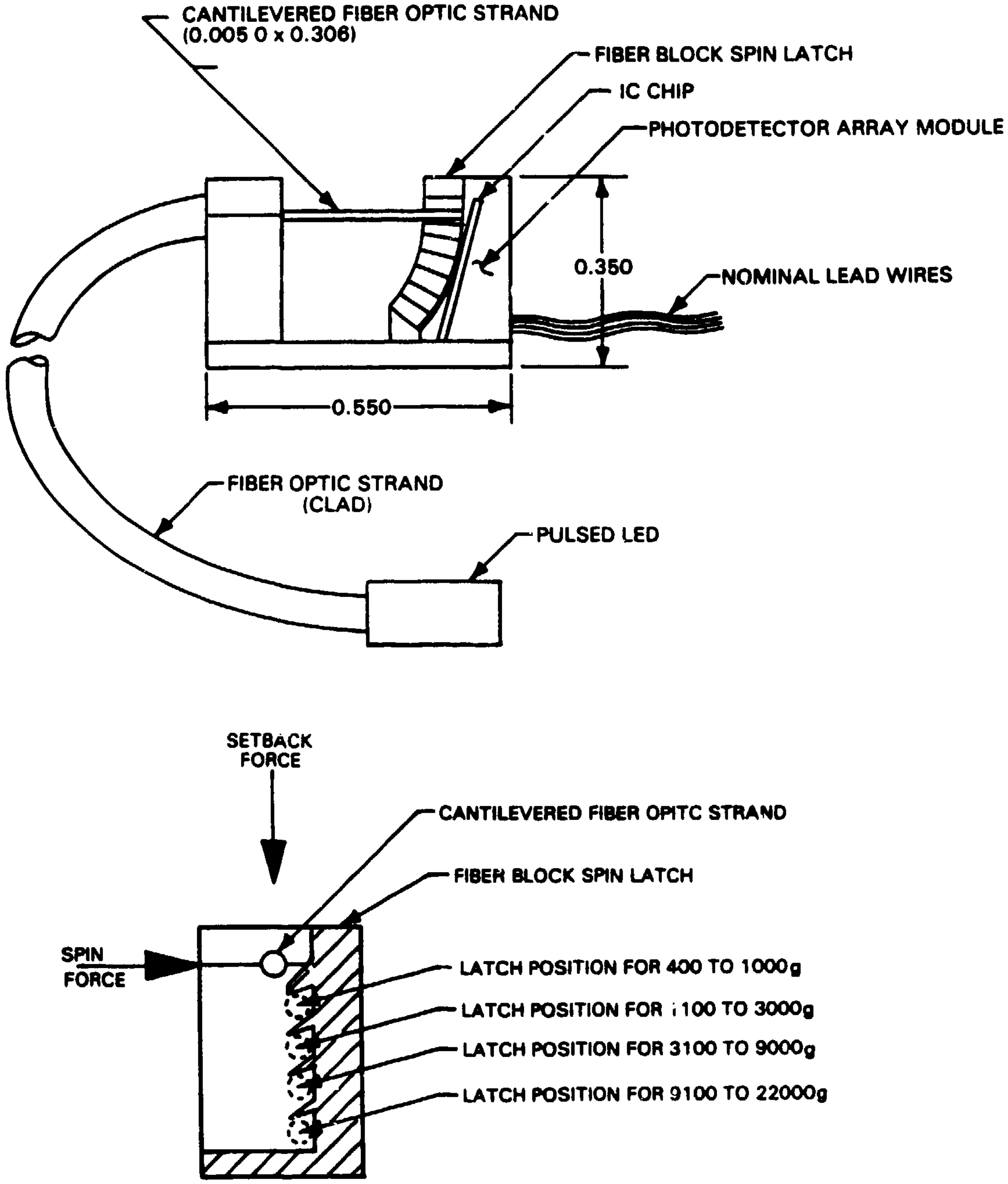

Figure 34. Setback and Spin Sensor (side and rear view)

One breadboard sensor was fabricated, tested, and delivered. The sensor met the requirements of the contract and appears feasible for further development. A photo of the sensor breadboard is shown in figure 35. Figure 36 shows the sensor assembly.

6.4.3.1 Setback Sensor Requirements -- The sensor investigation was performed to determine what sensing techniques are feasible for artillery projectile fuze applications. The sensors shall be capable of monitoring the desired environments and transmit the sensed signals electronically to the safing and arming electronic logic. The sensors must be compatible with the artillery munition, and with the constraints set forth by applicable military standards.

A preliminary design specification was generated to establish the requirements for the sensor to functionally operate over the environmental conditions established by applicable military standards.

MIL-STD-1316 requires that one of the two sensor inputs must derive its energy from the sensed environment. To be compatible with the Electronic S&A device, the setback sensor must provide its own signal and store the signal until the battery power is available.

6.4.3.2 Setback Sensor Design -- The transducer to be designed is the piezoelectric accelerometer. This sensor requires a mechanical force or strain and will produce an electric charge output. While the charge per unit force applied is rather small (microcoulombs), significant voltages are easily obtained by proper capacitor selection. Characteristics of a piezoelectric crystal are: (1) efficient, (2) very sensitive, (3) low electrical leakage, (4) no moving parts, (5) small in size, (6) very inexpensive, and most important (7) no minor input or bias current is required for operation.

In selecting which of the sensors are most desirable for an electronic safing and arming fuze system for an artillery projectile, the constraints of the end item must be considered. A limitation in sensing the setback force is that it must be accomplished while the projectile is undergoing acceleration, which is a period when electrical power is not available. A typical minimum time for the artillery family of 105MM, 155MM, 8 inch Howitzers, and 175MM gun is approximately 4 milliseconds under maximum charge. This requires that the sensing be accomplished without the aid of any stored electrical energy

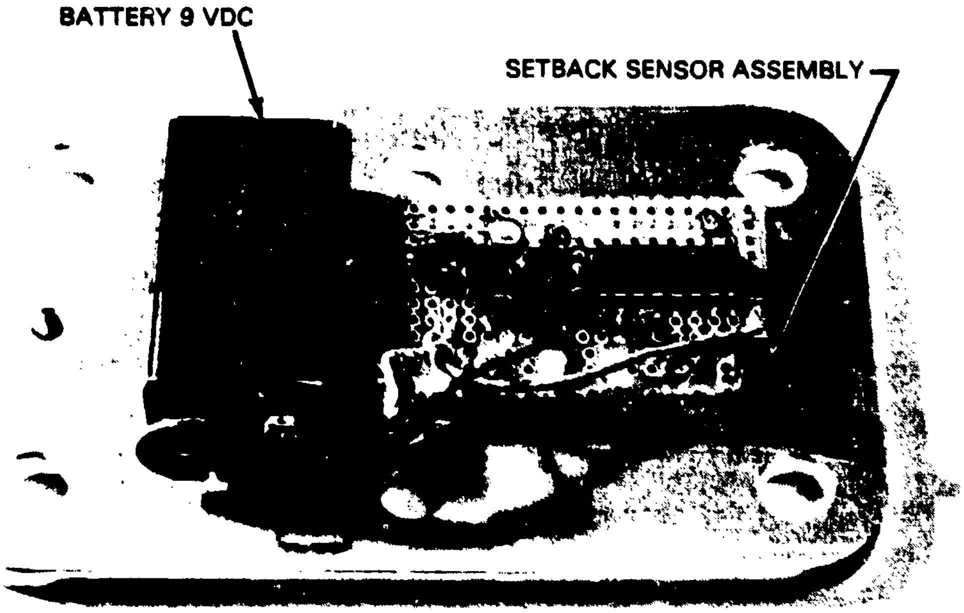

Figure 35. Setback Sensor and Breadboard

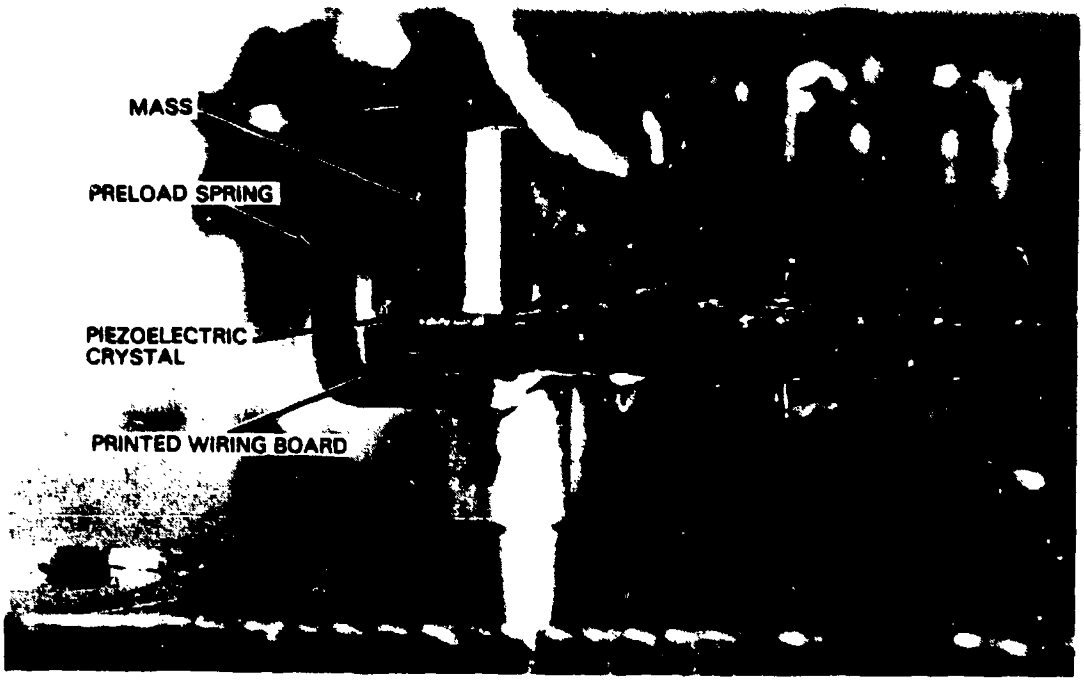

Figure 36. Setback Sensor Assembly

because the Electronic S&A device can have a delay in available electrical power for up to 50 milliseconds.

The remaining portion of this discussion will explain the design, selection, and demonstration of the piezoelectric in the artillery projectile fuze.

The ceramic piezoelectric crystals were selected over the other types of materials exhibiting piezoelectric characteristics for the reasons listed below:

1. High curie temperature (300°C)
2. Variable geometric design
3. Rugged
4. Low cost
5. Ease in fabrication
6. Withstand extreme acceleration (85K PSI compressive strength)
7. High piezoelectric constant
8. High resistivity
9. Relatively unaffected by temperature variations.

The piezoelectric transducer produces an electric charge as a result of being mechanically stressed. The stress may be by compression, tension, or torsion with the amount of charge produced determined by the orientation of crystal poling. In most cases, maximum charge per unit force is obtained when the force applied is in the same direction as the crystal polarization. The charge is produced in the crystal faces perpendicular to the polarization. The factor relating charge and the force is the piezoelectric constant, d_{ij}, where i and j are used to represent the force direction and polarization. When maximum sensitivity is desirable, d_{33} will be used. The material selected for stability over temperature, high piezoelectric constant, and availability was Honeywell C-16 lead-zirconate/lead titanate material fabricated by a hot press process. A conservative value d_{33} for Honeywell C-16 lead-zinconate/lead titanate material is 400 picocoulombs/square meter/newton/square meter. Other characteristics are listed in table XVIII.

The piezoelectric factor relates the amount of free charge that is available on the crystal face, for a proportional amount of force, where the voltage on the crystal is determined only by the crystal capacitance and available charge. The effect of this voltage is

TABLE XVIII. PROPERTIES OF HONEYWELL CERAMIC C-16

Material	Lead Zirconate/ Titanate
Dielectric Properties at 25°C	
Relative Dielectric Constant (free) at 1 kilocycle	1,800
Dissipation Factor (at 1 kilocycle and low field) (%)	2.0
Dielectric Strength (volts/mil)	120
Piezoelectric Properties at 25°C	
Piezoelectric Constants:	
d_{33} (coulomb/newton X 10^{-12})	380
g_{33} (volt-meter/newton X 10^{-3})	26
d_{31} (coulomb/newton X 10^{-12})	-130
g_{31} (volt-meter/newton X 10^{-3})	-9.0
Coupling Coefficients at 25°C:	
K_p	0.52
K_{33}	0.67
K_{31}	0.31
Elastic Properties at 25°C	
Frequency Constants:	
N_1 (transverse) (kilocycle/inch)	58
N_3 (thickness mode) (kilocycle/inch)	71
N_r (radial mode) (kilocycle/inch)	82
N_c (circumferential mode) (kilocyle/inch)	39
Young's Modulus:	
$Y^E_{11} = \frac{1}{S^E_{11}}$ (newton/meter^2 X 10^{10})	8.7
$Y^E_{33} = \frac{1}{S^E_{33}}$	5.8

TABLE XVIII. PROPERTIES OF HONEYWELL CERAMIC C-16 (Concluded)

Material	Lead Zirconate/ Titanate
Physical Properties	
Compressive Strength (psi)	85,000
Density Kg/meter^3	7,600
Miscellaneous Properties	
Curie Temperature (^oC)	300
Resistivity (ohm-cm) at 25^oC	10^{13}
Mechanical Q	75
Thermal Expansion (X $10^{-6}/^oC$)	2.2
Aging Properties	
Dielectric Constants (%/decade)	-1
Coupling Coefficient (%/decade)	-0.15
Resonant Frequency (%/decade)	+0.1
Mechanical Q (%/decade)	+3

transferred to the electrons in the crystal by an electrostatic field that is built up across the crystal.

$$E = V/d. \qquad 4)$$

The electric field induces a force on the electrons that is in opposition to the piezoelectric effect. If the electric field is reduced by lowering the voltage across the crystal, additional charge becomes available. This is analogous to increasing the piezoelectric factor, d_{33}, by an amount that is proportional to the capacitive load. The additional charge that is available is significant and the smaller the crystal thickness, the greater the effect of unloading.

In designing the piezoelectric setback sensor, the following conditions must be evaluated:

1. The environment must be sensed during the positive signature acceleration curve.

2. The sensor output should be independent of the magnitude of acceleration above some predefined threshold. This will be used to establish the arm/not arm decision based on the g's at launch.

3. The sensor shall retain its output after sensing for a period of 50 ms to allow the Electronic S&A device power supply to reach operating potential.

4. The sensor must be able to discriminate between intentional and accidental environments. In this application, time duration will be used for this purpose. Intentional launch accelerations half sine wave are above the minimum arming g level for at least four milliseconds, while the accidental type accelerations are never above the minimum arming g level for longer than two millisecond, see figure 37 for the desired function characteristics.

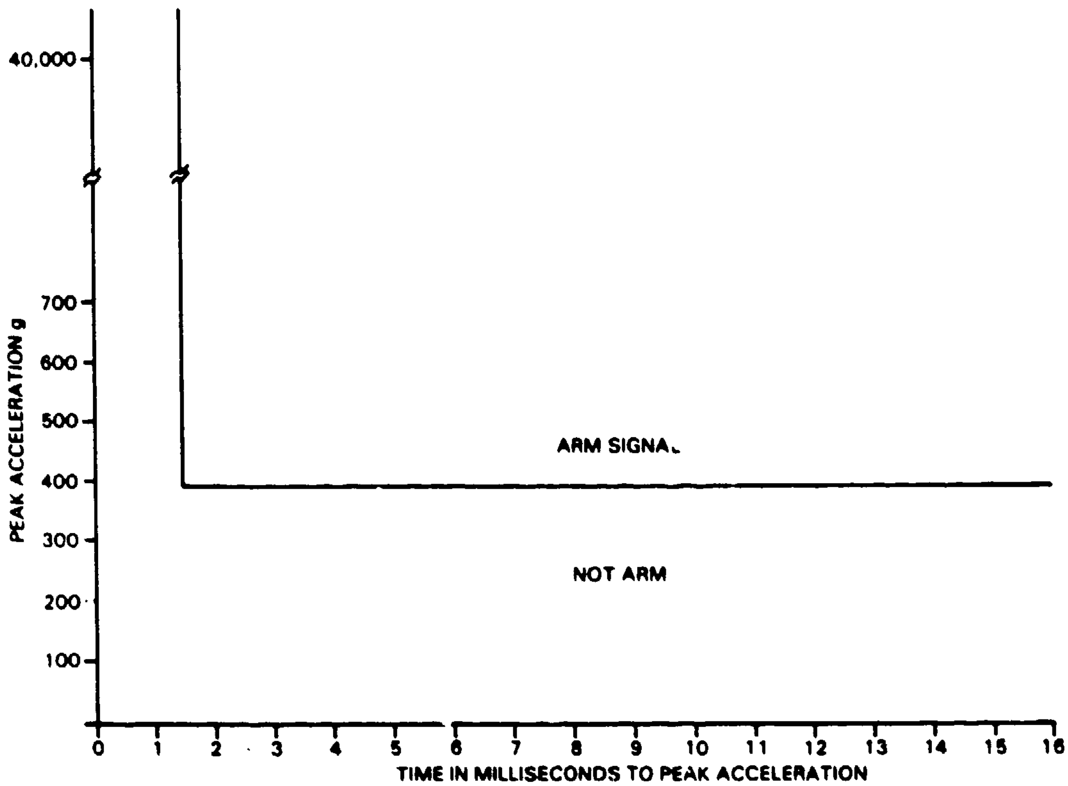

Figure 37. EBM Setback Acceleration Response (9/22/80)

An electrical circuit designed to perform these four functions is shown in figure 38.

The amount of charge produced by the setback sensor crystal is determined by:

$$Q = d\,m\,a \qquad 5)$$

where m = mass undergoing axial acceleration (kg),

a = axial acceleration of the projectile (m/second^2), and
d = piezoelectric constant (coulombs/newton).

In the sensor, once the physical configuration is determined, the charge that is available is fixed. The system is designed such that the minimum force derived from the setback environment will produce a sufficient charge to reach the threshold voltage of the zener diode reference,

$$Q = (C_L + C_S) V_Z \quad 6)$$

That insures that the charging rate of the discriminator circuit is independent of setback amplitude and variations of the piezoelectric constant, d.

During the setback environment, the voltage across the crystal and load capacitor reaches the designed zener voltage, V_Z. The voltage on the load capacitor attempts to charge to this voltage as long as a sufficient charge is generated for both capacitive loads:

$$Q = V_Z (C_L + C_S) \quad 7)$$

When the acceleration begins to decrease, charge production decreases and when the voltage on the sensor capacitor, V_S, is equal to the load voltage, V_L, the charge transfer ceases. At this point, if the load voltage has not reached the gate threshold voltage, the logic function will not switch when power is applied at a later time when the first environment is interrogated. This operation provides for the discrimination of signals. The signal waveforms for two pulses are illustrated in figure 39. Characteristics of the setback environments show the acceleration pulse width a minimum at 1.65 milliseconds. The signal rejected has a pulse width of 1.15 millisecond. This requirement represents the actual case where accidental acceleration durations are shorter than the launch accelerations. It is the time-constant associated with R_sC_s that determines the signals to be accepted. The voltage on the gate of the logic element will remain for a period proportional to the capacitance and gate resistance. Calculations show a memory of 1000 seconds can be obtained. Typical gate input resistance of CMOS is 10^{13} ohms and 100×10^{-12} farads = 1000 sec = RC. A resistor may be required to dissipate the energy in a shorter period.

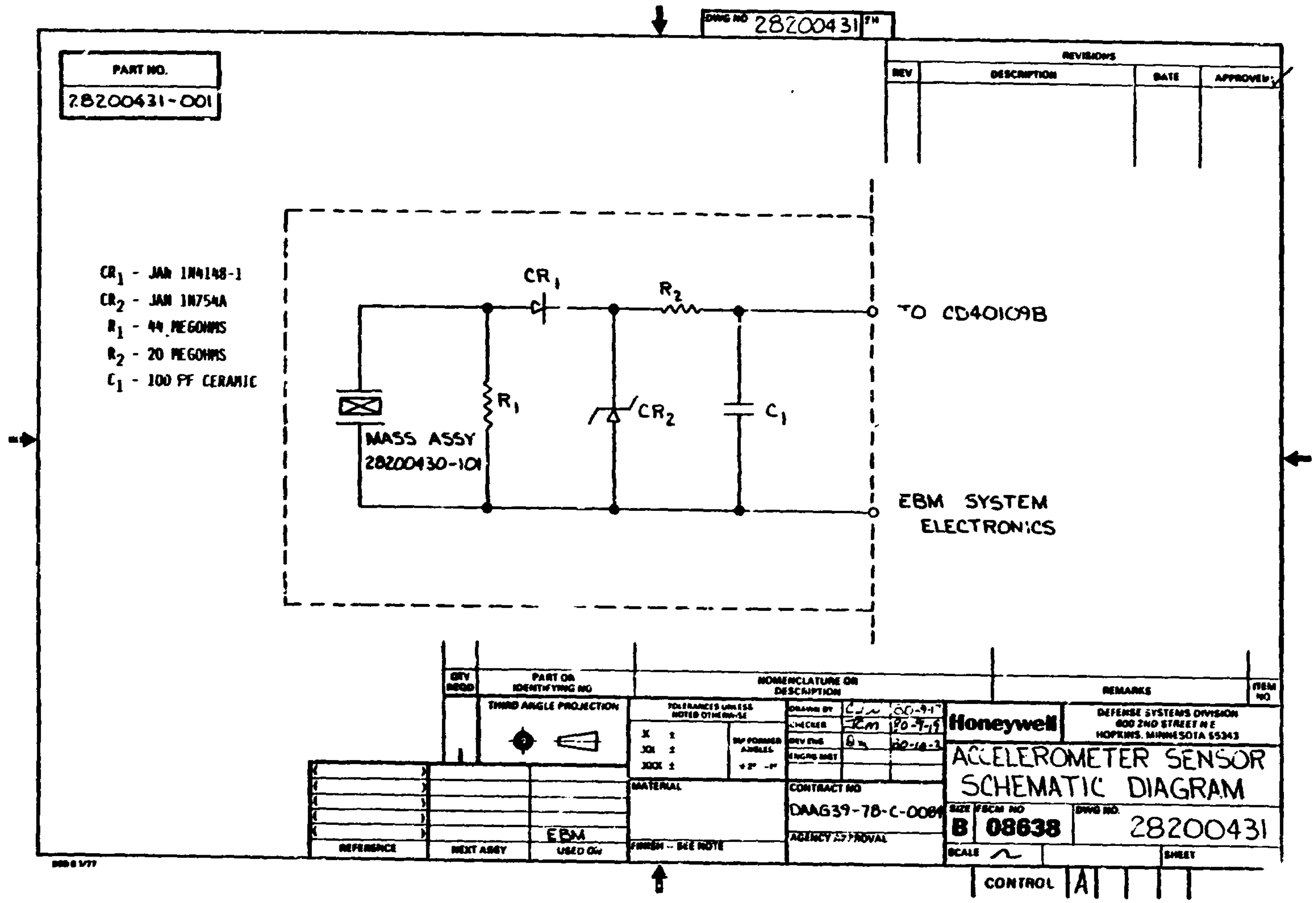

Figure 38. Setback Sensor Electronics Interface Schematic

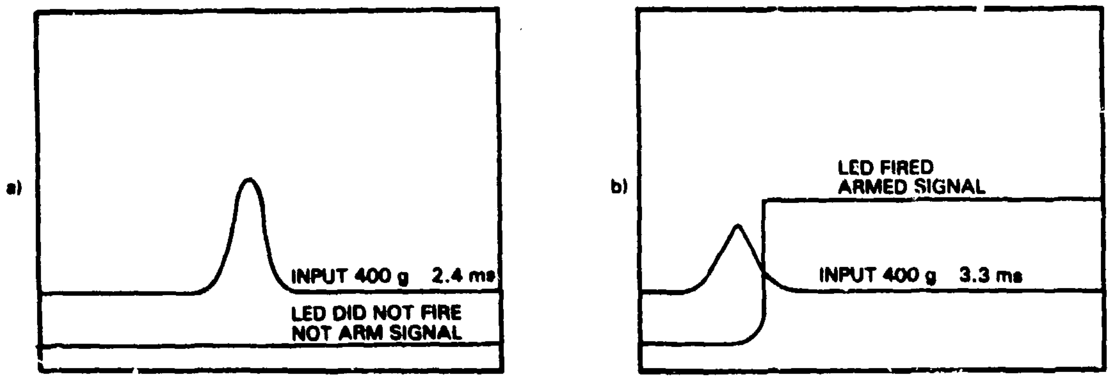

Figure 39. Setback Pulse Width Discrimination

6.4.3.3 Setback Sensor Test and Results -- A setback sensor system was demonstrated with the results closely aligned to the predicted analytical calculations. The discriminator could differentiate between a 1.2 and 1.6 millisecond pulse rise time repeatably when the magnitude at the 1.2 millisecond pulse was twice that of the 1.6 millisecond pulse.

6.4.4 Air Travel Sensor Exploratory Development -- A minor effort of the contract was to explore the feasibility of a projectile air travel sensor. The sensor must be small size and compatible with the Electronic S&A device.

A breadboard sensor was fabricated, tested and delivered. Funding for this portion of the program was diverted to resolve EBM problem areas resulting in only preliminary tests being conducted. Wind tunnel background noise was predominant in both the piezoelectric sensing and acoustic sensing test. These concepts are not feasible for testing in a wind tunnel.

6.4.4.1 Air Travel Sensor Requirements -- The primary requirement is the detection of a projectile in free flight at greater than 200 ft/sec as a signal vs. less than 50 ft/sec as noise. Major changes to the ogive to alter the drag may not be permitted because it effects the projectile trajectory and that will require alteration of the firing tables which would be a major expense.

6.4.4.2 <u>Air Travel Sensor Designs</u> -- Two piezoelectric sensing elements were encapsulated on the inner surface of a XM587 fuze nose cone and wires were extended to the aft end of the fuze as shown in figure 40. One sensor was positioned as recommended in Report Number HDL-CR-77-025-1 for investigation of pressure oscillations in Axis-Symmetric Cavity Flow to obtain a maximum sensitive area on the nose cone at low velocity air flow. The sensor was positioned at 2.15 inches from the flat nose front end. The second sensor was positioned at the bottom of the nose plug cavity. Separate amplifiers were designed and built to couple the high impedance input to the low impedance of a Tanberg tape recorder. Tests were conducted on the bench and in the wind tunnel to determine the background flight noise levels. No definitive signature was obtained which could be identified as air velocity. The wind tunnel background noise exceeded any signature which may have been present.

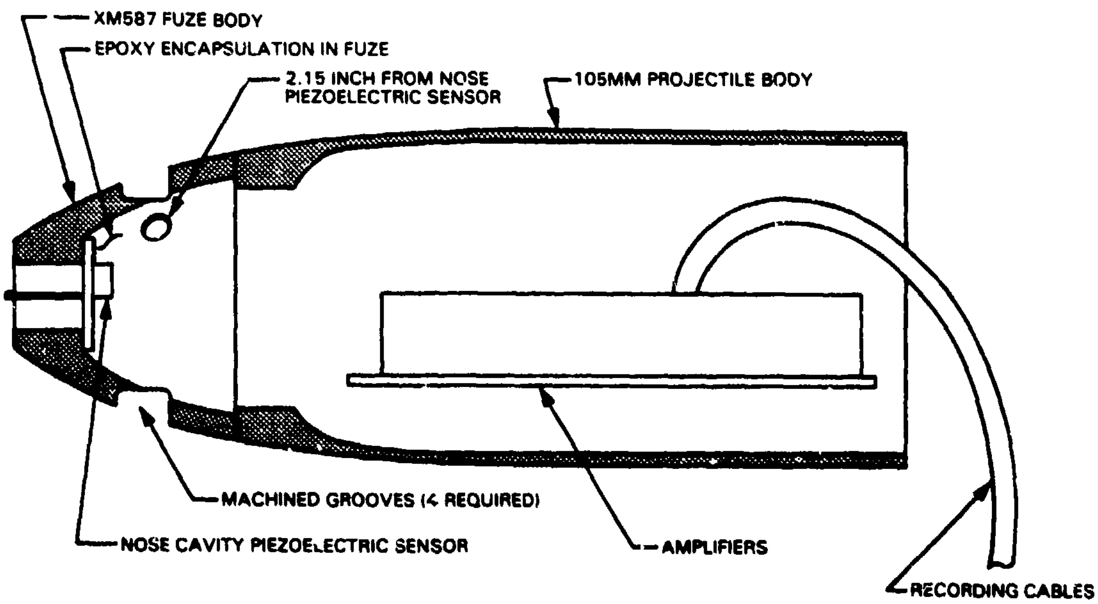

Figure 40. Air Travel Sensor Test Setup

Grooves were machined 0.1 inch deep and at the rear sensor location to increase the signature level. These were tested in the wind tunnel with the same result.

The final test conducted utilized a microphone and amplifiers mounted inside the fuze nose. A 0.125 inch hole with a rigid plastic pipe was used to conduct the sound to the microphone. No discernable change in frequency or significant amplitude change was detected when the tape was monitored on a frequency analyzer over and above the wind tunnel noise.

The funding for this portion of the program was redirected to the EBM.

6.5 Considerations for Sensor Development

With results from these preliminary tests, several items must be considered in developing the air flight sensor. These would include:

- o An absolutely quiet wind tunnel or other free flight method of recording data must be fabricated.
- o The sensor may need to be delicate and mounted on the fuze external surface where it would be subjected to physical abuse during handling and loading into the breech.
- o Configurations or adjustment to the aerodynamics of the projectile which will cause drag or change ballistics which render ballistic table inaccurate must consider the cost of re-establishing and re-issue of adjusted tables.
- o The free flight characteristic may be so unique it cannot be tested in a laboratory or in production without firing the sensor from a gun. This could make it difficult to obtain data and inspect the product in manufacturing.

7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations result from our study. The EBM is certainly feasible, but the major problem centered on the charge used to position the mechanical elements and problems directly related to this area of fuze development.

1. The EBM design provides an effective barrier between the primary and secondary explosive.

2. The EBM concept appears feasible with more than adequate safety for fuzing systems.

3. The physical containment of the charge pressure needs better confinement to prevent charge to charge propagation. The feasibility program perhaps over stressed low cost in production rather than demonstrating the working solution of the concept. The reliability of the EBM was not adequately demonstrated.

4. The output of the EED is the variable not specifically controlled in the EBM. The volume of the charge does not represent adequate control.

5. The electronics and EBM overlap the sequence function of the bolts and provide assurance against non-sequential firing.

6. The electronic element breadboard met all the requirements of the program. Further development could reduce the components to their smallest packaging configuration.

7. Miniature sensors are one of the top priorities of most fuzing developments. Monitoring the state of the art will provide expandable concepts for further development in specific environments.

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