

DEVELOPMENT OF RF-INSENSITIVE ELECTRIC PRIMERS

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ABSTRACT

The Naval Surface Warfare Center, Dahlgren Division (NSWCDD), is the lead technical activity in an effort to develop electric primers which are insensitive to radio frequency (RF) energy. The program is specifically directed at solving the Navy's worst Hazards of Electromagnetic Radiation to Ordnance (HERO) problem, 20 mm ammunition used with the PHALANX Close-In Weapon System (CIWS). The technical approach highlights a novel semiconductor device, which is used as an ignition element for the primer. By eliminating the need to ignite the mix directly with the firing voltage, it is possible to replace the electrically sensitive mix with a less sensitive, non-conductive mix. This significantly reduces the risk of initiation from stray RF energy. Results from direct current (DC) firing, RF sensitivity, and interior ballistics tests are very encouraging. RF-insensitive electric primers will greatly improve the safety of electrically primed ammunition without the need to limit the emissions of critical shipboard surveillance and communications equipments.

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1.0 BACKGROUND

The incompatibility of electrically initiated ordnance with radiated electromagnetic environments (EMEs) poses an enormous safety problem for the U.S. Navy. This problem is most severe during shipboard operations as ordnance is transported and/or handled while being exposed to high levels of radiation from radars and communications equipments. The Navy's concern for the Hazards of Electromagnetic Radiation to Ordnance (HERO) problem is evidenced by the vast amount of resources that are expended annually to reduce the possibility of a HERO accident. Much of this effort is concentrated on measuring EMEs at selected ship and shore station ordnance operating areas and on assessing the sensitivity of specific weapon systems/ordnance to those environments. Another important part of the HERO program is concerned with what might be called "protection engineering", i.e., the application of effective design practices and hardening technologies¹. This effort includes participation in design reviews and consulting with manufacturers to ensure that good grounding, shielding, and filtering techniques are incorporated. For ordnance which employs bridgewire type electroexplosive devices (EEDs), such techniques, when used properly, generally provide adequate protection against even the most severe EMEs found aboard U.S. Navy ships. The result is HERO SAFE ordnance, which can be handled aboard ship without the need to limit the output of critical radar and communications transmitters.

However, the M52A3B1 Electric Primer represents a type of EED so sensitive to RF energy that no intrinsic measures have been developed that provide adequate protection against accidental initiation. When configured in MK 149 PHALANX Close-In Weapon System (CIWS) ammunition (Figure 1), these conductive composition primers constitute the root cause of a severe HERO problem. The problem is exacerbated because:

- (a) The primers are extremely sensitive to RF energy across a wide frequency range.
- (b) PHALANX ammunition is found throughout the Fleet as almost all ships have one or more PHALANX systems.
- (c) A combination of emission control (EMCON) and ammunition handling restrictions² are necessary to reduce the risk of RF-induced (accidental) initiation; such restrictions can be detrimental to the ship's warfighting capability.

For these reasons, PHALANX ammunition is widely regarded as the Navy's worst HERO problem.

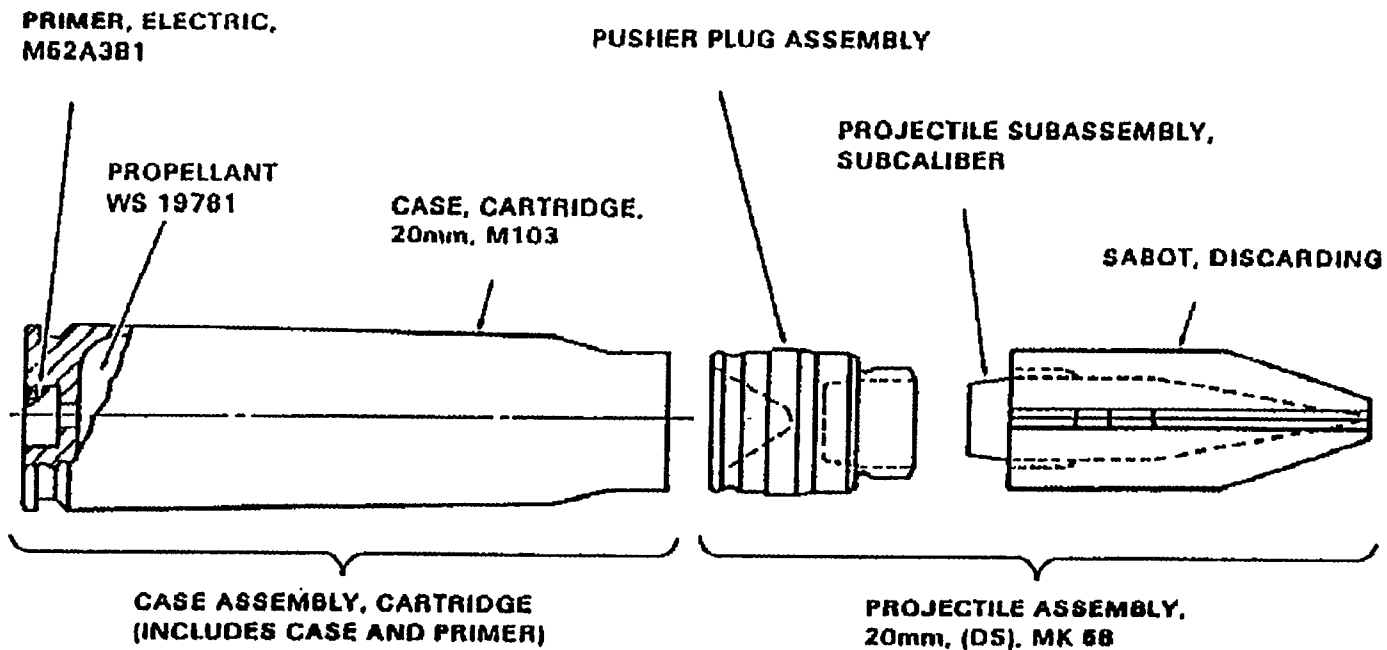


Figure 1. MK 149 Cartridge (with M52A3B1 Electric Primer)

Some measure of protection is afforded by the MK 7 Radiation Hazard (RADHAZ) link. PHALANX ammunition is normally stored and transported in the linked configuration and is de-linked only as it is loaded into the PHALANX ammunition feed system. As shown in Figure 2, each link has a metal tab which extends across the base of the cartridge and the primer. Preventing physical contact with the primer button is the single most effective protective measure against RF actuation, aside from turning off the sources of the radiation. Unfortunately, the metal tab creates a resonance condition at certain radar frequencies, actually making this configuration more susceptible. In addition, the tab is known to increase the chance of gun jams during loading operations. However, the biggest drawback with this form of protection is that it isn't "built into" the ammunition. Once a cartridge is de-linked, whether it is in the ammunition feed system or outside the gun altogether, there is no way to prevent incidental contact of the primer with conducting objects; such contact greatly increases RF pickup into the primer much like a receiving antenna enhances the pickup to an FM radio. Bare or loose cartridges can be actuated at very low radiation levels if the primer is touched or even brought close to electrically conductive objects, e.g., screwdrivers, components of the gun system feed system, fingers, etc. The most reliable form of protection does not depend on links, shrouds, enclosures, or other external hardware - intrinsic protection is clearly the best way to ensure the safety of electrically primed ammunition.

In the past, attempts to develop a "HERO SAFE" primer were unsuccessful because of failure to achieve an adequate level of RF protection or because the primer's firing reliability had been compromised. More recently, however, the Navy has employed semiconductor technology to develop an RF-hardened primer that also satisfies firing reliability requirements. This paper will describe the approach and summarize the positive test results to date.

2.0 THE SEMICONDUCTOR IGNITOR PRIMER

2.1 Hardening Design Concepts

The RF-insensitive primer is best explained as a modification to the existing M52A3B1 design, which is illustrated in Figure 3. The firing voltage (from the firing pin) is applied to the brass button, and ground return is provided through the brass primer cup, which is common with the cartridge case. The firing circuit's capacitive discharge current thus flows directly through the conductive FA 874 explosive mix. The extreme electrical sensitivity of the mix accounts for the very low firing

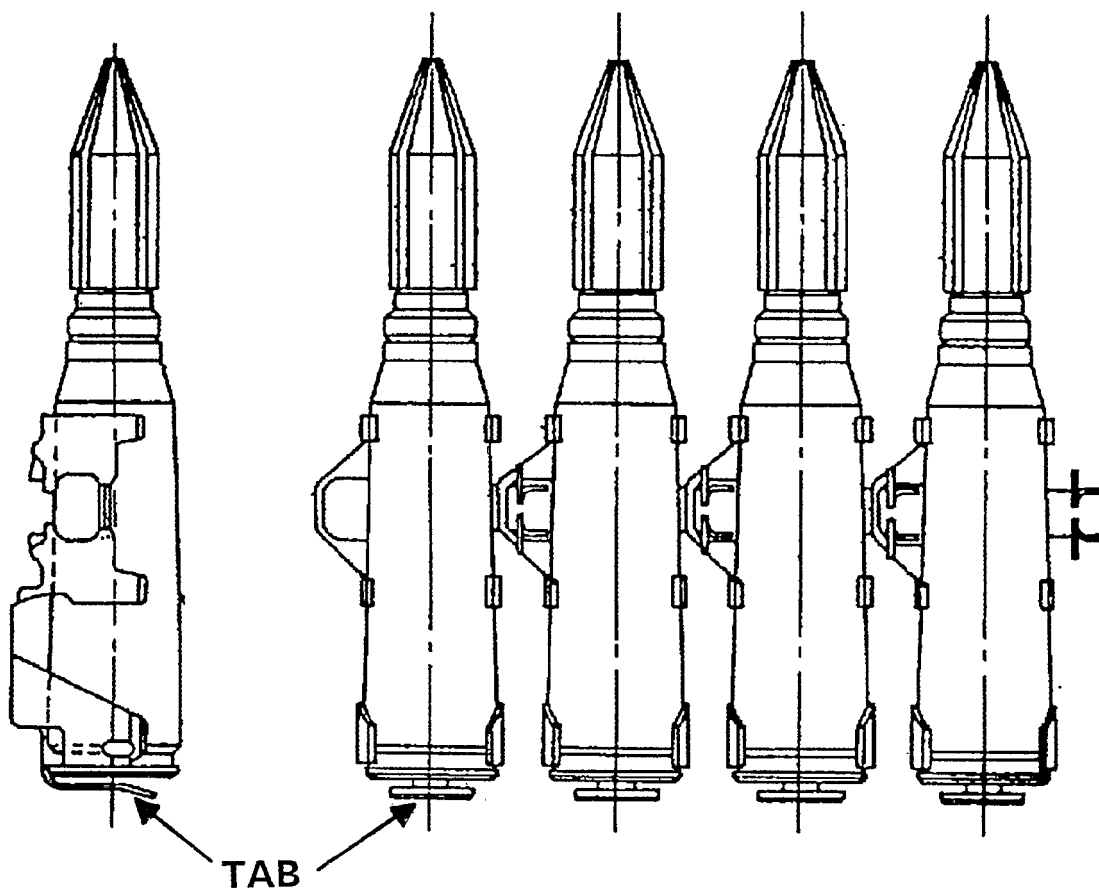


Figure 2. MK 7 RADHAZ Links

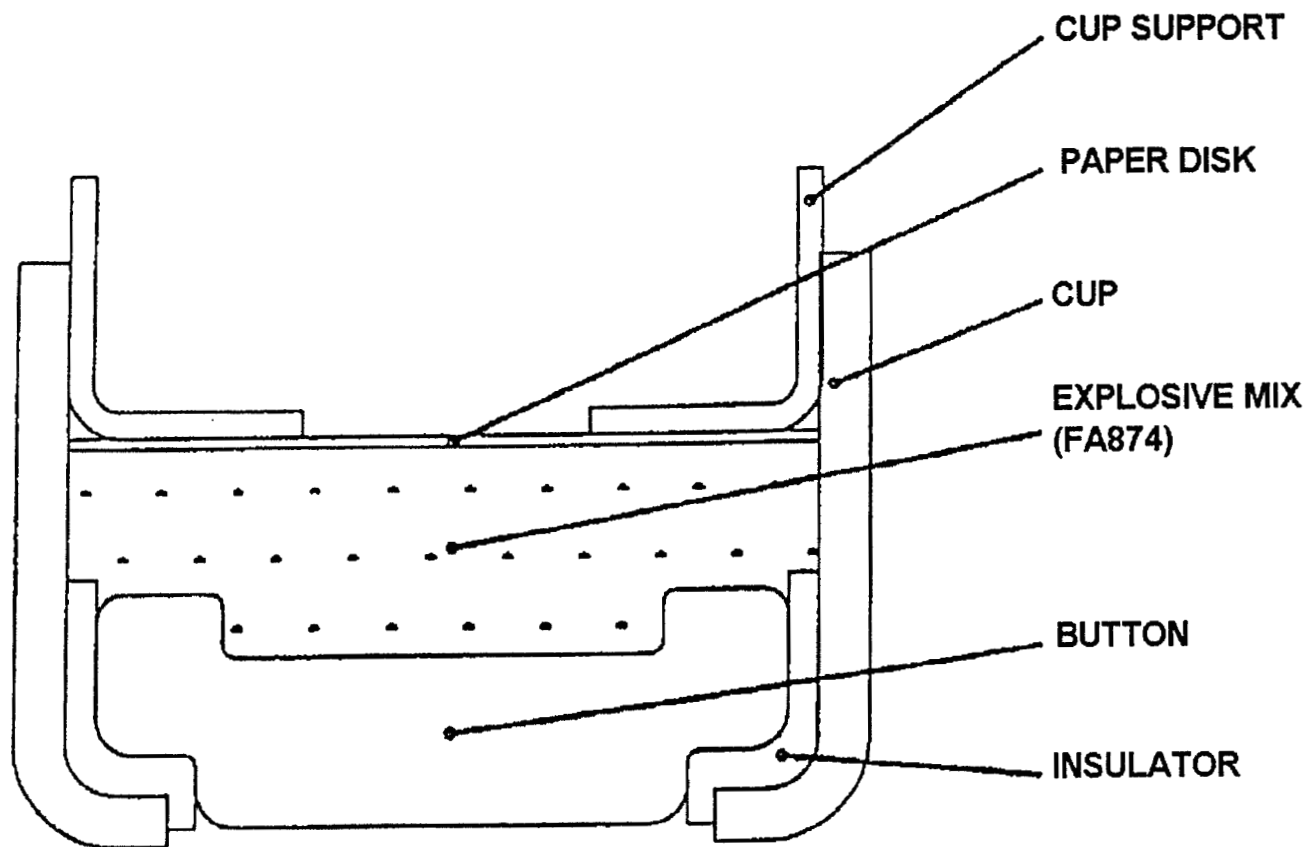


Figure 3. M52A3B1 Electric Primer

energy threshold, less than 50 mJ, which promotes a high degree of (DC) firing reliability. Unfortunately, the mix cannot discriminate against stray RF energy and is subject to unintentional initiation if such energy propagates from various shipboard emitters to the primer. Conceivably, the primer could be desensitized by blocking the flow of RF energy into the mix; however, the method(s) used must not interfere with the path for (legitimate) DC firing voltages. An alternative is to simply replace the FA 874 with another mix that is less sensitive to RF energy, e.g., a non-conductive composition like the type used in percussion primers. The problem then becomes how to ignite this electrically insensitive mix with the relatively low firing energy available. A novel device called a Semiconductor Ignitor (SCI) provides a solution to the problem. This semiconductor "chip", conceived by Dr. Tom Baginski of Auburn University³, was designed as an electrothermal transducer to convert a low energy electrical discharge into a thermal impulse, capable of igniting most primary explosives. The device itself is inherently immune to the adverse effects of RF energy and will "trigger" only at a specified DC voltage threshold; thus it also discriminates against both RF and sub-threshold DC (or low frequency) voltages. By semiconductor industry standards, the SCI is a rather simple device, easy to manufacture and reasonably inexpensive in high volume production.

2.2 The SCI: Construction and Theory of Operation

The physical construction of the SCI is illustrated in Figure 4. Although the SCI is large compared to most semiconductor devices, it is small enough to fit into the M52A3B1 primer body. The electrical design (shown in Figure 5) consists of two diodes, one at the top of the chip (the cathode) and one at the bottom (the anode). The diodes are configured in a back-to-back arrangement, so that when a voltage is impressed across the device, the bottom diode is forward biased and the top diode is reversed biased. When a sufficiently high voltage is impressed across the device, current will flow with the characteristic current/voltage relationship shown in Figure 5. Returning to Figure 4, it can be seen that the top diode area is very small compared to the bottom diode area; the result is a highly concentrated current flow at the top center region of the chip as depicted in Figure 6a. Typical gun firing circuits provide more than enough capacitive discharge energy to melt the aluminum metallization at the top surface as shown in Figure 6b. The melting temperature of aluminum (660 degrees Centigrade) exceeds the ignition temperatures of most explosives (250-600 degrees Centigrade). Thus, as an electrothermal transducer, the chip is an excellent candidate as an ignition element for EEDs.

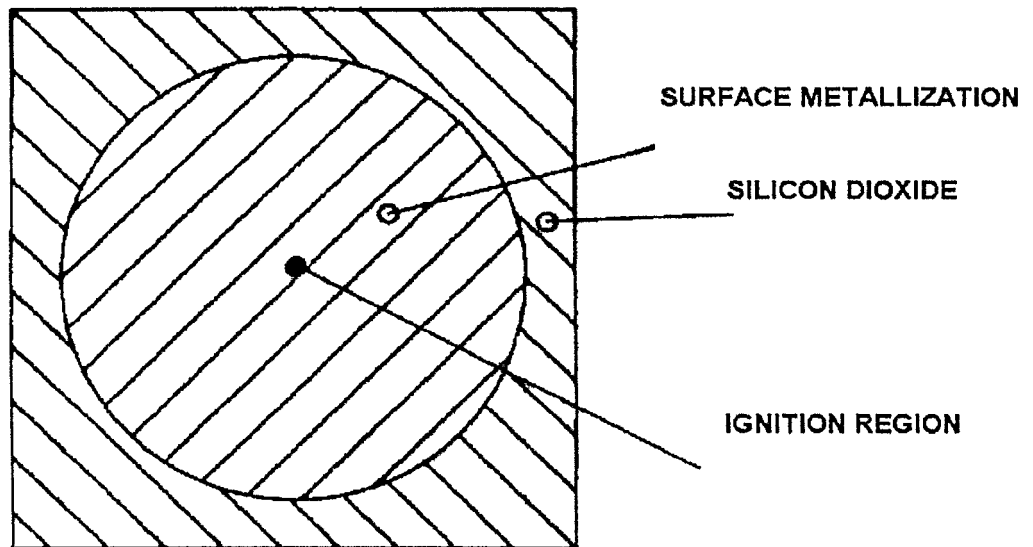


Figure 4a. Top View SCI

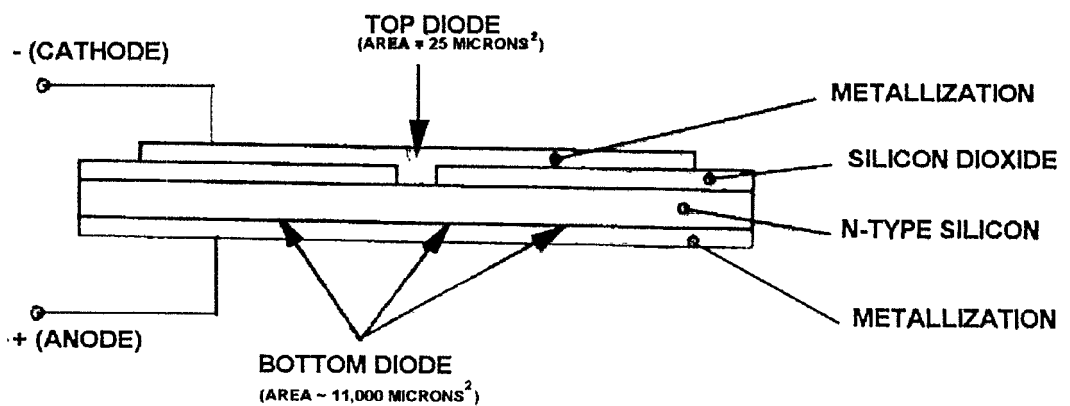


Figure 4b. Cross Section of SCI (not to scale)

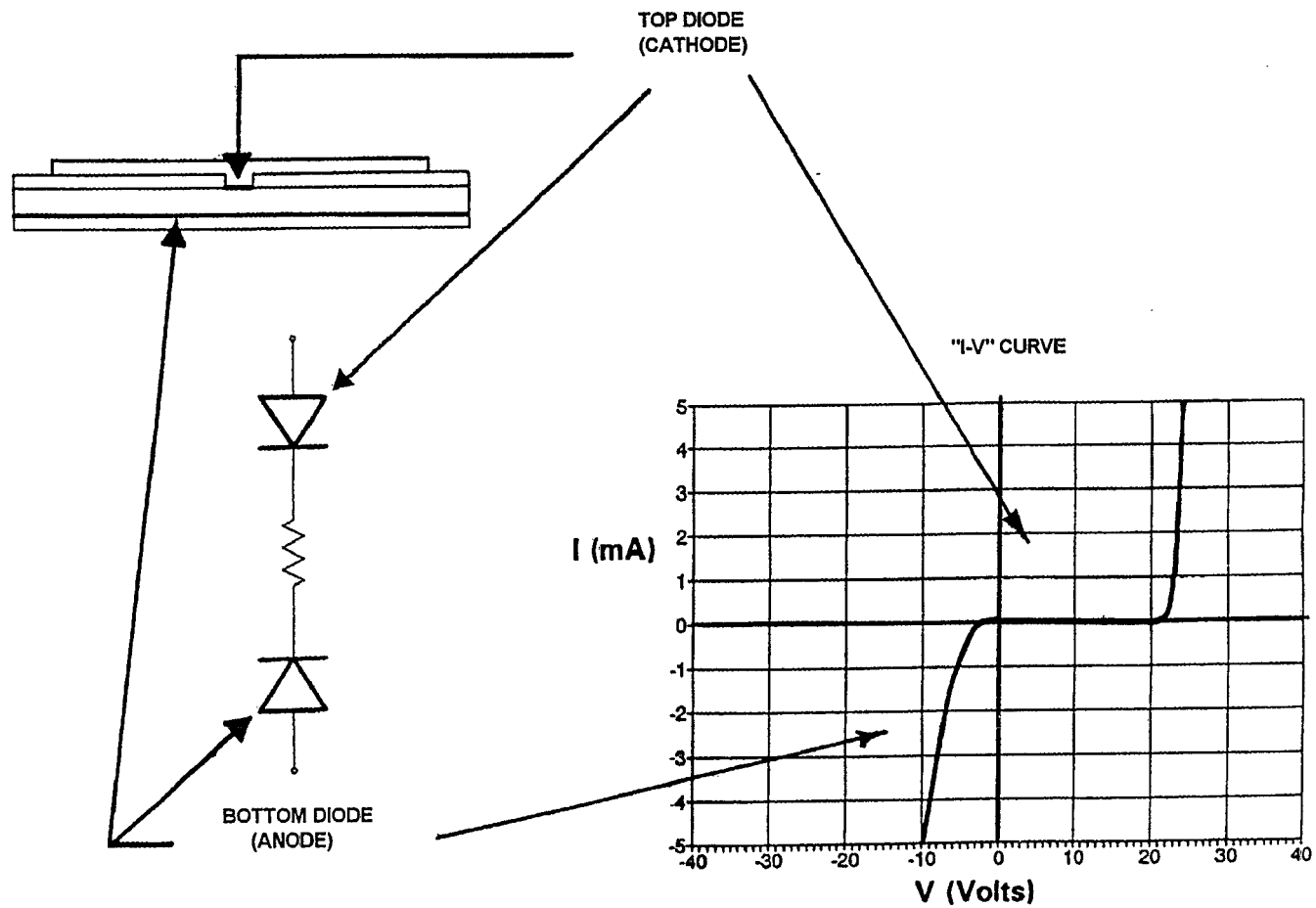


Figure 5. SCI DC Characteristics

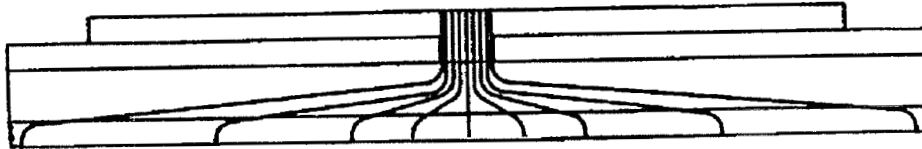


Figure 6a. Current Concentration at Top Diode

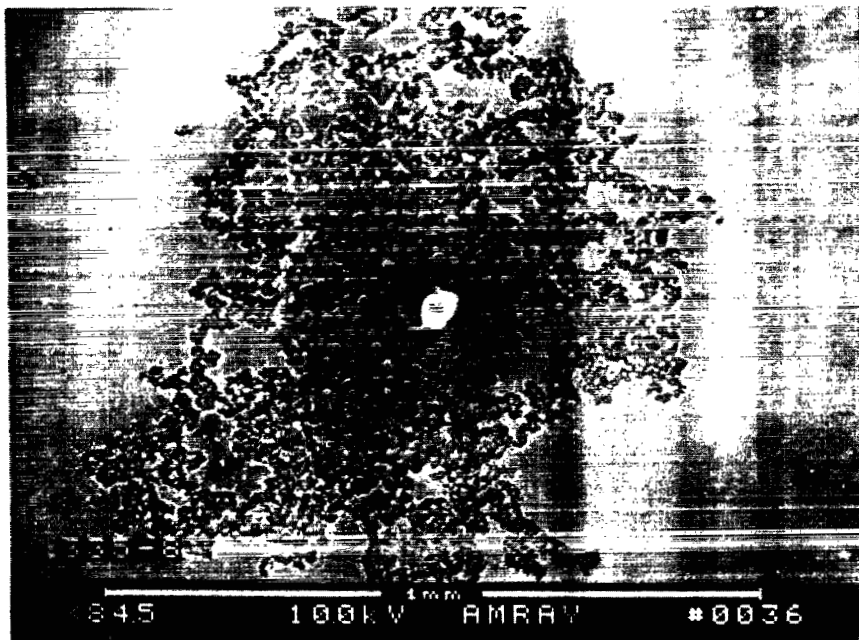


Figure 6b. Surface Metallization Melting at Top Diode Region

Equally important is the RF immunity offered by the SCI. Figure 7 depicts the device as essentially capacitive at RF, which means that as RF currents flow across the device, there is little real power absorbed, i.e., there is little heat generated. Of course, in practice it is impossible to build a purely capacitive device, particularly at microwave frequencies. There are semiconductor substrate resistances and parasitic inductances and resistances associated with the interconnection elements and other primer components. The associated resistances are undesirable as they will absorb RF power and generate heat. Fortunately, most of the primer components are good thermal conductors (as is the cartridge case), and there is good thermal contact between the chip and the primer cup; this natural heat-sinking system counters the heat buildup by conducting the heat away from the chip-mix interface.

2.3 Integration of the SCI into the Primer

As shown in Figures 8 and 9, the SCI is integrated into the primer between the button and the explosive mix. Electrical contact must be established between the bottom of the SCI and the primer button (primer anode) and between the top of the SCI and the primer support cup (cathode). Conductive epoxy is used for this purpose. The most recent integration schemes use a paste type epoxy at the bottom and a pre-formed epoxy washer at the top, both of which are cured at elevated temperatures (150 degrees Centigrade). Thin, electrically insulating outer washers at the top and bottom prevent shorting and provide a cushion for the SCI when the epoxy is cured and when the explosive mix is consolidated into the assembly under high pressure.

2.4 Prototype Primers

The development of RF-insensitive primers has relied heavily on building and evaluating a series of prototype lots. The iterative design/build/modify approach began with a "pre-prototype" lot to resolve basic engineering issues and has since included two additional prototype lots. These latter two prototype lots have been a crucial element in the assessment of basic performance and the impact of minor changes to the chip design and primer assembly, specifically by helping to:

- (a) Select the best materials for certain primer components,
- (b) Identify and solve primer assembly problems,
- (c) Provide samples needed for performance testing, and
- (d) Identify and solve problems related to quality assurance.

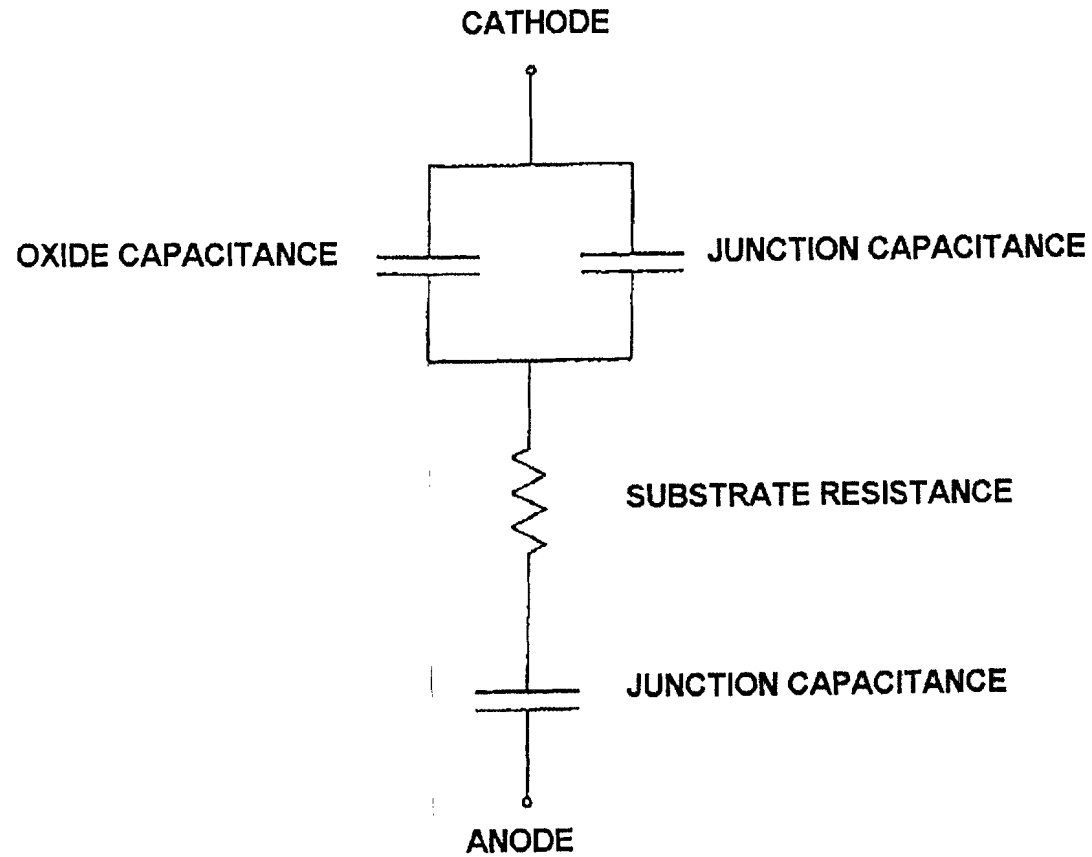


Figure 7. SCI RF Equivalent Circuit

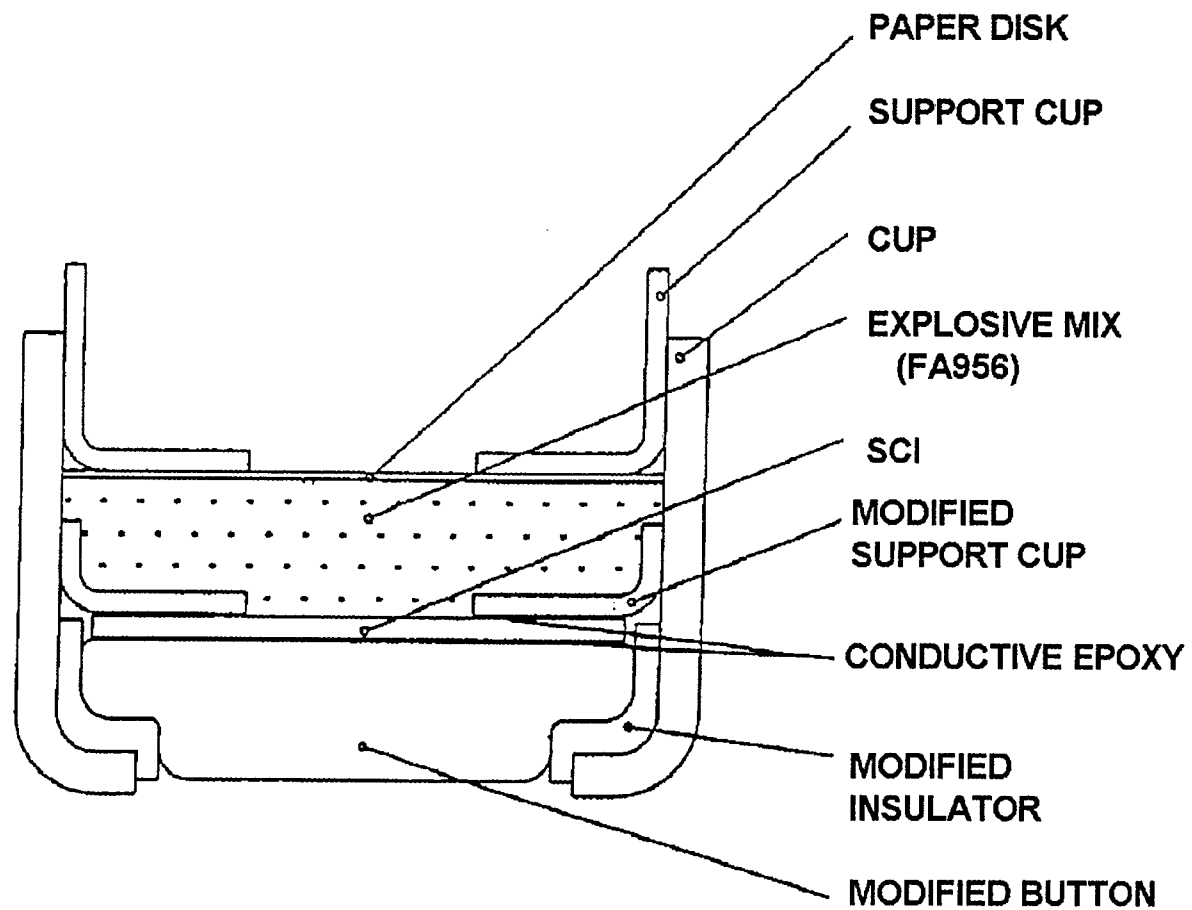


Figure 8. Semiconductor Ignitor (SCI) Primer

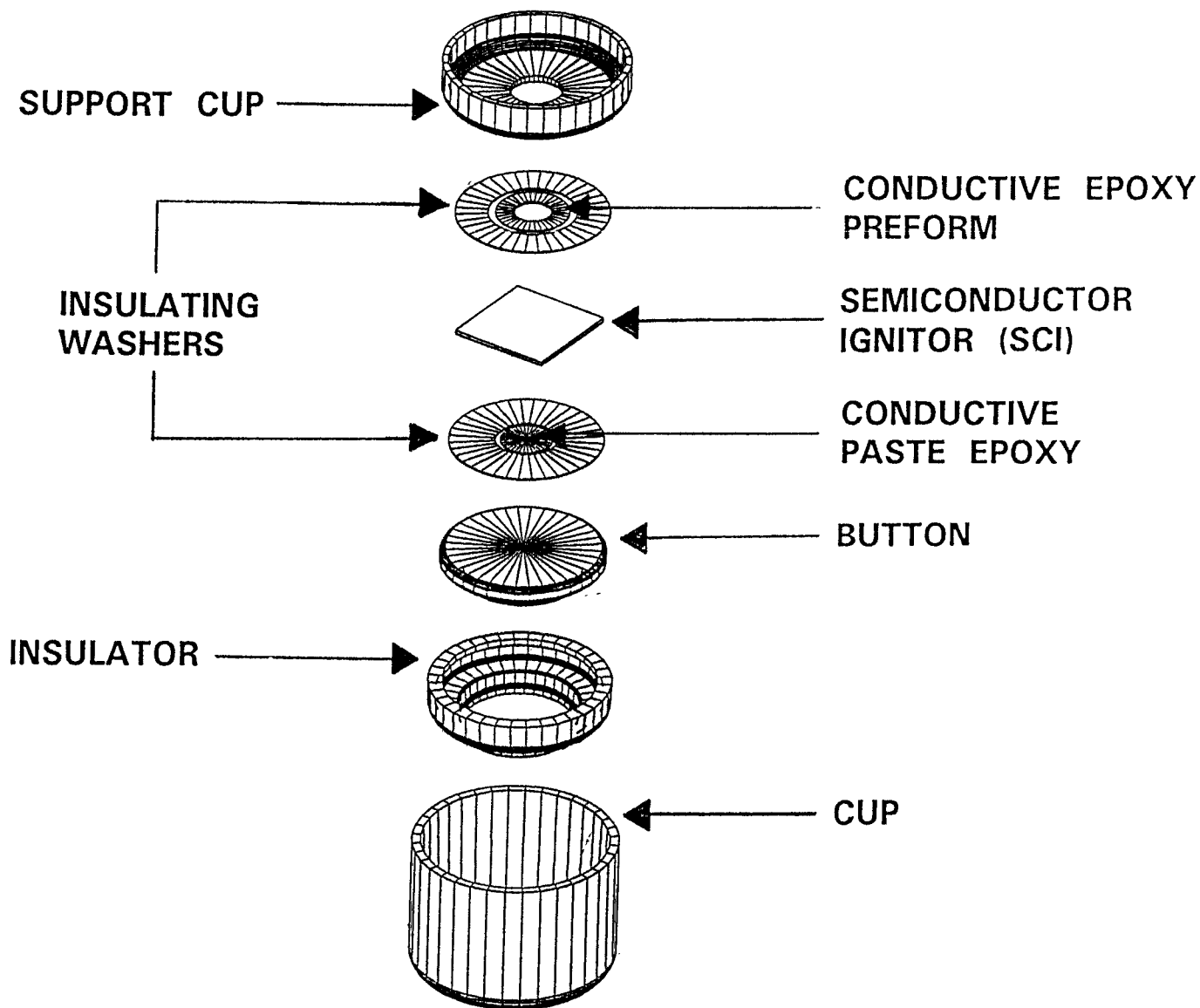


Figure 9. SCI Primer Subassembly (Exploded View)

A technical team was established, consisting of specialists from various Department of Defense (DOD) laboratories, the primer manufacturer, and support contractors, to be the driving force for prototype development. This team has been responsible for identifying and resolving design and assembly problems, overseeing the fabrication of the prototype lots, and evaluating the performance of the SCI primers/cartridges. The team's ultimate goal is to finalize a primer design which is both practical for high volume production and satisfies the performance requirements for PHALANX ammunition⁴. Table 1 identifies the team members and their respective responsibilities.

Table 1. Technical Team

TEAM MEMBER	RESPONSIBILITY
NAVAL SURFACE WARFARE CENTER DAHLGREN DIVISION	LEAD LABORATORY SCI INTEGRATION RF TESTING
NAVAL SEA SYSTEMS COMMAND PHALANX PROGRAM OFFICE (PMS-413)	PROGRAM DIRECTION TECHNICAL REVIEW
HARRY DIAMOND LABORATORIES	SCI DESIGN PROTOTYPE SCI FABRICATION FAILURE ANALYSIS
NAVAL SURFACE WARFARE CENTER INDIAN HEAD DIVISION	PRIMER DESIGN/ASSEMBLY/TEST DOCUMENTATION
OLIN CORPORATION	PRIMER DESIGN PRIMER MANUFACTURER
AT&T (KANSAS CITY)	PROTOTYPE SCI FABRICATION SCI INTEGRATION
DEFENSE TECHNOLOGY, INC BOOZE-ALLEN & HAMILTON EG&G	SUPPORT CONTRACTORS

Details concerning the construction and evaluation of the Pre-Prototype and Prototype Lots follow.

2.4.1 Pre-Prototype Lot

Fabricating and evaluating the Pre-Prototype Lot helped the technical team resolve specific concerns about primer assembly procedures and the choice of materials and dimensions for certain primer components. In addition, there were questions about the choice of a non-conductive explosive mix to replace the FA 874 as well as the optimum mix consolidation pressure (pressure at which the mix is pressed onto the SCI during primer charging). Besides helping the technical team resolve these engineering issues, the Pre-Prototype Lot demonstrated that SCI primers could be produced by the primer manufacturer with the same production equipment used for M52A3B1 production. A total of 240 cartridges, consisting of eight combinations of mix type and consolidation pressure, were built and evaluated; Table 2 summarizes this Pre-Prototype Lot matrix. The two candidate percussion mixes, FA 956 and 5061, were selected on the basis of their relative insensitivity to RF energy (compared to the FA 874 composition) and, as a practical matter, their availability at the primer manufacturing site.

Table 2. Pre-Prototype Lot Matrix

MIX TYPE	MIX CONSOLIDATION PRESSURE (PSI)			
	2000	3000	4000	5000
FA 956	GROUP A	GROUP B	GROUP C	GROUP D
5061	GROUP E	GROUP F	GROUP G	GROUP H

The choice of consolidation pressure was considered to be a tradeoff between the minimum needed to ensure proper primer explosive performance and a maximum above which the SCI would suffer mechanical stress damage, i.e., fracture during primer charging. Prior to the assembly of the Pre-Prototype Lot, samples of FA 956 and 5061 were subjected to direct injection RF sensitivity testing⁵ at Franklin Research Center, Philadelphia, PA. Both compositions were less sensitive to initiation than FA 874, but with little difference between the two. Other tests showed that there was no appreciable difference in firing reliability or ballistics performance as a function of consolidation pressures between 2000 and 5000 psi. Interior ballistics performance and firing reliability test results were excellent. In summary, the Pre-Prototype Lot helped to establish a baseline SCI primer design. The dimensions of all primer components were finalized, and FA 956 was selected as the explosive mix, consolidated at 4000 psi; the first prototype lot was built to these specifications.

2.4.2 Prototype Lots 1 and 2

Two prototype lots of SCI primers and cartridges have been fabricated and evaluated thus far. Both lots were built under contract by Olin Corporation and were provided to the Navy as contract deliverables. The primers were assembled at the Lake City Army Ammunition Plant (LCAAP), Independence, Missouri, and the cartridges were assembled at Olin Corporation's facility at Marion, Illinois. Harry Diamond Laboratories fabricated the SCIs and AT&T, Kansas City Works, was subcontracted to assemble them into inert primer subassemblies. Mix loading and final assembly is accomplished at LCAAP. The prototype lots consisted of 180 inert cartridges (cartridges with live primers but no propellant) and 70 all-up rounds (AURs). These samples were electrically interrogated at various stages of assembly to determine the health of the SCI and the integrity of the connections to the SCI. After final assembly, they were evaluated for firing reliability, RF sensitivity, and ballistics performance.

2.4.3 Firing Reliability Tests

Two types of firing reliability tests have been conducted: static tests in a Mann barrel (Figures 10 a,b) and dynamic firing tests using PHALANX M61A1 gun systems (Figure 11) operating at normal firing rates (3000 or 4500 shots/minute, depending on Block number of the PHALANX system). The primers were configured in inert cartridges, i.e., live primers pressed into cartridges without propellant. Reliability was calculated as the number of successful fires divided by the total number of firing attempts. In both tests a PHALANX Gun Control Unit (GCU) supplied the firing stimulus, a 300 volt discharge from a 3.0 microfarad capacitor through a 60 ohm series current limiting resistor. Table 3 summarizes the firing reliability test results for each of the prototype lots. It was determined that the poor performance of Prototype Lot 2 was due to a component misalignment problem, which occurred during the SCI integration assembly stage. The misalignment allowed arcing to occur within the primer, away from the ignition area, and the associated loss of energy prevented the SCI from functioning properly.

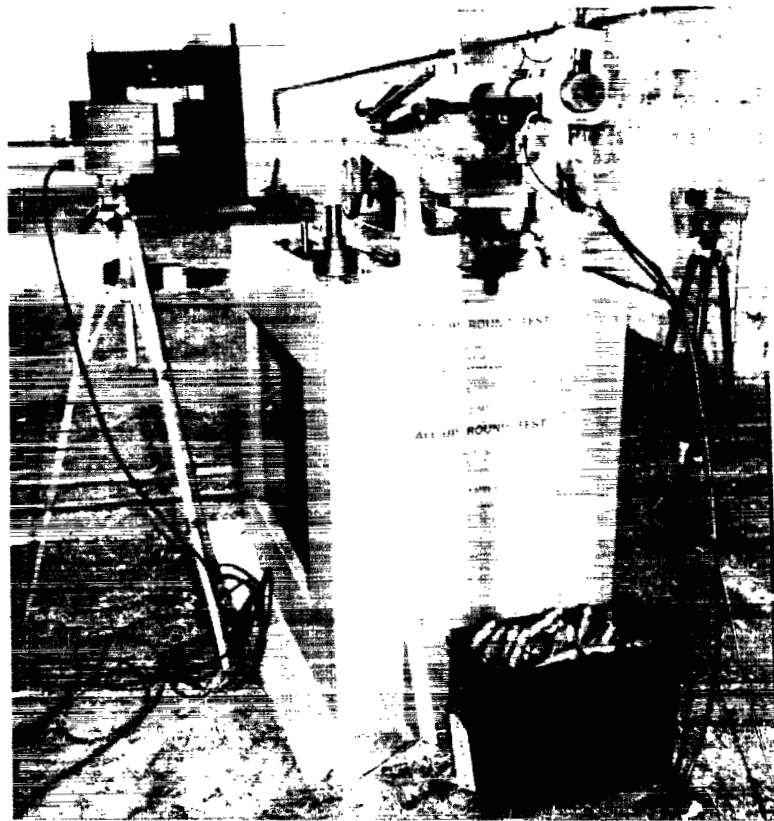


Figure 10a. Ballistic Testing: Instrumented Mann Barrel

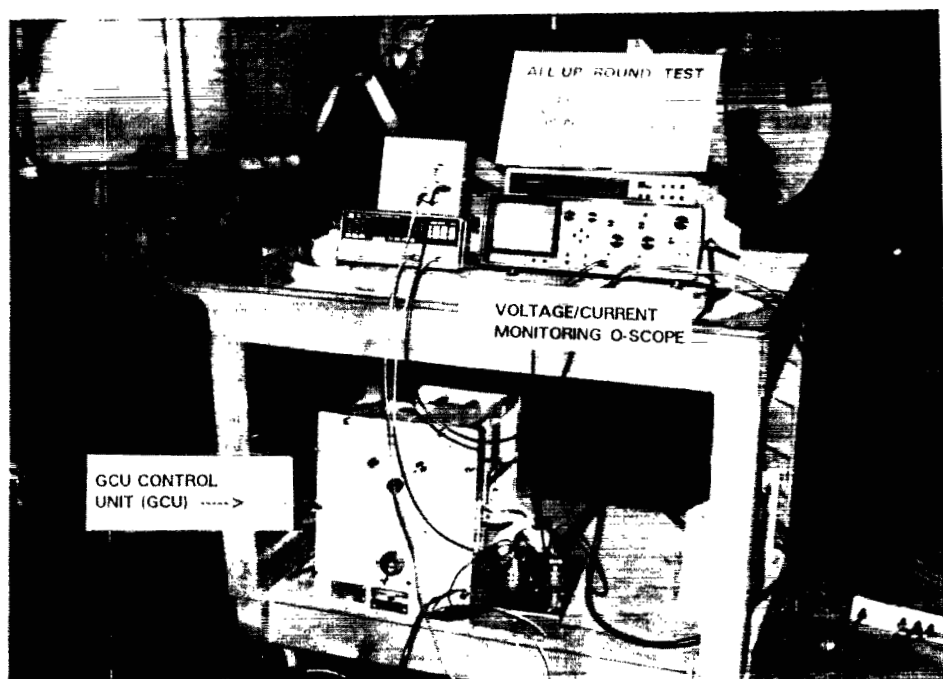


Figure 10b. Ballistic Testing: Firing Circuit/Instrumentation



Figure 11. M61A1 Gun (PHALANX)

Table 3. Firing Reliability Test Results

PROTOTYPE LOT	TYPE TEST	NO. OF ATTEMPTS	NO. FIRED	RELIABILITY (PERCENT)
PRE-PROTOTYPE	MANN BARREL	240	238	99
	PHALANX M61A1	320	317	99
1	MANN BARREL	65	65	100
	PHALANX M61A1	50	50	100
2	MANN BARREL	85	60	71
	PHALANX M61A1	75	55	73

Aside from the problem with Prototype Lot 2, results are very encouraging. Of course, it is recognized that statistical confidence suffers from the small number of samples tested, but there is a strong indication that excellent firing reliability can be achieved.

2.4.4 RF Sensitivity Tests

There are two basic types of primer RF sensitivity tests, conducted (sometimes called direct injection), and radiated. The former is a laboratory test in which a known amount of RF power is matched into the primer. The latter test exposes the primers to very high level radiated RF environments similar to those produced by shipboard radars and communications equipments. Direct Injection tests were very useful for comparing the relative sensitivities of primers made up with different explosive mixes, such as FA 874, 5061, and FA 956. However, in most of the RF sensitivity testing, the primers were exposed to radiated environments similar to those produced by shipboard radars and communications equipments. The objectives of the tests were to:

- (a) Determine if SCI primers, configured in inert 20 mm cartridges, could be initiated when exposed to maximum (worst case) shipboard EMEs, and

- (b) Determine the susceptibility thresholds (minimum EME levels that cause primer ignition) for both SCI and M52A3B1 primers.

Radiated testing was conducted at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) HERO Ground Plane Facility, Dahlgren, VA. The facility, shown in Figure 12, consists of a large (30.5 x 73.2 meter) steel ground plane with radar and communications equipments for generating high intensity radiated EMES. Thresholds were established in terms of either the minimum field strength for High Frequency (HF, 2-30 MHz) environments or power density for radar (200-10,000 MHz) environments. During ground plane testing, there is an emphasis on handling the ammunition in the same manner as would be done aboard ship in the presence of high level radiated EMES. This includes touching the primers to metal objects, loading the cartridges into the PHALANX gun, and cycling the gun as the ammunition feed system is exposed to the RF test environment. Handling procedures tend to increase the coupling of RF energy into the primer; such procedures included:

- (a) Touching the primer to the wing of an aircraft which is being radiated by HF test environments (Figure 13);
- (b) Touching the primer to M61A1 gun barrels (Figure 14); and
- (c) Touching a screwdriver blade to the primer (Figure 15).

Other so-called "presence" tests, which do not involve handling the cartridges, included:

- (a) Two cartridges in a "tip to tail" configuration (Figure 16);
- (b) Cartridges in MK 7 RADHAZ links (Figures 17a,b); and
- (c) Gun cycling, at slow rates (Figure 18).

Previous tests of M52A3B1-primed cartridges at the Ground Plane Facility had provided a data base of "worst case" configurations, i.e., those combinations of frequency, polarization, and handling procedures, where the primers are most susceptible. Cartridges with SCI primers were tested under these same worst case conditions to determine their RF immunity relative to cartridges with M52A3B1 primers. Some of the procedures used in this test were, admittedly, improbable and/or unauthorized for PHALANX ammunition operations. However, these procedures supported the objective of determining how much more RF-resistant the SCI



Figure 12. NSW CDD HERO Ground Plane Test Facility



Figure 13. Primer Touching Aircraft Wing (Note Arcing)

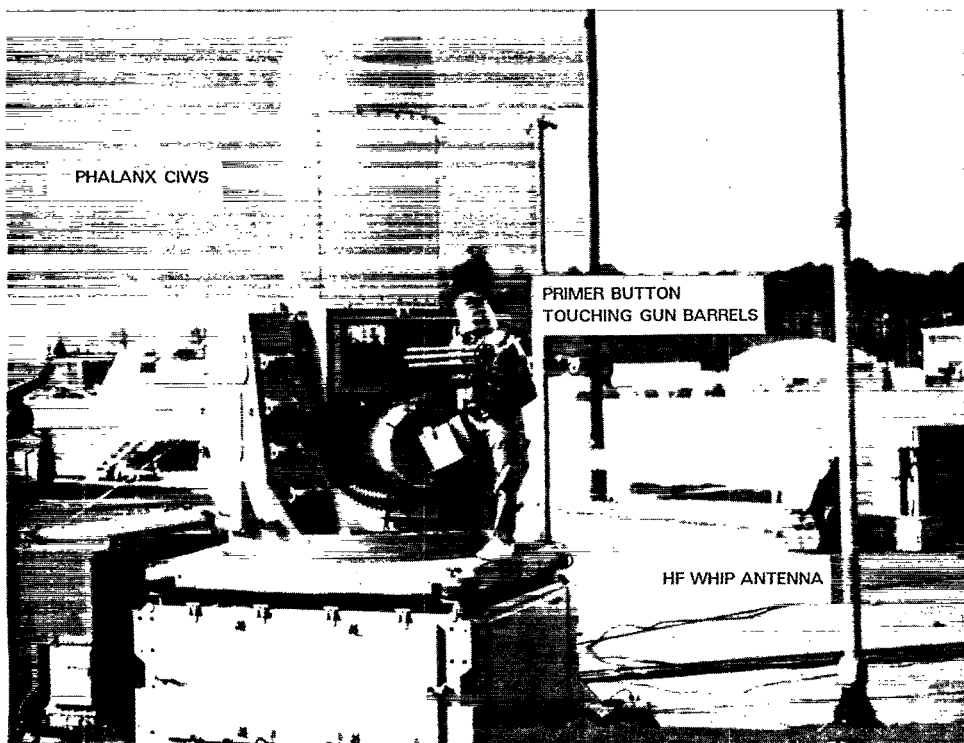


Figure 14. Primer Touching M61A1 Gun Barrels



Figure 15. Screwdriver Touching Primer



Figure 16. Cartridges in Tip to Tail Configuration

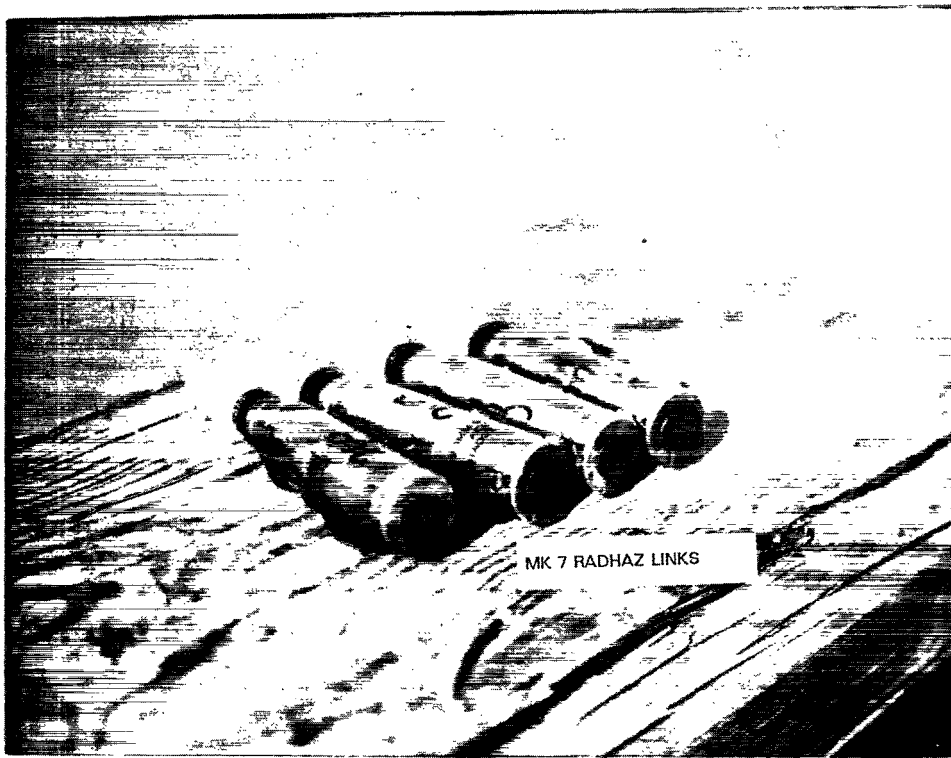


Figure 17a. Cartridges in MK 7 RADHAZ Links



Figure 17b. Cartridges in MK 7 RADHAZ Links (Being Radiated)

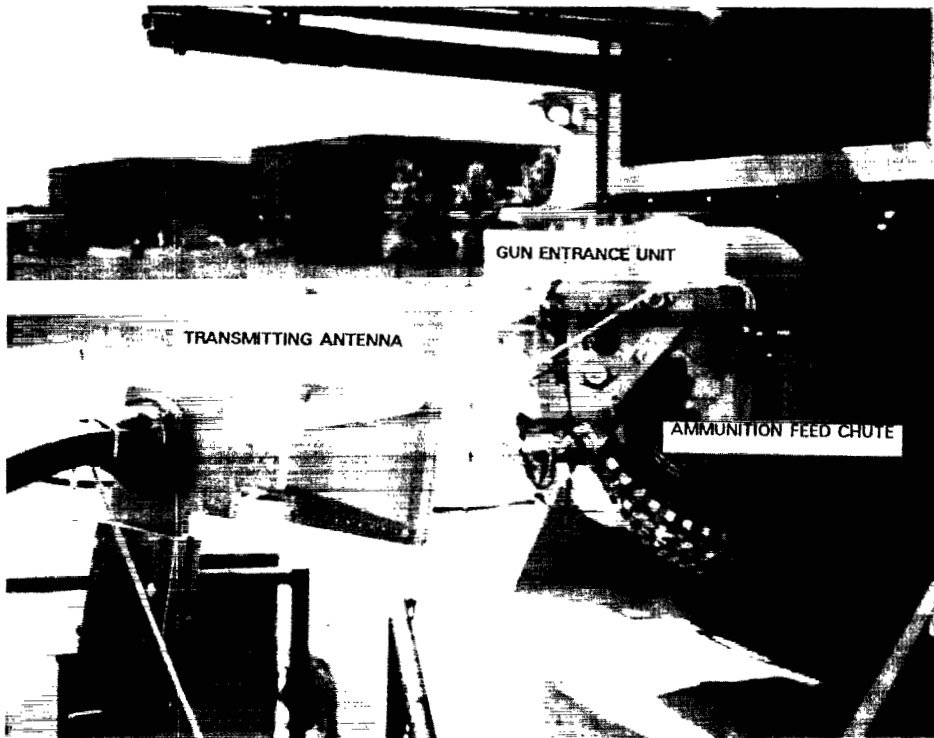


Figure 18. Gun Cycling

primers were than the M52A3B1 primers. For example, in one HF procedure, the primer was touched to the M61A1 gun barrels of a PHALANX system located ten feet from a transmitting HF whip antenna. In this configuration, at some HF test frequencies, arcs were drawn to the primer as it was touched to the tip of the barrels. An even more severe test consisted of touching the primer to the wingtip of an F-4 aircraft located ten feet away from a HF transmitting antenna. This configuration is conducive to the generation of intense arcing to the primer, as seen in Figure 13. Another procedure involved touching a screwdriver to the primer (while being radiated) to simulate inadvertent contact during removal of a jammed round from the ammunition feed system.

Table 4 provides a sample of the radiated susceptibility data (at radar frequencies), comparing the RF susceptibility thresholds for Prototype Lot 1 cartridges to the thresholds of M52A3B1 primed cartridges. As the table indicates, the Prototype Lot 1 primer is much less sensitive to RF energy. Except in one instance at 5650 MHz, no actuation resulted from exposure of the test cartridges at any of the radar test environments. (The one exception at 5650 MHz occurred when the test environment exceeded the HERO certification level specified in MIL-STD-1385B, and that actuation occurred only when a screwdriver was touched directly to the primer.

**TABLE 4. RADIATED SUSCEPTIBILITY OF PROTOTYPE LOT 1 CARTRIDGES AT RADAR FREQUENCIES
SUMMARY OF NSWCCD HERO GROUND PLANE TEST THRESHOLDS**

FREQ (MHZ)	MODULATION		MAX EME (MW/CM ²)		AVERAGE THRESHOLDS ¹ (MW/CM ²)			PEAK THRESHOLDS ¹ (MW/CM ²)			TEST CONFIGURATION
	PRF (Hz)	PW (uSEC)	AVG	PEAK	M52 ²	PROTO 1	DELTA ³ (DB)	M52 ²	PROTO 1	DELTA ³ (DB)	
215	310	20	20	3.2K	2.0	> 20	> 10	0.32K	> 3.2K	> 10	PRESENCE: TIP - TAIL
410	300	33	50	5.1K	2.5	> 50	> 13	0.25K	> 5.1K	> 13	PRESENCE: TIP - TAIL
1300	150	1.0	12	80K	6	> 12	> 3	40K	> 80K	> 3	SCREWDRIVER ON PRIMER
2875	1000	1.0	400	400K	100	> 400	> 6	100K	> 400K	> 6	SCREWDRIVER ON PRIMER
5650	1000	1.0	400	400K	200	> 600	> 4.8	200K	> 600K	> 4.8	GUN CYCLING EXPOSURE
5650	1000	1.0	600	600K	100	600	7.8	100K	600K	7.8	SCREWDRIVER ON PRIMER
7800	1000	1.0	150	150K	75	> 150	> 3	75K	> 150K	> 3	IN MARK 7 RADHAZ LINKS
7800	200	0.5	18.2	182K	4.6	> 18.2	> 6	45.5K	> 182K	> 6	IN MARK 7 RADHAZ LINKS

NOTES:

- (1) THRESHOLDS ARE MINIMUM POWER DENSITIES AT WHICH AT LEAST ONE PRIMER FIRED, UNDER WORST CASE TEST CONFIGURATIONS. A ">" INDICATES THE PRIMER DID NOT FIRE AT THE MAXIMUM TEST ENVIRONMENT GENERATED; THE ACTUAL THRESHOLDS ARE THUS HIGHER THAN ANY LEVELS PRECEDED BY A ">".
- (2) M52A3B1 THRESHOLDS ARE DETERMINED FOR THE PURPOSE OF ESTABLISHING A REFERENCE (BASELINE) SUSCEPTIBILITY THRESHOLD.
- (3) A COMPARISON BETWEEN M52A3B1 AND PROTOTYPE LOT 1 THRESHOLDS, TERMED "DELTA", IS CALCULATED AS:
10 LOG (PROTOTYPE LOT 1 THRESHOLD / M52A3B1 THRESHOLD).

2.4.5 Primer Output Tests

Primer output tests were conducted at the Naval Surface Warfare Center, Indian Head Division⁶, to compare performance of M52A3B1 and Prototype Lot 1 primers. One of the concerns was that the SCI primer, loaded with FA 956, might be too brisant for the propellant used in the MK 149 cartridge since FA 956 contains PETN. It was theorized that similar energetic yields from the two primers would produce equivalent cartridge ballistic performance; different energetic yields would imply different ballistics, suggesting a need for some modification to the primer design (e.g., changing the charge weight, consolidation pressure, etc.) The method of measuring primer energy output used the McDonnell Douglas Energy Sensor⁷. In this test, the output of the primer acts against a piston that, in turn, crushes a column of aluminum honeycomb. The honeycomb has the characteristic of having a uniform crush strength once it has been pre-crushed a short distance. The energy required to crush the honeycomb can be calculated as the crush distance times the crush strength. It is believed that this type of test offers a reasonable method of comparing the outputs of the two respective primers.

Fifty-one M52A3B1 primers and forty SCI primers were tested. It was reassuring to find that the outputs were nearly identical, with the M52A3B1 samples averaging 613 inch-pounds of force and the SCI primer averaging 612 inch-pounds. This was regarded as a preliminary indication that the SCI primer would not degrade the cartridge ballistic performance. Of course, this conclusion ignores possible differences in the primer combustion rates, a fact that could also influence propellant ignition.

2.4.6 Interior Ballistics Tests

Interior ballistics tests were conducted at the Olin-Marion ballistic test range on all-up rounds from the prototype lots. Muzzle velocity, peak chamber pressure, and action time were measured as basic performance indicators on cartridges pre-conditioned at temperatures of -20, 70, and 150° F. All cartridges were fired in a 20 mm Mann barrel, which was instrumented with copper crush gauges and piezo-electric sensors. A PHALANX GCU was used in all ballistics tests to provide the firing stimulus, and firing voltage and current waveforms were recorded. Ten Prototype Lot 1 cartridges, loaded with 628 grains of WC859-lot 64 propellant, were tested at each temperature. For Prototype Lot 2, a total of eighty-five cartridges, loaded with the same propellant lot (WC859-lot 64) with a 628 grain charge weight, were tested (twenty-five at -20 and 150° F and thirty-five at 70° F)..

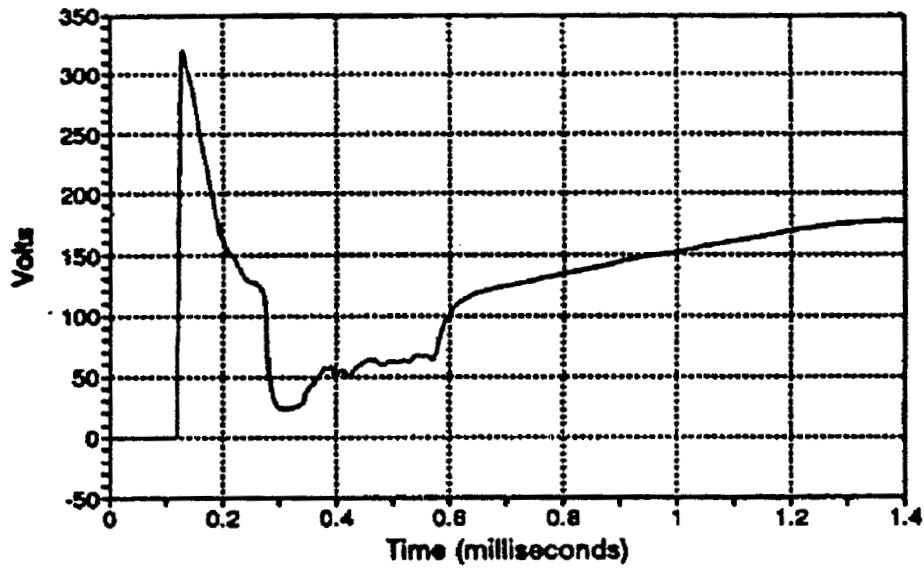
Figure 19 shows typical current and voltage waveforms measured across the primer with a storage oscilloscope and a representative plot of a pressure-time history, measured with a piezo-electric sensor, is shown in Figure 20.

In all cases, the data verify that ballistic performance meets the specifications for PHALANX ammunition with respect to velocity, peak chamber pressure, and action time. Table 5, is a representative sample of such ballistics data, summarizing the performance of Prototype Lot 2 cartridges conditioned at 70° F. Note that the Test Lot satisfies the PHALANX Weapon Specification WS 21703A.

Table 5. Example of Interior Ballistics Performance (70° F)

CHARACTERISTIC	MK 149 REFERENCE LOT	PROTOTYPE LOT 2	WS 21703A
MUZZLE VELOCITY (ft/sec)	3664	3686	3650-3720
PEAK CHAMBER PRESSURE (psi)	52,590	53,823	< 60,500
ACTION TIME (msec)	2.29	2.36	< 4.00

Firing Voltage Waveforms Proto1.1



Firing Current Waveform Proto1.1

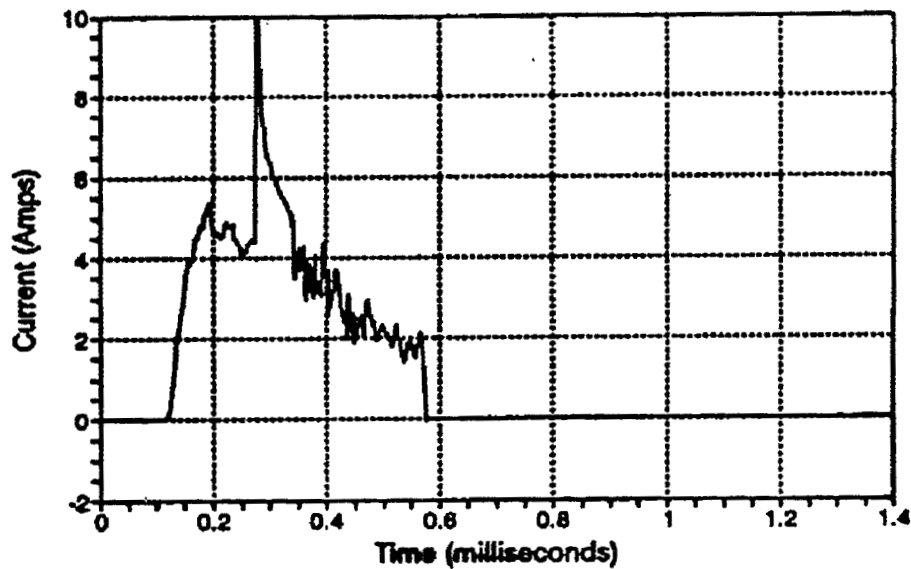
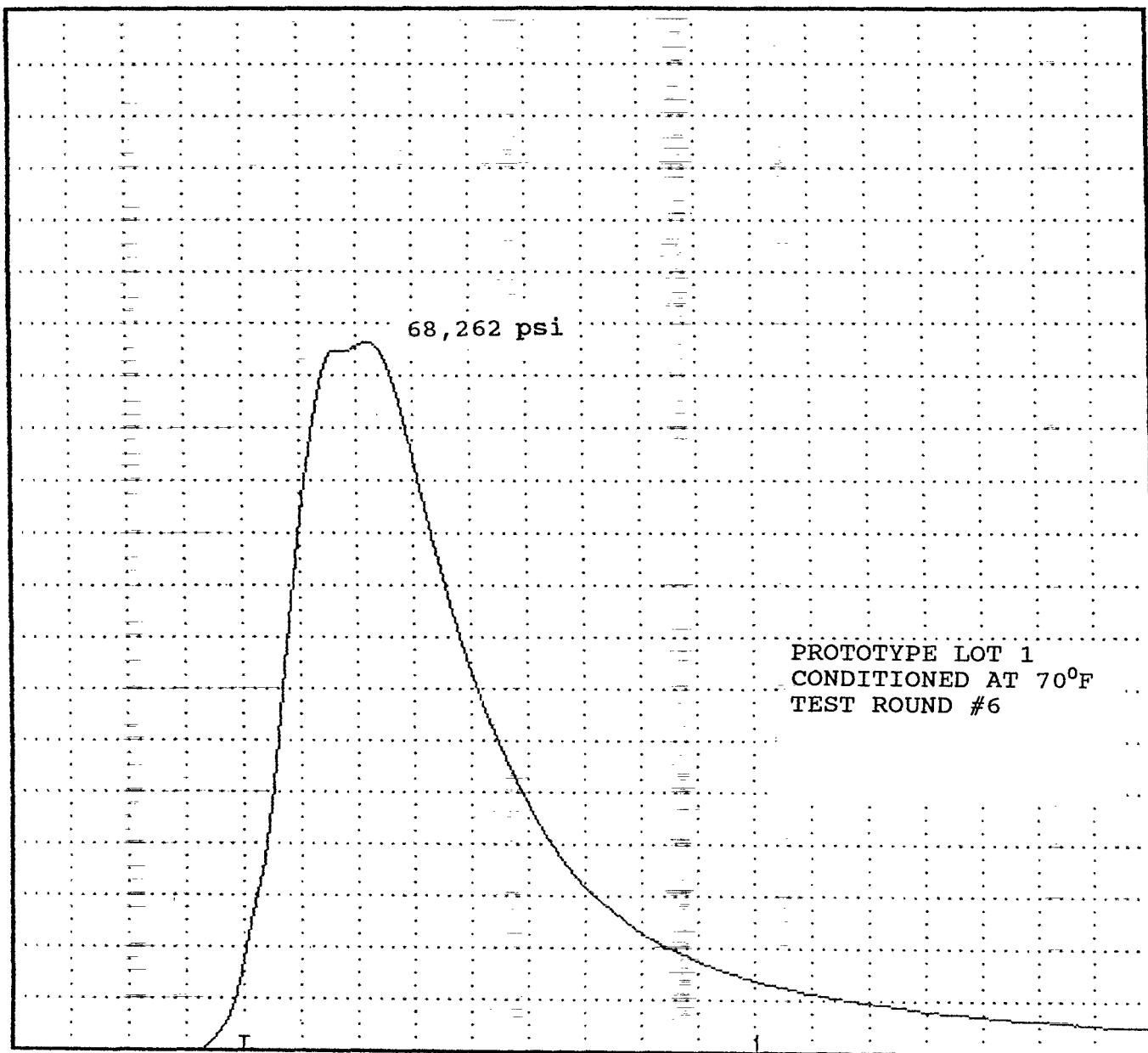


Figure 19. Typical Voltage and Current Waveforms



Curve #18 of File D:A06801L1.CRV

5000 PSI per division and 200 microseconds per division

Plot includes offset of 0 PSI.

Time from FIRE to "T" trigger point = 577 microseconds.

Time from FIRE to "I" muzzle point = 2382 microseconds.

Figure 20. Time-Pressure Curve (Typical)

3.0 CONCLUSIONS AND PROJECTIONS

The Navy is making great progress toward solving it's worst HERO problem, PHALANX MK 149 ammunition. The technical team is attacking the problem at its source, the extremely RF-sensitive M52A3B1 electric primer, because it is recognized that the most effective solution is to build the protection directly into the primer itself. The effort thus far demonstrates success of the technical approach, evidenced by the excellent performance of prototypes in firing reliability, RF sensitivity, and ballistics tests. The most significant benefits of a successful development effort will be:

- (a) Improved ammunition safety - the risk of a HERO accident will be minimized; and
- (b) Relief from emission control and ammunition handling restrictions - the limitations on critical radars and communications equipments can be reduced/eliminated.

Interestingly, this most recent attempt to harden the primer has not involved the development of any new technology but rather the marriage of traditionally unrelated technologies. As a further break from tradition, the SCI represents a semiconductor device "designed to fail". This unconventional use of semiconductors may represent only the "tip of the iceberg"; there is no reason why RF immunity could not be similarly built into other electric primers or the myriad of bridgewire EEDs, used in countless military and commercial applications.

As far as the HERO SAFE PHALANX ammunition development program is concerned, future efforts will focus on improving Quality Assurance (QA) test methods and determining appropriate pass/fail criteria. This work is very important to ensure that there is a reliable method for screening defective primers. Verification of an acceptable QA test is expected to be demonstrated in a third prototype lot presently being built. After completing the prototype phase, a 29,000 sample qualification lot will be manufactured and extensively evaluated. A successful qualification phase is a prerequisite for approval for production.

5.0 ACKNOWLEDGEMENTS

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