April 1981

Cost-Reduced M587 Electronic Time Fuze: Root Cause Analysis of July 1979 Early Bursts

by Norman J. Doctor

U.S. Army Electronics Research
and Development Command
Harry Diamond Laboratories
Adelphi, MD 20783

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HDL-TR-1945	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* Cost-Reduced M587 Electronic Time Fuze: Root Cause Analysis of July 1979 Early Bursts		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Norman J. Doctor		8. CONTRACT OR GRANT NUMBER(s) DA Proj: 1X464602D454 PRON: 1A920829011AA9
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harry Diamond Laboratories 2800 Powder Mill Road Adelphi, Maryland 20783		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Ele: 64602A
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Armament Research and Development Command Dover, NJ 07801		12. REPORT DATE April 1981
		13. NUMBER OF PAGES 50
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

HDL Project: 498945
DRCMS Code: 6446024540012

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Electronic time fuze
Cost-reduction
Early burst analysis

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The Root Cause Analysis effort directed at explaining the two early bursts noted during the July 1979 validation test of a cost-reduced design for the M587 electronic time fuze has been completed. This cost-reduced fuze design contains three integrated circuits and one printed-circuit board. The early burst was identified as having resulted from the poor quality of the cost-reduced interface and firing circuit (IAFC) hybrid integrated circuit (IC). Detachment of the 820-pF capacitor during gunfire, coupled with an intermittent wire bond (which opens during setback and then closes again) can defeat the initialization circuit and preclude proper generation of the short and long pulses needed to establish the starting count of the timer IC. In the absence of these pulses, the timer has a strong tendency to initialize at about 257 counts (26 s).

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

Corrective actions are now being defined not only to improve the quality of these connections but also to assure that this combination of faults cannot result in an unsafe fuze.

Other weaknesses in the cost-reduced design, not believed to be related to the early burst, were identified and corrective actions defined.

It was determined that a like combination of faults in the current production design would cause the counter to initialize at about 1790 counts (179 s), which, for all practical missions, would be a safe fail-long condition. (The current design contains four integrated circuits and two printed-circuit boards.)

CONTENTS

APPENDICES

Page

FIGURES

TABLES

1. BACKGROUND

1.1 Type Classification

In December 1978 it was recommended* to the Department of the Army that the M587 electronic time (ET) fuze, the M724 ET fuze, the M36 fuze setter, and the M744 training fuze be type classified STANDARD, with Logistic Control Code A (LCC-A). On 12 January 1979, the Army approved† that recommendation. A system description appears as appendix A to this report. A more detailed examination of system operation appears as appendix B.

1.2 Cost Analysis

During the latter phase of Engineering Development of the M587/M724/M36 ET fuze system, a Producibility Engineering and Planning (PEP) study was prepared by the fuze development contractor, Honeywell. The unit product cost estimate contained in that study[1] identified the four special-purpose integrated circuits (IC's) employed in the fuze as being high cost drivers in the overall cost of the fuze. The analysis showed that the four special-purpose IC's comprised 70 percent of the total material costs of the fuze.

1.3 RDT&E-Funded Studies

Studies funded through Research, Development, Test, and Evaluation (RDTE) were undertaken to address methods of reducing the cost of the four special-purpose IC's.

1.3.1 Oscillator IC

Two studies addressed the oscillator hybrid IC. In one of these studies, Raytheon (contract DAAG39-76-C-0082) eliminated the thin-film resistor networks by using thick-film resistors and converted from chip ceramic capacitors to silicon-dioxide capacitors.

In the second study, Honeywell (subtask of contract DAAG39-77-C-0056) redesigned the gain and shaping portion of the oscillator circuit to be fabricated as a single silicon monolithic chip in tape automatic bonding (TAB) configuration. That chip, along with four ceramic chip capacitors and leads, was soldered to a rectangular, ceramic substrate bearing conductors and precision thick-film resistors.

1.3.2 Interface and Firing Circuit IC

Two studies also addressed the interface and firing circuit (IAFC) hybrid IC. In one of these studies, RCA (contract DAAG39-76-C-0146) combined a major portion of the circuit into a silicon monolithic chip which was mounted along with a silicon-controlled-rectifier (SCR) chip and capacitor on a thick-film substrate containing conductors and resistors.

---

[1] *J. C. Ravis and G. R. Harrison, Conceptual Design of a Base Production Facility for the XM587E2/XM724 Electronic Time Fuzes, Honeywell, Inc., Government and Aeronautical Products Division, under contract DAAG39-76-C-0048 (28 April 1976), 112-118.*

**DRDAR-LC, letter to Department of Army, Material Acquisition DAMA-CSM, 21 December 1978, Subject: Development Acceptance In-Process Review (DEVA-IPR) on Electronic Time Fuze XM587E2/XM724/XM36E1 Setter— Approval of Recommendations.*

† DAMA-CSM (21 December 1978) 1st Ind, dated 12 January 1979, Subject: as above.

In the second study, Honeywell (subtask of contract DAAG39-77-C-0056) worked with Motorola in an attempt to redesign the entire IAFC into a single silicon monolithic chip. This design proved to be unsuccessful, and the effort was terminated.

1.3.3 Combination Timer IC

A study by Nitron (contract DAAG39-77-C-0139) resulted in combining the counter/memory (C/M) IC and the scaler/logic plus overhead safety (S/L + OHS) IC into a single silicon monolithic chip which also included two zener diodes previously handled as discrete devices. That chip was mounted in the same 16-pin dual-in-line ceramic flat package used for both the C/M and S/L + OHS IC's.

1.4 MM&T-Funded Projects

Subsequent to the aforementioned RDT&E-funded studies, three Manufacturing, Methods, and Technology (MM&T) contract efforts were funded by the Project Manager for Production Base Modernization and Expansion (PM-PBM) to define high-volume production methods for manufacturing these lower cost IC's. Funded were the Honeywell oscillator, the RCA IAFC, and a Nitron effort to package the combination timer in a plastic dual-in-line package.

1.4.1 Honeywell Oscillator IC

A Cost-Plus-Fixed-Fee (CPFF) contract (DAAG39-78-C-0010) for MM&T efforts on the oscillator hybrid IC was awarded to Honeywell on 12 January 1978.

In the oscillator hybrid IC, silicon monolithic chips handled in 35-mm tape carriers were tape automatic bonded to ceramic substrates containing precision thick-film resistors. In a single solder-reflow process, each ceramic substrate had the semiconductor chip, a lead frame, and four ceramic capacitors attached to it. The completed substrates were subsequently encapsulated in a metal can to provide shielding. Figure 1 shows that the new oscillator (shown uncased on the lower right) is considerably less complex than the original.

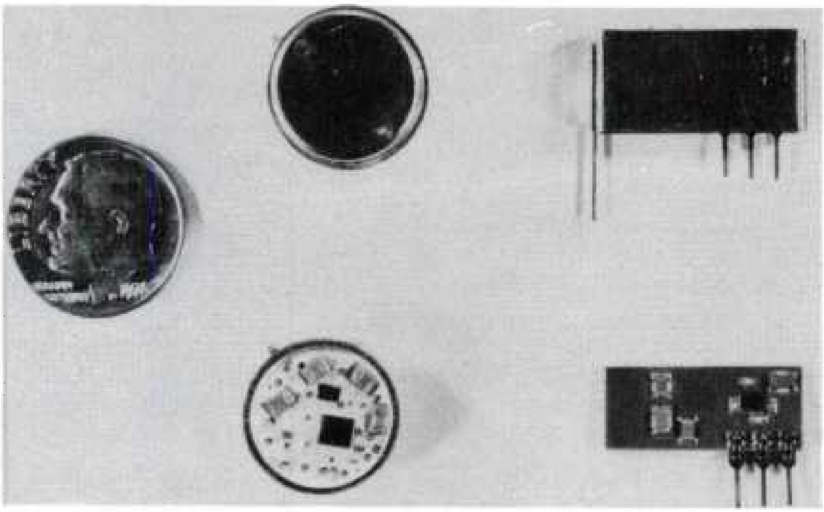


Figure 1. Oscillator hybrid IC's.

1.4.2 *RCA IAFC IC*

A CPFF contract (DAAG39-78-C-0002) for MM&T efforts on the IAFC IC was awarded to RCA on 31 October 1977.

In the IAFC hybrid circuit, two silicon monolithic chips were attached by automatic wire bonding to a substrate bearing thick-film resistors, a ceramic capacitor, and a lead frame. The resultant assembly was then injection molded to produce a 14-lead double-width dual-in-line package. A set of multi-image screens permitted 20 substrates to be simultaneously processed on a single ceramic sheet. Figure 2 shows that although the new IAFC (shown uncased on the lower right) is a pin-for-pin replacement for the original IC, it is a much less complex device to fabricate.

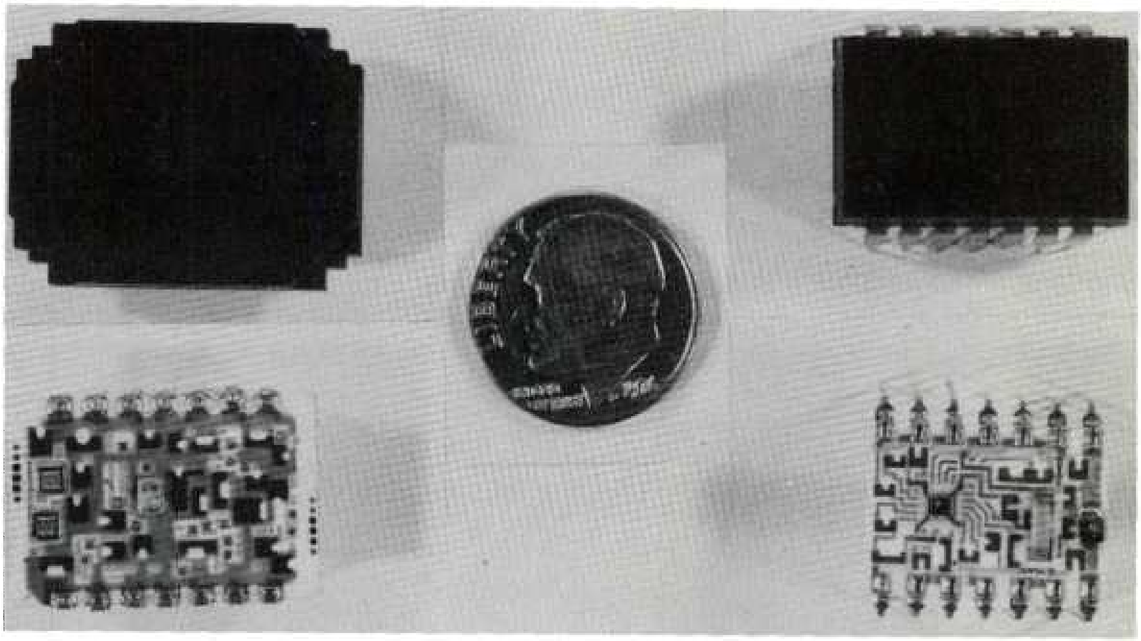


Figure 2. IAFC hybrid IC's.

1.4.3 *Nitron Combination Timer IC*

A CPFF contract (DAAG39-78-C-0014) for MM&T efforts on the combination timer IC was awarded to Nitron on 22 December 1977.

A combination timer chip (combining all the functions of the counter/memory and the scaler/logic plus overhead safety IC's and two discrete diodes) was bonded onto lead frames and molded into a 16-pin dual-in-line plastic package in a multicavity mold. Using the combination timer IC chip developed under RDT&E-funded contract DAAG39-77-C-0139, personnel involved in the MM&T effort concentrated on achieving further savings by replacing the ceramic package with a plastic one and by addressing possible simplifications in electrical testing during manufacture.

1.5 Design of the Validation Fuzes

Although the lower-cost special-purpose IC's were subjected to a full gamut of component testing during the MM&T-funded contract efforts, it was necessary to validate their performance in actual field firings of full-up (loaded) fuzes.

Approximately 300 M587 fuzes incorporating all the newly developed IC's and a smaller transformer onto a single printed-circuit board were fabricated and prepared for validation testing. Figure 3 compares the E-head of the new fuze design (shown on the right) with the type-classified design. Note that the combination timer IC's used in the validation fuzes were of the ceramic package type, because the plastic package type was unavailable at the time assembly had to proceed.

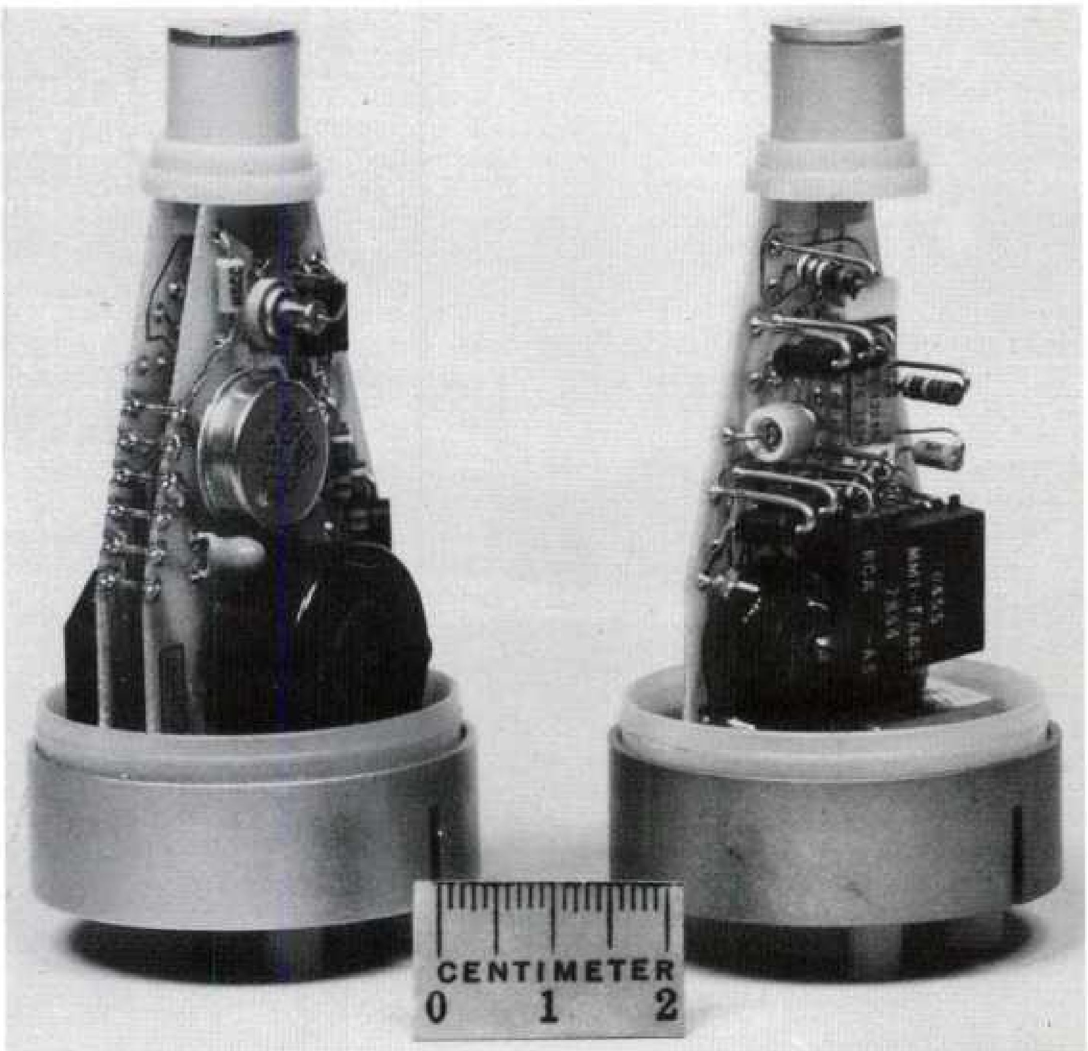


Figure 3. E-heads.

It can also be seen in figure 3 that many of the discrete components in the new single-board E-head are mounted upright on the board rather than flat as is the case with the type-classified two-board E-head. This upright mounting is one of the factors which permitted a single-board design because it conserves board space.

The validation fuzes differed only in the E-head from the fuzes fabricated for Developmental Test II (DT-II) and Operational Test II (OT-II) of the type-classified fuze. The rear-fitting assemblies (RFA's)—including batteries, safing and arming mechanisms (S&A's) and explosive components—were identical. In fact, DT-II/OT-II RFA's were laid aside during DT-II/OT-II fabrication specifically for use in later validation testing of the cost-reduced design.

The new cost-reduced E-heads were subjected to the same battery of tests prior to assembly into fuzes as were used for the DT-II/OT-II E-heads. Electrical tests were made on the same test equipment used for the earlier build. The only notable parameter difference was that the cost-reduced E-heads drew significantly less operating current. In fact, the tester would frequently annotate the operating current printout with the symbol REJ, for reject, because the current was below the minimum programmed into the test equipment.

All E-heads were tested at room temperature both before and after potting. A sample quantity of units was also tested at temperature extremes. The E-heads seemed in all ways operationally equivalent to the two-printed-circuit board version. They were built into fuzes.

2. TEST RESULTS

2.1 Test Design Plan

On 13 February 1980, a Test Integration Working Group (TIWG) meeting was held to formulate an Outline Validation Test Plan for the cost-reduced fuzes. Representatives who participated in the meeting were from the U.S. Army Test and Evaluation Command (TECOM), Army Materiel Systems Analysis Activity (AMSAA), Ballistic Research Laboratory (BRL), Office of the Project Manager for Selected Ammunition (PM-SA), and the Harry Diamond Laboratories (HDL).

The Outline Test Plan shown in table 1 resulted. Because only a limited number of fuzes would be available, it was decided to heavily bias the firings toward temperature and weapon extremes. Most firings were scheduled either for −40 or +145 F. All but 20 rounds were scheduled for firing at maximum charge. Both temperature-cycled fuzes and fuzes subjected to sequential rough handling (SRH) were included. No base-down drops were included in rough handling because the batteries in the rear-fitting assemblies were of an early design that had been shown during DT-II/OT-II to be very sensitive to base-down drops. The problem has been corrected and demonstration firings have shown the new design to be insensitive to drops. Since only the E-head was being modified, we did not believe that use of the old design batteries would cause any difficulties in subsequent analysis.

Twenty fuzes (later revised upward to 24 fuzes) were chosen for low zone firing, and for this zone 1 in the M110A2 weapon was chosen. These 24 fuzes were specially assembled with the new battery design, which had been proven out during DT-II/OT-II check tests and became the battery that is in the technical data package for the type-classified fuze. Since the other tests were to be at high zones where the original battery was quite acceptable, we made the change only for the 24 low zone firings.

Before testing another change was made in the Outline Test Plan. Because of the limited availability of M549A1 155-mm rocket-assisted projectiles, M483 projectiles were substituted for those scheduled for firing "rocket off," i.e., with the rocket assist feature not employed.

TABLE 1. OUTLINE VALIDATION TEST PLAN FOR COST-REDUCED FUZES

	SET FOR TIME FUNCTION					PD-SET
CALIBER	105mm	155mm		8-inch		
WEAPON	M204	M198		M110A2		
PROJECTILE	M760	M549A1		M106		
PROPELLANT	M200	M203		M188EI	MI	M!
CHARGE ZONE	8	8		9	1	1
		ROCKET ON	ROCKET OFF			
-40° F	24	12 + 16[a]	12	24	10[c]	10[c,d]
AMBIENT	12[b]	12[b]		12[b]		
145°F	24	12 + 16[a]	12	24		

a. SRH (NO BASE DROPS)
b. TEMP. CYCLED
c. CORRECTED AMPULE
d. NO FIRING PIN

2.2 Test Methods

Testing was conducted at the Yuma Proving Ground (YPG), Yuma, AZ, from 26 July through 1 August 1979. The sequential rough handling and temperature cycling of specified fuzes took place before that time.

A typical test consisted of conditioning the fuze, projectile, and propellant in a chamber set to the test temperature for a period of time at least equivalent to overnight. The projectiles were then removed one at a time from the test chamber, set with M36 setter S/N 210, interrogated by M36 setter S/N 214 (with the interrogated time photographed for the record), chambered in the weapon, supplemented with a powder charge, and fired. An infrared chronometer triggered by the muzzle flash and stopped by the projectile flash in the target area measured the function time. During rocket-assisted projectile flights, a HAWK radar tracked the early flight of the projectile to about 35 s from the weapon, at which point the return radar signal was lost in the noise.

2.3 Detailed Results

Results are summarized in table 2. All improper functions resulted in function on ground impact unless otherwise noted. At 8-in., zone-1, time-set, the improper function was a dud. Since the fuze contained a mechanical impact backup, it was concluded that this malfunction must have resulted from a defective S&A mechanism which failed to arm. The two M549A1 failures at +145 F were early bursts and will be addressed separately in the next section of this report.

It can be seen that reliability in the high-zone firings was lower at −40 F than at +145 F. The rough-handled fuzes did not appear to be degraded at all by that exposure.

The fuzes set for point detonation, fired at zone 1, were built without firing pins. That means that the fuze batteries must have been activated so that the fuzes could function by means of their electric impact switches.

Two of the 12 fuzes set for point detonation and scheduled for firing at 8-in., zone 1, were inadvertently fired without booster cups, dudded, and were considered no test.

TABLE 2. VALIDATION TEST RESULTS FOR COST-REDUCED FUZES

	SET FOR TIME FUNCTION					PD-SET
CALIBER	105mm	155mm		8-INCH		
WEAPON	M204	M198		M110A2		
PROJECTILE	M760	M549A1	M483A1	M106		
PROPELLANT	M200	M203	M203	M188E1	M1	M1
CHARGE ZONE	8	8	8	9	1	1
−40°F	20/24	NOT FIRED	10/11	21/24	11/12	10/10
−40°F AFTER SEQ. ROUGH HANDLING		15/16				
AMBIENT AFTER TEMP. CYCLING	10/12	NOT FIRED		12/12		
+145°F	22/24	6/8	12/12	23/24		
+145°F AFTER SEQ. ROUGH HANDLING		16/16				

2.4 Early Bursts

On 31 July 1979, two of eight M549A1 155-mm rocket-assisted projectiles, fired hot (+145 F) with M203 (zone 8) propelling charges and set to 48.0 s, functioned early at about 26 s.

The remaining six projectiles were proper airburst functions at set-time. On 1 August 1979, during 16 additional firings under ostensibly identical conditions—with eight set to 39.0 s and eight set to 60.0 s—all functioned properly at set time. The latter 16 fuzes had been previously subjected to sequential rough handling at +145 F, whereas the original eight had not. Also on 1 August 1979, 16 M549A1's were fired cold (−40 F) with M203 (zone 8) propelling charges. All eight set for 48.0 s functioned properly. Seven of eight set for 58.0 or 59.0 s functioned properly. The eighth functioned on ground impact.

After the above-cited firings, the balance of the testing program was cancelled in order to conserve fuzes which might prove useful in isolating the causes of the early bursts. Twenty-eight fuzes which had originally been scheduled were not fired. Altogether, 50 unfired cost-reduced fuzes remain at YPG.

The early bursts are pictured in figure 4. Shown in the figure are the interrogation times of the fuzes, rocket-on and rocket-off times, and times of the early bursts. The rocket and early-burst times were obtained from tapes of the HAWK radar which tracked all rocket-assisted projectile firings.

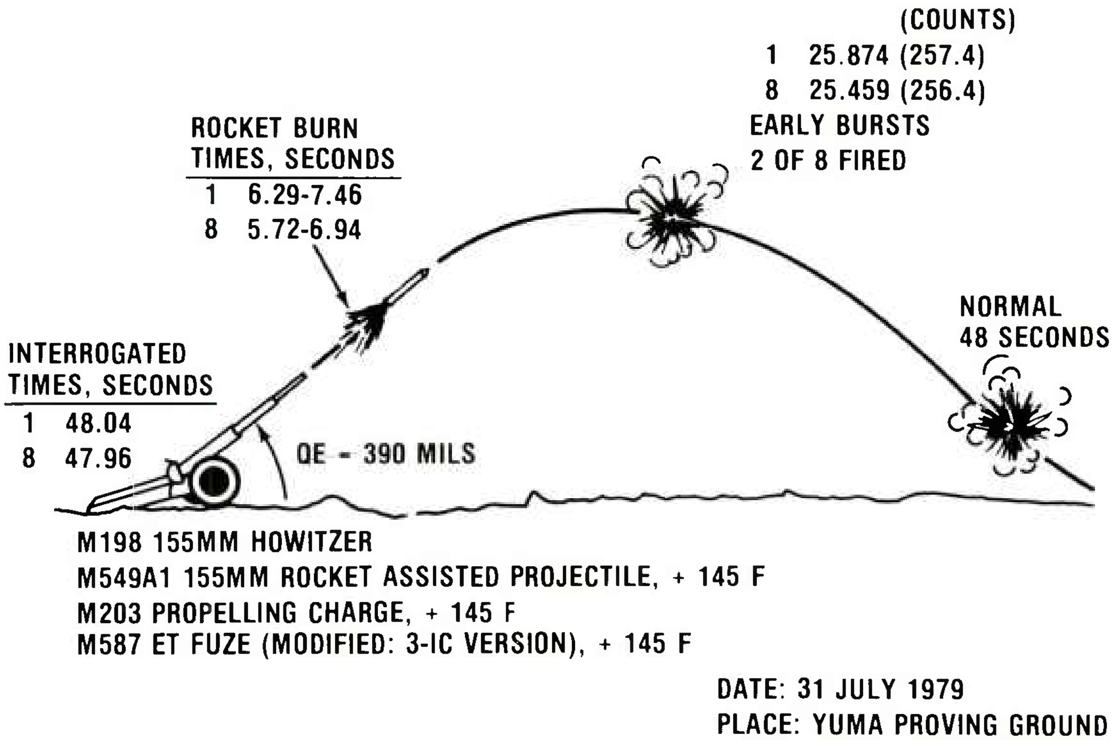


Figure 4. Pictorial representation of early bursts.

3. ROOT CAUSE ANALYSIS

The Root Cause Analysis was begun by formulating a list of possible causes for the reported early bursts, followed by a systematic analysis of available data that would either lend credence to the proposed mechanism or would refute it. The list of proposed mechanisms follows. These proposed mechanisms are treated in the following sections.

(1) Projectile/weapon flaws

(2) Impact backup function in flight

(3) Spontaneous ignition of explosive component

(4) Mis-set fuze

(5) Coupling of dc-to-dc converter pulses into oscillator

(6) Corona discharge scrambling of timer

(7) Improper initialization of fuze timer

3.1 Projectile/Weapon Flaws

For this category it is hypothesized that the fault lay not with the fuze but rather either with the projectile or the weapon.

a. Supporting data: None

b. Refuting data:

(1) X rays of the M549A1 projectiles used in the test were taken before the field test. The Program Manager (PM) for the Cannon Artillery Weapons System (CAWS) was asked to examine the x rays of those projectiles which had functioned early. PM-CAWS reported no detectable projectile flaws in the x rays.

(2) HAWK radar tracked the early portion of all rocket-assisted projectile flights during the validation field test. A U.S. Army Armament Research and Development Command (ARRADCOM) analysis of the radar tapes confirmed high-order detonation at the early burst times following otherwise normal flights. That is, projectile velocity and spin were normal and no significant yaw was detected.

(3) Data from the ball gages included in every firing and reported in YPG Firing Report No. 14621, 10 December 1979, showed that weapon chamber pressures were normal and uniform and did not differ significantly between those rounds which functioned at set time and those producing the early bursts.

c. Conclusion: Projectile/weapon flaws are not likely contributing factors to early bursts.

3.2 Impact Backup Function In Flight

Since the validation fuzes were fabricated from the M587 design, an independent mechanical impact backup was incorporated. This backup comprises a firing pin mounted forward of the S&A module and for an armed S&A poised directly over the M55 stab detonator. In normal operation the S&A module will slide forward on impact, causing the M55 to be initiated by the firing pin.

Possible Scenario One.—Due to excessive projectile yaw, the S&A module creeps forward and impacts the M55 stab detonator, detonating the projectile at other than set time.

a. Supporting data: None

b. Refuting data:

(1) ARRADCOM analysis of radar tapes (as stated earlier) showed no sign of significant projectile yaw.

(2) Because the firing pin is a part of the bias spring assembly, it is not possible to have a firing pin present without providing the spring bias to the S&A module.

c. Conclusion: Excessive projectile yaw is not a likely contributing factor to early bursts.

Possible Scenario Two.—Projectiles encountered real targets, such as large high-flying birds, and functioned via the mechanical impact backup system.

a. Supporting data:

(1) There have been reported sightings* of eagles, ravens, vultures, and hawks (all indigenous to the Yuma, AZ, area) at altitudes higher than the 11,000 ft at which the early bursts occurred. Migratory flocks of ducks and geese, on occasion, will fly that high.

(2) A number of years ago an early burst function of a projectile fuzed with an M577 MTSQ (mechanical time superquick) fuze was attributed to this phenomenon.

b. Refuting data:

The probability of a single such occurrence would be quite rare. To have two such occurrences in a single day's firing would border on the impossible.

c. Conclusion: Impact with large birds is not a likely contributing factor to early bursts.

3.3 Spontaneous Ignition of Explosive Component

For this category it is hypothesized that as a result of a combination of temperature, setback forces, spin, and/or rocket motor burn, some element of the fuze's explosive train is so sensitized that it spontaneously ignites and detonates the projectile.

**Telephone conversation with Office of Migratory Birds, Fish and Wild Life Service, Department of Interior (31 July 1980).*

a. Supporting data: None

b. Refuting data:

The explosive components used in the fuze are not new. There have been no reported cases of explosive components of the type used in these fuzes ever having spontaneously ignited more than 24 hours after manufacture.

c. Conclusion: Spontaneous ignition is not a likely contributing factor to early bursts.

3.4 Mis-Set Fuze

For this category it is hypothesized that the fuzes were actually set to some other time than 48.0 s (in this case to 26 or 27 s) and then proceeded to function normally.

Possible Scenario One.—The operator simply entered the wrong time on the dials of the M36 setter and proceeded to set the fuzes to that wrong time.

a. Supporting data: None

b. Refuting data:

(1) All eight fuzes in the subgroup were set for the same 48.0 s. The dials on the setter would not normally be changed during the testing. Since rounds 2 to 7 functioned properly at 48.0 s, there is no reason to believe that rounds 1 and 8 (the early bursts) were set with the dials at some other setting.

(2) The proper setting of the fuzes on all rounds was verified by interrogation with a second setter. Photographs of the interrogated times for rounds 1 and 8 confirm the correctness of the settings.

c. Conclusion: Operator error is not a likely contributing factor to early bursts.

Possible Scenario Two.—The setter, although indicating a proper setting, was actually malfunctioning in such a manner as to set a time different from that shown on the setter dials and display.

a. Supporting data: None

b. Refuting data:

(1) Because the fuzes were set with one setter and interrogated with a second setter, this scenario would require not one but two defective setters with complementary faults. This is most unlikely.

(2) The setter used for setting (S/N 210) was returned to the laboratories following the test and was shown to be in good working order and well within all electrical specification limits. In addition, that setter has been used for many months since then with no evidence of a malfunction.

c. Conclusion: Defective setters are not a likely contributing factor to early bursts.

3.5 Coupling of DC-to-DC Converter Pulses into Oscillator

This category hypothesizes that the spikey signals generated in the dc-to-dc converter somehow modulate the oscillator output or some other input to the scaling and counting circuits, providing false counts and resulting in an early timeout.

a. Supporting data:

(1) Since the frequency of the dc-to-dc converter is about the same as the fuze oscillator, it would, if mixed with the oscillator pulses, produce timeouts in the range observed.

(2) If the filter capacitor in the dc-to-dc converter should open, large voltage spikes would appear on the V_{DD} line, since the regulator in the new IAFC IC is a poor filter.

(3) The filter capacitor is not checked during settings nor is any other part of the dc-to-dc converter. A defective converter could have existed without causing the setter to display "Error."

b. Refuting data:

(1) The open filter capacitor, while permitting significant voltage swings on the V_{DD} line of the fuze, causes both negative and positive swings. If the negative swing were to dip to as low as 18 to 21 V, the circuit would reinitialize on each swing and the fuze would never time out. It was found that the system input voltage had to be about 2½ V before the negative spike would no longer swing low enough to reinitialize the cost-reduced fuze circuit. The maximum voltage available from the fuze battery is 1.93 V.

(2) An extensive investigation of other types of failures in the dc-to-dc converter produced no other mechanism for coupling the converter frequency to the timer.

c. Conclusion: Although it is unlikely that this mechanism was a factor in producing the early bursts, the voltage regulator of the IAFC IC should be improved so as to clip high-voltage spikes and prevent their appearance on the fuze V_{DD} line if the filter capacitor should fail in an open condition.

3.6 Corona Discharge Scrambling of Timer

Since projectiles in flight, and particularly rocket-assisted projectiles, can acquire a significant electrostatic potential, it is hypothesized that corona discharge currents, perhaps emanating from the area of the fuze setter rings, are of sufficient magnitude to cause upset in the fuze timer.

a. Supporting data:

(1) Hecht[2] showed that the timer count could be scrambled by the direct application of positive pulses of 10-ms duration and greater than 9-V amplitude to the fuze monitor line while the fuze was operating.

(2) Titus* reported on an investigation to measure the charging current and to determine the net charge produced by functioning of a rocket motor from the M549A1 projectile. He determined that the rocket-assisted projectile could acquire a cumulative charge during rocket burn of 3 to 5 microcoulombs and sustain a corona current as high as 70 μA.

b. Refuting data:

(1) Reiter, using the facilities of the Lightning and Transients Research Institute of St. Paul, MN, operated a series of ET fuzes on positively and negatively charged M549A1 projectile bodies. He found that with negatively charged projectiles he could draw corona currents exceeding 600 μA (the limit of the equipment) without interfering with the proper timeout of the fuze. With positively charged projectiles he could draw corona currents exceeding 200 μA without interfering with the proper timeout of the fuze. At higher positive corona currents occasional upset was noted, but the upset was very random and nonrepetitive.

(2) The sky on the day of the observed early bursts was totally free of storm clouds, so no meteorological sources of additional electrostatic potentials existed.

(3) In Reiter's experiments the grounding plate was placed within 13 in. of the nose of the fuze, forcing most of the corona discharge to emit from near the setting rings, making his a worst-case test.

c. Conclusion: Corona discharge is not a likely contributing factor to early bursts.

3.7 Improper Initialization of Fuze Timer

For this category it is hypothesized that the starting count associated with the desired timeout which is stored in the metal nitride oxide semiconductor (MNOS) memory elements of the timer IC is improperly read out, so the counter initializes for an improper early time; in this particular case, the improper reading causes the counter to initialize at 256½ or 257½ counts.

Possible Scenario One.—Due to some damage during gunfire the read voltage (Vg) applied to the memory devices is more negative than proper, causing all normally OFF devices except M_{11} to turn ON during initialization (yielding 257 counts) or except M_0 and M_{11} (yielding 256 counts).

---

[2]*D.C. Hecht, The Effect of Electrostatic Discharge on the Operation of the M587/M724 Electronic Time Fuze, Proceedings of the 20th HDL Annual Student Symposium, Harry Diamond Laboratories (August 1979), 87-98.*

**John Titus, Electrostatic Charging of an M549A1 Rocket-Assisted Projectile: Test Stand Measurements, Harry Diamond Laboratories Internal report, R-34500-80-1 (March 1980).*

a. Supporting data:

A careful selection of a read voltage well outside the normal tolerance range can create a variety of improper early timeouts for a fuze set to 48.0 s, and these early timeouts could include 256 and 257 counts.

b. Refuting data:

(1) The voltage range between which no OFF memories in a timer IC are turned ON (with the result being proper time out at 48.0 s) and all OFF devices in the timer IC including M_{11} are turned ON (with the result being a safe function on ground impact) is very small—only a few tenths of a volt around −8 V.

(2) A fair number of other timeouts, other than 256 and 257 counts, would have high probability of occurrence.

(3) This mechanism does not produce any 1/2 count conditions.

c. Conclusion: Excessive negative read voltage is not a likely contributing factor to early bursts.

Possible Scenario Two.—Due to some damage during gunfire, the read voltage (Vg) applied to the memory devices is more positive than nominal, causing all normally ON devices except M_{10} and M_9 to turn OFF. This will produce a timeout of 254 counts.

a. Supporting data:

(1) Physical examination of the E-head of the cost-reduced M587 revealed that because of the upright mounting of some of the components, a certain resistor lead could touch the nose cone of the fuze. Since the nose cone is at fuze ground potential, that point (the intersection of R3/R4) would also take on the ground potential. Since that point provides the read bias to the memories, the scenario could be created.

(2) Fifteen fuze E-heads were placed in a temperature chamber at 145 F and each was set to 48.0 s. After 5 min they were run in real time with the R3/R4 intersection shorted to ground. All 15 timed out at 48.0 s. After a wait of 1 to 3 hr, the units were functioned again (without resetting) with the R3/R4 intersection shorted to ground. Thirteen of the E-heads timed out at 48.0 s. One timed out at 185.0 s (1790 counts), and one timed out at 25.6 s (254 counts). A third run-through with the intersection shorted was performed the following day, after letting the units sit at ambient temperature overnight. This time three more units timed out short at 227, 243, and 254 counts.

b. Refuting data:

(1) Since fuzes will not set with the R3/R4 intersection grounded, the short to the nose cone would have had to occur after setting (probably during gunfire), not a likely occurrence since the E-head is potted within the nose cone in a silica-filled epoxy.

(2) Timeouts equivalent to 256 or 257 counts cannot be created by the scenario; 254 is as close as one can get.

(3) All rounds were fired within 3 to 7 min of setting. For this short time period none of the 15 tested E-heads produced an improper timeout.

c. Conclusion: Excessive positive read voltage is not a likely contributing factor to the observed early burst, but the opportunity to create an early function by a short to nose cone could be a potential safety hazard with timer IC's of slightly different device characteristics. The design should be altered to preclude component-to-nose cone shorts.

Possible Scenario Three.—Due to some component failure(s) during gunfire, the initialization pulse from the IAFC IC to the timer IC is not properly delayed so as to allow the initialization flip-flops in the timer IC to properly set up. If the short pulse is consequently not generated, the counter could initialize at 257 counts. Three separately identified mechanisms could create this scenario: (1) a short between pin 5 of the IAFC IC and V_{DD}, (2) an open ground connection at pin 4 of the IAFC IC, or (3) an open connection between the dc-to-dc converter and the IAFC IC which is reestablished on gunfiring, coupled with opening of the 820-pF delay capacitor in the IAFC.

a. Supporting data:

(1) The IAFC IC proved to have a high number of quality faults which contributed to low manufacturing yield.

(2) In an analysis* of 89 IAFC IC's which failed electrical testing during manufacture, a large number of defective, and in some cases intermittent, connections were found. In fact, the second most frequent connection fault (nine instances) was in the pin 9 path which connects the unregulated voltage from the dc-to-dc converter to the regulator in the IAFC IC.

(3) During 57-mm vertical recovery testing[3] of a sample of IAFC IC's from the lot used in fabrication of the cost-reduced M587 fuzes, 4 of 25 devices were found to have detached 820-pF capacitors when subjected to post-gunfire testing.

(4) In laboratory tests employing each of the above cited mechanisms, it was found that the timer IC would most frequently initialize so as to time out at between 256 and 258 counts; 256½ and 257½ counts were common.

b. Refuting data:

Frequently, the absence of proper initialization of the timer IC will also be accompanied by the absence of proper initialization of the overhead safety circuit. Two of the four undirected possible starting states for the overhead safety circuit result in locking out the timer output, with consequent ground impact functions. In laboratory testing, this safe condition occurred with greater frequency than the short timeouts. In the field, no ground impacts at all accompanied the early bursts obtained at +145 F when fired top zone from the M198.

---

[3]*Interface Circuit 11726909, Materials, Methods, and Technology Program, Harry Diamond Laboratories, HDL-CR-80-002-1, RCA Corporation (January 1980), 23-26.*

**H. Davison, Memorandum, 8 July 1980: Analysis of Production Rejects in Interface Circuit 11726909.*

c. Conclusion: The mechanism involving an open 820-pF capacitor and late connection to the dc-to-dc converter appears the most likely cause of the early bursts. It creates the exact timeouts observed and requires fault mechanisms observed with fair frequency during other testing.

4. CONCLUSIONS AND DISCUSSION

The Root Cause Analysis effort directed at explaining the two early bursts noted during July 1979 validation testing of the cost-reduced design (three IC's, one printed-circuit board) for the M587 ET fuze was completed.

The early bursts were attributed to poor quality of the cost-reduced IAFC IC's. Detachment of the 820-pF capacitor during gunfire (it had to be there during setting), coupled with an intermittent wire bond (which opens during gunfire and then closes again), can defeat the initialization circuit. This precludes proper generation of the short and long pulses needed to firmly establish the starting state of the timer IC. In the absence of these pulses the timer has a strong tendency to initialize at about 257 counts (26 s).

Corrective action would entail either incorporating the initialization circuit in the timer IC chip or outboarding a redundant delay circuit. In either case the safety of the timer IC in the absence of short and/or long pulses should be improved.

It was determined that a like combination of faults in the production design (four IC's, two printed circuit boards) would cause the counter to initialize at about 1790 counts (179 s), which, for all practical missions, would be a safe fail-long condition.

Other faults, not believed to be a factor in creating the early bursts, were uncovered during the investigation. Some of the upright-mounted components on the printed-circuit board came dangerously close to touching the nose cone. In fact, if they are bent slightly askew, they definitely can touch. One of these components contributes to creating the read bias voltage for the memory elements. Needless to say, the physical design should be altered to prevent such an occurrence.

The poor dynamic reponse of the IAFC voltage regulator permits serious spikes to appear on the V_{DD} line if the filter capacitor of the dc-to-dc converter opens. High positive spikes could modulate the oscillator output in such a manner as to make it appear to be operating at a high frequency. This is dangerous. In the cost-reduced design, all that prevented this from causing an early timeout was the presence of negative spikes as well. The negative spikes (dropping below the 18- to 21-V initializing threshold) reinitialized the timer on every count. Either the response of the integrated regulator to spikes must be improved or a zener must be put on the output to clip positive spikes.

It is believed that if the above-cited corrective actions are incorporated into the technical data package for the cost-reduced fuze, a safe and reliable low-cost electronic time fuze will result.

APPENDIX A.--M587/M724/M36 Electronic Time Fuze System

CONTENTS

FIGURES

TABLES

Appendix A provides a description of the M587/M724/M36 electronic time fuze system in fairly general, nontechnical terms. It discusses the nomenclature, setting method, operation, and performance. It also provides comparisons with mechanical time fuzes, emphasizes the tactical advantages provided by the electronic time fuze system, and examines the pros and cons of an electronic setter.

A-1. INTRODUCTION

This appendix discusses a high-accuracy, moderate-cost, electronic time (ET) fuzing technology that has been successfully applied to the field of artillery projectiles.

A-1.1 Description of ET Fuzes

In essence, two highly similar fuzes are addressed: the M587 ET fuze, intended for use with high-explosive rounds, and the M724 ET fuze, intended for use with canister rounds (fig. A-1). The two fuzes differ only in that the M724 does not employ a booster cup assembly or inertial stab detonator clean-up. Both fuzes and their companion M36 electronic time fuze setter completed engineering development at the Harry Diamond Laboratories in December 1978. The M587/M724/M36 electronic time fuze system was type classified Logistic Control Code A and released for initial procurement in January 1979.

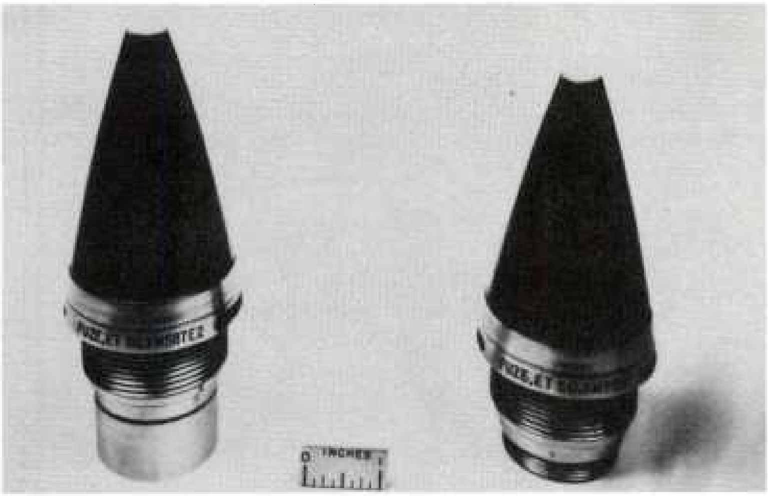


Figure A-1. M587 and M724 electronic time (ET) fuzes. (XM nomenclature made obsolete by type classification.)

A training fuze, the M744, was also type classified. The M744 contains no power supply, safing and arming (S&A) mechanism, nor any explosive components, but does contain electronics identical to the M587 and M724, and consequently can also be set by the M36 fuze setter.

The M744 has the same physical configuration as the M587 (or the M724 if the booster cup is removed), except for the presence of four radial 3/8-in. holes through the sleeve where the S&A would be located and a 1-in. wide blue stripe painted on the nose cone to identify it as a training fuze. The word INERT also appears at two places on the nose cone.

Both the M587 and M724 fuzes can be used on projectiles for 105-mm, 155-mm, 175-mm, and 8-in. guns and howitzers. Both can be set in time increments of 0.1 s to any time between 0.2 and 199.9 s or for point detonation (PD). In the time mode the fuzes can be expected to function with a root-mean square (RMS) error from set time of less than 0.100 s over the entire range.

A-1.2 Setting the ET Fuze

A comparison with a typical mechanical time (MT) fuze (fig. A-2) which employs the common turning capsule method of setting with engraved time scale and vernier reveals a significant difference in the ET fuze. The ET fuze employs no moving parts in setting and hence contains no scale markings on the fuze housing. The ET fuze does, however, contain a three-ring bull's-eye at its nose which interfaces directly with a separate fuze setter. This bull's-eye is easily visible in figure A-3.

The ET fuze is set by entering the desired time or PD on the dials of the M36 fuze setter and contacting the setter to the nose of the fuze as shown in figure A-4. The M36 (also shown in figures A-3 and -4) is a hand-held device powered by self-contained rechargeable nickel-cadmium batteries.

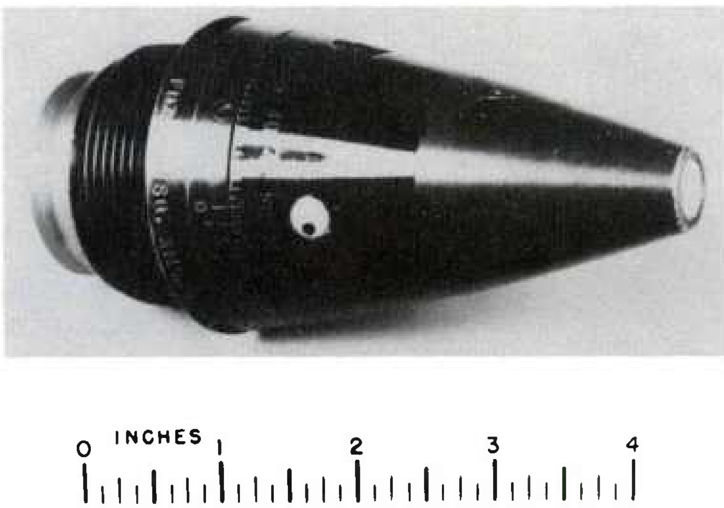


Figure A-2. Typical mechanical time fuze employing turning capsule method of setting.

There are many tactical advantages to this manner of setting time fuzes.

(1) The setting operation is faster. Once the desired time has been entered on the setter wheels, setting of the fuze requires a contact between fuze setter and fuze of less than 1 s. Additional fuzes may be set using the identical setting, if so desired, without making any changes to the setter.

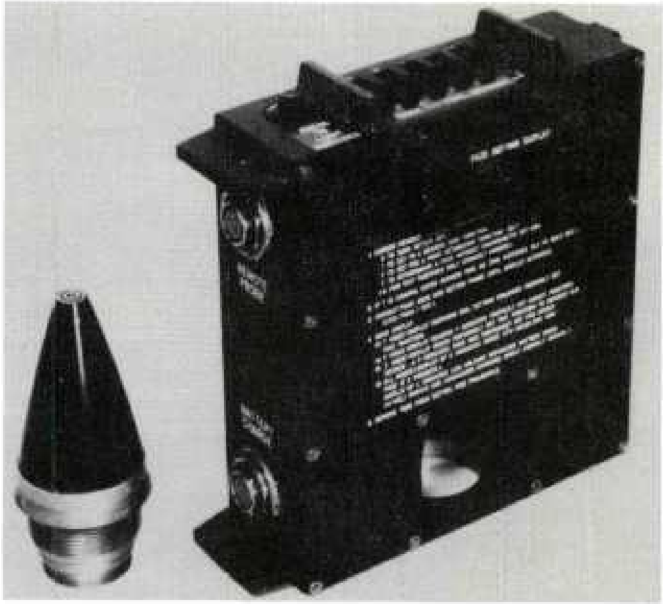


Figure A-3. M724 ET fuze shown with M36 fuze setter.

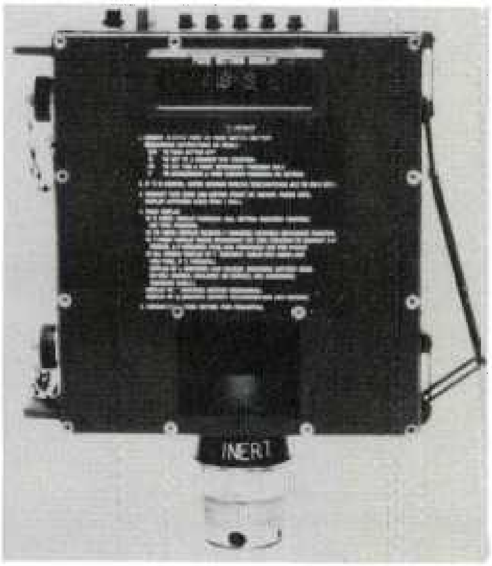


Figure A-4. Fuze setting: probe of setter is placed over nose cone of fuze to initiate setting sequence.

(2) The setting is simpler. No reading of scales, interpolation between engraved numbers, or use of verniers is required, nor is a fuze-setting wrench required. The desired time is entered on four-decade wheel switches in such a fashion that the set time is displayed as an in-line decimal. The wheel switches may be rotated either forward or backward and are independent of each other.

(3) The setting is more all inclusive. Not only is the desired time set into the fuze during the period that the fuze is contacted with the setter but also (a) the scaling and counting electronics are checked, (b) the fuze time base is calibrated, (c) the set time is checked out in fast time to verify that the setting has actually been achieved, and (d) the setter visually communicates to the operator. If any of the check tests should detect a malfunction, the operator is informed by the appearance of the letter "E" (for error) instead of the set time in the readout, thus precluding the firing of a round with a known defective fuze. In the event the setter batteries should need recharging, the letter "L" (for low battery) will appear in addition to the set time in the readout, suggesting that the battery be recharged at the earliest opportunity. Approximately 100 fuzes can be set following first appearance of the low battery indication. Setters are recharged using a cable which plugs directly into a 24-V connector located on all self-propelled weapons and in the cab of many trucks servicing an artillery battery. The setter may be used while its battery is being recharged.

(4) The setting operation permits nondestructive stockpile surveillance of about 90 percent of the fuze electronics.

(5) The time setting of a fuze may be changed at the operator's discretion an indefinite number of times without degrading accuracy or reliability.

A-2. DIFFERENCES OF ET FROM MT FUZES

The ET fuze is significantly different in construction from the MT fuze.

(1) The time base is an electronic oscillator rather than a mechanical balance wheel.

(2) Integrated electronic scaling and counting circuits perform the function of a mechanical gear reduction train.

(3) Integrated electronic logic circuits provide the output signals accomplished by cam functions in mechanical fuzes.

(4) A reserve-type electrochemical power supply provides the operational energy for the system, paralleling in function the wound main spring or acceleration-driven gear train of the mechanical fuze. It is a lead/fluoboric acid/lead dioxide electrochemical system. The electrolyte is isolated in a copper ampule until the projectile is fired.

Figure A-5 is a block diagram of the ET fuze. After being gated by the initializing circuit which assures that all circuits have reached operating voltage, the oscillator (nominally 10,240 Hz), is scaled by a factor of 1024 in the logic and scaler circuits and delivers approximately 0.1-s pulses to the counter. The counter requires 2048 pulses before it will overflow. In use, the counter is made to start at an initial count X short of overflow, where X is the number of pulses corresponding to the desired set time. For example, if the desired time was 10.0 s (or 100 0.1-s counts) the counter would be initialized at 1948 when power first came on. After an additional 100 counts the counter would overflow, giving the firing signal. Approximately 3.4 s (34 counts) and 0.2 s (2 counts) before time out, electronic logic generates also an arming pulse. The arming pulse permits charging of the firing capacitor. This withholding of energy from the firing circuit until shortly before target time provides electronic overhead safety.

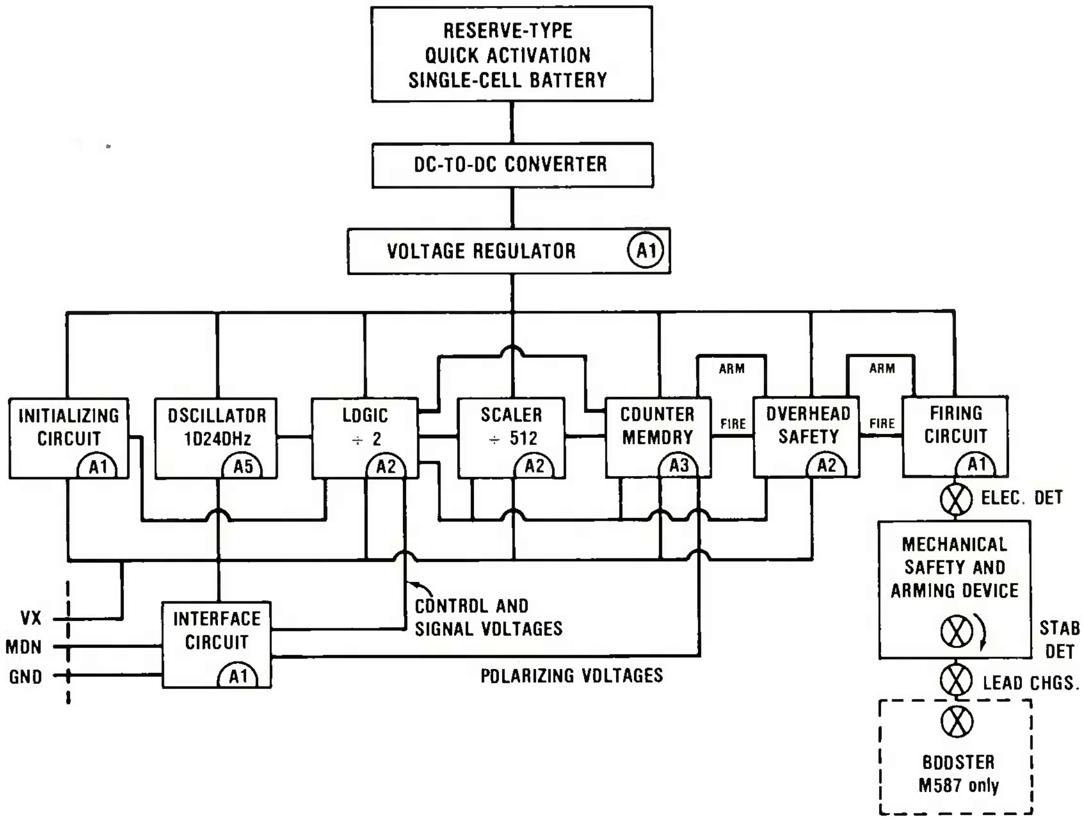


Figure A-5. Block diagram of M587/M724 ET fuze.

The initializing count is stored nonvolatilely (i.e., without requiring power) in the counter memory. The M587/M724 ET fuze utilizes metal nitride oxide semiconductor (MNOS) memory devices which are integrated in a single counter/memory silicon monolithic integrated circuit. The memory is set during the setting procedure when power is furnished by the fuze setter. The fuze power supply is not activated until the projectile is actually fired from the cannon. The memory will retain the setting for at least several days.

The interface circuit permits communication between fuze and fuze setter over a three-wire system. The overhead safety circuit requires that the arming signal precede the firing signal and withholds power from the firing circuit until the arming signal is received.

Nine of the ten purely electronic blocks shown in figure A-5 are constructed with integrated circuit techniques. Two of the integrated circuits are silicon monolithic and contain the four system blocks labeled A2 and A3. The remaining two integrated circuits are of thick-film-hyrid construction and contain the five system blocks labeled A1 and A5. There is no A4.

The oscillator function is achieved in a thick-film hybrid integrated circuit twin-T oscillator (A5) which contains a 12-V regulator to make the oscillator frequency insensitive to supply voltage. One of the reasons for choosing the twin-T design was because it was possible to preclude fail-fast failure modes.

The counter/memory function is achieved in a silicon monolithic integrated circuit (A3) containing a 12-stage binary counter and 12 MNOS memory elements, one associated with each stage. The 12th counter stage registers overflow and generates the call for a firing pulse.

The functions of the logic, scaler, and overhead safety blocks are all incorporated into a single silicon monolithic integrated circuit (A2).

The voltage regulator, interface, initializing, and firing circuit functions are all incorporated into a single thick-film hybrid integrated circuit (A1).

Figure A-6 is an artist's cross section of the M587 ET fuze in which many of the key components are identified.

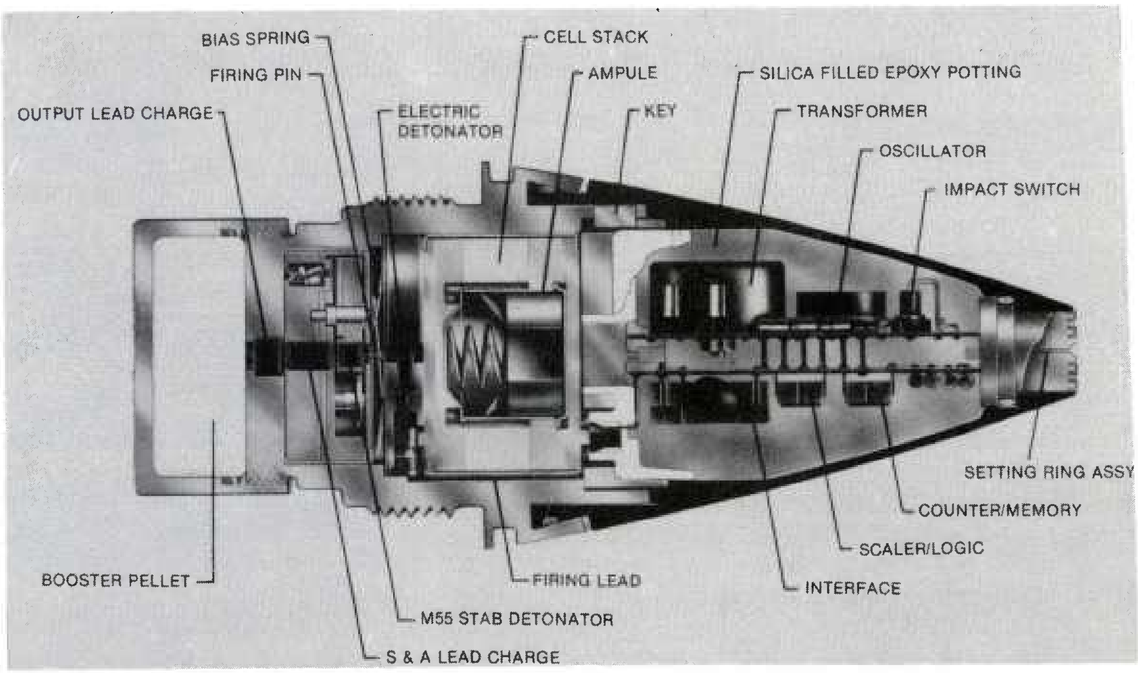


Figure A-6. M587 ET fuze.

A-3. ADVANTAGES AND CHARACTERISTICS OF ET FUZE SYSTEMS

Several of the advantages which accrue from use of this ET fuzing system are listed below.

(1) A single fuze is used for a wide variety of projectiles and cannons.

(2) A rapid, simple setting system is employed.

(3) Increased accuracy results from use of an electronic oscillator which is calibrated during setting.

(4) The timer is unaffected by spin or shock and therefore presents no problems in rocket-assisted projectile (RAP) applications.

(5) This concept provides an alternative and viable mobilization base for time fuzes—the U.S. electronics industry.

(6) The ET fuze is expected to be cost competitive with precision MT fuzes. A production price of between $40 and $50 is projected.

(7) The fuze is immune to electronic countermeasures. Although this is no advantage over MT fuzes which are also immune, it has become necessary to cite this factor in order to correct an erroneous impression that ET fuzes can be jammed. Since the ET fuze neither radiates nor receives electromagnetic energy and is almost totally shielded with metal, it CANNOT be jammed by enemy countermeasures. The Office of Missile Electronic Warfare independently confirmed this conclusion.

(8) The ET fuze contains many fail-safe features which are permitted by its sophisticated electronic system.

A-3.1 Fail-Safe Features

An enumeration of these fail-safe features follows:

(1) There is less chance of error in setting because the set time is entered in simple digital in-line format. The M36 setter also plays back the set time in self-illuminating digital in-line format following verification, thus affording the operator yet another chance to recognize an entry error. In addition, the M36 fuze setter has an interrogation mode in which a set fuze may be interrogated to the nearest 0.01 s without changing its setting.

(2) Most of the circuitry is proved out during settings.

(3) Any momentary interruption of fuze power during flight resets the counter, ensuring "fail-long."

(4) Power is withheld from the firing capacitor until approximately 3.4 s prior to set time.

A-3.2 Future Applications

This ET fuze system is highly adaptable. Some future probable applications are listed below.

(1) The basic system can be modified for other time ranges and/or for greater accuracy if desired.

(2) Setting during ramming in automatic loader/rammer sequences is quite feasible.

(3) The setter can be designed to interface directly with the range computer (e.g., TACFIRE) to eliminate the man interface and permit rapid adjustment in range during sequential firing. A basic prototype of such a system was successfully demonstrated during the Human Engineering Laboratory Battery Artillery Test (HELBAT) VI in October 1976 and HELBAT VII in March 1979.

(4) Although designed for an artillery application, the electronic design and setter are directly applicable to rockets and offer particular appeal in multirail remotely set (umbilical) systems such as the Multiple Launch Rocket System (formerly known as the General Support Rocket System), whose XM445 fuze now in engineering development uses identical timer electronics.

A-3.3 Pros and Cons of Electronic Fuze Setters

Because the use of an ET fuze setter is a new concept and does represent a departure from the way things have been done in artillery, the advantages and disadvantages of using a time fuze system requiring such a device have been enumerated in table A-1. Some of the advantages have already been noted elsewhere in this report but are repeated for completeness.

TABLE A-1.
ADVANTAGES AND DISADVANTAGES OF THE M36 ELECTRONIC FUZE SETTER

ADVANTAGES

1. Requires no moving parts in fuze.

   a. Eliminates parts wear on repeated setting. Fuzes may be reset an indefinite number of times without affecting accuracy or performance.

   b. Immune to mechanical displacement under high twist environments, which may change time setting if setting mechanism is part of fuze.

   c. Eliminates need for precision alignments in assembly of fuzes.

2. In-line decimal setting.

   a. By eliminating the need for interpolation between engraved markings and/or use of vernier scales, both training time and sources of human error will be minimized.

   b. Exact setting of digital dials eliminates one source of time inaccuracy.

   c. No need for concern about gear backlash.

3. Rapid set.

   a. Setting is independent of angular orientation of the fuze; that is, it is not necessary to rotate projectile to make scale or dial face operator.

   b. Independence of setting digits and ability to increment each digit either forward or backward reduces average setting time to about 10 s.

   c. Setting of additional fuzes to same time takes only 2 s.

   d. Permits rapid incrementing for barrage applications.

4. Ease of night setting.

   a. Internal illumination of setting dials and LED display eliminates need for flashlight or other external illumination.

5. Self-check feature.

   a. Minimizes probability of firing a defective fuze.

6. Calibration on setting.

   a. Permits use of less expensive fuze time base, since exceptionally long-term stability and very low temperature coefficient of frequency are no longer necessary.

7. Reduction in fuze proliferation.

   a. Ability to set artillery time fuzes in range when employed by armor.

   b. Ability to use same fuze in various tank guns by simply employing different setters with different guns, rather than requiring different fuzes with different range scales.

8. Growth potential (only setters need change, not the fuzes).

   a. Time settings entered automatically by direct interfacing with range computers.

   b. Incorporation in automatic setter/loaders.

   c. Central display of time setting made at each of the guns in an artillery battery (peacetime range safety).

DISADVANTAGES

1. Introduces another item into the inventory.

2. More costly than the setting wrench currently used with many mechanical time fuzes.

3. Battery requires periodic recharging.

4. Procedures must be established to prevent loss or gross mishandling of setter and its recharging cables.

A-3.4 Accuracy of ET Fuze

Table A-2 is a tabulation of the results from a typical field test and shows on a round-by-round basis the excellent accuracy of the ET fuze. Note that not only does the system satisfy the requirement of less than 0.100 s RMS error from set time, but also the system's agreement with interrogated time is exceptional.

TABLE A-2. SUMMARY OF FIELD TEST RESULTS ON XM587E2 ELECTRONIC TIME FUZE

11-12 OCT 1978: 8-inch M110A2 howitzer
M106 Projectile
XM188E1 (zone 9) propellant

Tube round No.	Fuze No.	Set time, s	Interrogated time, s	Function time, s	Difference from interrogated time, s	Difference from set time, s
970	7509	30.0	29.99	29.981	−0.01	−0.019
971	8279	30.0	29.97	29.962	−0.01	−0.038
972	8277	30.0	30.04	30.032	−0.01	+0.032
973	7209	30.0	29.99	29.979	−0.01	−0.021
974	7347	30.0	30.01	30.002	−0.01	+0.002
942	7063	60.0	60.05	60.044	−0.01	+0.044
943	8002	60.0	59.99	59.987	0.00	−0.013
944	7168	60.0	60.05	60.068	+0.02	+0.068
945	7010	60.0	60.05	60.070	+0.02	+0.070
946	7343	60.0	59.96	59.993	+0.03	−0.007
936	7545	75.0	75.01	75.012	0.00	+0.012
937	7462	75.0	74.96	75.001	+0.04	+0.001
938	7489	75.0	74.96	74.963	0.00	−0.037
939	7609	75.0	75.02	75.050	+0.03	+0.050
940	7128	75.0	74.97	74.988	+0.02	−0.012
931	7546	90.0	90.04	89.986	−0.05	−0.014
932	7723	90.0	90.03	90.045	+0.01	+0.045
933	7538	90.0	89.98	89.999	+0.02	−0.001
934	8065	90.0	90.00	90.034	+0.04	+0.034
935	8163	90.0	90.04	90.057	+0.02	+0.057

A-4. SUMMARY

The M587 and M724 are high-accuracy, digital ET fuzes for artillery projectiles which are simply and rapidly set either by direct contact or via umbilical connection to the M36 fuze setter. This ET fuze system provides

a. Major electronic system checkout during setting.

b. Fail-long circuit design.

c. Utilization of the electronic industry as an alternative mobilization base for time fuzes.

d. Incorporation of very recent microelectronic innovations, such as

(1) CMOS low-power circuitry in the setter and

(2) nonvolatile MNOS memory elements integrated into large-scale silicon monolithic integrated circuits in the fuzes.

e. Exceptional cost-reduction opportunities which should evolve gradually during the life cycle.

Each fuze contains (1) a stable, low-temperature coefficient, twin-T oscillator which is calibrated during setting, (2) a single cell reserve electrochemical battery, and (3) an electronic dc-to-dc converter.

As the M587/M724/M36 ET fuze system now enters production, the real potential of ET fuzing is just beginning to be tapped. Electronic time fuzing will play a major role in the fuzing of tomorrow's weapons.

APPENDIX B.--M587/M724/M36 Electronic Time Fuze System Details

CONTENTS

FIGURES

Table

B-1. INTRODUCTION

This appendix provides a more detailed description of the M587/M724/M36 electronic time fuze system. It describes the operation of metal nitride oxide semiconductor (MNOS) memory elements and how they are employed with other circuitry to provide the desired starting state for the fuze timer. It describes how the initializing pulse is generated by the interface and firing circuit (IAFC) IC, how this pulse triggers the circuitry in the timer IC which generates the long and short pulses, and how these pulses combine with the MNOS memory elements to provide the desired starting state for the fuze timer. Also discussed is the normal operation of the overhead safety circuit (OHS) and the effect on the OHS of failure to generate the long and short pulses. In addition, normal fuze setting is described in terms of the voltages appearing on the monitor line (MON) and operating voltage (Vx) inputs to the fuze.

B-2. THE MNOS TRANSISTOR

The MNOS transistor is a variable-threshold p-channel field-effect device. The amount of threshold voltage change depends on the duration and amplitude of the polarizing voltage applied between the gate and substrate. This polarizing voltage applied across the gate dielectric must exceed a certain minimum level (typically 20 to 50 V) before the threshold will shift.[1]

Figure B-1(a) is an artist's cross section of a typical metal oxide semiconductor (MOS) field-effect transistor (FET). It is fabricated on an n-type silicon substrate with p+ source and drain wells, a silicon dioxide gate insulator, and a metal gate. It has a characteristic as shown below. As the gate voltage becomes more negative, a p-channel depletion region beneath the insulator provides a current path between the p+ source and drain wells. The voltage at which the device conducts significant current is termed the threshold voltage.

Figure B-1(b) is a typical MNOS FET. It is fabricated in a similar manner to the MOS transistor described above. It differs only in that it contains a two-layer gate insulator consisting of a very thin silicon dioxide layer next to the silicon and a much thicker silicon nitride layer next to the metal gate. Operating characteristics are similar to those seen for the MOS device but with a more negative threshold voltage.

If a large positive voltage, with respect to the substrate, is applied to the gate of an MNOS transistor, electrons will tunnel through the very thin silicon oxide insulator and become trapped at the interface between the oxide and the nitride. After the positive voltage is removed, the device exists as it is pictured in figure B-1(c). If one plots the operating voltage for an MNOS device with trapped charge, one obtains the characteristic shown at the right. Note that the less negative threshold results from the bias provided by the trapped negative charge.

If a large negative voltage is applied, the trapped electrons will tunnel back through the thin oxide, returning the device to the state pictured in figure B-1(b).

---

[1]*J. W. Miller, Jr., An Electronic Timer Using Integrated MNOS Transistors for Memory, GOMAC Digest (1970), 175-177.*

Note that if the devices as pictured in figures B-1(b) and B-1(c) are "read" at a bias voltage of $^{-}4$ V, the (b) device will be nonconducting while the (c) device will be conducting. In further discussions we will refer to the (b) device as being OFF and the (c) device as being ON. We will use this distinction to force the desired initialization states of the timer during setting and functioning.

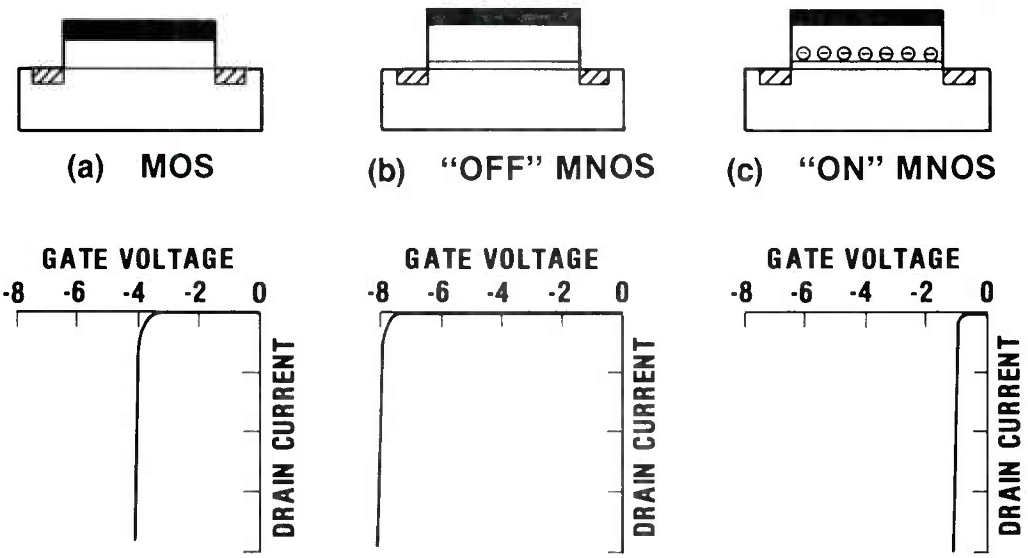


Figure B-1. MNOS memory transistor.

B-3. HOW THE MNOS TRANSISTOR FORCES THE STARTING STATE OF THE TIMER

Figure B-2 is a schematic of the electronics of the cost-reduced M587 fuze.

What we will concentrate on first is the circuitry inside one of the blocks labeled M_0 through M_{10}. These blocks appear at the lower right in the schematic and are the steered flip-flops comprising the binary counter stages of the timer. Figure B-3 is a schematic of one of these identical blocks.

For simplification figure B-4 shows the flip-flop schematic with the steering circuitry removed. Note that when the Q6 transistor is turned on, the $\overline{M}$ output is grounded. Also note that when Q5 is turned on, the M output is grounded if Q3 is also ON. Q5 and Q6 are turned on by two different signals both going LOW at about the same time, but with the short pulse going HIGH 50 μs earlier than the long pulse. If one examines the consequences of this pulse sequence it will become apparent that the state of the flip-flop after both short and long signals have gone high is determined by whether or not the memory transistor Q3 is ON or OFF. If it is ON the M output of the flip-flop will be HIGH (near ground potential). If it is OFF the $\overline{M}$ output of the flip-flop will be LOW (near V_{DD}).

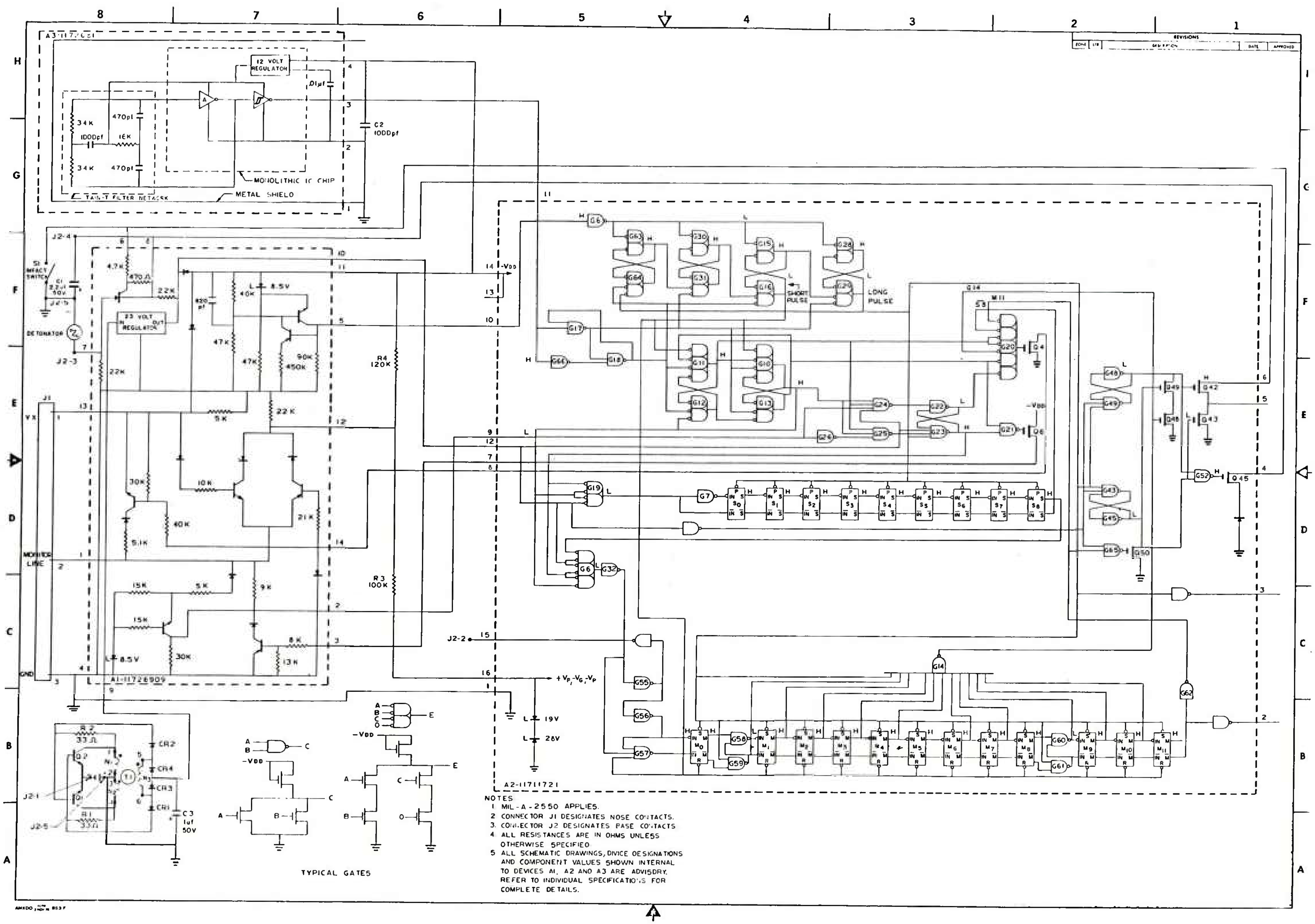


Figure B-2. Circuit schematic.

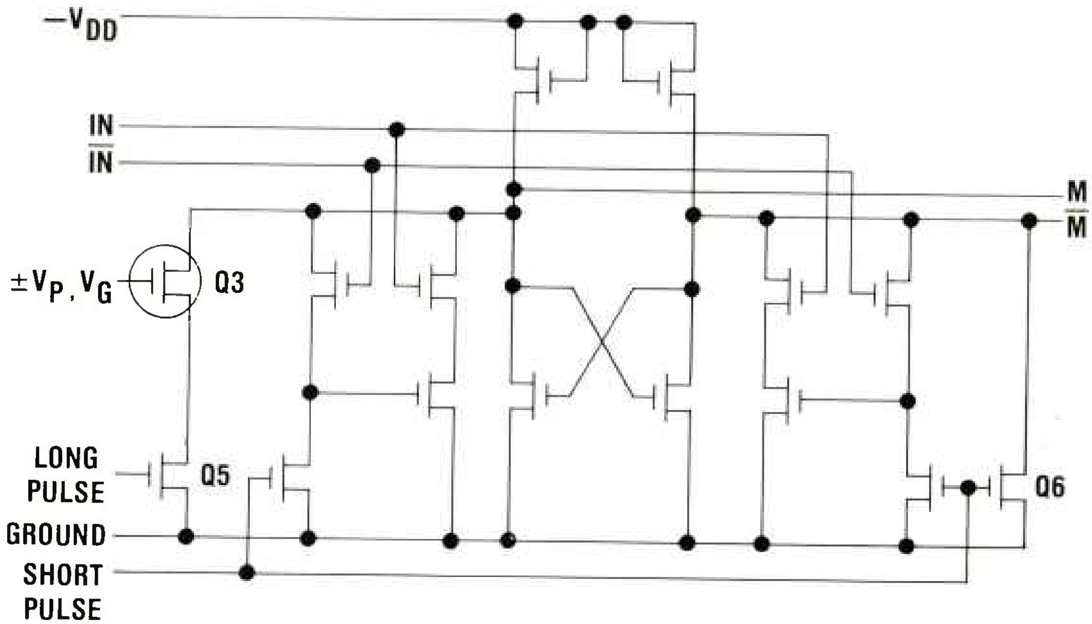


Figure B-3. M_0 through M_{10} counter stages.

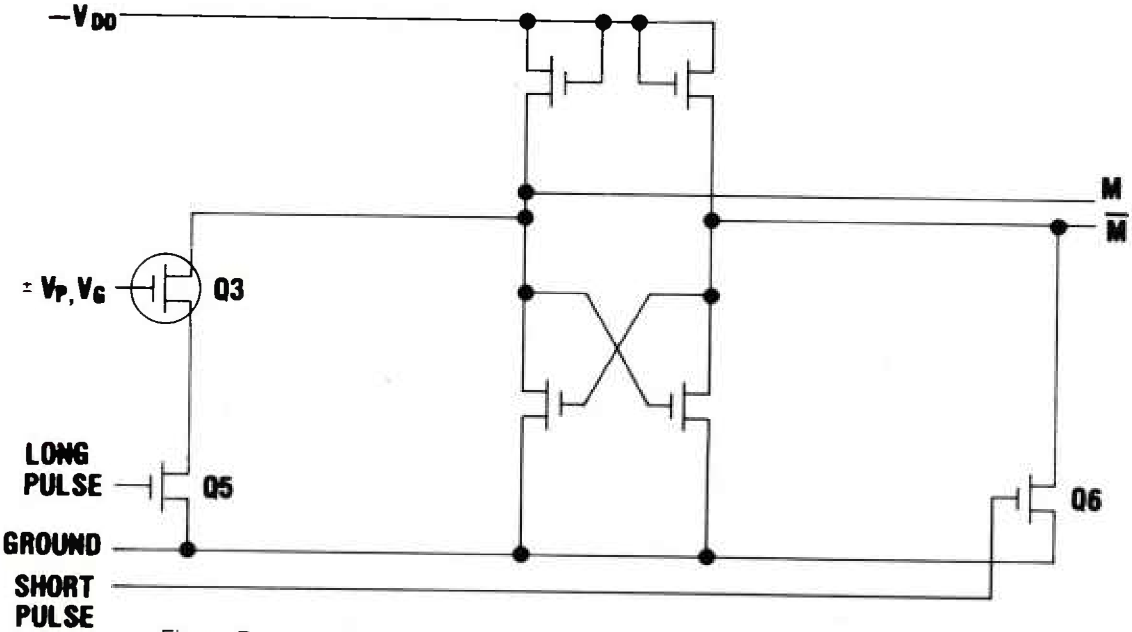


Figure B-4. M_0 through M_{10} counter stages, with steering circuitry removed.

B-4. HOW THE LONG AND SHORT PULSES ARE GENERATED

Your attention is directed to the fuze circuit schematic appearing in figure B-2. The group of four flip-flops appearing at the top center of the schematic is responsible for generating the short and long pulses. The parts of the schematic important to the short and long pulses have been reproduced in figure B-5 along with the waveforms generated.

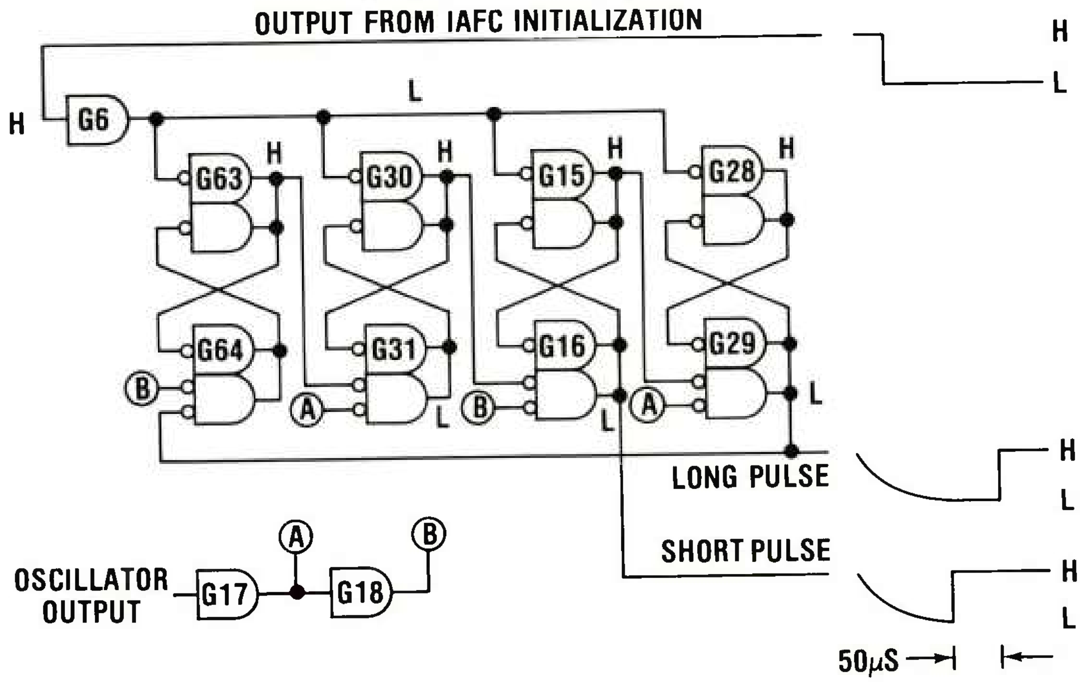


Figure B-5. Timer SP/LP circuitry.

Note that G18 and G17 provide outputs in phase and out of phase with the oscillator output, respectively.

As long as the input to G6 remains HIGH (and its output consequently LOW), each of the four flip-flops G63/G64, G30/G31, G15/G16, and G28/G29 will have the output of their upper side held HIGH. Because of the interconnection wiring it can be seen that a further consequence is that the outputs of the lower sides of G30/G31, G15/G16, and G28/G29 are also held LOW. Only the G64 side of G63/G64 follows the oscillator waveform.

When the input to G6 goes LOW (and its output goes HIGH) the flip-flops are no longer clamped. At 50-μs intervals (at one-half the oscillator period, to be more exact) the flip-flops change to their alternate state. Consequently, the short pulse switches HIGH 50 μs before the long pulse also switches HIGH.

This entire logic sequence is dependent on a sufficient delay (before the change of the input to G6 from HIGH to LOW) to permit the flip-flops to be forced into their initial states.

If for some reason the input to G6 goes LOW as V_{DD} is applied to the timer IC, some or all of the flip-flops may set up improperly and either the short pulse, long pulse, or both may never be generated.

IF	THEN
Both LP and SP	Timer initializes properly
SP but no LP	Timer initializes at 1790 counts (179 seconds, safe for all practical missions)
LP but no SP	Indeterminate by simple theory
Neither LP nor SP	Indeterminate by simple theory

In practice, if the proper input to G6 is subverted, the timer in the cost-reduced M587 fuze tends to initialize at around 257 counts (256, 256½, 257, and 257½ being the most frequently obtained experimentally).

B-5. HOW OVERHEAD SAFETY CIRCUIT OPERATES

The overhead safety circuit denies energy to the firing circuit until receipt of the arming pulse from the timer. For most time settings this occurs 34 counts (approximately 3.4 s) before timeout. For very short time settings this occurs at 2 counts (approximately 0.2 s) before timeout. The overhead safety circuit also guarantees that the arming pulse precedes the firing pulse and that fuze power is on. This latter function assures that the firing capacitor is shorted out during setting, thus providing a second safety against operation of the firing circuit during setting. The first safety is a back-biased diode in the IAFC IC which keeps the Vx voltage from the firing circuit.

Figure B-6 details the important circuit elements related to overhead safety. The long pulse (LP) which starts out momentarily low (L) resets flip-flops G48/G49 and G43/G45 as indicated. Q42 which has L on its gate and Q43 which also has L on its gate as long as M11 is low (normal condition for time set fuze) short out the firing capacitor. The gate of Q48 goes L on receipt of the arming pulse and since Q49 is already L, this will pull the gate of Q42 to the high (H) state, turning off Q42 and permitting the firing capacitor to charge. Flip-flop G48/G49 will also be flipped to the H state, thus holding the gate of Q42 H even after the arming pulse goes away. This H level is also applied to one gate of G52, completing half of the necessary firing condition.

If for any reasons the firing pulse should precede the arming pulse, Q49 will be turned off permanently by flip-flop G43/G45, and the necessary H signal to G52 will never be generated. That way the fuze can never time out. The same output from Q50, however, will turn off Q43 and permit the firing capacitor to charge.

When M11 goes H, after receipt of a normal arming pulse, the gate of Q45 will be switched L and ground the gate of the SCR through the 4.7-kohm resistor, thus firing the SCR and dumping the energy on the firing capacitor into the detonator.

If the LP is not generated during initialization, the two flip-flops G48/G49 and G43/G45 could come up randomly in four possible combinations. A summary of the malfunctions follows:

CONDITION 1. Both normal—Circuit would arm and function normally as directed by timer.

CONDITION 2. G48/G49 inverted; G43/G45 normal—Firing capacitor would arm immediately, and fuze would function when timer timed out.

CONDITION 3. G43/G45 inverted; G48/G49 normal—Firing capacitor would arm immediately, but fuze would never time out.

CONDITION 4. Both G43/G45 and G48/G49 inverted—Firing capacitor would attempt to charge immediately, but turned-on SCR would limit voltage to about 5 to 6 V. Fuze would never function.

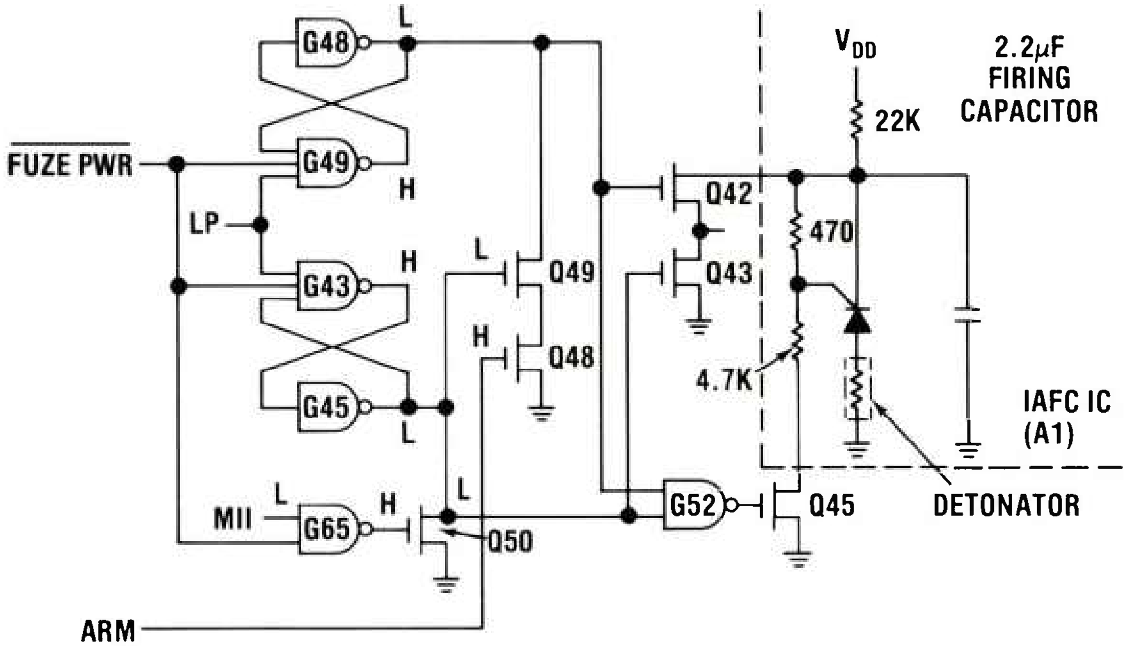


Figure B-6. Overhead safety circuit.

B-6. HOW A FUZE IS SET

The fuze setter communicates with the fuze by means of the three-wire system which exists whenever the setter probe contacts the bull's-eye pattern on the nose of a fuze.

The center dot of the bull's-eye receives an operating voltage (termed Vx) which powers the fuze during setting. The fuze power supply is a single-shot battery activated only upon firing from an artillery weapon and is inert during setting. The outer ring of the bull's-eye is ground. The center ring of the bull's-eye provides the actual control and communication functions.

The voltage level of the MON line provides system control. Four voltage levels are defined; in order of most positive to most negative they are POSITIVE (approx +27 V), HIGH (near ground), LOW (near V_{DD}, approx −24 V), and NEGATIVE (approx −27 V). The POSITIVE and NEGATIVE voltages when they appear are routed to the common gate of the MNOS devices and provide the polarizing voltages for writing and erasing the memory. The LOW voltage condition on the MON line disconnects the fuze clock (equal in frequency to that of the fuze oscillator divided by two) from the scaling and counting circuitry in the fuze. When the LOW voltage is switched HIGH, the connection to the fuze clock is reestablished and the fuze clock drives the fuze scaler and counter in parallel.

The parallel hookup of the scaler and counter exists at all times during setting of a fuze. Only the appearance of power from the fuze power supply will convert the parallel hookup into a series one. This parallel hookup permits the setting sequences to be accomplished 512 times faster than real time.

The setting sequence is most easily understood by following the MON and Vx waveforms. These waveforms appear in figures B-7 and B-8.

Figure B-7. Monitor-line waveform.

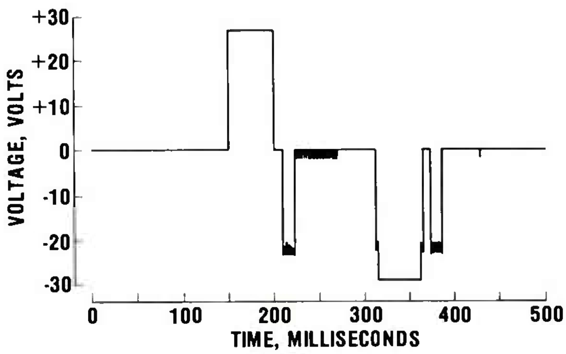
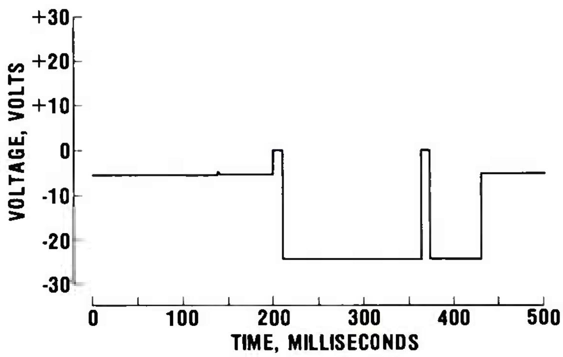


Figure B-8. Vx-line waveform.



Whenever the mode switch of the setter is set to other than OFF, approximately −6 V exists at the Vx pin of the probe. When contact is made between fuze and setter, the Vx connection is made last because the Vx pin is shorter than the other two. When the Vx contact is made, current flows into the fuze, and this triggers the setting sequence. The setter waits approximately 150 ms to assure contact chatter has ended and then generates a POSITIVE voltage on the MON line. The 50-ms-duration voltage turns ON all the MNOS memory transistors in the timer.

Next, the MON line is driven LOW to disconnect the fuze clock from the scaler and counter. Then the Vx line is driven first to ground and then to a level of approximately −24 V. The fuze circuitry goes through the initialization sequence, generating the short and long pulses and initializes the counter at 111 011 111 110. The M_0 and M_8 stages initialize to 0 instead of 1 because of inverter stages placed in the counter chain (see fig. B-2). The starting count is 257 counts short of all 1's. The scaler is initialized at 11 111 111.

The setter looks for oscillator pulses on the MON waveform. If these are not present the setter will initiate a NOT SET sequence.

If setter pulses are present, the MON line is shifted HIGH, connecting the fuze clock to the scaler and counter in parallel. The fuze clock pulses appear on the MON line and these are counted by the setter. Circuitry in the fuze shortens the pulse width whenever either ARM signal occurs or the S8 stage of the scaler shifts HIGH. The setter assures that both ARM signals and the S8 transition occur at the appropriate count during the check cycle.

When the fuze counter gets to 111 111 111 111, a gated time interval equal to SET TIME/512 permits additional pulses to flow into the counter. No pulses are visible on the MON line during the gated time interval, because once M_{11} switches LOW the pulse train is blocked out. At the end of the gated time interval, the MON line is driven LOW to disconnect the fuze clock and then is driven NEGATIVE for approximately 50 ms. The MNOS transistors are selectively left ON or turned OFF depending on the count in the counter. If the drain of the MNOS transistor is near ground (HIGH), the transistor will be shifted to OFF. If the drain of the MNOS transistor is near 20 V (LOW), the transistor will be left ON. The memory transistor associated with M_{11} is always turned OFF regardless of the state of the flip-flop, because in M_{11} the drain of the memory transistor is connected to the source of the transistor activated by the long pulse rather than to the drain of a flip-flop transistor.

Table B-1 illustrates the relationship between memory states and counter counts. The top line shows that following the POSITIVE 50-ms pulse all memories were turned ON: Initialization with all memories ON results in a count of 111 011 111 110 because M_8 and M_0 contain inverter stages. At the end of the check cycle, the counter reads 111 111 111 111. If a 10.0-s setting is now put into the fuze, a gated time interval of 10.0/512 s permits approximately 100 pulses to enter the counter. The table assumes exactly 100 full pulses (101 transitions, since the gated interval is always started with a transition). The NEGATIVE polarizing voltage now does its work leaving ON M_{10}, M_9, M_7, M_4, M_3, and M_1 and turning OFF M_{11}, M_8, M_6, M_5, M_2, and M_0. M_{11} is always turned OFF. M_6, M_5 and M_2 are turned OFF because the 1 signifies that the drains of the memory transistors associated with these stages were near ground. M_8 and M_0 are turned OFF, because with inversion, a 0 signifies that the drains of the memory trainsistors associated with these stages were near ground.

TABLE B-1. RELATIONSHIP BETWEEN MEMORY STATES AND COUNTER COUNTS

Position in Setting Sequence	M_{11}	M_{10}	M_9	M_8	M_7	M_6	M_5	M_4	M_3	M_2	M_1	M_0
State of MNOS Devices Following $+V_p$	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
Initial State	1	1	1	0	1	1	1	1	1	1	1	0
Arm Pulse 1	1	1	1	1	1	1	0	1	1	1	1	0
Arm Pulse 2	1	1	1	1	1	1	1	1	1	1	1	0
S_6 Flip	1	1	1	1	1	1	1	1	1	1	1	1
Start of Gated Time	0	0	0	0	0	0	0	0	0	0	0	0
10.0-s Set	0	0	0	0	0	1	1	0	0	1	0	0
State of MNOS Devices Following $-V_p$	OFF	ON	ON	OFF	ON	OFF	OFF	ON	ON	OFF	ON	OFF
Initialized State	0	1	1	1	1	0	0	1	1	0	1	1
Time Out	1	0	0	0	0	0	0	0	0	0	0	0

Upon reinitialization these stages will now come up to the 1's complement of the set count as also shown in table B-1.

The Vx line is next switched off and then back on again, causing this reinitialization while the MON line is held LOW. Then the MON line is driven HIGH, permitting the fuze clock to drive the counter. When M_{11} of the counter switches HIGH, the output pulse is compared for time of occurrence against the precision gate used for setting the fuze. If the M_{11}-output occurred at the proper time the setter will display the set time and turn off except for the display. The display will go out when the setter is removed from the fuze. If the M_{11}-output did not occur at the proper time the setter will initiate a NOT SET sequence.

The NOT SET sequence applies a POSITIVE monitor voltage and causes the setter to display the letter E for error.

DISTRIBUTION

ADMINISTRATOR
DEFENSE TECHNICAL INFORMATION CENTER
ATTN DTIC-DDA (12 COPIES)
CAMERON STATION, BUILDING 5
ALEXANDRIA, VA 22314

COMMANDER
US ARMY RSCH & STD GP (EUR)
ATTN CHIEF, PHYSICS & MATH BRANCH
FPO NEW YORK 09510

COMMANDER
US ARMY ARMAMENT MATERIEL
READINESS COMMAND
ATTN DRSAR-LEP-L, TECHNICAL LIBRARY
ATTN DRSAR-ASF, FUZE AND
MUNITIONS SUPPORT DIV
ROCK ISLAND, IL 61299

COMMANDER
US ARMY MISSILE & MUNITIONS
CENTER & SCHOOL
ATTN ATSK-CTD-F
REDSTONE ARSENAL, AL 35809

DIRECTOR
US ARMY MATERIEL SYSTEMS ANALYSIS
ACTIVITY
ATTN DRXSY-MP
ABERDEEN PROVING GROUND, MD 21005

DIRECTOR
US ARMY BALLISTIC RESEARCH LABORATORY
ATTN DRDAR-TSB-S (STINFO)
ABERDEEN PROVING GROUND, MD 21005

US ARMY ELECTRONICS TECHNOLOGY
AND DEVICES LABORATORY
ATTN DELET-DD
FORT MONMOUTH, NJ 07703

HQ USAF/SAMI
WASHINGTON, DC 20330

TELEDYNE BROWN ENGINEERING
CUMMINGS RESEARCH PARK
ATTN DR. MELVIN L. PRICE, MS-44
HUNTSVILLE, AL 35807

ENGINEERING SOCIETIES LIBRARY
345 EAST 47TH STREET
ATTN ACQUISITIONS DEPARTMENT
NEW YORK, NY 10017

DIRECTOR
DEFENSE ADVANCED RESEARCH
PROJECTS AGENCY
ARCHITECT BLDG
1400 WILSON BLVD
ATTN ADVANCED CONCEPTS DIV
ATTN WEAPONS TECH & CONCEPTS DIV
ARLINGTON, VA 22209

UNDER SECRETARY OF DEFENSE
FOR RESEARCH AND ENGINEERING
ATTN TEST AND EVALUATION
ATTN RESEARCH & ADVANCED TECH
WASHINGTON, DC 20301

OFFICE OF THE DEPUTY CHIEF OF STAFF
FOR RESEARCH, DEVELOPMENT,
AND ACQUISITION
ATTN DAMA-CS, DIR OF COMBAT
SUPPORT SYSTEMS
ATTN DAMA-WS, DIR OF WEAPONS SYSTEMS
ATTN DAMA-CSM, MUNITIONS DIV
WASHINGTON, DC 20310

COMMANDER
US ARMY ARMAMENT RESEARCH AND
DEVELOPMENT COMMAND
ATTN DRDAR-ASD (3 COPIES)
ATTN DRCPM-CAWS, PM, CANNON ARTILLERY
WEAPONS SYSTEMS/SEMI-ACTIVIE
LASER GUIDED PROJECTILES
ATTN DRDAR-TDS, SYSTEMS DEV &
ENGINEERING
ATTN DRDAR-LC, LARGE CALIBER WEAPON
SYSTEM LABORATORY
ATTN DRCPM-PBM-T-F, J. RESTAINO
DOVER, NJ 07801

PRESIDENT
US ARMY FIELD ARTILLERY BOARD
ATTN ATZR-BDWT, WEAPONS TEST DIV
FORT SILL, OK 73503

COMMANDER
US ARMY MATERIEL DEVELOPMENT
AND READINESS COMMAND
ATTN DRCDE, DIR FOR DEVELOPMENT & ENG
5001 EISENHOWER AVE
ALEXANDRIA, VA 22333

COMMANDER
US ARMY MISSILE COMMAND
ATTN DRCPM-RS, MLRS (B. CROSSWHITE)
REDSTONE ARSENAL, AL 35809

DIRECTOR
US ARMY MISSILE LABORATORY
USAMICOM
ATTN DRSMI-RPR, REDSTONE SCIENTIFIC
INFO CENTER
REDSTONE ARSENAL, AL 35809

COMMANDER
US ARMY TEST & EVALUATION
COMMAND
ATTN DRSTE-CM-F
ABERDEEN PROVING GROUND, MD 21005

COMMANDER
US ARMY ABERDEEN PROVING GROUND
ATTN STEAP-TL, TECH LIB
ABERDEEN PROVING GROUND, MD 21005

COMMANDER
US ARMY YUMA PROVING GROUND
ATTN STEYP-MTW
YUMA, AZ 85364

COMMANDANT
US ARMY FIELD ARTILLERY SCHOOL
ATTN LIBRARY
ATTN ATSF-CD-MW
FORT SILL, OK 73503

COMMANDER
NAVAL SURFACE WEAPONS CENTER
ATTN E-40, TECHNICAL LIB
WHITE OAK, MD 20910

US ARMY ELECTRONICS RESEARCH
& DEVELOPMENT COMMAND
ATTN TECHNICAL DIRECTOR, DRDEL-CT

HARRY DIAMOND LABORATORIES
ATTN CO/TD/TSO/DIVISION DIRECTORS
ATTN RECORD COPY, 81200
ATTN HDL LIBRARY, 81100 (3 COPIES)
ATTN HDL LIBRARY, 81100 (WOODBRIDGE)
ATTN TECHNICAL REPORTS BRANCH, 81300
ATTN CHAIRMAN, EDITORIAL COMMITTEE
ATTN LEGAL OFFICE, 97000
ATTN CHIEF, 30000
ATTN CHIEF, 34000
ATTN CHIEF, 34200
ATTN CHIEF, 34300
ATTN CHIEF, 34400 (2 COPIES)
ATTN CHIEF, 34500 (10 COPIES)
ATTN CHIEF, 40000
ATTN CHIEF, 47000
ATTN CHIEF, 47700