Failure Investigation -
Multiple Grenade Launching

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This memo presents the results of the simultaneous grenade launching failure investigation. The failure investigation includes tests made in the field at El Mirage, California, laboratory tests made at BxA to determine the exact cause, and tests made to verify the effectiveness of corrective action implemented.

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During Space Ordnance Systems (SOS) grenade firing field tests of the DVT grenade launch assembly (GLA) two grenades were launched simultaneously on two occasions from a single simulated sequential firing command. This report is a summary of subsequent trouble shooting, tests, and analysis that identified the cause of the malfunction and demonstrated the effectivity of two modifications designed to prevent further multiple firings.

Description of Incident

Both on 10 February and 11 February, during the SOS field tests at El Mirage Dry Lake Bed near Palmdale, California, grenades #1 and #2 were launched simultaneously from a single simulated sequential firing command. In each instance, the GLA was installed in a Mortar Box and the grenades were fired thru firing circuits which are installed on a PC board in the mortar box exterior to the GLA. In each instance the GLA's contained all four grenades. The Mortar Box electronics and GLA are designed to fire only one grenade at a time from seperate sequential commands in the sequence Grenade #2, #4, #3, and #1. Since the GLA was fully loaded with all four grenades, only grenade #2 should have been launched when the simulated command was issued. The first scheduled firing test was made with the test unit (Mortar box and GLA) at ambient temperature, and the second with the test unit at approximately -4°F. The temperatures of the units, however, are not related to the malfunction.

Neither of the grenades launched in the second test unit detonated on impact. This has been determined to be a seperate failure, not related to multiple grenade launchings and is fully discussed in a seperate report by SOS, who was assigned the responsibility of that failure investigation.

Description of Firing Circuitry Design

A functional description of the entire firing circuit design is necessary to evaluate the tests and analysis that is reported herein. A simplified schematic of the rocket motor iniator firing circuitry is shown in Figure 1. It should be noted that each of the five firing circuits (Fire #1, #2, #3, #4 and sequential) are identical, therefore, a circuit discussion can be in terms of only one.

In actual lunar operation and in the field test, both the sequential (C_1) and the regular (C_2) firing capacitors, located on the Mortar Box electronic board, are charged to +24V to arm the firing circuits. After the circuits are armed, a positive 15 volt pulse is applied to the input of the unjunction transistor to trigger a selected grenade firing circuit. At the end of the

NOTES:

1. S1 IS A SAFE/ARM SWITCH SHOWN IN SAFE POSITION
2. ROCKET MOTOR INIATOR SAFE/ARM SWITCH NOT SHOWN
3. S2 S3 & S4 ARE MICROSWITCHES OPERATED BY GRENADES. SWITCHES SHOWN IN POSITION WITH GRENADES INSTALLED

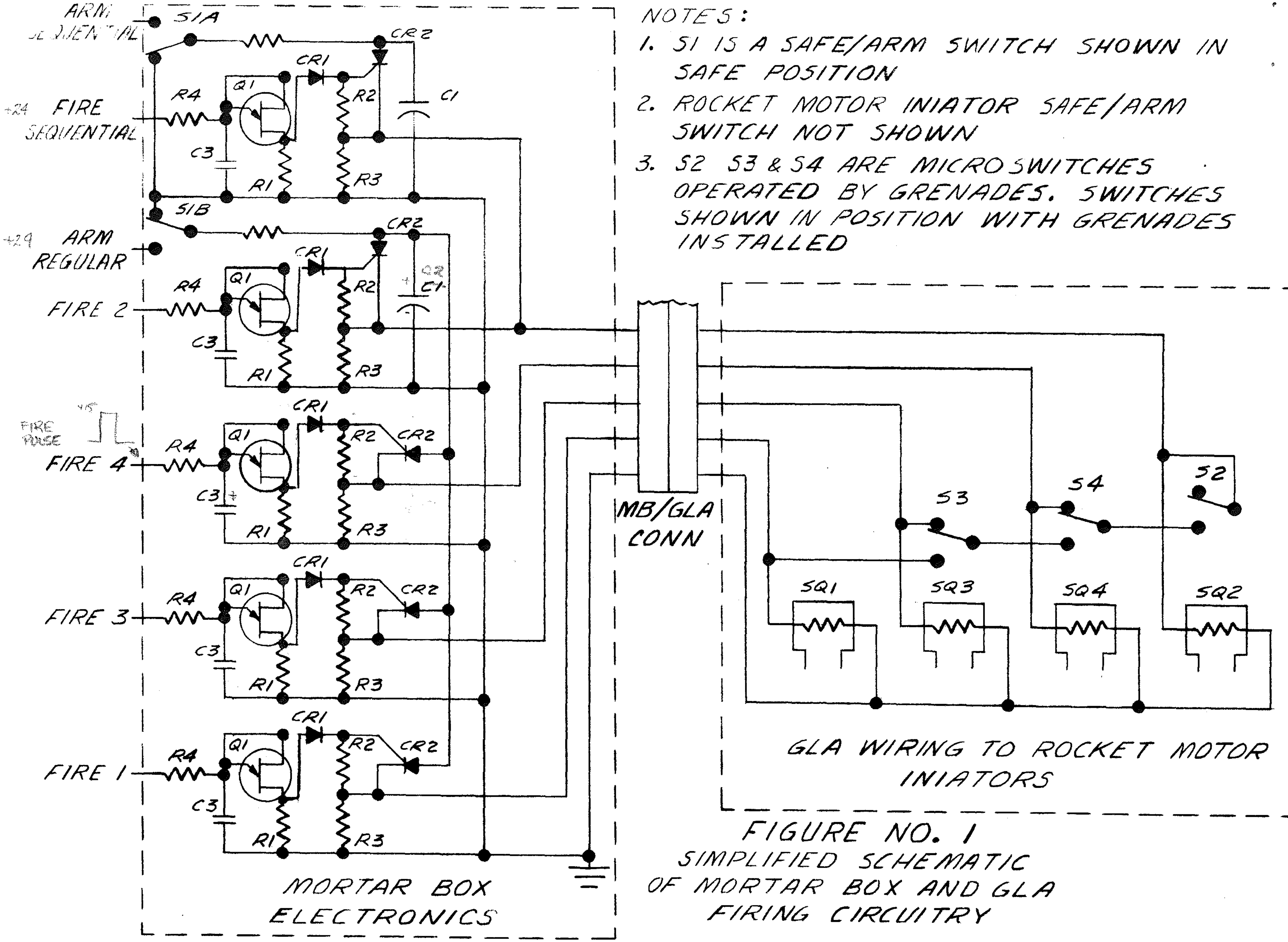


FIGURE NO. 1
SIMPLIFIED SCHEMATIC OF MORTAR BOX AND GLA FIRING CIRCUITRY

firing pulse, the unjunction transistor turns on, applying the charge of C_3 (thru the unjunction transistor) across the parallel paths of R_1 and the series connection D_1, R_2, and R_3 paralled by the 1 Ω resistance of the iniator in the GLA. When the voltage across R_2 reaches approx. 0.7 volts, the SCR turns on, applying the charge of C_2 (or C_1 if the sequential circuit is triggered) across the appropriate rocket motor iniator. C_1 (and C_2) has a capacity of 350 μf which when charged to 24V is sufficient to fire the iniators.

During lunar operation it is planned to fire the grenades in the sequence of 2, 4, 3, 1. The grenades may either be fired selectively by command to the proper firing circuit, or in deliberate sequence by repeated sequential commands (after re-arming) to the sequential firing circuit thru the operation of micro switches S_2, S_4, and S_3, located in launch tubes #2, #4 and #3 respectively. S_2 is closed when Grenade #2 is launched, permitting the charge on C_1 to be applied to Grenade #4 when the next command is iniated. Similarily, Grenades #4 and Grenades #3 operate S_4 and S_3 respectively to permit firing of the next grenade from sequential firing commands.

Failure Investigation

After the first multiple grenade firing on 10 February, a thorough review of the circuit and a long discussion of the problem resulted in a decision to procede in launching the two live grenades in the GLA to permit a complete and safe examination of the mortar box and GLA. Therefore, the #4 grenade was fired and then the #3 grenade, in the normal firing modes. Both were successful launches with grenade detonations.

Immediately after the firing of the #4 and #3 grenades the test unit was tested in the field to attempt to determine the cause. The test was made by connecting 1 ohm (resistive value of rocket motor ASIs) resistors to the GLA rocket motor iniator leads at the bottom of the launch tubes. Extensive firing tests were made by repeatedly triggering the mortar box firing circuits while monitoring two of the 1Ω resistors simulating the iniators with an oscilloscope and the capac. voltage arming lines with ammeters. No anomalies were observed by either oscilloscope or current monitoring equipment in arming capacitor charging lines. It was assumed that the multiple firings were caused by a short in the test setup that was eliminated or removed by the #4 and #3 grenade firings or in moving and disassembling the test unit during the tests. Evidence of debris was found in the mortar box and on the electronic board although no short existed. The MB was cleaned up and RTV was applied to the leads to the electronic board. A thorough electrical and functional check of the MB (regular and sequential firing modes) was made.

Immediately after the second multiple firing in the second test unit, the above tests were repeated again using 1 Ω resistors with no indications of a malfunction. ASI "headers" were then procured by SOS to use in place of the 1 Ω resistors to more realistically simulate iniator firings. "Headers" are partially assembled ASI's, with only dud bridgewires, the base, and pins. The headers burn open when fired, simulating an ASI or SBASI iniator.

Firing tests were again made using headers instead of resistors to simulate the rocket motor iniators. Single simulated sequential commands to either the sequential firing circuit or the Grenade #1 firing circuit now caused two headers (at Grenade #2 and Grenade #1) to ignite, duplicating the malfunction. The tests were repeated using a different GLA and again using a second Mortar Box with either of the GLAs. In all cases the tests repeatedly demonstrated double firing of headers from either a simulated firing command to the sequential firing circuit or Grenade #1 firing circuit in the regular firing mode.

Oscilloscope traces were obtained during these tests showing the time correlation between the double iniations. One of these photograph of these traces is shown in Figure 2. All traces taken of multiple firings were similar varying only slightly in indicated time required to iniate a header. An additional important observation was made. Every multiple firing indicated that both the sequential and the regular arming capacitors were discharging indicating that both regular and sequential firing circuits were being triggered.

These tests indicated that the high current pulse to the grenade #2 iniator (sequentially fired) was generating a transient which was coupling into the grenade #1 firing circuit. The transient occurs when the bridge-wire of the initiator opens up and does not occur when a 1 ohm resistor is used in place of headers or SBASIs. A further test was made to isolate the failure mode to either the GLA or the mortar box electronics. The GLA was removed from the mortar box and the headers connected directly to the firing leads at the mortar box/GLA connector. Repeated firing tests indicated only one header was iniated at a time with no anomalies. In examining the wiring of the one GLA after this series of tests, the wiring in the GLA was disturbed, seperating the leads of Grenade #1 and #2. The iniator leads to these two grenades are run pressed together along one side of the GLA. After this examination and inadvertent seperation of the leads, multiple header firings could not be repeated with this GLA. The inability to fire two headers when connected directly to the connector and with the GLA after spreading the wires tended to substantiate the theory that the transients were being coupled in the GLA.

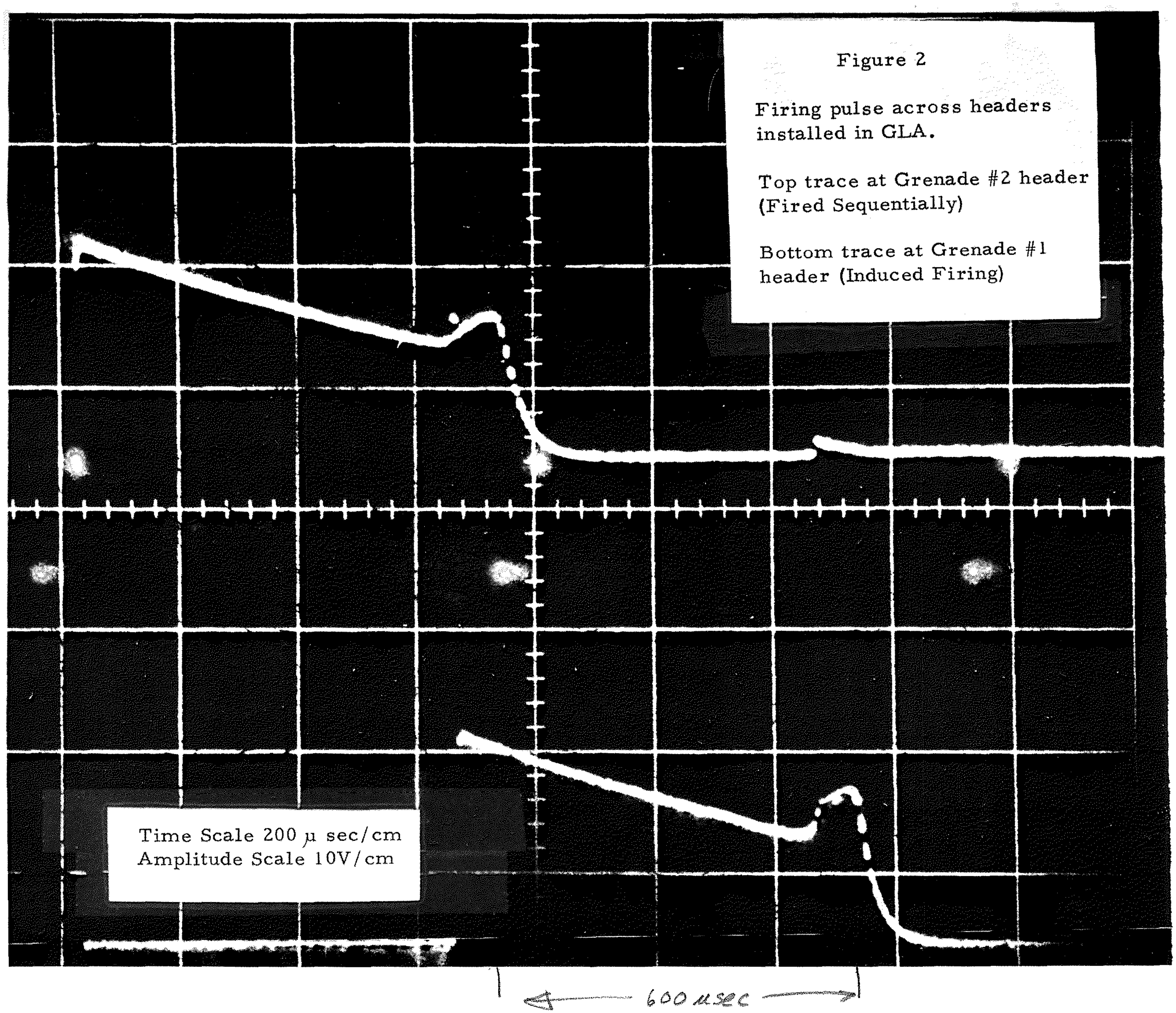


Figure 2

Firing pulse across headers installed in GLA.

Top trace at Grenade #2 header (Fired Sequentially)

Bottom trace at Grenade #1 header (Induced Firing)

Time Scale 200 µ sec/cm
Amplitude Scale 10V/cm

Prior to concluding the preliminary investigation while in the field a test was made to verify that the multiple firings was not due to dual triggering at the input of the firing circuit thru coupling in the fifty foot firing leads from the fire control center to the launch pad. In this test, headers were connected to the GLA installed in a mortar box, and all except the sequential firing circuits were grounded at the input of the mortar box electronics at the mortar box adapter board. Again, when simulated sequential firing commands were iniated to grenade #2, both grenades #1 and #2 ignited, verifying that the triggering was not exterior to the mortar box/GLA combination.

Although the malfunction during the field test occurred with Grenade #2 and #1 when grenade #2 was fired sequentially, a series of tests were made to determine if the malfunction was unique to #2 and #1 circuits. During this series of tests, headers were placed in all four grenades, but the microswitches were operated to place selected grenades in the sequential firing circuit.

Prior to leaving SOS, the film of the multiple launchings were also examined, in particular to observe the timing of the multiple launchings. The films indicate that the grenade #1 was launched approximately 250 μ sec. after grenade #2, consistent with the timing indicated by the photographs of multiple header firings. This evidence eliminates the possibility that the dual launchings were due to the shock environment. The shock generated by grenade #2, would occur several milliseconds after the iniator in grenade #2 was ignited since it takes several milliseconds to ignite the propellant to thrust the grenade and generate a shock. If the second grenade iniator was fired by microswitch operation or by electromagnetic/electrostatic energy due to the shock or blast the films would show the second grenade exiting the launch tube more than 8 frames after grenade #2 since the frame rate was approximately 250 μ seconds per frame. Actually the films show the grenades exiting within one frame of each other.

see fig 2

Detailed tests and Analysis

Two mortar boxes and two GLA's were returned to BxA for extensive tests to determine the exact cause of the malfunction and to verify the effectiveness of subsequent modifications. For these tests, 100 dual bridgewire headers were obtained from SOS for destructive tests.

Functional Tests with Headers

On February 16, the motar boxes and GLA's were connected together in the laboratory and the unit operated thru the S/S test set. A dual beam oscilloscope again was used to obtain the signal across the headers when grenades were fired sequentially.

Of ten firings only one multiple header firing was observed. It was then assumed that the GLA leads were no longer tightly coupled to generate enough cross coupling to induce false triggering. Further tests were then made using a dummy GLA made with all four positive firing leads tightly compressed together in one group, and the four ground leads tightly coupled together in a second group. The ground leads were soldered together with one only connected to the GLA/MB connector to simulate actual GLA single point grounding. Each of the four positive leads were connected to the proper pin. With this test fixture (or dummy GLA) every test made with all four headers connected duplicate multiple grenade launchings by igniting two headers and discharging both sequential and regular capacitors regardless of which firing circuit was triggered. The timing of the ignition of headers was identical to those obtained while at the El Mirage test site and is again shown in Figure 3.

Analysis of the traces indicated that a negative voltage was being induced on the cathode of the SCR while the trigger of the SCR was maintained at or near ground. Note from Figure 2 and Figure 3 that the second firing pulse (measured across the header) is triggered at the time of ignition of the first header. At this time the current due to the first pulse falls rapidly to zero since the 1 ~ header has opened up making the impedance infinite. The collapse of the current induces a negative voltage in the second pair of leads which is connected to the SCR cathode (Figure 1). The negative pulse induced at the SCR was photographed both with a GLA and with the dummy GLA connected to the mortar box electronics. Reproductions of these photographs showing the induced signal characteristics is shown in Figure 4 and 5. Figure 4 is a trace of the pulse induced with a GLA. Figure 5 is a trace of the pulse induced with the dummy GLA (Worst Case Wiring).

Modification and Retests

Any one of the following modifications were proven, by tests, to be sufficient to prevent multiple firings:

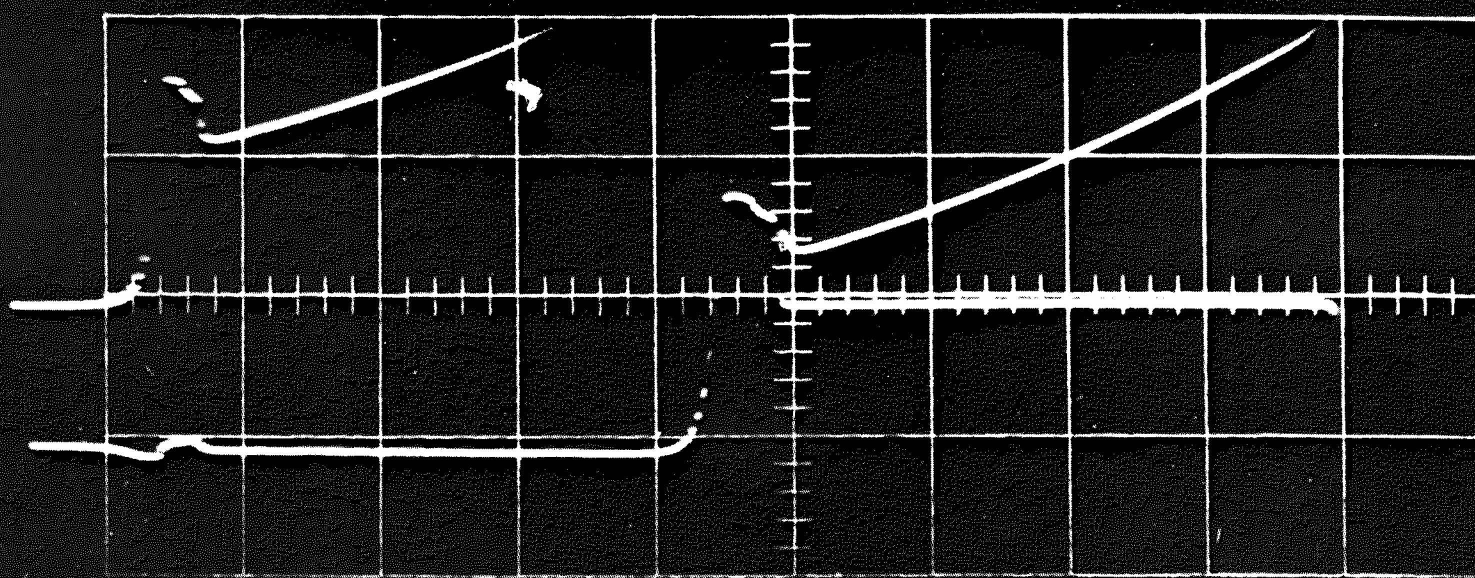
1. Desensitize the firing circuits to eliminate the effect of the negative induced transient.

2. Arm only one arming capacitor such that there would be sufficient energy to ignite an iniator.

3. Rewire the GLA to eliminate or reduce the negative transient.

Figure 3

Firing pulse across headers with worse case wiring (Dummy GLA). Top trace at Grenade #2 header (Fired Sequentially). Bottom trace @ Grenade #1 header (Induced Firing.)



Time Scale 200 u sec/cm
Amplitude Scale 10 V/cm

Note: Time scale from right to left.

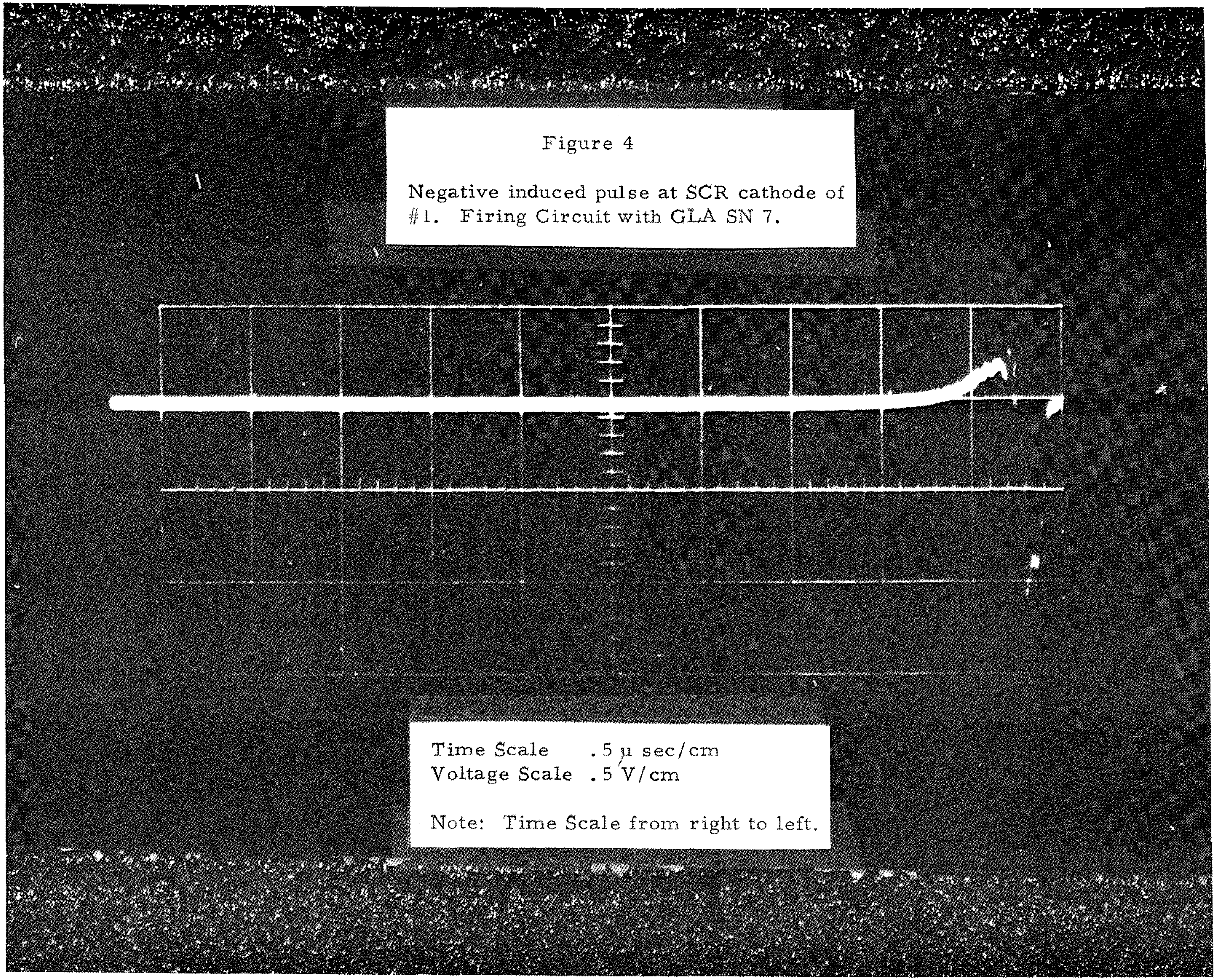


Figure 4

Negative induced pulse at SCR cathode of #1. Firing Circuit with GLA SN 7.

Time Scale .5 μ sec/cm
Voltage Scale .5 V/cm

Note: Time Scale from right to left.

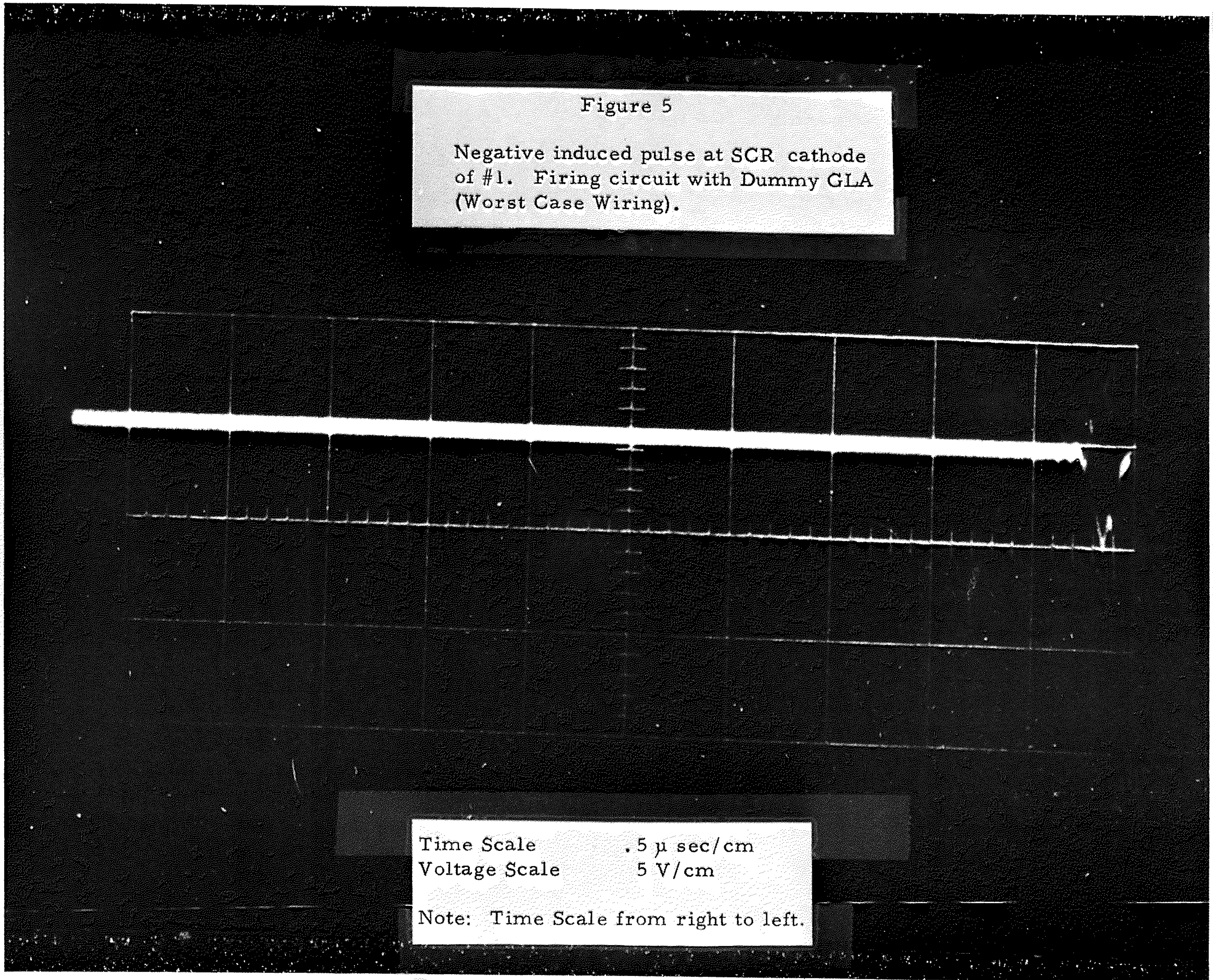


Figure 5

Negative induced pulse at SCR cathode of #1. Firing circuit with Dummy GLA (Worst Case Wiring).

Time Scale	.5 μ sec/cm
Voltage Scale	5 V/cm

Note: Time Scale from right to left.

Desensitization of Firing Circuits

The first modification was incorporated by decreasing the value of the resistor between the cathode and the trigger of the SCR (R_2) of Figure 1 and increasing the value of the unjunction resistor R_1. R_2 was originally 1.2 KΩ and R_1 was originally 47Ω. From Figure 1, it is obvious that with $R_2 \gg R_1$ the trigger is near ground potential (less the Diode drop). With $R_2 \ll R_1$, the potential at the trigger is very near the potential of the cathode, thus the negative voltage is essentially applied to both the trigger and the cathode and false triggering does not occur. This modification was made on all five firing circuits. The effectiveness of this desensitizing the firing circuits was then verified by connecting the modified circuit to the dummy GLA (worst case wiring) and performing firing tests with headers. 38 tests were performed with the dummy GLA with no evidence of dual firings from oscilloscopes monitorings. In these tests both arming capacitors were charged and in no test did both discharge. 21 tests were also performed after the circuit was modified with the GLA that had been brought back from El Mirage with no evidence of multiple firings.

In addition to destructive firing tests, two other tests were made to verify the circuit performance after modification.

In the first test, negative pulses were applied directly to the cathode of the SCR using a Rutherford pulse generator. The amplitude versus pulse width at the triggering level was then determined for firing circuits both before and after modifying the circuit.

This test indicates the circuits are very significantly desensitized to negative transients. The pulse width of the induced pulse with a GLA is between .2 and .3 μ sec. This test indicates that prior to modifying the circuit, induced triggering would occur with a negative pulse amplitude between 2 and 4 volts. After modification, the circuit is shown to insensitive to pulse of almost 40 volts at these pulse widths. The results of this negative pulse test is shown in Table 1.

Table I

Applied Pulse Width	Circuit #2 Voltage Req. to Fire	
	Modified	Unmodified
.1 μ sec	80 (no fire)	6 V
.2 μ sec	40	4 V
.4 μ sec	42	2 V
.6 μ sec	30	1.3 V
1.0 μ sec	17	.8 V
2.0 μ sec	10	.7 V
10 μ sec	6.0	.5 V
20 μ sec	5.0	.5 V
50 μ sec	4.5	.5 V
100 μ sec	6.0	.5 V
200 μ sec	6.0	.5 V

A second set of tests was made to determine the minimum pulse at the input to the firing circuit required to trigger the SCR after the circuit was modified. This test was made by gradually increasing the width of the input pulse to the unjunction transistor until switching of the unjunction provided sufficient drive to trigger the SCR. As shown by test data in Table II, there is an insignificant increase in sensitivity indicated by the small decrease in pulse width required to cause the SCR to trigger.

Modification of Arming Capacitor Circuitry

This modification would be made by modifying the central electronics logic. However, to test the effectiveness of the modification, the test set up was modified to supply only voltage to arm one of the firing capacitors. (C_1 or C_2 reference Figure 1) Fifteen tests were made with only one capacitor charged with no evidence of multiple firings. Incorporation of this modification, however, would require extensive modification of the ASE central electronics logic. Since desensitizing the SCR circuit and the rewiring the GLA, each individually effectively eleminates multiple firing, this modification is not planned.

Modification of GLA Wiring

A study of the GLA wiring shows that only Grenades #1 and #2 firing circuit leads are coupled together for any significant distance in the GLA. Grenades #3 and #4 are near each other for less than 3 inches. SOS has been instructed to rewire all GLAs with twisted pairs for grenade #1 and #2. The effectivity of twisting pairs was tested in the laboratory. All four pairs of wires were twisted approximately 3 turns per inch for the lab tests. The 4 twisted pairs leads were then tightly boundled together and firing tests performed. Fifteen tests were made with no evidence of multiple firings. In addition, the negative signal at the SCR cathode was again photographed. The photographs of the transient with twisted pairs show high frequency ripple for a time duration of less than .2 μ seconds with an amplitude of less than .8 V peak to peak. The signal photographed is actually meaningless since the ripple frequency observed is greater than 40 mc which could be picked up by the scope probe ground connector acting as an antenna. The traces on the photograph are not reproducible for this report and are not included.

fix # 2 for multiple firing problem

Summary

Complete testing of the mortar box and GLA have conclusively established the cause for the multiple firing. The exact cause is a negative transient on the SCR of #1 grenade which triggers this circuit due to close coupling of firing

Table II
Firing Circuit Sensitivity Test

	Pulse Repetition Rate	Min PW required to trigger SCR: Unmodified	Min PW required to trigger SCR: Modified
Firing Cht #1			
	1 per 28 sec	6.6 m sec	6.2 m sec
	1 per 2.8 sec	6.6 m sec	6.2 m sec
	1 per .280 sec	6.2 m sec	5.7 m sec
	1 per .140 sec	6.0 m sec	5.5 m sec
Firing Cht #2			
	1 per 28 sec	4.4 m sec	4.5 m sec
	1 per 2.8 sec	4.4 m sec	4.5 m sec
	1 per .280 sec	4.1 m sec	5.2 m sec
	1 per .140 sec	3.7 m sec	3.9 m sec
Firing Cht #3			
	1 per 28 sec		7.1 m sec
	1 per 2.8 sec		7.1 m sec
	1 per .280 sec		6.7 m sec
	1 per .140 sec		6.4 m sec
Firing Cht #4			
	1 per 28 sec		6.1 m sec
	1 per 2.8 sec		6.1 m sec
	1 per .280 sec		5.7 m sec
	1 per .140 sec		5.4 m sec
Sequential Firing Cht			
	1 per 28 sec		6.6 m sec
	1 per 2.8 sec		6.6 m sec
	1 per .280 sec		6.2 m sec
	1 per .140 sec		6.0 m sec

leads in the GLA. Contributing causes were identified as SCR circuit sensitivity and the arming of both sequential and regular circuits.

Tests were made that verified that either reducing the coupling, or desensitizing the firing circuits, or charging only one arming capacitor would effectively prevent multiple firings. As a result of this investigation, two of the modifications were incorporated into hardware; 1.) twisting the firing leads to decrease coupling and 2.) changing bias and load resistors in the mortar box electronic board firing circuits to desensitize the SCR.

the fixes