PART 3

THE EDM AND PRE-QUALIFICATION MODEL OF

THE FIRING UNIT

CONTENTS LIST

0185P

SECTION 1 - INTRODUCTION

Part 3 of this thesis deals with improvements to the XDM/ADM firing control system designed in Part 2.

Motivation for improvements was obtained from environmental, functional and electromagnetic testing completed in Part 2. Safety and system reliability have been the overriding criteria when considering any changes to the XDM/ADM circuitry.

Throughout the report the firing control system is referred to as the firing unit.

1.1 TERMS OF REFERENCE

The terms of reference are as for Parts 1 and 2. Further inputs are obtained from Part 2, Appendix 7, Mil-R-10509 and MIL-S-3950.

SECTION 2 : DISCUSSION OF REQUIREMENTS

There are no changes to the requirements as discussed previously.

SECTION 3 : IMPROVEMENTS TO THE FIRING UNIT

This section deals with the in-depth design of all changes in electronic circuitry within the firing unit. Special reference is made to reliability and safety. The following circuit changes will be dealt with individually.

- Implementation of the CSIR's Radio Frequency Susceptibility recommendations. (3.1)
- ICI filter capacitors and associated shielding. (3.1.1)
- The increased current through the Wheatstone bridge including the addition of D28 and ZD3. (3.1.2)
- The inclusion of a 1 mega-ohm static bleed-off resistor. (3.1.3)
- Removal of the latching relay and the introduction of a 4PDT toggle switch in place of the charge button. (3.2)
- Alteration of the interlock abort system from open circuit equals an error to closed circuit equals an error. (3.3)
- Improvements in the DISCHARGED indication. (3.4)
- Altering the CHARGED indicator to become a voltage regulator and subsequent removal of V1. (3.5)
- Raising of the stored voltage in C8 and C9 to 120V. (3.6)
- The introduction of a constant current source to prevent overloading of the fire button contacts. (3.7)
- Alterations to SCR1 and SCR2 to increase safety and reliability. (3.8)
- The transfer of the 2 x 1,5 ohm compensating resistors from the igniter to the PCB. (R40 and R41) (3.9)
- Replacement of the LM340T15 with a LM140K15 to improve reliability. (3.10)
- Static protection MOVS, V1 to V3. (3.11)
- Increasing the reliability of the safety discharge circuitry (3.12)

3.1 IMPLEMENTATION OF THE CSIR'S RADIO FREQUENCY SUSCEPTIBILITY RECOMMENDATIONS.

The NEERI department of the CSIR tested the firing unit towards the end of 1985. Their recommendations with respect to RF hardening of the firing unit are contained in their report. (CSIR document number E/85/247, included as Appendix 7). The electronic circuitry recommendations have been implemented as described in paragraphs 3.1.1 to 3.1.3 below. Mechanical recommendations are addressed in Section 4.

3.1.1 IC1 Filter Capacitors and Associated Shielding

NEERI recommended the use of an additional copper layer on the PC board to serve as a ground plane. The PC board layout was altered accordingly. This is shown in Figure 61.

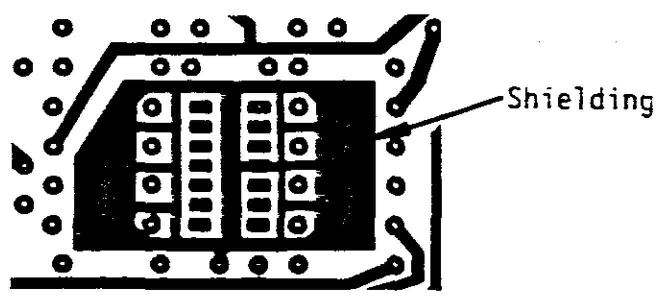


FIGURE 61: MODIFIED PC BOARD

This allowed easy implementation of the preferred method (Figure 62) of op-amp input decoupling. Surface-mounted 0,1 microfarad 50V chip capacitors were used due to their small size and low inductance (C11 to C14).

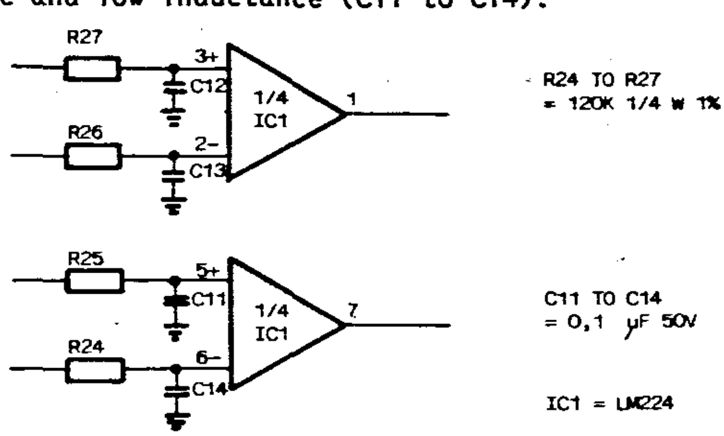


FIGURE 62: OP-AMP INPUT DECOUPLER

This configuration gives a theoretical 3dB cut-off frequency of:-

$$-3db = 20 \log \frac{V_{out}}{V_{in}}$$

$$\frac{V_{out}}{V_{in}} = 0{,}708$$

$$V_{out} = \frac{I}{2\pi fc}$$

$$V_{in} = I\left(\frac{1}{2\pi fc} + R\right)$$

where R = R24 = R25 = R26 = R27 = 120 x 10^3 ohm

$$0{,}708 = \frac{1}{1 + 120 \times 10^3 .\ 2\pi fc}$$

$$\frac{1}{0{,}708} - 1 = (120 \times 10^3)\ 2\pi fc$$

$$\frac{0{,}412}{120 \times 10^3 .2\pi .\ 0{,}1 \times 10^{-6}} = f$$

f = 5,47 hz
(stray capacitances and inductances are ignored).

This cut-off frequency will not affect circuit operation because the op-amp measures d.c. signals.

3.1.1.1 <u>Reliability</u>

The following calculations on reliability are based on MIL-HDBK-217D, Reliability Prediction of Electronic Equipment.

The capacitors used for C11 to C14 are classified as general purpose ceramic.

The part failure rate model (λp)

$\lambda p = \lambda b\ (\pi_E\ \pi_Q\ \pi_{CV})$ failures/10^6 hours.

λb is the base failure rate

π_E is the environmental factor

π_Q is the quality factor

π_{CV} is the capacitance factor

The ratio of operating to rated voltage = $\frac{1}{50}$ = 0,02

Therefore, from the applicable tables

$$\lambda p = 0{,}00079\ (7{,}8\ .\ 10\ .\ 1{,}45)$$
$$= 0{,}0896\ \text{failures}/10^6\ \text{hours}$$

3.1.2 <u>The increased current through the Wheatstone bridge, including the addition of ZD3 and D28</u>

The XDM/ADM design current through the fuzehead leg of the Wheatstone bridge was 5,6 mA. This resulted in a voltage across the fuzehead of approximately 11 mV. The CSIR noted that a very small RF voltage was enough to disturb the balance of the bridge. The CSIR suggested that this effect could be reduced by increasing the current through the fuzehead to 40 mA. Unfortunately this level is considered to be too close to the maximum allowable measuring current through the fuzehead (50 mA). Any failure of circuit components would overstress the fuzehead as the built-in safety margin will have been reduced to only 10 mA. The current through the fuzehead was accordingly increased from 5,6 mA to 10 mA.

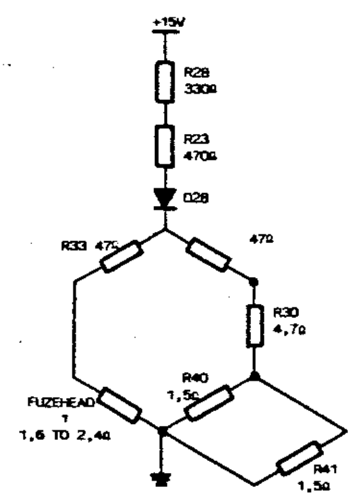


FIGURE 63: MODIFIED WHEATSTONE BRIDGE

at 10 mA the voltage across 2,4 ohm	=	24 mV
at 10 mA the voltage across 47 ohm (R33)	=	470 mV
		494 mV

494 mV across the combination of R30, R43, R40 and R41 results in a current flow of 9,42 mA.

The total bridge current is 19,42 mA.

R28 and R23 resistance must therefore be

$$\frac{(15-0{,}7-0{,}494)\text{V}}{19{,}42\ \text{mA}} = 711\ \text{ohms}$$

R28 was changed to 330 ohms and R23 was changed to 470 ohms, giving a total of 800 ohms.

This results in an actual worst case current through the fuzehead of:-

$$\text{total current} = \frac{15 - 0,7}{330 + 470 + (47 + 1,6)//(47 + 4,7 + 0,75)} = 17,33 \text{ mA}$$

$$\text{bridge voltage} = 17,33 \text{ mA} \times (47 + 1,6)//(47 + 4,7 + 0,75) = 437 \text{ mV}$$

$$\text{fuzehead current} = \frac{437 \text{ mV}}{47 + 1,6} = 8,99 \text{ mA}$$

Fuzehead measuring current under normal circumstances will not exceed 9 mA.

The worst case failure that can be tolerated is if R23, R33 and D28 go short circuit while R34 or R30 or R40 and R41 go open circuit. If the number of faults is less than these above, the current through the fuzehead will be of lower value.

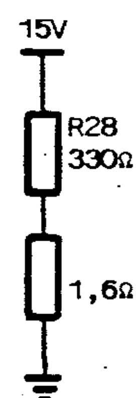


FIGURE 64: WORST CASE FUZE HEAD CURRENT

$$I = \frac{15}{331,6} = 45,24 \text{ mA}$$

This value is still less than the maximum fuzehead measuring current allowable. If both R28 and R23 fail short circuit an unsafe situation will result.

3.1.2.1 <u>The inclusion of ZD3 and D28</u>

During functional testing when using a 200 metre firing lead it was noticed that the firing unit attempted to automatically abort the ignition of the fuzehead and charging of the capacitors. This occurred as the firing button was pressed. Subsequent investigation revealed the following fault circuit due to the internal resistance of the cable (see Figure 65). This is shown as the shaded section of Figure 65.

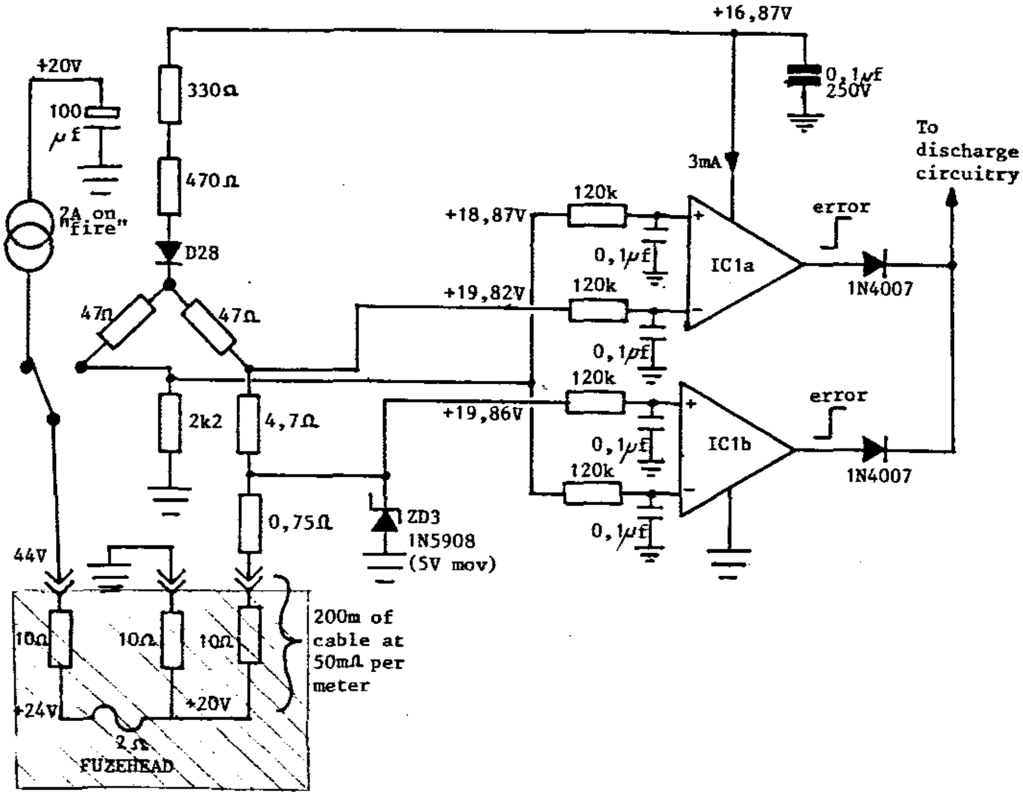


FIGURE 65: 200 m FIRING LEAD FAULT CIRCUIT

All voltages are measured with respect to earth and assume that ZD3 and D28 are not included in the circuit. The op-amp is assumed to draw a standby current of 3 mA.

The Wheatstone bridge part of the circuit can be simplified to

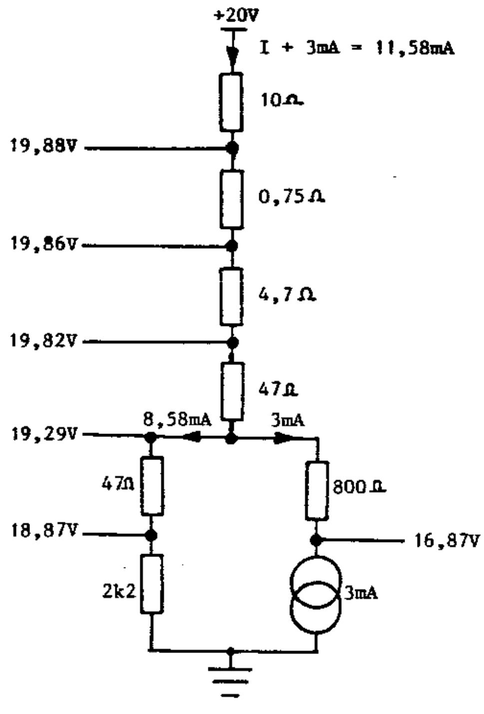


FIGURE 66: SIMPLIFIED WHEATSTONE BRIDGE

$$20 = I(47 + 2200) + (I + 3\text{ mA})(47 + 4,7 + 0,75 + 10)$$
$$20 = 2247I + 62,45I + 187,35\text{ mV}$$
$$\frac{20 - 0,187}{2247 + 62,45} = I = 8,58\text{ mA}$$

This calculation shows that IC1 has a supply in the order of 17 volts (normally 15V). IC1 b op-amp has a greater potential at its non-inverting input than at its inverting input. Therefore its output will attempt to go high, the current being supplied through the Wheatstone bridge and the supply decoupling capacitor. This output is enough to trigger the discharge circuitry and attempt to abort system operation.

The inclusion of D28 prevents any supply becoming available to the op-amp through the Wheatstone bridge. This will result in the inputs of the op-amps being markedly higher than the supply. Accordingly the inclusion of ZD3 (a 5V mov) limits the maximum voltage at any op-amp input to a maximum of approximately 5V. This value is within manufacturer's specifications. After inclusion of the above modifications the circuit worked according to the design requirements when coupled to a 200 metre firing cable.

3.1.2.2 <u>Reliability</u>

From section 3.1.2 it has become apparent that a catastrophic Wheatstone bridge failure can only occur if both R28 and R23 fail short circuit. This failure will cause premature fuzehead ignition when the firing unit is being tested. The reliability of these two resistors is calculated below.

These resistors are procured according to MIL-R-10509 F. The general model for resistors is as follows:

$\lambda p = \lambda b \, (\Pi_E \, . \, \Pi_R \, . \, \Pi_Q)$ failures/10^6 hours

λb is the base failure rate

Π_E , the environmental factor = G_M (Ground mobile)

Π_R , resistance factor = up to 100 K

Π_Q , Quality factor = MIL-R-10509

(a) R23, the 470 ohm resistor.

S represents, the ratio of operating to rated wattage:

Normal bridge current is 19,42 mA.

$$S = \frac{(19{,}42 \times 10^{-3})^2 \; 470}{0{,}5} = 0{,}355 \cong 0{,}4$$

$\lambda b = 0{,}0013$

$\lambda p = 0{,}0013 \, . \, 7{,}8 \, . \, 1 \, . \, 5$ failures/10^6 hours.
$= 50{,}7 \times 10^{-3}$ failures/10^6 hours.

(b) R28, the 330 ohm resistor.

S represents the ratio of operating to rated wattage:

Normal bridge current is 19,42 mA.

$$S = \frac{(19{,}42 \times 10^{-3})^2 \, . \, 330}{0{,}5} = 0{,}249 \cong 0{,}3$$

$\lambda b \doteq 0{,}0012$
Π factors are as per R23

$\lambda p = 0{,}0012 \, . \, 7{,}8 \, . \, 1 \, . \, 5$ failures/10^6 hours.

$= 46{,}8 \times 10^{-3}$ failures/10^6 hours.

The reliability safety model for the R23 and R28 combination is as follows:

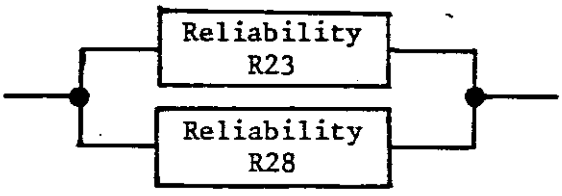


FIGURE 67: RELIABILITY SAFETY MODEL

let $t = 1 \times 10^6$ hours.

Reliability $R = e^{-\lambda pt}$

Reliability for R23 $= e^{-50,7 \times 10^{-9} \cdot 10^6} = 950,56 \times 10^{-3}$

Reliability for R28 $= e^{-46,8 \times 10^{-9} \cdot 10^6} = 954,28 \times 10^{-3}$

R total $= 1-(1-950,56 \times 10^{-3})(1-954,28 \times 10^{-3})$

$= 997,74 \times 10^{-3}$

therefore the total failure rate, λ total becomes :-

$\lambda p = -10^{-6} \ln R$

$= - \ln (997,74 \times 10^{-3})$ failures/10^6 hours

$= 2,263 \times 10^{-3}$ failures /10^6 hours

The probability of a catastrophic failure (assuming continuous operation) is once in every 50413 years.

A major failure will occur if a long firing lead (200 m) is used and D28 fails short circuit while ZD3 fails open circuit. This failure would not become apparent to the operator while testing the system. The effect would be that the stored capacitor energy in the SAD would be below specification and would result in system failure. Failure of D28 or ZD3 would not cause this problem.

The general model for D28 is as follows:

$$\lambda p = \lambda b \ (\pi_E \cdot \pi_Q \cdot \pi_R \cdot \pi_A \cdot \pi_{S2} \cdot \pi_C)$$

The environment, π_E (ground mobile) = 18

Quality factor, π_Q (plastic) = 15

Current rating, π_R (less than 1 amp) = 1

Application, π_A (Analog circuits) = 1

Contact construction, π_C (bonded) = 1

Voltage stress, π_{S2} = 0,7

$$\text{Voltage stress} = \frac{\text{Applied } V_R}{\text{Rated } V_R} \times 100 = \frac{20}{1000} \times 100$$

$$= 2 \text{ therefore } \pi_{S2} = 0,7$$

$$\text{Stress, } S = \frac{\text{operating current}}{\text{rated current}} = \frac{0,02}{1} = 0,02$$

λb = 0,00037 (an S of 0,1 at 60°C)

therefore the part failure rate

λp = 0,00037 . 18 . 15 . 1 . 1 . 1 . 0,7 = $69,93 \times 10^{-3}/10^6$ hours.

The general model for ZD3 is

$\lambda p = \lambda b \, (\pi_E \times \pi_A \times \pi_Q)$ failures/10^6 hours

π_E (Ground Mobile) = 18

π_A (Application) = Voltage regulator = 1

π_Q (Plastic) = 30

$$\lambda b\text{: Stress} = \frac{\text{Applied Energy}}{\text{Rated Energy}}$$

Applied power:

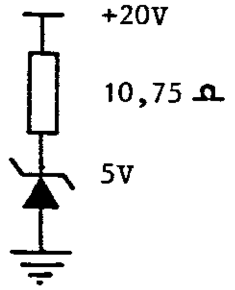


FIGURE 68: APPLIED POWER EQUIVALENT CIRCUIT

$$\frac{20 - 5}{10,75} .5 = \text{Applied power} = 6,98 \text{ watt}$$

Applied energy = watt x time
= 6,98 watt x 10 ms = 69,8 mJ

Rated energy

$\frac{165}{2}$ amps for an exponential decay of 1 ms.

therefore the effective zener resistance is $\frac{82,5}{5}$ = 16,5 ohm

The capacitance to achieve a 1 ms exponential decay time equals $\frac{t}{R} = \frac{1 \times 10^{-3}}{16,5} = 61 \times 10^{-6}$ farad.

The energy $= 0,5\ CV^2 = 0,5 \cdot 61 \times 10^{-6} \cdot (82,5)^2 = 206,3 \times 10^{-3}$J.

The stress therefore equals $\dfrac{69,8 \times 10^{-3}}{206,3 \times 10^{-3}} = 0,34$

therefore use a stress of 0,3 at 60 °C

λb therefore equals 0,00089

$\lambda p = 0,00089\ (18 \cdot 1 \cdot 30) = 0,481$ failures per 10^6 hours

For this section of the circuit to fail (cause a firing unit output to be below specification) both diodes have to fail.

The reliability model is therefore

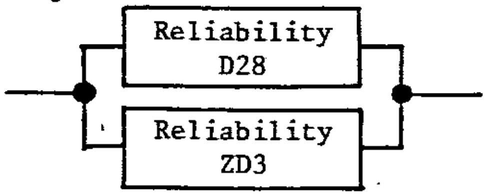


FIGURE 69: RELIABILITY MODEL

let $t = 1 \times 10^6$ hours and the reliability equals $R = e^{-\lambda pt}$

Reliability for D28 $= e^{-69,93 \times 10^{-9} \cdot 10^6} = 932,46 \times 10^{-3}$

Reliability for ZD3 $= e^{-481 \times 10^{-9} \cdot 10^6} = 618,41 \times 10^{-3}$

R total $= 1-(1-618,41 \times 10^{-3})(1-932,46 \times 10^{-3})$

$= 974,23 \times 10^{-3}$

Therefore the total failure rate λ total becomes

$\lambda p = -10^{-6}\ \text{Ln}\ R$

$= -\text{Ln}\ (974,23 \times 10^{-3})$ failure/10^6 hours

$= 26,11 \times 10^{-3}$ failure/10^6 hours

3.1.3 <u>The Inclusion of a 1 Mega-ohm Static Bleed-off Resistor</u>

Section 5.3 of the CSIR report (NEERI Report number E/85/247) (Appendix 8) mentions that under certain conditions a static charge could build up on the enclosure of the firing unit relative to the internal electronic ground. An electric discharge could then take place between the enclosure and the internal circuitry. They recommended that a 1 mega-ohm resistance be connected between the enclosure and circuit ground. R6, a 1 mega-ohm 0,25 watt metal film resistor was accordingly added to ensure no static charge build-up.

3.2 REMOVAL OF THE LATCHING RELAY AND THE INTRODUCTION OF A 4PDT TOGGLE SWITCH IN PLACE OF THE CHARGE BUTTON

During discussion with various interested parties it appeared that there was some concern about there being no indication as to a potential charge on the main storage capacitors. The question then arose "How can I see if the firing unit has been made safe without touching it?" At that juncture the answer was, "You cannot".

A further concern was that the latching relay could change state when subjected to mechanical shock and that this would cause a potentially hazardous situation to arise. Furthermore there were some reservations about the reliability of the latching relay and its associated circuitry (SCR 3). It was also noticed that an operator could easily release the charge button fractionally before he stopped cranking the hand crank. This aborted the firing unit without the operator being aware of it. Accordingly this section of the firing unit was completely redesigned. The first alteration was to change the charge push-button switch to a locking toggle type, marked "on" and "off". If this toggle switch is put in the "off" position the firing unit must be completely safe. This would comply with the criteria of a physical indication as to the safety of the system.

3.2.1 The ON-OFF Switch

A four pole double throw switch is used for the SAFE/ARM function. The same type of switch is used for the ON/OFF switch. Two contacts were used in exactly the same manner as the charge pushbutton contacts. The other two contacts were connected in parallel and replaced the contact of the latching relay. These contacts discharge C8 and C9 when in the off position.

The following circuit diagram shows this section of the firing unit before modification. The shaded areas indicate those components which have been removed.

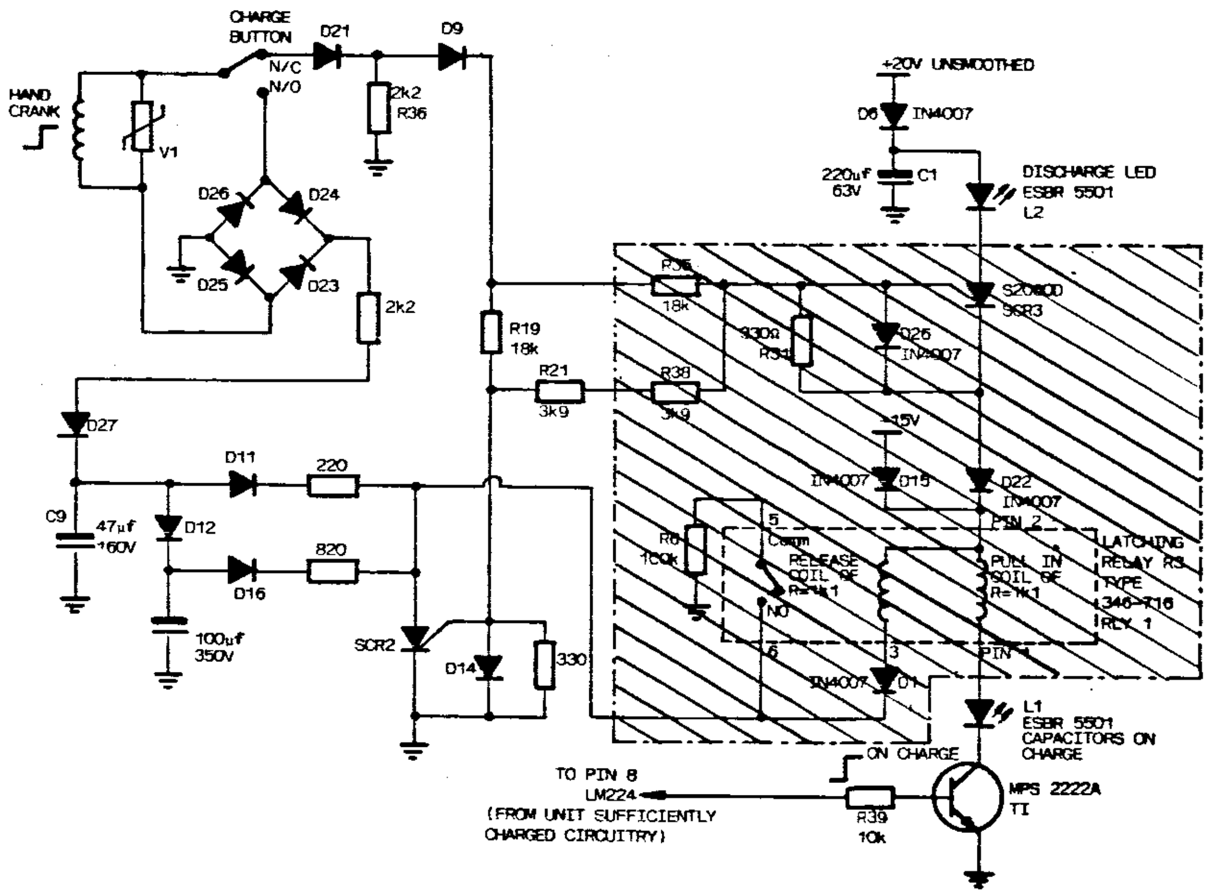


FIGURE 70: CIRCUIT DIAGRAM BEFORE MODIFICATION

The following circuit diagram shows the new, simpler circuit diagram. New circuitry connecting to LED1 and LED2 is described in 3.5 and 3.4 respectively. An additional modification has been included to supply power to LED2 when the unit is switched off and the hand-crank generator cranked. LED2 will then illuminate and inform the operator that the firing unit has been made safe. The other S.3 contact is unchanged. The shaded area of Figure 70 are components that have been deleted. Shaded areas of Figure 71 are new components.

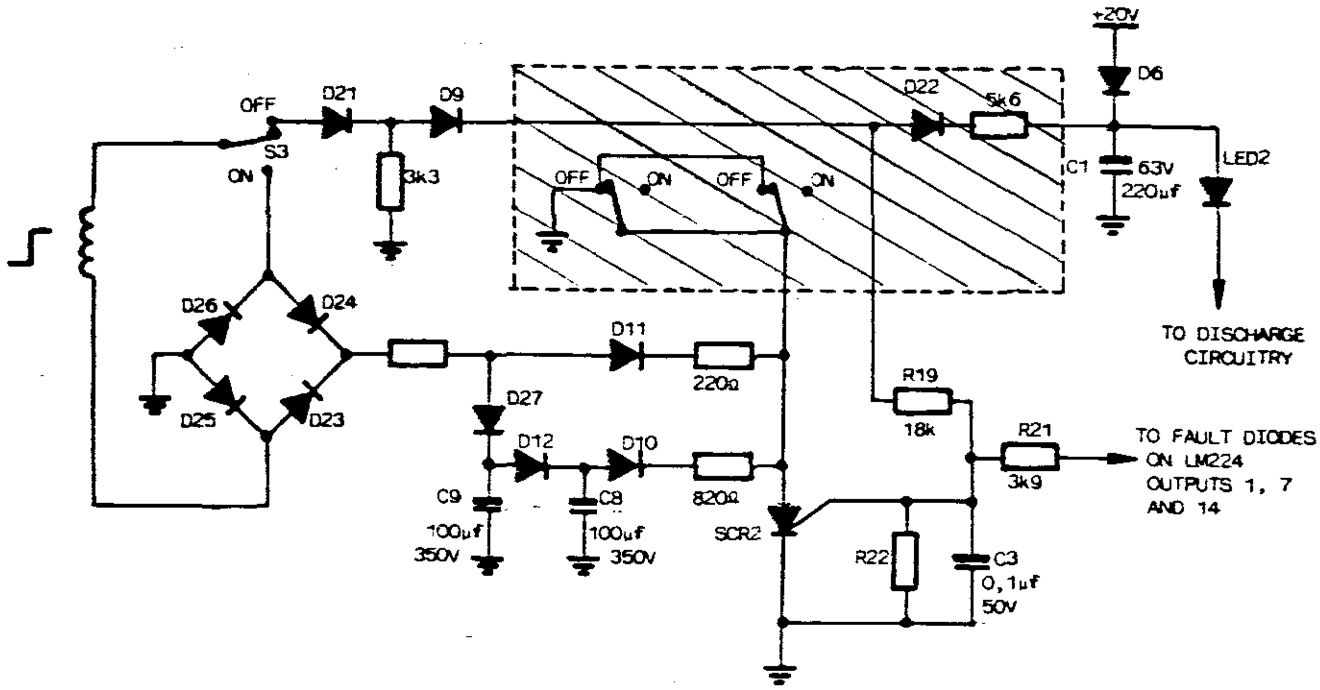


FIGURE 71: CIRCUIT DIAGRAM AFTER MODIFICATION

The two new paralleled contacts form a mechanical equivalent of SCR2 in parallel with SCR2 to ensure that C8 and C9 are discharged when the unit is off.

3.2.2 Reliability

Reliability calculations for the switch are shown below. A switch failure could cause a potentially hazardous situation to arise due to an inadvertent charge on C8 and C9. These parts have been procured in accordance with MIL-S-3950.

The part operating firing rate model (λp)

$\lambda p = \lambda b\, (\Pi_E \cdot \Pi_C \cdot \Pi_{CYC} \cdot \Pi_L)$ failures/10^6 hours.

λb is the base failure rate model = 0,00045

Π_E (Ground Mobile) = 14

Π_C (Contact form, used as 3PDT) = 4,25

π_{CYC} (Switching cycles per hour,) 1 = 1,0

π_L (Load stress factor) = 1,028

The contacts are rated 4A at 125 V dc. The worst case currents are:-

contact 1 ; 300 mA
contact 2 ; 17 mA
contact 3 & 4 in parallel ; 692 mA

Assume 1 contact at 10 milliohm and one at 3 milliohm.

(10 milliohm is the maximum permitted contact resistance).

The 3 milli ohm contact resistance contacts will sink 532 mA. A 532 mA maximum current is assumed.

S becomes $\frac{532 \times 10^{-3}}{4} = 0,133$

$\pi_L = e^{(S/0,8)^2} = 1,028$

$\lambda p = 0,00045\ (14 \ . \ 4,25 \ . \ 1 \ . \ 1,028)$

$= 27,5 \times 10^{-3}$ failures/10^6 hours

3.3 ALTERATION OF THE INTERLOCK ABORT SYSTEM

The existing circuit has the advantage that if any wire breaks open circuit or a connector is not plugged in, the firing unit automatically aborts deployment. This was a normally closed system, going open during a fault condition. The circuit requires power to the op-amp to test for a fault condition. This means that the hand crank must be cranked while testing for a fault. If an interlock fault occurs after the operator has tested and armed the unit, the system will not abort, allowing a dangerous situation to arise.

The circuit was therefore altered to become a normally open circuit going closed. This has the disadvantage that if an interlock is disconnected, the system will not sense that fault. On the other hand the advantage is that the system will automatically abort at any time throughout testing and deployment if an interlock error is sensed. This will occur irrespective of whether the hand crank is cranked or not. A LED will illuminate during the abort action to inform the operator of the fault.

The following circuit diagram shows the original circuit.

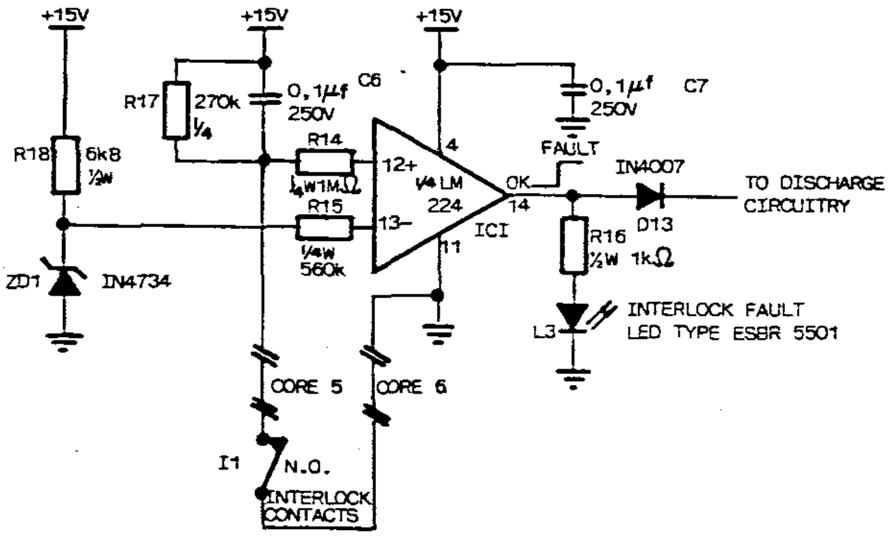


FIGURE 72: ORIGINAL CIRCUIT

This can be compared with the updated circuit diagram, Figure 73. All alterations and additions have been shaded.

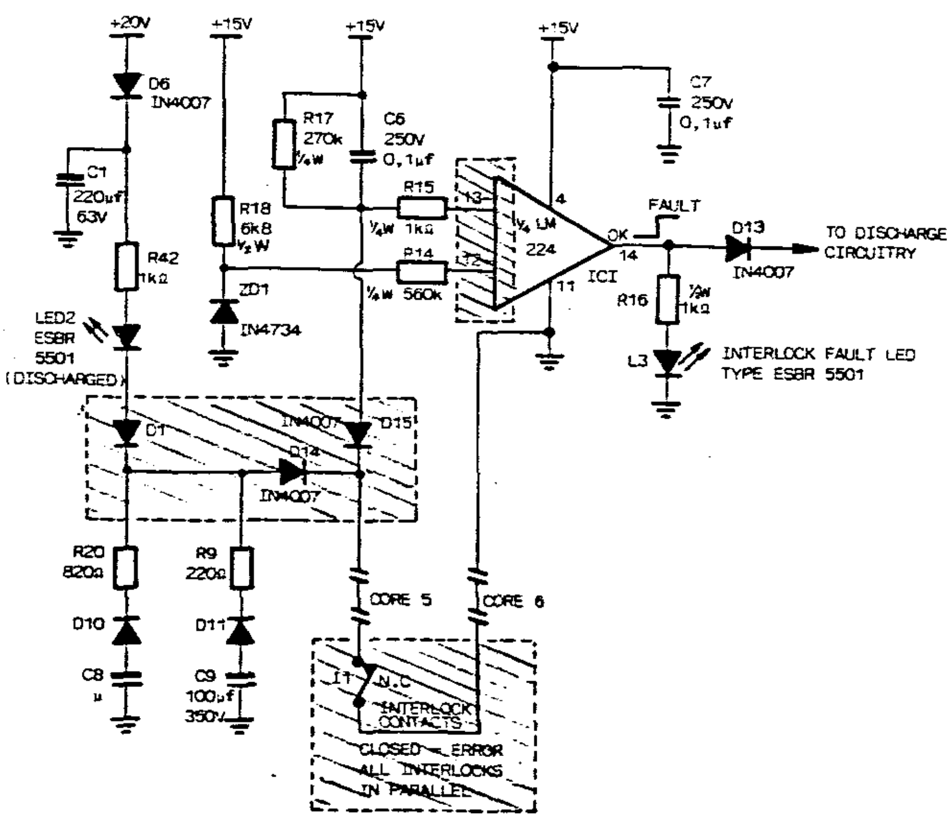


FIGURE 73: MODIFIED CIRCUIT

This circuit also ties up the unused end of LED 2 created by the removal of the latching relay (RLY 1).

It can be seen from the above circuit that if the interlock switch is closed, C8 and C9 discharge via R9 and R20 respectively, through D14 to ground; C1 discharges via D1 and D14 to ground. LED 2 illuminates, informing the operator. The op-amp senses the interlock switches through D15. When pin 13 of the op-amp is low the output of the op-amp goes high informing the operator of the interlock fault. The op-amp indication only works while the operator cranks the hand-crank. The other discharge paths are complete whenever the interlock switch is closed (an error condition). D1 prevents the LED breaking down and therefore 120 volts appearing on C1. D15 ensures that pin 13 of the op-amp is not destroyed by the 120 V C8 and C9 supply.

3.3.1 Reliability

Failure of either D1 or D15 will cause a major circuit failure but it is extremely unlikely that this failure will cause premature launching of the system.

The part failure rate model rate model for both D1 and D15 is :

$$\lambda p = \lambda b \; (\pi_E \cdot \pi_Q \cdot \pi_R \cdot \pi_A \cdot \pi_{S2} \cdot \pi_C)$$

π_E , Environmental Factor (ground mobile) = 18

π_Q , Quality factor (plastic) = 15

π_R , Current rating (less than 1A) = 1

π_A , Application (Analogue circuits < 500 mA) = 1

π_{S2} , Voltage stress = (0 to 60%) = 0,7

Voltage stress $= \dfrac{120}{1000} \times 100 = 12\%$

$\pi_{S2} = 0,7$

π_C (Construction factor; bonded = 1

λb.

S (Stress) $= \dfrac{20 \text{ mA}}{1\text{A}} = 0,02$

therefore λb at 60°C is 0,00037

therefore the part failure rate equals

$\lambda p = 0,00037 \; (18 \cdot 15 \cdot 1 \cdot 1 \cdot 0,7 \cdot 1)$

$= 0,0699$ failures/10^6 hours.

The mean time between failures is $14,3 \times 10^6$ hours.

3.4 IMPROVEMENTS IN THE DISCHARGED INDICATION

The additions to the circuitry connected to LED2 are shown below as shaded areas. Deletions have been shown in paragraph 3.2.1.

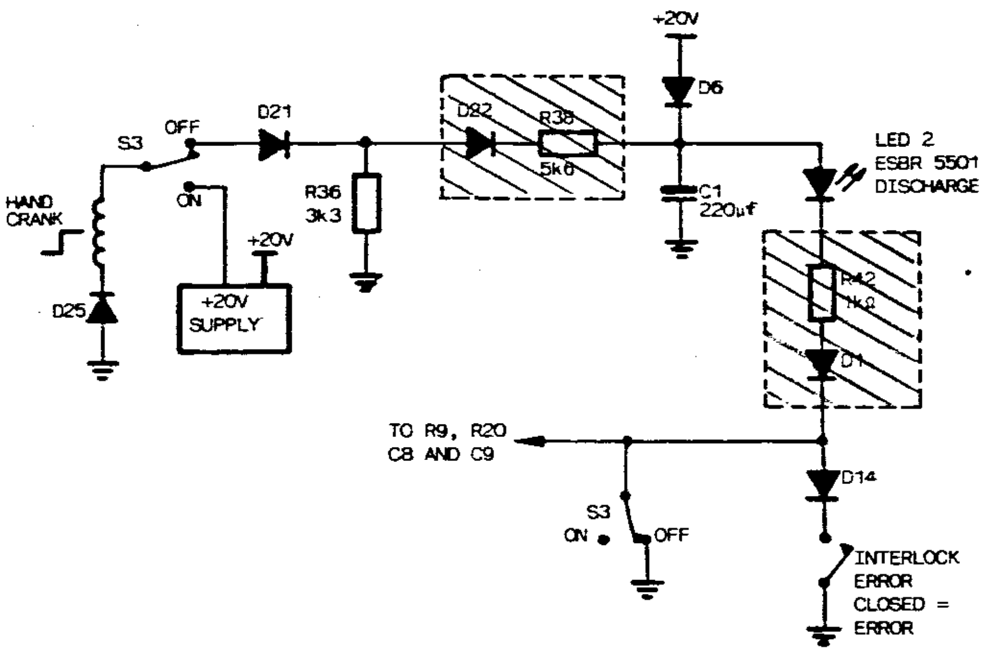


FIGURE 74: ADDITIONS TO THE CIRCUIT

When the firing unit is switched off and the hand-crank cranked, current passes through D21, D22, R38, LED 2, R42 and then D1 to ground. LED 2 thus illuminates, indicating that the internal storage capacitors are discharged. The firing unit is therefore safe. When the firing unit is correctly operated and there is no interlock error, C1 is charged to +20 Volts via D6. If an interlock error occurs, C1 discharges via LED 2, R42, D1 and D14 to ground. LED 2 therefore illuminates for approximately 1 second and this informs the operator that an interlock fault has occurred and that the firing unit has failed safe. The main storage capacitors (C8 and C9) also discharge via D14. It can be seen that this discharge path is also valid when the unit is switched off after testing the system, except that one contact of S3 substitutes for the interlock switch.

3.5 ALTERING THE CHARGED INDICATOR TO BECOME A VOLTAGE REGULATOR AND THE SUBSEQUENT REMOVAL OF V1

During functional testing it was noted that the voltage regulation provided by V1 was less satisfactory than desired due to the voltage across the device being dependent on the current through it. This is due to its relatively high on resistance. While not being ideal, the regulation provided by V1 was considered adequate. The removal of the latching relay (described in section 3.2) left the anode of LED1 (the "on charge" indicator) disconnected, presenting an ideal opportunity for using the associated op-amp to provide accurate regulation of the voltage on C8 and C9. This section of the firing unit circuit is shown below.

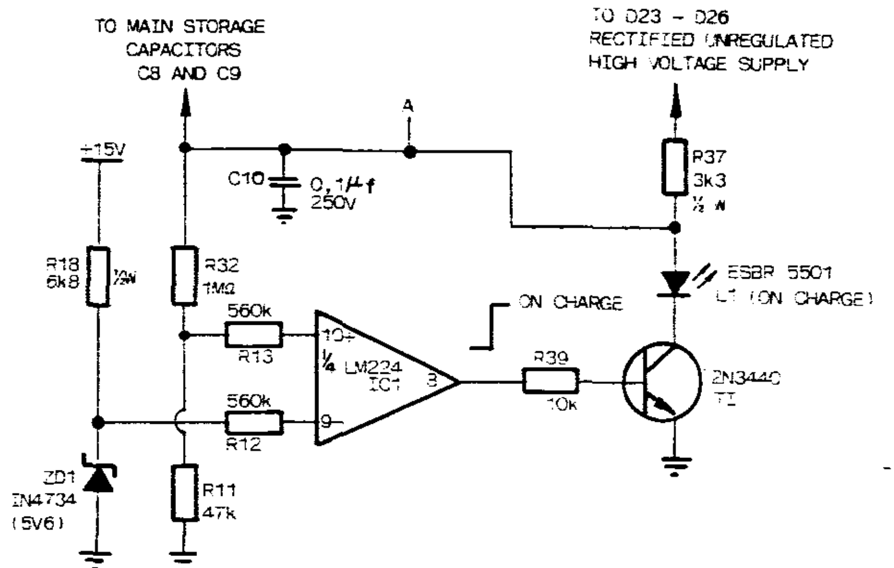


FIGURE 75: VOLTAGE REGULATOR DIAGRAM

The circuit regulates point A to a voltage determined by the zener diode voltage (ZD1) and the R32 - R11 potential divider. When point A reaches the desired voltage, the output of the op-amp rises and therefore switches T 1 on. The current through T 1 is such that the excess voltage is dropped across R37, leaving the desired voltage at point A and therefore across the main storage capacitors (C8 and C9).

3.5.1 <u>The Value of R37</u>

There are three considerations when choosing R37 :

a. R37 must be large enough to limit the current through LED 1 and T 1 to a value low enough to ensure their reliable operation.

b. R37 must be small to ensure that C8 and C9 charge rapidly.

c. R37 must be large so that if a catastrophic circuit failure occurs the maximum current through the fuzehead will be limited to less than 50 mA. This current would be supplied directly from the hand-crank through R37, D27, the constant current source, the fire button, the safe/ARM switch and the fuzehead to ground.

The generator specifications indicate a minimum voltage of 100 V RMS at no load. Assuming C10 was charged to 100 V the resistor would, when the failure occurred, need to be a minimum of

$$\frac{100}{50\ \text{mA}} = 2\ \text{k ohm.}$$

To ensure that T 1 is not overstressed, the resistor must limit the current through T 1 to less than 30 mA at 100V. (A 1 watt derating factor is applied for 60°C).

The LED has an operating current of 20 mA (from the manufacturer's specifications).

The current through T 1 should be limited to about 15 mA to ensure reliable operation.

To allow a safety margin the assumption is made that the hand crank generator can deliver 150 V with no limit on current.

Therefore 50 V must be dropped across R37, 100V across T1 at 15 mA current through T1. This would require R37 to be

$$\frac{50\ \text{V}}{15 \times 10^{-3}} = 3{,}33\ \text{k ohms.}$$ Therefore use 3K3.

At 150 V the short circuit current through R37 is

$$\frac{150}{3\text{K}3} = 45\ \text{mA}$$

A worst case charge time for C8 and C9 to charge to 100V is when the hand crank delivers 100V. The charge time would then be:

$10R.(C_8 + C_9)$

$= 10 \cdot 3{,}3 \times 10^3 \cdot (100\ uf + 100\ uf) = 6{,}6$ seconds.

R37 was therefore selected as 3K3.

3.5.2 Reliability

A reliability study was completed for the LM224 during the ADM/XDM phase. Accordingly reliability is only calculated for T 1.

The part operating failure rate model (λp)

$\lambda p = \lambda b\ (\pi_E \cdot \pi_A \cdot \pi_Q \cdot \pi_R \cdot \pi_{S2} \cdot \pi_C)$ failures/10^6 hours

π_E, Environmental Factor, (ground mobile) = 18

π_A, Application, (linear) = 1,5

π_Q, Quality, (lower) = 6

π_R, Power rating, (1 to 5 watt) = 1,5

π_{S2}, Voltage stress, (40%) = 0,48

π_C, complexity, (single transistor) = 1

The current stress is $\frac{15 \times 10^{-3}}{1} = 0{,}015$

therefore the base failure rate, λb – 0,00098

$\lambda p = 0{,}00098\ (18 \cdot 1{,}5 \cdot 6 \cdot 1{,}5 \cdot 0{,}48 \cdot 1)/10^6$ hours

$= 114{,}3 \times 10^{-3}$ failures/10^6 hours.

3.6 RAISING THE STORED VOLTAGE IN C8 AND C9 TO 120 V

During discussions with relevant parties it became apparent that the 20 uF capacitor in the SAD was required to have a bleed off resistor in parallel with it. The value of this resistor must be such that the potential across the capacitor must not be less than 45 volts 15 seconds after system deployment and must be less than 12,5 volts 3 minutes after system deployment. It was further noted that the capacitor charge must not be influenced by the energy transfer conductors wires becoming short circuit on launch. The following circuit complies with the above conditions.

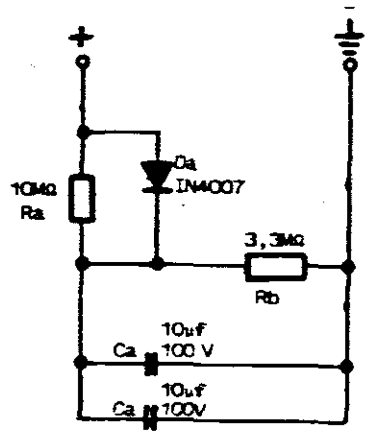


FIGURE 76: MODIFIED CAPACITOR CIRCUIT IN THE SAD

3.6.1 <u>The Circuit Design</u>

Two 10 microfarad capacitors were selected due to size constraints of the receptacle into which they were fitted. The diode, Da ensures a rapid charge time while ensuring that if points A and B become short circuit during system deployment the effect will be negligible.

Rb is the capacitor safety discharge resistor which gives the required discharge rate and ensures no static charge build-up across the capacitors. Ra, in conjunction with the ON/OFF switch in the firing unit, provides additional protection against unwanted charges on Ca and Cb.

The values of Ra and Rb:
The charge potential on Ca and Cb must be 45 volts after 15 seconds. Assume a worst case initial voltage of 60 V and Ra paralelled with Rb. Therefore, from

$$v = E\left(e^{\frac{-t}{RC}}\right)$$

$$R_x = \frac{-t}{C \ln\left(\frac{v}{E}\right)}$$

$$R_x = \frac{-15}{20 \times 10^{-6} \ln\left(\frac{45}{60}\right)}$$

$$R_x = 2{,}6 \times 10^{6} \text{ ohm}$$

Note R_x equals Ra and Rb in parallel.

The second case in question is when Rb only is in circuit. The capacitor potential must drop below 12,5 volts after 180 seconds (3 minutes) from a worst case initial voltage of 90 V.

therefore

$$R_b = \frac{-180}{20 \times 10^{-6} \ln (\frac{12,5}{90})}$$

$$R_b = 4,56 \times 10^6 \text{ ohm}$$

Rb was accordingly made 3,3 mega ohms to increase the margin for error.

Ra is therefore

$$\frac{1}{Ra} = \frac{1}{Rt} - \frac{1}{Rb}$$

$$= \frac{1}{2,6 \times 10^6} - \frac{1}{3,3 \times 10^6}$$

$$= 81,6 \times 10^{-9}$$

$$Ra = 12 \times 10^6 \text{ ohms}$$

Ra was therefore selected as 10 mega ohms.

This slightly lower value of Ra will affect the worst case discharge rate from 60 volts to 45 volts. This is accordingly checked below.

$$v = 60.e^{\frac{-15}{(2,48 \times 10^6 . 20 \times 10^{-6})}}$$

$$v = 44,35 \text{ V}$$

This is acceptable.

3.6.2 Conclusion

The calculations shown in 3.6.1 all assume a minimum capacitor potential of 60 volts. The original circuit design allowed a minimum capacitor potential of 50 volts, the 10 volt increase being to compensate for losses incurred by Ra and Rb. This increase is reflected back into the firing unit by an increased storage voltage needed on C8 and C9. The easiest way of achieving this is to alter the potential divider represented by R32 and R11. R32 was accordingly increased from 820 k ohm to 1 M ohm while leaving ZD1 a IN4734.

The potential on C8 and C9 therefore becomes:

5,4 V across R11 (47 k ohm) because ZD1 is being operated at 1 mA.

The current through R11:

$$\frac{5,4}{47 \times 10^3} = 114,9 \times 10^{-6} \text{ A}$$

The total voltage across R11 and R32 is:

$$114,9 \times 10^{-6} \cdot (47 \times 10^3 + 1 \times 10^6)$$

$$= 120,29$$

When practically tested this increase in voltage on C8 and C9 proved adequate to ensure that the voltage delivered to the 40 microfarad load remained above 60 volts (two of the previous circuits in parallel).

3.7 THE INTRODUCTION OF A CONSTANT CURRENT SOURCE TO PREVENT OVERLOADING OF THE FIRE BUTTON

This modification has come about due to the FIRE button contacts being fuzed together by a 30 amp current surge as the FIRE button is depressed. It appears that the best solution to this problem is to insert a constant current source of about 2 to 3 amps. This would solve the problem and still be able to transfer enough energy to the fuzehead to fire it reliably. Normal firing current of the fuzehead is one amp. The FIRE button reliability drops markedly at any current above 0,7 times the maximum rated value (2,8 amps).

The following circuit was introduced into the fuzehead firing lead.

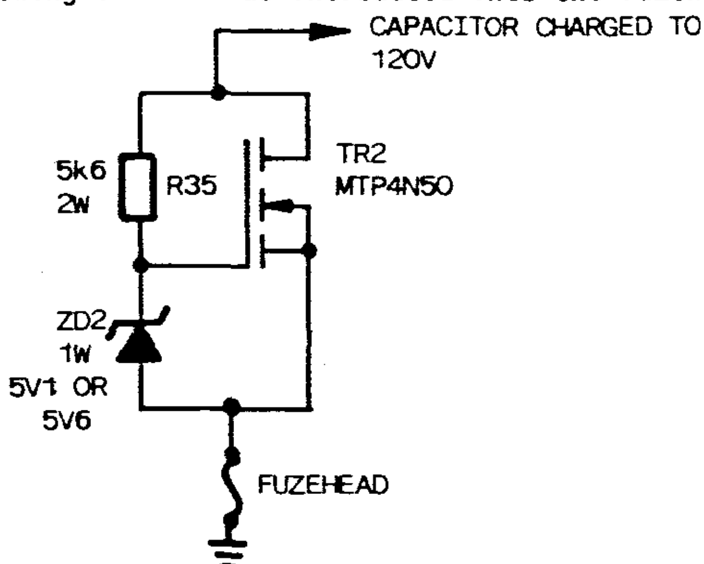


FIGURE 77: CONSTANT CURRENT SOURCE

3.7.1 <u>The Circuit Design</u>

From the manufacturer's data 2 amps through a MTP 4N50 requires a gate voltage of approximately 5,2 volts. The characteristic spread of the transistor would therefore require ZD2 to be either a 5V1 or a 5V6 device, selected during manufacture of the firing unit. For reliable circuit design the ratio of operating current to maximum current of the zener diode should be below 0,3.

A 5V1, 1 watt zener diode has a maximum current through it of 196 mA. 0,3 x 196 mA = 59 mA. A maximum zener diode current of 20 mA is therefore selected.

20 mA at 120 V would require a zener current limiting resistor of $\frac{120\ V - 5V1}{20 \times 10^{-3}} = 5{,}7$ k ohm

Therefore use a 5,6 k ohm.

This gives an actual zener voltage of
$5{,}1 + 7(20{,}5 \times 10^{-3} - 49 \times 10^{-3}) = 4{,}9$ V.

The minimum supply voltage at which the zener diode would regulate (zener current of 1,5 mA) is:

$(1{,}5 \times 10^{-3} \cdot 5600) + 4V9 = 13{,}3$ V

Assuming that the total load resistance is less than 6,6 ohms and 1 volt across TR2, the constant current source should control current to 2 amps with a supply voltage of between 14,3 volts and 120 volts.

The power dissipated is

$$\frac{\left(\frac{120 - 4V9}{\sqrt{3}}\right)^2}{5600} = 0{,}74 \text{ watt}$$

R35 was accordingly made a 5k6 2 W resistor.

3.7.2 <u>Reliability</u>

ZD2, the 5V6, 1 watt zener diode.

The part operating failure rate model is

$\lambda p = \lambda b \, (\Pi_E \times \Pi_A \times \Pi_Q)$ failures/10^6 hours

Π_E, Environment factor (ground mobile) = 18

Π_A, Application (voltage regulator) = 1

Π_Q, Quality (lower) = 15

$$S \text{ (Stress factor)} = \frac{\text{Applied current}}{\text{rated current}} = \frac{20{,}5 \times 10^{-3}}{196 \times 10^{-3}}$$

$= 0{,}106$

Therefore S equals 0,1 and $\lambda b = 0{,}00070$

$\lambda p = 0{,}0007 \, (18 \, . \, 1 \, . \, 15)$
$= 0{,}189$ failures/10^6 hours

TR2, the MTP 4N50 Transistor.

For group II the part operating failure rate model is

$\lambda p = \lambda b \, (\Pi_E \times \Pi_A \times \Pi_Q \times \Pi_C)$ failures/10^6 hours

Π_E , Environment (ground mobile) = 18

Π_A , Application (Linear) = 1,5

Π_Q , Quality (plastic) = 12

Π_C , Complexity (single device) = 1

$$\text{The stress factor } S = \frac{\text{operating power}}{\text{rated power}}$$

Rated and operating powers are calculated for a 4 ms pulse.

$$\text{Rated power} = 120 \times 4 \text{ A} \times \frac{1}{\sqrt{3}} = 277{,}13 \text{ watts}$$

$$\text{Operating power} = 120 \text{ V} \times 2 \text{ A} \times \frac{1}{\sqrt{3}} = 138{,}6 \text{ watts}$$

$$S = \frac{138}{277} = 0{,}5$$

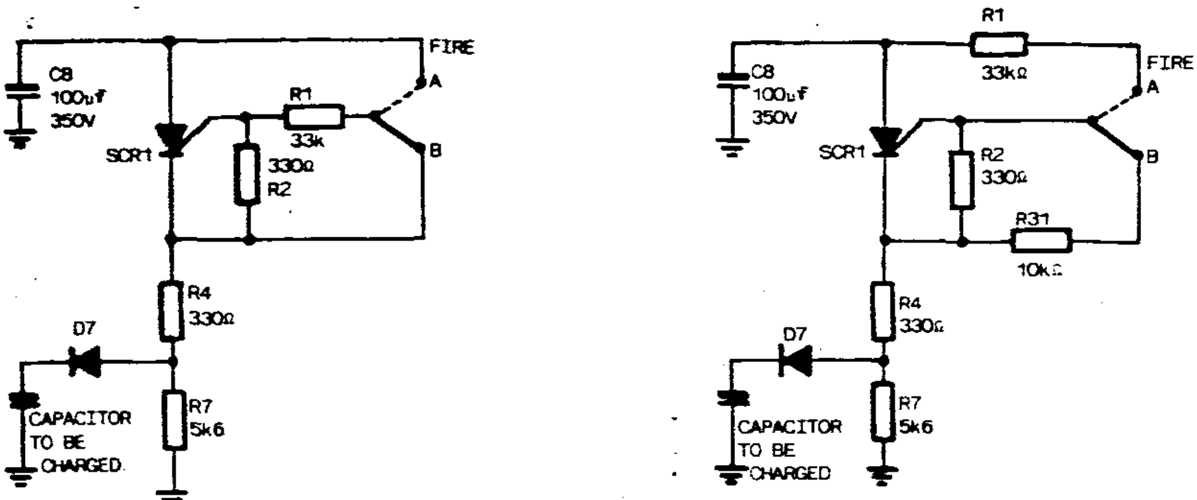
therefore $\lambda p = 0{,}039 \, (18 \, . \, 1{,}5 \, . \, 12 \, . \, 1)$ failures/10^6 hrs.
$= 12{,}6$ failures/10^6 hours

This relatively high failure rate is due, in part, to the high base failure rate. The part failure rate assumes continuous operation while this application has an operation time of approximately 4 ms per operational cycle. Consequently the reliability of this device should be adequate.

3.8 ALTERATIONS TO SCR1 AND SCR2 TO INCREASE SAFETY AND RELIABILITY

3.8.1 SCR1

This SCR controls the charging of the four 10 microfarad capacitors in the SAD simultaneously with rocket motor ignition. The original circuit is shown below with the revised circuit alongside for comparison.



ORIGINAL REVISED

FIGURE 78: ORIGINAL AND MODIFIED RECTIFIER CIRCUIT, SCR1

In the original circuit : If the fire button contacts fail short circuit between points A and B, the SAD capacitor to be charged will be charged simultaneously with C8 to 120 V. An unsafe condition will arise because the SAD capacitors are charged during testing of the system.

In the revised circuit it can be seen that if A and B fail short circuit, the maximum potential on the capacitor to be charged is:

$$\frac{120}{33 \times 10^3 + 330 + 330 + 5600} \times 5600 = 17 \text{ V}$$

instead of 120 V.

Consequently the safety of this circuit is enchanced by the repositioning of R1 and the introduction of R31.

3.8.2 SCR2

This SCR is triggered by the error sensing op amps, consequently discharging C8 and C9 (the automatic abort circuitry). The original circuit is shown below with the revised circuit alongside for comparison.

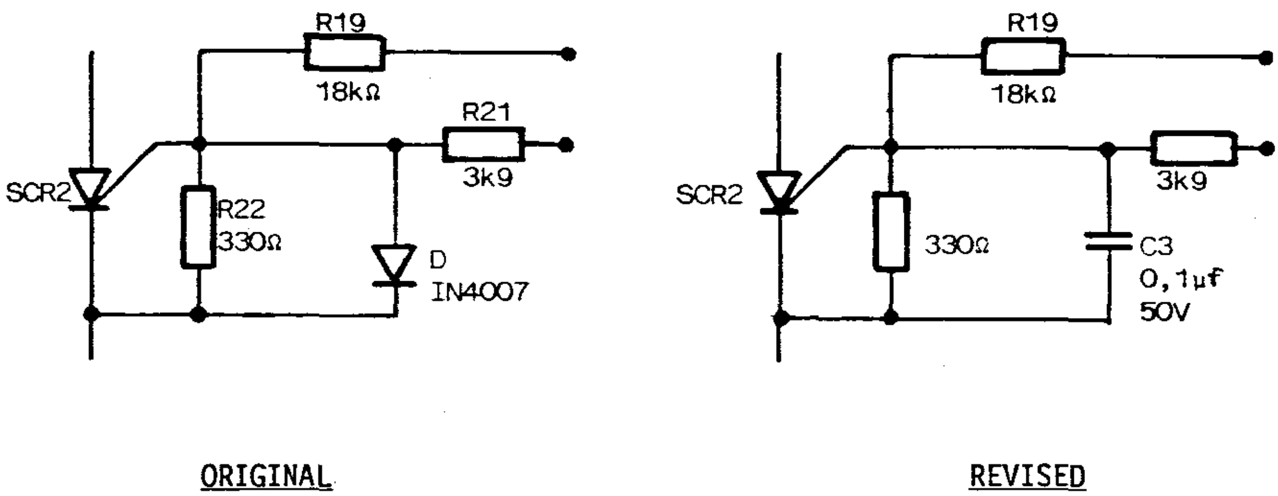


FIGURE 79: ORIGINAL AND MODIFIED RECTIFIER CIRCUIT, SCR 2

The diode was removed and replaced with a capacitor because unreliable triggering of SCR2 occurred due to the diode clamping the SCR trigger voltage below that needed to reliably trigger the SCR. C3 was therefore introduced, in place of the diode, to reduce circuit susceptibility to unwanted signals.

3.9 THE TRANSFER OF THE TWO 1,5 OHMS COMPENSATING RESISTORS FROM THE IGNITER TO THE PCB (R40 AND R41)

The original reason for including these two resistors in the igniter, instead of on the PCB in the firing unit, was to achieve a measure of temperature compensation between them and the fuzehead resistance being measured. This proved to be practically inconvenient due to the limited space available in the igniter. The two resistors were very cramped, resulting in reduced reliability. Accordingly R40 and R41 were removed from the igniter and mounted on the PCB in the firing unit.

3.10 REPLACEMENT OF THE LM340 T 15 WITH A LM140 K 15 TO IMPROVE RELIABILITY

The reliability of IC2 was calculated as part of the XDM/ADM report on the firing unit (Part 2) and found to be 8 failures/10^6 hours. As this component operates whenever the hand crank is turned, this failure rate was deemed too high. Accordingly the device was replaced with a more reliable one whose reliability is shown below.

From MIL-HDBK-217D page 5.1.2.2-1 the part operating failure rate model is

$\lambda p = \pi_Q (C_1 \pi_T \pi_V + (C_2 + C_3) \pi_E) \pi_L$ failures per 10^6 hours where -

λp is the device failure rate per 10^6 hours

π_Q is the quality factor (B - 0) = 2

π_T is the temperature acceleration factor (65°C) = 2

π_V is the voltage derating stress factor = 1

π_E is the application environment factor (ground mobile) = 4,2

π_L is the device learning factor (interruption in production)= 10

C_3 is the package complexity failure rate (hermetic can with 3 leads) = 0,0003

C_1 and C_2 are the circuit complexity failure rates based upon a transistor count of 17.

C_1 = 0,016

C_2 = 0,0040

therefore

λp = 2 . 10 (0,016 . 2 . 1 + (0,0040 + 0,0003) . 4,2)

λp = 1 failure/10^6 hours

This failure rate will improve by a further factor of 10 once these devices are in full production. This can be compared with the previous device's failure rate (λp) of 8 failures/10^6 hours.

3.11 STATIC PROTECTION VARISTORS, V 1 TO V 3

These metal oxide varistors (movs) were included to prevent any unwanted static build up between any of the cable conductors and ground. The voltage rating of each device was selected to be as close as practically possible to the operating voltage of the particular conductor being protected.

V1 was made a 65 volt device as the maximum working voltage is $2 \times (400 \times 50 \times 10^{-3} + 2) = 44$ V (a 400 metre conductor carrying 2 amps with a 2 ohm load).

V2 was selected as a 110 volt device as the peak voltage at that point is

$$\frac{120\ V}{330 + 5600}\ 5600 = 113 \text{ volts}$$

V3 was selected as a 240 volt device since the maximum continuous voltage on this conductor is 120 volts. This particular conductor will only become sensitive to static potentials in excess of 1000 V. The protection provided by this particular varistor is therefore considered adequate.

3.12 INCREASING THE RELIABILITY OF THE SAFETY DISCHARGE CIRCUITRY

During discussions on the safety of the firing unit it became apparent that a failure of D10 or R20 would prevent C 8 from discharging when a fault condition occurs. This is not acceptable because it would allow the SAD to be charged while the motor would not be launched. The safety of the system would then depend upon the SAD.

3.12.1 Changes to the Circuit Diagram

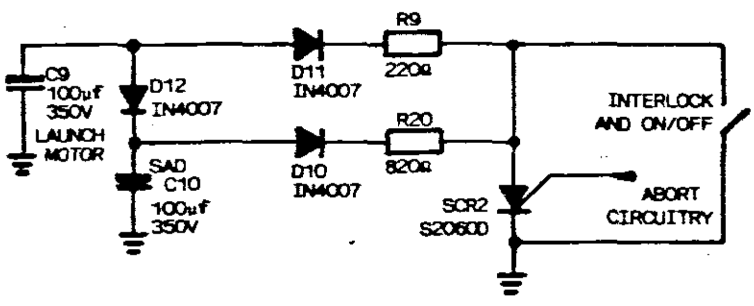


FIGURE 80: ORIGINAL SAFETY DISCHARGE CIRCUIT

It can be seen from the above that C9 has 2 discharge paths: D11, R9, SCR2 and D12, D10, R20, SCR2, while C10 can only discharge via D10 and R20.

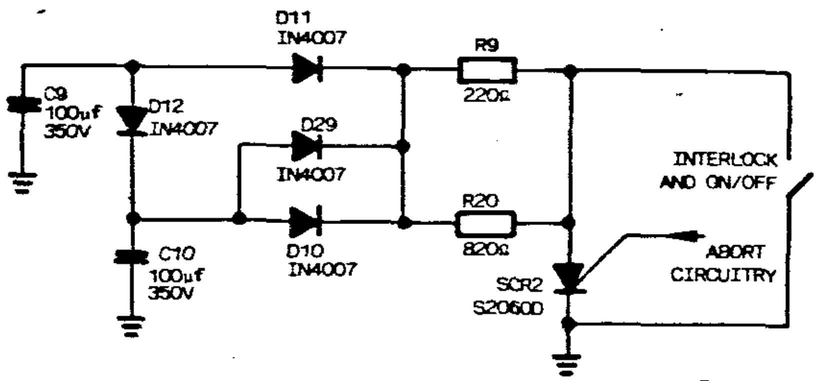


FIGURE 81: MODIFIED SAFETY DISCHARGE CIRCUIT

This circuit has the advantage that C9 and C10 have four possible discharge paths.

3.12.2 Influences of the Change

The change greatly increases the reliability of the safety discharge paths pertaining to C9 and C10. These two capacitors have the same discharge time constant and will therfore discharge equally in a 5RC time of approximately 175 milliseconds. The maximum holding current of SCR2 is 3mA and this will have to be supplied by C1 through LED 2, R42 and D1 (See section 5.3).

This current is calculated as follows:
C1 is charged to 20V during system operation.
20 - 2,0 - 0,7 = 17,3V

$$I \text{ actual} = \frac{17{,}3 . e^{\frac{-175 \times 10^{-3}}{1000 . 220 \times 10^{-6}}}}{1000}$$

$$= 7{,}8 \times 10^{-3} \text{ amps}$$

This is approximately 2,6 times the minimum holding current of SCR2. This circuit change is therefore acceptable.

SECTION 4 - IMPROVEMENTS TO THE PHYSICAL CONSTRUCTION OF THE UNIT

This section deals with conceptual changes to the mechanical enclosure of the firing unit.

4.1 THE CSIR REPORT

The following findings and conclusions are quoted verbatim from the NEERI department of the CSIR's contract report (E/85/247).

Polyurethane - Silver Sprayed Unit

The 10 to 30 dB additional shielding offered by the silver spray is not in accordance with the maximum potential shielding qualities of the product. This is probably due to (i) the degradation of the total shield by the cable harness (ii), cracks in the layer of spray and (iii) the undefined contact between the conductive spray and the metal of the box. Unless precautions are taken, the conductive layer can easily be damaged and penetrated during transportation, storage and handling.

It is recommended that the design should make provision for a semi-permanent, factory fitted, RF tight lid and that the mounting method be adapted accordingly.

Conclusions

The conductive silver spray is not considered a reliable solution and thought should be given to use the present lid of the box as a permanent shield.

The original idea was to have the base permanently attached the vehicle, the potted electronics being replaced in the event of a firing unit failure. Accordingly work was done in trying to implement a more robust form of RF shielding. Cost and production implications soon precluded these methods and it was decided to permanently attach the base of the firing unit to the firing unit body.

4.1.1 Attaching a RF Tight Base

The CSIR recommended using the present lid of the box (which forms the mounting base) as a permanent shield. This was achieved by using an RF caulking compound and the gasket supplied by the enclosure manufacturers.

This compound has the following characteristics:-

a. It consist of a Polyisobutylene binder filled with silver plated copper particles.

b. Its consistency is that of thick gritty paste.

c. It has a 4 hour drying time.

d. Its operating temperature range is between -55°C and 100°C.

SECTION 5 - SYSTEM WIRING DIAGRAMS

The following wiring and circuit diagrams are provided:

The launch pack wiring diagram	(5.1)
Vehicle wiring diagrams	(5.2)
The firing unit wiring diagram	(5.3)
The test unit circuit diagram	(5.4)

5.1 THE LAUNCH PACK WIRING DIAGRAM

The following wiring diagram is that which is fitted to each launch pack. The launch pack is that container containing the two pyrotechnic chains.

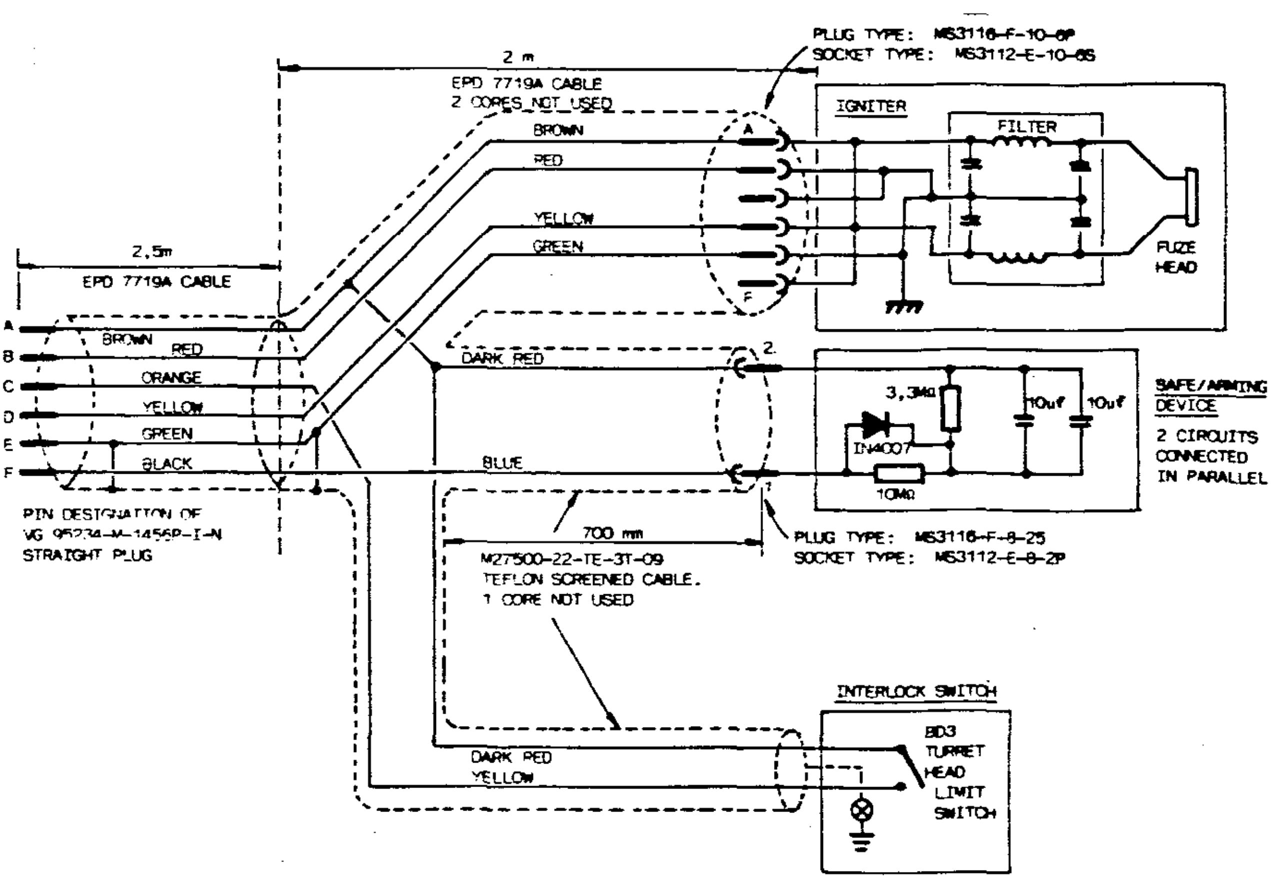


FIGURE 82: LAUNCH PACK WIRING DIAGRAM

5.2 VEHICLE WIRING DIAGRAMS

The following wiring diagram is duplicated in each vehicle.

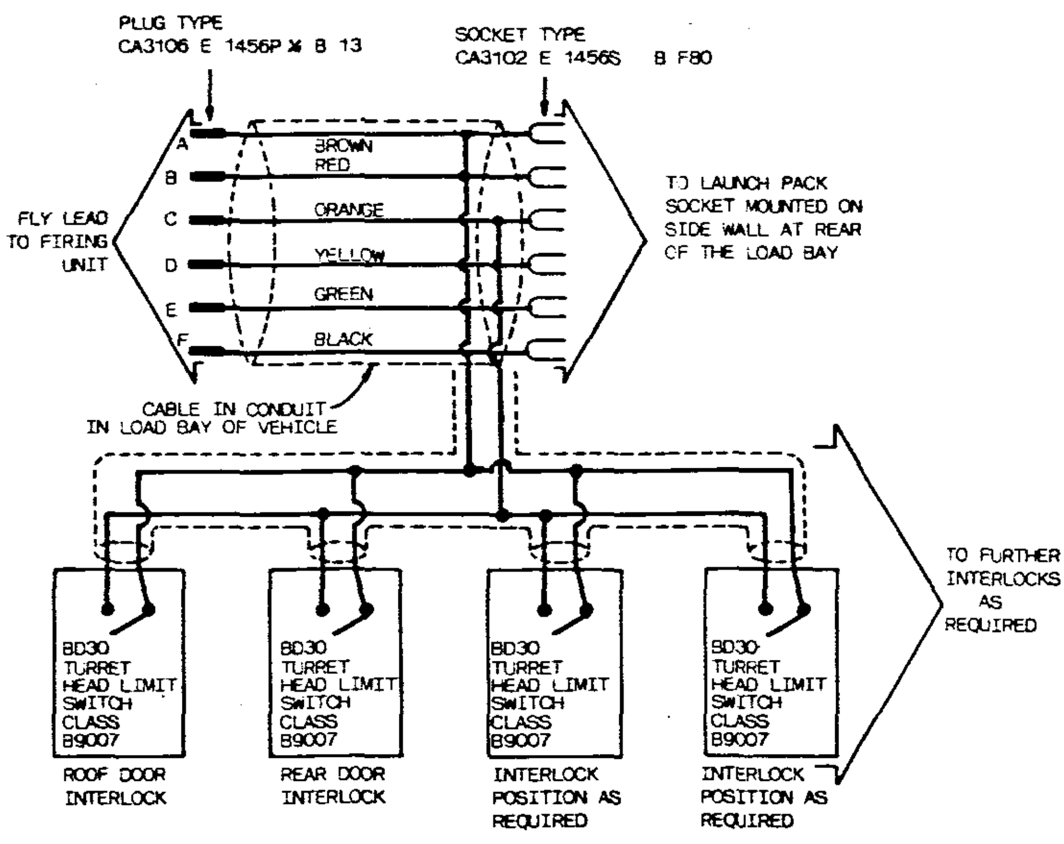


FIGURE 83: VEHICLE WIRING DIAGRAM

5.2.1 <u>Position of the Wiring Interfaces</u>

The following diagrams show the positioning of the cable runs, the launch packs and the firing unit.

5.2.1.1 <u>The side view</u>

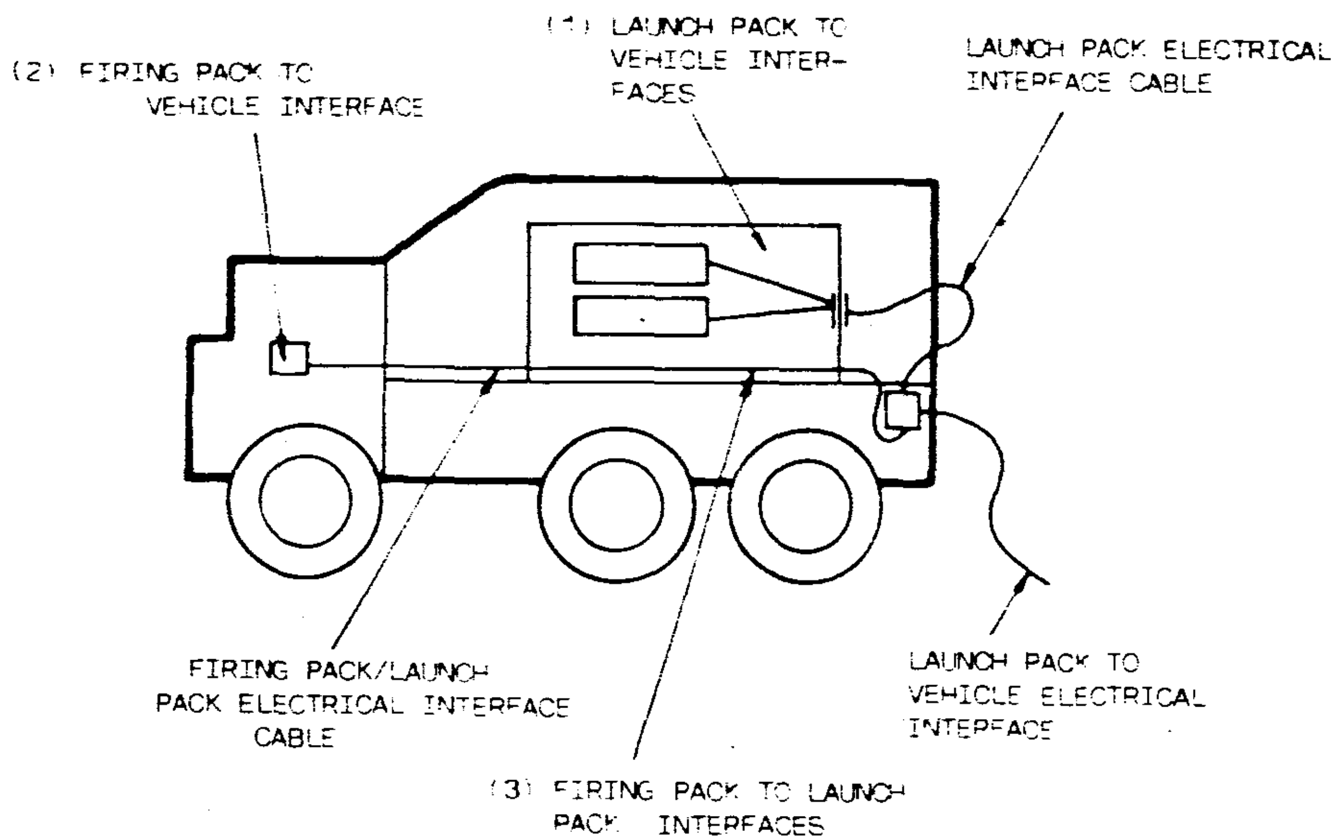


FIGURE 84: WIRING INTERFACES-VEHICLE SIDE VIEW

5.2.1.2 <u>Top view</u>

a The original diagram:

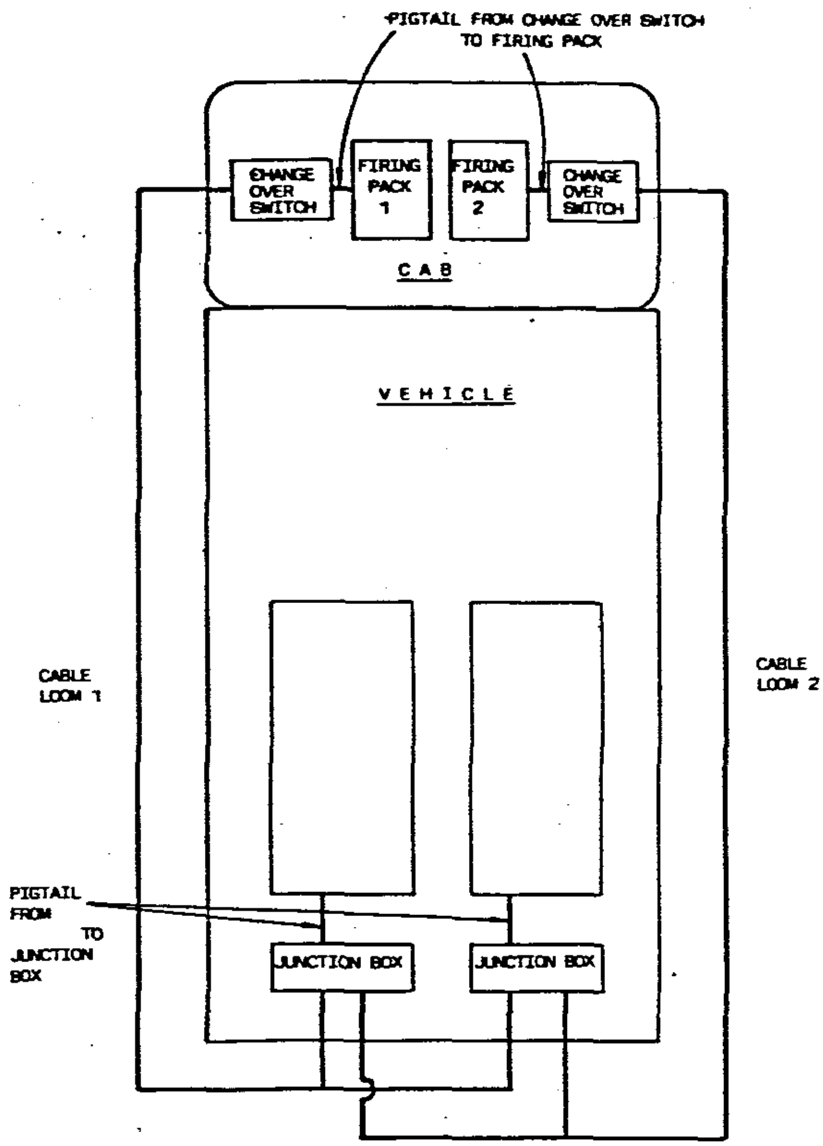


FIGURE 85: WIRING INTERFACES-VEHICLE TOP VIEW (ORIGINAL PLAN)

b The new diagram:

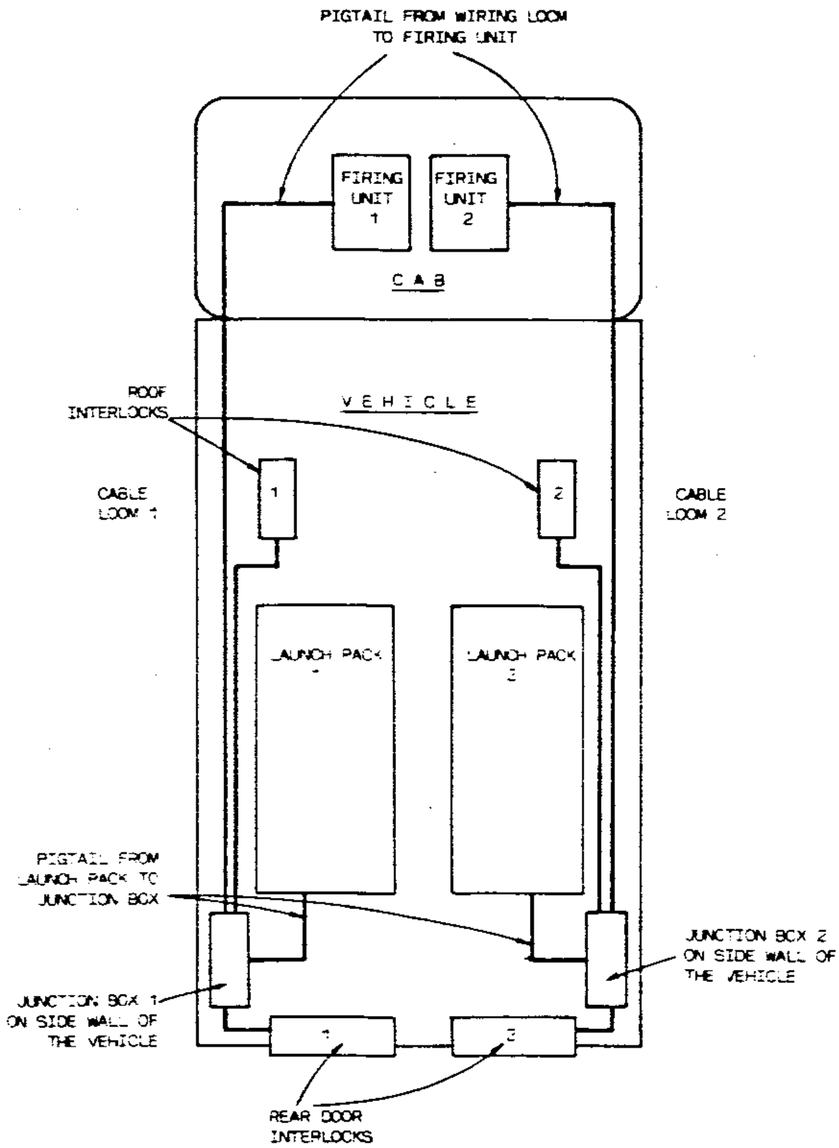


FIGURE 86: WIRING INTERFACES, VEHICLE TOP VIEW (LATER PLAN)

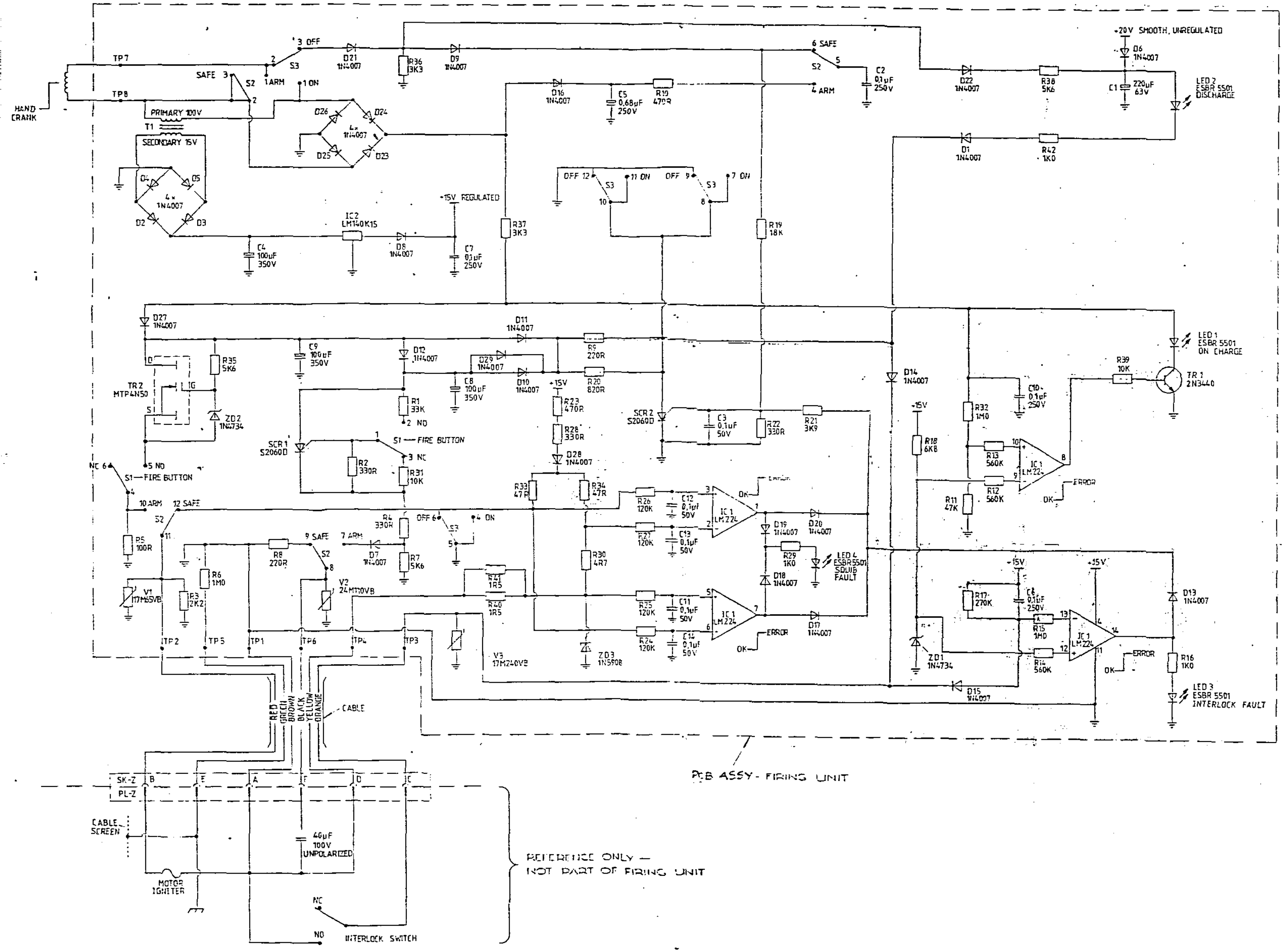
5.2.2 The Changes to the diagram

The change-over switches and more complex wiring looms were deleted primarily for reliability. During detailed design it became apparent that it was difficult to achieve the required function without having an enormous increase in cable loom complexity. A much more reliable solution was to have two completely separate cable looms as shown in 5.2. It must be noted that all interlock switches etc. are duplicated in their entirety and that the cable looms are positioned on opposite sides of the vehicle. The length of the pigtails are such that cable loom 1 can be connected to firing unit 2 and launch pack 2 or vice versa. It must be noted, however, that the operator will have to physically unplug the applicable cable and connect it to the desired unit. This applies to the connections in the cab and in the load bay of the vehicle.

5.3 THE FIRING UNIT WIRING DIAGRAM

For a detailed description of this circuit's operation refer to Part 2 of this thesis and the updated circuitry in Section 3 of this part. The complete diagram is shown here for convenience.

FIGURE 87: FIRING UNIT WIRING DIAGRAM


HAND CRANK
TP7
TP8
PRIMARY 100V
T1
SECONDARY 15V
SAFE 3
S2
3 OFF
S3
1 ARM
1 ON
D21 1N4007
R36 3K3
D9 1N4007
6 SAFE
S2
4 ARM
C2 0.1µF 250V
D16 1N4007
C5 0.68µF 250V
R19 470R
D26
D24
4x 1N4007
D25
D23
D4
D5
4x 1N4007
D2
D3
C4 100µF 350V
IC2 LM140K15
D8 1N4007
+15V REGULATED
C7 0.1µF 250V
R37 3K3
OFF 12
S3
11 ON
OFF 9
S3
7 ON
R19 18K
+20V SMOOTH, UNREGULATED
D6 1N4007
D22 1N4007
R38 5K6
C1 220µF 63V
LED 2 ESBR 5501 DISCHARGE
D1 1N4007
R42 1K0
D27 1N4007
D11 1N4007
R9 220R
R35 5K6
C9 100µF 350V
D12 1N4007
D29 1N4007
D10 1N4007
R20 820R
C8 100µF 350V
TR2 MTP4N50
ZD2 1N4734
R1 33K
2 NO
+15V
R23 470R
R28 330R
D28 1N4007
SCR 2 S2060D
C3 0.1µF 50V
R22 330R
R21 3K9
D14 1N4007
LED 1 ESBR 5501 ON CHARGE
R39 10K
TR 1 2N3440
C10 0.1µF 250V
R32 1M0
+15V
R18 6K8
R13 560K
R12 560K
IC 1 LM224
ERROR
OK
R11 47K
SCR 1 S2060D
S1 — FIRE BUTTON
R2 330R
3 NC
R31 10K
5 NO
NC 6
S1 — FIRE BUTTON
R33 47R
R34 47R
10 ARM
12 SAFE
S2
R26 120K
C12 0.1µF 50V
IC 1 LM224
D19 1N4007
D20 1N4007
R27 120K
C13 0.1µF 50V
R29 1K0
LED 4 ESBR 5501 SQUIB FAULT
D18 1N4007
R5 100R
R4 330R
OFF 6
S3
4 ON
9 SAFE
7 ARM
S2
D7 1N4007
R7 5K6
R8 220R
R6 1M0
R3 2K2
V1 17M65VB
V2 24M110VB
R41 1R5
R40 1R5
R30 4R7
ZD3 1N5908
R25 120K
C11 0.1µF 50V
R24 120K
C14 0.1µF 50V
IC 1 LM224
D17 1N4007
ERROR
OK
V3 17M240VB
TP2
TP5
TP1
TP6
TP4
TP3
+15V
R17 270K
C6 0.1µF 250V
+15V
R15 1M0
R14 560K
IC 1 LM224
ERROR
OK
D13 1N4007
R16 1K0
LED 3 ESBR 5501 INTERLOCK FAULT
ZD1 1N4734
D15 1N4007
RED
GREEN
BROWN
BLACK
YELLOW
ORANGE
CABLE
PCB ASSY - FIRING UNIT
SK-Z
PL-Z
B
E
A
F
D
C
CABLE SCREEN
40µF 100V UNPOLARIZED
MOTOR IGNITER
NC
NO
INTERLOCK SWITCH
REFERENCE ONLY —
NOT PART OF FIRING UNIT

5.4 THE TEST UNIT CIRCUIT DIAGRAM

This test lead is designed to be used in conjunction with a storage oscilloscope, decade resistance box and digital multimeter to test the firing unit. It provides for simulation of the capacitor in the SAD, the fuzehead and access to various parts of the internal circuitry of the firing unit. Various fault conditions can be simulated by means of the decade box and various switch positions. Detailed instructions in the use of this unit are attached as Appendix 8.

The Test unit

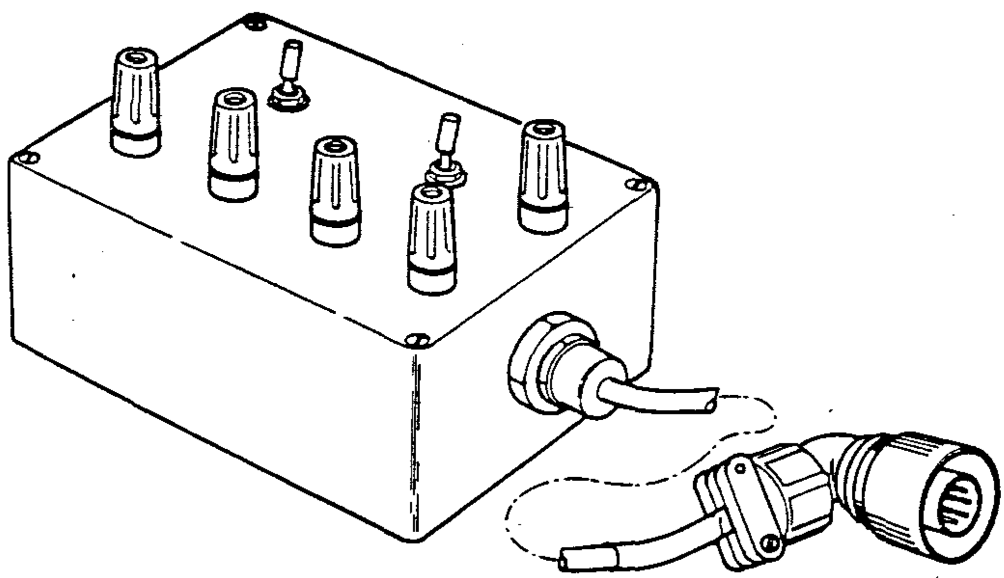


FIGURE 88: FIRING UNIT TEST UNIT

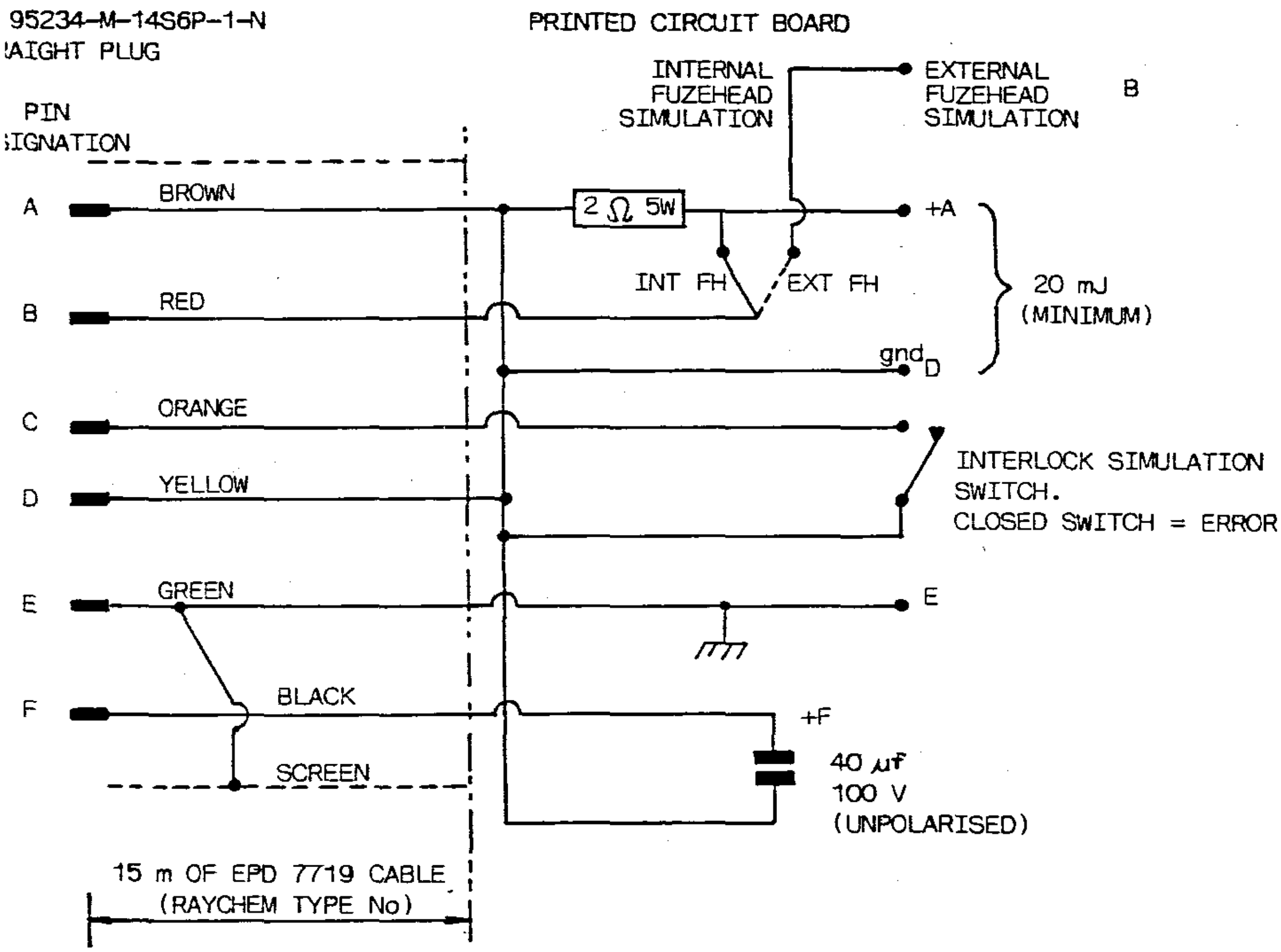


FIGURE 89: TEST UNIT CIRCUIT DIAGRAM

SECTION 6 - MODIFICATIONS TO ENVIRONMENTAL TESTING

This section details the changes to the environmental tests that the firing unit will be subjected to and the reasons for these changes.

6.1 MODIFICATIONS TO THE RAIN TEST

Details of this test are given in MIL-STD-810D method 506.2. and it is duplicated in part 2 of this thesis. This procedure is normally appropriate when equipment is protected from rain, but may be exposed to falling water from condensation or leakage from upper surfaces.

The test requires that the firing unit's mass be determined (4,6 kg ± 250 g), and thereafter, that the unit be exposed to moisture and its mass redetermined. If the mass of the firing unit increases by more than 0,5 g the firing unit would be rejected. 0,5 g represents a mass increase of 0,0115%. Equipment to measure a mass increase of such minute order is not currently available to the author.

The firing unit is potted in an integral skin closed cell foam. This means that if water did penetrate the box, the foam would prevent the water from reaching the electronic components.

Accordingly only a functional test is carried out after the rain test.

6.2 ALTERATIONS TO THE LOW TEMPERATURE TESTS

The low temperature specification was changed by the user from -10°C storage and 0°C operating to -15°C for both storage and operation.

After implementing these changes to the environmental testing procedures it was noted that the firing unit would be cooled to -15°C, for 24 hours, allowed to warm to ambient, tested, cooled to -15°C for 12 hours and then tested at -15°C.

It was decided to simplify the test by cooling the firing unit to -15°C for 36 hours and then completing a functional test, without allowing the units temperature to rise to ambient. The ambient functional test would then be done after temperature cycling. This effectively shortens environmental testing time by 1 functional test.

SECTION 7 - EDM ENVIRONMENTAL TESTING RESULTS

This section details the environmental testing carried out on the firing unit and the graphical results of all functional tests.

Section 7 is devoted to the EDM tests while Section 9 details pre-qualification tests.

The sequence of the tests was different for the two phases. The EDM tests were carried out as the test facilities became available, while the pre-qualification tests were carried out sequentially as specified. These tests are summarised graphically, in the same order, for easy interpretation.

7.1 CRASH HAZARD SHOCK TEST, 22-04-1986

The firing unit mounting plate was mounted on a shock table and an ADM firing unit was attached to the mounting plate as an equivalent mass to the EDM firing unit. Two shocks were applied in each direction along the 3 orthogonal axes.

The mounting plate did not deform, buckle or break loose from the mountings. It is possible that internal damage to the mountings did occur. On the basis of this test, the mounting plate and resilent rubber mountings are considered adequate.

Captured data representing one shock in each of the orthogonal axes is attached. (Figures 90 to 95)

No functional test is required after crash hazard shock tests.

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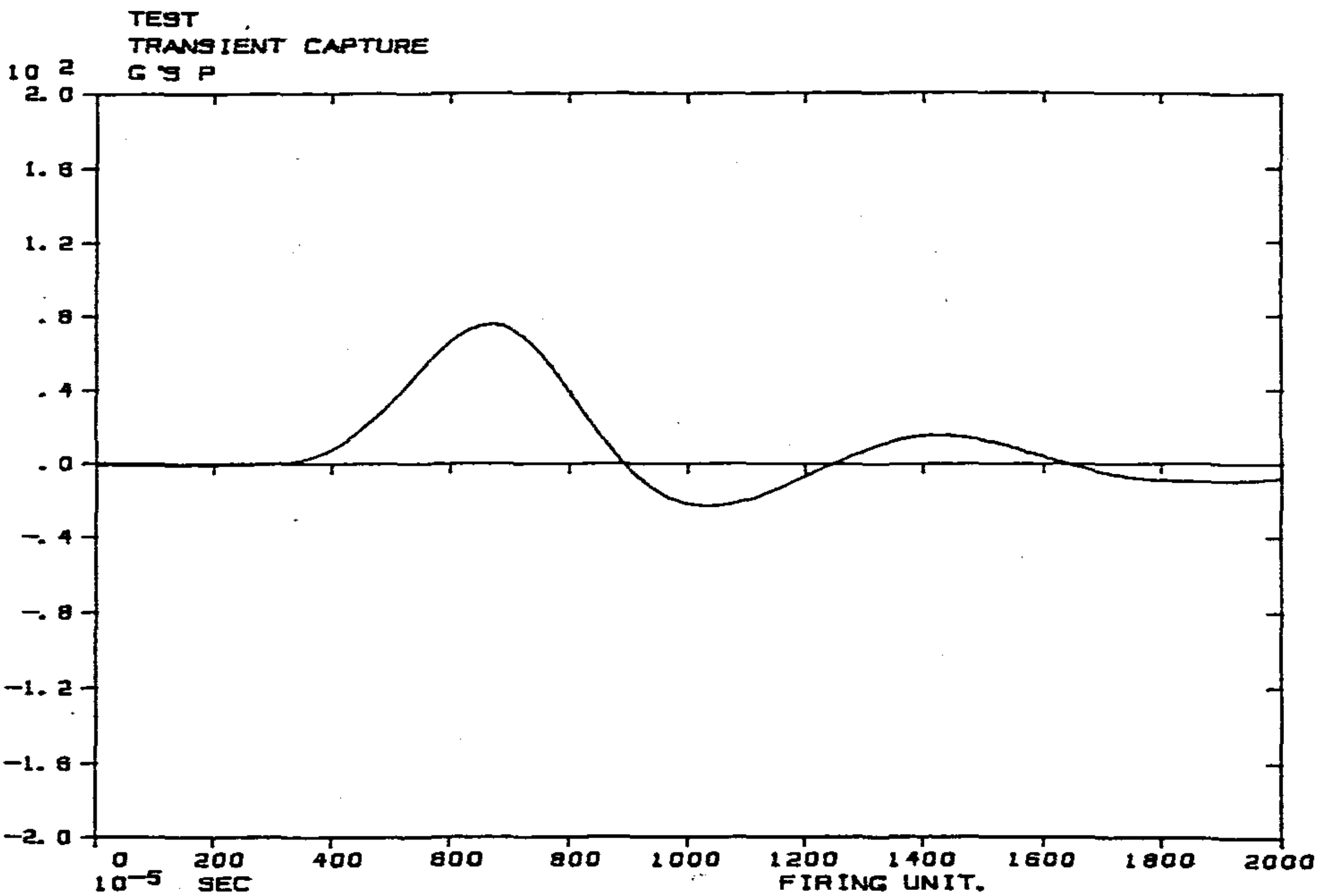


FIGURE 90: CRASH HAZARD VERTICAL AXIS, HAND-CRANKED GENERATOR UP

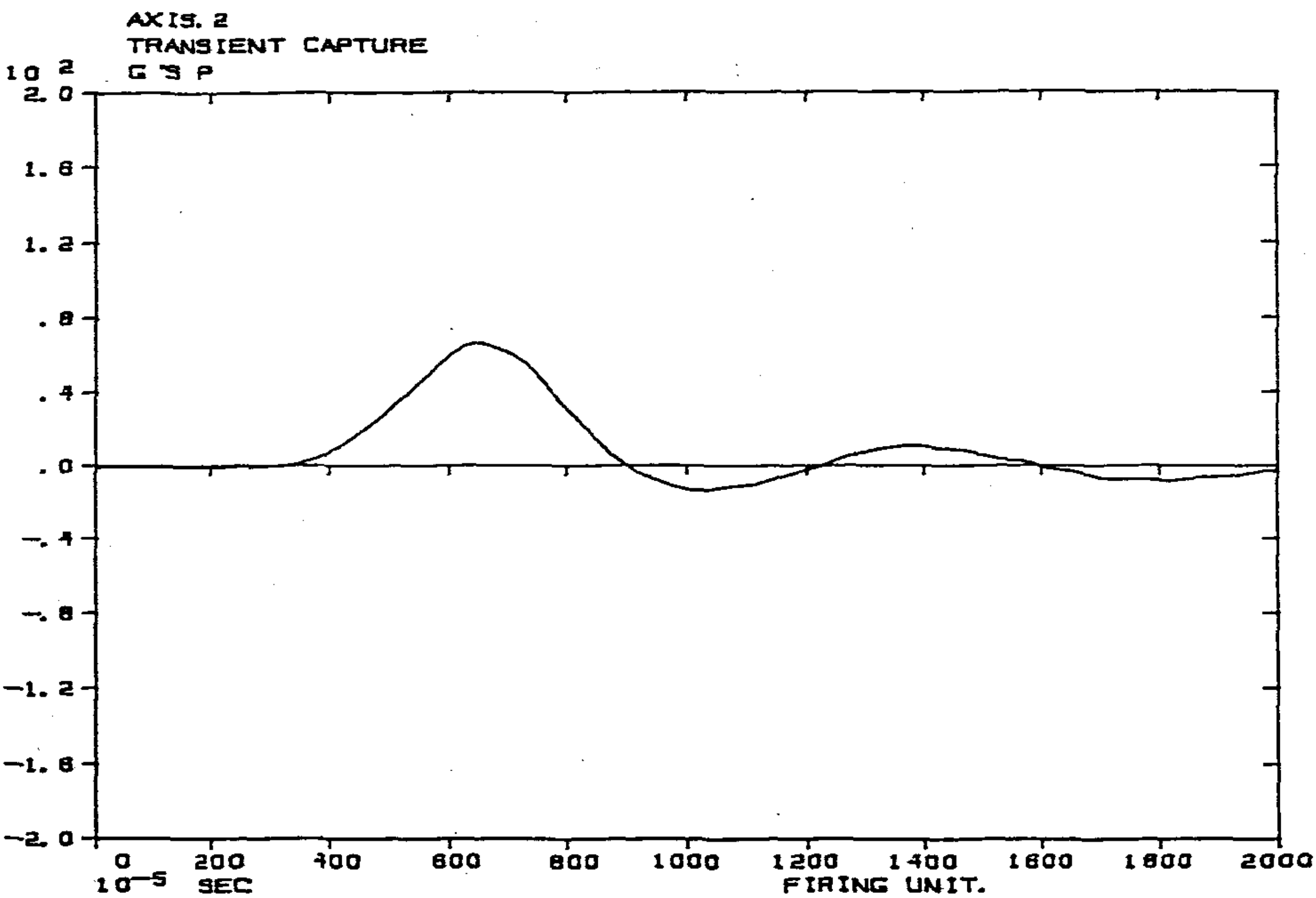


FIGURE 91: CRASH HAZARD, HAND CRANKED GENERATOR AT 90° CLOCKWISE

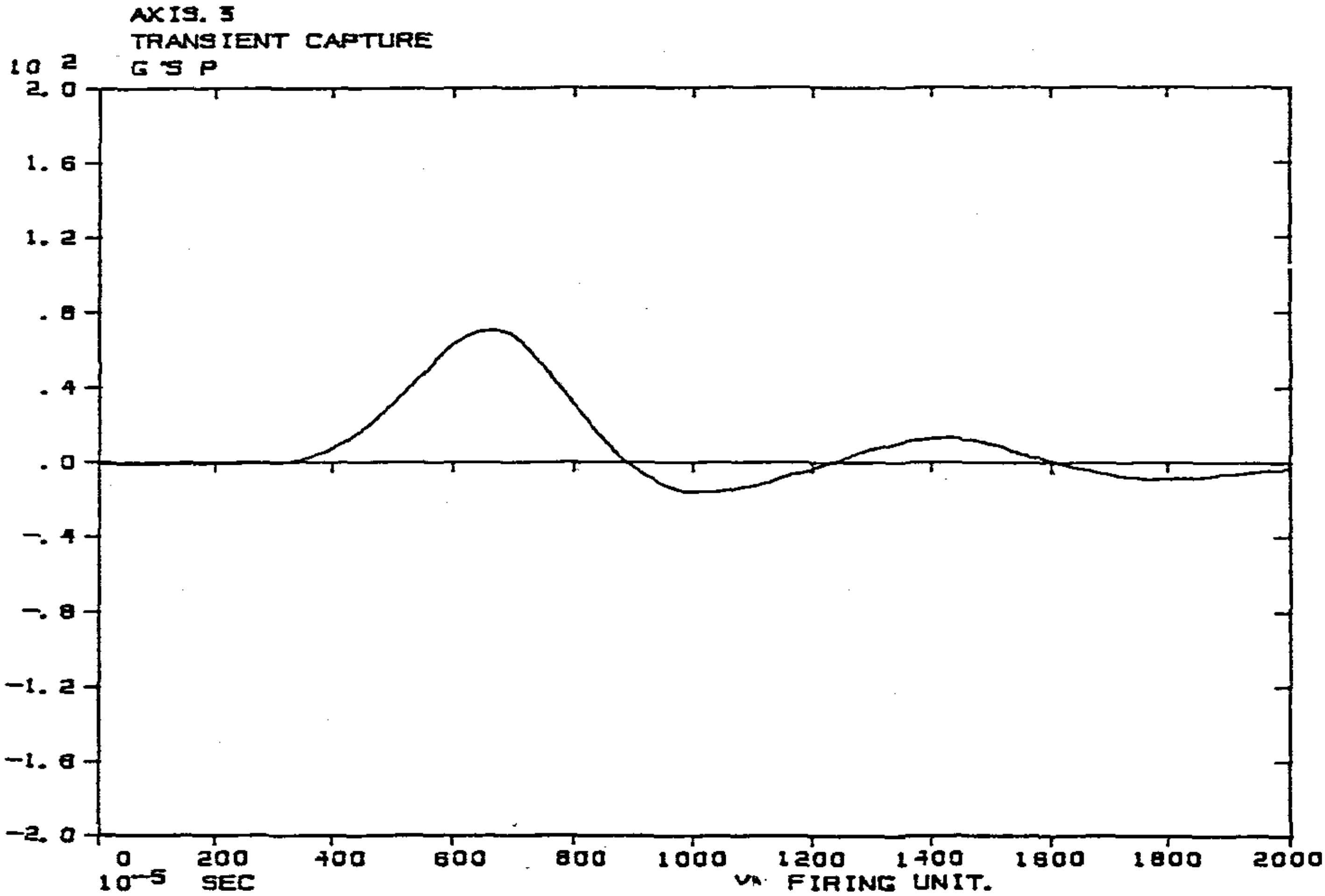


FIGURE 92: CRASH HAZARD, HAND CRANKED GENERATOR AT 180° CLOCKWISE

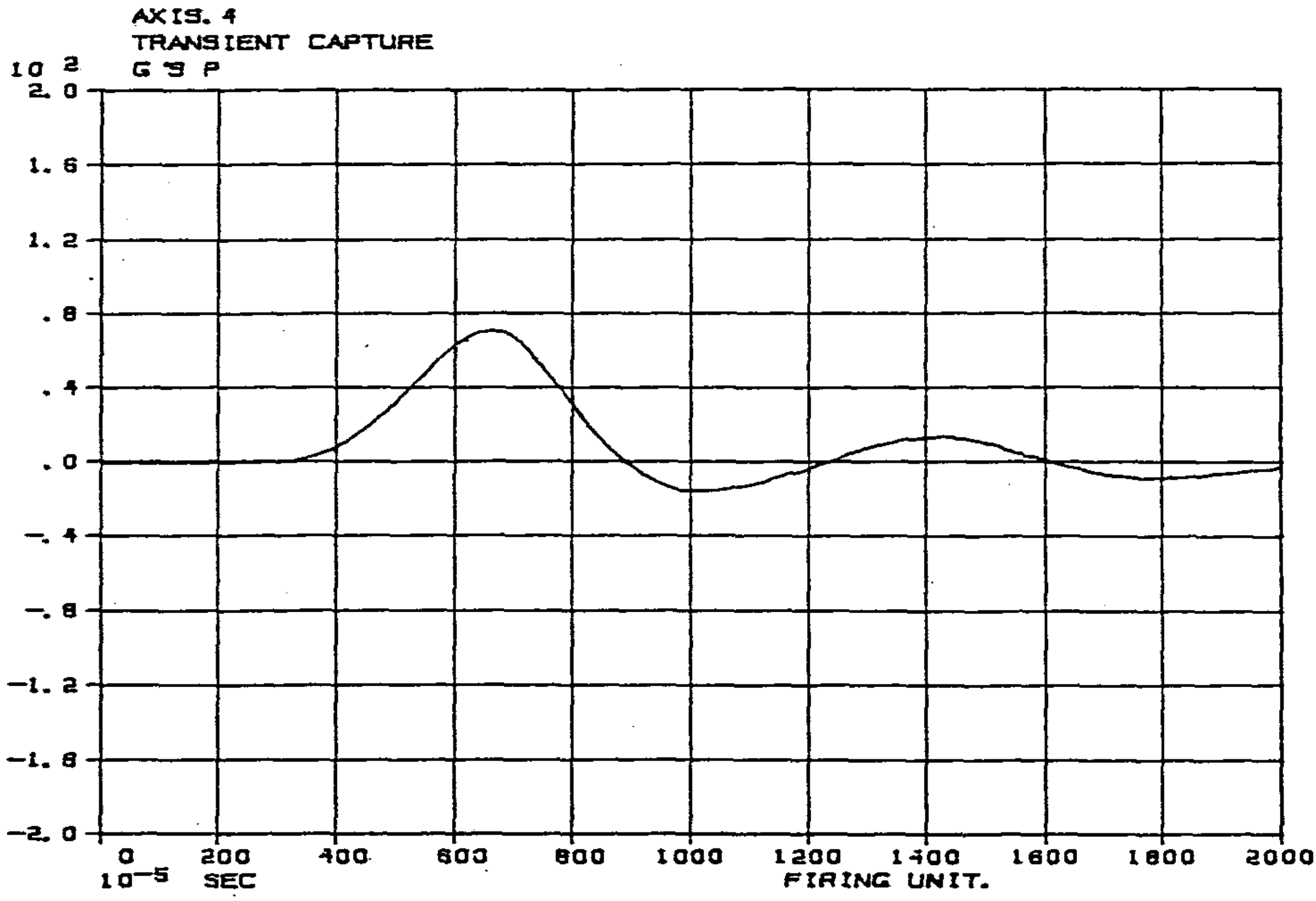


FIGURE 93: CRASH HAZARD, HAND CRANKED GENERATOR AT 270° CLOCKWISE

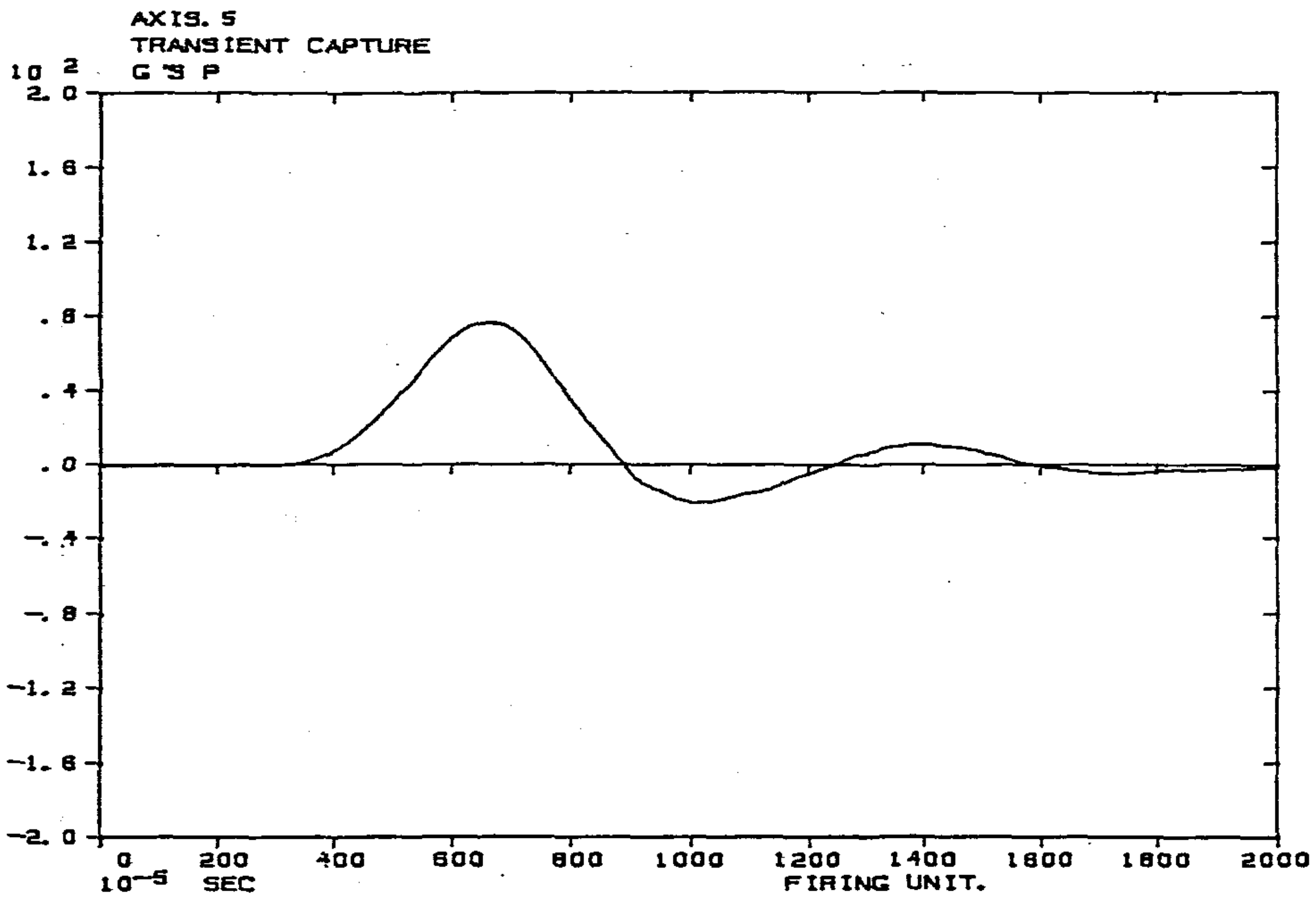


FIGURE 94: CRASH HAZARD, HORIZONTAL AXIS, INTO THE RUBBER MOUNTS

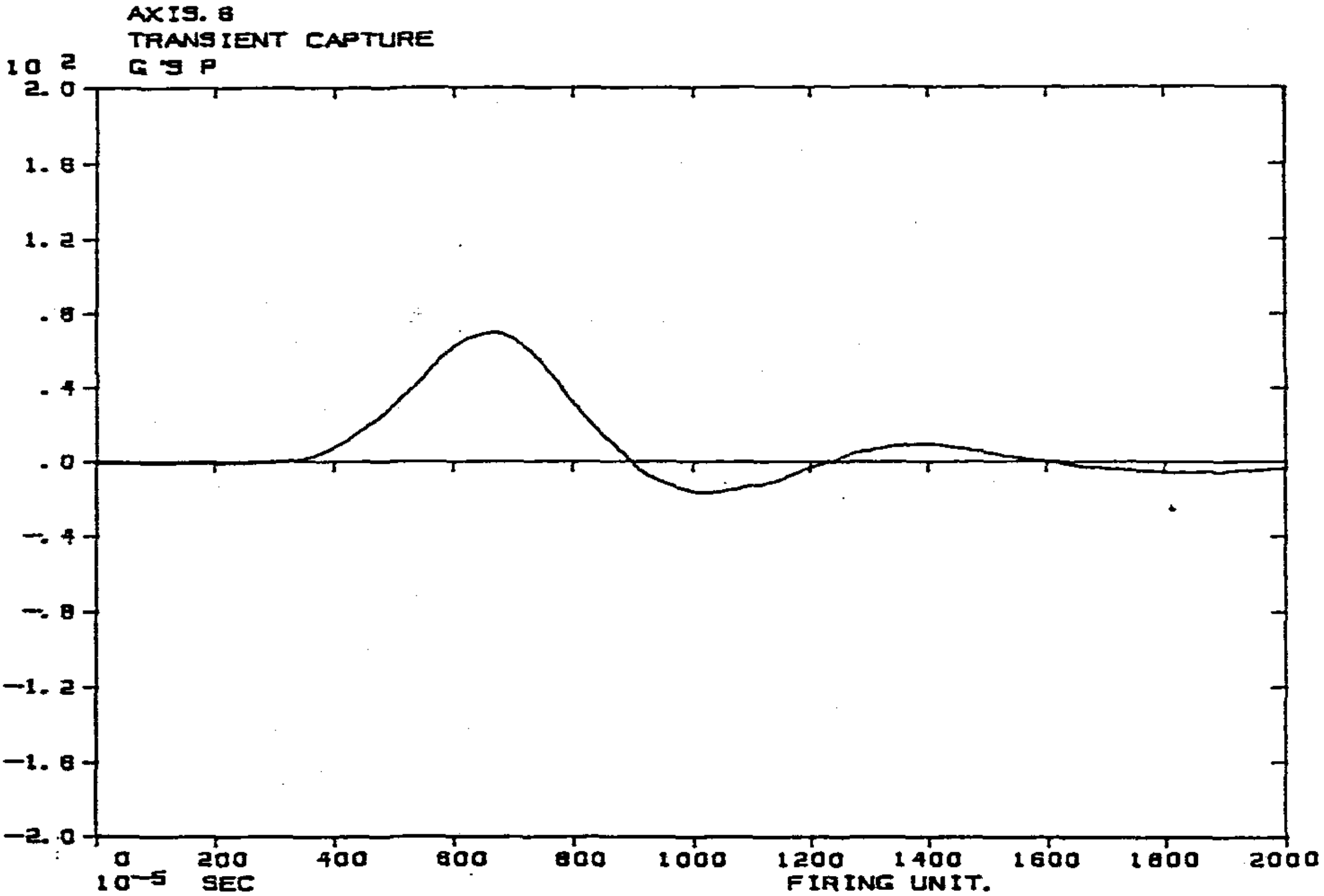


FIGURE 95: CRASH HAZARD, HORIZONTAL AXIS, OUT OF THE RUBBER MOUNTS

7.2 THE PRE POTTING TEST : 21-04-86

The test was carried out according to Appendix 8, Procedures for Functional Testing of the Firing Unit.

The firing unit passed the functional test. The data from this test is used as control data against which all the other test data is compared. The graphs depicting all the data are given in section 7.12.1.

7.3 THE POST-POTTING TEST : 23-04-86

This test was carried out as previously mentioned in 7.2. The results were similar to 7.2 except for the energies represented by the igniter voltage and the capacitor voltage. These energies were greater than those measured in 7.2 and can be ascribed to better formation of electrolytes within the main storage capacitors (C8 and C9).

7.4 THE LOW PRESSURE (ALTITUDE) TEST : 24-04-86

The item was adjusted to its transit configuration and placed in a vacuum chamber at ambient temperature (25°C). The chamber was then evacuated to 50 kPa.

After 1 hour the chamber air pressure was increased to atmospheric and the firing unit removed for inspection. Inspection of the firing unit revealed hairline cracking of the aluminium-filled epoxy. The epoxy was therefore rejected.

A functional test was carried out according to Appendix 8, the firing unit passed this test. No unusual values were noted.

7.4.1 Comments

The aluminium epoxy was added with a view to achieving a measure of RF protection. The aluminium epoxy was deleted in further units however and RF protection has been achieved by means of the aluminium base connected to the body by an RF gasket.

7.5 HIGH TEMPERATURE STORAGE

The oven was raised to 65°C ± 5°C. and the firing unit inserted at 16h00 for 24 hours. The firing unit was removed from the oven at 16h08 on 29-04-86 and allowed to cool overnight. The functional test was begun at 08h30 on 30-04-86.

7.5.1 Visual Examination

Externally the unit was satisfactory. Internally the cracks in the epoxy opened further and separation of the epoxy from the sides of the box also occurred. This is not a cause for concern, however, for the reasons given in 7.4.1.

7.5.2 Functional Testing : 30-04-86

The firing unit passed the test. The only sub-test which had an interesting result was the fuzehead safety short circuit resistance which was 1,6 ohms instead of 1,8 ohms. This circuit test showed a negative temperature coefficient characteristic. (Note the 2,4 ohm resistance when this test was carried out at -10°C). An attempt was made to isolate this phenomenon by repeating these measurements at 65°C, +60°C, 0°C, -10°C, -15°C and -30°C. The resistance remained 1,7 ohms, showing a negligible temperature coefficient.

7.5.3 Conclusion

The apparent negative temperature coefficient was coincidental and due to variation in plug contact resistance and measurement errors.

7.6 HIGH TEMPERATURE OPERATION : 30-04-86

The firing unit was placed in an oven (at 58,7°C) and removed after 16 hours. Testing was immediately begun. Visual inspection revealed that no further degrading of the aluminium epoxy coating had taken place. Further visual examination revealed no new faults.

7.6.1 Functional testing

The capacitor voltage showed a downward trend on the 1/2 hour storage test. This is due to increased capacitor leakage at elevated temperatures.

The fuzehead safety short circuit resistance showed a further decrease. This phenomenon is dealt with in 7.5.2.

The constant current source controlling the igniter voltage is made up of a zener diode and a Tmos transistor. Both these components have positive temperature coefficients, resulting in an increasing igniter voltage with increase in temperature. (TMOS is a Motorola trade name).

7.6.2 Conclusion

The firing unit passed this test.

7.7 LOW TEMPERATURE STORAGE : 01-05-86

The cooling chamber was adjusted to -10°C on 01-05-86 and the firing unit was inserted at 09h50. The unit was removed from the cooling chamber after 12 hours and the temperature allowed to rise for two hours towards ambient.

7.7.1 Functional Testing

The measured parameters were all within specification. It is worth mentioning that the centre of the firing unit, being potted in foam, might not have risen to 25°C. This would account for a slightly higher voltage after the 1/2 hour test measured on the capacitors, due to lower internal leakage at lower temperatures.

The igniter voltage peaked at 4,5 V. This measured voltage seemed questionable due to the positive temperature coefficients mentioned in 7.6.1. Accordingly this test was repeated on 01-08-86. The peak igniter voltage was normal, thus tending to confirm a possible measurement error in the original test. This is also borne out by the low temperature operation test.

7.8 LOW TEMPERATURE OPERATION : 07-05-86

The firing unit was inserted in the cooling chamber, set to 0°C, on 06-05-86 at 11h00 and removed after 22 hours 37 minutes. Functional testing was then carried out according to Appendix 8. Thereafter the visual check carried out revealed no further cracking of the epoxy coating. The firing unit passed the functional test.

7.8.1 Functional Testing

The fuzehead safety short circuit resistance increased to 2,4 ohms. Attempts were made to repeat this test result, but without success. This phenomenon is dealt with in section 7.5.2 and 7.5.3.

All other subsections of the functional test were according to specification.

7.9 TEMPERATURE SHOCK : 12-05-86

The firing unit was subjected to the following temperature shock graph:

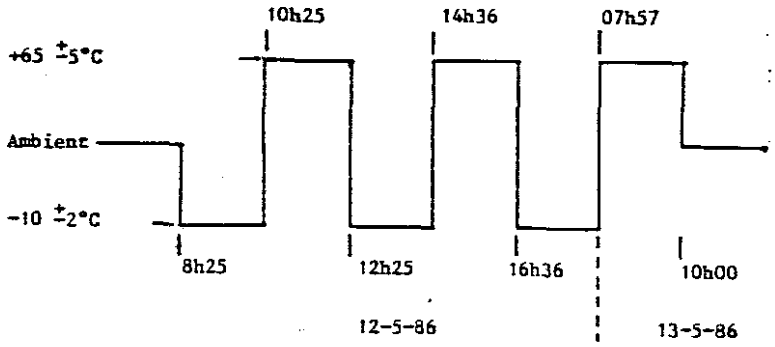


FIGURE 96: TEMPERATURE CYCLE DIAGRAM

7.9.1 Functional Testing

The firing unit passed all the tests. The only parameter worthy of comment was the capacitor voltage. The 30 minute test showed a decrease in voltage when compared to the low temperature test.

This can be ascribed to the high temperature part of the cycle causing increased leakage through the capacitor electrolyte.

7.10 VIBRATION : 15-05-86

The vibration test, as per action 5.3 of part 2, was begun on 15-05-1986. After 3 hours vibration in the vertical axis one shockmount broke. After examination it was noted that 3 of the 4 mounts were cracked. All 4 shockmounts were replaced. No further shockmount failures occurred during vibration. Two possible causes of shockmount failure were noted:

a. Overtightening of the mounting points on the vibration jig. Torque limits have been introduced to obviate this problem.
b. The crash hazard test was completed before vibration testing. If this shockmount failure had occurred during crash hazard testing the firing unit would have passed because the firing unit did not break loose from its mounting plate.

7.10.1 Vibration Graphs

The following three graphs provide data recorded during these tests.

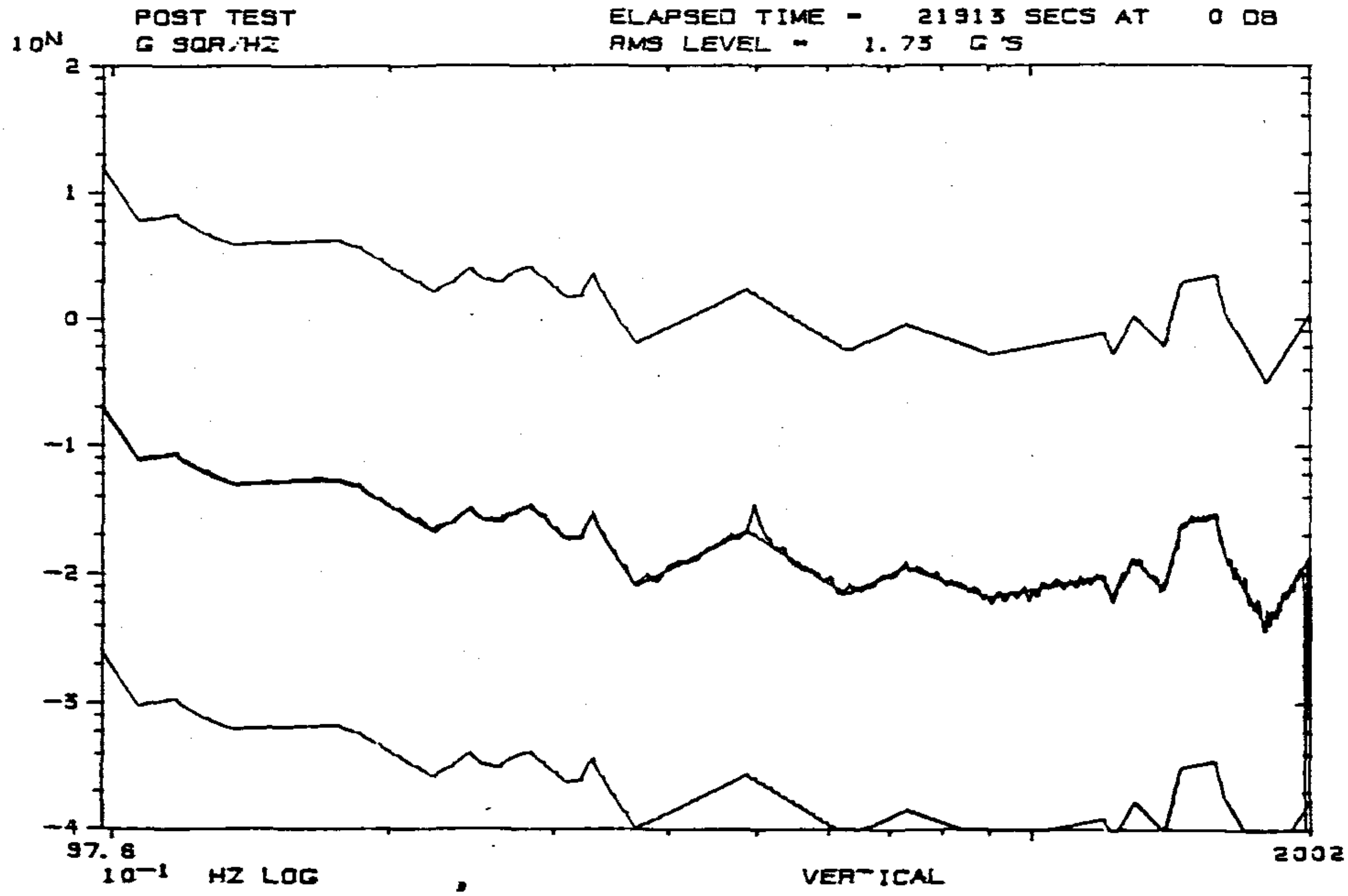


FIGURE 97: VIBRATION TEST, VERTICAL AXIS

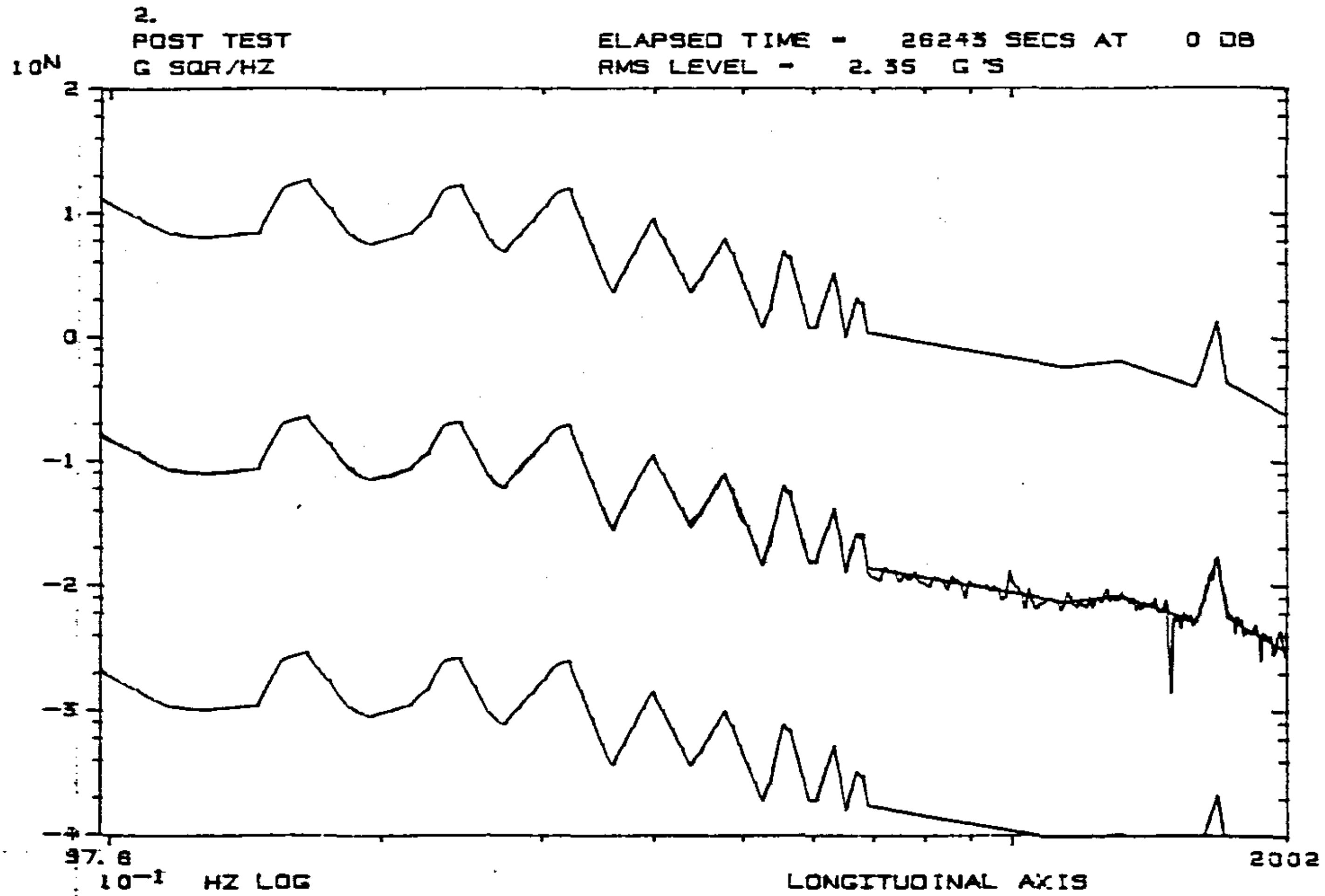


FIGURE 98: VIBRATION TEST, LONGITUDINAL AXIS

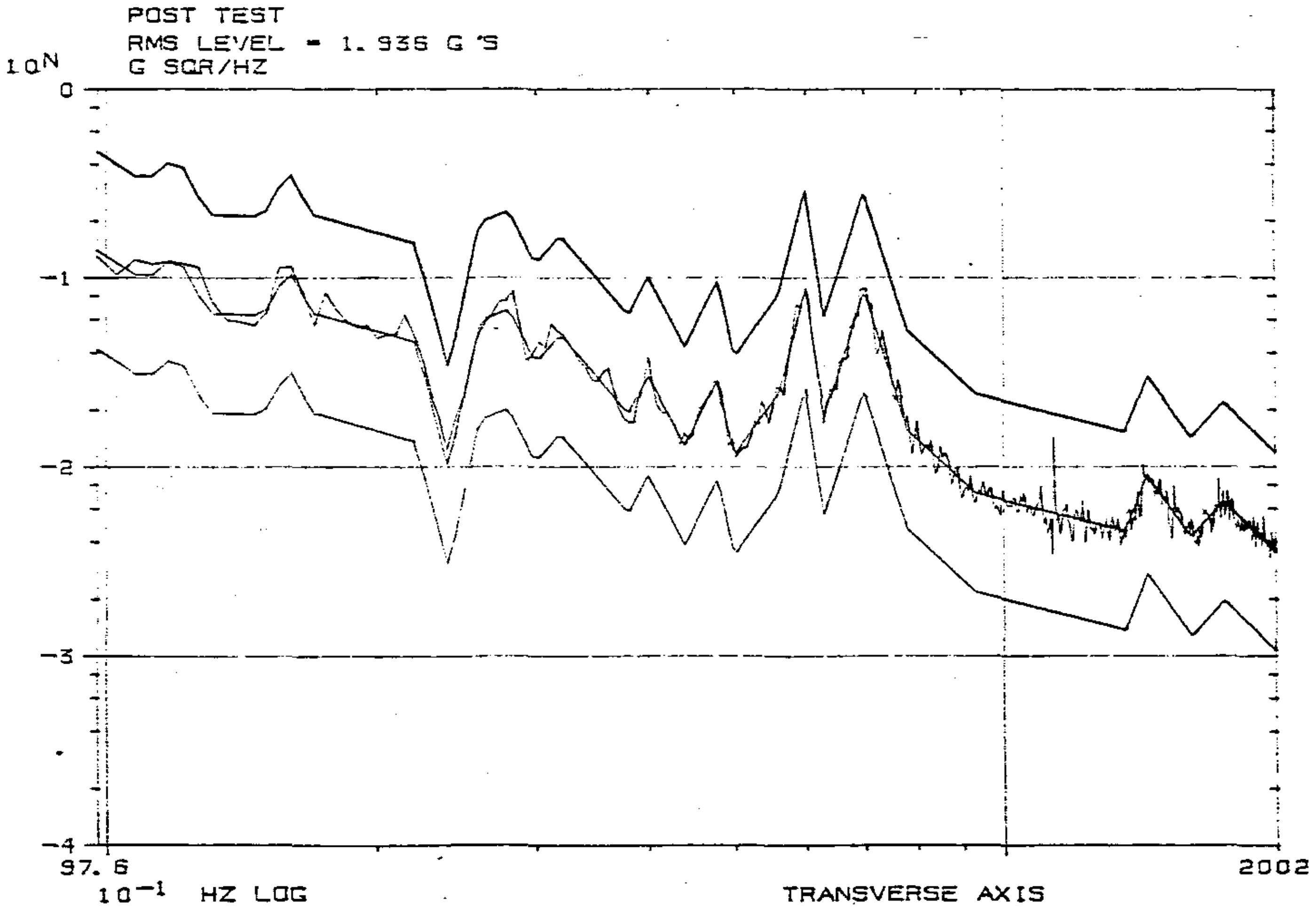


FIGURE 99: VIBRATION TEST, TRANSVERSE AXIS

7.10.2 *Functional Testing*

The firing unit passed the functional test. On the capacitor voltage graph it should be noted that the electrolyte in the capacitor had not fully recovered from the high temperature test and possible mechanical effects during vibration (30 minute test). This voltage is above the minimum required and therefore this effect on the electrolyte can be ignored.

7.11 TRANSIT SHOCK TEST : 22-05-86

The firing unit was subjected to 3 shocks in both directions along each of the orthogonal axes according to section 5.4 of part 2.

No problems were encountered during this test. Data captured during testing is attached as axis 1, 2 and 3 respectively.

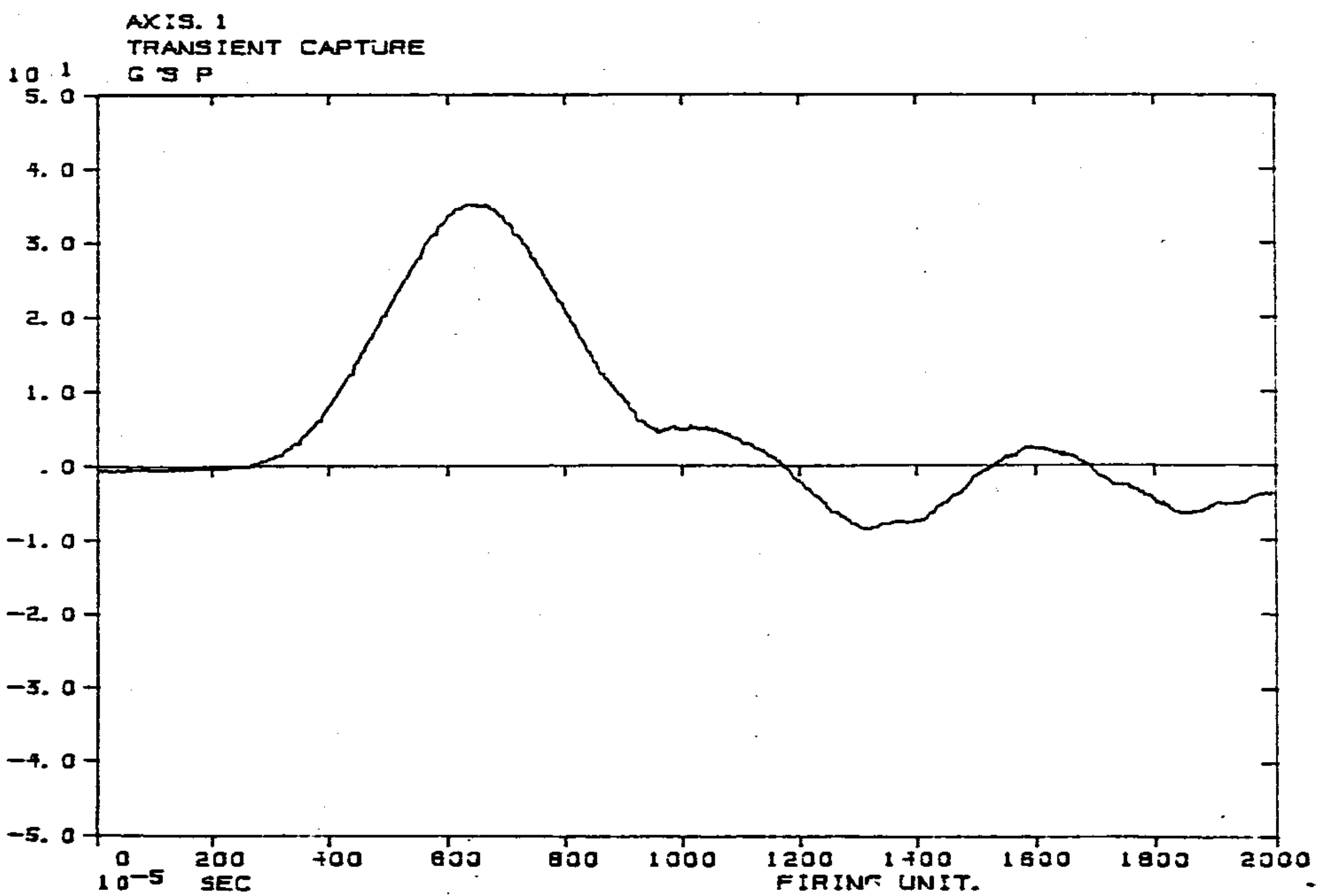


FIGURE 100: TRANSIT SHOCK TEST, AXIS 1

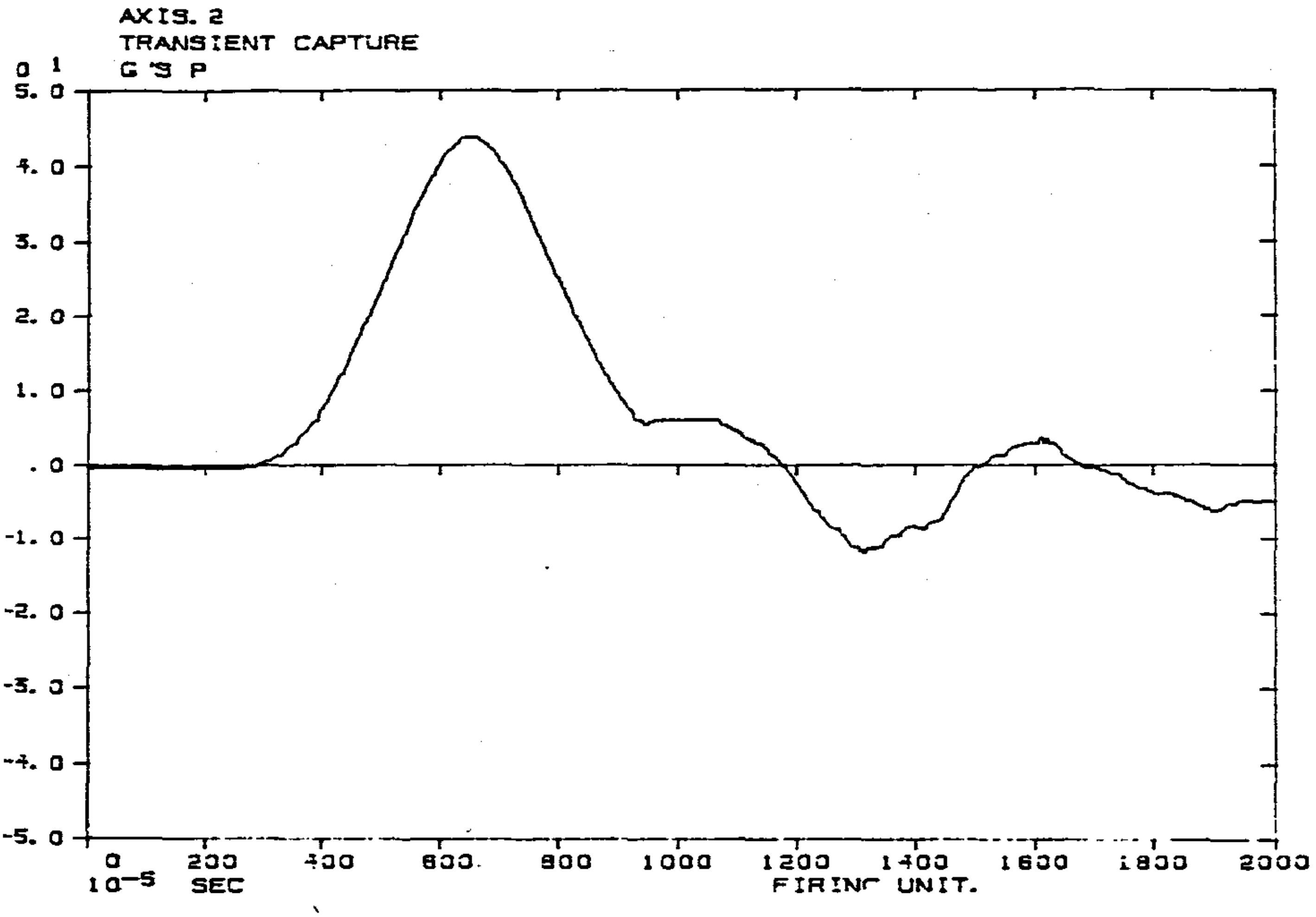


FIGURE 101: TRANSIT SHOCK TEST, AXIS 2

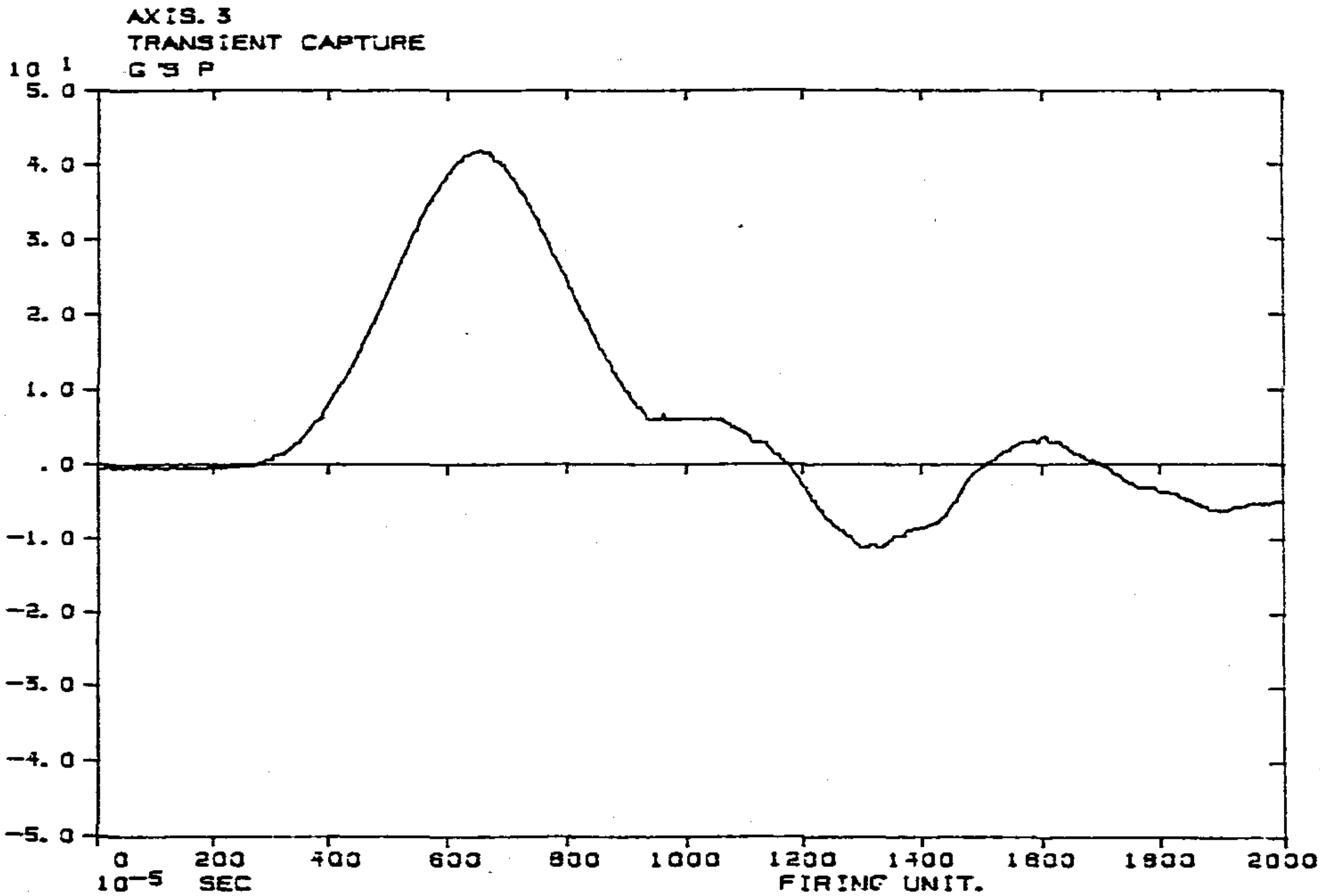


FIGURE 102: TRANSIT SHOCK TEST, AXIS 3

7.11.2 Post Transit Shock Functional Test

The firing unit passed this test with only one parameter change worthy of comment. The capacitor voltage 30 minute test showed that the electrolyte had completely recovered from previous environmental tests. The capacitor leakage current was accordingly less, resulting in a higher voltage being transfered to the load capacitor.

7.12 CONCLUSION

The firing unit passed all environmental testing as outlined in the section. Graphical representation of all the electrical results is shown in Figures 103 to 108.

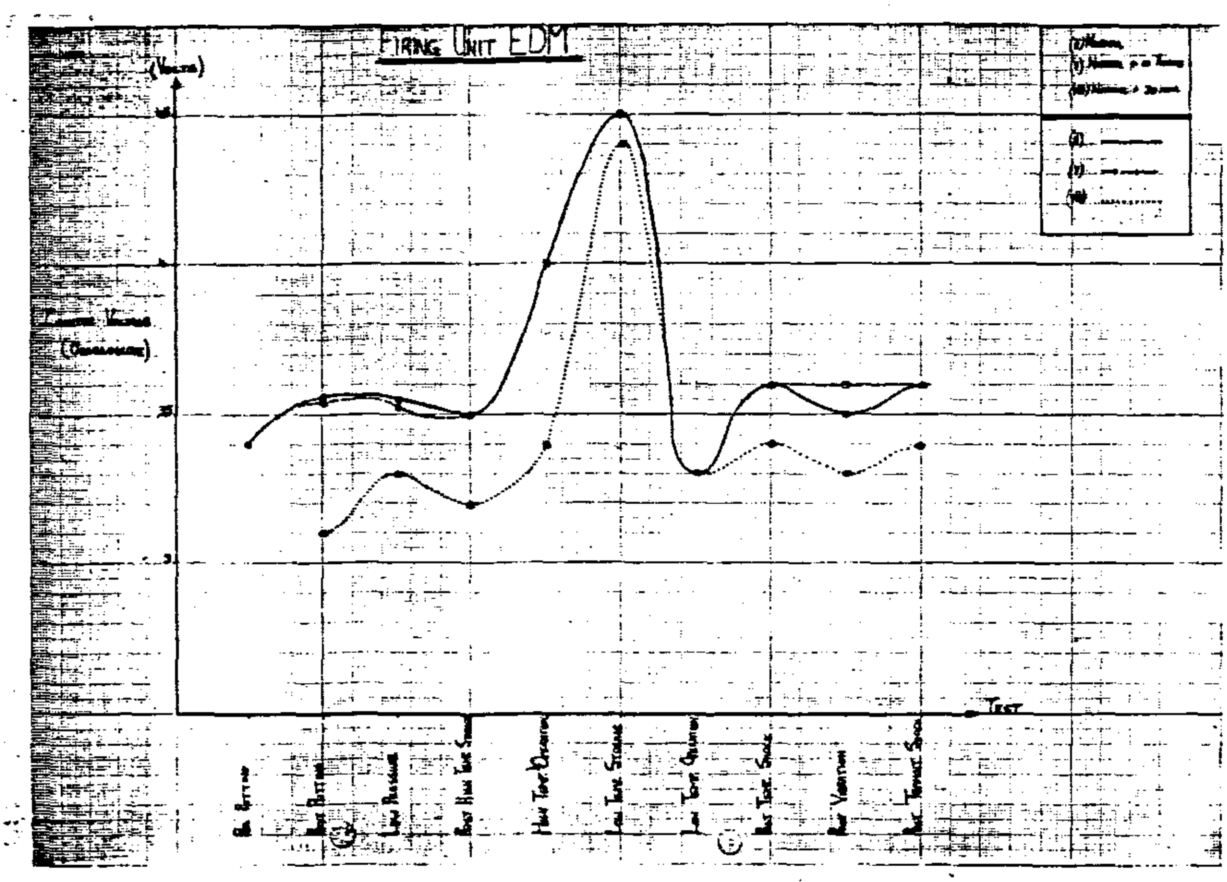


FIGURE 103: ELECTRICAL RESULTS OF EDM TESTS, IGNITER VOLTAGE

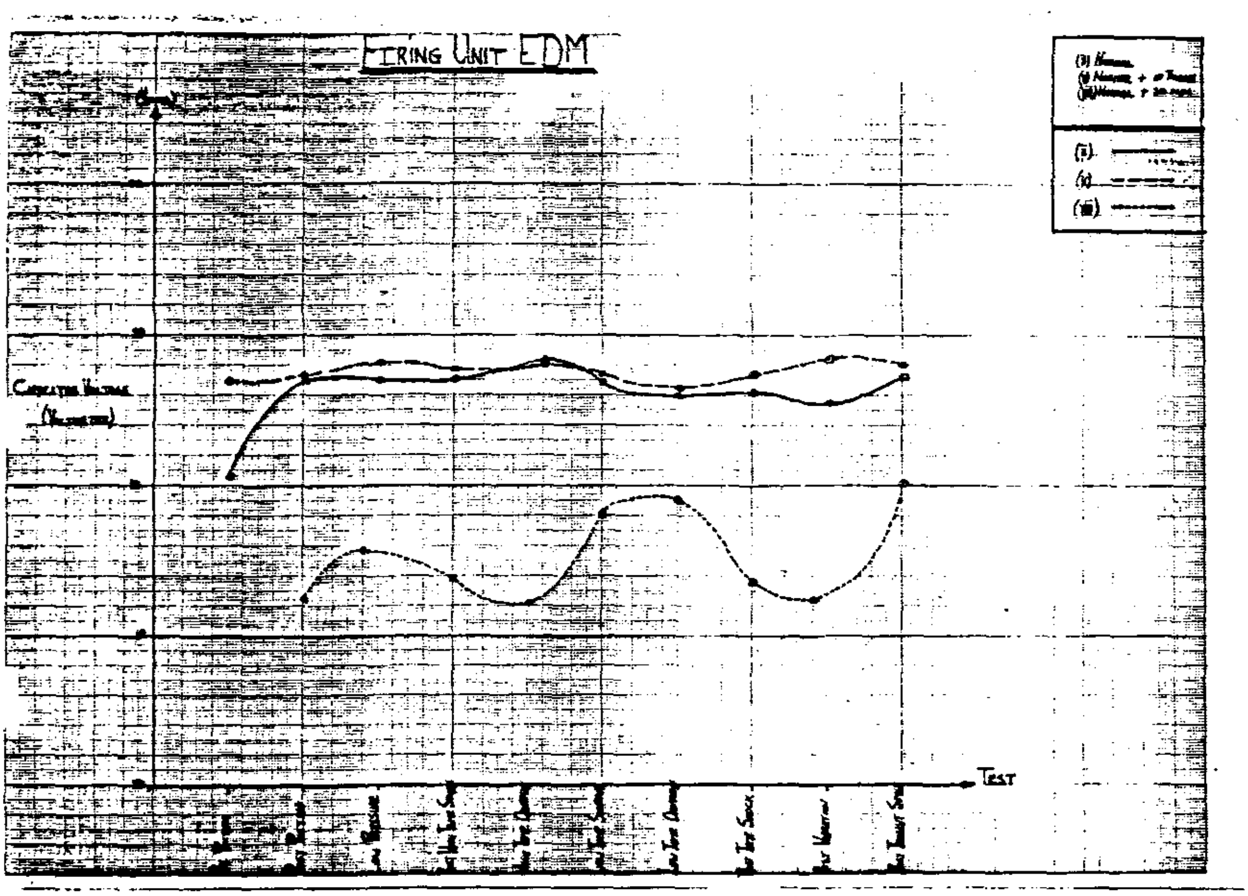


FIGURE 104: ELECTRICAL RESULTS OF EDM TESTS, CAPACITOR VOLTAGE

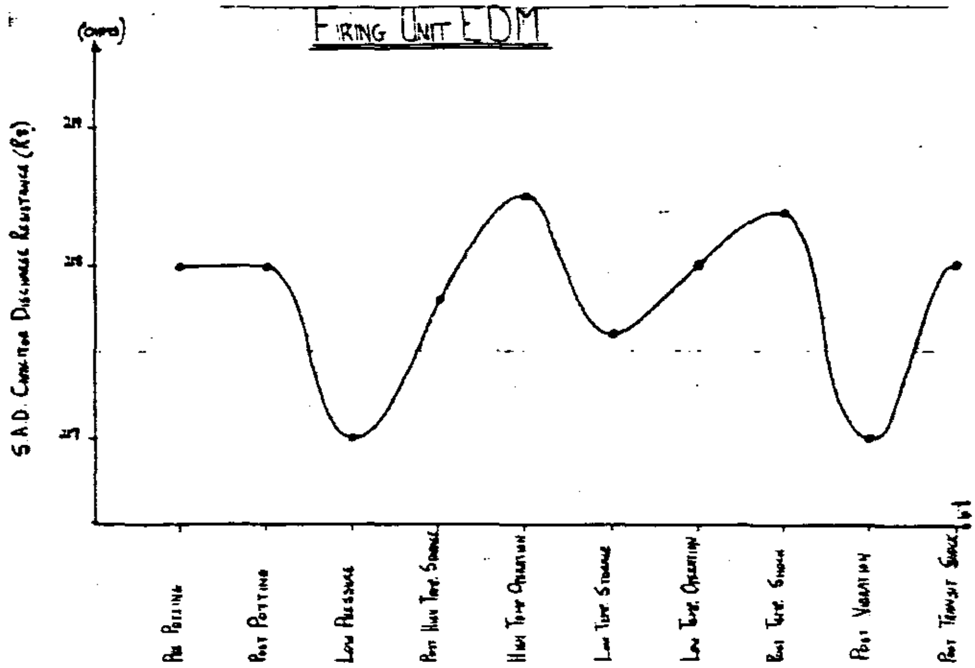


FIGURE 105: ELECTRICAL RESULTS OF EDM TESTS, SAD CAPACITOR DISCHARGE RESISTANCE

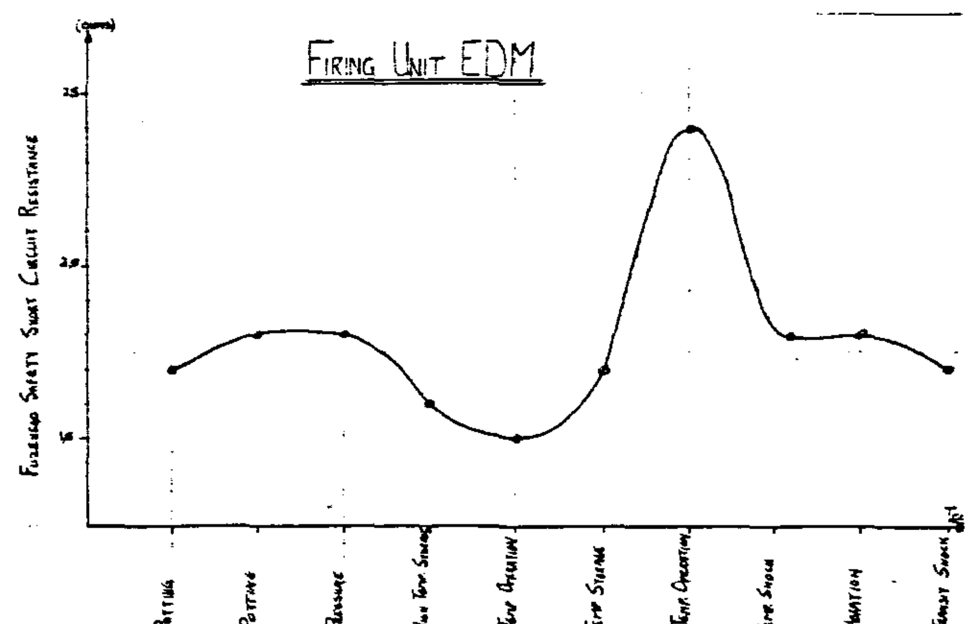


FIGURE 106: ELECTRICAL RESULTS OF EDM TEST, FUZE HEAD SAFETY SHORT CIRCUIT RESISTANCE

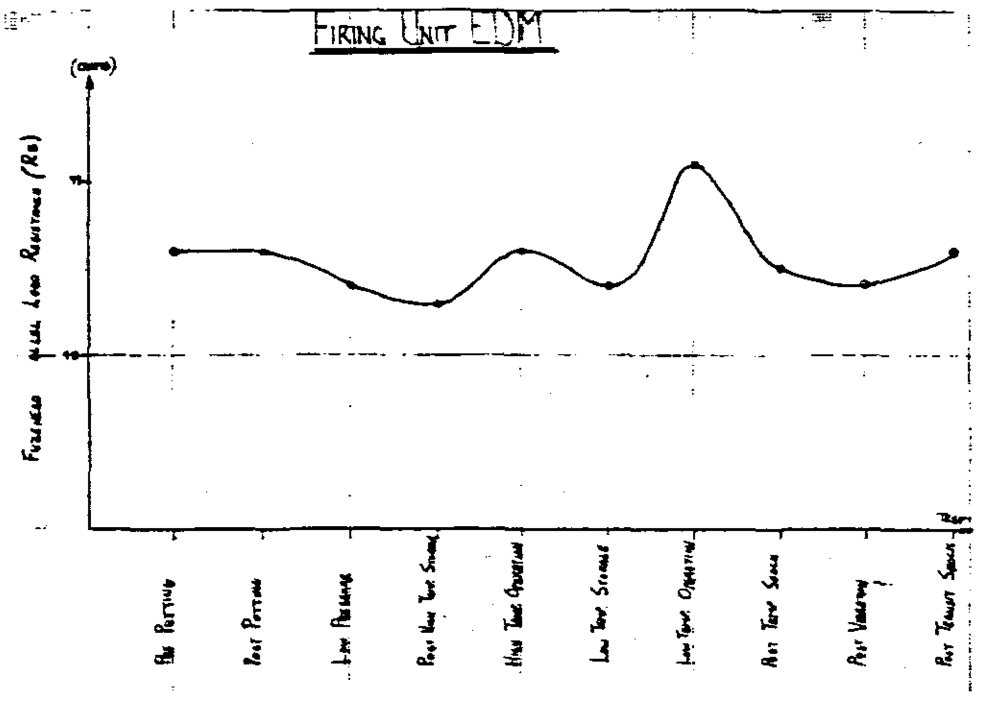


FIGURE 107: ELECTRICAL RESULTS OF EDM TESTS, FUZE HEAD PARALLEL LOAD RESISTANCE.

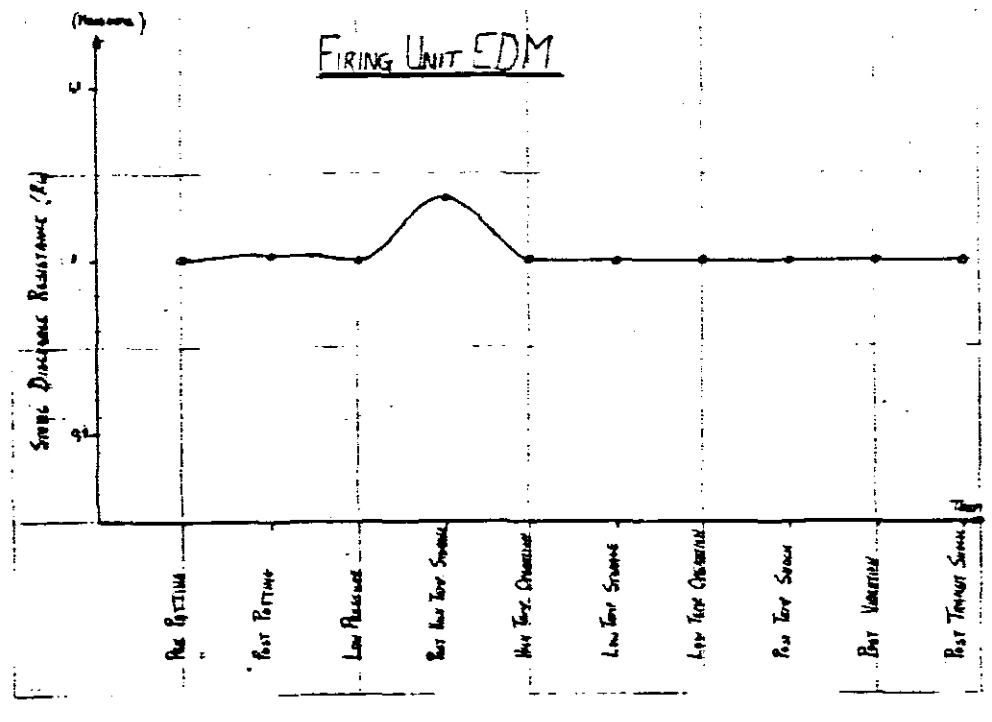


FIGURE 108: ELECTRICAL RESULTS OF EDM TESTS, STATIC DISCHARGE RESISTANCE

SECTION 8 - FIELD TESTING

The firing unit was field tested during the week of 04-08-86 till 08-08-86. These tests differed from the envisaged operational scenario in that a 200 meter firing cable was used. When the firing unit is installed in the carrier vehicle a firing cable of approximately 15 meter will be used. This change had no significant effect on firing unit performance.

The serial numbers denote physical characteristics of the firing units. 100 m max. refers to the maximum cable length the firing unit can accommodate. 250 V and 350 V refer to the voltage rating of the main energy storage capacitors used in the construction of those particular firing units.

8.1 SHOT 1 : 05-08-86

8.1.1 Firing Unit performance

Serial number : 100 m max
Fuzehead ignition : Yes
SAD operation : No
Residual charge on fuzehead igniter capacitor : $0,6 \times 10^{-6}$J
Residual charge on the SAD supply capacitor : 3×10^{-6}J

8.1.2 Comments

This firing unit has no protection for use with a 200 meter cable. The protection needed is dealt with in detail in Section 3.1.2.1.

The output closely approximates the protected firing unit's output when there is a delay of 30 minutes between testing, arming the system and firing of the system. This firing unit therefore delivers minimum fuzehead ignition current and SAD charge voltage when used in this configuration.

The SAD did not operate because the fuzehead did not activate correctly. This resulted in the SAD failing safe. When the firing unit was made safe all the LEDS functioned correctly.

8.2 SHOT 2 : 05-08-86

8.2.1 Firing Unit Performance

Serial number : 100 meter max.
Fuzehead ignition : Yes
Residual charge on fuzehead igniter capacitor : 20 mV
Residual charge on the SAD supply capacitor : $3,5 \times 10^{-6}$J (222 mV)

8.2.2 Comments

As per 8.2.2.

8.3 SHOT 3 : 06-08-86

8.3.1 Firing Unit Performance

Serial number : 350 V
Fuzehead ignition : Yes
SAD operation : Yes
Residual charge : These charges were not measured.

8.3.2 The firing unit is designed for use with a 200 meter firing lead. The discharged LED did flash when the firing unit was switched off. Consequently it can be said that the firing unit functioned correctly.

8.4 SHOT 4 : 06-08-86

8.4.1 Firing Unit Performance

Serial number : 350 V
Fuzehead ignition : Yes
SAD operation : No
Residual energy on the fuzehead ignitor capacitor : 20×10^{-6}J.
Residual energy on the SAD supply capacitor : 438×10^{-6}J.

8.4.2 Comments

The identical firing unit was used for shot 3. The mechanical operations in the SAD failed, consequently the SAD failed safe. This failure was no reflection on the firing unit's performance.

The discharged LED did flash when the firing unit was made safe and when switched off. The firing unit worked correctly.

8.5 SHOT 5 : 07-08-86

8.5.1 Firing Unit Performance.

Serial number : 250 V
Fuzehead ignition : Yes
SAD operation : Yes
Residual energy on the fuzehead ignitor capacitor and on the SAD supply capacitor were not measured.

8.5.2 Comments

This firing unit is electrically identical to that used for shots 3 and 4. The discharged LED did flash when the firing unit was switched to safe and when the unit was switched off.

The firing unit functioned correctly.

8.6 SHOT 6 : 07-08-86

8.6.1 Firing Unit Performance

Serial number : 250 V
Fuzehead ignition : Yes
SAD operation : No
The residual charge on the fuzehead igniter capacitor was not measured while that on the SAD supply capacitor was 324 x 10^{-6}J.

8.6.2 Comments

The identical firing unit was used for shot 5. The SAD did not function due to mechanical failure and therefore failed safe. The discharged LED did flash correctly when the firing unit was made safe and when switched off.

The firing unit functioned correctly.

SECTION 9

PRE-QUALIFICATION ENVIRONMENTAL TESTING RESULTS

This section deals with the environmental testing carried out on the Two Pre-Qualification units. The results are graphically presented for easy interpretation. These tests have been carried out sequentially as specified in this section.

9.1 THE PRE-POTTING TEST

The Firing Units were marked 350V and 250V. Both units passed this functional test before they were potted with foam. This test is used as a reference. All graphs depicting data are enclosed as Section 9.13.

9.2 THE POST-POTTING TEST (VISUAL AND DIMENSIONAL)

Both units passed this test successfully and were put into storage prior to field testing (04-8-86 to 08-8-86). Immediately prior to the field test both units were removed from storage and functionally tested. The unit marked 350V had developed an electrical fault during the interim. This was investigated and a potential problem area in the mounting of IC2 was discovered. The existing unit marked 350V was destroyed and a new unit, incorporating this modification was built. This new unit used the same mechanical enclosure as the faulty unit and hence has the same serial number. Testing on the new unit marked 350V was repeated and is shown graphically.

9.3 THE LOW PRESSURE TEST

The units were placed in a vacuum chamber and evacuated to 55kPa ±5kPa. After one hour had elapsed the pressure in the chamber was increased to atmospheric pressure (101,325 kPa) and the firing units removed.

Inspection of the two units revealed no cracking or delaminating of the potting. No other physical damage was noted. No functional test of the firing units is carried out after the low pressure test.

9.4 VIBRATION TESTING

Vibration testing, as per part 2 section 5.4, was completed on 31-10-86. On removal of the firing units from the vibration facility the following was noted:-

a. The 350V unit.

The rubber anti-vibration mounts were unable to withstand the stresses induced by vibration. One rubber mount's rubber shock absorbent material had split more than halfway through its diameter. A further 2 had minor stress marks on the rubber consistent with the item having completed its expected lifespan. The last rubber mount exhibited no signs of damage.

The earth straps had also failed to achieve their designed lifespan. One was broken in one place while the other was broken in 2 places.

b. The 250V unit

A very similar problem occurred with this unit. One rubber anti-vibration mount was split, consistent with the split on the 350V unit. One mount exhibited minor damage consistent with that expected after having completed its designed life cycle. The two remaining mounts showed no signs of damage.

Both earth straps broke in two separate places.

9.4.1 <u>Corrective Action</u>

The mass of the firing unit is to be reduced so that the stress on the rubber anti-vibration mountings is also reduced. This will be achieved by means of a change to a less dense potting material. This is dealt with in Section 10.

The earth strap design has been changed from a copper wire strap to a copper braid strap. This braid is much more flexible and therefore less prone to the copper work hardening.

9.4.2 <u>The Post-vibration Functional Test</u>

Both firing units passed the functional test. The parameters worthy of comment are outlined below.

The fuzehead safety short circuit resistance increased from the average of approximately 1,7 Ohms to 2,2 Ohms in both units. This change could be ascribed to contact resistance variation as the units had been unused for some months while awaiting availability of vibration facilities. After further environmental testing this parameter returned to approximately 1,7 Ohms.

The 250V device showed an increase in igniter voltage from approximately 6 volts to 8 volts. This is the maximum allowable. This parameter also returned to the norm after further environmental testing. The cause of this variation is unknown at this stage. Further investigation did not reveal the cause.

9.4.3 Vibration Spectra

The spectra to which the firing units were vibrated are shown below.

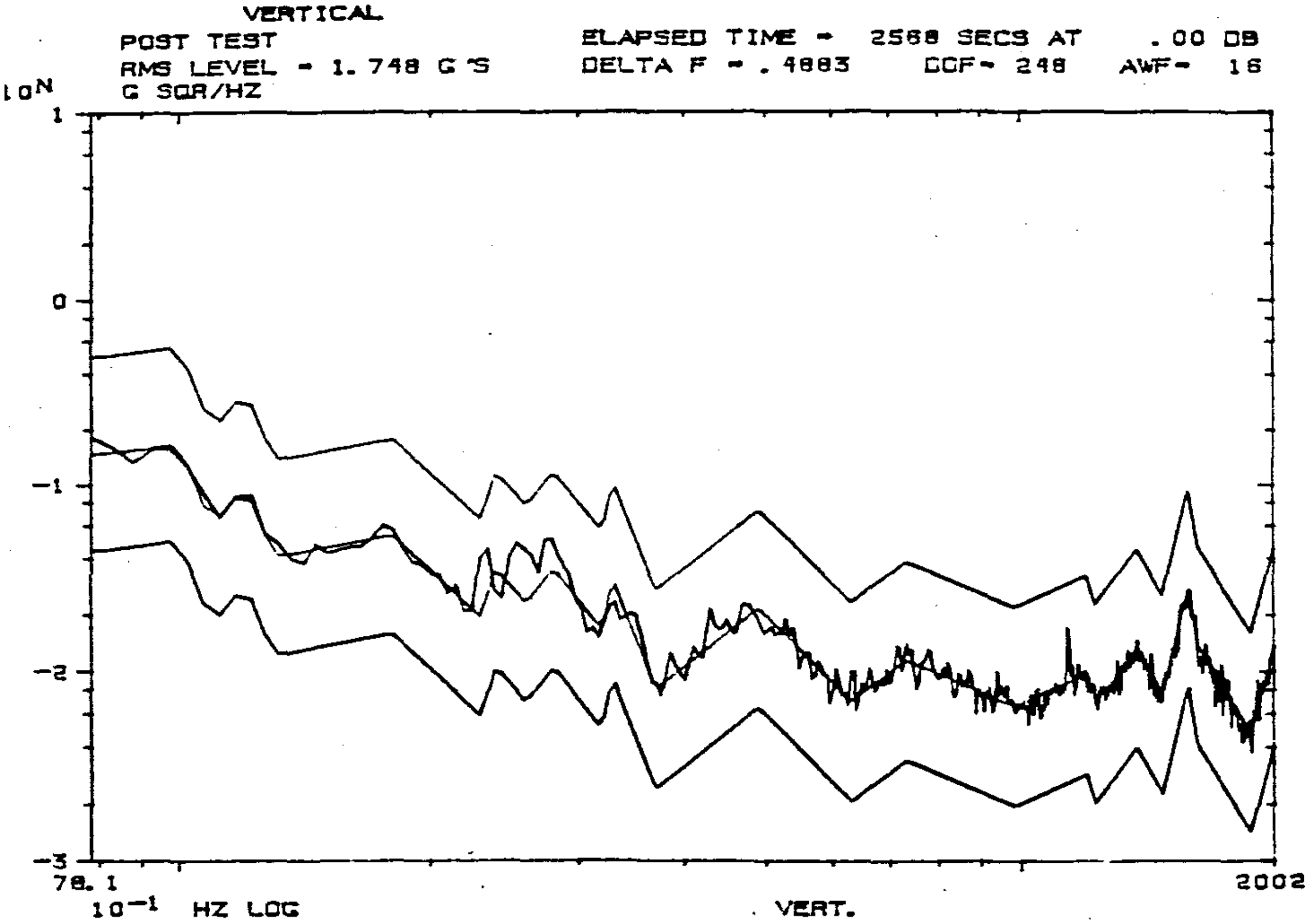


FIGURE 109: VIBRATION TEST, VERTICAL AXIS

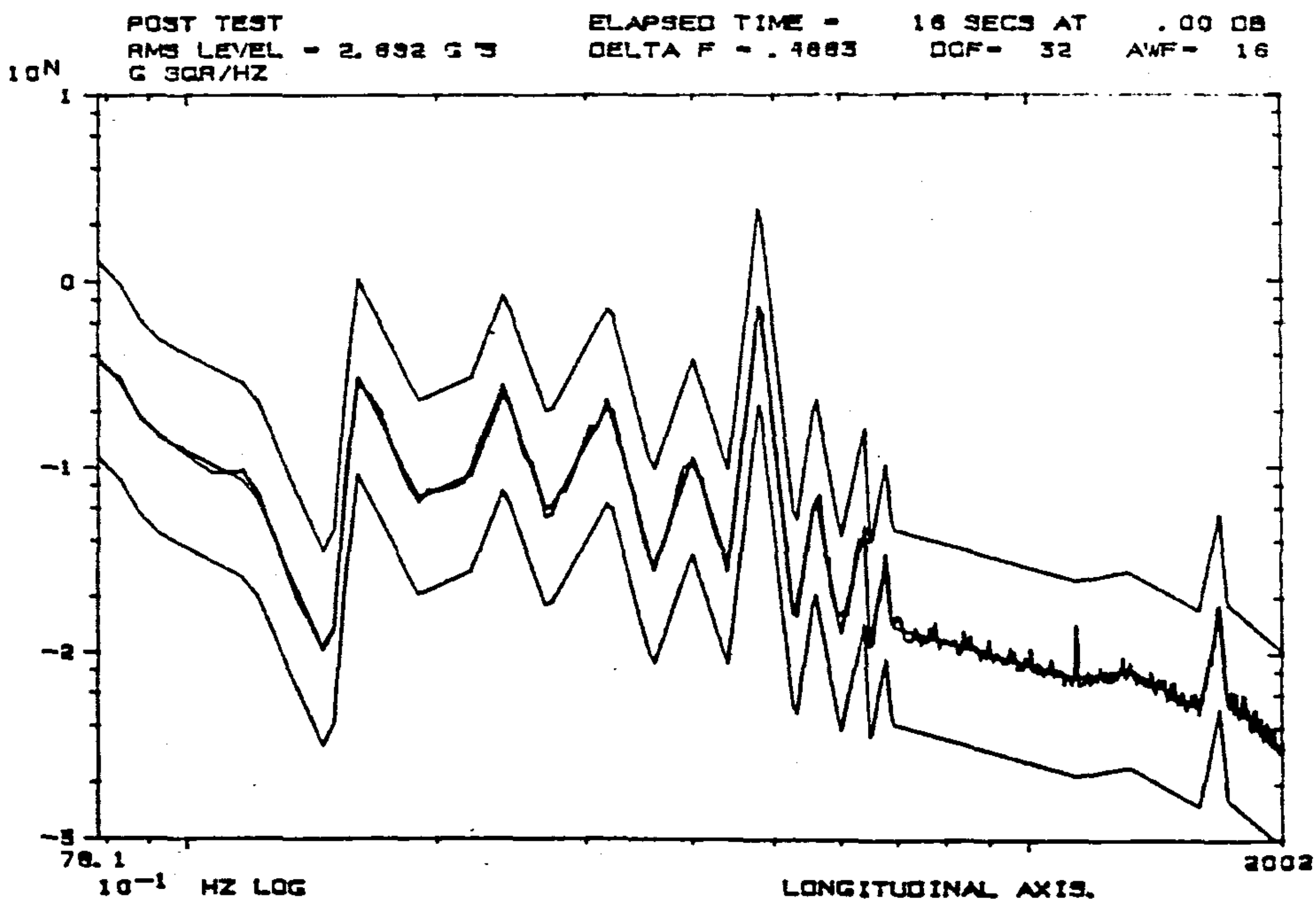


FIGURE 110: VIBRATION TEST, LONGITUDINAL AXIS

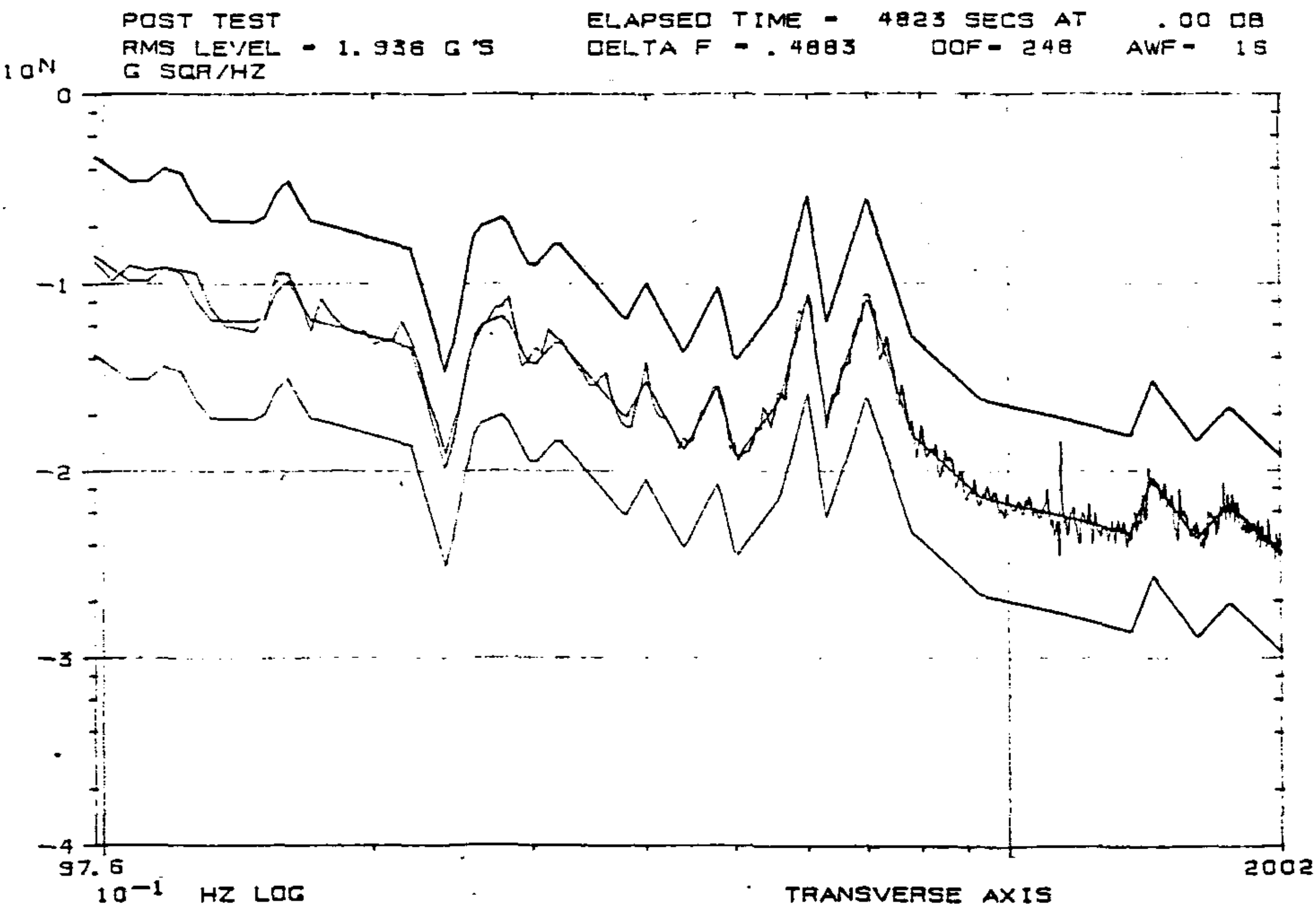


FIGURE 111: VIBRATION TEST, TRANSVERSE AXIS

9.5 HIGH TEMPERATURE STORAGE

The firing units were placed in a chamber at +65°C for the time period between 09h23 on 3-11-86 and 10h30 on 4-11-86. After expiry of this period the units were allowed to cool for a minimum of 2 hours, physically inspected and then subjected to a functional test.

9.5.1 Physical Inspection

No physical deterioration or damage was noted.

9.5.2 Functional Testing

The firing units passed the functional test.

9.6 HIGH TEMPERATURE OPERATION

The test chamber was adjusted to +60°C on 5-11-86. The 2 firing units were inserted at 10h26 and removed at 12h08 on 6-11-86. Physical inspection revealed no deterioration. Immediately after removal from the test chamber the firing units were functionally tested.

Positive temperature coefficients were noted on R5 (100Ω nominal) and R6 (1MΩ) nominal. These increases in resistance were consistent with the temperature of the firing unit.

The igniter voltage as measured by the oscilloscope also exhibited a positive temperature coefficient. This is due to the temperature coefficient of ZD1 (+2mV/°C) and TR2 (+6,5mA/°C). This will result in a current of approximately 3,25 A at 60°C. This is consistent with an increase in igniter voltage to about 7 volts. This is within specification.

The 250V unit displayed an intermittent minor fault on the 1/2 hour energy test. After the firing unit has been fired and then the SAFE/ARM switch returned to SAFE, the firing unit is supposed to discharge any residual energies and a LED illuminate. This did not occur until the unit was switched off. This fault repeated after the 250V unit was temperature cycled. On a repeat of the functional test it worked correctly. All other post-environmental testing functional tests proceeded according to specification. This failure can be attributed to either component failure (D16, C5) at high temperature or dirt on the PCB. More stringent cleaning of the PCB and coating of the PCB with a plastic spray has been introduced to help prevent a recurrence of this failure.

9.7 LOW TEMPERATURE STORAGE AND OPERATION

This test encompasses both low temperature operation and storage.

The test chamber was adjusted to -15°C and the test began at 12h00 on 7-11-86 and ended at 10h40 on 10-11-86 (longer than 36 hours). Immediately after removal of the units from the test chamber they were functionally tested. Both firing units passed the functional test.

Positive temperature coefficients commensurate with those in 9.6 were observed and are therefore no cause for further comment. No further deviations from the norm were observed.

9.8 TEMPERATURE CYCLING

The firing units were subjected to the following temperature cycle graph:

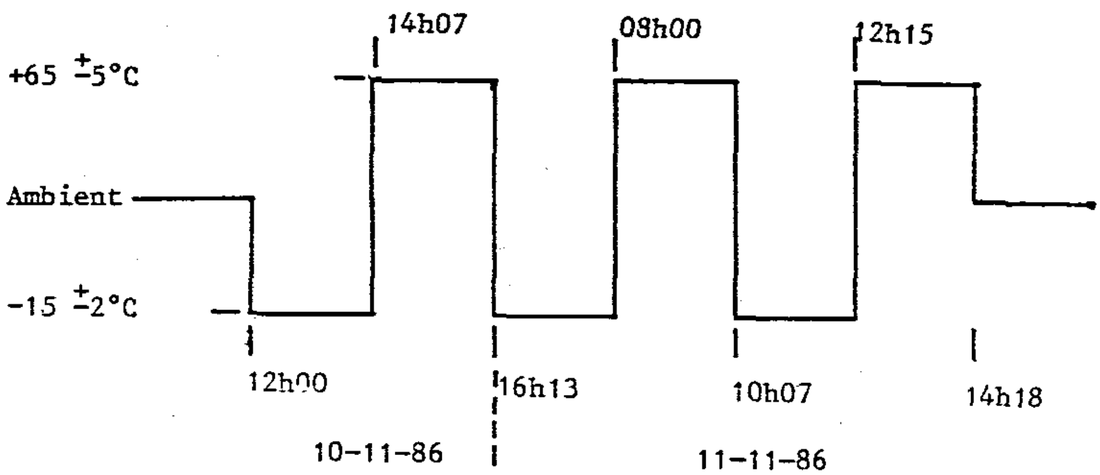


FIGURE 112: TEMPERATURE CYCLE DIAGRAM

After completion of the above temperature cycling graph both firing units were examined and no signs of physical or mechanical damage were observed. Thereafter the firing units were subjected to a functional test. The 350V unit passed with no parameters worthy of comment but the 250V unit showed a recurrence of the intermittent minor fault mentioned in 9.6. On repeat of that functional test the 250V device passed.

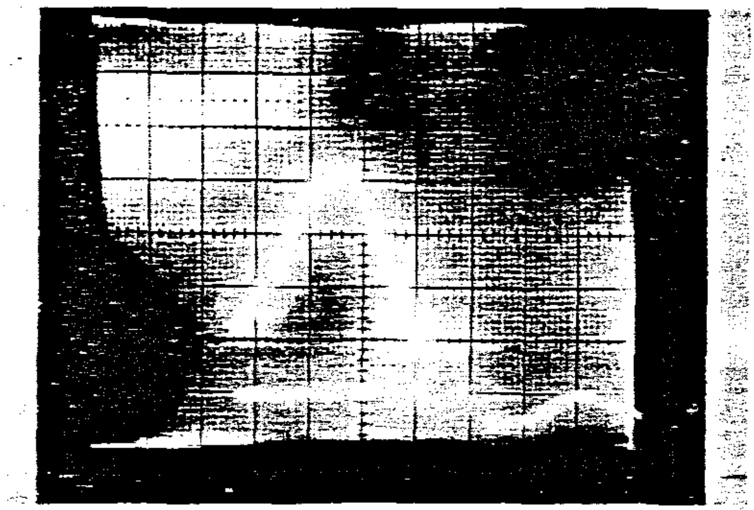
9.9 THE RAIN TEST

The rain test was performed as per the test instruction on 12-11-86. On completion of the rain test the units were opened and examined for water ingress. The 250V unit had no water inside while the 350V device had unacceptable amounts of water inside. This was due to the seal surface being damaged during removal of the first unit marked 350V. This is not considered a problem as this would not occur during production of the item. Further sealing has also been introduced in the form of a conductive caulking compound.

The firing units were then functionally tested according to Appendix 8 and passed. The effect of repeated use of the firing unit can be clearly seen by the charge on C8 (capacitor voltage graph). The 1/2 hour test shows a marked increase in energy transferred because of the correct formation of the electrolyte within C8, as expected. The measured voltage in this test was still well within tolerance.

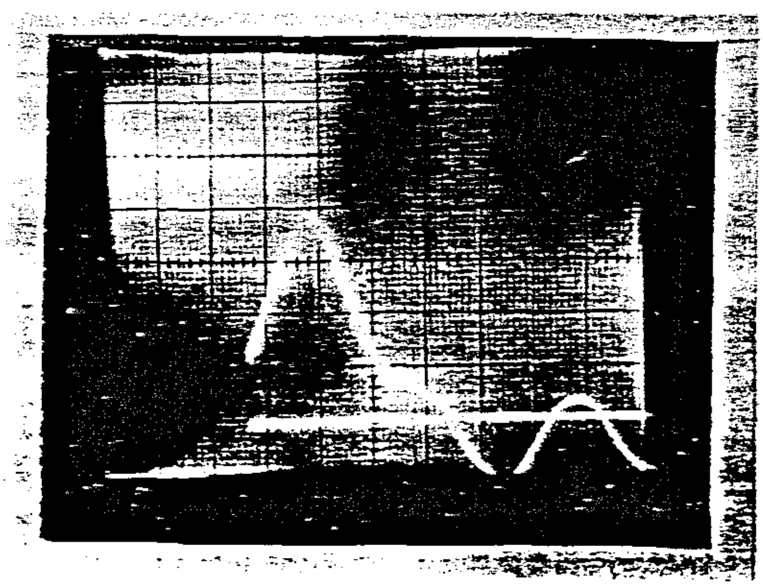
9.10 FUNCTIONAL SHOCK

The shocks to which the firing units were subjected are shown below. Each vertical division is equal to 10g's with the unmodulated line being zero. Each horizontal division equals 2 milliseconds.



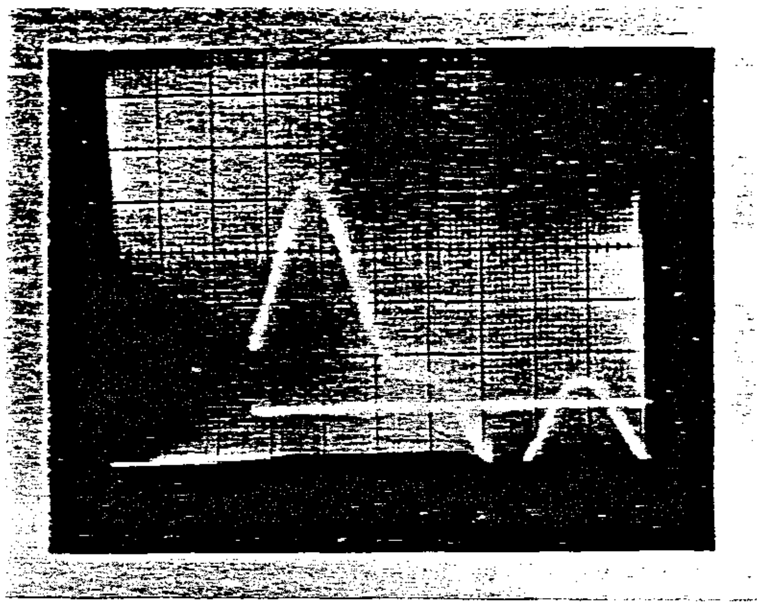
Peak = 43 g's
Time = 9 ms

FIGURE 113: FUNCTIONAL SHOCK, LONGITUDINAL 1



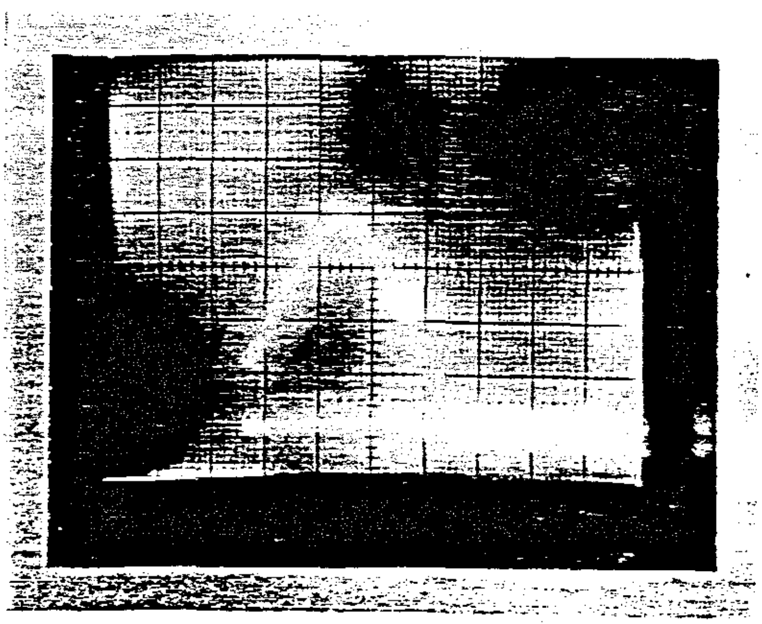
Peak = 38 g's
Time = 8 ms

FIGURE 114: FUNCTIONAL SHOCK, LONGITUDINAL 2



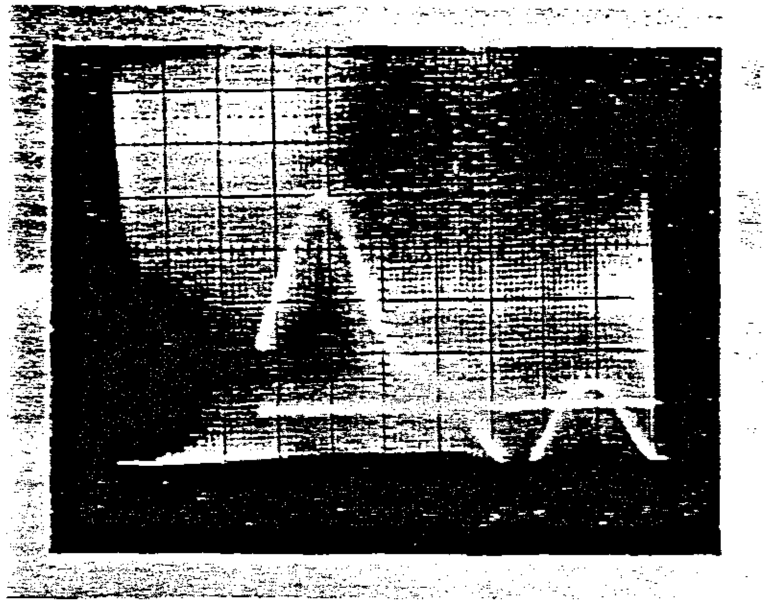
Peak 43 g's
Time = 8 ms

FIGURE 115: FUNCTIONAL SHOCK, TRANSVERSE 1



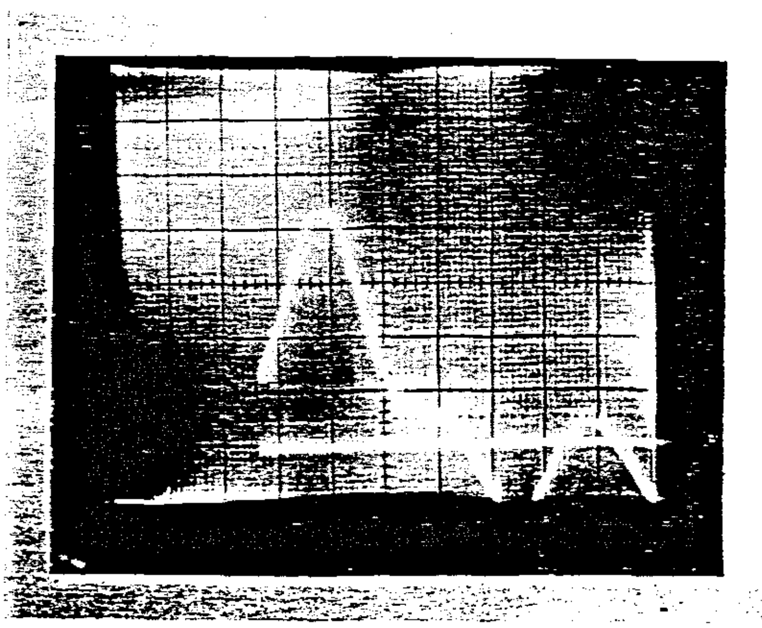
Peak = 39 g's
Time = 8,5 ms

FIGURE 116: FUNCTIONAL SHOCK, TRANSVERSE 2



Peak = 40 g's
Time = 8 ms

FIGURE 117: FUNCTIONAL SHOCK, VERTICAL 1



Peak = 44 g's
Time = 8 ms

FIGURE 118: FUNCTIONAL SHOCK, VERTICAL 2

After completion of 18 shocks (3 per direction per orthogonal axis) the units were removed for functional testing and visual inspection. Visual inspection revealed no defects. The firing units passed the functional tests. Formation of electrolytes within the capacitors as discussed in 9.9 was also evident.

9.11 TRANSIT DROP TEST

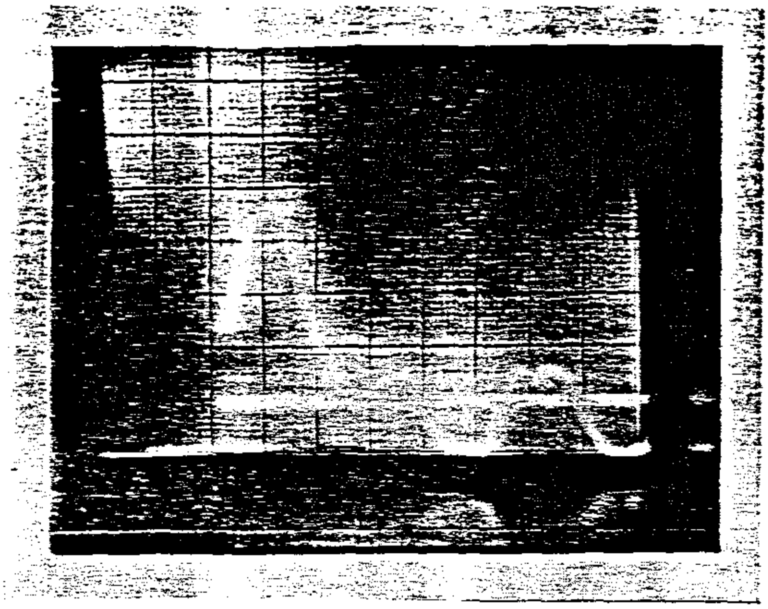
The firing units were attached in turn to a drop tester and dropped from a height of 1,22 metre onto a 51mm thick piece of plywood backed by concrete. Each unit was dropped once on each face, edge and corner (26 drops). Visual inspection revealed that the spring loaded cover over the firing button on both units was damaged but not unserviceable. The guard protecting this cover has been altered to prevent this. No other damage was noted.

Both firing units passed the functional test satisfactorily.

9.12 THE CRASH HAZARD TEST

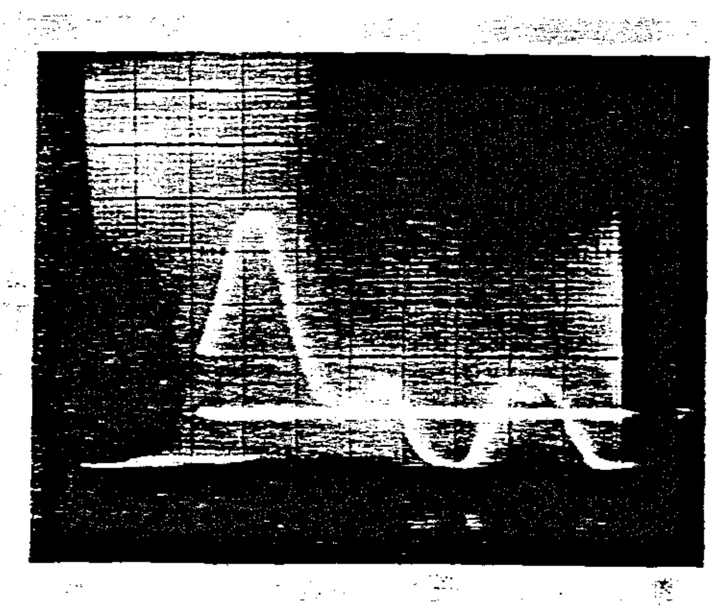
Two shocks of magnitude 75g's along each direction of each of the orthogonal axes were applied. Captured data is shown. Each vertical division equals 20 g's while each horizontal division equals 2 milliseconds. The unmodulated trace equals zero.

No damage to either unit occurred and accordingly they passed this test.



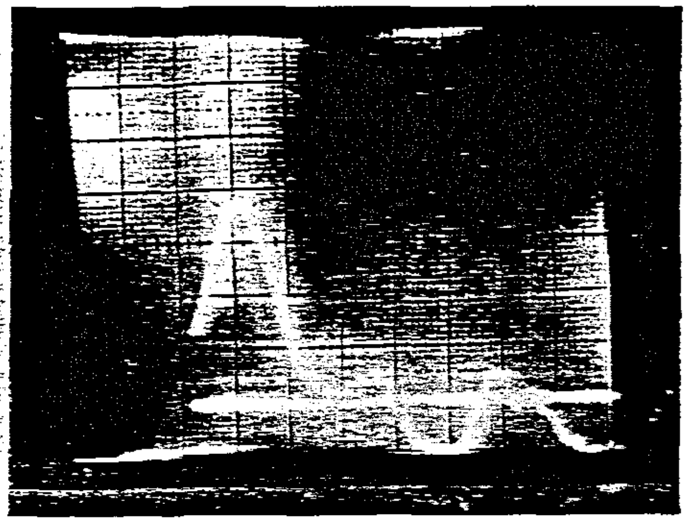
Peak = 73 g's
Time = 6 ms

FIGURE 119: CRASH HAZARD TEST, LONGITUDINAL 1



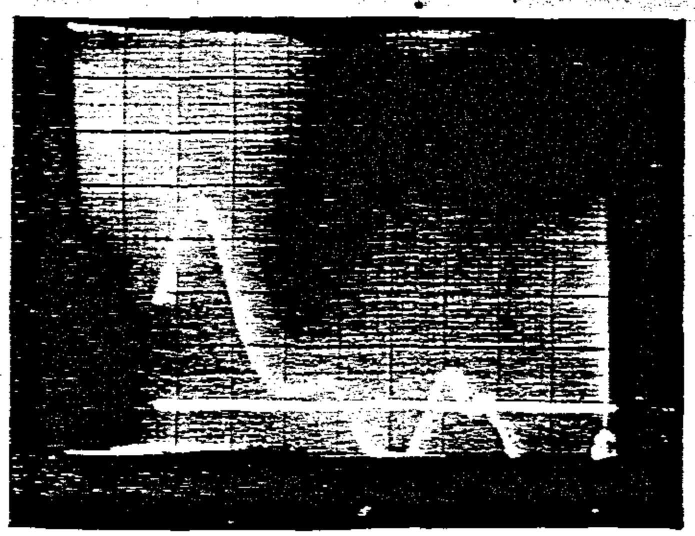
Peak = 75 g's
Time = 6 ms

FIGURE 120: CRASH HAZARD TEST, LONGITUDINAL 2



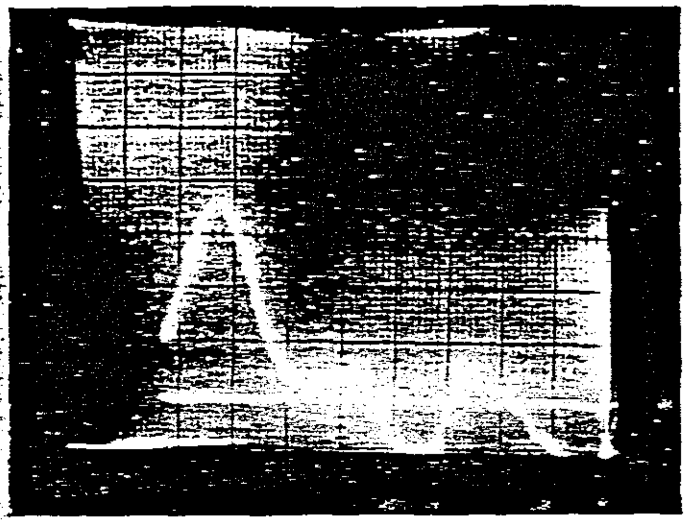
Peak = 75 g's
Time = 6 ms

FIGURE 121: CRASH HAZARD TEST, TRANSVERSE 1



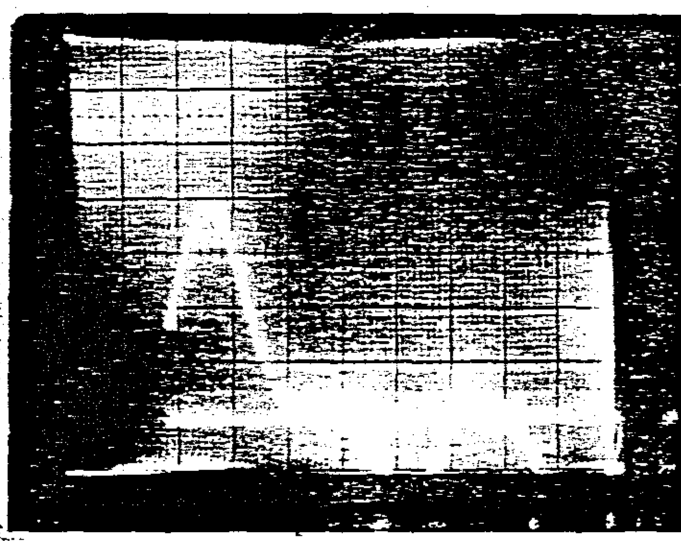
Peak = 75 g's
Time = 6 ms

FIGURE 122: CRASH HAZARD TEST, TRANSVERSE 2



Peak = 75 g's
Time = 6 ms

FIGURE 123: CRASH HAZARD TEST, VERTICAL 1



Peak = 78 g's
Time = 6 ms

FIGURE 124: CRASH HAZARD TEST, VERTICAL 2

9.13 FUNCTIONAL TESTING DATA

9.13.1 The 350V unit

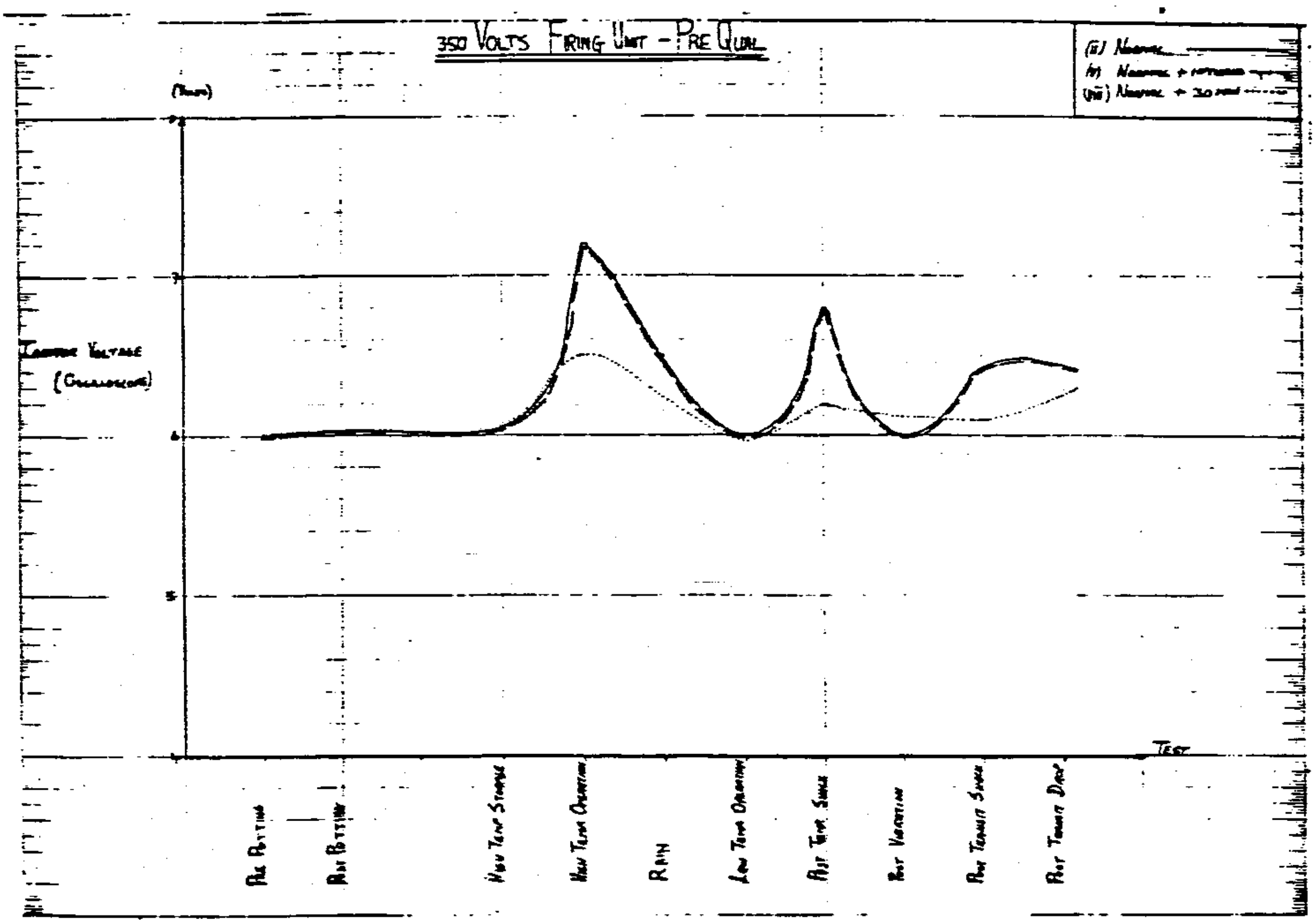


FIGURE 125: FUNCTIONAL TEST OF THE 350V UNIT, IGNITER VOLTAGE

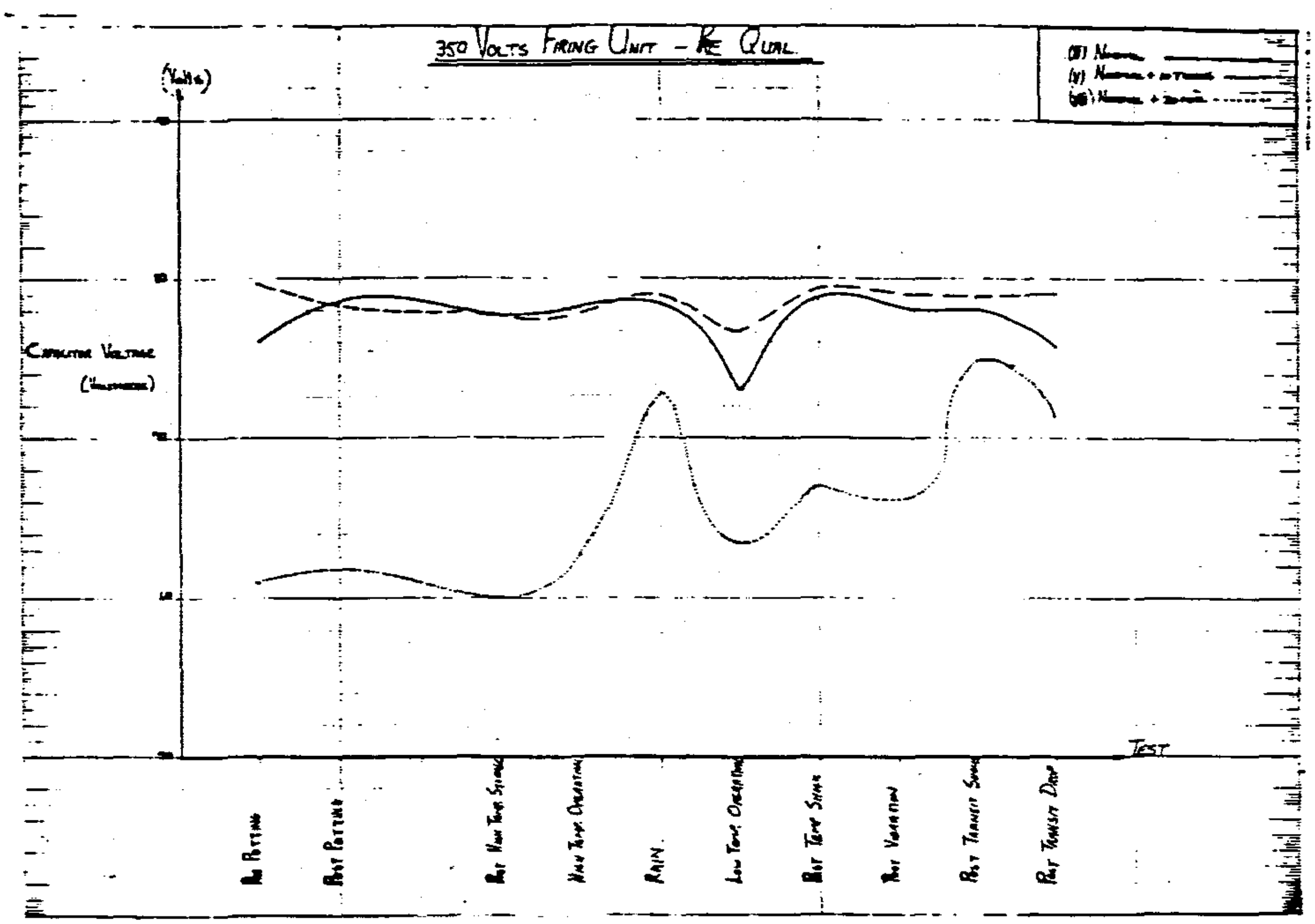


FIGURE 126: FUNCTIONAL TEST OF THE 350V UNIT, CAPACITOR VOLTAGE

9.13.1 The 350V unit (contd.)

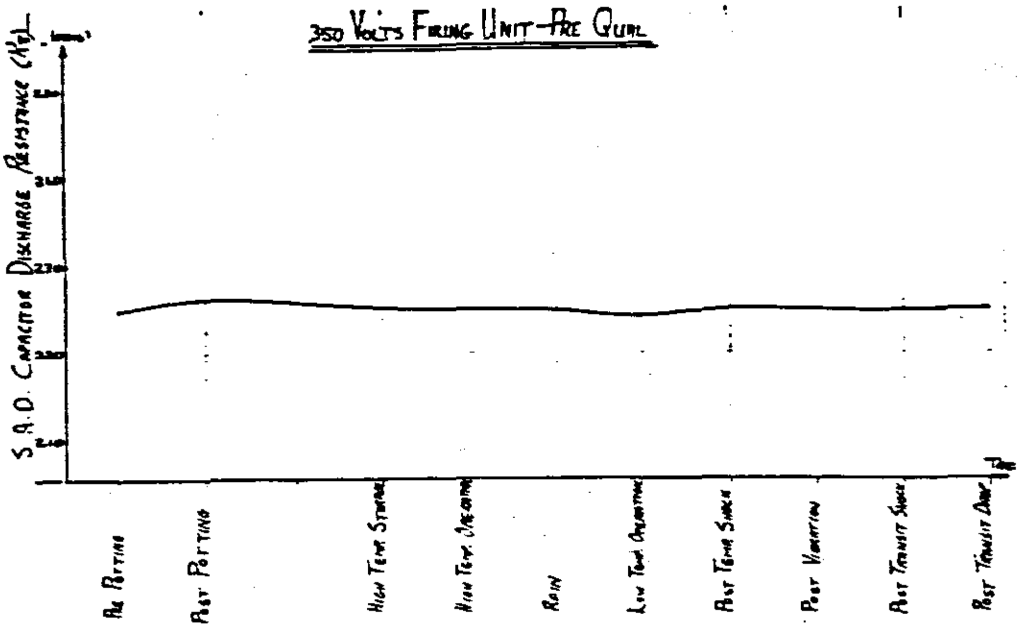


FIGURE 127: FUNCTIONAL TEST OF THE 350V UNIT, SAD CAPACITOR DISCHARGE RESISTANCE

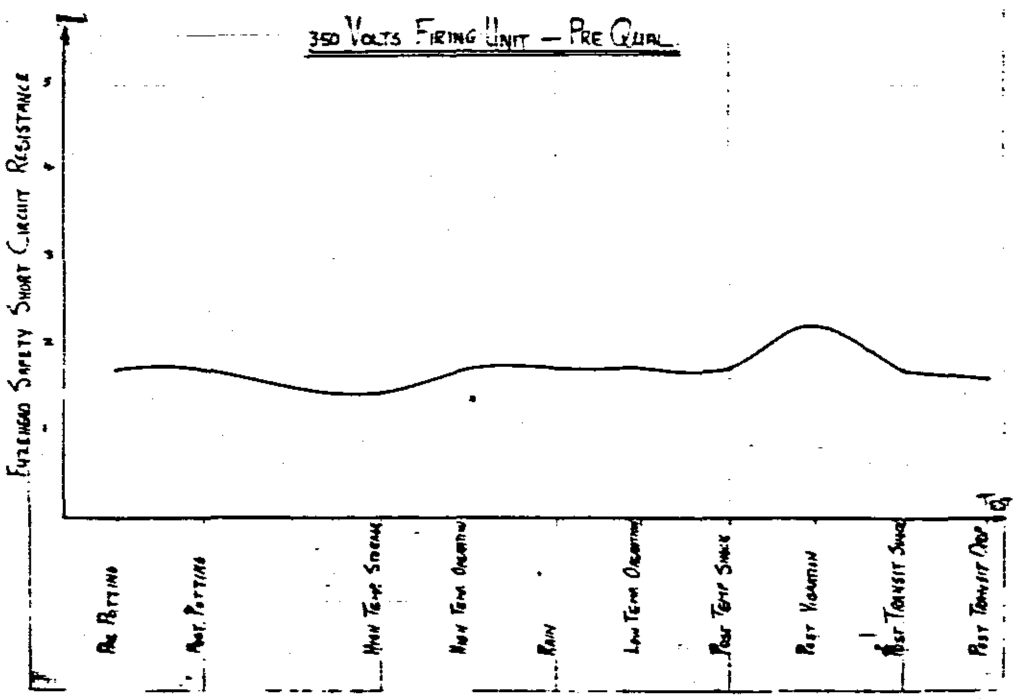


FIGURE 128: FUNCTIONAL TEST OF THE 350V UNIT, FUZE HEAD SAFETY SHORT CIRCUIT RESISTANCE

9.13.1 The 350V unit (contd.)

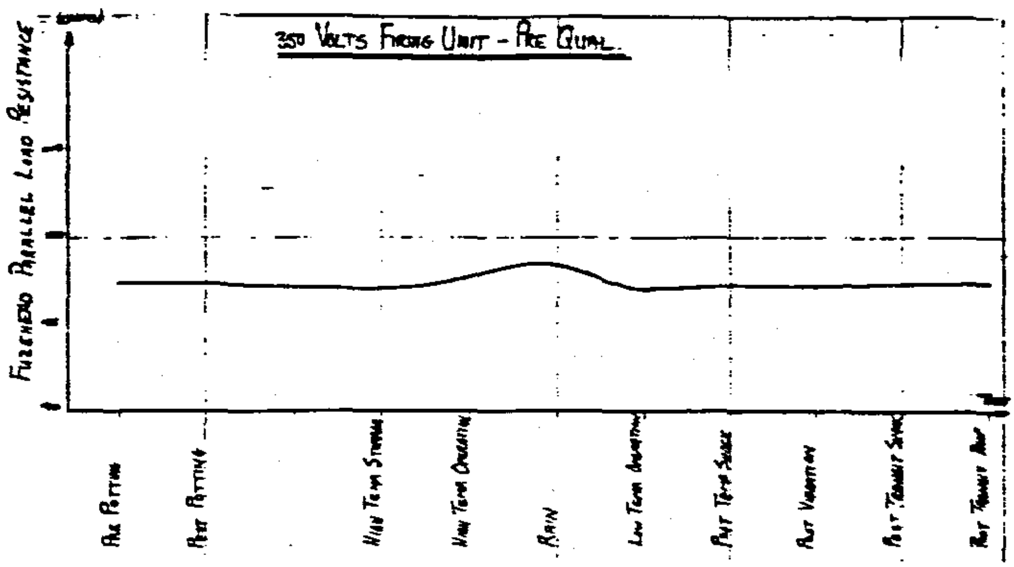


FIGURE 129: FUNCTIONAL TEST OF THE 350V UNIT, FUZE HEAD PARALLEL LOAD RESISTANCE

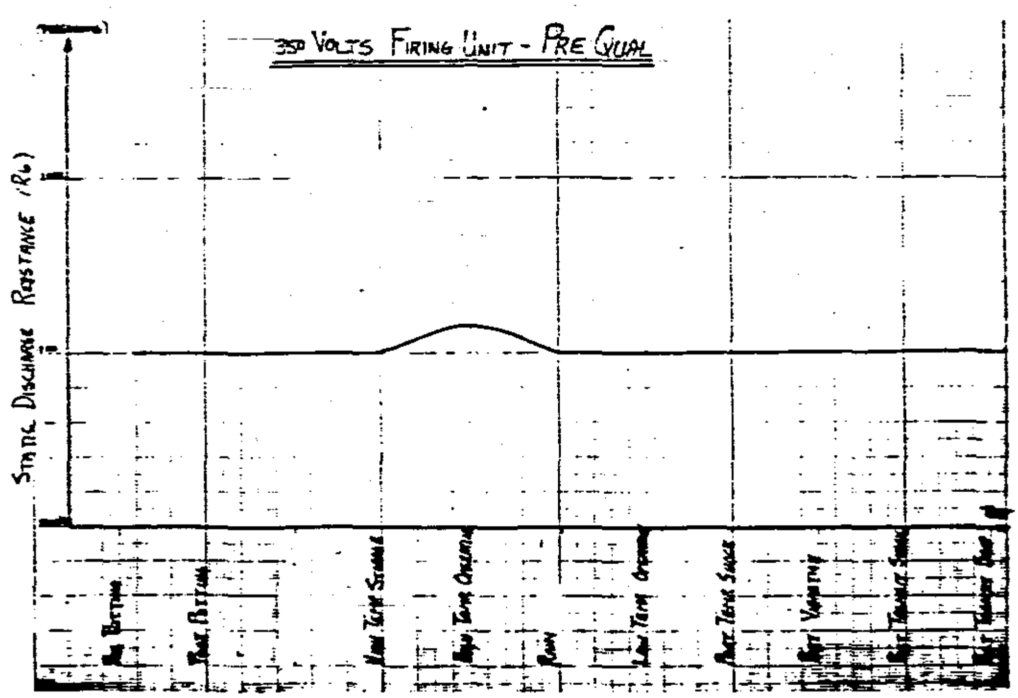


FIGURE 130: FUNCTIONAL TEST OF THE 350V UNIT, STATIC DISCHARGE RESISTANCE

9.13.2 The 250V unit

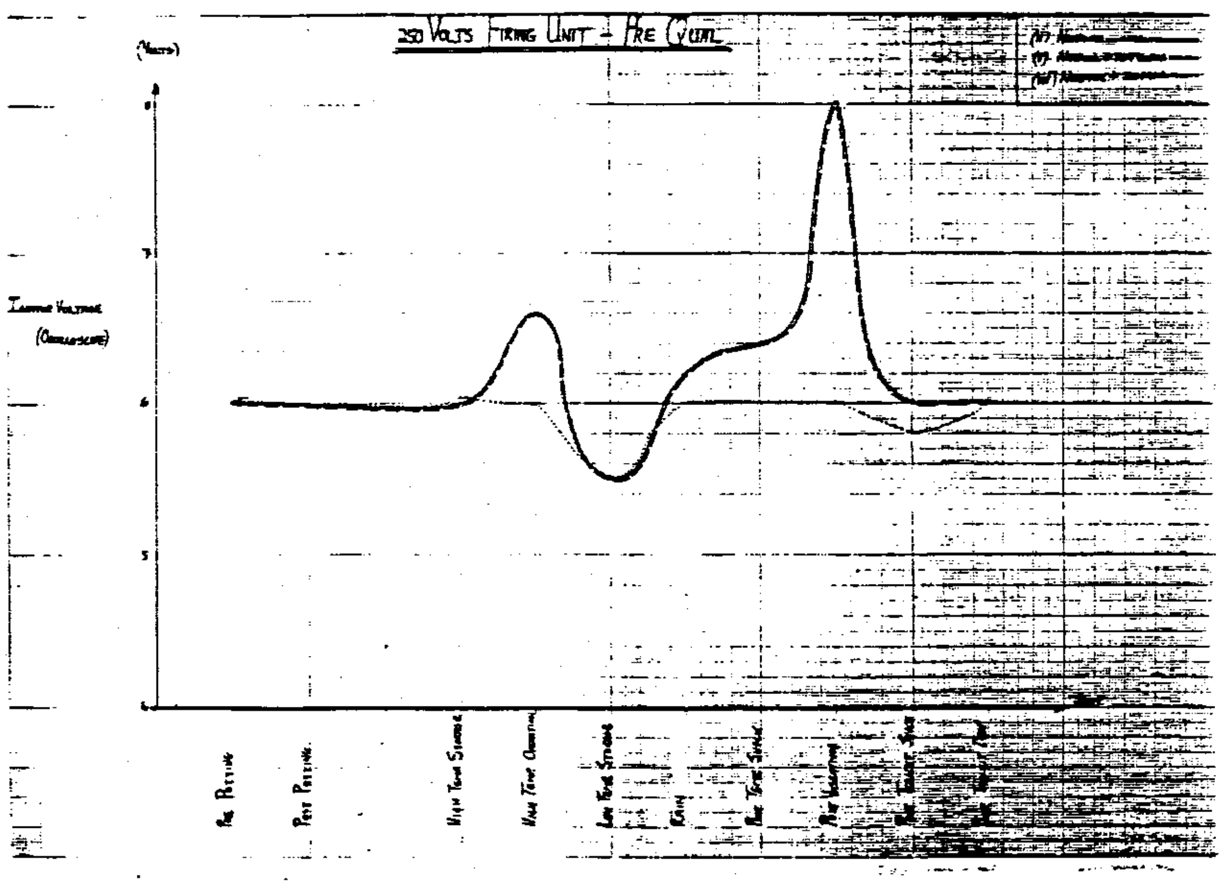


FIGURE 131: FUNCTIONAL TEST OF THE 250V UNIT, IGNITER VOLTAGE

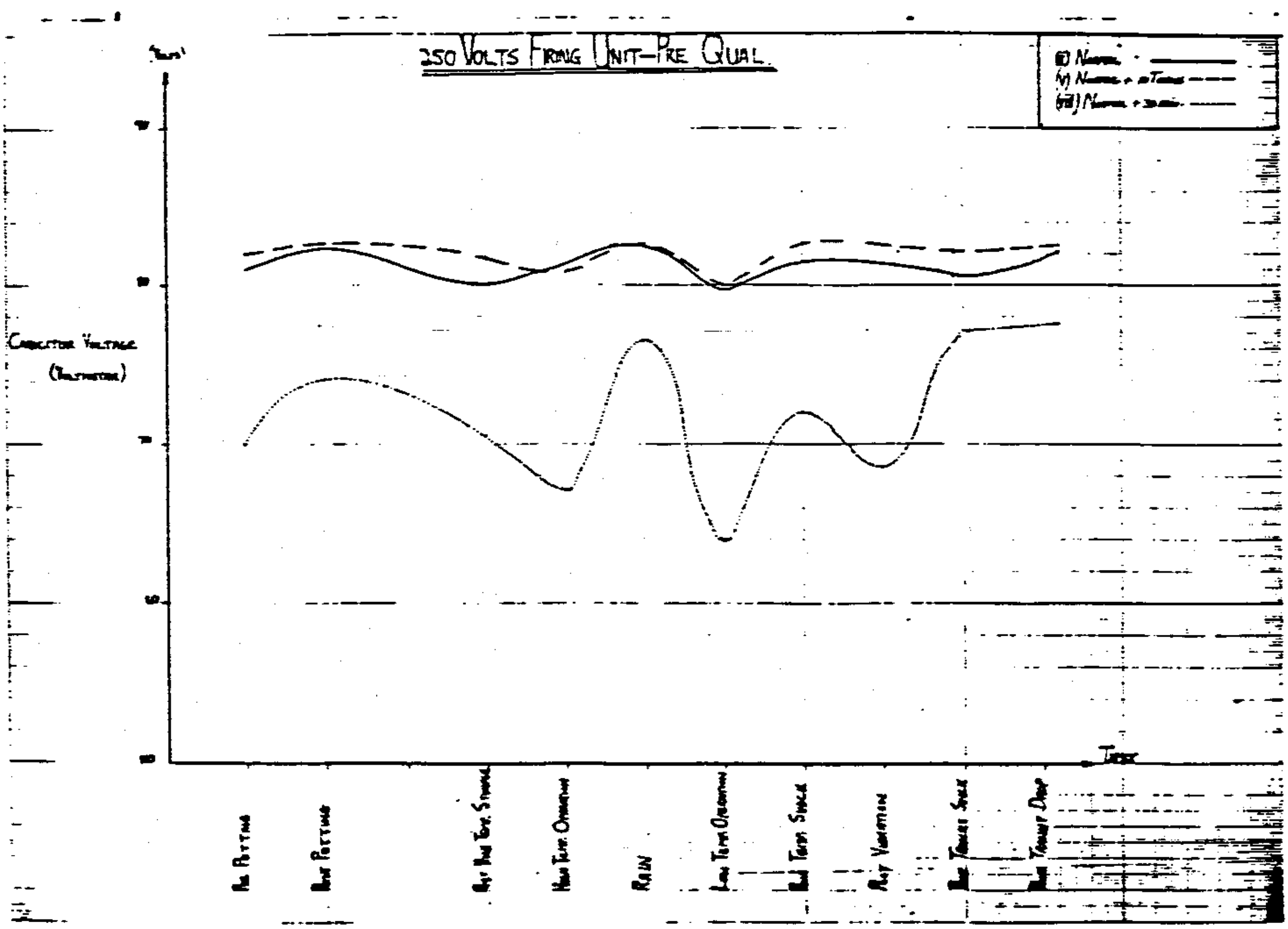


FIGURE 132: FUNCTIONAL TEST OF THE 250V UNIT, CAPACITOR VOLTAGE

9.13.2 The 250V unit (contd.)

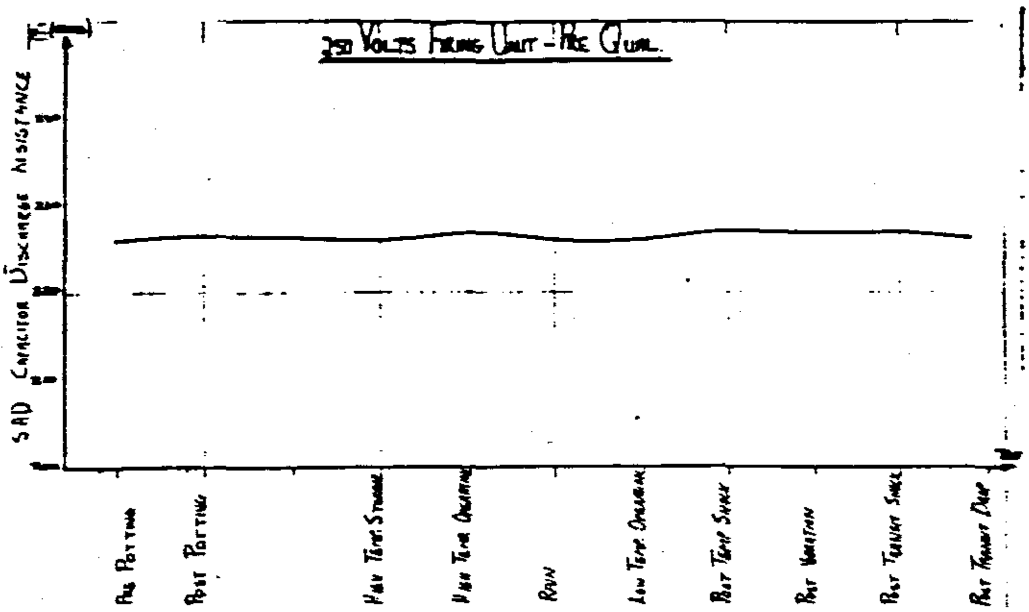


FIGURE 133: FUNCTIONAL TEST OF THE 250V UNIT, SAD CAPACITOR DISCHARGE RESISTANCE

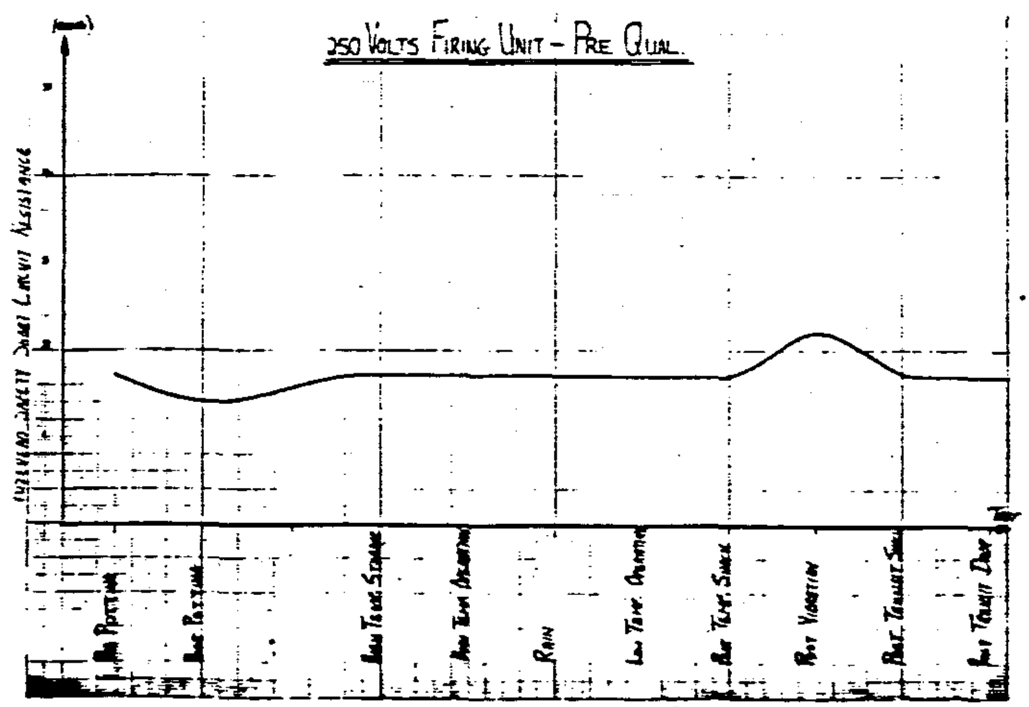


FIGURE 134: FUNCTIONAL TEST OF THE 250V UNIT, FUZE HEAD SAFETY SHORT CIRCUIT RESISTANCE

9.13.2 The 250V unit (contd.)

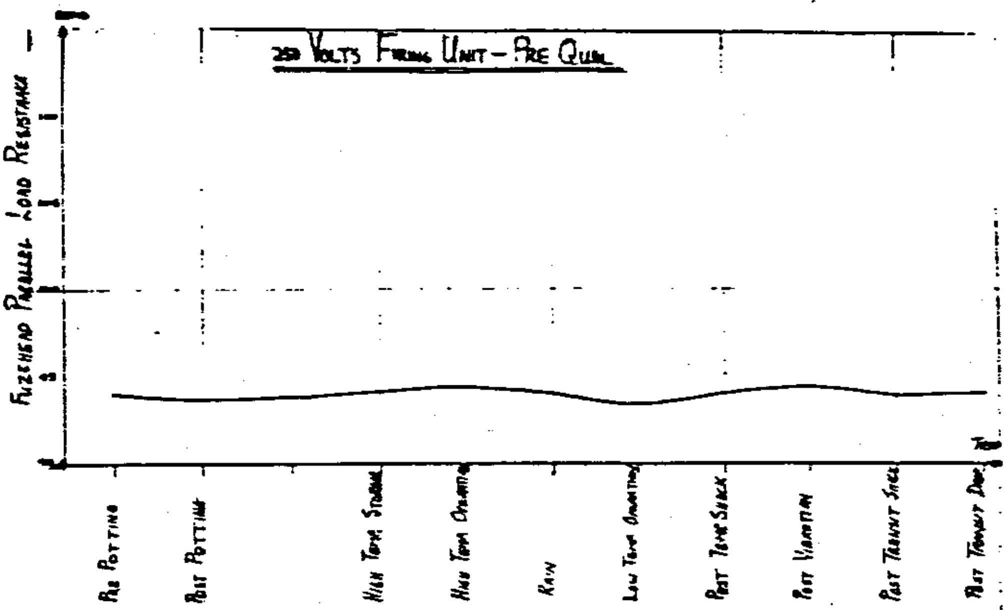


FIGURE 135: FUNCTIONAL TEST OF THE 250V UNIT, FUZE HEAD PARALLEL LOAD RESISTANCE

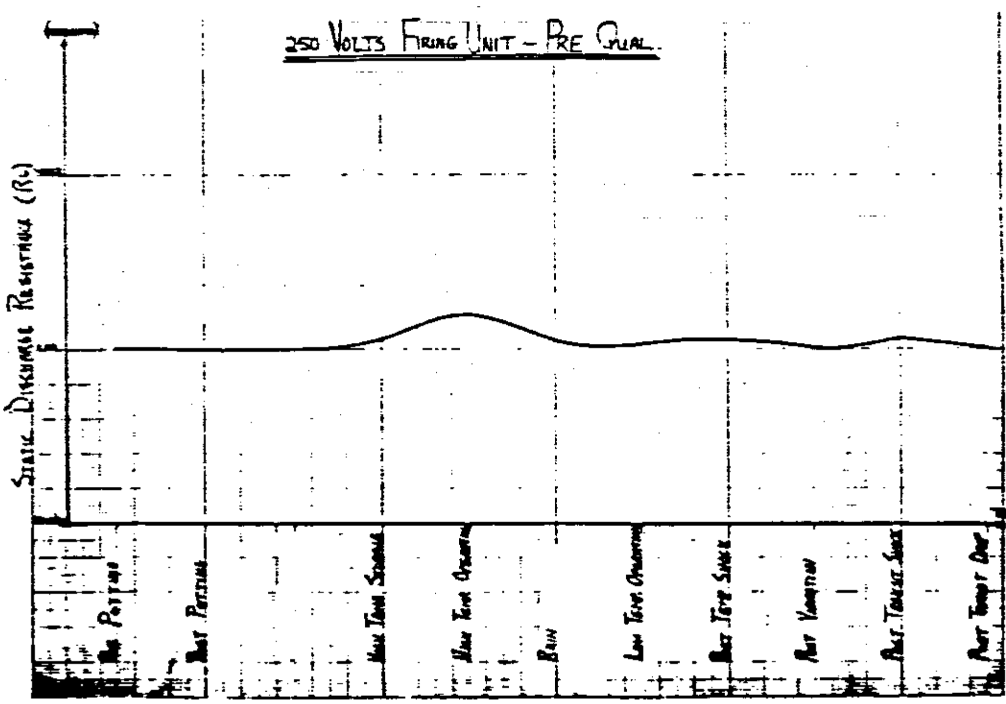


FIGURE 135A: FUNCTIONAL TEST OF THE 250V UNIT, STATIC DISCHARGE RESISTANCE

SECTION 10 - THE FOAM POTTING MEDIUM

10.1 INTRODUCTION

Various questions were posed with respect to the suitability of the foam potting medium used. The most pertinent of these were with respect to mass, density, ease of use and resistance to solvents.

10.1.1 Mass

During vibration testing several rubber mount failures occurred. One method of reducing these was to improve the mass to rubber mount ratio. Accordingly methods of reducing the mass of the firing unit by reducing the mass of the potting material used, were investigated.

10.1.2 Density

Originally a flexible foam of high density was used. This was to secure a degree of shock absorbtion by the foam, thereby helping to protect the electronics contained within the foam. Experience with other projects indicated the possible suitability of a lower density rigid foam.

10.1.3 Ease of Use

The importance of aspects such as working time, foaming time and hardening time became evident. The toxicity of the various materials also came into question.

10.1.4 Resistance to Solvents

Resistance to various common fluids and solvents used in a vehicle environment was queried. The fluids tested were petrol, diesel, brake fluid, lubricating oil, water, acetone and propanol.

10.2 BAYFLEX 0538LB AND DESMODUR PA 09 (BAYER)

10.2.1 Toxicity

The wearing of a facial mask and neoprene gloves is necessary when weighing off and mixing the constituents. The process should be completed in a well ventilated area.

10.2.2 Cycle Time

Preparation of the mould lid and box is identical for all foam types.

This material requires a 15 seconds mix time and then a 7 minute foam time, after which the mould lid can be removed.

This short time has the advantage of a high production output with 1 mould but an inconveniently short mixing time.

10.2.3 Mass

This mass given is the mass needed to fill the firing unit, in this case 800 gram.

10.2.4 Solvents

Petrol	-	Limited swelling of the foam Petrol was readily absorbed.
Diesel	-	Negligible swelling Absorption of diesel was unacceptably high
Brake fluid	-	Extreme swelling, the outer skin peeled off. The fluid was readily absorbed
Lubricating oil	-	No swelling could be noted Only small quantities of oil were absorbed
Water	-	No swelling was evident. Water is readily absorbed if the outer skin of the foam is damaged.
Acetone	-	Very severe swelling, the outer skin peeled off. The acetone was rapidly absorbed by the foam.
Propanol	-	Severe swelling and partial peeling of the outer skin occurred. The propanol was easily absorbed by the foam.

10.2.5 Conclusion

This is a flexible foam with good shock absorbtion properties. Its disadvantages are that it is not resistant to solvents and that it is too heavy. This foam was accordingly rejected.

10.3 RTF 762 SILICONE RUBBER FOAM (GENERAL ELECTRIC)

10.3.1 Toxicity

Precautions as outlined in 10.2.1 are recommended as exposure to high vapour concentration must be avoided.

10.3.2 Cycle Time

Two fifteen second mixing cycles culminating in complete expansion within 20 minutes.

10.3.3 Mass

The required mass would be approximately 400 gram.

10.3.4 Solvents

Petrol	-	Very bad swelling occurred Small quantities of petrol were absorbed and some of the foam was dissolved.
Diesel	-	Minor swelling, small amounts were absorbed and no RTV appeared to be dissolved.
Brake fluid	-	No apparent effect on the foam
Lubricating oil		Minor swelling and small amounts of oil were absorbed. No foam appears to be dissolved.

Water	–	No swelling occurred. Surface bubbles and irregularities were filled with water. Otherwise no absorbtion occurred.
Acetone	–	Negligible effect
Propanol	–	Negligible effect

10.3.5 Conclusion

This is a flexible foam less dense than that in 10.2. The foam was too soft to adequately support the PCB unless the density was increased. The mass advantage then was diminished. The foam had a better resistance to solvents than that in 10.2 and appears to be generally more suitable.

10.4 CW2215, HM HARDNER AND DY050 FOAMING AGENT (Ciba Geigy).

10.4.1 Toxicity

Paragraph 10.2.1 applies as this material is an irritant to the skin and eyes. It may cause sensitization by skin contact.

10.4.2 Cycle Time

The material has a 50 minute working time and a 24 hour cure time. This can be reduced by the application of heat to the mould. These times are too slow for production using one mould only.

10.4.3 Mass

The required mass of epoxy would be approximately 700 gram

10.4.4 Solvents

Petrol	-	Softening of the material occurred and some petrol was absorbed in the cells. Neglible expansion occurred.
Diesel	-	Diesel had neglible effect on this epoxy foam.
Brake fluid	-	The foam was extremely soft and fell to pieces. The fluid was absorbed in large quantities. Very marked expansion of the foam occurred.
Lubricating oil	-	This had a neglible effect on the foam
Water	-	As for lubricating oil
Acetone	-	Very bad softening causing crumbling of the material. Acetone caused a marked expansion and was also readily absorbed.
Propanol	-	This solvent caused marked softening and some expansion of the foam. Limited quantities of propanol was absorbed.

10.4.5 Conclusion

This is a rigid foam with good supportive properties but negligible shock absorbtion properties. Only a small mass advantage could be achieved with this material when compared to 10.2. The long cure time is a big disadvantage. The material was accordingly rejected.

10.5 <u>DESMOPHEN TPPU 1341 POLYOL AND DESMODUR 44V20B POLYISOCYANATE (BAYER)</u>.

10.5.1 Toxicity

Paragraph 10.2.1 applies

10.5.2 Cycle Time

This polyurethane foam requires an 11 second mix cycle and then 10 minutes for curing when the mould is heated to 40°C.

10.5.3 Mass

Approximately 350 gram

10.5.4 Solvents

Petrol	-	No softening, swelling or dissolution was noticed. A small amount of petrol was absorbed.
Diesel	-	No softening, dissolution or swelling were evident. Absorbtion was limited to approximately the outer 2mm only.
Brake fluid	-	No solvent action, swelling or softening were noticed. The fluid was absorbed to a depth of about 1mm into the sample.
Lubricating Oil	-	Similar to brake fluid

Water – No solvent action, swelling or softening were noted. Water adhered to the surface of the sample, but very little was absorbed.

Acetone – No solvent action, swelling or softening were noted. The acetone was absorbed throughout the specimen.

Propanol – No swelling, softening or solvent action were noted. Approximately 1/3 of the specimen had absorbed the propanol.

10.5.5 Summary

This is a rigid polyurethane foam with good supportive qualities and is the most resistant to solvents tested.
Its absorbtion of contaminants will be reduced in practice due to the integral skin of this foam. This skin was removed for the solvent tests, simulating worst case conditions. There is a mass advantage of approximately 450 gram when compared to 10.2. This foam's disadvantages are that it has no shock absorbent qualities and that the mixing cycle time is inconveniently short.

This foam was the best tested and was accordingly used to fill the firing unit.

10.6 CONCLUSION

During the next phase a firing unit will be built to check all documentation before beginning with qualification.

New work will be confined to designing and building a test jig to be used when checking the firing unit at base facilities.

10.7 RECOMMENDATIONS

It is considered that the Firing Unit complies with the user requirement and it is recommended that this will, in its present configuration, be submitted for qualification.

PART 4

THE FIRING UNIT'S FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

CONTENTS LIST

SECTION 1 - INTRODUCTION

1.1 THE FMECA

This part of the thesis deals with the Failure Mode, Effects and Criticality Analysis (FMECA) on the firing unit. It is deemed necessary to complete this exercise due to the potential dangers of a firing unit malfunction. An analysis of hardware items is made to determine those items contributing most to system unreliability and operational safety hazards.

The principles of reliability and the FMECA have been used throughout the design of the firing unit. Unacceptable reliability of components was often used as motivation for circuit changes.

The firing unit is the only item analysed. Reliability studies are conducted to estimate the lifetime of the device analysed and it is defined as fitness for purpose. This requires that any component of which the unreliability is significantly larger than any other component be re-evaluated so that reliability design goals are achieved. However, cost constraints may dictate it to be preferable to re-design an already reliable circuit and improve its reliability, so improving the total reliability of the unit, while accepting the significantly larger unreliability of another circuit.

Briefly a reliability study considers only the reliability of a unit and any failure is considered the end of the unit's life. The consequence of the failure is immaterial.

The Failure Mode, Effects and Criticality Analysis differs in that it concentrates on the failure itself and the effects of the failure.

Whereas an item might be perfectly acceptable from a reliability point of view, when the effects of the failure are taken into consideration the component may now be totally unacceptable. This component would have to be re-designed so that the chances of its failure were remote when compared to the overall lifetime of the equipment in which it is installed. On the other hand another part may be fairly likely to fail during the equipment lifetime, but this failure would hardly be noticeable. Consequently little or no time would be spent trying to improve its reliability.

The FMECA concentrates on the effect of a failure and the consequences thereof.

Due to the inherent reliability of the system and the lack of volume production, practical determination of failure rates has not been possible. MIL-HDBK-217D (Military Handbook, Reliability Prediction of Electronic Equipment), MIL-HDBK-338 (Electronic Reliability Design Handbook), and Electronic Reliability Data, part failure rate and modes, published 1981, have been used as a source of information to calculate these failure rates.

The method used, based on MIL-STD-1629A, is to calculate the failure rate of each component of the firing unit, starting with diodes and considering the remaining components in turn. One full example of each calculation is shown, thereafter just the component and the failure rate of like types. These components' failure rates will be grouped into functional blocks as shown in figure 1. The FMECA will then be performed on these functional blocks. New failure rates will be calculated for all components as previous failure rates were based on MIL-HDBK-217B, now superseded by MIL-HDBK-217D.

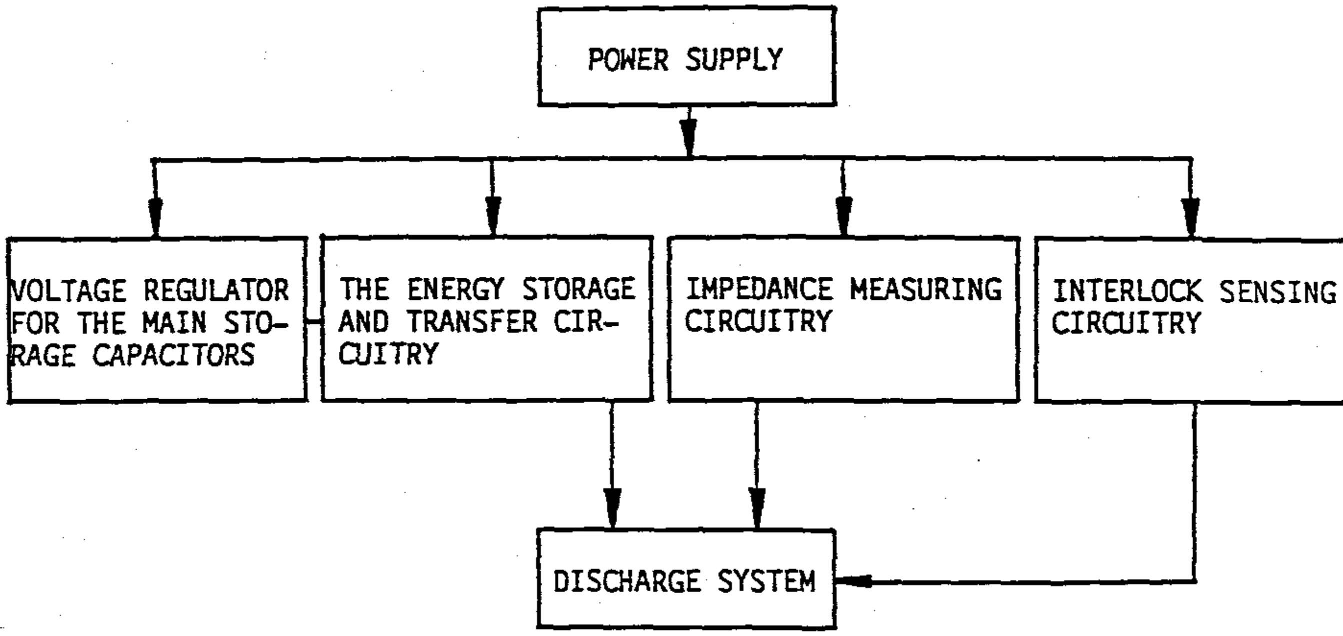


FIGURE 136 – BLOCK DIAGRAM OF THE PARTS OF THE SYSTEM SUBJECTED TO THE FMECA

1.2 APPLICABLE DOCUMENTS

a.	MIL-HDBK-217D	Reliability Prediction of Electronic Equipment
b.	MIL-HDBK-338	Electronic Reliability Design Handbook
c.	MIL-STD-1629A	Procedures for performing a Failure Mode, Effects and Criticality Analysis (FMECA)
d.	EXHIBIT : QR-844B	FMECA for Missile Systems

SECTION 2 - DISCUSSION OF REQUIREMENTS

2.1 INTRODUCTION

Military electronic systems and equipment are required to go through a reliability prediction phase. Item failure mode analysis shows the potential impact of each functional or hardware failure on mission success, personnel and system safety, system performance, maintainability and maintenance requirements. Each potential failure is ranked by the severity of its effects in order that appropriate corrective actions may be taken to eliminate or control high risk items.

The documents listed in Paragraph 1.2 establish a uniform procedure for conducting and documenting a systematic, critical examination of all potential failure modes and failure mechanisms of a design. (MIL-HDBK-217D, MIL-STD-1629A, QR-844-B).

2.2 LIMITATIONS OF RELIABILITY PREDICTIONS

(Extracted from MIL-HDBK 217 D Section 4.3)

The art of predicting the reliability of electronic equipment has practical limitations such as those depending on data gathering and technique complexity. Considerable effort is required to generate sufficient data on a part class to report a statistically valid reliability figure for that class. Casual data gathering on a part class occasionally accumulates data more slowly than the advance of technology in that class; consequently, a valid level of data is never attained. In the case of many part classes, the number of people participating in data gathering all over the industry is rather large with consequent varying methods and conditions which prevent exact co-ordination and correlation. Also part reliability in the field use of equipment is difficult to examine due to the lack of suitable data being acquired.

Thus, it can be seen that derivation of failure rates (being mean values) is empirically difficult and obtaining valid confidence values is practically precluded because of lack of correlation. The use of failure rate data, obtained from field use of past systems, is applicable on future concepts depending on the degree of similarity existing both in the hardware design and in the anticipated enivironments. Data obtained on a system used in one environment may not be applicable to use in a different environment, especially if the new environment substantially exceeds the design capabilities. Other variants that can affect the stated failure rate of a given system are: different uses, different operators, different maintenance practices, different measurement techniques or definitions of failure. When considering the comparison between similar but unlike systems, the possible variations are obviously even greater.

Thus, a fundamental limitation on reliability prediction is the ability to accumulate data of known validity for the new application. Another fundamental limitation is the complexity of prediction techniques. Very simple techniques omit a great deal of distinguishing detail and the prediction suffers inaccuracy. More detail techniques can become so bogged down in detail that the prediction becomes costly and may actually lag the principal hardware development efort.

This revision of the Handbook includes two methods of reliability prediction - "Part Stress Analysis" in Section 5.1 and "Parts Count" in Section 5.2. These methods vary in degree of information needed to apply them. The Part Stress Analysis requires the greatest amount of detail and is applicable during the later design phase where actual hardware and circuits are being designed. The Parts Count Method requires less information, generally that dealing with quantity of different part types, quality level of the parts, and the application environment. This method is applicable in the early design phase and during bid proposal formulation. Both methods will be revised periodically and new prediction methods will be added as they are developed. Neither method applies to a nuclear survivability environment nor do they consider the effects of ionizing radiation.

The content of the Handbook provides a common basis for reliability predictions during acquisition programs for military electronic systems and equipments. It also establishes a common basis for comparing and evaluating reliability predictions of related or competitive designs. The failure rates and their associated adjustment factors presented are based upon evaluation and analysis of the best available data at the time of issue.

SECTION 3 - FAILURE RATE CALCULATIONS

3.1 INTRODUCTION

This section deals with each component type in turn and calculates their failure rates. Only one example of each type of calculation is given. Thereafter only part numbers and failure rate are shown.

3.2 DIODES, INCLUDING ZENER AND LIGHT EMITTING

3.2.1 Diodes, General Purpose.

There are 29 1N4007 diodes, two Zener diodes and four ESBR 5501 superbright light emitting diodes.

Section 5.1.3.4.1 of MIL-HDBK-217D applies, discrete semiconductors.

Description : Silicon, general purpose discrete diodes, group IV.

Part operating failure rate model (λp) for D1 is given by:

$$\lambda p = \lambda b (\pi_E \times \pi_Q \times \pi_R \times \pi_A \times \pi_{S2} \times \pi_C) \text{ failures}/10^6 \text{ hours}$$

where:-

π_E	=	Environmental Mode factor, Ground Mobile (GM); 18.
π_Q	=	Quality Factor, Plastic ; 15
π_R	=	Current Rating (Amps), $\leqslant$ 1;1
π_A	=	Application, Switching $\leqslant$ 500 mA; 0,6
π_{S2}	=	Voltage Stress (see below) ; 0,7
π_C	=	Construction factor, Metallurgically bonded ; 1
λ_b	=	Base Failure Rate (see below) ; 0,00041

π_{S2} :

$$\text{Voltage stress, } S_2 = \frac{\text{Applied } V_R}{\text{Rated } V_R} \times 100$$

where V_R = diode reverse voltage

$$S_2 = \frac{100}{1000} \times 100 = 10\%$$

therefore from the tables π_{S2} = 0,7

The Stress ratio, used in determining the base failure rate is given by:

$$S = \frac{\text{operating current}}{\text{maximum rated current}} \times \text{correction factor}$$

The stress correction factor (C.F.) is determined by using the manufacturer's data concerning T_{max}, the maximum permissible junction temperature and T_S, the maximum ambient or case temperature at which 100% rated load can be dissipated. Motorola data on the 1N4007 diode gives T_{max} as 175°C and T_S as 75°C.

$$CF = \frac{175 - T_S}{150}$$, for devices where

$T_S > 25°C$ and T_{max} = 175 to 200°C

$$\text{Therefore } CF = \frac{175 - 75}{150} = 0,667$$

$$\text{Therefore } S = \frac{17 \times 10^{-3}}{1} \times 0.667 = 11,4 \times 10^{-3}$$

The lowest stress column available is for an S of 0,1 and a maximum operating temperature of 65°C. Therefore λ_b equals 0,00041. Consequently the part operating failure rate is:-

λ_p = 0,00041 (18 x 15 x 1 x 0,6 x 0,7 x 1)

= 46,5 failures per 10^9 hours.

D2 to D7 = 60,1 failures per 10^9 hours
D8 and D9 = 46,5 failures per 10^9 hours
D10 and D11 = 79,4 failures per 10^9 hours
D12 and D13 = 46,5 failures per 10^9 hours
D14 = 79,4 failures per 10^9 hours
D15 to D28 = 46,5 failures per 10^9 hours
D29 = 79,4 failures per 10^9 hours

3.2.2 Zener Diodes

These are group V devices with a part failure rate model as shown below. The calculation for ZD1 is shown.

$$\lambda_p = \lambda_b (\Pi_E \times \Pi_A \times \Pi_Q) \text{ failures per } 10^6 \text{ hours.}$$

where:

Π_E = Environmental Factor, Ground Mobile (GM); 18
Π_A = Application, Voltage Regulator ; 1,0
Π_Q = Quality Level, lower ; 15

The stress ratio is given by:

$$S = \frac{\text{Power dissipated}}{\text{Max Power}} \times \text{Correction Factor.}$$

This correction factor is equal to:

$$CF = \frac{175 - T_S}{150°C} = \frac{175°C - 75°C}{150°C} = 0,667$$

therefore

$$S = \frac{7,74 \times 10^{-3}}{1} \times 0,667 = 5,2 \times 10^{-3}$$

A value of 0,1 for S is applied to the tables (S is not given for less than 0,1),

therefore λ_p = 0,00072 (18 x 1 x 15)

= 194,4 failures per 10^9 hours.

ZD2 = 194,4 failures per 10^9 hours.
ZD3 is dealt with under transient suppressors.

3.2.3 Light Emitting Diodes (LED)

LED1 to LED4 have the same operating characteristics and environment. The single calculation therefore holds true for all four devices. The part failure rate model is shown below. (Opto -electronic Semiconductor Devices, group X)

$$\lambda_p = \lambda_b \pi_T \pi_E \pi_Q \text{ failures per } 10^6 \text{ hours,}$$

where:

π_T = Temperature Factor ; 1200
π_E = Environmental Factor, Ground Mobile (GM) ; 7,8
π_Q = Quality Factor, Plastic ; 1.

π_T *is selected from Table 5.1.3.10-2 where*
T_j = T_A + 20°C
T_A = 65°C
T_j = 85°C, therefore π_T = 1200.

For the purposes of this calculation a base failure rate of 0,00065 is assumed, taken from the worked example, as the required table has been omitted from the copy of MIL-HDBK-217D used,

therefore λ_p = 0,00065 x 1200 x 7,8 x 1

= 6,08 failures per 10^6 hours.

LED's 2, 3, 4 = 6,08 failures per 10^6 hours

3.3 RESISTORS

There are 42 resistors of various values and wattages. R1 is a 33k ohm 0,5 Watt metal film device procured according to MIL-R-10509 F and MIL-R-22684 B.

The part operating failure rate model is given by:

$$\lambda_p = \lambda_b (\pi_E \times \pi_R \times \pi_Q) \text{ failures per } 10^6 \text{ hours,}$$

where

π_E = Environmental Factor, Ground Mobile (GM) ; 7,8
π_R = Resistance Range (ohms), up to 100K ; 1
π_Q = Quality Factor, MIL-R-10509 ; 5

S, the stress ratio is the ratio of operating to rated wattage.

$$S = \frac{0{,}001}{0{,}250} = 4 \times 10{-}3,$$

(a pulse width of 2,5 uS is used at a 1 mS repetition rate)

therefore an S of 0,1 is used and λ_b = 0,0011

$$\lambda_p = 0{,}0011\ (7{,}8 \times 1 \times 5)$$

$$= 42{,}9 \text{ failures per } 10^9 \text{ hours}$$

The remaining resistor part failure rates are:

R2,3,4 = 42,9 failures per 10^9 hours
R5 = 382 failures per 10^9 hours
R6 = 47,2 failures per 10^9 hours
R7 = 70,2 failures per 10^9 hours

R8 = 299 failures per 10^9 hours
R9 = 382 failures per 10^9 hours
R10,11 = 42,9 failures per 10^9 hours
R12,13 = 47,2 failures per 10^9 hours
R14,15 = 47,2 failures per 10^9 hours
R16 = 54,6 failures per 10^9 hours
R17 = 47,2 failures per 10^9 hours
R18,19 = 42,9 failures per 10^9 hours
R20 = 62,4 failures per 10^9 hours
R21,22 = 42,9 failures per 10^9 hours
R23 = 42,9 failures per 10^9 hours
R24,25 = 47,2 failures per 10^9 hours
R26 = 47,2 failures per 10^9 hours
R27 = 47,2 failures per 10^9 hours
R28 = 50,7 failures per 10^9 hours
R29 = 42,9 failures per 10^9 hours
R30 = 94,6 failures per 10^9 hours
R31 = 42,9 failures per 10^9 hours
R32 = 47,2 failures per 10^9 hours
R33,34 = 42,9 failures per 10^9 hours
R35 = 94,6 failures per 10^9 hours
R36 = 137 failures per 10^9 hours
R37 = 323 failures per 10^9 hours
R38 = 115,8 failures per 10^9 hours
R39 = 42,9 failures per 10^9 hours
R40,41 = 94,6 failures per 10^9 hours
R42 = 70,2 failures per 10^9 hours

3.4 CAPACITORS

There are 14 capacitors used in the firing unit, consisting of polarised aluminium electrolytic, non-polarised polyester and surface mounted ceramic types. The example for C1 is shown.

Section 5.1.7.6 of MIL-HDBK-217D applies, Aluminium Electrolytic Capacitors.

The part operating failure rate model (λ_p) pertaining to C1, a 220 uf 63V device.

$$\lambda p = \lambda b \times \pi_E \times \pi_Q \times \pi_{CV} \text{ failures per } 10^6 \text{ hours}$$

where:

π_E = Environmental Factor, Ground Mobile (GM) ; 12
π_Q = Quality Factor, M ; 1
π_{CV} = Capacitance Factor, 100uf ; 0,9

The stress ratio, S, used in determining the base failure rate is determined as follows :

$$S = \frac{\text{operating voltage}}{\text{rated voltage}} = \frac{20}{63} = 0{,}317,$$

therefore λ_b = 0,029 and consequently

$$\lambda p = 0{,}029 \times 12 \times 1 \times 0{,}9 \text{ failures per } 10^6 \text{ hours}$$

$$= 313 \text{ failures per } 10^9 \text{ hours}$$

The remaining calculations showed that:

C2 = 38,5 failures per 10^9 hours
C3 = 24,8 failures per 10^9 hours
C4 = 224 failures per 10^9 hours
C5 = 47 failures per 10^9 hours
C6,7 = 9,2 failures per 10^9 hours
C8,9 = 271 failures per 10^9 hours

C10 = 38,5 failures per 10^9 hours
C11 = 24,8 failures per 10^9 hours
C12 = 24,8 failures per 10^9 hours
C13 = 24,8 failures per 10^9 hours
C14 = 24,8 failures per 10^9 hours

3.5 TRANSISTORS AND FIELD EFFECT TRANSISTORS

There is only one device in each of these categories. Their reliability calculations are shown below.

3.5.1 TR1, Transistor, NPN, Silicon, General Purpose, Group I

The part operating failure rate model (λp):

$\lambda p = \lambda b\ (\pi_E \times \pi_A \times \pi_Q \times \pi_R \times \pi_{S2} \times \pi_C)$ failures per 10^6 hours

where:
π_E = Environmental Mode Factor, Ground Mobile ; 18
π_A = Application, linear ; 1,5
π_Q = Quality level, lower ; 6
π_R = Power Rating (watts), 10 watts ; 2
π_{S2} = Voltage stress, 48% ; 0,61
π_C = Complexity, single transistor, 1

S, the stress factor for use in determining the base failure rate is given by:

$$S = \frac{P_{op}}{P_{max}} \quad (CF)$$

$$S = \frac{0,73}{10} \quad (1)$$

$$= 0,073$$

therefore λ_b = 0,001 failures per 10^6 hours (at 65°C).

The part failure rate is given by:

λp = 0,001 (18 x 1,5 x 6 x 2 x 0,61 x 1)

= 198 failures per 10^9 hours

3.5.2 TR2

TR2 = 10 failures per 10^6 hours

3.6 SWITCHES

There are three switches in the firing unit. S2 and S3 are identical four pole double throw toggle devices while S1 is double pole double throw pushbutton type.

3.6.1 S1

MIL-HDBK-217D paragraph 5.1.11 applies (pushbutton switches, single body)

The part operating failure rate model (λ_p):

$\lambda_p = \lambda_b\ (\pi_E \times \pi_C \times \pi_{CYC} \times \pi_L)$ failure per 10^6 hours.

where:

λ_b = Base Failure Rate Model, MIL-S-3950; 0,00045

π_E = Environmental Mode Factor, Ground Mobile ; 14
π_C = Contact Form and Quantity, DPDT ; 3,0
π_{CYC} = Switching Cycles per Hour, 1 ; 1
π_L = Stress Factor and Load Type, resistive load ; 1,15.

The stress factor is such that 2A flows for 4 mS through the switch, at a repetition rate of 10 sec, worst case. To achieve a more accurate model, a 30% duty cycle is assumed, making S equal to 0,2 and therefore π_L = 1,06.

The part failure rate is given by:

$$\lambda p = 0{,}00045\ (14 \times 3 \times 1 \times 1{,}06)$$

$$= 20 \text{ failures per } 10^9 \text{ hours.}$$

3.6.2 S2 and S3

S2 = 36,73 failures per 10^9 hours.
S3 = 26,8 failures per 10^9 hours.

3.7 INTEGRATED CIRCUITS

3.7.1 IC1, the LM224, military number M38510/110005

MIL-HDBK-217D gives the following details:
VCC: 36V
Pd(W): 0,35
θjc: (°C/W) 60
Complexity: 96t (number of transistors)
Np: 14 (number of pins)

The part failure rate model for Monolithic Bipolar Devices (λ p) per 10^6 hours is shown below:

$$\lambda p = \pi_Q\ [C_1\pi_T\pi_V + (C_2 + C_3)\pi_3]\ \pi_L$$

where:

π_Q = Quality factor, B-1 ; 3
π_T = Temperature Acceleration factor, 65°C ; 2
π_V = Voltage Derating Stress factor, not CMOS ; 1
π_E = Application Environment, Ground Mobile ; 4,2
C_1 and C_2 are circuit complexity failure rates based on transistor count; C_1 = 0,055 ; C2 = 0,0092
C_3 = package complexity failure rate, 14 pin hermetic ; 0,0048
π_L = learning factor, continuous production ; 1

The part failure rate is given by:

$$\lambda p = 3 \; [0{,}055.2.1 + (0{,}0092 + 0{,}0048)\; 4{,}2]\; 1$$

$$= 506 \text{ failures per } 10^9 \text{ hours}$$

3.7.2 IC2

IC2 = 176 failures per 10^9 hours

3.8 THYRISTORS

There are only two thyristors (SCR 1 and SCR 2) in this circuit (RCA type S2060D). The part operating failure rate model (λ p) is shown below for SCR1:

$$\lambda p = \lambda b \times \pi_Q \times \pi_E \times \pi_R \text{ failures per } 10^6 \text{ hours}$$

where:

π_Q = Quality Factor, Plastic ; 50
π_E = Environment, Ground Mobile ; 18
π_R = Rated Average Forward Anode Current, 1 to 5 ; 3

The stress factor S is calculated below:

$$S = \frac{I_{op}}{I_{max,}} \quad (CF)$$

$$\text{where } CF = \frac{T_{max} - 25°C}{150°C} = \frac{110°C - 25°C}{150°C} = 0,567$$

and enter λ b table with T = 65+ (175 - 110)
thus T = 130°C.

$$\text{therefore } S = \frac{0,21}{4} \times 0,567 = 0,03.$$

The part failure rate is given by:

λ p = 0,01 x 50 x 18 x 3 failures per 10^6 hours
= 27 failures per 10^6 hours.

SCR2: λ p = 27 failures per 10^6 hours.

3.9 VARISTORS

V1 to V3 and ZD3.

Information pertaining to this type of electronic component reliability does not appear to be currently available.

These components cannot, however, be ignored, so an arbitary value has been assigned to them, namely the average failure rate of all the other components in the firing unit. Ninety five percent of varistor failures are open circuit, which lessens their impact on the circuit (MIL-HDBK-338).

V1, V2, V3 = 278,5 failures per 10^9 hours
ZD3 = 278,5 failures per 10^9 hours

3.10 PRINTED WIRING BOARDS

The printed wiring board used is an assembly using plated through holes (PTH).

λp is given as:

$$\lambda p = \lambda_b \pi_Q \pi_E \left[N_1(\pi_C + \pi_S) + N_2 (\pi_C + 13) \right] \text{ failures per } 10^6 \text{ hours,}$$

where:

λb = base failure rate, printed wiring assembly ; 0,000041
π_Q = Quality Factor, MIL-SPEC ; 1
π_E = Environmental Factor, Ground Mobile ; 7,7
N_1 = Quantity of Wave Soldered Functional PTHs ; 214
N_2 = Quantity of Hand Soldered PTHs ; 48
π_C = Complexity Factor, 2 ; 1
π_S = Wave Solder Application Factor, unknown ; 6.

The part failure rate is given by:

$$\lambda p = 0{,}000041 \times 1 \times 7{,}7 \, [214 \, (1 + 6) + 48 \, (1 + 13)]$$

$$= 685 \text{ failures per } 10^9 \text{ hours}$$

3.11 CONNECTORS

There is only one connector, a MIL-C-5015 type device. The failure rate model (λp) is for a mated pair of connectors. The part failure rate is given by:

$$\lambda p = \lambda b \, (\pi_E \times \pi_p \times \pi_K) \text{ failures per } 10^6 \text{ hours,}$$

where:

π_E = Environmental Mode factor, Ground Mobile ; 8,3
π_p = Number of active contacts, 6; 2,02
π_K = Unmating factor, 0-0,05 ; 1.

The base failure rate:

$\lambda b = Ae^{x}$,

where $x = \frac{NT}{T + 273} + \left[\frac{T + 273}{To}\right]^{P}$

where

e = 2,718

T = system operating temperature (°C) ; 66°C.

Constants due to material (MIL-C-5015) are:

A = 0,77

To = 358

NT = -1528,8

P = 4,72,

therefore $x = \frac{-1528,8}{66 + 273} + \left[\frac{66 + 273}{358}\right]^{4,72}$

$= -3,74$,

therefore $\lambda b = 0,77\ e^{-3,74}$

$= 0,0184$ failure per 10^{6} hours

The part failure rate is given by:

$\lambda_{p} = 0,0184\ (8,3 \times 2,02 \times 1)$ failures per 10^{6} hours

$= 307,7$ failures per 10^{9} hours

3.12 TRANSFORMERS

The failure rate of the only transformer used is shown below

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q$$

where:
π_E = Environment Mode Factor, Ground Mobile ; 12
π_Q = Quality Factor, lower ; 30.

The hot spot temperature, T_{HS} is 65°C and a maximum insulation temperature of 130°C,

therefore the part failure rate is:

$$\lambda_p = 0{,}0026 \times 12 \times 30$$
$$= 936 \text{ failures per } 10^9 \text{ hours}$$

3.13 THE HAND-CRANK GENERATOR

Generators as such, are not dealt with in MIL-HDBK-217D, however, the electrical model for a motor and a generator are very similar and so that part model is used.

$$\lambda_p = \left[\frac{t^2}{\alpha B^3} + \frac{1}{\alpha W} \right] \times 10^6 \text{ (failures per } 10^6 \text{ hours)}$$

where:
t is taken as the time needed to perform 5000 operations of the firing unit, Viz 2000 minutes or 33,3 hours

αB is the Weibull characteristic for the bearings ; 27300

It is assumed this holds true for the bushes used.

αW is the Weibull characteristic for the windings ; $1{,}4 \times 10^5$.

$$\lambda p = \left[\frac{33{,}3^2}{(27300)^3} + \frac{1}{1{,}4 \times 10^5}\right] \times 10^6 \text{ failures per } 10^6 \text{ hours}$$

$= 7{,}14$ failures per 10^6 hours

3.14 THE TOTAL DEVICE FAILURE RATE

All figures are in failures per 10^9 hours

Diodes	$1{,}562 \times 10^3$	(29 off)
Zener Diodes	388	(2 off)
Light Emitting Diodes	$24{,}3 \times 10^3$	(4 off)
Resistors	$3{,}531 \times 10^3$	(42 off)
Capacitors	$1{,}345 \times 10^3$	(14 off)
Transistors and FET's	$10{,}198 \times 10^3$	(2 off)
Switches	83,53	(3 off)
Integrated Circuits	682	(2 off)
Varistors	$1{,}114 \times 10^3$	(4 off)
Thyristors	54×10^3	(2 off)
PCB	685	(262 off)
Connectors	307,7	(1 off)
Transformer	936	(1 off)
The Hand Cranked Generator	$7{,}14 \times 10^3$	(1 off)
Total Failure Rate	$102{,}76 \times 10^3$	(369 components)

$\Sigma\lambda_p = 102{,}76$ failures per 10^6 hours

Any single component failure is taken to constitute unit failure. This is equivalent to a Mean Time Between Failures (MTBF) of 9731 hours continuous operation, or assuming 10 minutes per operation (average) a lifetime of $58{,}4 \times 10^3$ operations.

The percentage units surviving at any one instant is given by

$$100e^{-\frac{t}{T}}$$ in percent,

where t = time elapsed
and T = the MTBF.

This indicates that 36,8% of the units should survive after $58,4 \times 10^3$ operations. After 5000 operations this should have increased to:

$$100\ e^{-\frac{5000}{58,4 \times 10^3}}\ \%$$

= 91,8%

SECTION 4 - THE UNIT LEVEL FMECA

4.1 INTRODUCTION

The methods used to perform this FMECA are based on an interpretation of both MIL-STD-1629A and EXHIBIT-QR-844B. Portions of both have been used to complement each other in this analysis. The levels of severity used in determination of criticality are as follows:

a. Level 1. Single point failure leading directly to serious injury or death of personnel, or disabling damage to mission essential equipment.

b. Level 1R. Failure of all redundant elements leading to level 1 effects.

c. Level 2. Single point failure leading to minor injury or loss of mission or mission phase.

d. Level 2R. Failure of all redundant elements leading to level 2 effects.

e. Level 3. System operation is degraded but still operable in certain modes or conditions.

f. Level 4. No significant effect on system operation.

4.1.1 LEVELS OF OCCURENCE

The levels of occurrence used are as follows.

a. Level A.

Frequent. Defined as a single failure mode with a probability of greater than 20% of the overall probability of failure during the item operation time interval. Twenty percent failure is equivalent to a failure rate of 20,552 x 10^{-6} hours.

b. Level B.

A moderate probability of occurrence which is more than 10% but less than 20% of the overall probability of failure during the item operating time. Ten percent failure is equivalent to a failure rate of 10,28 x 10^{-6} hours.

c. Level C.

Occasional, defined as between 1% and 10% of the overall probability of failure during the item operating time. One percent failure is equivalent to a failure rate of 1,028 x 10^{-6} hours.

d. Level D.

Remote. Between 0,1% and 1% probability of occurrence. A tenth of a percent failure is equivalent to a failure rate of 103 x 10^{-9} hours.

e. Level E.

Extremely unlikely. A failure of which the probability of occurrence is essentially zero, defined as a probability of occurrence of less than 0,1%.

When calculating the probability of occurrence, it must be noted that the part failure rate calculated in Section 3, applies to any failure mode. Each failure mode of a particular component might have a different end effect, so a failure rate will be assigned which describes both the component and its supposed failure mode. The summation of all these failure rates must necessarily equal the part failure rate calculated in Section 3.

The failure mode of each unit (4.2 to 4.7) is dealt with by means of the following output functions:

Premature operation
Failure to operate at a prescribed time
Failure to cease operation at a prescribed time
Failure during operation
Degraded or excessive operational capability

In certain instances some of these output functions are unlikely to occur and are therefore neglected, eg. the hand-cranked generator cannot operate prematurely because if it is not cranked it is impossible for it to deliver power.

Each unit shall be analysed according to the following list.

(i) Item Identification
(ii) Function
(iii) Failure mode
(iv) Mission phase
(v) Next level effects
(vi) End effects
(vii) Failure detection means
(viii) Compensating provisions
(ix) Severity level
(x) Probability of occurrence
(xi) Criticality
(xii) Retention rationale

All values used in this section were calculated in part 3 of this document. The failure mode percentages were obtained from MIL-HDBK-338 and from Electronic Reliability Data, part failure rate and modes, published 1981.

Criticality is determined from the table below.

TABLE 5 - CRITICALITY DETERMINATION

		Probability of occurrence					
		A	B	C	D	E	
		> 20%	20%-10%	10%-1%	1%-0,1%	< 0,1%	
Level of severity	1	X	X	X	X	X	(X denotes within critical area)
	1R	X	X	X	X		
	2	X	X	X			
	2R	X	X	X			
	3	X	X				
	4	X					

4.2 THE POWER SUPPLY

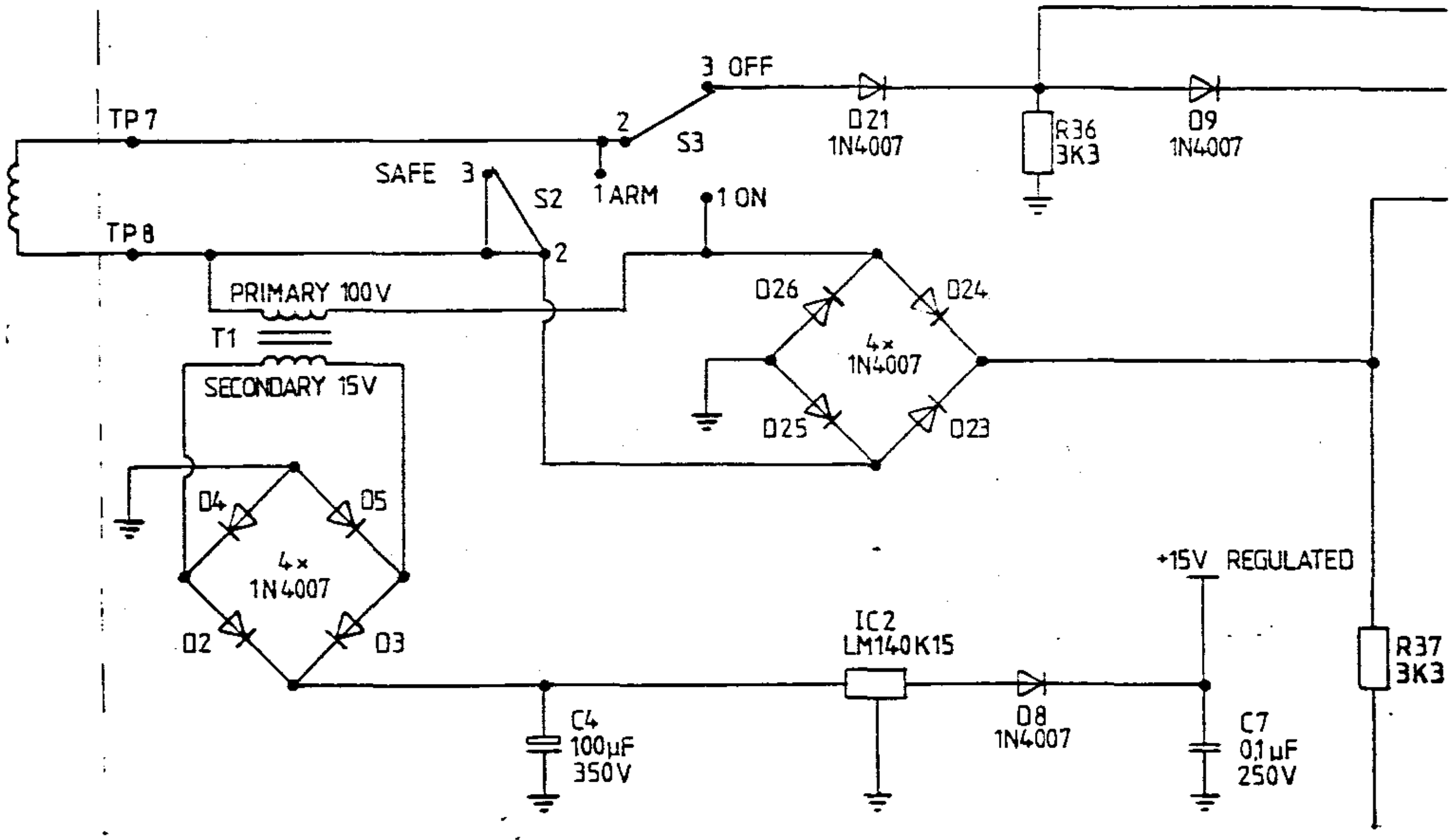


FIGURE 137: FIRING UNIT POWER SUPPLY CIRCUIT

4.2.1 General

The following output functions will not be considered, as they either cannot occur or are covered by other functions.

a. Premature operation
b. Failure to operate at a prescribed time
c. Failure to cease operation at a prescribed time

Failure during operation (no output voltage) and degraded or excessive operational capability (low output or excessive output voltage) will be considered.
A further distinction must be made between the 15V output and the 120 volt output of this power supply.

The 15V power supply will only cause a failure of the firing unit if the output goes below 3V or above 36V. Output below 3V is considered as zero volts.

4.2.2 Function : Failure During Operation

4.2.2.1 Failure causes of the 15V supply

The following component failures and component failure modes will cause the output of this power supply to drop to zero volts.

Figure 138 is a reliability diagram for diodes D2, D3, D4, and D5, where two diodes must fail to cause a zero volt output.

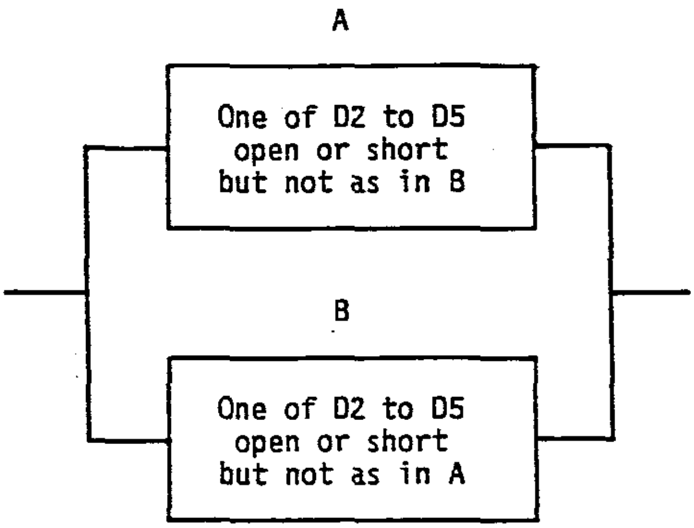


FIGURE 138: DIODE RELIABILITY DIAGRAM

The calculation of reliability for the parallel circuit is shown below.

$R = 1 - (1 - e^{-yt})(1 - e^{-zt}),$

where $R = e^{-xt}$

x, y and z are reliabilities.

If reliability is integrated, the MTBF is the result:

$\therefore$ MTBF $= \int_0^\infty 1 - (1 - e^{-yt})(1 - e^{-zt}) \; dt.$

$$\int_0^\infty e^{-xt} dt = \int_0^\infty 1 - (1 - e^{-zt} - e^{-yt} + e^{-(y+z)t}) \; dt$$

$$= \int_0^\infty + e^{-zt} + e^{-yt} - e^{-(y+z)t} \; dt.$$

$$\left[\frac{-1}{x} e^{-xt} \right]_0^\infty = \left[-\frac{1}{z} e^{-zt} - \frac{1}{y} e^{-yt} + \frac{1}{y+z} e^{-(y+z)t} \right]_0^\infty$$

$$\left[\frac{1}{x} e^{-xt} \right]_0^\infty = \left[\frac{1}{z} e^{-zt} + \frac{1}{y} e^{-yt} - \frac{1}{y+z} e^{-(y+z)t} \right]_0^\infty,$$

When t is substituted with zero and infinity the following formula emanates:

$$\frac{1}{x} = \frac{1}{y} + \frac{1}{z} - \frac{1}{y + z}$$

where:

$$y = z = 60{,}1 \times 10^{-9}$$

$$\frac{1}{x} = \frac{1}{60{,}1 \times 10^{-9}} + \frac{1}{60{,}1 \times 10^{-9}} - \frac{1}{120{,}2 \times 10^{-9}}$$

$$\frac{1}{x} = 24{,}96 \times 10^{+6}.$$

Therefore the parallel part failure rate, $x = 40 \times 10^{-9}$.

Component	Rate	Mode & Factor		Applied Rate
Generator	$7{,}14 \times 10^{-6}$.	open or short, 20%		$1{,}428 \times 10^{-6}$
T1	936×10^{-9}.	open or short,	85%	$795{,}6 \times 10^{-9}$
2 diodes of D2,D3,D4,D5	$40{,}07 \times 10^{-9}$.	open or short,	81%	$32{,}5 \times 10^{-9}$
C4	224×10^{-9}.	short,	30%	$67{,}2 \times 10^{-9}$
1C2	176×10^{-9}.	open,	83%	$146{,}1 \times 10^{-9}$
D8	$46{,}5 \times 10^{-9}$.	open,	6%	$2{,}79 \times 10^{-9}$
C7	$9{,}2 \times 10^{-9}$.	short,	30%	$2{,}76 \times 10^{-9}$
		TOTAL FAILURE RATE		$2{,}48 \quad 10^{-6}$

4.2.2.2 Failure mode 2

Power output goes above 35V

The possibility of this failure is so remote that it can be neglected. Two short circuits would be needed for power transfer between the primary and secondary windings, which are physically separated by the insulating mechanical former.

4.2.2.3 Mission phase

This failure would become apparent during the pre-mission checkout phase.

4.2.2.4 Next level effects

Mode 1 : No power to monitoring circuitry
Mode 2 : Monitoring circuitry overstressed

4.2.2.5 End effects

Mode 1, No indication of "circuit ready"
Mode 2, Constant indication of "fault and "on charge" LEDs in an illogical pattern

4.2.2.6 Failure detection means

Incorrect LED indications

4.2.2.7 Compensating provisions

This is one of two parallel systems. The second system is unaffected by this failure.

4.2.2.8 Severity level

Level 3, system operation is degraded

4.2.2.9 Probability of occurrence

this is calculated from:

$$\frac{\text{Calculated failure rate}}{\text{Total failure rate}} \times 100\%$$

$$\text{Mode 1} : \frac{2.48 \times 10^{-6}}{102,76 \times 10^{-6}} \times 100 = 2,4\%$$

Mode 2 : NIL

4.2.2.10 Criticality

Not critical

4.2.2.11 Retention rationale

Overall mission capability is not effected.

4.2.3 Function : Failure During Operation

An overvoltage on the 120V supply is dealt with in Section 4.3. A fault resulting in undervoltage could occur and is therefore investigated.

4.2.3.1 Failure causes

A list of components and failure type causing this failure mode is listed.

Component	Rate	Mode & Factor		Applied Rate
Generator	$7,14 \times 10^{-6}$	open or short,	20%	$1,428 \times 10^{-6}$
T1	936×10^{-9}	short,	80%	$748,8 \times 10^{-9}$
2 diodes of D23, D24, D25, D26	31×10^{-9}	open or short,	81%	$25,11 \times 10^{-9}$
R37	323×10^{-9}	open,	80%	$258,4 \times 10^{-9}$
C5	47×10^{-9}	short,	30%	$14,1 \times 10^{-9}$
C2	$38,5 \times 10^{-9}$	short,	30%	$11,5 \times 10^{-9}$
		TOTAL FAILURE RATE		$2,48 \times 10^{-6}$

4.2.3.2 Mission phase

Pre-mission checkout

4.2.3.3 Next level effects

No power to capacitors C9 and C8

4.2.3.4 End effects

No indication of circuit ready. No charge on C8 and C9. Impossible to initiate the system.

4.2.3.5 Failure detection means

No indication of circuit ready.

4.2.3.6 Compensating provisions

This is one of two parallel systems. The second system is unaffected by this failure.

4.2.3.7 Severity level

Level 3, system operation is degraded

4.2.3.8 Probability of occurrence

2,42%

4.2.3.9 Criticality

Not critical

4.2.3.10 Retention rationale

Overall mission capability is not effected.

4.3 THE VOLTAGE REGULATOR

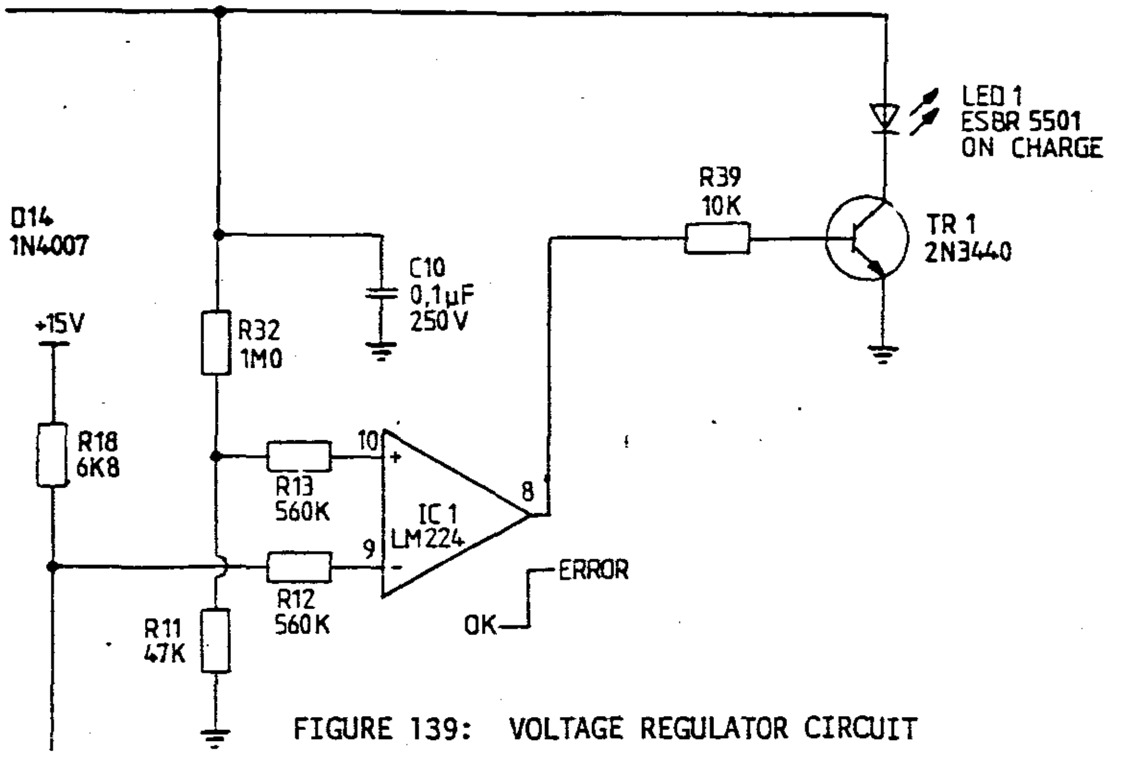


FIGURE 139: VOLTAGE REGULATOR CIRCUIT

4.3.1 General

This section of the circuit regulates the charge on C8 and C9. The following functions will be considered.

A. Premature operation.
B. Failure to operate at a prescribed time.
C. Degraded operational capability.

4.3.2 Function : Premature Operation (A)

Premature operation of this section of the circuit would be a false "on charge" indication.

4.3.2.1 Failure causes

The following component failures would cause premature operation:

Component	Rate	Mode & Factor	Applied Rate
ZD1	$194{,}4 \times 10^{-9}$	short circuit 75%	$145{,}8 \times 10^{-9}$
R11	$42{,}9 \times 10^{-9}$	open circuit 80%	$34{,}32 \times 10^{-9}$
IC1	506×10^{-9}	output high 21%	$106{,}3 \times 10^{-9}$
TR1	198×10^{-9}	short circuit 59%	$116{,}8 \times 10^{-9}$
		TOTAL FAILURE RATE	$403{,}2 \times 10^{-9}$

4.3.2.2 Mission phase

Pre-mission checkout

4.3.2.3 Next level effects

No charge on C8 and C9

4.3.2.4 End effects

Failure to initiate the system when required.

4.3.2.5 Failure detection means

LED 1 would illuminate sooner than anticipated, but the failure might not be noticed by an inexperienced operator.

4.3.2.6 Compensating provisions

The second system could be initiated immediately the failure on system 1 becomes apparent.

4.3.2.7 Severity level

Level 2R

4.3.2.8 Probability of occurence

0,4%

4.3.2.9 Criticality

Not critical

4.3.2.10 Retention rationale

Parallel system not effected.

4.3.3 Function : Failure to Operate at a Prescribed Time (B)

This failure could be defined as the "On Charge" LED not illuminating once C8 and C9 had been charged to 120V.

4.3.3.1 Failure causes

The following components and their failure modes would cause the failure mentioned in 4.3.3:

Component	Rate	Mode & Factor	Applied Rate
ZD1	$194,4 \times 10^{-9}$	open circuit 6%	$11,66 \times 10^{-9}$
R11	$42,9 \times 10^{-9}$	short circuit 20%	$8,58 \times 10^{-9}$
IC1	506×10^{-9}	output low 21%	$106,3 \times 10^{-9}$
R39	$42,9 \times 10^{-9}$	open circuit 80%	$34,3 \times 10^{-9}$
TR1	198×10^{-9}	open circuit 4%	$7,92 \times 10^{-9}$
LED1	$6,1 \times 10^{-6}$	open or short 81%	4925×10^{-9}
		TOTAL FAILURE RATE	5094×10^{-9}

4.3.3.2 Mission phase

Pre-mission checkout

4.3.3.3 Next level effects

Nil

4.3.3.4 End effects

Lack of "on charge" indication prevents operator from continuing to next mission phase.

4.3.3.5 Failure detection means

LED 1 would not illuminate.

4.3.3.6 Compensating provisions

Fault will be noticed in pre-mission checkout. The firing unit could be replaced or the second parallel system used.

4.3.3.7 Severity level

Level 3

4.3.3.8 Probability of occurrence

4,96%

4.3.3.9 Criticality

Not critical

4.3.3.10 Retention rationale

The operator becomes aware of the fault during initial stages of operation. The parallel system is also not effected.

4.3.4 Function : Degraded Operational Capability (C)

This failure would be defined as the potential on C8 and C9 being less than 120V.

4.3.4.1 Failure causes

The applicable components and their failure modes are listed below.

Component	Rate	Mode & Factor		Applied Rate
R32	$47,2 \times 10^{-9}$	value change	20%	$9,4 \times 10^{-9}$
R11	$42,9 \times 10^{-9}$	value change	20%	$8,6 \times 10^{-9}$
TR1	198×10^{-9}	high leakage	59%	$116,8 \times 10^{-9}$
IC1	506×10^{-9}	degradation	21%	$106,3 \times 10^{-9}$
		TOTAL FAILURE RATE		$241,1 \times 10^{-9}$

4.3.4.2 Mission phase

Pre-mission checkout

4.3.4.3 Next level effects

Insufficient charge on C8 and C9

4.3.4.4 End effects

Complete or partial failure to initiate the system when required, depending on value of charge on C8 and C9. The most serious of these is partial failure.

4.3.4.5 Failure detection means

None, until complete or partial deployment failure is noted. Partial deployment will result in the loss of one system.

4.3.4.6 Compensating provisions.

Second system unaffected by this failure.

4.3.4.7 Severity level

2R

4.3.4.8 Probability of occurrence

0,23%

4.3.4.9 Criticality

Not critical

4.3.4.10 Retention rationale

Parallel system not affected

4.4 THE ENERGY STORAGE AND TRANSFER CIRCUITRY

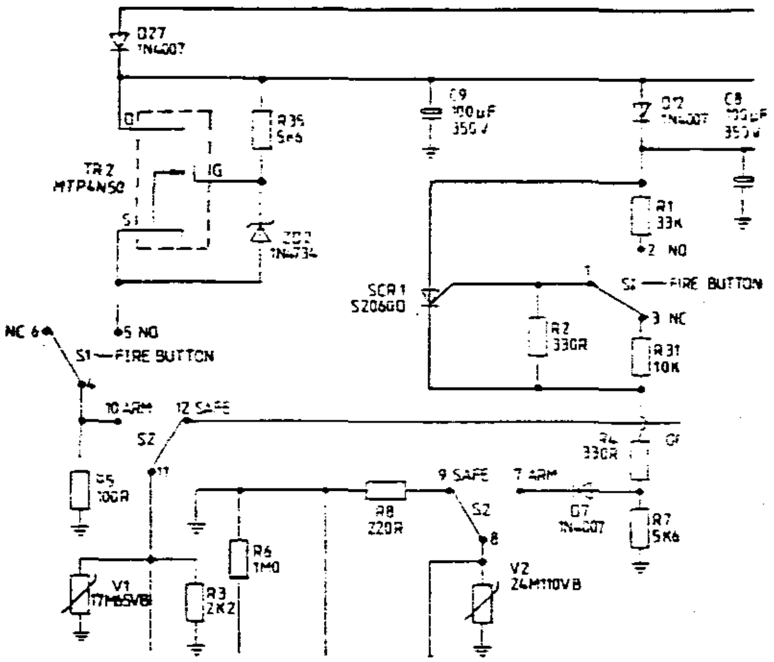


FIGURE 140: ENERGY STORAGE AND TRANSFER CIRCUITS

4.4.1 General

This section of the firing unit stores the energy used for initiating the pyrotechnic chains and transfers it to the pyrotechnic chains when required. The following failure modes will be considered in turn:

A. Premature operation
B. Failure to operate at a prescribed time
C. Failure during operation

This section of the firing unit circuit is the final safety barrier between the operator and launching of the system.

4.4.2 Function : Premature Operation(A)

4.4.2.1 Failure causes

The following component failures, modes and reliability circuits would cause premature operation. Premature operation could occur at any instant from pre-mission checkout to system deployment.

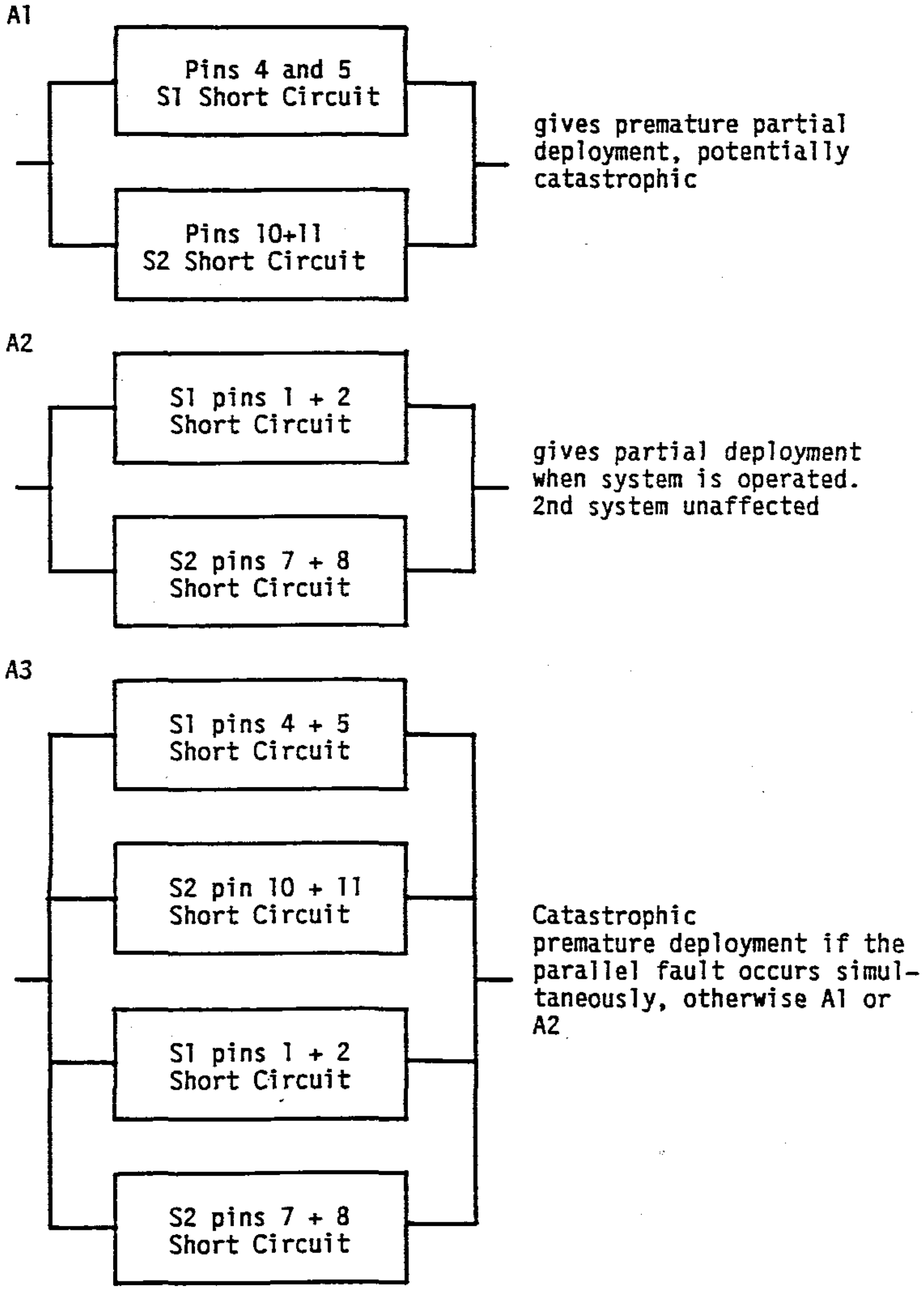


FIGURE 14 : FAILURE CIRCUITS CAUSING PREMATURE OPERATION

The probability of occurrence of A1 and A2 are the same while A3 is less likely to occur. The calculations pertaining to A1,A2 and A3 are shown below.

SWITCH	λ p	FACTOR	TOTAL
S1 :	20×10^{-9}	40%	8×10^{-9}
S2 :	$36{,}73 \times 10^{-9}$	40%	$14{,}69 \times 10^{-9}$

All have a common factor of spring breakage through fatigue being the failure mode. This apportions a factor of 40%.

Parallel failure rate λ_t for the two switches A1 and A2: (see 4.2.2.1 for formula derivation)

$$\frac{1}{\lambda t} = \frac{1}{\lambda S_1} + \frac{1}{\lambda S_2} - \frac{1}{\lambda S_1 + \lambda S_2}$$

$$= \frac{1}{8 \times 10^{-9}} + \frac{1}{14{,}69 \times 10^{-9}} - \frac{1}{8 \times 10^{-9} + 14{,}69 \times 10^{-9}}$$

$$= \frac{1}{6{,}7 \times 10^{-9}}$$

$$\therefore \lambda_t = 6{,}7 \times 10^{-9}$$

It can be noticed that A3 is actually A1 and A2 in parallel, therefore

$$\frac{1}{\lambda T} = \frac{1}{\lambda t} + \frac{1}{\lambda t} - \frac{1}{2\lambda_t}$$

$$= \frac{1}{6{,}7 \times 10^{-9}} + \frac{1}{6{,}7 \times 10^{-9}} - \frac{1}{13{,}4 \times 10^{-9}}$$

$$= \frac{1}{4{,}47 \times 10^{-9}}$$

$$\therefore \lambda_T = 4{,}47 \times 10^{-9}$$

4.4.2.2 Mission phase

From pre-mission checkout to deployment of the system.

4.4.2.3 Next level effects

A1 Premature partial deployment
A2 Partial deployment when launched
A3 Catastrophic premature deployment

4.4.2.4 End effects

As per paragraph 4.4.2.3

4.4.2.5 Failure detection means

As per paragraph 4.4.2.3 No prior indication.

4.4.2.6 Compensating provisions

Mode A1, A2 and A3 do not affect the second parallel system, however A1 and A2 could also cause loss of other mission elements which would cause the mission to be aborted. Mode A3 could cause serious injury or death of personnel.

4.4.2.7 Severity level

A1 Level 1R
A2 Level 2
A3 Level 1

4.4.2.8 Probability of occurence

A1 0,0065%
A2 0,0065%
A3 0,0043%

4.4.2.9 Criticality

Neither A1, A2 nor A3 in paragraph 4.4.2.7 are critical

4.4.2.10 Retention rationale

The probability of occurrence is essentially zero.

4.4.3 Function : Failure to Operate at a Prescribed Time(B)

4.4.3.1 Failure causes

Data pertaining to 4.4.3 is shown below.

Component	Rate	Mode & Factor	Applied Rate
TR2	10×10^{-6}	open circuit 50%	5×10^{-6}
R35	$94,6 \times 10^{-9}$	open circuit 80%	$75,6 \times 10^{-9}$
ZD2	$194,4 \times 10^{-9}$	short circuit 50%	$97,2 \times 10^{-9}$
S1	20×10^{-9}	open circuit 20%	4×10^{-9}
R5	382×10^{-9}	short circuit 20%	$76,4 \times 10^{-9}$
S2	$36,7 \times 10^{-9}$	open circuit 10%	$3,7 \times 10^{-9}$
V1	$278,5 \times 10^{-9}$	short circuit 5%	$13,9 \times 10^{-9}$
R3	$42,9 \times 10^{-9}$	short circuit 20%	$8,6 \times 10^{-9}$
SCR1	27×10^{-6}	open circuit 50%	$13,5 \times 10^{-6}$
R2	$42,9 \times 10^{-9}$	short circuit 20%	$8,6 \times 10^{-9}$
S1	20×10^{-9}	open circuit 20%	4×10^{-9}

Component	Rate	Mode & Factor	Applied Rate
R4	$42,9 \times 10^{-9}$	open circuit 80%	$34,32 \times 10^{-9}$
R7	$70,2 \times 10^{-9}$	short circuit 20%	$14,04 \times 10^{-9}$
D7	$60,1 \times 10^{-9}$	open circuit 6%	$3,6 \times 10^{-9}$
V2	$278,5 \times 10^{-9}$	short circuit 5%	$13,93 \times 10^{-9}$
SKZ	$307,7 \times 10^{-9}$	open circuit 1,7%	$5,13 \times 10^{-9}$
S2	$36,73 \times 10^{-9}$	open circuit 10%	$3,67 \times 10^{-9}$
R1	$42,9 \times 10^{-9}$	open circuit 80%	$34,3 \times 10^{-9}$
		TOTAL FAILURE RATE	$18,9 \times 10^{-6}$

4.4.3.2 Mission phase

From pre-mission checkout to deployment

4.4.3.3 Next level effects

Partial or no deployment of the system, when system deployment is attempted.

4.4.3.4 End effects

See paragraph 4.4.3.3

4.4.3.5 Failure detection means

As per 4.4.3.3 No prior indication.

4.4.3.6 Compensating provisions

The second system is not affected by this fault.

4.4.3.7 Severity level

Level 2R

4.4.3.8 Probability of occurrence

18,4%

4.4.3.9 Criticality

This falls in the critical zone.

4.4.3.10 Retention rationale

Although overall mission reliability is acceptable, more reliable devices should be substituted for both TR2 and SCR1. If their reliabilities can be increased to approximately 200 failures per 10^9 hours, this would become non-critical. However other effects would be that the percentage fault probability of other circuits would rise and some of them would enter into the critical area when compared to the overall reliability of the system. A further school of thought could well be that since this is mission reliability and not safety reliability, this high probability of failure is acceptable, in that the overall system reliability is acceptable.

The separate output functions were combined for this part of the analysis as a failure of one affects the whole system. The seperate percentage failure rates are indicated below.

Fuze head initiating circuitry	5,1%
Capacitor charging circuitry	13,3%
TOTAL	18,4%

These figures still fall within the criticality matrix for severity class 2R.

4.4.4 Function : Failure During Operation (C)

4.4.4.1 Failure causes

Components not listed in 4.4.3.1 which could cause this function to fail are listed below.

Component	Rate	Mode & Factor	Applied Rate
D27	46,5 x 10^{-9}	open circuit 6%	2,79 x 10^{-9}
SKZ	307,7 x 10^{-9}	open circuit 1,7%	5,13 x 10^{-9}
C9	271 x 10^{-9}	open circuit 40%	108,4 x 10^{-9}
C8	271 x 10^{-9}	open circuit 40%	108,4 x 10^{-9}
D12	46,5 x 10^{-9}	open circuit 6%	2,79 x 10^{-9}
		TOTAL FAILURE RATE	227 x 10^{-9}

4.4.4.2 Mission phase

This fault could occur from pre-mission checkout to deployment of the system. It would only be noted at attempted system deployment.

4.4.4.3 Next level effects

Partial or complete failure of the system to deploy.

4.4.4.4 End effects

As per 4.4.4.3

4.4.4.5 Failure detection means

None, until deployment is attempted.

4.4.4.6 Compensating provisions

The second system is unaffected by this fault.

4.4.4.7 Severity level

Level 2R

4.4.4.8 Probability of occurrence

0,22%

4.4.4.9 Criticality

This falls outside the critical zone.

4.4.4.10 Retention rationale

The probability of occurrence is so small that it is not economically viable to improve this section of the firing unit circuitry.

4.5 THE IMPEDANCE MEASURING SYSTEM

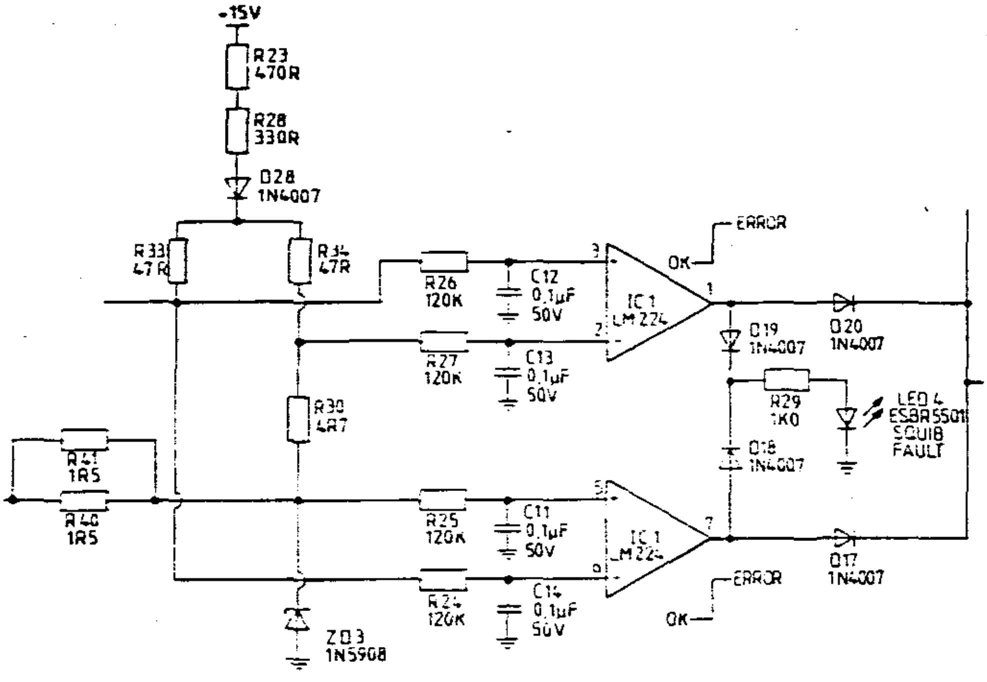


FIGURE 142: IMPEDANCE MEASURING CIRCUIT

4.5.1 General

The circuitry must safely measure the acceptable resistance range of the fuze-head before allowing deployment to continue. The following failure modes will be considered.

A. Failure to operate at a prescribed time

B. Degraded or excessive operational capability

C. Safety reliability

4.5.2 Function : Failure to Operate at a Prescribed Time (A)

4.5.2.1 Failure causes

Listed below are component failures and their modes which would result in failure to operate at a prescribed time.

Component	Rate	Mode & Factor		Applied Rate
IC1	506×10^{-9}	2 outputs low	41%	$207,5 \times 10^{-9}$
D17	$46,5 \times 10^{-9}$	open circuit	6%	$2,79 \times 10^{-9}$
D20	$46,5 \times 10^{-9}$	open circuit	6%	$2,79 \times 10^{-9}$
C11	$24,8 \times 10^{-9}$	short circuit	50%	$12,4 \times 10^{-9}$
C12	$24,8 \times 10^{-9}$	short circuit	50%	$12,4 \times 10^{-9}$
R25	$47,2 \times 10^{-9}$	open circuit	80%	$37,76 \times 10^{-9}$
R26	$47,2 \times 10^{-9}$	open circuit	60%	$37,76 \times 10^{-9}$
R40 & R41	63×10^{-9}	short circuit	20%	$12,6 \times 10^{-9}$
R30	$94,6 \times 10^{-9}$	open circuit	80%	$75,7 \times 10^{-9}$
		TOTAL FAILURE RATE		$401,68 \times 10^{-9}$

4.5.2.2 Mission phase

Pre-mission checkout.

4.5.2.3 Next level effects

Failure to trigger discharge circuitry.

4.5.2.4 End effects

Possible failure to initiate system when required.

4.5.2.5 Failure detection means

No prior indication of failed system initiation.

4.5.2.6 Compensating provisions

The system would fail to deploy only if the fuze-head was also out of tolerance. The second parallel system is unaffected by the failure.

4.5.2.7 Severity level

Level 2R

4.5.2.8 Probability of occurrence

0,4%

4.5.2.9 Criticality

Not critical

4.5.2.10 Retention rationale

The probability of occurrence and the seriousness thereof is outside the criticality matrix.

4.5.3 Function : Degraded or Excessive Operational Capability (B)

4.5.3.1 Failure causes

Listed below are component failures and modes that would cause this type of failure.

Component	Rate	Mode & Factor		Applied Rate
R23	$42,9 \times 10^{-9}$	open circuit	80%	$34,3 \times 10^{-9}$
R28	$50,7 \times 10^{-9}$	open circuit	80%	$40,6 \times 10^{-9}$
D28	$46,5 \times 10^{-9}$	open circuit	80%	$37,2 \times 10^{-9}$
R33	$42,9 \times 10^{-9}$	short circuit	20%	$8,6 \times 10^{-9}$
R34	$42,9 \times 10^{-9}$	short circuit	20%	$8,6 \times 10^{-9}$
R30	$94,6 \times 10^{-9}$	short circuit	20%	$18,9 \times 10^{-9}$
R40	$94,6 \times 10^{-9}$	open circuit	80%	$75,7 \times 10^{-9}$
R41	$94,6 \times 10^{-9}$	open circuit	80%	$75,7 \times 10^{-9}$
SKZ	$153,85 \times 10^{-9}$	1 of 3 pins open	10%	$15,4 \times 10^{-9}$
R24	$47,2 \times 10^{-9}$	open circuit	80%	$37,8 \times 10^{-9}$
R25	$47,2 \times 10^{-9}$	open circuit	80%	$37,8 \times 10^{-9}$
R26	$47,2 \times 10^{-9}$	open circuit	80%	$37,8 \times 10^{-9}$
R27	$47,2 \times 10^{-9}$	open circuit	80%	$37,8 \times 10^{-9}$
		TOTAL FAILURE RATE		$466,2 \times 10^{-9}$

4.5.3.2 Mission phase

Pre-mission checkout.

4.5.3.3 Next level effects

Erratic or no triggering of discharge circuitry.

4.5.3.4 End effects

Possible failure to initiate the system when required, or erroneous fuze-head fault indication which aborts system operation.

4.5.3.5 Failure detection means

Erroneous fuze-head fault indication, otherwise failure to initiate the system when required.

4.5.3.6 Compensating provisions

An erroneous fuze-head fault gives prior indication that the parallel system must be used. Failure to deploy when required would only occur if the fuze-head was also out of tolerance. This would also necessitate use of the parallel system.

4.5.3.7 Severity level

Level 2R

4.5.3.8 Probability of occurrence

0,45%

4.5.3.9 Criticality

This potential fault is not critical.

4.5.3.10 Retention rationale

The probability of occurrence is so low that investigation into improving reliability is uneconomical.

4.5.4 Function : Safety Reliability (C)

4.5.4.1 Failure causes

Due to the seriousness of this potential failure and for other related reasons, this section of the circuit was re-appraised in depth. New values for failure rates, according to MIL-HDBK-217E, were calculated. The following are the results of that re-appraisal:

As calculated in the Reliability Calculation on pages 4.63 to 4.71, IC2 failure rate is equal to 4 failures per 10^9 hours, of which 50% can be ascribed to high output. If this occurs, the voltage at D8 cathode will rise from 15V to approximately 25V and will be applied to IC1. The manufacturers allow a *maximum of* 32V *on* IC1 (LM224). ($\lambda p = 61{,}1 \times 10^{-9}$). The equivalent circuit is shown below.

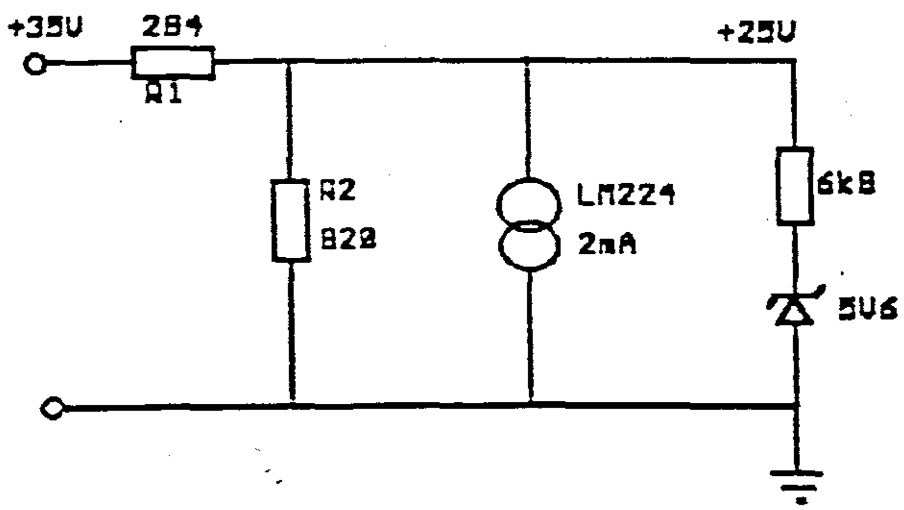


FIGURE 143: THE EQUIVALENT INPUT IMPEDANCE

R1 comprises the equivalent reflected resistance of the hand-cranked generator, transformer primary and transformer secondary circuits. R2 is *the equivalent resistance of the* measuring circuitry.

The maximum no-fire current through the fuze-head used is 50 mA. The firing unit's normal measuring current is 10 mA. If IC2 failed this current would rise to 15 mA.

The safety reliability diagram of the impedance measuring circuitry is shown below. These circuits are subdivided into smaller sections, their failure rates calculated and then combined once more to provide the overall failure rate.

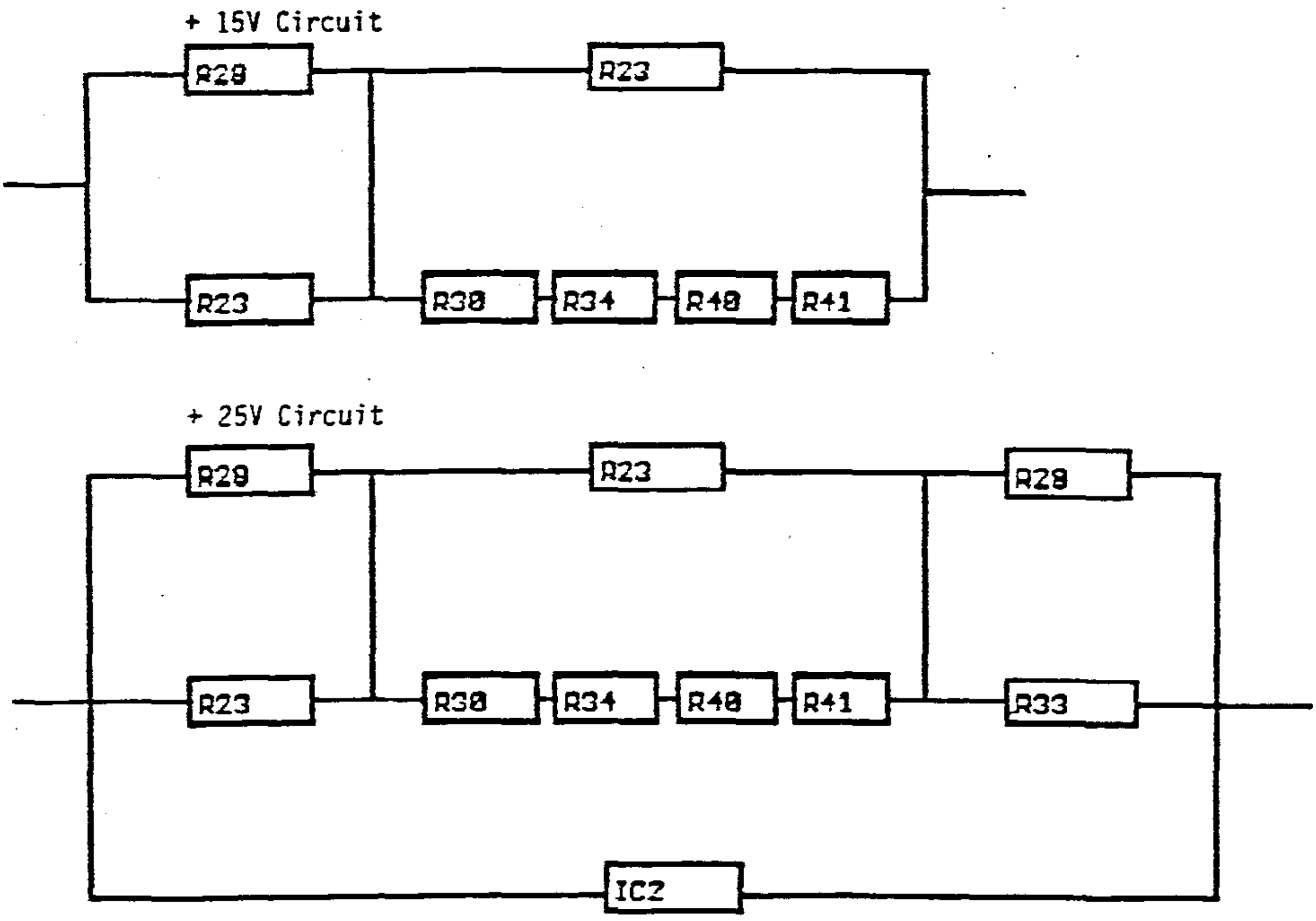


FIGURE 144: SAFETY RELIABILITY DIAGRAM OF THE IMPEDANCE MEASURING SYSTEM

RELIABILITY CALCULATION

All calculations shown below are based on information contained in MIL-HDBK-217E. (Released 27th October 1986).

IC2

The part operating failure rate (λp):

$$\lambda p = \pi_Q(C_1 \pi_T \pi_V + C_2 \pi_E) \pi_L \text{ failures}/10^6 \text{ hours}$$

π_Q = Quality factor = 0,25
π_T = Temperature acceleration factor = 1,5
π_V = Voltage stress derating factor = 1
π_E = Application Environment factor, ground mobile = 4,2
C_1 = Circuit complexity factor = 0,01
C_2 = Package complexity failure rate = 0,0003
π_L = Device learning factor = 1

$$\lambda p = 0{,}25\ (0{,}01 \times 1{,}5 \times 1) + (0{,}0003 \times 4{,}2) \text{ failures per } 10^6 \text{ hours}$$
$$= 4{,}07 \text{ failures per } 10^9 \text{ hours}$$

IC1

The part operating failure rate model is as for IC2

$$\lambda p = \pi_Q\ (C_1\ \pi_T\ \pi_V + C_2\ \pi_E)\pi_L$$

π_Q = 2
π_T = 1,5
π_V = 1
π_E = 4,2
C_1 = 0,01
C_2 = 0,0037
π_L = 1

λp = 2(0,01 x 1,5 x 1) + (0,0037 x 4,2)1

= 61,08 failures per 10^9 hours

The following failure rate calculations are for the resistors in the circuit. Two values are quoted, one for a supply of 15V and the second for a supply of 25V. The 25V supply is valid when IC2 fails short circuit. The Π factors are identical for both voltages.

Information is also quoted for failure rate modes.

<u>R23 0.5 W 1% 470 Ω MIL-R-10509</u>

The part operating failure rate model is:

$$\lambda p = \lambda b \, (\Pi_E \times \Pi_R \times \Pi_Q)$$

where

Π_E = Environmental factor = 7,8

Π_R = up to 100 K = 1

Π_Q = Quality factor = 5

λb for 15V = 0,0010 (60°C)

λb for 25V = 0,0013 (60°C)

<u>15V</u>:

λp = 0,001 (7,8 x 1 x 5)

= 39 failures per 10^9 hours

<u>25V</u>:

λp = 0,0013 (7,8 x 1 x 5)

= 50,7 failures per 10^9 hours

R28 0.5 W 1% 330 Ω MIL-R-10509

The part operating failure rate is as for R23, as are the π_E, π_R and π_Q factors.

λb for 15V = 0,00092
λb for 25V = 0,0012

15V:

λp = 0,00092 (7,8 x 1 x 5)
= 35,88 failures per 10^9 hours

25V:

λp = 0,0012 (7,8 x 1 x 5)
= 46,8 failures per 10^9 hours

R30 0.5 W 5% 0.47 Ω MIL-R-11 Carbon Film

The part operating failure rate model is as per R23.

π_E = Ground mobile = 8,3
π_R = Resistance factor, up to 100 k = 1
π_Q = Quality, MIL-R-11 = 5

15V:

λ_b = 0,00063

25V:

λ_b = 0,00063

Therefore the 15V and 25V part failure rates are identical, viz.

λ_p = 0,00063 (8,3 x 1 x 5)
λ_p = 26,15 failures per 10^9 hours

<u>R33 AND R34 0.5W 1% 47Ω MIL-R-10509</u>

The rates and Π factors are as per R23.

Π_E = 7,8
Π_R = 1
Π_Q = 5

<u>15V</u>:

λ_b = 0,00092

<u>25V</u>:

λ_b = 0,00092

<u>The 15V and 25V part failure rates are both</u>:

λ_p = 0,00092 (7,8 x 1 x 5)
λ_p = 35,88 failures per 10^9 hours

<u>R40 and R41 0.5W 5% 1,5 Ω MIL-R-11 Carbon film</u>

The rates and Π factors are as per R30.

Π_E = 8,3
Π_E = 1
Π_Q = 5

15V:

λ_b = 0,00063

25V:

λ_b = 0,00063

The 15V and 25V part failure rate is:

λ_p = 0,00063 (8,3 x 1 x 5)
= 26,15 failures per 10^9 hours

The Safety Failure Rate

FIGURE 145 : THE SERIES CIRCUIT

The total series' failure rate of the above resistors is the algebraic sum of the individual failure rates. This summation is valid for the stress due to a 25V or a 15V supply.

Component	Rate	% open circuit
R30	$23,53 \times 10^{-9}$	90%
R34	$34,1 \times 10^{-9}$	95%
R40	$23,53 \times 10^{-9}$	90%
R41	$23,53 \times 10^{-9}$	90%
TOTAL	$104,68 \times 10^{-9}$	(for the stress due to a 25V or a 15V supply)

R23 in parallel with the previous combination

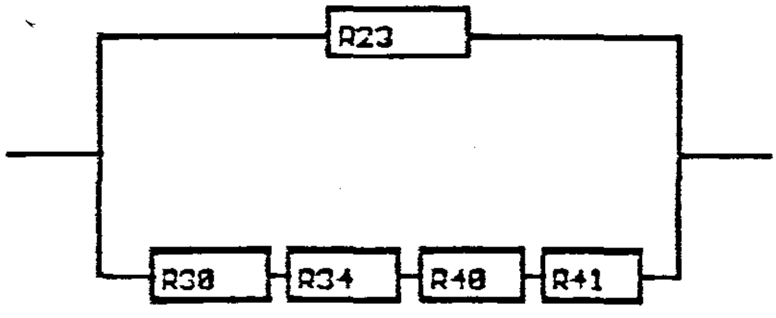


FIGURE 146 : THE PARALLEL CIRCUIT, R23 IN PARALLEL WITH R30,34, 40,41

5% of metal film resistors fail short circuit resulting in the applied R23 failure rate being $1,79 \times 10^{-9}$ for 15V and $2,34 \times 10^{-9}$ for 25V.

The parallel combination formula is:

$$\frac{1}{\lambda t} = \frac{1}{\lambda p1} + \frac{1}{\lambda p2} - \frac{1}{\lambda p1 + \lambda p2}$$

A 15V supply causes the following stress:

$$\frac{1}{1,79 \times 10^{-9}} + \frac{1}{104,68 \times 10^{-9}} - \frac{1}{1,79 \times 10^{-9} + 104,68 \times 10^{-9}}$$

$$\lambda_{t15} = 1,79 \times 10^{-9}$$

While the 25V supply causes a greater stress as shown below:

$$\frac{1}{2,34 \times 10^{-9}} + \frac{1}{104,68 \times 10^{-9}} - \frac{1}{2,34 \times 10^{-9} + 104,68 \times 10^{-9}}$$

$$\lambda_{t25} = 2,34 \times 10^{-9}$$

<u>R23 in parallel with R28</u>.

R28 rate is $35,88 \times 10^{-9}$ for 15V and $46,8 \times 10^{-9}$ for 25V, as calculated previously. The failure mode factor (short circuit) is 5%.

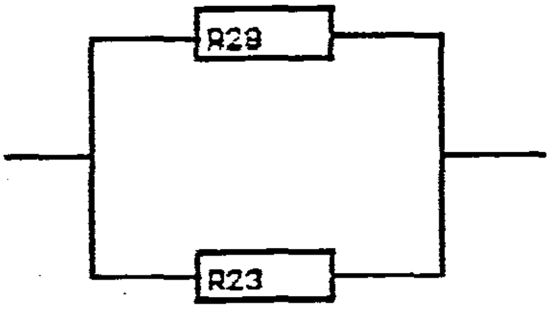


FIGURE 147 : THE PARALLEL CIRCUIT. R23 IN PARALLEL WITH R28

A 15V stress gives the following failure rate:

$$\frac{1}{\lambda_{t15}} = \frac{1}{1,79 \times 10^{-9}} + \frac{1}{1,79 \times 10^{-9}} - \frac{1}{1,79 \times 10^{-9} + 1,79 \times 10^{-9}}$$

$$\lambda_{t15} = 1,196 \times 10^{-9}$$

While a 25V stress level gives:

$$\frac{1}{\lambda_{t25}} = \frac{1}{2,34 \times 10^{-9}} + \frac{1}{2,34 \times 10^{-9}} - \frac{1}{2,34 \times 10^{-9} + 2,34 \times 10^{-9}}$$

$$\lambda_{t25} = 1,56 \times 10^{-9}$$

<u>R28 in parallel with R33 (25V only)</u>

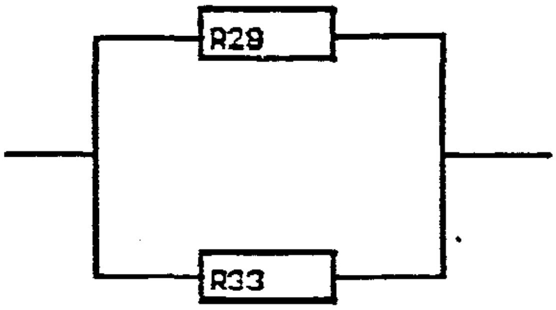


FIGURE 148: THE PARALLEL CIRCUIT, R28 IN PARALLEL WITH R33

$$\frac{1}{\lambda_{t25}} = \frac{1}{2,34 \times 10^{-9}} + \frac{1}{1,79 \times 10^{-9}} - \frac{1}{1,79 \times 10^{-9} + 2,34 \times 10^{-9}}$$

$$= 1,345 \times 10^{-9}$$

The total safety combination for a 15V supply (Figure 9) is calculated below:

$$\lambda_t = 1,196 \times 10^{-9} + 1,79 \times 10^{-9}$$

$$= 2,986 \times 10^{-9} \text{ failures per hour}$$

While for the 25V circuit the total failure rate is:

$$\lambda_t = 1,345 \times 10^{-9} + 2,34 \times 10^{-9} + 1,56 \times 10^{-9}$$

$$= 5,25 \times 10^{-9} \text{ failures per hour,}$$

and taking IC2 into consideration, as shown in Figure 9,

$$\lambda_T = \frac{1}{5,25 \times 10^{-9}} + \frac{1}{4,07 \times 10^{-9}} - \frac{1}{5,25 \times 10^{-9} + 4,07 \times 10^{-9}}$$

$= 3,04 \times 10^{-9}$ failures per hour.

This represents a failure rate increase from 1 failure per 335 million hours (15V) to 1 failure per 329 million hours (25V).

The probability of a catastrophic failure at a stress induced by a 15V supply is 0,00291%, while the stress induced by 25V supply is 0,00296%, during the lifetime of the unit. This assumes a lifetime of 102,76 failures per 10^6 hours as previously calculated (para. 3.14)

4.5.4.2 Mission phase

Pre-mission checkout

4.5.4.3 Next level effects

Potentially catastrophic premature partial initiation of the system.

4.5.4.4 End effects

As per paragraph 4.5.4.3

4.5.4.5 Failure detection means

None

4.5.4.6 Compensating provisions

Notwithstanding paragraph 4.5.4.3, the second parallel system is unaffected.

4.5.4.7 Severity level

Level 1R

4.5.4.8 Probability of occurrence

25V : 0,00296%

15V : 0,00291%

Note: The original total failure rate of 102,76 failures per 10^6 hours was still used as the base factor. If MIL-HDBK-217E was used throughout, this base figure would change, but not enough to significantly affect the final percentages. Due to the sensitivity of this failure it was decided to use the most up-to-date data available. This resulted in MIL-HDBK-217E being used in preference to MIL-HDBK-217D for this calculation. All other calculations are based on MIL-HDBK-217D.

4.5.4.9 Criticality

Not critical

4.5.4.10 Retention rationale

As per paragraph 4.5.3.9

4.6 THE INTERLOCK SENSING CIRCUITRY

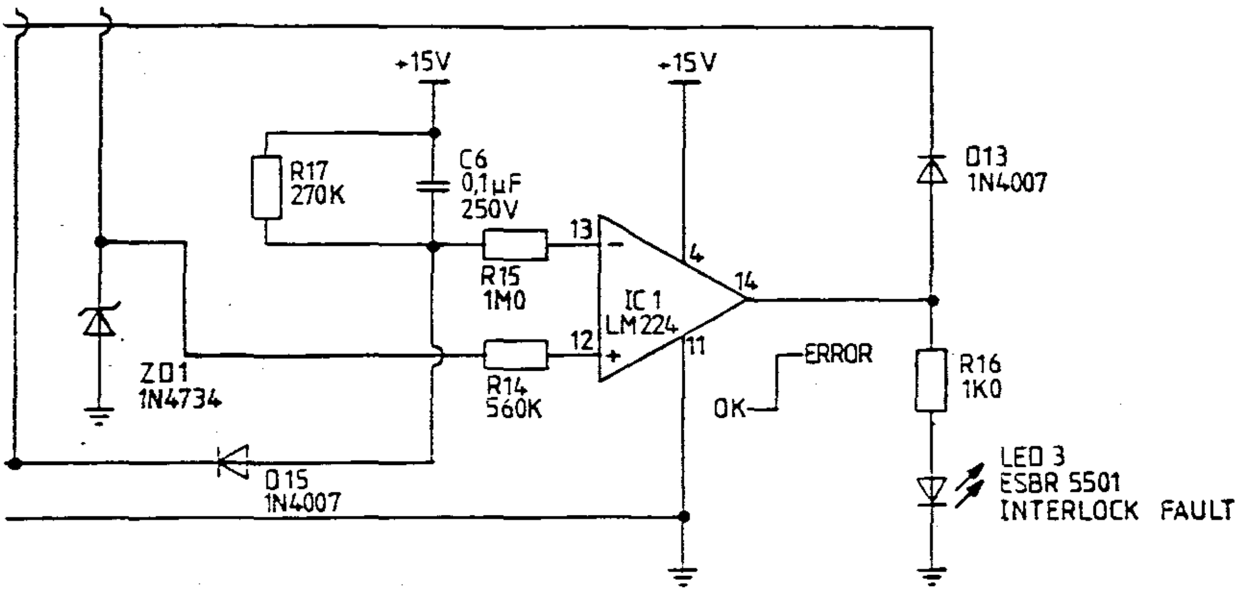


FIGURE 149: INTERLOCK SENSING CIRCUITRY

4.6.1 General

This circuit must sense an interlock error, attract the operators attention and automatically abort system deployment. This circuit only operates when the hand-cranked generator is cranked. Other parallel redundant circuitry has the same function when the firing unit is not being operated. The following failure modes will be considered:

A. premature operation

B. failure to operate at a prescribed time

4.6.2 Function : Premature Operation (A)

4.6.2.1 Failure causes

Component	Rate	Mode & Factor	Applied Rate
ZD1	$194,4 \times 10^{-9}$	open circuit 50%	$97,2 \times 10^{-9}$
IC1	506×10^{-9}	1 output high 2.5%	$12,7 \times 10^{-9}$
R15	$47,2 \times 10^{-9}$	open circuit 20%	$9,4 \times 10^{-9}$
R17	$47,2 \times 10^{-9}$	open circuit 20%	$9,4 \times 10^{-9}$
		TOTAL	$128,65 \times 10^{-9}$

4.6.2.2 Mission phase

Pre-mission checkout

4.6.2.3 Next level effects

Unwanted triggering of discharge circuitry and erroneous interlock fault indication

4.6.2.4 End effects

Erroneous rejection of that section of the total system

4.6.2.5 Failure detection means

Interlock error LED will illuminate, warning the operator of a fault.

4.6.2.6 Compensating provisions

The operator is warned of a system malfunction while he is still in a safe position. The other parallel system is unaffected by this fault.

4.6.2.7 Severity level

Level 2R.

4.6.2.8 Probability of occurrence

0,13%

4.6.2.9 Criticality

Not critical

4.6.2.10 Retention rationale

It is not economically viable to continue an investigation in order to improve the reliability of this circuit.

4.6.3 Function: Failure to Operate at a Prescribed Time (B)

4.6.3.1 Failure causes

The components pertaining to this failure are listed below.

Component	Rate	Mode & Factor		Applied Rate
D13	$46,5 \times 10^{-9}$	open circuit	6%	$2,79 \times 10^{-9}$
IC1	506×10^{-9}	output low	2.5%	$12,6 \times 10^{-9}$
R14	$47,2 \times 10^{-9}$	open circuit	80%	$37,76 \times 10^{-9}$
ZD1	$194,4 \times 10^{-9}$	short circuit	50%	$97,2 \times 10^{-9}$
D15	$46,5 \times 10^{-9}$	open circuit	6%	$2,79 \times 10^{-9}$
D13	LED3 + R16	parallel series circuit		$2,79 \times 10^{-9}$
		TOTAL		$155,9 \times 10^{-9}$

4.6.3.2 Mission phase

Pre-mission checkout

4.6.3.3 Next level effects

Failure to abort system deployment if an interlock fault is present.

4.6.3.4 End effects

If certain types of faults are present, which should have triggered the interlock error sensing circuitry, a catastrophic failure could occur when system deployment is attempted.

4.6.3.5 Failure detection means

The interlock fault LED and/or the discharged LED will illuminate. If certain combinations of faults occur, neither will illuminate and the operator will be unaware of the problem.

4.6.3.6 Compensating provisions

This fault would require that:

a. there was an interlock fault at the time of system initiation

b. the interlock fault indication was not working

c. the automatic abort system (dealt with seperately) was also unserviceble.

4.6.3.7 Severity level

1R

4.6.3.8 Probability of occurrence

0,152%

4.6.3.9 Criticality

Marginally critical if 4.6.3.6 is not included.

4.6.3.10 Retention rationale

A combination of three faults must occur before this fault (B) becomes critical. Referring to paragraph 4.6.3.6, mode (a) is dependent on training while (b) and (c) are firing unit related. Mode (c) is totally independent of the circuit under review.

4.7 THE DISCHARGE SYSTEM

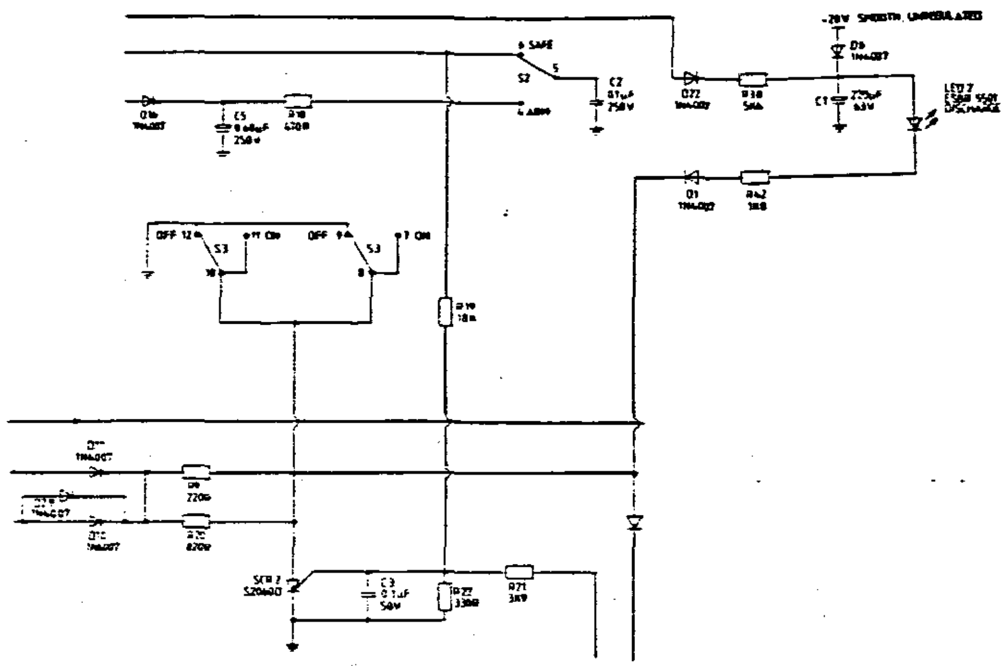


FIGURE 150: DISCHARGE CIRCUIT

4.7.1 General

The function of this circuitry is to abort deployment of the system under the following conditions:

a. Incorrect sequence of operation of the firing unit.
b. Returning the system to the safe mode after it has been armed.
c. Switching the unit off.
d. An interlock error occurs between pre-mission checkout and system deployment.

4.7.1.1 FAILURE MODES

The following failure modes will be investigated:

A. premature operation
B. failure to operate at a prescribed time
C. failure to cease operation at a prescribed time

4.7.2 Function : Premature Operation (A)

4.7.2.1 Failure causes

Listed below are the associated components and their applicable modes of failure.

Component	Rate	Mode & Factor	Applied Rate
SCR2	27×10^{-6}	short circuit 50%	$13,5 \times 10^{-6}$
S3, contacts 10 and 12 or/and 8 and 9	$26,8 \times 10^{-9}$	intermittent 50%	$8,9 \times 10^{-9}$
S2 contacts 5 and 4 and/or 2 and 3	$36,7 \times 10^{-9}$	intermittent 50%	$9,2 \times 10^{-9}$
		TOTAL	$13,5 \times 10^{-6}$

4.7.2.2 Mission phase

At any time during system operation.

4.7.2.3 Next level effects

Immediate system abort.

4.7.2.4 End effects

Failure to initiate the system when required.

4.7.2.5 Failure detection means

"Discharged" indication at time of failure and during the pre-mission checkout phase

4.7.2.6 Compensating provisions

a. This is a system fail-safe mode
b. The second system is unaffected by this failure

4.7.2.7 Severity level

Level 3

4.7.2.8 Probability of occurrence

13,2%

4.7.2.9 Criticality

This falls within the criticality matrix.

4.7.2.10 Retention rationale

SCR 2 is the major contributor to the high probability of this failure mode. This SCR is the same type as SCR1, mentioned in 4.7.3.10. A more reliable device should be substituted, having the same characteristics, but a more reliable construction.

4.7.3 Function : Failure to Operate at a Prescribed Time (B)

4.7.3.1 Failure causes

There are 3 different sub-circuits which are analysed individually. Their failure causes are shown individually below. They are thereafter combined in a safety reliability diagram.

B1. On/off failure

S3 contacts 8,9 and/or 10,12	$26,8 \times 10^{-9}$	intermitted 50%	$8,9 \times 10^{-9}$
		TOTAL	$8,9 \times 10^{-9}$

B2. Safe/Arm/Safe and fuze head error failure

Component	Rate	Mode & Factor		Applied Rate
C2	$38,5 \times 10^{-9}$	open or short	95%	$36,6 \times 10^{-9}$
R19	$42,9 \times 10^{-9}$	open circuit	80%	$34,3 \times 10^{-9}$
R21	$42,9 \times 10^{-9}$	open circuit	80%	$34,3 \times 10^{-9}$
R22	$42,9 \times 10^{-9}$	short circuit	20%	$8,6 \times 10^{-9}$
C3	$24,8 \times 10^{-9}$	short circuit	50%	$12,4 \times 10^{-9}$
SCR2	27×10^{-6}	open circuit	50%	$13,5 \times 10^{-6}$
		TOTAL		$13,6 \times 10^{-6}$

B3. C9, C8 associated circuit failure

Component	Rate	Mode & Factor	Applied Rate
R9	382×10^{-9}	open circuit 40%	$152{,}8 \times 10^{-9}$
R20	$62{,}4 \times 10^{-9}$	open circuit 80%	50×10^{-9}
D10	$79{,}4 \times 10^{-9}$	open circuit 6%	$4{,}76 \times 10^{-9}$
D11	$79{,}4 \times 10^{-9}$	open circuit 6%	$4{,}76 \times 10^{-9}$
D12	$46{,}5 \times 10^{-9}$	open circuit 6%	$2{,}80 \times 10^{-9}$
D29	$79{,}4 \times 10^{-9}$	open circuit 6%	$4{,}76 \times 10^{-9}$

The total failure rate is, however, not the sum of the individual rates and is calculated as follows:

The safety reliability diagram pertaining to B3.

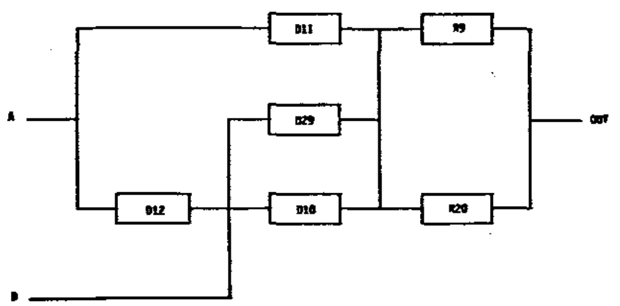


FIGURE 151: SAFETY RELIABILITY DIAGRAM, DISCHARGE SYSTEM

Input A designates C9 circuitry while input B designates C8 circuitry. Input A alone is used for further calculations as it is a marginally worse case than input B.

The parallel safety formula is:

$$\frac{1}{\lambda_t} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{\lambda_1 + \lambda_2}$$ (See 4.2.3 for derivation)

where λ_t is the overall value while λ_1 and λ_2 are the 2 individual components making up the parallel circuit. The contribution of each combination is calculated in turn and then combined to achieve an overall answer.

<u>R9 and R20</u>

$$\frac{1}{\lambda_t} = \frac{1}{152{,}8 \times 10^{-9}} + \frac{1}{50 \times 10^{-9}} - \frac{1}{202{,}8 \times 10^{-9}}$$

$$\therefore \lambda_t = 46{,}3 \times 10^{-9}$$

<u>D10 and D29</u>

$$\lambda_t = \frac{1}{4{,}76 \times 10^{-9}} + \frac{1}{4{,}76 \times 10^{-9}} - \frac{1}{9{,}52 \times 10^{-9}}$$

therefore $\lambda_t = 3.17 \times 10^{-9}$

The total rate for B input is $49,44 \times 10^{-9}$ as D11 and D12 are not in circuit.

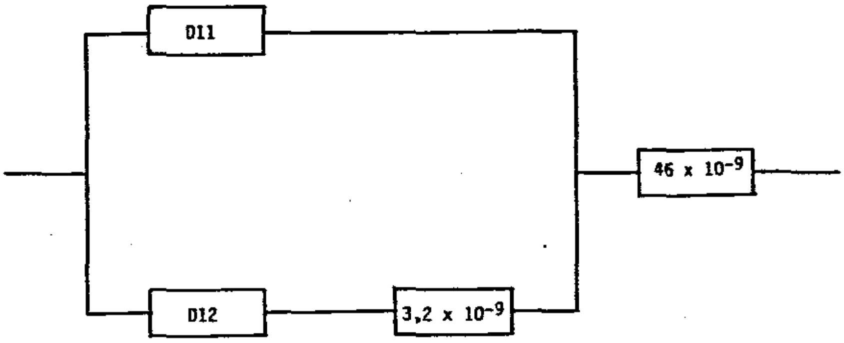


FIGURE 152: CONSIDERING D12 IN THE PARTIAL SAFETY DIAGRAM

taking into account D12, the failure rate becomes $5,97 \times 10^{-9}$,

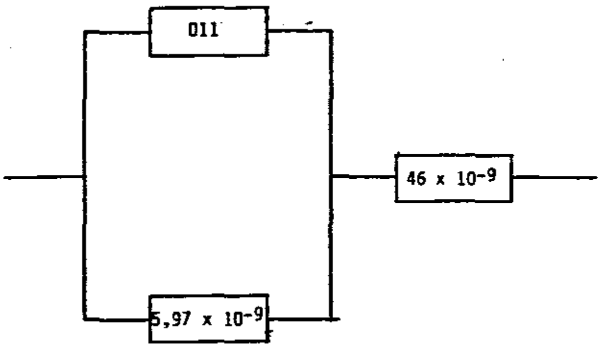


FIGURE 153: CONSIDERING D11 IN THE PARTIAL SAFETY DIAGRAM

then taking D11 into consideration the failure rate becomes $3,51 \times 10^{-9}$

The overall failure rate of input A, Figure 15 becomes

$$3,51 \times 10^{-9} + 46,3 \times 10^{-9} = 49,8 \times 10^{-9}$$

this is represented below as the block marked B3 in Figure 154.

The complete safety diagram of the circuit shown in Figure 150 is shown below,

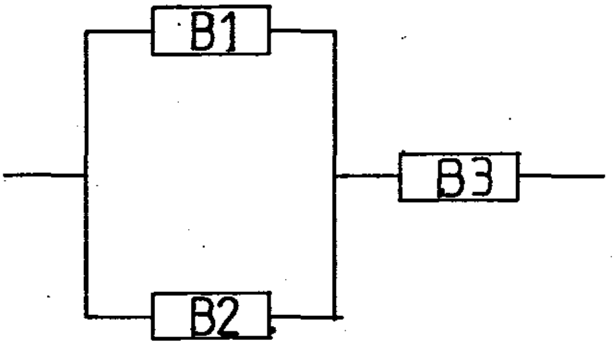


FIGURE 154: THE DISCHARGE SYSTEM EQUIVALENT SAFETY DIAGRAM

where the value of B1 is $8,9 \times 10^{-9}$, B2 is $13,6 \times 10^{-6}$ and B3 is $49,8 \times 10^{-9}$ as previously calculated.

Combining B1 and B2 results in a failure rate of:

$$\frac{1}{\lambda_t} = \frac{1}{13,6 \times 10^{-6}} + \frac{1}{8,9 \times 10^{-9}} - \frac{1}{13,6 \times 10^{-6} + 8,9 \times 10^{-9}}$$

$$\therefore \lambda_t = 8,9 \times 10^{-9}$$

When taking B3 into account, the final failure rate for Figure 150 becomes $58,7 \times 10^{-9}$ failures per hour.

4.7.3.2 Mission Phase

Fault combinations B1 and B2 could occur during pre-mission checkout or during standby

While combination B3 could occur during pre-mission checkout, at any time during the mission if an interlock error occurs or during standby.

4.7.3.3 Next level effects

B1. Failure to discharge the main energy storage on switch off

B2. Failure to discharge the main energy storage when a fuze-head error occurs or when the firing unit is switched from "Armed" to the "Safe" mode.

B3. The same effect as B1 and B2 and also if an interlock error occurs during the mission.

4.7.3.4 End effects

Failure of the system to become totally safe after the events in 4.7.3.3 occur.

4.7.3.5 Failure Detection Means

B1. None

B2. Fuse head fault and/or interlock fault will still light up during pre mission checkout

B3. None

4.7.3.6 Compensating provisions

B1 and B2 will not cause mission loss or any other operator noticeable effect if the system is operated correctly.

B3 This fault could cause a catastrophic failure if an interlock fault occurs during the mission, immediately prior to system deployment. This would also require that the operator does not notice the discharged indication as the interlock fault occurs.

4.7.3.7 Severity level

B1 and B2, Level 3

B3 Level 1R

If B1 and B2 and B3 occur, level 1R.

4.7.3.8 Probability of Occurrence

B1 0,01%

B2 13,2%

B3 0,048%

B1, B2 and B3 0,057%

4.7.3.9 Criticality

B1 Not critical

B2 This is in the critical area. See 4.7.2.10

B3 Not critical

B1, B2 and B3 Not critical

4.7.3.10 Retention rationale

See paragraph 4.7.2.10 when considering B2

4.7.4 Function : Failure to Cease Operation at a Prescribed Time (C)

4.7.4.1 Failure causes

The components and their failure modes which would cause the fault are listed below.

Component	Rate	Mode & Factor	Applied Rate
S3 contacts 10,12 and/or 8,9.	$26,8 \times 10^{-9}$	intermittent 50%	$8,9 \times 10^{-9}$
S2 contacts 4 and 5.	$36,73 \times 10^{-9}$	intermittent 50%	$4,6 \times 10^{-9}$
SCR2.	27×10^{-6}	short circuit 50%	$13,5 \times 10^{-6}$
		TOTAL	$13,5 \times 10^{-6}$

4.7.4.2 Mission phase

Pre-mission checkout

4.7.4.3 Next level effects

Prevention of any charge stored in C8 and C9.

4.7.4.4 End effects

Failure to initiate the system when required.

4.7.4.5 Failure setection means

No "On Charge" indication to indicate system ready and a continuous "discharged" indication although neither "Squib Fault" nor "Interlock Fault" is indicated.

4.7.4.6 Compensating provisions

The operator would very quickly notice that the firing unit is not functional when the system is tested in the Pre-mission phase. This fault does not effect the second parallel system.

4.7.4.7 Security level

Level 3

4.7.4.8 Probability of occurrence

13,1%

4.7.4.9 Criticality

This falls within the criticality matrix

4.7.4.10 Retention rationale

See paragraph 4.7.2.10

4.8 SUMMARY

TABLE 6 - SUMMARY OF CRITICALITY DETERMINATION

Paragraph numbers within a block marked "X" are those rated as critical

LEVEL OF SEVERITY	PROBABILITY OF OCCURRENCE > 20%	20%-10%	10%-1%	1%-0,1%	< 0,1%
1	X	X	X	X	X
1R	X	X	X	X 4.6.3	4.4.2 (A1) 4.5.4 (25V) 4.5.4 (15V) 4.7.3 (B3) 4.7.3 (B1+B2+B3)
2	X	X	X		4.4.2 (A2)
2R	X	X 4.4.3	X	4.3.2 4.3.4 4.4.4 4.5.2 4.5.3 4.6.2	
3	X	X 4.7.2 4.7.3(B2) 4.7.4	4.2.2 4.2.3 4.3.3		4.7.3 (B1)
4	X				

4.4.2(A3) has a 0,0043% probability failure at level 1, which is considered essentially zero and therefore not critical.

The three components most contributing to the criticality of 4.4.3; 4.7.2; 4.7.3(B2) and 4.7.4 are TR2, SCR1 and SCR2. SCR1 and SCR2 are identical types. The reliability of TR2 can be much improved by selecting an equivalent device in an hermetic package. An improvement in stress ratios would also be helpful. The major factor contributing to SCR1 and SCR2 unreliability is the plastic packaging which caries a weighting factor of 50. A compatible device with a more robust and reliable form of packaging would tend to alleviate the problems posed by these devices.

The interlock error sensing circuitry (4.6.3) is marginally critical, 0,152%, while 0,1% is not critical. This figure does not take the following into account, which would make this fault less critical:

a. there was a system fault at the time of system initiation
b. the interlock fault indication was also not working
c. the automatic abort system was also unserviceable.

For this reason 4.6.3 is accepted as not critical.

4.9 RECOMMENDATION

The reliability of this unit, as theoretically calculated, exceeds the user requirement. The firing unit is accordingly submitted for qualification testing.