DEFINITION STUDY,

DESIGN AND DEVELOPMENT

OF A FIRING UNIT TO

INITIATE TWO PYROTECHNIC

CHAINS

ROBERT PHILIP SYKES

THESIS SUBMITTED IN PART FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER'S DIPLOMA IN TECHNOLOGY IN THE SCHOOL OF ELECTRICAL ENGINEERING (LIGHT CURRENT) AT THE CAPE TECHNIKON.

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ABSTRACT

THE SUBJECT OF THIS THESIS IS THE DEVELOPMENT OF A HIGHLY
RUGGEDISED, RELIABLE ELECTRONIC CIRCUIT. THE CIRCUIT IS TO
BE USED FOR THE INITIATION OF FUZE HEADS AND TO CHARGE A
CAPACITOR FOR LATER USE IN A PYROTECHNIC CHAIN. THIS CIRCUIT
AND ITS ASSOCIATED PACKAGING WILL BE CALLED THE FIRING UNIT.

THE THESIS CAN BE BROADLY DIVIDED INTO THE FOLLOWING FACETS.

I.   THE DEFINITION STUDY, WHICH DEFINES WHAT IS NEEDED AND
      PROPOSED MEANS OF ACHIEVING THE CUSTOMER REQUIREMENTS.

II.   THE DESIGN OF THE ELECTRONIC CIRCUITRY IN THE SYSTEM.

III. THE DESIGN OF THE PACKAGING CONTAINING THE ELECTRONICS.

IV.   ADAPTATION OF ENVIRONMENTAL TESTING, TO VERIFY SYSTEM
      DESIGN.

V.   IMPLEMENTATION OF ENVIRONMENTAL TESTING.

VI.   RELIABILITY ANALYSIS.

VII. FAILURE ANALYSIS AND THE DETERMINATION OF THE EFFECT OF
      THE SUPPOSED FAILURE.

ACTIONS V TO VII WERE USED AS INPUTS TO IMPROVE II AND III,
SO ACHIEVING OPTIMUM PERFORMANCE AND SAFETY. THE WHOLE
SYSTEM WAS DESIGNED WITH THE OVERRIDING OBJECTIVE OF
RELIABILITY AND SAFETY OF PERSONNEL AND EQUIPMENT.

THE CONTENTS OF THIS THESIS REPRESENT MY OWN WORK AND THE
OPINIONS CONTAINED HEREIN ARE MY OWN, NOT NECESSARILY THOSE
OF THE CAPE TECHNIKON.

THIS THESIS COMPRISES 6 PARTS:

PART 1 -   THE DEFINITION STUDY

PART 2 -   THE EXPERIMENTAL/ADVANCED DESIGN MODEL OF THE FIRING UNIT

PART 3 -   THE ENGINEERING DESIGN AND PRE-QUALIFICATION MODEL

PART 4 -   THE FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS (FMECA)

PART 5 -   THE TEST UNIT DESIGN

PART 6 -   THE QUALIFICATION REPORT

Parts 1 and 2 comprise Volume 1, Parts 3 and 4 are contained in Volume 2 while Parts 5 and 6 comprise Volume 3.

As part of the detailed definition study of the whole system, studies were done on the firing unit and the communications system.   Part 1 of this thesis details the results, conclusions and recommendations from those studies.

Included are:

1. Safety Interlocking devices
2. Fuzehead impedance measuring circuitry
3. Firing unit emergency power supply
4. Radio Frequency Interference suppression

Excluded are:

5. Vehicle electrical requirements
6. Communications requirements

Each of 1 to 4 were studied in turn and different methods of achieving the required performance considered. In each case this resulted in a relatively clear path towards the design stage of the project.

Many questions were raised, at this stage of the project, which had considerable bearing on the direction of the project. These queries, had they been asked at a later stage, would have had serious time and financial implications for the entire project.

Part 2 of the thesis deals with the in-depth design and reliability studies of the firing unit. Included in this part is field, environmental and electromagnetic compatability testing.

The input for this phase of the project was the now, more formalised system specification and the clear guidelines given by Part 1 (The Definition Study). Policies on implementation of the system were finalised. From the end of this stage the basic principles of operation and most of the circuitry remained unchanged.

Attention was also paid to the design of the packaging around the firing unit circuitry, taking into account the enviromental stresses expected during the lifetime of the unit. Tests designed to simulate these enviromental stresses, extracted from MIL-STD-810D, were applied to the unit. Human engineering was also considered at this stage to ensure ease of operation.

Electromagnetic testing of the firing unit was carried out by the NEERI department of the CSIR Pretoria, to ensure correct and safe operation in areas of high electromagnetic field strength.

Their recommendations are attached as Appendix 7. The first formal drawings of the firing unit were completed during this stage.

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 were the overriding criteria when any changes were considered to the XDM/ADM circuitry.

Further inputs were obtained in the field of human engineering and ergonomics, notably in connection with finger clearance around switches and the text and letter size on the fascia of the firing unit.

Drawings were finalised during this stage, with firing units being constructed by people other than the designer, to check the documentation package. Aspects pertaining to ease of manufacture were addressed and finalised. The firing units produced at the end of this stage were essentially the same as those produced during qualification of the firing unit.

Part 4 of the thesis deals with the Failure Mode, Effects and Criticality Analysis (FMECA) on the firing unit. It was deemed necessary to complete this exercise due to the potential dangers of a firing unit malfunction. An analysis of hardware items was made to determine those items most likely to contribute to system unreliability and operational safety hazards.

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

The firing unit was the only item analysed. Reliability studies were conducted to estimate the lifetime of the device analysed. This required that any component of which the unreliability was significantly larger than any other component be re-evaluated, so that reliability design goals were achieved. However, cost constraints often dictated that it was 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, that was difficult to improve.

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 that
failure.

Whereas an item might be perfectly acceptable from a reliability
point of view, when the effects of the failure were taken into
consideration, the component would be totally unacceptable.

This component was then re-designed so that the chances of it
failing were remote when compared to the overall lifetime of the
equipment in which it was 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 was spent trying to improve its reliability.

Due to the inherent reliability of the system and the lack of
volume production, practical determination of failure rates was
not 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, were used as a source
of information to calculate these failure rates.

The method used, based on MIL-STD-1629A, was 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 were grouped into functional blocks. The FMECA was performed on these functional blocks. New failure rates were calculated for all components as previous failure rates were based on MIL-HDBK-217B, superseded by MIL-HDBK-217D and 217E.

The following is 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."

Part 5 of the thesis deals with the preliminary design of two test
units, namely;

  a training aid and confidence building unit.

  a workshop unit that actively measures the various outputs of
  the firing unit.

The scope of the original contract did not make provision for this
extra equipment and consequently only basic design information was
submitted. The final design of these units was considered outside
the scope of this document.

The concept behind the training aid was that it had to be totally
portable and independant of any external power supply.
Consequently the designed unit is both small and very simple,
drawing its power requirements from the energy output of the
firing unit.

Simple system faults can be introduced using this unit, by means
of a system of switches. These faults would then be echoed by the
firing unit itself. An indication is also provided to show the
training authority when the firing unit has been operated
correctly.

The training unit is a small hand held unit, which is likely to be badly treated. The packaging of this unit consequently needed much thought and encapsulation in epoxy was specified.

The workshop unit is intended to approximate the laboratory situation where expensive electronic equipment is available. This resulted in it being substantially more complex than the training aid and requiring an external supply. After much deliberation a 28 volt DC supply was used, as supplied by the parent vehicle. This contributed its own particular problems, in that a vehicle supply is inherently very noisy and subject to power dips and surges. These surges are not normally encountered in other environments.

This unit preformed most of the tests stipulated in the product specification, including the amplitude/time relationships of the firing unit outputs, essential for correct operation of the complete system.

Part 6 of this report deals with the qualification tests, and the results of those tests needed to bring the firing unit to qualification status.

The three firing units were built according to sealed documentation and then two were subject to extensive environmental testing extracted from MIL-STD-810D. The third firing unit was subjected to electromagnetic interference testing by the CSIR to ensure that the implementation of their recommendations (Part 2) were effective. The firing unit showed no faults during these tests and consequently were accepted as a qualified items, after the necessary formalities were completed.

The completion of these formalities signalled the end of the development phase of this firing unit.

In conclusion it remains for me to thank my mentors both at the Cape Technikon, at my place of employment and those at other institutions who so kindly helped me with the many problems posed by such a thesis. A special word of thanks must definitely go to the typists who endured the whims of a cranky student in preparing this manuscript.

AUTHOR   :   ROBERT PHILIP SYKES

MENTORS :   J L DAVIES
             C J DU PLESSIS
             G D RODGERS

TYPED BY :   G BERGMANN
             D BESTER
             D BOTHA
             S CILLIERS
             S MöLLER
             M MURRAY
             L VAN DER VOORT

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THE DEFINITION STUDY, DESIGN AND DEVELOPMENT

OF A

FIRING UNIT TO INITIATE TWO PYROTECHNIC CHAINS

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ABBREVIATIONS

A	Ampere
ADM	Advanced Design Model
Amp	Ampere
C	Capacitor
°C	Degrees Celsius
D	Diode
DC	Direct Current
DPDT	Double Pole Double Throw
EDM	Engineering Design Model
Hz	Hertz (cycles per second)
K	Kilo (ohms)
Kg	Kilograms
LED	Light Emitting Diode
M	Mega (ohm)
m	meter
mA	milliampere
mJ	millijoule
mm	millimeter
ms	millisecond
Ni–Cd	Nickel Cadmium
PCB	Printed Circuit Board
R	Resistor
RCA	A manufacturer of Semi Conductors
RLY	Relay
SAD	Safe and Arming Device
SCR	Silicon Controlled Rectifier (Thyristor)
uF	microfarad
uJ	microjoule
V	Volts
ZD	Zener Diode
	ohms
4PDT	Four Pole Double Throw

PART 1 - THE DEFINITION STUDY

CONTENTS LIST

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PART 1

SECTION 1 : INTRODUCTION

This thesis' subject is the development of a highly
ruggedised, reliable electronic circuit. The circuit is
to be used for the initiation of fuzeheads and to charge
a capacitor for later use in a pyrotechnic chain. This
circuit and it's associated packaging will be called the
firing unit.

As part of the detailed definition study of the whole
system, studies were done on the firing unit and the
communications system. This part of this thesis details
the results, conclusions and recommendations from those
studies.

SECTION 2 : THE LAUNCH PACK FIRING SYSTEM

2.1   PURPOSE

The purpose of this definition study is to set guidelines
for the design and development of a firing unit.

2.2   SCOPE

Included are:

a.   Safety Interlocking devices
b.   Fuzehead impedance measuring circuitry
c.   Firing unit emergency power supply
d.   Radio Frequency Interference suppression

Excluded are:

e.   Vehicle electrical requirements
f.   Communications requirements

2.3   APPLICABLE DOCUMENTS

MIL-STD-810D
MIL-Std-1275 A
MIL-Std-47231
MIL-E-8189 H
KA 3117
MIL-HDBK-217 B
MIL-Std-461B
MIL-Std-454
SABS-0111

2.4 DEFINITION

The launch pack firing control system will, throughout this report and all other reports, be referred to as the firing unit.

The function of the firing unit is to provide safety barriers to prevent accidental firing of the system and to initiate two pyrotechnic chains.

2.5 REQUIREMENTS

a. The firing unit must be located inside the carrier vehicle driver's compartment.
b. The operator must be able to select which one of two pyrotechnic systems is to be used.
c. It must be as small and compact as possible.
d. Standby batteries or an emergency power supply must be provided.
e. The continuity of the igniter must be tested by the firing unit before the system is activated.
f. The possibility of premature firing must be insignificant.
g. All units must be easily interchangeable.
h. Two complete parallel systems are required.
i. The system must be operational over a temperature range of 0°C to 60°C and be able to withstand a storage temperature range of -10°C to 60°C.

2.5.1 Sequence of Operations

STEP   ACTION

1) Switch "power on" switch to the on position.
2) Remove any physical interlocks - which removes the first safety barrier.
3) Remove the short circuit across the fuzehead by means of a relay - the second safety barrier.
4) Check the fuzehead continuity.
5) If the fuzehead is within specification, activate the pyrotechnic chains.

2.6 SYSTEM DEFINITION

2.6.1 General

All electrical systems must be operable from inside the vehicle driver's cab.

The system will include a transceiver. There must be no Radio Frequency Interference danger to the firing pack.

Standard components must be used whenever possible. Cross compatibility between all systems is a prerequisite.

The firing pack will be contained in a single, commercially
available aluminium box. It will be duplicated up to but
excluding the pyrotechnic chains. A change-over switch will
be used to switch between the two discrete systems, ensuring
redundancy and a high mission reliability.

All power lines will be short circuited when the unit is
switched off. Firing lines will be short-circuited until
such time as the ignition pulse for the pyrotechnic chains is
generated. The ignition pulse will be a single, fixed period
current pulse. Thereafter the firing lines will again be
short circuited.

2.6.2   <u>Function</u>

The firing system must ensure safe deployment of the
pyrotechnic subsystems. This is achieved by means of a
system of safety barriers which must be removed in a
predetermined sequence before ignition can occur. Any
malfunction will be brought to the operator's attention and
the ignition of the system will be automatically aborted.

2.6.2.1   <u>The fuzehead impedance measuring circuitry</u> (FIGURE 1)

The function of this circuitry is to compare the fuzehead
impedance against that of a known standard. The standard
will be placed in close proximity to the fuzehead to ensure
temperature compensation. A constant current design may be
used to achieve reliability and safety requirements of this
circuitry.

This circuitry will be included in the firing system safety
barriers.

POWER FROM
VEHICLE

EMERGENCY SUPPLY
SYSTEM (HAND
CRANK) IN VEHICLE
CAB

ON/OFF POWER
SWITCH

INTERLOCK 1 . CLOSED
WHEN LAUNCHER DOORS OPENED

Z MEASURING
LINES

FIRING
LINES   NC   NC   SQUIB

SHORT   SHORT
CIRCUIT 2   CIRCUIT 1

CONTROL BOX IN
VEHICLE CAB.
CHANGE OVER SWITCH
FOR TWO COMPLETE
PARALLEL SYSTEMS.
IMPEDENCE DETECTOR
FOR ALL INTERLOCKS

ARM REMOVE SHORTCIRCUIT 1

IS SQUIB Z TOO HIGH

IS SQUIB Z TOO LOW

REMOVE SHORT CIRCUIT 2

FIRE PULSE

PARALLEL SYSTEM CHANGE OVER LINE

FIRING UNIT AND SQUIB
IMPEDENCE MEASURING
SYSTEM PLACED IN CAB

Z   Z

TROLLEY CORRECTLY
CLAMPED ON

LAUNCHER DOORS
OPENED

INTERLOCKS 2

FIXED PERIOD
SINGLE PULSE
SQUIB IGNITER
CURRENT

TEMPERATURE
COMPENSATING
Z RUN WITH FIRE
LINES FOR SQUIB
Z MEASUREMENT

FIGURE 1: FUZEHEAD IMPEDANCE MEASURING CIRCUITRY

2.6.2.2 Man/machine interface (FIGURE 2)

Legend — Indication of an input or operation carried out by the operator.

Legend — Indication of an event or indication automatically carried out by the firing unit.

Legend — A question. An unfavourable answer automatically aborts deployment.

Operator functions	Indication lights
1 on-off switch	a. power light on
2 safe/arm switch	b. green indicates safe position
	c. red indicates armed position
	d. yellow (1) indicates fuse head open circuit
	e. yellow (2) indicates fuse head short circuit

3 firing switch

4 change-over switch between
   channel 1 and channel 2 of the firing unit.
   (duplication)

5 change-over switch
   between system 1
   and system 2.
   (duplication).

START

F

OPEN LAUNCHER DOORS

INTERLOCK 1 & 2 REMOVED POWER AVAILABLE TO FIRING PACK

SWITCH FIRING PACK ON

LIGHT INDICATES POWER IS ON

LIGHT INDICATES FIRING PACK IS SAFE

ARM THE THE FIRING PACK

LIGHT INDICATES THE FIRING PACK IS ARMED

A

A

REMOVE THE SHORT CIRCUIT FROM THE SQUIB

TEST THE Z OF THE SQUIB

IS THE SQUIB Z ABOVE SPEC — YES → C

NO

IS THE SQUIB Z BELOW SPEC — YES → D

NO

OPERATE THE FIRING SWITCH

REMOVE SHORT CIRCUIT FROM THE FIRING LINES

SEND FIRING PULSE TO THE SQUIB

B

B

REPLACE SHORT CIRCUIT ON LINES AND SQUIB

MAKE FIRING PACK SAFE ELECTRICALLY

SET SAFE/ARM SWITCH TO SAFE

LIGHT INDICATES FIRING PACK SAFE

SWITCH FIRING PACK OFF

CLOSE LAUNCHER DOORS

END

C

INDICATE SQUIB OPEN CIRCUIT

D

INDICATE SQUIB SHORT CIRCUIT

REPLACE SHORT CIRCUIT ACROSS THE SQUIB

SWITCH FIRING PACK TO SAFE

LIGHT INDICATES FIRING PACK IS SAFE

RESET SQUIB SHORT CIRCUIT INDICATOR

RESET SQUIB OPEN CIRCUIT INDICATOR

SWITCH FIRING PACK OFF

CLOSE LAUNCHER DOORS

CORRECT THE FAULT IN THE SQUIB CCT

F

FIGURE 2: MAN/MACHINE INTERFACE FLOW DIAGRAM

2.6.2.3   <u>System interface</u>

   a.   Electrical interface

        The firing system power supply must include:-

   (1)   R.F.I protection.   Refer to paragraph 2.6.12
   (2)   Reverse polarity protection   MIL-STD-1275 A (AT)
   (3)   Short circuit protection MIL-STD-1275 A (AT)
   (4)   Over-voltage protection   MIL-STD-1275 A (AT)

        This supply must regulate the nominal vehicle battery
        voltage to a level compatible with the firing pack
        circuitry.   Energy for this power supply must be obtained
        from the vehicle battery.   This interface must comply
        with MIL-STD-1275 A (AT).

   b.   The firing pack emergency power supply

        This supply can be either standby batteries or an
        emergency hand-cranked generator.

        A lamp will be used to indicate when the emergency power
        supply output is within specifications.   When the firing
        pack is switched off, any residual energy in the hand
        cranked power supply must be discharged.

        This supply must comply with MIL-1275 A (AT).   Refer to
        paragraphs 4.3 and 4.4.

2.6.3   Customer Furnished Equipment

One vehicle complying with MIL-STD-1275 A (AT).

2.6.4   Operational and Organisational Concepts

See the flowchart Figure 2.

2.6.5   Performance Characteristics

The equipment must operate safely between 0°C and +60°C.
Storage temperatures will be between -10°C and +60°C. The
subsystem will operate within the following electrical
specifications and comply with the following construction
methods where applicable.

    Mil-Std-1275 A   (AT)
    Mil-E-47231
    MIL-E-8189 H
    KA 3117
    MIL-STD-461 B

2.6.6   Physical Characteristics

The subsystem must be as small and light as possible and must
be sealed against ingress of moisture and dust. Conformance
with MIL-STD-810D where applicable, is necessary. Refer to
paragraph 2.6.10. Hookup wiring must be of the MIL W 22759/32
type.

Wire looms must be of EPD 7719A 6 core cables (asbestos
insulated stainless steel armoured cable) or similar.

2.6.7   Reliability

The missile and activation system must have mission
reliability of 98% (1000 hours).

$$R = e^{-(time/MTBF)} = 98\%.$$

$$MTBF = \frac{- time}{- Ln\ R}$$

Taking time to equal 1000 hours

$$MTBF = \frac{1000}{- Ln\ 0,98} = \underline{49,45 \times 10^3\ hours}$$

$49,45 \times 10^3$ is the mean time between failures in hours,
however the system must have a safety reliability of 99,99%
(100 000 hours).

2.6.8   Maintainability

2.6.8.1   Downtime

Downtime is to be kept to a minimum by the inclusion of an
identical system as a standby. If one channel fails the other
is used until a replacement can be procured. Downtime
therefore becomes replacement time.

2.6.8.2   Turn around time

This is the time taken to unplug the unit from the wiring
looms, unbolt it from the vehicle and replace the unit with a
new, identical unit. Turn around time is thus minimised.

2.6.8.3   Maintenance action

The firing pack container will be cleaned by the user when
required. Periodic replacement of the desiccator is necessary.

2.6.9   Operational Availability

To be determined by the user.

2.6.10   Environmental Conditions

The subsystem will comply with Mil-Std-810D vehicle and
aircraft vibration specifications.

Refer to paragraph 5.6.6.

2.6.11   Transportability

The subsystem will be mounted inside the driver's cab for
normal usage. No special methods of transportation will
therefore be needed.

2.6.12   Radio Frequency Interference Suppression

The firing pack will be built into a standard aluminium box,
closely approximating a Faraday cage.

All loom cables will be protected by a single armoured screen.

Radio frequency interference filters will be fitted to all
cabling. Extra cables must be included for redundancy and
expansion. A two wire system is to be used to enhance R.F
filtering. The only connection to the vehicle negative will
be directly to the battery. (Negative grounded vehicles).

The system is to be tested by the C.S.I.R. according to MIL-STD-461 B class 3A Test method RS 03.

The R.F energy limits for the test are:-

<u>Frequency</u>	<u>Level</u>
2 MHz to 30 MHz	10 v/m
30 MHz to 2 GHz	5 v/m
5 GHz	2 v/m
10 Ghz	2 v/m

Refer to the conversion graph, Figure 3.
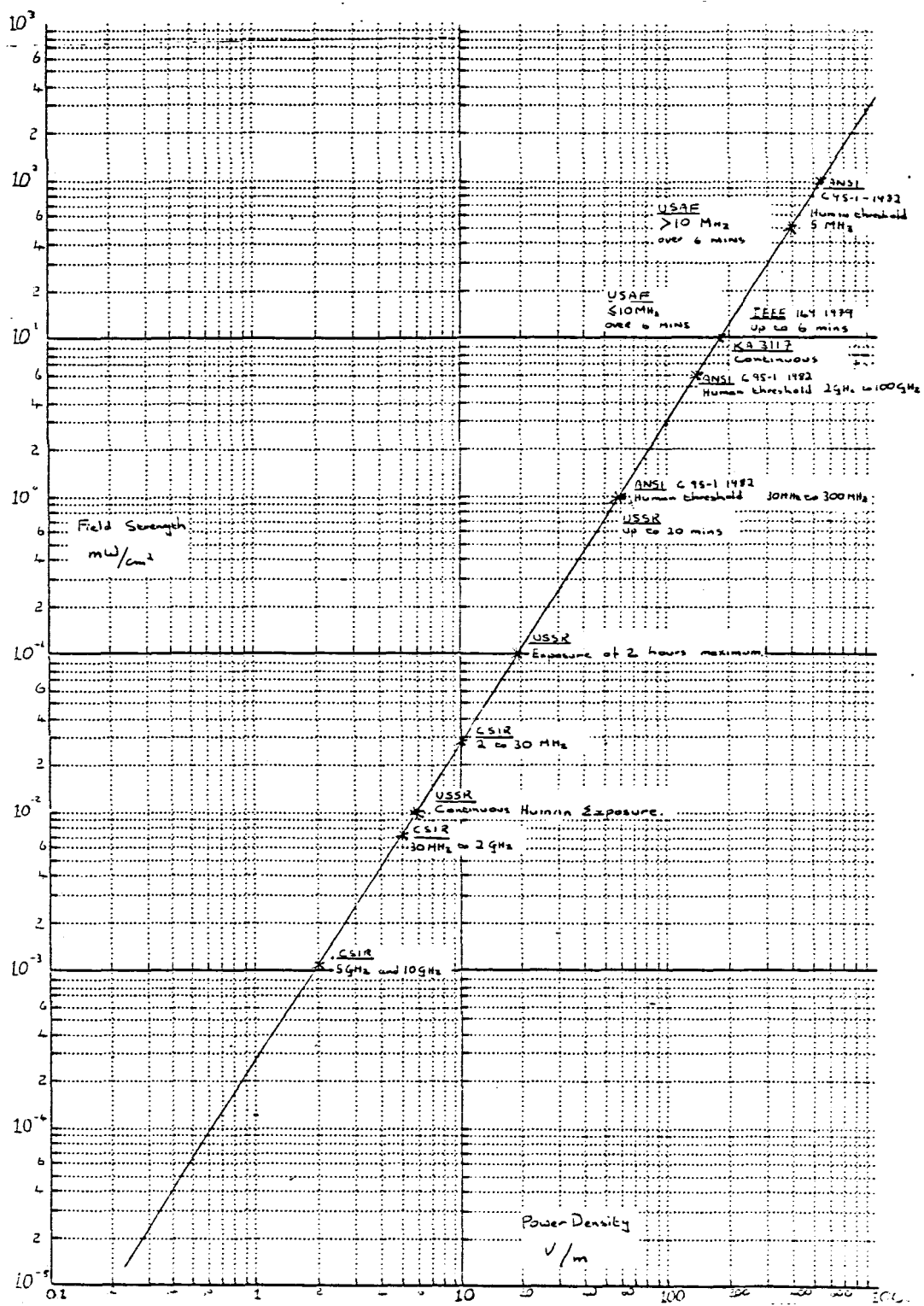
FIGURE 3: THE CONVERSION BETWEEN mW/cm² AND V/m.
HUMAN EXPOSURE LEVELS PLOTTED AGAINST CSIR TEST LEVELS.

2.7   CRITERIA FOR CONSTRUCTION

2.7.2   Materials, Processes and Parts

Extended reliability components are to be used where
possible. Special equipment and long lead time items to be
limited to the absolute minimum.

2.7.3   Nameplates, Product Marking and Finish

The complete system must be a dull colour. Markings and
colour are to conform to user requirements.

2.7.4   Workmanship

Workmanship must comply to KA 3117. Quality control
procedures must be adhered to throughout manufacture. The
equipment is to be designed for a mass production environment.

2.7.4   Interchangeability

All individual subsystems must be interchangeable between the
individual systems.

2.7.5   Safety

The firing pack must be rendered inoperable by safety barriers
if these are inadvertently opened. The possibility of
spurious, inadvertent or premature system firings must be
insignificant. The system is to conform to Mil-Std-454
Requirement 1. Refer to paragraph 2.6.7.

2.7.5.1   Safety interlocking devices

Interlocking devices must be included to ensure that premature
or inopportune ignition is avoided.

The design of the interlock circuitry must be such that if the
cabling is damaged (either short circuit or open circuit)
system deployment will be automatically aborted.

A short circuit must be positioned directly across the
fuzehead and also across the firing lines when the firing
system is made safe.

Refer to paragraph 2.6.1 and Figure 1

2.7.6   Human Performance/Engineering

There are no special or unique requirements for the
man-machine interface.

2.8   DOCUMENTATION

The following documentation will be required:

a. Full manufacturing drawings
b. Component lists and specifications
c. Performance specifications
d. Workshop repair manuals
e. System operation and procedure manuals
f. Illustrated parts catalogue

All documentation is to conform to SABS 0111 and to relevant
user specifications.

2.9   LOGISTICS

2.9.1   Maintenance

When one of the two firing units becomes defective the other
identical firing unit is switched on. The defective unit is
then replaced. Damaged cables are replaced by new, spare
cables. Defective modular items are replaced.

1.9.2   Repairs and Replacements

Replacement of items and repair of cables are to be carried
out at the second line. Repair of replaced items will be at
base workshop.

2.9.3   Cleaning

Occasional cleaning of all surfaces is required.

2.9.4   Facilities and Equipment

A test jig comprising the following is needed:

a. a power supply
b. firing lead and dummy fuzehead
c. compensating firing lead
d. all interlock switches
e. the applicable connectors

Standard workshop test equipment.

2.10   PERSONNEL AND TRAINING

2.10.1   Personnel

A maximum of two people are permitted in the vehicle when the system is operated.

Repair work is to be carried out by suitably qualified technicians.

2.10.2   Training

Training shall be according to the operator's manual.

2.11   FUNCTIONAL AREA CHARACTERISTICS

The power supply interfaces between the firing unit and the vehicle batteries. The supply is described in Section 1 paragraph 2.6.2.3.

Refer also to Figure 1.

2.12   PRECEDENCE

The emergency hand-cranked generator and associated circuitry are to be developed first. This is to ensure that the emergency supply delivers enough power to operate the firing unit. Conversely, the firing unit must not overload the emergency hand-cranked generator.

2.13   TEST AND INSPECTION REQUIREMENTS

The test methods as set out in the relevant MIL documents must be adhered to. Refer to paragraph 2.6.5.

Inspection must be carried out according to user specifications.

These tests will be carried out when qualifying the design, after building the prototype and on the first production model.

Thereafter routine testing shall be carried out as per user requirements.

2.14   PREPARATION FOR DELIVERY

The firing unit shall be installed in the vehicle prior to delivery.

SECTION 3 : THE COMMUNICATIONS SYSTEM

3.1   ## PURPOSE

The purpose of this definition study is to set guidelines for the design and development of a communication system to be installed as part of the vehicle in which the firing unit is installed.

3.2   ## SCOPE

This specification covers the requirements of the communication system.

Included are

a. The radio transceiver
b. The antenna
c. All associated wiring
d. Electromagnetic Radiation filtering

Excluded are

e. The design of the transceiver
f. The antenna design
g. The antenna tuning unit design

3.3   ## APPLICABLE DOCUMENTS

MIL-STD-1275A
MIL-STD-454E
MIL-STD-461B
KA 3117
MIL-HDBK-217B
IEEE 149-1979
S.A.B.S. 0111
MIL-E-47231
MIL-E-8189 H
MIL-STD-810D

3.4   DEFINITIONS

3.4.1   Transceiver

           A system capable of receiving and transmitting information
           over free space by means of electromagnetic waves.

3.4.2   Whip Antenna

           A vertical rod of appropriate length connected to the center
           conductor of a coaxial cable. The antenna launches
           electromagnetic radiation into free space.

3.4.3   Coaxial Cable

           A cable having one center conductor separated from an outer
           screening conductor. The latter is used as the return
           conductor.

3.4.4   Antenna Tuning Unit

           A device used for matching the antenna length to the radio
           frequency transmitted. The result is matching the antenna
           impedance to that of the transmitter, so optimising power
           transfer.

3.5   REQUIREMENTS

           a.   A transceiver must be located in the driver's compartment.

           b.   The unit is to be easily interchangeable.

           c.   The system must be operational over a temperature range
                of 0°C to 60°C and to be able to withstand a storage
                temperature range of -10°C to +60°C.

           d.   The antenna must be located according to the customer's
                specifications.

                Refer to paragraph 3.7.1.

3.6   SYSTEM DEFINITION

3.6.1   General

           A transceiver must be an FM System operating in the range
           required by the user. Radio frequency filtering will be used
           on the power lines . Energy will be obtained from the vehicle

batteries. The transceiver will be short circuit and reverse polarity protected according to MIL-STD-1275A(AT)

Coaxial cable will be used to connect the transceiver to the antenna. A whip antenna can be used, matched to the coaxial cable and transceiver by an antenna tuning unit.

Refer to Paragraph 3.6.5.

3.6.2   Function

The function of the communications system is to provide a reliable two way information flow between the vehicle crew and their commanding officers. This is to be achieved without there being any electromagnetic radiation hazard to either the vehicle crew or any associated equipment.

3.6.3   System Diagrams
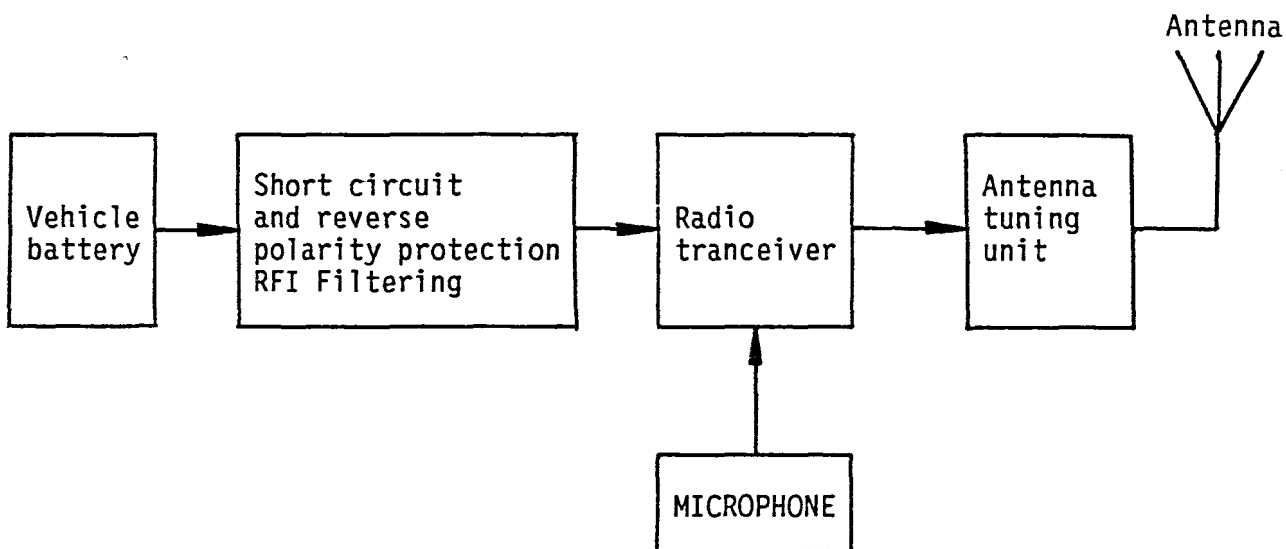
FIGURE 4:   COMMUNICATIONS FLOW DIAGRAM

A two wire system shall be used throughout.

3.6.4   Interface Definitions

3.6.4.1   Man/machine interface

Consult the transceiver technical manuals.

3.6.4.2   System interface

The energy supply from the vehicle battery will be a two
wire system. Protection for the transceiver and the
vehicle's equipment will be achieved by:

a. Electromagnetic radiation filtering (Paragraph 6.3.14)

b. Short circuit protection   MIL-STD-1275A (AT)

c. Reverse polarity protection   MIL-STD-1275A (AT)

Consult the transceiver handbook for information on the
transceiver – antenna interface. This interface is the
antenna tuning unit.

3.6.5   Customer Furnished Equipment

One Radio transceiver.
One antenna tuning unit.
One whip antenna.

3.6.6   Operational and Organisational Concepts

Consult the transceiver handbook.

3.6.7   Performance Characteristics

See the transceiver specification documents.

3.6.8   Physical Characteristics

Wiring shall be according to the transceiver workshop
manual. Wire looms shall be of the EPD 7719 A type.
Coaxial Cable shall be used for RF wiring.

3.6.9   Reliability

The complete system must have a reliability of 98% per 1000
hours. The communications system must therefore have a
reliability of approximately 98,5%.

$$R = e^{-(time/MTBF)} = 98,5\%.$$

$$MTBF = \frac{time}{- Ln\ R}$$

$$MTBF = \frac{1000}{- Ln\ 0,985} = 66,17 \times 10^3\ hours$$

66,17 thousand hours is the proposed time between failures for the communications system. This is dependent on the transceiver reliability.

3.6.10   Maintainability

a. Downtime

Downtime is to be kept to a minimum by ensuring interchangeability of all units. Downtime therefore becomes replacement time.

b. Turn around time

Turn around time is to be kept to a minimum. This will become the time to unplug the unit from the power supply and unbolt it from the vehicle. The radio is then replaced.

3.6.11   Operational Availability

To be determined by the user.

3.6.12   Environmental Conditions

The subsystem must comply with MIL-STD-810 D vehicle and aircraft vibration specifications.

3.6.13   Transportability

The subsystem will be mounted inside the vehicle crew compartment for normal usage. No special methods of transportation will therefore be needed.

3.6.14   Electromagnetic Radiation

All loom cables will have an armoured screen.

Power conductors will be terminated in Radio frequency interference filters.

A two wire power system is to be used to enhance R.F. filtering. The only connection to vehicle negative will be directly to the battery (negative grounded vehicles).

Electromagnetic radiation levels inside the cab must be less than 10 V/m in the range 2 MHz to 30 MHz, less than 5 V/m from 30 MHz to 2 GHz and less than 2 V/m at 5 GHz and 10 GHz as measured by the C.S.I.R.

At no point greater than 2 meters from the radio antenna shall the power density be greater than 170 Volts/meter. 170 Volts/per meter corresponds to 10mW/$_{cm}2$ as specified in KA3117. See Fig. 1.

Equipment shall comply with MIL-STD-461 B Part 1. See Section 2 Paragraph 5.2.5.

3.7   CRITERIA FOR CONSTRUCTION

3.7.1   Materials, Processes and Parts

The radio transceiver, antenna, antenna tuning unit and associated equipment is to be supplied by the user.

The power supply and RF filtering section must contain standard mil spec components where possible. Special equipment and long lead time items must be limited to the absolute minimum.

3.7.2   Nameplates, Product Marking and Finishes

The complete system must have a dull colour. Marking and colour are to conform to user requirements.

3.7.3   Workmanship

Workmanship must comply to KA3117. Quality control procedures must be adhered to throughout manufacture. The equipment is to be designed for a mass production environment.

3.7.4   Interchangeability

All the individual subsystems must be interchangeable between the individual systems.

3.7.5   Safety

The transceiver system must conform to Mil-Std-454 Requirement 1. See Section 2 paragraph 5.1.15.

3.7.6   Human Performance/Engineering

There are no special or unique requirements necessary for the man – machine interface.

3.8   DOCUMENTATION

               The following documentation will be required:

               a   Full manufacturing drawings

               b   Component lists and specifications.

               c   Performance specification.

               d   Workshop manuals.

               e   System operation and procedure manuals.

               All documentation is to conform to SABS 0111 and the user
               specifications.

3.9   LOGISTICS

3.9.1   Maintenance

               Maintenance in the field will consist of replacement of
               modular items. Damaged cables can be replaced by spare
               cables as required.

               Replacement of items and repair of cables are to be carried
               out at the second line. Repair of replaced items will be
               at base workshop.

               Maintenance shall be according to the transceiver technical
               manual.

3.9.2   Facilities and Equipment

               A test facility according to the vehicle tranceiver
               technical manual is needed.

3.10   PERSONNEL AND TRAINING

3.10.1   Personnel

               A maximum of two people are permitted in the vehicle when
               the system is operated.

               Repair work is to be carried out by suitably qualified
               technicians.

3.10.2   Training

               Personnel are to be trained in operating the transceiver as
               outlined in the operators instructions.

3.11   FUNCTIONAL AREA CHARACTERISTICS

An interface circuit shall be connected between the
transceiver and the vehicle battery. It shall comprise:

Radio frequency interference filters.
Short circuit protection.
Reverse polarity protection.

Refer to paragraphs 3.6.3 and 3.7.1.

3.12   PRECEDENCE

None

3.13   TEST AND INSPECTION REQUIREMENTS

General

The test methods as set out in the relevant MIL documents
shall be adhered to. Refer to paragraphs 3.3, 3.5 and
3.6.7. Inspection shall be carried out according to user
specifications. These tests will be carried out when
qualifying the design, after building the prototype and on
the first production model. Thereafter routine testing
shall be carried out as per user requirements.

3.14   PREPARATION FOR DELIVERY

The transciever shall be installed in the vehicle as part
of the system.

SECTION 4: THE INVESTIGATION INTO ALTERNATIVES TO THE IMPLEMENTATION OF SECTIONS 1 AND 2

4.1   INTRODUCTION

This section deals with:

a.   The Emergency Power Supply
b.   The Main Power Supply
c.   Radio Frequency Interference Filtering

4.1.1   The Emergency Power Supply

The alternatives available are

- A hand-cranked generator
- Ni-Cad rechargeable cells
- Sealed lead acid rechargeable batteries
- Gates rechargeable cells
- Non-rechargeable lithium inorganic cells

The alternatives are discussed in detail in paragraph 4.2.

4.1.2   The Main Power Supply

Alternatives are

- Linear Regulator Supplies
- Switching Regulator Supplies

These aspects are discussed in paragraph 4.3.

4.1.3   Radio Frequency Interference Filtering

The alternatives that can be considered are:

- Prototype T and TT lowpass filters
- M derived T and TT lowpass filters
- Composite lowpass filters

These are dealt with in paragraph 4.4.

4.2   EMERGENCY POWER SUPPLIES

4.2.1   Hand-Cranked Generator

PTI Communications telephone ringer generator type
288-0000-4A. Manufacturers data is available in Appendix 1.

4.2.1.1   Advantages

a.   An operating temperature range of -30°C to +60°C is
specified for this device. This is in excess of the
system specification.

b.   Temperature variations during storage have a negligible
influence on output capacity.

c.   No charging system is necessary.

d.   The generator can be operated in a gas tight enclosure

e.   This generator is a Mil spec item

4.2.1.2   Disadvantages

a.   The generator must be mounted in an ergonomically
acceptable position.

b.   The energy available is dependent on operator endurance.

c.   The generator would require a complete power supply to
compensate for operator variations.

4.2.1.3   Comments

This generator is capable of a maximum current of 250 mA at
12V. This is equivalent to 3 watts. This current may not be
adequate due to the inherent internal impedance of this device.

4.2.2 Nickel Cadmium Sealed Rechargeable Batteries

Technical details are given in the manufacturers literature attached hereto as Appendix 2.

4.2.2.1 Advantages

a. These batteries are suitable for high cyclic, standby and float applications.

b. The RST extended temperature cells have acceptable temperature specifications. Charging is permissible between -10°C and +65°C; discharging from -40°C to +65°C and storage from -45°C to 65°C. It is permissable to discharge these cells at a temperature of 75°C for a maximum time period of 24 hours. This is in excess of the user specifications.

c. Sealed Ni-Cd batteries can be operated in any position. However, in stationary use they should not be mounted upside down.

d. These cells can be operated in a gas tight enclosure.

e. Ni-Cd batteries have a service life of 4 to 6 years. Service life ends when the batteries fail to deliver 60% of nominal capacity.

4.2.2.2 Disadvantages

a. These cells, if stored at 30°C, will self discharge to 10% capacity in approximately 2 months.

b. These cells require a two rate constant current charger. This charger must be sensitive to cell output voltage and total energy drawn from the cell.

4.2.2.3 Comments

a. This information is based on Varta Ni-Cd cells. Eveready do not appear to manufacture suitable cells.

b. 800 to 1000 cycles can be obtained from RST cells at normal temperature and nominal charge/discharge operation. A cycle refers to one complete charge and discharge of a battery's capacity. The batteries service life ends when less than 80% of its nominal capacity is delivered. If a battery is discharged by 50% capacity or less, more than double the number of charge/discharge cycles may be obtained.

c. A 12V [nominal] battery comprising 12 cells, has a fully charged open circuit voltage of approximately 14,4V and when discharged, 10,8V.

d. These cells are at present used in other firing units and they withstand the applicable specifications. Comprehensive electrical characteristics and mechanical stress data is available.

4.2.3 Sealed Lead Acid Rechargeable Cells

The Yuasa batteries are described in detail in Appendix 3.

4.2.3.1 Advantages

a. These batteries are suitable for high cyclic, standby and float applications.

b. The batteries can be mounted in any position.

c. These batteries are suitable for constant voltage, constant current or two rate charging.

d. Service life is approximately 5 years. After 5 years available capacity drops to approximately 30%.

e. If the batteries are discharged no more than 30% of the battery's capacity during any one discharge period, they will be able to sustain more than 1200 such discharges.

4.2.3.2 Disadvantages

a. They have an operating temperature range of -10°C to 50°C. The system specification requires an operating temperature range of 0°C to 60°C and a storage range of -10°C to +60°C. The Yuasa batteries do not comply in this area.

b. These batteries, if stored at 40°C will self discharge to approximately 30% available capacity after 9 months.

c. These batteries should not be charged in an unventilated enclosure.

d. These batteries have not previously been tested to military specifications.

4.2.3.3   Comments

    a.   A 12V[nominal] battery at 20°C has a fully charged voltage
         of approximately 12,5V and when discharged 10,5V.

    b.   Charging lead acid cells is simpler than Ni-Cd cells.

4.2.4   The Gates Rechargeable Cell

    Further information is enclosed as Appendix 4.

4.2.4.1   Advantages

    a.   These batteries are suitable for high cycle, standby and
         float applications.

    b.   They have an operating range of -40°C to +65°C. This is
         in excess of the system specifications.

    c.   These cells can be mounted in any position.

    d.   If the batteries are discharged no more than 25% of the
         battery capacity during any one discharge period, the
         cells will be capable of delivering 1500 such discharges.

    e.   The expected float life of the Gates cell is greater than
         8 years at room temperature. End of life is defined as
         the failure of the cell to deliver 80% of rated capacity.

    f.   These cells are suitable for constant current, constant
         voltage, two rate charging or taper current charging.

4.2.4.3   Disadvantages

    a.   These cells, if stored at 40°C, will self discharge to
         approximately 30% available capacity after $2^1/2$ months.

    b.   The battery should not be used in a gas-tight container.

    c.   These cells have not previously been tested to military
         specifications.

4.2.4.3   Comments

    a.   A 12V nominal battery has a fully charged open circuit
         voltage of about 13,05V and when discharged 11,85V.

    b.   Charging is relatively easy when compared to Ni-Cd cells.

4.2.5   Non Rechargeable Lithium Inorganic Batteries

The following points are excerpts from Tadiran's Technical report on their Lithium inorganic primary cells. Further information is attached as Appendix 5.

4.2.5.1   Advantages

a. Tadiran have an operating temperature range of -30°C to +75°C for normal operation. Under certain conditions operation is permissable up to 125°C. This is in excess of the system specifications which requires a range from -10°C to +60°C.

b. These cells have been tested to MIL-B-18D, MIL-STD-810D and SCS-459.

c. Operation in sealed environments is permissable.

d. The expected no load life of the cell is in excess of 10 years. Tadiran lithium inorganic cells will maintain 80% of their capacity after 10 years of storage at 20°C.

4.2.5.2   Disadvantages

a. These cells are suitable for low to medium standby applications. High cyclic operations need a duration of longer than 10 minutes.

b. Lithium cells must be operated upright. Inverted cells result in a 60% energy loss while 20% of capacity is lost if the cells are mounted horizontally.

4.2.5.3   Comments

a. These batteries must have sufficient energy to operate the firing pack a minimum of 100 times, as required by the system specification.

b. These cells must NOT be charged.

c. A cell stored for 3 months at +72°C is considered adequate simulation for storage of 10 years at 20°C. A cell stored at +72°C for 3 months displays a capacity loss of less than 10%.

4.3   THE MAIN POWER SUPPLY

The main power supply will be used to interface between the vehicle electrical system and the firing pack. It is intended to use linear voltage regulators as they are cheap, reliable and readily available.

4.3.1   Three Terminal Fixed Output Regulators

4.3.1.1   Advantages

a.   Easy to use.
b.   Internal overcurrent and thermal protection is provided.
c.   No circuit adjustments are necessary.
d.   Low cost.

4.3.1.2   Disadvantages

a.   The output voltage cannot be precisely adjusted. These devices are available in a limited range of voltage and current ratings.

b.   Obtaining a larger current capability is more difficult than with other types of regulators.

c.   The device output parameters are not monitored.

4.3.2   The Three Terminal Adjustable Output Regulator

4.3.2.1   Advantages

a.   These devices are easy to use.

b.   The device includes overcurrent and thermal protection.

c.   The output voltage can be set by means of two resistors. The range is from 1,2 to 40V.

d.   Current ranges from 100 mA to 3A are available.

e.   Low cost.

4.3.2.2   Disadvantages

a.   Obtaining a larger current capability is more difficult than with other types of regulator.

b.   The device output parameters are not monitored.

4.3.2.3   Comments

Further information is available from the Motorola linear/switchmode voltage regulator manual.

4.3.3   14 Pin Dual in Line Regulators

4.3.3.1   Advantages

a.   External current limit facility.

b.   Voltage selection is by means of two resistors.

c.   These devices can be designed to accommodate any current rating.

d.   They incorporate a soft switch on routine, eliminating current surges.

e.   Foldback current limiting is possible.

f.   These devices can be coupled to other I.C.'s for power line monitoring. Under power line fault conditions, selection of alternate supplies is automatic.

4.3.3.2   Disadvantages

a.   These supplies are more costly than three terminal devices.

b.   A more complex power supply results.

4.3.3.3   Comments

The 14 pin dual in line regulators are devices such as the Motorola MC 1723. THe MC 3423 is an example of a power line monitoring device.

4.3.4   The Switching Power Supply

4.3.4.1   Comment

This type of supply is not recommended because:

a.   The supply voltage is 24V dc. Linear regulators will therefore not require a transformer.

b.   The power dissipation of the supply is expected to be less than 15W.

c.   Power supply efficiency is of negligible importance.

4.4   RADIO FREQUENCY INTERFERENCE FILTERING

4.4.1   Filtering

(Extract from MIL-STD-461B Part 1, 1 April 1980
Paragraph 4.3.1)

The use of line-to-ground filters for EMI control shall be
minimized. Such filters establish low impedance paths for
structure (common-mode) currents through the ground plane and
can be a major cause of interference in systems, platforms or
installations because the currents can couple into other
equipment using the same ground plane. If such a filter must
be employed, the total line-to-ground capacitance shall not
exceed 0.1 microfarads (μF) for 60 hertz (Hz) equipment and
0.02 μF for 400 Hz equipment. The filtering employed shall be
fully described in the equipment or sub-system technical
manual as well as the EMI Test Report.

4.4.2   Prototype T and π Low Pass Filters
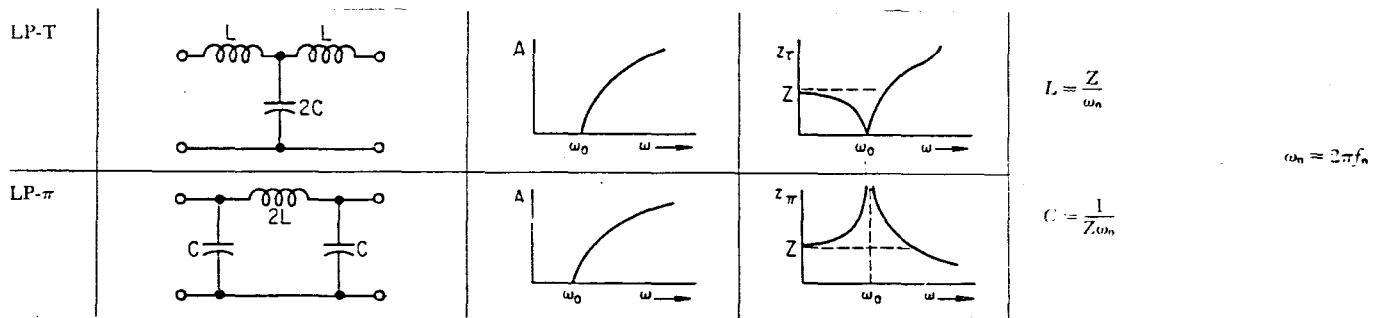
FIGURE 5:   DESIGN EQUATIONS FOR FILTER SECTIONS BASED
ON IMAGE PARAMETERS-PROTOTYPE FILTERS

4.4.2.1   Advantages

a.   Low component count.
b.   Cheap.
c.   Easy to construct.

4.4.2.2   Disadvantages

a.   The cutoff impedance is low.

b.   The rise of impedance with respect to frequency may be
inadequate.

c. The load and source impedances must equal the design
impedance of the filter.

4.4.2.3 Comment

Selection between the two types is made on the basis of
parasitic inductances and capacitances. Convenience of
component values is also a determining factor.

4.4.3 M Derived T and TT Low Pass Filters
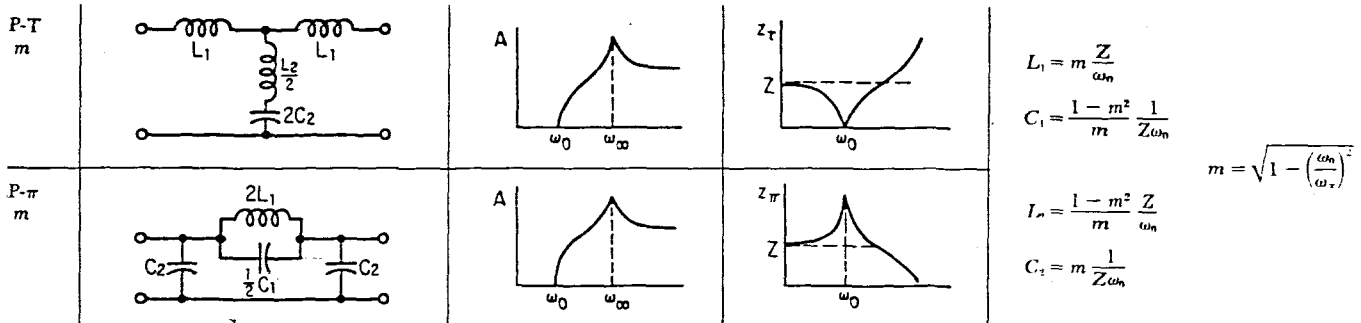
FIGURE 6: DESIGN EQUATIONS FOR FILTER SECTIONS BASED ON
IMAGE PARAMETERS - M DERIVED FILTERS

4.4.3.1 Advantages

a. Low component count.
b. Cheap.
c. Easy to construct.
d. The cutoff impedance is sharper than that of prototype
filters. The impedance slope is dependent on the m
selected.

4.4.3.2 Disadvantages

a. The impedance drops with respect to frequency after the
frequency of maximum attenuation.

b. The load and source impedances must be made equal to the
design impedance of the filter.

4.4.3.3 Comments

Selection between the two types is made on the basis of
parasitic inductance and capacitances. Convenience of
component values is also a determining factor.

4.4.4 Low Pass Composite Filter
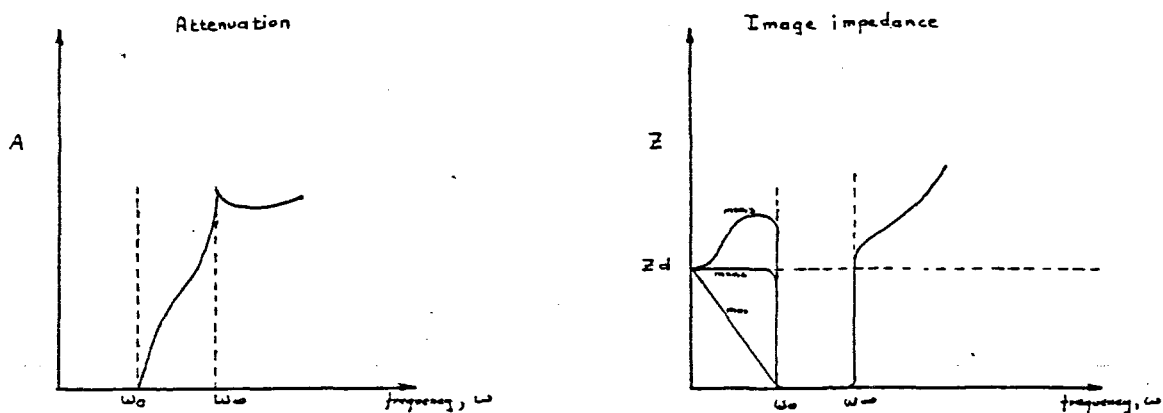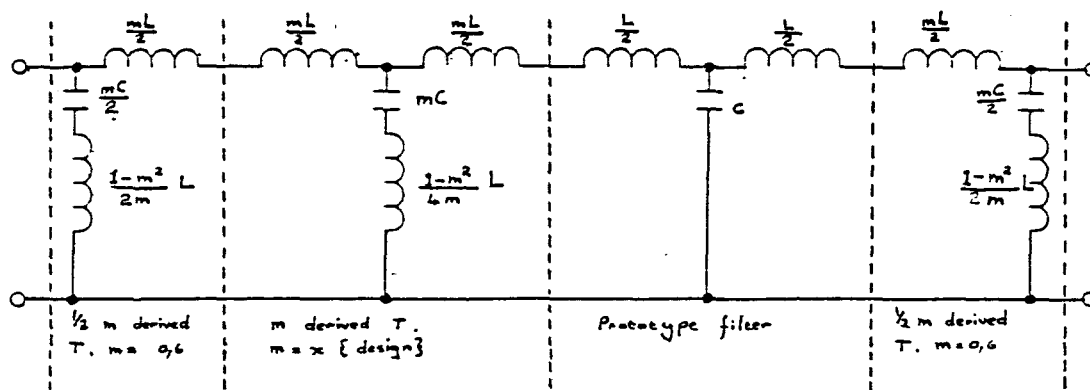
FIGURE 7: LOW PASS COMPOSITE FILTER

4.4.4.1 Advantages

a. This design has a very sharp cutoff.

b. Greater attenuation of unwanted signals is achieved compared to either prototype or m derived filters.

c. The image impedance is relatively constant till the cutoff frequency.

4.4.4.2 Disadvantages

a. high component count.

b. relatively expensive.

c. More difficult to construct than either the prototype or m derived filter.

d. The load and source impedances must be made equal to the design impedance of the filter.

SECTION 5: THE EXPENDABLE FIRING UNIT

5.1   PURPOSE

The purpose of this concept design specification is to set
specifications for the design and testing of an expendable
firing unit.

5.2   SCOPE

This specification covers the design of the expendable firing
unit.

Included are:

a.   Safety Interlocking devices.
b.   Interconnecting cables.
c.   Radio Frequency Interference suppression.
d.   The hand-cranked power supply.
e.   The firing pack container. (Physical characteristics)

5.3   APPLICABLE DOCUMENTS

MIL-STD-454E
MIL-STD-461B
MIL-STD-810D
MIL-E-8189 H
MIL-HDBK-217B
KA 3117
SABS 0111

Refer to paragraph 5.6.4 and 5.6.6.

5.4   DEFINITION

5.4.1   Firing unit

The Firing Unit checks all safety barriers and then ignites
two pyrotechnic chains, so deploying the system.

5.5 REQUIREMENTS

a. The firing unit must be as small and compact as possible.

b. The continuity of the fuzehead and the pyrotechnic chain must be tested by the firing unit before the system is initiated.

c. The possibility of premature firing must be insignificant.

d. The system must be operational over a temperature range of 0°C to 60°C and be able to withstand a storage temperature range of -10°C to +60°C.

e. The firing pack cost must be minimal when compared to the overall system cost.

5.5.1 Sequence of Operations

STEP	ACTION
1	Open the system's protective barriers.
2	Depress the "Charge" switch.
3	Crank the hand-cranked generator until the "ready" light emitting diode glows.
4	Activate the "Safe/Arm" switch, a light emitting diode should glow.
5	Depress the "Fire" button and initiate the system.
6	Depress the "Detonate" button, initiating the second pyrotechnic chain. Six could automatically follow five without incorporating a "Detonate" button. This is to be decided in the XDM phase.
7	Release the "Charge" switch.
8	Discard the used system.

Refer to paragraph 5.6.2.2

5.6 SYSTEM DEFINITION

5.6.1 General

All electrical systems must be operable from the firing unit.

Standard components must be used whenever possible. Cross compatibility between all systems is a prerequisite.

The firing pack will be built on an L-shaped anodised aluminium plate. Once built, the firing unit will be potted to form a rectangular block. An integral skin, flexible polyurethane foam may be used. DURAUTO FIB/L POLYOL and DURANATE B POLYISOCYANATE is suggested.
See Section 4, paragraph 5.1.6.

All power lines will be short circuited when the unit is switched off. Firing lines will be short-circuited until such time as the ignition pulse for the pyrotechnic chains is generated. The ignition pulse will be a single, fixed period current pulse.

5.6.2 Function

The firing unit must ensure safe deployment of the pyrotechnic sub-systems. This is achieved by means of a system of safety barriers which must be removed in a predetermined sequence before initiation of the system. Any error will cause the initiation of the system to be automatically aborted.

5.6.2.1 The detonator impedance measuring circuitry

The function of this circuitry is to compare the fuzehead impedance against that of a known standard. The standard will be placed in a close proximity to the fuzehead to ensure temperature compensation. A constant current design may be used to improve the reliability and safety of this circuitry. Refer to paragraph 5.6.4.1 and 5.6.4.2.

5.6.2.2 Man/machine interface

Operator functions	Indication lights
1 Depress "Charge" button	All light emitting diodes extinguished.
2 Crank generator handle	Crank until ready light emitting diode is energised. [Red]
3 Activate the "Safe/Arm: switch	If the fuzehead impedance is within specification, a red light emitting diode will glow.
4 "Fire" pyrotechnic chain	No indication
5 "Detonate" button	No indication

Operator function 5 may not be required. This is to be decided in the XDM phase.
Refer to paragraph 5.5

5.6.2.3   <u>System interface</u>

There will be no electrical connection between the firing unit
and any transporting vehicle.

5.6.2.4   <u>The firing unit power supply</u>

It is proposed that this supply is a hand-operated magneto
type generator, fitted with a built-in commutator. P.T.I.
communications telephone ringer generator type G3-2 appears
suitable.

A lamp will be used to indicate when the generator's output is
within specification. When the "Charge" button is released a
discharge path will be provided to ensure no spurious charge
build-up.

5.6.3   <u>Customer Furnished Equipment</u>

Nil

5.6.4   <u>Performance characteristics</u>

The equipment must operate safely between 0°C and +60°C.
Storage temperatures will be between -10°C and +60°C. The
sub-system will operate within the following electrical
specifications and comply with the following construction
methods where applicable.

MIL-E-8189 H
KA 3117
MIL-STD-461 B

Refer to paragraph 5.3.

5.6.4.1   <u>Firing pulse</u>

The firing unit must provide a firing pulse such that a
minimum of twice the minimum firing energy is delivered, above
the minimum fire current, to the fuzehead. The duration of
the firing pulse must be compatible with the type of fuzehead
used.
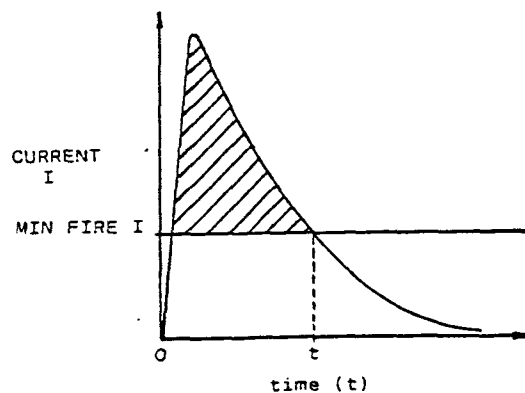
FIG 7A: THE FIRING PULSE

The shaded area represents twice the minimum firing energy in Joules. Energy = I^2Rt
where I = firing current, R = fuzehead resistance and t = time.
Refer to paragraph 5.6.2.1.

5.6.4.2   Test current

When testing the fuzeheads of the pyrotechnic chain, the test current shall not exceed ^{1}/10 x the maximum *no fire* current of the fuzehead.
Refer to paragraphs 5.6.2.1 and 5.6.4.1.

5.6.4.3   Radio frequency interference

Radio frequency interference filters will be fitted where necessary.
Refer to paragraph 4.4

The system is to be tested by the C.S.I.R. according to MIL-STD-461B class 3A test method RS 03.

The RF energy limits for this test are:-

Frequency	Level
2 MHz to 30 MHz	10v/m
30 MHz to 2 GHz	5v/m
5 GHz	2v/m
10 GHz	2v/m

5.6.6   Physical Characteristics

The sub-system must be as small and light as ergonomically possible. The unit will be sealed against dust and water ingress by being potted with an integral skin, flexible polyurethane foam. This foam will form the container of the firing unit.

This foam must comply with the following:-

a.   low cost.
b.   easily cast.
c.   must not absorb water or be affected by immersion.
d.   adhere to anodised aluminium.
e.   non-conducting.
f.   the temperature must not rise above +60°C when curing.
g.   flexible and shock-resistant.
h.   not affected by broadband light.
i.   minimal effects by most solvents.
j.   The mechanical and electrical properties must not vary significantly in the range -10°C to +60°C.
k.   Fire retardent.

Durauto FIB/L Polyol and Duranate B Polyisocyanate is
suggested. Manufacturers data is attached as Appendix 6.
Refer to paragraph 5.6.1.
Hook-up wiring shall be of the MIL-W-22759/32 type. Wire
looms shall be of EPD 7719A cables (asbestos insulated
stainless steel armoured) or similar.

5.6.6   Environmental Conditions

The following environmental testing shall be carried out
during the XDM phase of the firing unit, subject to the
availability of the necessary equipment. These test methods
are contained in MIL-STD-810D.
Refer to paragraph 5.7.3 and 5.11

Method	Comment
500.1	Low pressure [altitude]. The equipment shall not be tested at a pressure lower than 429,1 mm Hg.
501.1	High temperature. Procedure II. The equipment shall not be tested above +60°C.
502.1	Low temperature. The firing unit shall not be tested below -10°C storage and 0°C operating.
503.1	Temperature shock. The equipment shall be tested between -10°C and +60°C.
506.1	Rain. Procedure II shall apply.
507.1	Humidity. Procedure IV shall be used.
509.1	Salt fog. Procedure I.
510.1	Dust [fine sand]. Procedure I.
511.1	Explosive atmosphere. Procedure I.
512.1	Leakage [immersion]. Functional tests must be carried out. The test item will not be opened.
514.2	Vibration. Category f, procedure VIII. Vehicle and mileage unknown.
516.2	Shock. Procedure II, transit drop test.

5.6.7 Reliability

The pyrotechnic chain and activation system must have mission reliability of 98% (1000 hours).

$$R = e -(time/MTBF) = 98\%$$

$$\frac{1}{MTBF} = \frac{time}{-Ln \ R}$$

Taking time to equal 1000 hours.

$$\frac{1}{MTBF} = \frac{1000}{-Ln \ 0,98} = 49,45 \times 10^3 \ \underline{hours}$$

$49,45 \times 10^3$ is the mean time between failures in hours. The system must have safety reliability of 99,99% (100 000 hours).

5.6.8 Maintainability

5.6.8.1 Downtime

Downtime is replacement time. If a firing unit malfunctions, the complete firing unit is replaced. The defective system is then returned to the manufacturer.
Refer to paragraph 5.9.1.

5.6.8.2 Replacement time

The electrical system is a self-contained unit. Replacement time therefore becomes the time needed to unload the used or defective system and to load a new system. Replacement time is thus minimised.
Refer to paragraph 5.9.2.

5.6.8.3 Maintenance action

The system container will be cleaned by the user when required. Periodic checking of all seals is necessary. See Refer to paragraph 5.9.1.

5.6.8.4 Transportability

The firing unit shall be transportable by land, sea and air.

5.7 CRITERIA FOR CONSTRUCTION

5.7.1 Materials, Processes and Parts

Standard mil spec components are to be used where possible. Special equipment and long lead time items to be limited to the absolute minimum.

5.7.2 Nameplates, Product Marking and Finish

The complete system must be a dull colour. Markings and colour are to conform to user requirements.

5.7.3 Workmanship

Workmanship must comply to KA 3117. Quality control procedures must be adhered to throughout manufacture. The equipment is to be designed for a mass production environment. Refer to paragraph 5.6.6 and 5.11

5.7.4 Interchangeability

All individual sub-systems must be interchangeable between the individual systems.

5.7.5 Safety

The firing unit must be rendered inoperable by safety barriers if the system is incorrectly operated. The possibility of spurious, inadvertent or premature firings must be insignificant. The system is to conform to MIL-STD-454 Requirement 1.

5.7.5.1 Safety interlocking devices

Interlocking devices must be included to ensure that premature or inopportune ignition is avoided.

The design of the interlock circuitry must be such that if the cabling is damaged (either short circuit or open circuit) missile deployment will be aborted automatically.

A short circuit must be positioned directly across the squib and also across the firing lines when the firing system is made safe.

5.7.6 Human Performance/Engineering

There are no special or unique requirements for the man-machine interface.

5.8 DOCUMENTATION

The following documentation will be required:-

a. Full manufacturing drawings.
b. Component lists and specifications.
c. Performance specifications.
d. System operation and procedure manuals.

All documentation is to conform to SABS 0111 and to relevant user specifications.

5.9   LOGISTICS

5.9.1   Maintenance

If any system becomes defective, the entire system must be replaced. The defective system must then be returned to the manufacturer for repair.
Refer to paragraph 5.6.8.1 and 5.6.8.3.

5.9.2   Repairs and Replacements

Replacement of systems is to be carried out at the second line. Repair of malfunctioning items will be done by the manufacturer.
Refer to paragraph 5.6.8.2.

5.9.3   Cleaning

Occasional cleaning of all surfaces is required.

5.9.4   Facilities and Equipment

A test jig comprising the following is needed.

a.   Firing lead and dummy fuzehead.
b.   Compensating firing lead.
c.   all interlock switches.
d.   the applicable connectors.

Standard workshop test equipment.

5.10   PERSONNEL AND TRAINING

5.10.1 Personnel

A maximum of two people are permitted in the vehicle when the system is operated.

5.10.2 TRAINING

Training shall be according to the operator's manual.

5.11   TEST AND INSPECTION REQUIREMENTS

The test methods as set out in the relevant MIL documents must
be adhered to.

Inspection must be carried out according to user
specifications.

These tests will be carried out when qualifying the design,
after building the prototype and on the first production model.

Thereafter routine testing shall be carried out as per user
requirements.
Refer to paragraph 5.6.6.

5.12   PREPARATION FOR DELIVERY

The firing unit shall be installed in the transporting vehicle
as part of the complete system.

PART 2

THE EXPERIMENTAL/ADVANCED DESIGN MODEL OF THE FIRING UNIT

C O N T E N T S   L I S T

0193P/

SECTION 1:   INTRODUCTION

This thesis deals with the development and design of a highly
ruggedised electronic package used to ignite a fuzehead and
to charge a capacitor for later use as part of a pyrotechnic
chain.

This part of the thesis deals with the in-depth design and
reliability studies of the firing unit. Included in this
part is field, environmental and electromagnetic
compatability testing.

```
+------------------+                 +----------------------+
|  FIRING          |                 | CONTAINER HOUSING    |
|  CONTROL         |  FIRING CABLE   | TWO PYROTECHNIC       |
|  SYSTEM          |                 | CHAINS               |
+------------------+                 +----------------------+
```
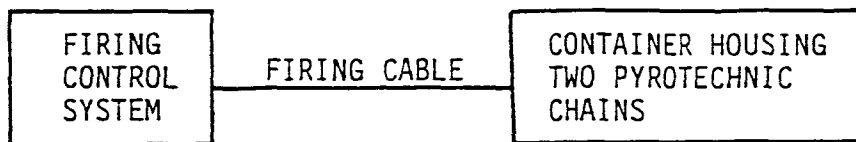
FIGURE 8:   SYSTEM BLOCK DIAGRAM

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

1.1   TERMS OF REFERENCE

The system specification gave the following requirements for
the firing unit:

a.   The firing unit must be located inside the driver's
      compartment of the system vehicle.

b.   The operator must be able to select which of two systems
      is to be activated.

c.   It must be as small and compact as possible.

d. Standby batteries or an emergency power supply must be provided for.

e. The continuity of the igniter must be tested by the firing unit before the system is operated.

f. The possibility of premature firing must be non-existent.

g. All units must be easily interchangeable.

h. The system must be duplicated up to the fuze-head.

i. The system must be operational over a temperature range of 0°C to 60°C and be able to withstand a storage temperature range of -10°C to 60°C.

In Section 2 of this part each of the above aspects is considered in turn and reasons given for the courses of action chosen to meet the stated requirements. Subsequent sections are devoted to the technical design considerations of the firing unit.

SECTION 2:   DISCUSSION OF REQUIRMENTS

2.1   **LOCATION OF FIRING UNIT**

No difficulties are foreseen in mounting the firing unit in
the cab in a position ergonomically acceptable to the
operator. As the vehicle selected by the user has not been
made available as yet, the exact positioning of the firing
unit in the cab has not been finalised.

2.2   **SELECTION OF SYSTEMS**

The operator must be able to select which of two systems is
to be operated.

Two complete, but separate firing units are to be
installed.   Separate firing units enhance reliability when
compared with two firing units in one enclosure. This is
especially pertinent when physical damage occurs to one of
the systems.

2.3   **PHYSICAL SIZE**

The firing unit must be as small and compact as possible.

Minimum size is determined by the ergonomic constraints of
the operator while maximum size is limited by the vehicle cab
design. The enclosure was selected as being able to contain
the necessary hardware, protect the electronics and be
physically acceptable.

Rose Enclosures Aluminium housing type 11 626 09 of
dimensions 260 mm length, 160 mm width and 90 mm height was
deemed suitable. This does not include anti-vibration
mountings of 18 mm height. These products are manufactured
in South Africa.

The mass of the complete firing unit is expected to be in the
order of 4 kg.

2.4   STANDBY BATTERIES AND EMERGENCY POWER SUPPLY

2.4.1   Alternatives

As a power source for the firing unit the following were considered:

a.   A hand-cranked generator

b.   Ni-Cd rechargeable cells

c.   Sealed lead acid rechargeable batteries

d.   Gates rechargeable cells

e.   Non-rechargeable Lithium inorganic cells

Detailed technical information on the preceeding five alternatives is available in Appendices 1 to 5.

2.4.2   Preference

From the points of view of safety, reliability and ease of operation the hand-cranked generator appears to have many advantages over rechargeable batteries viz:

a.   It will operate over the temperature range of -30°C to 60°C.

b.   Temperature variations during storage have a negligible influence on output capacity.

c.   No charging system is required.

d.   Operation in a gas tight enclosure is possible.

e.   It meets military specifications DEF 133 and DEF 5000.

f.   Energy becomes available to the firing unit only when the operator cranks the generator. The possiblility of an unintentional firing is therefore extremely remote.

2.4.3   Comments

2.4.3.1   Suitability

The following are not suitable:

a   Sealed lead acid cells
b   The "Gates" rechargeable cell

The following are suitable:

c.   The hand-cranked generator
d.   Nickel cadmium sealed rechargeable batteries
e.   Non-rechargeable Lithium inorganic cells

2.4.3.2   Safety

Safety and complexity criteria indicate that it is not
desirable to connect the firing unit to the vehicle
electrical system. This precludes the use of Nickel Cadmium
batteries. This point is further reinforced by the
desirability of a throw away system at a later date. The
possibility of using one type of firing unit for all system
derivatives has been borne in mind.

The hand-cranked generator and Lithium cells are both
suitable for the task. The hand-cranked generator was chosen
on the following basis:

a.   It is less expensive than the Lithium cells.

b.   System safety is enhanced because no energy is either
      stored in or available to the firing unit until the
      operator cranks the handle.

Two discrete firing units are provided. It is therefore
unnecessary to provide an alternative power supply to the
individual firing units. The hand-crank is the only source
of power provided.

2.5   IGNITER IMPEDANCE MEASURING CIRCUITRY

The firing unit must test the continuity of the igniter
before initiating the system. It was assumed that a P54 fuze
head (or an approved equivalent) would be fitted. It has the
following specifications:

```
Resistance          :  2   ± 0,4 ohm
Functioning energy  :  1,5 ± 0,5 mJ/ohm = 4,8 mJ max
Minimum firing current:  350 mA
Normal firing current :  1A
Safe measuring current:  50mA
```

2.5.1 Test Current

It is normal practice to use a test current which is substantially less than the maximum safe measuring current.

2.5.2 Igniter Impedance Measuring Methods

Two possible methods were investigated:

A constant current method and a Wheatstone bridge circuit.

2.5.2.1 The constant current method
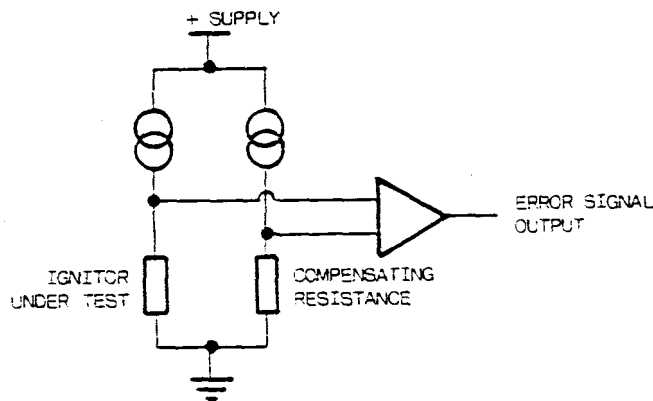
FIGURE 9: CONSTANT CURRENT TEST METHOD

This system requires two constant current sources which have to be closely matched for it to work effectively. Unmatched sources would require calibration during production. This circuit compensates for firing cable length.

2.5.2.2 The Wheatstone bridge
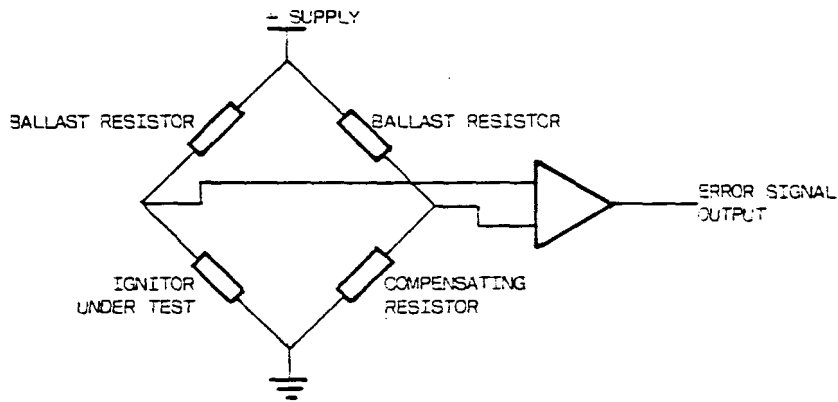
FIGURE 10: WHEATSTONE BRIDGE TEST METHOD

This system requires resistors whose tolerance spread is small when compared to the igniter impedance. Resistors are much more reliable and cheaper than constant current sources. This circuit also compensates for firing cable length.

2.5.3 Findings

The Wheatstone bridge circuit is preferable to the constant current circuit because of lower cost and greater reliability.

2.6 PREMATURE FIRINGS

The possibility of premature firing must be non-existent. Refer to paragraph 2.6.7, Section 1.

a. The use of a hand-crank to provide power ensures that no energy is available to cause inadvertent firings when the system is not being operated.

b. The igniter current, when testing igniter impedance will be limited to less than $1/2$ the safe measuring current.

c. A definite sequence of operations must be carried out in order to deploy the system. Any interlock or operator error will cause the system to automatically abort. The error will be brought to the operators attention.

Environmental and electromagnetic compatibility testing will be carried out to prove system integrity and safety.

2.7   <u>INTERCHANGEABILITY</u>

All firing units and firing cables are identical and
therefore fully interchangeable.

Rapid release fastenings and MIL-C-5015 type connectors will
be used throughout the system. Bolt-down units will be kept
to a minimum.

2.8   <u>SYSTEM DUPLICATION</u>

The system must be duplicated up to the fuzehead circuitry.
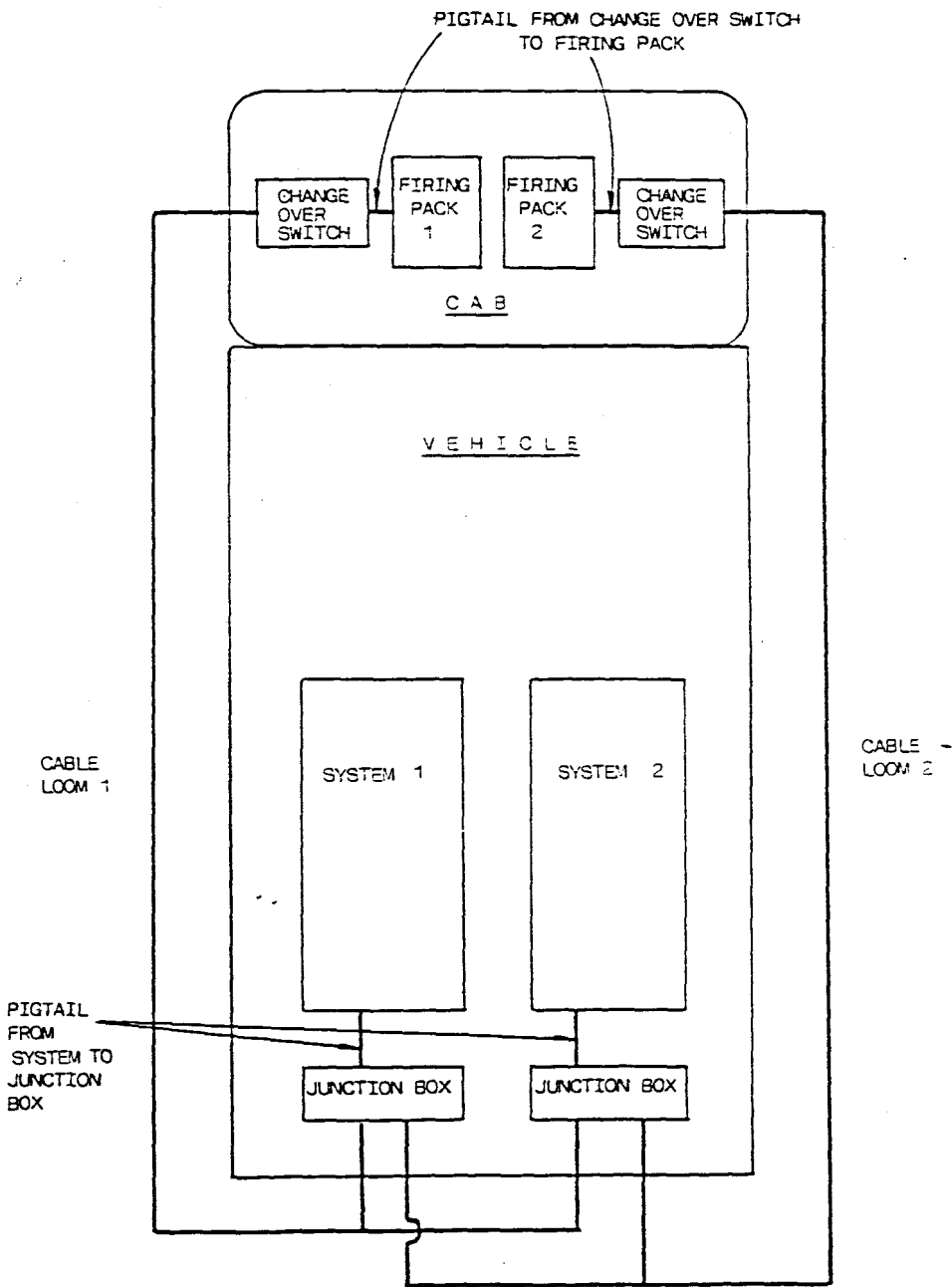
FIGURE 11:   GENERAL LAYOUT OF A SYSTEM USING TWO FIRING UNITS

2.8.1   <u>Mounting</u>

The physical mounting of the system must be such that firing
unit 1 can be connected to firing cable 2 and connected in
turn to system 1 or any permutation thereof.

Firing cable 1 and firing cable 2 are fitted in conduit on
opposite sides of the vehicle. This will reduce the
possibility of both firing cables being damaged at any one
instant.

2.9   <u>OPERATIONAL AND STORAGE TEMPERATURE RANGE</u>

The system must be operational over a temperature range of
0°C to 60°C and be able to withstand a storage temperature
range of -10°C to 60°C.

SECTION 3: THE FIRING UNIT DESIGN

This section deals with the in-depth design of the electronics contained in the firing unit. The following subsections of the circuit will be dealt with individually.

3.1   THE FIRING CAPACITOR [(C9)-Refer to paragraph 3.1.1.2]

The object of this section of the firing unit is to provide reliable storage of energy. This energy, derived from the hand-crank generator and is discharged from this capacitor into the fuzehead, is used to deploy the system. This is to be achieved reliably and with maximum safety.

3.1.1   Considerations

a.   The capacitor must be able to store the required charge.

b.   It must be relatively small.

c.   The capacitor leakage current must be negligible.

d.   It must be able to withstand surge currents.

e.   The device must be reliable.

3.1.1.1   Capacitor charge

The P54 fuzehead (or approved equivalent) as fitted in the igniter requires a functioning energy of 4,8 mJ. However, as energy losses occur throughout the system, the capacitor charge must be significantly larger than 5 mJ.

To initiate the fuzehead reliably the firing unit must provide a firing pulse such that at least twice the minimum firing energy is delivered, above the minimum fire current, to the fuzehead. The duration of the firing pulse must be compatible with the type of initiator used. The minimum fire current is specified as 1 amp.

CURRENT
I

MIN FIRE I

O   t
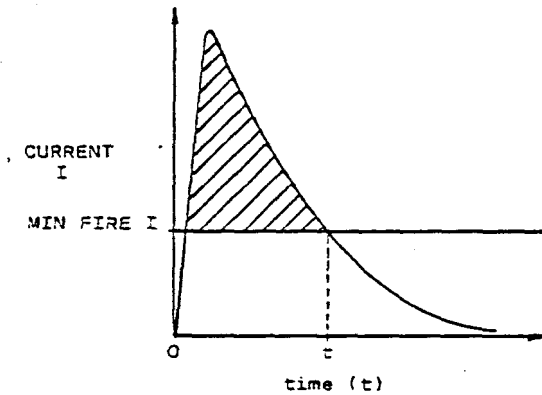
time (t)

FIGURE 12: PULSE REQUIRED TO INITATE A FUZE HEAD

The shaded area represents twice the functioning energy in Joules. Energy = I^2Rt

where I = firing current, R = fuzehead resistance and t = time.

The maximum resistance of the P54 fuzehead is 2,4 ohm.

Therefore 1A at 2,4 Ω = 2,4V use 3V. Resistance of 100 m of EPD 7719 cable (Raychem type no.) is 5 Ω per core giving a total resistance of 10 Ω :- 10 Ω x 1 amp = 10 volts. Assume a further 2 Ω resistance comprising printed circuit resistance and switch contact resistance: 2 Ω x 1 amp = 2 volts.

The capacitor charge voltage = 3V + 10V + 2V = 15 volts to achieve a 1 amp current through the fuzehead. In addition to the energy represented hereby, a further 10 mJ must be added. This 10 mJ is the shaded area of the graph above.

The functioning time of the fuzehead is 2,5 ms ±1,5 ms. A maximum of 4 ms is used.

The energy dissipated in the fuzehead and all losses to the 1 amp current level is therefore 15V x 1 A x 4 ms = 60 mJ.

The energy dissipated due to losses in delivering 10 mJ to the fuzehead is approximately:

$$10 \text{ mJ} \times \frac{15 \, \Omega}{2,4 \, \Omega} = 62,5 \text{ mJ}$$

The total energy storage of the capacitor must therefore be in the order of

10 mJ + 60 mJ + 62,5 mJ = 132,5 mJ.

A capacitor's stored energy in Joules is given by
$J = \frac{1}{2} CV^2$. The minimum output voltage of the generator
at no load is 100V RMS (Appendix 1). Therefore, taking V to
equal 100 Volts.

$$\frac{2J}{V^2} = C = \frac{2 \times 132.5 \times 10^{-3}}{100^2} = 26,5 \text{ uf}$$

A 47 uf capacitor charged to 100V will therefore deliver
nearly double the required energy and was therefore selected.

$$E = \frac{1}{2} CV^2 \text{ ie. } \frac{1}{2}. 47 \times 10^{-6}. 100^2 = 235 \text{ mJ}$$

The capacitor voltage rating was selected as 160V.

3.1.1.2   _Circuit diagram_
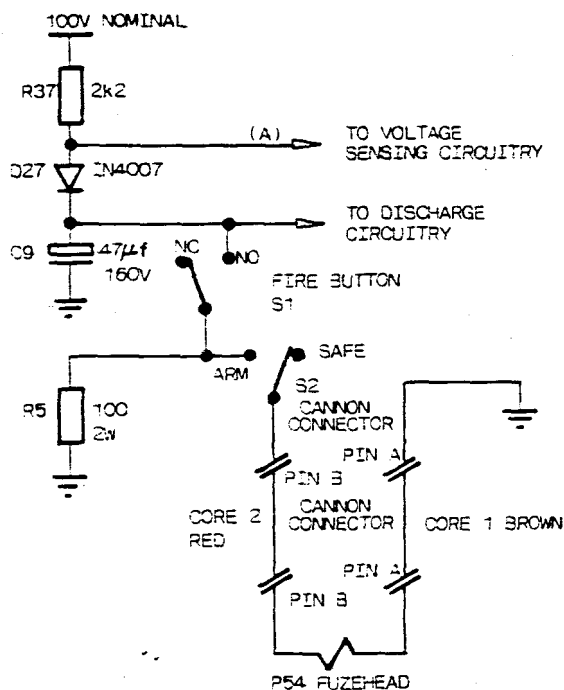
FIGURE 13:   CIRCUIT DIAGRAM – FIRING UNIT TO A P54 FUZE-HEAD

D27 is used to ensure that C9 cannot discharge into any other circuit connected to the power supply.

C9 is the energy storage element. This energy is used to initiate the fuzehead.

R37 is used as a current limiting resistor when C9 is being charged.

R37 and R5 form a potential divider if the fire button is depressed while attempting to charge the system. This will prevent point A reaching 100V. Point A will reach

$$\frac{100^2}{(2K2 + 100)} = 4,35 \text{ volts (nominal)}$$

This is equivalent to an energy of 0,5 mJ. This is not sufficient to fire the fuzehead. Increasing R37 will further reduce this energy level and increase the safety of the system.

Conversely the 100V (nominal) supply will have to rise to

$$\frac{100}{100} \times (2K2 + 100) = 2300 \text{ volts in order to fire the fuzehead}$$

The peak output voltage of the generator is given in Appendix 1 (taken from the graph) as 110V x $\sqrt{2}$ = 156V.

Point A can therefore not reach 100V.

R5 has the added advantage that if the "FIRE" button is pressed before the unit is armed, C9 will be discharged in approximately 10 x C9 x R5 = 10 x 47 x 10^{-6} x 100 = 47 x 10^{-3} seconds.

This has the effect of ensuring that the unit must be armed before firing, otherwise the system will not deploy.

3.1.1.3   Conclusion

If C9 was charged prior to system deployment, the "FIRE" button pressed, then the system armed, the system might be deployed. This would occur if the "FIRE" action and then the "ARM" action occurred within 47 x 10^{-3} seconds. If this was the case the system would operate as per a normal firing. Notwithstanding this provision, the system would not be deployed if the firing unit's "FIRE" button was depressed before the unit was armed.

Increasing R37 would increase the safety of the system. This will be investigated in the next development phase.

3.1.2 Capacitor Size

The complete firing unit is to be housed in an ergonomically acceptable aluminium enclosure. The enclosure selected is of 260 mm length; 160 mm width and 90 mm in height.

Two types of capacitor were investigated:

Non-polarised capacitors

Polarised capacitors

3.1.2.1 Non-polarised capacitors

Wima capacitors
250V DC 10 uf
Dimensions 22 mm wide; 43,5 mm high; 31,5 mm long.
Each 47uf capacitor would have an area of PCB of
6,93 cm^2 x 5 = 34,65 cm^2.
This is too large.

Larger values of capacitor at sufficiently high voltage rating do not appear to be available.

3.1.2.2 Polarised capacitors

Roederstein manufacture a 47uf 160V axial capacitor of 30 mm long and 16 mm in diameter. This capacitor's physical size and quality of manufacture seem satisfactory.

3.1.2.3 Conclusion

Polarised aluminium oxide capacitors are satisfactory if the leakage current and internal resistance are acceptable.

3.1.3 Leakage Current

All electrolytic capacitors have a leakage current which is necessary to maintain the insulating layer (dielectric). The leakage current rises with an increase of ambient temperature or may also occur after a long storage time without voltage applied. When charging the capacitor after storage, the initial leakage current may, for a short period, reach 100 times its average D.C. leakage.

Charging the capacitor right after storage will not result in damage or reduction of its life expectancy. The leakage current will generally reach its standard level or again fall below after approximately 10 minutes.

(Roederstein and Türk KG)

The DC leakage of the Roederstein capacitor is given as 246 micro Amps at 160V. When operated at 100V this leakage is substantially lower and appears acceptable.

3.1.4   Surge Currents

The capability of this type of capacitor to withstand a high discharge rate will be investigated in the next development phase.

3.1.5 Reliability

Refer to MIL-HDBK-217B page 2.6.6-1.

Aluminium oxide electrolytic capacitors were selected.

λp = failures per 10^6 hours

λb = stress rating factor

Π_E = environment factor

Π_Q = quality factor

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

$$S = \frac{actual\ voltage}{rated\ voltage} = \frac{100V}{160V} = 0,625$$

therefore from MIL-HDBK-217B table 2.6.6.3 λb = 0,072

let Π_E = 12 ; a ground mobile environment

let Π_Q = 1 ; upper quality level

λp = 0,072 (12) x 1 = 0,864 failures/10^6 hours

This indicates the mean time between failure of this capacitor to be $\frac{10^6}{0,864}$ = 1,16 x 10^6 hours

Further failure analysis of this circuit has not been done during this phase.

3.2 THE INTERLOCK CIRCUITRY

The object of the circuitry is to provide the operator with an indication of an interlock fault and to abort system deployment automatically.

3.2.1 Considerations

a. The circuit must indicate an error if the cable or switch is open circuit, eg; a broken joint in the cable. It has been assumed that a short circuit condition within the cable would be as a result of external physical damage. A short circuit condition would be detected by the fuzehead impedance measuring circuitry.

b.   Noise immunity of the system.

c.   Reliability.

3.2.2   The Circuit

A conventional comparator circuit based around $1/4$ of the LM 224 series operational amplifiers was chosen for simplicity. This IC contains 4 amplifiers, the other three being used elsewhere in the firing unit.
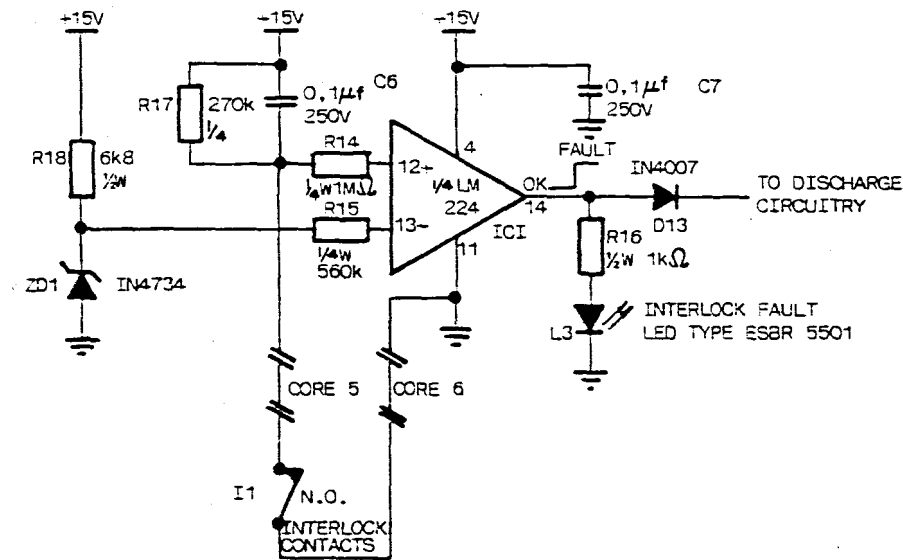
FIGURE 14: COMPARATOR CIRCUIT FOR THE FIRING UNIT

3.2.2.1   Circuit operation

R18 and ZD1 form a stable reference for the IC of approximately 5V6. This is fed, via R15 to the inverting input of the IC. R15 limits the maximum current flowing into the IC to $\dfrac{5V6}{560K}$ = 10 uA

If I1 or cores 5 or 6 are open circuit, the potential on the non-inverting input of the IC rises to approximately 15V due to R14 and R17. This is a fault condition. Pin 12 of the IC is therefore at a higher voltage than pin 13. The output, pin 14, rises to approximately 12V, illuminating L3 and activating the discharge circuitry.

If core 5, 6 and I1 are closed circuit, pin 12 of the IC is near ground potential. Pin 12 is thus at a lower potential than pin 13. IC1 has no output and deployment of the system can continue.

The maximum current into pin 12 of the LM 224 (IC1) is

approximately $\dfrac{15V}{270K + 1M} = 12uA$

3.2.2.2 Circuit design

R18 and ZD1

The IN4734 is a 5,6V device rated at 1 watt while the 6K8 resistor is rated at 0,5 watt.
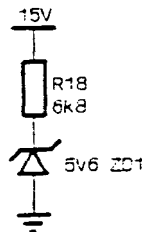
FIGURE 15: ZENER REGULATOR CIRCUIT

A Zener diode current of about 1,5 mA is selected for reliability.

R18 is therefore $\dfrac{15V - 5,6V}{1,5 \times 10^{-3}} = 6K3$ ∴ use a 6K8

Zener power dissipated $= \dfrac{15V - 5V6}{6800} \times 5V6 = 7,7 \times 10^{-3}$ watt

R1 power dissipation is $\dfrac{(15 - 5,6)^2}{6800} = 13 \times 10^{-3}$ watt

The actual zener diode voltage can be calculated from the following :

$$V'z = Vz + Z (I'z - Iz)$$

where

$V'z$ = the new zener voltage
Vz = the former zener voltage
$I'z$ = the new zener current
Iz = the zener current flowing at Vz
Z = the zener impedance at Iz.

from the Motorola diode data book.

$$V'z = 5,6 + 5(1,5 \times 10^{-3} - 45 \times 10^{-3}) = 5,38 \; V$$
(using a reference of 45 mA.)

$$V'z = 5,6 + 600 (1 \times 10^{-3} - 1,5 \times 10^{-3}) = 5,3 \; V$$
(using a reference of 1 mA.)

The zener diode is operating in the constant voltage region because a current of greater than 1 mA is flowing through the zener diode. (Motorola data).

The actual zener diode voltage is in the order of 5,4 V.
This means that the zener diode voltage temperature coefficient is practically zero.

3.2.2.3   LED current

The LM224 output voltage is typically $V_{supply} - 1,5V$; in this case 15V - 1,5V = 13,5V and the typical forward voltage of the LED is 1,7V. (Stanley type ESBR 5501). Operating current of the device is 20mA. A current of 10mA is selected.
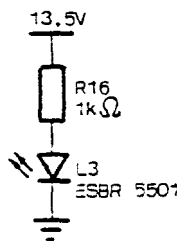
FIGURE 16:   LIGHT EMITTING DIODE CIRCUIT

$$R16 = \frac{13.5V - 1.7V}{10 \times 10^{-3}} = 1,181K \quad \text{therefore use a 1K resistor.}$$

Power dissipated in R16

$$\frac{V^2}{R} = \frac{(13.5 - 1.7)^2}{1000} = 139 \text{ mW}$$

let R16 be a 1K ^{1}/2 watt resistor.

The guaranteed maximum output current available from a LM224 of amp is 20 mA. The current through the LED is
$$\frac{13.5V - 1.7V}{1000} = 11,8 \text{ mA}$$
The LM224 can supply the LED current required.

An interlock fault condition occurs when pin 12 of IC 1 rises to a potential above that of pin 13.

ZD 1 voltage is a minimum of approximately 5,3 V.
R = interlock resistance.
$$\text{therefore} \quad \frac{15-5,3}{270 \times 10^3} = \frac{5,3}{R}$$

$$R = \frac{5,3 \cdot 270 \times 10^3}{15-5,3} = 147 \text{ K}$$

The maximum equivalent series resistance of the interlock circuitry to guarantee a no fault condition is 140 K

ZD 1 voltage is a maximum of approximately 5,5 V
$$\text{therefore} \quad \frac{15-5,5}{270 \times 10^3} = \frac{5,5}{R}$$

$$R = \frac{5,5 \cdot 270 \times 10^3}{15-5,5} = 156 \text{ K}$$

The minimum equivalent series resistance of the interlock circuitry to guarantee a fault condition is 160 K .

3.2.3   Noise Immunity

Two capacitors are included for noise immunity. C7 is to ensure a relatively noise free power supply for IC 1. It is situated as close as possible to pins 4 and 11 of IC 1.

C6 is used to decouple any noise induced in cores 5, 6 and switch I 1. Any noise occuring at pin 12 would have to be greater than the zener diode voltage to cause the output of the IC to go high.

3.2.4   <u>Reliability</u>

3.2.4.1   The zener diode, ZD1 (refer to MIL-HDBK-217B page 2.2.5-1)

Part failure rate model (λp)

$\lambda p = \lambda b$ (Π_E x Π_A x Π_Q) failure /10^6 hours

$\Pi E = 25$ (ground mobile)

$\Pi A = 1,5$ (voltage reference)

$\Pi Q = 25$ (hermetic packaged device)

λ_b, the base failure rate:-

T (°C) $=$ a maximum of 60°C

$$\text{Stress} = \frac{\text{Power dissipated}}{\text{Max power}} = \frac{7.7 \times 10^{-3}}{1} = 7,7 \times 10^{-3}$$

CF (correction factor) $= 1$

    from MIL-HDBK-217B table 2.2.5.4 $\lambda_b = 0,041$

   $\lambda_p = 0,041$ (25.1,5.25) failure/10^6 hours

      $= 38$ failure/10^6 hours

therefore the MTBF (mean time between failures)

    $= \dfrac{10^6}{38}$ $= 26 \times 10^3$ hours

3.2.4.2 <u>The LM224 (IC1)</u> (refer to MIL-HDBK-217B page 2.1.2-1)

This is calculated for the entire device of 4 operational amplifiers containing 48 transistors (T).

$$\lambda p = \Pi L \Pi_Q (C_1 \Pi T_2 + C_2 \Pi E)$$

where λp = failure rate per 10^6 hours

Π_Q = quality factor

ΠL = learning factor

ΠT_2 = temperature acceleration factor

Π_E = environmental multiplier

C1 and C2 = circuit complexity failure rate

From the associated tables in MIL-HDBK-217B

ΠQ = 2

ΠL = 1

ΠT_2 = 0,1

ΠE = 4

C_1 = 0,00056 (T)^{0,763} = failure/10^6 hours

= 0,00056 (48)^{0,763} = 10,74 x 10^{-3}

C_2 = 0,0026 (T)^{0,547} = failures/10^6 hours

= 0,0026 (48)^{0,547} = 21,61 x 10^{-3}

The failure rate, $\lambda p = \Pi_L \Pi_Q (C_1 \Pi_{T2} + C_2 \Pi_E)$

λp = 1.2 (10,74 x 10^{-3}.0,1 + 21,61 x 10^{-3}.4)

= 175 x 10^{-3} failures/10^6 hours

$$MTBF = \frac{10^6}{175 \times 10^{-3}} = 5,7 \times 10^6 \text{ hours}$$

3.3   THE IMPEDANCE MEASURING SECTION

This circuitry is designed to check whether the fuzehead has
a resistance that is within the manufacturers'
specifications. If the fuzehead is within tolerance, the
deployment of the system is allowed to continue. If
tolerance limits are exceeded, deployment is automatically
aborted and the fault brought to the operator's attention.
This circuitry will also detect short circuit or open circuit
firing cable faults.

3.3.1   Considerations

a.   The igniter measuring current will be limited to less
      than 10 mA. The safe measuring current of the P54
      fuzehead (or approved equivalent) is 50 mA.

b.   The circuit must compensate for cable length.

c.   The circuit must compensate for the temperature
      coefficients of the cable and the fuzehead over the
      desired operating range (0°C to 60°C).

d.   The circuit must be safe.

e.   The circuit must be reliable.

3.3.2   The Circuit

A Wheatstone bridge supplying two comparators is used. One comparator detects when the fuzehead resistance is too low while the other comparator detects when the fuzehead resistance is too high.
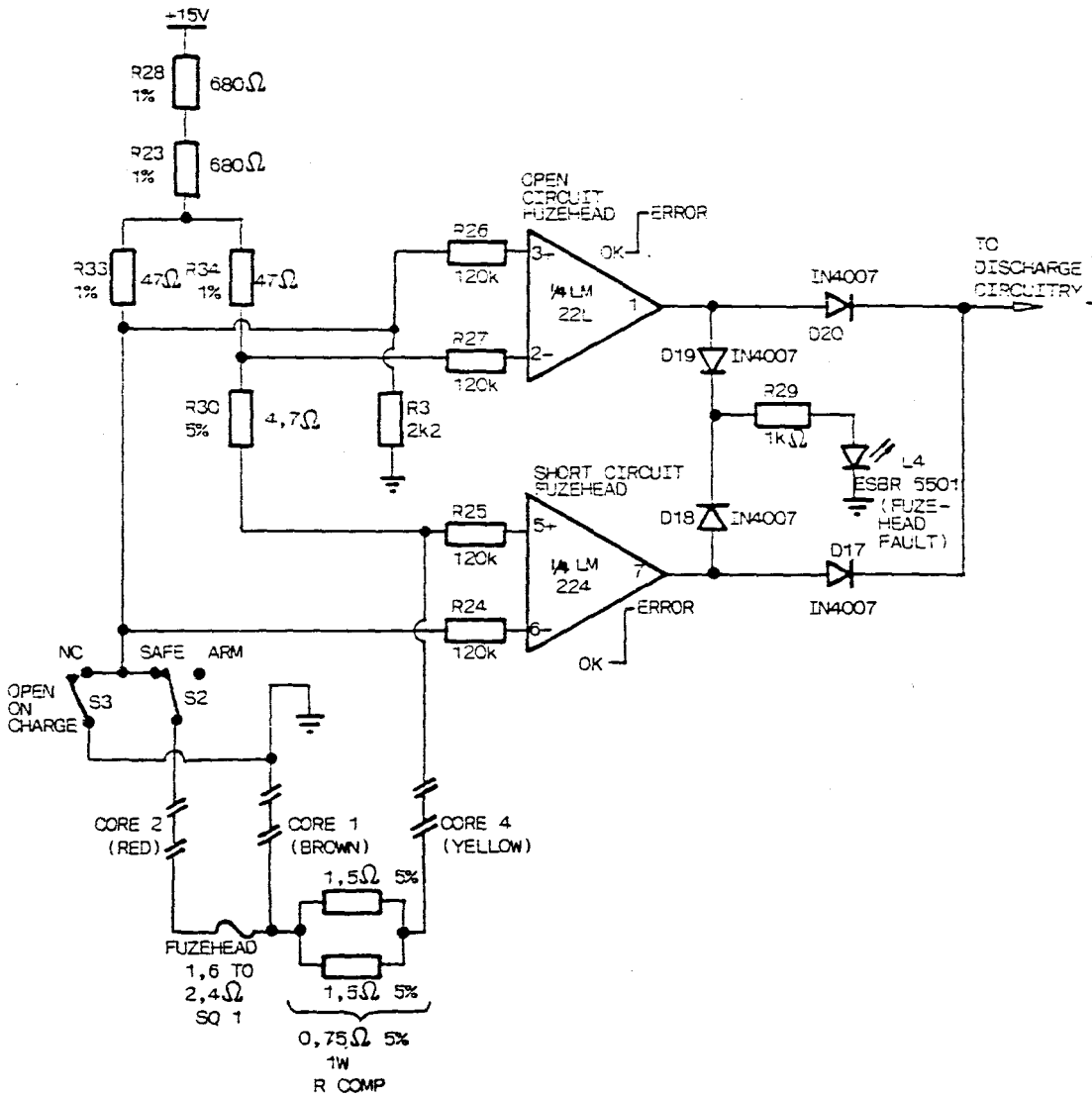
FIGURE 17:   FUZE-HEAD IMPEDANCE LIMIT DETECTING CIRCUITRY

3.3.2.1   Circuit Operation

R23 and R28 are current limiting resistors through the Wheatstone bridge. The Wheatstone bridge consists of resistors R30; R33; R34; R_{comp} and the fuzehead.

If the fuzehead goes open circuit:

The pin numbers refer to IC 1.

The voltage on pins 6 and 3 rise to a value above that of pin 2 and 5 respectively.

Output pin 7 stays low because its associated inverting input has a potential above that of its non-inverting input.

Output at pin 1 goes high because its associated non-inverting input (pin 3) is at a greater potential than the inverting input (pin 2). Pin 1, at approximately 15V, cause L4 to illuminate, via D19 and R29. L4 attracts the operators attention to the fuzehead fault. Current is also passed via D20 to the discharge circuitry, aborting the system deployment.

If the fuzehead goes short circuit:

The potential on Pins 3 and 6 of the LM 224 decrease to ground while pins 5 and 2 are higher. Pin 7 is then at a high potential and pin 1 is low. Current passes through D18 and R29, illuminating L4. L4 attracts the operators attention. Current passes through D17, aborting the system deployment.

R30 provides the range of fuzehead resistance during which neither pin 1 nor pin 7 of the LM 224 is high. R_{comp} dictates the minimum fuzehead resistance acceptable.

3.3.2.2   Circuit Design
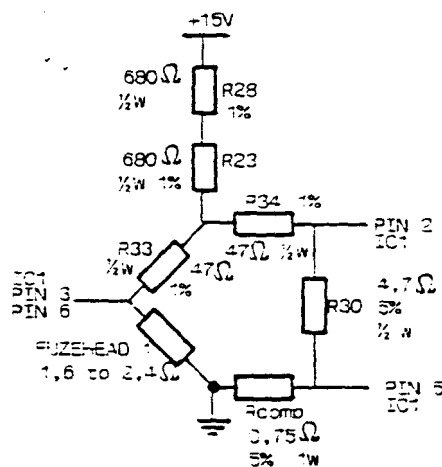
FIGURE 18:   WHEATSTONE BRIDGE AND CURRENT LIMITING RESISTORS

The fuzehead tolerance is from 1,6 to 2,4 Ω; i.e. a Δ R of 0,8Ω.
Let R33 and R34 tolerance be $1/2$ x 0,8Ω = 0,4Ω .
A 1% tolerance resistor having 0,4 Ω variation will

be $\dfrac{0,4}{1}$ x 100 = 40 Ω. Therefore use a 47 Ω resistor.

The fuzehead resistance, R30 and R_{comp} resistance will be low compared to R33 and R34.

Total bridge current must be less than 25 mA. A current of 10 mA was selected.
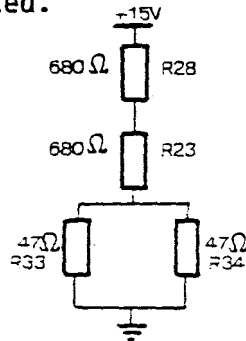
FIGURE 19:   CURRENT LIMITING RESISTORS, R23 AND R28

Total resistance of the circuit is $\dfrac{15\ V}{10\ mA}$ = 1K5.

$\quad$ R23 and R28 must equal   1K5 - 47 Ω//47 Ω
$\qquad\qquad\qquad\qquad\qquad$ = 1K5 - 23,5 = 1K48

Let R23 = R28 = $1/2$ x 1K48 = 738 Ω

a resistor of 680 Ω was selected.

An acceptable fuzehead resistance range for the firing unit was selected as being from 0,75 Ω to 5 Ω .
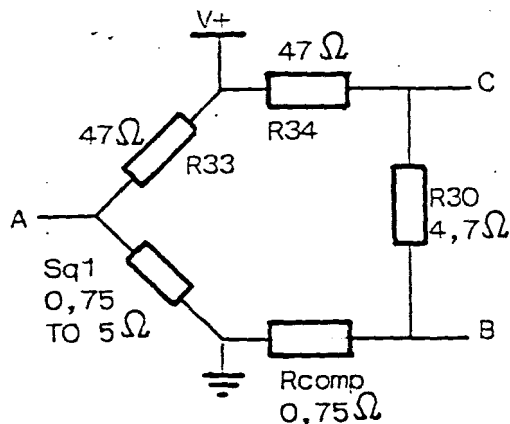
FIGURE 20:   WHEATSTONE BRIDGE RESISTANCE VALUES

Therefore, when the fuzehead resistance $= 0,75\Omega$ the voltage at point A must equal that at point B.

let $R_{comp} = 0,75\Omega$

when Sql $= 5\Omega$ the voltage at point C must equal that at point A. Let R30 $= 5\Omega - 0,75\Omega = 4,25\Omega$. Therefore, use a $4,7\Omega$ resistor.

Using the indicated values the following resistance range is calculated. Let the fuzehead resistance $=$ Sql.

Lower limit of fuzehead resistance

$$\frac{V}{47 + Sql} \times Sql = \frac{V}{47 + 4,7 + 0,75} \times 0,75$$

$$\frac{Sql}{47 + Sql} = 14,3 \times 10^{-3}$$

$$Sql = 14,3 \ 10^{-3} \ (47 + Sql)$$

$$Sql = 672 \times 10^{-3} + 14,3 \times 10^{-3} \ Sql$$

$$Sql - 14,3 \times 10^{-3} \ Sql = 672 \times 10^{-3}$$

$$Sql = \frac{672 \times 10^{-3}}{985,7 \times 10^{-3}} = 0,682\Omega$$

Upper limit

$$\frac{V}{47 + Sql} \times Sql = \frac{V}{47 + 4,7 + 0,75} \times (4,7 + 0,75)$$

$$Sql = 103,9 \times 10^{-3} \ (47 + Sql)$$

$$Sql - 103,9 \times 10^{-3} \ Sql = 4,88$$

$$Sql = \frac{4,88}{0,896} = 5,45\Omega$$

The effects of tolerance.

Lower limit of Sql lower limit

$$\frac{Sql}{(47 - 1\%) + Sql} = \frac{(0,75 - 5\%)}{(47 + 1\%) + (4,7 + 5\%) + (0,75 - 5\%)}$$

$$\frac{Sql}{46,53 + Sql} = \frac{0,712}{47,47 + 4,94 + 0,712}$$

$$Sql = 13,414 \times 10^{-3} (46,53 + Sql)$$

$$Sql = \frac{624,1 \times 10^{-3}}{0,987}$$

$$Sql = 0,633\Omega$$

Upper limit of Sql lower limit

$$\frac{Sql}{(47 + 1\%) + Sql} = \frac{(0,75 + 5\%)}{(47 - 1\%) + (4,7 - 5\%) + (0,75 + 5\%)}$$

$$\frac{Sql}{47,47 + Sql} = \frac{0,7875}{46,53 + 4,465 + 0,7875}$$

$$Sql = 15,21 \times 10^{-3} (47,47 + Sql)$$

$$Sql = \frac{0,722}{0,985}$$

$$Sql = 0,733\Omega$$

Upper limit of Sql upper limit

$$\frac{Sql}{(47 + 1\%) + Sql} = \frac{(0,75 + 5\%) + (4,7 + 5\%)}{(47 - 1\%) + (0,75 + 5\%) + (4,7 + 5\%)}$$

$$\frac{Sql}{47,47 + Sql} = \frac{0,7875 + 4,94}{46,53 + 0,7875 + 4,94}$$

$$Sql = 109,6 \times 10^{-3} (47,47 + Sql)$$

$$Sql = \frac{5,2}{0,89}$$

$$Sql = 5,8\Omega$$

<u>Lower limit of Sq1   upper limit</u>

$$\frac{Sq1}{(47 - 1\%) + Sq1} = \frac{(0,75 - 5\%) + (4,7 - 5\%)}{(47 + 1\%) + (0,75 - 5\%) + (4,7 - 5\%)}$$

$$\frac{Sq1}{46,53 + Sq1} = \frac{0,712 + 4,465}{47,47 + 0,712 + 4,465}$$

$$Sq1 = 0,0983 (46,53 + Sq1)$$

$$Sq1 = \frac{4,58}{0,902}$$

$$Sq1 = 5,07\,\Omega$$

3.3.2.3   <u>Conclusion</u>

The preceeding calculations are summarised in the following table:

TABLE 1:   SUMMARY OF FUZE HEAD RESISTANCE CALCULATIONS

5,8 Ω	Resistances above this level are rejected
5,07 Ω	Intermediate area due to component tolerance
0,733 Ω	Resistance in this region will be accepted
0,633 Ω	Intermediate area due to component tolerance
	Resistances below this level are rejected
0	Resistance in ohms

The preceeding calculations do not take into account contact resistance variations, PCB track length variations and any difference in temperature coefficient of the fuzehead and compensating resistance. It therefore becomes necessary to open up the intermediate areas, especially in the 0,733 and 0,633 ohm areas. These areas are especially prone to contact resistance variation.

The following table will be more applicable.

TABLE 2: PRACTICAL FUZE HEAD RESISTANCE LEVELS

6,5Ω	Reject resistance above this level (5,8Ω + 12%)
4Ω	Intermediate area due to component tolerance and contact resistance etc. (5,07Ω - 21%)
Resistance in ohms 1Ω	Acceptable fuzehead resistance limit (0,733Ω + 36%)
0,4Ω	Intermediate are due to component tolerance and contact resistance etc. (0,633Ω - 37%)
0Ω	Reject resistances below this level

3.3.3   Cable Length Compensation

The circuit is designed on the Wheatstone bridge principle.
Cores 2 and 4 of the firing cable are in opposite legs of the
bridge. This fact results in core 2 resistance compensating
for core 4 resistance and vice versa, while core 1 is common
to both. Hence any change in firing cable length will have
only a negligible effect on the acceptable fuzehead
resistance limits.

3.3.4   Circuit Safety

3.3.4.1   Worst case current due to component failure

Calculation of worst case currents through the fuzehead due
to normal usage and failure of individual sections of this
circuit. Failure rates are dealt with separately under
reliability. Refer to paragraph 3.3.5.

a   Under normal circumstances the maximum current flows through the fuzehead when it is 1,6 Ω.
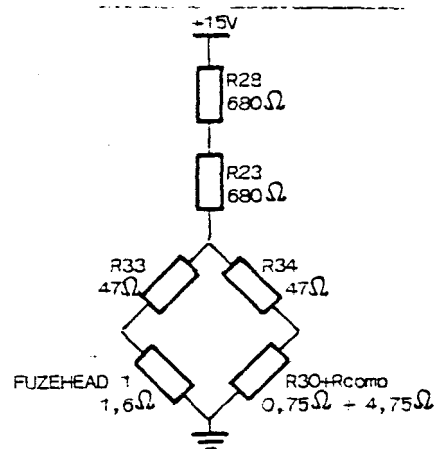
FIGURE 21:   COMPLETE WHEATSTONE CIRCUIT

Bridge equivalent resistance:

$(4,7 Ω + 1,6 Ω)//(47 Ω + 0,75 Ω + 4,7 Ω) = 25,23 Ω$

$$\text{total current flow} = \frac{15V}{680 + 680 + 25,23} = 10,83 \text{ mA}$$

the voltage across the Wheatstone bridge is

10,83 mA x 25,23 Ω = 273,16 mV

The current through the fuzehead leg is given by

$$\frac{273,16 \times 10^{-3}V}{47 Ω + 1,6 Ω} = 5,62 \text{ mA or}$$

approximately [1]/10 the normal safe measuring current of 50 mA.

b   Fuzehead current if the 47Ω (R33) resistor fails short circuit.

To facilitate worst case calculations it is assumed that the 0,75 Ω leg of the Wheatstone bridge is open circuit.
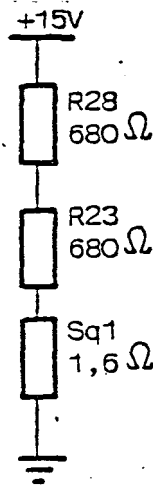
FIGURE 22: WHEATSTONE EQUIVALENT CIRCUIT

The current through the fuze head $= \dfrac{15V}{680 + 680 + 1,6} = 11$ mA

This is 0,22 x the maximum safe measuring current.

c   Assuming one 680Ω resistor (R28) and one 47Ω resistor fail short circuit (R33).

The current through the fuzehead $= \dfrac{15V}{680 + 1,6} = 22$ mA

This is 0,44 x the safe measuring current.

d   Assuming two 680 Ω resistors fail short circuit.

The current through the fuzehead $= \dfrac{15V}{47 + 1,6} = 309$ mA.

This is an unsafe condition as the minimum firing current is 350 mA. It should be noted, however, that the hand-cranked generator used in the circuit has a minimum short circuit current of 50 mA. This, reflected through the transformer to the low voltage winding (TR1) gives a short circuit current

$\dfrac{50 \times 100V}{15V} = 333$ mA

The actual current through the system must necessarily be less than this due to the circuit impedance.

3.3.4.2   Test circuit

A test circuit was then constructed according to the circuit below and the current through the fuzehead measured. Two hand-cranks were evaluated in turn.
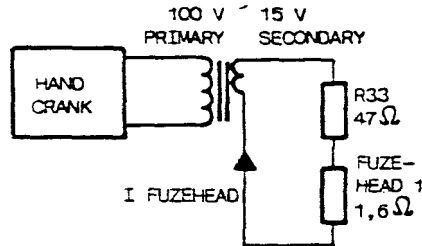
FIGURE 23:   TEST CIRCUIT FOR HAND-CRANK GENERATORS

The bridge rectifier and the voltage regulator have been omitted to facilitate worst case measurement.

Hand crank 1:   I fuzehead measured was 268 mA

Hand crank 2:   I fuzehead measured was 252 mA

These are unsafe values.

3.3.4.3   LM 224 failure

In the event of any failure of the LM 224 such that any of pins 2, 3, 5 and 6 become short circuited to +15V, the current flow per pin will be $\dfrac{15V}{120 \times 10^3} = 125 \times 10^{-6}A$

This results in a maximum current, if all four pins become short circuit to supply, of 0,5 mA. This is 0,01 x the safe measuring current.

If a (R26) 120K resistor fails short circuit and the assosiated IC pin fails short circuit to supply, an unsafe condition will arise.

3.3.5   Reliability

3.3.5.1   R28, the 680 Ω 1/2 watt resistor:

Under normal conditions a current of 10,83 mA flows through R28 (Paragraph 3.3.4.1).

From MIL-HDBK-217B page 2.5.2-1.:-

$\lambda p = \lambda b (\Pi_E \times \Pi_R \times \Pi_Q)$ failure/10^6 hours; the part failure rate model for metal film resistors.

Π_E The environmental factor is Ground Mobile (GM). This is a factor of 10 (MIL 10509)

Π_R The resistance range is up to 100K, factor is 1

Π_Q The failure rate level (MIL 10509). A factor of 1

The operating wattage of the resistor is $(10.83 \times 10^{-3})^2 \times 680 = 80 \times 10^{-3}$ watt.

$$\text{Stress} = \frac{\text{operating wattage}}{\text{rated wattage}} = \frac{80 \times 10^{-3}}{500 \times 10^{-3}} = 0.16$$

A maximum temperature of 60°C is specified.

This gives a base failure rate, λb, of 0,0019.

$\lambda p = 0.0019 (10 \times 1 \times 1) = 0.019/10^6$ hours

This is equal to a MTBF of 52.6×10^6 hours.

When a 680 Ω resistor fails, the other 680 Ω resistor would have an increased current through it of:-
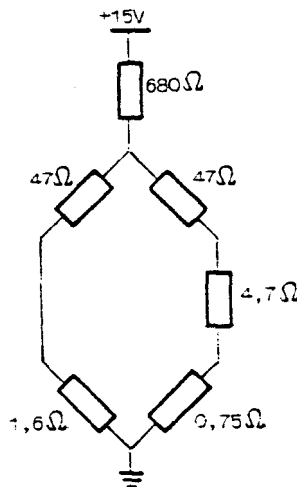
FIGURE 24:   R23 OR R28 FAILURE CIRCUIT

This is equivalent to:
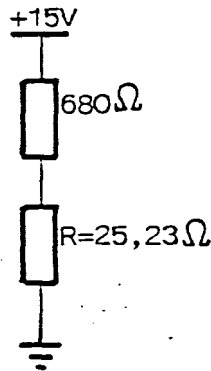
FIGURE 25: R23 OR R28 EQUIVALENT FAILURE CIRCUIT

$$\frac{1}{R} = \frac{1}{47 + 1,6} + \frac{1}{47 + 4,7 + 0,75} = 39,6 \times 10^{-3}$$

$$R = 25,23\Omega$$

The current in the circuit is $\frac{15}{680 + 25,23} = 21,3$ mA

In the failure rate model, the ratio of operating to rated wattage becomes

$$\frac{(21,3 \times 10^{-3})^2 \times 680}{500 \times 10^{-3}} = 0,62$$

λp becomes 0,0033 (10 x 1 x 1) = 0,033 failures per 10^6 hours

This has an equivalent MTBF of 30,3 x 10^6 hours.

For an unsafe condition both resistors R23 and R28 have to fail
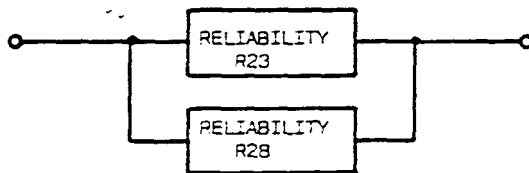
FIGURE 26: SAFETY RELIABILITY DIAGRAM FOR R28 AND R23

Let $t = 1 \times 10^6$ hours

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

Reliability for R23 $= e^{-0,019} \times 10^{-6}t = 981,179 \times 10^{-3}$

Reliability for R28 $= e^{-0,033} \times 10^{-6}t = 967,539 \times 10^{-3}$

Total reliability of the combination R23 and R28

$$R_{total} = 1-(1-981,179 \times 10^{-3})(1-967,539 \times 10^{-3})$$

$$= 999,389 \times 10^{-3}$$

$\lambda p_{total} = 611,135 \times 10^{-3}$ failures/10^6 hours

$\lambda p_{total} =$ the failure rate of the parallel resistor combination

3.3.5.2   <u>120 K resistor failure</u>

Failure of a 120 K resistor such as R8:

The failure model, λp, becomes:-

The ratio of operating to rated wattage is equal to

$$\frac{(15)^2}{(250 \times 10^{-3})\quad(120 \times 10^3)} = 0,0075$$

therefore λb = 0,0018

   λp = 0,0018 (10 x 1,1 x 1) = 0,0198 failures/10^6
   hours

since these are 4 resistors

λp becomes 4 x 0,0198/10^6 hours

= 0,0792 failure/10^6 hours

this gives a MTBF of 12,63 x 10^6 hours

For this failure to be unsafe the LM 224 must also fail.
From para 3.2.4.2 the MTBF of the LM 224 is 5,7 x 10^6 hours.

For an unsafe condition both IC 1 and any one of the four
120 K resistors must fail.
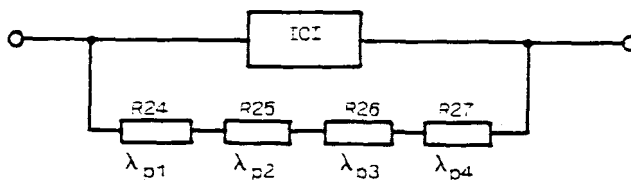
FIGURE 27:   SAFETY RELIABILITY DIAGRAM OF IC 1 AND THE FOUR
             120 K RESISTORS.
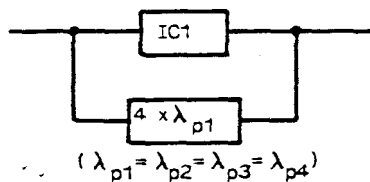
FIGURE 28:   EQUIVALENT RELIABILITY DIAGRAM OF IC 1 AND THE FOUR
             120 K RESISTORS.

Let $t = 1 \times 10^6$

Reliability IC 1 $= e^{-\lambda pt} = e^{-175 \times 10^{-9}t} = 0.83909$

Reliability R24 - R27 $= e^{-\lambda pt} = e^{-0.0792 \times 10^{-6} t} = 0.92386$

Reliability of the combination of IC 1 and R24 - R27

$R_{total} = 1-(1-0.83909)(1-0.92386)$

$= 987.748 \times 10^{-3}$

λp_{total} $12.37 \times 10^{-3}/10^6$ hours

3.3.5.3   Unsafe failure rate

The unsafe failure rate of the complete circuit is the sum of all the individual failure rates.
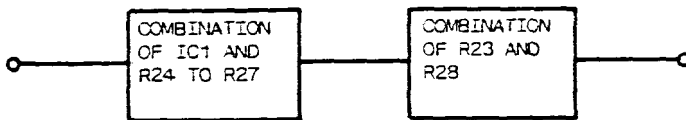
FIGURE 29: SAFETY RELIABILITY DIAGRAM

for 10^6 hours

$\lambda p_{total} = 611.135 \times 10^{-6} + 12.37 \times 10^{-3}$

$= 12.98 \times 10^{-3}$ failures/10^6 hours

$MTBF_{unsafe} = \frac{1}{\lambda p} = 77 \times 10^6$ hours

3.4   THE LATCHING RELAY SECTION

3.4.1   The Circuit
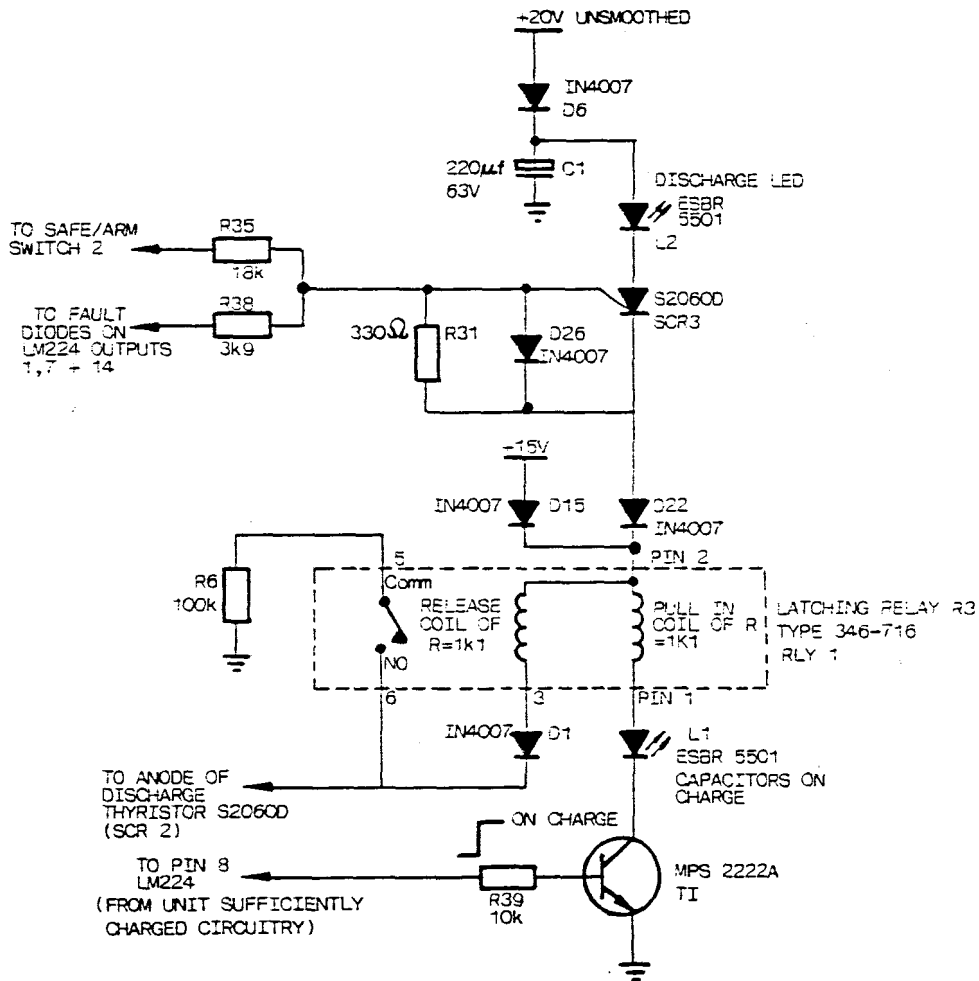
FIGURE 30:   LATCHING RELAY CIRCUIT

3.4.1.1   Circuit operation

When the hand-crank generator is cranked, C1 is charged via D6 to approximately 20V. This energy is stored in C1 until such time as the latching relay, RLY 1, changes state from the armed position to the safe position.

When LM 224 pin 8 goes high, the unit is sufficiently charged, T1 switches on. Current passes through D15, pin 2 to pin 1 coil of RLY 1, through L1, T1 to ground. L1 then indicates that the main storage capacitors have been sufficient charged.

This current also latches RLY 1 in the "ARMED" position, opening the contact between pins 5 and 6 of RLY 1. This disconnects R6 from the main storage capacitors. R6 is used as a charge leakage resistor when the latching relay is in the "SAFE" position.

Making the firing unit safe:

This will automatically be achieved when cranking the hand crank without depressing the "Charge" button or, after switching the "SAFE/ARM" switch to "ARM", and then returning it to the "SAFE" position.

As either one of these two actions occur, both SCR 2 (see paragraph 3.8.2) and SCR 3 are simultaneously triggered to the on state. The charge in C1 passes through L2, SCR3, D22, Pin 2 to pin 3 relay coil, D1 and SCR 2 to ground.

L2 flashes due to the passage of this charge, informing the operator that the main storage capacitors have been discharged. RLY 1 also changes state to the "SAFE" position, closing the contacts between pins 5 and 6 of RLY 1.

Any energy build up in the main storage capacitor after SCR 2 switches off is discharged through R6.

D1, D15 and D22 are current steering diodes to ensure that, for example, C1 is not partially discharged into the +15V supply. D26 ensures that the gate cathode voltage on SCR 3 never exceeds 0,7 V.

3.4.2   Circuit Design

3.4.2.1   Capacitor C1

The capacity of C1;

RLY 1 requires a voltage pulse of between 9 V and 30 V for a minimum of 1,5 ms.

The voltage drops in the Cl discharge path are

L2	1,7 V
SCR 3	1,0 V
D22	0,7 V
Dl	0,7 V
SCR 2	1,5 V
	5,6 V

Therefore the voltage available to the coil is a maximum of 20 V – 5,6 V = 14,4 V.

This must not drop by more than 5,4 V in 15 ms. 15 ms is 10 times the minimum pulse width required to change the relay state.

$$V = E \left(e^{\frac{-t}{RC}} \right) ; \text{ the discharge voltage curve of a capacitor}$$

$$C = \frac{-t}{R \, Ln \, \frac{V}{E}}$$

where R is the circuit resistance

V is the final voltage value

E is the initial voltage value

t = the current pulse width in seconds

$$C = \frac{-15 \times 10^{-3}}{1110. \; Ln \left(\frac{9}{14,4} \right)} = 28,8 \text{ uf}$$

The above calculation does not take into account the effect of capacitor leakage. The flash of light from the discharge LED, L2, will also be extremely short. Cl can therefore be increased. A 220 uf 63 V device is selected. t therefore becomes 115×10^{-3} seconds.

The maximum peak current through L2 is $\frac{14,4V}{1110} = 13$ mA.

This is acceptable.

3.4.2.2   RESISTOR R31

The value of R31 must be as low as possible to prevent false triggering of SCR 3, but high enough to facilitate easy triggering of the device.

An arbitary value of 330 Ω was selected.

The following information is from the RCA data sheet on the S2060D silicon controlled rectifier.

Peak gate current for 10 us   - 0,2A
Peak gate forward power for 10 us - 0,5 W
Average gate forward power   - 0,1 W
DC gate trigger current   - 200 uA (max)
DC gate trigger voltage   - 0,65 V

3.4.2.3   Resistor R38
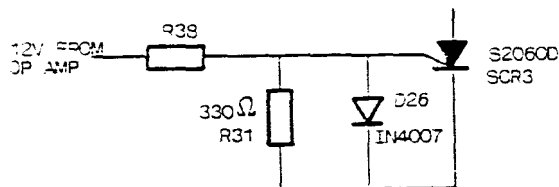
FIGURE 31:   R38 VALUE

Let the DC trigger current be 150 uA, the gate voltage 0,65 V and the diode current 1 mA. 150 uA should be sufficient to trigger the SCR reliably from -40°C to +60°C.

Current through R31 $= \dfrac{0,65V}{330} = 2$ mA

total current through R38 = 2 mA + 1 mA + 150 uA = 3,12 mA

$$R38 = \frac{12 - 0,65}{3,12 \text{ mA}} = 3K64$$

a resistor of 3K9 was selected.

3.4.2.4   Resistor R35
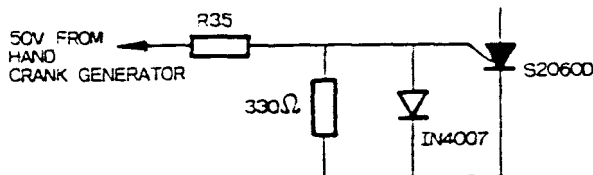
FIGURE 32:   R35 VALUE

The current consideration is as for 3.4.2.3.

$$R35 = \frac{50 - 0.65}{3.12 \text{ mA}} = 15.8K$$

a 18K resistor was selected.

3.4.2.4 Resistor R6

R6 must be a high resistance for the hand crank to generate 100V across it, when in series with a 2K2 resistor. R6 must also be low enough to discharge the main storage capacitors in a reasonable length of time. A 100K resistor was selected.

This gives a discharge time of $10 \cdot 100 \times 10^3 \cdot 150 \times 10^{-6} = 150$ seconds.

150 seconds would only be valid if the unit's main storage capacitors were charged to less than 100 V, the "Ready" LED did not light up and the unit was not made safe.
The maximum current through R6 and RLY 1 contacts is 1 mA. RLY 1 contacts are rated at 150 V 2A.

3.4.3 Reliability

3.4.3.1 The SCR (SCR 3) (Refer to MIL-HDBK-217B page 2.2.6-1.)

The part failure rate model λp

$$\lambda p = \lambda b \times \Pi Q \times \Pi E \times \Pi R \quad \text{failure}/10^6 \text{ hours}$$

ΠQ = Quality = hermetically packaged = 25

ΠE = Environment = ground mobile = 25

ΠR = Rated forward anode current = 1A to 5A = 3

$$Stress = \frac{Iop}{Imax}(CF)$$

where (CF) is the stress correction factor

$$and \quad CF = \frac{Tmax - 25°}{150°} = \frac{110° - 25°}{150°} = 0.567$$

from the λb table; $T = T_A + (175 - T_{max})$

$$= 60 + (175 - 110) = 125°C$$

$$S = \frac{12 \times 10^{-3} \cdot 0.567}{2.75} = 0.0025$$
from the table $\lambda b = 0.009$

Therefore $\lambda p = 0,009 \times 25 \times 25 \times 3 = 16,8$ failure/10^6 hours

This is equivalent to a mean time between failures of $59,26 \times 10^3$ hours

3.4.3.2   <u>The latching relay [RLY 1]</u>(Refer the MIL-HDBK-217B page 2.9-1)

The part failure rate model λp.

$\lambda p = \lambda b \; (\; \Pi_E \times \Pi_C \times \Pi_{cycle} \times \Pi_F)$ failures/10^6hours

   ΠE = environmental conditions = ground mobile = 30

   ΠC = contact form = single pole single throw = 1

   ΠF = magnetic latching; dry circuit = 12

   $\Pi cycle$ = cycles per hour of operation = less than 10 = 1

   λb = $\Pi_T(\; \Pi_L)$

   ΠT = 0,0085 (85°C relay at 60°C)

Stress = $\dfrac{12mA \text{ inductive}}{2A}$ = S of 0,006. $\Pi_L = 1,02$

∴ λb = 0,0085 x 1,02 = 0,00867

   λp = 0,00867 (30 x 1 x 1 x 12) = 3,12 failure/10^6 hours

the mean time between failures is 320×10^3 hours

3.5   <u>THE VOLTAGE SENSING CIRCUITRY</u>

3.5.1   <u>Considerations</u>

The objective of the circuit is to provide reliable sensing of the voltage on the main storage capacitors. When the storage capacitor voltage reaches 100V the latching relay must be pulled in. A LED informs the operator that the firing unit is ready to deploy the system.

3.5.2   The Circuit
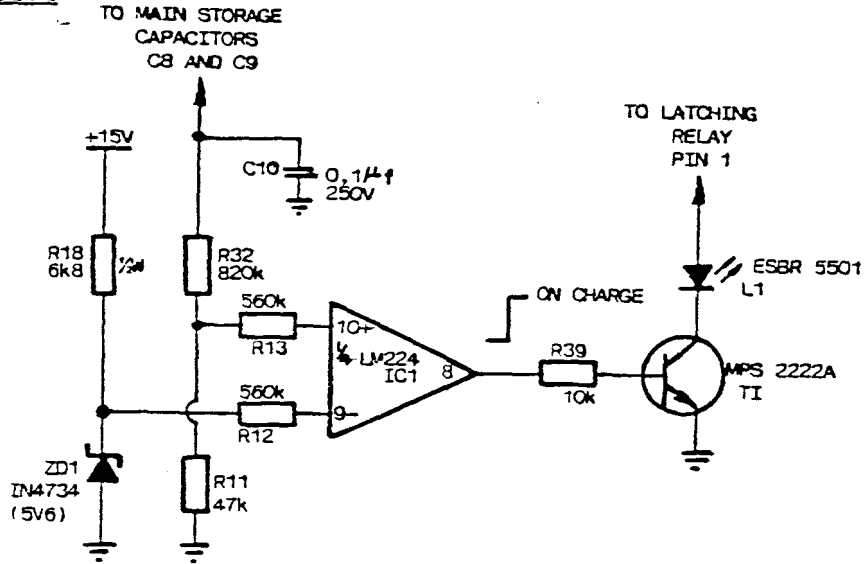
FIGURE 33: VOLTAGE SENSING CIRCUIT

3.5.2.1   Circuit operation

The circuit is designed as a comparator. When the voltage on
pin 10 exceeds that on pin 9, the output voltage of IC 1
(pin 8) rises to approximately 13V. Base current is then
supplied to T1 via R39.

T1 is saturated, the collector current flows through the
latching relay, pin 1, and the LED (L1).

C10 is a smoothing capacitor.

3.5.2.2   Circuit Design

R18 and ZD1 are dealt with in paragraph 3.2.2.2.

R11 and R32:

These two resistors are a load to the main storage capacitors
during charge.

The input bias current into IC 1 is a maximum of 300 nA. The
current through R11 and R32 must be large compared to this
value. A current of 100 uA at 100 V was selected. A total
resistance of 1 M   is used.

The voltage across R11 must equal the zener diode voltage
when the main storage capacitors are charged to 100V. The
zener diode voltage is approximately 5,4 V due to the very
low zener diode current.

$$R11 = \frac{5,4}{100 \times 10^{-6}} = 54K$$

$$R32 = 1M - 54K = 946K$$

select R11 as 47K

$$I(R_5) = \frac{5,4}{47 \times 10^3} = 114,9 \ uA$$

$$R32 = \frac{100 - 5,4}{114,9 \ uA} = 823K$$

let R32 = 820K

3.5.3 Reliability

3.5.3.1 ZD1

ZD1 is dealt with in para 3.2.4.1.

3.5.3.2 LM 224

The LM 224 is dealt with in para 3.2.4.2.

3.5.3.3 MPS 2222A

The MPS 2222A transistor (T1)
(Refer to MIL-HDBK-217B page 2.2-1).

The general failure rate model for transistors is:

$$\lambda p = \lambda b \ (\ \Pi E \times \Pi A \times \Pi Q \times \Pi R \times \Pi s_2 \times \Pi C) \ failure/10^6$$
hours

ΠE = environment = ground mobile = 25

ΠA = application = logic switch = 0,7

ΠQ = quality factor = plastic = 20

ΠR = power rating = 625 mW = 1

Πs_2:-

$$S_2 \ voltage \ stress = \frac{applied \ VCE \times 100\%}{rated \ V_{ceo}}$$

$$= \frac{15}{40} \times 100 = 37,5\% \cong 40\%$$

ΠS_2 = 0,48

ΠC = complexity = 1 transistor = 1

$\lambda b :-$

$$S = \frac{Pop}{Pmax} \ (CF)$$

$$CF = \frac{Tmax - 25}{150} = \frac{150 - 25}{150} = 0,833$$

$$S = \frac{0,3 \ . \ 13,5 \times 10^{-3}}{625 \times 10^{-3}} \times 0,833 = 0,00541$$

from MIL-HDBK-217B, 2:2:1-7 with T = 60°C and S = 0,1
$\lambda b = 0,0067$

$\lambda p = 0,0067 \ (25 \times 0,7 \times 20 \times 1 \times 0,48 \times 1)$
failures/10^6 hours

$= 1,13$ failures/10^6 hours

MTBF $= 888,4 \times 10^3$ hours

3.6 THE POWER SUPPLY

The purpose of this section of the firing unit is to provide
a stable +15V DC supply for the IC and associated circuitry
as well as a 100V supply for charging the main storage
capacitors.

3.6.1 The Circuit
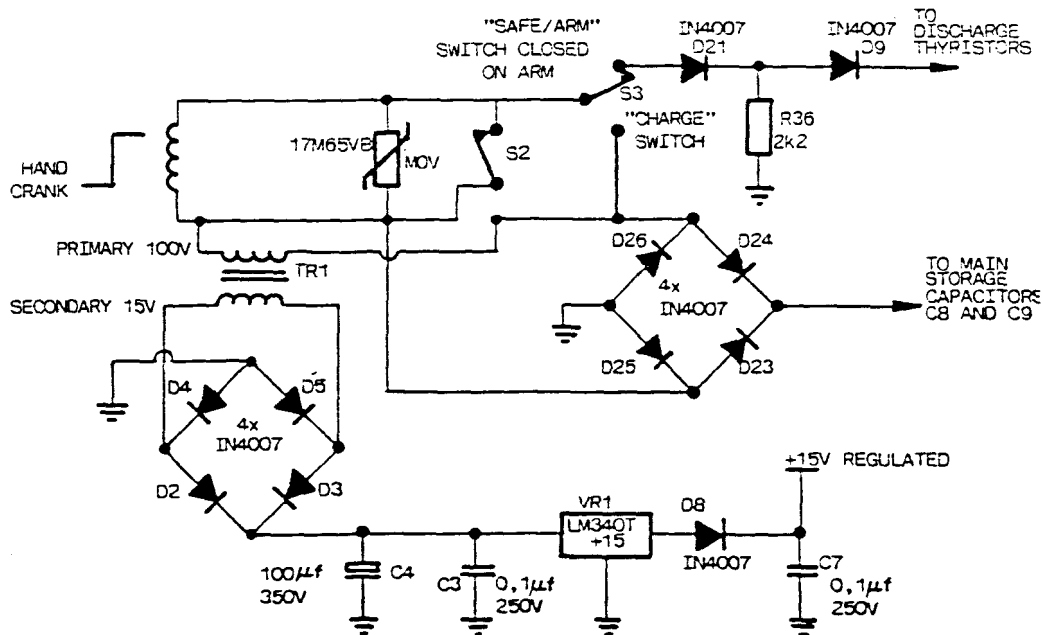
FIGURE 34: POWER SUPPLY CIRCUIT

3.6.2 Circuit Operation

The 17m65VB mov limits the output of the hand cranked generator to between about 120 and 130 volts.

When neither the "SAFE/ARM" (S2) nor "Charge" (S3) switch is operated, the power generated by the hand crank is fed via D9 and D21 to the discharge thyristors. This discharges any energy stored in the main storage capacitors.

When the "SAFE/ARM" switch is switched to the "ARM" position, a short circuit is connected directly across the hand-crank generator's output. No energy can be transferred to the circuit. This ensures that the main storage capacitors cannot be charged if the unit is "ARMED".

When the "SAFE/ARM" switch is switched to the "SAFE" position and the charge button depressed, the output of the hand-crank generator is rectified by D23 to D26. This DC supply charges the main storage capacitors.

The hand-crank generator output is transformed down to approximately 20V by TR1 and rectified by D2 to D5. This DC is smoothed by C3 and C4. VR1 regulates this smooth unregulated supply to +15 V. D8 ensures that the output of VR1 never rises to a potential greater than its input. D8 cathode is connected to a decoupling capacitor, C7, and to the current consuming circuitry. C7 is positioned physically close to the LM 224 (IC1).

3.6.3 Circuit Design

TR1 was chosen such that the hand-cranked generator would be capable of transfering the maximum power to VR1. This data was obtained from the manufacturer's data attached as Appendix 1.

The selection of R36, 2K2, was also based on this data.

D9 and D21 prevent unwanted current paths when the hand crank is operated with the charge button released.

3.6.4   <u>Reliability</u> (Refer to MIL-HDBK-217B page 2.2.-1)

3.6.4.1   <u>D2 to D5</u>

The part failure rate model

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

     π_E environmental factor = ground mobile = 25

     π_Q quality level = plastic = 50

     π_R current rating =   1 amp = 1

     π_A small signal =   500 mA = 1

Voltage stress = S2 = $\dfrac{\text{applied VR}}{\text{rated VR}}$ x 100

$$= \frac{20}{1000} \times 100 = 2\%$$

$\pi_{S2} = 0,7$

π_C = contact construction = bonded = 1

Stress $= \dfrac{\text{Iop}}{\text{Imax}}$ (CF)

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

$$S = \frac{0,3}{1 \times 0,667} = 0,2 \text{ therefore } \lambda b = 0,0025$$

$\lambda p = 0,0025 \times (25 \times 50 \times 1 \times 1 \times 0,7 \times 1)$

$\lambda p = 2,188$ failures/10^6 hours

therefore for the 4 diodes the failure rate is 4 x 2,188/10^6 hours = $8,752 \times 10^{-6}$

the MTBF is 114×10^3 hours

3.6.4.2   <u>D23 to D26</u>

The part failure rate model is as given in paragraph 3.6.4.1.

where ΠE = 25

ΠQ = 50

ΠR = 1

ΠA = 1

$\Pi S2:-$

Voltage stress = $S2 = \dfrac{100}{1000}$ x 100 = 10%

therefore $\Pi S2 = 0,7$

$\Pi C = 1$

$S = \dfrac{Iop}{Imax}$ (CF)

$CF = \dfrac{175 - 75}{150} = 0,667$

$S = \dfrac{0,05}{1}$ x 0,667 = 0,033 therefore λb = ,0019

λp = 0,0019 x (25 x 50 x 1 x 1 x 0,7 x 1)

= 1,66   failures/10^6 hours

for the 4 diodes the failure rate is 4 x 1,66/10^6 hours

= 6,65 failures/10^6 hours

The MTBF = 150 x 10^3 hours

3.6.4.3   <u>The voltage regulator, VR1</u>

Refer to MIL-HDBK-217B page 2.1.2-1.

The part failure model $\lambda p = \Pi L\ \Pi Q$ (C1 $\Pi T2$ + C2 ΠE) failures per 10^6 hours.

ΠQ = quality factor = quality level D   = 150
ΠL = learning factor = continuous production = 1

C_1 = 0,00056$(T)^{0,763}$ failures/10^6 hours

where T is the number of transistors in the device

$T = 18$

$C1 = 0,00056 \ (18)^{0,763} = 5,08 \times 10^{-3}$

$\pi T2 = 0,57$

$C_2 = 0,0026 \ (18)^{0,547} = 12,64 \times 10^{-3}$

πE = environmental factor = ground mobile = 4

$\lambda p = 1 \times 150 \ (5,08 \times 10^{-3} \times 0,57 + 12,64 \times 10^{-3} \times 4)$

= 8 failures/10^6 hours

= a MTBF of $124,7 \times 10^3$ hours

3.7   <u>THE CAPACITOR CHARGE AND DISCHARGE CIRCUITRY</u>

The purpose of this section of the firing unit circuitry is
to transfer energy from a storage capacitor inside the firing
unit to the capacitor. This is to be achieved as the
fuzehead is ignited.

When the firing unit is in the "SAFE" mode any residual
charge on the capacitor must be discharged.

3.7.1 The Circuit
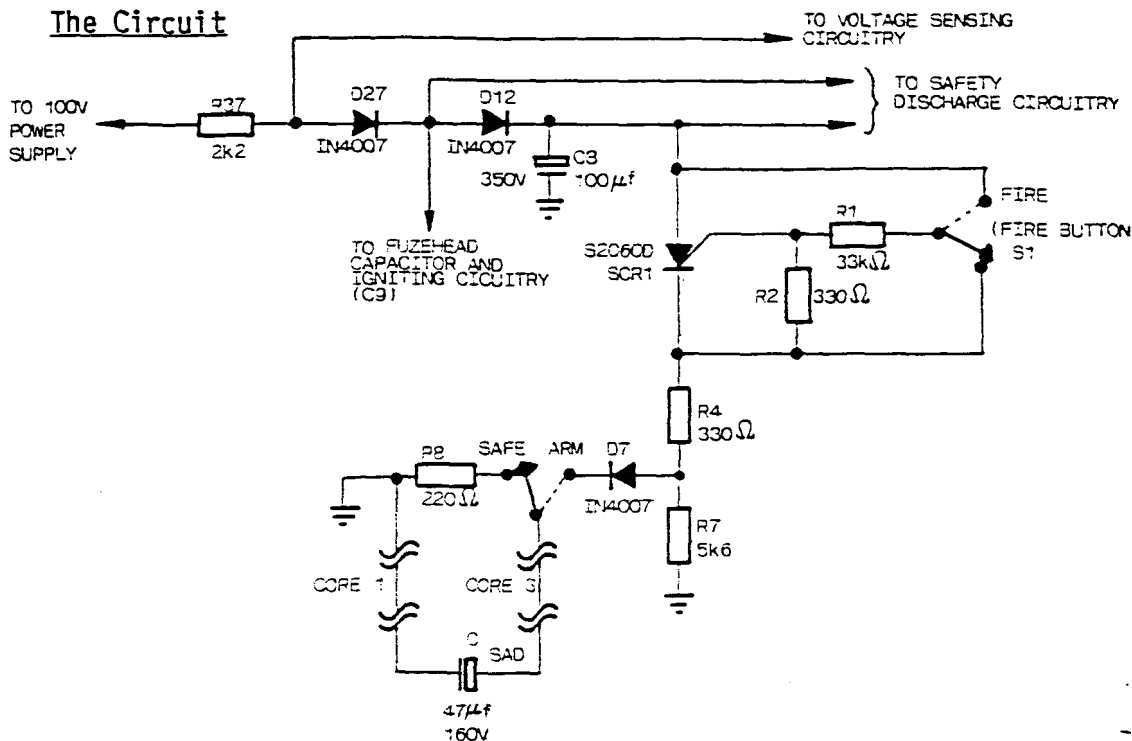
FIGURE 35: CHARGE AND DISCHARGE CIRCUITS

3.7.2 Circuit Operation

C8 is charged to a level determined by the voltage sensing circuitry, via R37, D12 and D27. D12 and D27 are in series so that any residual charge which might remain on the fuzehead capacitor after initiation, can also be used to charge C_{SAD}. C_{SAD} is the capacitor charged by the firing unit simultaneously with fuzehead initiation.

SCR1 is used as a contact de-bounce device to ensure that C8 is completely discharged into C_{SAD} and R7.

R4 protects the "SAFE/ARM" switch contacts from excessive surge currents.

R7 is a load for SCR1 and C8 if the firing button is depressed without arming the device.

D7 prevents the charge on C_{SAD} being discharged through R7.

R8 ensures that C_{SAD} cannot accumulate a charge when the firing unit is in the "SAFE" mode. R8 is also a discharge element for C_{SAD}.

The electronic circuitry around C_{SAD} is dealt with as part of the SAD. This circuitry will include charge leakage resistors.

3.7.3 Circuit Design

3.7.3.1 Capacitor C8

C8 must have a value such that C_{SAD} is charged to a minimum of 50V, in spite of the losses represented by SCR 1, R4, R7 and D7. C8 was selected as a 100 uf 350 V device.

Therefore at equilibrium, after discharging energy into C_{SAD} the energy in C8 + C_{SAD} + Energy$_{losses}$ max = C8 initial energy.

$$\tfrac{1}{2} C_1 V_1^2 = \tfrac{1}{2} C_1 V_2^2 + \tfrac{1}{2} C_2 V_2^2 + \text{losses}$$

V2 must be not less than 50V and V_1 = 100V.

$$\text{Losses} = 0,5.100 \times 10^{-6}.100^2 - 0,5.100 \times$$

$$10^{-6}.50^2 - 0,5.47 \times 10^{-6}.50^2$$

$$= 316,25 \times 10^{-3} \text{ Joules}$$

This maximum loss is five times the energy transferred to C_{SAD} by C8. A 100 uf capacitor is adequate.

R4: A max surge current of $1/3$ amp was selected

This gives R4 as $\dfrac{100 \text{ v}}{0,33A} = 300\,\Omega$

R4 was therefore selected as 330 Ω

3.7.3.2 Resistor R7

C8 must discharge via R4 into C_{SAD}, with C_{SAD} final voltage being a minimum of 50V. The addition of R7 further loads C8, lowering the final voltage of C_{SAD}. R7 was therefore experimentally selected so that C_{SAD} final voltage was about 60V. This gave a value for R7 of 5K6.

R2 was made 330 Ω as stated in para 3.4.2.2.

R1:

The DC gate trigger voltage of SCR1 is 0,65V

The gate current is 200 uA.

$$R1 = \frac{100 - 0,65}{0,65/330 + 200 \times 10^{-6}} = 46 \text{ K}$$

R1 was made 33K

R37 was selected as 2K2 as stated in paragraph 3.6.3.

R8 was selected so that C_{SAD} will be discharged at a 10 RC time of 100 ms. This is twice the discharge rate of C9 (see paragraph 3.1.1.3).

$$RC = 10 \text{ ms}$$

$$R = \frac{10 \times 10^{-3}}{47 \times 10^{-6}} = 212,8\Omega \quad \text{a } 220\Omega \text{ resistor was selected}$$

The peak discharge current, assuming C_{SAD} to charge to 100V, is
$$\frac{100}{220} = 455 \text{ mA}.$$ This is unlikely in practice as C_{SAD} is rarely charged above 60V. The "SAFE/ARM" switch is rated at 2 amp 250V. The switch is not overstressed.

3.7.4   Reliability

3.7.4.1   Capacitor C8, 100 uf 350 V   (Refer to MIL-HDBK-217B page 2.6.6-1)

The part failure rate model $= \lambda p = \lambda b \; (\pi_E) \times \pi_Q$

π_E = Environment = ground mobile = 12

π_Q = quality   = upper   = 1

$S = \frac{\text{operating voltage}}{\text{rated voltage}} = \frac{100}{350} = 0,3$

$T = 60°C$

therefore $\lambda b = 0,032$

$\lambda p = 0,032 \times 12 \times 1$ failures/10^6 hours

$= 0,384$ failures/10^6 hours

This gives a MTBF of $2,6 \times 10^6$ hours

3.7.4.2   Capacitor C_{SAD}

The part failure rate model, λp is as per 3.7.4.1.

ΠQ and ΠE are as stated in paragraph 3.7.4.1.

$$S = \frac{\text{operating voltage}}{\text{rated voltage}} = \frac{60}{160} = 0.375 \cong 0.4$$

$T = 60°C$

$\lambda b = 0.04$

$\lambda p = 0.04 \times 12 \times 1 = 0.48$ failures/10^6 hours

$= $ a MTBF of 2.1×10^6 hours

3.7.4.3   Rectifier SCR1

The part failure rate model $= \lambda p$ (Refer to MIL-HDBK-217B page 2.2.6-1)

$\lambda p = \lambda_b \times \Pi_Q \times \Pi_E \times \Pi_R$ failures/10^6 hours

   ΠE = environment = ground mobile = 25

   ΠQ = quality = hermetically packaged = 25

   ΠR = rated forward anode current = 1A to 5A = 3

λb: $S = \frac{Iop}{Imax}$ (CF)

where CF is the stress correction factor.

$$CF = \frac{Tmax - 25}{150} = \frac{110 - 25}{150} = 0.567$$

$T = TA + (175 - Tmax)$

   $= 60 + (175 - 110) = 125°C$

$S = \frac{0.3}{2.75} \cdot 0.567 = 0.062$

   from the table $\lambda b = 0.009$

therefore $\lambda p = 0.009 \times 25 \times 25 \times 3 = 16.88$ failures per 10^6 hours

This gives a MTBF of 59.26×10^3 hours

3.8   SCR SAFETY DISCHARGE SYSTEM

3.8.1   Considerations

This circuitry must rapidly discharge the main storage
capacitors when the firing unit is made safe. If an
interlock fault, fuzehead fault or operator error is
detected, then this circuitry must prevent the main storage
capacitors from accumulating any charge.

3.8.2   The Circuit
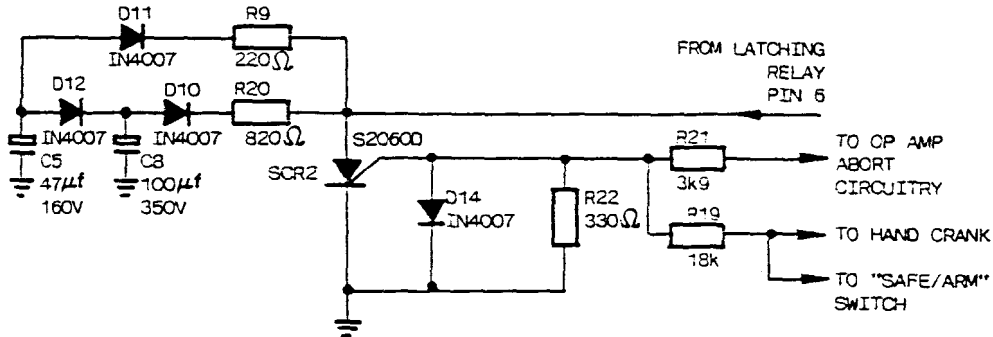
FIGURE 36:   SAFETY DISCHARGE CIRCUIT

3.8.3   Operation

If SCR 2 is triggered by either the fuzehead measuring
circuit, the interlock measuring circuit, the hand crank
generator or the "SAFE/ARM" switch; C5 and C8 will
discharge, C5 more rapidly than C8. C5 is the fuzehead
initiating capacitor. C8 is discharged into C_{SAD} when the
firing button is pressed. The smaller current from C8
ensures that SCR2 stays conductive long enough for the
latching relay to latch into the safe position.

3.8.4   Circuit Design

3.8.4.1   Resistor R9

R9 is intended to rapidly discharge C5, without overstressing
SCR2. The initial current through R9 must be high enough to
make SCR2 latch.

Maximum DC current is 2,75 A
Aim for $^1/5$ x 2,75A = 550 mA.

$$\frac{120V}{550mA} = 218\,\Omega \therefore \text{use } 220\,\Omega$$

The maximum latching current at 25°C is 4 mA. Under normal circumstances when C5 is charged to 100V, the initial current is more than 100 times the maximum latching current.

The 10 x RC discharge time is

$10 \times 47 \times 10^{-6} \times 220 = 103,4$ m sec

3.8.4.2   Resistor R20

R20 must have a value sufficient to supply the minimum holding current long enough for the latching relay to pull in. This longer time constant will also tend to reduce the effect of C5 and C8 recovering a charge after SCR2 has switched off.

The latching relay time allowed is 150×10^{-3} seconds (paragraph 3.4.2.1).

The time constant R20 C8 is therefore made such that the minimum holding current of 3 mA is reached after 300×10^{-3} seconds.

$$V = E\ (e^{\frac{-t}{RC}})$$

therefore $3 \times 10^{-3}.R = 100\ (e^{\frac{-0,3}{R.100 \times 10^{-6}}})$

$-Ln\dfrac{3 \times 10^{-3}.R}{100} = \dfrac{0,3}{R.100 \times 10^{-6}}$

$R.Ln\ 30 \times 10^{-6}\ R = -3 \times 10^3$

R is equivalent to approx 806 Ω

an 820 Ω resistor is selected.

The worst case thyristor current is:

$$\frac{120V}{820} + \frac{120V}{220} = 692mA$$

this is $\frac{692 \times 10^{-3}}{2,75} = 1/4$ of the max

thyristor current allowable.

C8 discharge time is taken as 10RC

$= 10.\ 820.\ 100 \times 10^{-6} = 0,82$ seconds

3.8.4.3 Resistors R22, R21 and R19

Calculations are shown in paragraphs 3.4.2.2, 3.4.2.3 and 3.4.2.4 respectively.

3.8.5 Reliability

3.8.5.1 Rectifier SCR2

The part failure rate model λp

$\lambda p = \lambda b \times \pi_Q \times \pi_E \times \pi_R$ failure/10^6 hours

π_Q = quality factor = hermetically packaged = 25

π_E = environmental factor = ground mobile = 25

π_R = rated forward anode current = 1A to 5A = 3

λb: $S = \frac{Iop}{Imax}$ (CF)

CF is the correction factor

$CF = \frac{Tmax - 25}{150} = \frac{110°C - 25}{150} = 0,567$

λb table:- $T = Ta + (175 - Tmax)$

$60 + (175 - 110) = 125°C$

$S = \frac{692 \times 10^{-3}}{2,75}\ (0,567) = 0,143$

from the table $\lambda b = 0,012$

$\lambda p = 0,012 \times 25 \times 25 \times 3 = 22,5$ failures/10^6 hours

This is equivalent to a MTBF of $44,4 \times 10^3$ hours

3.9   PRINTED CIRCUIT LAYOUT

3.9.1   General

A double sided PCB was selected so that all surge current
tracks could be identically duplicated on both sides. This
increases reliability and lowers track resistance. This also
allowed increased track width throughout the PCB. The use of
jumpers is also avoided due to through-hole plating. This
simplifies production.

The switches and LED's have all been mounted on the bottom of
the PCB. This obviates the need for wiring looms connecting
the switches and LED's to the PCB, so reducing the cost of
the device.

All the remaining components are mounted on the top of the
PCB. Certain components are mounted vertically. This is not
considered a problem as the final unit will be potted in an
integral skin polyurethane foam. This foam will lend support
to the components.

The connections to the firing cable socket are made with
bolted contacts, simplifying assembly.

The following printed circuit layouts are not to scale.
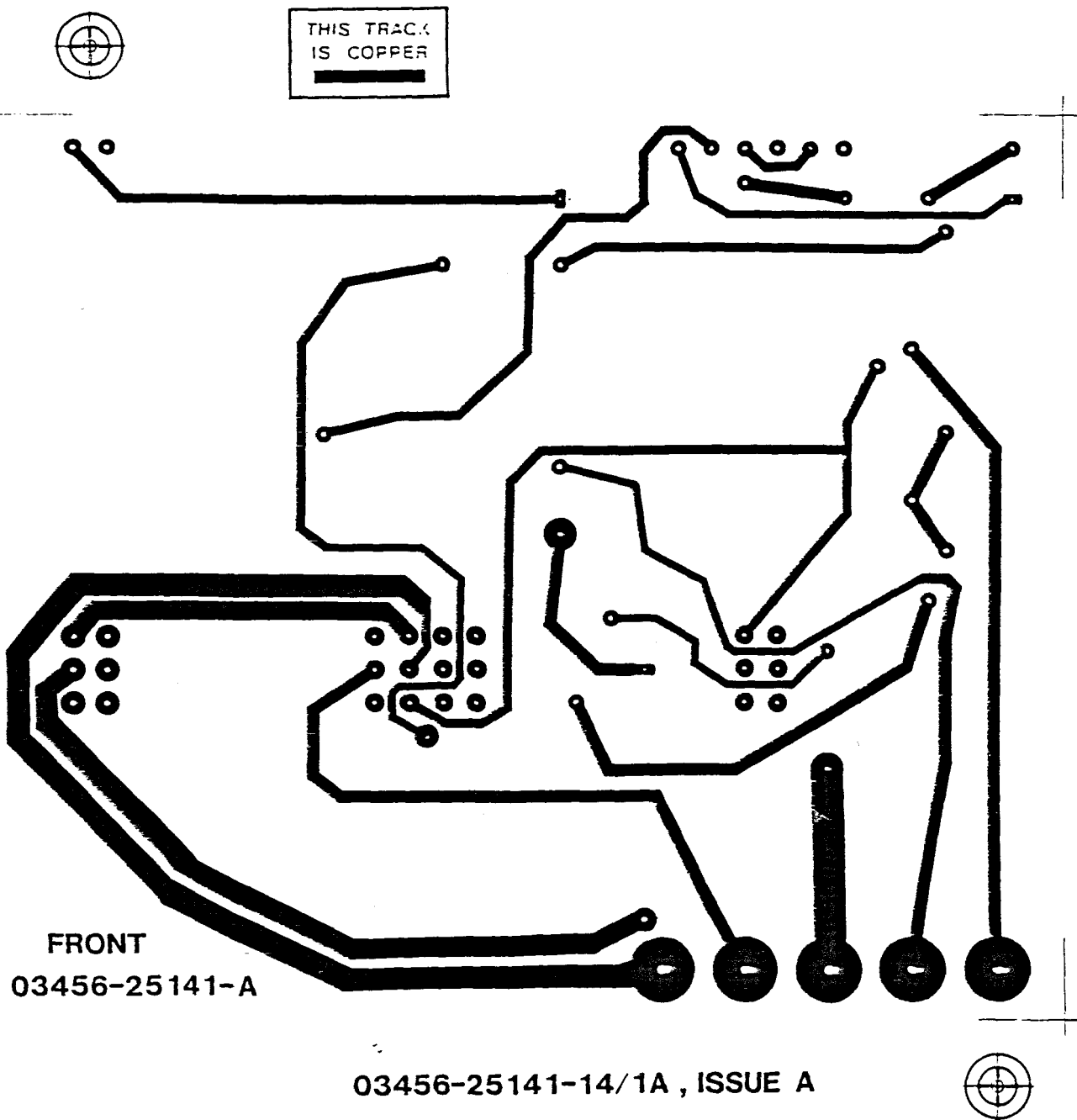
FIGURE 37:   LAYOUT OF THE PRINTED CIRCUIT (FRONT (TOP) SIDE)

The scale is approximately 1:1

THIS ~ACK
IS C... PER

152,4 ±0,1

BACK
03456-25141-A

03456-25141-14/1B , ISSUE A
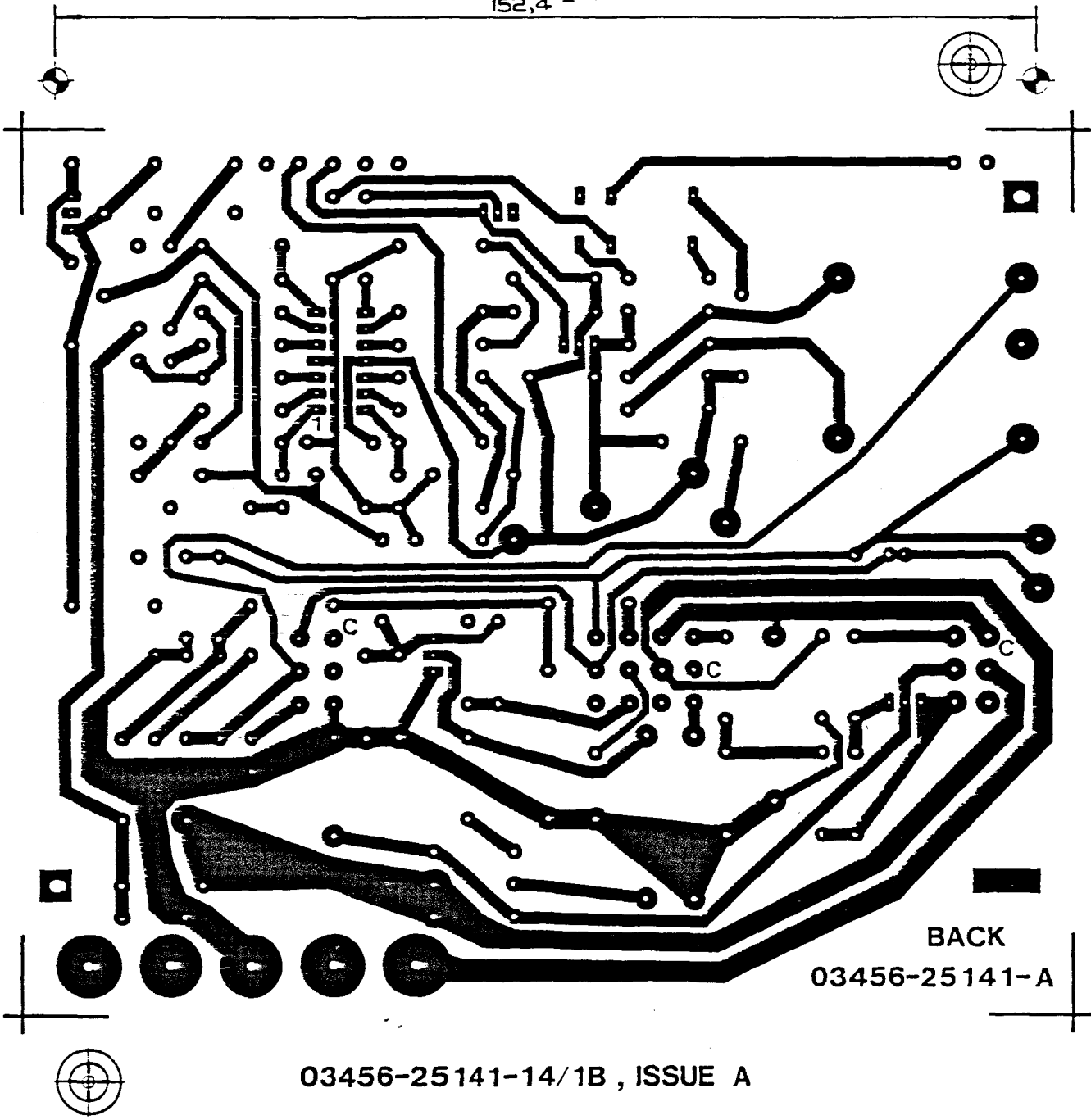
FIGURE 38:   LAYOUT OF THE PRINTED CIRCUIT (BACK (BOTTOM) SIDE)

The scale is approximately 1:1

3.9.4 Hole Schedule

1mm- ▪ 1,5mm- ⬤

1mm- ○ 6,5mm- ⬤
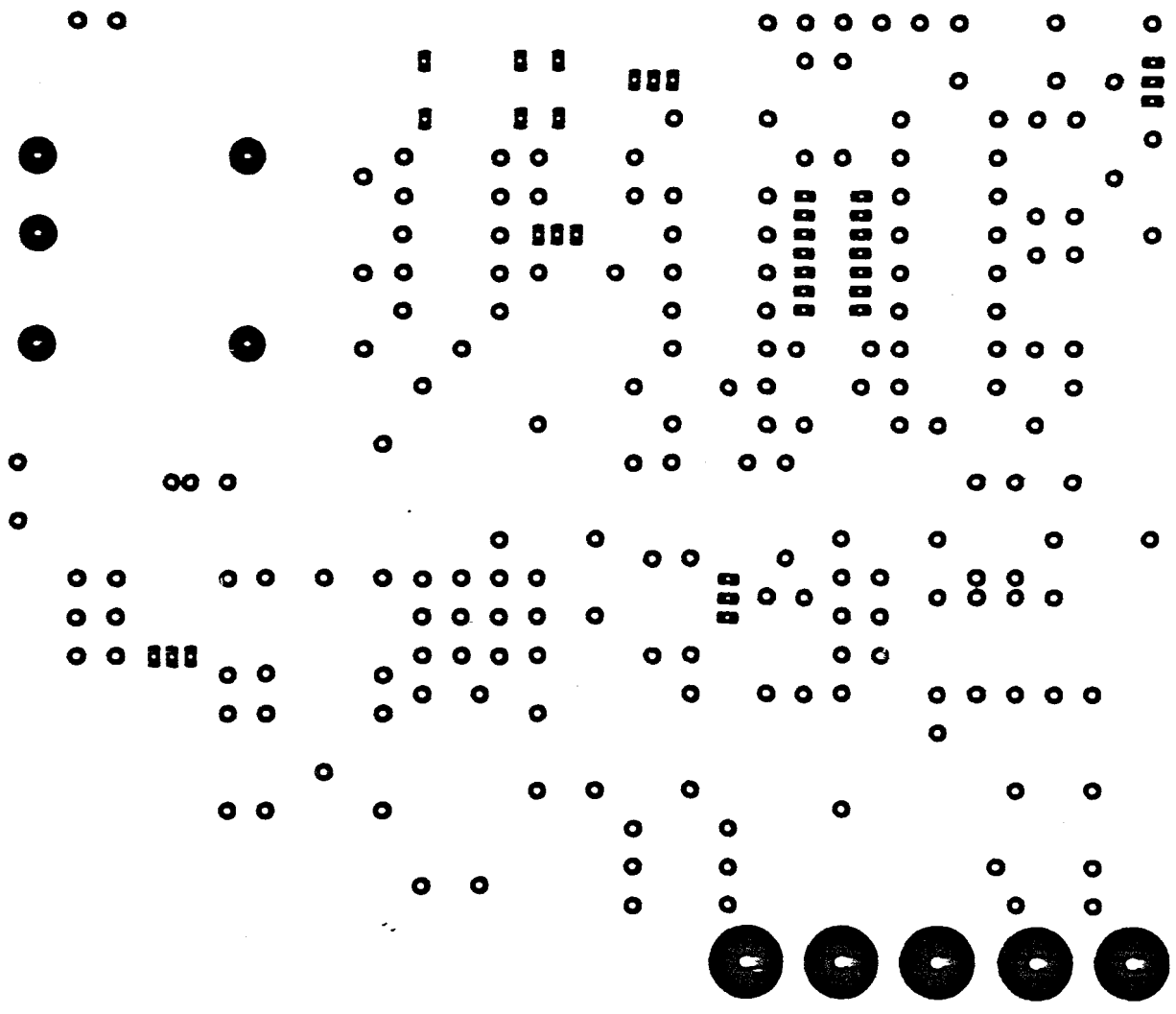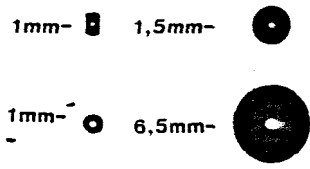
FIGURE 39: HOLE SCHEDULE FOR THE PCB FRONT SIDE

The scale is approximately 1:1

3.9.5 Component Position
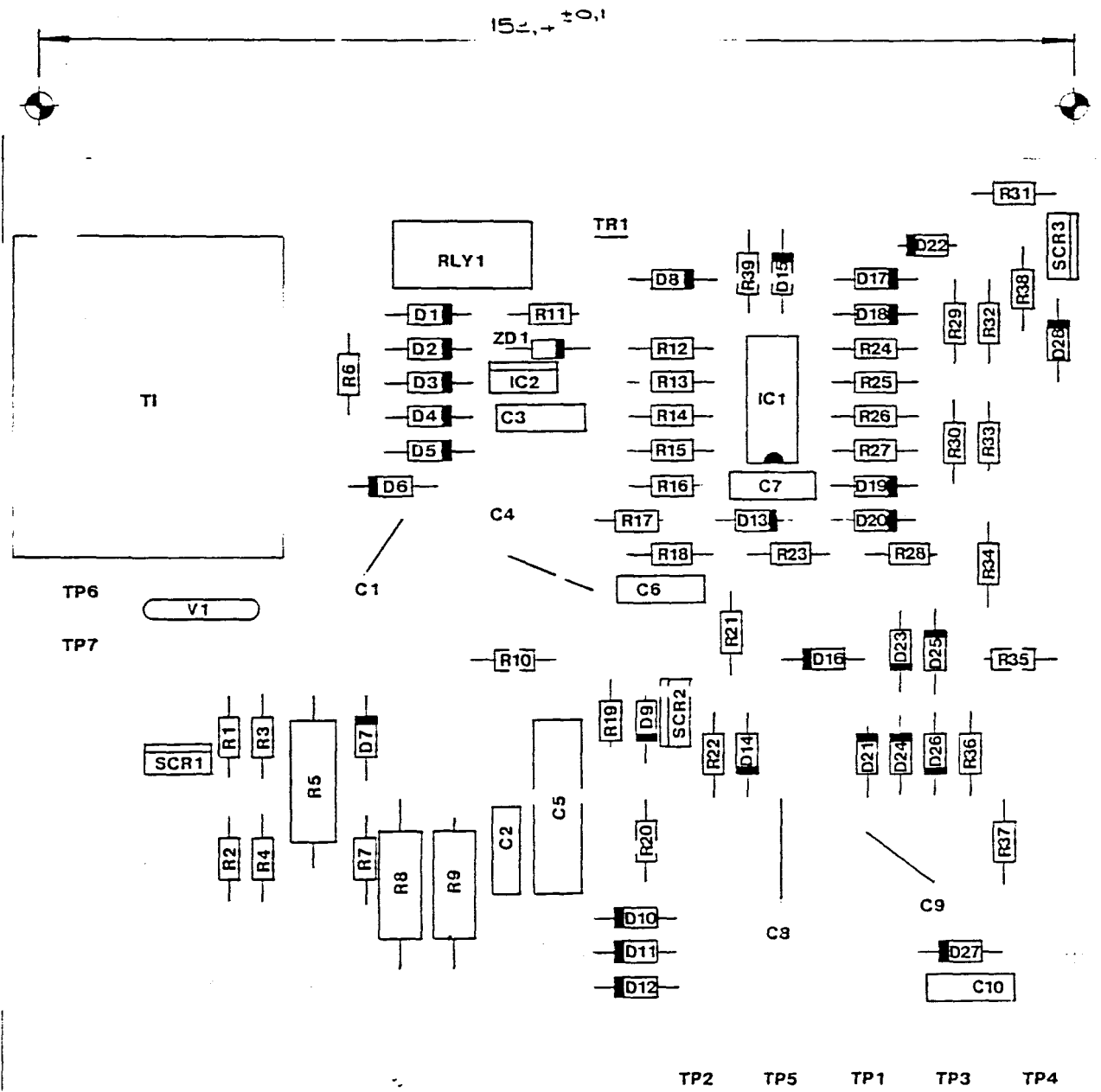
03456-25141-14/3A , ISSUE A

FIGURE 40: COMPONENT POSITION FOR THE PCB FRONT SIDE

The scale is approximately 1:1

3.9.6 Component Position

$152,4 \pm 0,1$

LED4 ( ) LED3 ( ) ( ) LED2

( ) LED1

S3

S2

S1
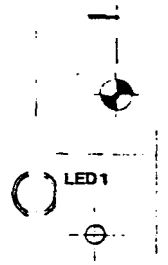
03456-25141-14/3B , ISSUE A

FIGURE 41: COMPONENT POSITION FOR THE PCB BACK SIDE

The scale is approximately 1:1

3.9.7   Component list

3.9.7.1   Tranformer

TRSF 1   25Hz 100V prim. 15V   100 mA sec. Dynamis type or
equivalent

3.9.7.2   Relays

RLY 1   RS magnetically latching relay
RS type 346-716 or equivalent

3.9.7.3   Transistors

TRI   Motorola type MPS 2222A or equivalent

3.9.7.4   Switches

S1 and S3 DPDT push button
APR type   BE13445-CD-B+UI401 or equivalent

S2 4PDT   Locking toggle APR
type 12166-AKG-2V-038+U41 or equivalent

3.9.7.5   Integrated circuits

IC1   National quad op amp
type LM 224 or equivalent

3.9.7.6   Voltage regulators

VR1   National 15V regulator type LM 340T 15 or equivalent

3.9.7.7   Diodes

D1 to D28	1000V 1A diodes type 1N4007
L1 to L4	Red LEDS type ESBR 5501 (Stanley)
ZD1	1N4734 5V6 1 watt zener diode
SCR1 to SCR3	S2060D 500V 3A (RCA)

3.9.7.8   Capacitors

C1	220 uf 63V Aluminium Electrolytic
C2, C3, C6, C7, C10	0,1 uf 250V Wima MKS3 Polyester
C4 + C8	100 uf 350V Aluminium Electrolytic
C5	0,68 uf 250V Wima MKS4 Polyester
C9	47 uf 160V Aluminium Electrolytic

3.9.7.9   Varistors

M1 17M65VB MOV Conradty type varistor

3.9.7.10   Resistors

R1	33K	$^1/4$ w		R20	820	$^1/2$ w
R2	330	$^1/2$ w		R21	3K9	$^1/4$ w
R3	2K2	$^1/2$ w		R22	330	$^1/2$ w
R4	330	$^1/2$ w		R23	680	$^1/2$ w
R5	100	2 w		R24	120K	$^1/4$ w
R6	100K	$^1/4$ w		R25	120K	$^1/4$ w
R7	5K6	$^1/2$ w		R26	120K	$^1/4$ w
R8	220	5 w		R27	120K	$^1/4$ w
R9	220	5 w		R28	680	$^1/2$ w
R10	470	$^1/2$ w		R29	1K	$^1/2$ w
R11	47K	$^1/4$ w		R30	4,7	$^1/2$ w 5% carbon
R12	560K	$^1/4$ w		R31	330	$^1/2$ w
R13	560K	$^1/4$ w		R32	820K	$^1/4$ w
R14	1M	$^1/4$ w		R33	47	$^1/4$ w
R15	560K	$^1/4$ w		R34	47	$^1/4$ w
R16	1K	$^1/2$ w		R35	18K	$^1/4$ w
R17	270K	$^1/4$ w		R36	2K2	$^1/2$ w
R18	6K8	$^1/2$ w		R37	2K2	$^1/2$ w
R19	18K	$^1/4$ w		R38	3K9	$^1/4$ w
				R39	10K	$^1/4$ w

Resistors 1 to 29 and 31 to 39 are 1% metal film devices
while R30 is a 5% carbon device.

3.9.7.11   PC Pins

TE1 + TE2   1 mm Vero PC pins

3.9.7.12   Contacts

T1 to T5   PCB M3 self broaching fastener (PSM fasteners) or
approved substitute.
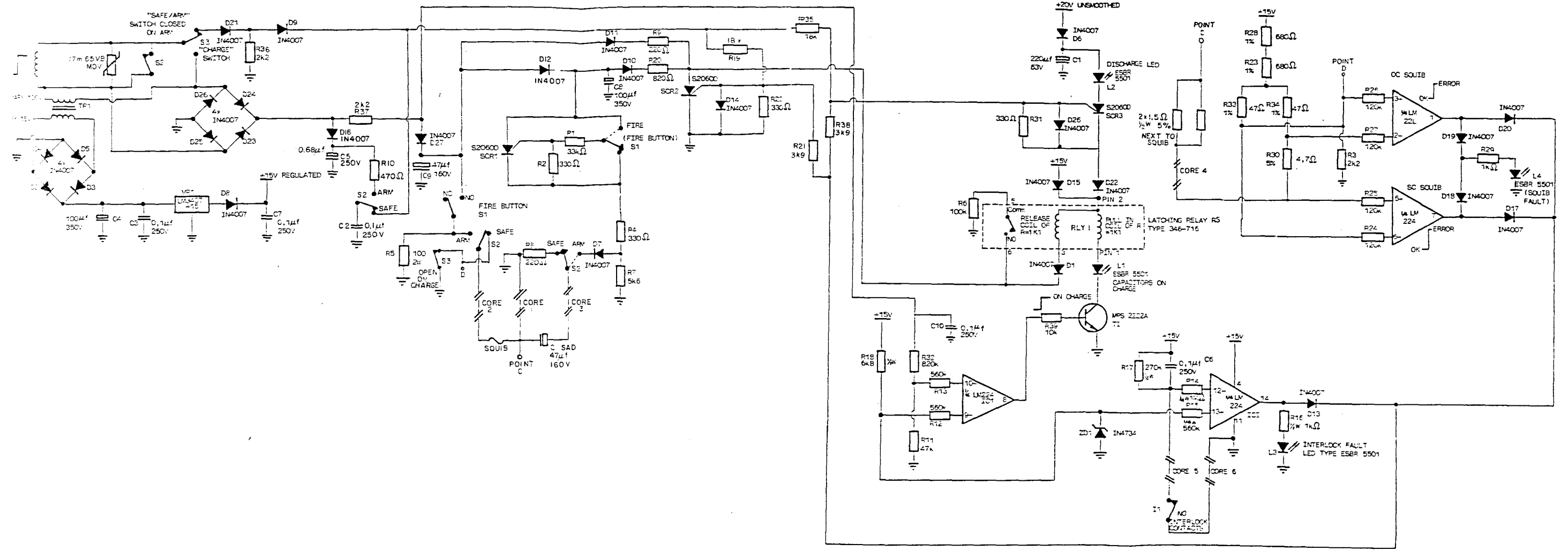
FIGURE 42: FIRING UNIT CIRCUIT DIAGRAM

TE1

TE2

T2   T5   T1   T3   T4
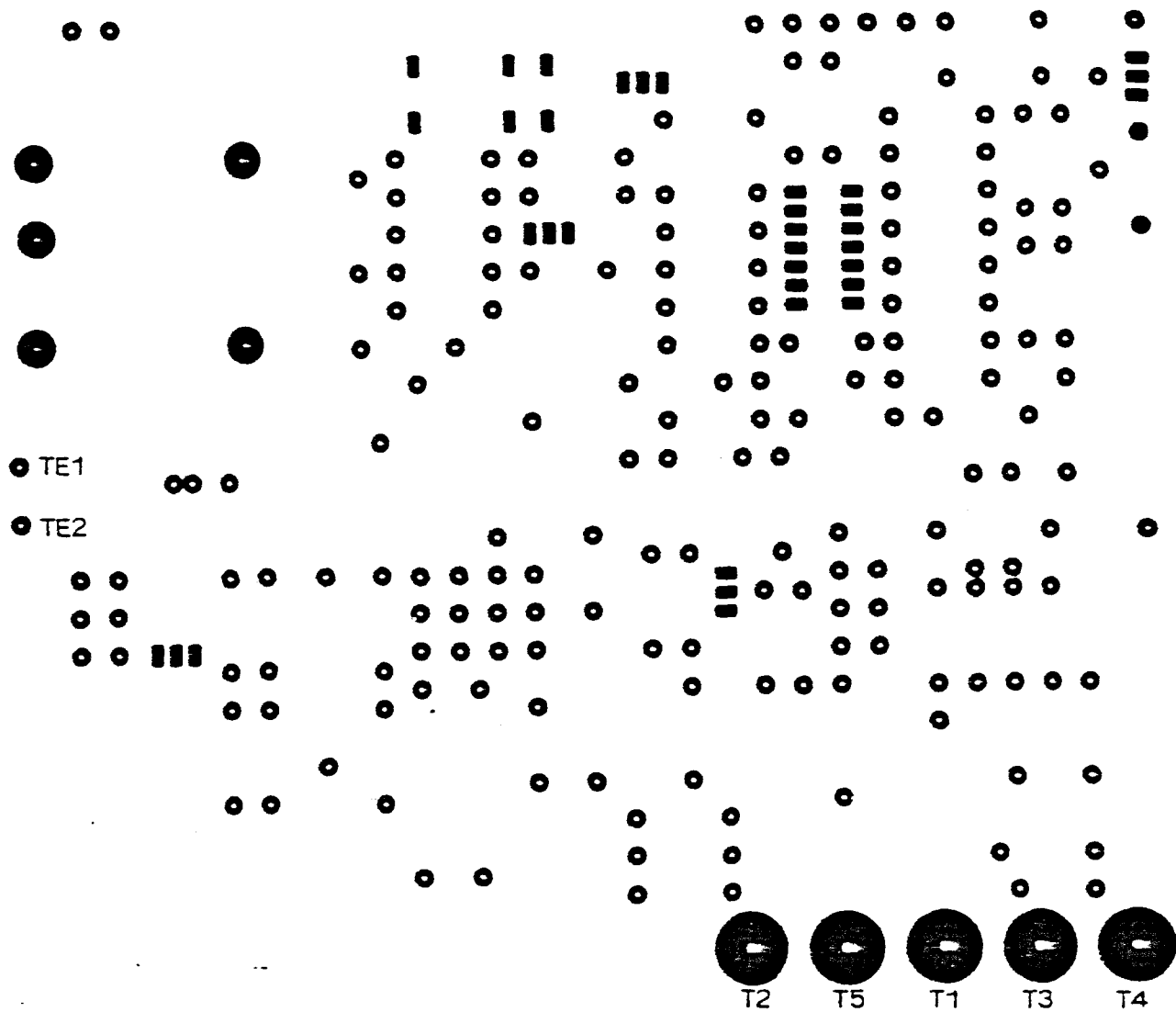
FIGURE 43:   THE WIRING SCHEDULE, COMPONENT SIDE

The cable used for T1 to T5 is Raychem type EPD 7719A or approved substitute.

The wire attached to TE1 and TE2 is Raychem type 55A0111-24 or approved substitute.

3.10.1   Firing Lead/Firing Unit Interface

FIG 2.10.1
FIRING LEAD/FIRING PACK INTERFACE
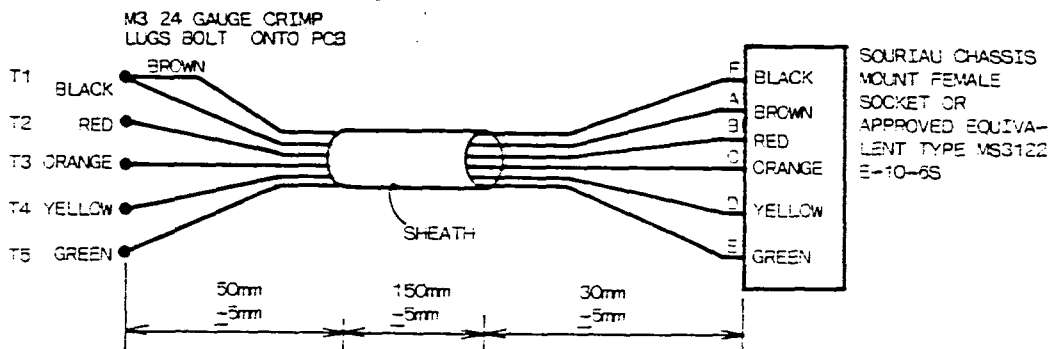
FIGURE 44: THE FIRING LEAD/FIRING UNIT INTERFACE

3.10.2   PCB/Hand Crank Interface
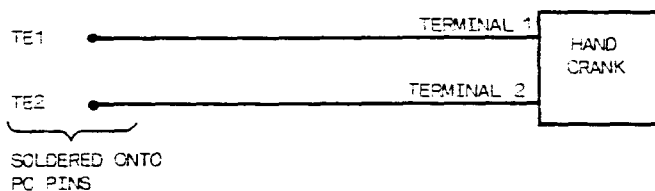
FIGURE 45: THE PCB/HAND CRANK INTERFACE

3.10.3   The Firing Lead

Each lead consists of three distinct circuits.

The firing current circuit.

The capacitor charging system.

The interlock circuit.

Dimensions and plugs have not all been finalised as the appropriate vehicle has not been procured.

3.10.4   Firing Lead Connections

FIRING PACK

SOURIAU CONNECT-
OR TYPE VS3126-
F10-6P OR
EQUIVALENT

B A D C F E

SCREEN TO FIRING PACK
SCREEN VIA PLUG

GREEN

BLACK

RED

BROWN

YELLOW

ORANGE

BLACK

SCREEN TO
CONNECTOR

SCREEN TO
CHASSIS OF
SWITCH

SCREEN TO SAD
CHASSIS

COMPENSATING
RESISTOR
0,75Ω

NORMALLY OPEN LIMIT
SWITCH FOR THE
INTERLOCK
AS MANY IN SERIES
AS REQUIRED

47μf
160V or
EQUIVALENT

FUZEHEAD
(1,6 TO 2,4Ω)

IGNITOR

FIGURE 46:   THE FIRING LEAD CONNECTIONS

3.11   CONCLUSION

3.11.1   Reliability

The overall reliability of the electronic circuitry is in the order of:-

$$\lambda \text{ overall} = \Sigma \lambda \text{ parts}$$

i.e. Overall reliability = sum of the individual part reliabilities in failures/10^6 hours.

Paragraph	failures/10^6 hours
3.1.5	0,864
3.2.4.1	38,0
3.2.4.2	0,175
3.3.5.1	0,033
3.3.5.2	0,0792
3.4.3.1	16,88
3.4.3.2	3,12
3.5.3.3	1,13
3.6.4.1	8,75
3.6.4.2	6,64
3.6.4.3	8,0
3.7.4.1	0,384
3.7.4.2	2,1
3.7.4.3	16,88
3.8.5	22,5
	125,54 failures/10^6 hours

This is equivalent to an overall mean time between failures of 8 x 10^3 hours or 333 days continuous use. This figure can be improved if the following components are replaced with more reliable devices:

Paragraph	Component type
3.2.4.1	Zener diode type IN4734
3.4.3.1	SCR type S2060D
3.4.3.2	Latching relay type RS 346 716
3.6.4.1	Diodes type IN4007
3.6.4.2	Diodes type IN4007
3.6.4.3	Voltage regulator LM340 T + 15
3.7.4.3	SCR type S2060D
3.8.5	SCR type S2060D

This problem will be addressed during the Engineering Design Model phase.

3.11.2   Function

The firing circuit functionally appears to comply with the
guidelines laid down by the user.

SECTION 4:   THE ENCLOSURE DESIGN

This section contains the mechanical drawings pertaining to
the enclosure.   A family tree of the firing unit is also
included.

4.1   THE FIRING UNIT ASSEMBLY FAMILY TREE
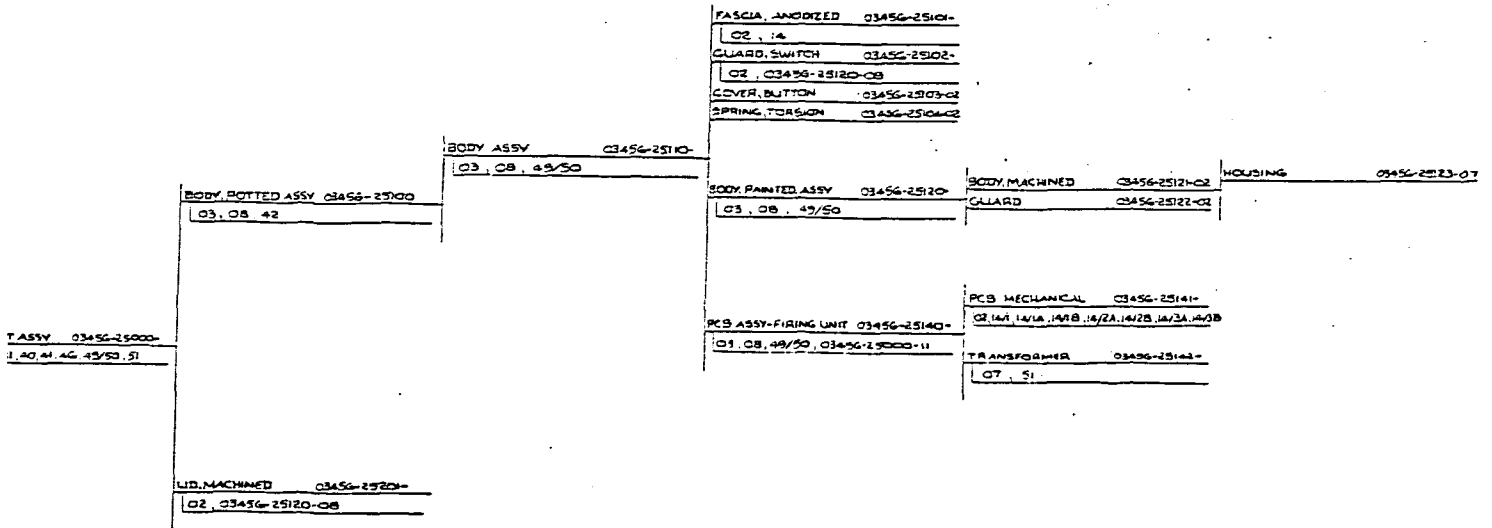
FIGURE 47:   THE FIRING UNIT ASSEMBLY FAMILY TREE

.4.2   PILLAR

Drawing Number 03456-25001-02

12 MIN FULL THREAD

M6×1-6H

8 A/F

(⌀10)

10

56

TOOLS AND GAUGES	ASSOCIATED DOCUMENTS	NEXT ASSEMBLY	USED ON	MICRO FILMED	INTER FACE	APPROVED	CHECKED	DRAWN	CHANGE NOTE NO	DATE	REV
								CLW			

ORIGINAL SCALE 1 : 1	MATERIAL:	MASS			UNCLASSIFIED
THIRD ANGLE PROJECTION	BAR, ROUND, ALUMINIUM ALLOY, HULETT 6261-TF, ⌀10	ESTIMATED Kg			
DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED.	SURFACE TEXTURE: N8	ACTUAL Kg			PILLAR
DO NOT SCALE	TREATMENT: NONE	UNQUOTED TOLERANCES			
IF IN DOUBT ASK	FINISHING PROCESS: ANODIZE TO KE 006-10-06-13	± 0,2	±	DRG No.	03456-25001-02

0   150

FIGURE 48: THE PILLAR

4.3 LID, MACHINED

Drawing Number 03456-25201-02

FIGURE 49: THE LID, MACHINED

4.3   LID, MACHINED

Drawing Number 03456-25201-02
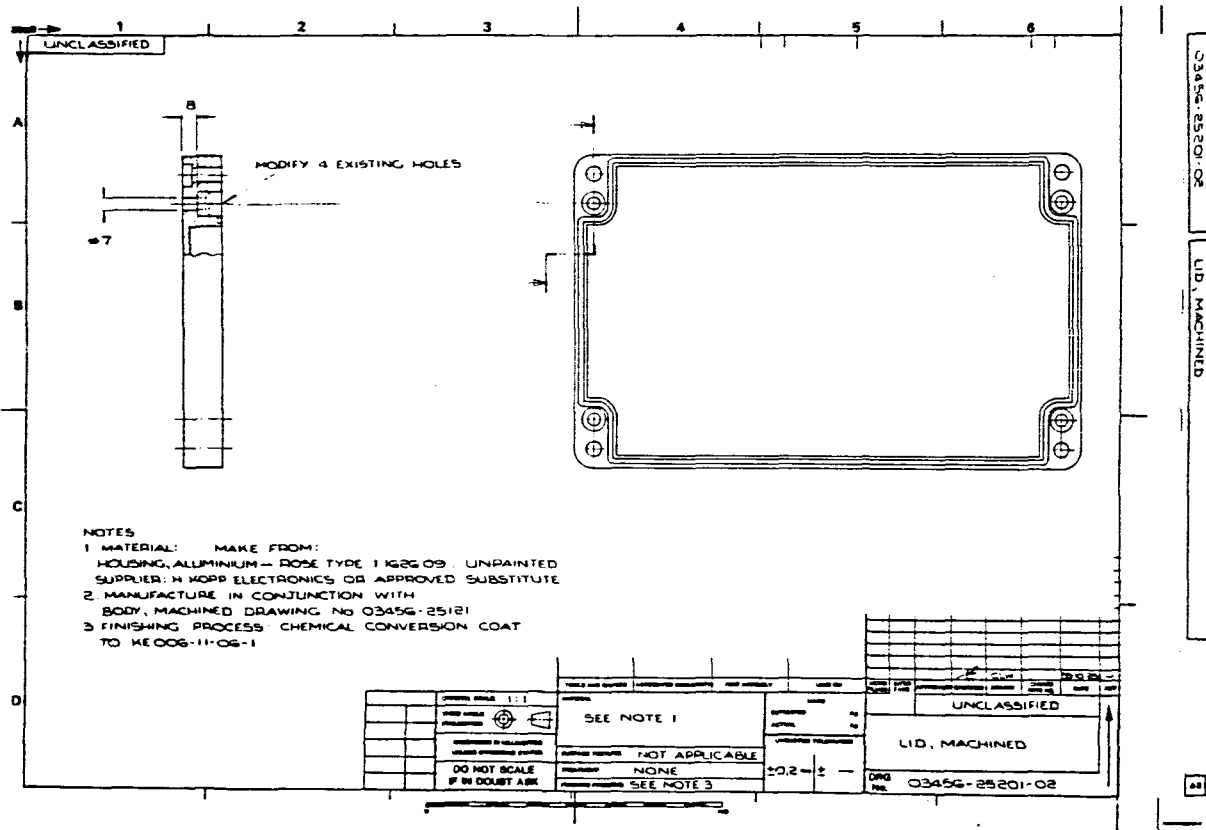
FIGURE 49:   THE LID, MACHINED

4.4   BODY, MACHINED

Drawing Number 03456-25121-02
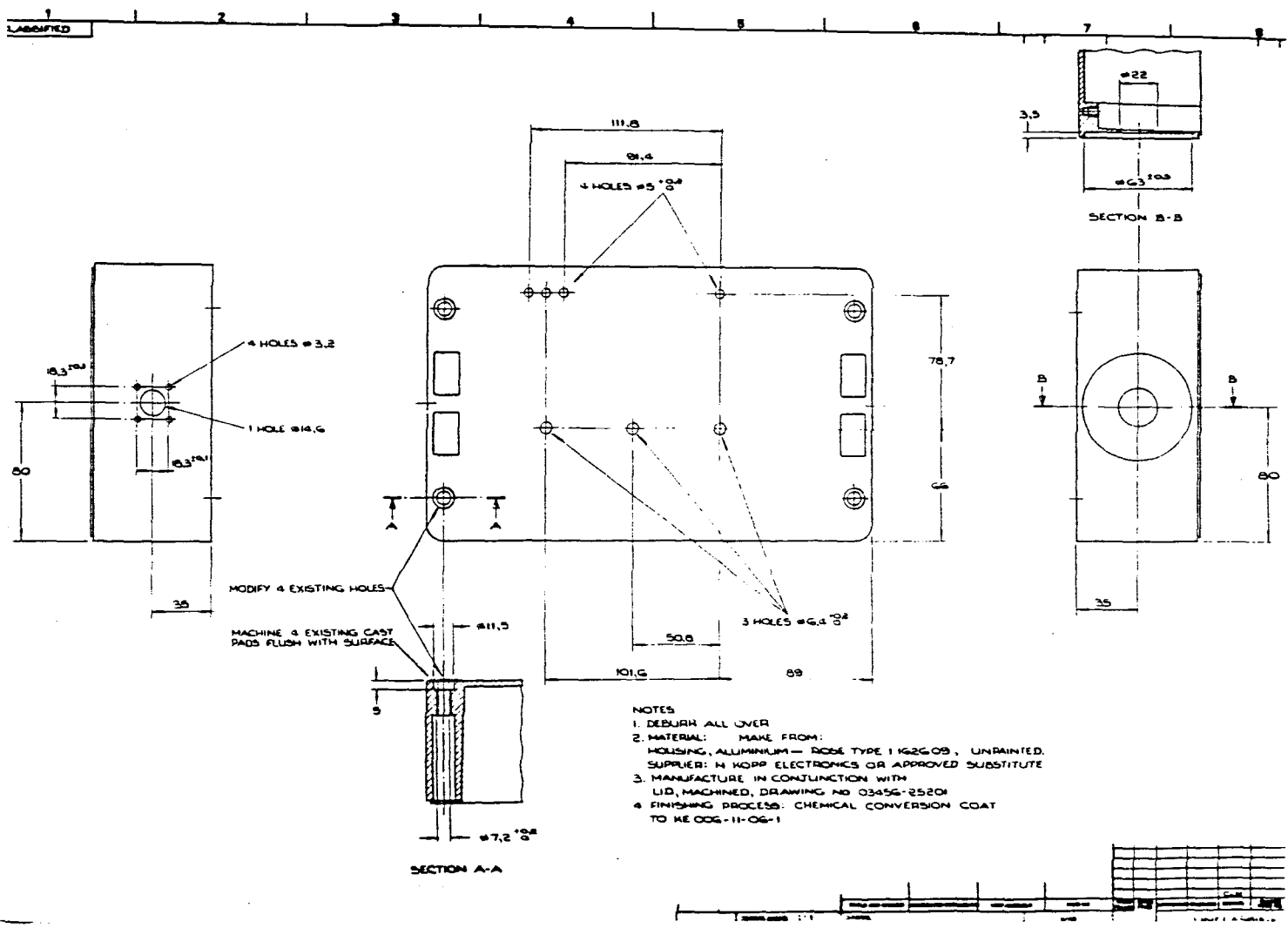
FIGURE 50:   THE BODY, MACHINED

SECTION 5: FIRING UNIT TESTS

This section deals with the environmental and functional testing of the firing unit. The following tests will be dealt with individually.

Functional tests	(5.1)
Low pressure (altitude)	(5.2)
Vibration	(5.3)
Shock	(5.4)
High temperature	(5.5)
Low temperature	(5.6)
Temperature shock	(5.7)
Rain test	(5.8)
Electromagnetic interference tests	(5.9)
Qualification testing	(5.10)
Acceptance testing	(5.11)

5.1   FUNCTIONAL TESTING

This subsection deals with the following functional tests in turn.

Operating Instructions	(5.1.1)
Interlock circuitry	(5.1.2)
Impedance measuring circuitry	(5.1.3)
Charge bleed away circuitry	(5.1.4)
Energy transferred to the fuzehead	(5.1.5)
The hand crank safe-ing circuitry	(5.1.6)
SAD capacitor leakage resistor	(5.1.7)
The safety short circuit on the fuzehead	(5.1.8)
Disconnected cable test	(5.1.9)

5.1.1   <u>Operating Instructions</u>

5.1.1.1   <u>To DEPLOY the system</u>

STEP   ACTION

1. Depress the CHARGE button
2. Crank the hand-crank generator
3. Note which LED glows
4. Stop cranking, then release the CHARGE button.
5. a) FUZEHEAD FAULT LED – Check all interconnecting cables.
    b) INTERLOCK ERROR LED – Check the interlocks. Then
        repeat from 1.
    c) READY LED – Proceed to the launch point.
6. Put the SAFE/ARM switch to the ARM position.
7. Lift the cover over the FIRE button.
8. Depress the FIRE button to initiate the pyrotechnic
    chains.

5.1.1.2   <u>To make the system SAFE</u>

STEP   ACTION

1. If the SAFE/ARM switch is in the ARM position, then
    return it to the SAFE position.
2. Without depressing the CHARGE button, crank the hand-
    crank generator.
3. The DISCHARGED LED will glow momentarily during action 1
    or action 2. This indicates the firing unit has been
    made SAFE.

5.1.2 Testing the Interlock Circuitry

5.1.2.1 Equipment needed for this test

The following is needed for this test.

a. A storage oscilloscope, Tektronix type number 466 or similar

b. a digital multimeter of input impedance 1M or greater

c. a test lead as shown below
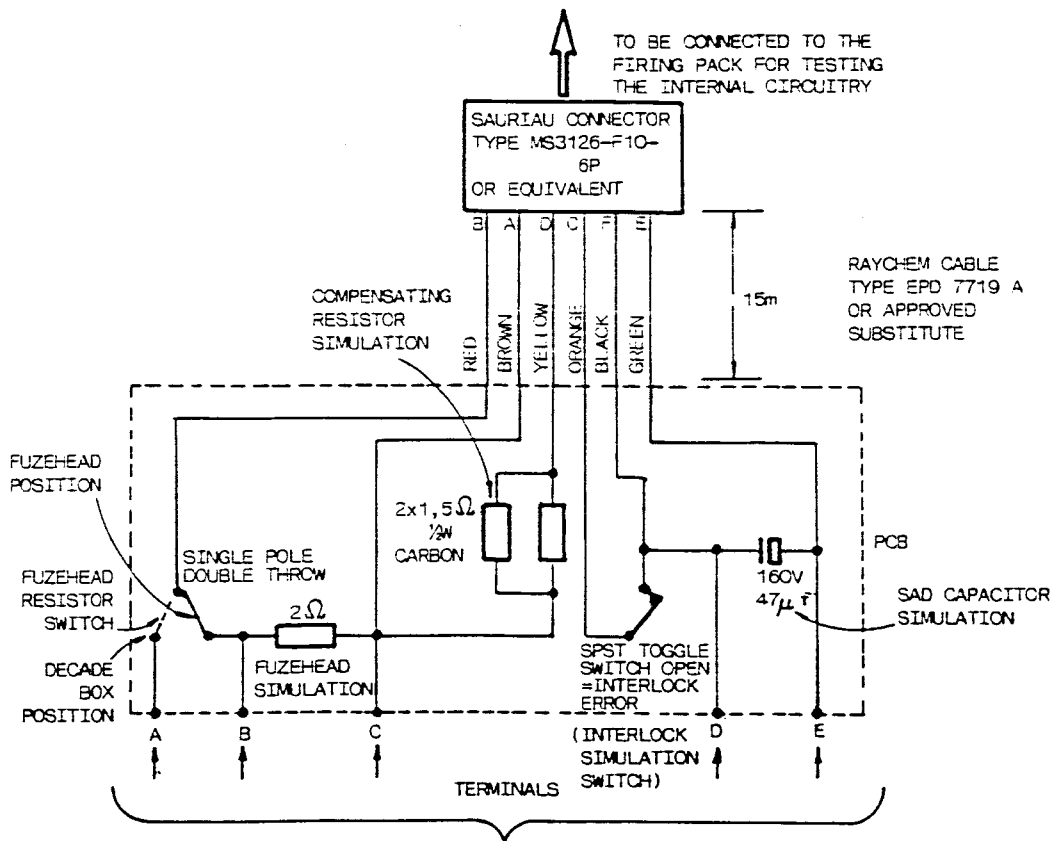
5.1.2.2   Setting up

    a.   Connect the test lead to the firing unit.

    b.   Connect the digital voltmeter to terminals D and E;
          positive on terminal E.

    c.   Connect the oscilloscope to terminals B and C;
          positive on terminal B.

    d.   Ensure the "Interlock Error" switch is "Closed".

    e.   Ensure the "Fuzehead Resistor" switch is on "Fuzehead".

5.1.2.3   The test

    a.   The "SAFE/ARM" switch on "SAFE". Depress the charge
          button and crank the hand-crank generator till the
          "Ready" LED illuminates.

    b.   Open the "Interlock Error" switch. Depress the charge
          button and crank the hand-crank generator. The
          "Interlock Error" LED should illuminate.

    c.   "ARM" the firing unit and depress the "FIRE" button
          within 2 minutes of (b).

    d.   Record the peak voltage on the voltmeter and the peak
          voltage on the oscilloscope.

5.1.2.4   Criteria for rejection

    a.   The "Ready" light does not light up in 5.1.2.3 (a).

    b.   The "Interlock Error" LED does not light up in
          5.1.2.3 (b).

    c.   The voltages recorded in 5.1.2.3 exceed 10 V.

5.1.2.5   Technical considerations

    This test ensures that the LM 224 op amp (pins 12, 13 and 14)
    as well as it's associated circuitry is working correctly.
    SCR2, SCR3, L1 and L2 are checked. The limit of 10 V
    mentioned in 5.1.2.4 is to ensure that SCR2 does discharge C8
    and C9 correctly. The initial potential on C8 and C9 is in
    the order of 100 V.

5.1.3   The Impedance Measuring Circuitry

5.1.3.1   The equipment needed for this test

The following is needed for this test.

a.   A decade resistor box with a minimum range of 0 to 10Ω in 0,1Ω steps; 1% tolerance.

b.   A test lead as shown in 5.1.2.1 (c).

5.1.3.2   Setting up

a.   Connect the test lead to the firing unit.

b.   Ensure the "Interlock Error" switch is closed.

c.   Ensure the "Fuzehead Resistor" switch is on "Decade Box" (external fuzehead).

d.   Connect the decade box to terminals (a) and (c) of the test lead.

5.1.3.3   The test

a.   Set the decade box to Zero.

b.   The "SAFE/ARM" switch on "SAFE", depress the charge button and crank the hand-crank generator.

c.   Record whether the "Fuzehead Fault" and/or the "Ready" LED illuminate.

d.   Repeat (a); (b); (c) with the decade box set at 0,4Ω ; 1Ω ; 2Ω ; 3Ω ; 4Ω ; 6,5Ω ; 8Ω respectively.

e.   Do not "Fire" the firing unit at any stage with the decade box connected.

5.1.3.4   Criteria for rejection

If the recorded information disagrees with the table below, the firing unit is rejected.

TABLE 3:   TEST CRITERIA FOR THE FIRING UNIT IMPEDANCE CIRCUIT

RESISTANCE	"FUZEHEAD FAULT" LED	"READY" LED
0 Ω	on	off
0,4 Ω	on	off
1Ω	off	on
2Ω	off	on
3Ω	off	on
4Ω	off	on
6,5 Ω	on	off
8 Ω	on	off

5.1.3.5   Technical considerations

This test checks the LM 224 op amps (defined by pins 3,2 and 1) as well as pins 6,5 and 7, the Wheatstone Bridge and the associated circuitry for correct functioning.

5.1.4   The Charge Bleed-away Circuitry

5.1.4.1   Equipment needed for this test

The following equipment is needed for this test.

a.   A storage oscilloscope, Tektronix type number 466 or similar.

b.   A digital multimeter of input impendance 1M   or greater.

c.   A test lead as shown in 5.1.2.1 (c).

5.1.4.2   Setting up

a.   Connect the test lead to the firing unit.

b.   Connect the digital voltmeter to terminals D and E; positive on terminal E.

c.   Connect the oscilloscope to terminals B and C; positive on terminal B.

d.   Ensure the "Interlock Error" switch is "Closed".

e.   Ensure the "Fuzehead Resistor" switch is on "Fuzehead".

5.1.4.3   The test

a.   Switch the "SAFE/ARM" switch on "SAFE". Depress the
      charge button and crank the hand-crank generator,
      stopping just before the "Ready" LED lights up. If the
      "Ready" LED lights up, crank the hand-crank generator,
      without pressing the charge button, then start again
      with (a).

b.   Wait 3 minutes $\pm$ 1/2 minute.

c.   "ARM" the firing unit and fire it.

d.   Record the peak voltage measured on the oscilloscope
      and on the voltmeter.

5.1.4.4   Criteria for rejection

The firing unit shall be rejected if either voltage recorded
is above 1 V.

5.1.4.5   Technical considerations

This test ensures that the latching relay contact between
pins 5 and 6 as well as R6 is correct. When this test is
done in conjunction with the previous test it also ensures
that SCR3 and associated circuitry is correct. D1, D22 and
Pin 2 – Pin 3 latching relay coil is also checked.

5.1.5   Energy Transferred to the Fuzehead and C_{SAD}

5.1.5.1   Equipment needed for this test.

The following equipment is needed for this test.

a.   A storage oscilloscope, Tektronix type number 466 or
      similar.

b.   A digital multimeter of input impedance 1M   or
      greater.

c.   A test lead as shown in 5.1.2.1 (c).

5.1.5.2   Setting up

a.   Connect the test lead to the firing unit.

b.   Connect the digital voltmeter to terminals D and E,
      positive on E.

c. Connect the oscilloscope to terminals B and C, positive on B.

d. Ensure the "Interlock Error" switch is "Closed".

e. Ensure the "Fuzehead Resistor" switch is on "Fuzehead".

5.1.5.3 The test

a. The "SAFE/ARM" switch on "SAFE"; Depress the "Charge" button and crank the hand-crank generator until the Ready LED lights up.

b. "ARM" the firing unit and press "Fire". Record the voltage on the oscilloscope and on the voltmeter.

c. Return the "SAFE/ARM" switch to "SAFE". The "Discharged" LED should flash.

d. Depress the "Charge" button and crank the hand-crank generator till the "Ready" LED glows, then crank a further 10 times.

e. Repeat (b).

f. Repeat (c).

g. Return the "SAFE/ARM" switch to "SAFE". The discharged LED should flash. Depress the "Charge" button and crank the hand-crank generator until the "Ready" LED lights up.

h. "ARM" the firing unit. Wait 30 minutes ±5 minutes and then press the "Fire" button. Record the peak voltage on the oscilloscope and the voltmeter.

i. Return the "SAFE/ARM" switch to "SAFE".

5.1.5.4 Criteria for rejection

The voltages measured in 5.1.5.3

TABLE 4: TEST CRITERIA FOR THE FIRING UNIT

WHEN MEASURED		OSCILLOSCOPE VOLTAGE	VOLTMETER VOLTAGE
5.1.5.3	(b)	not less than 40 V	not less than 50 V
5.1.5.3	(e)	not greater than 100 V	not greater than 80 V
5.1.5.3	(h)	not less than 35 V	not less than 40 V

If the voltages measured do not comply with the above value, tests 5.1.5.3 (a) to (e) shall be repeated 10 times. If the voltages then measured when 5.1.5.3 is repeated still do not comply with the above, the unit shall be rejected.

If the LED's as indicated in 5.1.4.3 (a) and (c) do not light up, the unit shall be rejected.

5.1.5.5   Technical considerations

This test checks the LM 224 op amp defined by pins 12; 13 and 14 and it's associated circuitry. The pull in coil of the latching relay is also checked. 5.1.5.3 (d) checks that the voltage regulating MOV is working correctly.

The capacity of C8 and C9 is also checked. The reason for repeating Test 5.1.5.3 (a) to (e) 10 times after an initial failure of the test is to ensure that C8 and C9 have had their electrolytes correctly formed. The "SAFE/ARM" and "FIRE" circuitry is also checked.

5.1.6   The Hand Crank Generator Safe-ing Circuitry

5.1.6.1   Equipment needed for this test

The following equipment is needed for this test.

a.   A storage oscilloscope, Tektronix type number 466 or similar.

b.   A digital multimeter of input impedance 1M   or greater.

c.   A test lead as shown in 5.1.2.1 (c).

5.1.6.2   Setting up

a.   Connect the test lead to the firing unit.

b.   Connect the digital voltmeter to terminals D and E; positive on terminal E.

c.   Connect the oscilloscope to terminals B and C, positive on terminal B.

d.   Ensure the "Interlock Error" switch is "Closed".

e.   Ensure the "Fuzehead Resistor" switch is on "Fuzehead".

5.1.6.3   <u>The test</u>

    a.   The "SAFE/ARM" switch on "SAFE". Depress the "Charge" button and crank the hand crank till the "Ready" LED lights up.

    b.   Release the charge button and crank the hand crank. The "Discharged" LED should light up.

    c.   "ARM" the firing unit and press the "Fire" button.

    d.   Record the peak voltage measured on the oscilloscope and the voltmeter.

    e.   Return the "SAFE/ARM" switch to "SAFE".

5.1.6.4   <u>Criteria for rejection</u>

The unit shall be rejected if the "Discharged" LED does not light up in 5.1.6.3 (b).

The unit shall be rejected if the voltage measured on the oscilloscope or the voltmeter is above 10 V.

5.1.6.5   <u>Technical considerations</u>

This test checks that the circuit comprising S3; D9, D21; R19; R35, R36 and the associated thyristors is working correctly.

5.1.7   <u>The SAD Capacitor Leakage Resistor</u>

5.1.7.1   <u>Equipment needed for this test</u>

The following equipment is needed for this test:

    a.   a digital multimeter of input impedance 1M or greater

    b.   a test lead as shown in 5.1.2.1 (c).

5.1.7.2   <u>Setting up</u>

    a.   Connect the test lead to the firing unit

    b.   Connect the ohm meter to terminals D and E, positive on E

    c.   Ensure the "SAFE/ARM" switch is on "SAFE".

5.1.7.3   The test

Record the resistance between terminals D and E, after the
meter has stabilised.

5.1.7.4   Criteria for rejection

The firing unit shall be rejected if the resistance measured
is greater than 250 Ω or less than 200 Ω .

5.1.7.5   Technical considerations

This test ensures that the "SAFE/ARM" switch contacts and R8
are functioning correctly. This will ensure no charge build
up on the SAD capacitor.

5.1.8   The Safety Short Circuit on the Fuzehead

5.1.8.1   Equipment needed for this test

The following equipment is needed for this test:

a.   a digital multimeter of input impedance 1M   or greater

b.   a test lead as in 5.1.2.1 (c).

5.1.8.2   Setting up

a.   Connect the test lead to the firing unit.

b.   Connect the ohm meter to terminals A and C, positive on
       terminal A.

c.   Ensure the "Fuzehead Resistor" switch is on "Decade
       Box".

5.1.8.3   The test

a.   Ensure the "SAFE/ARM" switch is on "SAFE".

b.   Record the resistance as indicated on the ohm meter.

c.   Switch the "SAFE/ARM" switch to "ARM".

d.   Record the resistance as indicated on the ohm meter.

5.1.8.4   Criteria for rejection

The firing unit is rejected if:

a.   the resistance recorded in 5.1.8.3 (b) is greater than
      5Ω .

b.   the resistance recorded in 5.1.8.3 (d) is less than
      90Ω or greater than 115Ω .

5.1.8.5   Technical considerations

This test checks R5 and one contact of S3 for correct
functioning.

5.1.9   The Disconnected Cable Test

5.1.9.1   Equipment needed for this test

No equipment is needed for this test.

5.1.9.2   Setting up

a.   Ensure that all cables are disconnected from the firing
      unit.

b.   Ensure that the "SAFE/ARM" switch is on "SAFE".

5.1.9.3   The test

a.   Depress the "Charge" button and crank the hand-crank
      generator.

b.   Record which LED's light up.

5.1.9.4   Criteria for rejection

The unit shall be rejected if either the "Interlock Error" or
"Fuzehead Fault" or both do not light up.

5.1.9.5   Technical considerations

This test ensures that R3 is present. R3 ensures that if the
fuzehead is disconnected (including compensating resistor),
the firing unit fails safe and informs the operator. The
"Interlock Error" LED lights up as if the "Interlock" switch
was open circuit.

5.2   LOW PRESSURE (ALTITUDE) TEST

5.2.1   General

MIL-STD 810D   Method 500.2.

This test is to ensure that negligible changes occur in the
physical and chemical properties of the polyurethane foam
used to pot the firing unit.

The test objective is to ensure that the firing unit can be
transported by air in its normal storage configuration.
Procedure 1 applies, to a minimum cargo compartment pressure
of 57,2 kPa and duration of 1 hour.

5.2.2   Procedure 1 - Storage

STEP   ACTION

(1)   Adjust the test item's configuration to that required
for storage or transit.

(2)   With the test item in the chamber, adjust the chamber
air pressure, at any convenient rate, to 55 kPa ±5 kPa.

(3)   Maintain 55 kPa ±5 kPa for a minimum of 1 hour.

(4)   Adjust the chamber air pressure to standard ambient
atmospheric conditions at a convenient rate.

(5)   Conduct a complete visual examination and a functional
checkout of the test item (Section 5.1). Document the
results.

5.3 VIBRATION

5.3.1 General

MIL-STD-810D   Method 514.3

Vibration testing is performed to determine the resistance of equipment to vibrational stresses expected in its shipment and application environments. Two vibration categories have been selected.

a.   Transport/cargo induced vibration, category 1 (Basic Transportation). This refers to equipment carried as secured cargo. Test procedure 1 applies.

b.   Application induced vibration, category 8 (ground mobile). This refers to equipment installed in wheeled vehicles. Test procedure 1 applies.

The nature of the system is such that it will only be operated when the carrier vehicle is stationary. The application induced vibration (ground mobile) therefore falls away. To compensate, the transport/cargo induced vibration is increased to include common carrier and mission/field environments. The levels for this environment are taken from figures 514.3-7; 514.3-8 and 514.3-9 (MIL-STD-810D).

5.3.2 Basic Transportation, Composite Tactical Wheeled Environment, Vibration Testing

5.3.2.1 Time duration of the test

Figures 514.3-7; 3-8 and 3-9 call for a test duration of 120 minutes per 500 miles. The operational scenario calls for 100 operational cycles, each cycle being a round trip of 300 Km. The total operational distance is therefore 30 000 km, or a vibration time of 75 hours per axis. This test time duration is considered excessive because:

a.   The firing units will be mounted in the cab of the vehicle on vibration mounts. The vibration graphs and times are based on an item protected by packaging and secured with load securing devices.

b.   The vibration graphs include equipment transported on a two wheeled trailer. This is further motivation for reducing vibration times.

Accordingly the test item was directly attached to the vibration table with the aid of a fixture. It was vibrated for a duration of 15 hours per axis as specified in figures 514.3-7, 514.3-8 and 514.3-9, between the frequencies 10 - 200 Hz.

5.3.2.2 Vibration type

The firing unit will be subjected to random vibration only.

TEST DURATION : 120 MINUTES PER 500 MILES
OVERALL RMS LEVEL : 1,98 G
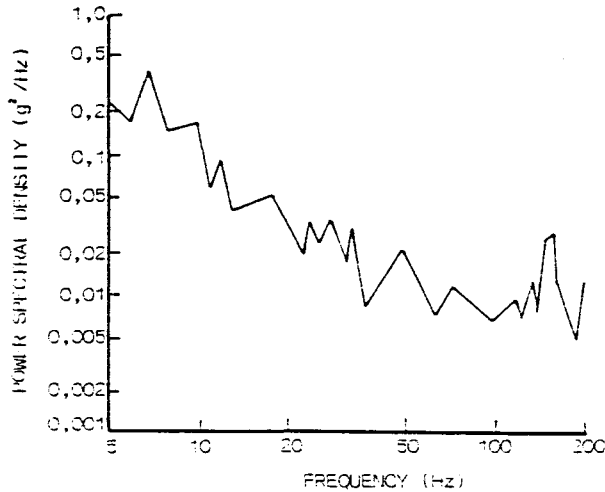
BASIC TRANSPORTATION, COMPOSITE TACTICAL
WHEELED ENVIRONMENT, VERTICAL AXIS

BREAKPOINT		BREAKPOINT	
FREQUENCY	PSD VALUE	FREQUENCY	PSD VALUE
5	0,2384	37	0,0081
6	0,1684	49	0,0219
7	0,3823	63	0,0070
8	0,1487	73	0,0115
10	0,1604	98	0,0066
11	0,0593	120	0,0097
12	0,0975	123	0,0068
13	0,0489	130	0,0134
18	0,0537	140	0,0076
23	0,0191	146	0,0249
24	0,0352	159	0,0282
26	0,0231	163	0,0138
28	0,0352	180	0,0040
32	0,0167	200	0,0134
33	0,0311		

FIGURE 51: MIL-STD-810D FIGURE 514.3-7 BASIC TRANSPORTATION,
COMPOSITE TACTICAL WHEELED ENVIRONMENT, VERTICAL AXIS.
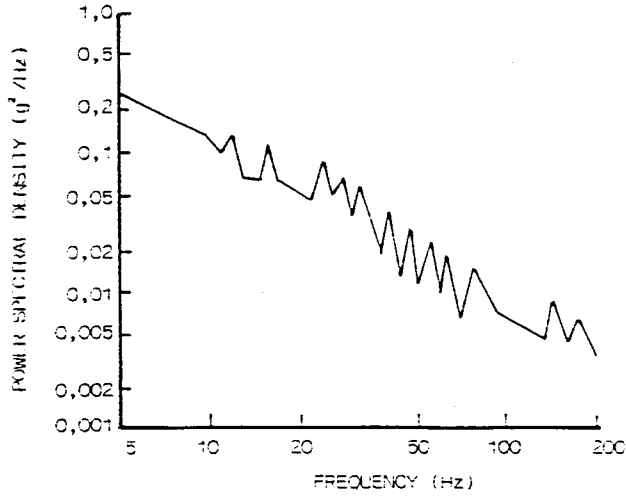
BASIC TRANSPORTATION, COMPOSITE TACTICAL
WHEELED ENVIRONMENT, TRANSVERSE AXIS

BREAKPOINTS		BREAKPOINTS	
FREQUENCY	FSD VALUE	FREQUENCY	FSD VALUE
5	0,2549	44	0,0129
10	0,1303	48	0,0294
11	0,0967	50	0,0114
12	0,1336	56	0,0246
13	0,0650	60	0,0896
15	0,0634	63	0,0188
16	0,1123	70	0,0856
17	0,0650	78	0,0158
22	0,0459	93	0,0073
24	0,0098	137	0,0046
26	0,0597	145	0,0091
28	0,0683	162	0,0043
30	0,0357	176	0,0066
32	0,0508	200	0,0036
38	0,0192		
40	0,0306		

FIGURE 52: MIL-STD-810D FIGURE 514.3-8 BASIC TRANSPORTATION,
COMPOSITE TACTICAL WHEELED ENVIRONMENT, TRANSVERSE AXIS.

TEST DURATION : 120 MINUTES PER 500 MILES
OVERALL RMS LEVEL : 2,54 G
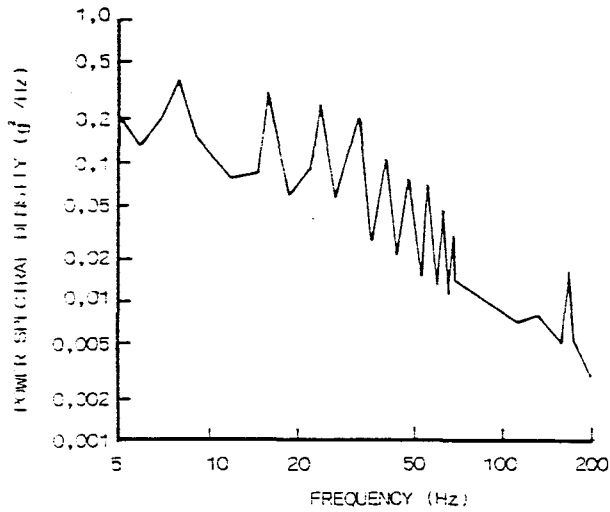
BASIC TRANSPORTATION, COMPOSITE TACTICAL
WHEELED ENVIRONMENT, LONGITUDINAL AXIS.

BREAKPOINTS		BREAKPOINTS		BREAKPOINTS	
FREQENCY	PSD VALUE	FREQUENCY	FSD VALUE	FREQUENCY	FSD VALUE
5	0,2213	32	0,2269	114	0,0074
6	0,1314	36	0,0282	132	0,0083
7	0,2054	40	0,1160	160	0,0051
8	0,3823	44	0,0289	169	0,0171
9	0,1563	48	0,8190	173	0,0055
12	0,0799	53	0,0140	200	0,0031
15	0,0083	56	0,0742		
16	0,3294	60	0,0127		
19	0,0688	64	0,0498		
22	0,0928	65	0,0110		
24	0,2634	68	0,0326		
27	0,0564	69	0,0140		

FIGURE 53: MIL-STD-810D FIGURE 514.3-9 BASIC TRANSPORTATION,
COMPOSITE TACTICAL WHEELED ENVIRONMENT, LONGITUDINAL AXIS

5.3.3 **Functional Testing**

Conduct a complete visual examination and a functional checkout of the test item (paragraph 5.1) and document the results.

5.4 **SHOCK TESTING**

5.4.1 **General**

MIL-STD-810D   Method 516.3

Shock tests are performed to ensure that material can withstand the relatively infrequent non-repetitive shocks or transient vibrations encountered in handling, transportation and service requirements. Shock tests are also used to test the strength of devices that attach equipment to platforms that can crash.

5.4.1.1 **Test procedures to be performed**

Functional shock   (5.4.2)
Transit drop   (5.4.3)
Crash hazard   (5.4.4)

5.4.2 **Functional shock**

This is intended to test equipment assemblies in their functional mode.

5.4.2.1 **Test Axes and number of shocks**

The firing unit shall be subjected to three shocks in both directions along each of three orthogonal axes.

5.4.2.2 **Test response spectrum**

The shock shall be a half sine pulse, critically damped conforming to MIL-STD-810D figure 516.3-1 as shown.(Figure 54)

5.4.2.3 **Functional Tests**

Conduct a complete visual examination and a functional checkout of the test item (paragraph 5.1) and document the results.
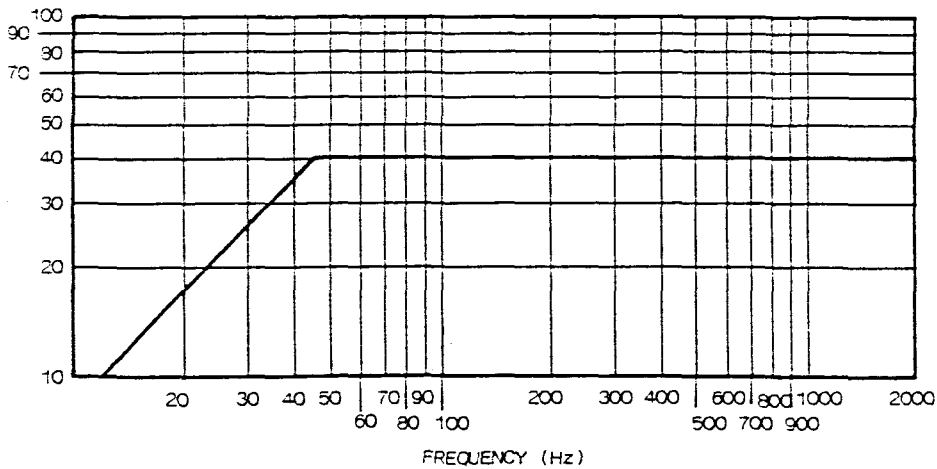
TEST PROCEDURE	PEAK ACCELERATION	T_E	CROSS OVER FREQUENCY
FUNCTIONAL TEST FOR GROUND EQUIPMENT	40 g's	6-9 ms	45 Hz

FIGURE 54: MIL-STD-810D FIGURE 516.3-1 - TEST VALUE 40 g

5.4.3   Transit Drop

This test is intended for equipment in transit. It is used to determine if a test item is capable of withstanding shocks normally induced by loading and unloading of equipment.

5.4.3.1   Test axes and number of drops

Height of drop   122 cm

Number of drops   Drop on each face; edge and corners. A total of 26 drops.

Drops shall be made from a quick release hook or drop tester. The test/item shall be so orientated that upon impact a line from the struck corner or edge to the center of gravity of the case and its contents shall be perpendicular to the impact surface.

Toppling of the item following impact will occur in the field. Toppling of the test item following its initial impact should not be restrained as long as the test item does not leave the required drop surface.

The floor or barrier receiving the impact shall be of two inch (51 mm) plywood backed by concrete.

5.4.3.2   Functional tests

Conduct a complete visual examination and a functional checkout of the test item (Paragraph 5.1) and document the results.

5.4.4   Crash Hazard

This procedure is for equipment mounted in a ground vehicle which could break loose and present a hazard to vehicle occupants. It is intended to verify the structural integrity of equipment mountings during simulated crash conditions. The equipment need not pass functional tests after a crash hazard test. The test item shall be a representitive item or a mechanically equivalent mockup. If a mockup is used it will represent the same hazard potential, mass, center of mass and mass moments about the attached points as the item simulated.

5.4.4.1   Test axes and number of shocks

Perform two shocks in each direction along three orthogonal axes of the test item for a maximum total of 12 shocks.

5.4.4.2   <u>Test response spectrum</u>

The shock shall be a half sine pulse, critically damped, of
amplitude and duration conforming to MIL-STD-810D figure
516.3-1, as shown. (Figure 55)

5.4.4.3   <u>Functional tests</u>

The test item must not break loose from its mountings.
Buckling and deforming of mounting plates is permitted. No
tests as in paragraph 5.1 are to be carried out.
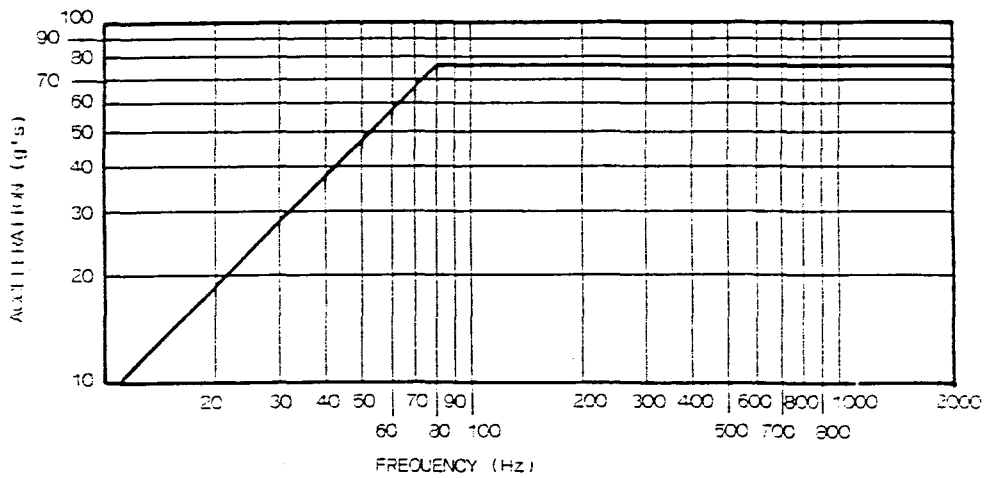
TEST PROCEDURE	PEAK ACCELERATION	T_E	CROSS OVER FREQUENCY
CRASH HAZARD TEST FOR GROUND EQUIPMENT	75 g's	3.5-5 ms	80 Hz

FIGURE 55: MIL-STD-810D FIGURE 516.3-1, TEST VALUE 75 g

5.5   HIGH TEMPERATURE TESTS

5.5.1   General

            MIL-STD-810D   Method 501.2.

            High temperature chamber tests are performed to determine if
            material can be stored and operated under hot climatic
            conditions without experiencing physical damage or
            deterioration in performance. This method provides for two
            sub tests. Procedure 1 (storage) and 2 (operation).

5.5.2   Storage test (Procedure 1)

            STEP   ACTION

            1)   Install the required temperature sensors on the test
                  item.

            2)   Place the test item in its storage configuration.

            3)   Adjust the chamber temperature to +65°C ±5°C.

            4)   Expose the test item to +65°C ±5°C for a minimum of
                  24 hours.

            5)   At the completion of a minimum of 24 hours, remove the
                  test item from the chamber and allow to cool for a
                  minimum of 2 hours.

            6)   Conduct a complete visual and functional test as shown
                  in section 5.1. Document the results.

5.5.3   Operation (Procedure 2)

            STEP   ACTION

            1)   Adjust the chamber temperature to +65°C   ±5°C.

            2)   Place the test item in the chamber in its operational
                  configuration. (Test lead as shown in 5.1.1.1.C
                  plugged in.)

            3)   Expose the test item to +65°C ±5°C for a minimum of
                  12 hours.

            4)   Remove the test item after a minimum of 12 hour
                  exposure time.

            5)   Conduct an operational checkout as described in Section
                  5.1.4.

6) Repeat 5.1.4.3 (a) and return the test item to the chamber for 25 minutes ±5 minutes.

7) Remove the test item from the chamber and carry out test 5.1.4.3 (b) and the associated tests in paragraph 5.1.4.4.

5.6 LOW TEMPERATURE TESTS

5.6.1 General

MIL-STD-810D   Method 502.2.

Low temperature chamber tests are performed to determine if material can be stored, manipulated and operated under pertinent low temperature conditions.

This procedure provides for two sub tests. Procedure 1 (storage) and Procedure 2 (operation).

5.6.2 Storage test: (Procedure 1)

This test shall be conducted as in paragraph 5.5.2 except that the chamber temperature shall be -10°C ±2°C.

5.6.3 Operation (Procedure 2)

This test shall be conducted as in paragraph 5.5.3 except that the chamber temperature shall be 0°C ±2°C.

5.7 TEMPERATURE SHOCK TEST

5.7.1 General

MIL-STD-810D   Method 503.2

Temperature shock tests are conducted to determine if material can withstand sudden changes in the temperature of the surrounding atmosphere without experiencing physical damage or deterioration in performance. The test objectives are to determine if marginal design or workshop practices have occurred in the item.

5.7.2 Procedure

STEP   ACTION

1)   Adjust the temperature of 1 chamber to +65°C ±5°C and allow to stabilise.

2)   Adjust the temperature of a second chamber to -10° ±2°C and allow to stabilise.

3)   Subject the test item to the following temperature shock cycle.
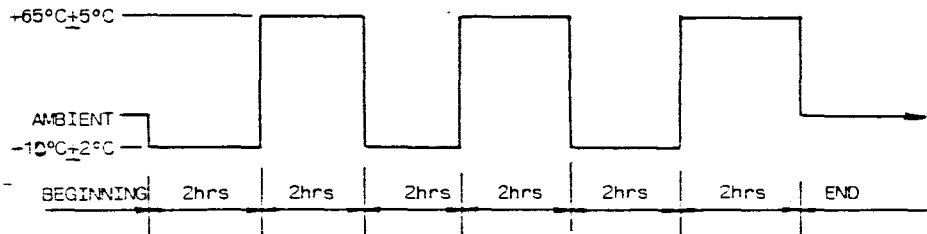
FIGURE 56:   TEMPERATURE CYCLE DIAGRAM

The temperature must be maintained for a minimum of two hours at each extreme. The test item shall be transferred between chambers within five minutes.

4)   Conduct a complete visual and functional checkout of the test item (section 5.1). Document the results.

5.8 RAIN TESTS

5.8.1 MIL-STD-810D   Method 506.2

The rain test is conducted to determine the following:

a.   The effectiveness of protective covers in preventing the penetration of rain.

b.   The capability of the test item to satisfy its performance requirements after exposure to rain.

c.   The physical deterioration of the test item caused by the rain.

Procedure 2 is appropriate when equipment is normally protected from rain, but may be exposed to falling water from condensation or leakage from upper surfaces.

The apparatus shown in Figure 57 was manufactured for this test. MIL-STD-810D Figure 506.2-1 was used as a basis for this apparatus.

The apparatus should provide a volume of water between 280 and 310 $L/m^2/h$.

WATER LEVEL

WATER INLET

WATER OVERFLOW

75 mm

1,5 mm (DIMPLES)

A   A

WATER DROPLETS

1,5 mm DEEP DIMPLES PRESSED INTO 0,8 mm BRASS PLATE WITH 4,8 mm MILD STEEL ROD WITH A 5 mm END RADIUS

25,4 mm (TYP)

25,4 mm (TYP)

HOLES (0,33 mm DIA) DRILLED THROUGH DIMPLES IN 0,8 mm BRASS PLATE

VIEW A - A

DETAILS OF DISPENSER FOR DRIPPROOFNESS TEST

FIGURE 57: RAIN TEST WATER DISPENSER

5.8.2   Procedure 2 (Drip)

STEP   ACTION

1)   Record the mass of the item.

2)   Pre heat the test item to 30°C.

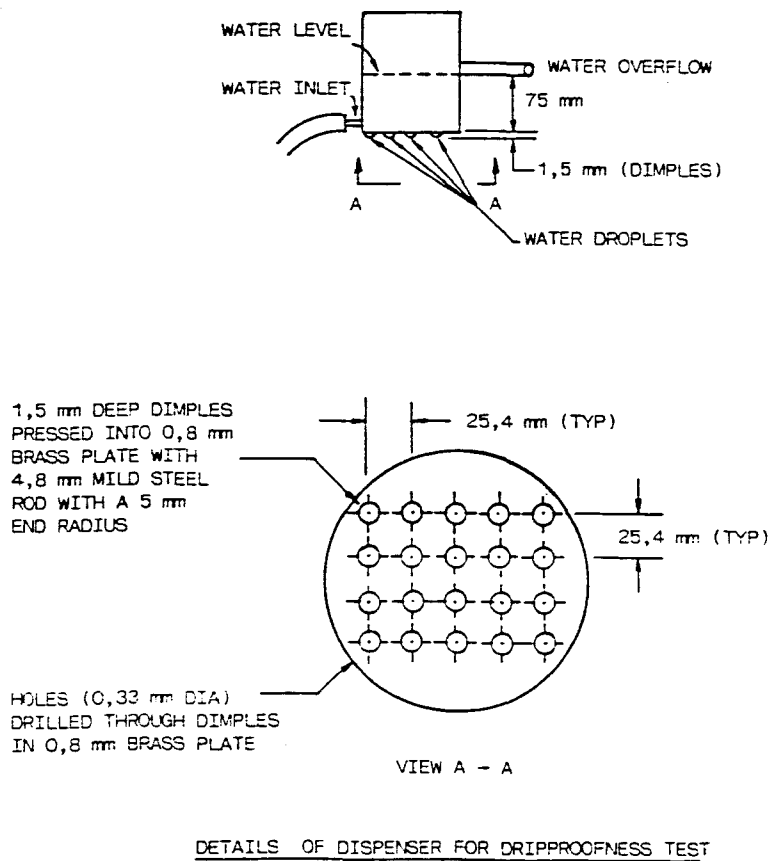3)   Install the test item in the test facility in its
       operational configuration.

4)   Subject it to water falling from the dispenser (shown
       in 5.8.1.1) at a height of approximately one meter, for
       15 minutes. The rate of water flow is determined by a
       75 mm high water level in the dispenser. The test
       setup shall be arranged so that all of the upper
       surface gets droplets on it at some time during the
       test.

5)   At the conclusion of the 15 minute exposure, remove the
       test item from the test facility and dry the exterior
       thoroughly.

6)   Record the mass of the item.

7)   The item will be rejected if the mass has increased by
       more than 0,5 gram ±5%.

8)   Conduct a complete functional test as detailed in
       Section 5.1.

5.9   ELECTROMAGNETIC INTERFERENCE TESTS

These tests have been carried out by the N.E.E.R.I.
department of the C.S.I.R. Pretoria. Please refer to the
C.S.I.R. document which is attached as Appendix 7.

5.10   QUALIFICATION TESTING

Qualification testing will consist of all the tests detailed
in Sections 5.1 to 5.9 inclusive.

5.11   ACCEPTANCE TESTING

Acceptance testing will consist of functional tests before
and after the unit is potted (Section 5.1). Thereafter tests
shall be done as per user requirements.

SECTION 6 : FIELD TESTING

6.1   GENERAL

The firing unit was field tested at the test range during the period 4th to 8th November 1985. This test differed from the envisaged operational use in that a 100 meter firing cable was used. The vehicle will have a firing cable of about 15 meters. This change is not expected to alter the firing unit performance.

6.2   DISCUSSION OF TESTS

6.2.1   Shot 1 on 85-11-5

The fuzehead did ignite.
There was no SAD attached.

6.2.1.1   Residual charges

a.   The igniter capacitor

The firing unit was made "SAFE" after the first shot, thereafter "ARMED". The residual charge was then measured as zero to all practical purposes.

b.   The S.A.D. energy supply capacitor

The residual charge in this capacitor was zero; for the same reason as 6.2.2.1.

c.   The residual charge on the capacitor in the S.A.D.

Not applicable (paragraph 6.2.1).

6.2.1.2   Comments

The firing unit functioned correctly. The connection between the firing unit and the firing cable may not be robust enough in terms of current carrying capability.

6.2.2   Shot 2 on 85-11-05

The fuzehead did ignite.
There was no S.A.D. attached.

6.2.2.1   Residual charges

    a.   The fuze head igniter capacitor

The residual charge on the igniter capacitor in the firing unit was greater than 50 mV. The trace overshot the visible vertical range on the oscilloscope tube. This reading must therefore be ignored.

    b.   The S.A.D. energy supply capacitor

1,7 Volts was measured on this capacitor.

This relates to:

$$0,5.(1,7)^2.100 \times 10^{-6} = 145 \text{ uJ}$$

whereas the S.A.D. fuzehead requires 11mJ.

The residual energy pertains to 0,013 of the energy required to initiate this fuzehead.

    c.   Residual charge on the capacitor in the S.A.D.

Not applicable.

6.2.2.2   Comments

The first attempt at launching the system misfired. The reason was due to unclear marking of the firing unit controls, resulting in the incorrect button being pushed. This indicates that the ergonomics and marking of the controls must be improved. A red flap-up cover over the firing button was also suggested.

The firing unit functioned currectly on the second attempt.

6.2.3   Shot 3 on 85-11-5

The fuzehead and S.A.D. ignited correctly.

6.2.3.1   Residual charges

6.4.2   a.   The fuze head igniter capacitor

The residual voltage on the motor ignitor capacitor was 0,7V. This represents an energy of:

$$0,5.47 \times 10^{-6}.0,7^2 = 12 \text{ uJ}$$

This energy is 0,007 times that required to ignite the fuzehead.

b. The S.A.D. energy supply capacitor

The residual voltage was 1,8V. This represents $0,5.100 \times 10^{-6}.1,8^2 = 162$ uJ or 0,015 times the energy required to initiate the S.A.D. fuzehead.

c. Residual charge on the capacitor in the S.A.D.

There was no measurable charge left on the capacitor in the S.A.D.

6.2.3.3 Comments

The section of the firing lead inside the motor compartment of the container was severely damaged by the rocket motor gasses. This included the S.A.D. lead. This section of the lead must have increased protection.

6.2.4 Shot 4 on 85-11-6

The fuzehead did ignite.
There was no S.A.D. electrical connection.

6.2.4.1 Residual charges

a. The motor igniter capacitor

The residual voltage on the motor ignitor capacitor was 1,2V.

This represents an energy of:

$0,5.47 \times 10^{-6}.1,2^2 = 34$ uJ.

This is 0,021 times the minimum firing energy.

b. The S.A.D. energy supply capacitor

A residual voltage of 2,2 V was measured. This represents an energy of $0,5.100 \times 10^{-6}.2,2^2 = 242$ uJ or 0,022 times the energy required to fire the S.A.D. fuzehead.

c. Residual charge on the capacitor in the S.A.D.

Not applicable

6.2.4.2 Comments

The firing unit functioned correctly.

6.2.5   Shot 5 on 85-11-6

The fuzehead did ignite.

There was no S.A.D. electrical connection.

6.2.5.1   Residual charges

a.   The fuze head igniter capacitor

1,5 Volts was measured on the fuzehead igniter capacitor
after activating the system. This represents an energy of

$0,5.47 \times 10^{-6}.1,5^2 = 53$ uJ.

This represents 0,033 times the energy required to ignite
the fuze head.

b.   The S.A.D. energy supply capacitor

The residual voltage was 1,99 V. This represents an
energy of:
$0,5.100 \times 10^{-6}.1,99^2 = 200$ uJ, or 0,018 times the
energy required to initiate the S.A.D. fuzehead.

c.   The residual charge on the capacitor in the S.A.D.

There was no S.A.D. electrical connection.

6.2.5.2   Comments

The firing unit functioned correctly.

6.2.6   Shot 6 on 85-11-6

The fuzehead did ignite.

The S.A.D. did not ignite.

6.2.6.1   Residual charges

a.   The fuze head igniter capacitor

The residual voltage on the igniter capacitor was 3 V.
This represents an energy of:

$0,5.47 \times 10^{-6}.3^2 = 212$ uJ.

This energy is 0,132 times that required for ignition.

b. The S.A.D. energy supply capacitor

The residual voltage was 2,5 V. This represents $0.5.100 \times 10^{-6}.2,5^2 = 312$ uJ or 0,028 times the energy required to initiate the S.A.D. fuzehead.

c. Residual charge on the capacitor in the S.A.D.

There was no residual charge stored in this capacitor.

6.2.6.2 Comments

The firing cable to the S.A.D. was not severly damaged by system exhaust gasses.

The S.A.D. system was returned intact to the manufacturer for complete checkout.

The interlead resistance of the connection between the S.A.D. and the firing unit was checked with a high voltage insulation tester. This resistance was greater than 100 M.

The firing unit was then connected to a test firing lead. A simulated S.A.D. capacitor was connected via the lead originally used for shot No 6. The capacitor charged with correct polarity.

The lead originally used for shot 6 functioned correctly.

The firing unit was then connected to a test loom to check the internal electronics of the firing unit. On "FIRE" the capacitor on the test loom charged correctly to 55 Volts.

The 100 m firing lead and the lead used to connect the S.A.D. to the firing lead was connected and the firing unit operated. The dummy S.A.D. capacitor charged correctly to 59 Volts.

From the aforegoing, it appears that the firing unit; 100 m lead and the lead used to connect the S.A.D. to the firing lead worked correctly for shot 6.

The S.A.D. was then connected as per shot 6. The S.A.D. functioned correctly.

The apparent reason for the S.A.D. malfunction during shot 6 was that the connecting plug between the S.A.D. and the firing lead was pulled out during loading of the system.

6.3   <u>CONCLUSION</u>

The following points must be investigated:

a.   The labeling on the firing unit.

b.   The connectors used throughout the electrical system.

c.   Why the residual charge on the fuzehead igniter
       capacitor increased with number of shots.

NOTE: This residual charge would have been dissipated if the
      firing unit was returned to "SAFE" after launching the
      system.

SECTION 7: ENVIRONMENTAL TEST RESULTS

7.1   GENERAL

This section details the results of the environmental testing carried out on the firing unit.

Unfortunately only high temperature storage (Section 5.5) and vibration (Section 5.3) could be completed within the time constraints of this phase. Complete environmental testing will be carried out during the EDM phase of the firing unit development.

7.2   THE PRE-ENVIRONMENTAL TESTING FUNCTIONAL TEST RESULT

The following details the results of the functional tests of Section 5.

7.2.1   Section 5.1.2.3

(b)   The "Interlock Error" LED did light up.

(d)   The voltage on the voltmeter was 4V while that on the oscilloscope was 0V.

7.2.2   Section 5.1.2.3

Resistance	"Fuzehead Fault" LED	"Ready" LED
0 Ω	on	off
0,4 Ω	on	off
1 Ω	off	on
2 Ω	off	on
3 Ω	off	on
4 Ω	off	on
6,5 Ω	on	off
8 Ω	on	off

7.2.3   <u>Section 5.1.4.3</u>

   d)   The Voltmeter and oscilloscope readings were OV.

7.2.4   <u>Section 5.1.5.3</u>

	Voltmeter reading	Oscilloscope reading
(b)	55V	60V
(e)	90V	80V
(h)	45V	55V

   (c + f)   The "Discharged" LED did light up when the
             "SAFE/ARM" switch was returned to "SAFE"

7.2.5   <u>Section 5.1.6.3</u>

   (b)   The "Discharged" LED did light up.

   (d)   The voltmeter and oscilloscope readings were OV.

7.2.6   <u>Section 5.1.7.3</u>

   The resistance was measured as 215 Ω .

7.2.7   <u>Section 5.1.8.3</u>

   (b)   The resistance was measured as 2,1 Ω .

   (d)   The resistance was measured as 98,3 Ω .

7.2.8   <u>Section 5.1.9.3</u>

   (b)   Both the "Fuzehead Fault" and "Interlock Error" LEDs
         lit up.

7.2.9   <u>Conclusion</u>

   The firing unit worked correctly.

7.3   THE HIGH TEMPERATURE STORAGE TEST FUNCTIONAL TEST RESULT

The following paragraphs detail the results of the functional tests of Section 5:

7.3.1   Section 5.1.2.3

(b)   The "Interlock Error" LED did light up.

(d)   The voltage on the voltmeter was 0,1V while that on the oscilloscope was 2V.

7.3.2   Section 5.1.3.3

Resistance	"Fuzehead Fault" LED	"Ready" LED
0 Ω	on	off
0,4 Ω	on	off
1 Ω	off	on
2 Ω	off	on
3 Ω	off	on
4 Ω	off	on
6,5 Ω	on	off
8 Ω	on	off

7.3.3   Section 5.1.4.3

The voltmeter and oscilloscope readings were 0V.

7.3.4   Section 5.1.5.3

	Voltmeter reading	Oscilloscope reading
(b)	56V	53V
(e)	70V	60V
(h)	41V	35V

(c + f)   The "Discharged" LED did light up when the "SAFE/ARM" switch was returned to "SAFE"

7.3.5   Section 5.1.6.3

(b)   The "Discharged" LED did light up.

(d)   The voltmeter meassured 0,133V while the oscilloscope
       measured 1,5V.

7.3.6   Section 5.1.7.3

The resistance was measured as 218 Ω .

7.3.7   Section 5.1.8.3

(b)   The resistance was measured as 2,1 Ω .

(d)   The resistance was measured as 98,3 Ω .

7.3.8   Section 5.1.9.3

(b)   Both the "Fuzehead Fault" and "Interlock Error" LEDs
       lit up.

7.3.9   Conclusion

The firing unit worked correctly.

7.4   THE VIBRATION FUNCTIONAL TEST RESULTS

The vibration frequency spectra as shown in MIL-STD-810D
Figures 514.3-7; 3-8 and 3-9 were unacceptable to the
vibrator used for this test and were subsequently modified to
10 - 200 Hz from 5 - 200 Hz.

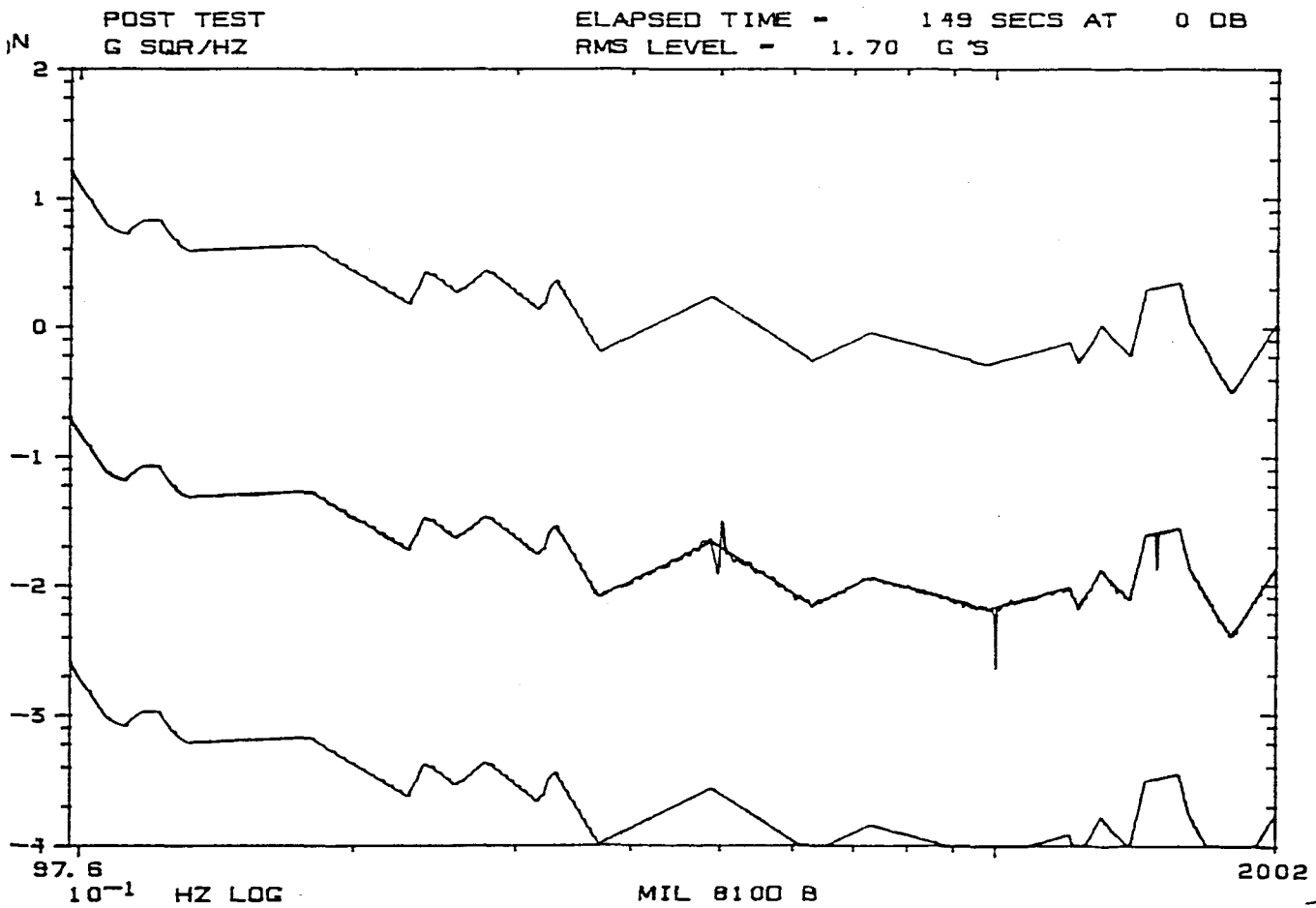The following graphs are the frequency spectra as recorded by
the vibrator.

FIGURE 58: VIBRATION GRAPH FOR BASIC TRANSPORTATION,
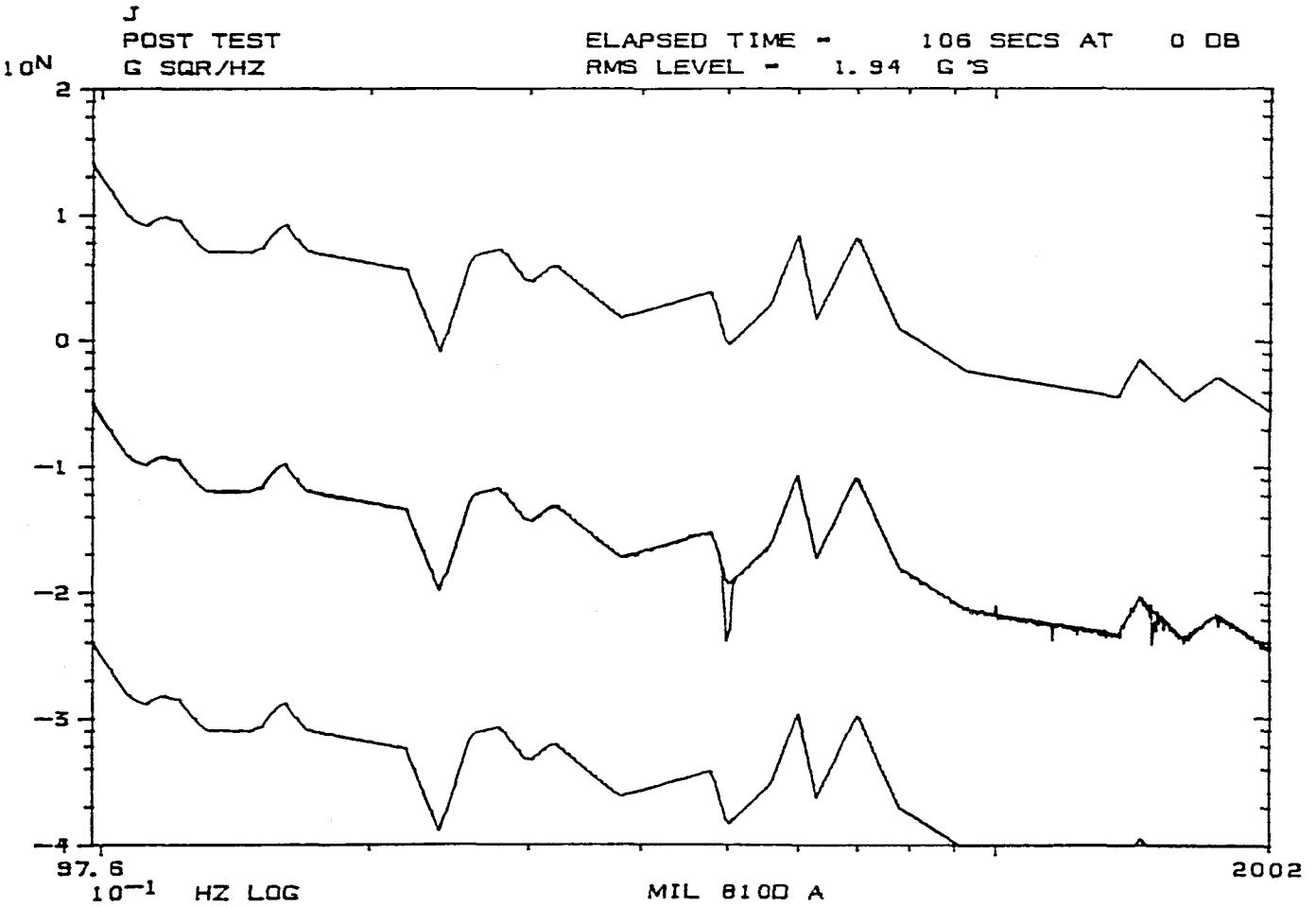COMPOSITE TACTICAL WHEELED ENVIRONMENT VERTICAL AXIS.

FIGURE 59: VIBRATION GRAPH FOR BASIC TRANSPORTATION,
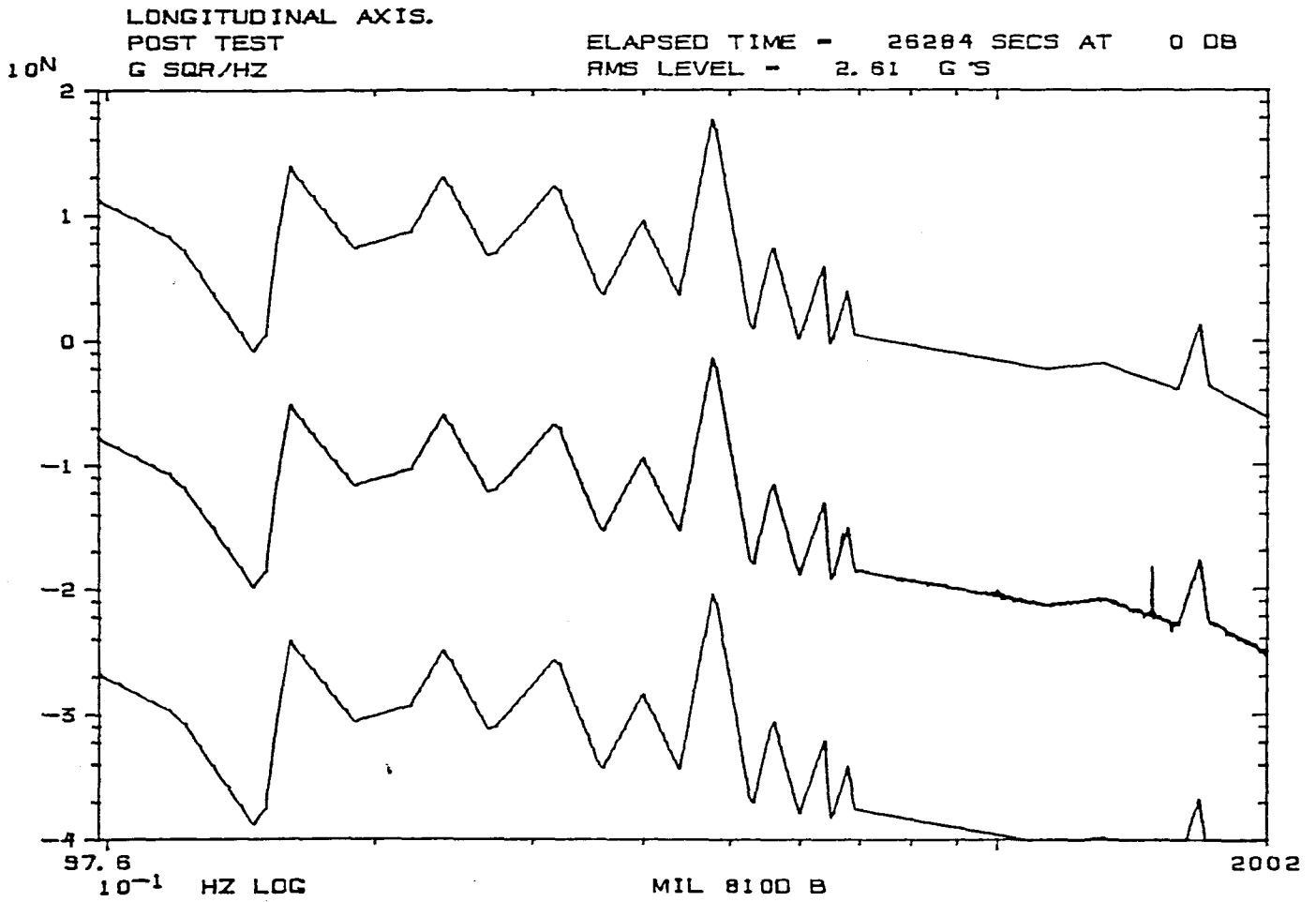COMPOSITE TACTICAL WHEELED ENVIRONMENT, TRANSVERSE AXIS

FIGURE 60: VIBRATION GRAPH FOR BASIC TRANSPORTATION,
COMPOSITE TACTICAL WHEELED ENVIRONMENT, LONGITUDINAL AXIS

7.4.1   <u>Section 5.1.2.3</u>

   (b)   The "Interlock Error" LED did light up.

   (d)   The voltage on the voltmeter was 1,4 V while that on
         the oscilloscope was 6,5 V.

7.4.2   <u>Section 5.1.3.3</u>

Resistance	"Fuzehead Fault" LED	"Ready" LED
0 Ω	on	off
0,4 Ω	on	off
1 Ω	off	on
2 Ω	off	on
3 Ω	off	on
4 Ω	off	on
6,5 Ω	on	off
8 Ω	on	off

7.4.3   <u>Section 5.1.4.3</u>

   (d)   The voltmeter reading was 120 mV.
         The oscilloscope reading was 0,4 mV.

7.4.4   <u>Section 5.1.5.3</u>

	Voltmeter reading	Oscilloscope reading
(b)	57V	53V
(e)	70V	65V
(h)	47V	40V

   (c + f)   The "Discharged" LED did light up when the
             "SAFE/ARM" switch was returned to "SAFE"

7.4.5   <u>Section 5.1.6.3</u>

(b)   The "Discharged" LED did light up.

(d)   The voltmeter reading was 0,09V.
The oscilloscope reading was 1,5V.

7.4.6   <u>Section 5.1.7.3</u>

The resistance was measured as 215 Ω .

7.4.7   <u>Section 5.1.8.3</u>

(b)   The resistance was measured as 1,8 Ω .

(d)   The resistance was measured as 98,2 Ω .

7.4.8   <u>Section 5.1.9.3</u>

(b)   Both the "Fuzehead Fault" and "Interlock Error" LEDs lit up.

7.5   <u>CONCLUSION</u>

The firing unit worked correctly.

7.6   <u>RECOMMENDATION</u>

The firing unit appears to comply with the user requirement. Minor technical considerations will be addressed during the next phase.