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A CAPACITOR DISCHARGE SQUIB FIRING UNIT

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In 1973, Wentworth Institute (WI) was asked to produce a practical, reliable, off-the-shelf CD unit for firing standard squibs. Design objectives included simultaneous four-bridgewire firing capability, one-second recovery, 0.5A supply drain, and three outputs. A +28 VDC supply is required. The Model CD-B is described: a +28 volt firing command closes a selected firing relay for 30 ms; at 20 ms, the firing capacitors are discharged into the squib circuit through an SCR. The unit includes standard safety features (ARM/SAFE

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relay and 100 k-ohm squib isolation), and monitors for both capacitor voltage and squib current. Nine CD units have been built by WI for use in sounding rockets. Four flights have used the CD units for primary squib ignition; no malfunctions have been indicated. CD squib current data is shown for eight in-flight firings. This data suggests that a reduction in the size of the CD unit may be possible. (The Model CD-B measures 10.2 x 12.7 x 5.7 cm (4 x 5 x 2.25 in.) and weighs 0.7 kg (24.7 oz.)).

CONTENTS

A CAPACITOR DISCHARGE SQUIB FIRING UNIT

INTRODUCTION

Capacitor discharge (CD) ignition systems of various types are in use. However, a practical, reliable, off-the-shelf CD unit for firing standard electro-explosive devices (squibs) has not been available. In 1973, investigations by the AFCRL Aerospace Instrumentation Laboratory indicated that such a device should be feasible, and Wentworth Institute was asked to produce a flight-qualified unit for field evaluation.

A preliminary design (Model CD-A) operated satisfactorily in the ALADDIN Program (Wallops Island, Virginia, June, 1974); the final design (Model CD-B) was flown successfully in October, 1975, at White Sands Missile Range, New Mexico.

The body of this report introduces the Model CD-B in terms of design requirements, unit description, and flight results.

DESIGN REQUIREMENTS

The following requirements were formulated within the context of AFCRL sounding rocket instrumentation practice; they are numbered consecutively as introduced.

Design Objectives

These requirements represent engineering judgment as to the best compromises between capability and cost.

Quantitative Objectives

(1) Sufficient energy capacity to fire four standard (1 ohm) bridgewires simultaneously.

(2) Full recovery within 1 second after each firing.

(3) Maximum supply drain of 0.5 ampere.

(4) Capability to fire three independent squib circuits in any order.

Qualitative Objectives

(5) Minimum size and production cost for the CD unit.

(6) Maximum reliability and flexibility for the CD unit.

Design Constraints

These are basic parameters that must be fixed before design calculations can be made.

(7) Firing energy per bridgewire was taken as 0.1 joule--a conservative interpretation of commercial DC firing data for standard "1 ohm, 1 watt no-fire" squibs.

(8) A design value for the wiring resistance of each squib circuit was needed: 0.5 ohm was included with each bridgewire, and 0.5 ohm for common circuitry. These values give a conservative design.

(9) The frequent use of 28 volt power sources in sounding rocket payloads suggested a supply voltage constraint of +28±4 VDC.

(10) The entire CD unit, as well as each component, was subject to appropriate environmental specifications.

Other Requirements

Certain design requirements are essential for safety and verification purposes, regardless of the design objectives and constraints chosen.

Safety Requirements

(11) A remotely controlled ARM/SAFE device to preclude squib firing when the SAFE mode is selected.

(12) Provisions to ensure that any squib circuit not connected for firing be a continuous loop, isolated from system ground through a 100 k-ohm resistor.

Verification Requirements

(13) Means for remote verification of the mode of the ARM/SAFE device.

(14) Means for remote monitoring of the voltage on the firing capacitors.

(15) Means for remote monitoring of squib current from the firing capacitors.

MODEL CD-B DESCRIPTION

This section indicates how the design requirements were met in the Model CD-B.[1] The Functional Description section tells how the unit operates, and

1. The Model CD-B is functionally identical to the Model CD-A. However, the Model CD-B includes design and packaging improvements.

relates each function to the design requirements. The Circuit Operation section explains how the functions are achieved. The Appearance section provides photographs of the interior and exterior of the Model CD-B.

Functional Description

Figure 1, a functional block diagram for the Model CD-B, shows the organization of the unit. The following explanations refer to this figure.

Normal Operation

If the unit is in the ARM mode, energy from the supply battery flows through the current limiting circuit, charging the firing capacitors. A +28 volt step applied to a firing input (X, Y, or Z) closes the selected firing relay for at least 30 ms. At the end of the first 20 ms, the SCR is triggered, allowing the firing capacitors to discharge through the selected squib circuit. When the firing relay opens, the SCR turns off, and the firing capacitors recharge through the current limiting circuit.

The Firing Capacitance

The firing capacitance (6.6 mF = 6600 uF) was determined primarily by the energy capacity requirement (1) and by the design constraints. Also affecting this selection were (a) SCR and contact voltage drops, and (b) the firing capacitance tolerance (+50%, -10%).

The Current Limiting Circuit

With the firing capacitance fixed, the recovery time and maximum supply drain requirements (2 and 3) might have conflicted. This was avoided by using a nearly constant current, rather than an exponentially decreasing one, to recharge the firing capacitors.

The Pulse Circuits

Essentially, these are capacitors in series with the firing relay coils. Their purpose is to limit the closure time of the relays. Only 30 ms of relay closure is needed, and much more is not desirable because of the recovery time requirement (2). In addition, the pulse circuits allow firing voltages to be left on until they can be removed conveniently.

The Firing Relays

The firing relays are included primarily to enable the unit to fire three independent squib circuits in any order (Des. Req. 4). They are wired to comply with the squib circuit safety requirement (12). Also, each relay acts as a redundant switch in series with the firing SCR. This avoids separating squibs and energy source in an armed unit by only a solid state switch. The relays are also used to turn off the firing SCR.

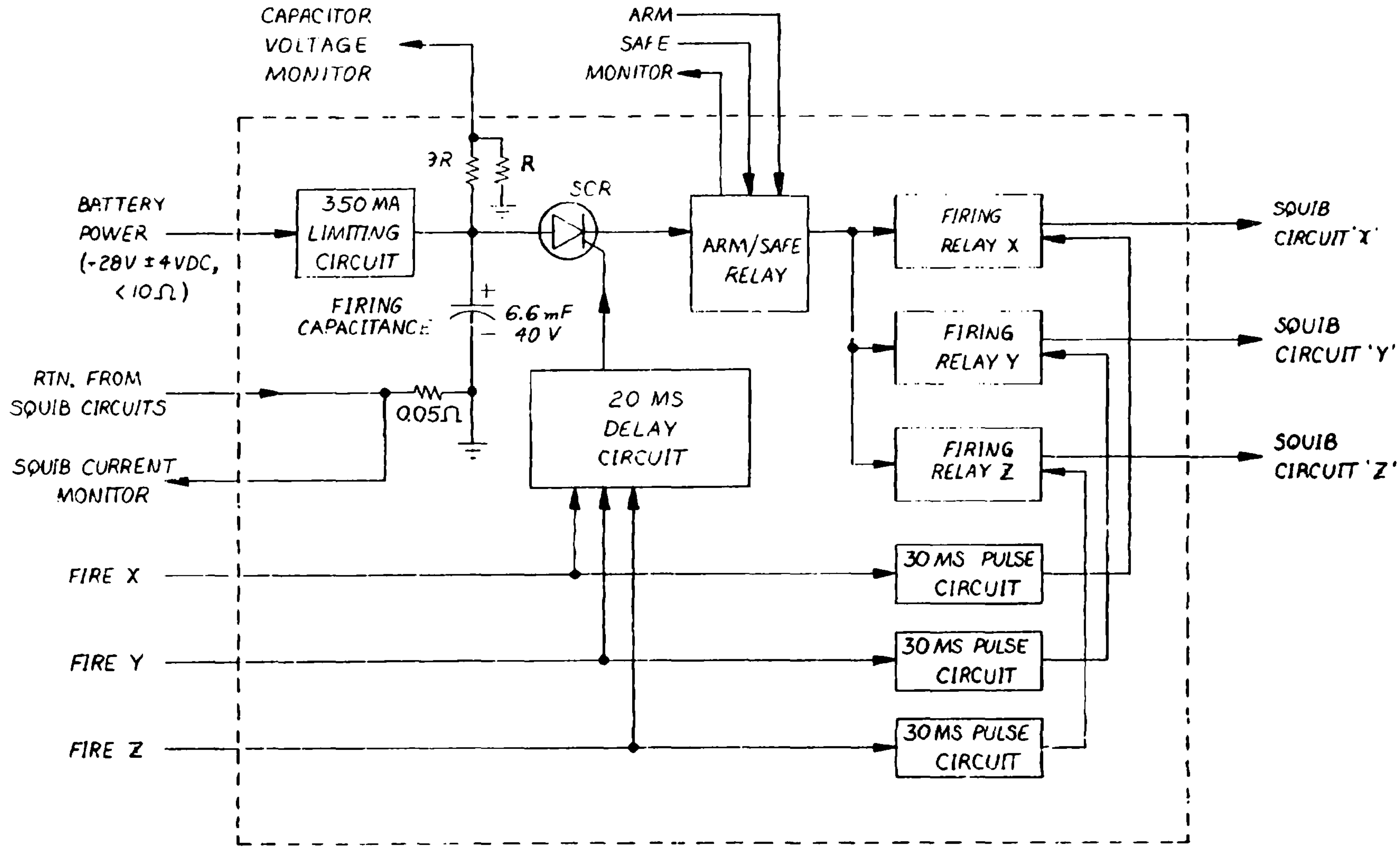

FIGURE 1. CAPACITOR DISCHARGE SQUIB FIRING UNIT
FUNCTIONAL BLOCK DIAGRAM
MODEL CD-B

The ARM/SAFE Relay

This relay meets the ARM/SAFE requirement (11). The relay contacts are so wired that the squib circuit safety requirement (12) will not be violated by inadvertent operation of a firing relay when the unit is in the SAFE mode.

The Firing SCR

An SCR is used for squib current turn-on because of the clean switching it provides. Relay switching involves contact bounce which would commutate the squib current. In a CD unit, the resulting loss of efficiency would almost double the energy requirement.

The Delay Circuit

This circuit allows the firing relay contacts to close firmly before the SCR is triggered. This condition gives the full advantage of SCR current turn-on. Also, the delay is long enough (20 ms) to allow the firing voltage to operate a squib circuit steering relay before the SCR triggers.[2]

The Monitors

The ARM/SAFE monitors are for remote verification of mode (Des. Req. 13). The capacitor voltage and squib current monitors are a partially redundant means for remote verification of firing operation of the CD unit and the associated squib circuits (Des. Req's. 14 and 15).

Circuit Operation

A schematic diagram of the Model CD-B circuitry is shown in Figure 2. Parts of the schematic are labeled to correspond with the Functional Block Diagram of Figure 1. This section explains briefly the operation of the current limiting, pulse, and delay circuits; the capacitor voltage and squib current monitors are also discussed. References to specific components are by the alphanumeric identifiers on the schematic. (Example: transistor Q1). Component values are listed in the Appendix.

The Current Limiting Circuit

The aim here is to feed a constant charging current to the firing capacitors (C2, C3, and C4) while the voltage difference between supply and capacitors is decreasing. The key component is current regulator diode CR1: it maintains a constant base current in transistor Q1 until the

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2. Relays can be used to direct an output of the CD unit successively to different squib circuits. The 20 ms delay feature avoids the need for a separate delay device in such cases. This capability contributes to the flexibility of the unit (Des. Req. 6).

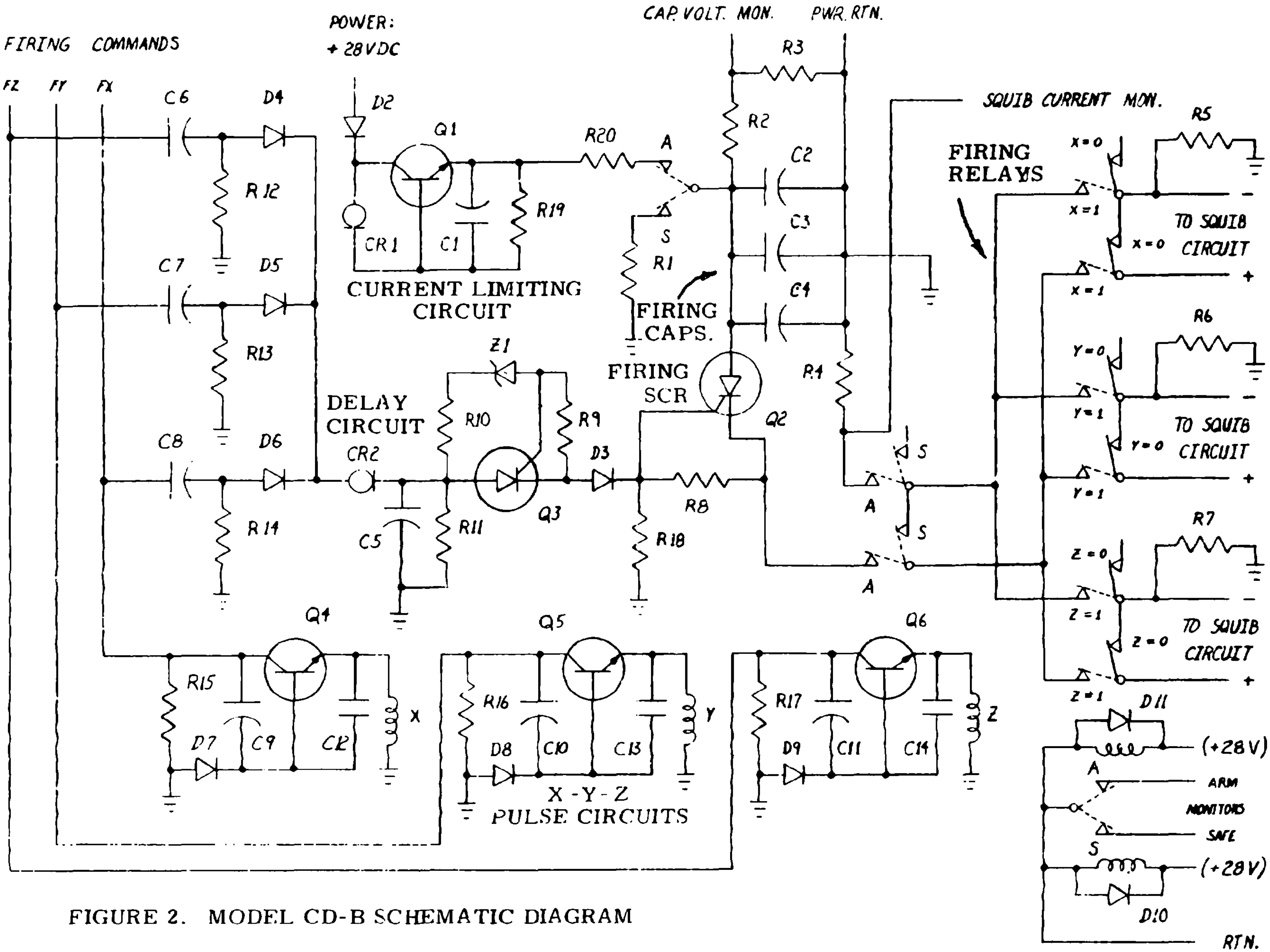

FIGURE 2. MODEL CD-B SCHEMATIC DIAGRAM

collector-emitter voltage drops to a low value. This constant base current results in an almost constant emitter current, which feeds the firing capacitors.[3]

Capacitor C1 prevents a sharp current step when charging begins. Resistor R19 allows adjustment of the current limit, and also protects electrolytic capacitor C1 from inadvertent reverse overvoltage. (Diode D2 acts as a valve to block temporary or accidental loss of charge from the firing capacitors while the unit is armed).

The Pulse Circuits

These three identical circuits are discussed in terms of the X relay circuit. The purpose of this circuit is to limit the time that the firing relay remains closed after a voltage (FX) is applied to the firing command input. The circuit could operate with only a capacitor between the firing voltage and the relay coil; however, the transistor (Q4) is used to substantially reduce the physical size of the capacitor (C9).

The base-emitter shunt capacitor (C12) prevents parasitic oscillations during relay operation. The diode-resistor network (D7 and R15) restores C9 to the ready condition quickly if the firing command input is opened, rather than grounded, after a firing command.

The Delay Circuit

The heart of the delay circuit is three components: current regulator diode CR2, capacitor C5, and zener diode Z1. If a voltage, say FX, is applied at the firing command input, components C8 and D6 allow the constant current determined by CR2 to flow into capacitor C5, charging it linearly. After the selected delay time, the voltage on C5 reaches the zener breakdown voltage, and SCR Q3 is triggered. (Resistor R10 limits the trigger current; resistor R9 is selected to prevent premature triggering by zener leakage current). When Q3 triggers, the voltage on C5 causes current to flow through Q3 and D3, triggering SCR Q2. (The two-stage SCR circuit is more efficient than a single-stage circuit). R8 and R18 stabilize Q2.

C8, R11, and R14 prepare the delay circuit for another input: first, C8 stops the firing command current; then, R11 discharges C5; and, finally, when the firing command voltage is removed, R14 (with R15) discharges C8. Diodes D4 and D5 isolate the delay components from components in the unused inputs; diode D3 isolates the delay circuit from the squib current pulse.

The Capacitor Voltage Monitor

The voltage monitor for the firing capacitors (C2, C3, and C4) consists of the 10-to-1 resistive voltage divider formed by R2 and R3. These 1% resistors are selected to give a ±5% tolerance on the monitor output when

3. The decreasing collector-emitter voltage causes a slight decrease in the emitter current. To realize a high collector-emitter impedance over the voltage and current ranges involved, a high-power transistor in a large (TO-3) package was required.

the output is connected to a 500 k-ohm to 1 M-ohm input impedance. The divider current is less than 2 mA, keeping power use low and avoiding rapid energy drain from the firing capacitors in case of power loss. The divider current is the only steady power requirement of the CD unit when it is in the ARM mode; in the SAFE mode, the unit draws no current.

The Squib Current Monitor

R4 is a straight piece of No. 22 resistance wire, 33 mm long, and having a resistance of 0.05 ohm ±5%. Any current flowing from the firing capacitors through the external squib circuits must return to the capacitors through this wire. The return sides of the firing capacitors are connected both to system ground and to R4, and a lead goes directly from the other side of R4 to the current monitor output. As a result, this output provides a voltage (with respect to system ground) which is 1/20th of the total squib current.

Appearance

Four photographs of the interior and exterior of the Model CD-B are included here. Figure 3 shows an oblique front view with case on. The smaller connector goes to the squib circuits; the larger one handles power and control. Figures 4 and 5 are oblique side views with case off. In Figure 4, the ARM/SAFE relay is visible below the cable; one of the three firing relays appears on the opposite side in Figure 5. The three firing capacitors are below the printed circuit board (PCB), supported by their ends in two counterbored nylon plates. Two of the capacitors can be glimpsed through the holes in the PCB support plates.

Figure 6 is a direct top view of the PCB. The large (TO-3) package is transistor Q1 in the current limiting circuit. The three identical pulse and isolation circuits are near one end of the board. The medium-size (TO-5) package near the connector is the firing SCR, Q2.

INITIAL FLIGHTS

This section gives background and flight data for the in-flight squib firings made to date by Model CD-A and CD-B Units.

Background

In 1974 and 1975, nine CD squib firing units were developed and fabricated by Wentworth Institute for use in AFCRL sounding rockets. Three Model CD-A units were flown in 1974; one Model CD-B unit flew in October 1975, and two are in a rocket to be launched in December 1975. Spares--one Model CD-A and two Model CD-B--account for the other three units.

In the three 1974 flights, a Model CD-A unit was the primary squib energy source for each payload. As these were the initial flights for

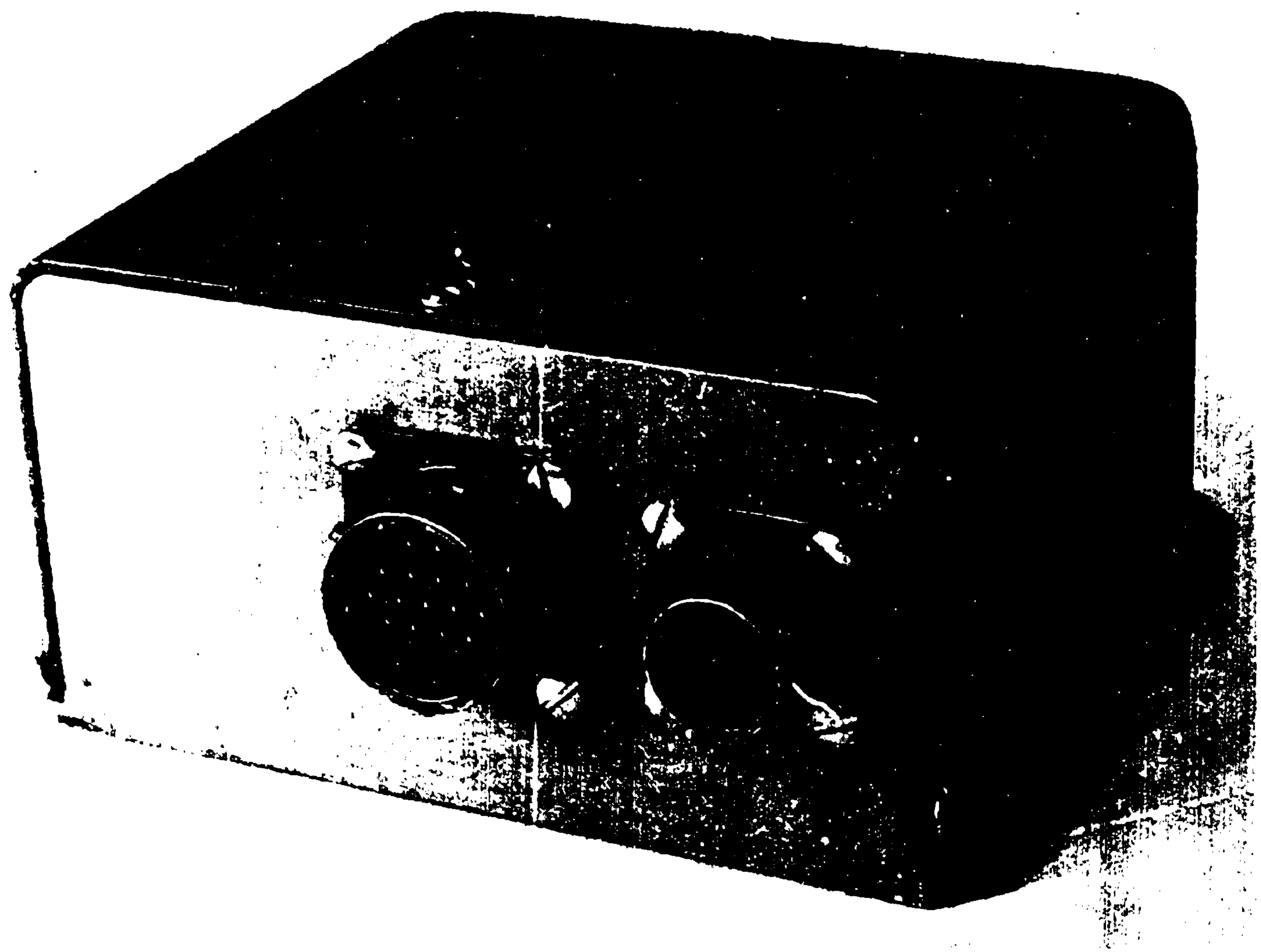

FIGURE . MODEL CD-B. OBLIQUE FRONT VIEW WITH CASE ON

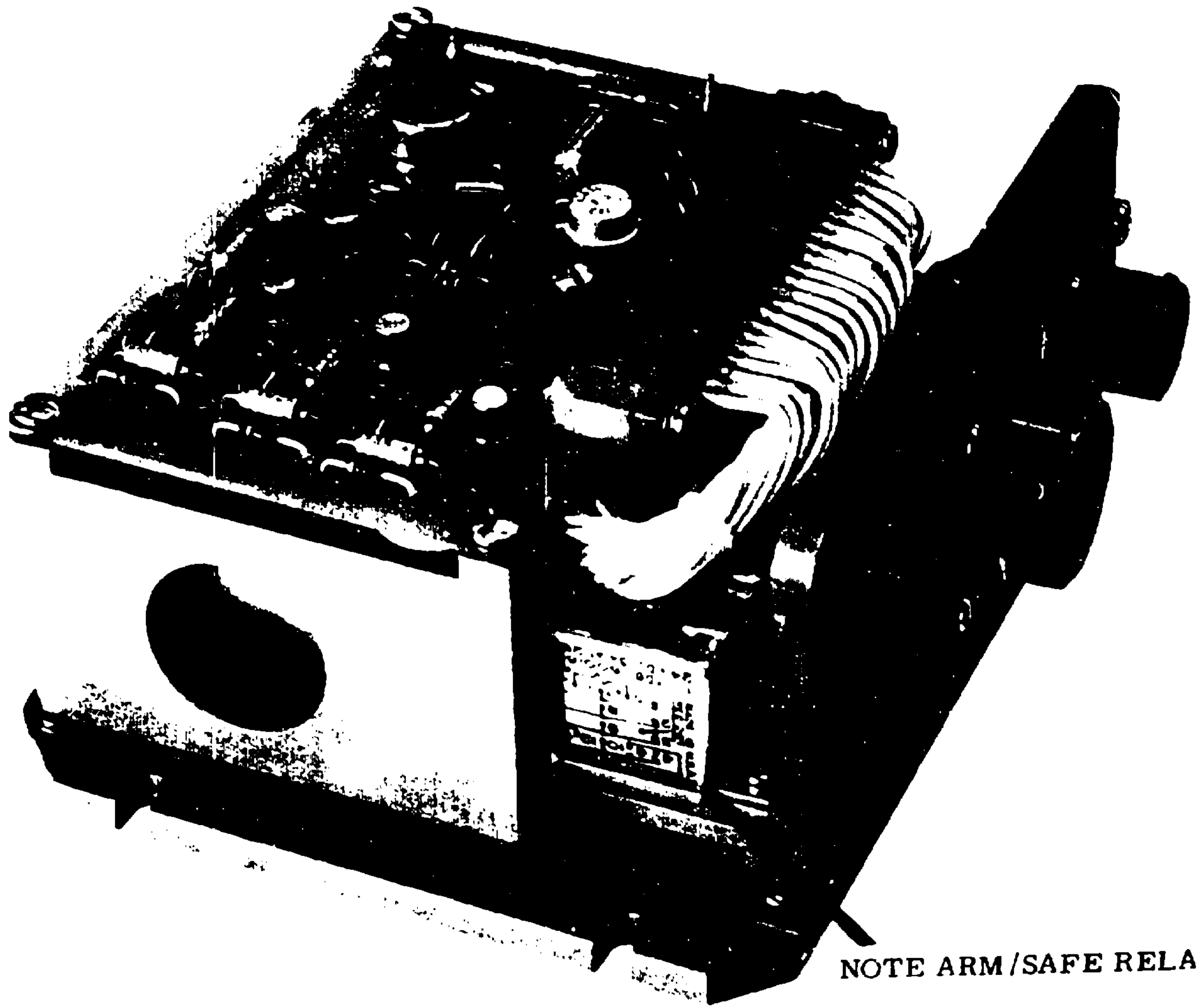

FIGURE 4. MODEL CD-B. OBLIQUE SIDE VIEW WITH CASE OFF

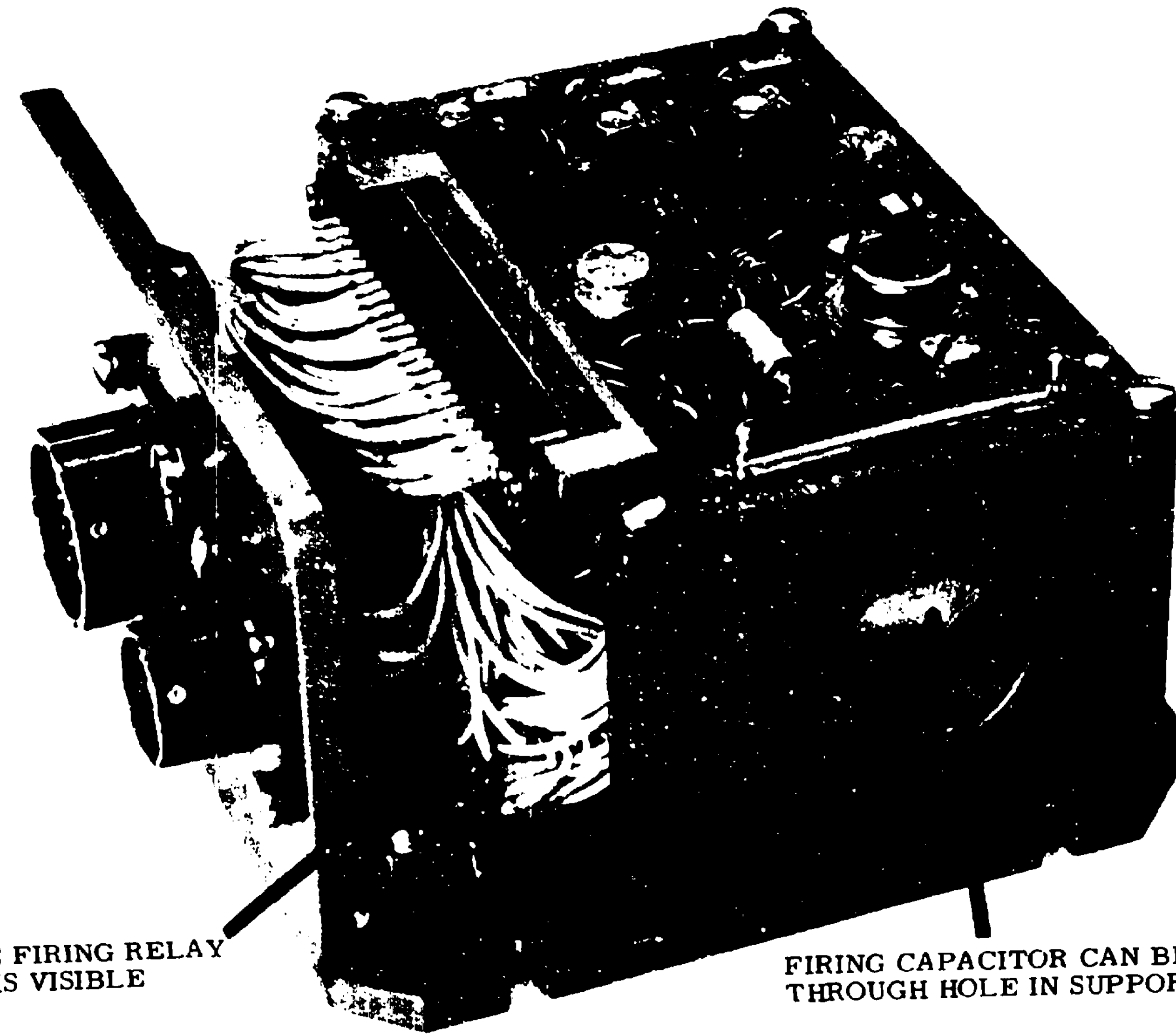

FIGURE 5. MODEL CD-B. OBLIQUE SIDE VIEW WITH CASE OFF

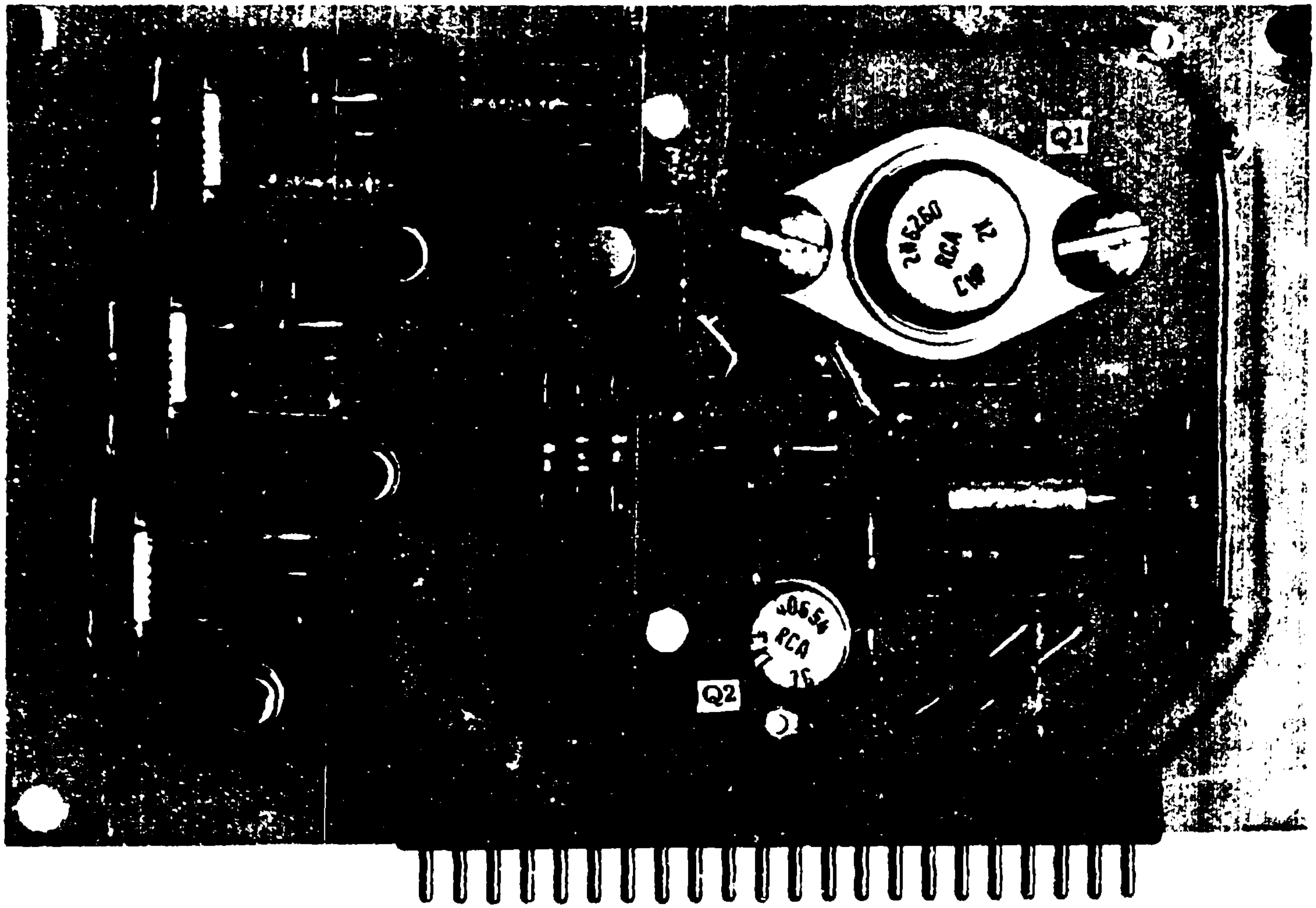

FIGURE 6. TOP VIEW OF MODEL CD-B PRINTED CIRCUIT BOARD

the CD units, redundant squib energy sources of the traditional type (Yardney PM-1 Silvercel batteries) were also carried.

The Model CD-B unit which flew in October 1975 had battery back-up for one function, but performed two other functions without back-up. The December 1975 flight has two CD units operating in parallel for redundancy.

Flight Data

CD squib firing data was obtained from three of the four flights that have carried CD units[4]; Figure 7 shows graphs of this data. Each graph represents the total current flowing through all (parallel) bridgewires in the energised circuit. Table 1 summarises the technical information relating to the graphs.

The initial current surge in the graphs of Figure 7 is apparently the bridgewire current. The irregular current transients, which in some cases follow the initial surge, are believed to be due to plasma conduction in the high pressure/high temperature explosion products.

CONCLUSIONS

Production tests are conducted with each CD unit to confirm that its performance exceeds the quantitative design objectives. All aspects of circuit operation are checked to avoid marginal adequacy that could be lost through environmental variations. Through the processes of production testing and eight successful and verified firings in flight, the initial field evaluation of the CD squib firing unit may be considered accomplished.

There has been no indication of unanticipated problems, and the results of initial use verify that the CD ignition principle is both effective and practical for firing squibs in sounding rockets. The application of the CD squib ignition concept in other areas should be encouraged by these results.

It is to be expected that experience with a relatively untried application will indicate directions for improvement. Probably the most significant direction suggested so far by the flight results is reduction of the energy capacity requirement. Inspection of the squib current data in Figure 7 leads to the impression that the energy capacity requirement--which was based on commercial DC firing results--may be much larger than necessary for a CD ignition device. If further experience confirms this possibility, a substantial reduction in the size of the CD unit could be made without sacrificing performance or reliability.

4. During the exceptional flight, the doors that were to be ejected by the CD unit apparently separated from the payload prematurely due to mechanical failure.

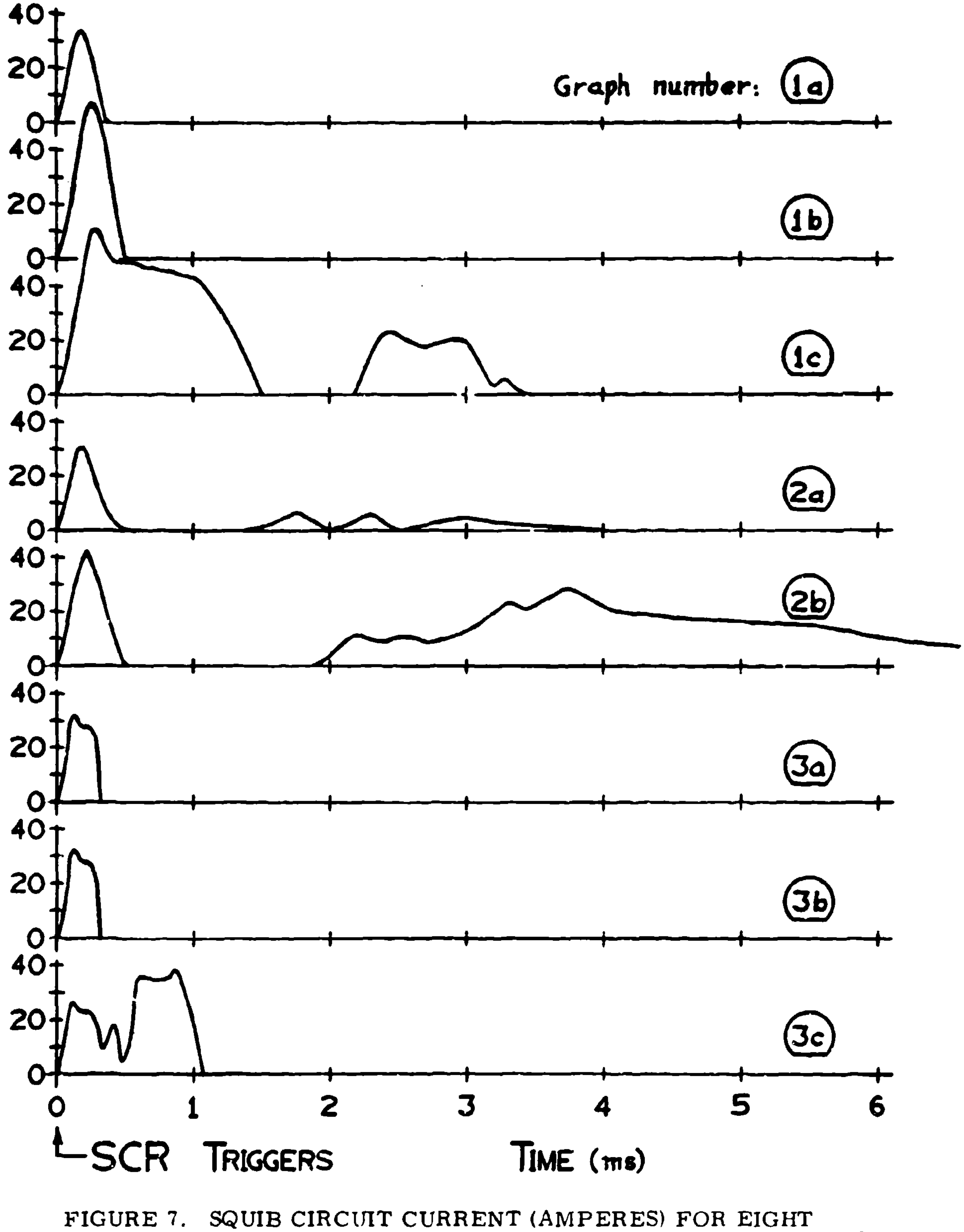

FIGURE 7. SQUIB CIRCUIT CURRENT (AMPERES) FOR EIGHT CD FIRINGS IN SOUNDING ROCKETS. [SEE TABLE 1.]

TABLE 1. TECHNICAL DATA FOR THE GRAPHS IN FIGURE 7

FLIGHT DATA	GRAPH NUMBER	NUMBER OF BRIDGEWIRES[1]	TYPE OF SQUIB	NUMBER OF SQUIBS
A10.306-4 11 Jun. 74 Model CD-A Channel 18 (1.6 kHz filter)	1a	2	Holex 5801 Guillotines	2
	1b	3	Holex 5800 Guillotines	3
	1c	4	Hercules BA60E1 Bellows	2
A09.407-1 13 Dec. 74 Model CD-B Channel D (4 kHz filter)	2a	2	Holex 5801 Guillotines	2
	2b	3	Holex 5800 Guillotines	3
A10.000-2 16 Oct. 75 Model CD-B Channel 19 (5 kHz filter)	3a	2	Atlas 86113 Pin-pusher[2]	1
	3b	2	Atlas 86113 Pin-pusher[2]	1
	3c	2	U.S. Flare 1209 Igniter	2

1. In some cases, one of two bridgewires in a squib was connected to a CD unit, and the other to a back-up source.

2. These units have 0.17±0.01 ohm (one-sigma) bridgewire resistance. A one-ohm resistor was added externally in series with each bridgewire. (All other units have standard 1 ohm bridgewires).

APPENDIX

Model CD-B Parts List (P.C.B.)

Symbols	Description	QTY.	Comments
C1	47 uF, 6 V	1	CS13B-B476K
C2, C3, C4	2200 uF, 40 V	3	B41010-B7228-T
C5, C6, C7, C8	1 uF, 35 V	4	CS13B-F105K
C9, C10, C11	0.22 uF, 50 V	3	M39003/01-2344J
C12, C13, C14	0.0022 uF, 50 V	3	GE
CR1	1N5312, 3.90 mA	1	Motorola
CR2	1N5290, 0.47 mA	1	Motorola
D2 thru D11	1N3611	10	Unitrode (2A, 200 V)
P1	WD22P	1	Winchester
Q4, Q5, Q6	2N2222A	3	TEL (TO-18) NPN
Q1	2N6260	1	RCA (TO-66) NPN
Q2	40654	1	RCA (TO-5) SCR
Q3	2N878	1	GE (TO-18) SCR
R1	270, ½ W	1	
R2	20.0 k, 1%, ¼ W	1	RN55D-2002F
R3	2.21 k, 1%, ¼ W	1	RN55D-2211F
R4	0.05 ohm	1	33 mm #22 Manganin
R5, R6, R7, R18	100 k	4	
R8	1 k	1	
R9	Selected	1	(10 k to 100 k)
R10	220	1	
R11, R12, R13, R14	220 k	4	
R15, R16, R17	10 k	3	

Model CD-B Parts List (Cont'd.)

Symbols	Description	QTY.	Comments
R19	27 k	1	
R19T	Selected	1	
R20	1 ohm, ½ W	1	
T1, T2, T3, T4	2043-2	4	Cambion
(for Q1)	#6-32 x 5/16"	2	Use lock washer top & bottom
(for P.C.B.)	#4-40 x ¼"	6	Use lock washer
Z1	1N756A	1	

All resistors are ¼ W, carbon composition, 10% unless otherwise indicated.

Model CD-B Mechanical Parts

QTY.	Description	Nomenclature	MFR.
1	Relay, latching, DPDT	TL17DB-24 V	P&B
3	Relay, P.I.D.O., DPDT (Alternative part:	BR26-S11 BR26-700B2-26 V	Babcock ")
1	Box mounting receptacle	PT02SE-14-18P	Bendix
18	Contacts, male, No. 20	10-314980-20P	Bendix
1	Straight plug	PT06SE-14-18S	Bendix
18	Contacts, female, No. 20	10-314980-20S	Bendix
1	Box mounting receptacle	PT02P010-6S	Bendix
1	Straight plug (with potting hood)	PT06P-10-6P	Bendix
1	Receptacle (P.C.B.)	WD22S	Winchester

QTY.	Description	DWG. NO.
1	Capacitor Discharge Box, per W.I. Dwgs. including the following parts:	
1	Base	D-9148
1	Cover	C-9149
2	Capacitor support plate	B-9150
1	Capacitor side support (L)	B-9151-1
1	Capacitor side support (R)	B-9151-2
1	Connector retainer (for WD22S)	A-9152
2*	Relay stand-off (for TL17DB)	A-9236
6	Small relay stand-off (for BR26-S11)	A-9245
22	#4-40 x (as required) Binder Head	
4	#6-32 x 3/8 Binder Head	

*1 ea when BR26-700B2-26 V relays are used instead of BR26-S11 relays.