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CAPACITANCE DISCHARGE SYSTEM FOR IGNITION OF SINGLE BRIDGE APOLLO STANDARD INITIATORS (SBASI)

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16. Abstract

Design support data were developed during SBASI pulse discharge ignition energy tests. A circuit was designed and bread-board tested to verify operational capabilities of the circuit. Test data, design criteria, weight and reliability trade-off considerations, and final design recommendations are presented.

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FOREWORD

This final report presents the results of a feasibility study and preliminary design effort performed by Vought Systems Division (VSD) of LTV Aerospace Corporation to determine the feasibility of incorporating a capacitive discharge ignition system into the Scout Launch Vehicle. This report contains a review of the component selection process, test results and a circuit design for an operational system. The study was conducted under NASA Contract NAS1-10000, Task R-70.

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ABBREVIATIONS

amp - ampere
bw - bridgewire
CDI - Capacitive Discharge Ignition
chan - channel
COS/MOS - Complementary Metal Oxide Substrate
Cv - capacitive voltage
dc - direct current
DOD - Department of Defense
DTL - Diode - Transistor Logic
ESR - Equivalent Series Resistance
fm - frequency modulated
GFE - Government Furnished Equipment
gnd - ground
Hz - cycles per second
I - current
in - inch
JEDEC - Joint Electron Device Engineering Council
k - kilo (10^3)
kg - kilogram
LRC - Langley Research Center
ma - milliamp
ma hr - milliamp hour
mfd - microfarad (10^{-6} farad)
Mil - 0.001 inch
misc - miscellaneous
mj - millijoules
mon - monitor
ms - millisecond
NASA - National Aeronautics and Space Administration
No. - number
osc - oscillator
prv - peak reverse voltage
R or res - resistance
S - Switch
SBASI - Single Bridgewire Apollo Standard Initiator
SCR - Silicon Controlled Rectifier
S/N - Serial Number
T - time
Ta - tantalum
T/M - telemetry
V - voltage
VAFB - Vandenberg Air Force Base
V_s - timer start voltage
VSD - Vought Systems Division
V_z - Zener voltage
w - watt
WI - Wallops Island
wvdc - working voltage direct current
°C - degrees Centigrade
μsec - 10^{-6} second

CAPACITANCE DISCHARGE SYSTEM FOR IGNITION OF SINGLE BRIDGE APOLLO STANDARD INITIATORS (SBASI)

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1.0 SUMMARY

The Scout Fourth Stage Capacitive Discharge Ignition System Study Program was initiated in April of 1973. The study was authorized under Contract NAS1-10000, Task R-70. In support of this study the Single Bridgewire Apollo Standard Initiator (SBASI) was tested at NASA Langley Research Center (LRC) to determine the minimum pulse energy required for initiation. From this testing an energy level of 34 millijoules was determined to be sufficient when supplied by a 460 microfarad (mfd) capacitor charged to 24 volts. From the preliminary testing at LRC, support data was generated to develop a breadboard circuit to perform Scout fourth stage payload initiation functions. The breadboard circuit was packaged inside a Government Furnished Equipment (GFE) Scout Payload Separation System timer. The ignition design concept eliminated the firing batteries and a safe-arm relay assembly used in the existing system. The modified timer was tested at LRC to verify operational concepts. The evaluation testing proved that incorporation of the Capacitive Discharge Ignition (CDI) System in the Scout launch vehicle is feasible. The testing also proved that sufficient energy was available from the CDI System to fire two SBASI's in parallel. The weight of the tested CDI System was significantly less than the existing design. Range Safety at Wallops Island (WI) and Vandenberg Air Force Base (VAFB) were contacted. Both have affirmed that with the incorporation of safety provisions in the final design, the CDI system as presented herein is consistent with Range Safety guidelines.

A method was developed which allows checkout of the entire ignition system including the squibs while installed in the vehicle. A preliminary study was performed to evaluate the complexity of implementing the checkout method as presented herein.

Based on the findings of this study, VSD recommends progression into a production system of the design presented.

2.0 INTRODUCTION

The NASA/DOD Scout has been operational since 1960. During this period of operation, a wide variety of scientific and military application satellites have been launched on orbital, reentry, and probe missions. Flight reliability of the Scout vehicle has been demonstrated by twenty-nine consecutive successful missions. This high degree of reliability has been attained through a program of carefully planned and designed improvements. In keeping with the history of planned improvements, NASA/LRC contracted Vought Systems Division (VSD) to study the feasibility of upgrading the method of performing payload ignition functions. The statement of work (SOW) covering this study was released in April 1970.

2.1 SCOPE AND OBJECTIVES

The basic scope of the SOW was to study the feasibility of the incorporation of capacitive discharge techniques into the Scout Fourth Stage payload ignition functions. As detailed by VSD, feasibility was to be established by performing with positive results the following tasks and objectives:

(1) Evaluate switching methods.

(2) Reduce weight of the ignition system.

(3) Maintain or increase theoretical reliability values for the ignition system.

(4) Establish pulse firing characteristics of the SBASI.

(5) Design and breadboard a capacitive discharge ignition system for evaluation testing by NASA/LRC.

(6) Design the SBASI ignition circuit to provide the level of firing energy determined in tests at LRC.

(7) Package timing, safing and ignition circuitry in one unit.

(8) Select components for the breadboard design using existing Scout environmental criteria (i.e., temperature and altitude).

(9) Coordinate breadboard design with VAFB and WI Range Safety.

2.2 STUDY APPROACH

2.2.1 Preliminary Testing

Tests to determine the energy levels necessary to fire the SBASI were performed at Langley Research Center Environmental Test Facility. Data obtained during these tests established relationships between voltage levels, component values, system electrical characteristics and squib firing energy requirements. The relationship thus established provided the guidelines for the preliminary design of a capacitive discharge ignition system. Results of these tests are described in paragraph 3.3.

2.2.2 Range Safety

During the preliminary design effort, VSD personnel visited with Range Safety personnel at Wallops Island (WI) and Vandenberg Air Force Base (VAFB) to coordinate safety considerations. The final design concept incorporated all suggestions made by Range Safety personnel.

2.2.3 Design

The capacitive discharge ignition system was designed through the following steps:

(1) Review of the existing system to assure weight reduction

(2) Selection of switching device

(3) Packaging concept

(4) Component selection

(5) Firing capacitor size selection from test data

(6) Reliability analysis

2.2.4 Design Evaluation

The breadboard circuit was assembled in a vector board configuration to evaluate interface compatibility with the Scout payload separation system timer, VSD P/N 23-004069-1. During this phase of the study, special tests were performed on the circuit to evaluate the design. Results of this testing are described in paragraphs 5.1 and 5.2. The preliminary design was configured on a printed circuit board to replace board Number 3 (13948-105) in the timer. After assembly of the circuit into the timer, evaluation tests were performed at LRC Environmental Facility. These evaluation tests verified operational capability to ignite the SBASI. Twenty-two SBASI's were fired with the timer during this evaluation with the results as shown in paragraph 5.3.

3.0 PRELIMINARY TEST

3.1 INITIAL SURVEY AND TEST

The energy-time firing requirement for the initiator had to be established and verified for design information for a capacitive discharge ignition system. Of the data reviewed, only Jet Propulsion Laboratory (JPL) had tested SBASI with the intention of determining minimum firing energy requirements with pulse application (Reference No's 1, 2 and 3). At the time of this study, the only other available data which characterize the energy necessary to fire a SBASI were those obtained from constant current initiation. These data define the level of constant current at which the SBASI will not ignite ("NO FIRE") and the level required for ignition ("ALL FIRE"). These data were not adequate to establish the energy versus time (watt-second/joules) relationship required to raise the bridgewire to ignition temperature.

LRC conducted the tests described in paragraphs 3.3.1 and 3.3.2 to generate additional data. The chronological sequence of preliminary testing at LRC was:

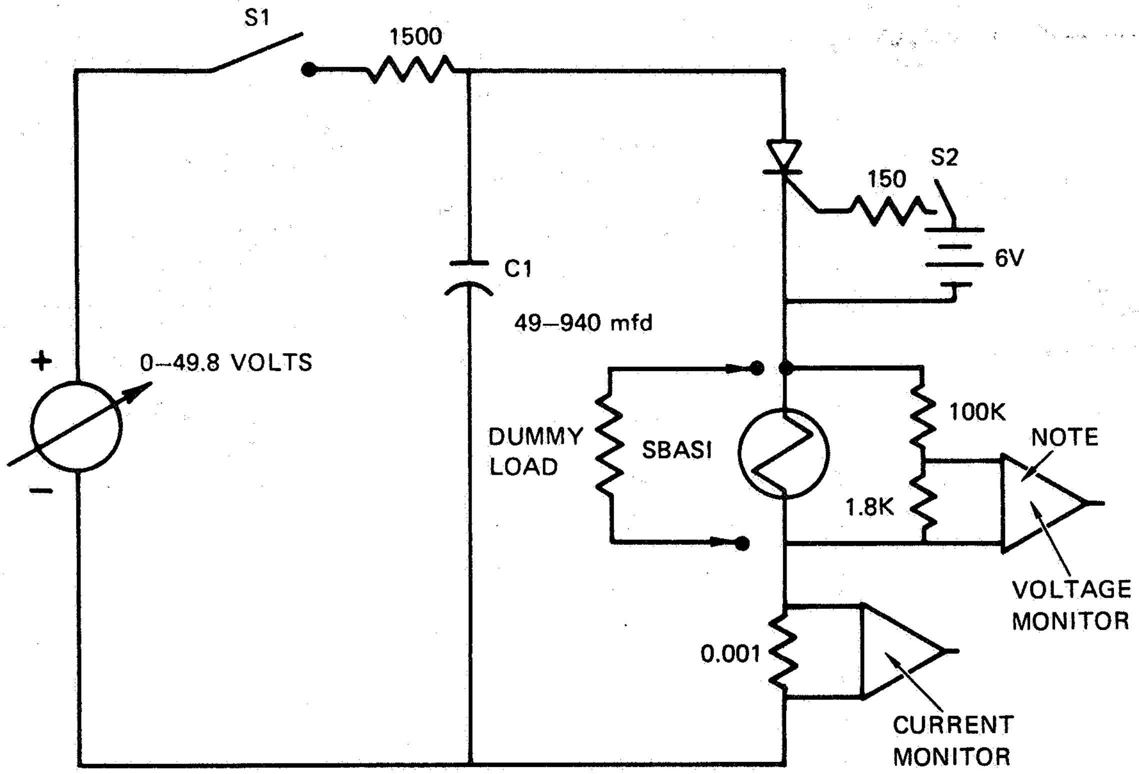
(1) Hardware characterization (paragraph 3.3.1)

(2) Energy evaluation by bridgewire break (paragraph 3.3.2.1)

(3) Energy evaluation by pulse firing (paragraph 3.3.2.2)

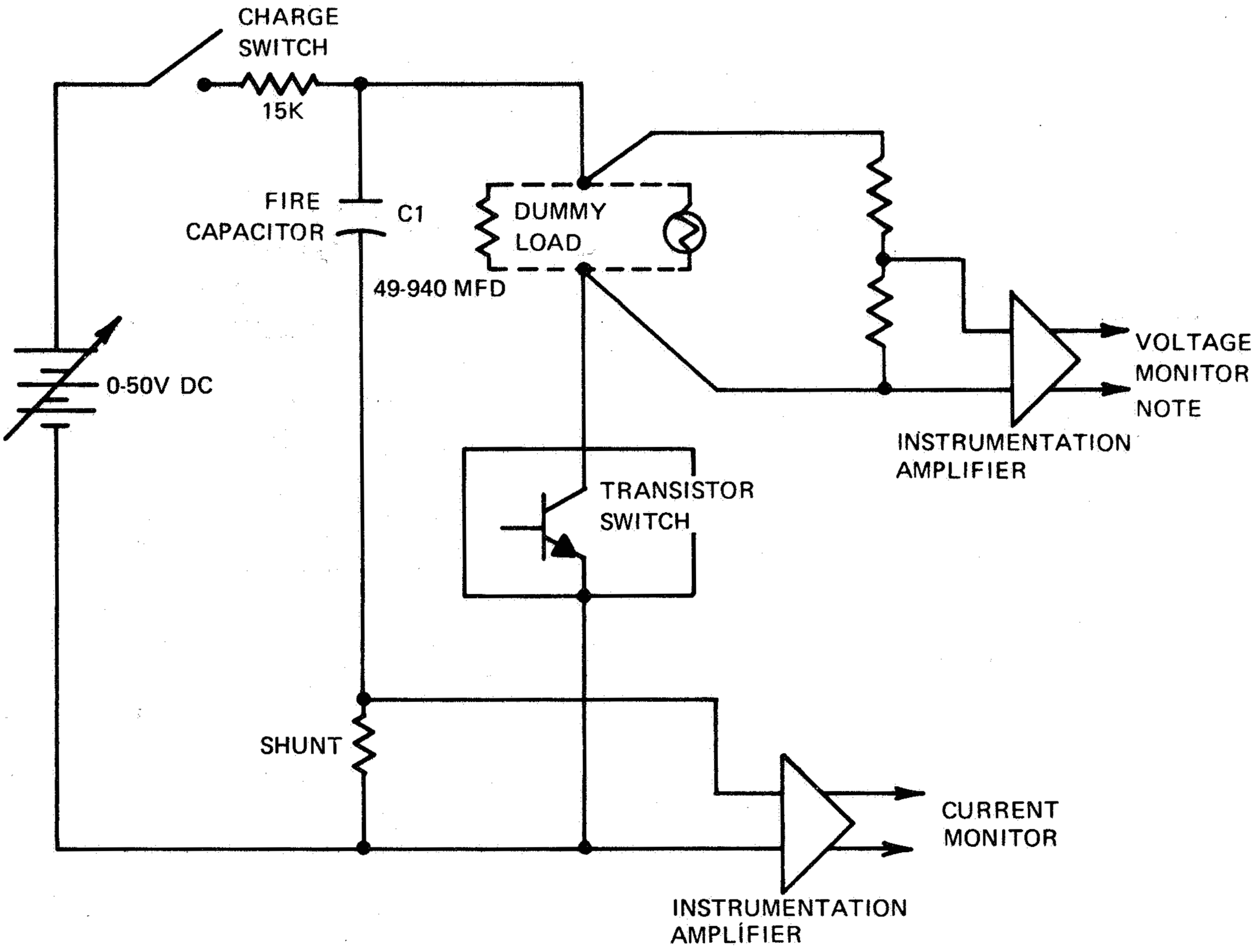
3.2 TEST CIRCUITS

In order to provide test data to establish SBASI minimum firing energy requirements, tests were performed at LRC using the circuits shown in Figures 1 and 2. Figure 1 depicts the test circuit used to evaluate switching methods, capacitor equivalent series resistance, variation of voltage, and variation of capacitance. Figure 2 shows the test circuit used to evaluate the transistor as a switch and to provide a method for generating a variable time firing pulse. For each test, current and voltage of the load (dummy load and SBASI) were recorded on a Frequency Modulated (FM) tape recorder. Test equipment used for these tests is listed in Table I.



NOTE: LOAD VOLTAGE WAS NOT MONITORED DURING HARDWARE CHARACTERIZATION TESTS

FIGURE 1 SCR TEST CIRCUIT



NOTE: LOAD VOLTAGE WAS NOT MEASURED DURING HARDWARE CHARACTERIZATION TESTS

FIGURE 2 TRANSISTOR TEST CIRCUIT

TABLE I TEST EQUIPMENT

(1)	CALIBRATION AND CHARGE VOLTAGE	DIGITAL VOLTMETER
(2)	CALIBRATION POWER AND CHARGE POWER	POWER SUPPLY, 50 AMPERE, 0–40 VOLT
(3)	RESISTANCE MEASURING	INITIATION RESISTANCE MEAS. EQUIP. 10 MA, DIGITAL READOUT
(4)	INSTRUMENTATION AMP.	DC DIFFERENTIAL AMPLIFIER
(5)	FM INSTRUMENTATION TAPE	FM TAPE 120 IPS RECORD (+ 1 db AT 40 KHz) 1 7/8 IPS PLAYBACK
(6)	OSCILLOGRAPH	LIGHT BEAM GALVANOMETER TYPE USING FIVE INCH PAPER
(7)	CURRENT SHUNT	50 AMP – 50 MV
(8)	FIRE CAPACITORS	TEST BOARD TOTAL OF 940 MFD AVAILABLE, TWENTY EACH OF TANTALUM (M39003/01-2072) JAN 12954 (713824) 47 MFD, 35 VOLTS DC
(9)	PULSE GENERATOR	VARIABLE PULSE WIDTH TYPE
(10)	OSCILLOSCOPE	FIVE INCH CATHODE RAY TUBE TYPE WITH HIGH GAIN DIFFERENTIAL AMPLIFIER.

3.3 PRELIMINARY LRC TEST RESULTS

3.3.1 Test Hardware

The purpose of this task was to evaluate various switches for energy transfer from a capacitor bank to a dummy load. The dummy load was selected to simulate the electrical resistance of a SBASI. Power switches evaluated were a mercury relay, two types of silicon controlled rectifiers (SCR), and one transistorized gate. Discharge pulses were recorded at each of five voltage steps (49, 40, 30, 20 and 10 volts) for each type switch. When the capacitor energy was switched with a mercury wetted relay, the contacts welded together, so no further tests were attempted using the relay. From this data, the capacitor equivalent series resistance was to be determined. At each voltage level four capacitance values (49.85, 233.8, 509.8 and 954.6 mfd) were used to evaluate variations in voltage and capacitance.

Data from the tests are recorded in the first four columns of Table II. Evaluation of the test data showed that instrumentation errors were present and affected the data. In most cases, the calculated voltage drop was greater than the capacitor charge voltage. Subsequent checking of the instrumentation set-up showed that the FM tape unit exhibited a 15% overshoot with a square wave input. Column 5 of Table II contains the data corrected for the aforementioned overshoot error. The SCR forward voltage drops are shown in Column 6. These values were taken from the typical curve of Figure 3 using the corrected current values.

The equivalent series resistance could not be determined from these tests, but its effect is insignificant compared to the other resistance elements in the circuit. The 110 amp SCR had a slightly lower voltage drop than the 7.4 amp SCR, but this was not of sufficient difference to justify its use since the 110 amp unit is much larger physically than the 7.4 amp SCR.

When the power transistor was used for switching, overshoot did not occur due to slow rise time of the transistor. The transistor conducted current up to saturation and then limited current to about 28 amps as the capacitor charge voltage was increased.

These tests showed the need for measuring voltage across the load during tests. Subsequent tests did include this voltage measurement.

TABLE II HARDWARE EVALUATION DATA
SCR SWITCH

SWITCH TYPE	CAP. IN MFD	CHARGE VOLTAGE	PEAK CURRENT	PEAK CORRECTED CURRENT 15% OVERSHOOT	SCR V DROP AT PEAK I	CIRCUIT RESIS.
7.4A SCR	509.8	10	11.25	9.56	1.49	1.071
	509.8	20	21.25	18.06	1.84	1.071
	509.8	30	32.5	27.63	2.15	1.071
	509.8	40	42.5	36.13	2.39	1.071
	509.8	49	52.5	44.63	2.59	1.071
	954.6	10	11.25	9.56	1.49	1.071
	954.6	20	21.874	18.59	1.86	1.071
	954.6	30	32.5	27.63	2.14	1.071
	954.6	40	43.124	36.65	2.4	1.071
	954.6	49	52.4	44.54	2.47	1.071
	49.85	10	9.374	7.96	1.4	1.071
	49.85	20	20	17.0	1.8	1.071
	49.85	30	30	25.5	2.08	1.071
	49.85	40	39.374	33.46	2.31	1.071
	49.85	49	48.75	41.44	2.51	1.071
	233.8	10	10.624	9.03	1.47	1.071
	233.8	20	20.624	17.53	1.82	1.071
	233.8	30	32.5	27.63	2.15	1.071
	233.8	40	43.124	36.65	2.4	1.071
7.4A SCR	233.8	49	51.874	44.09	2.57	1.071
2N1913-110A						
110A SCR	49.85	10	8.75	7.44	1.12	1.071
	49.85	20	18.75	15.94	1.21	1.071
	49.85	30	29.374	24.96	1.26	1.071
	49.85	40	40	34.0	1.3	1.071
	49.85	49	48.124	40.9	1.33	1.071
	233.8	10	9.374	7.96	1.12	1.071
	233.8	20	21.874	18.59	1.23	1.071
	233.8	30	33.75	28.69	1.28	1.071
	233.8	40	44.374	37.71	1.32	1.071
	233.8	49	53.75	45.69	1.35	1.071
	509.8	10	10.624	9.03	1.13	1.071
	509.8	20	22.5	19.13	1.23	1.071
	509.8	30	33.75	28.69	1.28	1.071
	509.8	40	44.374	37.72	1.32	1.071
	509.8	49	53.8	45.73	1.33	1.071
	954.6	10	10	8.5	1.13	1.071
	954.6	20	23.124	19.65	1.23	1.071
	954.6	30	33.124	28.15	1.27	1.071
	954.6	40	42.186	35.86	1.31	1.071
	954.6	49	55	46.75	1.36	1.071

TABLE II HARDWARE EVALUATION DATA
TRANSISTOR SWITCH – 2N3055 (CONTINUED)

SWITCH TYPE	CAP. IN MFD	CHARGE VOLTAGE	PEAK CURRENT	V_{CE} (SAT) AT PEAK I	CIRCUIT RESIS.
TRANSISTOR	49.85	10	8.75	.62	1.071
	49.85	20	17.5	1.25	1.071
	49.85	30	21.25	7.5	1.071
	49.85	40	22.5	15.9	1.071
	49.85	49	23.124	24.20	1.071
	509.6	10	11.87	*	1.071
	509.6	20	25	*	1.071
	509.6	30	26.874	1.2	1.071
	509.6	40	35	2.5	1.071
	509.6	49	49.374	*	1.071
	49.85	10	8.75	.62	1.071
	49.85	20	16.874	1.95	1.071
	49.85	30	21.25	7.2	1.071
	49.85	40	22.5	15.9	1.071
	49.85	49	24.374	22.9	1.071
	509.6	10	11.874	*	1.071
	509.6	20	22.5	*	1.071
	509.6	30	26.25	1.9	1.071
	509.6	40	27.5	10.6	1.071
	509.6	49	28.124	18.9	1.071
	509.6	10	13.124	*	1.071
	509.6	20	22.5	*	1.071
	509.6	30	26.874	1.2	1.071
	509.6	40	28.124	9.9	1.071
	509.6	49	28.124	18.8	1.071
	954.6	10	11.874	*	1.071
	954.6	20	21.874	*	1.071
	954.6	30	23.75	4.6	1.071
	954.6	40	25.624	12.6	1.071
	954.6	49	26.25	20.9	1.071

*PEAK CURRENT X CIRCUIT RESISTANCE > CHARGE VOLTAGE

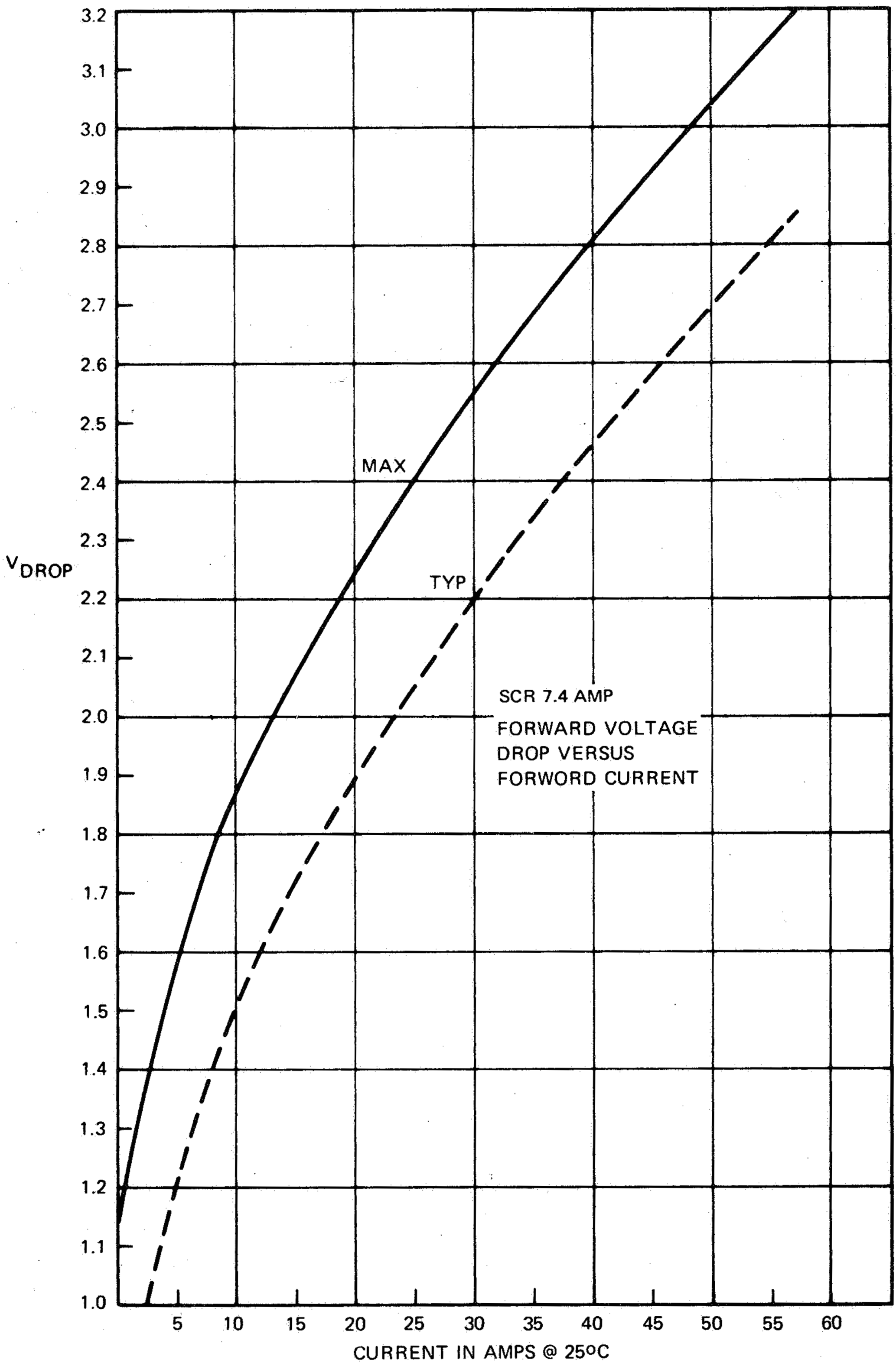


FIGURE 3 SCR FORWARD VOLTAGE DROP VS FORWARD CURRENT

3.3.2 SBASI Firing Energy

3.3.2.1 Bridgewire Break

These data were generated with the same test setup as in paragraph 3.2, Figure 1, except SBASI's were used instead of the dummy load. A total of seventeen SBASI's were used to evaluate firing characteristics through a·SCR switch with variations in voltage and capacitance. The SCR used as a switch was rated at 7.4 amps steady state current capability. Test sequence consisted of closing charge switch S1 until voltage across fire capacitor stabilized and then opening the charge switch. Charge voltage was monitored with a digital voltmeter that remained connected while fire switch S2 was closed to gate the SCR. SBASI instantaneous voltage and current data were recorded by connecting a dc differential amplifier as shown in Figure 1 to drive an FM tape recorder. A playback from the FM tape to a direct recording oscillograph furnished data to be reduced as shown in Table III. From this data Figures 4 and 5 were developed. Figure 4 is a plot of minimum charge voltage versus capacitance. Figure 5 is a plot of charge voltage versus calculated energy consumed during ignition. Note that the energy consumed during ignition was not the minimum energy required to raise the bridgewire to the pyrotechnic ignition temperature. Energy would continue to be consumed until bridgewire break, which would normally occur due to the burning propellant. Approximations that were made in calculating consumed energy are shown in Figure 6. The approximations were that capacitor discharge is a straight line and that initiator resistance can be approximated by a 30 percent increase. Action time as a function of the magnitude of applied energy (charge voltage) for each capacitor size is shown in Figures 7, 8, 9 and 10. Charge voltage versus time to bridgewire break and first indication of pressure for each capacitor size are also shown on Figures 7 thru 10.

3.3.2.2 Pulse Firing (Minimum Energy)

Using bridgewire break for evaluation of SBASI firing energy requirements indicated energy requirement in excess of the true level necessary. True energy requirements were determined by applying a terminated pulse to the SBASI's and gradually decreasing the pulse width while maintaining a constant amplitude until the initiator did not fire. To evaluate the SBASI for minimum energy required for ignition, the transistor circuit shown in Figure 11 was used. The data in Table IV were generated by reducing the pulse width of the pulse generator after each SBASI firing

TABLE III SBASI CAPACITOR IGNITION SCR SWITCH

TANTALUM CAPACITORS – M39003/01-2072 OBSERVER BEMENT/WARD

35VDC; CIRCUIT RESISTANCE = 0.116

UNIT SERIAL NO.	COLD BW RES	CAP SIZE MFD	CHARGE VOLTS	VOLTS PEAK LOAD	VOLTS BW BREAK OR GATE	VOLTS MEAN	TIME* BW BK OR MEAN PULSE TIME µsec	ENERGY MILLI-JOULES	ENERGY TOTAL AVAIL MJ	TIME* TO FIRST PRESSURE µsec
					SCR GATE					
667	1.05	49.8	49.2	45.1	13.0	22.6	108	52.6	60.2	168
500	1.05	49.8	45.0	40.76	8.0	24.38	144	45.0	50.4	205
457	1.07	233.8	49.2	45.0	37.3	41.15	80	97.4	283.0	149
552	1.07	233.8	40.15	36.2	30.8	33.5	89	71.7	188.4	163
645	1.02	233.8	30.07	27.7	20.0	23.89	130	55.8	105.7	210
534	1.05	233.8	20.0	18.5	4.6	11.55	570	55.7	46.8	611
513	0.985	233.8	17.5		NO FIRE				35.8	
513	0.988	233.8	18.75		NO FIRE				41.1	
661	1.05	509.8	49.2	45.8	43.4	44.6	79	115.1	617	163
647	1.03	509.8	40.1	37.3	30.6	33.96	84	72.3	409.8	163
495	1.06	509.8	30.06	27.7	25.0	26.35	113	56.9	230.3	191
423	1.064	509.8	20.06	17.9	13.6	15.75	252	45.2	102.6	327
429	1.043	509.8	15.05	13.6	5.6	9.6	761	51.7	57.7	813
						45.3	74			
549	1.063	954.6	49.08	45.6	45.0		98.5	109.8	1,149.8	144
492	1.037	954.6	41.2	36.6	36.0		121	96.2	810.0	168
635	1.034	954.6	30.06	27.4	26.6	17.56	238	65.5	431.0	201
540	1.060	954.6	20.01	18.5	16.6			53.2	191.0	318
486	1.059	954.6	10.0		NO FIRE					
486	1.059	954.6	15.06	13.6	10.4	12.0	504	52.7	108.2	542

*Zero time reference is from first indication of current flow.

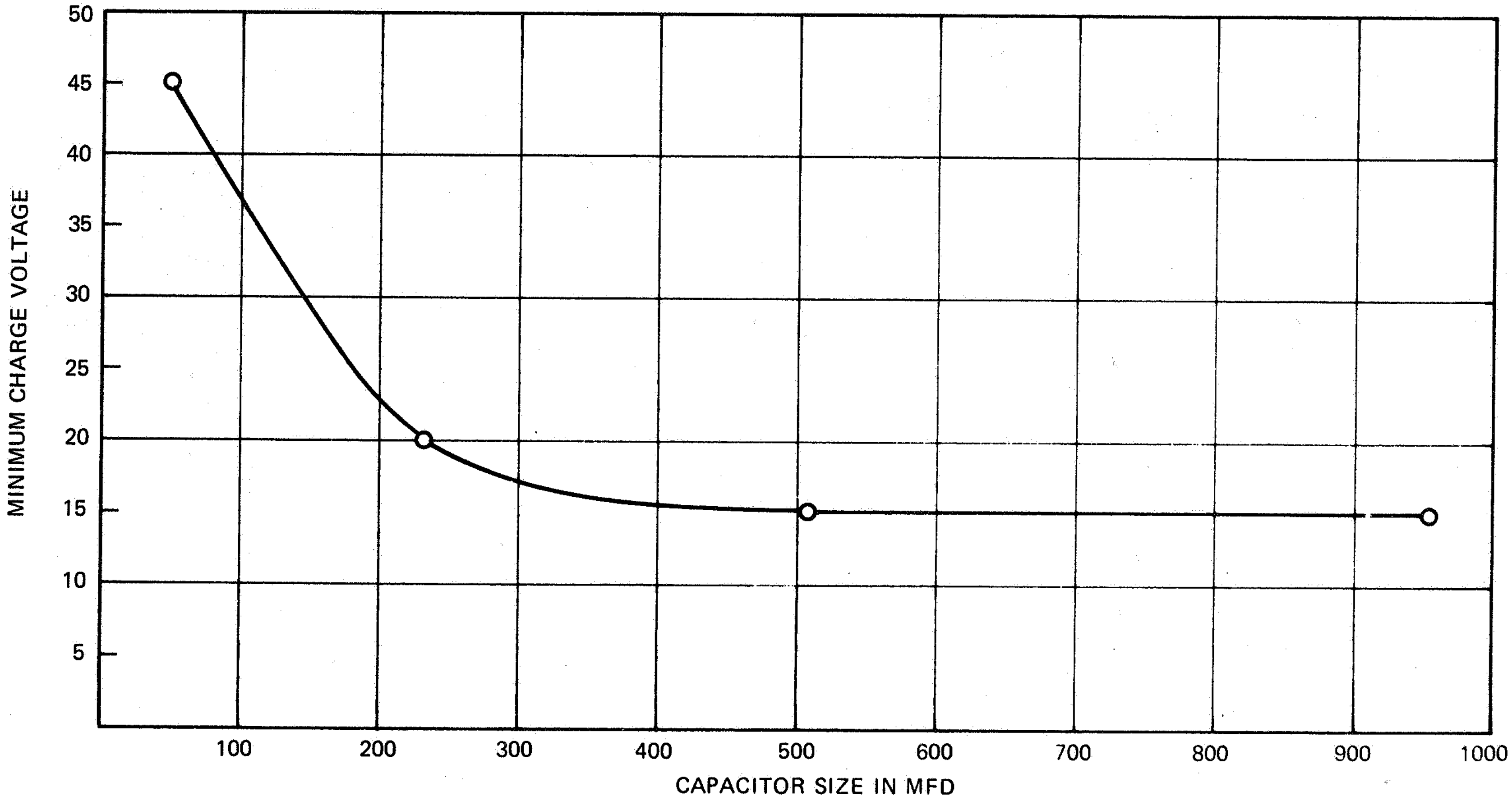


FIGURE 4 SBASI IGNITION CHARGE VOLTAGE VS CAPACITOR SIZE

SCR SWITCH
ENERGY = $IM^2 RT$
WHERE R = CONSTANT

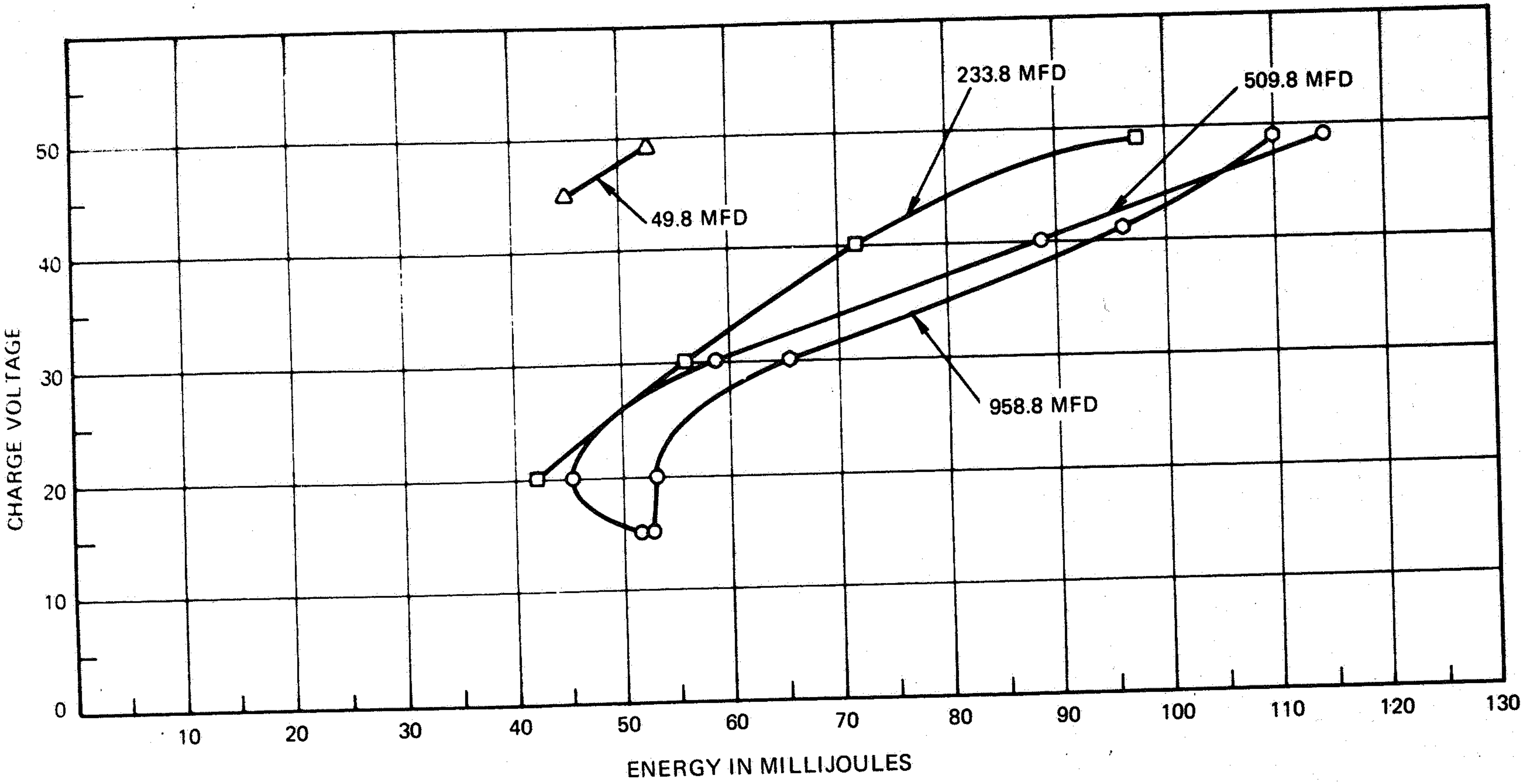
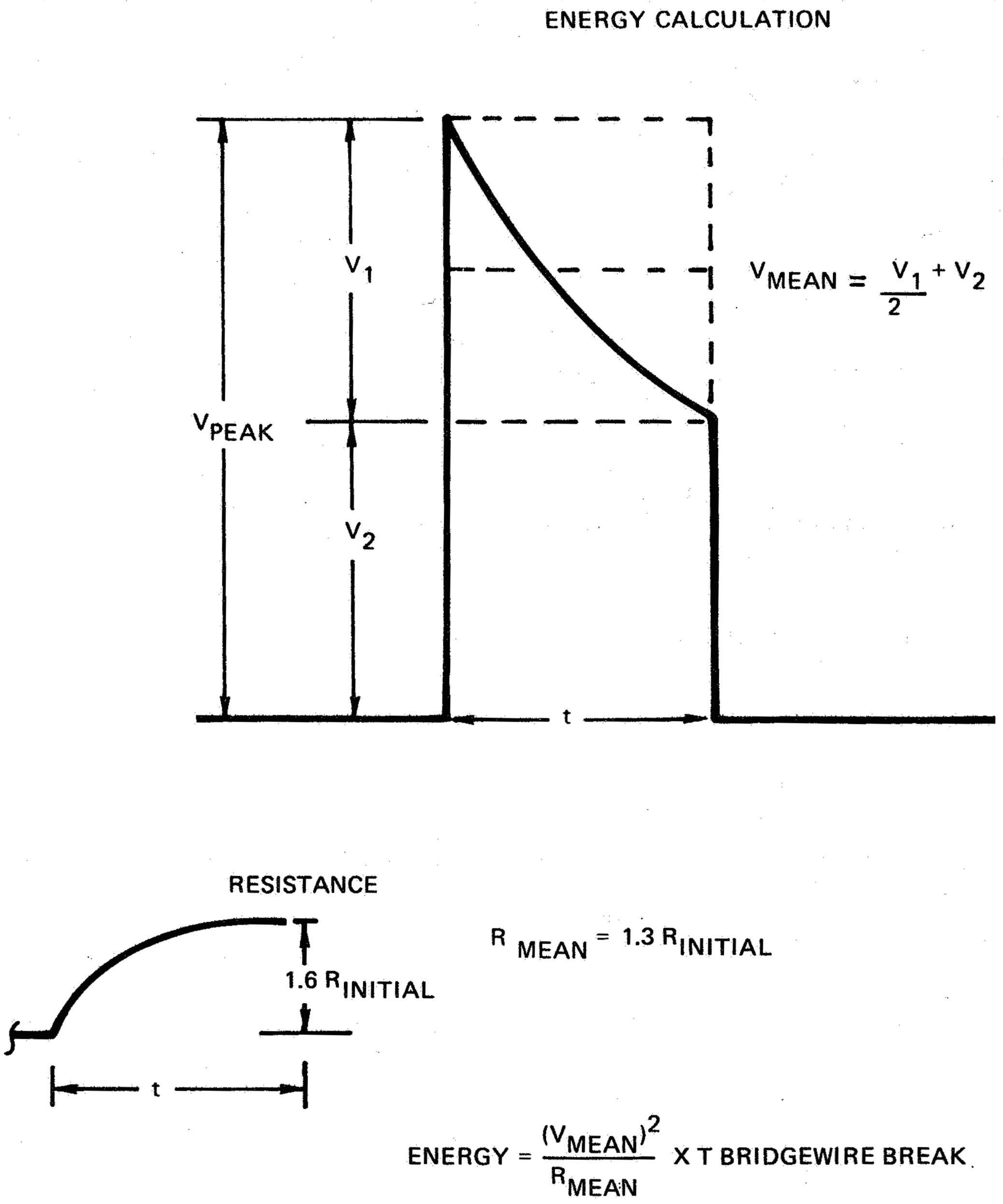


FIGURE 5 CAPACITOR IGNITION CHARGE VOLTAGE VS ENERGY AT BRIDGEWIRE BREAK

until a "NO FIRE" condition was reached. Fire capacitor charge and monitoring were the same as paragraph 3.3.2.1. Transistors were used as the fire switch instead of an SCR to terminate current flow to the ignitor. Two power transistors were used in parallel to keep the transistor (rated at 15 amperes) from current limiting. The pulse generator was manually triggered to initiate the firing signal. The pulse generator was preset to a duration of fire pulse based on the results of the previous test step. First fire pulse time was determined from the minimum function time of paragraph 3.3.2.1 data. Initiator serial No's. 0613, 0633, 0417 and 0554 were fired in the sequence as listed with fire pulse times of 500, 150, 100 and 71 microseconds, respectively. The next unit (S/N 0458) did not fire when subjected to a fire pulse of 60 microseconds. The unit was then subjected to fire pulses of 65 and 70 microseconds with ignition attained at 70 microseconds. SBASI serial Number 0686 was subjected to fire pulses of 50 and 65 microseconds with firing at 65. Unit number 0673 was subjected to three pulses of 63, 65 and 70 microsecond without ignition; test of this unit was then terminated due to a change in resistance. Likewise, Unit Number 0483 did not fire at 63 and 67 microseconds. Testing of these two units was terminated with no conclusive results. Units 0421 and 0568 provided additional data to bracket the minimum additional firing energy requirements by firing at 70 and 67 microseconds. In each case where more than one pulse was applied to an igniter, a "cool down" time of at least five minutes was allowed between pulses. Figure 12 shows the approximations used to calculate the energy required for SBASI ignition (Column 8 of Table IV). The calculation of energy utilized approximations of voltage, resistance and time represented in Figure 12 as Vmean, Rmean, and Tmean. SBASI Serial Number 421 required the least amount of energy to obtain ignition of 34.2 millijoules.



$$V_{MEAN} = \frac{V_1 + V_2}{2}$$

$$R_{MEAN} = 1.3\,R_{INITIAL}$$

$$\text{ENERGY} = \frac{(V_{MEAN})^2}{R_{MEAN}} \times \text{T BRIDGEWIRE BREAK}$$

FIGURE 6 BRIDGEWIRE BREAK ENERGY CALCULATION

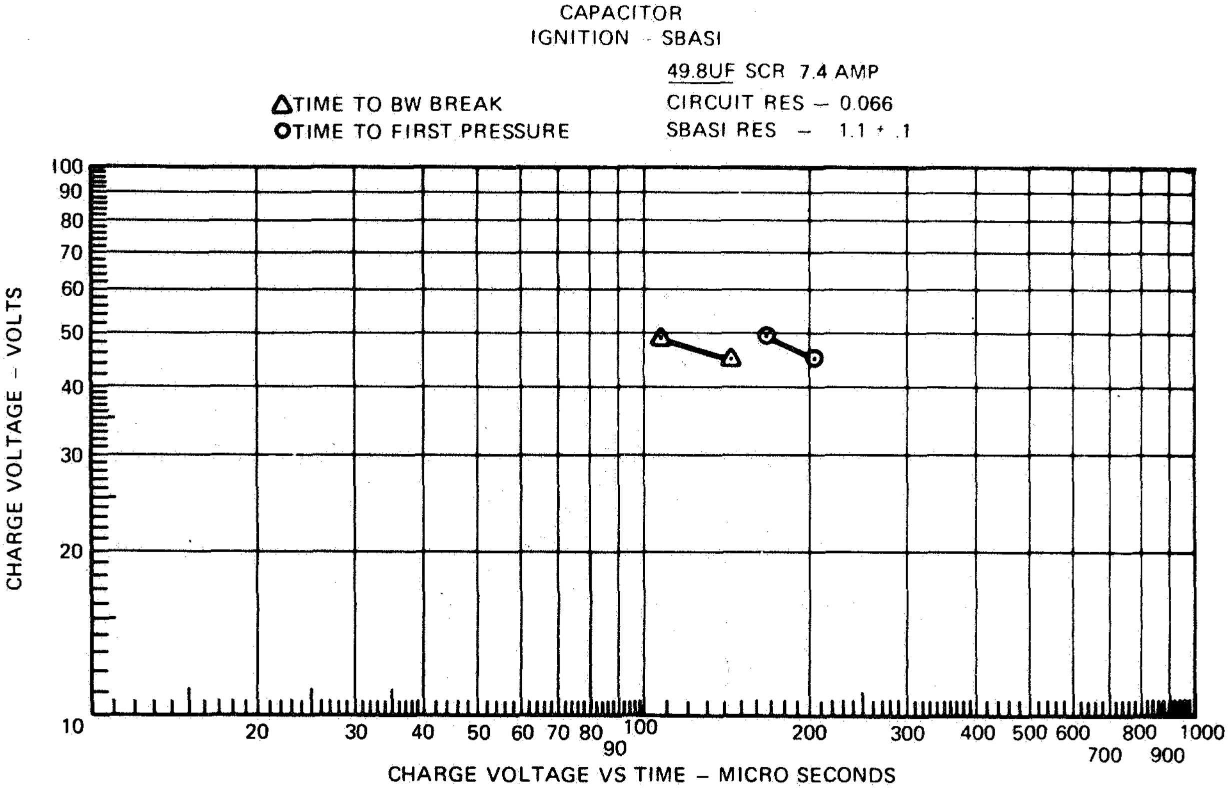


FIGURE 7 CHARGE VOLTAGE VS FUNCTION TIME – 49.8 MFD

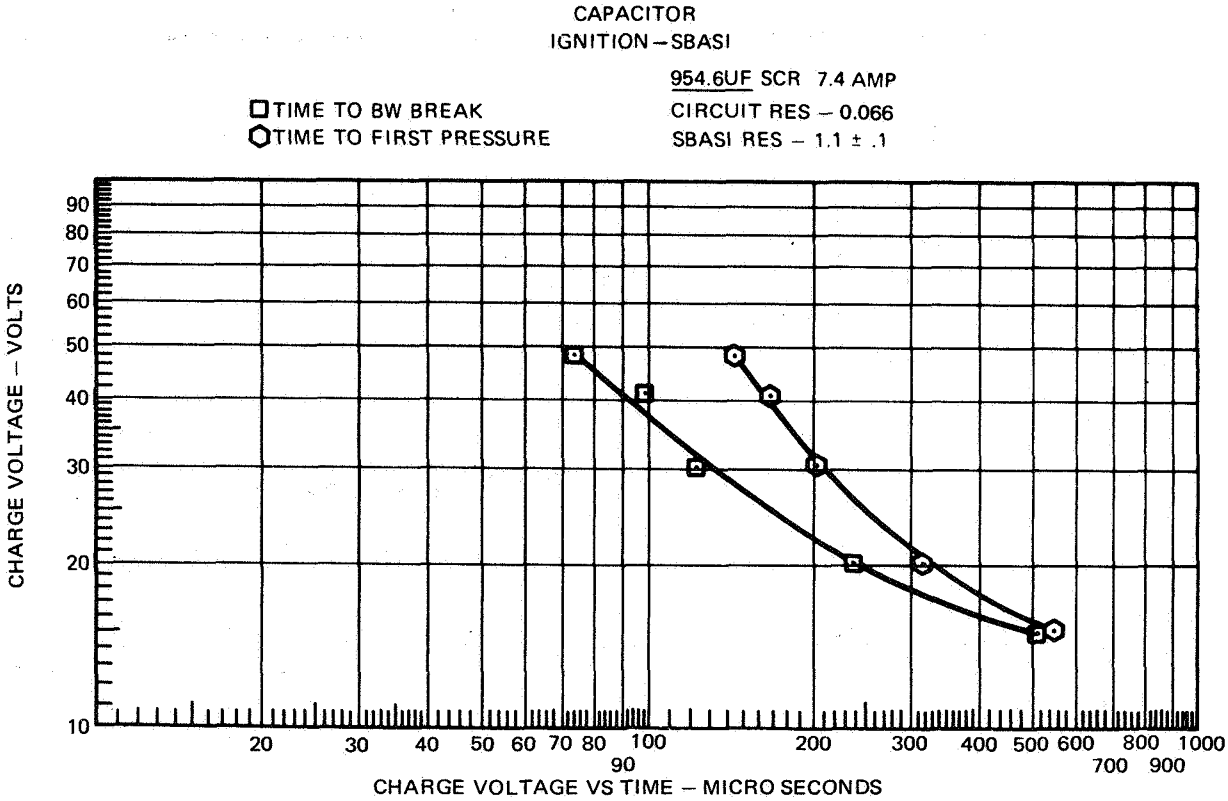


FIGURE 8 CHARGE VOLTAGE VS FUNCTION TIME – 954.6 MFD

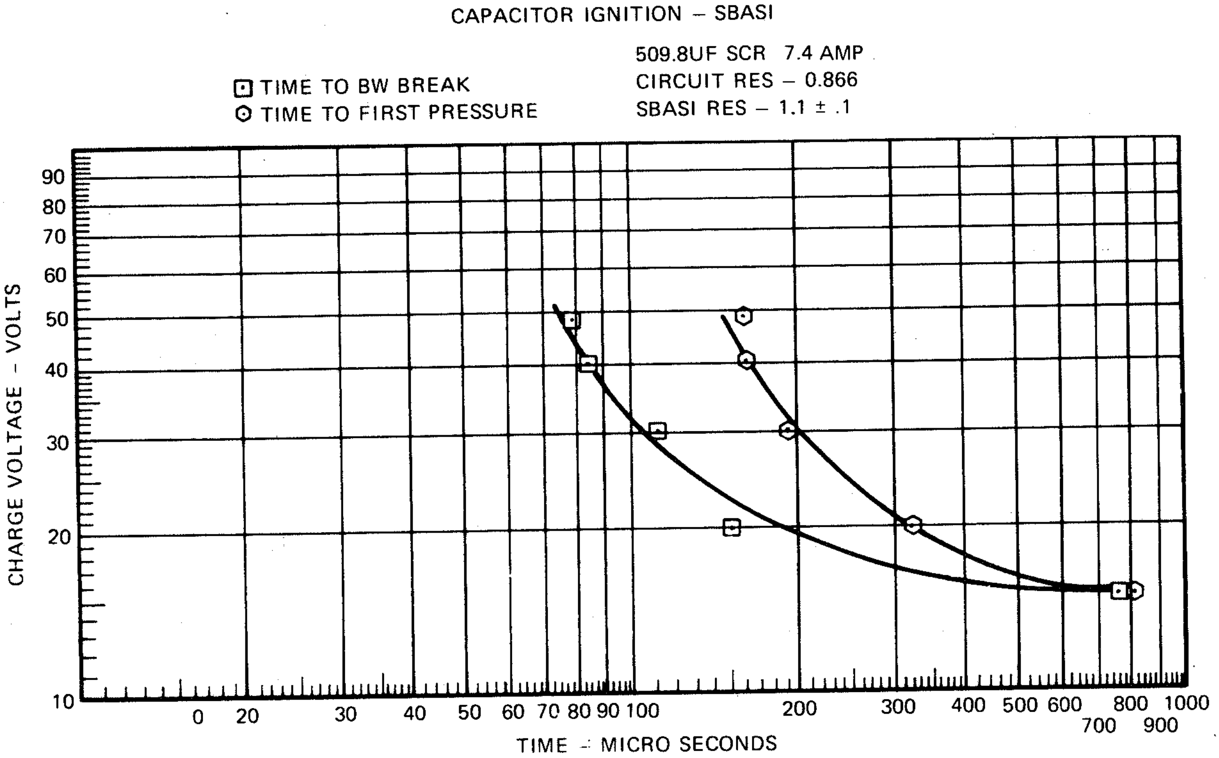


FIGURE 9 CHARGE VOLTAGE VS FUNCTION TIME – 509.8 MFD

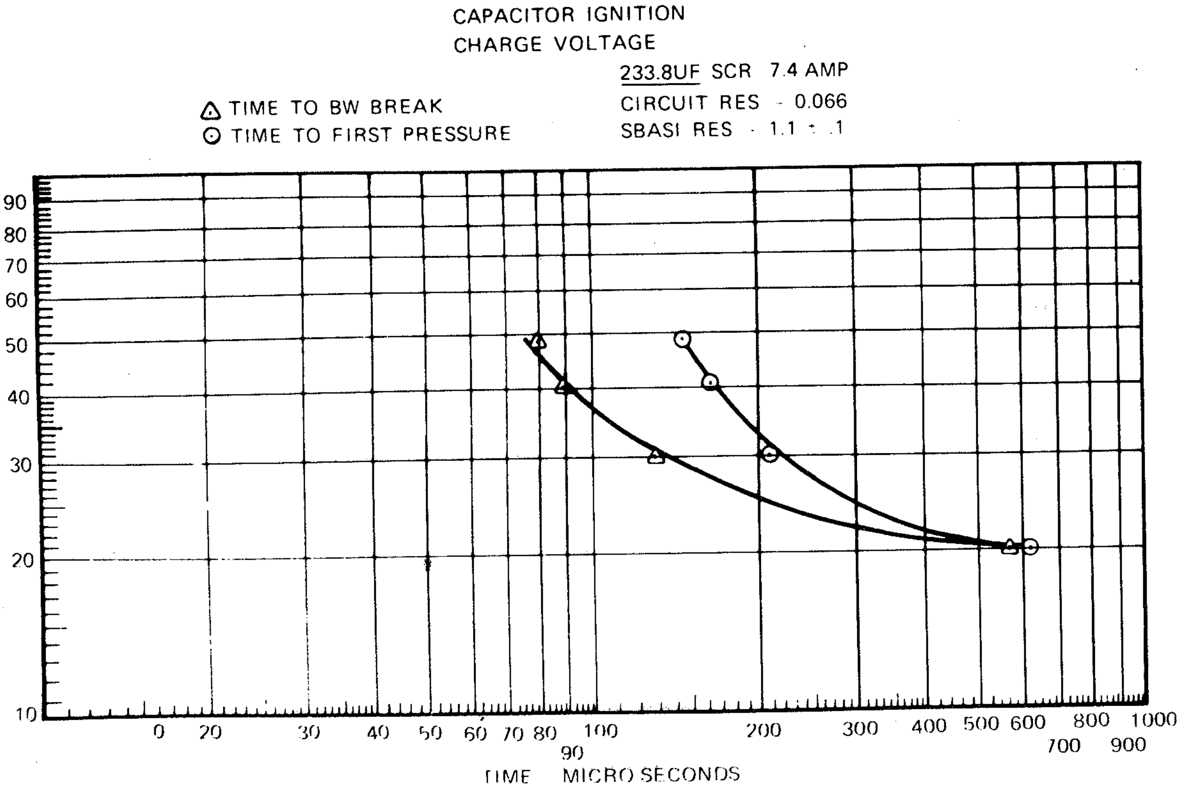


FIGURE 10 CHARGE VOLTAGE VS FUNCTION TIME – 233.8 MFD

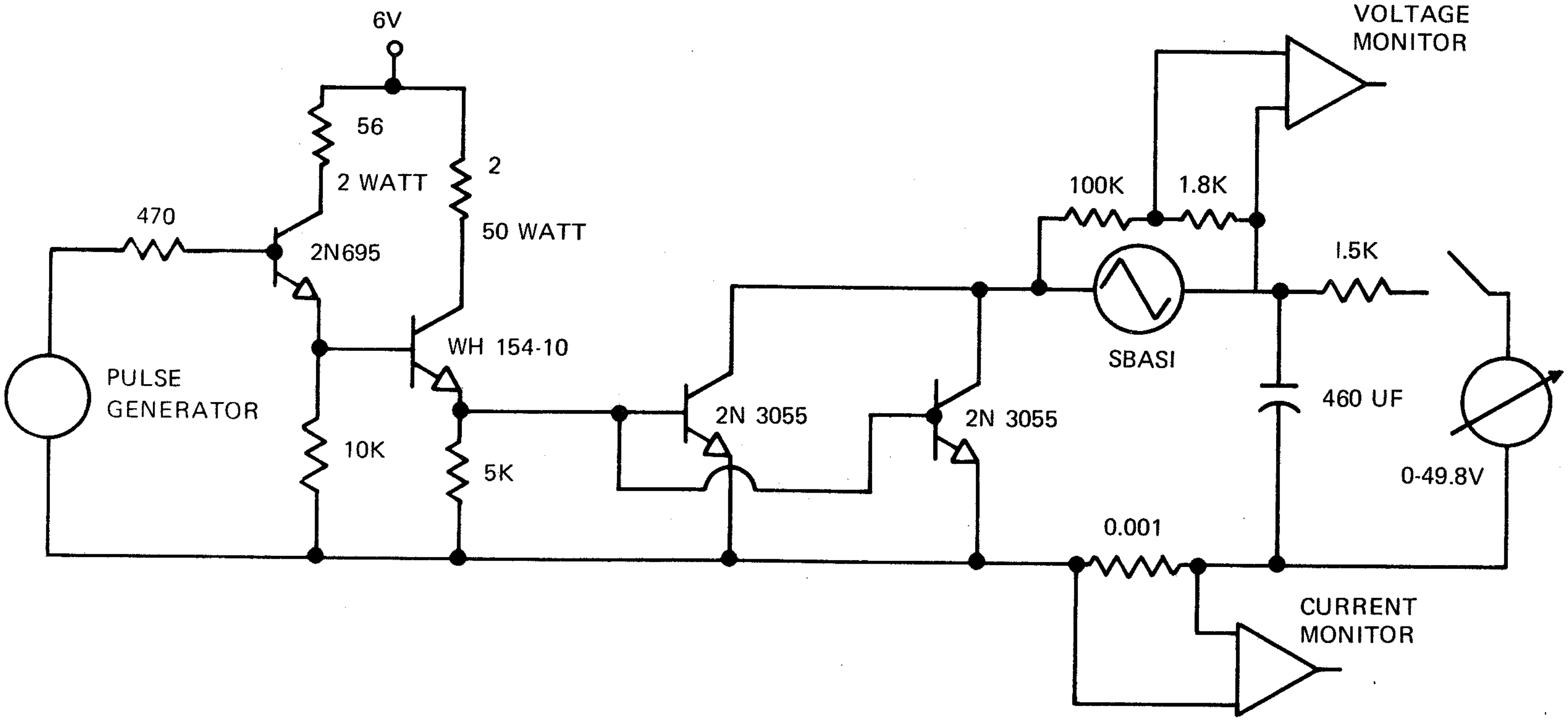


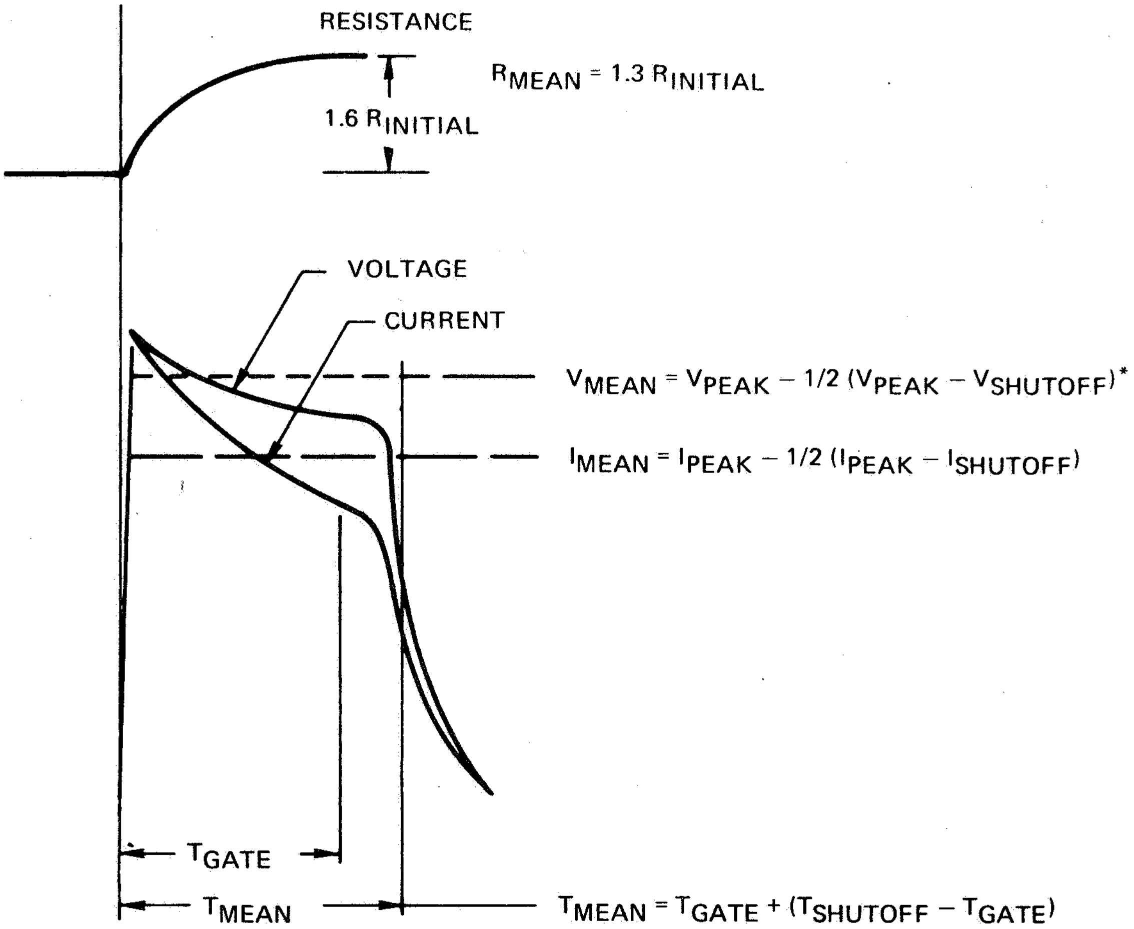
FIGURE 11 TRANSISTORIZED GATING FIRING CIRCUIT

TABLE IV SBASI CAPACITOR IGNITION VARIABLE TIME FIRE PULSE TRANSISTOR SWITCH

TANTALUM CAPACITORS – M39003/01-2072 OBSERVER BEMENT/WARD

35VDC CIRCUIT RESISTANCE = 0.116

UNIT SERIAL NO.	COLD BW RES	CAP SIZE uf	CHARGE VOLTS	VOLTS PEAK LOAD	VOLTS BW BREAK OR GATE	VOLTS MEAN	TIME BW BK OR MEAN TIME PULSE μsec	ENERGY MILLI-JOULES	ENERGY TOTAL AVAIL MJ	TIME PULSE WIDTH μsec	TIME TO FIRST PRESSURE μsec
				TRANSISTOR GATE – TWO 2N3055							
633	1.015	460	24.0	20.4	18.4	19.4	183	52.2	132.5	150	249
415	1.063	460	24.0	20.8	19.8	20.3	151	45.0	132.5	100	291
554	1.080	460	24.0	21.2	20.0	20.6	118	35.7	132.5	71	503
458	1.057	460	24.0	NO FIRE					132.5	60	
458	1.057	460	24.0	NO FIRE					132.5	65	
458	1.057	460	24.0	21.2	19.0	20.1	115	33.8	132.5	70	1,189
686	1.043	460	24.0	NO FIRE					132.5	50	
686	1.043	460	24.0	20.8	20.0	20.4	114	35.0	132.5	65	1,213
673	1.017	460	24.0	NO FIRE					132.5	63	
673	1.011	460	24.0	NO FIRE					132.5	65	
673	1.074	460	24.0	NO FIRE					132.5	70	
683	1.052	460	24.0	NO FIRE					132.5	63	
683	1.052	460	24.0	NO FIRE					132.5	67	
421	1.057	460	24.0	21.2	19.0	20.1	112	34.2	132.5	70	1,659
568	1.091	460	24.0	21.2	20.0	20.5	114	33.8	132.5	67	1,259



*SHUTOFF IS DETERMINED FROM DATA WHICH INCLUDES CIRCUIT DELAY.

$$\text{ENERGY} = \frac{(V_{MEAN})^2}{R_{MEAN}} \times T_{MEAN}$$

FIGURE 12 APPROXIMATIONS USED IN ENERGY CALCULATIONS PULSE FIRING

4.0 DESIGN

4.1 APPROACH

The CDI system was designed to perform the payload separation and ignition functions presently performed by the existing Scout fourth stage ring module payload separation system. The major assemblies on Scout are shown in Figure 13. The existing fourth stage payload separation system is mounted on the module ring assembly. This module ring assembly is in turn mounted on the fourth stage motor (see Figure 14). The complete 4th stage ring assembly is shown in Figure 15. The module ring assembly is composed of:

(1) Fourth stage telemetry package

(2) Telemetry transmitter

(3) Telemetry battery

(4) Accelerometers

(5) Umbilical bracket

(6) Safe-arm relay assembly

(7) Ignition batteries (two)

(8) Ignition timers (two)

Items 6, 7 and 8 listed above are the packages under consideration in the CDI study. Elimination of two ignition batteries and the safe-arm relay assembly is inherent with the design of the CDI system since firing energy is obtained from the timer battery. The safe-arm function is simplified in the CDI system by connecting a relay contact across the fire capacitor. The safe-arm function can be performed by one relay in the CDI system as compared to four in the existing system. Elimination of the two ignition batteries and the safe-arm relay assembly would result in a significant weight saving (see weight of existing ignition system in Table V). The concept of redundant ignition systems (two timers) was retained in the CDI design to optimize operational reliability.

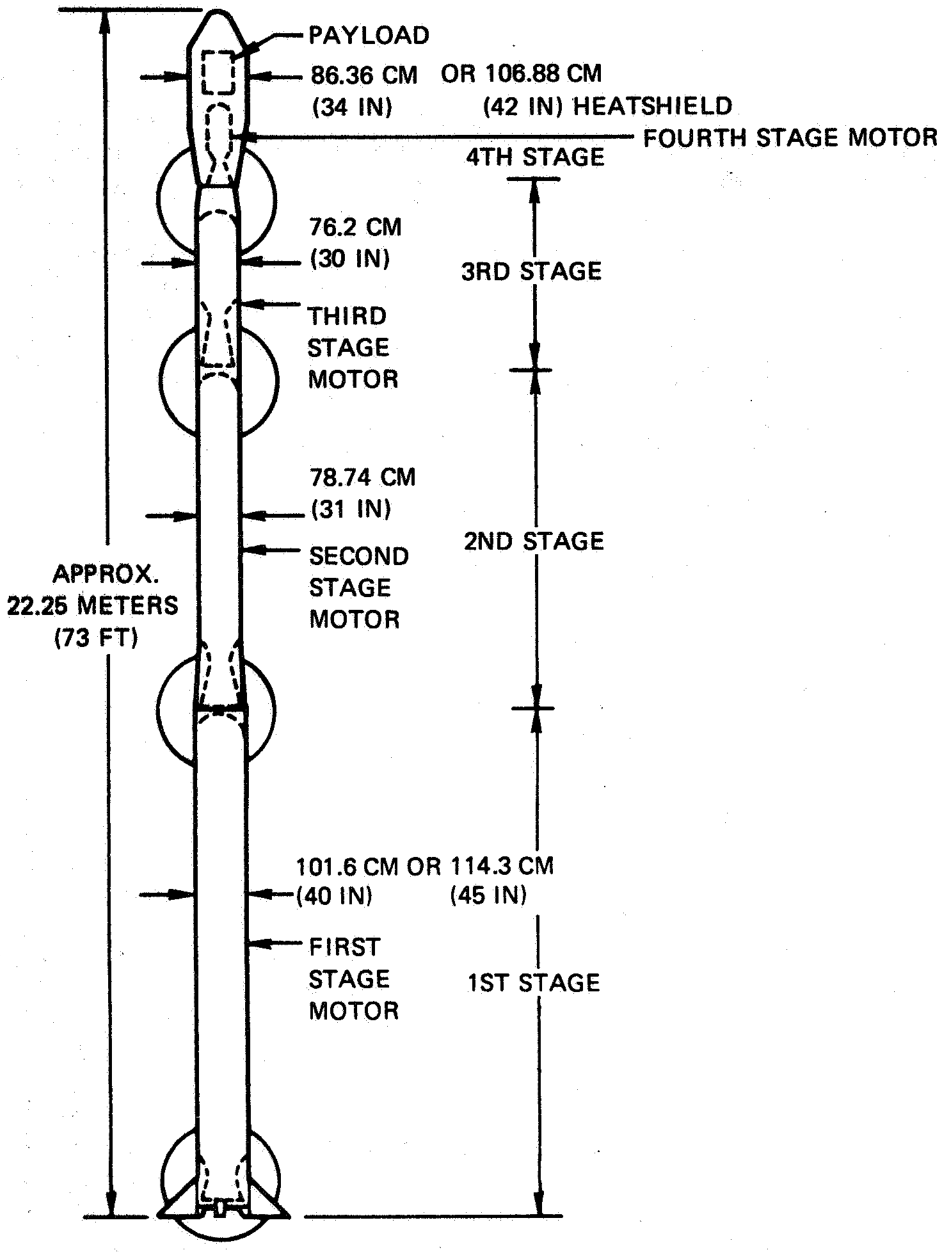


FIGURE 13 SCOUT MAJOR ASSEMBLIES

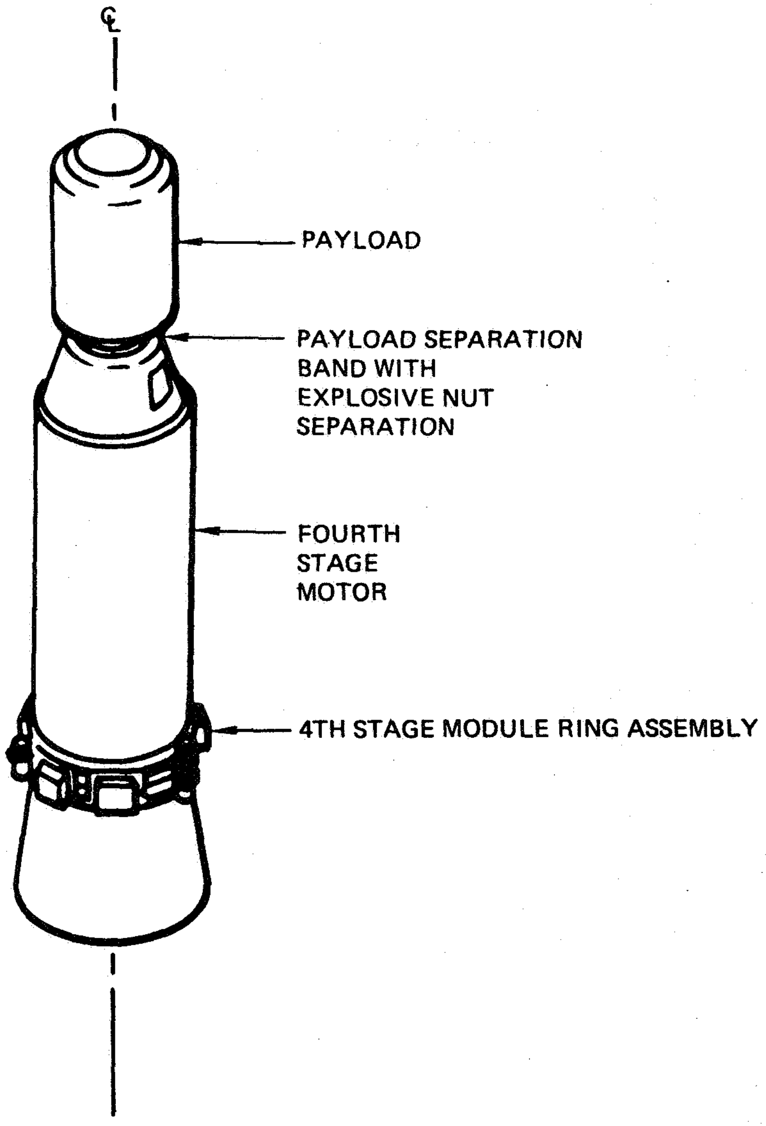
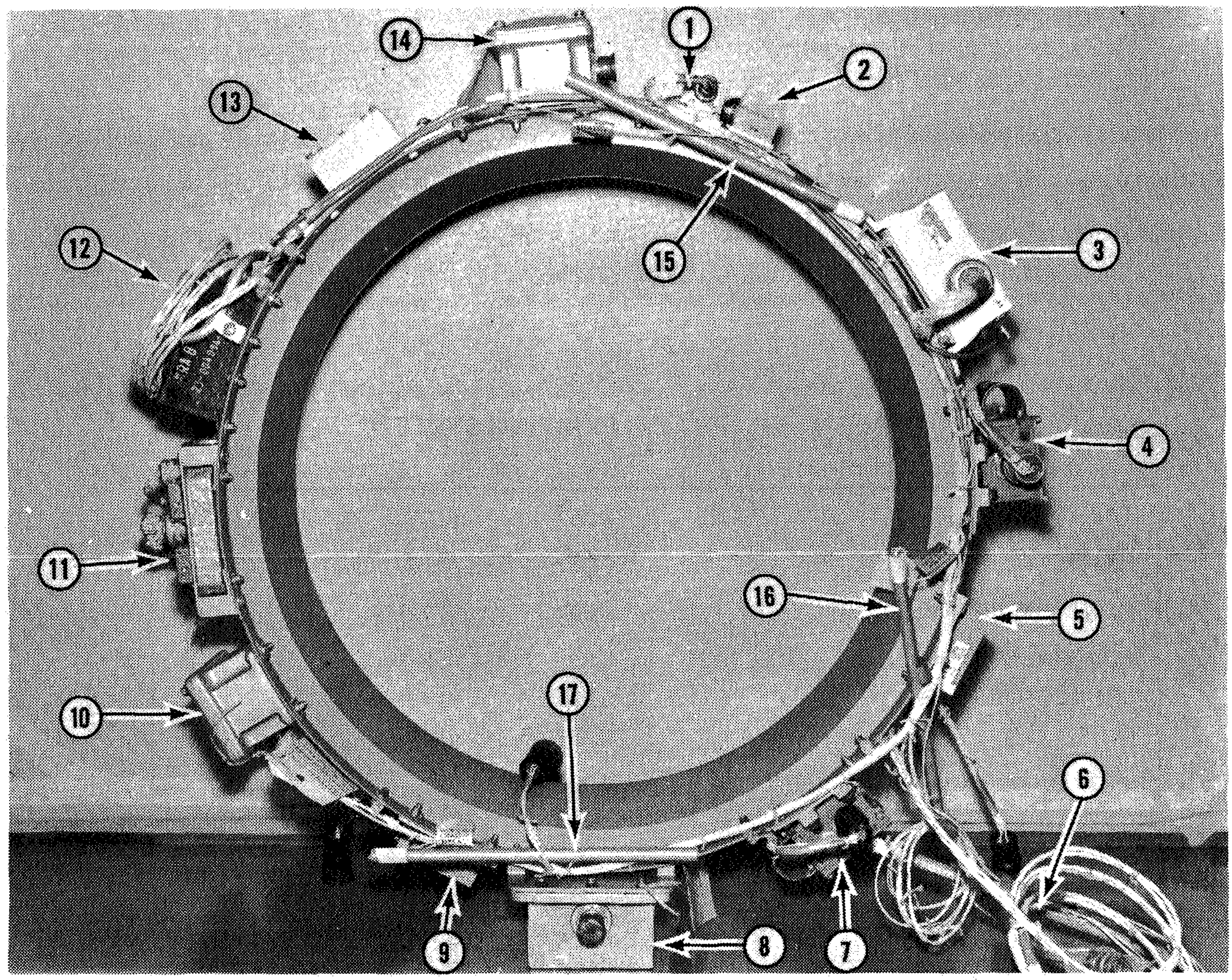


FIGURE 14 SCOUT FOURTH STAGE



1. ACCELEROMETER LONGITUDINAL
2. ACCELEROMETER LONGITUDINAL
3. T/M SIGNAL CONDITIONING PACKAGE
4. IGNITION TIMER NO. 1 ASSEMBLY
   23-004069-1 (W/O BATTERY)
5. ACCELEROMETER NORMAL
6. THERMISTOR
7. IGNITION TIMER NO. 2 ASSEMBLY
   23-004069-1 (W/O BATTERY)
8. TELEMETRY BATTERY
9. ACCELEROMETER TRANSVERSE
10. IGNITION BATTERY NO. 1
11. SAFE-ARM RELAY ASSEMBLY
12. UMBILICAL BRACKET
13. T/M TRANSMITTER
14. IGNITION BATTERY NO. 2
15. THERMISTOR
16. THERMISTOR
17. THERMISTOR

FIGURE 15 MODULE RING ASSEMBLY

TABLE V WEIGHT OF EXISTING SYSTEM

TIMER 1	0.357	(0.787)	(WITH BATTERY)
TIMER 2	0.357	(0.787)	(WITH BATTERY)
SAFE-ARM RELAY ASSEMBLY	0.327	(0.72)	
COMPONENT MOUNTING BRACKETS	0.821	(1.81)	
CONNECTORS	0.354	(0.78)	
WIRE	0.222	(0.49)	
MISC. HARDWARE (CLAMPS, ETC.)	0.045	(0.1)	
FIRING BATTERY NO. 1	0.499	(1.1)	(FILLED)
FIRING BATTERY NO. 2	0.499	(1.1)	(FILLED)
	3.481 KG	(7.674 POUNDS)	

NOTE: DOES NOT INCLUDE ANY T/M OR RING COMPONENTS

4.2 USER LIAISON

Several active programs are using capacitive discharge ignition systems. VSD reviewed capacitive discharge systems now in use by other programs to take advantage of experience gained through prior use and development. Of special concern during the user liaison and review were the switching devices, firing capacitor types and safe-arm methods. User liaison consisted of contact with personnel associated with the following programs which utilize capacitive discharge ignition systems:

Ames Research Center (PAET Program) - Used successfully in mission

Viking LPCA (Figure 16) - Contact NASA/LRC

HIT (Figure 17) - Contact VSD

Mansafe System (Figure 18) - Contact VSD

Explorer - Contact NASA/LRC

Viking Orbiter 75 (Figure 19) - Contact JPL

Space Shuttle SRB (Figure 20) - Contact Rockwell International

All of these programs except space shuttle have qualified a CDI system for flight. Range of the design concepts varies from relays used in Explorer and Mansafe systems to the thick film hybrid used on the HIT program. All of the systems surveyed except HIT were designed to fire 1 amp-1 watt initiators. Table VI summarizes the comparison of design concepts of programs listed above, with relation to the proposed Scout system.

The variation of design as noted by Table VI are due largely to performance and packaging restraints placed on the capacitive discharge ignition system. An example is the HIT design which was based on extremely limited space and severe weight constraints. As a result of the review of the Viking LPCA circuit, consideration of the ignition system checkout procedure as shown in paragraph 7.1 Ground Support Equipment was initiated.

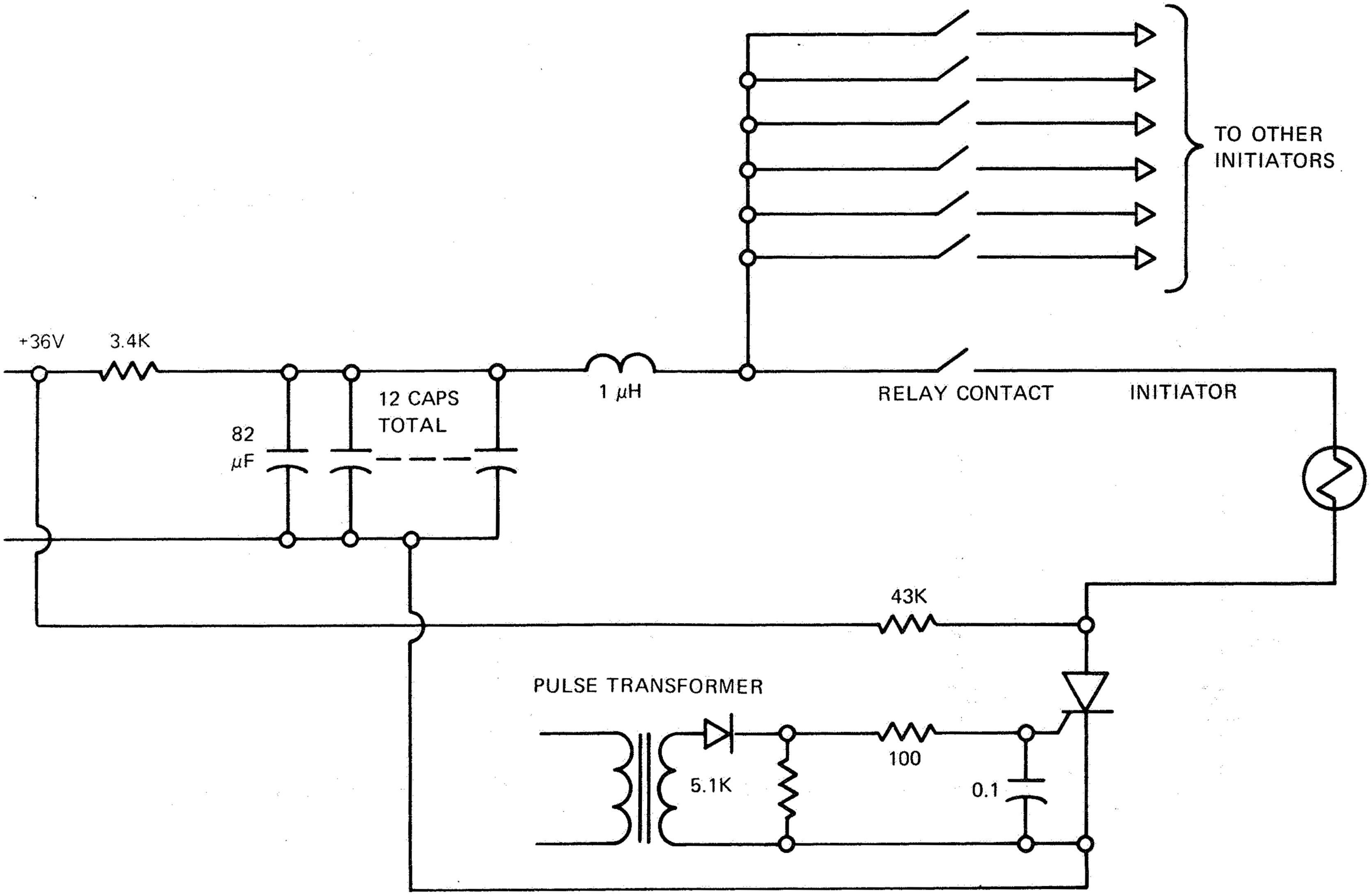


FIGURE 16 LPCA INITIATOR FIRING CIRCUIT

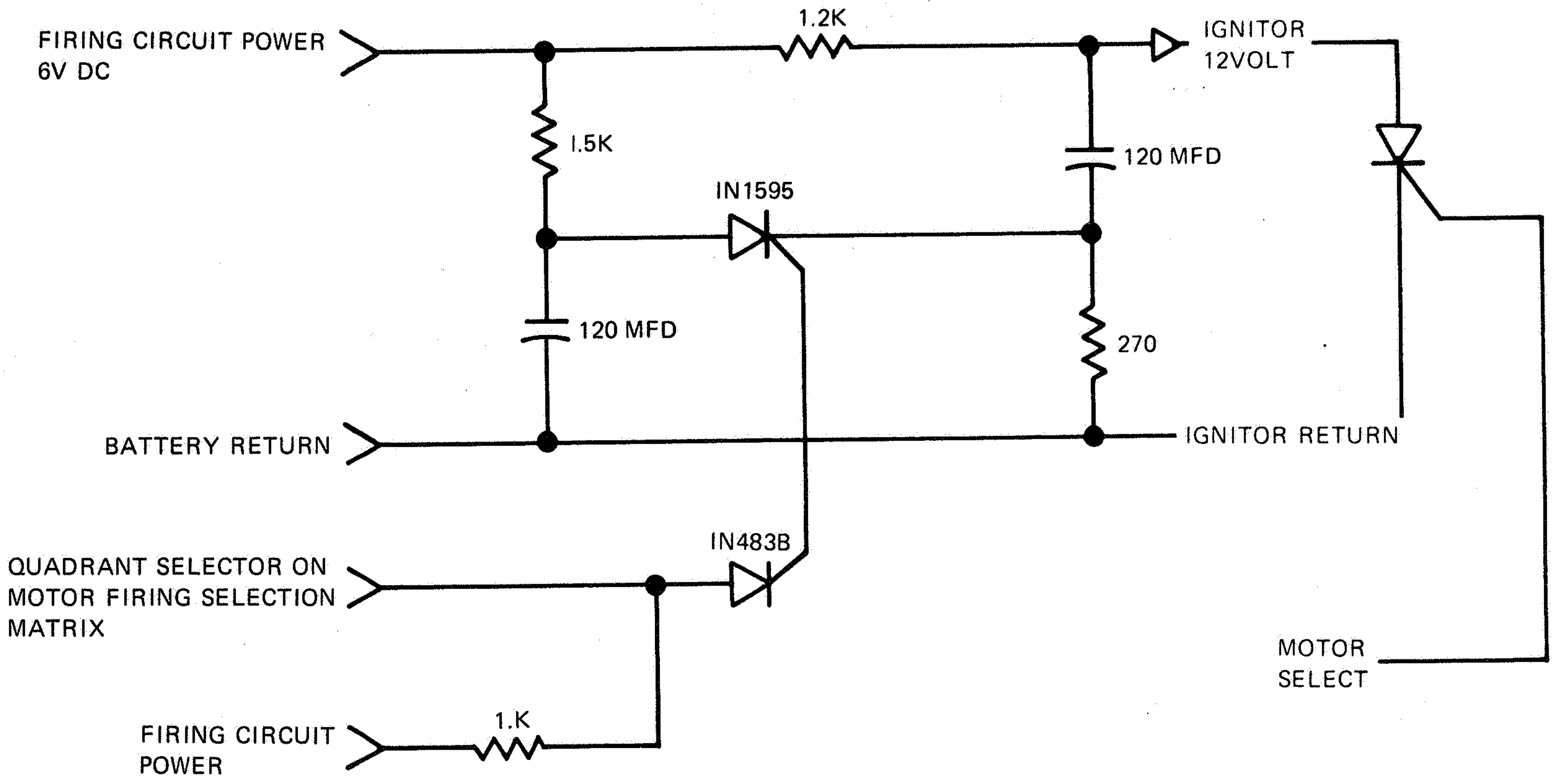


FIGURE 17 HIT TYPICAL MANEUVER MOTOR FIRING CIRCUIT

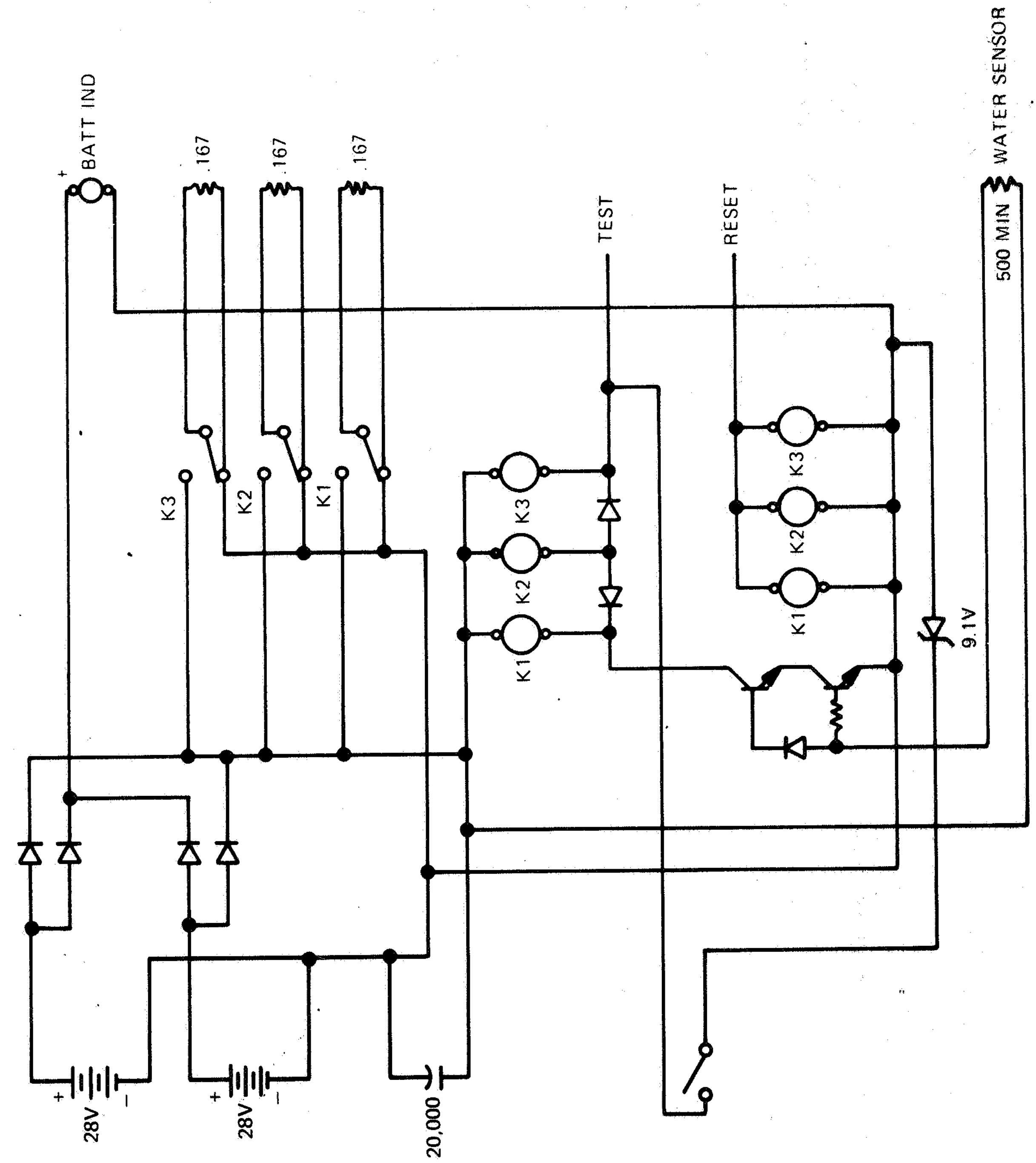


FIGURE 18 MANSAFE SYSTEM

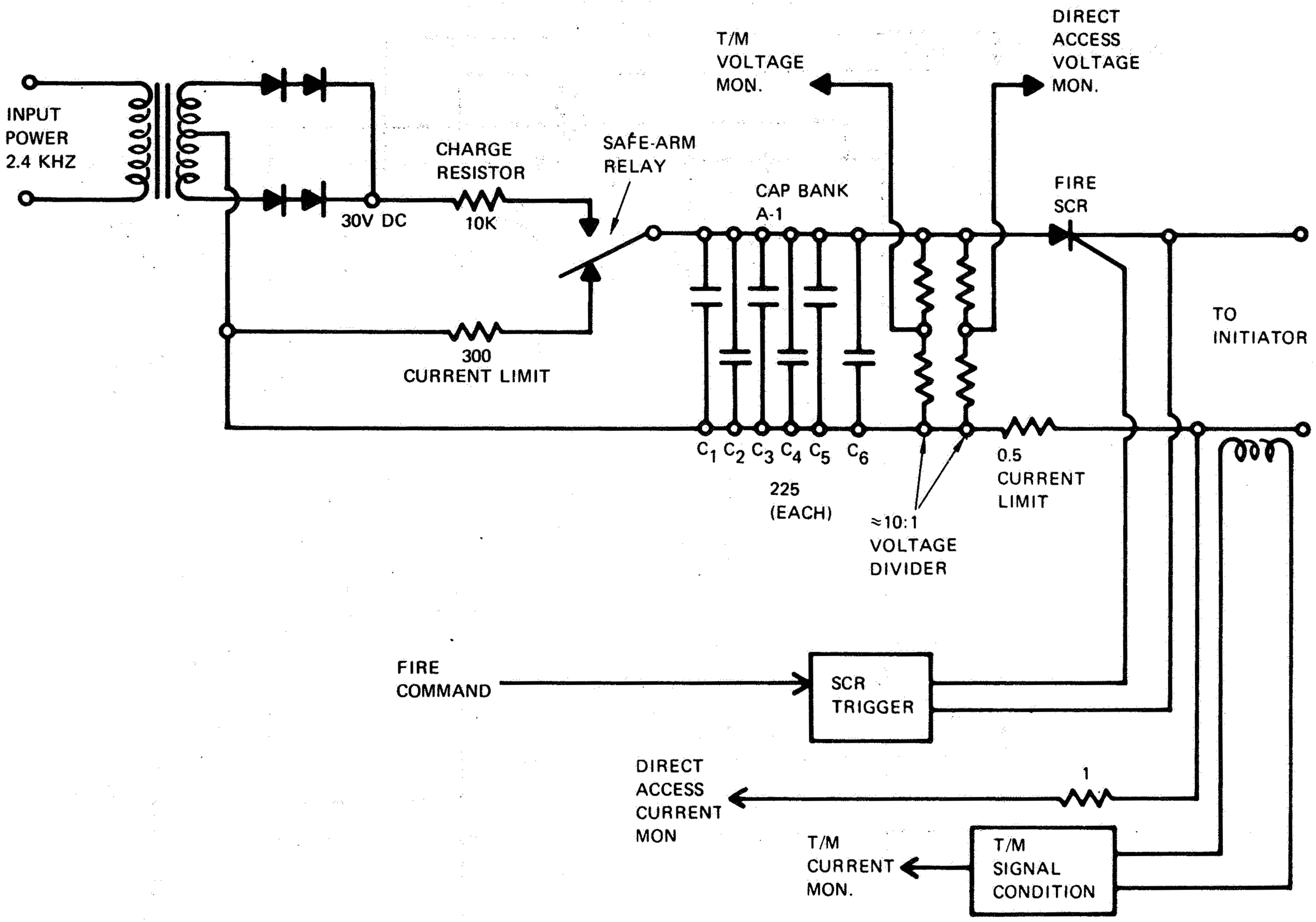
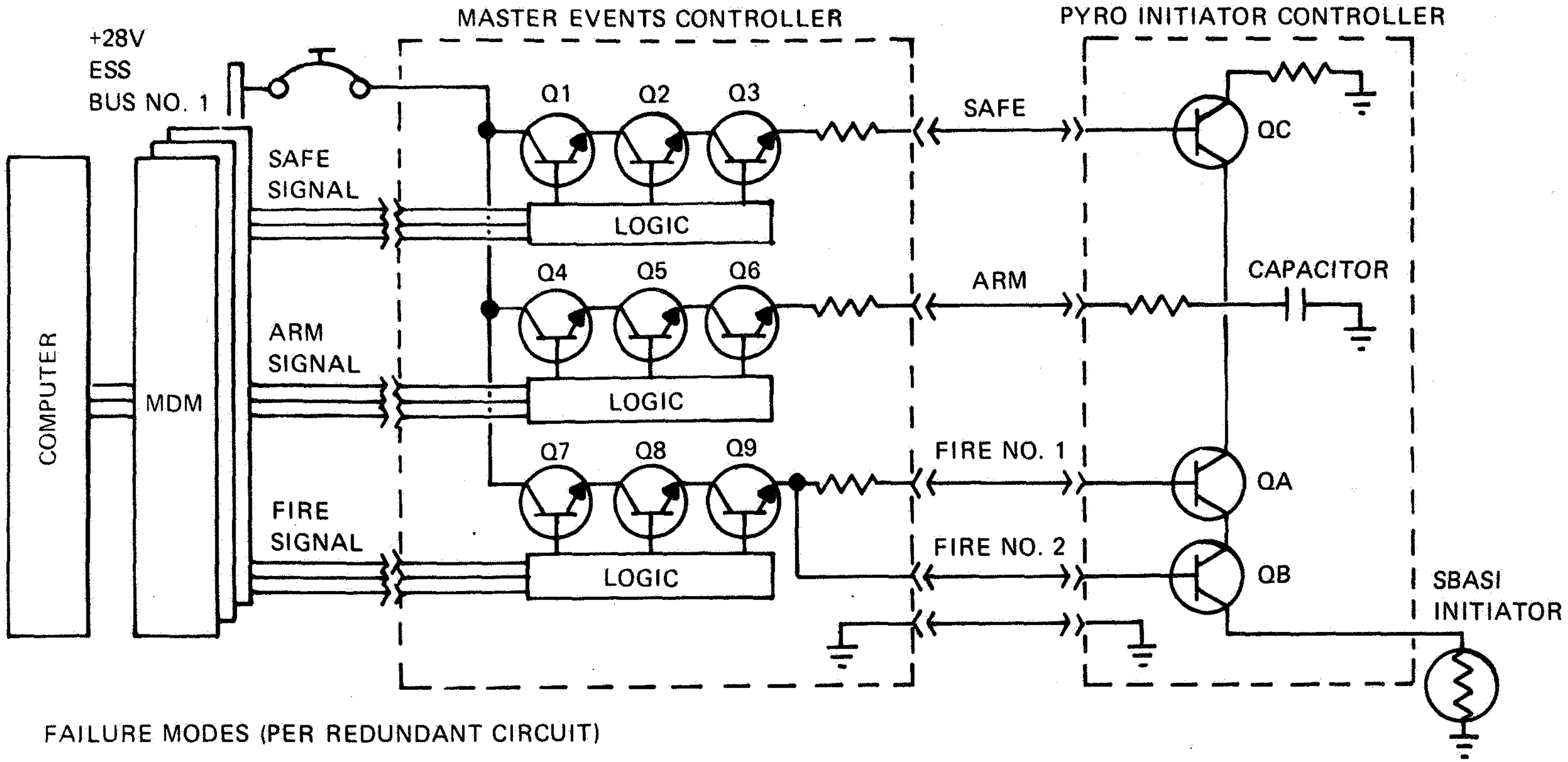


FIGURE 19 JPL VIKING ORBITER



FAILURE MODES (PER REDUNDANT CIRCUIT)

1–PREMATURE FIRING

- INADVERTANT ARMING FOLLOWED BY SHORTING OF FIRING TRANSISTORS
- FIRING WIRES SHORTED TO + 28V AFTER CAPACITOR IS ARMED
- COMPUTER GENERATES SIGNALS OUT OF SEQUENCE (NOT AN ACCEPTABLE FAILURE)

2–FAILURE-TO-FIRE

- ANY FIRE OR ARM TRANSISTOR IN MEC OPEN CIRCUIT
- QA OR QB OPEN CIRCUIT
- QC SHORTED
- SAFE LINE SHORTED TO +28V
- ESSENTIAL BUS NO. 1 FAILED

FIGURE 20 SPACE SHUTTLE PYRO CIRCUIT DESIGN

TABLE VI CIRCUIT SUMMARY

	SAFE-ARM	FIRING SWITCH	REDUNDANT FOR SAFETY	FIRE CAPACITOR	TOTAL CAPACITANCE	CHARGE VOLTAGE	CAPACITOR TYPE	COMMENTS
VIKING LPCA (NASA)	RELAY	SCR	NO	82 MFD (12 EACH)	984 MFD	36V	WET SLUG TANTALUM	1 CHECKOUT BY DISCHARGING LOW CURRENT THROUGH IGNITOR. 2 CURRENT LIMIT BY INDUCTANCE.
HIT (ARMY)	ACTIVE COMPONENT (SQUIB SWITCH)	SCR	YES*	120 MFD (1 EACH)	120 MFD	12V	TANTALUM FOIL	1 THICK FILM HYBRID CIRCUIT (16 CIRCUITS ON APPROX 1.9 CM) 2 VOLTAGE DOUBLING BY CAPACITANCE 3 *REDUNDANT AS A RESULT OF VOLTAGE DOUBLING.
MANSAFE SYSTEM (NAVY)	RELAY	RELAY	NO	20,000 MFD (1 EACH)	20K MFD	28V*	TANTALUM FOIL (TANSITOR)	1 *THERMAL ACTUATED BATTERY. 2 FIRES 12 SQUIBS AT ONE TIME.
EXPLORER (NASA) AIR DENSITY ENGINE	RELAY	RELAY	NO	1,000 MFD	1K MFD	30V	WET SLUG TANTALUM	1 DESIGN CURRENTLY BEING CHANGED TO SCR FIRING SWITCH
VIKING ORBITER "75" (NASA)	RELAY	SCR	NO	225 MFD (6 EACH)	1350 MFD	30V	TANTALUM ETCHED FOIL	1 0.5 OHM SERIES RESISTOR ADDED LIMIT CURRENT TO 22 AMP. 2 SAFE ARM SHORTS CAPACITOR ONLY (IGNITOR NOT SHORTED).
SPACE SHUTTLE (NASA) (BREADBOARD)	TRANSISTOR	TRANSISTOR	YES	82 MFD (5 EACH)	410 MFD	20V	WET SLUG TANTALUM	1 BREADBOARD (NOT AN OPERATIONAL CIRCUIT). 2 FIRE SWITCH IS TWO 20 AMP TRANSISTORS IN SERIES.
SCOUT (NASA) (BREADBOARD)	RELAY	SCR	NO	300 MFD 150 MFD (2 EACH)	450 MFD	24V	WET SLUG TANTALUM	1 CAPABILITY TO CHECKOUT SYSTEM BY DISCHARGING LOW CURRENT THROUGH IGNITOR. 2 REDUNDANCY TO ASSURE PROPER MISSION OPERATION OBTAINED BY USE OF TWO SEPARATE SYSTEMS.

4.3 RANGE SAFETY COORDINATION

From the onset of this study program and as a continuing effort throughout, Range Safety at WI and VAFB have been kept informed of the circuit design status. Coordination with Range Safety personnel at WI and VAFB was maintained so that the final circuit design would reflect safety margins consistent with range requirements.

Coordination meetings have been held with Wallops Island and Vandenberg Air Force Base Range Safety personnel and their requirements and comments have been considered and incorporated in the circuit design. Neither range had definitive requirements governing design of a CDI system. Each ignition circuit is evaluated for compliance to basic safety guidelines as a part of its total system.

The basic guidelines include:

(1) Ignition circuit electrical isolation

(2) Absolute safety of personnel when handling pyrotechnics

(3) Verification of firing circuit safe condition before connecting initiators

(4) A single point of failure cannot endanger personnel

(5) Adequate monitoring capability to assure safety of the firing circuit operation.

Personnel at both ranges indicated that severity of a malfunction and possible personnel injury is considered in review of any design. An example of this is whether the ignition system is used for a main stage motor or for a payload separation bolt. Range Safety personnel at Wl reviewed the design and their recommendations have been incorporated into the CDI circuit design. Recommendations from WI were to provide a method of dumping (discharging) the fire capacitor from the blockhouse and automatic shutdown for overvoltage on the firing capacitor during the safe condition. VAFB range safety found the design approach to be satisfactory and acceptable.

4.4 CIRCUIT

Based on review of existing CDI circuits, range safety and the concepts needed for a Scout functional system, a block diagram was developed. The capacitive-discharge ignition system is composed of the elements shown in the block diagram of Figure 21.

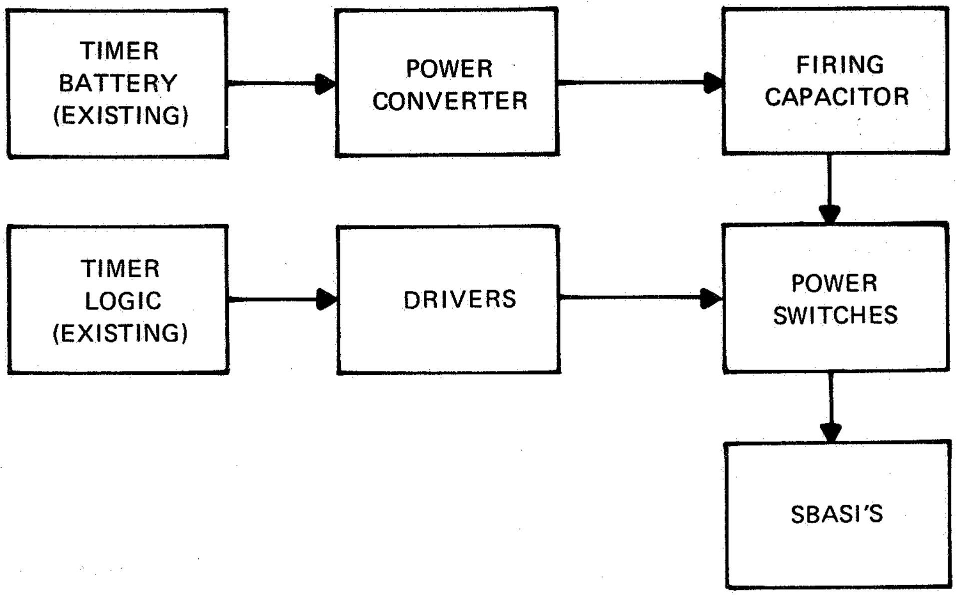


FIGURE 21 CDI BLOCK DIAGRAM

The design technique was to examine different ways of implementing the block functions and select one of the ways.

Table VII shows the ranking and selection factors that were used to evaluate the functional elements of the design. The table is configured so that the functional elements are ranked top to bottom and selecting factors in the order of importance left to right.

4.4.1 Power Switches

Two types of switching devices, SCR and transistor, were considered in selecting one to fire the SBASI's. The SCR proved to be better. Characteristics of both types were studied and tests were performed to determine how efficiently energy was transferred from a capacitor to a dummy load (paragraph 3.3.1). A schematic of the test setup using an SCR switch is shown in Figure 1.

TABLE VII SELECTION FACTORS

FUNCTION	RELIABILITY	SIZE/ WEIGHT	POWER EFFI-CIENCY	ELECT ISOLA-TION	PRODUCIBILITY
POWER SWITCH					
1 – SCR	1	1	1	NA	2
2 – TRANSISTOR	1	2	3	NA	1
DRIVERS					
1 – PULSE TRANSFORMER	1	2	1	1	1
2 – DIRECT-COUPLED	1	3	3	3	1
3 – OPTICAL ISOLATOR	1	1	2	1	3
POWER CONVERTERS					
1 – DC-DC	1	1	2	1	2
2 – CAPACITANCE MULTIPLICATION	1	3	1	2	1

EXPLANATION OF RANKING:

1 – MEETS ALL REQUIREMENTS.

2 – USABLE BUT REQUIRES SELECTION OR RELAXED REQUIREMENT.

3 – NOT ACCEPTABLE.

A schematic of the test setup using the transistor switch is shown in Figure 2. Tests using a dummy load showed that no difference could be detected between switching the load with a 7.4 amp SCR and a 110 amp SCR. When the transistor switch was used the current was limited to 25 amps by the transistor current saturation level. This limitation was considered when the minimum firing energy tests were performed using the transistor switch circuit. Transistors were considered because of their ability to be cut off at any predetermined time, thus conserving energy. A transistor capable of switching firing currents up to 25 amps requires two stages of amplification with subsequent current drain on power sources and another timing device for controlling the length of the firing pulse. Transistors with current carrying capacity to fire the devices are physically large unless bare chips are used. Transistors are subject to "second breakdown" when their maximum collector current is exceeded, therefore having no surge current capability. In comparison to a transistor, an SCR can carry a very heavy overload current for the short time required to fire the SBASI's without damage to the SCR. A small current is required for a very short time to trigger the SCR to turn on. The SCR current will cut off either by the bridgewire opening up or by discharge of the capacitor below minimum SCR hold current level. An SCR type switch was chosen as the switching device in the design.

These tests were also designed to determine the Equivalent Series Resistance (ESR) of the capacitors while discharging from a dc voltage level. The energy transfer tests to determine the ESR of the capacitors did not produce the desired results. The ESR of wet slug tantalum capacitors was so small compared to the resistance of the circuit that its existence could not be determined from the test data. This finding eliminated capacitor ESR value as a significant consideration in the operation of the ignition system.

4.4.2 Drivers

The driver circuit serves as an interface between the timer logic circuit and the power switch. It must supply sufficient power to reliably trigger the SCR's and provide electrical isolation between control and ignitor circuit. Three types of drivers were considered: direct-coupled, optical isolator and pulse transformer. A one-shot multivibrator was considered as a direct-coupled device so that the SCR firing pulse length could be shortened to a time less than the SBASI firing time. Two types of one-shots were evaluated - one of the COS/MOS family and one of the DTL family. The DTL multivibrator consumes too much power while the COS/MOS multivibrator requires an additional stage of amplification. No electrical isolation is provided by either type between the driving circuitry and the SCR's or between the four firing channels.

Several manufacturers of optical isolator devices were contacted to evaluate availability of currently produced devices. Only one manufacturer was found to produce the optical isolator and SCR in one package. This manufacturer stated, "In order to obtain reasonable sensitivity to light the SCR must be constructed so that it can be triggered with a very low current density. This requires the use of a fairly thin silicon pellet of small dimensions hence high current devices are not considered practical for light triggering at this time. The high sensitivity of the light activated SCR also causes it to respond to other effects which produce internal currents. As a result the light activated SCR has a higher sensitivity to temperature, applied voltage, rate of change of applied voltage and has a longer turn-off time than a normal SCR." With an optical-isolator device packaged separately from the SCR no significant advantage in size would be obtained over use of a pulse transformer. Additionally, the steady state current drain is higher than pulse transformers.

Isolation is gained when pulse transformers are used, but an additional stage of drive is required to couple the COS/MOS timer logic to the pulse transformer. Based on size, electrical isolation and current drain the pulse transformer was chosen for the CDI design.

4.4.3 Power Converter

Circuit power requirements based on testing at LRC (paragraph 3.3.2.1) indicate that a charge voltage of approximately 20 volts would be necessary to fire the SBASI. Available power sources in the Scout fourth stage as presently configured are ignition batteries (12 volts) and timer battery (6 volts). In order to substantially decrease weight of the fourth stage firing circuit, the existing firing batteries must be eliminated. The existing fourth stage timer requires 0.6 milliamp (ma) of current from the 180 milliamp-hour timer battery. Analysis of the CDI system maximum power requirements, including timer, showed steady state power consumption not to exceed 10 milliamp-hours. This gives an energy reserve of 170 milliamp hours at a mission time of 2.77 hours.

Two types of converters were examined for changing the timer battery voltage of 6 volts to the capacitor charge voltage of 24 volts. These were voltage multiplier using SCR's and capacitors, and dc to dc converter.

Schematic of these alternatives are shown in Figure 22. Advantages and disadvantages of the dc-dc converter listed in order of their importance are:

Advantages

(1) Smaller size - The dc-dc converter will be approximately one-fourth the size of the multiplier. Since only one circuit will be required as compared to four multiplier circuits, the total system requirement would be smaller by a ratio of approximately 16:1.

(2) Electrical isolation between initiators and the timing circuit - This item is important from a safety standpoint in order to keep one ground fault in the ignition circuit from causing a system malfunction.

Disadvantages

(1) Lower electrical efficiency.

(2) Requires special transformer design.

Since the power requirements with the lower efficiency can be supplied by the timer battery and preliminary design indicates the special transformer is feasible, the dc-dc converter method was selected for the CDI design.

4.5 COMPONENT SURVEY FOR BREADBOARD EVALUATION TESTING

After the circuit design was completed, a component survey for parts availability was made.

4.5.1 SCR's

Requirements for the SCR were specified as:

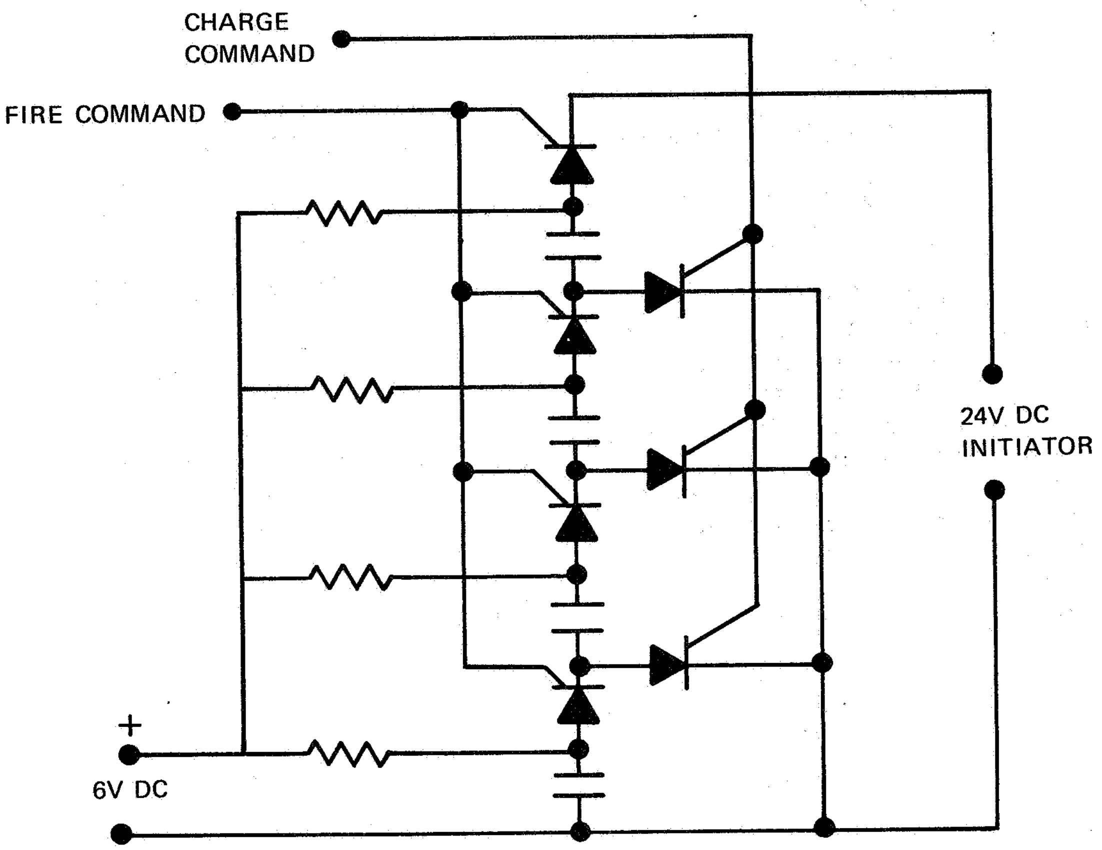
Peak Reverse Voltage = 50 volts minimum

Gate Firing Current = 1 ma minimum, 15 ma maximum

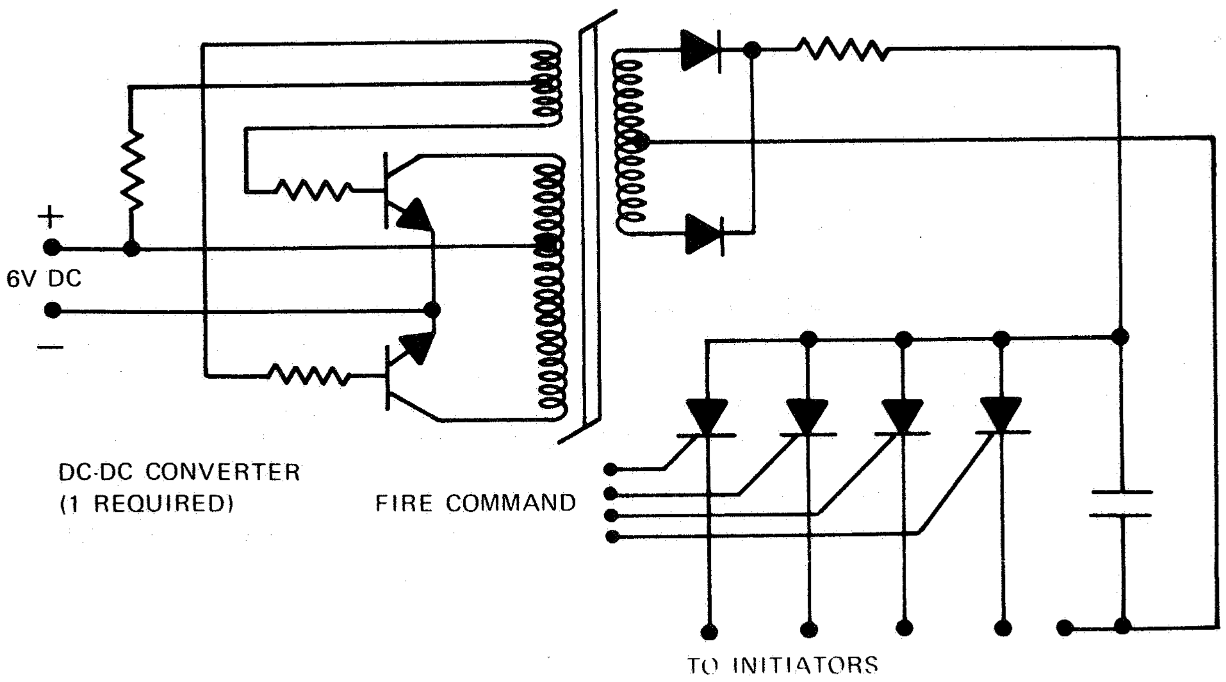
Forward Voltage Drop = 2.5 maximum at 12 amp

Forward Current = 60 amp for 1 ms

Available in bare chip form



VOLTAGE MULTIPLIER (4 REQUIRED)



DC-DC CONVERTER (1 REQUIRED)

FIGURE 22 POWER CONVERSION METHODS

Available in TO-5 can for breadboarding

JEDEC approved type number

Turn-on time of 2 microseconds maximum

Holding current = 20 ma minimum (To assure turn-off with shorted squib)

Many SCR's are available that meet the breakdown voltage and dc current requirements. The gate firing current requirement, case size and forward voltage drop requirements quickly reduced the number of devices available to two, neither of which has a JEDEC approved type number. One of these was rejected because one lead would have to be connected to the case. This left the selection to be a SCR per the specifications shown in Appendix A. Although the required minimum holding current of 20 ma is within the specified range for this SCR, the typical holding current for this SCR is 9 ma. A screening test was required for selection of SCR's with holding currents of 20 ma minimum.

4.5.2 Power Converter Transformer

A catalog survey was made to find a transformer for the dc-dc converter. All transformers that would work electrically were too large physically to be used in this installation. A transformer was designed on paper to establish requirements for purchase of a transformer to be wound specially for this application. A specially built transformer with a volume small enough to fit dimensional requirements was purchased for breadboard evaluation testing. Specifications for the power converter transformer are shown in Table XV (Reference T5).

4.5.3 Transistors

A search was made to find transistors for both the power converter and in the pulse transformer drive circuit. They should be in as small a package as possible so that bare chips would not have to be used with the breadboard circuit. The transistor selected is a 2N3904 except the packaging is a micro-miniature annular lead configuration. This package is 0.234 cm (.092 inch) diameter and 0.147 cm (.058 inch) high. The 2N3904 transistor meets all electrical requirements of the transistors in the converter and the pulse transformer drive circuit.

4.5.4 Diodes

Diodes per the specification of Appendix B were selected for all diodes in the circuit.

4.5.5 Pulse Transformer

The fire command signal generated by the ignition timer (23-004069-1) at Pin 6, Circuit A1, card No. 13948-105, is a 62.5 millisecond pulse. This signal was chosen as the interface point from the existing timer circuit to the capacitive discharge ignition circuit. Design criteria for the interface between the existing timer circuit and the capacitive discharge ignition circuit are:

(1) Provide electrical isolation (both high side and ground) from timer circuit to firing circuit.

(2) Saturate after 10 microseconds and not overheat with a 62.5 millisecond fire command pulse.

(3) Provide sufficient current to trigger the SCR.

(4) Have a minimum current drain when not firing an SCR.

(5) Minimum size

(6) Maximum current transfer efficiency

From the SCR operating characteristics and current drive available from the timer COS/MOS logic a 10 ma SCR gate turn-on signal was selected. The 10 ma gate current will give an SCR turn-on time of approximately 10 milliseconds as derived from the SCR data sheet. A 1:1 ratio pulse transformer with an open circuit primary inductance of 2 millihenries was selected as the SCR driver. The selected transformer will saturate and produce positive and negative pulses of approximately 10 microseconds duration. The negative pulse will be eliminated by the use of a diode. An encapsulated module package pulse transformer will meet the requirements as outlined. Packaging of this transformer is four separate transformers in a configuration similar to a dual-in-line package.

4.5.6 Capacitor Type (Breadboard only)

Selection of the firing capacitor type for the Breadboard design was based on size. Figure 23 shows that in the range of capacitance multiplied by rated voltage (15,000) the three candidates requiring the least volume are Tantalum Wet, Tantalum Solid, and Tantalum Foil. Tantalum Wet type capacitors require the least amount of space per unit capacitance. A Tantalum Wet slug capacitor of construction similar to Figure 24 was chosen for the breadboard evaluation testing.

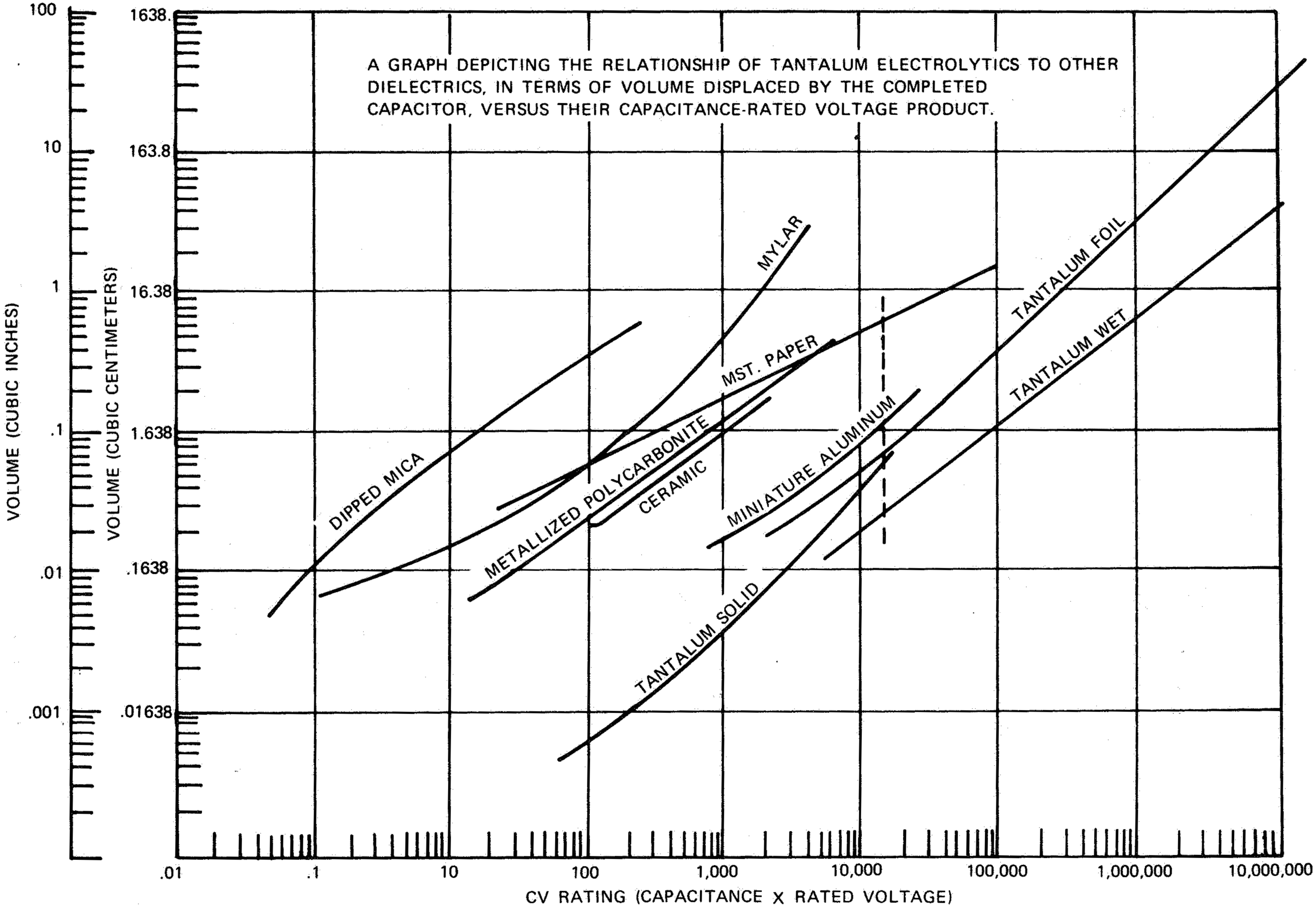
4.6 CAPACITOR SIZE VS VOLTAGE

Testing was performed at LRC to evaluate the firing energy requirement of the SBASI (paragraph 3.3.2.1). Based on results of this testing and supported by various technical reports from JPL, a minimum firing level of 34 millijoules was selected as a guide for design. The delivery of this energy to the bridgewire is a time-dependent function complicated by varying bridgewire resistance.

Several SBASI's were fired using four different sizes of capacitors charged to voltages from 49 volts down to 10 volts to find the best combination of capacitance and charge voltage (Table III). The capacitor sizes were 49.8, 233.8, 509.8 and 954.6 mfd's.

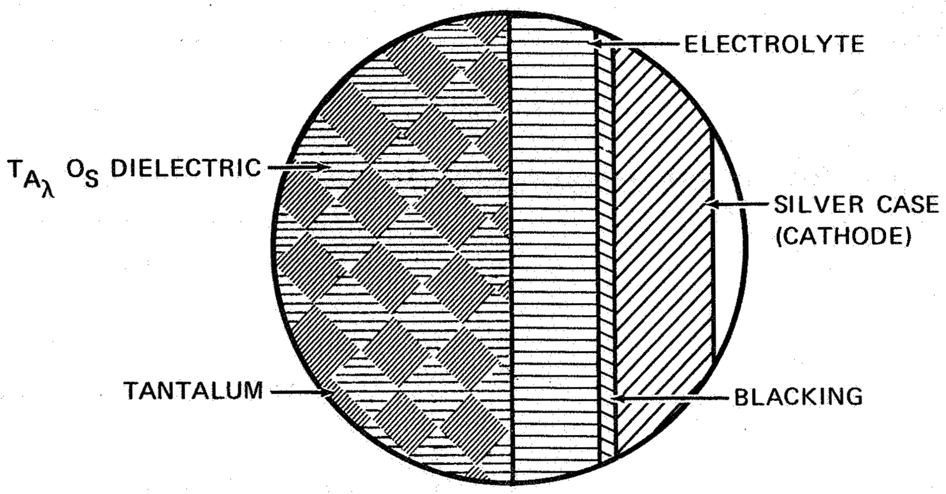
Two devices were fired from the 49.8 mfd capacitor when charged to 49.2 and 45 volts. A lower charge voltage would not provide sufficient energy to fire the device with this value of capacitance.

When using the 233.8 mfd capacitor, the lowest charge voltage that would fire a device was 20 volts. When the capacitance was increased to 509.8 mfd the minimum firing voltage changed to 15 volts but did not go lower when the capacitance was increased to 954.6 mfd. A plot of minimum charge voltage vs capacitor size in mfd is shown in Figure 4. This chart shows that any capacitance larger than 500 mfd would not allow the charge voltage to be lowered significantly. For the breadboard evaluation circuit, a standard capacitance size of 470 mfd at 30 working volts was selected. A capacitor charge voltage of 24 volts would provide sufficient energy for SBASI ignition. A safety factor of 0.8 is maintained between operating voltage and capacitor working voltage for reliability. Existing Scout firing circuit resistance is approximately 0.25 ohm plus the initiator resistance. Therefore 24 volts capacitor charge voltage will provide sufficient peak current to assure initiator firing under worst case



A GRAPH DEPICTING THE RELATIONSHIP OF TANTALUM ELECTROLYTICS TO OTHER DIELECTRICS, IN TERMS OF VOLUME DISPLACED BY THE COMPLETED CAPACITOR, VERSUS THEIR CAPACITANCE-RATED VOLTAGE PRODUCT.

FIGURE 23 CAPACITOR SIZE



WET ANODE SECTIONAL ENLARGEMENT

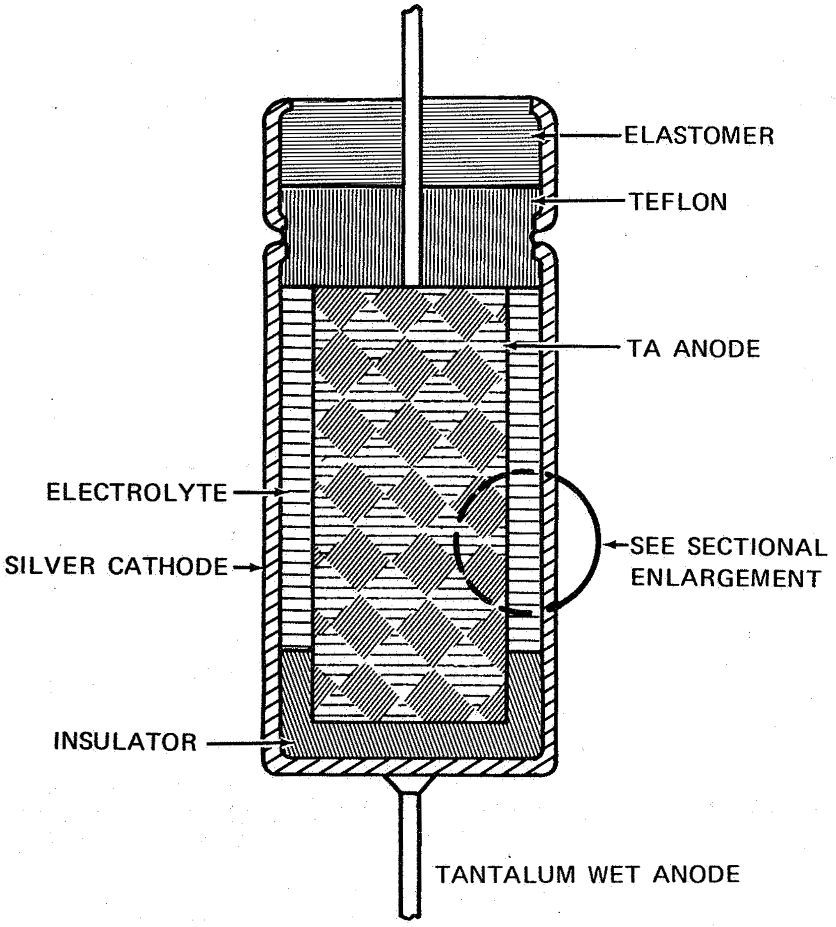


FIGURE 24 WET SLUG TANTALUM – ELASTOMER SEAL

conditions. The energy level provided by a 470 mfd charged to 24 volts is as follows:

Nominal Energy: (470 mfd capacitor)

$$Q = \frac{E^2C}{2} = 135 \text{ millijoules (mj)}$$

Worst Case (Temperature and capacitor tolerance, constant voltage)

$$Q = 176 \text{ mj maximum}$$

$$Q = 108 \text{ mj minimum}$$

The minimum energy calculated above shows an energy reserve of 71 mj when compared to the JPL data of reference 3 (37 mj required for ignition).

4.7 SAFE-ARM DESIGN

Safe-arm considerations for the capacitive discharge ignition system were:

(1) Personnel safety while connecting firing unit to initiator

(2) Fail safe mode with power off

(3) Reliable components

(4) Capability to allow initiator checkout

(5) Maintain or exceed reliability concepts used in existing firing circuit

(6) Minimum system weight without sacrificing safety

(7) Provide method of verifying capacitor charge voltage in the safe position.

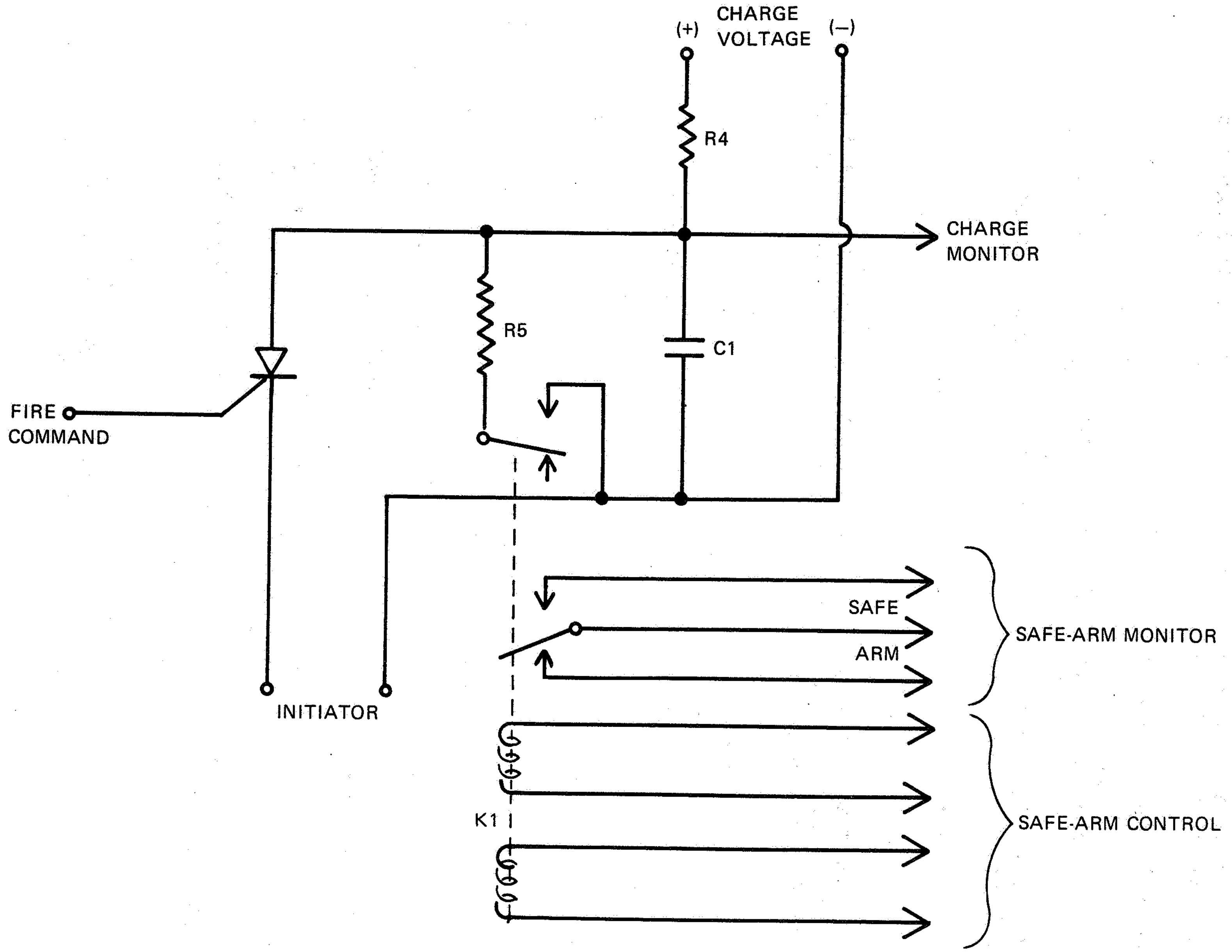


FIGURE 25 SAFE-ARM CIRCUIT

A schematic of the method chosen for the safe-arm function is depicted in Figure 25. Safe-arm relay K1 is selected to the safe or armed position from an external source. A magnetic latch on the relay contacts provides a fail safe means of locking the relay to the selected position. The relay is a double-pole, double-throw, type with one set of contacts used for the safe-arm function and the other set used to provide external means of monitoring relay position.

In the safe position a 348 ohm resistor R5 is shorted across the firing capacitor C1. Resistor R5 provides a means of discharging the firing capacitor without damaging the relay contacts. The resistance value was chosen in relation to the charge resistor R4 to allow a 3 volt charge across the firing capacitor for a final countdown firing circuit check. It is possible to monitor the capacitor charge voltage while triggering the firing SCR through the ignition circuit with the relay in the safe position.

4.8 BREADBOARD CIRCUIT DESIGN

The functional blocks of Figure 21 were detailed with specific components and circuits as shown in Figure 26. This circuit was evaluated in the breadboard testing.

4.8.1 Packaging

Prime consideration in the design trade-off associated with the Scout fourth stage CDI system was packaging in order to achieve weight reduction. A review of existing fourth stage Scout ignition circuit (reference paragraph 4.1) indicated that any significant weight reduction would have to be by elimination of ignition batteries and/or the safe-arm package. The proposed capacitive discharge ignition system could be built on a printed circuit board the same size and mounting as existing timer (23-004069-1), board number three (13948-105). Further investigation revealed that sufficient power is available from the existing timer battery for operation of the capacitive discharge ignition system. Based on the weight saving and the ability to design the system without compromising functional aspects of the existing firing circuit, packaging internal to the existing timer, Figures 27 and 28, was chosen.

After design and component selection was completed, it was determined that discrete components could be packaged on existing timer board number 3 for the breadboard evaluation (Figures 28, 29 and 30), provided that the extended capacitance wet slug capacitor was used.

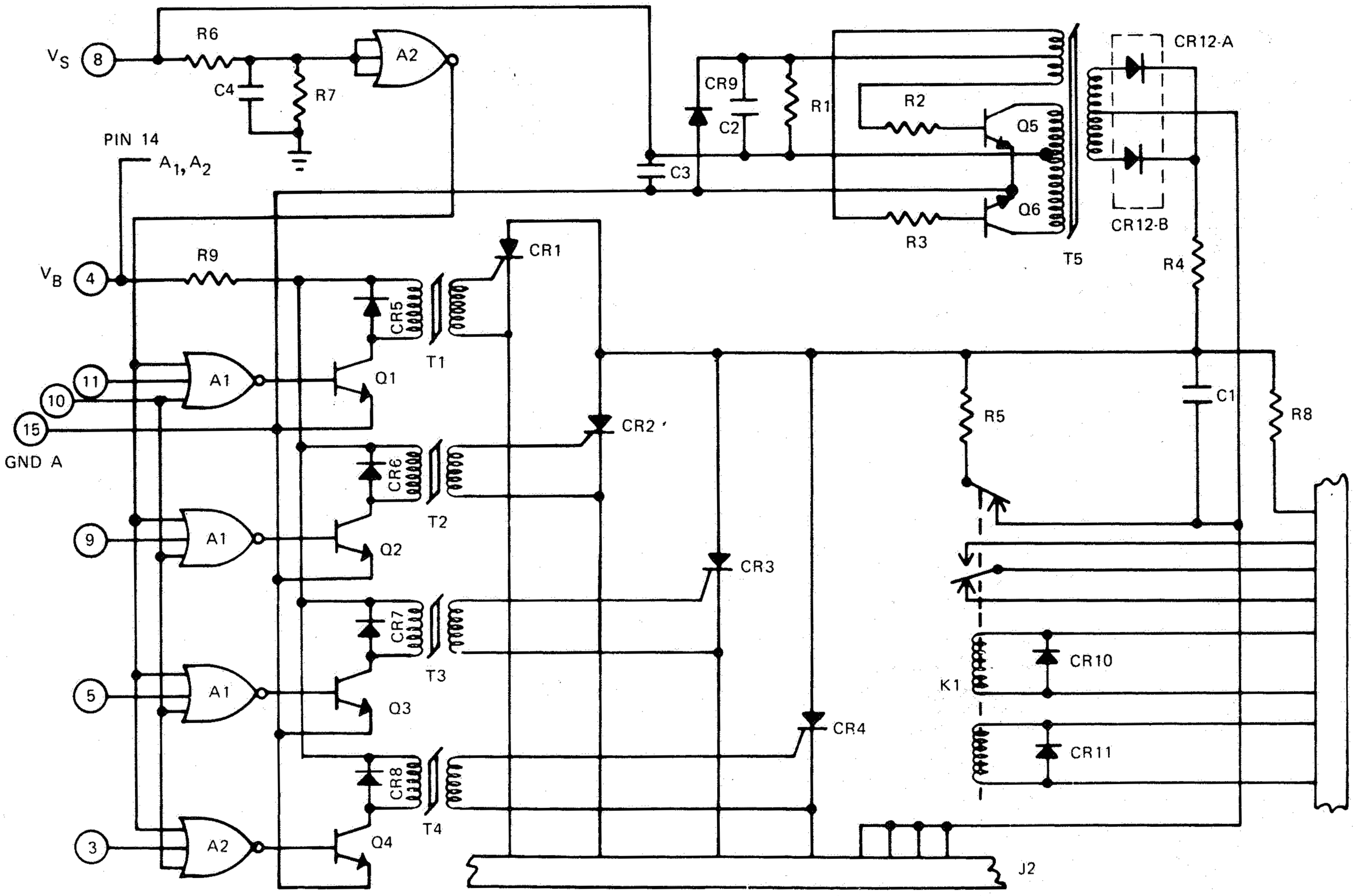


FIGURE 26 BREADBOARD CIRCUIT

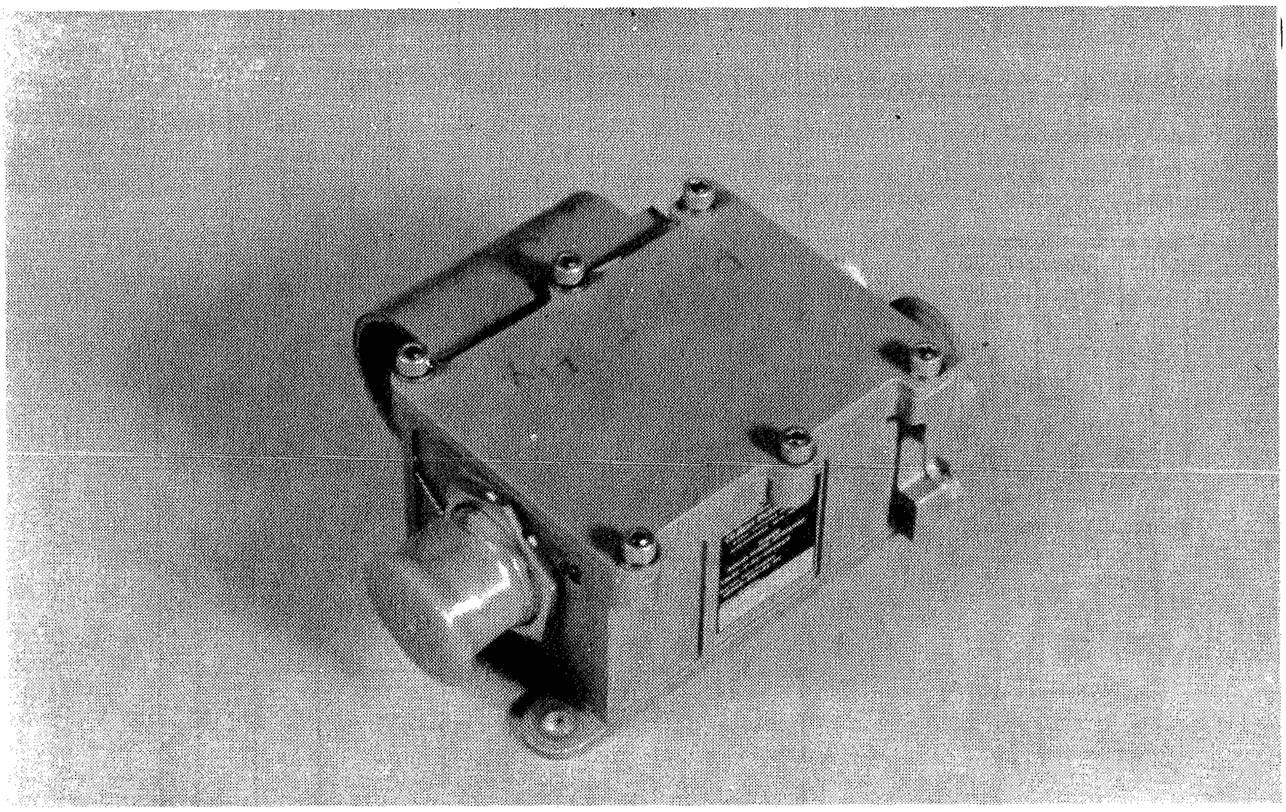


FIGURE 27   SCOUT FOURTH STAGE TIMER

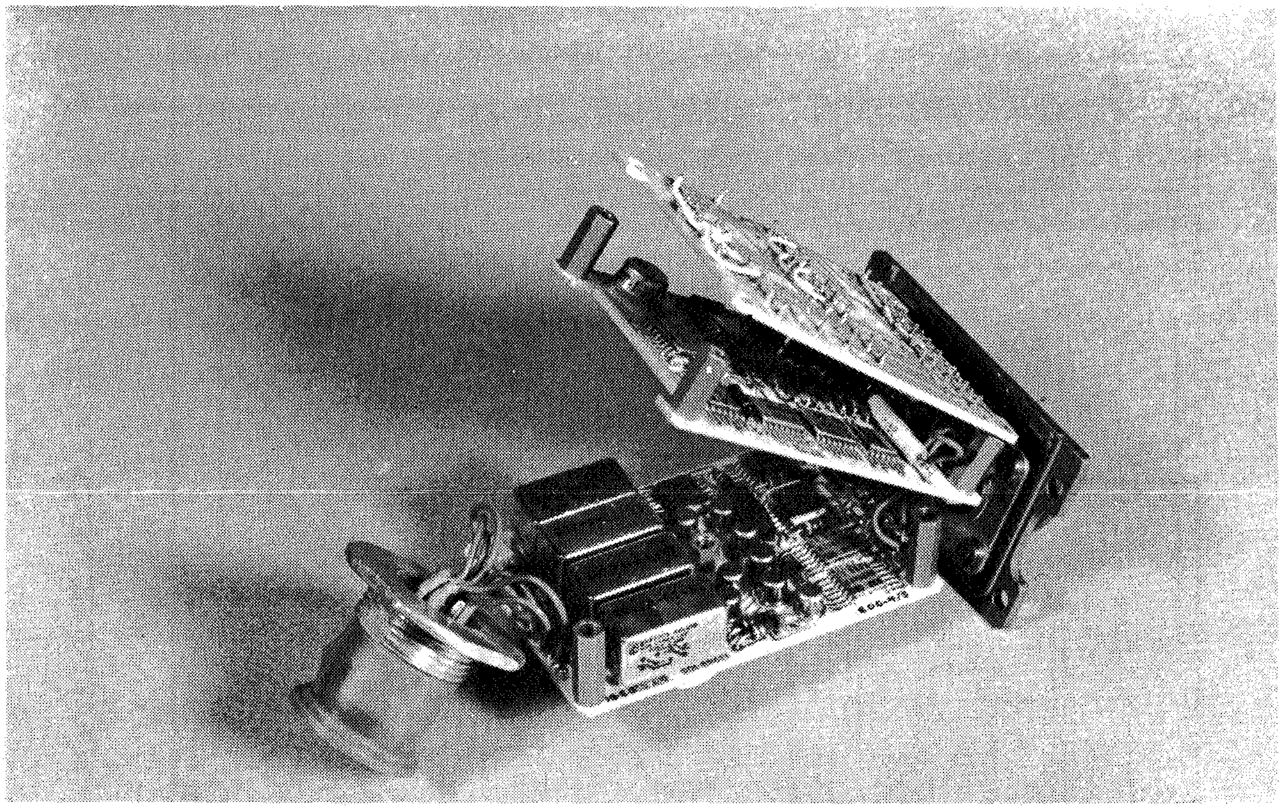


FIGURE 28 SCOUT FOURTH STAGE TIMER – INTERNAL VIEW

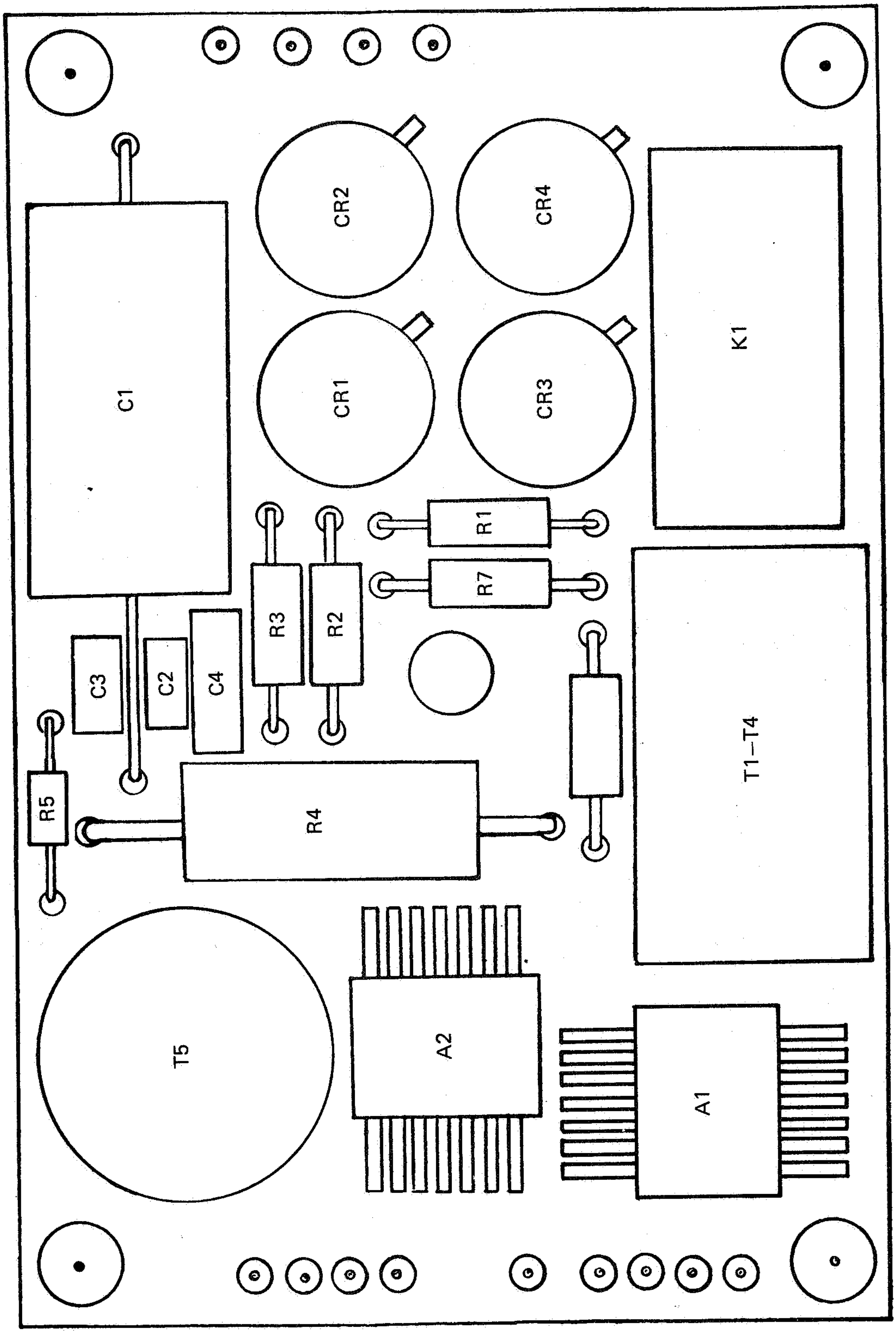


FIGURE 29 CDI BREADBOARD LAYOUT

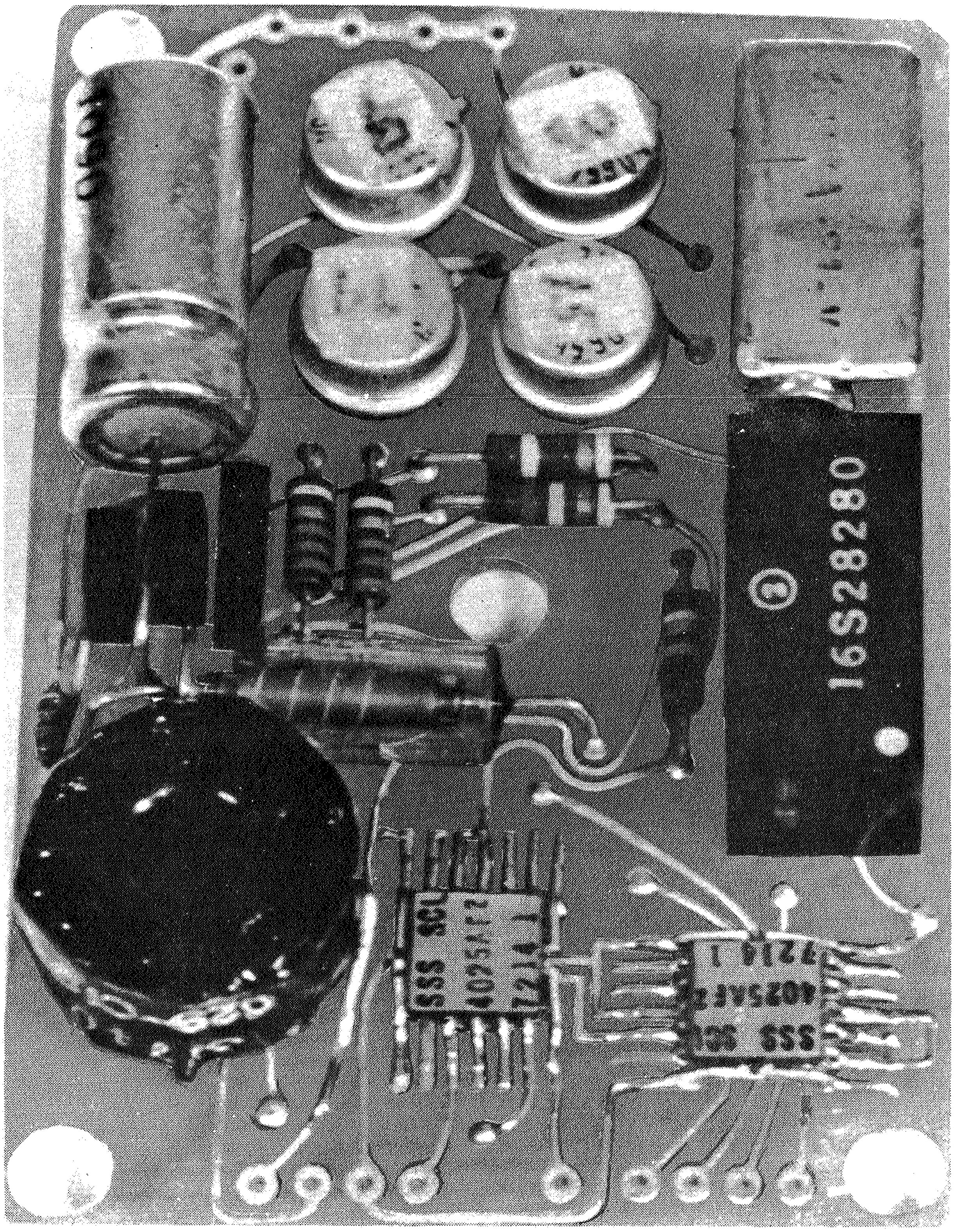


FIGURE 30 CDI CIRCUIT BOARD

4.9 WEIGHT

Since a weight reduction in the fourth stage payload separation system increases payload capability by the same amount, the decreased weight of the CDI system to the existing system was based on actual weights whenever possible. An example of the method of determining component weights that were estimated is the connector weight. Nine connectors weighing a total of 0.354 kg (0.78 pound) are used in the existing system, four of these are eliminated in the CDI design; therefore, CDI connector weight = 0.354 - (0.354 x 4/9) = 0.195 kg (0.43 pound).

Comparison of the weight of the existing fourth stage payload separation system versus the CDI system is shown in Table VIII. The indicated weight saving of 1.95 kg (4.30 pounds) will result in 1.95 kg (4.30 pounds) of additional payload capability. The balance of the module ring assembly can be maintained by adjusting the location of components on the module ring.

4.10 RELIABILITY TRADE-OFF EVALUATION

4.10.1 General

The reliability design goal for the Scout Fourth Stage Capacitive Discharge Ignition (CDI) System was that "No Degradation of Reliability" of the existing ignition system occur as a result of the CDI design. The objective of the Reliability Trade-off Analysis was to evaluate the CDI design with respect to the existing ignition system to determine if the CDI design is consistent with the reliability goal. The evaluation was performed by identifying the inherent reliability characteristics of the existing and CDI systems and comparing them for relative superiority. As used herein, the term "ignition system" shall be taken to mean one member of the redundant pair of ignition systems used to initiate Scout fourth stage payload separation events by firing SBASI's. Only one member of the redundant pair was evaluated (as opposed to both members as a unit) for simplicity and because they are identical. The present ignition system, which employs the ignition timer (or sequencer) is referred to herein as the "existing ignition system" or the "existing system".

The Reliability Trade-off Analysis included both a quantitative and qualitative reliability evaluation of the two ignition system designs. The quantitative evaluation was performed so that a strictly numerical ignition system reliability comparison could be obtained. The qualitative

TABLE VIII WEIGHT COMPARISON

TIMER 1	0.357	(0.787) WITH BATTERY	0.355	(0.783*)
TIMER 2	0.357	(0.787) WITH BATTERY	0.355	(0.783*)
SAFE/ARM RELAY ASSEMBLY	0.327	(0.72)	(0)	(INCLUDED IN TIMER)
COMPONENT MOUNTING BRACKETS	.821	(1.81)	.494	(1.09)
CONNECTORS	.354	(0.78)	.195	(0.43)
WIRE	.222	(0.49)	.190	(0.24)
MISC. HARDWARE (CLAMPS, ETC.)	.045	(0.1)	.023	(0.05)
FIRING BATTERY NO. 1	.499	(1.1) CHARGED	0.00	(0.00) USES TIMER BATT.
FIRING BATTERY NO. 2	.499	(1.1) CHARGED	0.00	(0.00) USES TIMER BATT.
	3.481 KG	(7.674 POUNDS)	1.331	(3.376 POUNDS)
WEIGHT SAVING = 3.481 – 1.531 = 1.95 KG (4.298 POUNDS)				

*ACTUAL WEIGHT OF BREADBOARD MODIFIED TIMER WITH BATTERY evaluation was performed to provide a comparison of the qualitative reliability features which each system contains. These qualitative features are those design characteristics which enhance or degrade the probability that the predicted inherent system reliability will be realized. No quantitative reliability value can be assigned to the system's qualitative characteristics. However, they can be ranked relative to similar characteristics in another system. These qualitative features may also reflect any extraordinary elements or characteristics which would enhance or degrade the reliability in a manner not reflected in the reliability prediction.

4.10.2 Quantitative Evaluation

The quantitative evaluation was performed by means of piece-part reliability predictions for the CDI system and the existing system. The prediction methodology employed was the same for each of the contending systems. The failure rates employed during the predictions was the same for equivalent component types in either system. By employing the same methodology and equivalent part failure rates during predictions, the resultant reliability values represent relative inherent reliability differences between the systems and assures a representative comparison.

The piecepart failure rates used for the prediction were obtained from Reference 4 and previous scout reliability studies. The electronic parts failure rates were obtained from Reference 4. Failure rates for the other components were obtained from previous scout studies and applicable manufacturer's data.

Figure 31 presents the reliability block diagrams and the corresponding reliability calculations. The individual block diagram's success probability values were calculated in the manner shown below.

$$R_X = e^{-\lambda_X t} = \text{Reliability of Block "X"}$$

Where: $\lambda_X = \sum_{i=1}^{m} k_i n_i \lambda_i$

k_i = Environmental Modifier for the $i^{\underline{th}}$ Component (From MIL-HDBK-217A, Reference 4)

λ_i = Failure Rate for the $i^{\underline{th}}$ Component

t = 0.234 hr. (14 min.) Mission Time (From Typical Scout Mission Profile)

e = Base of Natural Logarithms (2.718)

i = An Index Variable (Values: 1, 2, . . ., m-1, m)

n_i = Number of Components of the $i^{\underline{th}}$ Component Type

m = Number of Component Types in Block "X" (Block "X" is Any Block)

The system reliability calculations are shown in Figure 31. Additionally, Figure 31 presents the calculation of the expected improvement in the "per mission failure rate" (the rate of ignition system failures). This ratio gives a figure-of-merit indicating the degree of reliability improvement expected for each member of the redundant pair of fourth stage ignition systems.

The results of the reliability prediction indicate an inherent reliability value of 0.99990 for the CDI system. This value compares favorably with the value 0.99986 predicted for the existing ignition system. The expected improvement in the per mission failure rate is 30.7%. These results indicate that the CDI design is consistent with the reliability goal of "no degradation".

4.10.3 Qualitative Evaluation

The qualitative factors evaluated during the trade-off analysis are indicated in Table IX. The factors were evaluated to the extent of comparing significant differences between the two ignition systems.

4.10.3.1 Complexity Comparisons

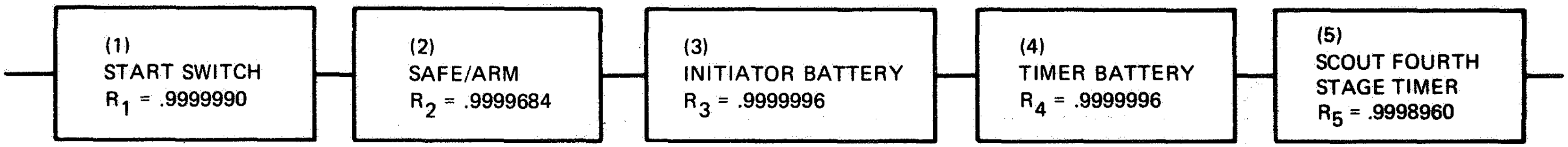
An evaluation of relative complexity between the existing system and the CDI design was performed. The evaluation was separated into three categories:

(1) Functional Complexity

(2) Component Count

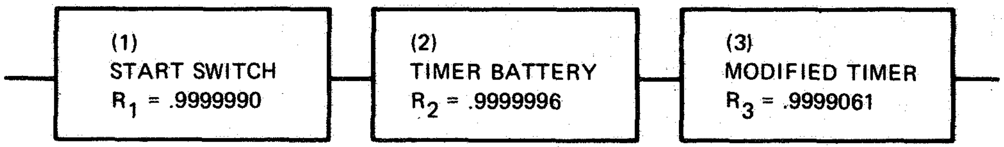
(3) Component Complexity

Each of these three categories of complexity have an impact on system reliability. It is usually difficult or impossible to fully reflect this impact in a quantitative manner. The qualitative complexity evaluation provided herein was intended to augment the quantitative evaluation previously discussed. The



EXISTING IGNITION SYSTEM

$$R_{ES} = \prod^{5} R_i = (.9999990)\ (.9999684)\ (.9999996)\ (.999996)\ (.9998960) = \underline{.9998626}$$



CAPACITIVE DISCHARGE IGNITION SYSTEM

$$R_{CDI} = \prod^{3} R_i = (.9999990)\ (9999996)\ (.9999061) = \underline{.9999047}$$

$$\text{RATIO OF PER MISSION FAILURE RATES} = \frac{\lambda_{CDI}}{\lambda_{ES}} = \frac{1-R_{CDI}}{1-R_{ES}} = \frac{1-.9999047}{1-.9998626} = 0.893$$

EXPECTED IMPROVEMENT = 1.0 −0.693 = 30.7%

FIGURE 31 RELIABILITY BLOCK DIAGRAMS AND PREDICTION

TABLE IX QUALITATIVE RELIABILITY EVALUATION FACTORS

COMPLEXITY COMPARISONS
- FUNCTIONAL COMPLEXITY
- COMPONENT COUNT
- COMPONENT COMPLEXITY

GENERAL RELIABILITY COMPARISONS
- CHECKOUT CAPABILITY
- ENVIRONMENTAL CONSIDERATIONS
- INITIATION DATA
- EXPERIENCE

complexity comparison was performed by identification and evaluation of the specific complexity differences between the two ignition systems. The results of the evaluation were indicated by the ranking of one system or the other as superior (more reliable) in each complexity category.

4.10.3.1.1 Functional Complexity

The evaluation of functional complexity resulted in identification of the principal functional complexity differences between the existing system and the CDI system. The significance of these differences is that the number of critical failure modes is reduced in proportion to any decrease in functional complexity. There are two principal differences between the two ignition systems. The first occurs as a consequence of the method used to terminate ignition current on the redesigned Timer Board No. 3 for the CDI design. Specifically, the existing system employs relays to perform each of the contact closures which cause power to be applied to the initiators. Subsequent to each initiator firing the corresponding relay resets in response to timer logic commands. The reset state terminates any remaining current which will flow in the event that the expended initiator has shorted. The CDI system employs SCR's to perform the power switching and current termination functions. The functional difference between the two implementations is in the current termination function. Unlike the existing system, the CDI does not require a timer command to terminate the residual ignition current. Instead, the current termination function occurs spontaneously when the initiator current drops below the minimum dc holding current value for the SCR. The spontaneous occurrence of this current termination switching function in the CDI system eliminates those failure modes which could prevent current termination in any or all of the four ignition channels of the existing system. This elimination of failure modes enhance the CDI reliability relative to the existing system.

The second area of functional complexity difference between the contenting ignition systems occurs as a consequence of the requirement in the CDI design to increase the supply voltage applied to the fire capacitor. This function is performed by the dc-dc converter (see Figure 26). No converter is required in the existing ignition system because the required voltage is supplied by a separate battery. The absence of a converter in the existing system enhances its reliability relative to the CDI system.

One of the principal functional differences between the ignition systems favors the CDI system. The other difference favors the existing system. The net result is deemed to be that the differences are offsetting and neither system was given an advantage in this particular complexity category.

4.10.3.1.2 Component Count Complexity

A Component Count Complexity comparison was made comparing the number of components required to perform identical system functions in the existing and CDI systems. The principal ignition system areas affected by changes due to the CDI design are:

(1) Elimination of the existing initiator battery at the system level.

(2) Simplification of the safe-arm mechanization by performing the safe-arm function with one relay instead of two.

(3) Simplification of the ignition function component mechanization by performance of the ignition functions with fewer components.

The specific reductions in component count complexity are given by Table X. These reductions result in a corresponding decrease in the number of critical failure modes. This results in reliability improvements of the CDI relative to the existing system.

4.10.3.1.2.1 Safe-Arm Component Count

As indicated by Table X, the CDI performs the safe-arm function with one relay. The existing system's safe-arm function requires two relays. This reduction significantly decreases the number of spurious contact closures, chatter failures or contamination induced failures which can occur during flight. Enhancement of system reliability can be expected as a result of the CDI safe-arm function simplification.

4.10.3.1.2.2 Ignition Function Component Count

The components assumed herein to correspond to performance of the ignition functions are: (1) the ignition battery (part of the existing system) and (2) those components on timer board number 3 (which was redesigned for the CDI timer configuration). The principal ignition function component count complexity differences are those listed in Table X. The elimination of the requirement for a specific battery dedicated to firing the initiators results in operational improvements and reliability enhancement. The decreased component count on the redesigned timer board will result in some decrease in the

TABLE X COMPONENT COUNT COMPLEXITY COMPARISONS

I. SAFE/ARM FUNCTION COMPONENT COUNT
- EXISTING SYSTEM REQUIRES: TWO RELAYS (5 CONTACT SETS)
- CDI SYSTEM REQUIRES: ONE RELAY (2 CONTACT SETS)

II. IGNITION FUNCTION COMPONENT COUNT

A. IGNITION BATTERY
- EXISTING SYSTEM REQUIRES: 1 BATTERY
- CDI SYSTEM REQUIRES: NONE

B. SCOUT FOURTH STAGE TIMER BOARD NO. 3 (13948-105)
- EXISTING SYSTEM REQUIRES: 36 COMPONENTS
- CDI SYSTEM REQUIRES: 31 COMPONENTS

number of critical failure modes inherent to the CDI as compared to the existing system. This complexity category advantage favors the CDI system design.

4.10.3.1.3 Component Complexity

The complexity of the individual components is also a factor which affects inherent reliability. In the case of the CDI system vs the existing system, most of the components used are of approximately equal complexity. The single exception to this occurs in the comparison of the relay ignition switches of the existing system versus the SCR ignition switches employed by the CDI design. Each of the relays which are used in the existing design to perform the ignition and current termination switching functions are replaced by an SCR in the CDI design. These relays are considerably more complex than the SCR's of the CDI design. They are a relatively complex assemblage of coils, mechanical contacts, interconnections and mounting structure. This complexity is considerable as compared to that of the SCR which is a solid state device with no moving parts. The lower complexity of the SCR's will result in a decrease in the number of ignition system critical failure modes in the CDI and thereby enhance this system's reliability relative to the existing system.

4.10.3.2 General Reliability Comparisons

The general reliability comparisons performed during the qualitative evaluations fell into four categories as presented in Table XI. The evaluation of the contending ignition systems was performed so as to identify the significant differences in each category. The results of the evaluation are a ranking assessment of one system or the other as superior (more reliable) in each category. The significance of a superior ranking in any one of the categories is a higher probability of achievement of the inherent reliability of the corresponding system. As in the case of the "complexity comparisons", these "general comparisons" are of a nature which makes a full assessment of their quantitative contribution to reliability difficult or impossible to make. However, the relative ranking which was obtained provides the necessary information for a qualitative trade-off.

4.10.3.2.1 Checkout Capability

The ground checkout capability of the ignition system provides knowledge about the functional integrity of the system. The nearer this ground checkout approximates the flight functions and configurations, the closer this checkout will approach a complete verification of the system. Greater system

TABLE XI GENERAL RELIABILITY CONSIDERATIONS

CHECKOUT CAPABILITY

- EXISTING SYSTEM – LIMITED CHECKOUT ON PAD
- CDI SYSTEM – CAN SIMULATE A COMPLETE EVENT SEQUENCE WHILE IN THE FLIGHT CONFIGURATION

ENVIRONMENTAL CONSIDERATIONS

- VIBRATION – CDI MAY BE SOMEWHAT LESS SUSCEPTIBLE DUE TO MINIMAL DEPENDENCE ON RELAYS. IGNITION SYSTEM CAN BE SUBJECTED TO PRE-FLIGHT VIBRATION
- SCR'S ARE KNOWN TO BE SOMEWHAT SENSITIVE TO EMI AND SYSTEM TRANSIENTS
- NO OTHER EXPECTED SIGNIFICANT DIFFERENCE IN ENVIRONMENTAL SUSCEPTIBILITY

INITIATION DATA

EXPERIENCE

flight reliability will result from a more comprehensive ground checkout because a higher percentage of potential failure modes can be checked for during the countdown.

In the case of the CDI, checkout capability exists to perform a very comprehensive system verification. This capability will permit simulation of a complete ignition sequence in the flight configuration (after installation and mating of all flight hardware). This simulation will include the application of "no fire" energy pulses at the initiators. The "no fire" pulses result when the system functions with the safe-arm relay in the "safed" condition wherein a reduced voltage is applied to the firing capacitor. System checkout is performed by a monitoring voltage on the firing capacitor. The voltage signal obtained from this monitor during the simulated ignition sequence contains all the information necessary to verify proper function of the system. The information includes: capacitor charge voltage, circuit continuity, RC time constant and event times. Any deviation in the expected values of these parameters will indicate the existence of an ignition system failure mode. After the ignition sequence check is complete, the system is "armed" and positive verification of the "armed" state can be observed at the firing capacitor voltage monitor.

Ground checkout capability of the existing ignition system is somewhat less complete. The ignition sequence cannot be simulated with the initiator firing battery installed without firing the initiators.

Due to its superior checkout capability, the CDI system must be ranked above the existing ignition system in the checkout category.

4.10.3.2.2 Environmental Considerations

An evaluation of environmental characteristics was performed for each of the ignition systems. The evaluation resulted in identification of potential problem areas related to component environmental susceptibility. This type of evaluation results in determination of areas of potential design risk. The potential risks are typically treated by designer emphasis during the design phase and testing emphasis during the test phase. Continued effects after design and testing can sometimes be observed in the magnitude of the reliability achieved by the system or the number of rejected systems screened through production testing. The overall effect on reliability and/or cost is not always predictable. The objective of the evaluation documented herein was to identify possible areas of different risks inherent to each ignition system due to the different components used.

As a result of the evaluation of the inherent susceptibility of the components used in each of the designs it was determined that each design contained one component type which would cause that system to be subject to a potential environmental susceptibility which was different from the other ignition system design. The components involved are: ignition relays in the existing design and SCR's in the CDI design. The environments involved are vibration in the case of relays and EMI/System transients in the case of the SCR's. The relays will cause the existing ignition system to be potentially somewhat more susceptible to vibration induced failures and the SCR's will cause the CDI system to be potentially somewhat more susceptible to EMI/System transients. Design emphasis and adequate testing are expected to provide adequate solutions to both of these potential problems but a risk of environmentally induced failures and/or system screening rejections does exist for each type of ignition system.

No trade-off advantage was identified for either the existing system or the CDI System as a consequence of the different types of environmental risks identified. These potential risks were assumed to be offsetting (of equal trade-off rank). It must be noted, however, that the potential risk of EMI/transient problems will require that adequate testing of the CDI System against these environments be performed. Those tests were performed during the qualification testing of the existing system.

4.10.3.2.3 Initiation Data

Prior to the recent advent of initiator firing by transient techniques (pulse initiation), constant current initiation was the conventional method. Normally, initiator firing characterization is given in terms of "all fire" and "no fire" parameters. The SBASI initiator "all fire" and "no fire" constant current characterization data are presently available. These constant current parameters are based on comprehensive Bruceton tests involving large statistical samples of SBASI's. The Scout CDI feasibility program has performed testing which generated data from which pulse energy "all fire" SBASI characterization was derived. During these CDI tests, the firing energy was gated until the minimum firing energy was found below which no initiation would occur. The smallest value of energy at which SBASI firing did occur was 33.8 millijoules. As compared to the constant current sample size, the CDI testing sample size was small and does not justify a high statistical confidence value. However, independent testing performed by the Jet Propulsion Laboratory (JPL) and documented in Reference Number 2 indicates an "all fire" sensitivity of 37.2 millijoules. These results are consistent with the CDI testing in that the pulse "all fire" values derived are of the approximate same magnitude. These results plus the fact that the Scout CDI design will deliver no less than 108 millijoules under worst case firing conditions are consistent with a high level of confidence in the CDI design for firing the SBASI initiators.

The highest firing capacitor charge voltage possible for the CDI design will not exceed 30 volts. This voltage level will not cause dudding of the SBASI initiators when fired by CDI. This conclusion is based upon tests at LRC wherein successful SBASI firings were performed with the firing capacitor charged to 49 volts (40.2 amps peak). In addition, the dudding phenomenom was investigated in more than 100 tests by Jet Propulsion Laboratory (Reference 2) and found not to be a problem at firing amplitudes as high as 160 amps. Comparison of these peak current values indicates a considerable margin of safety for the CDI design for an overvoltage or overcurrent consideration.

No CDI testing was performed during the program for the purpose of obtaining the SBASI "no fire" pulse characteristics. However, the CDI design will deliver only 2.1 millijoules to the SBASI initiators during ground checkout. Although this energy is deemed to be small enough to assure that the initiators will not fire during checkout, it is necessary to obtain test data to verify that high confidence "no fire" conditions will exist during checkout. The Viking Program has obtained some "no fire" data and it was made available to VSD for evaluation.

The evaluation of the Viking Program "no fire" data received by VSD does not indicate that the CDI design "no fire" levels are inappropriate. However, the Viking data was apparently obtained in such a way that additional data will be required to fully support the CDI design to a sufficient level of confidence in the "no fire" (checkout) mode of operation.

Although there is considerably more constant current firing data available, which is applicable to the existing system's initiator firing technique, the pulse initiation method is deemed to have adequate data supporting the flight critical initiation mode of operation. For this reason no trade-off advantage has been given to the existing system in this trade-off category. All available information indicates the CDI checkout characteristics provides insufficient energy for SBASI ignition but additional testing must be performed in order to establish this to a high level of confidence. Further, it appears that only slight modifications of the CDI parameters would be necessary should subsequent "no fire" data indicate an energy value lower than 2.1 millijoules is required.

4.10.3.2.4 Experience

In the experience category, the existing system must be assigned a trade-off advantage over the CDI design. This advantage of experience is due to the great amount of constant current type system experience available as compared to the presently limited amount of CDI type system experience available to the industry.

4.10.4 Reliability Trade-Off Summary

The summary of results of the reliability trade-off evaluation between the CDI system and the existing system are presented in Table XII. The check marks in the table indicate which of the contending systems is deemed superior in each of the evaluation categories. As indicated by the table, the CDI was found superior in 6 of the 10 evaluation categories. These overall reliability trade-off results favor the CDI design as superior to the existing system. This is consistent with the design goal of no reliability degradation.

The three evaluation elements in Table XII which favor the existing system are EMI/Transient Susceptibility, Converter Function and Experience. None of these areas of potential advantage for the existing system are deemed to imply a problem area for the CDI system. The EMI/Transient Susceptibility and Converter Function elements are offset by an equivalent advantage in the CDI system column. The experience element although significant is partially offset as several other CDI systems have been built, tested and flown. The Viking LPCA and Viking Orbiter "75" CDI systems have been qualified for flight.

In conclusion, the reliability trade-off results indicate the CDI system design has achieved the reliability goal established for the feasibility program. The CDI system quantitative reliability prediction indicates an inherent reliability value slightly greater than the existing system. The qualitative evaluation did not reveal any problem area which is likely to prevent the realization of the predicted reliability value.

TABLE XII RELIABILITY TRADE-OFF SUMMARY

IGNITION SYSTEM / EVALUATION CATEGORY	SUBCATEGORY	SUBCATEGORY DETAIL	CDI SYSTEM	EXISTING SYSTEM
RELIABILITY PREDICTION			√	
COMPLEXITY	FUNCTIONAL COMPLEXITY	CURRENT TERMINATION	√	
		CONVERTER FUNCTION		√
	COMPONENT COUNT		√	
	COMPONENT COMPLEXITY		√	
GENERAL RELIABILITY CONSIDERATIONS	CHECKOUT CAPABILITY		√	
	ENVIRONMENTAL CONSIDERATIONS	EMI/TRANS.		√
		VIBRATION	√	
	INITIATION DATA FOR SBASI'S		*EVEN	*EVEN
	EXPERIENCE			√

*SINCE ADEQUATE DATA IS AVAILABLE SUPPORTING CDI INITIATOR TECHNIQUE, THERE IS NO TRADEOFF ADVANTAGE FOR EXISTING SYSTEM. (SEE TEXT PARAGRAPH 4.10.3.2.3)

5.0 EVALUATION TEST RESULTS

The circuit described in paragraph 4.8 was assembled on a vector board and electrically connected to the ignition timer. The breadboard was functionally tested and evaluated for compatibility with the timer. The circuit was then incorporated on a new printed circuit board to replace Board #3 in the ignition timer and tested further. The tests were conducted at Langley Research Center.

5.1 SCR AND PULSE TRANSFORMER TESTS

From twenty SCR's the four with the highest holding current were selected for installation in the test circuit. The circuit was set-up as shown in Figure 32.

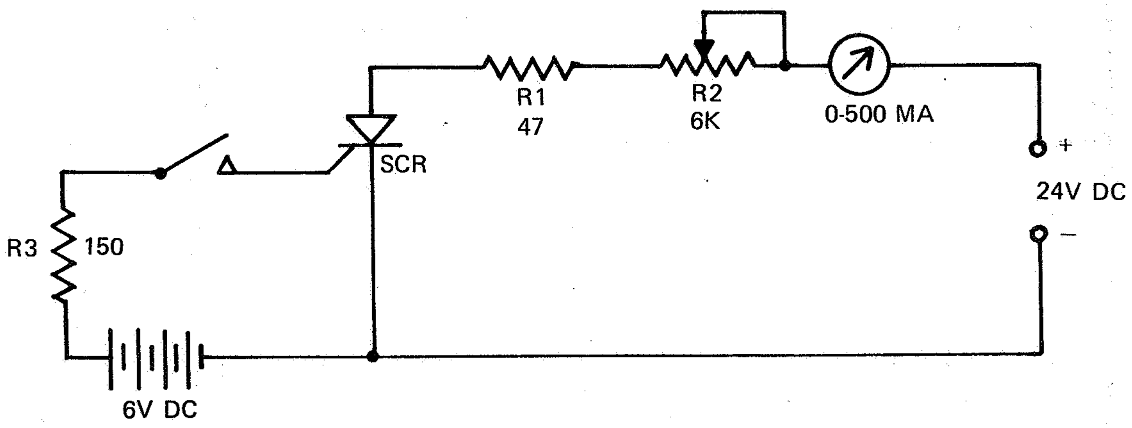


FIGURE 32 SCR HOLDING CURRENT-TEST CIRCUIT

Resistor R2 was first adjusted for zero resistance. The SCR was triggered "on" and then R2 was increased until the SCR was shut off. The current just prior to shut off was recorded as the holding current. The test was repeated three times. The results are shown in Table XIII.

TABLE XIII SCR HOLDING CURRENTS

SCR NUMBER	RUN 1	HOLDING CURRENT IN MA RUN 2	RUN 3
1	8	8	8
2	5.5	6	6
3	7	7	7
4	3.8	3.8	3.8
5	3.8	3.8	3.8
6	11.5	11.5	11.5
7	9	9.3	9.3
8	5.5	5.5	5.5
9	17	16.5	17
10	4.5	4.5	4.5
11	5.2	5.2	5.2
12	5.2	5.2	5.2
13	8.2	8.2	8.2
14	4	4	4
15	9.2	9.2	9.2
16	7.9	7.9	7.9
17	8	7.9	7.8
18	4	4	4
19	8	8	8
20	3.8	3.8	3.8

A pulse transformer and SCR were connected as shown in Figure 33 to determine the minimum drive to the pulse transformer that would fire the SCR.

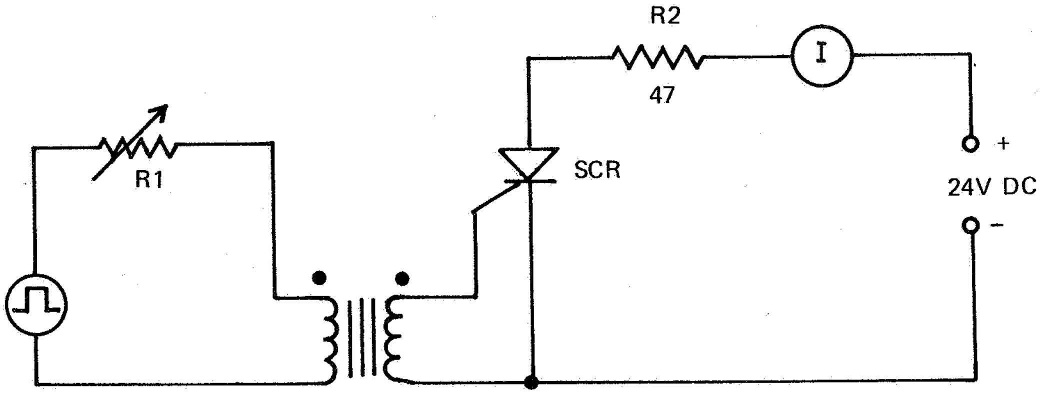


FIGURE 33 PULSE TRANSFORMER TEST CIRCUIT

The circuit was driven by a square wave pulse that had an amplitude of 6 volts, a duration of 10 microseconds and a rise time of 0.5 microsecond. The resistance of R1 was 1200 ohms initially and then was lowered in resistance until the SCR fired. Four different SCR's were tested. The maximum value of R1 for SCR firing is shown below:

SCR Number	6	9	15	7
R_1 in ohms	630	370	780	590

This test showed that the highest minimum drive current was 16 milliamperes. The pulse transformer vendor stated that the transformer could stand 250 milliamps for 1 second; therefore the drive current to the transformer should be between 16 and 250 milliamps. SCR's with higher holding currents require higher trigger currents.

5.2 EXPERIMENTAL BREADBOARD

Fuse clips were attached to the experimental breadboard so that one-fourth amp and one-half amp fuses could be used as loads simulating SBASI's. A control panel was also attached to the experimental breadboard to provide arm-safe control and indication and provide a timer start switch. Each one-fourth amp fuse had a resistance of about 3 ohms and each one-half amp fuse had a resistance of about 1 ohm which is approximately the resistance of a SBASI.

The lower board was removed from the timer and the experimental breadboard circuit was tied into the other two boards in the timer. A photograph of the experimental breadboard and the timer interconnection is shown in Figure 34. The interconnection circuit diagram is shown in Figure 35. Six-volt power to the dc-dc converter was initially supplied through diode CR3 on middle board No. 13948-107. The additional load of the converter burned out the diode. The diode was replaced and the converter load was tied in ahead of the diode. The circuit shown in Figure 35 includes this change.

Output voltage from the dc-dc converter was monitored for wave shape and frequency at room temperature and at 77°C. Photographs of oscilloscope traces of these voltages are shown in Figure 36. The upper trace was taken at room temperature and the lower trace taken at 77°C. The frequency was 7353 Hz and the voltage was 24 volts. Neither voltage or frequency changed when the temperature was raised to 77°C.

A one-half amp fuse was installed in the fuse clip and the timer was cycled with the relay in the "safe" condition. The relay was switched to the "arm" condition and the timer was cycled. The fuse did not blow. A one-fourth amp fuse was installed in the clip and the timer recycled. The one-fourth amp fuse did blow. Traces of voltage across C1 during these firings are shown in Figure 37. Double pulsing occurred when the one-half amp fuse was used. The second pulse appeared one second after the first. Double pulsing did not appear in fire capacitor (C1) voltage data when the one-fourth amp fuse was used because no load was available when the second pulse arrived. This additional firing signal came from the timing gates having very short coincident pulses from the latch gate and channel selector gate. These coincident pulses existed in the timer prior to modification but did not cause problems because their duration was so short that the relay operation was not affected. The pulse time was such that it could not be measured with the equipment on hand. It was less than 1 microsecond wide. The four channels were programmed for 10, 20, 30 and 40 seconds. At 50 seconds, a second pulse occurred on Channel 4. A 1000 picofarad capacitor was installed across the input to Channel 4 and eliminated the timing anomaly at 50 seconds.

The latch gate input to the vector board was disconnected and grounded, resulting in the drive to the vector board being a 1 second pulse instead of a 62.5 millisecond pulse. Double pulsing did not occur after this change was made.

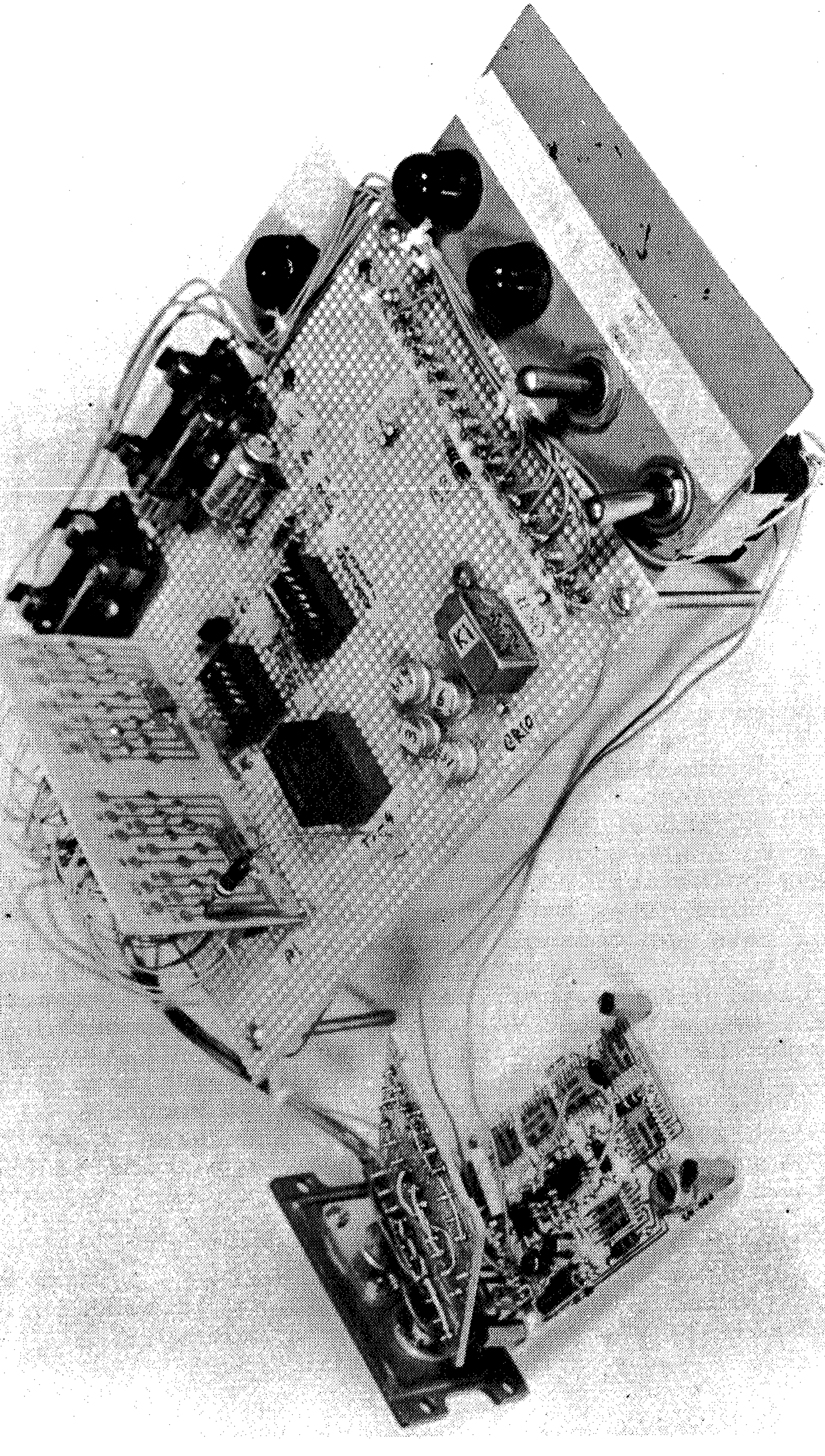


FIGURE 34 EXPERIMENTAL BREADBOARD

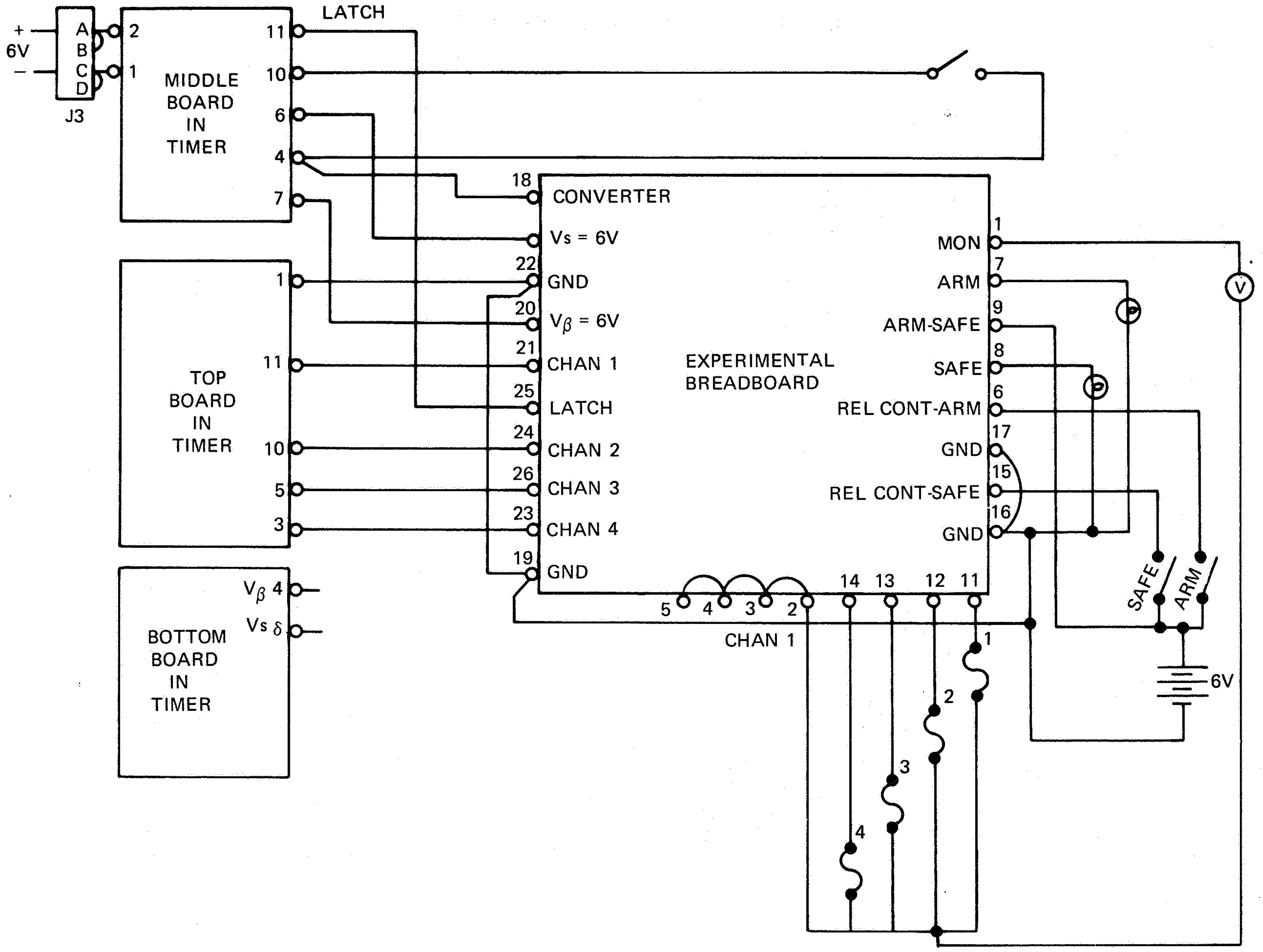


FIGURE 35 EXPERIMENTAL BREADBOARD INTERCONNECT DIAGRAM

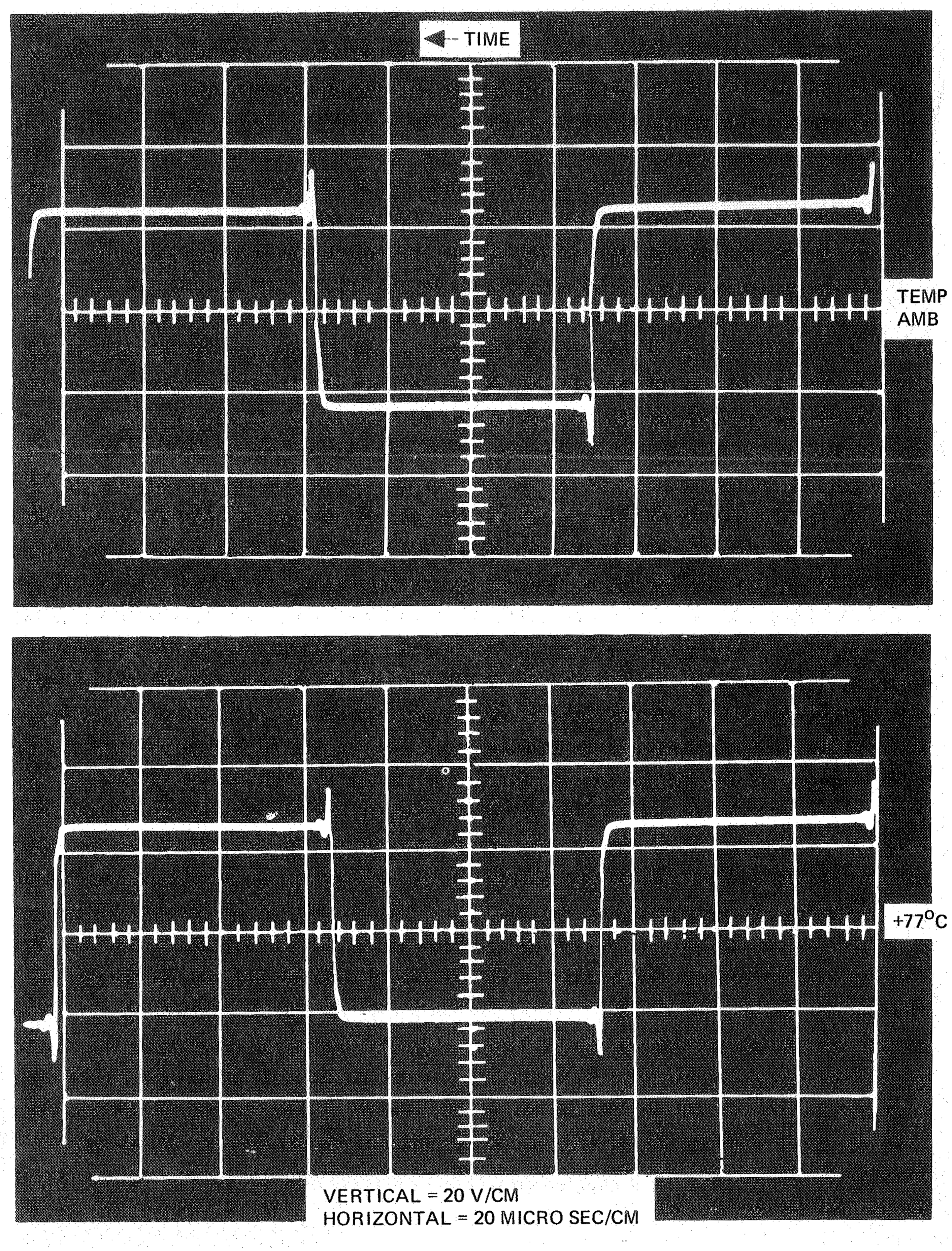


FIGURE 36 DC-DC CONVERTER OUTPUT

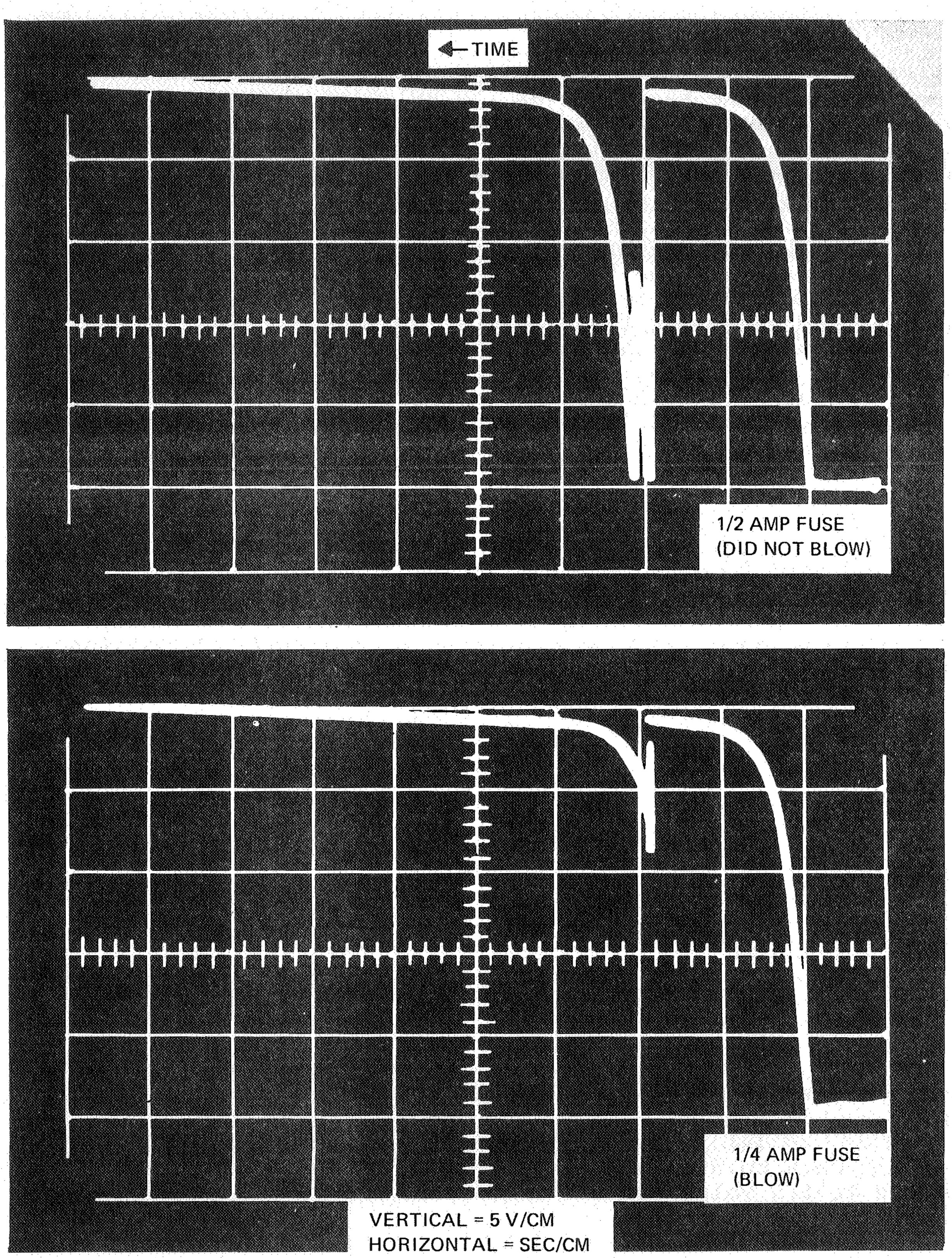


FIGURE 37 DOUBLE PULSING ON CDI OUTPUT

When the fuses did not blow and when 1 ohm resistors were used as loads the previously fired channel fired again at the same time as the selected channel. Drive to the pulse transformers was reduced by adding a resistor in series with the power lead going to the pulse transformers. When the drive was sufficiently reduced, the repeat firing did not occur.

Four one-half amp fuses were connected and the timer was cycled in the "safe" mode. A trace of the voltage on C1 is shown in Figure 38. The upper trace covers all four channels and the lower trace covers one channel only. The relay was switched to the "arm" mode and the timer was cycled. None of the fuses blew. A trace of C1 voltage is shown in the lower half of Figure 39. Four one-fourth amp fuses were fired and a voltage trace of C1 was made. It is shown in the upper half of Figure 39. All four fuses blew.

5.3 BREADBOARD EVALUATION TEST

The circuit was layed out on a printed circuit board and used to replace Board Number 3 in the ignition timer. Input currents to the timer were measured. When the battery was connected the timer drew from 6.9 to 8 milliamps. When start voltage (Vs) was energized in the "safe" condition the timer drew 46 milliamps. When the arm-safe relay was changed to the "arm" condition the current dropped to 11 milliamps. When a device was fired the input current immediately increased to 50 milliamps and then decreased to 11 milliamps in about 6 seconds while the capacitor was being recharged.

The timer was taken to LRC and used in evaluation tests. The tests included:

(1) Four SBASI's fired at room temperature with the timer programmed for 10, 20, 30 and 40 seconds.

(2) Firing of 4 squibs, 2 in parallel on two channels, at room temperature and timed for 10 and 20 seconds.

(3) Firing of 4 squibs after the timer and ignitors were hot soaked at 80.6°C.

(4) Firing of 2 squibs after the timer and ignitors were cold soaked at -17.8°C and the battery voltage reduced to 5.5 volts and 6.0 volts.

(5) Firing of 4 squibs after the timer and ignitors were cold soaked at -17.8°C and the battery voltage set at 5.2 and 6.5 volts.

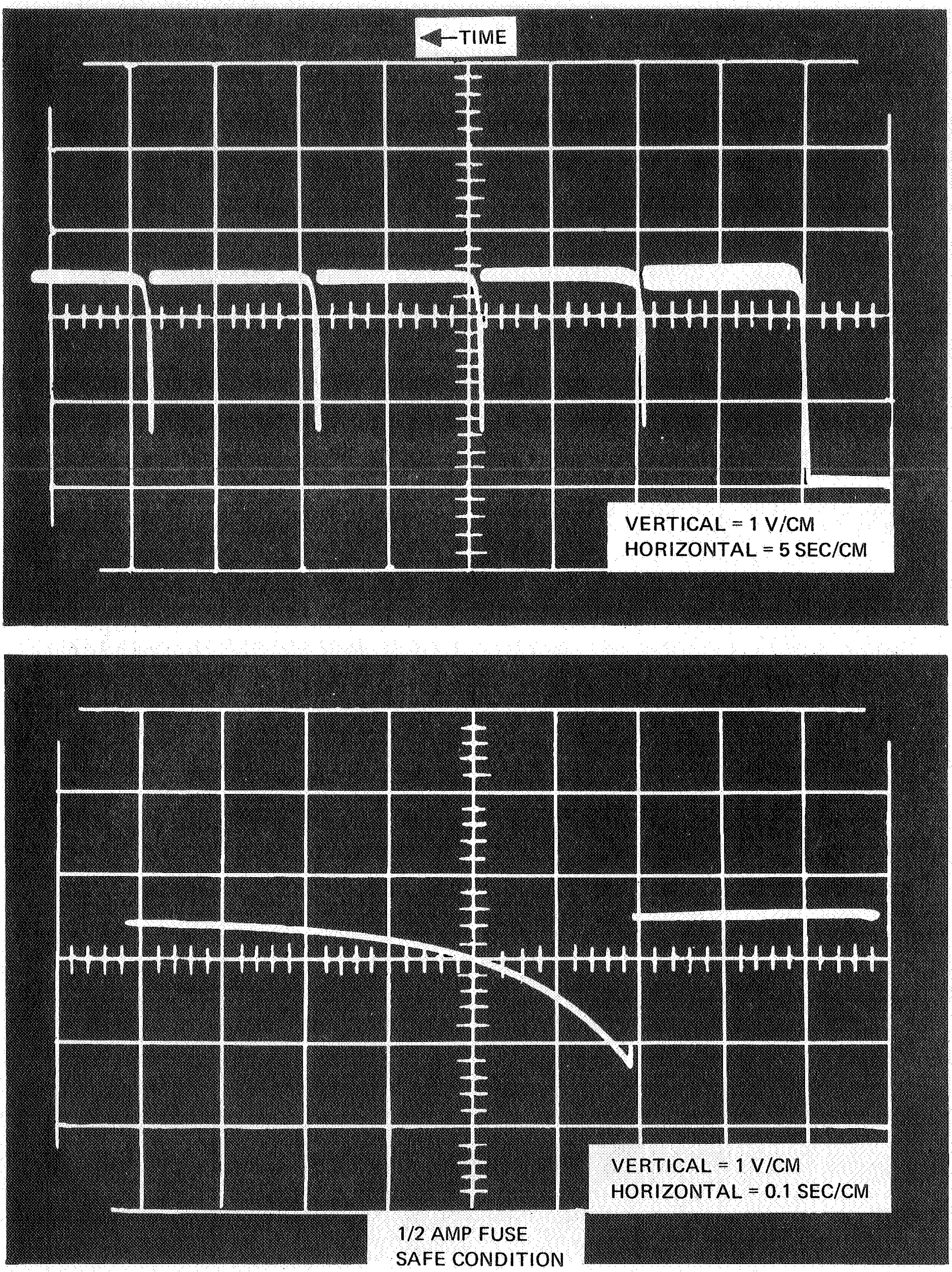


FIGURE 38 OUTPUT VOLTAGE IN SAFE POSITION

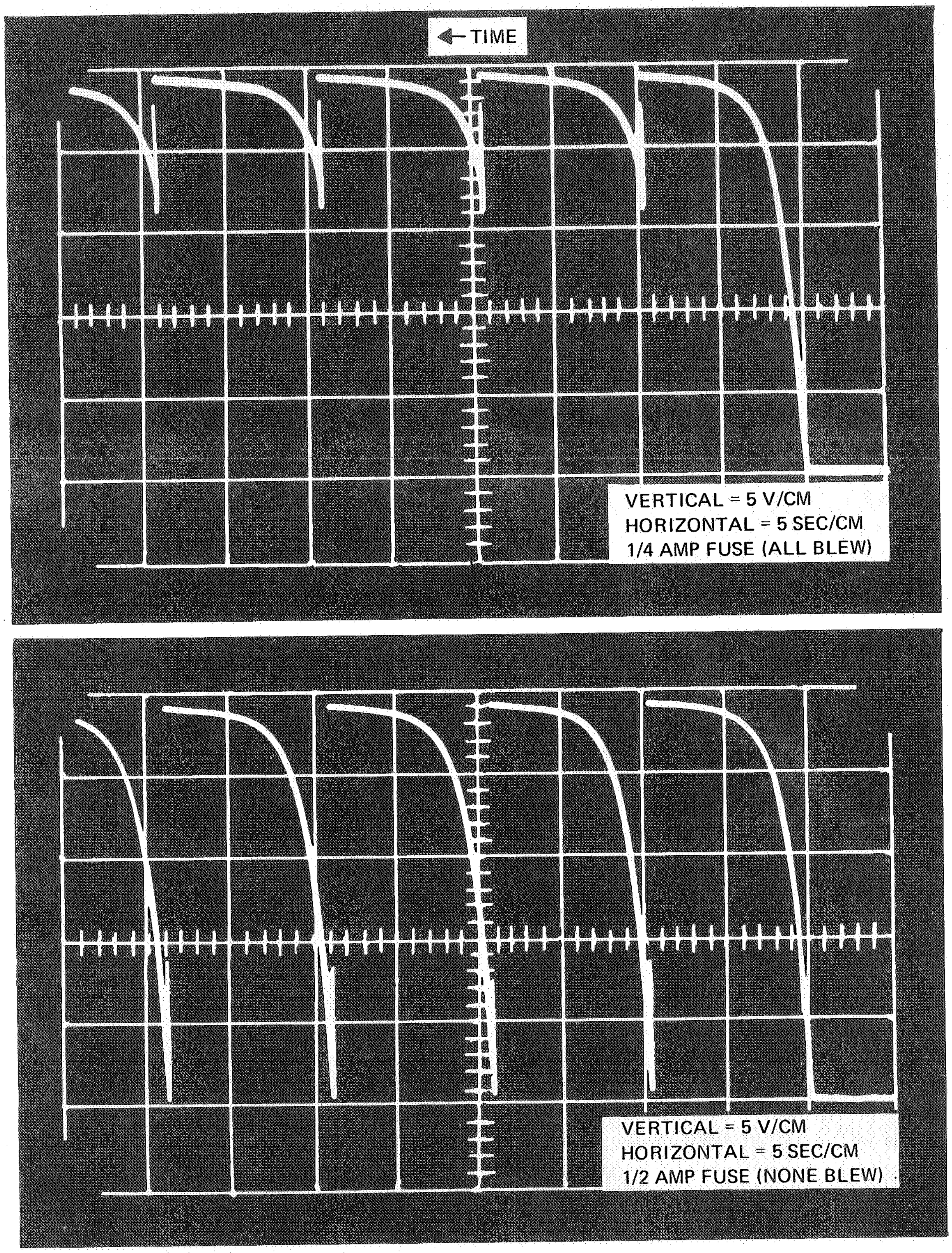


FIGURE 39 SIMULATED FIRING

(6) Firing of 4 squibs at room temperature with the timer programmed for 10, 9960, 9970 and 9980 seconds.

A total of 22 SBASI's were fired during these tests with several parameters monitored. These were; current through the ignitor, voltage across the ignitor, capacitor charge voltage, temperature, battery voltage and function time. The breadboard was set up and connected as shown in Figure 40.

A single current monitor was used to measure the current in all four channels. Voltage across the initiators was measured by using a voltage divider of 2.7K ohms and 100 ohms. Charge voltage on C1 was measured by using a voltage divider of 2 megohms and 68K ohms. Voltage and current monitors were calibrated in a static condition. Squib resistances and circuit resistances were measured.

An oscillograph record of one initiator firing is shown in Figure 41. These data are typical of that obtained from all the other firings. Vc is the voltage across the squib. It is the current through the bridgewire. The trace at the top of the chart is a 10 kHz timing calibration trace. The peak load voltage of 27.2 volts was adjusted downward to compensate for overshoot. The voltage value selected as true was midway between the first high peak and the first negative-going peak. The value selected was 25.6 volts. The current monitor appeared to be properly damped and required no adjustment for overshoot. The initial current was 16.6 amps and was 11.8 amps at bridgewire break. Bridgewire break occurred when the load voltage was at its lowest point of 21.2 volts. The time that current flowed through the bridgewire was 0.152 milliseconds. Current continued to flow after bridgewire break as evidenced by the current trace and also the discharge of the capacitor after bridgewire break.

Test data taken during the evaluation test firings are shown in Table XIV. All parameters shown were measured except V_M, I_M, and R_M which were calculated from the following formulas:

$$V_M = \frac{V_I + V_{BW}}{2} \quad \text{where;}$$

V_M = Mean load voltage

V_I = Initial load voltage

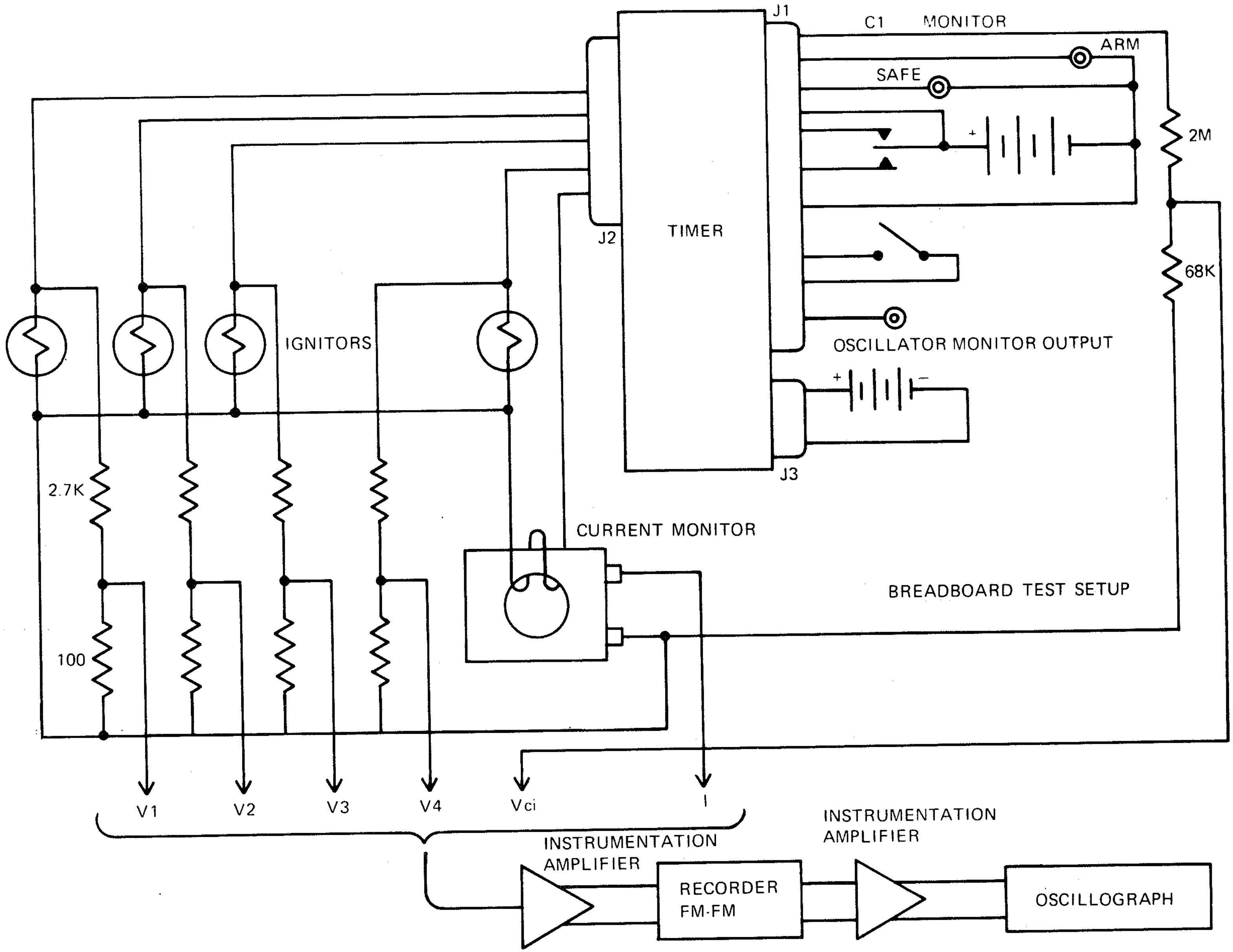


FIGURE 40 INTERCONNECT DIAGRAM FOR EVALUATION TEST

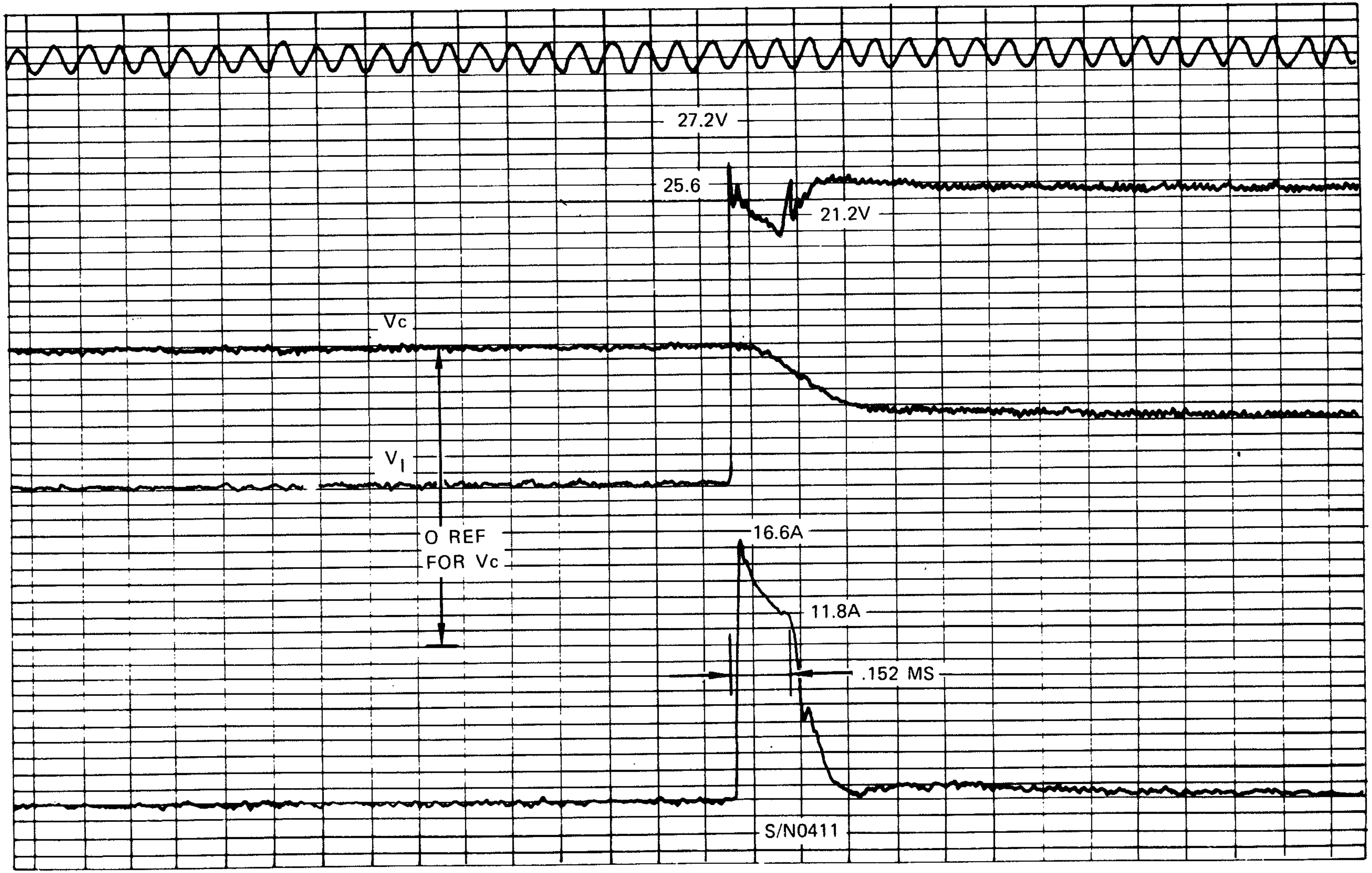


FIGURE 41 SBASI FIRING TRACE

V_{BW} = Load voltage at bridgewire break

$$I_M = \frac{I_I + I_{BW}}{2} \quad \text{where;}$$

I_M = Mean load current

I_I = Initial load current

I_{BW} = Load current at bridgewire break

$$R_M = \frac{R_I + R_{BW}}{2} \quad \text{where;}$$

R_M = Mean load resistance

R_I = Initial load resistance $\left(\frac{V_I}{I_I}\right)$

R_{BW} = Load resistance at bridgewire break $\left(\frac{V_{BW}}{I_{BW}}\right)$

In Test No. 1, 4 squibs were fired at 10-second intervals at room temperature. All four units fired within the limits of their programmed time. The voltage drops inside the timer were between 3.1 and 4.13 volts during peak current. This voltage drop includes the SCR drop. The time to bridgewire break was approximately 0.19 millisecond. The energy consumed before bridgewire break was about 48 millijoules.

In Test No. 2, two initiators were fired in parallel on two different channels. This time it took over 0.4 millisecond for bridgewire break. The energy consumed was 87 millijoules or 43.5 millijoules per initiator. When fired in parallel, the initiators fired with ten percent less energy than when fired one at a time.

TABLE XIV BREADBOARD EVALUATION TEST

TEST NO.	UNIT S/N	AMB. TEMP. C	BW RESIS. AT AMB	BW RESIS. AT 176°F OR 0°F	CAP. CHG. VOLT.	LOAD VOLTS AT PEAK LOAD VI	LOAD VOLTS AT BW BREAK VEW	CURRENT AT PEAK LOAD II	CURRENT AT BW BREAK IBW	TIME TO GATE 1 SEC	TIME TO GATE 2 SEC	TIME TO GATE 3 SEC	TIME TO GATE 4 SEC	TIME TO BW BREAK IN MS	BATT VOLT. PRE-TEST	BATT VOLT. POST-TEST	TIME TO CHARGE TO 70% V IN SEC	VM	IM	RM	ENERGY $\frac{V_M^2 t}{R_M}$	ENERGY $I_M^2 R_M t$
1	0403	24.4	1.037	–	27.3	20.4	16.44	16.4	10.2	10.001	–	–	–	.19	6.42	6.28	3.24	18.42	13.3	1.428	45.1	48.0
1	0688	24.4	1.084	–	27.6	21.12	16.8	16.3	10.0	–	20.001	–	–	.19	6.42	6.28	1.52	18.96	13.15	1.488	45.9	48.9
1	0521	24.4	1.036	–	27.6	21.6	17.04	15.2	10.6	–	–	30.002	–	.19	6.42	6.28	1.38	19.32	13.4	1.471	48.2	50.2
1	0483	24.4	1.094	–	27.5	21.6	17.26	15.7	9.8	–	–	–	40.003	.20	6.42	6.28	2.93	19.44	12.8	1.57	48.1	51.4
2	0669	25.6	1.046	–	27.6	15.6	7.68	24.2	10.0	10.001	–	–	–	.428	6.42	6.37	3.14	11.64	17.1	.707	82.0	88.5
2	0409	25.6	1.022	–	27.6	15.6	7.68	24.2	10.0	10.001	–	–	–	.428	6.42	6.37	–	–	–	–	–	–
2	0663	25.6	1.065	–	27.6	16.3	8.2	24.2	10.2	–	20.001	–	–	.419	6.42	6.37	2.52	12.25	17.1	.739	85.1	90.5
2	0524	25.6	1.087	–	27.6	16.3	8.2	.24.2	10.2	–	20.001	–	–	.419	6.42	6.37	–	–	–	–	–	–
3	0687	24.4	1.059	1.114	26.7	24.09	20.1	16.8	11.0	10.004	–	–	–	.19	6.417	6.408	3.16	22.1	13.9	1.631	56.9	59.9
3	0627	24.4	1.018	1.066	27.0	23.95	20.4	17.4	12.4	–	20.00	–	–	.18	6.417	6.408	1.37	22.18	14.9	1.511	58.6	60.4
3	0401	24.4	1.020	1.067	27.3	24.6	20.52	17.0	11.5	–	–	30.011	–	.171	6.417	6.408	1.04	22.56	14.25	1.616	53.9	50.1
3	0556	24.4	1.028	1.078	27.0	24.6	19.7	16.4	11.5	–	–	–	40.014	.181	6.417	6.408	3.24	22.15	13.95	1.607	55.3	56.6
4	0437	24.4	1.106	1.054		18.99	10.88	12.4	6.0	10.000	–	–	–	.476	5.5	5.5	–	14.49	9.2	1.636	61.1	65.9
4	0539	24.4	1.050	1.004		NO FIRE																
4	0665	24.4	1.060	1.012		NO FIRE																
4	0691	24.4	1.048	1.005		20.26	13.7	13.8	7.6	–	–	–	40.000	.285	6.0	6.0		16.98	10.7	.636	50.2	53.4
4	0547	24.4	1.103	1.080	24.9	18.6	11.4	12.4	5.8	11.66	–	–	–	.447	5.64	5.2	3.53	15.0	9.1	1.733	58.0	64.1
4	0560	24.4	1.063	1.016		20.4	14.3	13.2	8.0	–	19.999	–	–	.285	6.385	6.379		17.35	10.6	1.667	51.5	53.4
4	0619	24.4	1.057	1.010		19.97	14.0	13.8	7.6	–	–	30.000	–	.271	6.385	6.379		16.99	10.7	1.675	47.6	51.0
4	0624	24.4	1.094	1.046		20.5	13.7	13.4	7.4	–	–	–	40.000	.299	6.385	6.379		17.1	10.4	1.691	51.7	54.7
5	0411	24.4	1.117	-	27.2	25.6	21.2	16.6	11.8	10.000	–	–	–	.152	6.85	6.45	3.4	23.4	14.2	1.671	47.8	51.2
5	0539	24.4	1.050	-	30.76	29.0	24.5	20.0	14.0	–	9960.66	–	–	.124	6.85	6.45	1.37	26.75	17.0	1.6	55.5	57.3
5	0665	24.4	1.060	-	25.7	23.9	19.2	16.6	11.4	–	–	9970.68	–	.171	6.85	6.45	2.12	21.55	14.0	1.562	50.8	52.4
5	0598	24.4	1.089	-	25.5	23.2	18.6	16.0	11.0	–	–	–	9980.71	.190	6.85	6.45	2.95	20.9	13.5	1.571	52.8	54.4

NOTES

1. CIRCUIT RESISTANCE
   CHANNEL 1 – 0.169 Ω
   CHANNEL 2 – 0.145 Ω
   CHANNEL 3 – 0.179 Ω
   CHANNEL 4 – 0.157 Ω
2. ON TEST 4 ONLY S/N 0437 FIRED. BATT VOLTAGE WAS RAISED AND CYCLE REPEATED. ONLY S/N 0691 FIRED.
3. ON TEST 4 REPEAT ONLY S/N 0547 FIRED. BATT VOLTAGE WAS RAISED AND CYCLE REPEATED. S/N 0560, 0619 AND 0624 FIRED. ON REPEAT CYCLE C1 VOLTAGE WAS NOT OBTAINED.
4. ON TEST 4 REPEAT, 0 F BW RESISTANCE WAS CALCULATED.
5. TESTS WERE PERFORMED 10-9-73 THRU 10-18-73 AT LRC WITH JACK BATES, JACK McNETT AND JIM BAILEY AS OBSERVERS.

In Test No. 3, the timer, battery and initiators were put in an environmental chamber for 30 minutes at 80.6°C prior to firing. The energy consumed was approximately 18 percent more than that used at room temperature.

In Test No. 4, the timer and initiators were put in an environmental chamber at -17.8°C prior to firing. The battery used was a dry cell mounted outside the chamber with a voltage divider connected across the battery to reduce the timer input voltage to 5.5 volts dc. Only the initiators in Channel 1 fired. The battery voltage was raised to 6 volts dc and the cycle was repeated. Only the initiator in Channel 4 fired. The timer was disassembled to find the cause of channels 2 and 3 not firing. It was determined that moisture provided a ground path to the power input side of the pulse transformers. Moisture had entered the timer through two holes left open when the battery was removed from the timer when using an external battery. The moisture is not considered a design problem since the breadboard made no provision for humidity testing (i.e., board was not conformal coated).

The moisture was removed, the holes were plugged, and the timer was wrapped in a bag of dessicant. The timer was put in the environmental chamber at 0°F and Test No. 4 was repeated with the battery voltage at 5.5 volts dc. Only the initiator in Channel No. 1 fired with no indication that the SCR's in the other three channels received firing signals. The battery voltage was raised to its full voltage of 6.4 volts dc and the timer was recycled. This time the other three initiators fired.

In Test No. 5 the timer was reprogrammed to fire initiators at intervals of 10, 9960, 9970 and 9980 seconds from initiation. Between the 10 second and 9960 second firing the capacitor voltage climbed to 34 volts.

5.4 TEST CONCLUSIONS

(1) The voltage spike on the output of the dc-dc converter is integrated by capacitor C1 and gradually raises the capacitor voltage to the spike peak voltage value. This occurs in about 5 minutes. It is recommended that a zener diode be connected in parallel with the capacitor to keep the capacitor voltage from increasing above preset voltage, and this be verified by additional testing.

(2) After the bridgewire break the initiator continued to draw current erratically for about another 100 microseconds.

(3) After an SCR fired it continued to be turned on due to the 5.7 to 7 milliamp load provided by the instrumentation voltage divider until the capacitor voltage bled down low enough to reduce the current below the SCR holding current.

(4) The circuit will fire two initiators in parallel but takes approximately twice the time as firing a single initiator.

(5) Operation of the timer was not significantly different at 80.6°C and at 24.4°C.

(6) At -17.8°C the mean current and mean voltage were less than at 24.4°C but the time to bridgewire break was longer, resulting in essentially the same amount of energy needed to fire the squib.

(7) The counters in the timer put out unwanted very short time pulses when switching from one count to another. These short pulses did not cause any problems when driving relays, but did cause unintended firings of the SCR's in the modified circuit. In the final design, a resistor was added to solve this problem.

(8) Accuracy of the timing was not affected by the modification.

(9) The capacitor will charge to full voltage in less than 10 seconds after full capacitor discharge.

(10) The dc-dc converter oscillator did not create any interference in the remainder of the circuit.

(11) The sensitivity resistor (R9) was a carbon resistor with a temperature coefficient of a magnitude to allow a possible 25 ohm change during temperature testing. It is concluded that this resistance change coupled with the low voltage of test No. 4 (repeat of low temperature) caused non-triggering of the SCR's at 5.5 volts. Elimination of the short duration non-programmed outputs from the timer logic would eliminate the need for resistor R9.

6.0 FINAL DESIGN

Based on evaluation testing, design review and range safety comments, the circuit as shown in Figure 42 and parts list per Table XV is the recommended final design. Changes or addition to the breadboard circuit as tested are:

(a) Hermetically Sealed Capacitor

(b) Thick Film Hybrid Packaging

(c) SCR Selection

(d) Isolation Diode (CR13)

(e) Protection Zener (CR14)

6.1 HERMETICALLY SEALED CAPACITOR

The fire capacitor selected for use in the breadboard evaluation testing was an elastomer sealed wet slug tantalum type. This selection allowed use of discrete components for the breadboard circuit. Due to electrolyte leakage problems associated with the elastomer sealed capacitor it is not recommended for the final circuit design. A glass to metal hermetic seal wet slug tantalum capacitor is presently used in the payload separation system timer (LTV P/N 23-004069-1) and is of proven reliability. Two capacitors should be used to provide 450 mfd (150 + 300) of ignition energy storage capability for the final design of the CDI circuit. This capacitor will provide nominal energy level of 130 millijoules as compared to the breadboard of 136 millijoules. Wet foil tantalums type capacitors were considered but rejected due to the increased space (approx. 5:1) required for mounting. Use of the wet foil would also require additional evaluation testing because of the equivalent series resistance. A complete redesign of the timer would also be necessary to accommodate the capacitor mounting space which would be equal to existing board No. 3 (i.e., redesign timer logic and programming to be contained on boards 1 and 2). In the circuit as designed, no advantage is obtained by use of the wet foil tantalum type capacitor. Therefore, redesign of the timer is not warranted.

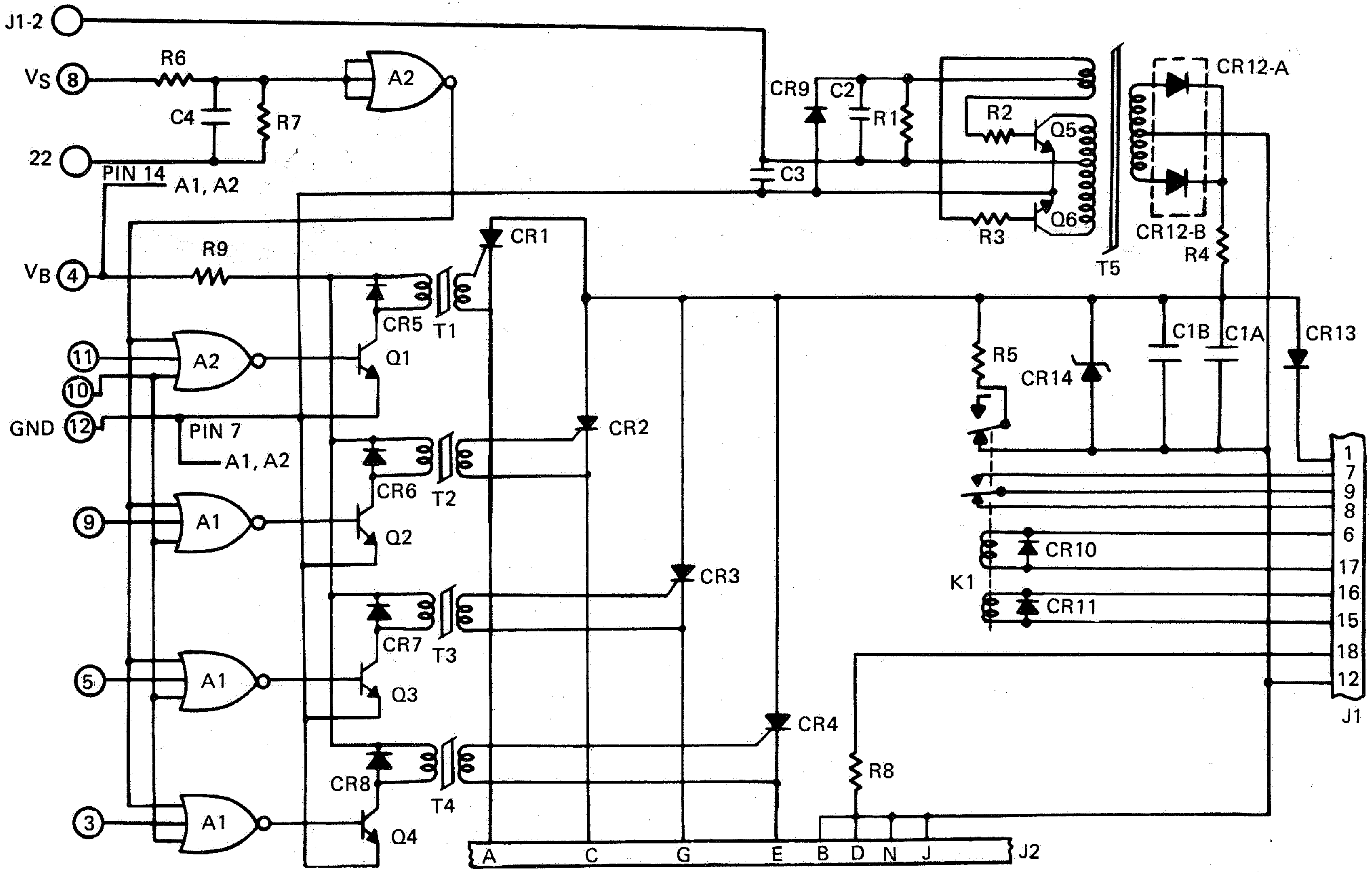


FIGURE 42 CDI CIRCUIT – FINAL DESIGN

TABLE XV FINAL DESIGN PARTS LIST

A, A2	DIGITAL INTEGRATED CIRCUIT, 3 INPUT NOR GATE, COS/MOS LOGIC
C1A	WET SLUG TANTALUM CAPACITOR, GLASS TO METAL HERMETIC SEAL, 150 MFD, 30 WVDC
C1B	WET SLUG TANTALUM CAPACITOR, GLASS TO METAL HERMETIC SEAL, 300 MFD, 30 WVDC
C2, C3	CAPACITOR, 1000 PF, CRK05BX102K
C4	CAPACITOR, 0.47 MFD, CK06BX473K
CR1, CR2, CR3, CR4	SCR (SELECTED FOR MINIMUM HOLDING CURRENT – 19 MA ±5 MA), BARE CHIP FOR MOUNTING ON HYBRID SUBSTRATE
CR5, CR6, CR7, CR8, CR9, CR10, CR12-A, CR12-B	DIODE, SILICON EPITAXIAL MINIATURE SWITCHING. REVERSE VOLTAGE = 70 VDC, FORWARD CURRENT = 200 MA, FORWARD SURGE CURRENT = 500 MA, OPERATING TEMPERATURE = –50 TO +135°C. BARE CHIP FOR MOUNTING ON HYBRID SUBSTRATE
CR13	DIODE SILICON, PIV = 1000 V, IO – 1.5 AMP, IN5054
CR14	DIODE ZENER, VZ = 30 V, IN972 B/JAN
J1	RTK 57H-10-19P CONNECTOR
J2	DTK 07H-12-8S CONNECTOR
K1	RELAY, MAGNETIC LATCHING, DOUBLE POLE-DOUBLE THROW, 6 VOLT DC COIL.
Q1, Q2, Q3, Q4, Q5, Q6	TRANSISTOR NPN SILICON, GENERAL PURPOSE SWITCHING TYPE BARE CHIP FOR MOUNTING ON HYBRID SUBSTRATE (TYPE 2N3904)
R1	RESISTOR, CARBON, ±5%, 1/2W, 2.4K OHMS – RCR07-G242-J-M
R2, R3	RESISTOR, CARBON, +5%, 1/2W, 220 OHMS – RCR07-G221-J-M
R4	RESISTOR, 1%, 1W, METAL FILM, 2430 OHMS, RNR65K-2431-F-M
R5	RESISTOR, 1%, 1/2W, METAL FILM, 348 OHMS – RNR50K-3480-F-M
R6	RESISTOR, 5%, 1/4W, CARBON, 10K OHMS, RCR07-G-103-J-M
R7	RESISTOR, 5%, 1/4W, CARBON, 510K OHMS, RCR07-G-514-J-M
R8	RESISTOR, 5%, 1/4W, CARBON, 150K OHMS, RCR07-G-154-J-M
R9	RESISTOR, 1%, 1/2W, METAL FILM, 390 OHMS, RNR50K-3900-F-M

TABLE XV FINAL DESIGN PARTS LIST (CONTINUED)

T1, T2, T3, T4	PULSE TRANSFORMER, QUAD PACK PRINTED CIRCUIT PACKAGE, MIL-T-21038C, TP-5-Q-X-1100 AL* – (*) (*ENVELOPE SIZE EXCEPTION, PRINTED CIRCUIT STYLE AND W = 0.4 INCHES)
T5	DC-DC CONVERTER TRANSFORMER (SPECIAL DESIGN PER MIL-T-27C EXCEPT SIZE MAXIMUM DIAMETER = 0.625 INCHES (INCLUDING CASE) MAXIMUM HEIGHT = 0.44 INCHES HIGH CONNECTOR – PRINTED CIRCUIT SOLDER PIN TERMINALS PIN CONFIGURATION – PER STANDARD 9 PIN BUTTON BASE (MIL-T-27C) INPUT VOLTAGE – 6.0 VDC OUTPUT VOLTAGE = $24 \pm \frac{0.5}{0.0}$ VDC @ 25 MA WITH $V_{IN} = 6.0 \pm 0$ VDC FREQUENCY OF OSCILLATION = 5 KHZ MIN, 10 KHZ MAX. EFFICIENCY = 75% MIN. $\left(\frac{\text{DC POWER OUT}}{\text{DC POWER IN}}\right) \times 100$ FEEDBACK VOLTAGE = 1.9V MIN., 3.0V MAX. FEEDBACK CURRENT – 5.0 MA MIN.

6.2 PACKAGING

Thick Film Hybrid packaging of the SCR control circuit and dc-dc multivibrator circuit are recommended for the final design. Components mounted on the Thick Film substrate are:

SCR Control (Substrate No. 1)

- --A1 and A2
- --R6, R7, R9
- --CR1 through CR8
- --Q1 through Q4

DC-DC Multivibrator (Substrate No. 2)

- --C2, C3
- --CR9, CR12-A, CR12-B
- --R1, R2, R3
- --Q5, Q6

6.3 SCR SELECTION

Difficulty was encountered in selecting SCR's with a holding current as specified in the circuit design (Reference Paragraph 5.1, Table XIII. The selection process was aggravated by the use of off-the-shelf prepackaged SCR's (TO-5 can) which had already been screened for a low holding current). For this reason an SCR which can be obtained in the pretested state for selection by the manufacturer for holding current is recommended. The recommended SCR for the final design is a larger chip than the SCR chip used in the breadboard tests. The larger chip size increases holding current and allows a better yield in selecting for minimum holding current of 19 ma +5, -0 ma. Use of the larger chip (60 mil compared to 50 mil) is possible due to packaging in the final design by the thick film substrate method.

6.4 ISOLATION DIODE

Range safety at NASA Wallops Station recommended that provision be provided in the design to dump the stored energy of the fire capacitor into an external load via blockhouse control. The breadboard circuit had an isolation resistor (R8) of 150k ohms in the charge voltage monitor line. By replacing R8 with a silicon diode (IN5054), capacitors C1A and C1B may be discharged through the monitor connection. Possible reasons for emergency discharge of the fire capacitors are failure of the safe-arm relay, premature start of the timing sequence, or any failure that could cause the fire capacitor to be prematurely charged. The external discharge path for the fire capacitor should contain at least 20 ohms resistance so that CR13 will not be damaged.

6.5 PROTECTION ZENER

During breadboard evaluation testing (paragraph 5.4), it was determined that the dc-dc power supply was capable of outputting high frequency positive pulses, which over a period of time (approx. 5 minutes), would increase the charge voltage to 35 volts on the fire capacitor. The recognized failure mode of wet slug tantalum capacitors due to reverse voltage from external sources was also a concern during the circuit design. The addition of zener diode CR14 in parallel with C1A and C1B would eliminate both aforementioned problems from occurring. Diode CR14 is a 30 volt zener, which will limit the maximum charge voltage to 30 volts ±5%.

7.0 GSE TEST

The engineering breadboard was used to measure the initiator circuit resistance, and to demonstrate the performance of the capacitive discharge circuitry in terms of accuracy and repeatability when in the "safe" condition.

A test method was developed to measure the elapsed time between the initiation of capacitor discharge and the time when the voltage reached a predetermined value. This elapsed time varied with the resistance of the discharge circuit, which included an SCR, a SBASI, and associated wiring and connectors. Therefore, a change in circuit resistance could be detected by comparing the elapsed discharge time with historical discharge times. The test method is illustrated with a functional block diagram shown in Figure 43.

When the timer function was initiated, the capacitor voltage climbed to 3 volts at a rate slower than the differentiator would detect. When the SCR fired, the capacitor voltage dropped at a rate fast enough to be detected by the differentiator. This signal was shaped by the one-shot and then set the flip-flop which in turn gated the clock and started the counter. When the capacitor voltage dropped to the reference voltage, the comparator sent a reset signal to the flip-flop, which gated the clock off and stopped the counter.

The functions shown in Figure 43 were mechanized into a practical circuit. The schematic is shown in Figure 44. Test runs were made using various values of simulated load resistance. An oscilloscope was used to substitute for the counter. The time intervals measured with the oscilloscope were within a narrow band and were repeatable. The times measured with the oscilloscope with various load resistances were recorded and are shown in Table XVI. A plot of average time versus squib resistance is shown in Figure 45.

Figure 45 shows that the discharge time changed 30 microseconds for a resistance change of 0.1 ohm. The maximum time variation for a single squib resistance value at or near 1 ohm was 3 microseconds. From these data it appears that a resistance change of 0.05 ohm can be detected if other parameters are constant or compensated. These parameters are temperature, timer battery voltage, test equipment variations and connector resistance. It is possible to negate the influence of these variables by circuit design, if warranted. Such a circuit design compensation would be to use a voltage gate to start the counters instead of the differentiator in

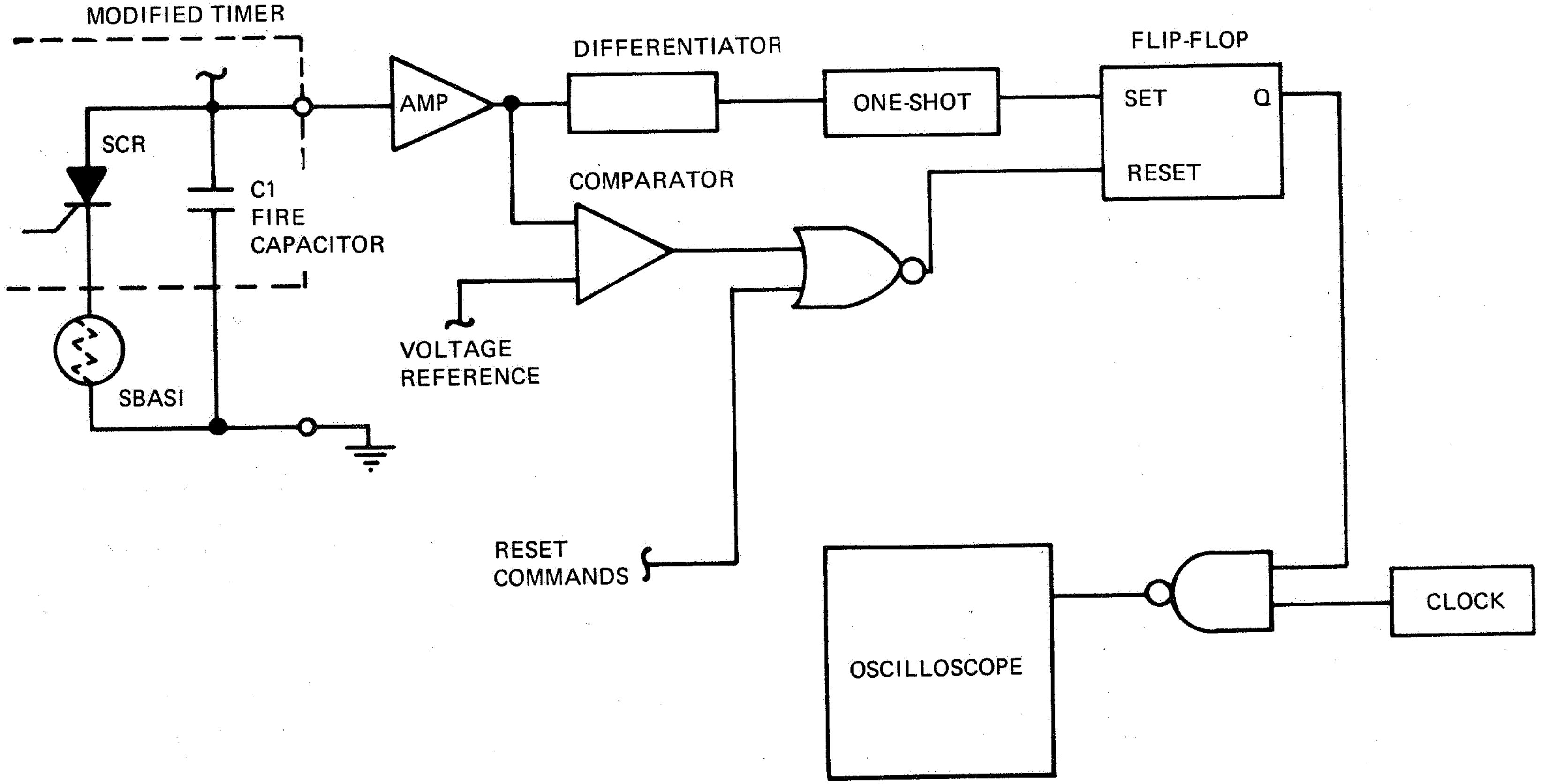


FIGURE 43   FUNCTIONAL BLOCK DIAGRAM GSE TEST METHOD

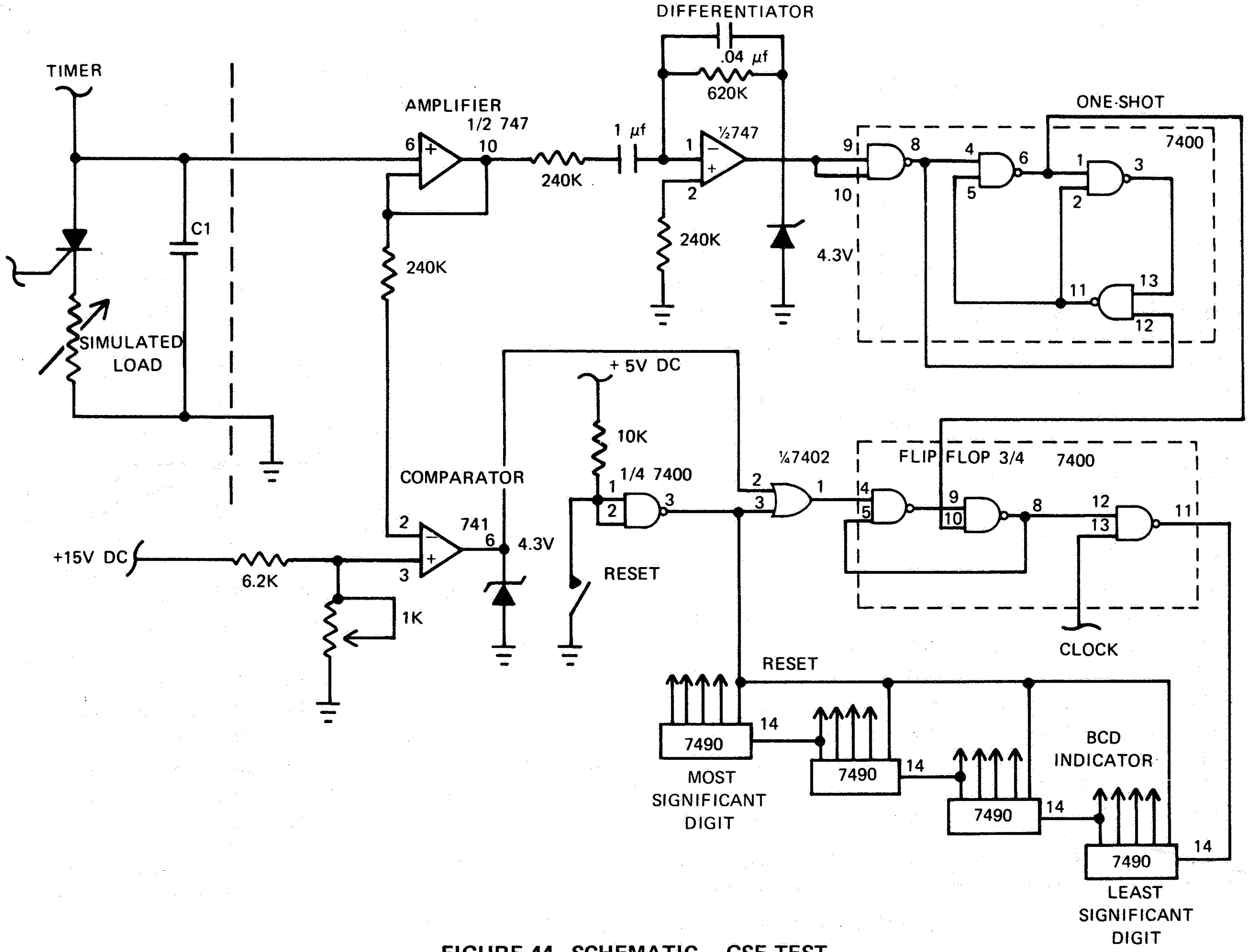


FIGURE 44 SCHEMATIC – GSE TEST

TABLE XVI DISCHARGE TIME VS SQUIB RESISTANCE

R	TIME	R	TIME	R	TIME	R	TIME	R	TIME	R	TIME	R	TIME	R	TIME
1.0Ω	162μs	0.8Ω	109μs	0.6Ω	55μs	1.1Ω	192μs	1.3Ω	250μs	1.5Ω	318μs	1.7Ω	375μs	1.9Ω	430μs
1.0Ω	162μs	0.8Ω	106μs	0.6Ω	52μs	1.1Ω	192μs	1.3Ω	254μs	1.5Ω	315μs	1.7Ω	375μs	1.9Ω	430μs
1.0Ω	162μs	0.8Ω	110μs	0.6Ω	52μs	1.1Ω	193μs	1.3Ω	253μs	1.5Ω	318μs	1.7Ω	373μs	1.9Ω	430μs
1.0Ω	162μs	0.8Ω	108μs	0.6Ω	52μs	1.1Ω	192μs	1.3Ω	253μs	1.5Ω	318μs	1.7Ω	378μs	1.9Ω	433μs
1.0Ω	162μs	0.8Ω	108μs	0.6Ω	53μs	1.1Ω	190μs	1.3Ω	250μs	1.5Ω	317μs	1.7Ω	375μs	1.9Ω	430μs
1.0Ω	162μs	0.8Ω	108μs	0.6Ω	53μs	1.1Ω	192μs	1.3Ω	253μs	1.5Ω	312μs	1.7Ω	373μs	1.9Ω	430μs
1.0Ω	162μs	0.8Ω	110μs	0.6Ω	50μs	1.1Ω	192μs	1.3Ω	253μs	1.5Ω	318μs	1.7Ω	373μs	1.9Ω	430μs
1.0Ω	162μs	0.8Ω	108μs	0.6Ω	52μs	1.1Ω	192μs	1.3Ω	250μs	1.5Ω	310μs	1.7Ω	380μs	1.9Ω	428μs
1.0Ω	162μs	0.8Ω	108μs	0.6Ω	51μs	1.1Ω	193μs	1.3Ω	250μs	1.5Ω	317μs	1.7Ω	375μs	1.9Ω	428μs
1.0Ω	162μs	0.8Ω	108μs	0.6Ω	52μs	1.1Ω	193μs	1.3Ω	253μs	1.5Ω	312μs	1.7Ω	375μs	1.9Ω	432μs
0.9Ω	135μs	0.7Ω	78μs	0.5Ω	12μs	1.2Ω	222μs	1.4Ω	283μs	1.6Ω	348μs	1.8Ω	402μs	2.0Ω	460μs
0.9Ω	137μs	0.7Ω	78μs	0.5Ω	10μs	1.2Ω	222μs	1.4Ω	283μs	1.6Ω	348μs	1.8Ω	403μs	2.0Ω	460μs
0.9Ω	134μs	0.7Ω	78μs	0.5Ω	12μs	1.2Ω	222μs	1.4Ω	282μs	1.6Ω	348μs	1.8Ω	403μs	2.0Ω	460μs
0.9Ω	135μs	0.7Ω	78μs	0.5Ω	12μs	1.2Ω	220μs	1.4Ω	283μs	1.6Ω	348μs	1.8Ω	403μs	2.0Ω	460μs
0.9Ω	135μs	0.7Ω	78μs	0.5Ω	12μs	1.2Ω	222μs	1.4Ω	283μs	1.6Ω	348μs	1.8Ω	403μs	2.0Ω	460μs
0.9Ω	134μs	0.7Ω	78μs	0.5Ω	12μs	1.2Ω	222μs	1.4Ω	283μs	1.6Ω	345μs	1.8Ω	403μs	2.0Ω	460μs
0.9Ω	134μs	0.7Ω	78μs	0.5Ω	12μs	1.2Ω	222μs	1.4Ω	283μs	1.6Ω	350μs	1.8Ω	398μs	2.0Ω	465μs
0.9Ω	135μs	0.7Ω	75μs	0.5Ω	12μs	1.2Ω	220μs	1.4Ω	283μs	1.6Ω	348μs	1.8Ω	405μs	2.0Ω	460μs
0.9Ω	137μs	0.7Ω	75μs	0.5Ω	12μs	1.2Ω	222μs	1.4Ω	285μs	1.6Ω	348μs	1.8Ω	395μs	2.0Ω	463μs
0.9Ω	135μs	0.7Ω	75μs	0.5Ω		1.2Ω	222μs	1.4Ω	283μs	1.6Ω	348μs	1.8Ω	400μs	2.0Ω	460μs
				0.4Ω	noise										
				0.4Ω	noise										
				0.3Ω	noise										
				0.3Ω	noise										
				0.2Ω	noise										
				0.1Ω	noise										
				0.0Ω	noise										

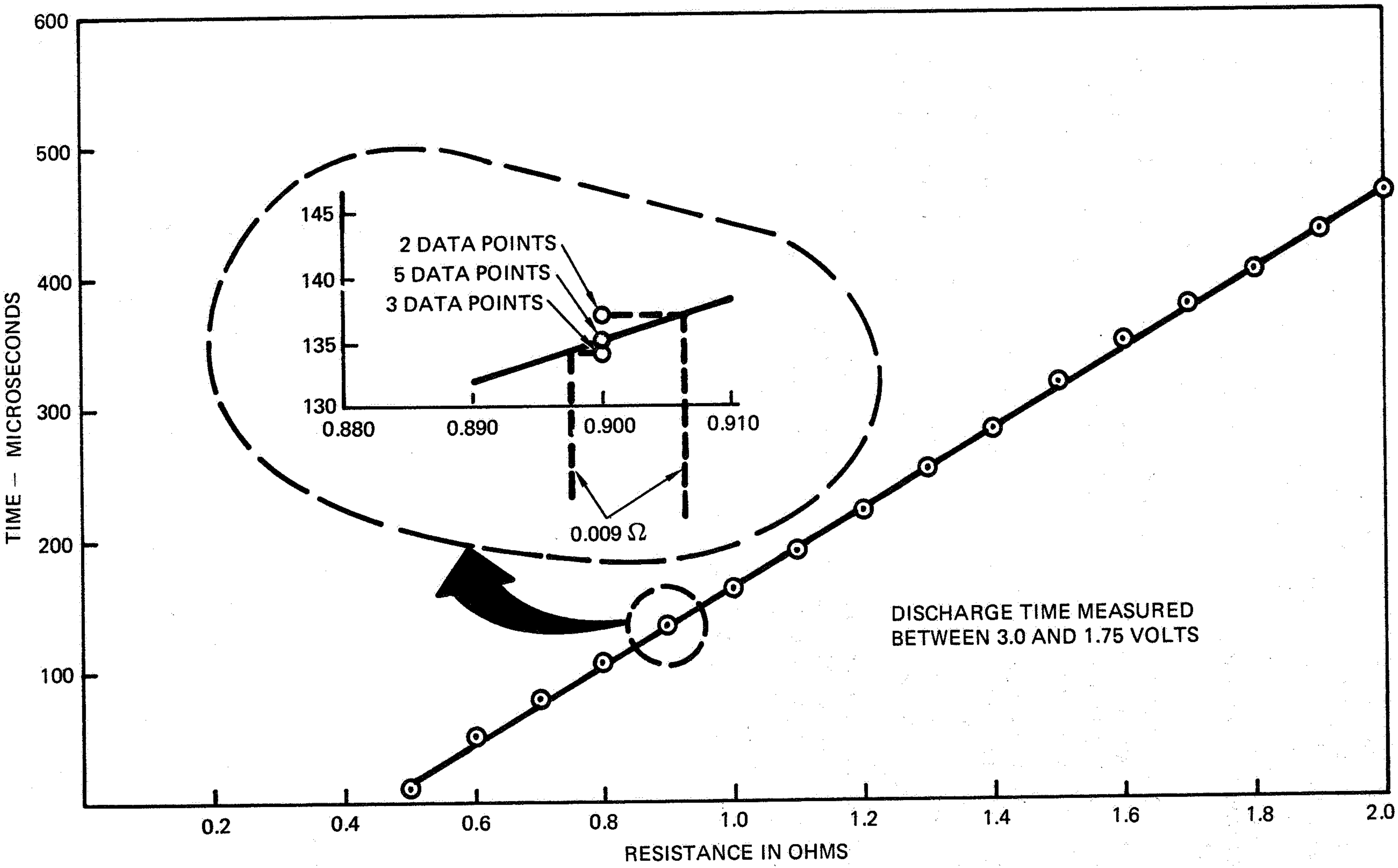


FIGURE 45 GSE EVALUATION DATA

Figure 44. This method would make the time measurement insensitive to timer battery voltage variations. The GSE time readouts must be judged relative to readings taken after the squib or a simulated squib is installed in the vehicle. Provisions must be made to store the readouts of all four channels because the samples can be spaced as close as 10 seconds apart.

The measuring circuit shown in Figure 44 can be integrated into an overall checkout scheme for the modified timer. This concept is shown in Figure 46. Operation of the circuit is described below.

The timer is switched to the "safe" condition and the multiplexer is reset. The battery voltage is checked to see if it is within specified limits. The timer and multiplexer are started from the blockhouse. If the timer capacitor voltage is outside its limits the timer is stopped. If the voltage is too high the capacitor is also dumped. The first discharge information is recorded on displays in the blockhouse. The multiplexer then switches the measuring circuit to the next display, ready for the next channel discharge. The timer can also be stopped and the capacitor dumped manually from the blockhouse. Verification of timer accuracy is made and displayed in the blockhouse.

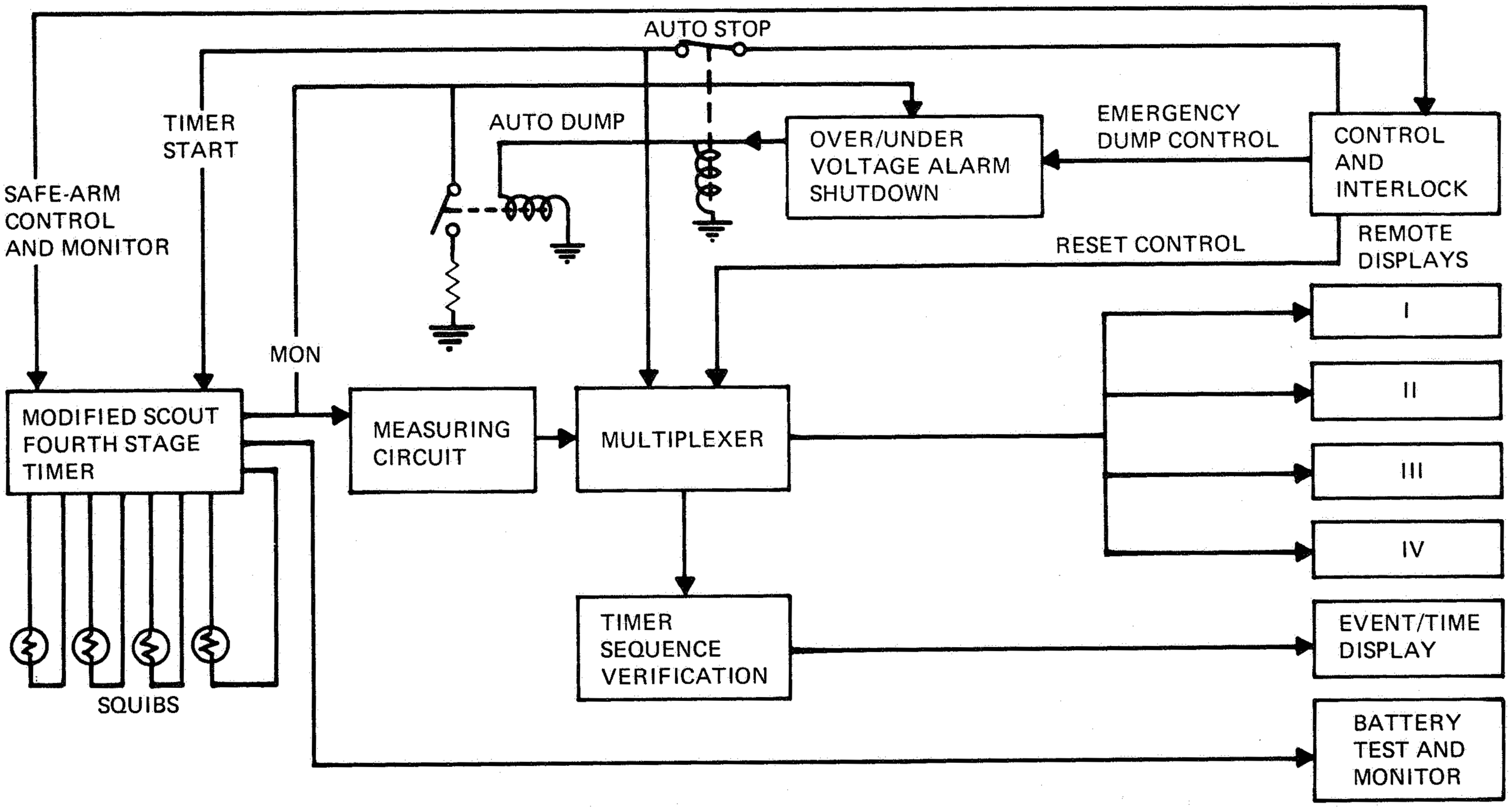


FIGURE 46 MODIFIED TIMER CHECKOUT CONCEPT

8.0 CONCLUSIONS AND RECOMMENDATIONS

This study program has shown the feasibility of using capacitive discharge ignition for the Scout 4th stage payload ignition system, provided that the user (payload) systems are compatible with SBASI requirements. The circuit designed under this study has been demonstrated as being workable, and will provide an additional 1.95 Kg (4.3 pounds) of payload capability. Hardware testing determined that wet slug tantalum capacitors are satisfactory for this application and equivalent series resistance is not a significant circuit parameter for wet slug capacitors. SBASI firing energy test results agrees with testing previously conducted at JPL showing a minimum firing energy requirement of 34 millijoules. Reliability analyses indicate a theoretical reduction in the per mission failure rate of 30.7% with the CDI system.

Based on the data compiled during the study program, VSD recommends testing and production of a hybrid thick film equivalent of the CDI design. A prototype engineering unit and a qualification unit should be built using GFE ignition timers. The engineering model would be fabricated first and would provide verification of the thick film hybrid circuit and the ignition timer. Final design of the GSE could then be completed along with associated drawings and documentation. Testing would be accomplished during the prototype engineering phase to verify ground test safety considerations of discharging a three volt pulse into a SBASI. This testing would establish a high confidence level that the SBASI will not fire under any condition of system checkout. VSD further recommends that testing be conducted on the PC-19 cartridges to characterize this ignitor for "all fire" and "no fire" requirements using the CDI system. The user's manual would be revised to specify payload ignitor energy characterization as a prerequisite to use of Scout P/L CDI Separation System.

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3. NASA Technical Report 32-1534

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APPENDIX A
SPECIFICATION FOR SILICON CONTROLLED RECTIFIER

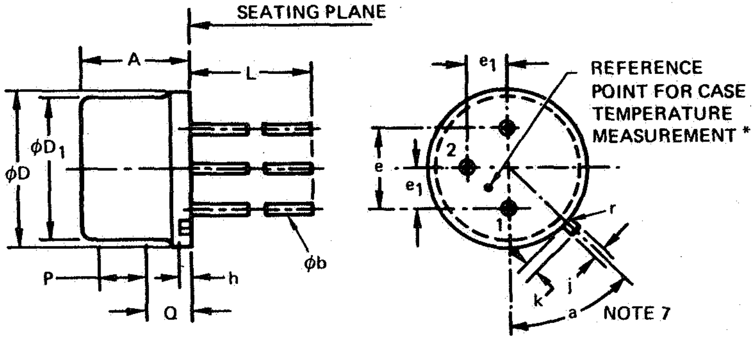
I. SILICON CONTROLLED RECTIFIER (SCR) TO BE DESIGNED FOR POWER SWITCHING CIRCUITS.

II. ELECTRICAL CHARACTERISTICS;

CHARACTERISTIC	SYMBOL	MIN.	TYP.	MAX.	UNITS
INSTANTANEOUS FORWARD BREAKOVER VOLTAGE: GATE OPEN AT $T_C = +100^oC$	$v_{F(BO)O}$	250	–	–	V
PEAK OFF-STATE CURRENT: (GATE OPEN, $T_C = +100^oC$) FORWARD, $V_{DO} = V_{DROM}$	I_{DOM}	–	0.1	0.5	mA
REVERSE (REPETITIVE), $V_{RO} = V_{RROM}$	I_{RROM}	–	0.05	0.5	mA
INSTANTANEOUS ON-STATE VOLTAGE: FOR $i_T = 30$ A AND $T_C = +25^oC$	v_T	–	1.9	2.6	V
DC GATE TRIGGER CURRENT $V_D = 12V$ (DC) $R_L = 30\Omega$ $T_C = +25^oC$	I_{GT}	–	6	15	mA
DC GATE TRIGGER VOLTAGE: $V_D = 12V$ (DC) $R_L = 30\Omega$ $T_C = +25^oC$	V_{GT}	–	0.65	1.5	V
INSTANTANEOUS HOLDING CURRENT: GATE OPEN AND $T_C = +25^oC$	i_{HO}	–	9	20	mA
CRITICAL RATE-OF-RISE OF OFF-STAGE VOLTAGE: $V_{DO} = V_{F(BO)O}$ MIN. VALUE EXPONENTIAL RISE, $T_C = +100^oC$	dv/dt	20	200	–	V/μs
GATE CONTROLLED TURN-ON TIME: $V_D = V_{F(BO)O}$ MIN. VALUE, $i_T = 4.5A$ $I_{GT} = 200$ mA, 0.1 μs RISE TIME $T_C = +25^oC$	t_{gt}	–	1.5	–	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{F(BO)O}$ MIN. VALUE, $i_T = 2A$ PULSE DURATION = 50μs dv/dt = –20V/μs, di/dt = –30 A/μs $I_{GT} = 200$ mA AT TURN ON, $T_C = +75^oC$	t_q	–	15	50	μs

APPENDIX A

III. DIMENSIONAL OUTLINE:



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	.160	.180	4.06	4.57	
ϕb	.017	.021	.432	.533	2
ϕD	.355	.366	9.017	9.296	
ϕD_1	.323	.335	8.204	8.51	
e	.190	2.10	4.83	5.33	
e_1	.100 TRUE POSITION		2.54 TRUE POSITION		4, 5
h	.015	.035	.381	.889	
j	.028	.035	.711	.889	5
k	.029	.045	.737	1.14	3, 5
L	.985	1.015	25.02	25.78	2
P	.100		2.54		1
Q					6
r		.007		.179	
a	42°	48°			5, 7

NOTES:

1. THIS ZONE IS CONTROLLED FOR AUTOMATIC HANDLING. THE VARIATION IN ACTUAL DIAMETER WITHIN THE ZONE SHALL NOT EXCEED .012 IN. (.279 MM).
2. (THREE LOADS) ϕb APPLIES BETWEEN SEATING PLANE AND 1.015 IN. (25.78 MM).
3. MEASURED FROM MAXIMUM DIAMETER OF THE ACTUAL DEVICE.
4. LEADS HAVING MAXIMUM DIAMETER .021 IN. (.533 MM) MEASURED AT THE SEATING PLANE OF THE DEVICE SHALL BE WITHIN .007 IN. (.178 MM) OF THEIR TRUE POSITIONS RELATIVE TO THE MAXIMUM WIDTH TAB.
5. THE DEVICE MAY BE MEASURED BY DIRECT METHODS OR BY THE GAGE AND GAGING PROCEDURE DESCRIBED ON GAGE DRAWING GS-1 OF JEDEC PUBLICATION 12E, MAY 1964.
6. DETAILS OF OUTLINE IN THIS ZONE OPTIONAL.
7. TAB CENTERLINE.

*CASE TEMPERATURE MEASUREMENT

THE SPECIFIED TEMPERATURE-REFERENCE POINT SHOULD BE USED WHEN MAKING TEMPERATURE MEASUREMENTS. A LOW-MASS TEMPERATURE PROBE OR THE THERMOCOUPLE HAVING WIRE NO LARGER THAN AWG NO. 26 SHOULD BE ATTACHED AT THE TEMPERATURE REFERENCE POINT.

APPENDIX B
SPECIFICATION FOR DIODES

I. MAXIMUM RATINGS (EACH DIODE)

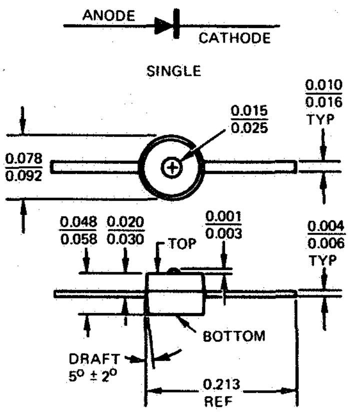
RATING	SYMBOL	VALUE	UNIT
REVERSE VOLTAGE	V_R	70	Vdc
PEAK FORWARD RECURRENT CURRENT	I_F	200	mA
PEAK FORWARD SURGE CURRENT (PULSE WIDTH = 10 μs)	$I_{FM(SURGE)}$	500	mA
POWER DISSIPATION @ $T_A = 25^{\circ}C$ DERATE ABOVE 25°C	P_D	225 2.05	mW mW/°C
OPERATING AND STORAGE JUNCTION TEMPERATURE RANGE	T_J, T_{STG}	–55 TO +135	°C

II. ELECTRICAL CHARACTERISTICS ($T_A = 25^{\circ}C$ UNLESS OTHERWISE NOTED)

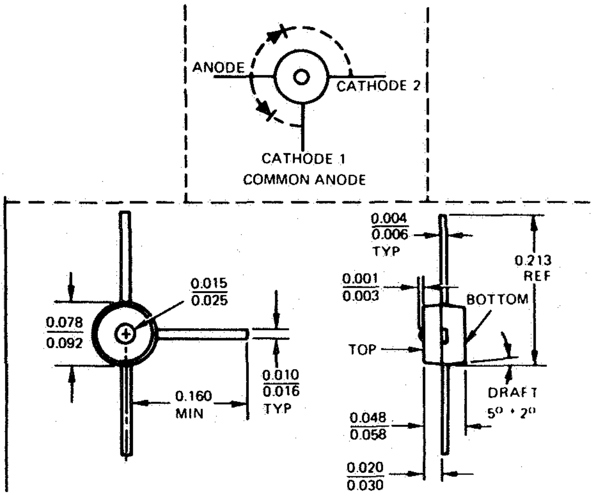
CHARACTERISTIC	SYMBOL	MIN	TYP	MAX	UNIT
BREAKDOWN VOLTAGE ($I_{(BR)} = 100\ \mu$Adc)	$V_{(BR)}$	70	–	–	Vdc
REVERSE CURRENT ($V_R = 50$ Vdc)	I_R	–	–	0.1	μAdc
FORWARD VOLTAGE ($I_F = 1.0$ mAdc) ($I_F = 100$ mAdc)	V_F	 0.55 0.85	 – –	 0.7 1.1	Vdc
CAPACITANCE ($V_R = 0$)	C	–	1.2	2.0	pF
REVERSE RECOVERY TIME ($I_F = I_R = 10$ mAdc)	t_{rr}	–	1.5	5.0	ns

III. DIMENSIONAL OUTLINE

A. SINGLE DIODE



B. DUAL DIODE



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>
> —NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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