https://ntrs.nasa.gov/search.jsp?R=19750002396 2020-03-23T03:24:25+00:00Z

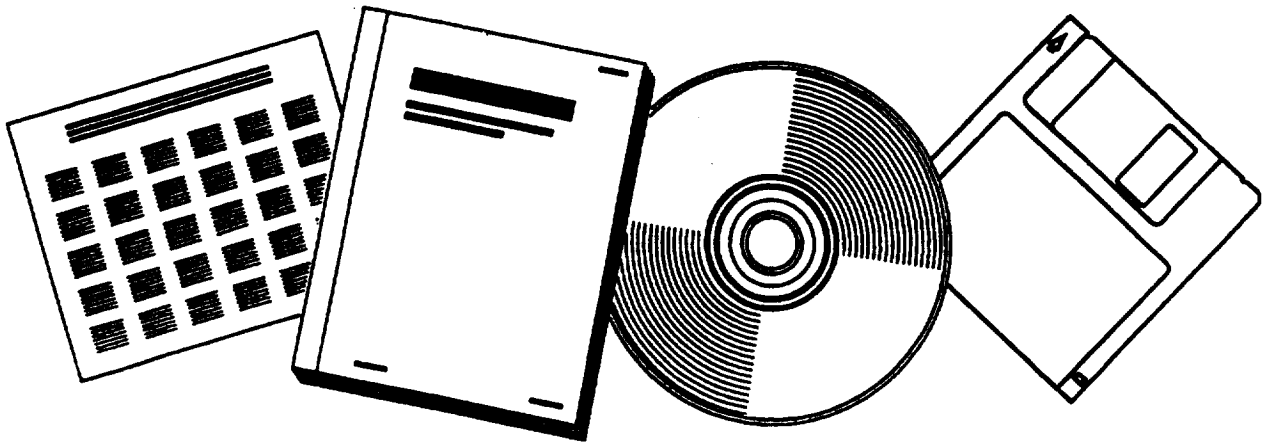
N7510468

NTIS®
Information is our business.

# INVESTIGATION OF TANTALUM WET SLUG CAPACITOR FAILURES IN THE APOLLO TELESCOPE MOUNT CHARGER BATTERY REGULATOR MODULES

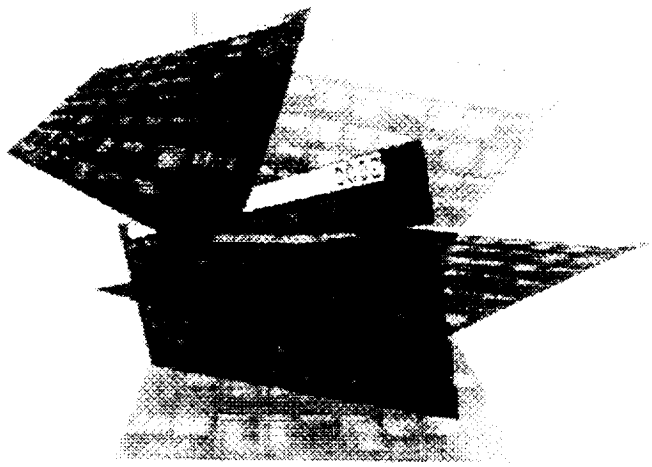
INTERNATIONAL BUSINESS MACHINES CORP., HUNTSVILLE, ALA. ELECTRONICS SYSTEMS CENTER

31 JAN 1973



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

*Tailored to Your Needs!*



# Selected Research In Microfiche

**SRIM®** is a tailored information service that delivers complete microfiche copies of government publications based on your needs, automatically, within a few weeks of announcement by NTIS.

## SRIM® Saves You Time, Money, and Space!

Automatically, every two weeks, your SRIM® profile is run against all *new* publications received by NTIS and the publications microfiched for your order. Instead of paying approximately $15-30 for each publication, you pay only $2.50 for the microfiche version. Corporate and special libraries love the space-saving convenience of microfiche.

## NTIS offers two options for SRIM® selection criteria:

**Standard SRIM®**–Choose from among 350 pre-chosen subject topics.

**Custom SRIM®**–For a one-time additional fee, an NTIS analyst can help you develop a keyword strategy to design your Custom SRIM® requirements. Custom SRIM® allows your SRIM® selection to be based upon *specific subject keywords*, not just broad subject topics. Call an NTIS subject specialist at (703) 605-6655 to help you create a profile that will retrieve only those technical reports of interest to you.

SRIM® requires an NTIS Deposit Account. The NTIS employee you speak to will help you set up this account if you don't already have one.

For additional information, call the NTIS Subscriptions Department at 1-800-363-2068 or (703) 605-6060. Or visit the NTIS Web site at *http://www.ntis.gov* and select SRIM® from the pull-down menu.

**U.S. DEPARTMENT OF COMMERCE**
**Technology Administration**
**National Technical Information Service**
**Springfield, VA 22161 (703) 605-6000**
**http://www.ntis.gov**

73W-00050

# INVESTIGATION of TANTALUM WET SLUG CAPACITOR FAILURES in the APOLLO TELESCOPE MOUNT CHARGER BATTERY REGULATOR MODULES

(NASA-CR-120497) INVESTIGATION OF TANTALUM WET SLUG CAPACITOR FAILURES IN THE APOLLO TELESCOPE MOUNT CHARGER BATTERY REGULATOR (International Business Machines Corp.) 112 p HC $5.25 CSCL 09A

N75-10468

G3/38

Unclas
52213

# INVESTIGATION of TANTALUM WET SLUG CAPACITOR FAILURES in the APOLLO TELESCOPE MOUNT CHARGER BATTERY REGULATOR MODULES

JANUARY 31, 1973

PREPARED UNDER
CONTRACT NAS8-20899
SKYLAB PROGRAM OFFICE
DIRECTIVE 0370

IBM NO. 73W-00050

PREPARED BY

J. F. WILLIAMS
ELECTRICAL SYSTEMS DESIGN

D. H. WIEDEMAN
RELIABILITY and PARTS
ENGINEERING

TECHNICAL APPROVAL

V. H. JOHNSON, MANAGER
ELECTRICAL SYSTEMS DESIGN

A. P. DAVIS, MANAGER
RELIABILITY and PARTS
ENGINEERING

SKYLAB PROGRAM OFFICE APPROVAL

M. R. ROBINSON, MANAGER
SKYLAB PROGRAM OFFICE

IBM Federal Systems Division, Electronics Systems Center/Huntsville, Alabama

# ACKNOWLEDGEMENTS

Appreciation is expressed to all members of the MSFC CBRM team for their assistance in providing much background information and technical expertise as a base for the activities discussed in this report.

Personnel other than CBRM team members also provided assistance in various areas of the CBRM capacitor investigation. Special thanks are due to them as representatives of the following organizations:

Boeing Company

General Electric Company

Federal Electric Corporation

Martin Marietta Corporation

McDonnell Douglas Corporation

NASA-Kennedy Space Center

NASA-Marshall Space Flight Center

Sperry Rand Corporation

# TABLE OF CONTENTS


| Section | | | Page |
|---|---|---|---|
| 1.0 | INTRODUCTION | | 1 |
| | 1.1 | CBRM FAILURE BACKGROUND | 1 |
| | 1.2 | CAPACITOR DESCRIPTION | 1 |
| 2.0 | SUMMARY | | 6 |
| | 2.1 | CBRM LEVEL | 6 |
| | 2.2 | CAPACITOR LEVEL | 6 |
| 3.0 | CONCLUSIONS | | 7 |
| 4.0 | RECOMMENDATIONS | | 9 |
| | 4.1 | CBRM-RELATED | 9 |
| | 4.2 | GENERAL | 9 |
| 5.0 | CAPACITOR CONSTRUCTION AND OPERATING PRINCIPLES | | 10 |
| | 5.1 | INTERNAL CAPACITOR CONSTRUCTION | 10 |
| | 5.2 | CAPACITOR OPERATION | 10 |
| 6.0 | INVESTIGATION AND TEST DETAILS | | 15 |
| | 6.1 | FAILURE HISTORY REVIEW | 15 |
| | | 6.1.1 Summary | 15 |
| | | 6.1.2 Conclusions | 15 |
| | 6.2 | PROCEDURE REVIEW | 17 |
| | | 6.2.1 CBRM Acceptance Tests | 17 |
| | | 6.2.2 Power Up/Down Sequence | 17 |


PRECEDING PAGE BLANK NOT FILMED

Table of Contents (Concluded)


| Section | | | Page |
|---|---|---|---|
| 6.3 | SNEAK CIRCUIT ANALYSIS | | 19 |
| | 6.3.1 | Summary | 19 |
| | 6.3.2 | Conclusions | 19 |
| | 6.3.3 | Details | 19 |
| 6.4 | COMPUTER-AIDED TRANSIENT ANALYSIS | | 29 |
| 6.5 | OVER-VOLTAGE TESTS | | 45/46 |
| | 6.5.1 | Summary | 45/46 |
| | 6.5.2 | Conclusions | 45/46 |
| | 6.5.3 | Details | 45/46 |
| 6.6 | REVERSE BIAS TESTING/EVALUATION | | 49 |
| | 6.6.1 | Summary | 49 |
| | 6.6.2 | Conclusions | 49 |
| | 6.6.3 | Details | 49 |
| 6.7 | CURRENT RIPPLE TEST | | 71 |
| 6.8 | RINGING TESTS | | 73 |
| | 6.8.1 | Summary | 73 |
| | 6.8.2 | Conclusions | 73 |
| | 6.8.3 | Details | 73 |
| 6.9 | MSFC CBRM LABORATORY TESTS | | 77/78 |
| 6.10 | KSC TESTS | | 79/80 |
| 6.11 | PROTOTYPE CBRM TESTS | | 81 |
| | 6.11.1 | IBM Laboratory Tests | 81 |
| | 6.11.2 | ATM Breadboard Tests | 81 |
| 6.12 | CHARACTERIZATION OF CAPACITORS REMOVED FROM FLIGHT CBRMs | | 105 |
| | 6.12.1 | Summary | 105 |
| | 6.12.2 | Conclusions | 105 |
| | 6.12.3 | Details | 105 |

# LIST OF ILLUSTRATIONS


| Figure | | Page |
|---|---|---|
| 1.1-1 | Schematic of CBRM Input and Output Filters ..... | 2 |
| | Photo 1.2-1. CBRM capacitor showing internal assembly and element construction ..... | 3 |
| 1.2-1 | Electrical Configuration of Capacitor Prior to Mid-1971 ..... | 5 |
| 1.2-2 | Electrical Configuration of Capacitor After Mid-1971 ..... | 5 |
| 2.2-1 | Capacitor Anode Silver Plating Criteria ..... | 8 |
| | Photo 5.2-1 ..... | 12 |
| | Photo 5.2-2 ..... | 12 |
| | Photo 5.2-3 ..... | 12 |
| 5.2-1 | Autonetics Reverse Bias Test Data ..... | 13 |
| 6.1.1-1 | Flight CBRM Failure/Test History..... | 16 |
| 6.3.3-1 | Simplified CBRM/ESE Schematic (Sheets 1 through 6) ..... | 21 |
| 6.3.3-2 | Schematic of CBRM Trickle Charger Circuit ..... | 27 |
| 6.3.3-3 | Schematic of CBRM Input and Output Filters Showing Decoupling Capacitors ..... | 28 |
| 6.4-1 | Equivalent Circuit for Electrical Conditions Immediately Following ESE Turn-Off ..... | 30 |
| 6.4-2 | Plot of Output Capacitor Voltage vs Time ..... | 31 |
| 6.4-3 | Plot of L1 Current vs Time ..... | 32 |
| 6.4-4 | Plot of Input Capacitor Voltage vs Time ..... | 33 |
| 6.4-5 | Plot of L1 Voltage vs Time ..... | 34 |
| 6.4-6 | Equivalent Circuit for the Electrical Conditions During Trickle Charger Turn-On ..... | 35 |

List of Illustrations (Continued)


| Figure | | Page |
|---|---|---|
| 6.4-7 | Plot of Input Capacitor Voltage vs Time | 36 |
| 6.4-8 | Plot of Output Capacitor Voltage vs Time | 37 |
| 6.4-9 | Plot of L2 Current vs Time | 38 |
| 6.4-10 | Plot of RC Current vs Time | 39 |
| 6.4-11 | Plot of L1 Current vs Time | 40 |
| 6.4-12 | Equivalent Circuit for Electrical Conditions During Trickle Charger Turn-Off | 41 |
| 6.4-13 | Plot of Input Capacitor Voltage vs Time | 42 |
| 6.4-14 | Plot of Output Capacitor Voltage vs Time | 43 |
| 6.4-15 | Plot of L2 Current vs Time | 44 |
| 6.6.3.3.2-1 | Sample No. 1 Data for Duty Cycle Test No. 2 (Sheet 1 and 2) | 55 |
| 6.6.3.3.2-2 | Sample No. 2 Data for Duty Cycle Test No. 2 | 57 |
| 6.6.3.3.2-3 | Sample No. 3 Data for Duty Cycle Test No. 2 (Sheet 1 and 2) | 58 |
| 6.6.3.4-1 | Reverse Bias Diode Effect | 61 |
| 6.6.3.5-1 | Normal Capacitor AC Waveforms | 62 |
| 6.6.3.5-2 | Test Schematic for AC Test on Capacitors | 62 |
| 6.6.3.5-3 | AC Voltage and Current Waveforms Showing Reverse Leakage Current | 64 |
| 6.6.3.6-1 | AC on DC Test Summary | 65 |
| 6.6.3.6-2 | Raw Data Sample AC on DC Test | 66 |
| 6.6.3.6-3 | Detail Plots of AC on DC Test Data | 67 |
| 6.6.3.6-4 | AC on DC Test Schematic | 69/70 |

List of Illustrations (Continued)


| Figure | | Page |
|---|---|---|
| 6.7-1 | AC Ripple Test Configuration | 72 |
| 6.8.3-1 | Schematic of Lab Model of CBRM Input Filter | 74 |
| | Photo 6.8.3-1 | 75/76 |
| | Photo 6.8.3-2 | 75/76 |
| 6.11.1-1 | IBM Laboratory Test Configuration for Prototype CBRM Tests | 82 |
| | Photo 6.11.1-1 | 83 |
| | Photo 6.11.1-2 | 83 |
| | Photo 6.11.1-3 | 83 |
| | Photo 6.11.1-4 | 84 |
| | Photo 6.11.1-5 | 84 |
| | Photo 6.11.1-6 | 84 |
| | Photo 6.11.1-7 | 85 |
| | Photo 6.11.1-8 | 85 |
| | Photo 6.11.1-9 | 85 |
| | Photo 6.11.1-10 | 86 |
| | Photo 6.11.1-11 | 86 |
| | Photo 6.11.1-12 | 86 |
| | Photo 6.11.1-13 | 87 |
| | Photo 6.11.1-14 | 87 |
| | Photo 6.11.1-15 | 87 |
| | Photo 6.11.1-16 | 88 |
| | Photo 6.11.1-17 | 88 |
| | Photo 6.11.1-18 | 89 |
| | Photo 6.11.1-19 | 89 |
| | Photo 6.11.1-20 | 89 |
| 6.11.1-2 | CBRM Power Line Transient Test Schematic | 90 |
| 6.11.1-3 | Trickle Charger Transient Test Schematic | 91 |
| 6.11.2.3-1 | Schematic of ATM Breadboard Test Setup | 94 |
| | Photo 6.11.2.3-1 | 97 |
| | Photo 6.11.2.3-2 | 97 |
| | Photo 6.11.2.3-3 | 97 |
| | Photo 6.11.2.3-4 | 98 |
| | Photo 6.11.2.3-5 | 98 |

## List of Illustrations (Concluded)


| Figure | | Page |
|---|---|---|
| | Photo 6.11.2.3-6 | 98 |
| | Photo 6.11.2.3-7 | 99 |
| | Photo 6.11.2.3-8 | 99 |
| | Photo 6.11.2.3-9 | 99 |
| | Photo 6.11.2.3-10 | 100 |
| | Photo 6.11.2.3-11 | 100 |
| | Photo 6.11.2.3-12 | 100 |
| | Photo 6.11.2.3-13 | 101 |
| | Photo 6.11.2.3-14 | 101 |
| | Photo 6.11.2.3-15 | 102 |
| | Photo 6.11.2.3-16 | 102 |
| | Photo 6.11.2.3-17 | 103 |
| | Photo 6.11.2.3-18 | 103 |
| 6.12.1-1 | Characterization of Flight CBRM Output Filter Capacitors | 106 |

# LIST OF TABLES


| Table | | Page |
|---|---|---|
| 6.6.3.1-1 | Reverse Voltage Evaluation of Capacitor Assemblies ..... | 49 |
| 6.6.3.2-1 | Steady State Reverse Bias Voltage Evaluation Data ..... | 52 |
| 6.6.3.3.1-1 | Reverse Bias Duty Cycle Test No. 1 Data ..... | 54 |
| 6.11.2.1-1 | CBRM Transient Data ..... | 93 |
| 6.11.2.3-1 | Trickle Charger Transient ..... | 95 |
| 6.11.2.3-2 | Transient at SAS Power On and Off ..... | 96 |

# INVESTIGATION OF TANTALUM WET SLUG CAPACITOR FAILURES IN THE APOLLO TELESCOPE MOUNT CHARGER BATTERY REGULATOR MODULES

## 1.0 INTRODUCTION

### 1.1 CBRM FAILURE BACKGROUND

The Apollo Telescope Mount (ATM) contains eighteen Charger Battery Regulator Modules (CBRMs). Each CBRM has an input filter and an output filter containing tantalum wet slug capacitors. (See Figure 1.1-1). During ATM system tests at MSFC, MSC and KSC, seven CBRM's experienced capacitor failures. One failure occurred in the input side of the input filter, and seven in the output side of the input filter. No failures have been experienced in the output filter.

Early failures were thought to have happened because of age and/or abuse since the failed capacitors were 1967 date coded. The decision was made to replace all 1967 date coded capacitors with 1972 date coded capacitors. Prior to the retrofit cycle, a failure of one of the 1972 date coded capacitors occurred. Subsequently, a team was organized to investigate the capacitor failures and recommend a solution to the problem. IBM was asked to participate in the investigation. This report describes IBM's activity in association with other contractors and NASA toward a solution of the problem of CBRM capacitor failures.

The purpose of the investigation described in this report was to determine the mechanism of the capacitor failures and to identify the cause of the failure mechanism.

Tantalum wet slug capacitors are historically susceptible to degradation via reverse bias. Caution is always in order to prevent the application of voltage to the capacitor in the reverse direction (reverse bias). A concentrated effort, therefore, was persued during this investigation to locate a source of reverse bias as a possible cause of capacitor failure.

### 1.2 CAPACITOR DESCRIPTION

The capacitors failing in the CBRM were wet tantalum electrolytic devices manufactured by the General Electric Company. Each capacitor is, in reality, an assembly containing sixteen individual capacitor elements potted in a case. (See Photograph 1.2-1).

Prior to mid-1971, the assembly contained sixteen capacitors wired in parallel. Each capacitor element is rated at 27 microfarads, 100 volts dc. Capacitor

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

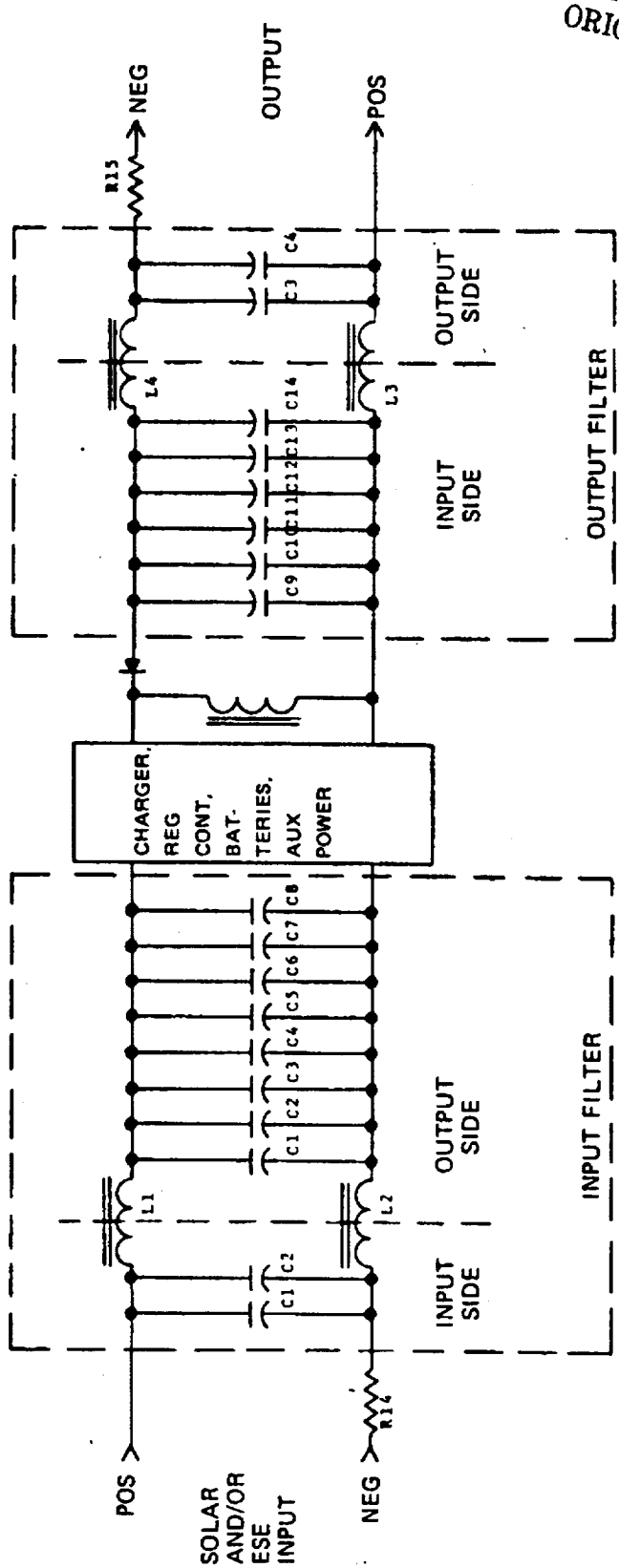



*Figure 1.1-1. Schematic of CBRM Input and Output Filters.*

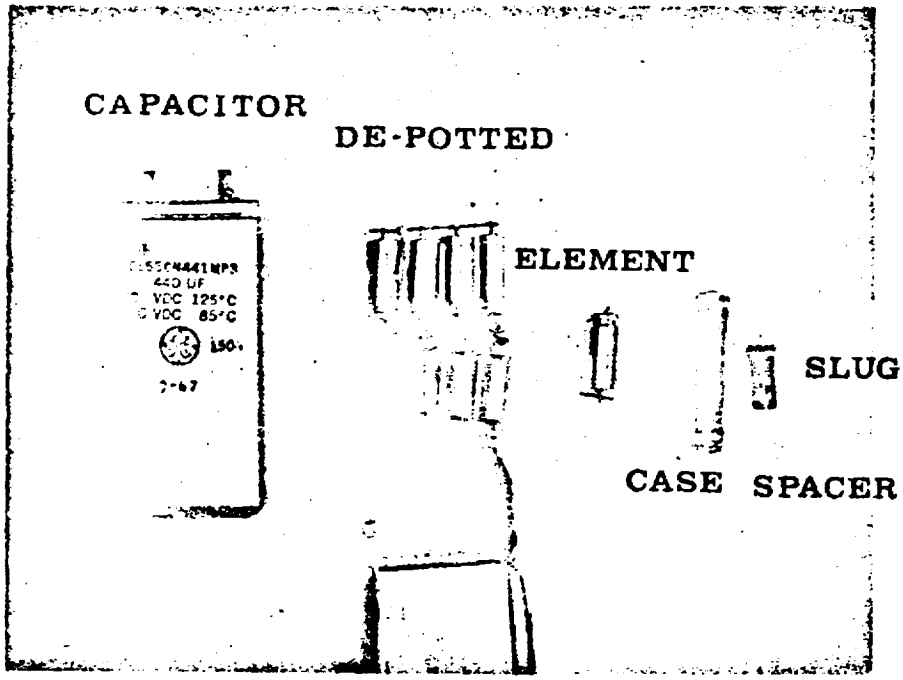



**Photo 1.2-1.** CBRM capacitor showing internal assembly and element construction.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

assemblies manufactured after mid-1971 have an internal series/parallel arrangement consisting of two series groups of eight capacitors in parallel. These capacitor elements are rated at 110 microfarads, 50 volts dc. (See Figures 1.2-1 and 1.2-2).

Details of capacitor construction and operation are given in Section 5.0.

Data relative to the capacitor assembly are as noted:

Military Part No. SCL55CN441MP3

General Electric Part No. 69F1164

Ratings: 440 microfarads

100 volts dc @ 85°C

70 volts dc @ 125°C

116 volts dc surge @ 85°C

81 volts dc surge @ 125°C

4.8 amperes (ripple) 60 Hz @ 25°C*

22 volts (ripple) 60 Hz @ 25°C*

22 micro amperes max leakage @ 100 volts dc

*Correction factors required for increased temperatures and/or frequencies.

The following terminology is used throughout this report when discussing the CBRM capacitors:

- capacitor element - One of sixteen capacitors contained in each CBRM capacitor.
- capacitor or capacitor assembly - Capacitor as installed in the CBRM.
- reverse bias - Reverse polarity voltage, transient or steady state, applied to CBRM capacitors.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

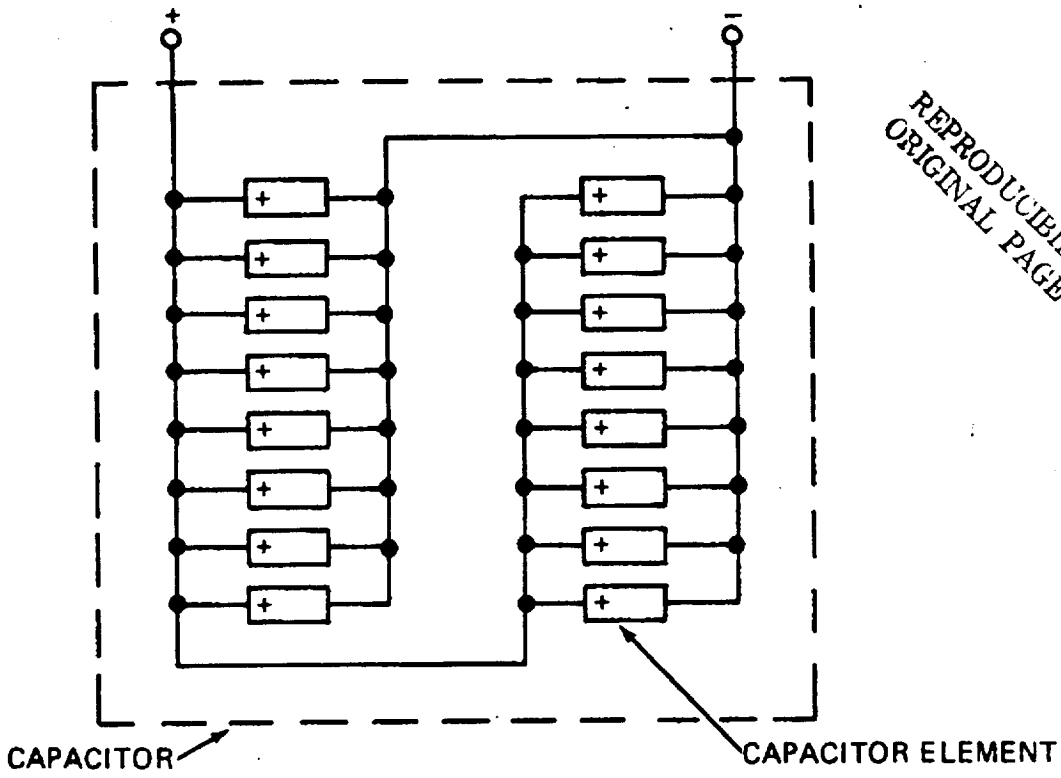



*Figure 1.2-1. Electrical Configuration of Capacitor Prior to Mid-1971.*

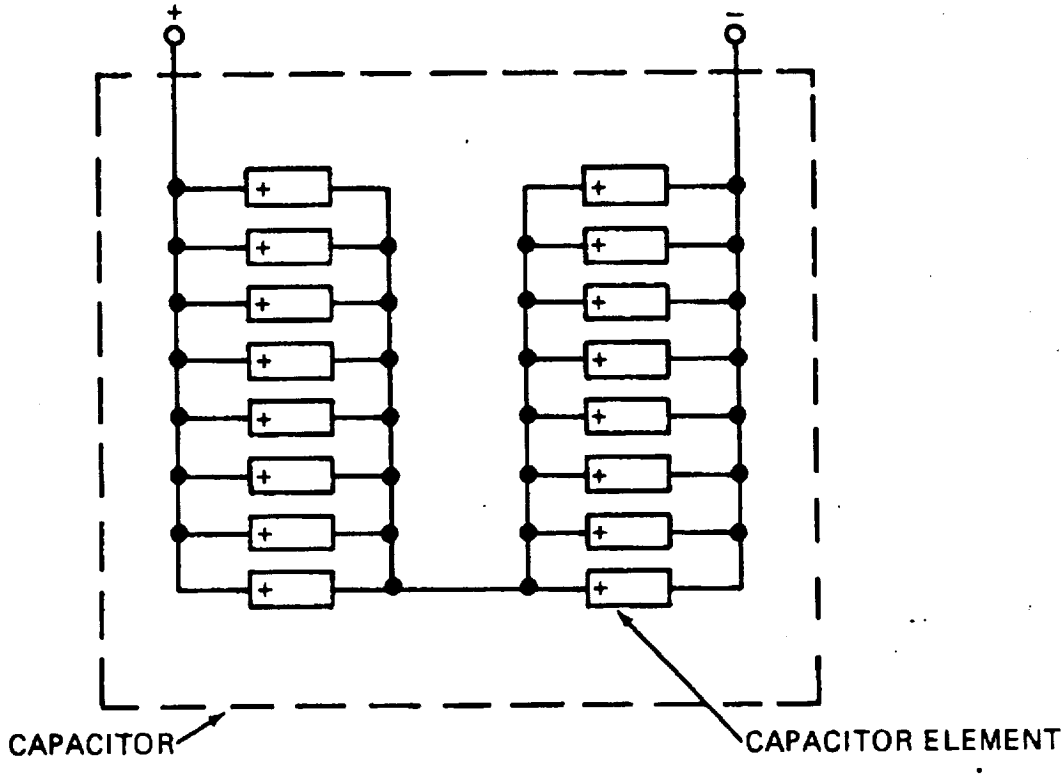



*Figure 1.2-2. Electrical Configuration of Capacitor After Mid-1971.*

## 2.0 SUMMARY

### 2.1 CBRM LEVEL

The CBRM capacitor investigation included a review of the history of the CBRMs having capacitor failures in an attempt to establish trends or patterns of failures. All failures were found to have occurred after the CBRM had been installed in a system configuration and mated with Electrical Support Equipment (ESE). Also, failures occurred only in the CBRM input filter.

A review of acceptance test procedures (ATPs) and power up/down sequences revealed areas of potential transient problems. These areas of concern suggested further analysis and tests which were pursued.

Both sneak circuit analysis and computer-aided transient analysis revealed sources of reverse bias that could be applied to the capacitors under investigation.

CBRM tests at IBM, at the MSFC ATM Breadboard and at KSC verified sources of reverse bias that could be applied to the input filter capacitors in the CBRM. Also verified were procedural changes that eliminated reverse bias from the capacitors.

### 2.2 CAPACITOR LEVEL

Various tests were run on CBRM capacitors in an attempt to duplicate the failures that occurred during ATM system test. The only method by which the failures were duplicated was the application of a reverse bias voltage to the capacitor followed by the application of rated voltage in the normal forward direction. Swelling of capacitor cases was observed under these conditions. The capacitors tested were not confined; if confined, the cases probably would have exploded as did some of the flight units that failed.

Subsequent tests were run on capacitors and capacitor elements in an attempt to define failure characteristics with regard to over-voltage of correct polarity, magnitude of steady state reverse voltage and current, magnitude and frequency of pulsating reverse voltage and current ripple as experienced with a CBRM with the capacitor operating at 90% rated voltage.

It was found that both over-voltage and reverse voltage are damaging to the capacitors, and the damage is directly proportional to the magnitude of each. Each capacitor, as well as each capacitor element, was found to have its own characteristics, similar to others but sufficiently different as to prevent predictability.

Normal CBRM current ripple (12 amperes peak) at normal CBRM operating voltage (90 vdc) apparently caused neither physical damage nor degraded capacitor operations.

The anode of the capacitor elements is tantalum, and the cathode is silver. The suspected cause of failure was plating of silver from the cathode onto the anode. Figure 2.2-1 shows the criteria established for defining the relative quantity of silver plated on the anode. Capacitors tested and opened were visually characterized for degree of silver plating. It was impossible to correlate failure with quantity of silver. Also, some off-the-shelf capacitors were opened and were found to have slight silver plating. Hence, although failure analysis with regard to quantity of plated silver was inconclusive, the silver plating with subsequent dielectric penetration is the apparent failure mechanism.

Replacement of all tantalum wet slug capacitors in the CBRM with tantalum foil capacitors was considered. Although less capacitance per unit volume is available from tantalum foil capacitors, they have a greater tolerance to reverse bias. However, there were insufficient foil assets available to replace both input and output filter capacitors.

It was decided to replace input filter capacitors with tantalum foil capacitors, since all capacitor failures had occured in the input filter and the reverse bias possibility was shown to be only on the input filter. Foils have a history of satisfactory operation in similar applications; and it was determined that the CBRM would function properly with the reduced capacitance in the input filter.

Although no failures had occured in the output filter capacitors, they were removed from the CBRMs, and a teardown inspection was performed on them.

No anomalies were observed during teardown; so the decision was made to replace all output filter capacitors with 1972 date coded tantalum wet slug capacitors. The series-parallel arrangement of elements of these capacitors give a greater reliability to the output filter.. If one element fails (short), the filter will continue to function since the output filter operates at a voltage less than the rated value of a single element. Also, no reverse bias was ever identified on the output filter capacitors. In addition, foil capacitors would have changed the output impedance of the CBRM possibly causing problems with other equipment.

## 3.0 CONCLUSIONS

The failure mechanism of the CBRM tantalum wet slug capacitors is a short through the $Ta_2O_5$ dielectric caused by either the penetration of silver or working voltage puncture after dielectric degradation.

Both the penetration of silver migrating from the cathode and dielectric degradation are caused by reverse bias voltage having been applied to the capacitors.

*Figure 2.2-1. Capacitor Anode Silver Plating Criteria.*

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

The cause of catastrophic failure in the flight CBRMs is reverse bias followed by the application of greater than 50% rated voltage. Reverse bias causes degradation or penetration of the dielectric resulting in reduced working voltage capability. Application of forward voltage then causes dielectric breakdown. Catastrophic failure in the CBRMs occurred because the forward voltage applied to the capacitors was supplied from a high current source. Upon dielectric breakdown the capacitor presented a short circuit to the voltage source and sufficient energy was available to cause explosion of the capacitors.

Reverse bias on the CBRM input filter capacitors is possible under the following conditions:

- Instant turn on/off of Solar Array Simulator (SAS) 15 volts to the CBRM
- Instant turn on/off of CBRM battery trickle charger when SAS voltage is at zero.

Reverse bias caused by the above actions can be prevented by eliminating the sudden turn on/off of SAS 15 volts and by holding SAS 15 volts on while turning on/off the trickle charger.

## 4.0 RECOMMENDATIONS

### 4.1 CBRM-RELATED

Modify the CBRM ground support procedures to require the following:

- Ramp SAS voltage up from 0 volts and down to 0 volts.
- Hold SAS 15 volts at the CBRM while turning trickle charger on and off.
- Ramp trickle charger voltage up from 0 volts and down to 0 volts when using portable trickle charger.

### 4.2 GENERAL

When using tantalum wet slug capacitors, insure that no reverse bias can be applied to the capacitors. If the application involves interface with other components or systems, e.g., ESE, test equipment, etc., insure that no sneak circuits exist whereby a reverse bias condition can occur. Also, review procedures for possible sequences which could generate negative transients producing reverse bias on capacitors.

## 5.0 CAPACITOR CONSTRUCTION AND OPERATING PRINCIPLES

### 5.1 INTERNAL CAPACITOR CONSTRUCTION

The elements utilized within the capacitor assembly are individual tantalum wet slug capacitors. Each element has an anode made from powdered tantalum which is formed in a cylindrical shape utilizing temperature and pressure.

The capacitor dielectric is tantalum pentoxide, $Ta_2O_5$. The pentoxide is formed on the anode or slug by subjecting the formed anode to an electrical potential (forming voltage) in the presence of an oxidizing agent such as phosphoric acid. The thickness of the pentoxide film is primarily dependent upon the potential applied and the duration of the forming voltage. The finished film thickness contributes directly to the unit's voltage rating and the capacitance value.

The electrolyte is sulphuric acid ($H_2SO_4$) $\approx 40\%$ concentration. A filler (CAB-O-SILL®) has been added to the electrolyte producing a gel.

The case is coined silver, which has had the internal surface etched and coated with platinum black. Normal electrical connection to the unit is plus to the anode or slug and ground or negative to the case.

### 5.2 CAPACITOR OPERATION

The general theory of operation is simplified by considering the total unit capacitance, i.e., tantalum anode one plate, the $Ta_2O_5$ film the dielectric and the case the cathode or opposing plate and the electrolyte as a conductor or extension of the case/cathode.

When a positive voltage is applied to the anode, electrons leave the anode and travel thru the external circuit to the case. The electrons enter the electrolyte where negative ions are formed. These negative ions collect at the sulphuric acid side of the pentoxide film as the film is an ionic barrier. Current (electron movement) in the external circuit continues until the charge across the pentoxide film equals the applied potential. Since the $Ta_2O_5$ dielectric contains minute flaws, the capacitor will exhibit a forward leakage current (usually in micro-amperes or nano-amperes). The tantalum pentoxide film has a unique characteristic that can be detrimental. This characteristic is the fact that the $Ta_2O_5$ film is an ion barrier and not an electron barrier. When the capacitor is reverse biased (ground or minus to the slug and plus to the case), electrons leave the slug thru the film and are converted to negative ions at the electrolyte. The reaction at the case is for silver to go into solution and in turn plate out on the slug. Since the $Ta_2O_5$ film allows electron flow in the reverse mode, a reverse leakage current is developed which is magnitudes larger than normal forward leakage. This reverse leakage current will continue as long as the reverse voltage is applied. Catastrophic failure of the capacitor can be attributed to heat generated by

the reverse current and/or excessive liberation of gas from the electrolyte. Even if catastrophic failure does not occur while in the reverse bias mode, the capacitor has usually been degraded. Degradation occurs at the pentoxide film covering the tantalum slug. This degradation is caused by silver plating out on the film and/or excessive gas generation (bubbles) at the anode.

Since the pentoxide film is relatively weak physically, bubbles can destroy the film integrity exposing the tantalum anode to the electrolyte. When the unit is again forward biased there is no ionic barrier at the tantalum/electrolyte interface. Depending on available voltage and current in the circuit, catastrophic failure can occur due to high forward current creating heat and excessive gas generation.

Note: If the circuit is current limited, the tantalum has the potential capability of healing by forming new tantalum pentoxide film at the tantalum/electrolyte interface. The formation of new film over a fault area appears to make the unit operational. However, there is no known test data available that can attest to the reliability of a unit that has repaired or healed itself.

Silver deposited on the pentoxide film with time, can migrate thru the film (pentoxide layer) creating a short from anode to cathode. A typical silver deposit is shown in Photos 5.2-1, 5.2-2, and 5.2-3.

Another area of concern is silver deposition on flaw sites. It was previously mentioned that the forward leakage current is due to flaws in the pentoxide film. Under normal forward conditions oxygen is present at these flaw sites. The normal reaction of oxygen at these sites is the formation of pentoxide film. Once a site has been covered by silver, new film cannot be formed. The net result is, as more sites are covered with silver, the forward leakage current can increase. When the forward leakage becomes large enough, catastrophic failure can occur primarily due to excessive heat and gas generation.

During the investigation of the capacitor failures in the CBRM, a concentrated effort was expended to determine the fragility level of typical capacitors under various degrees of reverse bias conditions. (Reference paragraph 6.6). During this investigation, available data from other sources were also researched.

Figure 5.2-1 presents results of tests performed by North American Rockwell, Autonetics Division. Tantalum wet slug capacitors were subjected to reverse voltages of 100 to 500 millivolts for 160 hours and then 50% of rated forward voltage was applied. As expected, the failure rate increased with increasing reverse voltage. It is concluded that the slope of the plot can be raised or lowered by varying reverse bias application time and/or amplitude of the forward voltage applied after the reverse time period has been completed. It is also suspected that the degree of current

Photo 5.2-1. Mag. 63X

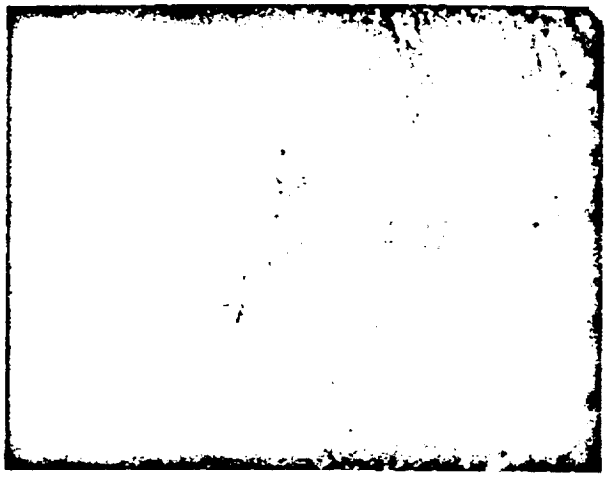
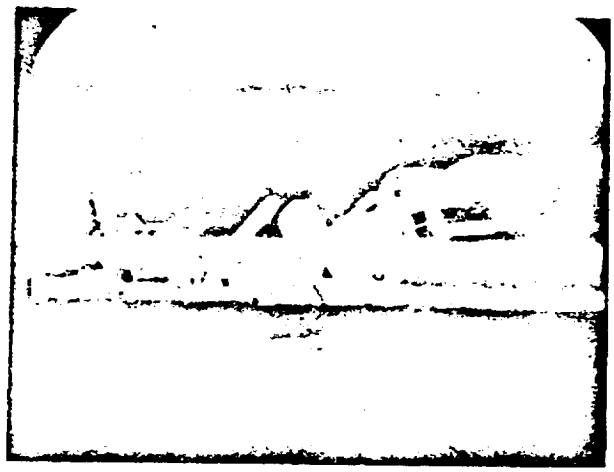
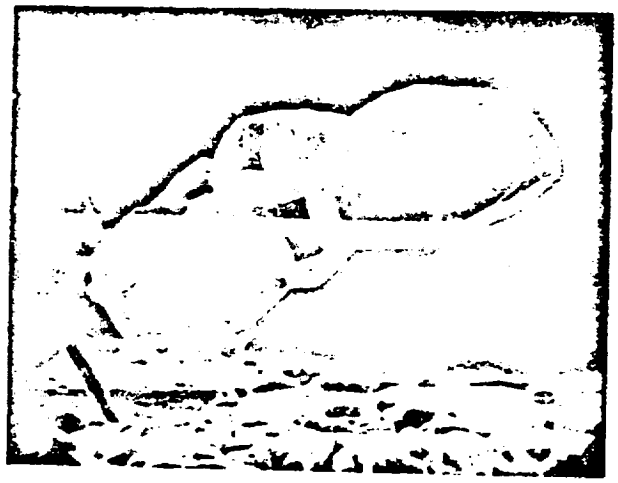


Photo 5.2-2. Mag. 350X



Photographs of tantalum slug showing silver crystal deposits on the pentoxide film-capacitor S/N 1098, Element No. 6 Date Code 1967.

Photo 5.2-3. Mag. 600X



REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

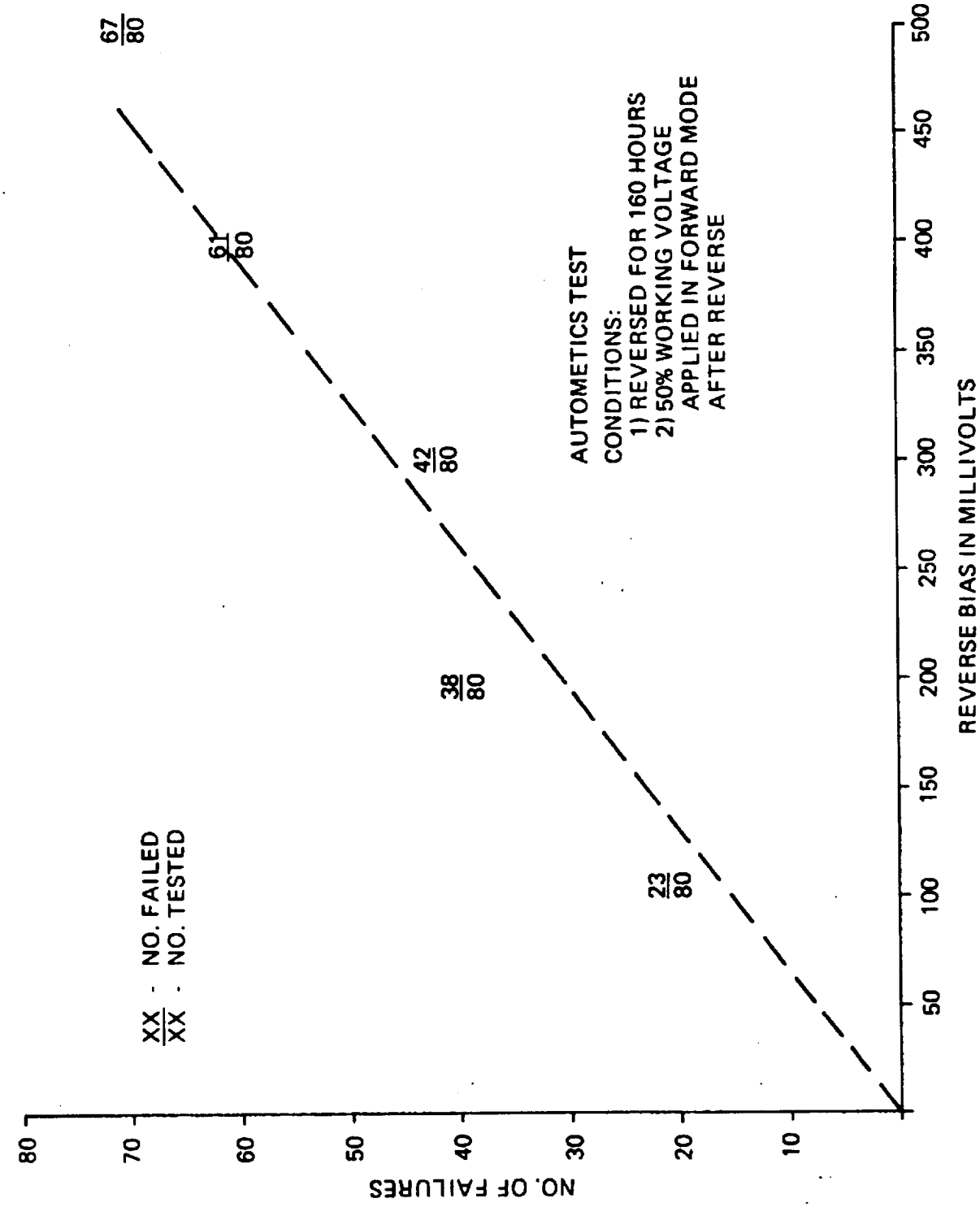



*Figure 5.2-1. Autonetics Reverse Bias Test Data.*

limiting utilized during the application of forward voltage would be a contributing factor to the failure rate.

The reverse bias testing contained in this report, the Autonetics test previously mentioned and numerous other reports generally conclude that reverse bias on tantalum wet slug capactiors can be detrimental and may lead to catastrophic failure of the capacitor.

The primary differences between various evaluations of reverse bias are in the following areas:

- Amplitude of reverse voltage/current
- Steady state versus pulse
- Frequency (ac)
- Duration of applied reverse bias
- Amplitude of forward or normal working voltage applied after reverse stress

Variations and combinations of the conditions noted above can produce varying failure rates for given applications. However, for reliable operation it is concluded that no reverse bias should be tolerated.

## 6.0 INVESTIGATION AND TEST DETAILS

## 6.1 FAILURE HISTORY REVIEW

### 6.1.1 Summary

Records of CBRM capacitor failures were studied in conjunction with CBRM log books. An attempt was made to correlate failures with age, location, number of turn on/off cycles, rework, number of test cycles and type of test, i.e., component of system, during which the failures occurred.

The review of all available records revealed that all known capacitor failures occurred after the CBRMs had been mated with ESE in a pre-launch configuration. No other trends or correlations were apparent. (See Figure 6.1.1-1.)

### 6.1.2 Conclusions

The cause of the CBRM input filter capacitor failures exists only in the pre-launch ESE configuration and is probably the result of a sneak circuit present only in the ESE configuration.

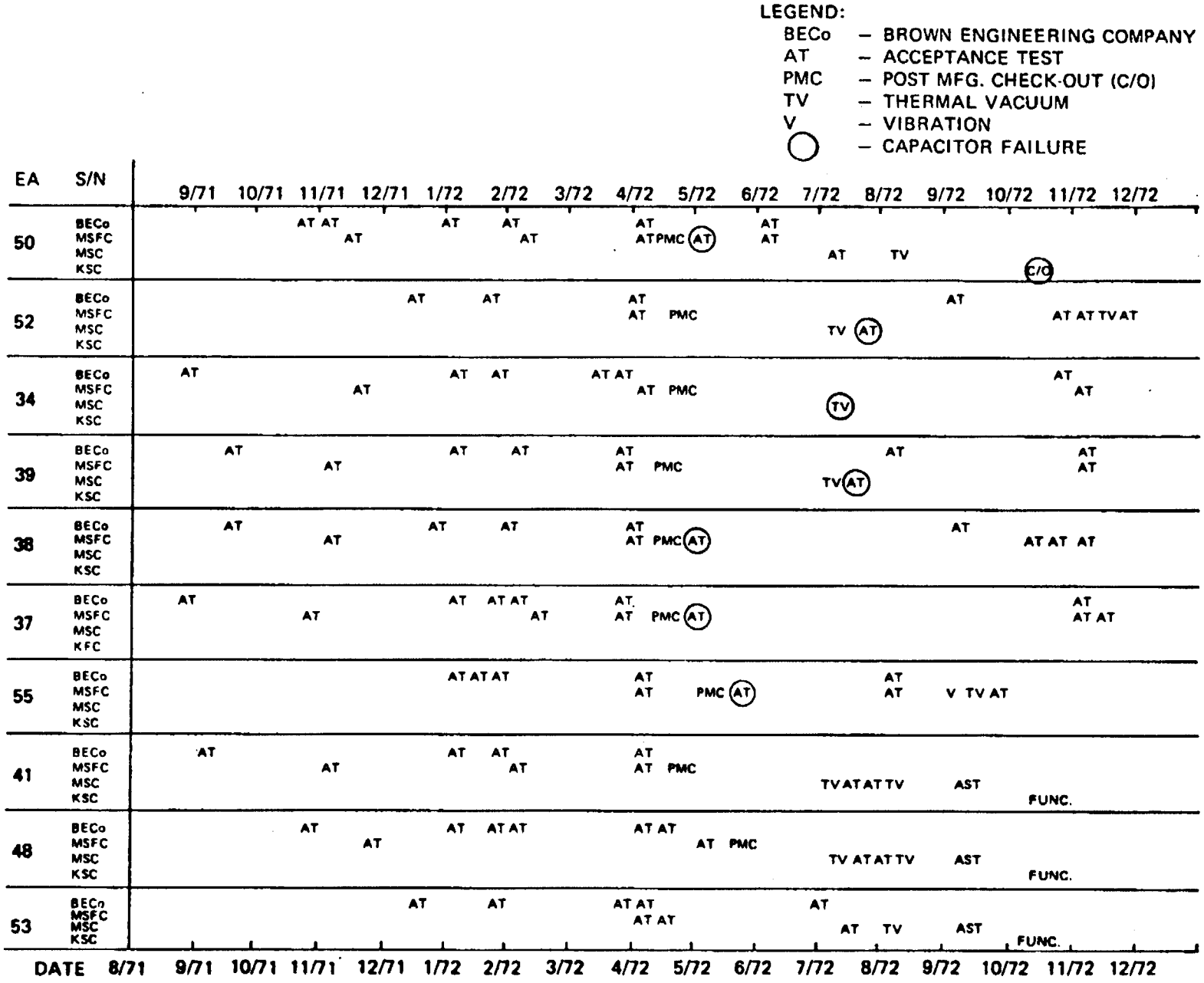



*Figure 6.1.1-1. Flight CBRM Failure/Test History.*

## 6.2 PROCEDURE REVIEW

### 6.2.1 CBRM Acceptance Tests

The MSFC ATP 40M26710A was reviewed in detail by IBM and MSFC personnel. Instrumentation was used in an effort to determine if reverse bias was present during an actual acceptance test. This test was conducted with the Flexible Automatic Circuit Tester (FACT) and included functional tests as follows:

| | |
|---|---|
| Voltage (Cells and Battery) | ESE Trickle Charge |
| Charge Retention | Battery Charger |
| Insulation Resistance | Power Sharing |
| Continuity | Command Signal |
| Output Voltage | Telemetry Status |

Also, the MSFC ATP 40M26705, utilized by Brown Engineering, was reviewed by MSFC personnel.

It was concluded that the ATPs were adequate and that no tests or sequences resulted in reverse bias being applied to the input or output filter capacitors.

### 6.2.2 Power Up/Down Sequence

The overall ATM power up/down sequence was reviewed with MSFC personnel at Huntsville and KSC. The purpose of this review was to determine configuration differences and possible reverse bias sources at the system level since previous failures had occurred during system test.

The review revealed procedure and configuration differences for the trickle charger power input to the CBRM at the component level, at the ATM Breadboard and at the ATM System level at KSC.

The following differences were noted:

- Trickle charger connections to the CBRM do not involve the CBRM input filter at the component level. At the system level different connections are used at the CBRM whereby the CBRM input filter circuit becomes part of the trickle charge circuit.

- Procedures allow trickle charger power on/off with no regard to the status of CBRM input voltage. In the system configuration, trickle charger on/off with CBRM input voltage at zero will cause ringing in the input filter and, consequently, possible reverse bias on the input filter capacitors.

- The method of turning trickle charger on/off differs between the ATM Breadboard and KSC.

  At the ATM Breadboard, the ac input power switch to the trickle charger supply is used to turn trickle charger voltage on/off. A ramping action occurs such that the CBRM input filter is not subjected to an instant turn-on/off of current in the filter.

  At KSC, a relay (dead face) is used to turn trickle charger voltage on/off. An instant current turn-on/off occurs in the CBRM input filter. Ringing will occur in the input filter possibly resulting in reverse bias being applied to the input filter capacitors.

- There is no transient suppression in the trickle charger circuit as is present in other ESE power circuits. Lack of suppression is a potential contributor to a reverse bias problem.

The above findings identified areas of concern which were investigated by means of sneak circuit analysis, computer aided transient analysis and CBRM tests at the MSFC ATM Breadboard and at KSC.

## 6.3 SNEAK CIRCUIT ANALYSIS

### 6.3.1 Summary

Sneak circuit analysis was performed both on all CBRM internal circuits and CBRM/ESE circuits. A sneak path was found whereby reverse bias could be applied to the CBRM input filter capacitors upon trickle charger turn-on/off.

### 6.3.2 Conclusions

The only sneak path, whereby reverse bias can be applied to the wet slug tantalum capacitors in the CBRM, is in the CBRM/trickle charger circuit. Only the input filter capacitors are involved with the trickle charger. No sneak paths were found relative to the output filter capacitors.

### 6.3.3 Details

The following documents were used to perform an analysis of both internal CBRM circuits and circuits connecting the CBRM with ESE:

| | |
|---|---|
| 40M26258 | CBRM Pin Function List |
| 40M26259 | Electrical System Schematic CBRM |
| 40M26201 | Wiring Diagram Electronics CBRM |
| 40M33662 | ATM Electrical Schematic |
| 40M68374 | ATM ESE LC-39 Advanced Electrical System Schematic |
| 40M70829 | Power Interconnection Diagram ATM ESE |
| 40M68507 | Cable Interconnection Diagram ATM ESE Checkout |
| 40M35659-2B | ICD Definition of ATM/AM Electrical Interface |
| PRO-TCP-P-40004 | ATM/Prototype Test and Checkout Procedure |
| 40M26995 | ATM CBRM Engineering and Development Report |

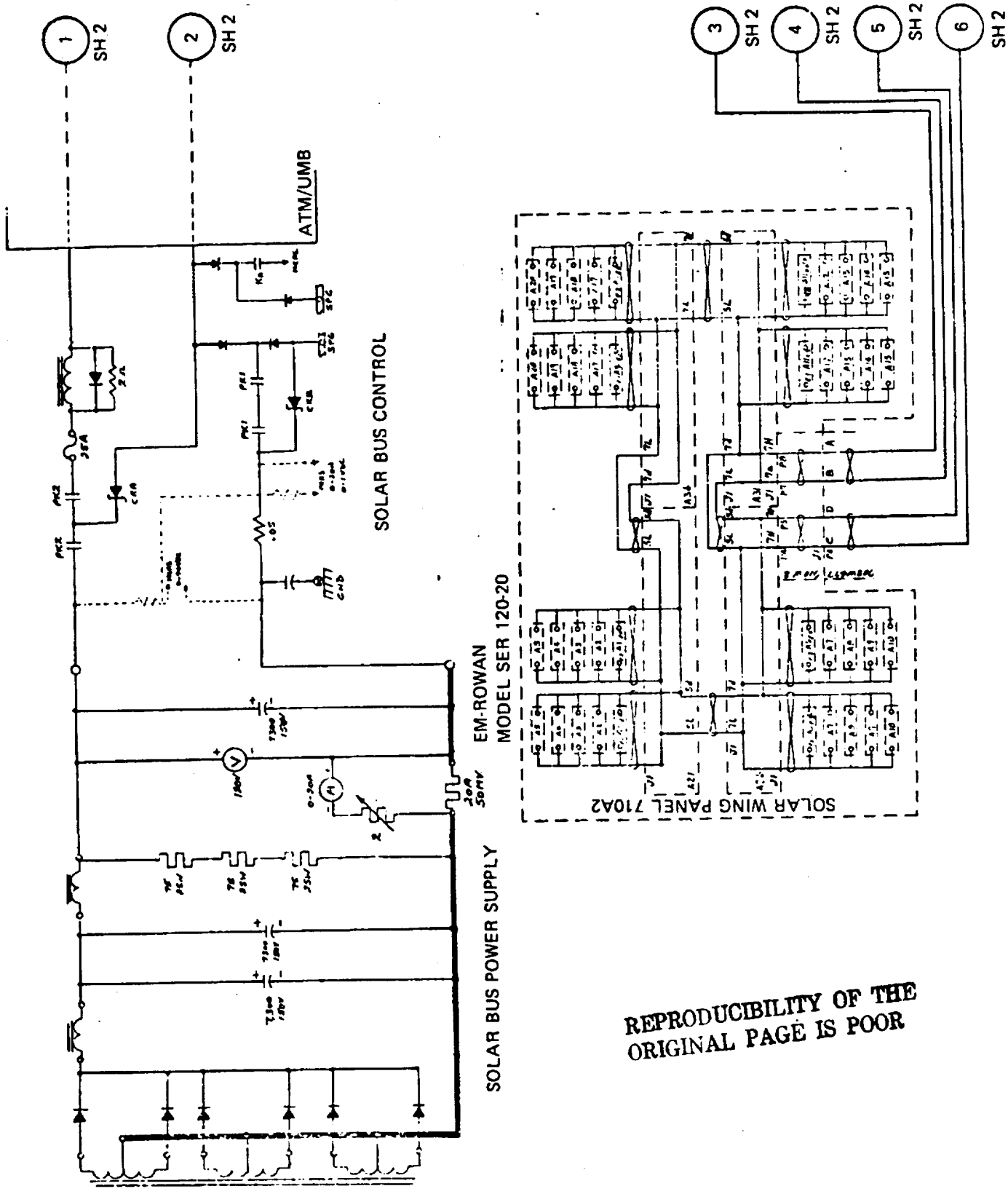
| | |
|---|---|
| 1953805 (Bendix) | ATM Control and Display Console Electrical Schematic |
| 61J760071 (MDAC) | Electrical Schematic Diagram ATM Carrier Instruction Manual Rowan Power Supply Model 120-20 |
| | Instruction Manual Kepco Power Supply Model JQE55-2 (M) |

An initial documentation check was performed for two reasons. The first was to look for wiring errors that could be the source of capacitor failures. Secondly, it was necessary to verify the accuracy and compatibility of the documentation to be used during the failure investigation. The documentation check included a complete wire-by-wire comparison of the CBRM electrical schematic against the CBRM wiring diagram.

Figure 6.3.3-1 shows a simplified schematic generated from the above documentation for use during the CBRM capacitor investigation.

Sneak circuit analysis was performed on the CBRM/ESE circuitry to determine if a sneak path existed whereby reverse bias could be applied to wet slug tantalum capacitors in the CBRM. Such a path was found to exist in the trickle charge circuit. When the trickle charger is turned on/off, reverse bias can be applied to the input filter capacitors due to resonant ringing of input filter components. (See Figure 6.3.3-2.) Subsequent tests verified that reverse bias transients can occur when switching the trickle charger on and off.

Decoupling capacitors were suspected as providing a sneak path for reverse bias. Sneak circuit analysis revealed such a sneak path (see Figure 6.3.3-3). However, laboratory measurements proved that the reverse bias thus generated was too small to cancel or reverse the normal static forward voltage present on the wet slug tantalum capacitors.




REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

*Figure 6.3.3-1. Simplified CBRM/ESE Schematic. (Sheet 1 of 6)*

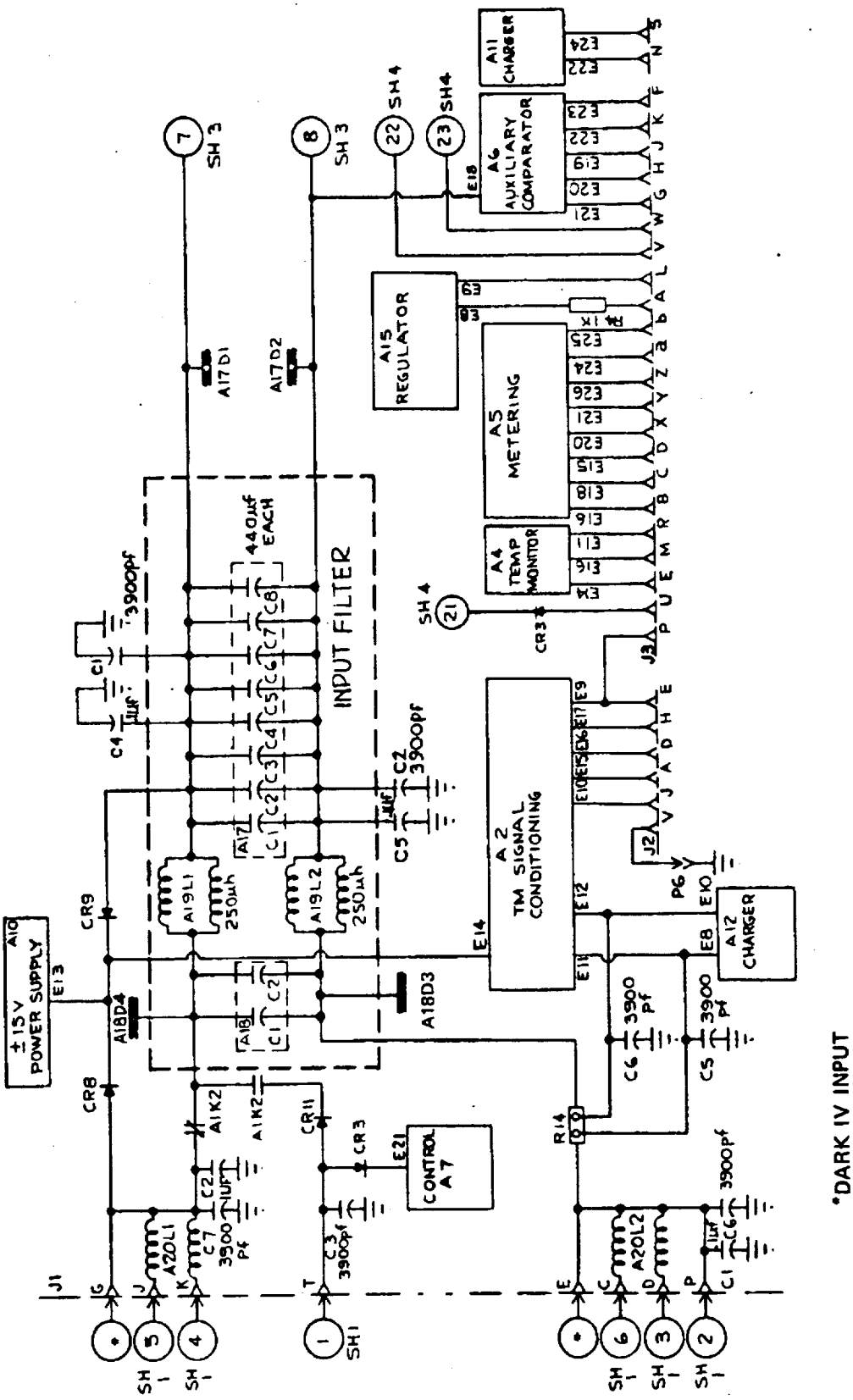



*Figure 6.3.3-1. Simplified CBRM/ESE Schematic. (Sheet 2 of 6)*

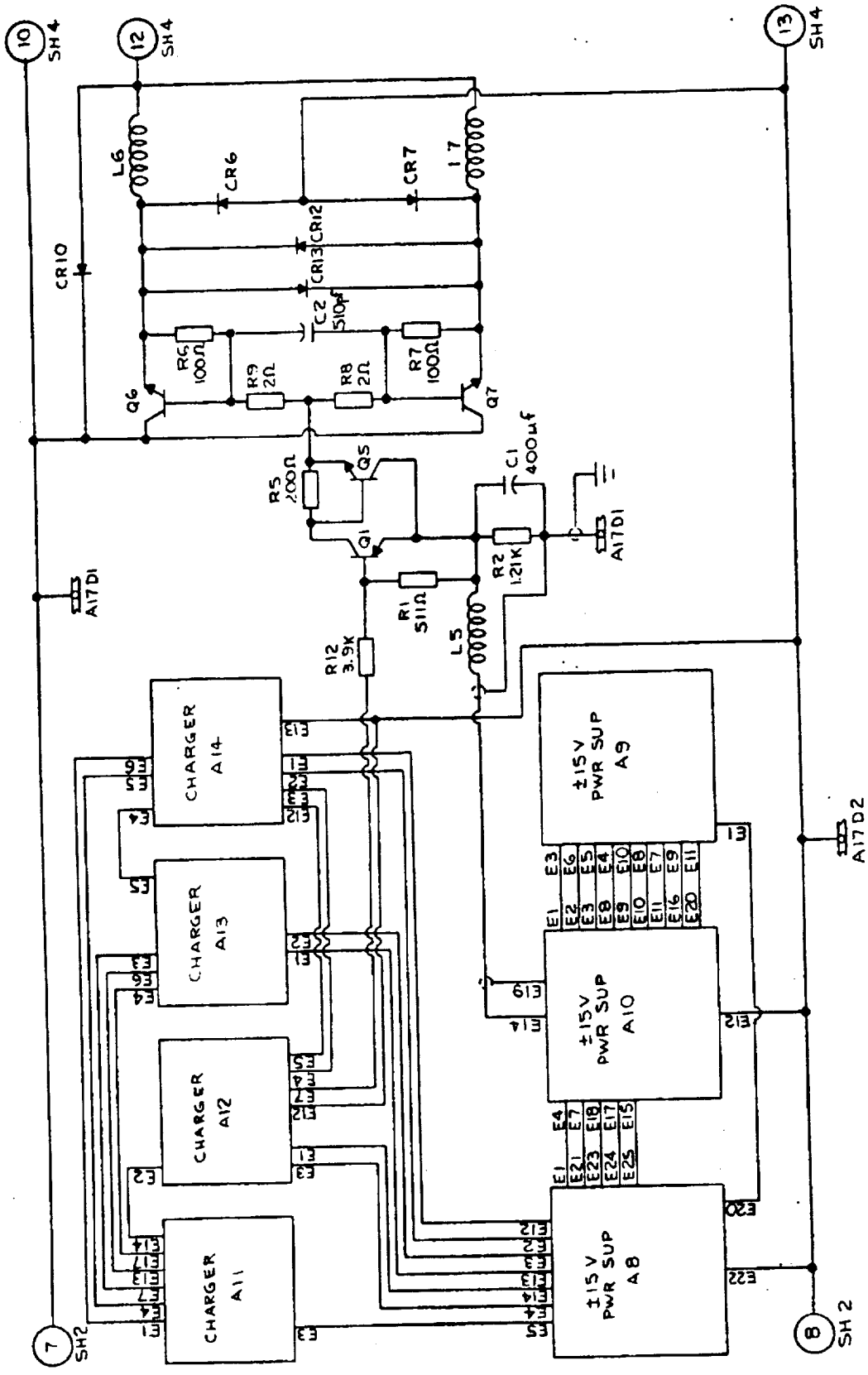



*Figure 6.3.3-1. Simplified CBRM/ESE Schematic. (Sheet 3 of 6)*

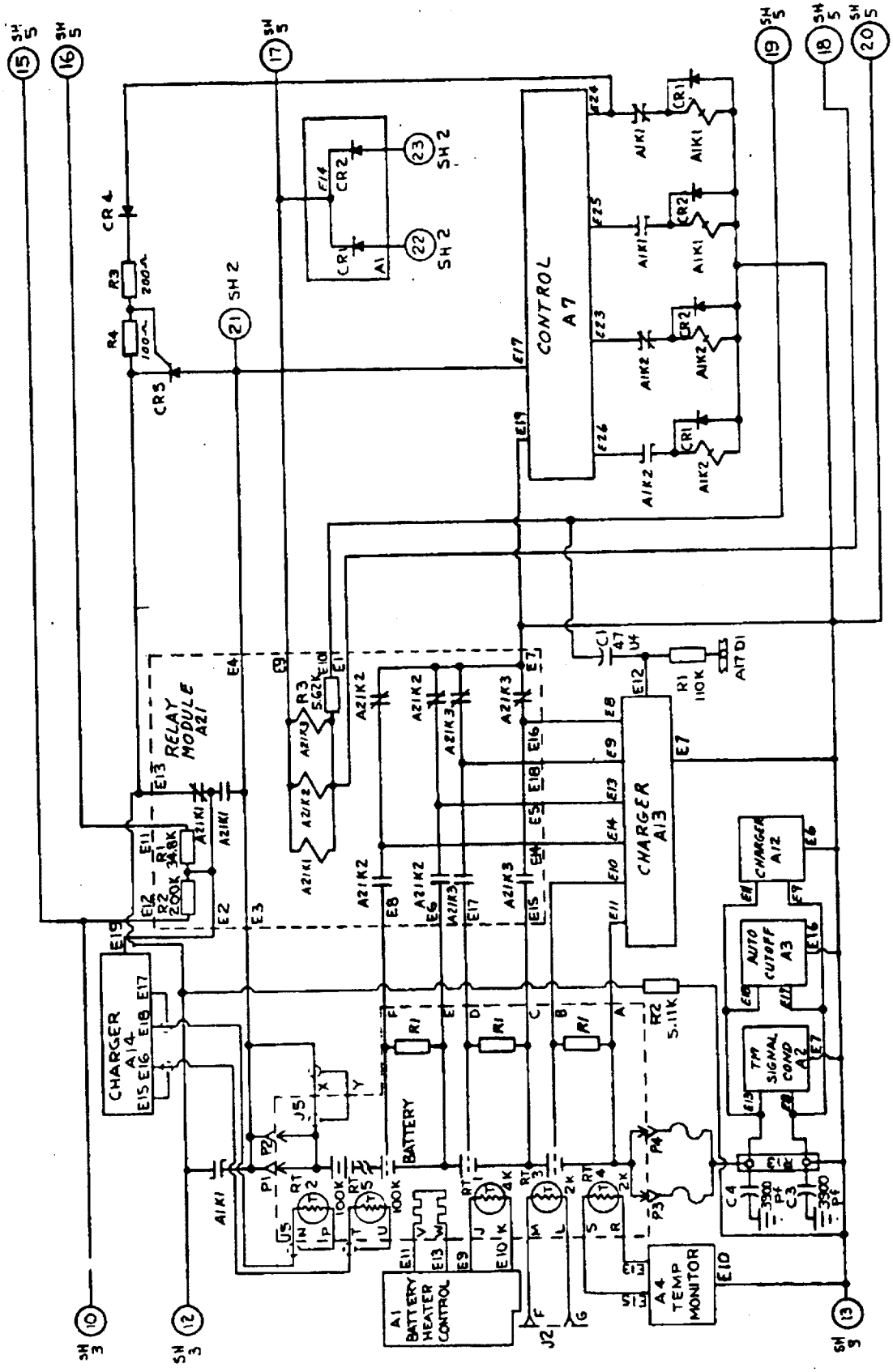



*Figure 6.3.3-1. Simplified CBRM/ESE Schematic. (Sheet 4 of 6)*

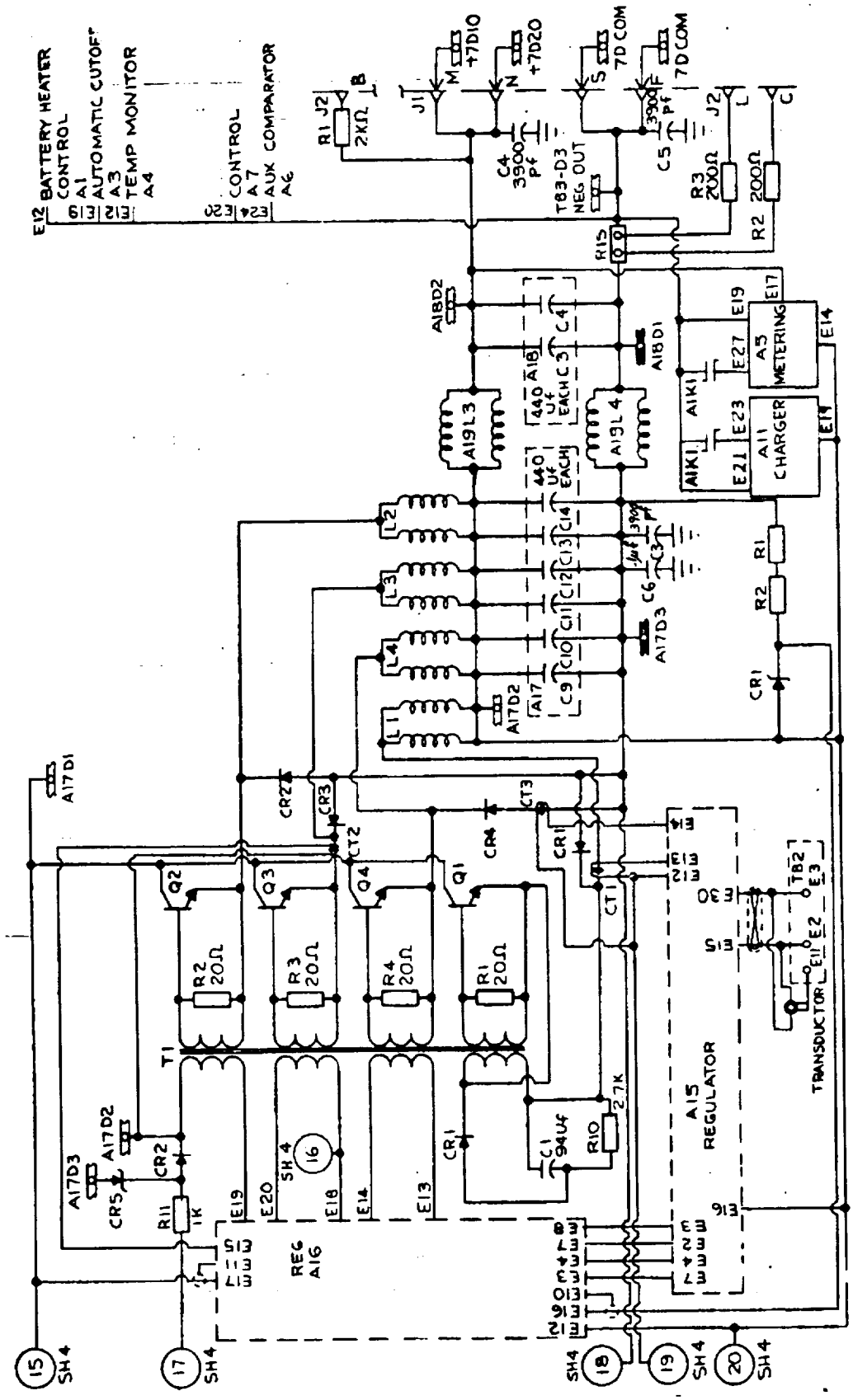



*Figure 6.3.3-1. Simplified CBRM/ESE Schematic. (Sheet 5 of 6)*

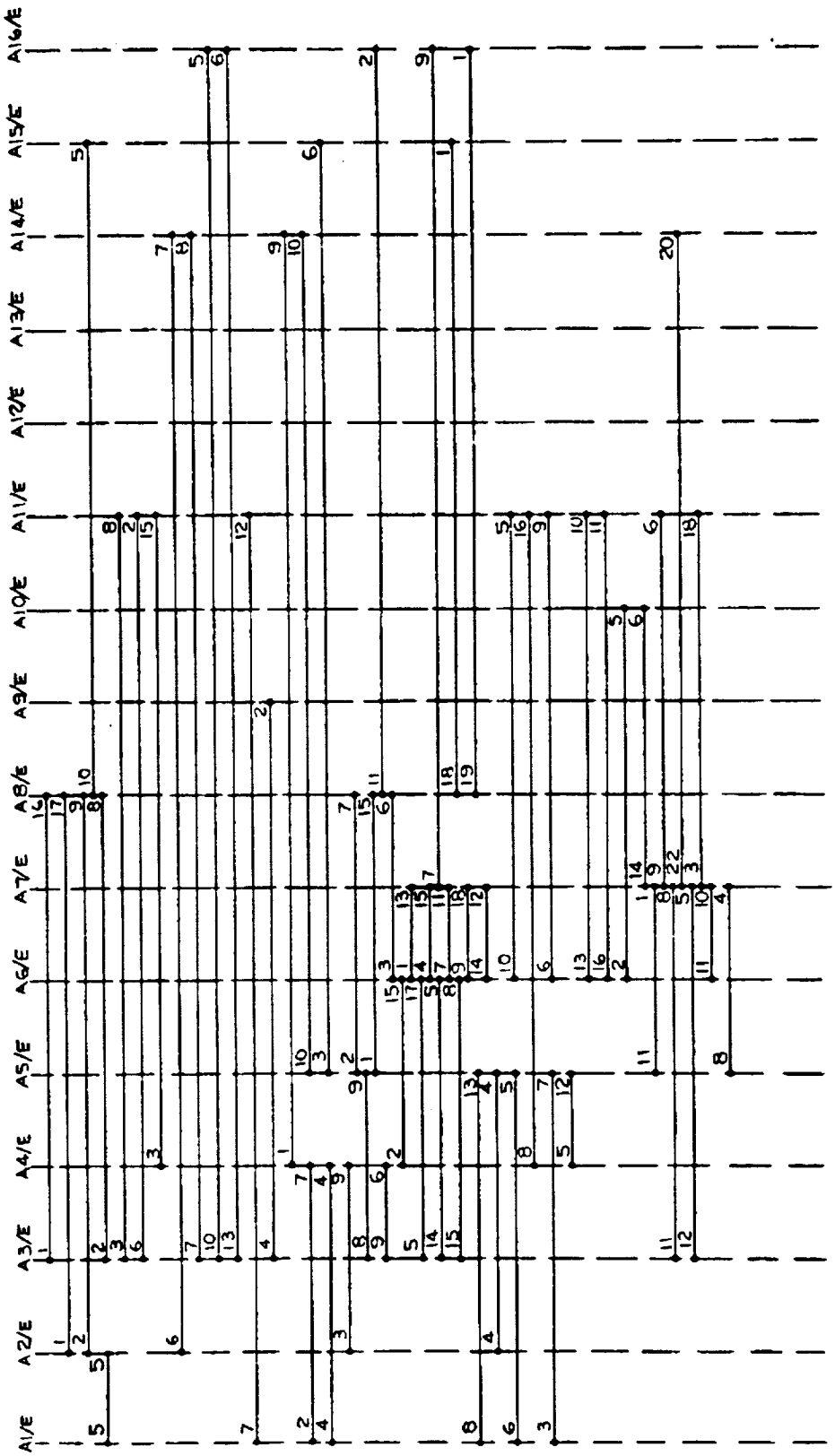
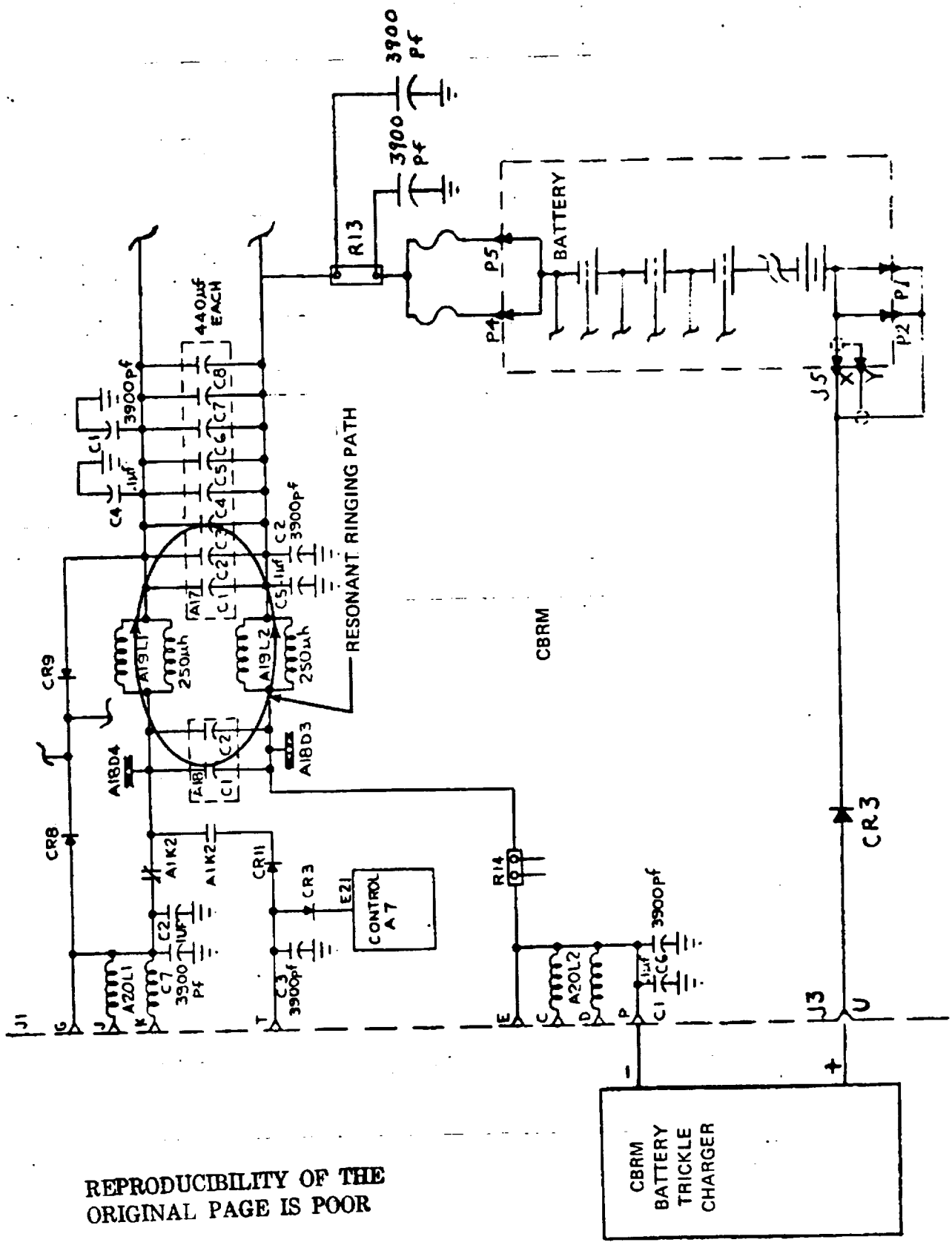



*Figure 6.3.3-1. Simplified CBRM/ESE Schematic. (Sheet 6 of 6)*




REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

*Figure 6.3.3-2. Schematic of CBRM Trickle Charger Circuit.*

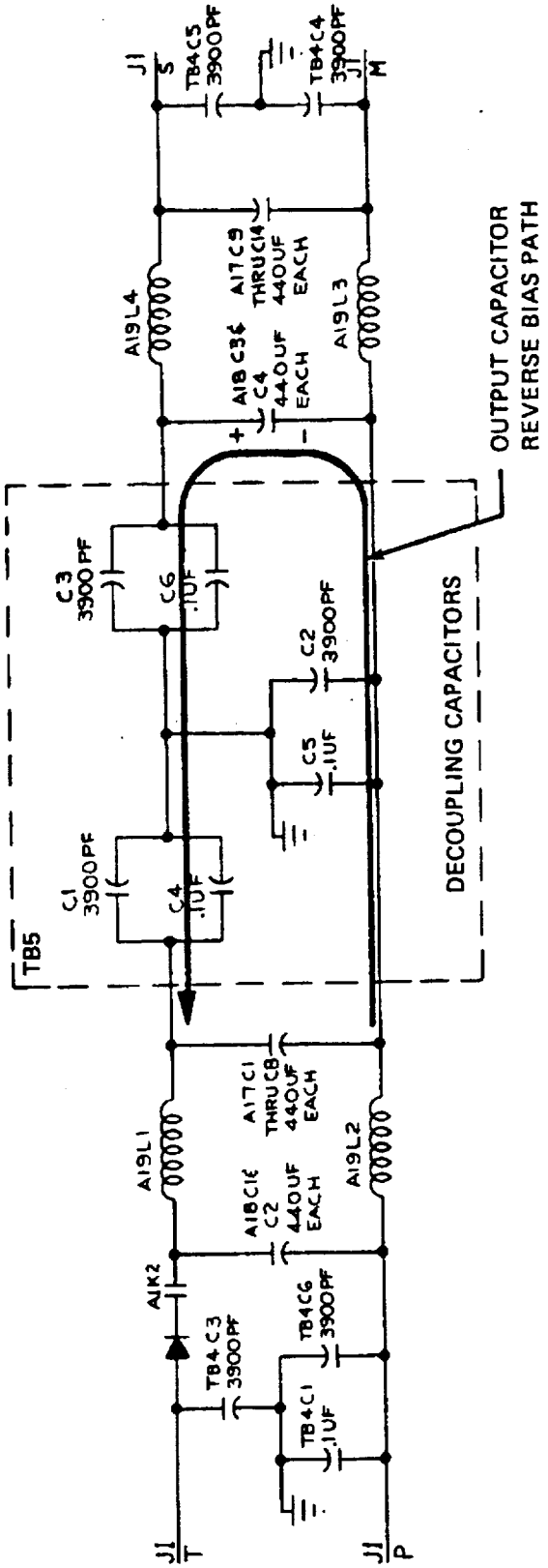



*Figure 6.3.3-3. Schematic of CBRM Input and Output Filters Showing Decoupling Capacitors.*

## 6.4 COMPUTER-AIDED TRANSIENT ANALYSIS

A computer-generated analysis of the CBRM input filter was performed under various configurations to determine if any conditions exist in which a reverse bias is present on the input capacitors.

Transient analysis was performed with the use of SCEPTRE (Systems for Circuit Evaluation and Prediction of Transient Radiation Effects), an IBM System/350 Computer Program which automatically computes the transient response of large electrical networks. The program automatically writes the set no differential equations describing the circuit configuration and subsequently solves the equations by numerical integration routines.

The equivalent circuit for the electrical conditions immediately following ESE turn-off is shown in Figure 6.4-1. An initial worst case condition of 20.0 amperes was placed on the two inductors, and the capacitors were assumed to be charged to 26.0 volts. The load generator, ILOAD, was made voltage dependent such that after the output voltage drops below 9.0 volts, the load current is removed. This simulates the turn-off of the CBRM electronics after the input voltage drops below a preset level. The electrical transient resulting from these initial conditions is shown in Figures 6.4-2 through 6.4-5. The voltage across the input capacitors can be seen in Figure 6.4-4 to reverse polarity to a maximum of 1.4 volts, approximately 4.7 milliseconds after ESE turn-off.

The equivalent circuit for the electrical conditions during battery trickle charger turn-on is shown in Figure 6.4-6. All initial conditions were assumed to be zero. Small negative voltages were predicted on both the input and output capacitors in the input filter during turn-on. The input capacitors were reverse biased to a maximum of 0.022 volts and the output to a maximum of 0.055 volts. The transient waveforms are shown in Figures 6.4-7 through 6.4.11.

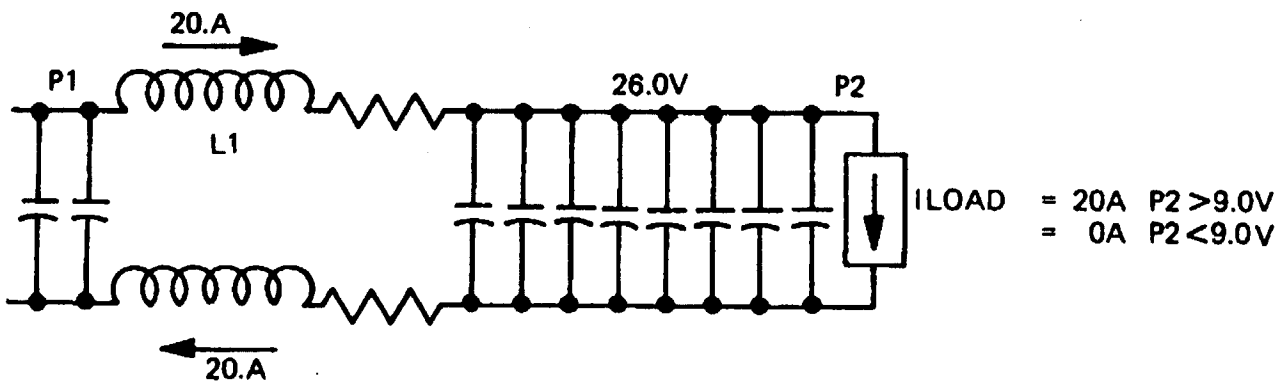
The equivalent circuit for the electrical conditions during battery trickle charger turn-off is shown in Figure 6.4-12. An initial condition of 1.5 amperes was assumed through inductor L2. Again reverse bias conditions were predicted across both the input and output capacitors in the input filter during the transient. The input capacitors saw a maximum of 0.93 volts reverse bias, and the output capacitors experienced a 0.19 volt reverse bias. The transient waveforms are shown in Figures 6.4-13 through 6.4-15.

TRANSIENT SOLUTION CONTROLS AFTER SIMULATION

| | |
|---|---|
| INTEGRATION ROUTINE | XPO |
| CURRENT SIMULATION TIME | 5.0056250D 01 |
| INTEGRATION STEP COUNTER | 6.9500000D 02 |
| INTEGRATION PASS COUNTER | 1.4650000D 03 |
| SOLUTION EXECUTION TIME (ELAPSED) | 1.1000000D-01 |
| SOLUTION EXECUTION TIME (CPU) | 0.0 |
| TERMINATION CONDITION | STOP TIME EXCEEDED (NORMAL STOP) |

VARIABLE DEFINITIONS

| | | |
|---|---|---|
| VJD | = | VOLTAGE ACROSS OUTPUT CAPACITORS |
| IL1 | = | CURRENT THROUGH L1 |
| P1 | = | VOLTAGE ACROSS INPUT CAPACITORS |
| VL1 | = | VOLTAGE ACROSS L1 |
| TIME | = | MILLISECONDS |




CBRM INPUT FILTER

*Figure 6.4-1. Equivalent Circuit for Electrical Conditions Immediately Following ESE Turn-Off.*

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

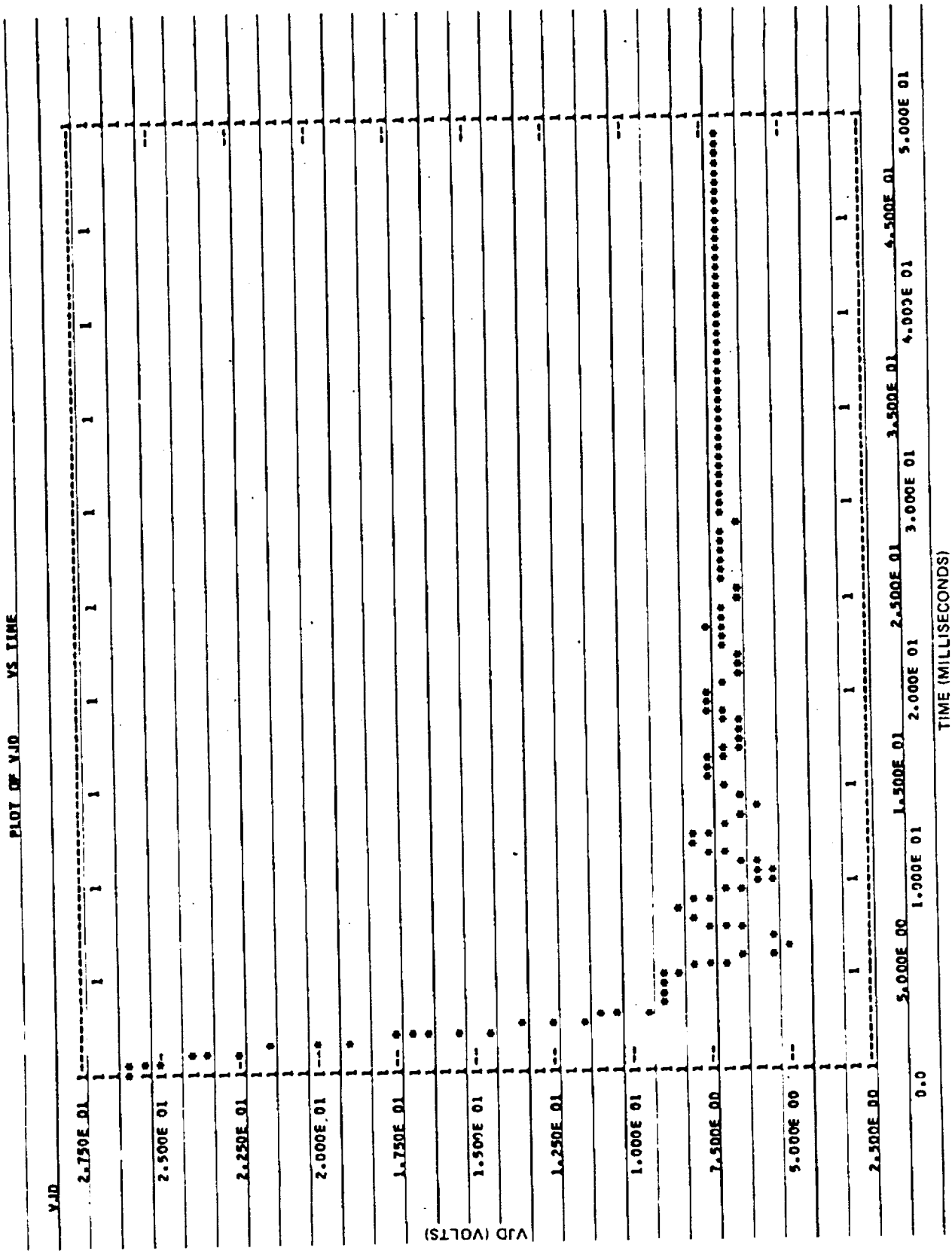



*Figure 6.4-2. Plot of Output Capacitor Voltage vs Time.*

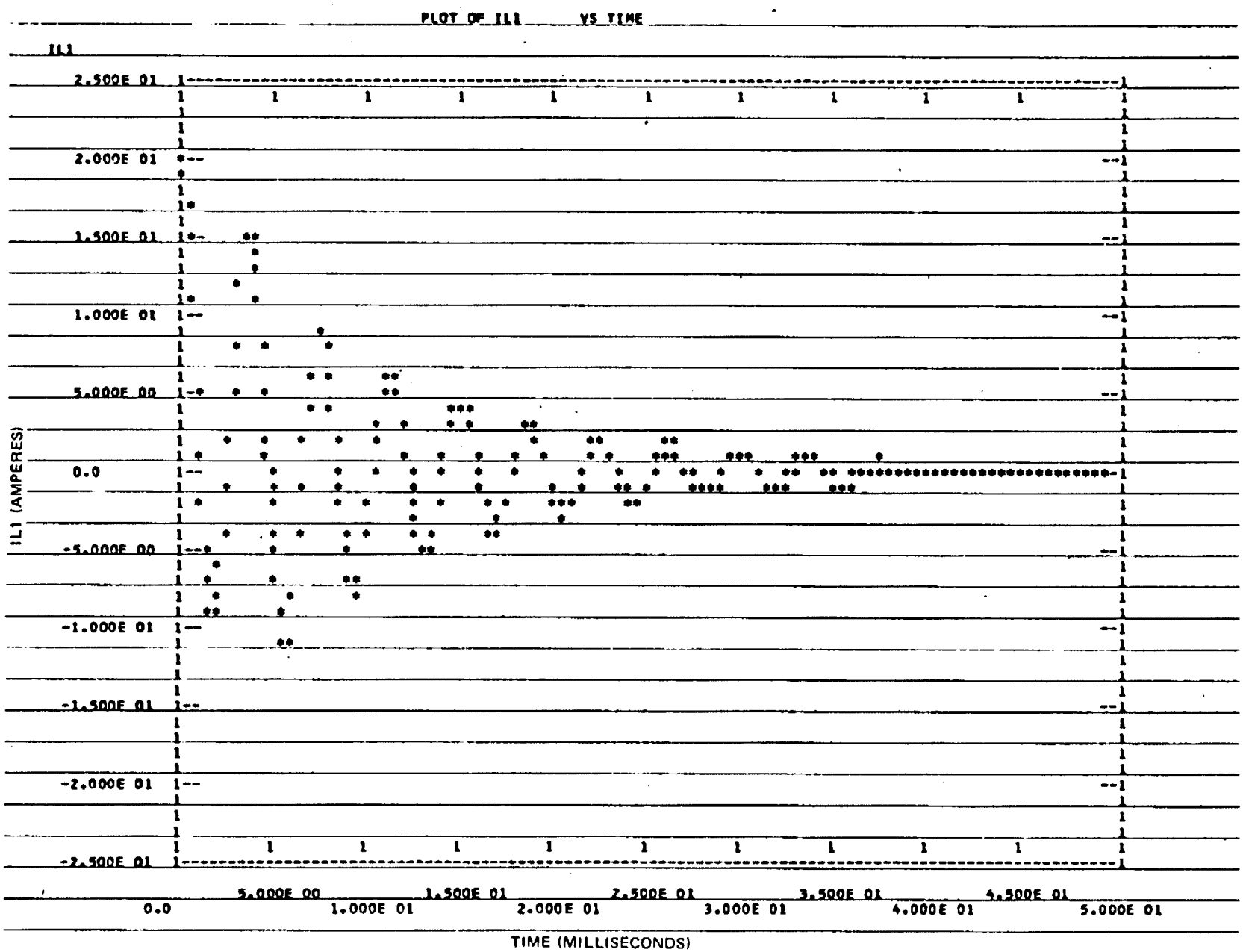



*Figure 6.4-3. Plot of L1 Current vs Time.*

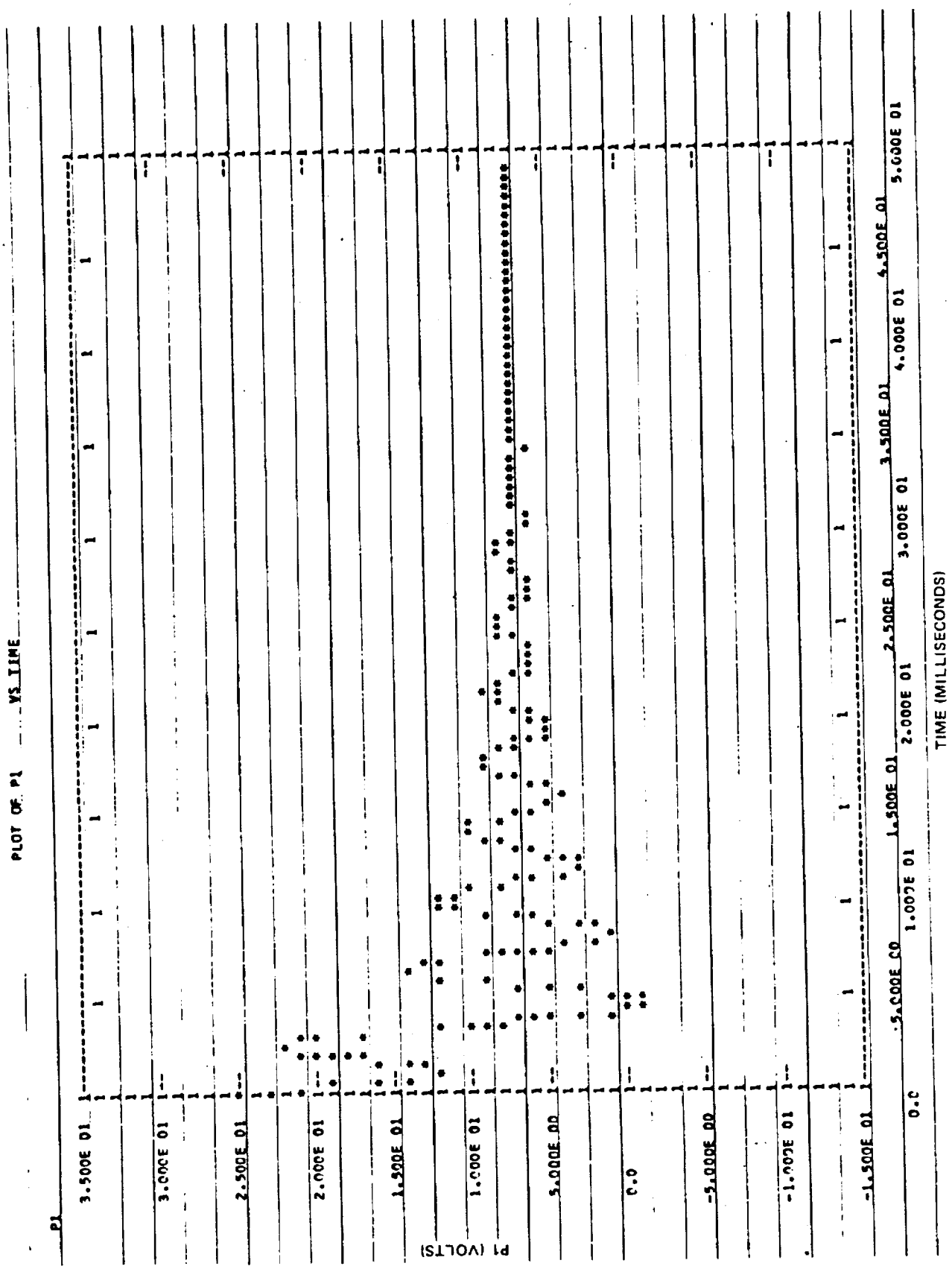



*Figure 6.4-4. Plot of Input Capacitor Voltage vs Time.*

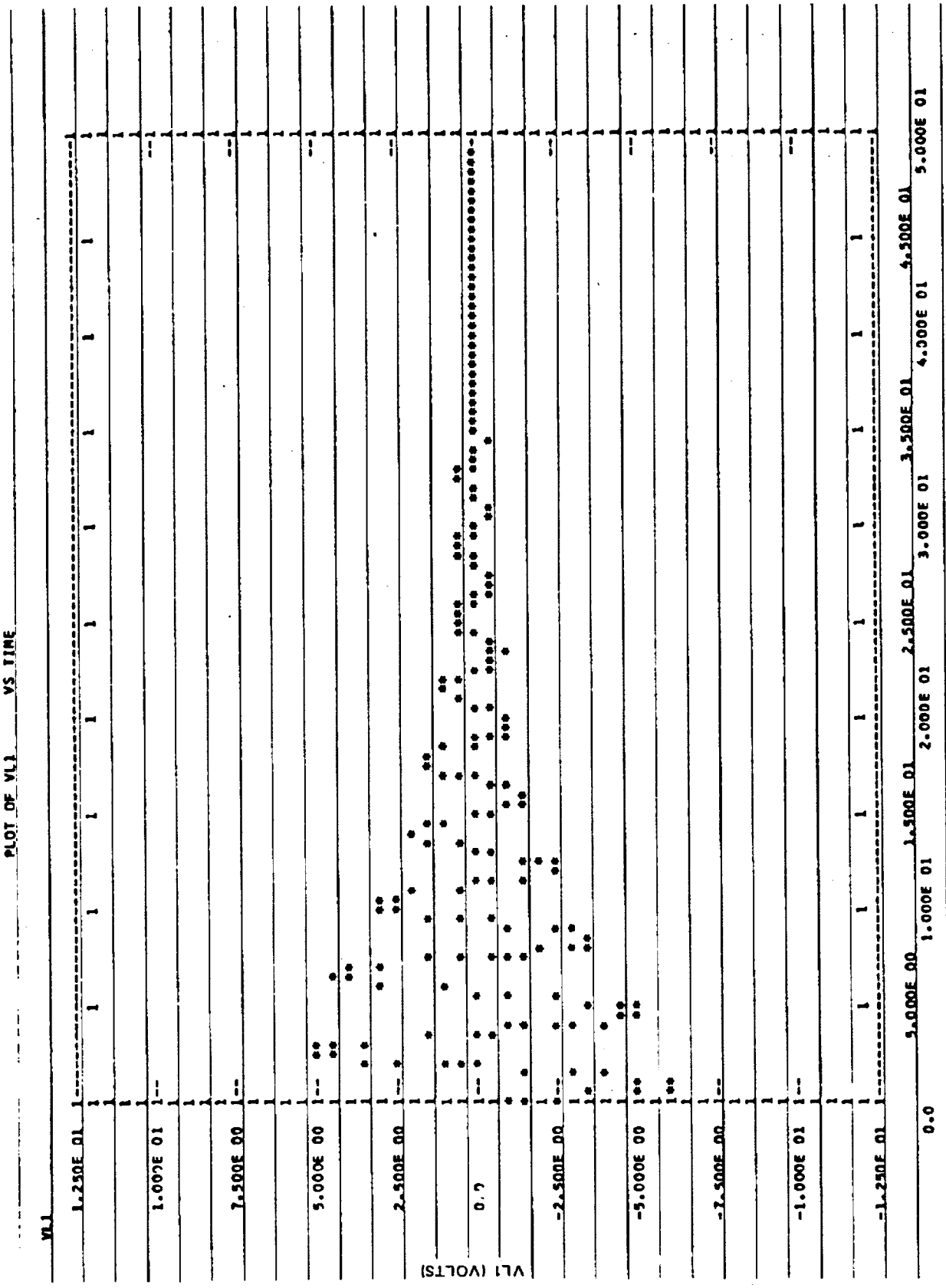



*Figure 6.4-5. Plot of L1 Voltage vs Time.*

TRANSIENT SOLUTION CONTROLS AFTER SIMULATION

| | |
|---|---|
| INTEGRATION ROUTINE | XPO |
| CURRENT SIMULATION TIME | 1.0110000D 01 |
| INTEGRATION STEP COUNTER | 9.4000000D 01 |
| INTEGRATION PASS COUNTER | 1.5100000D 02 |
| SOLUTION EXECUTION TIME (ELAPSED) | 3.0000000D 02 |
| SOLUTION EXECUTION TIME (CPU) | 0.0 |
| TERMINATION CONDITION | STOP TIME EXCEEDED (NORMAL STOP) |

VARIABLE DEFINITIONS

P1 = VOLTAGE ACROSS INPUT CAPACITORS
P2 = VOLTAGE ACROSS OUTPUT CAPACITORS
IL2 = CURRENT THROUGH L2
IRC = CURRENT THROUGH RC
IL1 = CURRENT THROUGH L1
TIME = MILLISECONDS

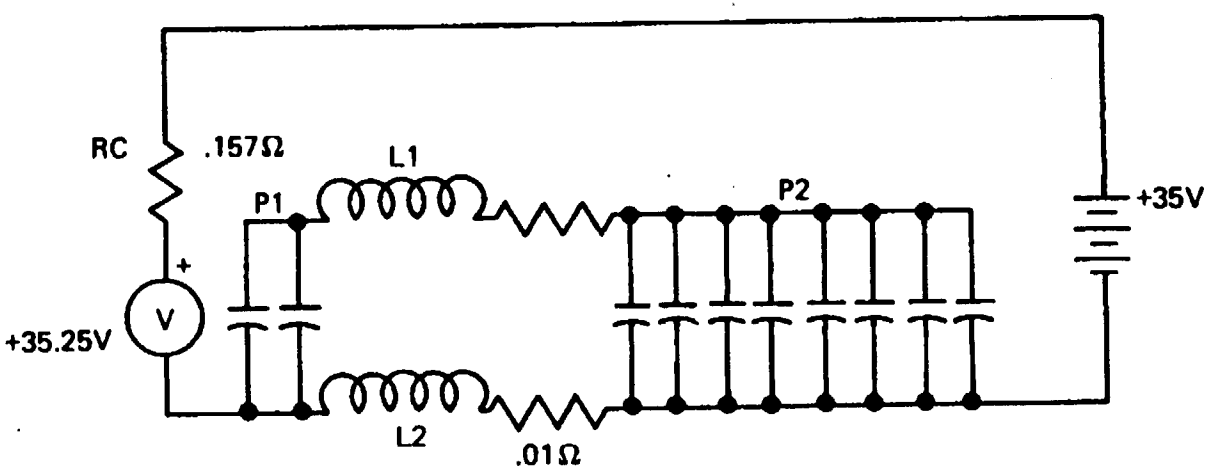



*Figure 6.4-6. Equivalent Circuit for the Electrical Conditions During Trickle Charger Turn-On.*

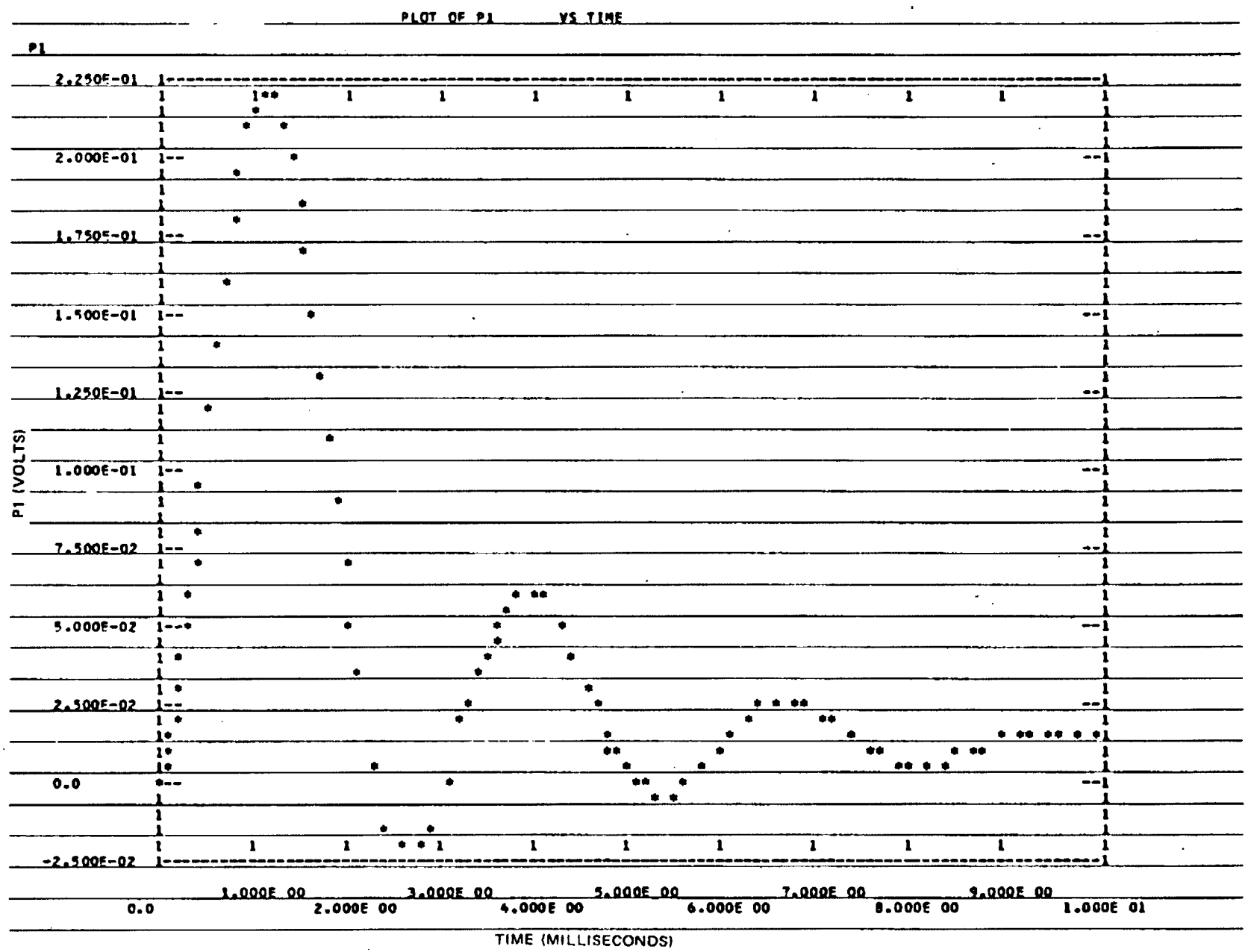



*Figure 6.4-7. Plot of Input Capacitor Voltage vs Time.*

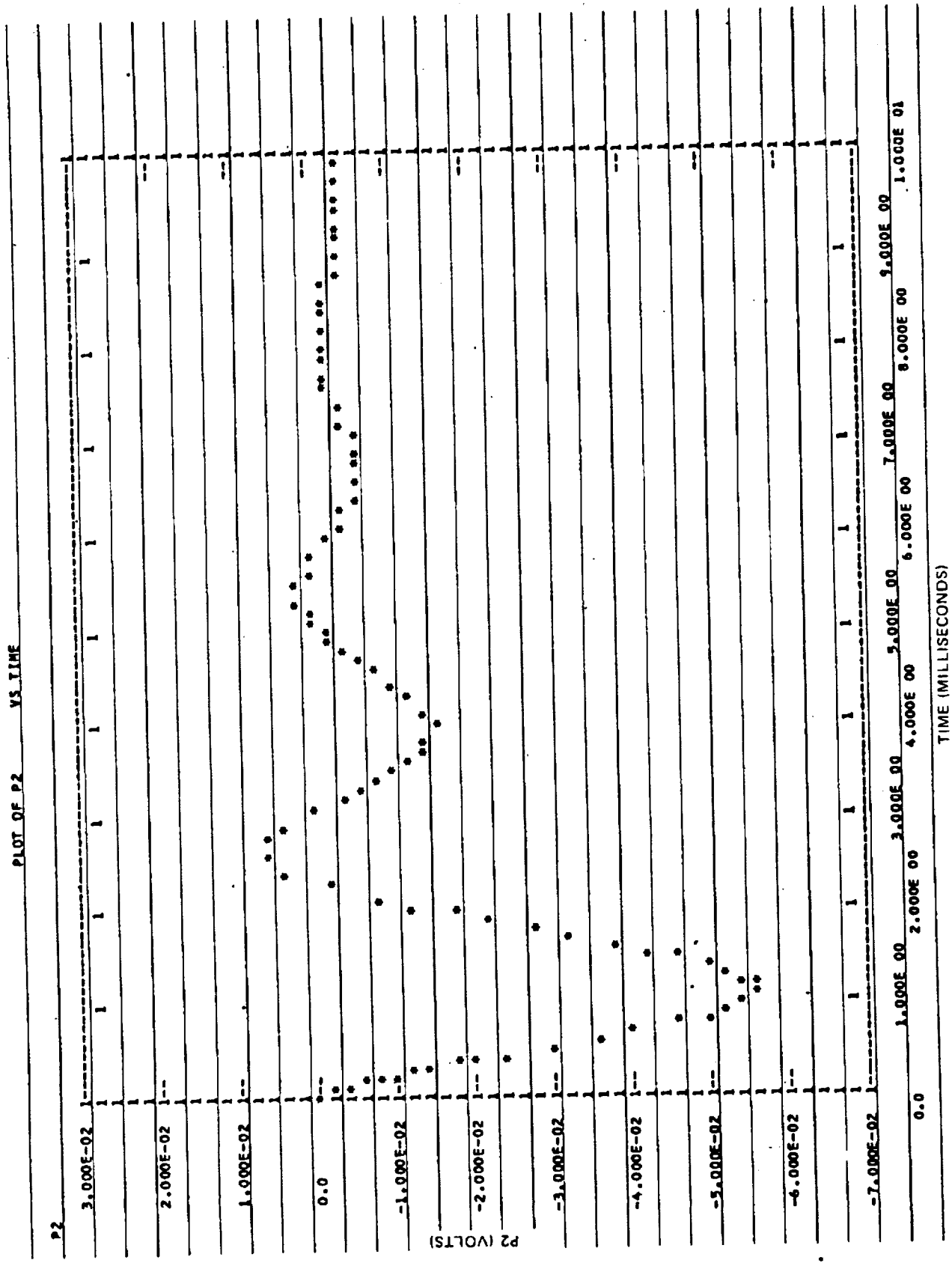



*Figure 6.4-8. Plot of Output Capacitor Voltage vs Time.*

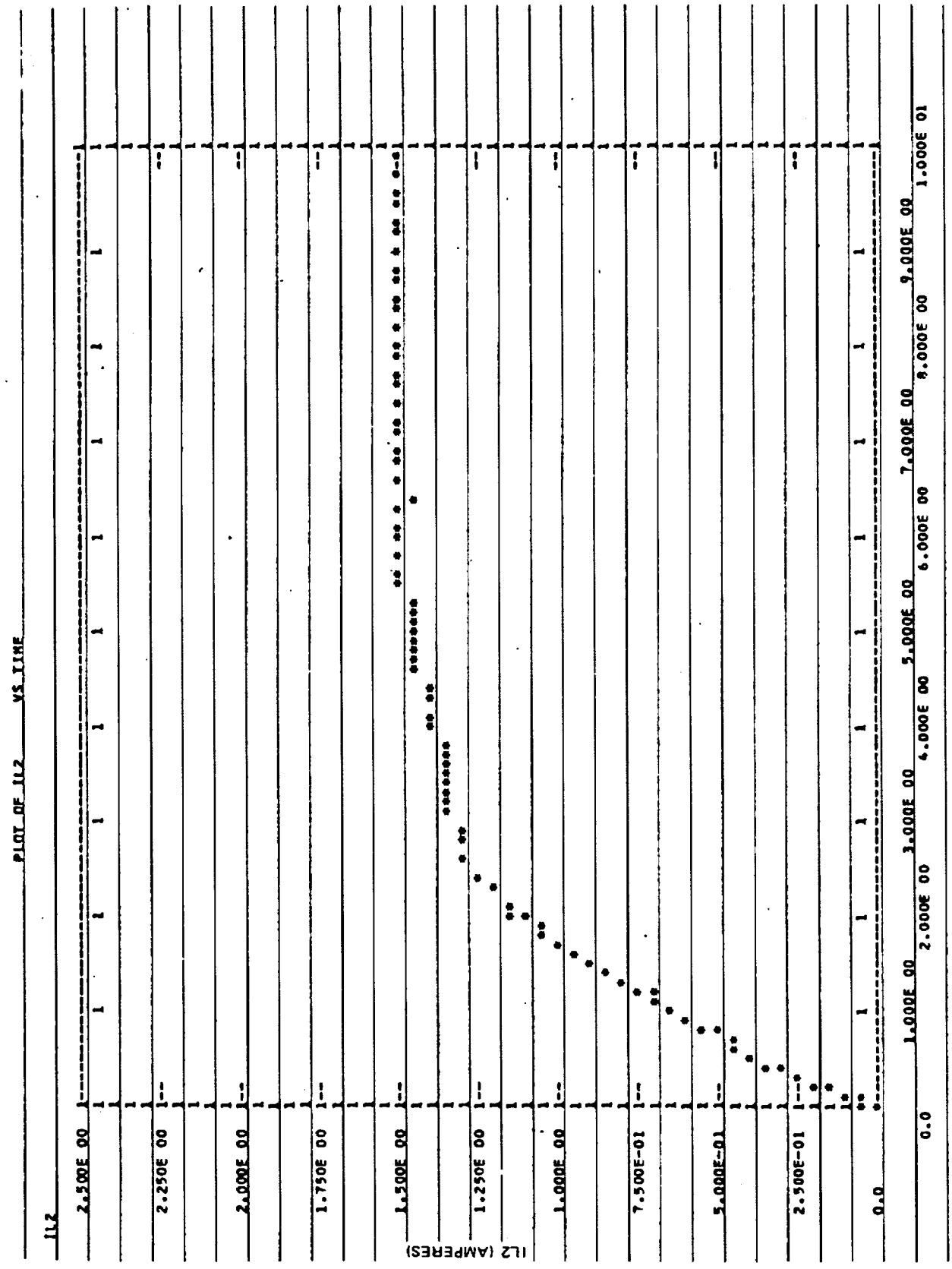



*Figure 6.4-9. Plot of L2 Current vs Time.*

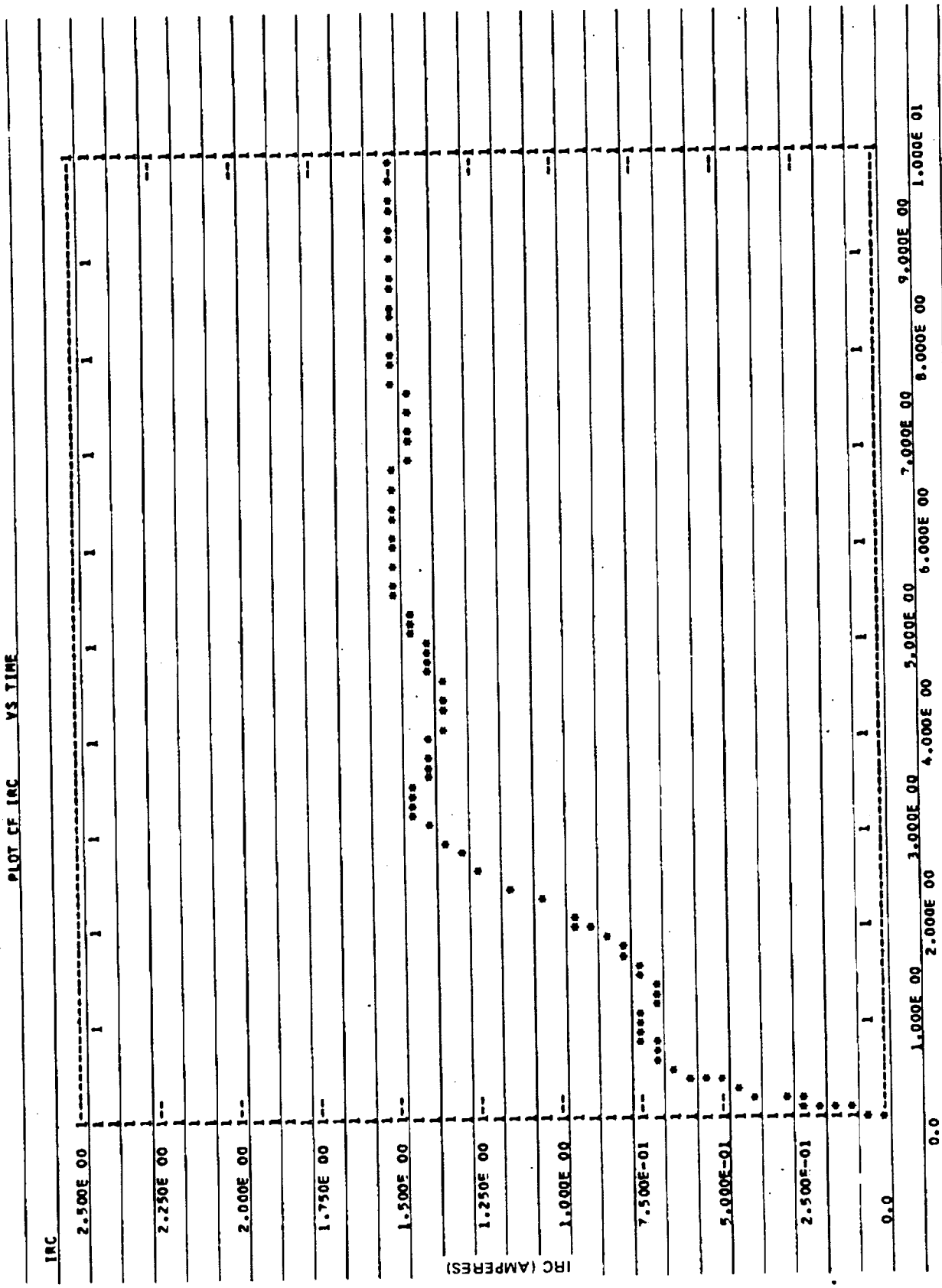



*Figure 6.4-10. Plot of RC Current vs Time.*

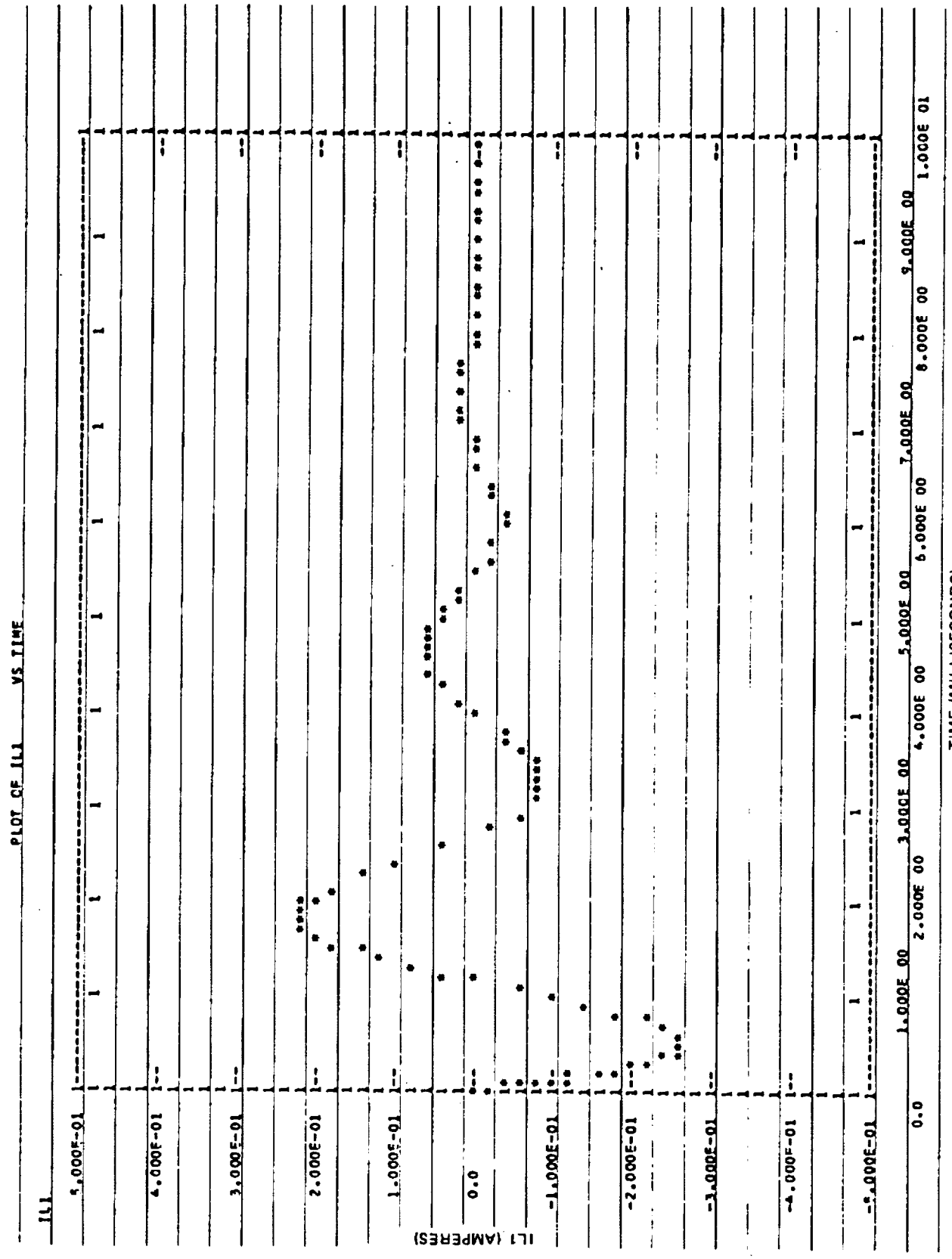



*Figure 6.4-11. Plot of L1 Current vs Time.*

TRANSIENT SOLUTION CONTROLS AFTER SIMULATION

| | |
|---|---|
| INTEGRATION ROUTINE | XPO |
| CURRENT SIMULATION TIME | 4.0200000D 01 |
| INTEGRATION STEP COUNTER | 3.9100000D 02 |
| INTEGRATION PASS COUNTER | 8.1400000D 02 |
| SOLUTION EXECUTION TIME (ELAPSED) | 1.3000000D-01 |
| SOLUTION EXECUTION TIME (CPU) | 0.0 |
| TERMINATION CONDITION | STOP TIME EXCEEDED (NORMAL STOP) |

VARIABLE DEFINITION

P1 = VOLTAGE ACROSS INPUT CAPACITORS
P2 = VOLTAGE ACROSS OUTPUT CAPACITORS
IL2 = CURRENT THROUGH L2
TIME = MILLISECONDS

CBRM INPUT FILTER

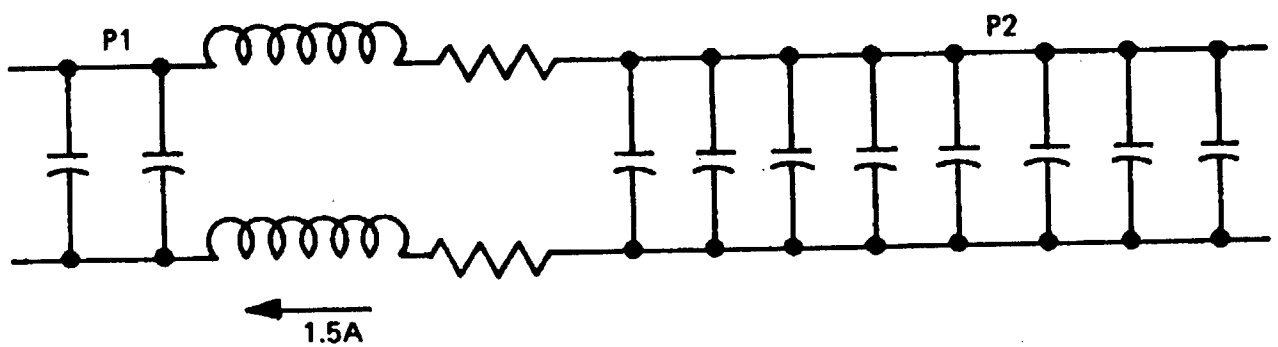



*Figure 6.4-12. Equivalent Circuit for Electrical Conditions During Trickle Charger Turn-Off.*

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

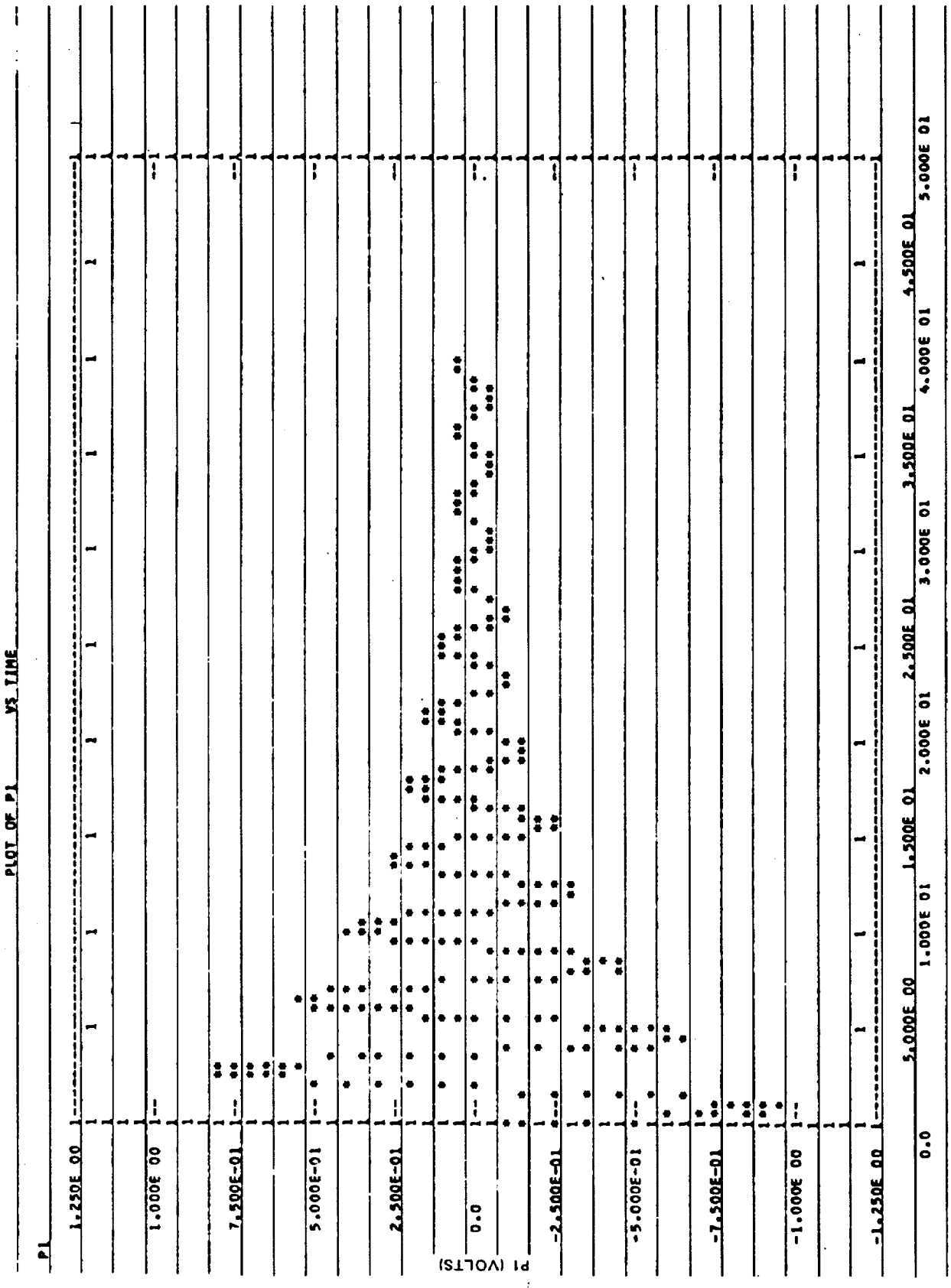



*Figure 6.4-13. Plot of Input Capacitor Voltage vs Time.*

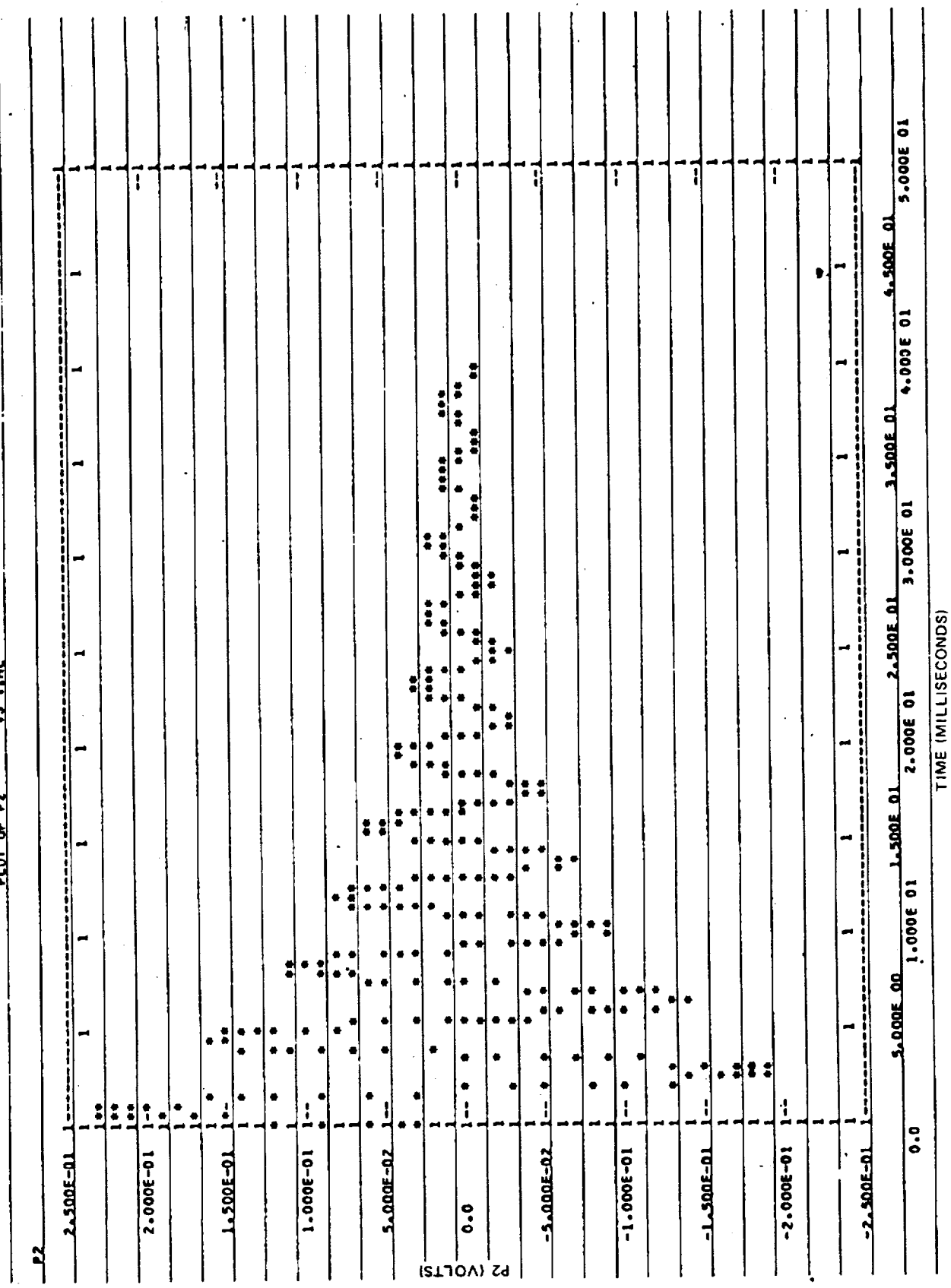



*Figure 6.4-14. Plot of Output Capacitor Voltage vs Time.*

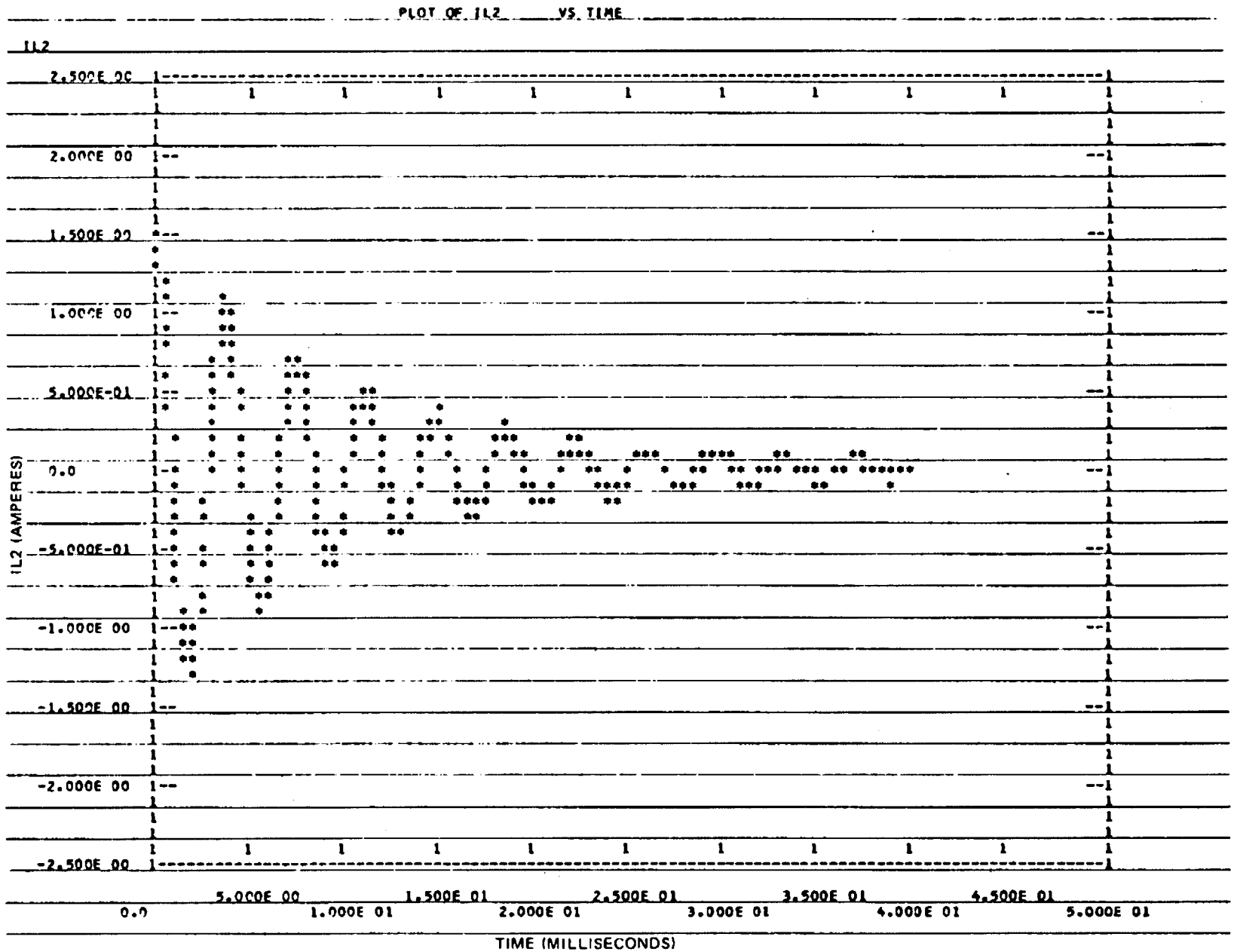



*Figure 6.4-15. Plot of L2 Current vs Time.*

## 6.5 OVER-VOLTAGE TESTS

### 6.5.1 Summary

Over-voltage tests were run on capacitors to establish the over-voltage range required to cause degradation or catastrophic capacitor failure.

### 6.5.2 Conclusions

The capacitor rating of 100 volts dc has an apparent margin of safety; i.e., the lowest over-voltage failure occurred at 130 volts. Failure of the capacitors in the CBRM is probably not caused by over-voltage.

### 6.5.3 Details

Three new 1967 date coded capacitors were subjected to various over-voltage conditions as noted:

Sample No. 1 - DC voltage increased from 100 to 170 volts thru a 100 kohm limiting resistor. Voltage increased in ten volt increments at 5 to 10 minutes per increment. Forward leakage current was continuously monitored.

Leakage current was stable up to 140 volts. At 150 volts leakage current increased from 13 to 30 micro amperes. As supply voltage was increased above 150 volts, current increased to 180 micro amperes. Voltage applied to the capacitor did not exceed 150 volts. The capacitor was unstable (voltage varying) at 150 volts and failed (shorted) after 40 minutes at 150 volts.

Sample No. 2 - Repeated the voltage step stress performed on sample no. 1 except current limiting resistor was reduced from 100 kohms to 1 kohms. Currents in the high voltage range, (150 volts and higher), were similar to those experienced with the 100 kohm limiting resistor. After step stress was completed, the capacitor was subjected to a hard turn on at 130 volts dc, current limited to five amperes. The capacitor failed in a shorted-mode.

Sample No. 3 - DC voltage was applied instantaneously and was removed when the capacitor was fully charged. The capacitor was subjected to dc voltages of 130, 140 and 150 volts current limited to 5 amperes. The capacitor failed at 150 volts in a shorted mode.

## 6.6 REVERSE BIAS TESTING/EVALUATION

### 6.6.1 Summary

Capacitors and capacitor elements were subjected to various levels of reverse voltages and currents. The testing was primarily oriented toward short time reverse effects; minutes and hours as opposed to days or months.

Degradation in the form of increased forward leakage currents was experienced after exposure to 10 milliamperes reverse current for 21 hours. Catastrophic failure was experienced by applying rated working voltage after exposure of 1 ampere reverse current for a period of two minutes.

Other tests conducted indicate that the effects of reverse bias are cumulative, i.e., repeated half-hour exposures to the same amplitude of reverse voltage increased both the forward and reverse leakage currents. On each successive application of reverse voltage it was also noted that the reverse current increases exponentially as reverse voltage is increased linearly.

Low frequency ac testing was utilized to demonstrate the presence of an abnormal current component that occurs during the negative half cycle of the voltage waveform.

### 6.6.2 Conclusions

Reverse voltage/current is detrimental to the reliable performance of tantalum wet slug capacitors. Predictions as to capacitor failure rate with different levels and durations of applied reverse voltage appear to be unreliable due to the many variations of individual capacitor characteristics.

### 6.6.3 Details

Reverse bias tests were performed at two different part levels:

- At the capacitor level as procured from General Electric: Internal visual inspection of elements (16 per capacitor) after capacitor test was limited to four elements per capacitor because of shortage of time and availability of personnel.

- At the element level after removal from new capacitors: Element testing and subsequent teardown inspection provided better correlation between a given test condition and internal visual observations.

The basic categories of reverse bias conditions evaluated were:

- Reverse current amplitudes versus time. (Paragraph 6.6.3.1).
- Steady state reverse voltage. (Paragraph 6.6.3.2).
- Cumulative effects of reverse bias. (Paragraph 6.6.3.3).
- Reverse bias diode affect. (Paragraph 6.6.3.4).
- Application of ac without dc bias. (Paragraph 6.6.3.5).
- Application of ac superimposed on a dc reverse bias. (Paragraph 6.6.3.6).

#### 6.6.3.1 Reverse Current Amplitudes vs Time

Results of tests performed on capacitors are given in Table 6.6.3.1-1. Capacitor degradation and catastrophic failures were created by the following worst-case conditions:

- Degradation - 10 milliamperes reverse for 21 hours
- Catastrophic Failures - 200 milliamperes reverse for 24 minutes
  - 1 ampere reverse for 2 minutes

Catastrophic is defined as shorting in the reverse mode or shorting as full rated voltage was applied in the forward direction after the capacitor was subjected to a reverse bias environment.

#### 6.6.3.2 Steady State Reverse Voltage

Four groups of capacitor elements were selected for this evaluation. Each group contained 8 elements; four elements of each group rated @ 50 volts and four elements of each group rated @ 100 volts. Each group of elements was subjected to a different reverse voltage (bias) level ranging from 50 to 500 millivolts. Reverse application time varied from 17 to 26 hours. Reverse current was monitored periodically, and forward leakage current was checked randomly during the test period. Forward leakage measurements were made at rated voltage utilizing a current limiting resistor. At the conclusion of the test period the units were opened and subjected to internal visual examination. Table 6.6.3.2-1 presents the results of this evaluation. Several observations can be made from these data:

Table 6.6.3.1-1. Reverse Voltage Evaluation of Capacitor Assemblies. (Sheet 1 of 3)

| Test Condition | | Results | Visual Observation |
|---|---|---|---|
| Reverse Current or Voltage | Time | | |
| 1 milliamp dc<br>20 milliamp dc | 25 minutes<br>20 minutes | Voltage across cap dropped from 1.5 volts to 1.3 volts (reverse resistance decreasing with time. | • Slug - Clean<br>• Silver dendrites in electrolyte adjacent to slug. |
| 8 millivolts dc | 19.5 hours | Forward leakage @ 100 volts<br>Initial - 2.9 microamp<br>Final - 2.4 microamp | • Slug - evidence of silver.<br>• Silver dendrites in electrolyte. |
| 2-12 millivolts dc<br>40 volt forward charge/discharge thru 5 ohms | 18.5 hours<br>1 cycle/min<br>960 total cycles | Forward leakage @ 100 volts<br>Initial - 3.3 microamp<br>Final - 3.8 microamp<br>Note - Capacitor stable during charge/discharge cycle. | • Slug - slight silvering. |
| 10 milliamp dc | 21 hours | Forward leakage @ 100 volts<br>Initial - 3.6 microamp<br>Final - 4 to 8 milliamp (unstable)<br>Note - Audible pops heard during final leakage measurement. | • Slug - light silvering.<br>• Electrolyte - silver dendrites. |
| 100 milliamp dc | 23 minutes | Forward leakage after 23 minutes - 1 microamp<br>Forward leakage unstable - 2 audible pops heard during final leakage measurement (current finally stabilized @ 9 microamps) | • Slug - trace of silver. |

*Table 6.6.3.1-1. Reverse Voltage Evaluation of Capacitor Assemblies. (Sheet 2 of 3)*

| Test Condition | | Results | Visual Observation |
|---|---|---|---|
| Reverse Current or Voltage | Time | | |
| 1 ampere dc | 11 minutes | Voltage across cap decreased from 3.8 volts to 0.15 volt (reverse resistance decreasing) audible pop heard @ 11 minutes | • Slug - clean<br>• Electrolyte - contained silver dendrites. |
| 1 ampere dc | 24 minutes | Audible pops heard @ 11 and 13 minutes. Voltage across cap dropped from 3.0 to 2.24 volts | • Slug - clean<br>• Electrolyte - contained silver dendrites. |
| 5 amperes dc | 1 millisecond pulse 1% duty cycle for 65 min. | Capacitor found to be shorted at end of test. | • Slug - clean<br>• Electrolyte - contained silver dendrites adjacent to slug |
| 12 amperes dc | 1 minute | Capacitor shorted | • Slug - clean<br>• Electrolyte - contained silver dendrites adjacent to slug. |
| 1 ampere dc<br>1 ampere dc<br>Applied forward dc voltage<br>70 volts - twice<br>80 volts - twice<br>90 volts - twice<br>100 volts - once | 1 minute<br>1 minute<br><br>Instantaneous hits applied for 1 minute each - no current limiting resistor | Initial forward leakage - 2 microamp<br>Unstable @ 90 volts forward - leakage gradually settled to 2 microamp<br><br>Capacitor failed @ 100 volts.<br>Case physically distorted. | • Slug - clean<br>• Electrolyte - clean |

*Table 6.6.3.1-1. Reverse Voltage Evaluation of Capacitor Assemblies. (Sheet 3 of 3)*

| Test Condition | | Results | Visual Observation |
|---|---|---|---|
| Reverse Current or Voltage | Time | | |
| 100 volts dc forward ten times | Instantaneous hits applied for 1 min. each | Initial Forward Leak - 2 microamp<br>Forward leakage - 1 microamp | |
| 2 amperes reverse | 1 minute | | |
| Forward dc voltage<br>70 volts - twice<br>80 volts - twice<br>90 volts - twice<br>100 volts - twice | Instantaneous hits applied for 1 min. each | Forward leakage - 5 microamps | |
| 2 amperes reverse | 1 minute | Capacitor shorted | |
| Forward dc voltage 100 volts three times | Instantaneous hits | 7.5 amp initial surge, capacitor voltage unstable, apparent healing but could not hold charge, capacitor shorted | • Slug - clean<br>• Electrolyte - clean |

*Table 6.6.3.2-1. Steady State Reverse Bias Voltage Evaluation Data.*

| REVERSE BIAS (MV) | ELE NO | CAP NO | VOLT RATING | FORWARD BIAS[1] | | CURRENT (AMP) | | INTERNAL VISUAL | | | REVERSE TIME | GLITCH FAILURE | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | VOLT | CYCLE | LEAK | REVERSE | SLUG | $H_2SO_4$ | CASE | | | |
| 50 | 5 | 209 | 100V | 100V | 1 | $13\times10^{-6}$ | $2\times10^{-9}$ $15\times10^{-9}$ | OK | OK | OK | 17 hr | NO | 1. CYCLE IS THE NO. OF TIMES FORWARD LEAKAGE WAS CHECKED.<br>2. CURRENTS ARE PRESENTED AS MAX AND MIN RECORDED.<br>3. GLITCH CURRENT SURGED/VOLTAGE UNSTABLE AS FORWARD LEAKAGE WAS CHECKED. |
| | 6 | 209 | 100V | 100V | 2 | $1\times10^{-6}$ | $13\times10^{-9}$ $04\times10^{-6}$ | OK | OK | Ag | 15 hr | NO | |
| | 7 | 209 | 100V | 100V | 1 | $15\times10^{-6}$ | $12\times10^{-9}$ $04\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| | 16 | 209 | 100V | 100V | 2 | $1\times10^{-6}$ | $13\times10^{-9}$ $03\times10^{-6}$ | OK | OK | Ag | 17 hr | NO | |
| | 2 | 145 | 50V | 50V | 2 | $12\times10^{-6}$ | $01\times10^{-6}$ | OK | OK | OK | 17 hr | NO | |
| | 5 | 145 | 50V | 50V | 1 | $14\times10^{-6}$ | $01\times10^{-6}$ | OK | OK | OK | 17 hr | NO | |
| | 11 | 145 | 50V | 50V | 2 | $15\times10^{-6}$ $5\times10^{-6}$ | $01\times10^{-6}$ | OK | OK | OK | 17 hr | NO | |
| | 15 | 145 | 50V | 50V | 2 | $15\times10^{-6}$ $5\times10^{-6}$ | $01\times10^{-6}$ | OK | OK | OK | 17 hr | NO | |
| 100 | 2 | 621 | 100V | 100V | 1 | $25\times10^{-6}$ | $1.5\times10^{-9}$ $1\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| | 6 | 621 | 100V | 100V | 2 | $25\times10^{-6}$ | $8\times10^{-9}$ $27\times10^{-6}$ | GRAY OUT | OK | Ag | 19 hr | NO | |
| | 8 | 621 | 100V | 100V | 2 | $27\times10^{-6}$ | $8\times10^{-9}$ $08\times10^{-6}$ | | | | 19 hr | NO | |
| | 12 | 621 | 100V | 100V | 1 | $25\times10^{-6}$ | $3\times10^{-9}$ $06\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| | 2 | 001 | 50V | 50V | 1 | $25\times10^{-6}$ | $08\times10^{-9}$ $06\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| | 5 | 001 | 50V | 50V | 2 | $1\times10^{-6}$ $26\times10^{-6}$ | $07\times10^{-9}$ $15\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| | 6 | 001 | 50V | 50V | 2 | $2\times10^{-6}$ $2\times10^{-6}$ | $1\times10^{-9}$ $3\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| | 10 | 001 | 50V | 50V | 1 | $3\times10^{-6}$ | $18\times10^{-9}$ $1\times10^{-6}$ | OK | OK | OK | 18 hr | NO | |
| 250 | 2 | 209 | 100V | 100V | 5 | $28\times10^{-6}$ $15\times10^{-6}$ | $16\times10^{-6}$ $60\times10^{-6}$ | Ag GREASY | OK | Ag | 21 hr | YES | |
| | 3 | 209 | 100V | 100V | 5 | $07\times10^{-6}$ $25\times10^{-6}$ | $12\times10^{-9}$ $3.0\times10^{-6}$ | OK | Ag SLIGHT | OK | 21 hr | NO | |
| | 4 | 209 | 100V | 100V | 5 | $08\times10^{-6}$ $3\times10^{-6}$ | $18\times10^{-9}$ $15\times10^{-6}$ | Ag GROSS | Ag | OK | 20 hr | NO | |
| | 15 | 209 | 100V | 100V | 5 | $23\times10^{-6}$ $61\times10^{-6}$ | $01\times10^{-3}$ $1.4\times10^{-3}$ | Ag MED | Ag | Ag | 21 hr | NO | |
| | 4 | 145 | 50V | 50V | 6 | $15\times10^{-6}$ $3\times10^{-6}$ | $01\times10^{-6}$ $120\times10^{-6}$ | Ag MED | Ag | OK | 22 hr | YES | |
| | 6 | 145 | 50V | 50V | 6 | $12\times10^{-6}$ $25\times10^{-6}$ | $01\times10^{-6}$ $1.8\times10^{-6}$ | OK | OK | OK | 22 hr | NO | |
| | 8 | 145 | 50V | 50V | 6 | $25\times10^{-6}$ $25\times10^{-6}$ | $01\times10^{-6}$ $120\times10^{-6}$ | OK | Ag | OK | 22 hr | NO | |
| | 12 | 145 | 50V | 50V | 6 | $15\times10^{-6}$ $24\times10^{-6}$ | $01\times10^{-6}$ $19\times10^{-6}$ | Ag SLIGHT | OK | Ag | 22 hr | YES | |
| 500 | 1 | 621 | 100V | 100V | 6 | $2\times10^{-6}$ $5\times10^{-6}$ | $05\times10^{-6}$ $1.4\times10^{-3}$ | Ag LIGHT | OK | Ag | 22 hr | YES | |
| | 5 | 621 | 100V | 100V | 7 | $12\times10^{-6}$ $9\times10^{-6}$ | $03\times10^{-6}$ $2\times10^{-3}$ | Ag LIGHT | Ag | Ag | 22 hr | NO | |
| | 10 | 621 | 100V | 100V | 7 | $4\times10^{-6}$ $28\times10^{-6}$ | $04\times10^{-6}$ $6\times10^{-3}$ | OK | Ag | Ag GROSS | 22 hr | YES | |
| | 13 | 621 | 100V | 100V | 7 | $2\times10^{-6}$ $175\times10^{-6}$ | $03\times10^{-6}$ $17\times10^{-6}$ | OK | OK | OK | 22 hr | NO | |
| | 4 | 001 | 50V | 50V | 11 | $28\times10^{-6}$ $1\times10^{-6}$ | $04\times10^{-6}$ $2\times10^{-3}$ | OK | Ag | OK | 26 hr | YES | |
| | 8 | 001 | 50V | 50V | 11 | $05\times10^{-6}$ $21\times10^{-6}$ | $06\times10^{-6}$ $6.3\times10^{-3}$ | OK | Ag | OK | 26 hr | NO | |
| | 13 | 001 | 50V | 50V | 11 | $05\times10^{-6}$ $4\times10^{-6}$ | $008\times10^{-6}$ $2\times10^{-6}$ | OK | Ag | OK | 26 hr | NO | |
| | 15 | 001 | 50V | 50V | 11 | $22\times10^{-6}$ $34\times10^{-6}$ | $014\times10^{-6}$ $1\times10^{-6}$ | OK | OK | OK | 26 hr | NO | |

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

- The degree of silvering found on the slug or anode is not directly related with the reverse bias condition; i.e., five elements in the 250 millivolt reverse group exhibited light to gross silver; whereas two elements in the 500 millivolt reverse group were found to have light silvering.

- Reverse current levels are unpredictable at the voltage levels used for this test. Current in the 50 and 100 millivolt reverse groups had a tendency to decrease during the test whereas current in the 250 and 500 millivolt groups remained constant or increased in the same time frame.

- Temporary breakdown (glitches) and subsequent healing were noted on several units in the 250 and 500 millivolt groups.

  Note: If a glitch occurred, the voltage was decreased and then again ramped toward the voltage rating.

#### 6.6.3.3 Cumulative Effects of Reverse Bias

##### 6.6.3.3.1 Duty Cycle Test No. 1 –

Twenty-three capacitor elements were selected and exposed to the following test cycle:

> 100 millivolts reverse for one minute followed by 25, 50 or 100% of forward rated voltage for one minute.

Groups of elements were removed from test at the end of 1, 5, 10 and 25 cycles. The test samples were opened and subjected to internal visual examination. (See Table 6.6.3.3.1-1). No direct results were obtained from this evaluation; however, it is assessed that if a longer test time were selected, meaningful results could have been obtained.

> Note: The intent of this particular evaluation was to demonstrate that the action of plating of silver on the slug due to reverse current is greater than the reaction of normal forward leakage current tending to move the silver back to the case; i.e., when reverse and forward currents are alternately equal in amplitude, degradation can occur.

##### 6.6.3.3.2 Duty Cycle Test No. 2 –

Three capacitors were selected for this evaluation. The first sample was subjected to 1.0 volt reverse bias for thirty minutes; then forward leakage was checked at rated voltage. This procedure was repeated until failure occurred. The second and

*Table 6.6.3.3.1-1. Reverse Bias Duty Cycle Test No. 1 Data.*

| 1 MINUTE REVERSE BIAS (MV) | 1 MINUTE FORWARD BIAS (V) | NUMBER OF CYCLES | ELE. NO. | CAP NO. | VOLT RATING | CURRENT (AMP) | | INTERNAL VISUAL | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | LEAK. | REVERSE | SLUG | $H_2SO_4$ | CASE |
| -100 | 50 | 1 | 7 | 1 | 50 | $.76\times10^{-6}$ | $.28\times10^{-5}$ | Ag SLIGHT | | |
| | 50 | 1 | 14 | 145 | 50 | $.55\times10^{-6}$ | $.02\times10^{-6}$ | BROWN DEPOSIT | BROWN | |
| | 25 | 1 | 13 | 145 | 50 | $.24\times10^{-6}$ | $.05\times10^{-6}$ | OK | OK | OK |
| | 100 | 1 | 15 | 621 | 100 | $.7\times10^{-6}$ | $.92\times10^{-6}$ | OK | OK | OK |
| | 50 | 1 | 14 | 621 | 100 | $.3\times10^{-6}$ | $.3\times10^{-6}$ | | | Ag |
| | 50 | 5 | 11 | 1 | 50 | $.7\times10^{-6}$<br>$.9\times10^{-6}$ | $.08\times10^{-6}$<br>$.36\times10^{-6}$ | OK | OK | OK |
| | 50 | 5 | 3 | 145 | 50 | $.55\times10^{-6}$<br>$.8\times10^{-6}$ | $.01\times10^{-6}$<br>$.3\times10^{-6}$ | Ag SLIGHT | | |
| | 25 | 5 | 10 | 145 | 50 | $.18\times10^{-6}$<br>$.25\times10^{-6}$ | $.005\times10^{-6}$<br>$.1\times10^{-6}$ | OK | OK | OK |
| | 100 | 5 | 7 | 621 | 100 | $.62\times10^{-6}$<br>$.5\times10^{-6}$ | $.14\times10^{-6}$<br>$.30\times10^{-6}$ | BROWN DEPOSIT | | |
| | 50 | 5 | 4 | 621 | 100 | $.3\times10^{-6}$ | $.08\times10^{-6}$<br>$.15\times10^{-6}$ | | | Ag |
| | 50 | 4 | 1 | 1 | 50 | $.56\times10^{-6}$<br>$.76\times10^{-6}$ | $.28\times10^{-6}$<br>$.53\times10^{-6}$ | OK | OK | OK |
| | 50 | 10 | 14 | 1 | 50 | $.83\times10^{-6}$<br>$.61\times10^{-6}$ | $.08\times10^{-6}$<br>$.30\times10^{-6}$ | OK | OK | OK |
| | 25 | 10 | 16 | 1 | 50 | $.35\times10^{-6}$ | $.06\times10^{-6}$<br>$.18\times10^{-6}$ | OK | OK | OK |
| | 50 | 10 | 7 | 145 | 50 | $.02\times10^{-6}$<br>$.04\times10^{-6}$ | $.005\times10^{-6}$<br>$.02\times10^{-6}$ | OK | OK | OK |
| | 25 | 10 | 16 | 145 | 50 | $.21\times10^{-6}$ | $.09\times10^{-6}$<br>$.12\times10^{-6}$ | Ag SLIGHT | | Ag |
| | 100 | 10 | 11 | 621 | 100 | $.50\times10^{-6}$<br>$.66\times10^{-6}$ | $.12\times10^{-6}$<br>$.5\times10^{-6}$ | | | |
| | 50 | 10 | 3 | 621 | 100 | $.25\times10^{-6}$ | $.07\times10^{-6}$<br>$.25\times10^{-6}$ | | | Ag |
| | 25 | 25 | 12 | 1 | 50 | $.4\times10^{-6}$<br>$.28\times10^{-6}$ | $.05\times10^{-6}$<br>$.18\times10^{-6}$ | Ag SLIGHT | | |
| | 50 | 25 | 9 | 621 | 100 | $.16\times10^{-6}$<br>$.22\times10^{-6}$ | $.14\times10^{-6}$<br>$.17\times10^{-6}$ | | | Ag |
| | 100 | 25 | 16 | 621 | 100 | $.40\times10^{-6}$<br>$.62\times10^{-6}$ | $.14\times10^{-6}$<br>$.34\times10^{-6}$ | OK | OK | Ag |
| | 50 | 25 | 1 | 145 | 50 | $.30\times10^{-6}$<br>$.7\times10^{-6}$ | $.01\times10^{-6}$<br>$.21\times10^{-6}$ | OK | DENDRITE | OK |
| | 25 | 25 | 8 | 136 | 50 | $.19\times10^{-6}$<br>$.26\times10^{-6}$ | $.01\times10^{-6}$<br>$.14\times10^{-6}$ | OK | OK | OK |
| -100 | 50 | 25 | 9 | 1 | 50 | $.9\times10^{-6}$<br>$.61\times10^{-6}$ | $.15\times10^{-6}$<br>$.41\times10^{-6}$ | OK | OK | OK |

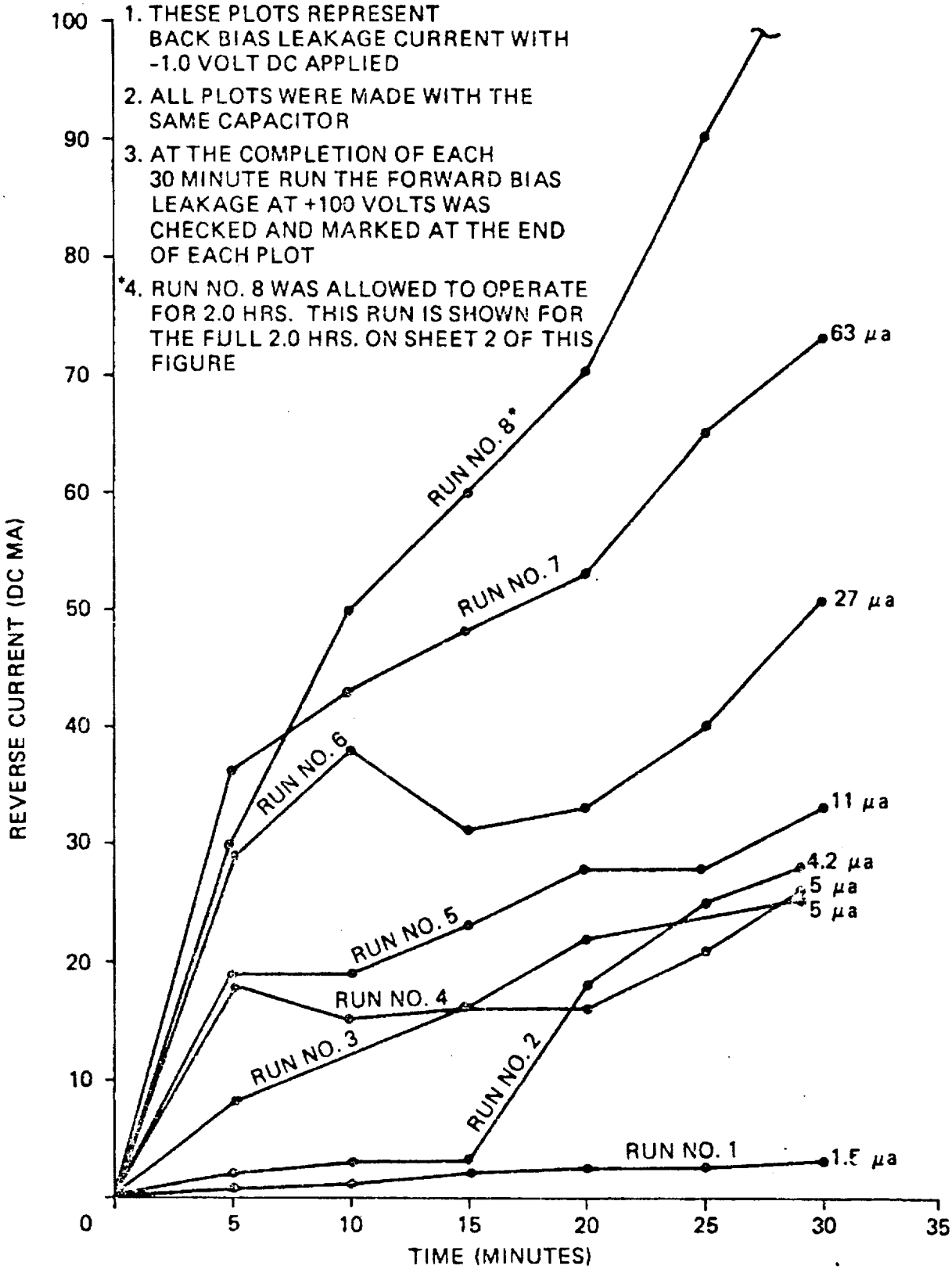



*Figure 6.6.3.3.2-1. Sample No. 1 Data for Duty Cycle Test No. 2. (1 of 2)*

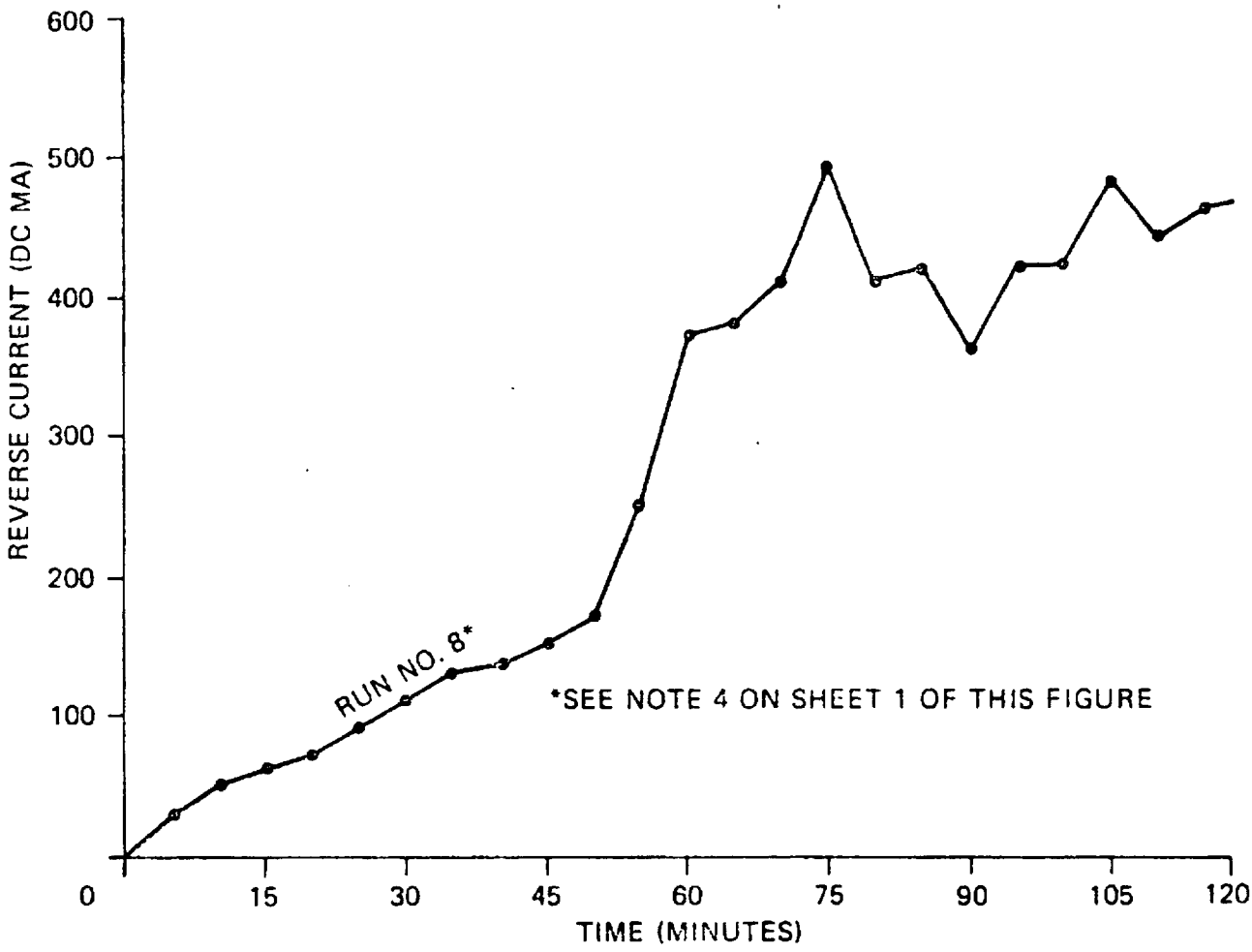



*Figure 6.6.3.3.2-1. Sample No. 1 Data for Duty Cycle Test No. 2. (2 of 2)*

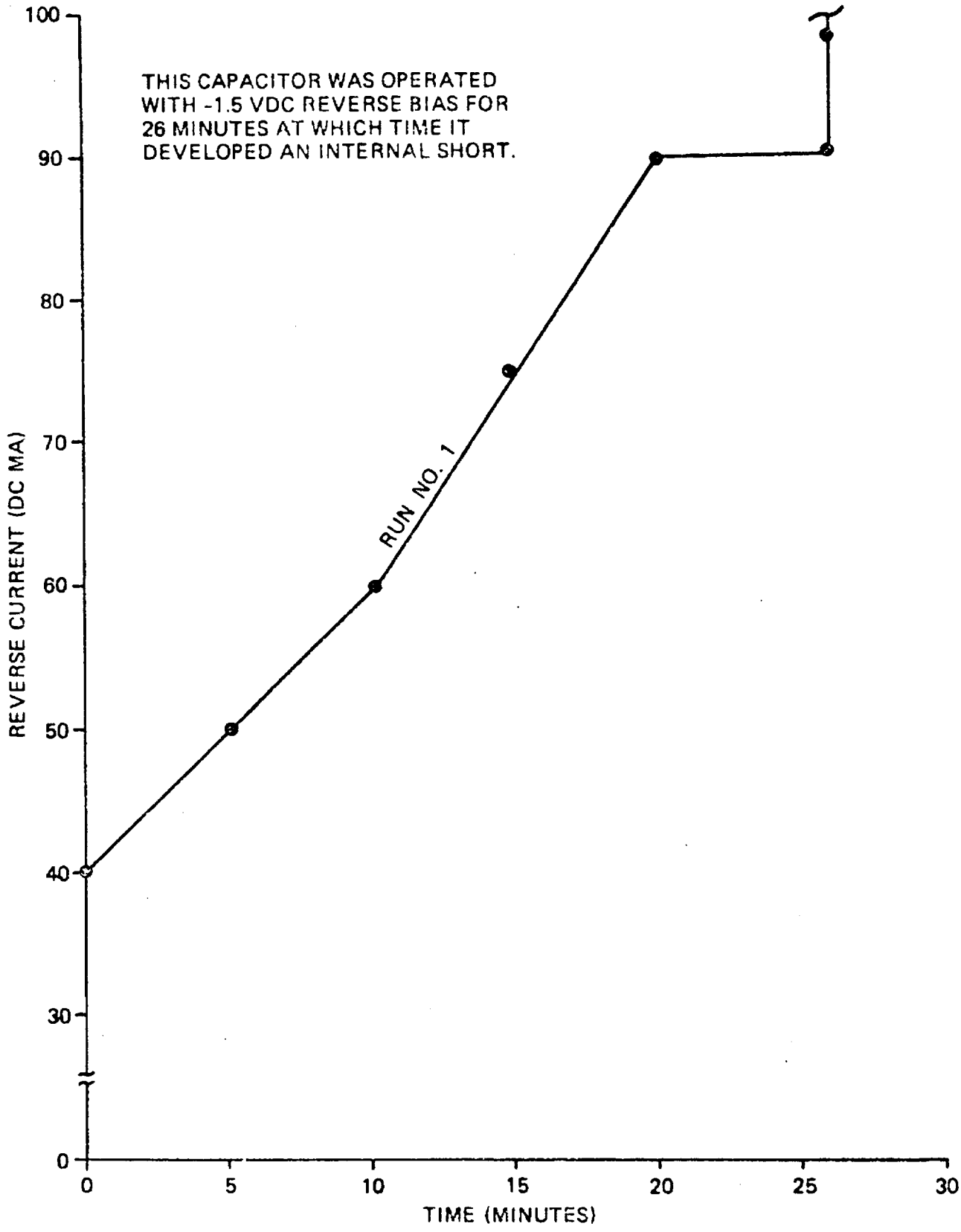



*Figure 6.6.3.3.2-2. Sample No. 2 Data for Duty Cycle Test No. 2.*

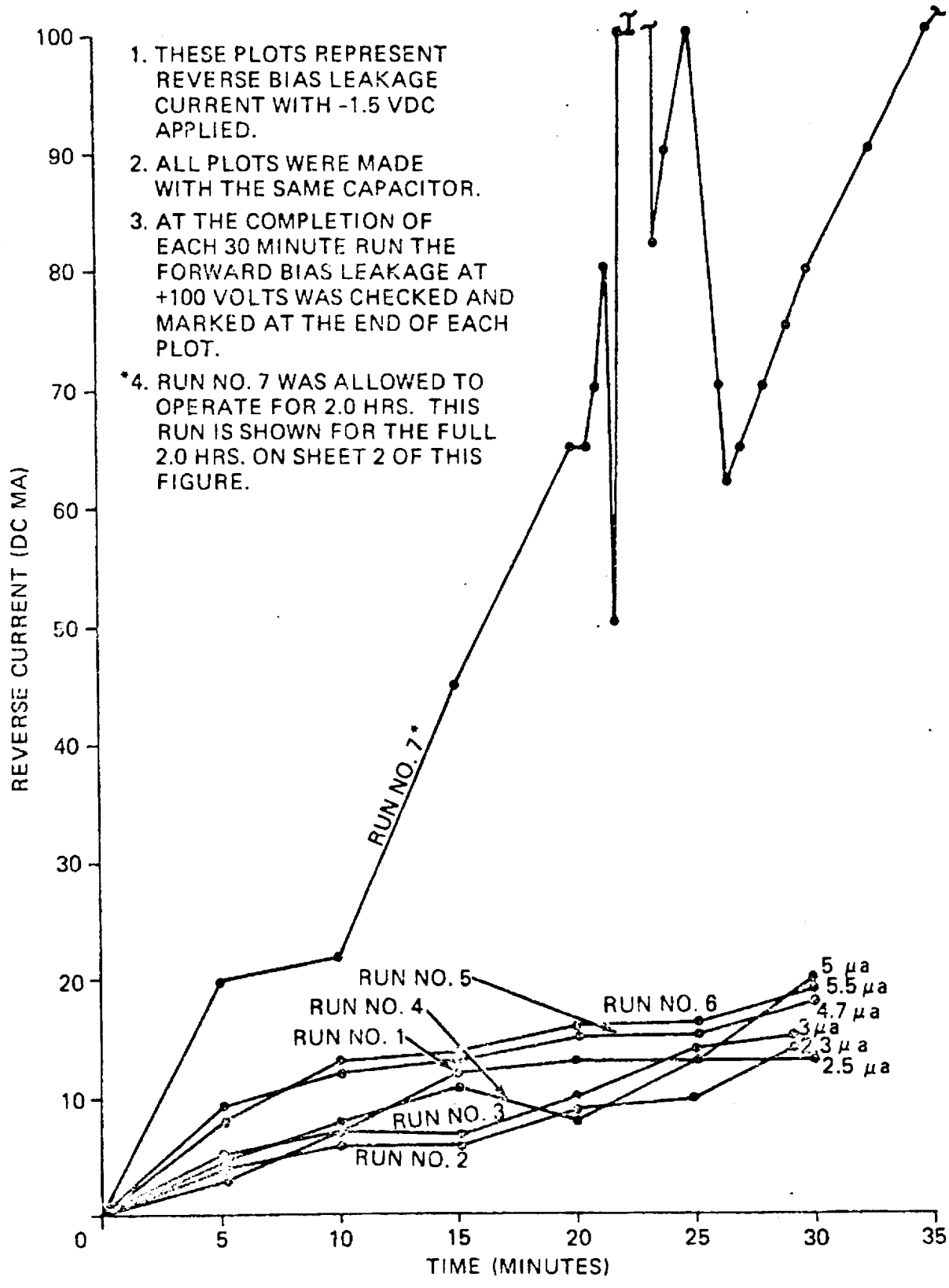



*Figure 6.6.3.3.2-3. Sample No. 3 Data for Duty Cycle Test No. 2. (1 of 2)*

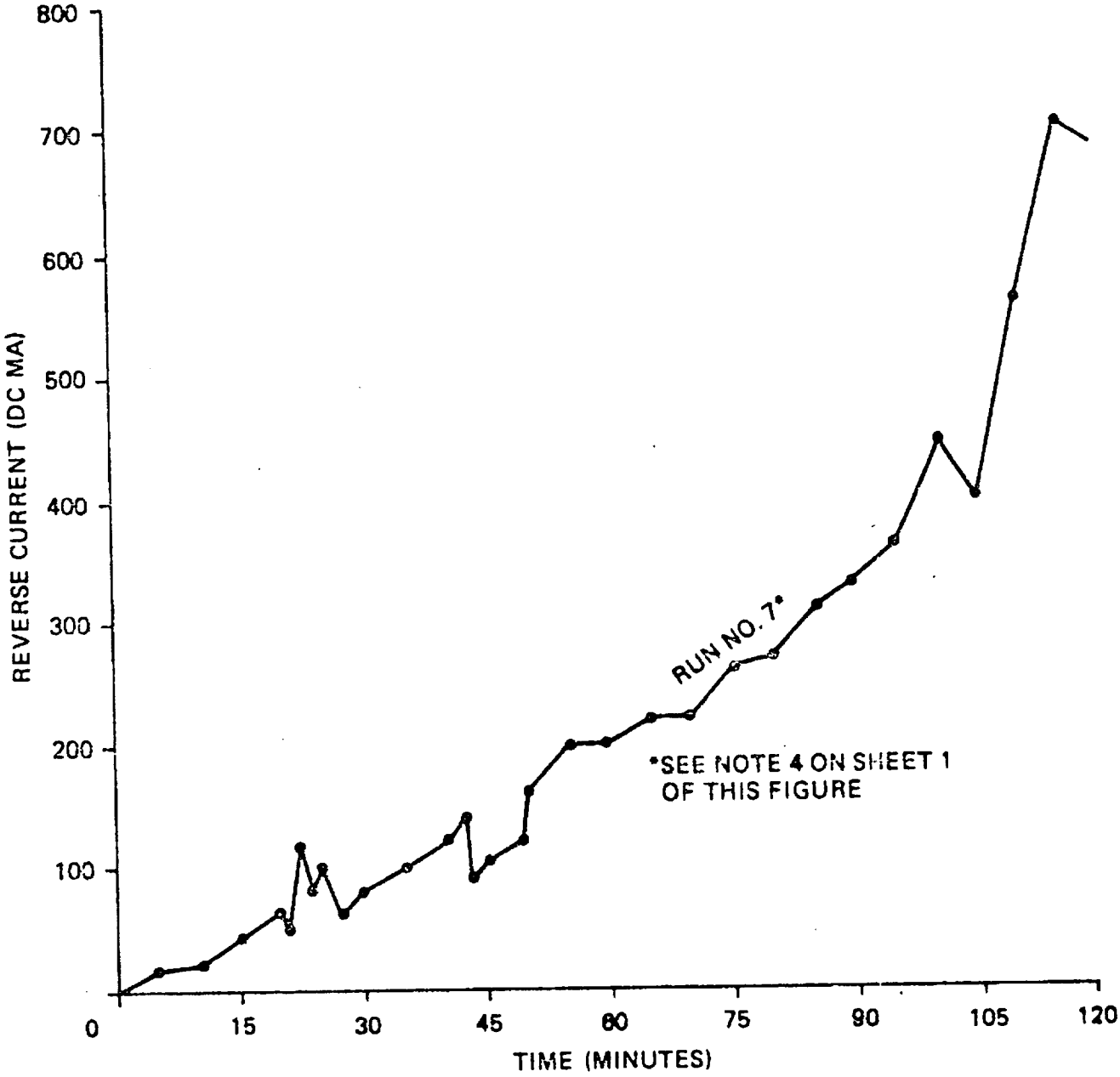



*Figure 6.6.3.3.2-3. Sample No. 3 Data for Duty Cycle Test No. 2. (2 of 2)*

third samples were evaluated in the same manner except the reverse bias was increased to 1.5 volts. The results of this evaluation are shown in Figures 6.6.3.3.2-1 thru 6.6.3.3.2-3.

The general observation is that the reverse bias current increased with time but returned to zero at the beginning of each new cycle. Sample no. 1 showed a progressively increasing rate of reverse leakage with each succeeding run as well as a larger forward leakage at the completion of each run. Sample no. 2 shorted during the first run. Sample no. 3 operated with very little degradation until run no. 7 at which time it approached a shorted condition.

### 6.6.3.4 Reverse Bias Diode Effect

Several elements were subjected to reverse bias voltage, increased in equal increments until catastrophic failure occurred. At each increment of reverse voltage the reverse current was measured and recorded. The results of this test are shown in Figure 6.6.3.4-1.

The primary observation made during this evaluation is the non-linear rise or increase of reverse current (diode effect) with linear increase of reverse voltage.

### 6.6.3.5 Application of AC Without a DC Bias

This test was primarily an experiment to verify the presence of an abnormal component of reverse leakage current when ac is applied to a tantalum wet slug capacitor. The basic operation of an unpolarized capacitor when ac is applied is as follows:

Figure 6.6.3.5-1 illustrates the normal voltage and current waveforms expected when an ac voltage is applied to a capacitor.

In reviewing Figure 6.6.3.5-1 the normal waveforms are as expected; i.e.:

- The current leads the voltage by $90^{\circ}$.
- Current is maximum when voltage is 0, or in terms of capacitor charging operation, current is maximum when changing voltage is applied, e.g., at $0^{\circ}$ and $180^{\circ}$.
- Current is 0 when voltage is maximum or again considering capacitor charging action, current is 0 when the capacitor becomes fully charged, e.g., at $90^{\circ}$ and $270^{\circ}$.

Considering the voltage waveform, $0^{\circ}$ to $180^{\circ}$ represents the capacitor charge and subsequent discharge utilizing a positive voltage. In like manner the voltage waveform from $180^{\circ}$ to $360^{\circ}$ represents the capacitor charge and subsequent discharge

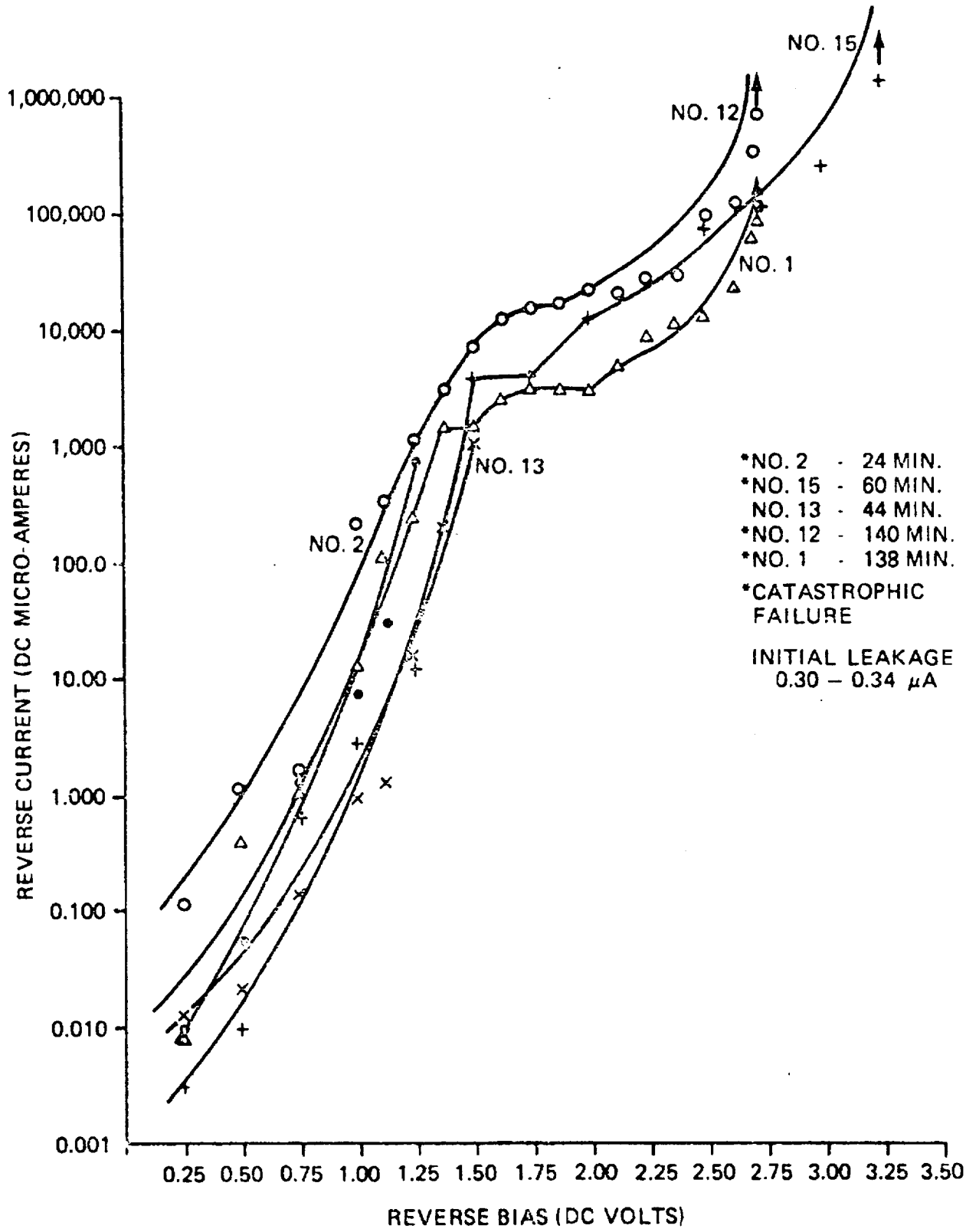



*Figure 6.6.3.4-1. Reverse Bias Diode Effect*

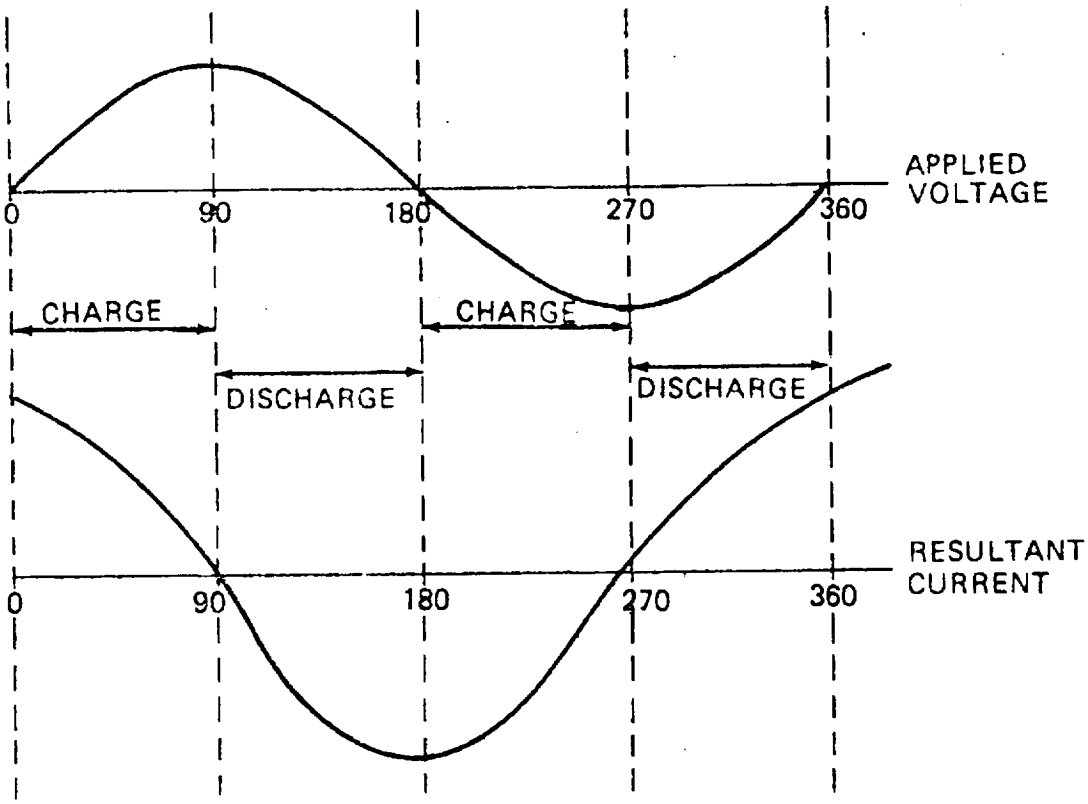



*Figure 6.6.3.5-1. Normal Capacitor AC Waveforms.*

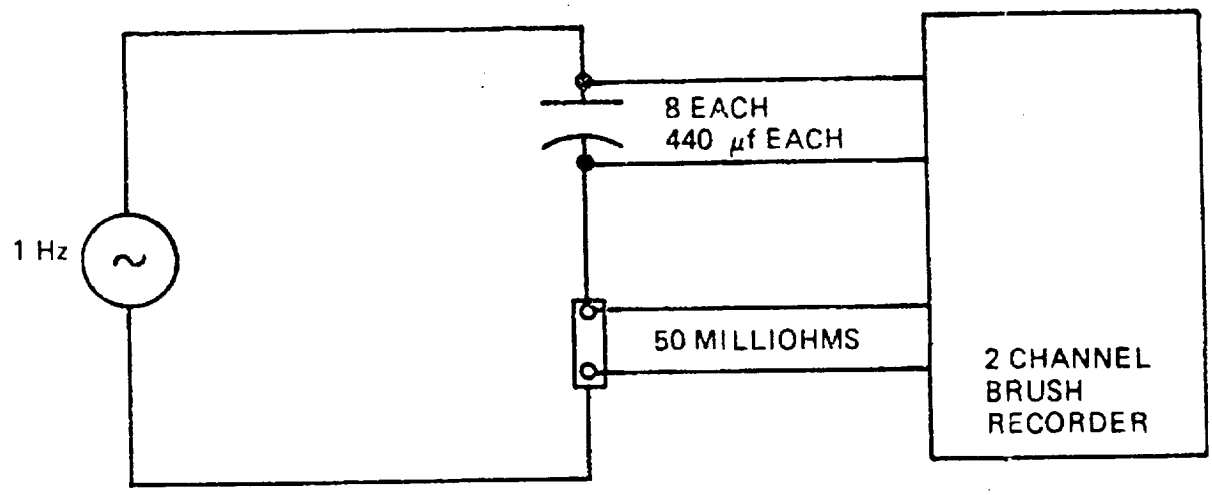



*Figure 6.6.3.5-2. Test Schematic for AC Test on Capacitors.*

utilizing a negative voltage. In reviewing the theoretical current waveform, the positive voltage charge/discharge current waveform (0 to 180°) is symmetrical with the negative voltage charge/discharge current waveform (180 to 360°).

For the first step of this experiment eight tantalum wet slug capacitors were connected in parallel (total capacitance ≈3500 microfarads). Utilizing a signal generator, a 1 Hertz, four-volt peak-to-peak sine wave was applied to the capacitors from a power amplifier. A meter shunt ( ≈50 milliohms) was placed in series with the capacitors in order to measure current. The shunt leads, plus a set of voltage monitoring leads connected directly across the capacitors, were connected to a two-channel brush recorder. (See Figure 6.6.3.5-2). Voltage and current waveforms obtained on the recorder are shown in Figure 6.6.3.5-3.

In reviewing these waveforms, the current waveform is as expected during the 180° of positive voltage application; however, during the 180° of negative voltage (capacitors reverse biased) the current waveform is distorted such that the waveform is unsymmetrical.

It is theorized the following sequence of events takes place:

As the voltage goes negative from 0 to -1.45 volts (1/8 cycle), the current waveform appears normal, i.e., current is maximum at the instant voltage starts negative and starts to decrease as voltage approaches maximum (normal capacitor action).

As the voltage increases further negative, the current, which is normally decreasing at this time, begins to increase as a result of the capacitor beginning to leak. (Reference Paragraph 6.6.3.4). This total current peaks out approximately 15° before the voltage peaks out indicating a large resistive as well as a reactive component of current at this instant. When the current returns to zero, it is leading the voltage by approximately 60° which still indicates the presence of a resistive or leakage component but considerably less than previously. The voltage at this time is -1.7 volts. The complete recovery to a normal 90° current lead over applied voltage is not seen until the applied voltage returns to a positive value. It should also be noted that power, hence heat, is developed within the capacitor during the leakage portion of the cycle because of the resistive component. This is not the case at other times since energy is alternately stored and returned to the circuit when a 90° phase shift exists. Power dissipation, and consequently, heat are probably responsible for the capacitor's expanding and sometimes exploding.

### 6.6.3.6 Application of AC Superimposed on a DC Reverse Bias

This test was an experiment to determine if the quantity of reverse bias leakage current is in any was related to the frequency of the applied voltage. The results of this test indicate that the leakage current is greater at lower frequencies. These results are summarized in Figure 6.6.3.6-1.

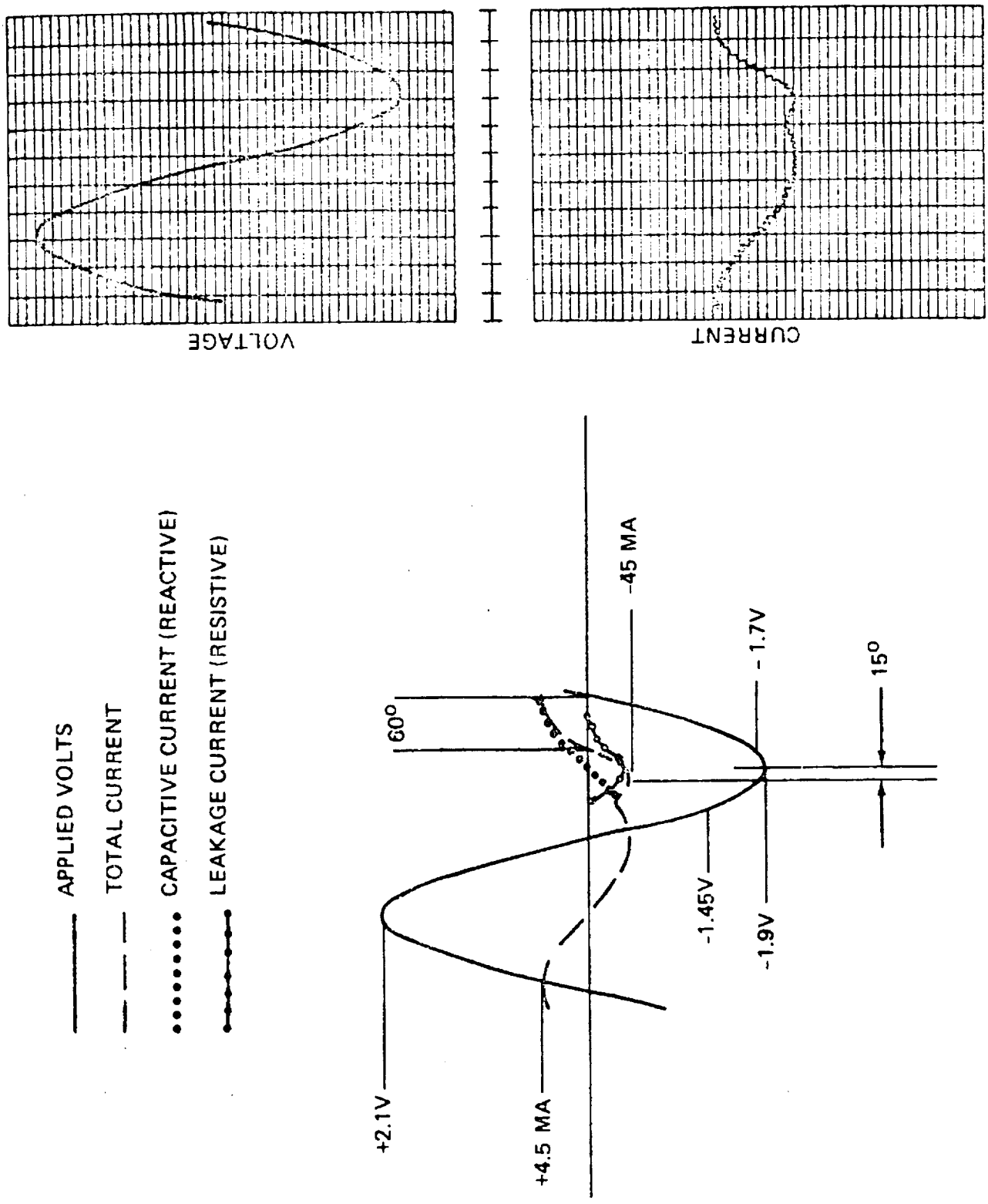



*Figure 6.6.3.5-3. AC Voltage and Current Waveforms Showing Reverse Leakage Current.*

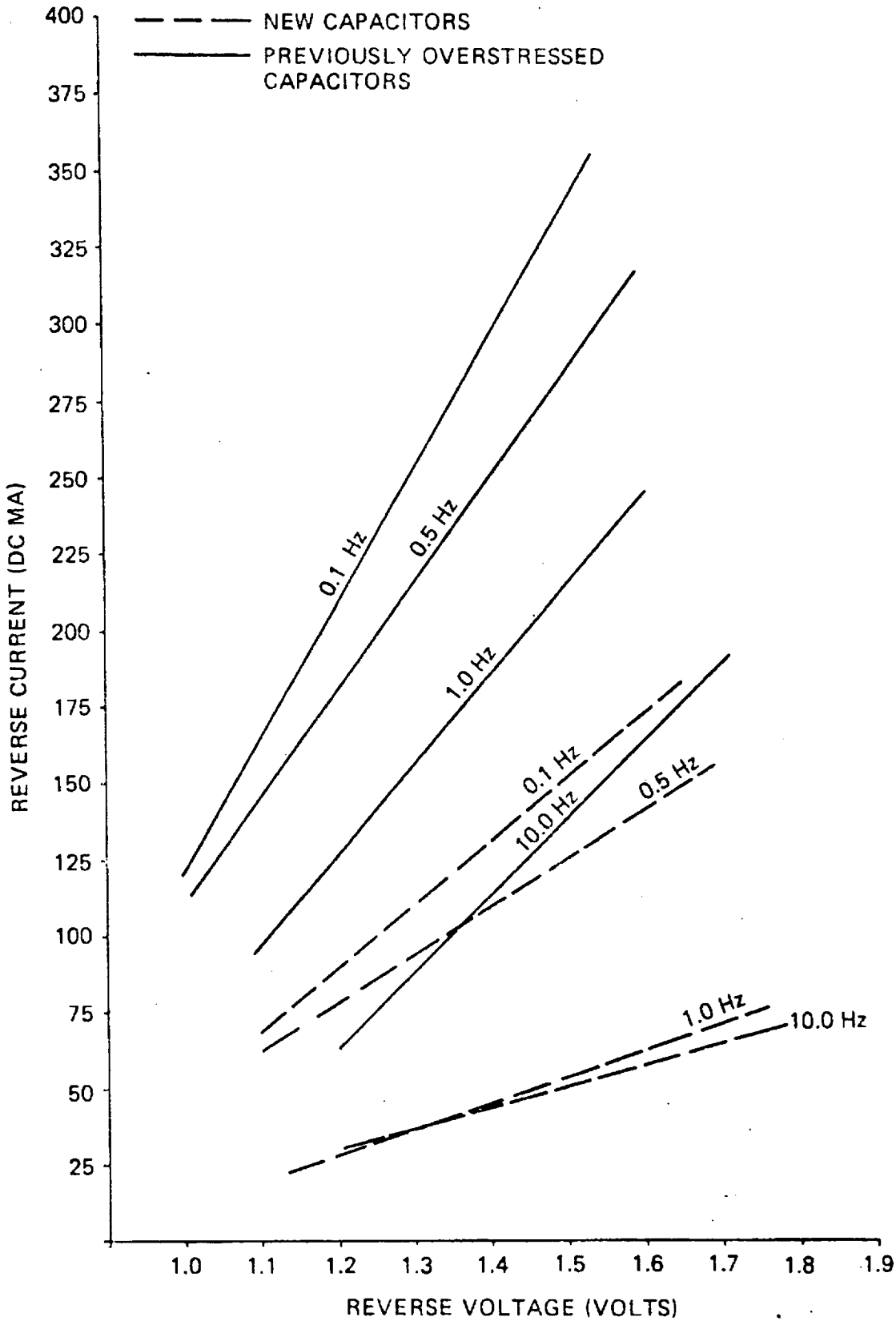



*Figure 6.6.3.6-1. AC on DC Test Summary.*

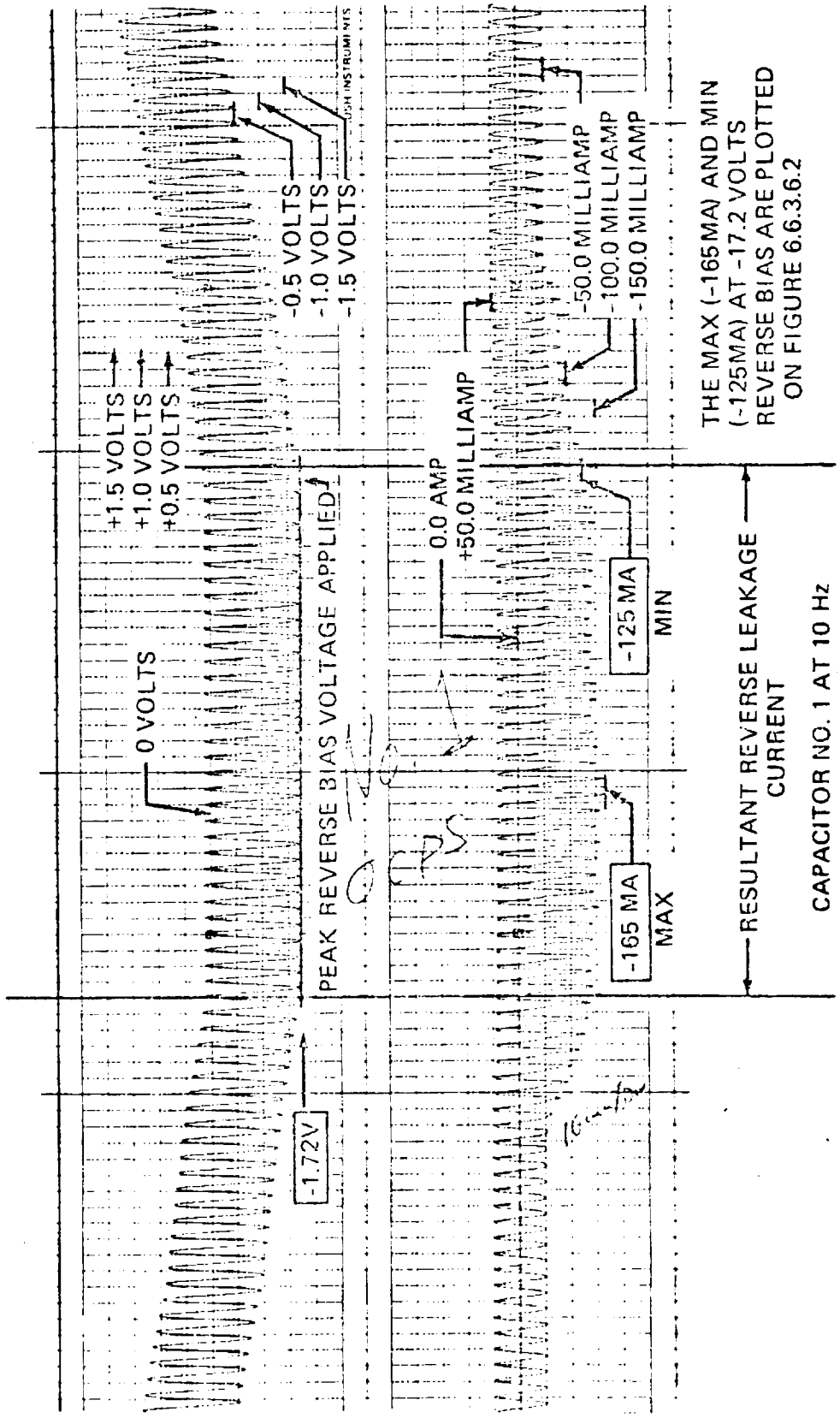



*Figure 6.6.3.6-2. Raw Data Sample AC on DC Test.*



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

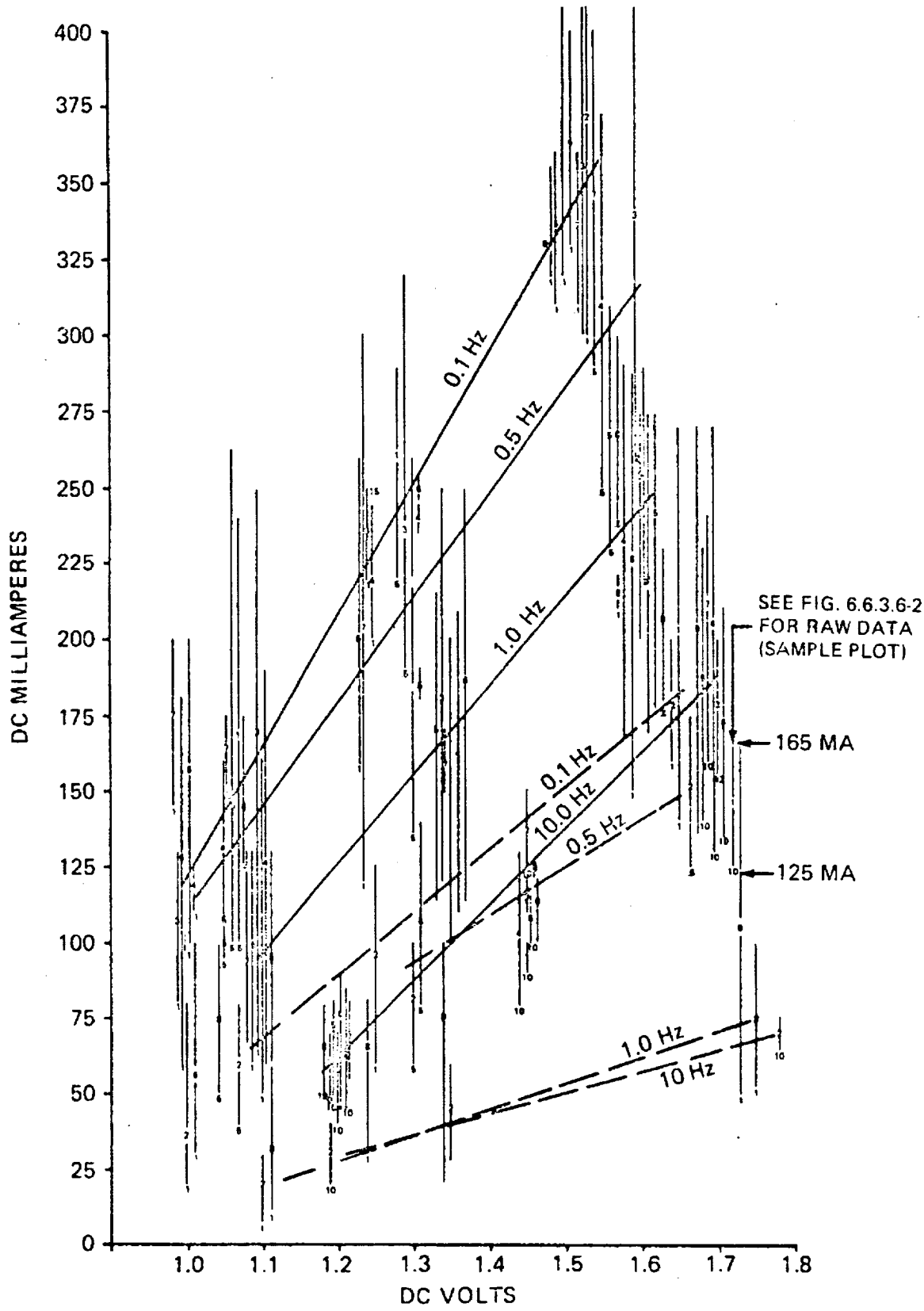



*Figure 6.6.3.6-3. Detail Plots of AC on DC Test Data.*

This test was performed on eight capacitors. Each capacitor was operated at four frequencies - 0.1 Hz, 0.5 Hz, 1.0 Hz, and 10.0 Hz. A sample run is shown in Figure 6.6.3.6-2. This sample shows test capacitor no. 1 being operated at 10.0 Hz. Data from these runs were used for plotting data points on Figure 6.6.3.6-3. After all points were plotted, diagonal lines connecting the average leakage currents at the given frequencies and voltages were drawn showing the overall leakage effect at a given frequency.

Figure 6.6.3.6-4 is a schematic of the laboratory setup for this test.

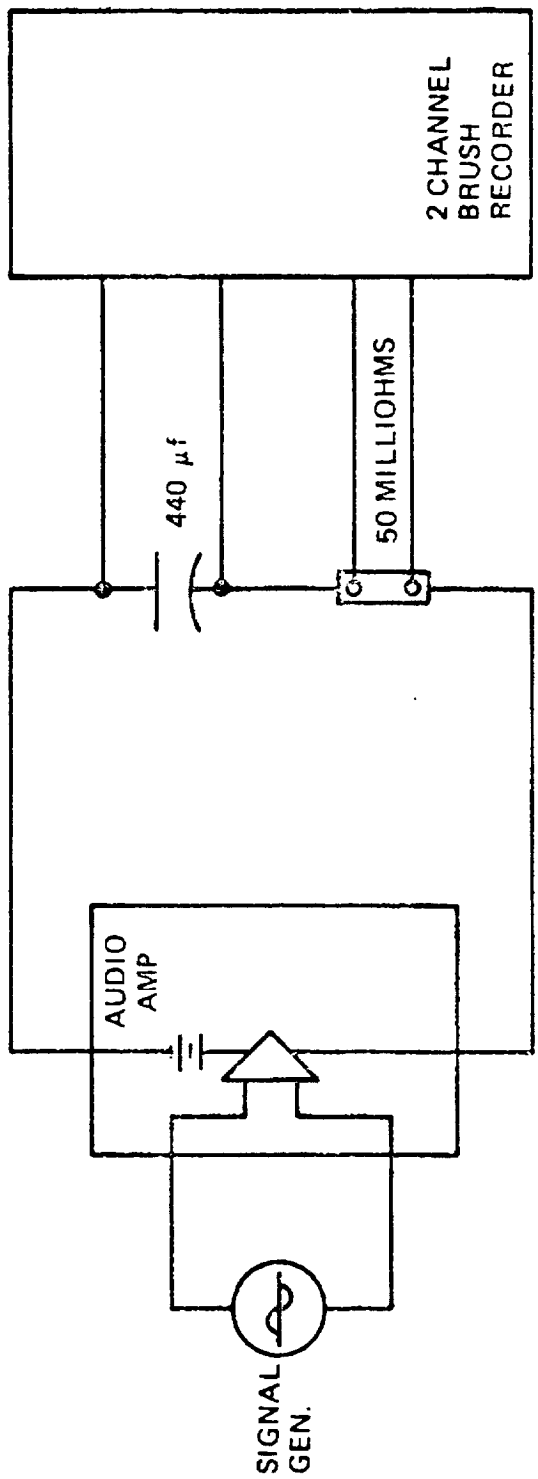
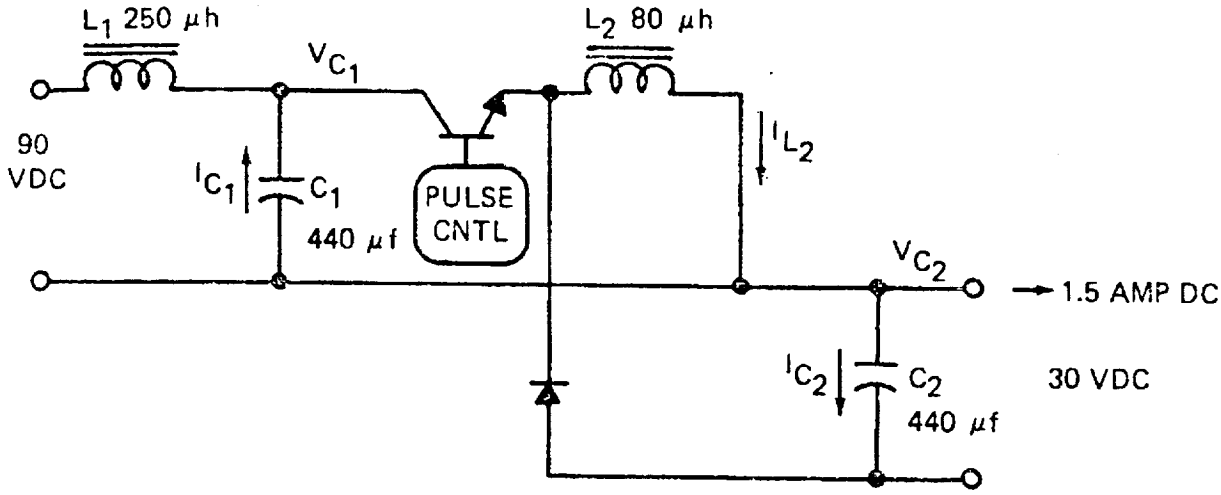



*Figure 6.6.3.6-4. AC on DC Test Schematic.*

## 6.7 CURRENT RIPPLE TEST

A ripple test was performed on six tantalum capacitors to determine if CBRM ripple current causes capacitor degradation. The ripple test exercised the capacitors at the normal CBRM rate when maximum (90 vdc) voltage, maximum (12 amperes peak) current is applied. Figure 6.7-1 describes the test configuration. The materials investigation disclosed traces of silver on the anode of the capacitor following current ripple testing. No degradation in capacitor operation was noted.



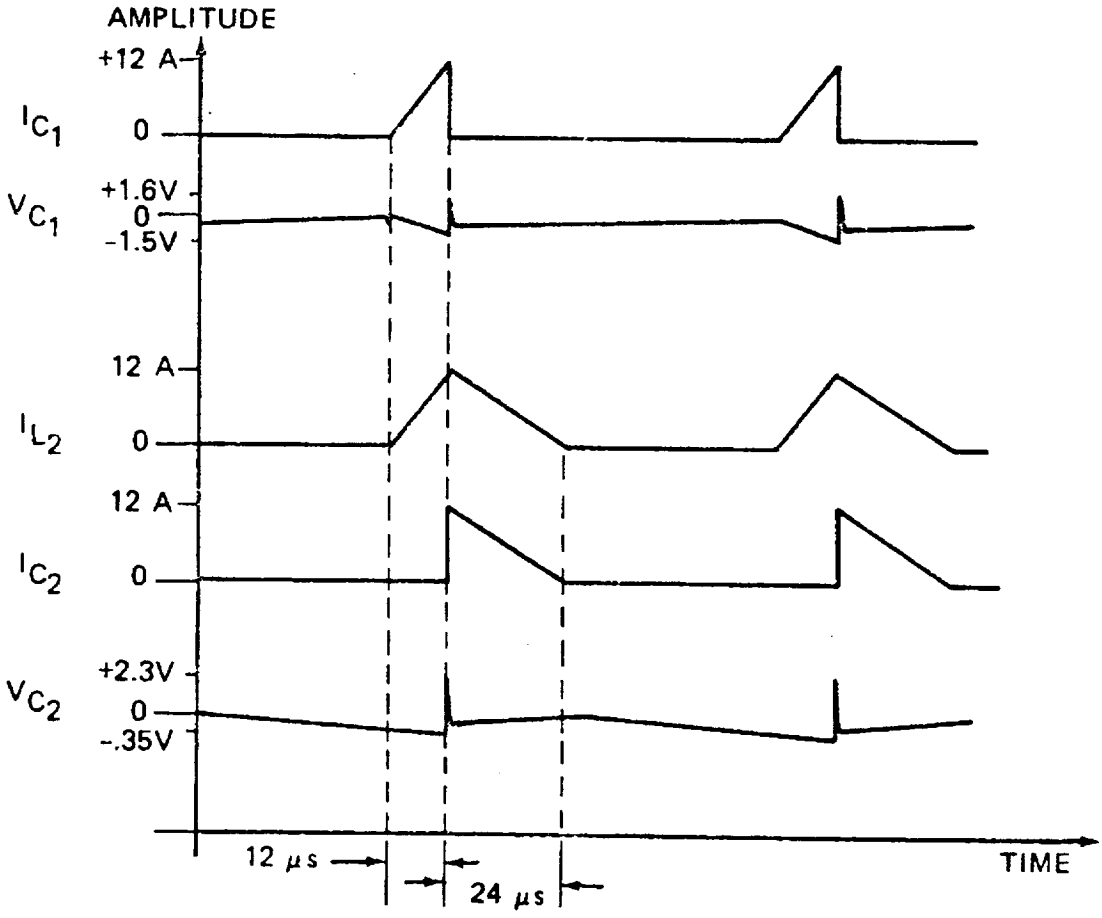




*Figure 6.7-1. AC Ripple Test Configuration.*

## 6.8 RINGING TESTS

### 6.8.1 Summary

Tests were run on a lab model of the CBRM input filter to determine if ringing (resonant oscillation) caused by instant application of input voltage, applies reverse bias to the input filter capacitors.

Current in the filter oscillated around zero indicating normal capacitor charge/discharge current. Voltage across the capacitors rang but did not go below zero. No reverse bias was observed as a result of circuit ringing.

### 6.8.2 Conclusions

Although ringing does occur in the CBRM input filter when input voltage is applied instantly, no reverse bias is applied to the input filter capacitors as a result of the single action of input filter circuit ringing. Any reverse bias is the result of filter action combined with other circuit actions in a system configuration.

### 6.8.3 Details

A lab model of the CBRM input filter was built for the ringing tests. ESE transient suppression components were included in the circuit, and a 205 kohm resistor simulated the circuit load at power on. (See Figure 6.8.3-1).

Upon application of 15 volts dc to the circuit via a mercury switch ringing occurred. Current was observed to ring positively and negatively around zero, indicating normal capacitor charge/discharge current. Capacitor voltage rang while charging to 15 volts but never went negative. Photos 6.8.3-1 and 6.8.3-2 show input filter circuit ringing.

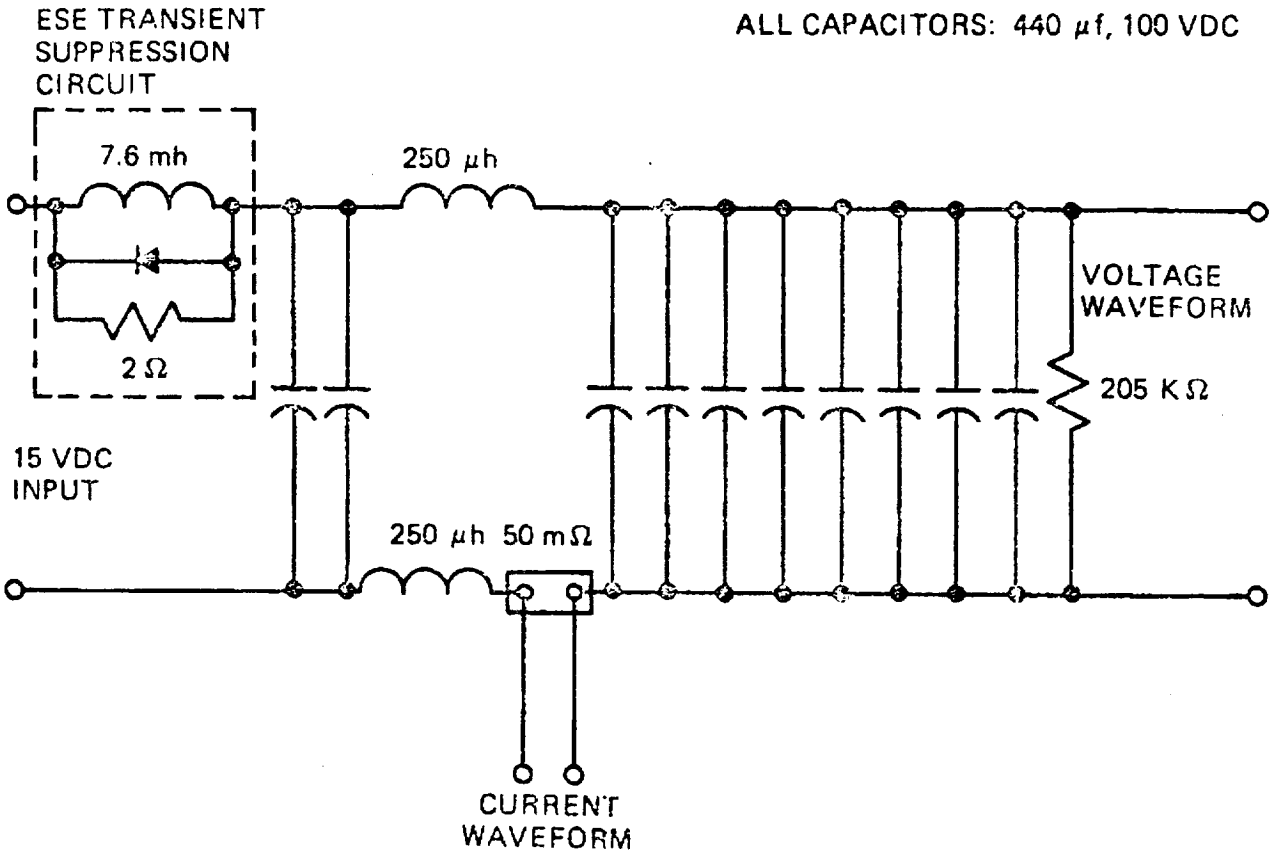



*Figure 6.8.3-1. Schematic of Lab Model of CBRM Input Filter*

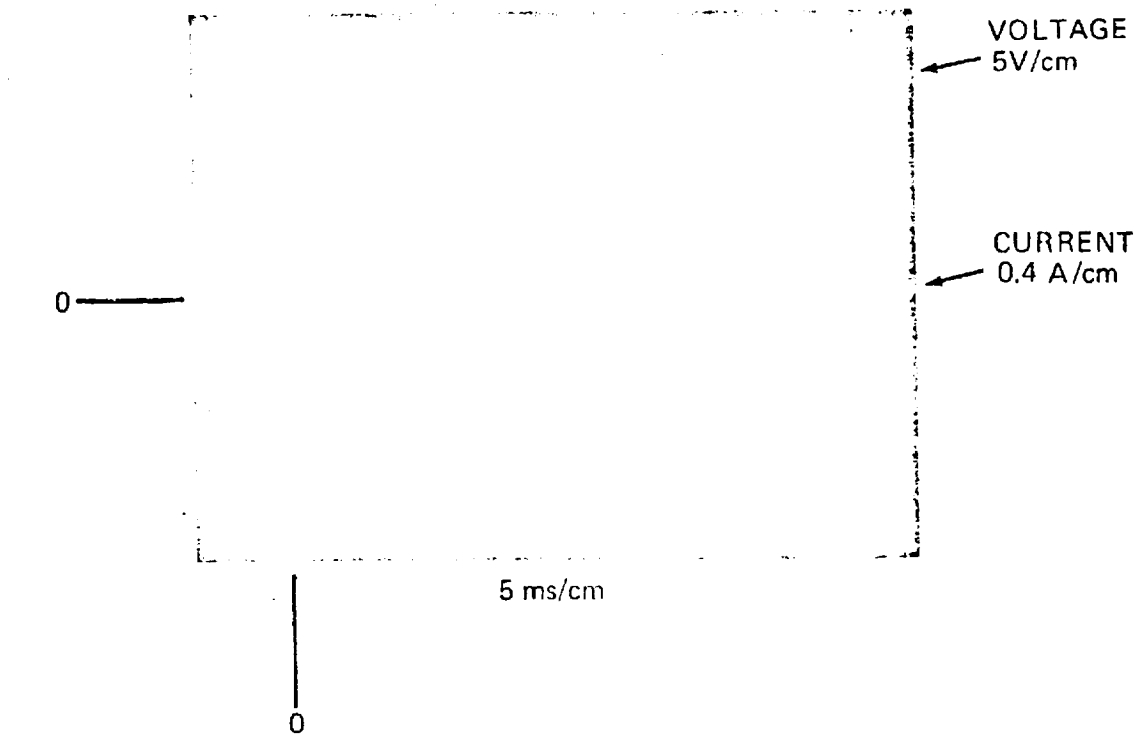



Photo 6.8.3-1. Voltage and current waveforms in lab model input filter output capacitors at 15 volts On.

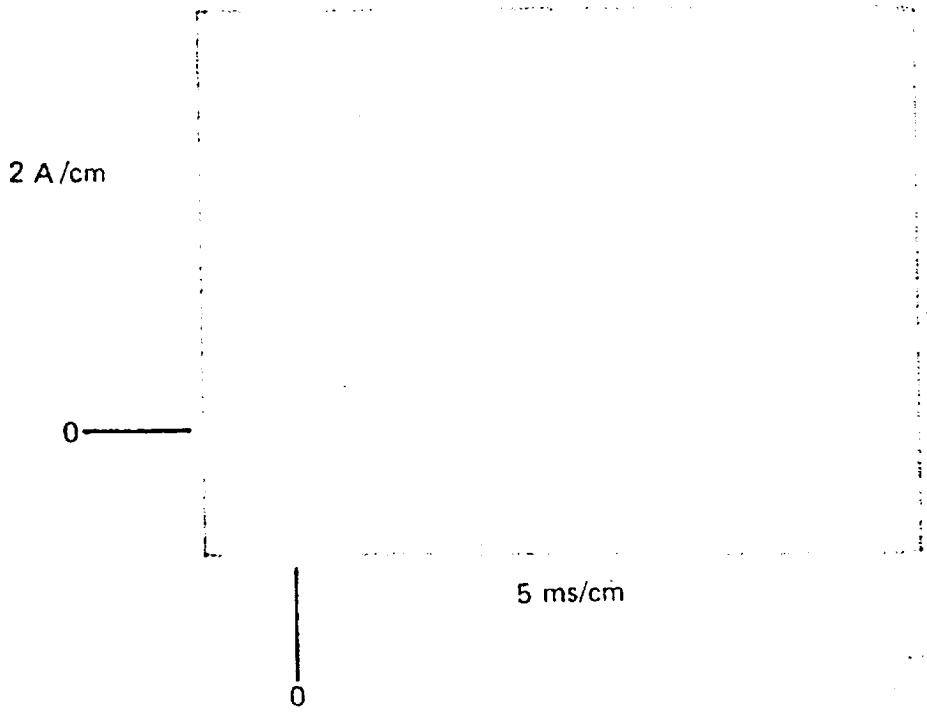



Photo 6.8.3-2. Current waveform in input filter output capacitors at 15 volts On.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

## 6.9 MSFC CBRM LABORATORY TESTS

Capacitors with 1967 date codes (parallel construction) were installed in a CBRM input filter at the Astrionics CBRM laboratory for time durations ranging from 48 hours to 160 hours. The CBRM was operated at nominal load continuously except for shut-downs to remove and install capacitors.

Capacitors with 1972 date codes (series-parallel construction) were installed in the same CBRM in the output filter. The CBRM was operated at nominal load continuously for 71.5 hours.

No capacitor failures occurred during these tests. All capacitors tested were opened for silver characterization. No patterns were defined for time, operating voltage, current ripple and silver plating.

## 6.10 KSC TESTS

IBM personnel supported EMC tests on the ATM CBRMs at KSC in an attempt to identify transients at the input and output of a CBRM. The tests were directed by MSFC personnel and were prompted by concern about reverse bias on the CBRM tantalum wet slug capacitors. Also, negative transients on CBRM power lines had been observed during ATM system test at MSC.

Negative transients were recorded on the input and output of CBRM no. 2 when trickle charge voltage was applied or removed and when the SAS power supplies were turned on. It was not determined if the negative transients were applied to the CBRM filter capacitors. Subsequent tests were run at the MSFC ATM Breadboard to further define transient parameters and to determine if the CBRM filter capacitors are experiencing any negative transients. Breadboard test results are given in Paragraph 6.11.2.

## 6.11 PROTOTYPE CBRM TESTS

### 6.11.1 IBM Laboratory Tests

Prototype CBRM No. 037 was obtained from MSFC Astrionics Laboratory to perform transient evaluation tests. The IBM laboratory test configuration is shown in Figure 6.11.1-1.

The test schematic for power line transient evaluation is shown in Figure 6.11.1-2. No negative transients were identified. (See photographs 6.11.1-1 thru 6.11.1-9).

The test schematic for trickle charger transient evaluation is shown in Figure 6.11.1-3. A condition of transient reverse bias was found to exist whenever the battery trickle charger was turned on or off. Worst-case transients were 1 ampere and (-)500 millivolts. (See photographs 6.11.1-10 thru 6.11.1-20).

### 6.11.2 ATM Breadboard Tests

#### 6.11.2.1 Summary

Earlier analysis and lab tests identified possible reverse bias sources and suggested tests on a CBRM in a system configuration to verify such sources.

Prototype CBRM No. 037 was instrumented to monitor voltage across and current thru the CBRM input filter capacitors and was installed in the ATM Breadboard at MSFC for tests.

The tests were performed in order to verify that the CBRM sees negative transients externally and reverse bias (voltage) on the input capacitors internally during the normal trickle charge switching mode. Tests were performed to demonstrate possible switching transients at "SAS power on" at the 15-volt level.

Further tests were performed to verify that ramping the "SAS power on" from 0 volt and turning the trickle charger on and off with greater than 15 volts on the system will not produce negative transients and will prevent reverse bias on the input capacitors.

Upon turning trickle charger on and off, negative transients were recorded at the CBRM inputs and at the CBRM input filter. Input transients at turn-on were as high as (-)2.3 volts and at turn-off were as high as (-)1.8 volts. Input filter transients at turn-on were as high as (-)0.95 volts and at turn-off were as high as (-)0.20 volts.

Upon turning SAS 15 volts on, negative transients were recorded at the CBRM input and at the CBRM input filter. Input transients were as high (-)2.5 volts. Input filter transients were as high as (-)0.90 volts.

Federal Systems Division
Space Systems Center,
Huntsville, Alabama

# DATA SHEET

Date 11-27-72

Sample CBRM Part No.

Serial No. No. 037 Test Reverse Bias - Transient

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

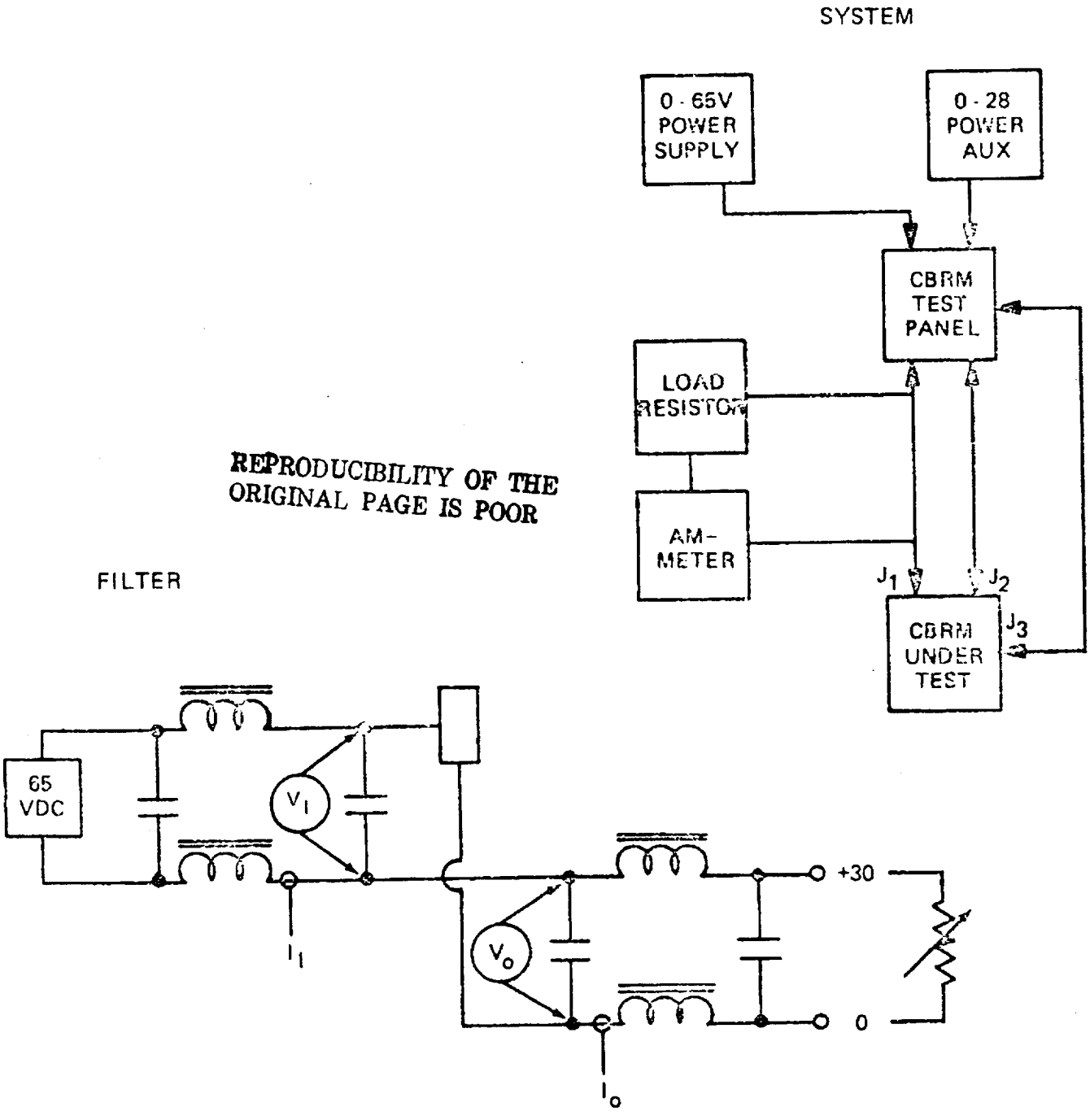



*Figure 6.11.1-1. IBM Laboratory Test Configuration for Prototype CBRM Tests.*

# DATA SHEET

Date 11-27-72

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test Initial Condition $V_O$ = -15 mv, $V_I$ = 340 mv

Photo 6.11.1-1
ESE & Solar Array = 0 vdc
$I_O$ = 10 a/d
$V_I$ = 20 v/d
$V_O$ = 20 v/d
10 ms/d
System Turn On

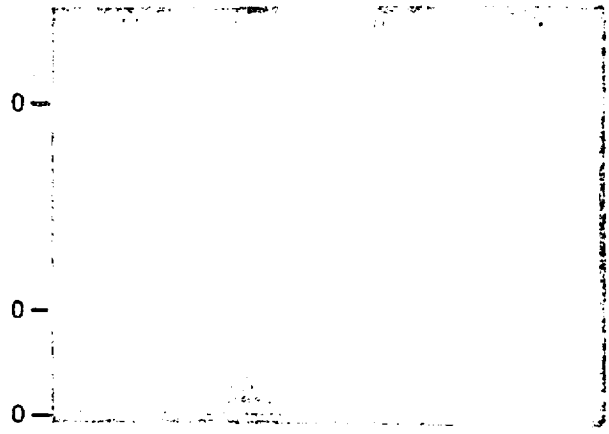



Photo 6.11.1-2
ESE & Solar Array = 0 vdc
$I_I$ = 10 a/d
$V_I$ = 20 v/d
$V_O$ = 20 v/d
10 ms/d
System Turn On

Photo 6.11.1-3
Turn On ESE @ 15 vdc
$I_I$ = 10 a/d
$V_I$ = 20 v/d
$V_O$ = 20 v/d
1 ms/d

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Federal Systems Division
Space Systems Center,
Huntsville, Alabama

# DATA SHEET

Date 11-27-72

mple _____ Part No. CBRM No. 037

rial No. _____ Test ESE Turn On

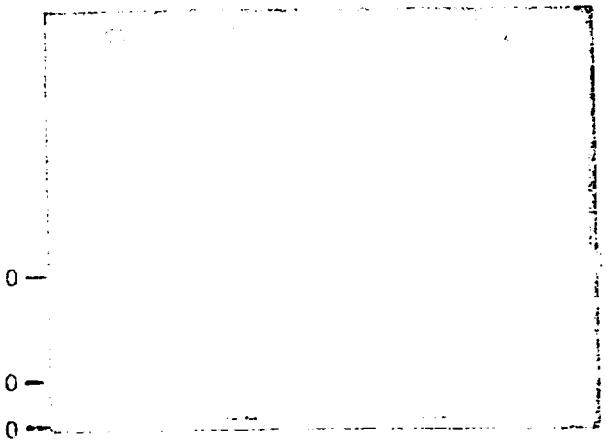



Photo 6.11.1-4
ESE Turn On @ 25 vdc
$I_I$ = 10 a/d
$V_I$ = 20 v/d
$V_o$ = 20 v/d
1 ms/d

Photo 6.11.1-5
ESE Turn On @ 65 vdc
$I_I$ = 10 a/d
$V_I$ = 20 v/d
$V_o$ = 20 v/d
5 ms/d

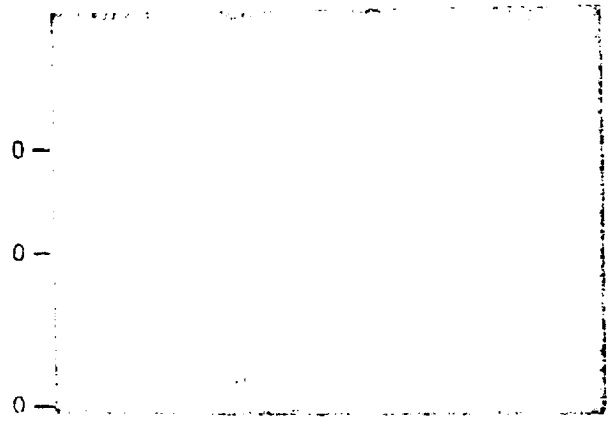



Photo 6.11.1-6
ESE Turn On @ 65 vdc
$I_o$ = 10 a/d
$V_I$ = 20 v/d
$V_o$ = 20 v/d
5 ms/d

# DATA SHEET

Date 11-27-72

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test Reg. Turn On @ 65 vdc

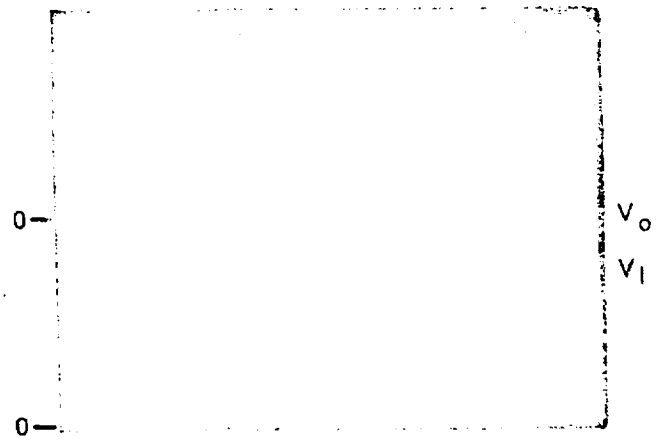



Photo 6.11.1-7
$V_o$ = 1 v/d
$V_I$ = 5 v/d
2 ms/d

Photo 6.11.1-8
$V_o$ = 10 v/d
$V_I$ = 50 v/d
2 ms/d

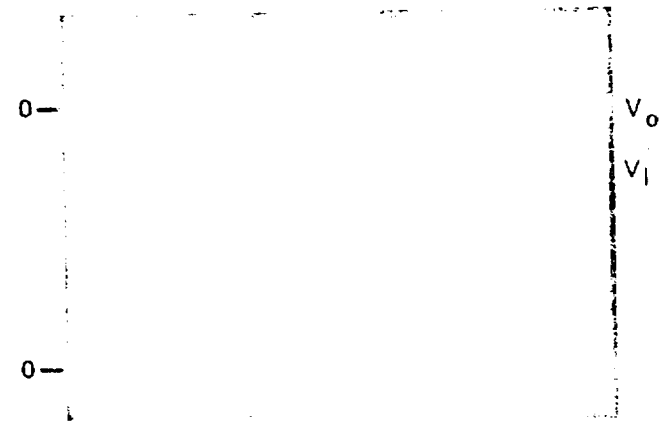



Photo 6.11.1-9
$V_o$ = 1 v/d
$V_I$ = 5 v/d
2 ms/d

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Federal Systems Division
Space Systems Center,
Huntsville, Alabama

# DATA SHEET

Date 11-28-72

Part No. CBRM No. 037

Test Trickle Charger Switching Test

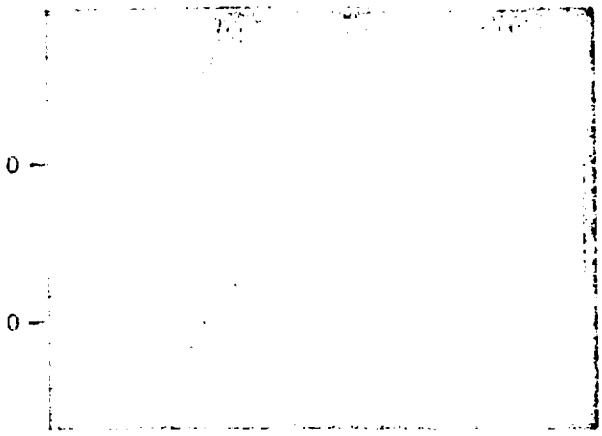



Photo 6.11.1-10
Trickle Charger Turn On
$I_I$ = 1 a/d
$V_I$ = 100 mv/d
2 ms/d

Photo 6.11.1-11
Trickle Charger Turn Off/On/Off/On
$I_I$ = 1 a/d
$V_I$ = 100 mv/d
5 ms/d

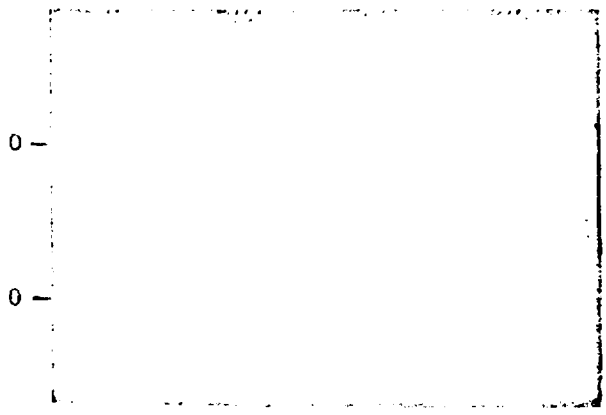



Photo 6.11.1-12
Trickle Charger Turn Off
$I_I$ = 1 a/d
$V_I$ = 100 mv/d
2 ms/d

# DATA SHEET

Date 11-29-72

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test Trickle Charger Turn On

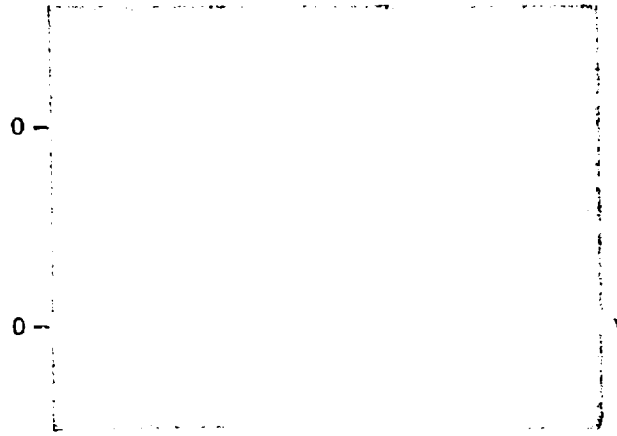



Photo 6.11.1-13
$I_I$ = .5 a/d
$V_I$ = 500 mv/d
5 ms/d

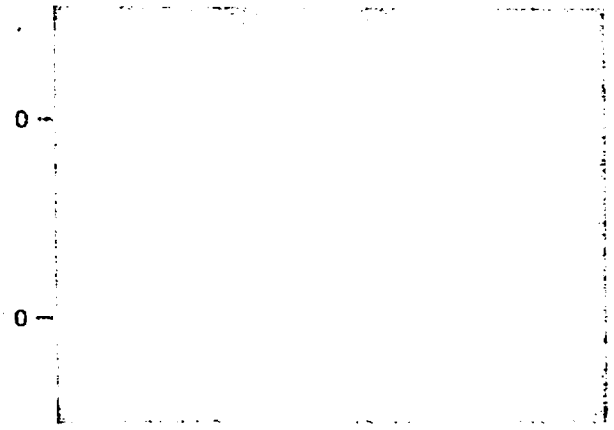



Photo 6.11.1-14
$I_I$ = .5 a/d
$V_I$ = 500 mv/d
2 ms/d

Photo 6.11.1-15
$I_I$ = .5 a/d
$V_I$ = 500 mv/d
2 ms/d

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

# DATA SHEET

Date 11-29-72

Part No. CBRM No. 037

Test Trickle Charger Turn On

Photo 6.11.1-16
$I_I$ = .5 a/d
$V_I$ = 200 mv/d
1 ms/d

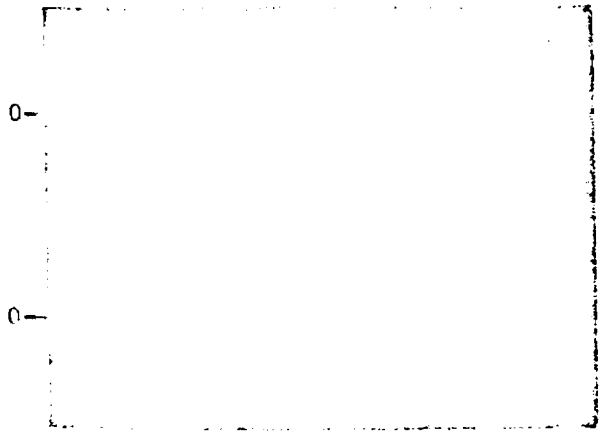



Photo 6.11.1-17
$I_o$ = .5 a/d
$V_o$ = 100 mv/d

Federal Systems Division
Space Systems Center,
Huntsville, Alabama

# DATA SHEET

Date 11-29-72

mple _____ Part No. CBRM No. 037

rial No. _____ Test Trickle Charger Negative Transients Turn Off

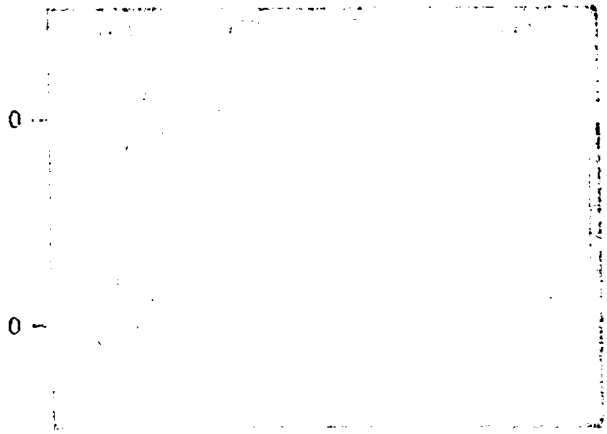



Photo 6.11.1-18
$I_o$ = 5 a/d
$V_o$ = 100 mv/d
5 ms/d

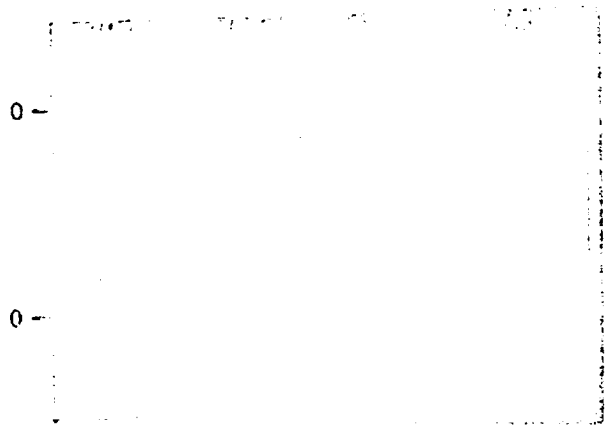



Photo 6.11.1-19
$I_o$ = .5 a/d
$V_o$ = 100 mv/d
2 ms/d

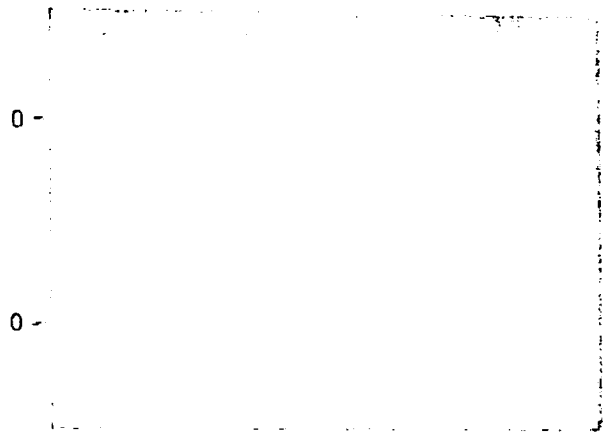
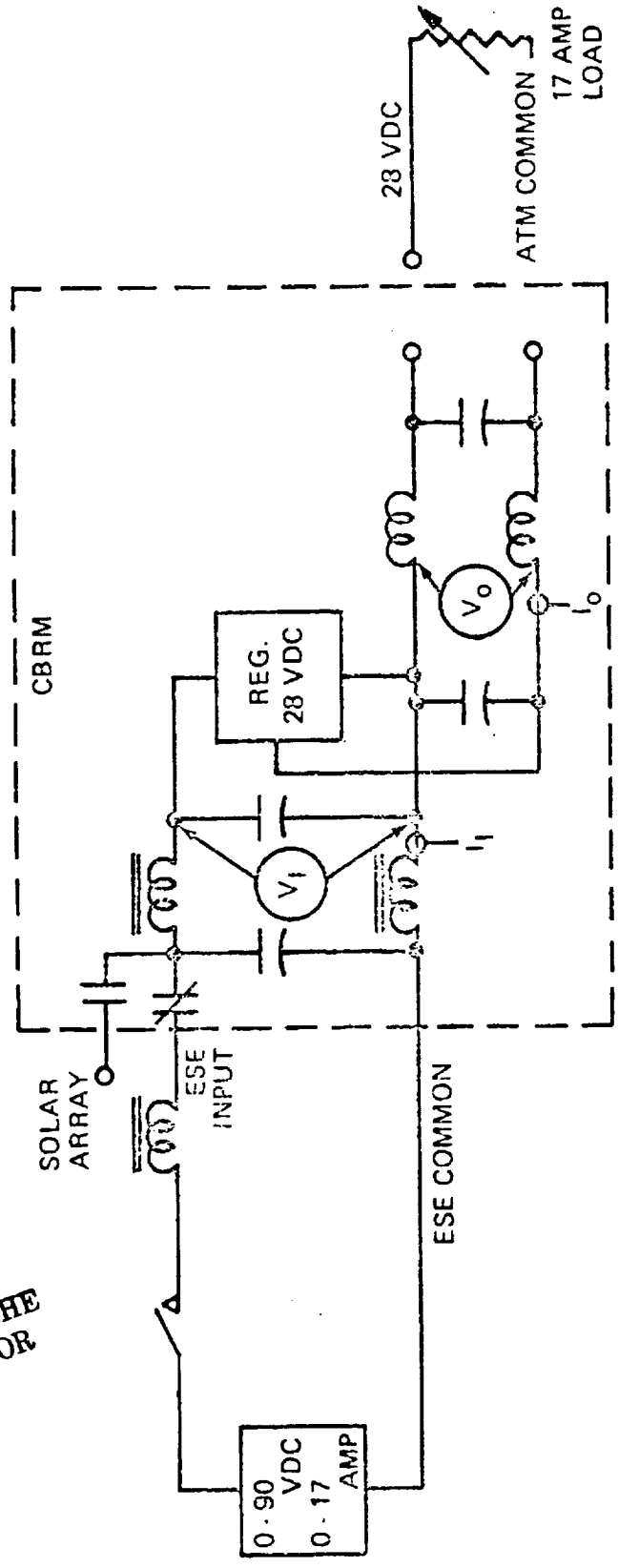



Photo 6.11.1-20
$I_o$ = .5 a/d
$V_o$ = 100 mv/d
1 ms/d




REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

*Figure 6.11.1-2. CBRM Power Line Transient Test Schematic.*

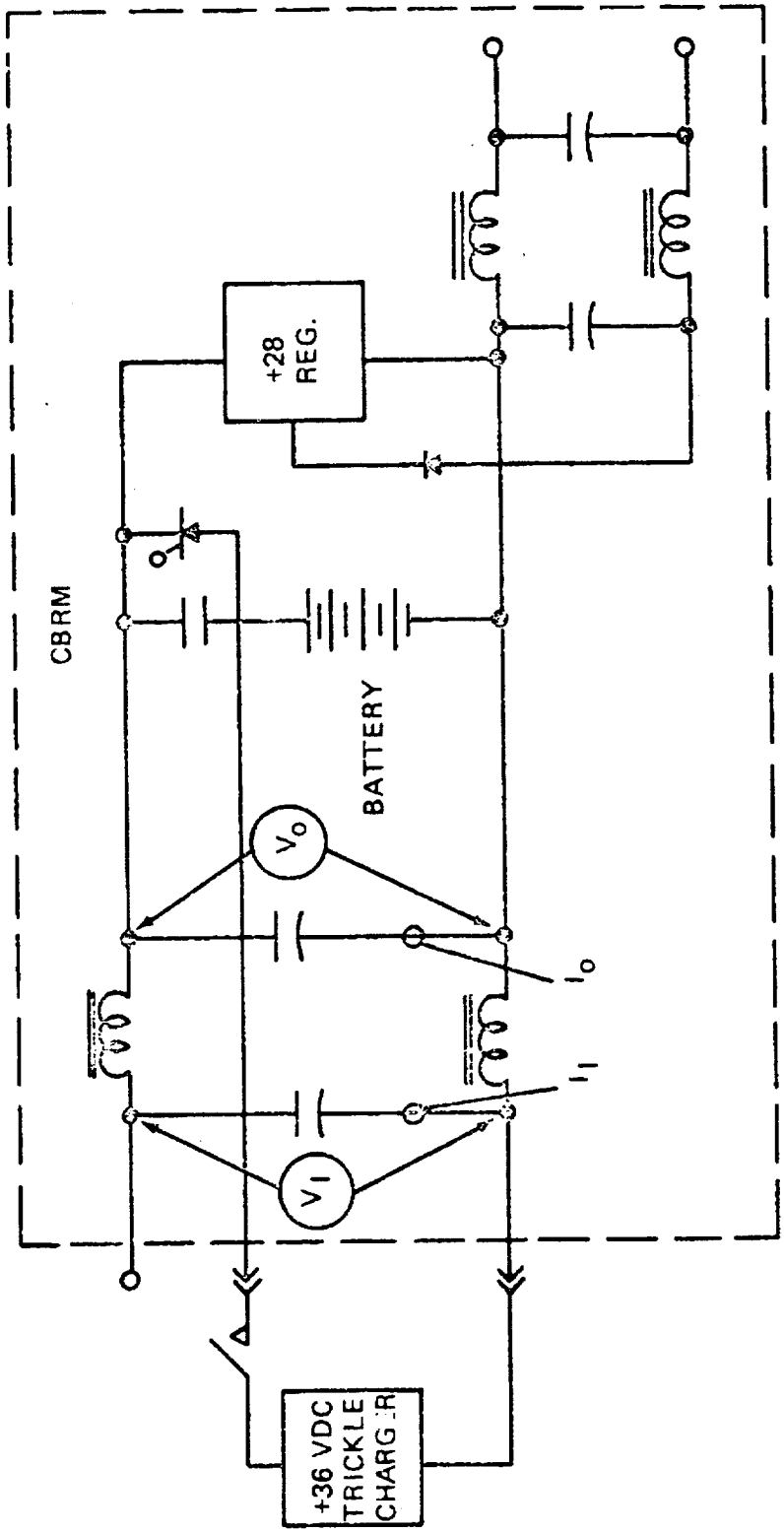



*Figure 6.11.1-3. Trickle Charger Transient Test Schematic.*

Upon ramping SAS voltage up and down, no negative transients were observed.

The trickle charger was turned on and off while holding SAS 15 volts on, and no negative transients were observed.

Table 6.11.2.1-1 gives a summary of transients recorded during the breadboard tests.

### 6.11.2.2 Conclusions

Negative transients are possible at the CBRM input and at the CBRM input filter during normal ground support operation of the CBRM. The undesirable condition of reverse bias on the input filter capacitors is the consequence of sudden turn on/off of either SAS 15 volts or trickle charger with SAS input at 0 volt.

Elimination of negative input transients can be accomplished by ramping SAS voltage up and down and turning trickle charger on and off only with SAS 15 volts applied.

### 6.11.2.3 Details

Modifications were made on the breadboard in order to simulate more closely the conditions at KSC. A Kepco power supply was installed for the trickle charge input at the deadface relay. A toggle switch was installed in the SAS power supply line. A breakout box was used between the CBRM and the input cable. In order to apply input power at J1/T (ESE) and J1/G (SAS) the input pin was switched in the cable between tests. The cable lengths at the breadboard were approximately 60 feet (18 meters) for ESE power and approximately 80 feet (24 meters) for the trickle charger power supply. Figure 6.11.2.3-1 describes the Breadboard test setup.

A peak recording voltmeter was used to monitor negative transients on the CBRM input lines at the SEE and at the CBRM during turn on and turn off (see Tables 6.11.2.3-1 and 6.11.2.3-2).

A Tektronix 564 oscilloscope with camera was set to record voltage and current at the input capacitors ($V_I$, $I_I$) and output capacitors ($V_O$, $I_O$) in the input filter of the CBRM.

A Biomation 610B transient recorder was used to detect negative transients at the input of the CBRM. The transients were displayed and photographed on a Tektronix 547 oscilloscope.

A second Biomation 610B transient recorder was used to detect negative bias on the input capacitors of the input filter. The transients were displayed and photographed on a Tektronix 547 oscilloscope.

Transients photographed during these tests are shown in Photographs 6.11.2.3-1 thru 6.11.2.3-18.

*Table 6.11.2.1-1. CBRM Transient Data.*

| CBRM TRANSIENT DATA | | | | |
|---|---|---|---|---|
| Action | Negative Transients (Volts) | | | |
| | ESE Output* | CBRM Input | $V_I$ | $V_O$ |
| Trickle Charger On-ESE Pins G&P | 1.25 | 1.00 | 0.95 | 0.18 |
| Trickle Charger On-ESE Pins G&P | 1.80 | 0.24 | 0.20 | 0.07 |
| Trickle Charger On-ESE Pins T&P | 1.60 | 2.30 | 0.90 | 0.12 |
| Trickle Charger Off-ESE Pins T&P | 2.30 | 1.80 | 0.14 | 0.04 |
| SAS 15 volts On-ESE Pins G&P | Not Recorded | 2.20 | 0.90 | 0.17 |
| SAS 15 volts On-ESE Pins T&P | 100 | 2.50 | 0.80 | 0.16 |

*ESE data recorded by McDonnell Douglas (East) personnel from Peak Recording Voltmeter (See Tables 6.11.2.3-2 and 6.11.2.3-3)

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

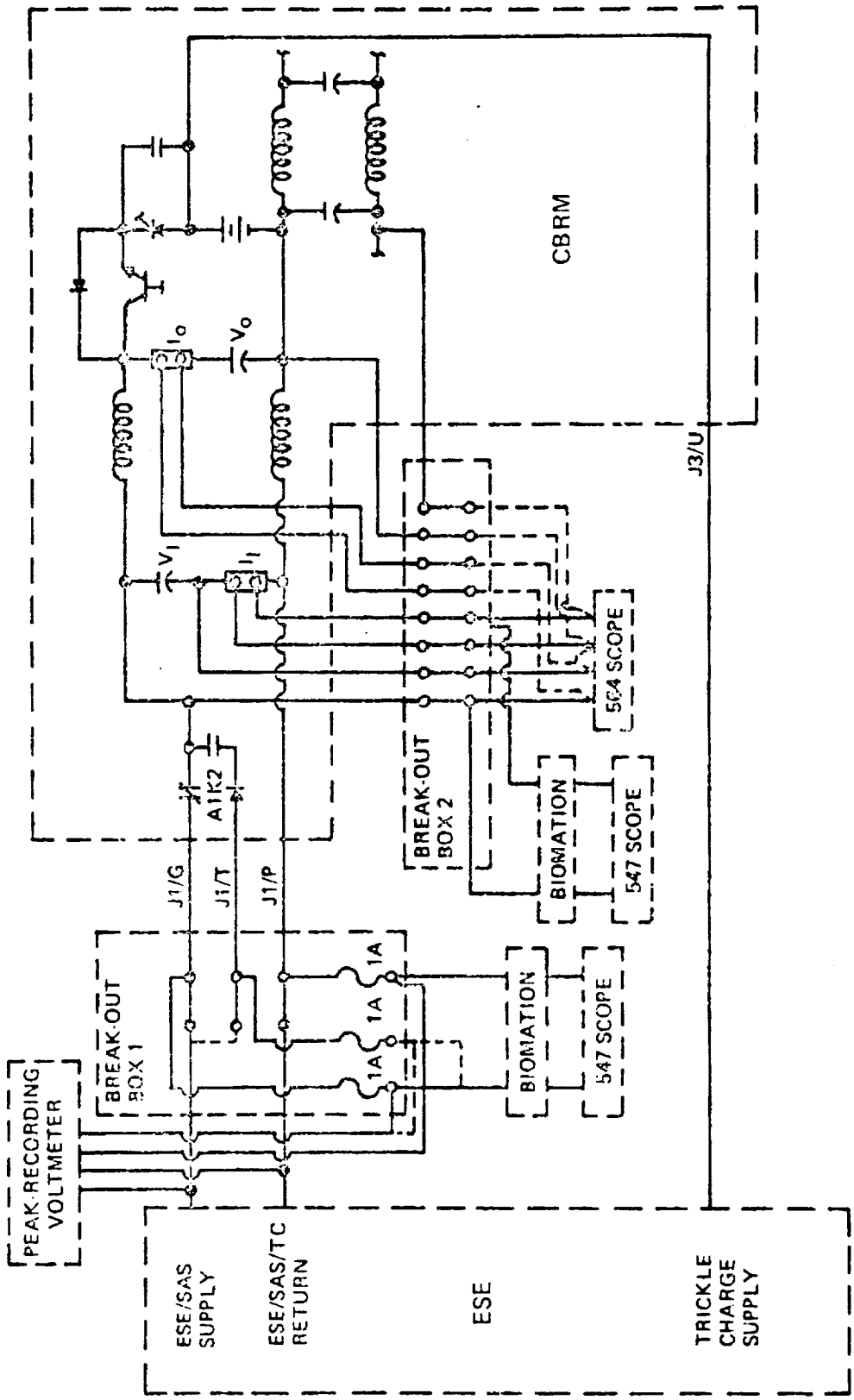



*Figure 6.11.2.3-1. Schematic of ATM Breadboard Test Setup.*

Table 6.11.2.3-1. Trickle Charger Transient

| | VOLTMETER RESPONSE | | | | |
|---|---|---|---|---|---|
| Configuration | 1 microsecond | 10 microsecond | 100 microsecond | 1 millisecond | 50 nanoseconds |
| Switching P.S. AC (G-P) | | | | | |
| On | 0.7 1.35 0.7 0.9 | 0.6 0.4 | | | 1 1.7 |
| Off | 1.7 2.4 2.4 2.2 | | | | 2.55 |
| At CBRM Switching D.F. Relay (G-P) | | | | | |
| On | 0.12 0.9 1.7 0.8 | | | | |
| Off | 1.85 1.05 2.0 0.8 | | | | |
| Switching D.F. Relay (G-P) | | | | | |
| On | 1.2 1.2 1.15 0.95 1.1 1.25 | 0.92 0.85 0.9 | 0.10 0.15 0.10 | 0.05 0.05 | |
| Off | 0.95 1.0 1.8 1.2 1.75 1.35 | 1.3 1.25 1.3 | 0.9 0.9 0.9 | 0.6 0.6 | |
| Switching D.F. Relay (T-P) | | | | | |
| On | 1.4 1.4 1.4 1.4 1.5 1.6 1.55 | | | | |
| Off | 2.0 1.75 1.7 1.8 1.7 1.8 2.0 | | | | |
| On | 1.5 1.55 1.52 1.52 1.5 | | | | |
| Off | 1.7 1.9 1.9 2.3 1.9 | | | | |

Note: All readings are negative volts.
D.F. = Dead Face

*Table 6.11.2.3-2. Transient at SAS Power On and Off*

| Configuration | VOLTMETER RESPONSE | | | | |
|---|---|---|---|---|---|
| | 1 microsecond | 10 microsecond | 100 microsecond | 1 millisecond | 50 nanoseconds |
| Switching Power Supply | | | | | |
| On | 0.6 | | | | |
| Off | 0 | | | | |
| Switching with Added Switch | | | | | |
| On | 30 15 19 30<br>22.5 17 75 | 5 3.5 5 | 3.0 0.5 | | 35 32 44 |
| Off | 1 0 0 0 0<br>0 0 | 0 0 0 | 0 0 | | 0 0 0 |
| On | 100 100 95 | | | | |
| Off | 0 0 0 | | | | |

(+ 15 V Ramp)
Pins T-P
All readings are in negative volts.

# DATA SHEET

Date _____

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test Trickle Charger On with ESE on Pins G&P

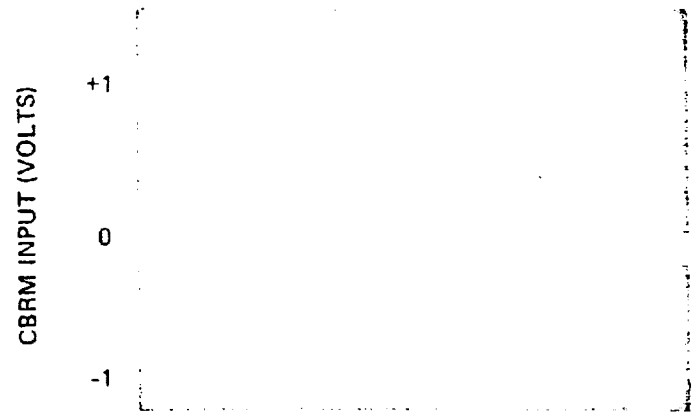



Photo 6.11.2.3-1

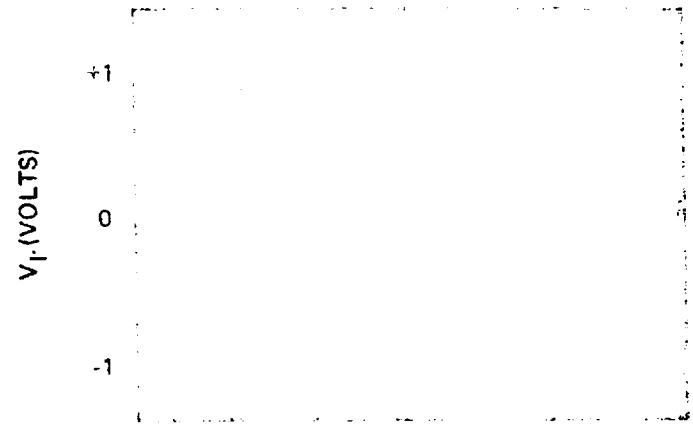



Photo 6.11.2.3-2

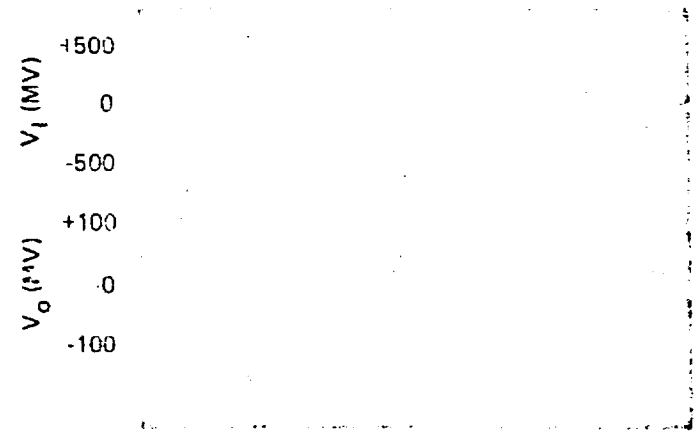



Photo 6.11.2.3-3

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

# DATA SHEET

Date _____

Part No. CBRM No. 037

Test Trickle Charger Off with ESE on Pins G&P

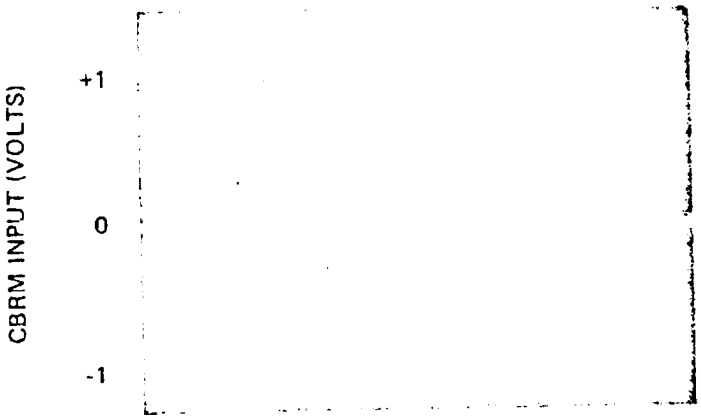



Photo 6.11.2.3-4

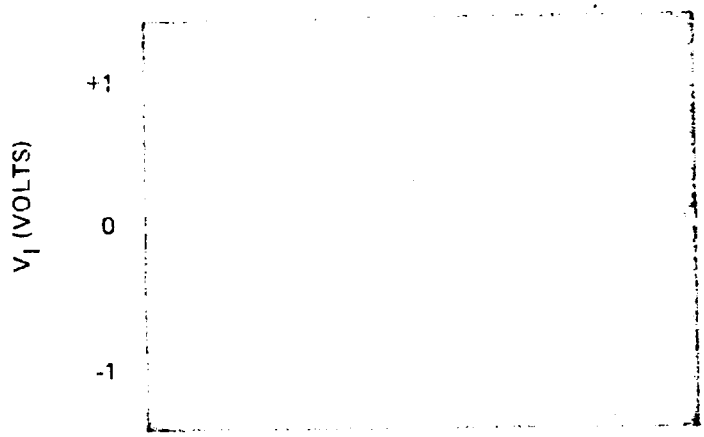



Photo 6.11.2.3-5

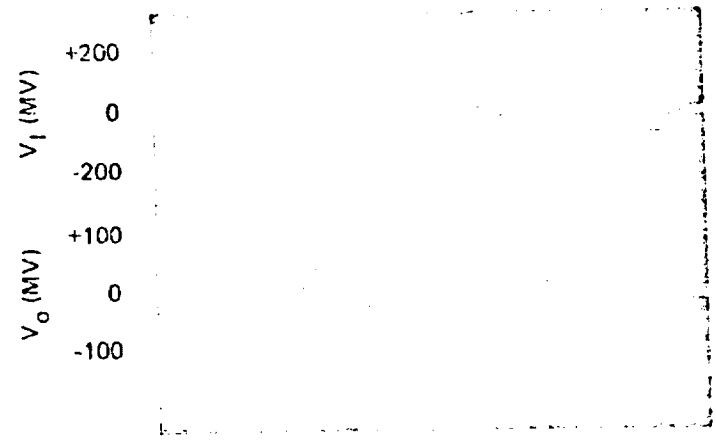



Photo 6.11.2.3-6

# DATA SHEET

Date _____

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test Trickle Charger On with ESE on Pins T&P

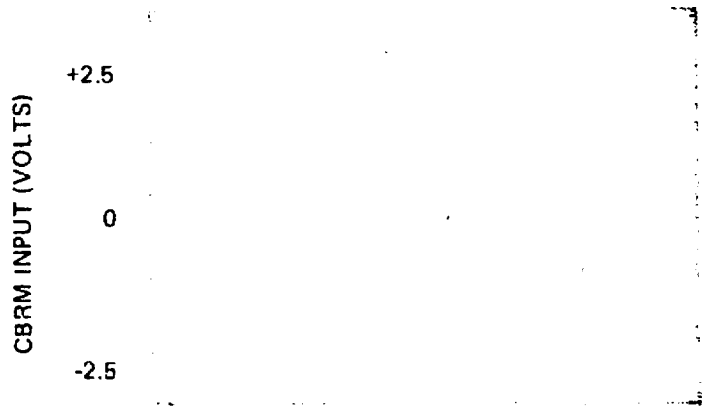



Photo 6.11.2.3-7

Photo 6.11.2.3-8

Photo 6.11.2.3-9

# DATA SHEET

Date _____

Part No. CBRM No. 037

Test Trickle Charger Off with ESE on Pins T&P

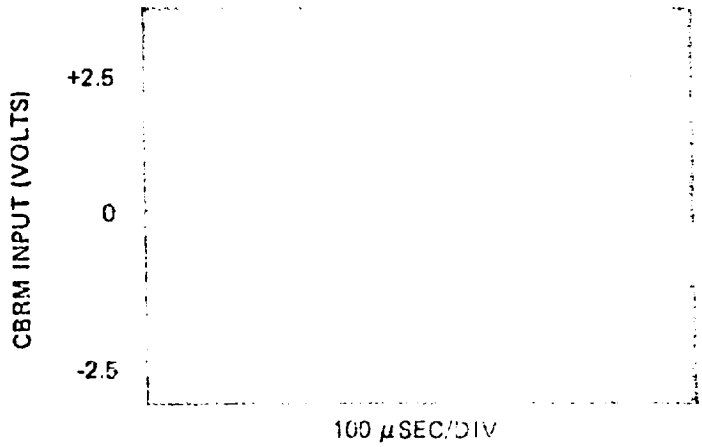



Photo 6.11.2.3-10

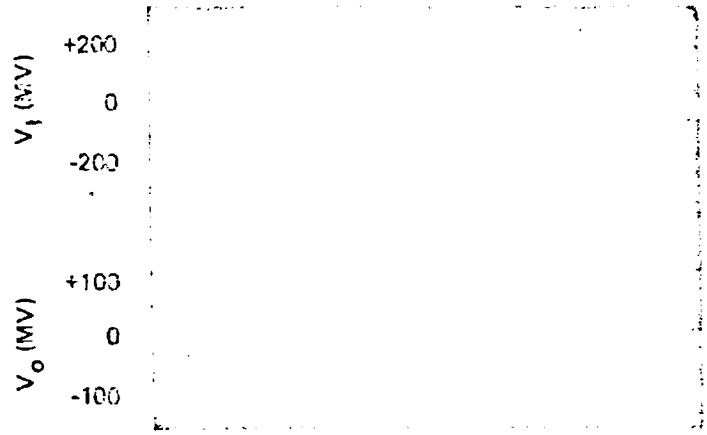



Photo 6.11.2.3-11

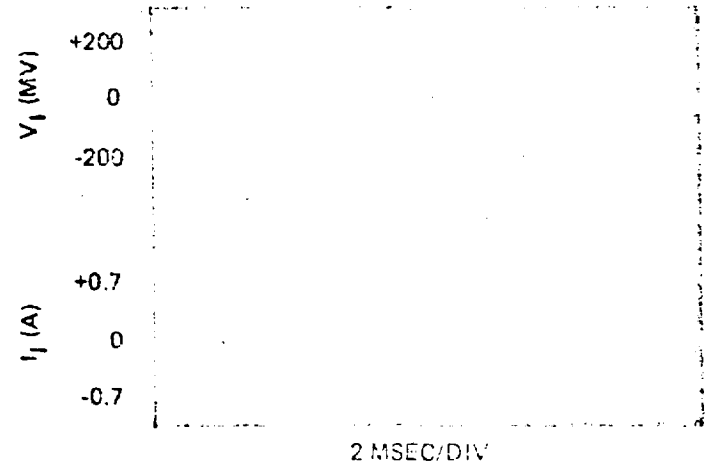



Photo 6.11.2.3-12

# DATA SHEET

Date _____

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test Trickle Charger ESE Pins on T&P

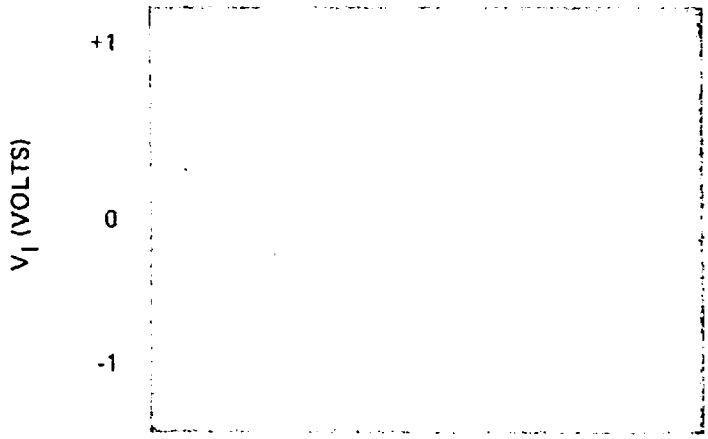



Photo 6.11.2.3-13
ESE Pins T&P
Trickle Charger Off

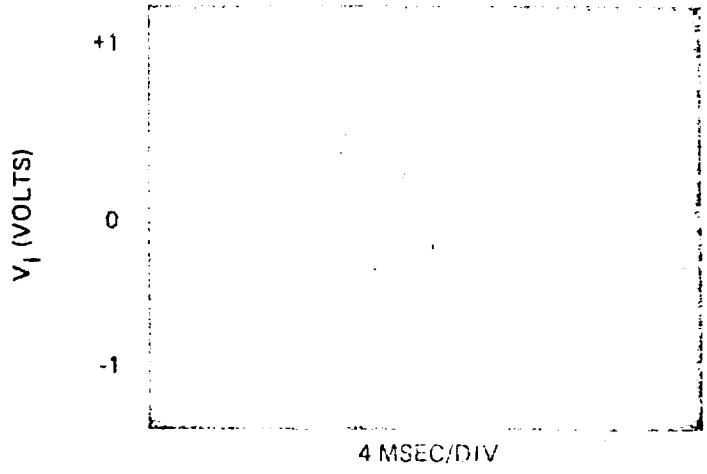



Photo 6.11.2.3-14
ESE Pins T&P
Trickle Charger On

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

# DATA SHEET

Date _____

Part No. CBRM No. 037

Test SAS 15 Volts On with ESE on Pins G&P

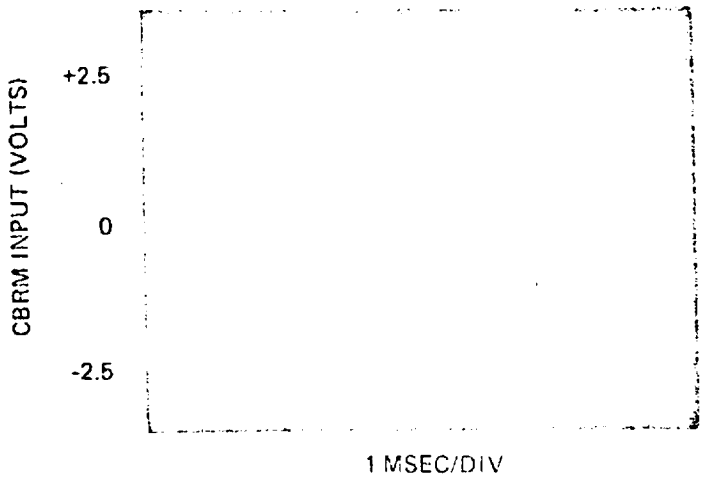



Photo 6.11.2.3-15

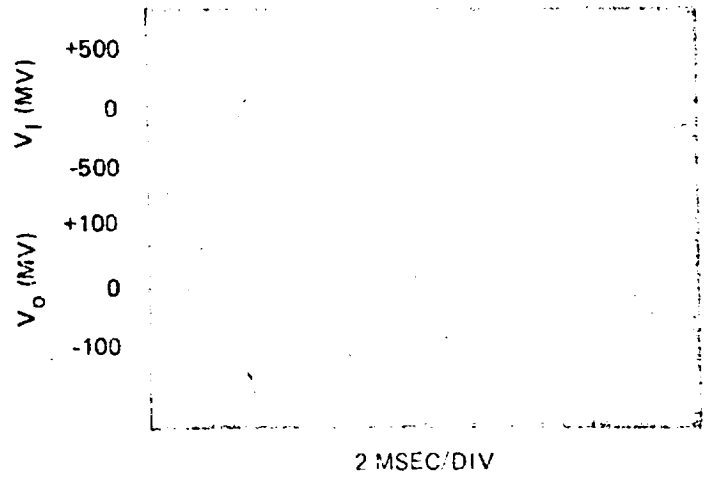



Photo 6.11.2.3-16

# DATA SHEET

Date _____

Sample _____ Part No. CBRM No. 037

Serial No. _____ Test SAS 15 Volts On with ESE on Pins T&P

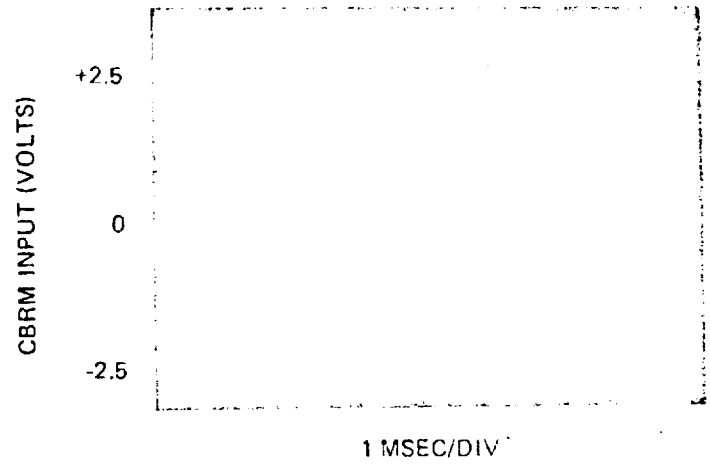



Photo 6.11.2.3-17

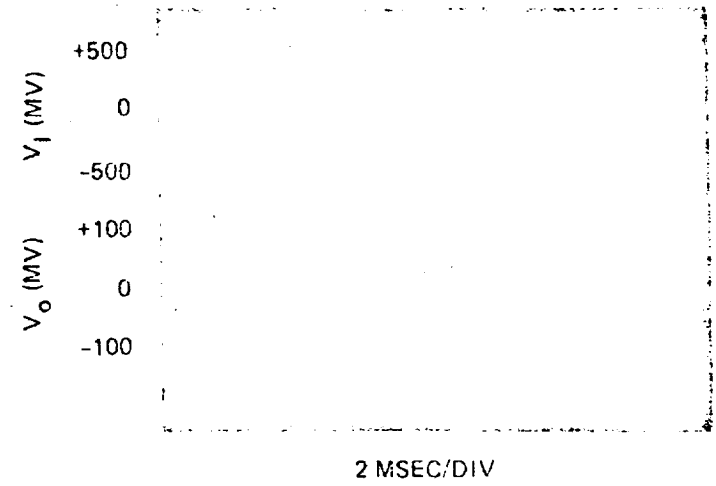



Photo 6.11.2.3-18

## 6.12 CHARACTERIZATION OF CAPACITORS REMOVED FROM FLIGHT CBRMs

### 6.12.1 Summary

Twenty-eight capacitors from eight different flight CBRM output filters were subjected to elemetrical test and teardown inspection. A total of 168 elements from these capacitors were opened and visually inspected. Of the elements examined, 153 had no evidence of silver on the slug, and 15 had indication of "slight" silvering on the slug. (See Figure 6.12.1-1). All units were found to have dc leakage characteristics within specified limits.

In comparison, four capacitors from relatively new CBRM input filters were examined. Four elements from each capacitor were inspected. Nine of these elements had no evidence of silver; however, three exhibited "slight" silver and four exhibited "light" silver deposits on the anodes. It was also noted that on failed CBRM input capacitors, the degree of silver was in the range of "medium" or "gross".

### 6.12.2 Conclusion

The application of tantalum wet slug capacitors in the flight CBRM output filter does not appear to be detrimental to the capacitors. Electrical test and visual observations revealed no anomalies in these devices.

### 6.12.3 Details

During the investigation of the CBRM capacitor failures, it was concluded that reverse bias in conjunction with near rated forward voltage was the most probable failure cause. All failures had occurred on the input filter operating from 65 to 90 volts. However, the same capacitors operating in the output filter (35 volts maximum) had never experienced a failure. The decision at that time was to rework the flight units, utilizing tantalum foil capacitors in the input filter. The foils selected have a 12% higher working voltage and can tolerate some reverse bias. Physically the input filter capacitors and the output filter capacitors are mounted (potted) in common cavities within the CBRM. Replacing the input capacitors made it necessary to also replace output capacitors. The primary problem at this time was the lack of foil assets. There were only enough new foils on hand for the input filter. If the output capacitors also were to be changed to foils, a decision was necessary. This decision was either to use foils that a vendor had in stock and were five years old, or slip schedule and have new foils made. It was decided to characterize or perform a teardown inspection of the output capacitors as they were removed from the flight CBRMs. If the testing and teardown of these units found no anomalies, then the output capacitors would be replaced with new tantalum wet slugs which were available in stock.

LEGEND:
S/N – SERIAL NUMBER
CAPS – CAPACITORS
ELEM – ELEMENTS
EX – EXAMINED
AFF – AFFECTED
* – SILVER PRESENCE
1 – SLIGHT/TRACE
2 – LIGHT
3 – MEDIUM
4 – GROSS

| | CAPS | ELEM | SILVER PRESENCE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S/N | EX / AFF | EX | SLUG | | | | ELECTROLYTE | | | | CASE | | | |
| | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 50 | 2 / 0 | 8 | | | | | | | | | | | | |
| 52 | 2 / 1 | 8 | 1 | | | | | | | | | | | |
| 35 | 5 / 2 | 40 | 3 | | | | | 4 | | | | 5 | | |
| 40 | 5 / 4 | 40 | 6 | | | | | 3 | | | 2 | 2 | | |
| 33 | 4 / 2 | 24 | 3 | | | | 1 | | | | 4 | 3 | 1 | |
| 54 | 5 / 3 | 28 | 2 | | | | | 1 | | | 1 | 1 | | |
| 47 | 3 / 0 | 12 | | | | | | 3 | | | | | | |
| 56 | 2 / 0 | 8 | | | | | | | | | | | | |
| TOTALS | 28 / 12 | 168 | 15 | | | | 1 | 11 | | | 7 | 11 | 1 | |

*Figure 6.12.1-1. Characterization of Flight CBRM Output Filter Capacitors.*

Note: Continuing investigation of the CBRM circuits later verified the application of reverse voltages to the input filter capacitors but not to the output filter capacitors.

The capacitors to be inspected were removed from the flight CBRMs by Brown Engineering. Since the capacitors were hard potted in the CBRM, some physical damage to the capacitors was encountered during capacitor removal. This damage was primarily to the header and terminations of each capacitor assembly.

In order to eliminate shorted terminals to case during the teardown and characterization, the header was cut off each capacitor. Electrical contact was made to the internal riser wires, and leakage was measured at rated voltage. The metal can was then removed by grinding, leaving the elements in a hard potted module configuration. The modules were subsequently "depotted" (potting dissolved) and the individual elements were removed for machining.

Note: If any capacitor assembly exhibited an out-of-tolerance leakage, then the leakage on each individual element in the assembly was measured.

The machining consisted of cutting a groove down one side of the element, across the bottom and back up the opposite side. The depth of the groove was controlled so as to leave ≈1 mil of the case wall intact. The case was then carefully pried open, much like a clam shell, and immediately subjected to internal visual examination.

To correlate the visual results a visual aid was developed (reference Figure 2.2-1). This visual aid categorized the appearance of silver on the slug or anode into four areas: Slight, Light, Medium or Gross. With this visual aid variations due to inspection were reduced. Also, data assessment was more manageable.

NTIS does not permit return of items for credit or refund. A replacement will be provided if an error is made in filling your order, if the item was received in damaged condition, or if the item is defective.

# *Reproduced by NTIS*

National Technical Information Service
Springfield, VA 22161

***This report was printed specifically for your order from nearly 3 million titles available in our collection.***

For economy and efficiency, NTIS does not maintain stock of its vast collection of technical reports. Rather, most documents are printed for each order. Documents that are not in electronic format are reproduced from master archival copies and are the best possible reproductions available. If you have any questions concerning this document or any order you have placed with NTIS, please call our Customer Service Department at (703) 605-6050.

## About NTIS

NTIS collects scientific, technical, engineering, and business related information — then organizes, maintains, and disseminates that information in a variety of formats — from microfiche to online services. The NTIS collection of nearly 3 million titles includes reports describing research conducted or sponsored by federal agencies and their contractors; statistical and business information; U.S. military publications; multimedia/training products; computer software and electronic databases developed by federal agencies; training tools; and technical reports prepared by research organizations worldwide. Approximately 100,000 *new* titles are added and indexed into the NTIS collection annually.

For more information about NTIS products and services, call NTIS at 1-800-553-NTIS (6847) or (703) 605-6000 and request the free *NTIS Products Catalog,* PR-827LPG, or visit the NTIS Web site **http://www.ntis.gov**.

***NTIS***
***Your indispensable resource for government-sponsored information—U.S. and worldwide***

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 605-6000