Active

Project #: E-21-T08   Cost share #: E-21-394   Rev #: 0
Center # : R6583-T08   Center shr #: F6583-T08   OCA file #: 128
                                                             Work type : RES
Contract#: F30602-88-D-0025-0008   Mod #:   Document : TO
Prime   #:   Contract entity: GTRC

Subprojects ? : N
Main project #:

Project unit: EE   Unit code: 02.010.118
Project director(s):
    PARIS D T   EE

Sponsor/division names: AIR FORCE   / GRIFFISS AFB, NY
Sponsor/division codes: 104   / 023

Award period: 880930   to   890731   (performance)   890831   (reports)

Sponsor amount   New this change   Total to date
    Contract value   98,374.00   98,374.00
    Funded   98,374.00   98,374.00
Cost sharing amount   661.00

Does subcontracting plan apply ?: Y

Title: POWER SUPPLY FAULT TOLERANT RELIABILITY STUDY

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg   894-4820

  Sponsor technical contact   Sponsor issuing office

  SEYMORE MORRIS   GARY SLOPKA/PKRM
  (315)330-7060   (315)330-2308
  DEPARTMENT OF THE AIR FORCE   ROME AIR DEVELOPMENT CENTER
  ROME AIR DEVELOPMENT CENTER / RBER   DIRECTORATE OF CONTRACTING (PKRM)
  GRIFFISS AFB, NY 13441-5700   GRIFFISS AFB, NY 13441-5700

Security class (U,C,S,TS) : U   ONR resident rep. is ACO (Y/N): Y
Defense priority rating   : DO-A7   GOVT supplemental sheet
Equipment title vests with: Sponsor   GIT
  NONE PROPOSED OR ANTICIPATED.

Administrative comments -
  DELIVERY ORDER FULLY FUNDS TASK N-8-5538 (MCDONNELL AIRCRAFT COMPANY).
  $10,269 COST-SHARING REQUIRED BY SUBCONTRACTOR.
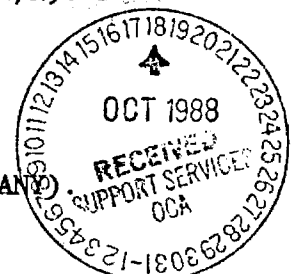
GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 03/07/90
Original Closeout Started ********

Project No. E-21-T08_____ Center No. R6583-T08_____

Project Director JOY E B_____ School/Lab EE_____

Sponsor AIR FORCE/GRIFFISS AFB, NY_____

Contract/Grant No. F30602-88-D-0025-0008_____ Contract Entity GTRC

Prime Contract No. _____

Title POWER SUPPLY FAULT TOLERANT RELIABILITY STUDY_____

Effective Completion Date 900216 (Performance) 900316 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	_____
Final Report of Inventions and/or Subcontracts	Y	_____
Government Property Inventory & Related Certificate	Y	_____
Classified Material Certificate	Y	_____
Release and Assignment	Y	_____
Other _____	N	_____

Subproject Under Main Project No. _____

Continues Project No. _____

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	Y
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
OCA/CSD	N
Other _____	N
_____	N

NOTE: Final Questionnaire sent to PDPI.

McDonnell Aircraft Company

GIT-346-18
16 March 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of First R & D Status Report
CLIN Ident Exhibit: 0002
PIIN: F30602-88-D-0025
ELIN: A001
Task Assignment Number: N-8-5538
Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the first submittal of the R & D Status Report as required by above contract. As required by Article II, paragraph C. of the enclosure (Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are sent to you. One additional reproducible copy of this deliverable item is sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by McDonnell Aircraft Company that you will comply with the additional distribution requirements for this deliverable data item as set forth in the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March 1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional distribution of one copy each to RADC/RB and RADC/PKRM.

This report covers activity during the month of February 1989. Each succeeding report will cover the program activity of the previous calendar month.

We received a signed contract dated 15 February 1989. That date will be the official go-ahead date for this program.

An internal kickoff meeting was conducted with the following key program personnel:

> Wilson D. Yates III - Program Manager
> David A. Followell - Reliability
> John H. Johnson - Power Supply Design
> Jerry W. McCormack - Electronic Technology

A short biography of each individual is enclosed as Enclosure (1).

A program schedule (Enclosure 2) was developed and distributed to the above personnel. Each task of this study was assessed in detail, and notes made for discussion at the formal kickoff meeting scheduled at RADC, on 3 March 1989.

The following specific accomplishments for Tasks 1 and 2 were initiated:

1. Began collecting procurement specifications for MCAIR products to determine operating environment, electrical input specifications and output requirements.

2. Began collecting technical literature on transient protection schemes and good power supply design practices.

3. Began collecting MIL handbooks on good power supply design practices.

4. Began polling MDC electronic designers for information on design practices and transient protection schemes.

5. Began preparing the industry survey.

6. Prepared presentation material for the 3 March kickoff meeting to be conducted at RADC.

One concern was expressed by the key personnel which may impact this study. Task 3 requires equipment for this study be selected from the Joint Stars equipment list. This list must be provided by RADC. Tasks 1 and 2 may proceed without the Joint Stars equipment list, however, Task 3 and beyond cannot begin until MCAIR has been provided with the equipment list. This will be addressed at the March kickoff meeting at RADC.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosures: (1) Key Personnel Biographies
            (2) Program Schedule

KEY PERSONNEL BIOGRAPHIES

WILSON D. YATES III, LEAD ENGINEER - RELIABILITY

- o PRESENTLY RELIABILITY MANAGER OF R&D ACTIVITIES
  - RELIABILITY ATTAINMENT IRAD
  - WARRANTY RESEARCH
  - POWER SUPPLY CRAD

- o PAST EXPERIENCE
  - METS PROJECT RELIABILITY ENGINEER
  - MAINTAINABILITY ENGINEER AT LTV
  - RETIRED AIR FORCE MAINTENANCE OFFICER

- o EDUCATION
  - B.S., MECHANICAL ENGINEERING
  - M.S., ENGINEERING MANAGEMENT (PRESENTLY ENROLLED)

DAVID A. FOLLOWELL, SENIOR ENGINEER - RELIABILITY

- o PRESENTLY PRINCIPAL INVESTIGATOR FOR RELIABILITY R&D
  - DEVELOPED FIBER OPTICS R&M HANDBOOK
  - RESEARCHED MARGINAL CHECKING OF ELECTRICAL CABLES USING TIME DOMAIN REFLECTOMETRY TECHNIQUES
  - P.I. FOR PS CRAD

- o PAST EXPERIENCE
  - F/A-18 PROJECT RELIABILITY ENGINEER
  - AIRCRAFT MECHANIC/ELECTRICIAN

- o EDUCATION
  - B.S., ELECTRICAL ENGINEERING

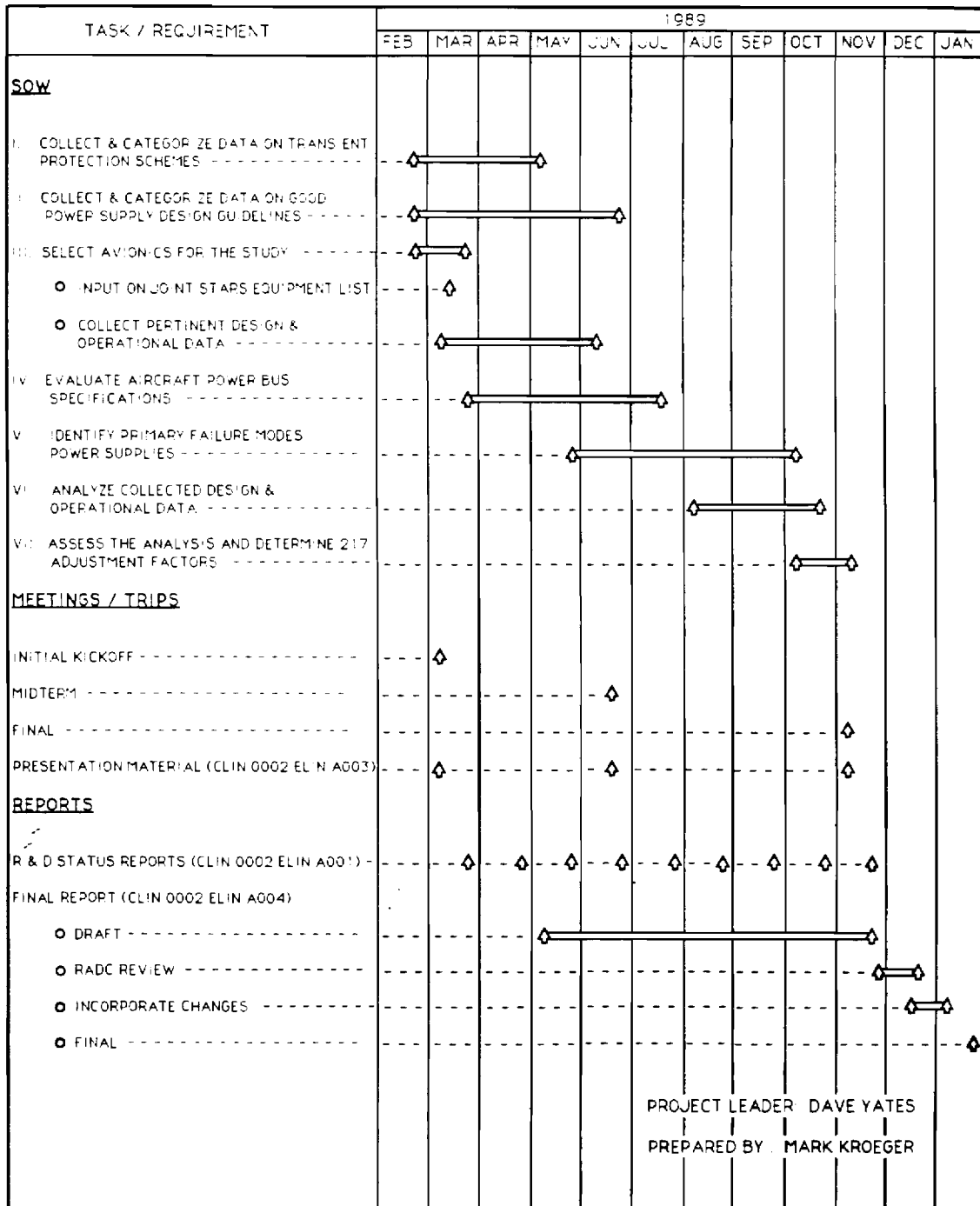## KEY PERSONNEL BIOGRAPHIES

JOHN H. JOHNSON, TECHNICAL SPECIALIST - ELECTRONIC DESIGN AND DEVELOPMENT

- o PRESENTLY SUPERVISOR IN POWER SUPPLY DESIGN GROUP

- o PAST EXPERIENCE
    - TWENTY YEARS EXPERIENCE WITH POWER SUPPLY DESIGN AND DEVELOPMENT; THIRTY-SEVEN YEARS IN AEROSPACE ELECTRONICS
    - DESIGN AND DEVELOPMENT OF OVER 50 POWER SUPPLIES
        - CRUISE MISSILE
        - ADVANCED HARPOON
        - NASP
        - SKYLAB/AIRLOCK
        - F-15
        - F/A-18
        - F-4

JERRY W. McCORMACK, SENIOR TECHNICAL SPECIALIST - ELECTRONIC TECHNOLOGY

- o PRESENTLY PRINCIPAL INVESTIGATOR FOR"
    - ELECTRO-MAGNETIC COMPATIBILITY REQUIREMENTS FOR COMMON MODULE ARCHITECTURE
    - MICROWAVE COUPLING TO AIRCRAFT
    - INTERACTION OF LIGHTNING AND COMPOSITES

- o PAST EXPERIENCE
    - ELECTRO-MAGNETIC PULSE TESTING AND ANALYSIS FOR F/A-18
    - RADIO FREQUENCY (RF) COMPATIBILITY PROGRAM FOR F-15

- o EDUCATION
    - M.S., ELECTRICAL ENGINEERING
    - NAVAL POSTGRADUATE PROGRAM

POWER SUPPLY FAULT TOLERANT RELIABILITY STUDY

TASK / REQUIREMENT	1989											
	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN

SOW

I. COLLECT & CATEGORIZE DATA ON TRANSIENT PROTECTION SCHEMES

II. COLLECT & CATEGORIZE DATA ON GOOD POWER SUPPLY DESIGN GUIDELINES

III. SELECT AVIONICS FOR THE STUDY

   O INPUT ON JOINT STARS EQUIPMENT LIST

   O COLLECT PERTINENT DESIGN & OPERATIONAL DATA

IV. EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS

V. IDENTIFY PRIMARY FAILURE MODES POWER SUPPLIES

VI. ANALYZE COLLECTED DESIGN & OPERATIONAL DATA

VII. ASSESS THE ANALYSIS AND DETERMINE 217 ADJUSTMENT FACTORS

MEETINGS / TRIPS

INITIAL KICKOFF

MIDTERM

FINAL

PRESENTATION MATERIAL (CLIN 0002 ELIN A003)

REPORTS

R & D STATUS REPORTS (CLIN 0002 ELIN A001)

FINAL REPORT (CLIN 0002 ELIN A004)

   O DRAFT

   O RADC REVIEW

   O INCORPORATE CHANGES

   O FINAL

PROJECT LEADER DAVE YATES

PREPARED BY MARK KROEGER

GIT-346-27
17 April 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
          CLIN Ident Exhibit: 0002
          PIIN: F30602-88-D-0025
          ELIN: A001
          Task Assignment Number: N-8-5538
          Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the second submittal of the R & D Status Report as required by above contract. As required by Article II, paragraph C. of the enclosure (Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are sent to you. One additional reproducible copy of this deliverable item is sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by McDonnell Aircraft Company that you will comply with the additional distribution requirements for this deliverable data item as set forth in the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March 1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occured during the month of March 1989:

    a. Submitted the February R & D Status Report.

    b. The project kick-off meeting was conducted at RADC on 3 March 1989. The presentation material (CDRL(DI-A-3024A/T) - CLIN Ident exhibit: 00002; ELIN: A003) was provided to the Air Force project manager at the kick-off meeting.

    c. We have contacted numerous manufacturers and requested information on transient protection characteristics and applications. Suppliers were very receptive and information from them has begun to arrive.

d. Continued collection of articles and books on transient protection and power supply design practices. Analysis and characterization of the collected information is underway.

e. Began assembling data into outline for rough draft. Transient protection information is subdivided into the following areas:

1. type of protection scheme
2. how does it work
3. performance characterisitcs
4. application
5. control, absorption, diversion

f. Refined the power supply manufacturer survey. Final form will be ready upon selection of the equipment to be evaluated under this study.

g. Enclosure (1) is the program schedule updated to reflect progress of effort and budget expendatures through the month of March 1989.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosures: (1) Program Schedule

External Copy: Seymour Morris RADC/RBER
               Griffiss AFB
               New York, 13441-5700

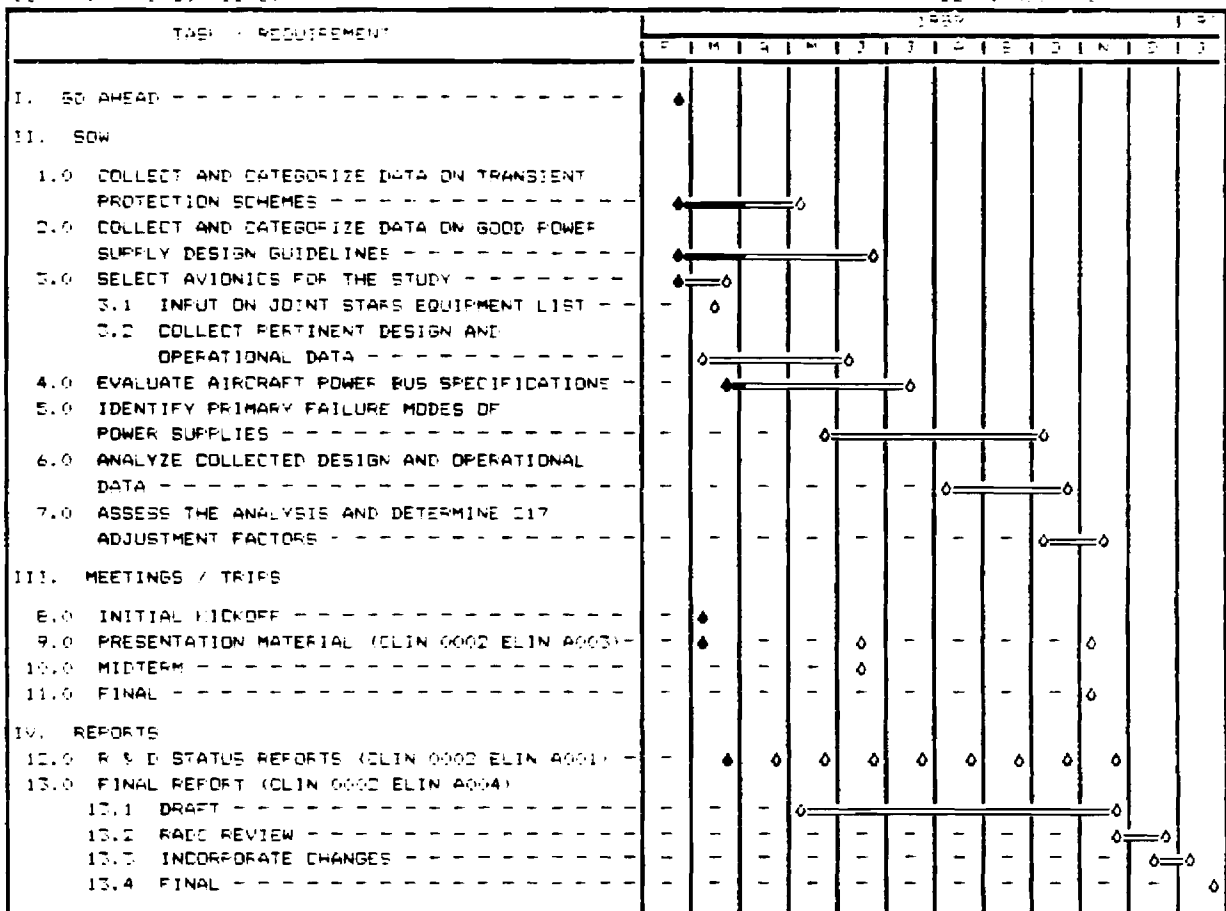   RADC/DAPT, Griffiss AFB
               New York, 13441-5700

POWER SUPPLY FAULT TOLERANT REL. STUDY

CONTRACT - F-01-T16-S1

TASK / REQUIREMENT	F	M	A	M	J	J	A	S	O	N	D	J

I. GO AHEAD -

II. SOW

1.0 COLLECT AND CATEGORIZE DATA ON TRANSIENT PROTECTION SCHEMES - - - - - - - - - - -

2.0 COLLECT AND CATEGORIZE DATA ON GOOD POWER SUPPLY DESIGN GUIDELINES - - - - - - - - -

3.0 SELECT AVIONICS FOR THE STUDY - - - - - - -
    3.1 INPUT ON JOINT STARS EQUIPMENT LIST - -
    3.2 COLLECT PERTINENT DESIGN AND OPERATIONAL DATA - - - - - - - - - -

4.0 EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS -

5.0 IDENTIFY PRIMARY FAILURE MODES OF POWER SUPPLIES - - - - - - - - - - -

6.0 ANALYZE COLLECTED DESIGN AND OPERATIONAL DATA - - - - - - - - - - - - - - -

7.0 ASSESS THE ANALYSIS AND DETERMINE C17 ADJUSTMENT FACTORS - - - - - - - - - - -

III. MEETINGS / TRIPS

8.0 INITIAL KICKOFF - - - - - - - - - - - - - -

9.0 PRESENTATION MATERIAL (CLIN 0002 ELIN A003) -

10.0 MIDTERM - - - - - - - - - - - - - - - - -

11.0 FINAL - - - - - - - - - - - - - - - - - -

IV. REPORTS

12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001) -

13.0 FINAL REPORT (CLIN 0002 ELIN A004)
    13.1 DRAFT - - - - - - - - - - - - - - - - -
    13.2 RADC REVIEW - - - - - - - - - - - - - -
    13.3 INCORPORATE CHANGES - - - - - - - - - -
    13.4 FINAL - - - - - - - - - - - - - - - - -

— LEGEND —

/═══/ SCHEDULED TIME SPAN
◆═══/ ACTUAL PROGRESS
/ SCHEDULED EVENT
◆ ACTUAL EVENT
△ RESCHEDULED EVENT
▲ ACTUAL RESCHEDULED EVENT
    BUDGET
    ACI (ACTUAL COSTS INCURRED)

CUSTOMER COST $ 92,422
COST SHARE   10,220
TOTAL BUDGET $102,692
FEE
TOTAL VALUE $102,692

	CUM TO DATE -		CURRENT -	
	BUDGET	$ 17,778	BAC	$ 102,692
	ACTUALS	$ 13,580	EAC	$ 102,692

CUM DOLLARS (X1000): 110 100 90 80 70 60 50 40 30 20 10 0

	F	M	A	M	J	J	A	S	O	N	D	J
BASELINE STAFFING	0.9	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	0.0
ACTUAL STAFFING	0.2	0.9										
ETC STAFFING		1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.0	0.7	0.3	

NOTES —

1. TASKS 3.0 - 3.2 ARE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED FROM THE CUSTOMER. THIS TASK WILL BE SHIFTED UPON RECEIPT OF THE LIST. NO END DATE CHANGES ARE ANTICIPATED. (APR)

2. STAFFING OF 0.3 MAN MONTHS IS EXPECTED TO BE SHIFTED FROM DEC. 89 TO JAN. 90 (VIA A BCR) TO ACCOMODATE THE ALLOWABLE TIME TO PUBLISH THE FINAL REPORT. (APR)

STATUS THROUGH MARCH, 1989

PROGRAM MANAGER   W. D. YATES
PLANNER   M. S. KROEGER

GIT-346-33
10 May 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
CLIN Ident Exhibit: 0002
PIIN: F30602-88-D-0025
ELIN: A001
Task Assignment Number: N-8-5538
Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the third submittal of the R & D Status Report as required by above contract. As required by Article II, paragraph C. of the enclosure (Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are sent to you. One additional reproducible copy of this deliverable item is sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by McDonnell Aircraft Company that you will comply with the additional distribution requirements for this deliverable data item as set forth in the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March 1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of April 1989:

a. Completed the literature search on transient protection schemes and devices. Collected information is being processed into a rough draft. Draft will include information on transients, transient sources, protection devices, device application, etc.

b. Continued effort to collect reliability design guidelines.

c. Industry survey was finalized and submitted to fifty-seven vendors specializing in power supply designs. Both commercial and military vendors were surveyed.

d. A Joint Stars equipment list was received. The list (approximately 100 pages of equipment listings) was examined and all power supplies were identified. This power supply list was then cross referenced with equipment listings of all Air Force platforms. This effort yielded zero equipment matches.

e. Acquired two years of monthly MTBM-1 data for individual E-3 squadrons. A cursory data integrity evaluation suggests the data is useable with caution.

f. Traveled to RADC to discuss the Joint Stars equipment situation with Seymour Morris. We decided to change the requirement to use Joint Stars equipment and agreed to select ten pieces of equipment from the E-3 and ten from the F/A-18. Discussed the Air Force data integrity problem with Seymour.

g. Submitted request to the Air Force for detailed E-3 maintenance data. Requested the last five years of available data.

h. Began preparing boiler plate procurement specification which addresses wording to ensure transient protection is incorporated into the design. Designers have commented that one of the main reasons that transient protection is not incorporated is it is not specified.

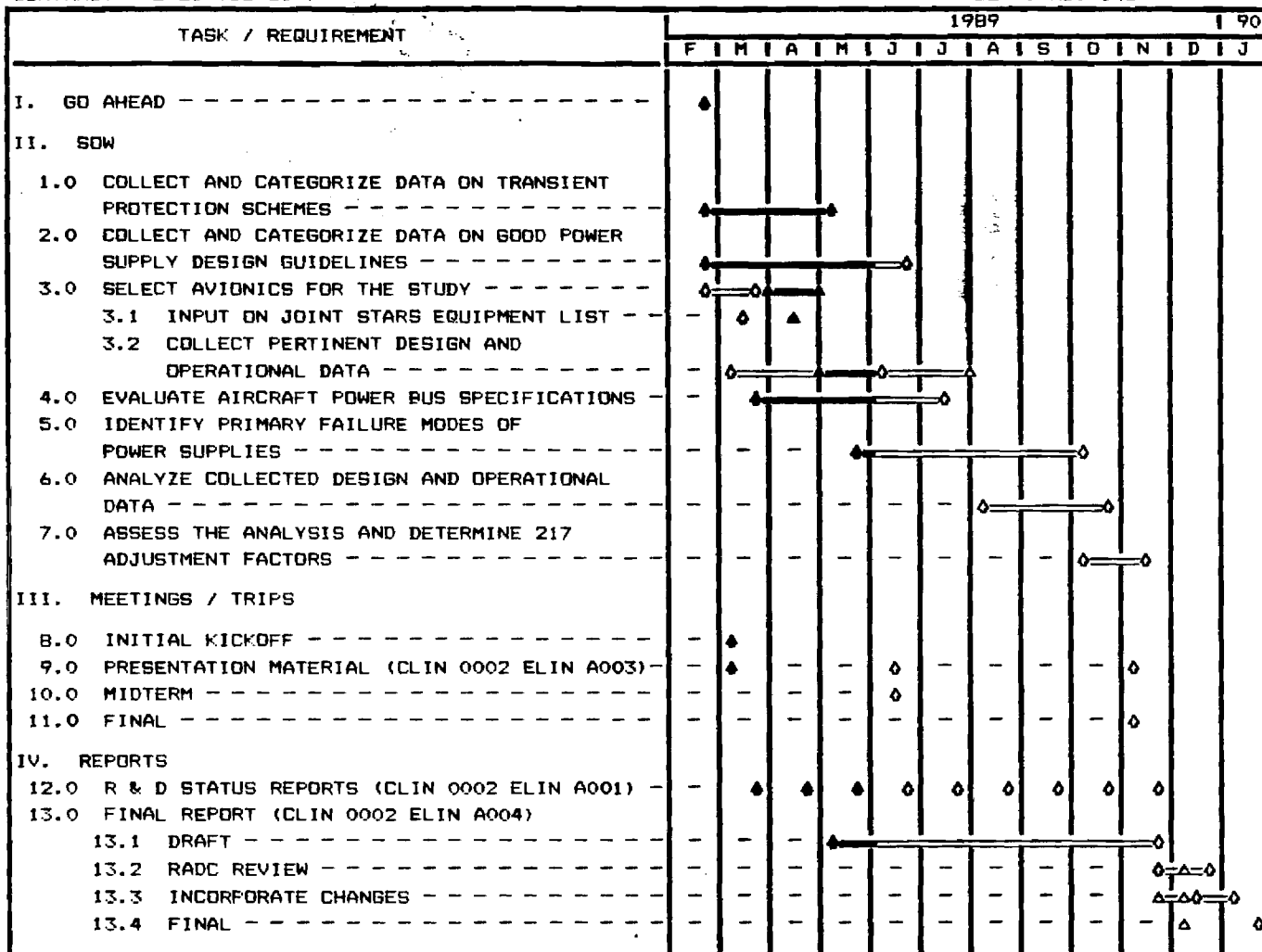i. Began reviewing E-3 and F/A-18 equipment lists for candidate power supplies.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1) Program Schedule

EC: Seymour Morris RADC/RBER

POWER SUPPLY FAULT TOLERANT REL. STUDY

M7Z-CA-101

CONTRACT - E-21-T08-S1

ETD   CRAD

DEPT. NO. 346

TASK / REQUIREMENT	1989	90

(Gantt chart with monthly columns: F M A M J J A S O N D J)

I. GO AHEAD

II. SOW

  1.0 COLLECT AND CATEGORIZE DATA ON TRANSIENT PROTECTION SCHEMES

  2.0 COLLECT AND CATEGORIZE DATA ON GOOD POWER SUPPLY DESIGN GUIDELINES

  3.0 SELECT AVIONICS FOR THE STUDY

     3.1 INPUT ON JOINT STARS EQUIPMENT LIST

     3.2 COLLECT PERTINENT DESIGN AND OPERATIONAL DATA

  4.0 EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS

  5.0 IDENTIFY PRIMARY FAILURE MODES OF POWER SUPPLIES

  6.0 ANALYZE COLLECTED DESIGN AND OPERATIONAL DATA

  7.0 ASSESS THE ANALYSIS AND DETERMINE 217 ADJUSTMENT FACTORS

III. MEETINGS / TRIPS

  8.0 INITIAL KICKOFF

  9.0 PRESENTATION MATERIAL (CLIN 0002 ELIN A003)

  10.0 MIDTERM

  11.0 FINAL

IV. REPORTS

  12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001)

  13.0 FINAL REPORT (CLIN 0002 ELIN A004)

     13.1 DRAFT

     13.2 RADC REVIEW

     13.3 INCORPORATE CHANGES

     13.4 FINAL

— LEGEND —

/====/ SCHEDULED TIME SPAN

◆===/ ACTUAL PROGRESS

/ SCHEDULED EVENT

◆ ACTUAL EVENT

△ RESCHEDULED EVENT

▲ ACTUAL RESCHEDULED EVENT

  BUDGET

  ACI (ACTUAL COSTS INCURRED)

CUSTOMER COST $ 92,423
COST SHARE 10,269

TOTAL BUDGET $102,692
FEE 0

TOTAL VALUE $102,692

CUM TO DATE —		CURRENT —	
BUDGET	$ 27,189	BAC	$ 102,692
ACTUALS	$ 23,504	EAC	$ 102,692

(Cumulative dollars graph, C U M D O L L A R S × 1000, scale 0–110)

	F	M	A	M	J	J	A	S	O	N	D	J
BASELINE STAFFING	0.9	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	0.0
ACTUAL STAFFING	0.2	0.9	1.0									
ETC STAFFING			1.1	1.0	1.1	1.1	1.0	1.1	1.0	1.0	1.0	0.0

NOTES —

1. TASKS 3.0 - 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED FROM THE CUSTOMER. (FEB)

2. TASKS 13.0 - 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)

STATUS THROUGH

APRIL, 1989

PROGRAM MANAGER W. D. YATES

PLANNER M. S. KROEGER

McDonnell Aircraft Company

2 1 JUN 1989

GIT-346-37
12 June 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
CLIN Ident Exhibit: 0002
PIIN: F30602-88-D-0025
ELIN: A001
Task Assignment Number: N-8-5538
Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the fourth submittal of the R & D Status Report as required by
above contract. As required by Article II, paragraph C. of the enclosure
(Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your
Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are
sent to you. One additional reproducible copy of this deliverable item is
sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by
McDonnell Aircraft Company that you will comply with the additional
distribution requirements for this deliverable data item as set forth in
the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March
1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional
distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of May 1989:

   a. Completed the literature search and industry questionnaire. 10%
   response to our questionnaire was achieved by the end of May.

   b. Final draft of Task 1 effort to be included in the program
   technical report is 95% complete. Only graphics remain to be
   completed. Task 1 content is:

        1) Definitions of transients
        2) Transient protection techniques
        3) Transient protection devices
        4) Applications to power supplies

c. A list of good power supply design practices has been compiled from the completed literature search. Additional good power supply design practices are being collected by the McDonnell Douglas Electronics System Company (power supply design group).

d. Applicable MIL documents have been collected.

e. Began collecting design information for the F/A-18 equipment selected for this study.

f. Submitted a letter of request for assistance to Capt. Lambert of the AWACS program office. This letter requested the design information on AWACS equipment needed for this study.

g, Began collecting failure data for the F/A-18 equipment selected for this study.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1) Program Schedule
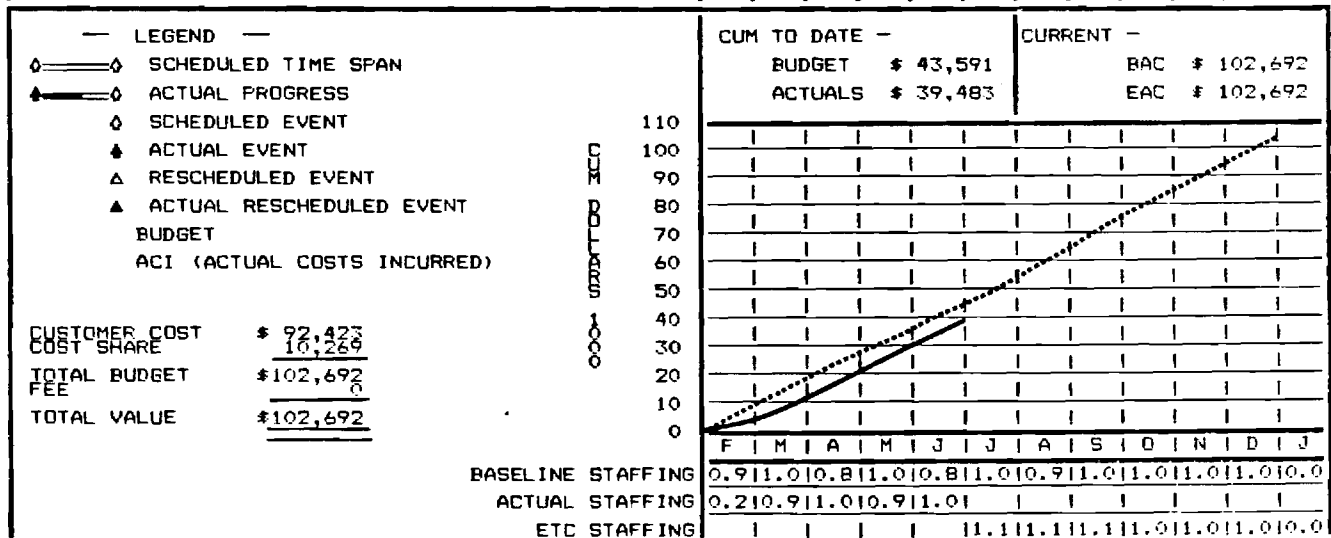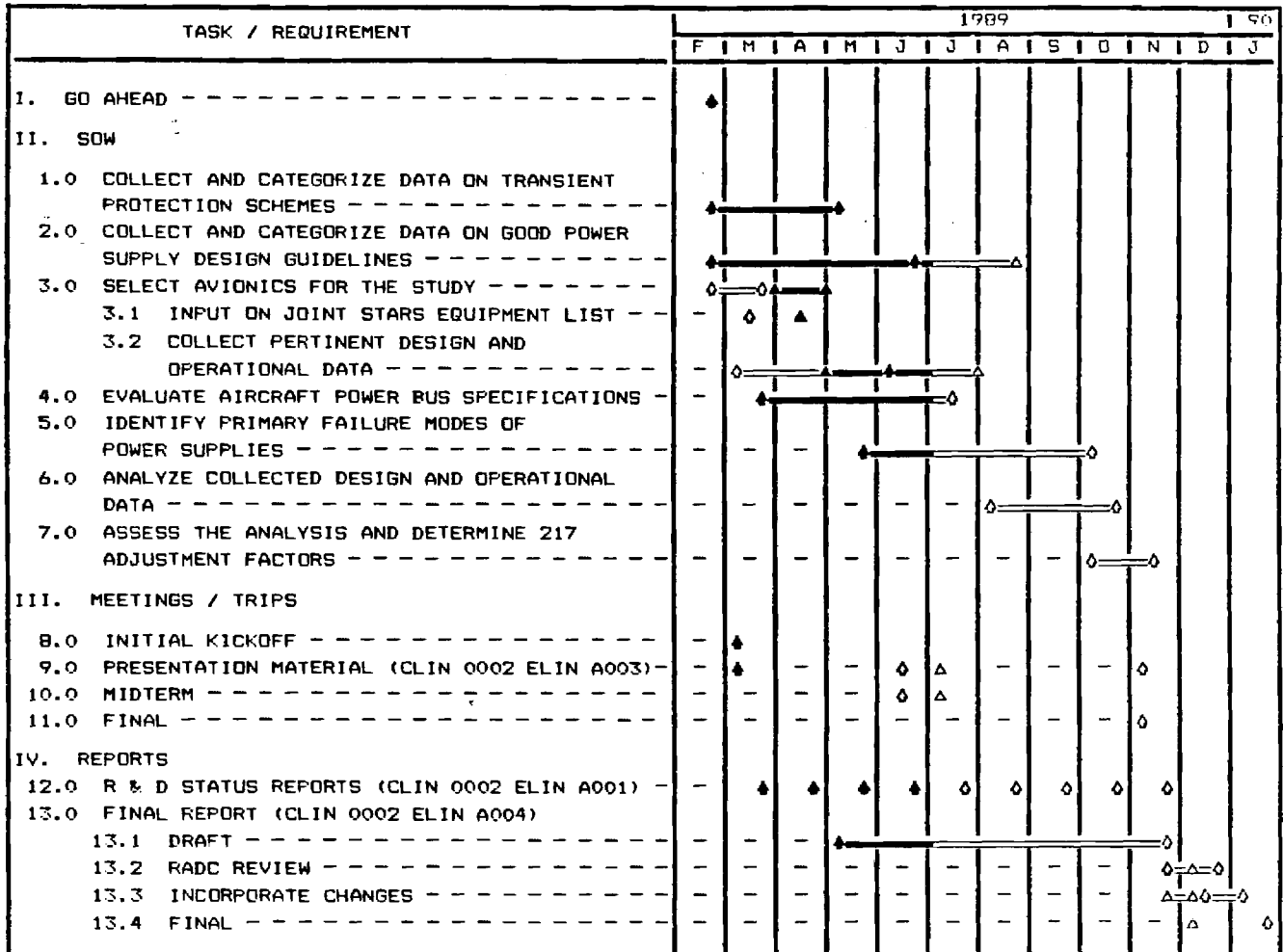
EC: Seymour Morris RADC/RBER

TASK / REQUIREMENT	1989												90
	F	M	A	M	J	J	A	S	O	N	D	J	

I.   GO AHEAD — — — — — — — — — — — — — — — — — — ▲

II. SOW

  1.0   COLLECT AND CATEGORIZE DATA ON TRANSIENT
        PROTECTION SCHEMES — — — — — — — — — —

  2.0   COLLECT AND CATEGORIZE DATA ON GOOD POWER
        SUPPLY DESIGN GUIDELINES — — — — — — — —

  3.0   SELECT AVIONICS FOR THE STUDY — — — — — —
        3.1   INPUT ON JOINT STARS EQUIPMENT LIST — —
        3.2   COLLECT PERTINENT DESIGN AND
              OPERATIONAL DATA — — — — — — — — — —

  4.0   EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS —

  5.0   IDENTIFY PRIMARY FAILURE MODES OF
        POWER SUPPLIES — — — — — — — — — — — —

  6.0   ANALYZE COLLECTED DESIGN AND OPERATIONAL
        DATA — — — — — — — — — — — — — — — — —

  7.0   ASSESS THE ANALYSIS AND DETERMINE 217
        ADJUSTMENT FACTORS — — — — — — — — — —

III. MEETINGS / TRIPS

  8.0   INITIAL KICKOFF — — — — — — — — — — — —
  9.0   PRESENTATION MATERIAL (CLIN 0002 ELIN A003)—
  10.0 MIDTERM — — — — — — — — — — — — — — — —
  11.0 FINAL — — — — — — — — — — — — — — — — —

IV. REPORTS
  12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001) —
  13.0 FINAL REPORT (CLIN 0002 ELIN A004)
        13.1 DRAFT — — — — — — — — — — — — — — —
        13.2 RADC REVIEW — — — — — — — — — — — —
        13.3 INCORPORATE CHANGES — — — — — — — —
        13.4 FINAL — — — — — — — — — — — — — —

— LEGEND —
/====/ SCHEDULED TIME SPAN
▲===/   ACTUAL PROGRESS
  /   SCHEDULED EVENT
  ▲   ACTUAL EVENT
  △   RESCHEDULED EVENT
  ▲   ACTUAL RESCHEDULED EVENT
        BUDGET
        ACI (ACTUAL COSTS INCURRED)

CUSTOMER COST $ 92,423
COST SHARE   10,269
TOTAL BUDGET $102,692
FEE   0
TOTAL VALUE $102,692

CUM TO DATE —		CURRENT —	
BUDGET	$ 36,114	BAC	$ 102,692
ACTUALS	$ 30,492	EAC	$ 102,692

CUM DOLLARS 1000:
110
100
90
80
70
60
50
40
30
20
10
0

F M A M J J A S O N D J

	F	M	A	M	J	J	A	S	O	N	D	J
BASELINE STAFFING	0.9	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	0.0
ACTUAL STAFFING	0.2	0.9	1.0	0.9								
ETC STAFFING				1.1	1.1	1.0	1.1	1.0	1.0	1.0	0.0	

NOTES —
1. TASKS 3.0 - 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED
    FROM THE CUSTOMER. (FEB)
2. TASKS 13.0 - 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)
3. UNDERRUN IS DUE TO DELAY OF TASK 3.0 - 3.2. (MAR, APR, MAY)

STATUS THROUGH   PROGRAM MANAGER W. D. YATES   X-
MAY, 1989   PLANNER M. S. KROEGER

MCDONNELL DOUGLAS

McDonnell Aircraft Company

GIT-346-41
10 July 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
           CLIN Ident Exhibit: 0002
           PIIN: F30602-88-D-0025
           ELIN: A001
           Task Assignment Number: N-8-5538
           Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the fifth submittal of the R & D Status Report as required by above
contract. As required by Article II, paragraph C. of the enclosure
(Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your
Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are
sent to you. One additional reproducible copy of this deliverable item is
sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by
McDonnell Aircraft Company that you will comply with the additional
distribution requirements for this deliverable data item as set forth in
the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March
1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional
distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of June 1989:

   a)   Continued compiling good power supply design practices.
   Obtained copies of and reviewed:
        1)   NAVMAT 4855-1A, Navy Power Supply Reliability - Design and
             Manufacturing Guidelines
        2)   RADC-TR-88-304, Reliability Design Criteria for High Power
             Tubes
      ' 3)   AFWAL-TR-88-4143, Designing and Building High Voltage Power
             Supplies

   b)   Collected F/A-18 data necessary for completion of Task III. This
   includes procurement specifications, prediction / stress analysis
   reports and schematics.

c) Evaluated MIL-STD-704 and determined what it required in terms of supply voltages. Additionally, the appropriate sections of MIL-STD-454 and MIL-E-5400 were reviewed and documented. IEEE-587 was obtained and reviewed.

d) Evaluated data items collected in b) above to assess input power requirements. Also evalutated procurement specifications to determine if any protection for other interface wiring was required.

e) Collected MIL-STD-6051 and MIL-B-5087 and began assessing lightning and EMI requirements.

f) Began analyzing F/A-18 failure data. Reworked existing software code to improve data integrity by eliminating duplicate maintenance records.

g) Began preparation of mid-term report for July 12, 1989.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1) Program Schedule

EC: Seymour Morris RADC/RBER

TASK / REQUIREMENT	1989											1 90
	F	M	A	M	J	J	A	S	O	N	D	J

I.   GO AHEAD

II. SOW

  1.0   COLLECT AND CATEGORIZE DATA ON TRANSIENT
        PROTECTION SCHEMES
  2.0   COLLECT AND CATEGORIZE DATA ON GOOD POWER
        SUPPLY DESIGN GUIDELINES
  3.0   SELECT AVIONICS FOR THE STUDY
        3.1   INPUT ON JOINT STARS EQUIPMENT LIST
        3.2   COLLECT PERTINENT DESIGN AND
              OPERATIONAL DATA
  4.0   EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS
  5.0   IDENTIFY PRIMARY FAILURE MODES OF
        POWER SUPPLIES
  6.0   ANALYZE COLLECTED DESIGN AND OPERATIONAL
        DATA
  7.0   ASSESS THE ANALYSIS AND DETERMINE 217
        ADJUSTMENT FACTORS

III. MEETINGS / TRIPS

  8.0   INITIAL KICKOFF
  9.0   PRESENTATION MATERIAL (CLIN 0002 ELIN A003)
  10.0 MIDTERM
  11.0 FINAL

IV. REPORTS

  12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001)
  13.0 FINAL REPORT (CLIN 0002 ELIN A004)
        13.1 DRAFT
        13.2 RADC REVIEW
        13.3 INCORPORATE CHANGES
        13.4 FINAL

— LEGEND —

◊════◊   SCHEDULED TIME SPAN
♦━━━◊   ACTUAL PROGRESS
◊   SCHEDULED EVENT
♦   ACTUAL EVENT
△   RESCHEDULED EVENT
▲   ACTUAL RESCHEDULED EVENT
         BUDGET
         ACI (ACTUAL COSTS INCURRED)

CUSTOMER COST $ 92,423
COST SHARE   10,269
TOTAL BUDGET $102,692
FEE   0
TOTAL VALUE $102,692

CUM TO DATE —		CURRENT —	
BUDGET	$ 43,591	BAC	$ 102,692
ACTUALS	$ 39,483	EAC	$ 102,692

C   110
U   100
M   90
     80
D   70
O   60
L   50
L   40
A   30
R   20
S   10
1   0
0
0
0

	F	M	A	M	J	J	A	S	O	N	D	J
BASELINE STAFFING	0.9	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	0.0
ACTUAL STAFFING	0.2	0.9	1.0	0.9	1.0							
ETC STAFFING					1.1	1.1	1.1	1.0	1.0	1.0	0.0	

NOTES —
  1.   TASKS 3.0 — 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED
       FROM THE CUSTOMER. (FEB)
  2.   TASKS 13.0 — 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)
  3.   UNDERRUN IS DUE TO DELAY OF TASK 3.0 — 3.2. (MAR — JUNE)
  4.   TASK 2.0 EXTENDED FOR COLLECTION OF ADDITIONAL GUIDELINES. (JUNE)
  5.   TASKS 9.0 AND 10.0 RESCHEDULED TO COINCIDE WITH CAARUFEM TRIP THUS ACCOMPLISHING TASKS
       WITH ONE TRIP INSTEAD OF TWO. (JUNE)

  CAARUFEM = COMPUTER AIDED ASSESSMENT OF RELIABILITY USING FINITE ELEMENT METHODS (CRAD)

STATUS THROUGH   PROGRAM MANAGER   W. D. YATES   X
JUNE, 1989   PLANNER   M. S. KROEGER

GIT-346-53
10 August 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
          CLIN Ident Exhibit: 0002
          PIIN: F30602-88-D-0025
          ELIN: A001
          Task Assignment Number: N-8-5538
          Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the sixth submittal of the R & D Status Report as required by above
contract. As required by Article II, paragraph C. of the enclosure
(Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your
Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are
sent to you. One additional reproducible copy of this deliverable item is
sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by
McDonnell Aircraft Company that you will comply with the additional
distribution requirements for this deliverable data item as set forth in
the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March
1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional
distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of July 1989:

    a) Submitted the July 1989 R & D status report.

    b) Completed prepartion of the mid-term briefing and status report.

    c) Traveled to RADC and presented the mid-term briefing.

        One significant change to the statement of work to this study was
verbally agreed to (during the mid-term briefing session) by RADC
Program Manager, Seymour Morris, and MCAIR Program Manager, Dave
Yates. This change was the result of failure to obtain the required
information on Joint Stars avionic equipment. The agreed change allows

use of F/A-18 avionic equipment for this study. A letter outlining the details has been submitted through contracts for coordination and approval.

d) Collected schematics and block diagrams for E-3 surveillance radar high voltage power supply.

e) Analyzed F/A-18 failure data to determine relationships between predicted failure rates and field failure rates, and between complexity and percent of predicted MTBF achieved.

f) Quantified part failures for the radar transmitter power supply and the flight control computer power supply.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1) Program Schedule
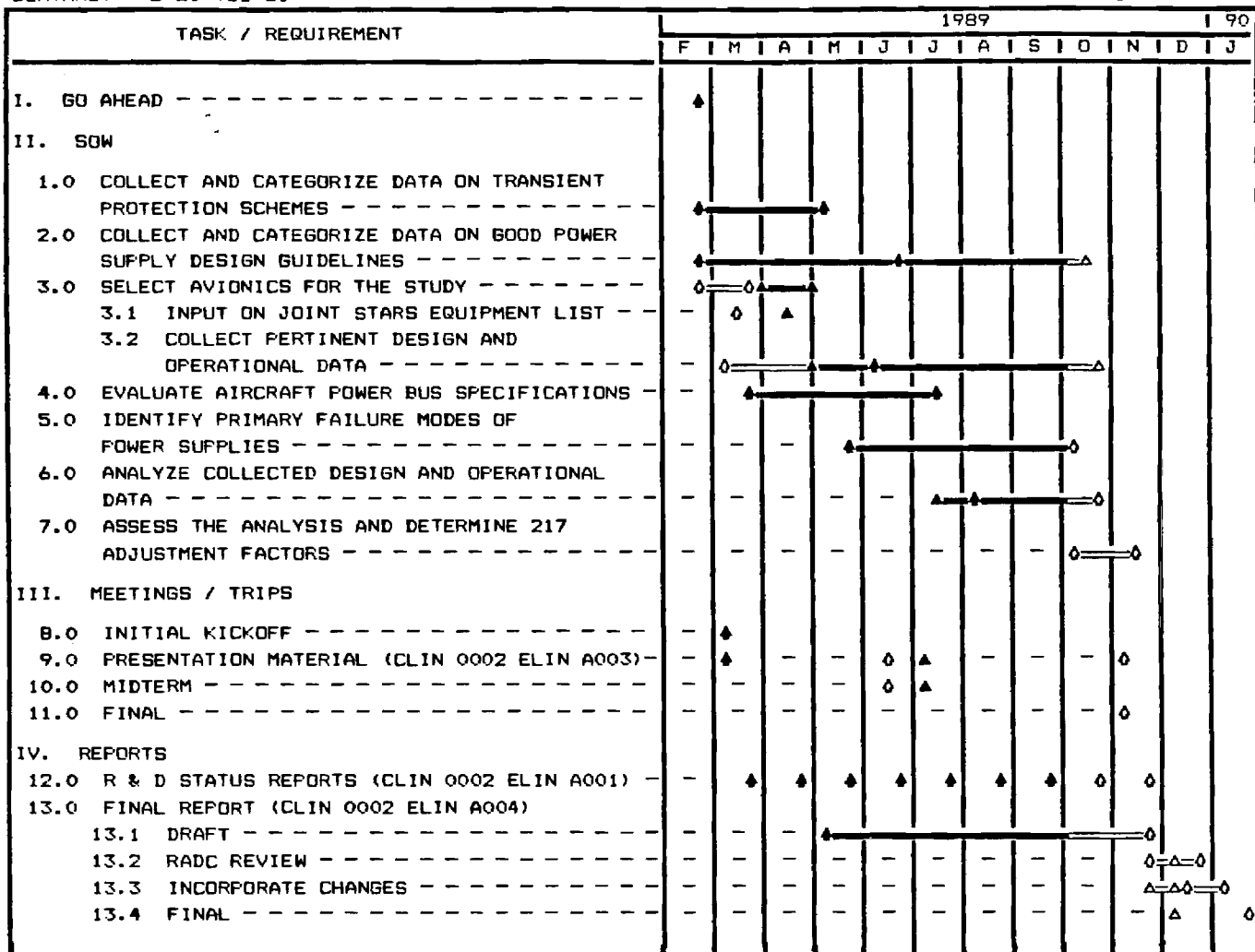
EC: Seymour Morris RADC/RBER

POWER SUPPLY FAULT TOLERANT REL. STUDY

M7Z-CA-101   ETD   CRAD

CONTRACT — E-21-TO8-S1   DEPT. NO. 346

TASK / REQUIREMENT	1989 (F M A M J J A S O N D J)	90

I. GO AHEAD

II. SOW

1.0 COLLECT AND CATEGORIZE DATA ON TRANSIENT PROTECTION SCHEMES

2.0 COLLECT AND CATEGORIZE DATA ON GOOD POWER SUPPLY DESIGN GUIDELINES

3.0 SELECT AVIONICS FOR THE STUDY

    3.1 INPUT ON JOINT STARS EQUIPMENT LIST

    3.2 COLLECT PERTINENT DESIGN AND OPERATIONAL DATA

4.0 EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS

5.0 IDENTIFY PRIMARY FAILURE MODES OF POWER SUPPLIES

6.0 ANALYZE COLLECTED DESIGN AND OPERATIONAL DATA

7.0 ASSESS THE ANALYSIS AND DETERMINE 217 ADJUSTMENT FACTORS

III. MEETINGS / TRIPS

8.0 INITIAL KICKOFF

9.0 PRESENTATION MATERIAL (CLIN 0002 ELIN A003)

10.0 MIDTERM

11.0 FINAL

IV. REPORTS

12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001)

13.0 FINAL REPORT (CLIN 0002 ELIN A004)

    13.1 DRAFT

    13.2 RADC REVIEW

    13.3 INCORPORATE CHANGES

    13.4 FINAL

— LEGEND —

◊═══◊ SCHEDULED TIME SPAN
◆═══◊ ACTUAL PROGRESS
◊ SCHEDULED EVENT
◆ ACTUAL EVENT
△ RESCHEDULED EVENT
▲ ACTUAL RESCHEDULED EVENT
    BUDGET
    ACI (ACTUAL COSTS INCURRED)

CUSTOMER COST	$ 92,423
COST SHARE	10,269
TOTAL BUDGET	$102,692
FEE	0
TOTAL VALUE	$102,692

CUM TO DATE —		CURRENT —	
BUDGET	$ 53,773	BAC	$ 102,692
ACTUALS	$ 48,642	EAC	$ 102,692

DOLLARS X 000: 110 100 90 80 70 60 50 40 30 20 10 0

Months: F M A M J J A S O N D J

	F	M	A	M	J	J	A	S	O	N	D	J
BASELINE STAFFING	0.9	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	0.0
ACTUAL STAFFING	0.2	0.9	1.0	0.9	1.0	0.8						
ETC STAFFING						1	1.1	1.1	1.1	1.0	1.0	0.0

NOTES —

1. TASKS 3.0 — 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED FROM THE CUSTOMER. (FEB)

2. TASKS 13.0 — 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)

3. UNDERRUN IS DUE TO DELAY OF TASK 3.0 — 3.2. (MAR — JULY)

4. TASK 2.0 EXTENDED FOR COLLECTION OF ADDITIONAL GUIDELINES. (JUNE)

5. TASKS 9.0 AND 10.0 RESCHEDULED TO COINCIDE WITH CAARUFEM TRIP THUS ACCOMPLISHING TASKS WITH ONE TRIP INSTEAD OF TWO. (JUNE)

6. TASK 6.0 STARTED EARLY TO ANALYZE DATA FROM TASK 3.2. (JULY)

CAARUFEM = COMPUTER AIDED ASSESSMENT OF RELIABILITY USING FINITE ELEMENT METHODS (CRAD

STATUS THROUGH JULY, 1989

PROGRAM MANAGER W. D. YATES X · · ·
PLANNER M. S. KROEGER

POWER SUPPLY FAULT TOLERANT REL. STUDY

M7Z-CA-101   ETD   CRAD

CONTRACT - E-21-T08-S1   DEPT. NO. 346

TASK / REQUIREMENT	1989 F M A M J J A S O N D	90 J

I.   GO AHEAD

II. SOW

1.0   COLLECT AND CATEGORIZE DATA ON TRANSIENT
      PROTECTION SCHEMES
2.0   COLLECT AND CATEGORIZE DATA ON GOOD POWER
      SUPPLY DESIGN GUIDELINES
3.0   SELECT AVIONICS FOR THE STUDY
      3.1   INPUT ON JOINT STARS EQUIPMENT LIST
      3.2   COLLECT PERTINENT DESIGN AND
            OPERATIONAL DATA
4.0   EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS
5.0   IDENTIFY PRIMARY FAILURE MODES OF
      POWER SUPPLIES
6.0   ANALYZE COLLECTED DESIGN AND OPERATIONAL
      DATA
7.0   ASSESS THE ANALYSIS AND DETERMINE 217
      ADJUSTMENT FACTORS

III. MEETINGS / TRIPS

8.0   INITIAL KICKOFF
9.0   PRESENTATION MATERIAL (CLIN 0002 ELIN A003)
10.0 MIDTERM
11.0 FINAL

IV. REPORTS

12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001)
13.0 FINAL REPORT (CLIN 0002 ELIN A004)
      13.1   DRAFT
      13.2   RADC REVIEW
      13.3   INCORPORATE CHANGES
      13.4   FINAL

LEGEND

◊═══◊   SCHEDULED TIME SPAN
◆═══◊   ACTUAL PROGRESS
◊   SCHEDULED EVENT
◆   ACTUAL EVENT
△   RESCHEDULED EVENT
▲   ACTUAL RESCHEDULED EVENT
        BUDGET
        ACI (ACTUAL COSTS INCURRED)

CUSTOMER COST	$ 92,423
COST SHARE	10,269
TOTAL BUDGET	$102,692
FEE	0
TOTAL VALUE	$102,692

CUM TO DATE -		CURRENT -	
BUDGET	$ 53,773	BAC	$ 102,692
ACTUALS	$ 48,642	EAC	$ 102,692

CUM DOLLARS (000)
110
100
90
80
70
60
50
40
30
20
10
0
F M A M J J A S O N D J

	F	M	A	M	J	J	A	S	O	N	D	J
BASELINE STAFFING	0.9	1.0	0.8	1.0	0.8	1.0	0.9	1.0	1.0	1.0	1.0	0.0
ACTUAL STAFFING	0.2	0.9	1.0	0.9	1.0	0.8						
ETC STAFFING						1.1	1.1	1.1	1.0	1.0	0.0

NOTES -

1.   TASKS 3.0 - 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED
     FROM THE CUSTOMER. (FEB)
2.   TASKS 13.0 - 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)
3.   UNDERRUN IS DUE TO DELAY OF TASK 3.0 - 3.2. (MAR - JULY)
4.   TASK 2.0 EXTENDED FOR COLLECTION OF ADDITIONAL GUIDELINES. (JUNE)
5.   TASKS 9.0 AND 10.0 RESCHEDULED TO COINCIDE WITH CAARUFEM TRIP THUS ACCOMPLISHING TASKS
     WITH ONE TRIP INSTEAD OF TWO. (JUNE)
6.   TASK 6.0 STARTED EARLY TO ANALYZE DATA FROM TASK 3.2. (JULY)

CAARUFEM = COMPUTER AIDED ASSESSMENT OF RELIABILITY USING FINITE ELEMENT METHODS (CRAD)

STATUS THROUGH   PROGRAM MANAGER W. D. YATES
JULY, 1989   PLANNER M. S. KROEGER

MCDONNELL DOUGLAS

McDonnell Aircraft Company

GIT-346-47
10 September 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
          CLIN Ident Exhibit: 0002
          PIIN: F30602-88-D-0025
          ELIN: A001
          Task Assignment Number: N-8-5538
          Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the seventh submittal of the R & D Status Report as required by
above contract. As required by Article II, paragraph C. of the enclosure
(Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your
Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are
sent to you. One additional reproducible copy of this deliverable item is
sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by
McDonnell Aircraft Company that you will comply with the additional
distribution requirements for this deliverable data item as set forth in
the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March
1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional
distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of August 1989:

a) Submitted the July R & D status report.

b) Analyzed F/A-18 failure data to determine relationships
    between predicted failure rates and field failure rates of
    power supplies. Initial analysis indicates there is no
    apparent relationship between the ratio of the predicted failure
    rate and the operational failure rate when comparing different
    types of power supplies, ie. high voltage supplies, low voltage
    supplies and DC-DC converters. When graphing the percent obtained
    from comparing the operational failure rate to the predicted
    failure rate, the overall trend shows power supplies with a high
    predicted failure rate perform worse than units with a low
    predicted failure rate.

c) Compared fielded performance of power supplies versus their
    host WRA/LRU performance. The analysis indicates two-thirds of
    the power supplies evaluated performed better than their host
    WRA/LRU.

d) Began mapping part failures on to schematics to determine
    failures of protective circuitry and protected circuitry. No
    conclusions have been reached.

e) Debugged field data analysis software after a logic error was
    discovered.

f) Selected F-15 avionics power supplies to provide a more
    statistically significant comparison of achieved failure rates to
    predicted failure rates.

Questions regarding this data submittal should be addressed to me at (314)
234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1) Program Schedule

EC: Seymour Morris RADC/RBER

POWER SUPPLY FAULT TOLERANT REL. STUDY

M7Z-CA-101

CONTRACT - E-21-T08-S1

ETD   CRAD
DEPT. NO. 346

TASK / REQUIREMENT	1989	90
	F M A M J J A S O N D	J

I.   GO AHEAD

II. SOW

  1.0   COLLECT AND CATEGORIZE DATA ON TRANSIENT
        PROTECTION SCHEMES

  2.0   COLLECT AND CATEGORIZE DATA ON GOOD POWER
        SUPPLY DESIGN GUIDELINES

  3.0   SELECT AVIONICS FOR THE STUDY
        3.1   INPUT ON JOINT STARS EQUIPMENT LIST
        3.2   COLLECT PERTINENT DESIGN AND
              OPERATIONAL DATA

  4.0   EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS

  5.0   IDENTIFY PRIMARY FAILURE MODES OF
        POWER SUPPLIES

  6.0   ANALYZE COLLECTED DESIGN AND OPERATIONAL
        DATA

  7.0   ASSESS THE ANALYSIS AND DETERMINE 217
        ADJUSTMENT FACTORS

III.   MEETINGS / TRIPS

  8.0   INITIAL KICKOFF
  9.0   PRESENTATION MATERIAL (CLIN 0002 ELIN A003)
  10.0   MIDTERM
  11.0   FINAL

IV. REPORTS
  12.0   R & D STATUS REPORTS (CLIN 0002 ELIN A001)
  13.0   FINAL REPORT (CLIN 0002 ELIN A004)
         13.1   DRAFT
         13.2   RADC REVIEW
         13.3   INCORPORATE CHANGES
         13.4   FINAL

NOTES -
1.   TASKS 3.0 - 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED
     FROM THE CUSTOMER. (FEB)
2.   TASKS 13.0 - 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)
3.   UNDERRUN IS DUE TO DELAY OF TASK 3.0 - 3.2. (MAR - JUNE)
4.   TASK 2.0 EXTENDED FOR COLLECTION OF ADDITIONAL GUIDELINES. (JUNE,AUGUST)
5.   TASKS 9.0 AND 10.0 RESCHEDULED TO COINCIDE WITH CAARUFEM TRIP THUS ACCOMPLISHING TASKS
     WITH ONE TRIP INSTEAD OF TWO. (JUNE)
6.   TASK 6.0 STARTED EARLY TO ANALYZE DATA FROM TASK 3.2. (JULY)
CAARUFEM = COMPUTER AIDED ASSESSMENT OF RELIABILITY USING FINITE ELEMENT METHODS. (CRAD)

STATUS THROUGH
AUGUST, 1989

PROGRAM MANAGER   W. D. YATES   X—
PLANNER   M. S. KROEGER

McDonnell Aircraft Company

GIT-346-56
16 October 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
                      CLIN Ident Exhibit: 0002
                      PIIN: F30602-88-D-0025
                      ELIN: A001
                      Task Assignment Number: N-8-5538
                      Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the eighth submittal of the R & D Status Report as required by
above contract. As required by Article II, paragraph C. of the enclosure
(Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your
Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are
sent to you. One additional reproducible copy of this deliverable item is
sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by
McDonnell Aircraft Company that you will comply with the additional
distribution requirements for this deliverable data item as set forth in
the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March
1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional
distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of September 1989:

a)   Submitted the August R & D status report.

b)   Compiled F/A-18 failure data to determine relationships
       between the replacement rates of protection circuitry to
       the replacement rates of the remaining power supply
       circuitry. The collected data will be summarized and
       reported on in the next status report.

c)   Obtained new data for the failure rate relationships
       which exist between power supplies and their host WRAs.
       This was necessary to account for the logic error which
       existed in previous data runs. The data will be summarized
       and reported on in the next status report.

        d)   Schematics of the high voltage sections of power supplies
in this study have been difficult to obtain. However, it
appears most protection circuitry is contained in the low
voltage portion which feeds the high voltage section. This
will not preclude us from assessing the relative
performance of high voltage supplies.

Questions regarding this data submittal should be addressed to me at (314)
234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1)   Program Schedule

EC: Seymour Morris RADC/RBER

POWER SUPPLY FAULT TOLERANT REL. STUDY

M7Z-CA-101   ETD   CRAD

CONTRACT - E-21-T08-S1   DEPT. NO. 346

TASK / REQUIREMENT	1989 F M A M J J A S O N D	90 J

I. GO AHEAD

II. SOW

  1.0 COLLECT AND CATEGORIZE DATA ON TRANSIENT
     PROTECTION SCHEMES

  2.0 COLLECT AND CATEGORIZE DATA ON GOOD POWER
     SUPPLY DESIGN GUIDELINES

  3.0 SELECT AVIONICS FOR THE STUDY

     3.1 INPUT ON JOINT STARS EQUIPMENT LIST

     3.2 COLLECT PERTINENT DESIGN AND
         OPERATIONAL DATA

  4.0 EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS

  5.0 IDENTIFY PRIMARY FAILURE MODES OF
     POWER SUPPLIES

  6.0 ANALYZE COLLECTED DESIGN AND OPERATIONAL
     DATA

  7.0 ASSESS THE ANALYSIS AND DETERMINE 217
     ADJUSTMENT FACTORS

III. MEETINGS / TRIPS

  8.0 INITIAL KICKOFF

  9.0 PRESENTATION MATERIAL (CLIN 0002 ELIN A003)

  10.0 MIDTERM

  11.0 FINAL

IV. REPORTS

  12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001)

  13.0 FINAL REPORT (CLIN 0002 ELIN A004)

     13.1 DRAFT

     13.2 RADC REVIEW

     13.3 INCORPORATE CHANGES

     13.4 FINAL

NOTES -

1. TASKS 3.0 - 3.2 WERE DELAYED BECAUSE THE JOINT STARS EQUIPMENT LIST WAS NOT RECEIVED
    FROM THE CUSTOMER. (FEB)

2. TASKS 13.0 - 13.4 ARE RESCHEDULED EARLIER TO ACCOMODATE CONTRACT END DATE. (APR)

3. UNDERRUN IS DUE TO DELAY OF TASK 3.0 - 3.2 (MAR-SEPT) AND ADJUSTMENT OF EFFORT AS
    AGREED UPON BY CUSTOMER (SEPT).

4. TASK 2.0 EXTENDED FOR COLLECTION OF ADDITIONAL GUIDELINES. (JUNE,AUGUST)

5. TASKS 9.0 AND 10.0 RESCHEDULED TO COINCIDE WITH CAARUFEM TRIP THUS ACCOMPLISHING TASKS
    WITH ONE TRIP INSTEAD OF TWO. (JUNE)

6. TASK 6.0 STARTED EARLY TO ANALYZE DATA FROM TASK 3.2. (JULY)

CAARUFEM = COMPUTER AIDED ASSESSMENT OF RELIABILITY USING FINITE ELEMENT METHODS (CRAD)

STATUS THROUGH
SEPTEMBER, 1989

PROGRAM MANAGER W. D. YATES   X-
PLANNER M. S. KROEGER

GIT-346-89-62
14 November 1989

Georgia Institute of Technology
Office of Contract Administration
Attn: Brian J. Lindberg
Centennial Research Building
Atlanta, Georgia, 30332-0420

SUBJECT: Submittal of R & D Status Report
          CLIN Ident Exhibit: 0002
          PIIN: F30602-88-D-0025
          ELIN: A001
          Task Assignment Number: N-8-5538
          Subcontract Number: E-21-T08-S1

Dear Mr. Lindberg:

This is the ninth submittal of the R & D Status Report as required by above
contract. As required by Article II, paragraph C. of the enclosure
(Subcontract No. E-21-T08-S1) to your letter dated February 15, 1989 (Your
Reference No. BJL/E-21-T08-S1), two copies of this deliverable item are
sent to you. One additional reproducible copy of this deliverable item is
sent to RADC/DAPT, Griffiss AFB, New York, 13441. It is assumed by
McDonnell Aircraft Company that you will comply with the additional
distribution requirements for this deliverable data item as set forth in
the revised Exhibit A (CONTRACT DATA REQUIREMENTS LIST) dated 14 March
1989, page 1, CLIN Ident Exhibit:0002, ELIN: A001. This requires additional
distribution of one copy each to RADC/RB and RADC/PKRM.

The following activity occurred during the month of October 1989:

    a) Submitted the September R & D status report.

    b) Analysis of part failure rate information with respect to power
    supplies suggests components associated with transient protection
    circuitry fail at a consistently lower rate than the remaining parts
    within the power supply. This analysis was made by comparing the
    replacement rate of the protection related parts to the replacement
    rate of the remaining power supply components. The results indicate
    adjustment factors for the predicted reliability of these components
    will be possible. Attempts at correlating this data with other
    attributes such as power supply types, application or complexity have
    not yielded results.

c) Analyzed the new failure rate data to determine relationships which exist between power supplies and their host weapon replaceable assemblies (WRA). With few exceptions, the power supplies performed at a lower reliability than the equipment they supply power to. Efforts to correlate the results with respect to power supply type, application or degree of transient protection incorporated have been unsuccessful. The only correlation of any kind is the propensity for the power supplies with a higher predicted failure rate to perform worse operationally (with respect to their predicted failure rate) than those with lower predicted failure rates.

d) Data collection for this study has been completed. We are now in the process of determining what the adjustment factors should be and generating the final report. Per the statement of work, the report is due at RADC on the eighth of December.

Questions regarding this data submittal should be addressed to me at (314) 234-2914.

Wilson D. Yates III
Program Manager
Power Supply Fault Tolerant Reliability Study

Enclosure: (1) Program Schedule

EC: Seymour Morris RADC/RBER

POWER SUPPLY FAULT TOLERANT REL. STUDY

M72-CA-101   ETD   CRAD

CONTRACT - E-21-T08-S1   DEPT. NO. 346

TASK / REQUIREMENT	1989	90
	F M A M J J A S O N D	J

I. GO AHEAD - - - - - - - - - - - - - - - - - - -

II. SOW

1.0 COLLECT AND CATEGORIZE DATA ON TRANSIENT
     PROTECTION SCHEMES - - - - - - - - - - - -

2.0 COLLECT AND CATEGORIZE DATA ON GOOD POWER
     SUPPLY DESIGN GUIDELINES - - - - - - - - -

3.0 SELECT AVIONICS FOR THE STUDY - - - - - - -

     3.1 INPUT ON JOINT STARS EQUIPMENT LIST - -

     3.2 COLLECT PERTINENT DESIGN AND
          OPERATIONAL DATA - - - - - - - - - -

4.0 EVALUATE AIRCRAFT POWER BUS SPECIFICATIONS -

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6.0 ANALYZE COLLECTED DESIGN AND OPERATIONAL
     DATA - - - - - - - - - - - - - - - - - - -

7.0 ASSESS THE ANALYSIS AND DETERMINE 217
     ADJUSTMENT FACTORS - - - - - - - - - - - -

III. MEETINGS / TRIPS

8.0   INITIAL KICKOFF - - - - - - - - - - - - - -

9.0   PRESENTATION MATERIAL (CLIN 0002 ELIN A003)-

10.0 MIDTERM - - - - - - - - - - - - - - - - - -

11.0 FINAL - - - - - - - - - - - - - - - - - - -

IV. REPORTS

12.0 R & D STATUS REPORTS (CLIN 0002 ELIN A001) -

13.0 FINAL REPORT (CLIN 0002 ELIN A004)

      13.1 DRAFT - - - - - - - - - - - - - - - -

      13.2 RADC REVIEW - - - - - - - - - - - - -

      13.3 INCORPORATE CHANGES - - - - - - - - -

      13.4 FINAL - - - - - - - - - - - - - - - -

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: JUL-SEP '89

CURRENT QUARTER FUNDING $476,000.00
    DO # 0017 $10,000
         0026 $15,000
         0027 $20,000
         0028 $50,000
         0029 $40,000
         0030 $30,000
         0031 $20,000
         0032 $66,000
         0033 $70,000
         0034 $85,000
         0035 $70,000

                   $476,000

CURRENT QUARTER EXPENDITURES $415,422.69

  CONTRACT CEILING $4,200,000.00
  FUNDING TO DATE   - $2,029,675.00
* PENDING COMMITMENTS   - $253,994.00

        AVAILABLE FUNDING $1,916,331.00

  FUNDING TO DATE $2,029,675.00
  YTD EXPENDITURES   - $849,451.48

        OUTSTANDING EXPENDITURES $1,180,223.52

* DO # 0007   INCREMENTAL FUNDING $20,000.00
        0011   INCREMENTAL FUNDING $19,568.00
        0012   INCREMENTAL FUNDING $24,700.00
        0015   INCREMENTAL FUNDING $29,783.00
        0016   INCREMENTAL FUNDING $31,250.00
        0018   INCREMENTAL FUNDING $12,000.00
        0019   INCREMENTAL FUNDING $12,000.00
        0022   INCREMENTAL FUNDING $54,693.00
     N-0-5703 UNIV OF SOUTHERN FLA/WILSON $50,000.00

        TOTAL PENDING $253,994.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: APR-JUN '89

CURRENT QUARTER FUNDING $160,350.00
    DO # 0021 $25,000
         0022 $45,000
         0023 $20,350
         0024 $50,000
         0025 $20,000

                     $160,350

CURRENT QUARTER EXPENDITURES $318,963.82

CONTRACT CEILING $4,200,000.00
FUNDING TO DATE   - $1,553,675.00
*   PENDING COMMITMENTS   - $718,994.00

        AVAILABLE FUNDING $1,927,331.00

FUNDING TO DATE $1,553,675.00
YTD EXPENDITURES   - $434,028.79

        OUTSTANDING EXPENDITURES $1,119,646.21

*   DO # 0007   INCREMENTAL FUNDING $20,000.00
         0011   INCREMENTAL FUNDING $19,568.00
         0012   INCREMENTAL FUNDING $24,700.00
         0015   INCREMENTAL FUNDING $29,783.00
         0016   INCREMENTAL FUNDING $31,250.00
         0017   INCREMENTAL FUNDING $10,000.00
         0018   INCREMENTAL FUNDING $12,000.00
         0019   INCREMENTAL FUNDING $12,000.00
         0022   INCREMENTAL FUNDING $54,693.00
    B-9-3621   SRI/LUNT $20,000.00
    N-9-5308   KAMAN SCIENCES $100,000.00
    E-9-7119   DARTMOUTH COLLEGE/CRANE $100,000.00
    N-9-5740   CHRISTIANSON $15,000.00
    N-9-5317   UNIV OF CO/NORGARD $50,000.00
    S-9-7625   UNIV OF CA/DAVIS/KOWELL $20,000.00
    N-9-5314   KAMAN SCIENCES $100,000.00
    N-9-5315   KAMAN SCIENCES $100,000.00

        TOTAL PENDING $718,994.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: JAN-MAR '89

CURRENT QUARTER FUNDING $574,457.00
       DO # 0001 $90,729
            0011 $75,000
            0012 $75,000
            0013 $59,989
            0014 $49,989
            0015 $70,000
            0016 $43,750
            0017 $30,000
            0018 $22,000
            0019 $38,000
            0020 $20,000

                        $574,457

CURRENT QUARTER EXPENDITURES $86,324.15

CONTRACT CEILING $4,200,000.00
FUNDING TO DATE   - $1,393,325.00
* PENDING COMMITMENTS   - $594,651.00

       AVAILABLE FUNDING $2,212,024.00

FUNDING TO DATE $1,393,325.00
YTD EXPENDITURES   - $115,064.97

       OUTSTANDING EXPENDITURES $1,278,260.03

* DO # 0007   INCREMENTAL FUNDING $20,000.00
        0011   INCREMENTAL FUNDING $19,568.00
        0012   INCREMENTAL FUNDING $24,700.00
        0015   INCREMENTAL FUNDING $29,783.00
        0016   INCREMENTAL FUNDING $31,250.00
        0017   INCREMENTAL FUNDING $10,000.00
        0018   INCREMENTAL FUNDING $12,000.00
        0019   INCREMENTAL FUNDING $12,000.00
   C-8-2404   STANFORD UNIV/WIDROW $100,000.00
   N-9-5732   GRIFFIN $25,000.00
   A-9-1476   BOWDOIN COLLEGE/CHONACKY $20,350.00
   E-9-7110   UNIV OF LOWELL/SALES $50,000.00
   S-9-7559   UNIV OF MICHIGAN/ROBINSON $20,000.00
   B-9-3621   SRI/LUNT $20,000.00
   N-9-5308   KAMAN SCIENCES $100,000.00
   E-9-7119   DARTMOUTH COLLEGE/CRANE $100,000.00

       TOTAL PENDING $594,651.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: OCT-DEC '88

CURRENT QUARTER FUNDING $120,834.00
    DO # 0004 $66,680
        0006 $54,154

              $120,834

CURRENT QUARTER EXPENDITURES $28,740.82

CONTRACT CEILING $4,200,000.00
FUNDING TO DATE   - $818,868.00
* PENDING COMMITMENTS   - $784,729.00

    AVAILABLE FUNDING $2,596,403.00

FUNDING TO DATE $818,868.00
YTD EXPENDITURES   - $28,740.82

    OUTSTANDING EXPENDITURES $790,127.18

* DO # 0001   INCREMENTAL FUNDING $90,729.00
     0007   INCREMENTAL FUNDING $20,000.00
  C-8-2400   STATE UNIV OF NY/FAM $95,000.00
  C-8-2402   RENSSELAER/SAULNER $100,000.00
  B-9-3592   UNIV OF CA/DAVIS/LEVITT $60,000.00
  N-9-5514   SOHAR INC./HECHT $50,000.00
  C-9-2015   NCS/O'NEAL $100,000.00
  A-9-1120   HITEC, INC./KAZAKOS $75,000.00
  E-9-7057   UNIV OF TX/ARLINGTON/FUNG $40,000.00
  E-9-7093   MONTANA STATE/JOHNSON $34,000.00
  S-9-7552   ALFRED UNIV/SYNDER $20,000.00
  C-9-2404   STANFORD UNIV/WIDROW $100,000.00

    TOTAL PENDING $784,729.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: JUL-SEPT '88

CURRENT QUARTER FUNDING $698,034.00
    DO # 0001 $56,000
         0002 $95,141
         0003 $78,854
         0004 $230,000
         0005 $45,561
         0006 $25,000
         0007 $20,000
         0008 $98,374
         0009 $29,403
         0010 $19,701

                     $698,034

CURRENT QUARTER EXPENDITURES $0.00

CONTRACT CEILING $4,200,000.00
FUNDING TO DATE   - $698,034.00
* PENDING COMMITMENTS   - $426,563.00

        AVAILABLE FUNDING $3,075,403.00

FUNDING TO DATE $698,034.00
YTD EXPENDITURES   - $0.00

        OUTSTANDING EXPENDITURES $698,034.00

* DO # 0001   INCREMENTAL FUNDING $90,729.00
        0002   INCREMENTAL FUNDING $66,680.00
        0003   INCREMENTAL FUNDING $54,154.00
        0004   INCREMENTAL FUNDING $20,000.00
    C-8-2400   STATE UNIV OF NY/FAM $95,000.00
    C-8-2402   RENSSELAER/SAULNER $100,000.00

        TOTAL PENDING $426,563.00

CONTRACT FUNDS STATUS REPORT (DD FORM 1586)
CONTRACT NUMBER F30602-88-D-0025
QUARTER: MAY-JUN '88

CURRENT QUARTER FUNDING		$0.00
CURRENT QUARTER EXPENDITURES		$0.00
CONTRACT CEILING		$4,200,000.00
FUNDING TO DATE	-	$0.00
* PENDING COMMITMENTS	-	$766,000.00
AVAILABLE FUNDING		$3,434,000.00
FUNDING TO DATE		$0.00
YTD EXPENDITURES	-	$0.00
OUTSTANDING EXPENDITURES		$0.00

* C-8-2120	WESTINGHOUSE/BEAUDET	$56,000.00
C-8-2129	RENSSELAER/DAS	$100,000.00
E-8-7066	UNIV OF PENN/STEINBERG	$100,000.00
E-8-7124	BOSTON COLLEGE/McFADDEN	$35,000.00
E-8-7125	BRANDEIS UNIV/HENCHMAN	$23,000.00
E-8-7126	PENN STATE/CASTLEMAN	$22,000.00
A-8-1631	UNIV OF PENN/STEINBERG	$100,000.00
B-8-3617	GA WASHINGTON UNIV/MELTZER	$100,000.00
B-8-3618	GA WASHINGTON UNIV/BERKOVICH	$100,000.00
C-8-2492	GA TECH/SMITH	$50,000.00
A-8-1203	GA TECH/HUGHES	$80,000.00
	TOTAL PENDING	$766,000.00

REPORT DOCUMENTATION PAGE

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2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
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	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Power Supply Fault Tolerant Reliability Study (Unclassified)

12. PERSONAL AUTHOR(S)
David A. Followell

13a. TYPE OF REPORT Final	13b. TIME COVERED FROM 2/89 TO 12/89	14. DATE OF REPORT (Year, Month, Day) 89,12,08	15. PAGE COUNT 134

16. SUPPLEMENTARY NOTATION

17.	COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	power supply reliability, reliability, transients,
9	0901		transient protection, reliability predictions,
10	1002		MIL-HDBK-217

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The elimination of transient protection circuitry from power supplies will increase the predicted reliability, but in all likelihood, will decrease the fielded reliability. The major objective of this investigation was to establish adjustment factors which could be applied to MIL-HDBK-217 reliability predictions for avionic power supplies. The secondary objective was to identify design weaknesses, which if resolved, will lead to a more reliable power supply. Both objectives were accomplished; adjustment factors for transient protection circuitry have been developed and power supply design guidelines were established.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Donna M. Masi	22b. TELEPHONE (Include Area Code) 315 330 7060	22c. OFFICE SYMBOL PKRM

DD FORM 1473, 84 MAR   83 APR edition may be used until exhausted.   SECURITY CLASSIFICATION OF THIS PAGE
All other editions are obsolete.

Unclassified

Introduction & Summary

The need for this study is based on the premise that power supply design-
ers eliminate transient protection devices from their design in order to
increase the predicted reliability via a part count reduction. Eliminating
them will certainly increase the predicted reliability, but in all
likelihood, will decrease the. fielded reliability of the design. Transient
protection is defined as input and output overvoltage protection, current
limiting (normal operation), soft start circuitry or in-rush current
suppressors and snubbing of internally generated transients.

The major objective of this investigation was to establish adjustment
factors which could be applied to MIL-HDBK-217 reliability predictions for
avionic power supplies. The adjustment factors were to be based on the
level of transient protection designed into the power supply, and when
applied, would allow the design engineer an enhanced opportunity to design
a power supply that will survive both in the field and in the reliability
design review. The secondary objective was to identify design weaknesses,
which if resolved, would lead to a more reliable power supply.

The main objective was accomplished to a limited extent. Although we
were not able to develop adjustment factors for the overall power supply
based on the complexity of transient protection incorporated, we were able
to develop an adjustment factor for the transient protection circuitry
based on the relationship between the failure rate of transient protection
circuitry and the remaining electronics of the power supply. After
numerous data analyses, it became obvious there was no correlation between
the reliability of the power supplies and the level of transient
protection. However, correlation between the failure rate of the
protection circuity and the remaining circuity was very clear - protection
circuitry fails at a lower rate.

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Secondary objectives were also met. Several areas of the design process were found lacking: power supply procurement specifications lack the detail a designer needs to incorporate transient protection effectively, development programs do not include transient conditions as part of the qualification or reliability testing and analytical techniques are not supported by laboratory measurements in certain critical areas. There are 39 design guidelines in this report which, if followed to the extent practical, will help the designer achieve a more reliable product, the ultimate goal of everyone.

The overall effort was divided into seven tasks. A brief description of each task follows.

1) The first task was to collect information on the transient protection schemes utilized in modern power supplies. An extensive literature search was performed through our technical library. Forty-two power supply design textbooks, technical papers and component handbooks were digested for this task. A survey distributed to fifty-seven power supply manufacturers requested information on transient protection schemes, failure modes of power supplies, design trade-offs, etc. Chapter I summarizes the literature search effort and the survey results. The list of manufacturers who received the survey is included as Appendix A. The actual survey is attached as Appendix B and the returned surveys are included as Appendix C.

2) The second task was to collect information on good power supply design practices. Sources for this information included military hand-books, technical reports from Air Force research facilities, power supply design textbooks, published literature, component manufacturer's application handbooks and power design engineers within McDonnell. The informa-tion is contained in Chapter II and includes the design guideline, the reasons for the guideline and the source of the data.

3) The third task was to select avionics equipment representing a wide range of applications. The chosen equipment would form the basis for the analytical comparison to determine the effectiveness of transient protection schemes in enhancing operational reliability. Initially, this

task required selecting twenty pieces of avionics from the Joint Stars
platform equipment list that were being used on other airborne platforms.
This objective was not met, however, and an alternate equipment list was
chosen. Chapter III contains further information on the chosen equipment.

4) The fourth task was to collect and analyze the input specifica-
tions for the selected power supplies. This effort was necessary as a
baseline for the comparison of power supply reliability and to determine
what type of transients power supplies are designed to meet, if any.
Chapter IV contains the input specification information collected.

5) The fifth task was to determine the primary failure modes of power
supplies. This was to be accomplished by analyzing the "How-Mal" codes
obtained from the Air Force and Navy maintenance data system (Air Force
66-1 system and the Navy 3-M system) and by reviewing historical
reliability test data. Chapter V contains the collected information.

6) The sixth task was to analyze the collected operational field data
to determine the impact transient protection has on the selected power
supplies. This was done by comparing the operational field failure rates
to the predicted failure rates. Numerous comparisons were made in an
attempt to find some correlation between the transient protection schemes
and achieved reliability. Chapter VI contains the detailed information for
this part of the effort.

7) The seventh and final task was to establish MIL-HDBK-217 adjust-
ment factors with respect to power supplies based on previous analyses
conducted in the first six tasks. Chapter VII contains conclusions and
recommendations derived from this study.

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Chapter I
Transient Schemes

This chapter addresses several issues. Transients are defined and their
sources identified. Transient suppression techniques are discussed,
devices used in protection schemes are identified and examples of transient
suppressor applications are illustrated. The results of the industry
survey are also included.

Transients Defined

An electrical transient is defined as the condition which exists while a
circuit is seeking equilibrium following the upset of a steady state
condition, the result of stored energy being quickly released into a
circuit. Transient voltage and current levels range from totally unpre-
dictable (lightning) to totally predictable (switching of well defined
inductive loads). This transient energy can originate from within the
circuit itself or be transmitted or coupled into the circuit from an
external source.

Transient Effects

Transients in excess of a few microseconds can damage semiconductor
devices. Damage is usually caused by a large reverse voltage across the
p-n junction causing avalanche conditions to occur at a small area of the
junction due to high electrical field concentrations. A device may survive
an avalanche condition as long as the current is limited. If the current
is not limited, the semiconductor is heated beyond the point where the
coefficient of resistivity becomes negative, allowing even higher currents
to flow. The semiconductor has now reached the second breakdown region
characterized by current instabilities which lead to filamentary currents.
These current concentrations induce the semiconductor to melt creating low

resistance paths. Transients can also cause leakage current on the surface
of the passivation, which over time, will create a low resistance path
between terminals virtually shorting the junction of the device. Lead
wires and circuit traces are subject to thermal melting if the current
density becomes too high.

Passive elements, such as resistors or wire, will melt when subjected to
current densities beyond their specified ratings. The dielectric in
capacitors will break down or puncture if subjected to voltages beyond
their specified ratings. The current which flows through the breakdown
region will degrade the dielectric such that subsequent breakdowns will
occur at lower and lower voltages, finally resulting in a shorted capaci-
tor. The life of insulation also degrades as a function of voltage. See
Chapter II, Figures 31, 32, 33 and Design Guideline #37 for further
information on this topic.

Transient Sources

Internally generated transients result from switching actions which
present high rates of voltage or current change (dv/dt or di/dt) at the
power supply inputs and from the release of energy stored in the circuit
capacitance and inductance. The main source of internally generated
transients in power supply circuits is energy stored in inductors which is
released when the current is suddenly switched off, either by a switching
action or a fault condition. The voltage produced, equal to $-L\,di/dt$, can
add to the operating voltage stored in capacitors. The energy stored in an
inductor is limited to $1/2Li^2$ and is generally dissipated very rapidly at a
high instantaneous power (energy/time).

Prior to energizing a power supply, the input and output filter capaci-
tors are completely discharged. Once energized, very high currents (re-
ferred to as in-rush currents) will flow in an attempt to charge the input
capacitors. Simultaneously, the regulator will sense the output voltage
and, since the output voltage is low, drive the pass transistor on,
allowing the high currents to flow through the transistor to charge the
output capacitor. Several negative events can take place under these

2

transient conditions. First, rectifier diodes may be overheated. Second, the pass transistor will be subjected to very high currents at a time when the voltage drop across it is at a maximum, creating high power dissipations and junction temperatures. This can lead to transistor failure or degradation. Third, any inductor in series with this large current pulse will store a great deal of energy. When the transistor finally turns off, this energy will be dissipated across the output capacitor and load in the form of a high overshoot voltage with potentially destructive effects.

GP93-0571-4-D
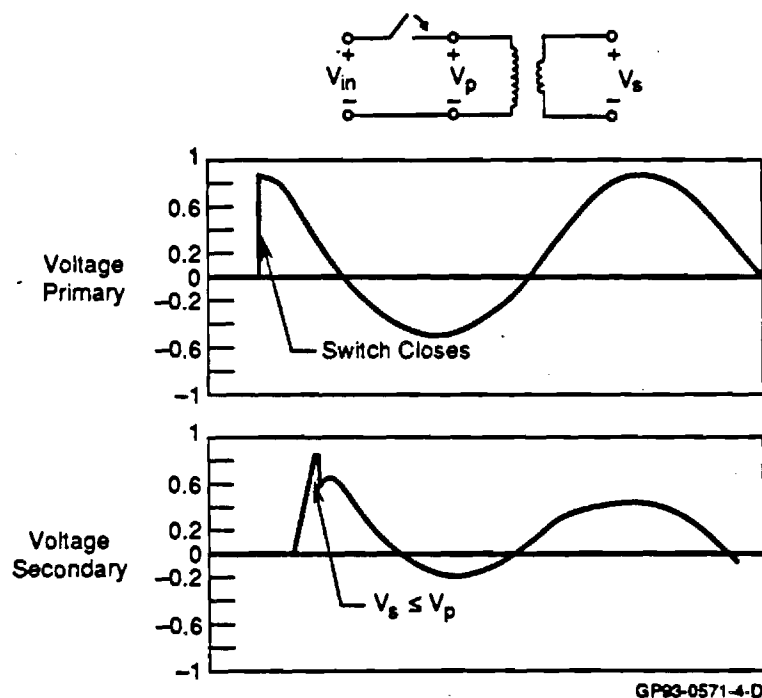
Figure 1.   Transformer Coupled Voltage Transient (Turn-on)

When a transformer has been switched into a circuit at the peak primary input voltage, the corresponding step input to the primary winding couples with the stray capacitance and inductance of the secondary winding to produce transient secondary voltages. The secondary side can be viewed as a capacitive divider via the interwinding capacitance. A capacitively coupled transient is not dependent on the turns ratio, so the secondary can possibly see a large fraction of the primary voltage as shown in Figure 1 (note, the turns ratio has nothing to do with the coupled energy in this scenario). Deenergizing the transformer initiates the rapid collapse of

the transformer's magnetic flux and magnetizing current inducing secondary
transients that can exceed ten times the normal secondary voltages as
illustrated in Figure 2.
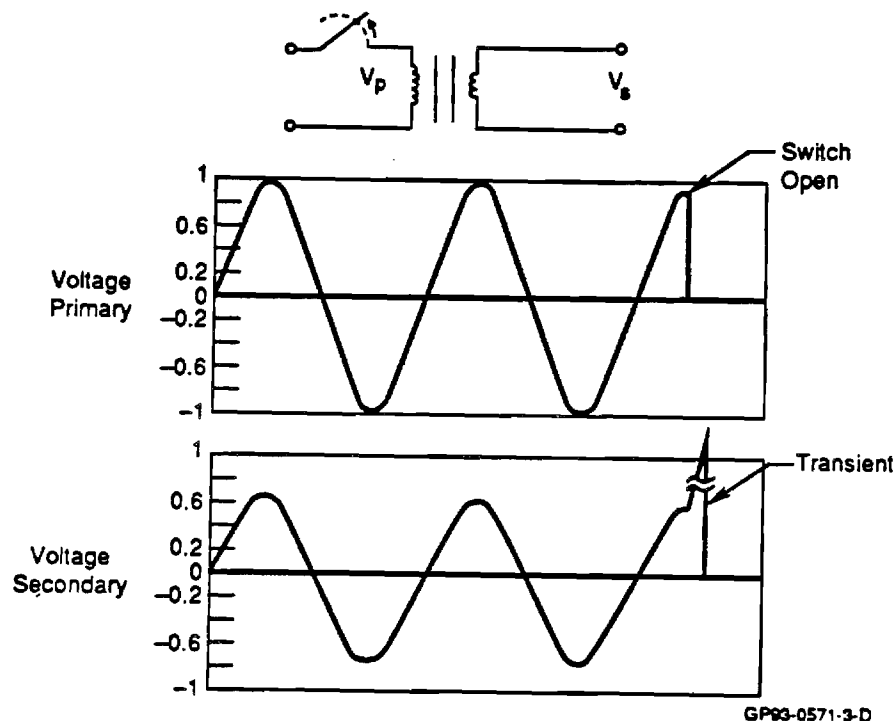
Figure 2.   Transformer Coupled Voltage Transient (Turn-off)

External sources of transients include electro-static discharges (ESD),
electro-magnetic pulses (EMP), power line transients and lightning. Pro-
tecting avionic power supplies from direct lightning strikes is impractical
since the strike may contain up to 200k amps of current. However, litera-
ture suggests that if one were to design a circuit to withstand peak
voltages to 5kV and peak current to 50A, the circuit would be protected
from 95% of transients induced by coupling from lightning strikes. IEEE
587, Guide for Surge Voltages in Low Voltage AC Systems, suggests three
different waveforms which simulate lightning induced transients for testing
electronic circuits. These waveforms represent IEEE's analysis of consumer
electrical systems, not military aircraft systems. However, in this case,
it appears the consumer requirements are more stringent than those of the
military, and in lieu of a military standard, it would be better to follow
the IEEE standard than none at all.

4

Figure 3 represents the wave shape the IEEE suggests using with
electrical devices used in the "indoor" environment, ie., low current
applications. This waveform tests the ability of the transient protection
circuitry to respond to a fast rising pulse with the associated nonlinear
voltage distributions within the circuit and the ability of semiconductors
to handle high dv/dt rates. The oscillating portion tests the ability of
the circuitry to handle voltage polarity reversals. For power supplies
that can be subjected to high currents, the IEEE provides two
unidirectional pulses as illustrated in Figures 4 and 5. Figure 4 is
generally used when testing a device with a high input impedance and Figure
5 is used for devices with a low input impedance. The new version of
MIL-STD-461 (Electromagnetic Emission and Susceptibility Requirements for
the Control of Electromagnetic Interference) contains two conducted
susceptibility tests which are being specified to simulate coupling of a
lightning strike into the interface wiring of military avionics. These two
tests are referred to as CS10 and CS11. Figure 6 illustrates the waveform
the equipment must be able to handle without any degradation of performance
or permanent malfunction.
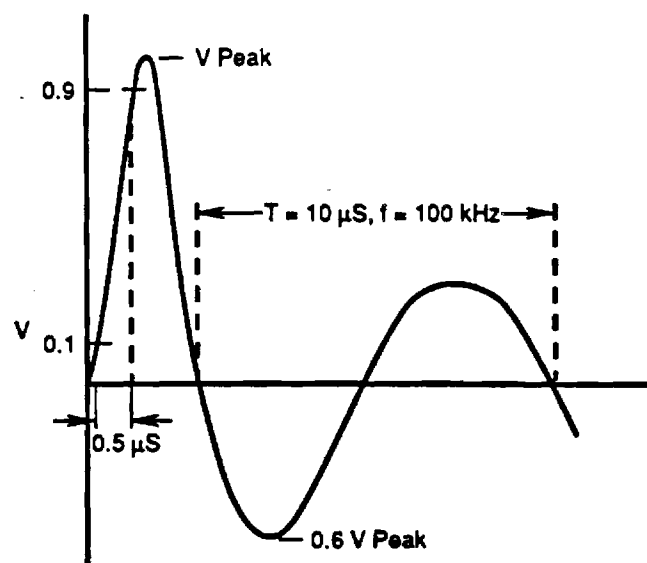
Figure 3. IEEE Oscillating Voltage Transient
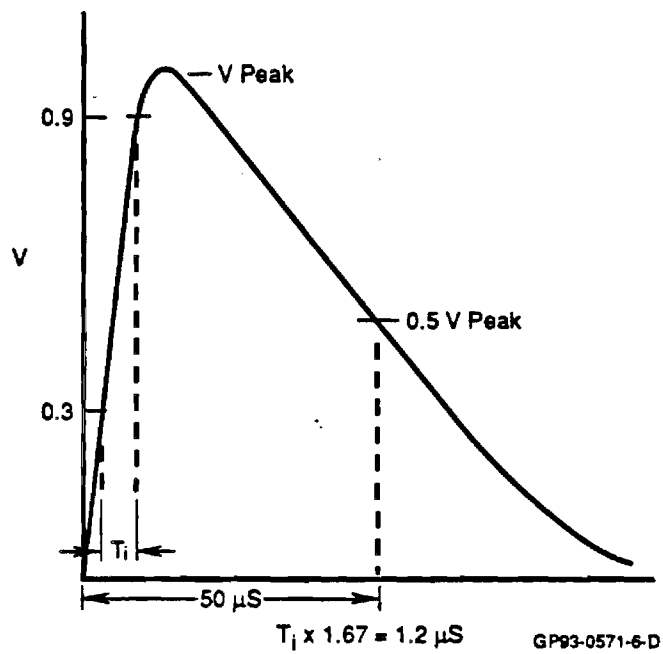
Figure 4. IEEE Unidirectional Voltage Transient
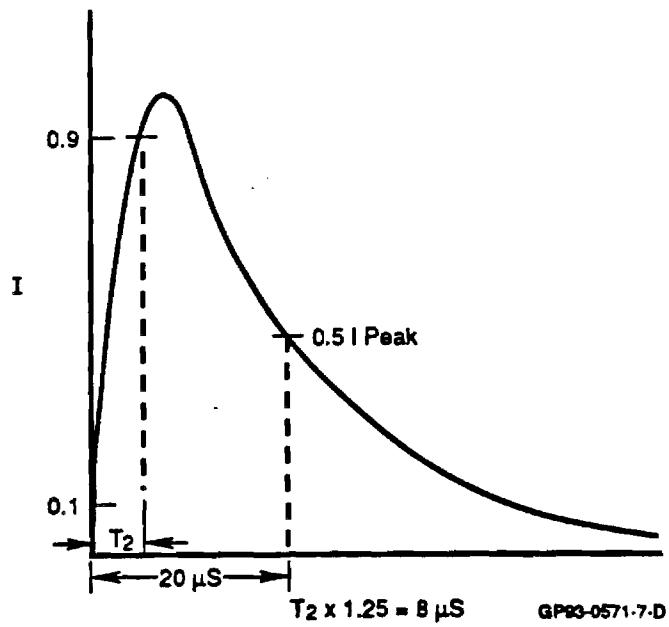
Figure 5. IEEE Unidirectional Current Transient

6

I (t) = Common Mode
     Current in Amps
f = Frequency, Hertz
t = Time, Seconds
Q = Decay Factor

$$I_{Cable}(t) = 1.05\, I_{max}\, e^{-\frac{\pi f t}{Q}} \sin(2\pi f t)$$

GP93-0571-8-D
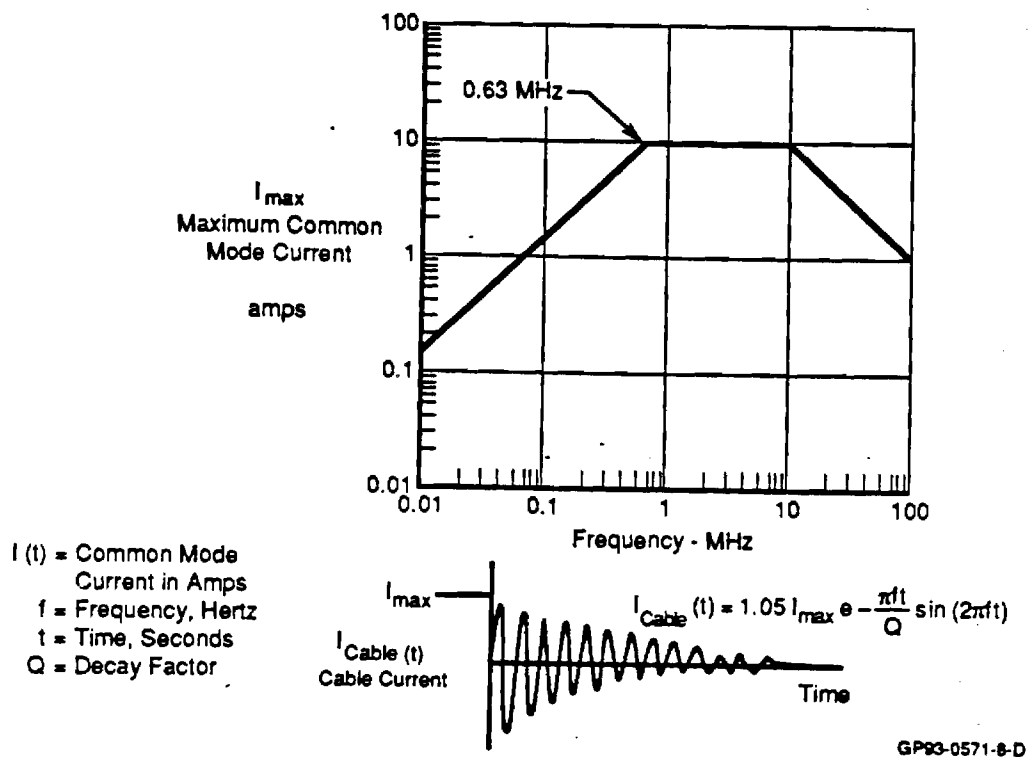
Figure 6. _MIL-STD-461 CS10/11 Current Transient_

ESD can produce even higher peak voltages of up to 20kV with a dv/dt of 2kV/nanosecond. Fortunately, the current associated with ESD is very small and most electronics at the I/O interface of power supplies are not ESD sensitive.

Transient Propagation

Once a transient condition is generated, there are two modes of propagation within the circuit: transverse (or normal) mode and common mode. Transverse mode transients are identical to normal signal propagation (the signal is transmitted down one line, through the load and back on the return line). They are generally a result of some switching action within the circuit. A common mode transient is one in which the transient propagates down the signal and return line in the same direction. They are generally caused by lightning strikes (either direct or coupled), NEMP or electro-magnetic interference (EMI) from another source. Common mode

transients have no trouble passing through the interwinding capacitance of a transformer since the components of transients are generally high frequency in nature. Similarly, transverse mode transients can be coupled through a transformer and be transformed into a common mode transient on the secondary side allowing the full transient to be present on the secondary side. Figure 7 illustrates a transverse mode transient and Figure 8 illustrates a common mode transient.

E = Transient Voltage

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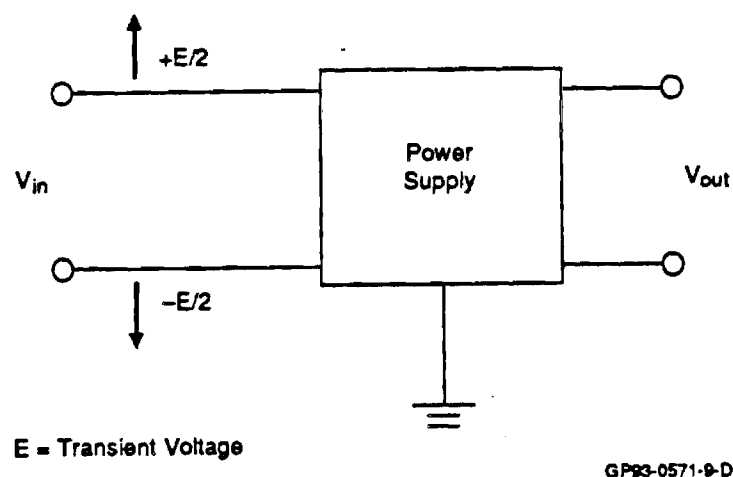
Figure 7. Transverse Mode Transient

E = Transient Voltage

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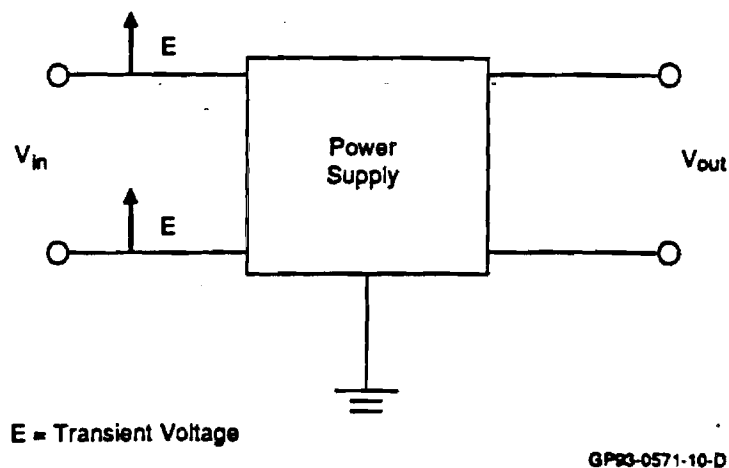
Figure 8. Common Mode Transient

8

Transient Suppression Techniques

There are three basic transient suppression techniques: redirect the
transient, shut down the power supply or attenuate the transient. A
transient can be redirected with voltage clamps and crowbars. Power
supplies are generally shut down via the action of a monitor/control device
or via the action of a fusing device. Filters, resistors and thermistors
are used to attenuate transients.

Voltage clamps are implemented with devices which have nonlinear
voltage-current (VI) characteristics as illustrated in Figure 9. The main
advantage of a voltage clamp is that the operating voltage is maintained
across the protected device, allowing normal circuit functions to continue.
Clamps are connected in parallel with the protected device and are some-
times referred to as passive transient protection. At normal voltage
levels, clamps present a high impedance, thus allowing little current to
flow while maintaining a large voltage drop (the steady state operating
voltage). As the voltage rises above normal operating levels, the turn-on
voltage will be reached and the clamps will begin to conduct. Ideally,
that voltage level (turn-on voltage) will be maintained (or clamped) while
the current flow will rise exponentially and be shunted to ground, thus
protecting the circuit and allowing the circuit to remain functional.
Clamps will remain conductive until the voltage drops below the turn-on
voltage. The main disadvantage of a clamp is that during the clamping
period, the clamp will dissipate a considerable amount of power if current
levels become excessive. Clamping efficiency depends on the source
impedance of the transient since the clamp forms a voltage divider network
with the source impedance, ie., the increased current flow causes a large
voltage drop across the source impedance. If the source impedance is very
small, clamping techniques will not be effective.

Crowbars are implemented with devices which are "switched" from a very
high (ideally infinite) impedance to a very low impedance (virtual short)
at a given voltage threshold. Crowbars are sometimes referred to as active
transient protection due to this switching action. When switched to the
low impedance state, the voltage across the circuit to be protected drops
very low (0-1 volts) and current flow is shunted to ground producing a

voltage current (VI) characteristic as shown in Figure 10. Since the
resulting voltage across the circuit is so low, the circuit becomes non-
functional, a major disadvantage of crowbars. Another disadvantage of a
crowbar is the current which flows after the device begins to conduct can
be very high. Referred to as the follow-on current, this current generally
will not damage the crowbar device since the dissipated power is so low,
but it can cause damage to other components through which the transient
current is flowing. Also, since the follow-on current is maintained at a
voltage much lower than normal operating voltages, the circuit continues to
not function. To stop the follow-on current, the voltage must be lowered
below the holding current, thus resetting the crowbar.

Power supplies can be shut down by removing the base drive from the drive
transistors or by a fusing device, the primary methods of handling an
overcurrent condition. Over-current protection is intended to protect the
power supply from the effects of shorted outputs by shutting down the power
supply. Shorted outputs can be manifested by conducting crowbar devices,
the load failing short, the transmission line shorting or through careless
maintenance practices. Short circuits cause high current levels to flow

I

Linear VI

Non-Linear VI

V   GP93-0571-11-D
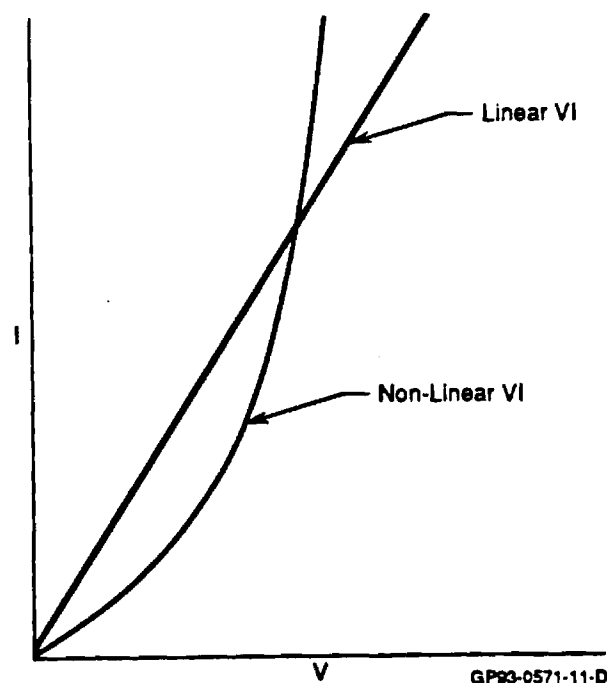
Figure 9. Linear and Nonlinear Volt - Current Characteristics

10
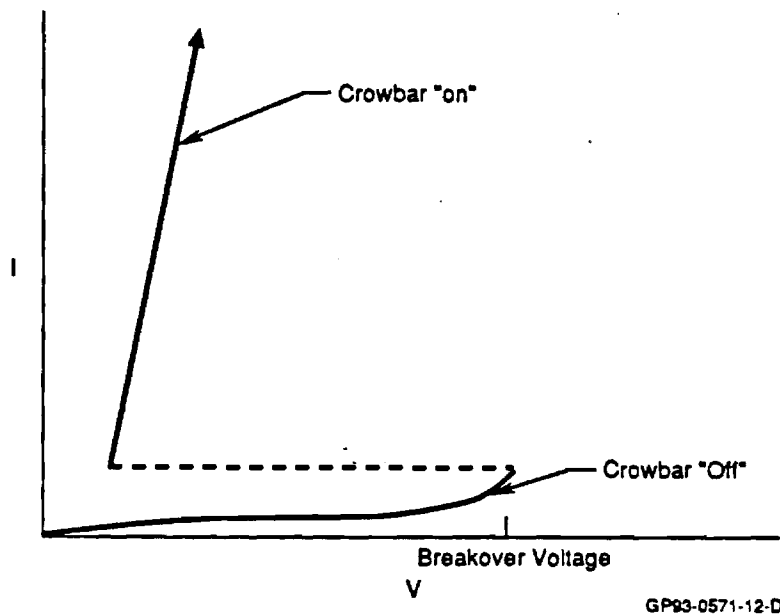
Figure 10. Crowbar V-I Characteristic

which will not be detectable by an overvoltage sensor. Overcurrent situa-
tions are sensed by current sensing transformers or voltage divider net-
works. The output of these devices is fed to voltage comparators with a
reference voltage as the other input. Excessive current provides an output
signal which will trip the comparator. The comparator outputs a signal
which can be used to shut down the supply. Fusing devices such as circuit
breakers or fuses can be used, but their response time is slow compared to
other techniques and some type of human action is generally necessary to
restore power to the circuit, ie. resetting a circuit breaker or replacing
a fuse, an undesirable situation.

Filters are used to attenuate transients. Since most transients are high
frequency in nature, a low pass filter is generally effective. Drawbacks
include self induced resonance with other active components in the circuit
and high in-rush currents during turn-on. Resistors, thermistors and
inductors can be used to limit the in-rush current, but they reduce the
efficiency of the power supply under normal operating conditions.

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Transient Suppression Devices

A good transient suppressor should possess the following characteristics:

1) No leakage current (standby power consumption).
2) High surge energy absorption capabilities.
3) No characteristic change/drift with time.
4) Instant response.
5) No follow-on current.
6) Be cheap and reliable.
7) A clamping ratio equal to one.

Items 1-6 are self explanatory. Item 7, the clamping ratio (CR), is a figure of merit for transient suppressors. It is defined as the clamped voltage (Vc) at some specified pulsed current condition divided by the stand-off voltage (Vr), the voltage at which the suppressor begins to conduct or bypass current. An ideal clamp would have a CR=1, ie., the clamped voltage equals the stand-off voltage regardless of the current flowing through the device, thus allowing the circuit to remain functional and not subjecting the protected components to voltage levels exceeding the standoff voltage. In order for a transient protection device to have a CR equal to one, the VI relationship must be nonlinear. This is represented by the equation $I = KV^n$ where I is the current, V is the voltage, K is a constant and n is equal to some value representative of the device. Figure 11 illustrates the effect various values of n have on the VI characteristic. On the graph, a vertical plot (high value of n) is equivalent to a CR equal to one. If the CR is greater than one, the voltage across the load will be greater than the standoff voltage. If the CR is less than one, the voltage across the load will be less than the standoff voltage.

There is one negative aspect to having a high value of n. As mentioned in the previous paragraph, high values of n are necessary to clamp voltages at a given value (CR=1). However, devices with a high value of n turn on much quicker than devices with a low n. If a supply has poorly regulated (within tolerances) inputs or outputs, the high n devices will be turning on and dissipating more power during normal steady state operations than devices with low values of n. This is illustrated in Figure 12.

12
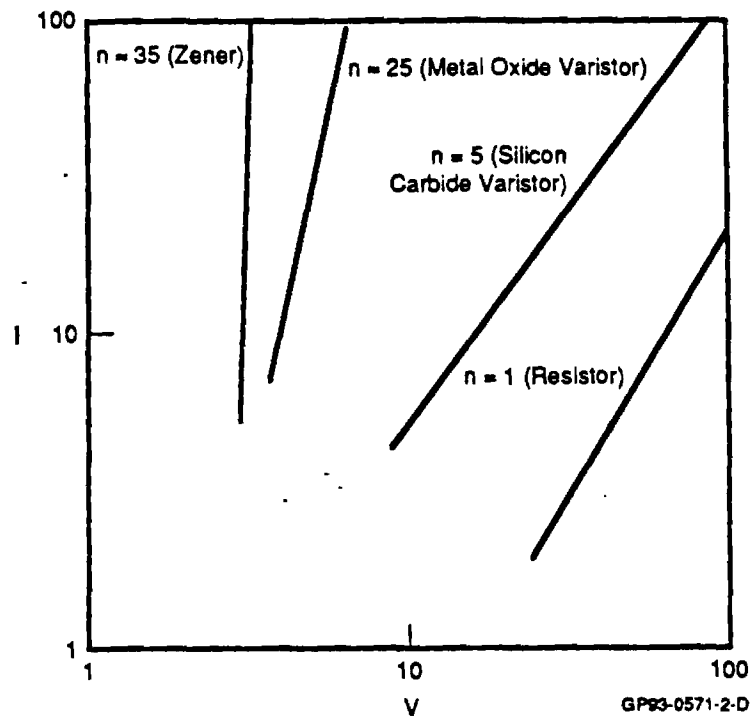
Figure 11. V-I Characteristics for Various Values of n
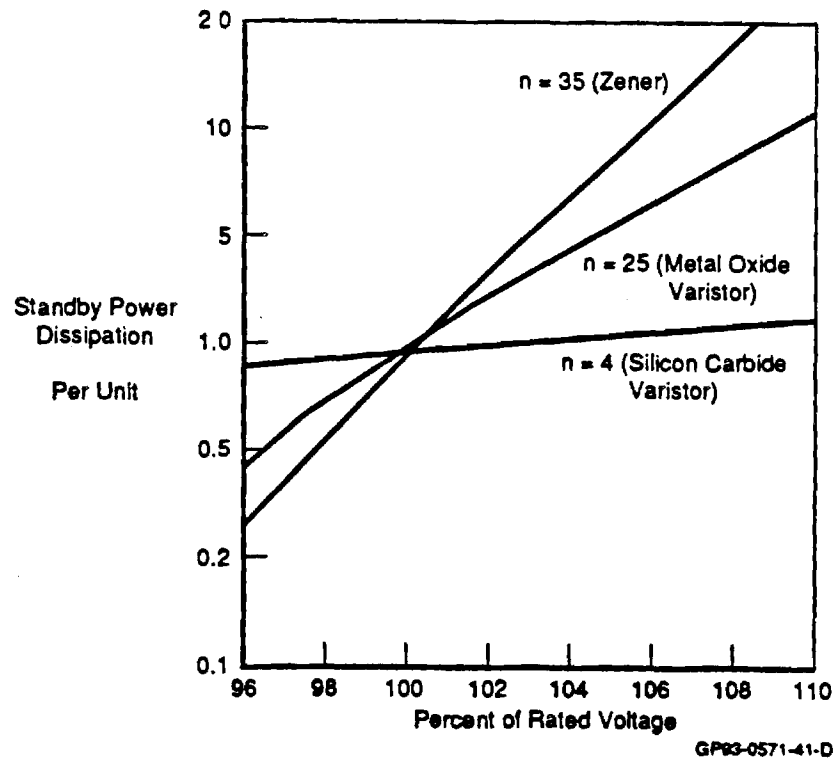
Figure 12. Standby Power Dissipation

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The attributes listed above are available in varying degrees depending on the device in question. Table 1 summarizes the advantages and disadvantages of the various protection devices. Unfortunately, there is no single transient protection scheme or device which can provide protection against all possible transients. Devices all have their niche whether it be high power dissipation, quick reaction times, available voltage ratings, precise clamping voltages, cost, size, operating temperatures, capacitance, etc. The following paragraphs will highlight the pros, cons and application of the various devices which are used in transient protection schemes.

Transient Suppression Diodes

Transient suppression diodes (TSD) are two terminal semiconductors with very sharp reverse voltage breakdown characteristics at a specific voltage. Under forward bias conditions, a TSD's VI characteristic is identical to a normal diode (see Figure 13a). But, when subjected to reverse bias, the TSD will breakdown at a specific voltage and begin conducting in the avalanche mode. The circuit symbol for a TSD is shown in Figure 13b. As

Device	Clamping Ratio	Response Time	Leakage Current	Allowable Currents	Voltage Ranges	Size
Zener(TSD)	1-1.5	10^{-12}	Medium	50A (1ms) 600A (200ns)	5-400V	Small
Thyristor(SCR)	~0	10^{-9}-10^{-6}	Low	2000A (1ms)	5-800V	Medium
Metal Oxide Varistor	1.25-2	10^{-9}-10^{-6}	Medium	6500A(1ms)	5-1200V	Medium
Spark Gap or Gas Tube	~0	10^{-6}-10^{-5}	Very Low	10000A (1ms)	90-20kV	Large
Surgector	~0	10^{-12}-10^{-9}	Low	200A (20μs)	30-270V	Medium
Thermistor	NA	10^{0}	NA	--	--	Small
Fuse/Circuit Breaker	0	10^{-9}-10^{0}	NA	--	--	Medium
Ideal	1	10^{-12}	Very Low	Very High	Low-High	Small

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Table 1. Transient Protection Device Comparison

illustrated, the symbol and the VI curve for a TSD is identical to a that of a Zener diode. TSDs differ from Zeners in that they have been designed to dissipate heat more efficiently and the surface geometry of the diode junction has been designed to eliminate localized high electric fields which allow reverse leakage current on the surface of normal Zener diodes. This ensures that bulk breakdown occurs at a specific reverse voltage.

TSDs are used to redirect transients away from the circuit that is being protected. As a transient suppressor, TSDs offer several major advantages over other devices. Response time to transients is measured in pico-seconds, several orders of magnitude better than other devices. TSDs are available for lower voltage applications, offer better clamping ratios and the capacitance of a TSD is minimal. The major disadvantage of a TSD is its limited power dissipation ability when compared to other devices. This is mainly due to the small junction area of the diode which results in high current densities and high junction temperatures. Additionally, the TSD maintains a working voltage across its terminals which causes a high power dissipation (power equals the product of voltage and current).

(a)   (b)
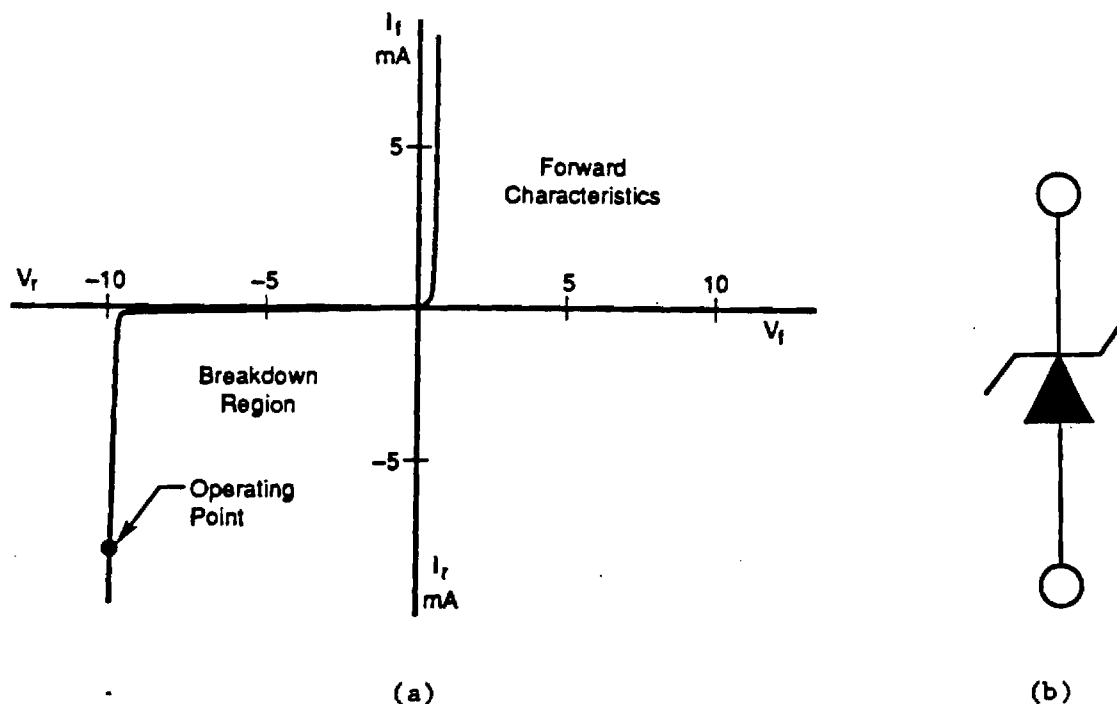
Figure 13. Transient Suppression Diode Characteristics

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When a TSD fails, it will generally fail short for long enough to allow a fuse or circuit breaker, somewhere in the power supply input, to open. Failing short is the result of current filamentation discussed earlier. A TSD can fail open if current filamentation continues long enough to melt the silicon, but it will almost always occur after failing short allowing enough time for a fuse or circuit breaker to open. Failing short guarantees a zero voltage drop across the circuits to be protected. Devices that fail open expose the protected circuit to the full transient condition and will not be able to divert the overvoltage condition.

Varistors

Varistors are voltage dependent, nonlinear resistors where the current (I) varies as a power of the applied voltage (V), or $I = KV^n$ (where n is typically 2 to 4). As illustrated in Figure 14a, varistors possess symmetrical VI characteristics similar to back-to-back Zener diodes. Their schematic representation is shown in Figure 14b. They are two terminal

(a)   (b)
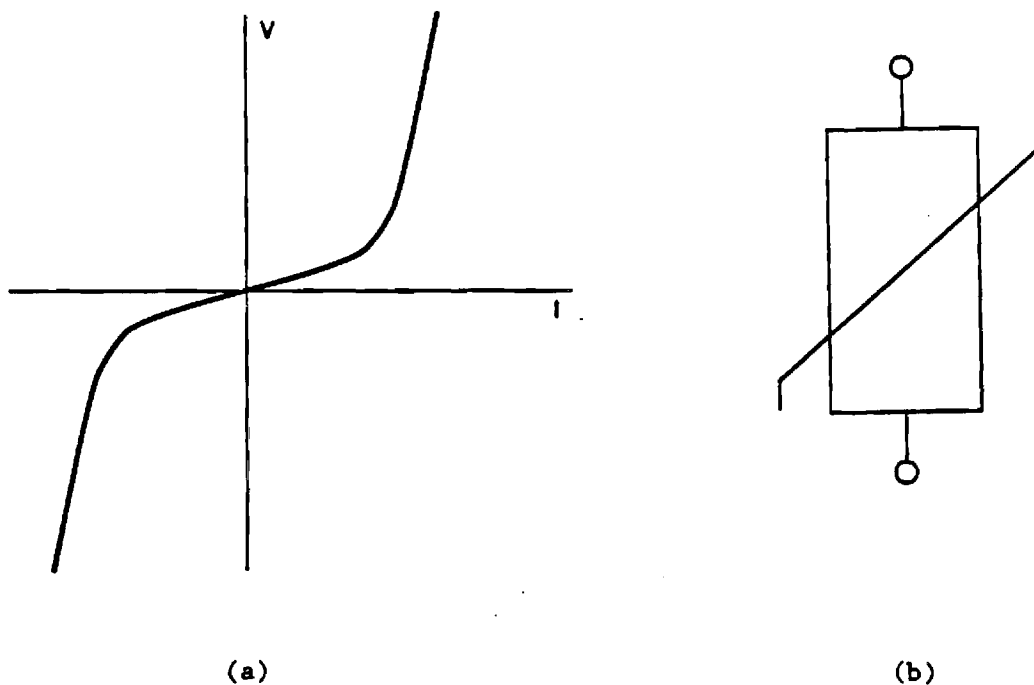
Figure 14. Varistor Characteristics

devices made of either silicon carbide or, more commonly, metal oxides. The metal oxide varistor (MOV) is composed primarily of zinc oxides with small additions of bismuth, cobalt, manganese and other metal oxides. The body of the varistor consists of a matrix of conductive zinc oxide grains separated by grain boundaries which act as PN junctions. These boundaries are responsible for blocking conduction at low voltages and nonlinear conduction at higher voltages. These numerous PN junctions distribute the current evenly throughout the device resulting in uniform heat distribution allowing the varistor to be used in high power situations.

When wired in parallel with the circuit to be protected, varistors do not affect normal circuit operation. When a transient voltage exists, the device begins to conduct when the turn-on voltage is reached. The voltage is then clamped while the current increases exponentially, just as in the TSD. However, the clamping ratio of a varistor is not as good as a TSD's. Therefore, under a given transient condition, the varistor will allow the voltage to rise to a higher clamping level than the TSD would. The response time of varistors is measured in nanoseconds and the capacitance of a varistor can become a factor in circuit performance given the right conditions. The major disadvantage of varistors, however, is their propensity to explode under energy conditions significantly in excess of rated values resulting in expulsion of hot material. Siemens, a MOV manufacturer, recommends physically shielding varistors to avoid damaging other components.

Thermistors

Thermistors are thermally sensitive resistors which can exhibit either positive or negative coefficients of resistance when their body temperature changes. Figure 15a illustrates this characteristic for both types of thermistors. Thermistors are made of manganese, nickel and cobalt oxides. These materials are mixed in suitable proportions and combined with binders before being pressed or extruded into the proper shape. The circuit symbol used for thermistors is shown in Figure 15b.
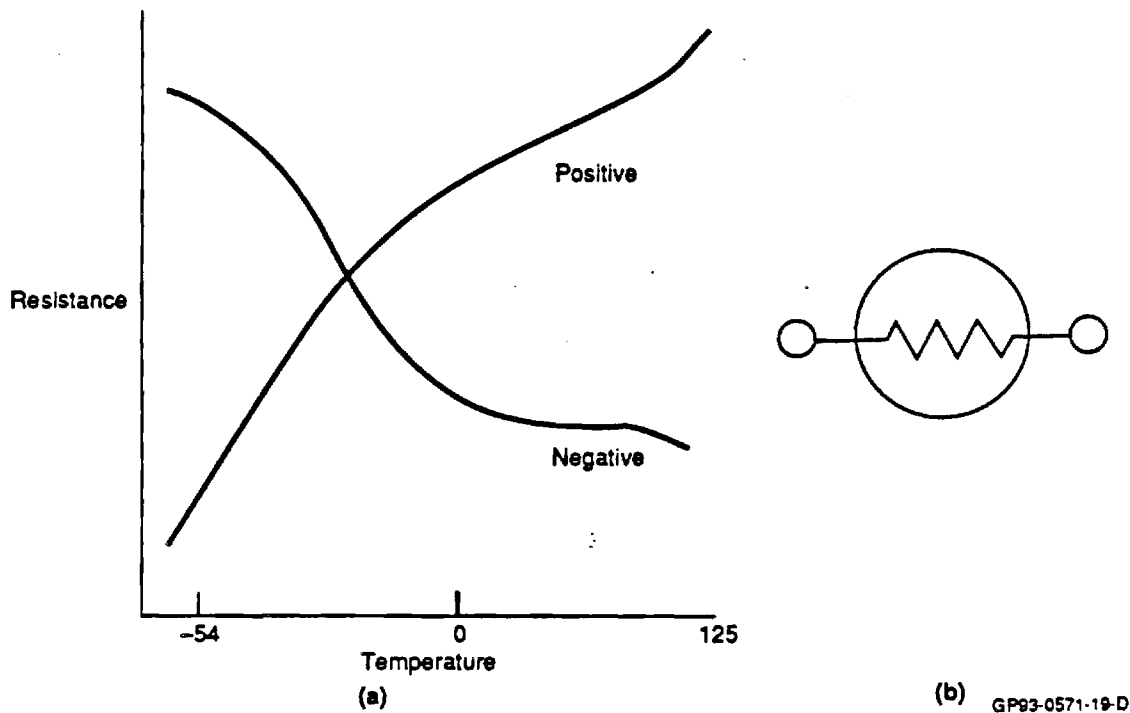
Figure 15. Thermistor Characteristics

The positive and negative coefficient of resistance allows thermistors to be used in unique functions. For example, when circuits are initially energized, a large transient in-rush current can be induced as the circuit charges a capacitor or by the low resistance of a cold filament. To limit in-rush current at turn-on, a thermistor with a negative coefficient of resistance can be placed in series with the primary supply. When the supply is energized, the cold thermistor limits the current flow due to its high resistance. Once current begins to flow, the device heats up and the resistance begins to drop allowing more current to flow. Ultimately, the thermistor reaches a resistance at which it dissipates negligible amounts of energy and allows the circuit to function normally. Positive coeffi-cient thermistors can be used to limit current during transient conditions by placing the device in series with the load. Under normal circuit condi-tions, the device presents a negligible resistance. If an overcurrent condition exists, the device begins to heat up raising the resistance until the current is controlled.

The major drawback of thermistors is the heating and cooling hysteresis (or time constant) they exhibit. For example, under normal operating

conditions, a thermistor used as an in-rush current limiter will be heated
to its operational temperature, thus exhibiting negligible resistance. If
a transient condition suddenly removes power from the circuit, the power
supply will shut down. When the transient condition ends, the power supply
will turn back on. However, since the thermistor can not cool down in-
stantly, it is still at its operational temperature and, therefore, is
incapable of limiting the in-rush current. Alternatively, a positive
coefficient thermistor which has limited an overcurrent situation will
continue to inhibit normal circuit operation until enough time has elapsed
for it to cool after the transient is removed.

Silicon Controlled Rectifier (SCR)

The SCR, also known as a thyristor, is a four layer p-n-p-n device with
three terminals (see Figure 16). Basically, it is a diode with a control
gate. The device will not conduct (other than a small leakage current)

b.   Anode O———⌐ p | n | p | n ⌐——————O Cathode

O Gate

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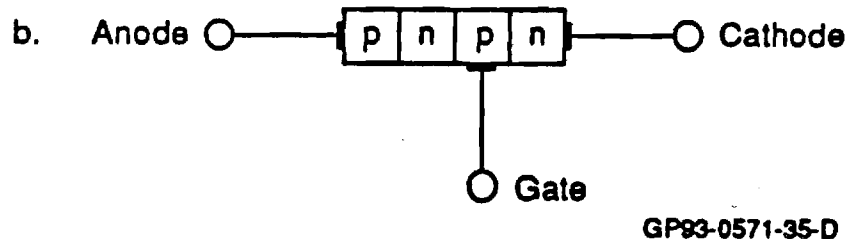
Figure 16.   SCR Construction

when forward biased until a voltage, referred to as the breakover voltage,
is reached. At this point, the current increases rapidly and the voltage
drop decreases drastically. The voltage applied to the gate serves to
decrease the breakover voltage point. Once the breakover voltage has been
exceeded, the SCR will conduct current as long as a forward bias is main-
tained, irregardless of the gate voltage or the voltage across the other
two terminals. The gate can not be used to shut down the SCR. To inhibit
current flow through the SCR, a reverse bias must be established. SCRs
have specified turn on times in the nano- to micro-second range and require
10-100 microseconds of reverse bias to reestablish forward blocking. The

circuit symbol and the VI characteristic for an SCR are shown in Figures 17a and b.

"On" State —

Reverse Blocking State —

Breakover Voltage

"Off" State

Reverse Breakdown Voltage

V

(a)   (b)
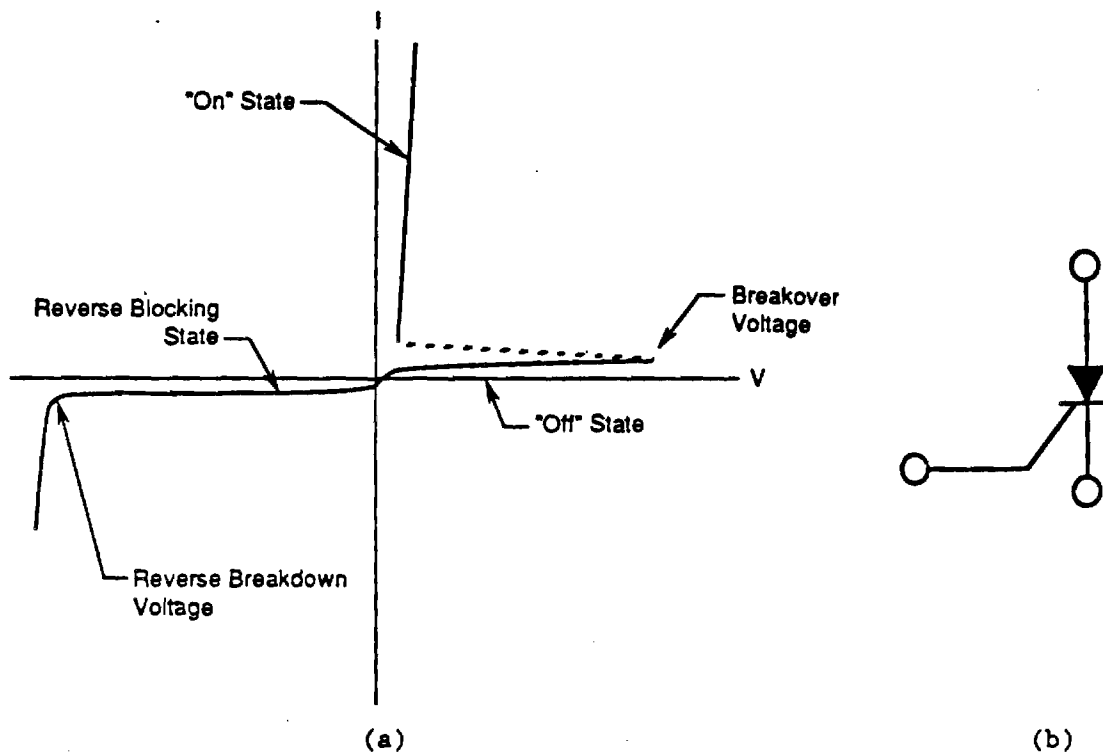
Figure 17.   SCR Characteristics

Gate Turn Off or Gate Controlled Switch (GTO or GCS)

The GTO/GCS device is a thyristor which can be turned off by applying a negative signal to the gate. It is sometimes referred to as a turn-off thyristor. The circuit symbol for one of these devices is shown in Figure 18. VI characteristics are identical to Figure 17b.

Gas Discharge Tubes (GDT)

GDTs operate by switching from a very high impedance to a very low impedance in the presence of a high voltage potential (breakdown voltage). This switching action occurs when the inert gas in the tube ionizes and begins to support conduction in the glow region. Increasing current causes the device to conduct with an arc, maintaining a constant voltage (typi-

20
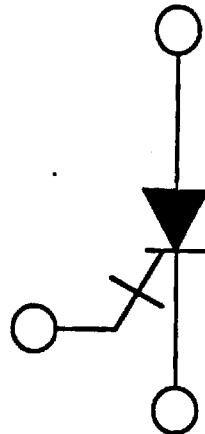
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Figure 18.

GTO/GCS Schematic Symbol
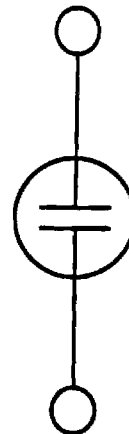
GP93-0571-26-D

Figure 19.

Gas Discharge Tube Schematic Symbol

cally 15 volts) regardless of the current flow. The GDT will stop con-
ducting when the voltage is dropped below the arc voltage. Since the
voltage necessary to maintain an arc is much less than the voltage neces-
sary to initiate an arc and may be less than typical operating voltages,
the arc will be maintained after the circuit voltage returns to normal.
Therefore, a method is needed to extinguish the arc. The major drawback to
these devices is the time it takes for the transient to ionize the gas and
the subsequent transition time to arc (typically microseconds). The
circuit symbol for a GDT is shown in Figure 19. The VI characteristic of a
GDT is similar to that of Figure 17b.

Transient Monitors/Controllers

There are many integrated chip suppliers who manufacture monolithic power
supply monitoring devices. These devices can sense overvoltage,
overcurrent, undervoltage and overtemperature conditions. Once sensed, the
devices respond by triggering crowbars or sending shutdown commands to the
regulator. Several examples have been included here to highlight the
capabilities of these chips.

The Silicon General SG1543 is a monolithic integrated output supervisory
circuit which provides overvoltage and undervoltage sensing, current

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sensing and an SCR crowbar trigger driver in a standard 16 pin DIP. The voltage monitors can respond to transients within 400 nanoseconds, but longer delays can be selected via appropriate choices of external capacitors. The current sense can respond within 200 nanoseconds. The output response can be configured for fault indication, voltage limiting, power supply shutdown or any combination of the three. The overvoltage output is directly connected to the onboard SCR driver. A remote activate pin for the SCR driver can be connected to the current sensor output or some other source for additional capabilities.

The RCA Surgector is a transient suppressor which consists of a thyristor with a Zener diode diffused across the gate region. This is accomplished on a monolithic substrate. The Surgector combines the quick response of a Zener and the large current capacity of an SCR. When the Zener begins conducting, the gate of the SCR is energized turning the SCR on. The Surgector turns off when the current drops below the holding current. The Surgector is capable of handling up to 10kV/uS dv/dt and is capable of turning on in nanoseconds. The schematic representation and the circuit symbol are shown in Figure 20. The VI characteristic is similar to that of Figure 17b.
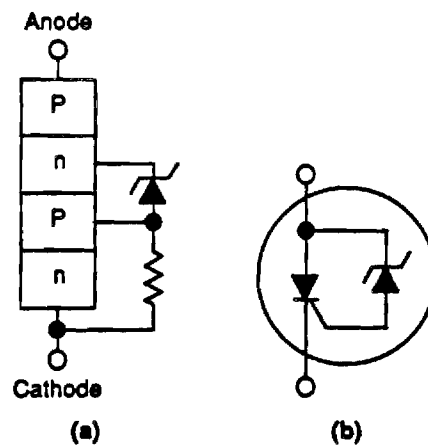
GP93-0571-28-D

Figure 20. RCA Surgector

SMARTPOWER is a monolithic integrated chip manufactured by Motorola. The device monitors for overvoltage and over temperature conditions. When

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these conditions exist, an onboard SCR is fired to redirect the transient condition. The device can switch on within 5 microseconds and shunt up to 35A of continuous current. An external line control is available to switch the SCR on if desired.

Applications of Transient Protection Devices

The following paragraphs will illustrate various ways of using transient protection devices as a means to clamp voltages, divert currents or attenuate transients. These designs will protect the power supply and the load from internally and externally generated transients.

Voltage Clamp

To protect a power supply from voltage spikes generated on the main power bus or from spikes generated at the load, transient suppression diodes (TSD) should be placed in parallel with the transient source and/or in parallel with the device to be protected. The output TSD will also protect the load from overvoltages generated by the supply. Figure 21 illustrates the use of a TSD at the input to a power supply and at the load. In these installations, the voltage at the input or output will be clamped at the rated value of the TSD. Varistors can be used to clamp the input or output of a power supply in the same manner as a TSD. For circuits subject to

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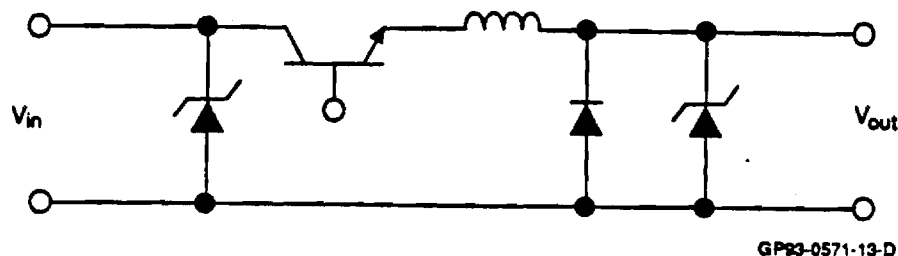
Figure 21. Voltage Clamp using TSDs

very high voltage transients and subsequent high current transients, a gas discharge tube can be used to replace the TSD.

If it is essential that voltages be maintained under some specified value due to the cost of the equipment or if it is acceptable to lose functionality during transients, a crowbar can be used to clamp overvoltages. Figure 22 illustrates a crowbar device consisting of a resistor, a varistor (or TSD) and an SCR. When the voltage rises to the point where the the TSD begins to conduct (or breakover), a voltage will be induced across the resistor and will turn on the SCR. When the SCR turns on, the voltage across the output will drop to approximately one volt. This technique has the advantage of a TSD's quick response and the SCR's high current capabilities. While this is a very simple and inexpensive design, it suffers from two disadvantages - 1) When the SCR begins to turn on, the voltage and current across the TSD begins to fall, thus robbing the
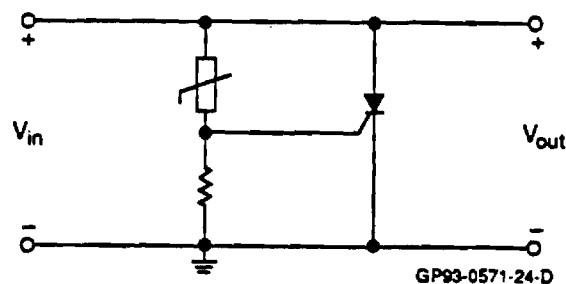
Figure 22. Crowbar Implementation
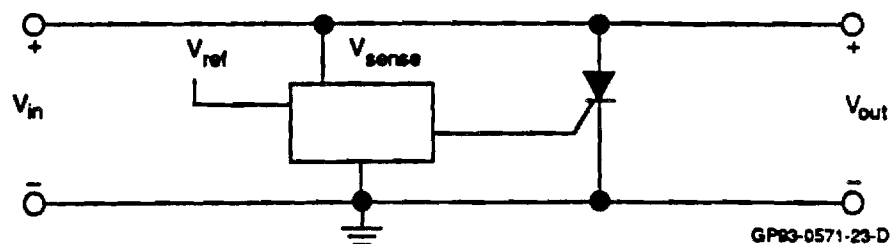
Figure 23. Latched Crowbar Implementation

gate drive for the SCR resulting in a "slow" gate turn on. A method of
latching the gate drive on may be desirable if space permits. This method
is illustrated in Figure 23 where a voltage monitor has been used to supply
the necessary gate drive to fire the SCR. 2) The power must be totally
removed, to reset the SCR, before operation can resume. A GCS or GTO,
which can be used in identical applications as SCRs, could be used
to avoid this problem.

When SCRs, GCSs or GTOs are used to suppress voltage transients, some
form of current limiting is necessary to avoid damage. Recall that an SCR
presents a very low impedance path and will therefore allow large amounts
of current to flow. In order that the power supply remains protected at
times of sustained high currents, some type of fusing device should be used
on the input supply. It should be selected so it will not open unless the
internal current limiting features (discussed in the next paragraph) fail.

Current Limiting

Current limiting encompasses several different techniques which are
designed to limit current under differing conditions. Overcurrent condi-
tions can be caused by several factors including shorted outputs, shorted
transient protection devices, start-up transients (discussed in the next
paragraph) and undervoltage input conditions.

There are two commonly used methods to implement short circuit protection
other than using a control circuit to shut down the supply - the constant
current protection and the current foldback protection. Constant current
protection puts an upper limit on the current that can flow through the
load. Once the current reaches this limit at some load impedance, the
current becomes constant no matter what the impedance drops to, as illus-
trated in Figure 24. In a linear power supply, this situation produces an
upper limit on power dissipation in the power transistor since the
collector to emitter voltage is at a maximum when the load voltage is at a
minimum (short circuit). Foldback circuit protection will begin to limit
the current at the same load impedance as the constant current method, but
as the impedance continues to drop, the current begins to decrease, or

foldback, as shown in Figure 24. Foldback current protection greatly reduces the power dissipation under shorted conditions since the current (short circuit) is at a much lower level than normal operating currents. The following is an explanation of how these techniques work.

(a) Constant Current   (b) Current Foldback

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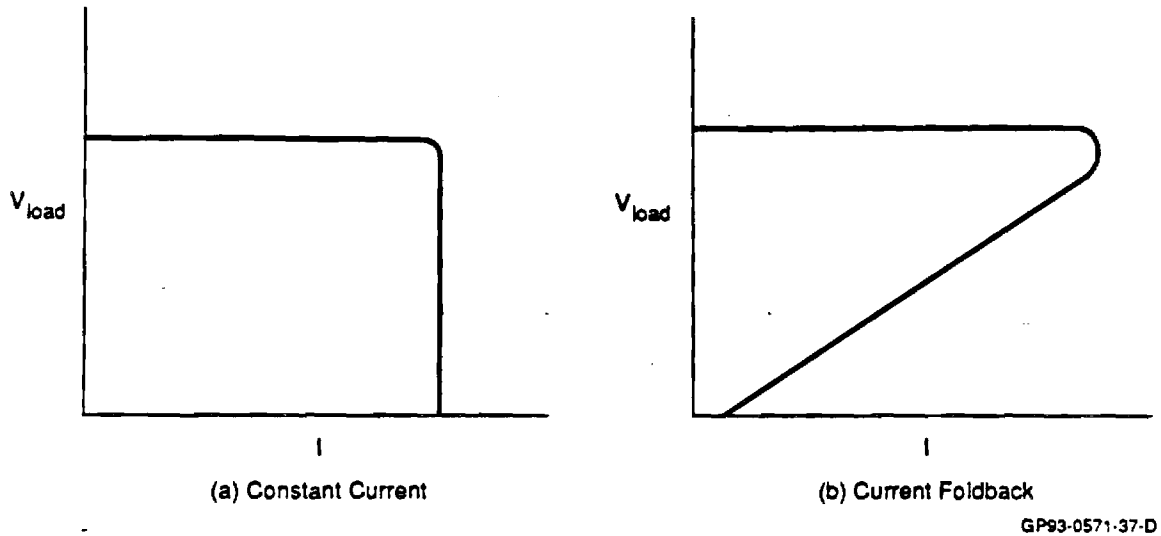
Figure 24. Current Limiting V-I Characteristics

A simple constant current circuit for a linear power supply is shown in Figure 25. As the current increased through R1, the base to emitter voltage of Q2 will reach a point where Q2 starts to conduct. Base current for Q1 is diverted through Q2 to the load. As the load impedance decreases, Q2 will allow only enough base current in Q1 to maintain the original current level in R1 which initially caused Q2 to start conducting.
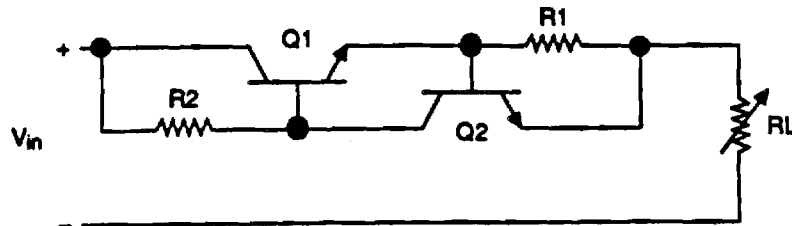
Figure 25. Constant Current Implementation

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Adding R3 and R4 to the constant current circuit creates a simple current foldback circuit as shown in Figure 26. To reach the trip point where the current begins to foldback, the voltage across R1 minus the voltage across R3 must equal the voltage needed for Q2 to conduct. At this point, Q2 begins to reduce the base drive for Q1 and Q1 begins to reduce the voltage across the load and the R3/R4 divider. As the load impedance decreases the voltage across R3, less voltage is required across R1 to keep Q2 turned on. Thus, the current required to hold the circuit in current limit is continually reduced as the load impedance is reduced.

Figure 27 illustrates the use of a thermistor as an overcurrent limiter. A positive coefficient of resistance should be used in this application.

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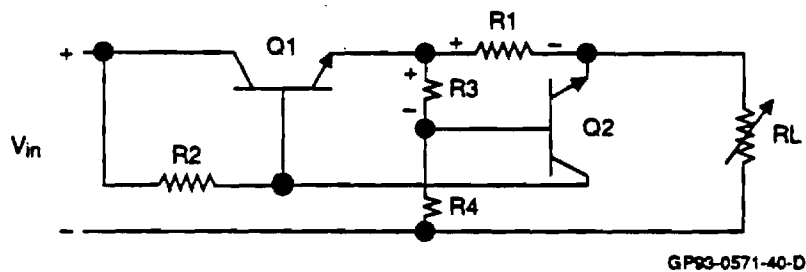
Figure 26. Current Foldback Implementation

GP93-0571-21-D
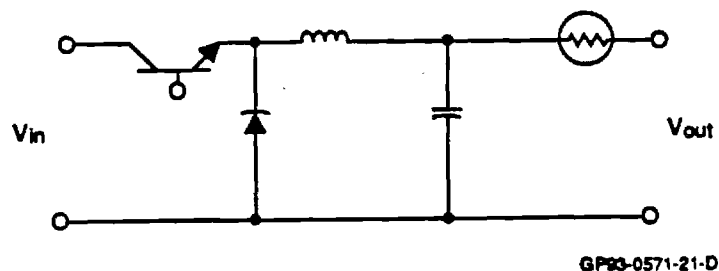
Figure 27. Thermistor Current Limiting

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Start-up Transient Suppression

To prevent high current from damaging power supplies during power up, two methods are commonly used. They are:

1) The first method uses some form of current limiting circuit in the input side of the power supply. This can take the form of a resistor or thermistor with a negative coefficient of expansion in series with the supply line as illustrated in Figure 28. Unfortunately, this method will increase steady state power dissipation unless the limiter is switched out of the circuit after steady state conditions are achieved. Switching can be accomplished with relays, transistors or SCRs. Thermistors do not significantly increase steady state power consumption, but they have a large thermal time constant which does not allow them to quickly respond to changing conditions on the power line. For example, if the power supply is at steady state conditions and the power is removed and immediately reapplied, the thermistor will not cool sufficiently during the off time to provide current limiting resistance when the power is reapplied.

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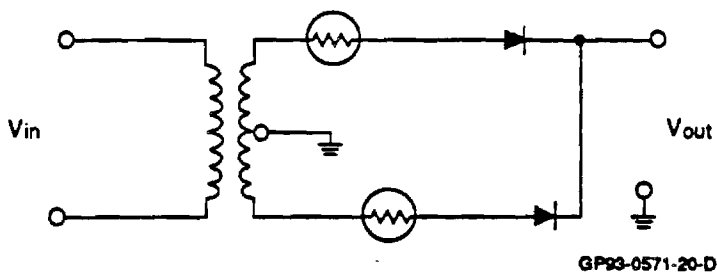
Figure 28. Thermistor In-rush Current Limiter

2) The second method limits the on-time of the pass transistor by controlling the reference voltage (which the output voltage is compared to for regulation), thus allowing the output voltage to come up more slowly.

The overshoot voltage caused by start up transients will be controlled by the two methods listed above. An alternate means to ensure low overshoot is to dissipate the energy released by the inductor in a snubber circuit. Snubbing circuits are described in the next paragraph.

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Transistor/Inductor Snubbing

Transients produced by switching voltages and currents with a transistor can be suppressed with snubber circuits. These circuits can reduce the peak voltage and currents which cause ringing that exceeds component electrical ratings and they can reduce the heat dissipated in switching transistors. Much of the peak power dissipated in the switching components can be shifted to the snubbing circuits without increasing the overall power dissipation of the circuit since the power will be dropped over the transistor if not over the snubber. Implementation of these snubbing circuits will decrease the possibility of thermal degradation of the transistor, and therefore, enhance the reliability.

Prior to a transistor being turned on, the collector to emitter voltage is at its highest state and the collector current is at its lowest state. Ideally, as the transistor turns on, the current would be delayed until the voltage has dropped to its minimum on value thus minimizing the power dissipated by the transistor, resulting in minimum junction temperatures and highest reliability. Unfortunately, the current rapidly begins to flow while the voltage begins to drop more slowly. In many applications, the stray wiring inductance helps to limit the current rate of rise; however, if it does not, the transistor temperature can rise above optimum levels. This higher temperature leads to higher collector to emitter voltages and degraded turn-off transition times which will lead to even higher temperatures, a form of thermal runaway called switching thermal runaway (STR). STR may or may not reach equilibrium prior to device failure. The turn-on snubber shown in Figure 29a a will provide the delay in collector current rise necessary to avoid STR or any semblance there of. The inductor supplies the necessary delay while the diode-resistor (Figure 29b) provides a dissipative path for the inductive voltage spike generated by the inductor when the transistor turns-off.

When a transistor is turned off, the voltage across the collector-emitter begins to rise before the current declines. As a result, the power dissipated in the transistor is very high since large values of current and voltage are present simultaneously. The turn-off snubber of Figure 30a will prevent this by delaying the collector to emitter voltage rise until

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the current has time to decay. Without this type of protection, the STR phenomenon may occur. Additionally, the turn-off snubber will perform as a current sink for the transistor, redirecting the collector current. The turn-off snubber can be modified as shown in Figure 30b and c. However, this modification will only help dissipate the inductive voltage spike, it will not delay the collector to emitter voltage rise.

The voltage spike generated by an inductor when the current is being shut down can be controlled by placing a snubber across the inductor as shown in Figure 29b,c and d. A diode and resistor (29b) combination placed in parallel with the inductor such that the diode is forward biased when the output voltage exceeds the input voltage by the voltage drop of the diode.
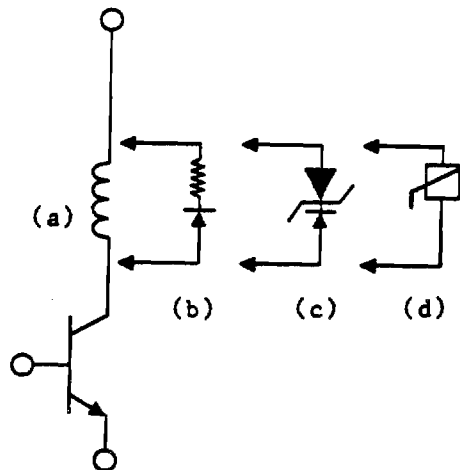
Figure 29. Turn-on Snubber
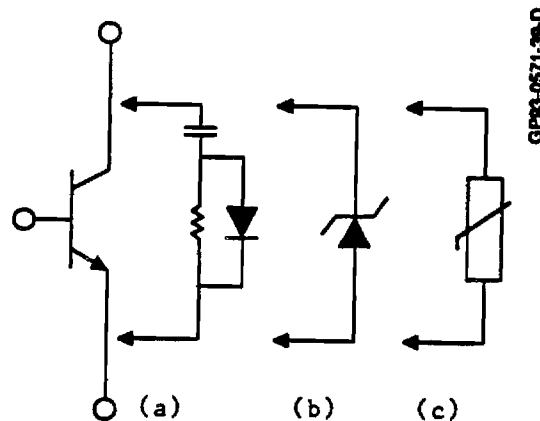
Figure 30. Turn-off Snubber

The Zener - diode (29c) combination will control the voltage spike only if the spike exceeds the threshold of the Zener. A varistor (29d) could be used instead of the diode/resistor combination, but control of the over-shoot would not be as good.

Industry Survey

In an attempt to determine the state-of-the-art practices for power
supply design with respect to transient protection, a questionnaire was
distributed to fifty-seven power supply manufacturers. These manufacturers
produce both commercial and military power supplies. It was quite
unfortunate, however, that only six manufacturers chose to respond. Most
either decided they did not have sufficient time to fill out the
questionnaire or, by responding, they would be divulging proprietary
information about their design. A list of the vendors who received the
questionnaire and the actual returned questionnaires are contained in
Appendix A. A short summary of the responses to the questionnaire follows.

The purpose of the first question of the survey was to gain insight into
the transient levels the vendor designed their power supplies to withstand.
Additionally, identification of the various power supply design specifica-
tions that are routinely used was requested. The input transients designed
for was the only type identified by any of the vendors. The input tran-
sient levels and durations varied from one-half sine wave pulses of 2.5kV
for 10 microseconds to 10kV rectangular pulses for one microsecond. It
should be noted that levels of this magnitude are not found in any of the
military specifications that are commonly referenced when specifying
avionics equipment. The more common specifications identified were MIL-
STD-704 (Aircraft Electrical Power Characteristics), DOD-STD-1399 (Inter-
face Standard for Shipboard Systems) and IEEE-587 (IEEE Guide to Surge
Voltages in Low Voltage AC Power Circuits).

The second question requested the vendors to identify the methods they
use to protect their designs from internally and externally generated
transients. Most vendors agreed that some type of protection was needed to
suppress input overvoltage transients. The method used was generally
either a Zener diode or metal oxide varistor placed across the input supply
and return. Suppression of in-rush current during power up was also
identified as a necessary protection scheme. Implementation examples
included

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thermistors or resistors in series with the input line along with topologies which switch these devices out of the circuit when the supply is at steady state conditions. This eliminates the major disadvantage of in-rush current suppressors - power dissipation. Several vendors indicated some form of output overvoltage protection was necessary. A simple crowbar can provide protection for the load during power supply surges and for the power supply when the load or transmission line generates a surge. Additionally, a scheme which will also shut down the pass transistor during output overvoltage or overcurrent conditions is desirable.

The third question asked the vendors to describe any inherent voltage protection in their designs. The only form of inherent protection appears to be the input and output filters which are used to reduce output ripple and to keep noise generated in the power supply off of the power bus. Unfortunately, the filters directly contribute to an increase in in-rush current.

The fourth question was asked in an attempt to get the vendor's opinion of the extent of transient induced power supply failures. The answers fell into two widely separated categories. The majority of vendors believed very few failures were a result of transient conditions (0-15%). One vendor had a totally different opinion, however, indicating 75-95% of power supply failures were a result of transients. The response of the first group brings two possible scenarios to mind. Either transients are not a problem and we should not waste time and money designing for them or transient protection schemes are very effective in protecting power supplies from the transients to which they are subjected.

The fifth question was an attempt to quantify the reliability of the actual transient protection devices. The vendors were asked to approximate the percentage of power supply failures caused be transient protection devices. The vendors appeared to be in total agreement on this issue. All suggested less than 2% of failures were a result of protection devices.

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The sixth question asked the vendors to assess the trade-offs of transient protection in terms of added cost, increased power dissipation and increased operational reliability. The main point emphasized was the notion of lowest life cycle cost. If transient protection is necessary to protect an expensive power supply or load, then use it. Otherwise, protection is a waste of energy and resources.

The final question asked what the real world limitations of transient protection were. There was the expected response dealing with the increased power dissipation of protection devices, but the most interesting response dealt with unspecified transient source characteristics. In particular, the source impedance is generally not specified, and when it is, it is unrealistic. This is a problem which was repeated over and over in the literature. Without this information, it is impossible to design an optimum protection scheme.

Chapter II
Power Supply Design Guidelines

Task II of the statement of work required MCAIR to develop power supply design guidelines which, if followed, would enhance the reliability of the power supply by decreasing its susceptibility to transients. These guidelines have been sorted into several groups depending on their nature. Each guideline presented is supplemented with the rationale for the guideline. Additionally, the source of the guideline is included if it was from only one or two sources. If the guideline was found in multiple sources, the source was not included.

Design Guidelines

Procurement Specification Language

1. Procurement specifications often do not clearly specify the type or amount of transient protection necessary to ensure high reliability in power supplies. This obviously leaves loopholes that allow the vendors to take shortcuts in the design to reduce the development and production costs. Good design practice must consider the transient conditions throughout the entire power supply including input power line voltage spikes, input current surges, transient voltage and current waveforms created during the switching transitions of the power transistors, current limiting outputs, output overvoltage protection, and the RF power generated by leakage inductance and stray capacitance in the switching circuits. As a minimum, the designer must identify the transients (voltage and current) which the circuit is expected to see (common and transverse mode) at the input, specify the source impedance of the input, specify the type of protection required and identify the type of load for which the power supply will be providing power.

2. The type of protection required should be based on trade-off studies considering the cost of the unit, the added cost of protection circuitry, the potential operational environment, the cost to repair the item, the cost to spare extra power supplies, the impact of a failure on the system/subsystem, etc. This will allow the design to reflect the minimum life cycle cost.

3. Transient waveforms and the transient source impedance must be clearly defined in the procurement specification. The peak voltage, peak current, rise time and transient duration should be included.

4. Specify the minimum hold-up time necessary for the design. NAVMAT 4855-1

5. Avoid using fuses or circuit breakers internal to the power supply. NAVMAT 4855-1

General Transient Protection Guidelines

6. Place the protection device between all potential sources of transients and the device to be protected. It is best to place the device as close to the circuitry to be protected as possible to avoid transients induced by parasitic impedances of the transmission lines. An additional device could be placed close to the transient source.

7. In a current diverter, the transient current is divided between the diverter and the load at a ratio determined by the impedance of each. To help ensure that the impedance of the diverter is much less than the load impedance, an impedance should be placed in series with the load. An inductor selected to offer negligible impedance at the operating frequency (to minimize operating power consumption) and a high impedance at the transient frequency should be used.

8. When using a voltage clamp across a load, the clamp regulates the voltage in a voltage divider network with the transient source. If the source has a very low impedance, the clamp will not be effective. There-

fore, an impedance should be placed in series with the load and clamp if the source impedance is undefined.

9. When using a crowbar device to protect against overvoltage, the crowbar should be selected so that it will not fail before the power transistor burns open if the transistor is failed short. If the crowbar device fails first, the overvoltage condition will be restored and the load will be unprotected. Fuses can be installed in the primary or secondary to protect against this possibility. The crowbar will provide quick protection while the fuse will provide "permanent" protection.

10. Protection from in-rush current during power up must be provided. This will protect the load and output filters from overshoot voltages and the input rectifiers and the pass transistor from the in-rush current. Methods include using control circuitry to limit pass transistor on-time during power up and current limiting resistors installed in the input lines. If efficiency is a concern, a design which switches the limiting resistor out after operating voltages have been reached should be considered. Examples of "switches" include thermistors, relays and SCRs. A small capacitor on the voltage reference input to the regulator will limit the on-time of the transistor during power up. See Chapter I for more details. STARTUP TRANSIENTS IN SWITCHING REGULATORS, SWITCHING AND LINEAR POWER SUPPLY DESIGN

11. Sequence the turn-off/turn-on logic in an orderly and controllable manner to prevent voltage overshoot. NAVMAT 4855-1

General Power Supply Guidelines

12. Use flex wiring wherever practical in wire routing throughout the power supply. The physical relationship of wires in a bundle varies from unit to unit which causes noise levels and transient propagation to vary from one unit to the next. With flex wiring, the spacing is uniform and will help keep transients and noise at a consistent and predictable level. Once these values are predictable, the circuit can be designed to accommo-

date them, enhancing reliability and performance. MCDONNELL DOUGLAS
ELECTRONICS SYSTEMS COMPANY

13. Use PCBs instead of point to point wiring. NAVMAT 4855-1

14. When point to point wiring must be used, use stranded wire only.

15. Derate voltage/current/power/frequency/thermal ratings of components
to applicable program levels.

16. Multiplier stacks used for high voltage applications (10-20kV) should
be designed such that the diodes and capacitors are not subjected to more
than one half their manufacturer's rated specifications to avoid potential
arcing problems. SWITCHING AND LINEAR POWER SUPPLY DESIGN

17. Transformers must be selected so they will not saturate when exposed
to normal balanced circuit drive voltages. If a balanced drive can not be
achieved through proper design, compensation techniques must be incorporat-
ed to achieve a balanced volt-second product. A volt-second product is
defined as the area enclosed by the voltage waveform when plotted with time
as the abscissa and voltage as the ordinate. A balanced volt-second
product is obtained when the area of the positive volt-second product is
equal to the area of the negative volt-second product. See Chapter V for a
more detailed discussion of this problem. MCDONNELL DOUGLAS ELECTRONICS
SYSTEMS COMPANY

18. Minimize the number of combined mechanical and electrical attachment
points used. Mechanical attachments which become loose cause intermittent
open circuits to appear. If they are required, use locking nuts, thread
locks (Loctite) and torque the nuts down. Avoid using materials with
widely varying thermal coefficients of expansion in the attachments,
otherwise they will work loose over time.

19. When selecting transformers or inductors for a design, choose designs
and manufacturing techniques which have been field proven. The design of
the winding to lead interface is very critical and will readily fail if
proper considerations for strain relief are not provided.

Silicon Controlled Rectifier Guidelines

20. The di/dt rating of an SCR should be matched to the expected transient. A transient di/dt which is too high will cause localized junction destruction due to overheating while waiting for the conduction region to expand beyond the original turn on point. Over driving the gate on an SCR will increase the di/dt capability of the device. An inductor placed in series with the SCR will limit the di/dt, but will also slow down the voltage reduction on the power bus. A resistor placed in series with the SCR can help dissipate surge current, but it will also lengthen the time to drop the voltage on the bus.

21. Motorola does not recommend using a Zener sense circuit to fire an SCR (a Zener in series with a resistor where the voltage between the two is used to fire the SCR gate). The setup provides slow gate drive and when the gate begins to turn on the SCR, the gate drive is depleted minimizing the portion of the junction which is conducting. Additionally, the turn on voltage can only be adjusted by changing component values. Variations in the Zener's breakdown voltage and in the firing voltage/current of the SCR can produce large variations of crowbar voltages. MOTOROLA LINEAR/ SWITCHMODE VOLTAGE REGULATOR HANDBOOK; SWITCHING AND LINEAR POWER SUPPLY DESIGN

22. Monitoring circuits provide advantages when using SCRs. Chips provide trip voltage adjustments, large gate drive, adjustable low temperature coefficient trip point, adjustable overvoltage duration before firing gate (to minimize noise induced tripping), status output and remote activation. The status can be used to shut down the power supply to avoid power dissipation in the SCR. The remote activation can be used to shut down the power supply whether a fault exists or not. MOTOROLA LINEAR/SWITCHMODE VOLTAGE REGULATOR HANDBOOK

23. When using a SCR as a crowbar providing overvoltage protection, a low impedance RC network should be placed in parallel with the gate-cathode leads. This will integrate narrow noise spikes which might otherwise turn

on the SCR. Additionally, the gate-cathode resistor will ensure leakage current from the SCR drive will not fire the SCR and will reduce low frequency noise pick up that the capacitor may not filter out. SWITCHING AND LINEAR POWER SUPPLY DESIGN

24. When firing an SCR, ensure that the initial gate drive is a pulse approximately five times the normal continuous gate drive. This pulse should have a rise time of one microsecond or less and have a duration of at least ten microseconds before allowing the gate drive to return to normal levels. This practice will ensure a quick SCR turn-on which will maximize the conduction area at the junction. This in turn maximizes the life of the SCR. CHARACTERIZING THE SCR FOR CROWBAR APPLICATIONS

Switching Transistor Guidelines

25. To minimize switching losses when turning a transistor off, Unitrode advises using the minimum base drive which will drive the transistor into saturation. Higher base drive will increase switching losses without appreciable improvement of on state power dissipation. The low base drive minimizes the stored charge in the base region, which minimizes the fall time of the collector current when the transistor is turned off, which minimizes the power dissipated during switching (remember that the Vce is the highest when the transistor is off, so you want low current, Ic). Secondly, a reverse biased base-emitter junction will help drive the stored charge out and will decrease the fall time. Finally, a snubber circuit should be used across the transistor to dissipate the inductive energy normally dissipated across the junction. UNITRODE POWER SUPPLY DESIGN SEMINAR HANDBOOK

26. To minimize the switching losses when turning a transistor on, the ideal situation is to delay the Ic until the Vce has dropped low. This can be accomplished by putting a small inductor in series with the Ic. The parasitic wire inductance and leakage inductance in transformers will sometimes be sufficient to delay Ic. A thorough analysis of the timing and waveforms present in a switching transistor should be conducted. The

object is to switch the transistor on and off in a manner which minimizes dissipated power. UNITRODE POWER SUPPLY DESIGN SEMINAR HANDBOOK

27. The peak collector current should never exceed continuous current rating of a switching transistor. POWER SYSTEMS, INC.

28. Do not operate a power transistor in an unclamped inductive circuit. Avoids over stressing the transistor when the energy in the inductor is released after the current is interrupted. THE INTERPRETATION OF EOS DAMAGE IN POWER TRANSISTORS

29. The derated voltage specification for switch transistors in a push-pull converter must be selected to withstand voltage levels four times greater than the line voltage. The voltage is doubled since the push-pull arrangement uses a center tapped primary. The voltage can easily be doubled again (or more) by the leakage inductance of the transformer. MCDONNELL DOUGLAS ELECTRONICS SYSTEMS COMPANY

30. Use isolated cases for switching power transistors, TO-3 type transistors which have chips mounted directly to the case must have an insulator between the case and chassis. If the insulator is one mil of Kapton, the capacitance from the TO-3 case to the chassis is approximately 220 pico-farads. High transient currents are injected into the chassis by these capacitors and must be returned to the source through the lowest impedance path available. MCDONNELL DOUGLAS ELECTRONICS SYSTEMS COMPANY

31. Field effect transistors (FET) are recommended for most switching power supply applications. Their positive temperature coefficient makes them easier to operate in parallel and tends to offset the transformer core saturation problem. If a FET in parallel begins to conduct more current than the other one, it will heat up inducing a higher resistance which begins to limit the current. With respect to the core saturation problem, as the current spike passes through the transistor, it will heat up and increase in impedance. Once the impedance increases, the voltage dropped across the transistor will increase thus altering the volt-second product of the transformer in a manner which will tend to bring it back towards balance. Additionally, FETs can be operated at higher frequency and the

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drive circuit is easier to design than for equivalent bipolar transistors.
MCDONNELL DOUGLAS ELECTRONICS SYSTEMS COMPANY

32. Base circuitry should be designed to drive the transistor into saturation very fast and then decay to a value which will barely keep the transistor in saturation. This will minimize the power dissipated during switching and will prepare the transistor for a quick turn off by minimizing the charge stored in the base. A base drive which has been designed to reverse bias the base to emitter during turn off will be much more effective in achieving a quick turn off since the reverse bias will remove the charge stored in the base.

33. In applications where transistors must be mounted in parallel to carry the necessary current, matched transistors should be used. Alternatively, some technique to balance the current between the two transistors is necessary. Balancing the current will ensure the transistors are both operated at the minimum power and thermal levels possible.

Analysis Guidelines

34. Ensure that the clamping voltage (at a specified peak pulse current and current rise time) is below the failure threshold of the equipment to be protected.

35. Ensure that measured peak voltages, peak power and peak currents do not exceed the rated limit of the component. Additionally, the worst case component temperatures should not exceed the rated limits. NAVMAT 4855-1.

36. Verify that the transformer and inductor coils are not in saturation during peak load and transient conditions. STARTUP TRANSIENTS IN SWITCHING REGULATORS, NAVMAT 4855-1

37. Compare the specified voltage, frequency and thermal rating of insulation to the applied levels and assess with respect to life degradation. Insulation resistance degrades inversely with applied voltage, frequency (or polarity reversals) and temperature. Figures 31, 32 and 33 represent

the life degradations associated with these environmental influences.
APPLYING AVIP TO HIGH VOLTAGE POWER SUPPLY DESIGNS

38. Require stability, stress and worst case analysis on power supplies.
The stress analysis should be supported with measured data from breadboard
or engineering models since the current and voltage wave forms induced
during switching action are difficult to calculate accurately.   MCDONNELL
DOUGLAS ELECTRONICS SYSTEMS COMPANY

39. A thorough vibrational analysis should be required on all large and
heavy components installed in. the power supply to .determine if the leads
are capable of supporting the component during operational maneuvers. This
will minimize the number components with failed leads by allowing the ·
designer to provide alternate support for the components.
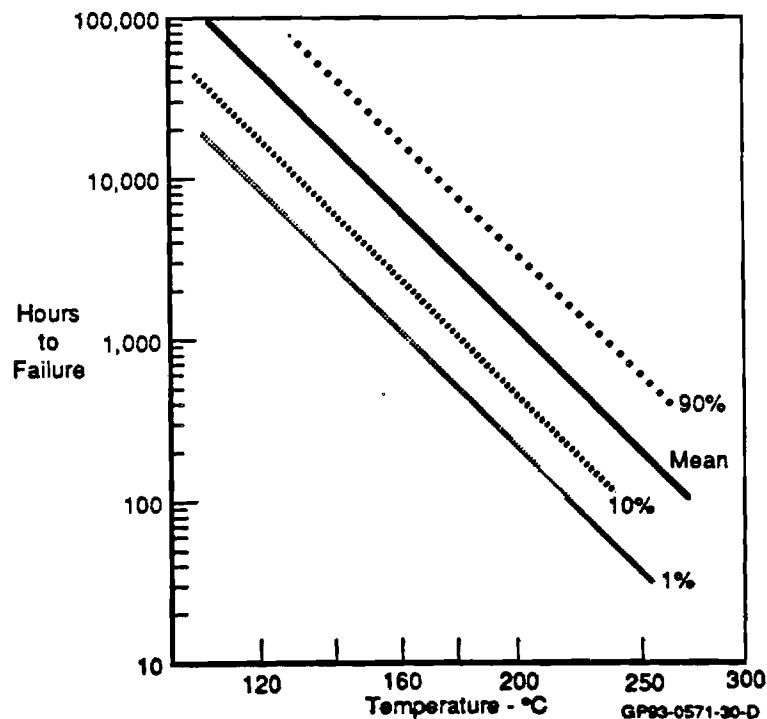
Figure 31. Temperature Dependence of Insulation Life

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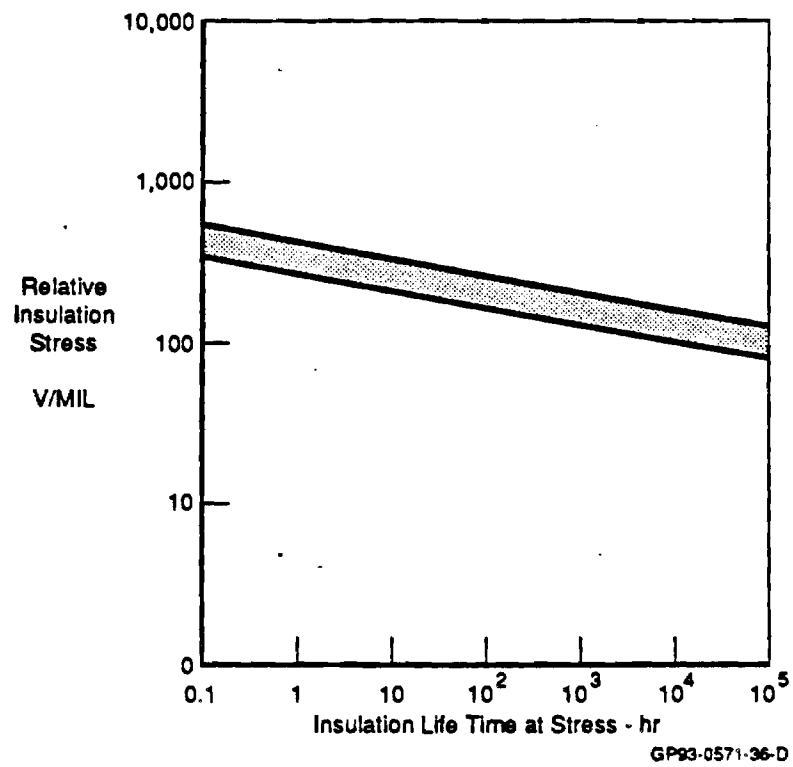
Figure 32. Voltage Dependence of Insulation Life

GP93-0571-29-D
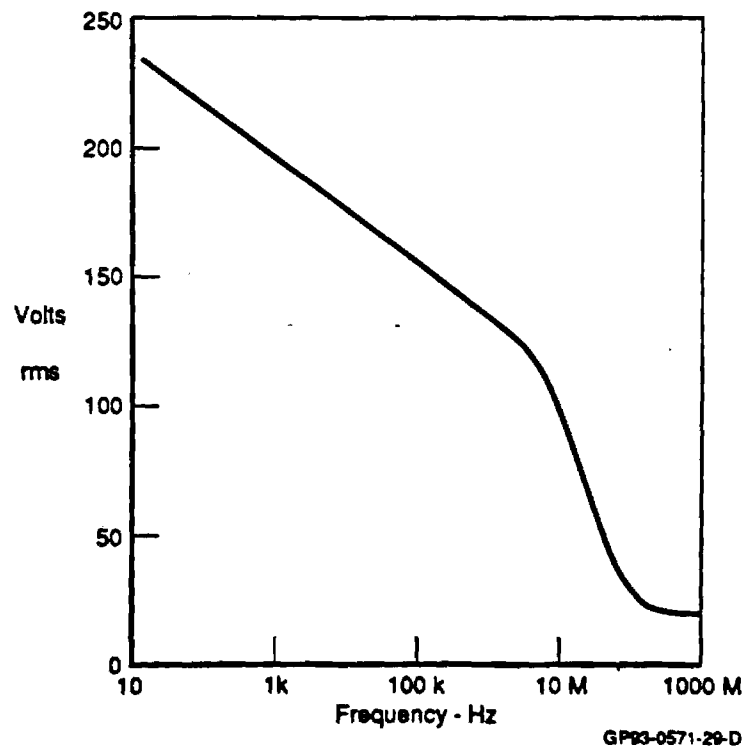
Figure 33. Insulation Voltage Rating Dependence on Frequency

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Chapter III
Avionics Selection

Task III of the statement of work required MCAIR to select twenty pieces of avionics from the equipment list of the Air Force's JOINT STARS program as the subjects of this study. It was stipulated that the equipment selected must be currently installed on an operational airborne platform for which field failure data was available. Furthermore, the chosen equipment was to be representative of various applications such as radar, navigation, communication, digital computers, etc. Once the equipment was selected, detailed engineering and failure data was to be collected. This data included input/output specifications, predicted failure rates, schematics, field failure data and operating hours. Field failure data was collected from the Air Force's 66-1 system and the Navy's 3-M data system.

In order to accomplish this task, support was required from RADC. First, RADC was to supply MCAIR with the JOINT STARS equipment list. Secondly, once the equipment was chosen, RADC would supply MCAIR with the name of the equipment manufacturer and the equipment engineer's names within the JOINT STARS program office.

MCAIR began this task by initiating a request for DO56E and GO33B data for the E-3A/B/C (AWACS) aircraft since it was believed that much of the JOINT STARS equipment was present in the AWACS platform. AFLC/MMDA complied with our request and supplied MCAIR with two years of data. This complemented information MCAIR already had on the F-4, B-52, A-7, FB-111, A-10, F-15, F/A-18, AV-8 and F-16.

Once MCAIR obtained the Logistics Support Analysis Control Number List (equipment list) for the JOINT STARS program, identification of potential avionics for the study began. Seventy-seven power supplies were identified as line items within this publication. These power supplies were then cross referenced with the Avionics Planning Baseline (APB) document

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(ASD-TR-88-5026) published by ASD-AFAL/AXP out of Wright Patterson AFB.
The APB lists the nomenclature (eg. ARC-173, ASN-119) of all of the
avionics which are used in the Air Force. It then cross references the
avionics to the platforms where it is installed. Unfortunately, none of
the equipment on the JOINT STARS platform cross referenced to any other
platform in the operational Air Force. The attempt to select JOINT STARS
equipment was terminated with RADC's concurrence.

It was then decided to select ten pieces of avionics from both the E-3
(AWACS) and the F/A-18 platforms. A candidate list of thirty-two power
supplies from the E-3 was submitted to RADC for approval. Subsequently,
contact was made with Tinker AFB to determine if they would be able to
provide the support necessary to gather the engineering data. The required
engineering data was not available; therefore, RADC decided to proceed with

Nomenclature	Work Unit Code
Flight Control Computer	57D91Y0/Z0
RT 1250 Receiver/Transmitter	62X2150
Inertial Navigation Set	73M18F0/G0/H0
Horizontal Situation Display	
Low Voltage	73X32Y0
High Voltage	73X32X0
Radar Receiver/Transmitter	
High Voltage	742G120
DC-DC Converter	742G150
Switching Regulator	742G180
Radar Computer Power Supply	
DC-DC Converter	742G410
Linear Regulator	742G420
Radar Target Data Processor	
DC-DC Converter	742G3N0
Linear Regulator	742G3M0
Multipurpose Display Indicator	
Low Voltage	74681M0
High Voltage	74681N0

Table 2. Selected Power Supplies

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the avionics equipment from the F/A-18 only. The equipment chosen is listed in Table 2.

Subsequent to selecting the power supplies for the study, the process of collecting failure data, operating hours and engineering documents began. Failure data was collected for a five year period spanning 1984 through 1988 during which the F/A-18 incurred approximately 500,000 flight hours. Three basic failure reports were processed for this study:

1) The piece part summary which provides a detailed list of every part which was replaced on a given circuit board/shop replaceable assembly (SRA). This data is taken from the H-Z records of the 3-M data system. The part number, reference designator and the number of parts replaced are included. Limitations of the report, a result of poor field reporting and data entry errors, include incomplete recording of reference symbols which results in some precision errors in the absolute count of part failures. However, this error is small.

2) The SRA replacement summary provides a detailed list of the power supplies which were removed from the aircraft. The report identifies the power supply by work unit code and part number. Information includes the total number of SRAs removed and how many of these removals fall under each of the general failure classifications (defective, can-not-duplicate, cannibalization, other). This information is processed from the E records of the 3-M data system.

3) The failure mode analysis report which categorizes power supply removals by the malfunction code recorded at the time of removal. This report includes the work unit code, the malfunction code and the number of removals charged against the malfunction code.

Several iterations were necessary before acceptable data was available. During the initial data analysis, numerous duplicate records were discovered resulting in inflated failure rates. Data analysis programs were modified to eliminate these duplicate records and the analyses continued without further trouble.

Engineering data was collected concurrently with the failure information. Schematics of the power supplies, block diagrams, detailed MIL-HDBK-217 reliability predictions, procurement specifications and intermediate level maintenance technical publications were acquired.

Chapter IV
Electrical Interface

The fourth task of this study was to evaluate the input power require-
ments of the avionics chosen for this study. The information collected
serves two purposes: it provides a means to determine if a more reliable
piece of avionics was subjected to a more benign environment than a less
reliable piece of hardware and it provides the specified electrical input
requirements to which the equipment was functionally designed. Table 3
summarizes the electrical interface requirements of the equipment.

Figure 34 illustrates the general requirements flow (ie., MIL-E-5400
calls out MIL-STD-454 which in turn call out MIL-STD-704) and the pertinent
paragraphs which apply to avionics electrical power supplies. Pertinent
paragraphs are not identified for MIL-STD-704 since the entire document is
applicable. All of the major equipments called out MIL-E-5400 paragraph
3.2.23 as the requirement for input power with the exception of the ARC-182
communication set. MIL-E-5400 in turn calls out Requirement 25 of MIL-
STD-454 as the governing document. Finally, Requirement 25 calls out
MIL-STD-704 as the governing document for airborne equipment. The procure-
ment specifications then further refined the requirement to encompass
MIL-STD-704 Category B. The ARC-182 Communication Set simply calls out
MIL-STD-704.

MIL-STD-704 defines overvoltage as a voltage which "... exceeds the
combined steady state and transient limits for normal operation and is
limited by the action of protective devices." Figure 35 illustrates the
overvoltage limits for AC voltages and Figure 36 illustrates the
overvoltage limits for DC voltages. The MIL-STD does not in turn define
the term transient, but it is interpreted to be the voltage limits and
durations which the equipment must operate through without malfunction.
These limits are illustrated in Figure 37 (AC voltages) and Figure 38 (DC
voltages). The standard fails to define the maximum transient the

MIL-E-5400

.. .. by the detail equipment .... or ...
...safety programs shall conform to MIL-STD-882 (see 6.2).

3.2.23   Service conditions (electrical). The equipment shall
be. designed to operate from power sources with characteristics conforming
to MIL-STD-454, Requirement 25.

3.2.23.1   ...mup time. Warmup time shall be such ...
...fied pe.   ...e within a period as specified ...
              ... otherwise .....c...

MIL-STD-454

REQUIREMENT 25

ELECTRICAL POWER

...iu associated equipment and for portions of syst...
...quipment shall be in accordance with MIL-STD-205 and MIL-STL

4.2 Airborne. The electrical power requirements for airborne and associated equip-
ment shall be in accordance with MIL-STD-704.

Shipboard. The electrical po...   ments for shipboard a...
         "..." in accordance with   Type II of Ser...

MIL-STD-704

Figure 34. Electrical Power Interface Specifications

equipment must be able to withstand without degradation. It simply states
at what voltage level protection devices must begin to protect the equip-
ment and at what voltages the equipment must continue to operate normally.
The definition of a wave shape to be used as representative of the environ-
ment is important for the design of protective devices since unrealistic
requirements, such as excessive duration of the voltage or very low source
impedance, place a high energy requirement on the suppressor with a result-
ing cost, weight and volume penalty. A complete specification should
include the maximum voltage transients which may appear, the voltage
waveform and the overvoltage source impedance.

Equipment	Specification	Input Power Requirements	Power Requirements	Transient Susceptibility	Spike Emission	Overload Protection	Lightning Requirements
Horizontal Situation Indicator	74-870078	MIL-E-5400 para. 3.2.23 MIL-STD-704 Category B	115/200 VAC, 440 VA 0-5 VAC, 10 VA	No degradation with each interface cabled bundled with a wire conducting a relay minimum switching transient of +/-600 volts peak.	Spikes (transients >500 microseconds) shall not exceed the following values when measured from the base of the transient: a) 28VDC, +14/42V b) 115VAC +/-60V	Equipment must meet the requirements of para. 3.2.20 of MIL-E-5400 except as noted: a) No permanent damage shall be sustained by the power supply due to any transient external to the WRA. b) Equipment shall not sustain chain reaction failures. Fuses and similar devices shall not be used without permission.	Not Specified
Flight Control Set	74-870086	MIL-E-5400 para. 3.2.23 MIL-STD-704 Category B	28 VDC 1300 W max @ 30 VDC	No degradation with each interface cable bundled with a wire conducting a relay minimum switching transient of +/-600 volts peak.	Spikes (transients >500 microseconds) shall not exceed the following values when measured from the base of the transient: a) 28VDC, +14/42V b) 115VAC +/-60V	Equipment must meet the requirements of para. 3.2.20 of MIL-E-5400 except as noted: a) No permanent damage shall be sustained by the power supply due to any transient external to the WRA. b) Equipment shall not sustain chain reaction failures. Fuses and similar devices shall not be used without permission.	Each flight critical interface wire shall withstand a 5000V peak double exponential pulse of either polarity as follows: $E=+/-Ae^-bt - ^--dt$ b = 1.4E4 d = 3.6E6 A = 510 Z (source) = 100 ohms Protection devices must have nanosecond response times.
Radar	78-870052	MIL-E-5400 para. 3.2.23 MIL-STD-704 Category B	115/200 VAC 5450 VA, XMTR 450 VA, remainder 28 VDC 400 W, antenna drive 200 W. remainder	No degradation with each interface cabled bundled with a wire conducting a relay minimum switching transient of +/-600 volts peak.	Spikes (transients >500 microseconds) shall not exceed the following values when measured from the base of the transient: a) 28VDC, +14/42V b) 115VAC +/-60V	Equipment must meet the requirements of para. 3.2.20 of MIL-E-5400 except as noted: a) No permanent damage shall be sustained by the power supply due to any transient external to the WRA. b) Equipment shall not sustain chain reaction failures. Fuses and similar devices shall not be used without permission.	
Multipurpose Display Indicator	74-870074	MIL-E-5400 para. 3.2.23 MIL-STD-704 Category B	115/200 VAC, 0-5 VAC, 10 VA max	No degradation with each interface cable bundled with a wire conducting a relay minimum switching transient of +/-600 volts peak.	Spikes (transients >500 microseconds) shall not exceed the following values when measured from the base of the transient: a) 28VDC, +14/42V b) 115VAC +/-60V	Equipment must meet the requirements of para. 3.2.20 of MIL-E-5400 except as noted: a) No permanent damage shall be sustained by the power supply due to any transient external to the WRA. b) Equipment shall not sustain chain reaction failures. Fuses and similar devices shall not be used without permission. c) I/O Devices must be able to withstand the following waveform: 3000 Vpeak, 1-3 nanosecond pulse, 500mA d) Arc suppressors shall be used to preclude damage to components from HVPS and HV CRT arcs.	Not Specified
ARC-182/ RT-1250	MIL-R-85664(AS)	MIL-STD-704	28 VDC, 150 W max	Not Specified	Not Specified	a) Unit shall not be damaged by voltages less than those allowed by 704. b) Reverse polarity shall not damage the XMTR/RCVR.	Not Specified
INS	PS 74-870082	MIL-E-5400 para. 3.2.23 MIL-STD-704 Category B	115 VAC, 1650 VA (warm up) 115 VAC, 250 VA (normal) 28 VAC, 20 VA	No degradation with each interface cable bundled with a wire conducting a relay minimum switching transient of +/-600 volts peak.	Spikes (transients >500 microseconds) shall not exceed the following values when measured from the base of the transient: a) 28VDC, +14/42V b) 115VAC +/-60V	Equipment must meet the requirements of para. 3.2.20 of MIL-E-5400 except as noted: a) No permanent damage shall be sustained by the power supply due to any transient external to the WRA. b) Equipment shall not sustain chain reaction failures. Fuses and similar devices shall not be used without permission.	Not Specified

Table 3. Electrical Interface Requirements

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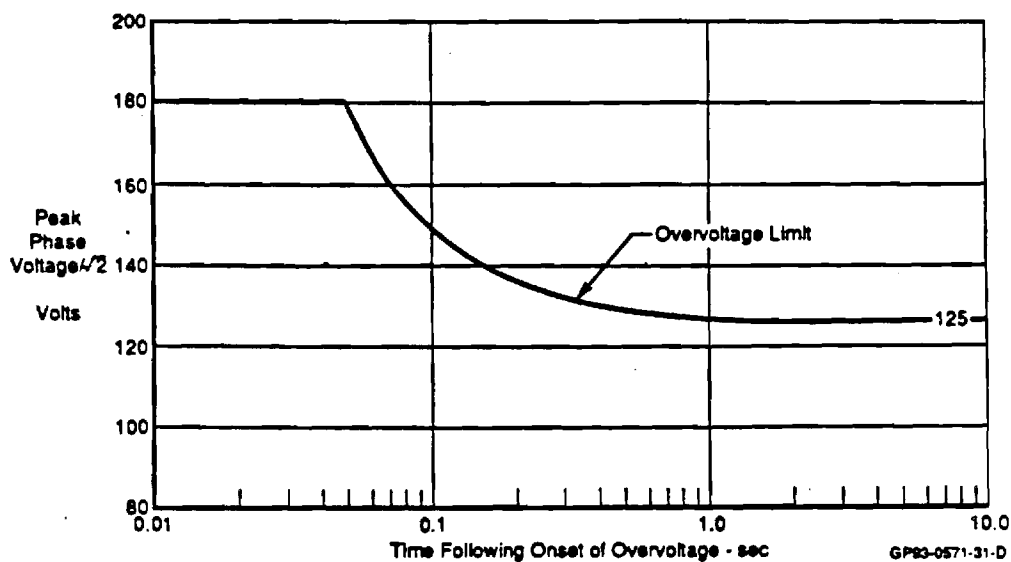
Figure 35. AC Overvoltage Limits

The transient susceptibility requirement of Table 3 is similar in that it calls out a requirement that the equipment must function normally when interface wiring is subjected to coupled transients emanating from a wire with 600V peak to peak transients, but does not call out the levels the equipment must protect itself from. The spike emission requirement defines the maximum voltage levels of electromagnetic interference that can be broadcast onto the power bus by the equipment.
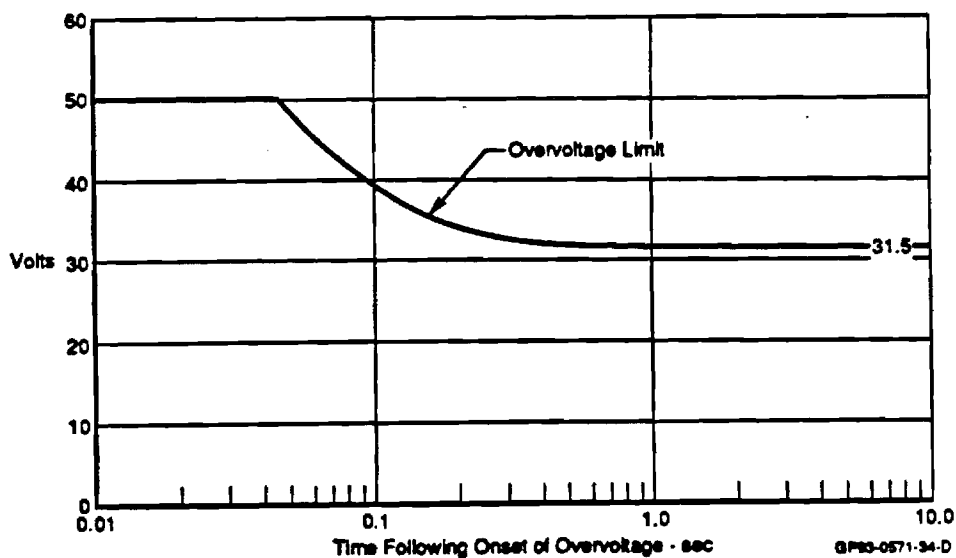
Figure 36. DC Overvoltage Limits
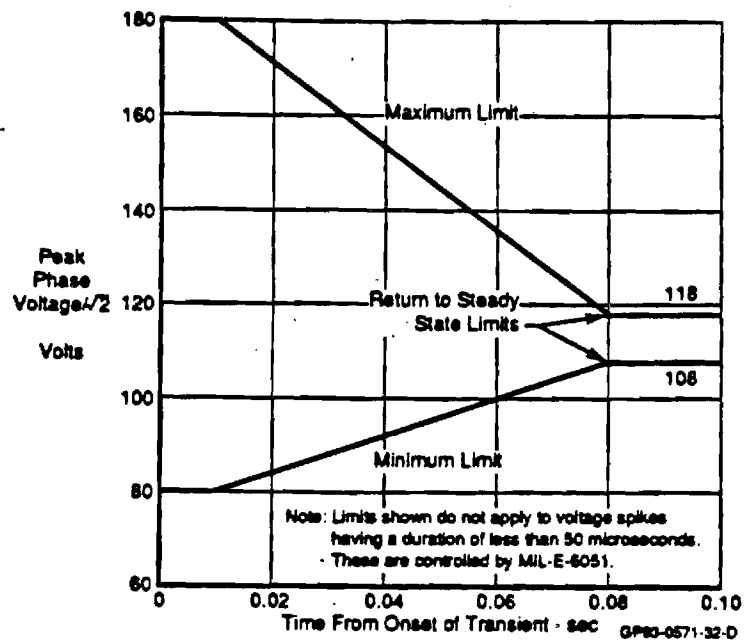
Figure 37. AC Transient Limits

The overload requirement of the procurement specification calls out paragraph 3.2.20 of MIL-E-5400 which then calls out Requirement 8 of MIL-STD-454. Requirement 8 specifies (for Class 2 equipment) that current
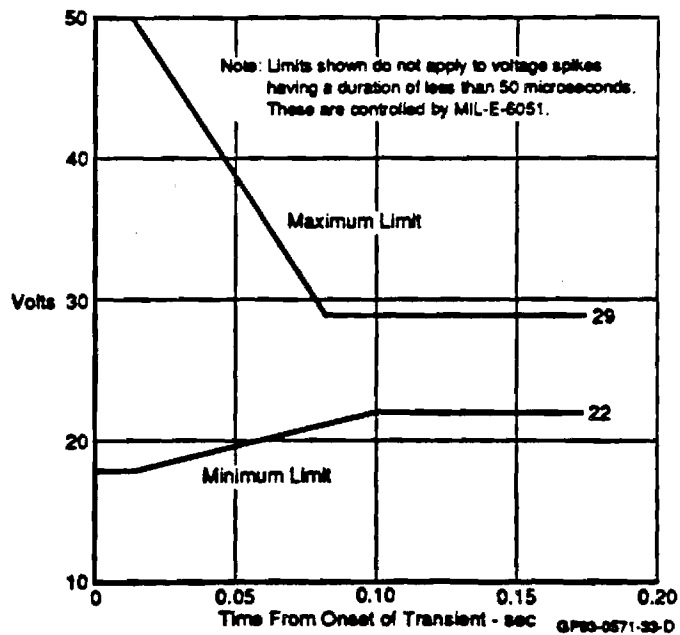
Figure 38. DC Transient Limits

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overload protection shall be provided via circuit breakers or fuses to avoid the hazards of fire, smoke, explosion or arc over. The procurementspecificat permanent damage may be sustained by the power supply due to any transient external to the avionics box. Furthermore, equipment can not sustain chain reaction failures due to transient conditions, ie., the failure of one component shall not in turn cause the failure of another component. Only one piece of equipment (the Multipurpose Display Indicator) actually defined a voltage waveform that the equipments' input/output lines must be capable of withstanding without failure. The requirement called out the peak voltage, the peak current and the transient duration. It did not, however, define the waveform in terms of rise time or fall time and it did not describe the transient as a square wave, sine wave, exponentially decaying, etc. A comprehensive requirement needs to have all of these parameters specified.

The final column of Table 3 contains the lightning requirements the equipment must withstand in terms of waveform, maximum voltage, maximum current and source impedance. Only one piece of equipment (the Flight Control Computer) had this requirement levied against it. Although this requirement is better than nothing, it is not as stringent as the IEEE waveforms for lightning induced transients discussed in Chapter I.

Overall, the equipment in this study was basically designed to the same requirements. It is not likely that differences in power supply reliability are due to the small variations in the power specifications.

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Chapter V

Power Supply Failure Modes

Task V of the statement of work required MCAIR to identify the failure modes of power supplies. This was to be accomplished by reviewing the failure data collected for the other analyses, reviewing historical F/A-18 test data and evaluating the How-Mal codes of power supply failures.

A historical view of power supply failure modes was obtained by reviewing the F/A-18 Reliability Development Test (RDT) Summary Report. This report covered tests conducted between 1979 and 1984. Many of the failures that appear in RDT are the result of unique circuit interactions which are very difficult to determine analytically, while some could be eliminated with up front, common sense engineering practices. Hopefully, lessons can be learned from this historical data base and applied to future designs, minimizing redesign effort and costs.

Wiring failures were reported more frequently than any other failure type. Failures included broken wires, chaffed wires, pinched wires, improperly routed wires, etc. This abundance of wiring problems is associated with the above average use of point to point wiring in power supplies instead of the more common use of printed circuitry as in other electronics. While wiring can not be avoided altogether, problems can be minimized. As stated in the design guidelines section, flex print circuitry should be used whenever possible so routing will be more consistent. Very precise wire routing, tie down locations and bend radii should be specified in the manufacturing instructions. While not wanting to state the obvious, the obvious is overlooked far too frequently to ignore. Whenever possible, route wiring in any manner to avoid wrapping the wire over a sharp edge. Invariably, if the opportunities are there, a technician will wrap the wire too tightly over the edge and failure will result. One other "obvious" failure mode turned up several times in the RDT report involving the use of solid core wire. This type of wire is less

flexible and more subject to fatigue cracking than stranded wiring. Stranded wiring should be the only wire type considered for use in avionics.

The second most common failure reported involved broken component leads of power supply components. The leads were always associated with large, heavy components typical to power supply designs such as transformers, inductors and capacitors. These components must be mounted very securely to the chassis or circuit board by some means other than the component leads. Mounting can be established via a mechanical means such as screws or clamps and by bonding. The components are too heavy for the leads to withstand the vibrational forces. Prudent designs will allow for this prior to the time when test and operational failures mandate a redesign.

Transformers and inductors suffered from numerous winding failures at the interface with lead wires. These very fine wires can not withstand much stress at all, either from vibration or temperature induced expansion and contraction. Some form of stress relief must be incorporated into the interface to eliminate this problem. Incorporating inductor and transformer design and manufacturing techniques which have been proven in the field is the best solution to this problem.

Mechanical attachment points (nuts and bolts) which also provide the electrical interface were reported as failures several times. Two problems exist with this type of design. First, vibration and thermal expansion work together to loosen the attaching hardware which leads to electrical discontinuities and poor thermal paths.. Using material with similar thermal coefficients of expansion will minimize the thermal aspects of this problem. The vibration problem is generally minimized by the use of locking nuts, torque values and Loctite. This in turn becomes a quality problem to ensure the proper nut is used, the nut has been torqued and the Loctite has been applied. Secondly, conformal coating material has a nasty habit of covering the mating surfaces of these electrical contacts if they are not properly masked. It is also capable of flowing between the mating surfaces of previously assembled hardware. Both of these situations lead to intermittent electrical opens which cause power supply failures.

As mentioned in Chapter I and II, soft start circuity should be designed
into the supply form the beginning. One supplier realized this too late
and had to incorporated the circuitry since the input filters were blowing
repetitively.

Finally, the drive transistors were the source of numerous failures both
in RDT and operationally among the various equipment. Causes of these
failures were numerous. One redesign was initiated because of the large
charge storage in the transistor. This storage would delay the transistor
from turning off resulting in increased power dissipation. Chapter I
discusses this problem in more detail. Several redesigns were initiated
due to current imbalances in parallel drive transistors. This imbalance
can cause one transistor to warm to the point where its resistance begins
to decrease, allowing thermal runaway to begin. This problem can be
eliminated by using matched pair transistors mounted on the same thermal
plane or with other techniques suitable for obtaining a balanced current
flow. One other problem was related to both transistors and wiring.
Transistors were failing due to excess parasitic capacitance in the wiring
leading from the transistor. This capacitance could alter switching
waveforms resulting in overheated junctions. Additionally, the extra
capacitance will draw extra current when the transistors are switched on.
Altering the wiring length and routing solved this problem. While the use
of flex print may not have eliminated this problem initially, it will keep
the problem from appearing randomly throughout production due to
inconsistent wiring practices.

Drive transistors have also been known to fail due to inattention to the
core saturation tendencies of power inverter transformers. When a core
goes into saturation (defined as the point where an increase in magnetizing
current no longer causes an increase in flux) based upon a given voltage
impressed across it, the current spikes since the inductor can no longer
inhibit the rate of current rise. This problem is caused by misapplication
of the transformer, ie. the transformer is too small, or by an unbalanced
drive volt-second product across the transformer. To remedy this problem,
the designer can select a core with higher saturation limits or ensure the
drive is balanced. An explanation of this problem follows.

First, a balanced drive is obtained when the volt-second product of the positive and negative drive pulses are equal, ie., the area of the pulses on each side of the time axis are equal. Figure 39a illustrates a balanced drive and Figure 39b illustrates an unbalanced drive. Second, transformers
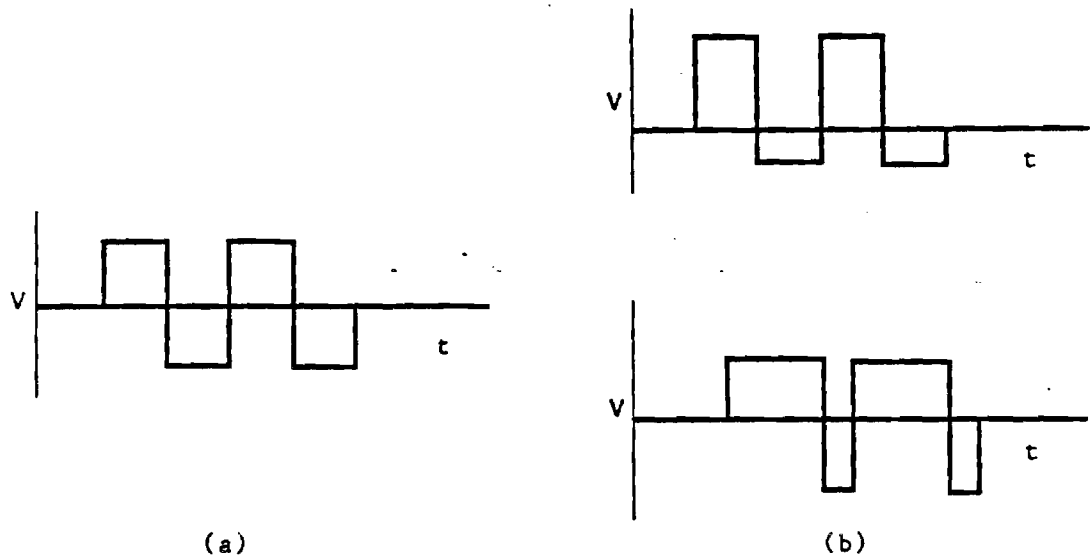
Figure 39. Balanced & Unbalanced Volt-Second Products

are usually selected to have a square hysteresis loop as shown in Figure 40a. When driven by a balanced drive, the properly selected transformer will have a square hysteresis loop which is smaller (see Figure 40b) than
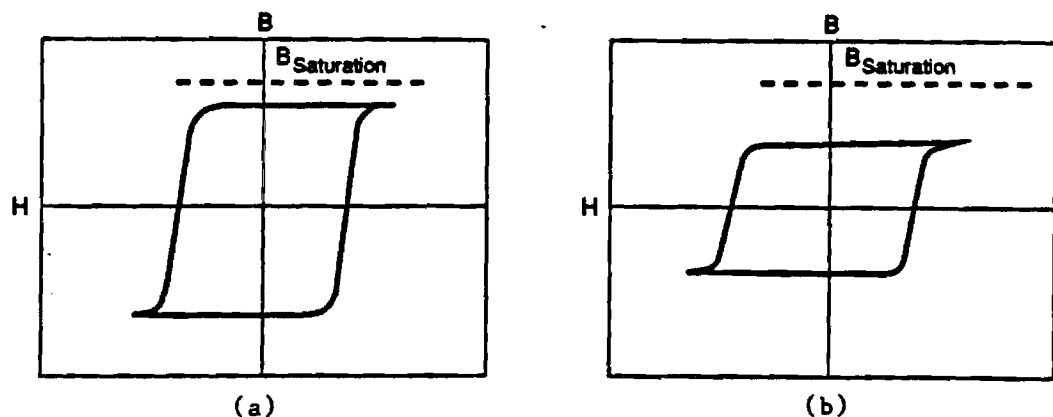
GP93-0571-44-D

Figure 40. Hysteresis Loop - Balanced

the maximum loop specified. Even with a balanced drive, a core will
saturate and cause problems if not selected properly for the application.
An unbalanced drive will have the effect of shifting the hysteresis loop up
(or down) on the magnetic flux density axis as shown in Figure 41. As
illustrated, the hysteresis loop has been shifted to the point where the
flux density can no longer be increased, identifiable by the large tail on
the top of the loop. When this happens, as explained earlier, the flux can
no longer inhibit current rise and a current spike results as illustrated
in Figure 42. If transistors are used to switch the drive waveform, the
high current allowed by the saturated core will pass through the transistor
and cause it to exceed its safe operating area (SOA) curves resulting in
overheated junction temperatures. Degradation and eventual failure will
result.

GP93-0571-45-D
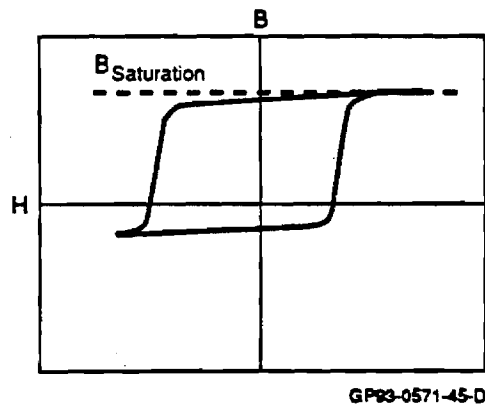
Figure 41. Hysteresis Loop - Unbalanced
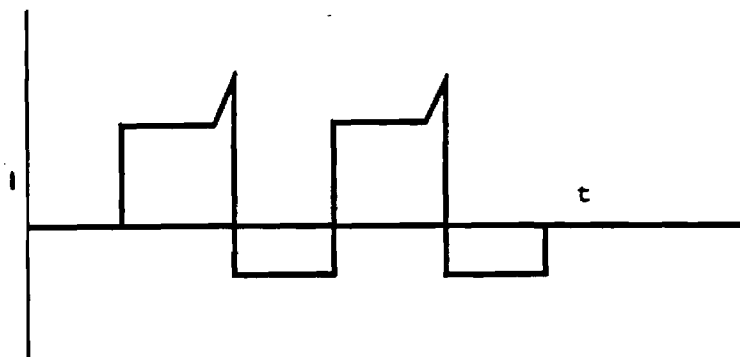
Figure 42. Current Spiking from Unbalanced Hysteresis

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The How-Mal analysis did not yield any useable results. The codes were
sorted by power supply and plotted, but the codes recorded were not
beneficial in determining failure modes of power supplies. The typical
How-Mal code used translated to "Fails - Diagnostic/Automatic Test", "No
Output", or "Voltage Incorrect". This effort was subsequently terminated.

Chapter VI

Data Analyses

Task VI of the statement of work required MCAIR to analyze the collected operational field data and design data to determine any relationships which may exist between unique design parameters and the field reliability of power supplies. Specifically, the relationships which needed to be determined include:

- a) The relationship between the operational reliability and the predicted reliability of power supplies.
- b) The relationship between power supply reliability and the reliability of other electronics housed within the same box as the power supply.
- c) The relationship between power supply reliability and overall complexity.
- d) The relationship between total part failures and protection part failures.
- e) The relationship between reliability and transient protection complexity.
- f) The relationship between power supply type and reliability.

The following paragraphs will explain the methodology used to determine these relationships, the reason they were needed and the results of the analyses.

Power Supply Operational vs Predicted Reliability

The first analysis of the field data was intended to determine how well the power supplies performed operationally with respect to their predicted reliability. Also, with the way Figure 43 is plotted, one can compare the ratio of operational to predicted failure rate as a function of complexity since units with a higher predicted failure rate are generally more com-

plex. To this end, the operational failure rate was plotted against the predicted failure rate as illustrated in Figure 43.
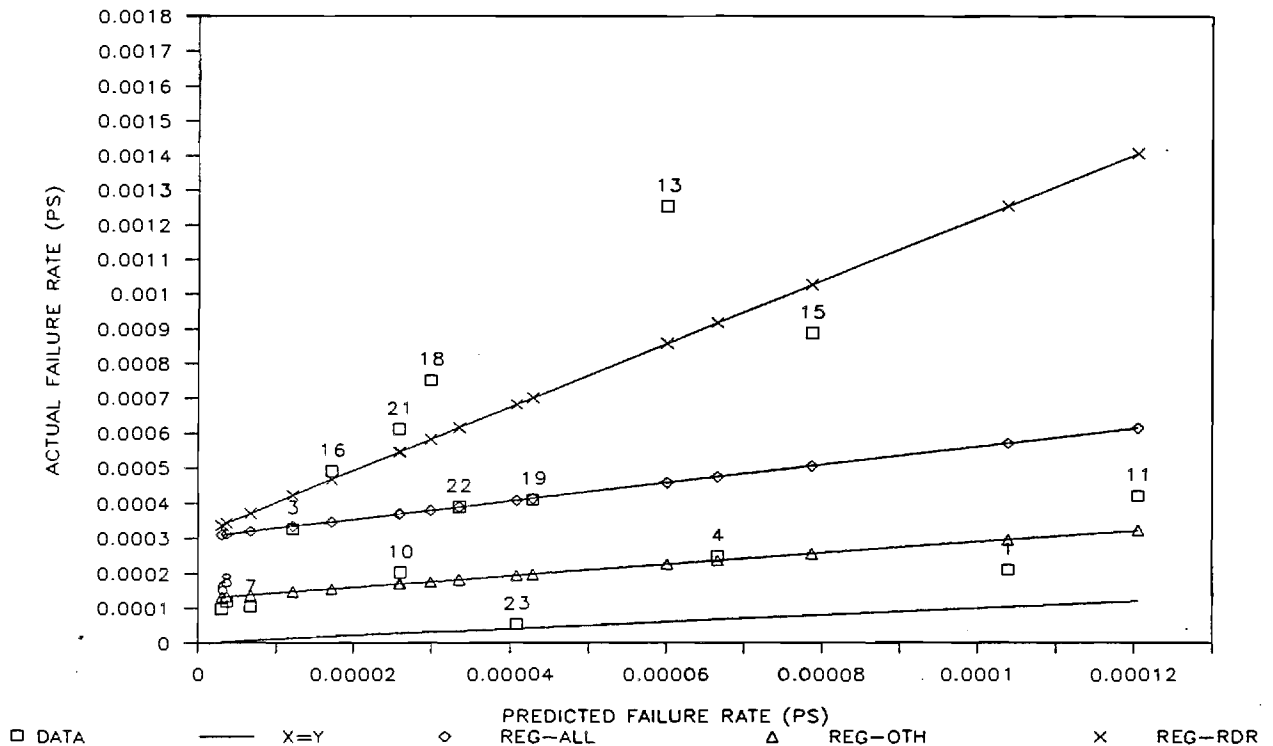
Figure 43. Predicted Power Supply Lambda vs Actual

This figure includes data points for each power supply SRA which were part of this study. Table 4 contains a list of these power supplies and their respective identifying number used in the following graphs. The line X=Y represents the plot obtained when the operational failure rate is set equal to the predicted failure rate. There are three regression lines plotted on the graph. REG-ALL represents the regression obtained when all SRA data points are considered together. REG-RDR represents the line obtained when only radar SRA data points are considered. Finally, REG-OTHER represents the line obtained when all other SRAs besides the radar SRAs were considered.

Identifying Number	Nomenclature
1	Flight Control Computer Low Voltage Supply
2	Multipurpose Display Indicator (MDI) Total (3&4)
3	MDI Low Voltage Supply
4	MDI High Voltage Supply
5	Inertial Navigation Set (INS) Total (6,7&8)
6	INS Rectifier
7	INS DC-DC Converter
8	INS Sequence Monitor
9	Horizontal Situation Display (HSD) Total (10&11)
10	HSD High Voltage Supply
11	HSD Low Voltage Supply
12	Radar Transmitter Total (13&14)
13	Transmitter High Voltage
14	Transmitter Low Voltage (15&16)
15	Transmitter DC-DC Converter
16	Transmitter Switching Regulator
17	Radar Target Data Processor (RTDP) Low Voltage (18&19)
18	RTDP DC-DC Converter
19	RTDP Linear Regulator
20	Computer Power Supply (CPS) Low Voltage (21&22)
21	CPS DC-DC Converter
22	CPS Linear Regulator
23	RT-1250 Radio Low Voltage Supply

Table 4. Power Supply Identification

The functions to which each line has been plotted are as follows:

$$X-Y, \quad y = x$$
$$REG-ALL, \quad y = 2.58x + .0003$$
$$REG-RDR, \quad y = 9.09x + .0003$$
$$REG-OTH, \quad y = 1.62x + .0001$$

A test for correlation was performed on the data used for each regression line. A confidence level of 95% was chosen as the criterion for the test. None of the three lines passed the test for correlation despite the appearance of correlation for the regression line REG-OTH.

Clearly, all of the SRAs performed at an operational failure rate in excess of their predicted rate, a situation which is not totally surprising. Unfortunately, most SRAs performed substantially worse than they were predicted to. As a final note, the radar SRAs appear to perform much worse than power supplies in other applications.

Reliability of Power Supplies vs Other Electronics

The previous paragraphs have documented power supply performance as "worse than predicted". The obvious question to ask next would be, "How do the power supplies compare with the rest of the electronics they are housed with?" Answering this question will explain whether the power supplies do perform poorly as a class of electronics or whether they are as just as good as the rest of the electronics. A poor performing power supply coupled with a poor performing electronic box is indicative of a problem such as application, design, environment or manufacturing techniques. A poor performing power supply coupled with a stellar performing box may indicate power supplies are not as reliable as other electronics. This assumes that the same manufacturer who designed and built the "other electronics" also built the power supply and applied the same engineering and production techniques to both. If this is the case, there must be some fundamental difference separating power supplies from other electronics. These major differences would include the thermal environment, a noisy electrical environment, the component mix (lots of high power devices) and the performance parameters (high speed switching of large currents and high voltages).

To determine the relative merits of power supplies as compared to their brethren housed in the same box, two figures were developed. Figure 44 compares the predicted failure rate of the power supply as a percentage of the total box predicted failure rate (x-axis) to the power supply operational failure rate as a percentage of the total box operational failure rate (y-axis). The power supply SRAs were grouped into functional units for this comparison to eliminate noise on the graph, ie., all failures of power supplies for a given box were combined. The data points for each of the boxes studied were plotted along with the line representing an actual failure rate percentage equal to the predicted percentage (X=Y). Additionally, several regression lines were plotted. REG-ALL is the regression line for all of the power supplies. On examination, it was discovered that the top three data points belonged to the radar power supplies. Therefore, two additional regression lines were plotted; one for the radar and one for the remaining boxes. REG-OTH represents the other boxes and REG-RDR

represents the radar boxes. The equation of the plotted lines are as follows:

X=Y,	y =	x
REG-ALL,	y =	.62x + 25.85
REG-RDR,	y =	1.43x + 46.86
REG-OTH,	y =	.42x + 10.83

The correlation analysis was performed on the regression lines with no success - all three lines failed to show correlation analytically.

Figure 44 clearly illustrates the fact that power supplies perform worse than their brethren. Every power supply in the study except one had consumed a higher percentage of total box failures than it was predicted to. As in Figure 43, the radar appears to be performing worse than the rest of the power supplies. The remaining power supplies performed fairly close to their expectations. In fact, if the regression line REG-OTH were to continue with the same slope, power supplies with a predicted failure
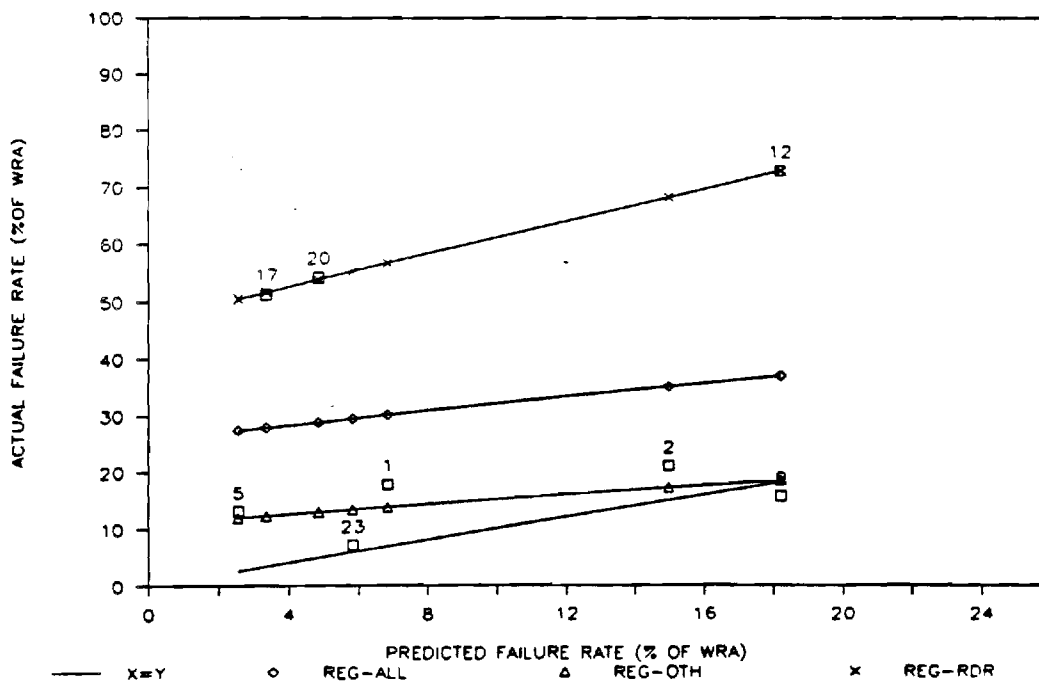
Figure 44. Normalized Predicted Lambda vs Actual

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rate greater than 18% of the total box failure rate would theoretically perform better than expected.

Figure 45 looks at the data a little differently. It compares a), the ratio of the operational failure rate to the predicted failure rate of the box to b), the ratio of operational failure rate to the predicted failure rate of the power supply. Again, as in Figure VI-2, 75% of the power supplies achieved a failure rate multiplier much higher than the overall box multiplier, confirming what many have stated as fact for quite some time - power supplies are less reliable than other electronic modules. The regression line is represented by the equation:

$$REG, \qquad y = 1.1x + 8.02$$

As in Figure 44, the correlation analysis test resulted in a determination of no correlation.
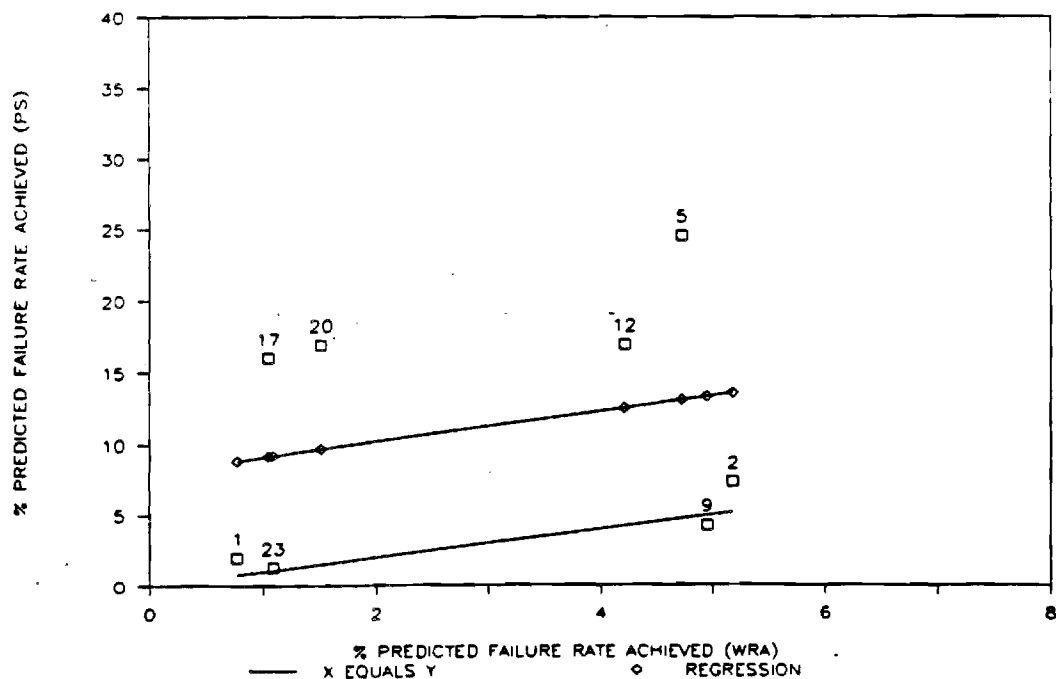
Figure 45.

Predicted Lambda Achieved (WRA) vs Predicted Lambda Achieved (SRA)

Power Supply Reliability vs Overall Complexity

The next analysis was performed in an effort to determine if reliability
was a function of complexity for the power supplies in this study. To this
end, three graphs based on the parts count of the power supplies were
generated. The x-axis in these charts represents the total piece part
count of the power supply with the achieved failure rate plotted against
the x-axis.

The first figure in this set of data (Figure 46) contains data points for
all of the SRAs of Table 4. As illustrated, the data is scattered over the
entire graph. The regression line was calculated using all of the data
points except for the one labeled (6). This data point has a drastic
effect on the regression line and was considered irrelevant. Additionally,
it is not a true power supply SRA; it is a rectifier sub-SRA for a low
voltage power supply. The regression line is represented by:

$$REG, \qquad y = .05x + 1.16$$
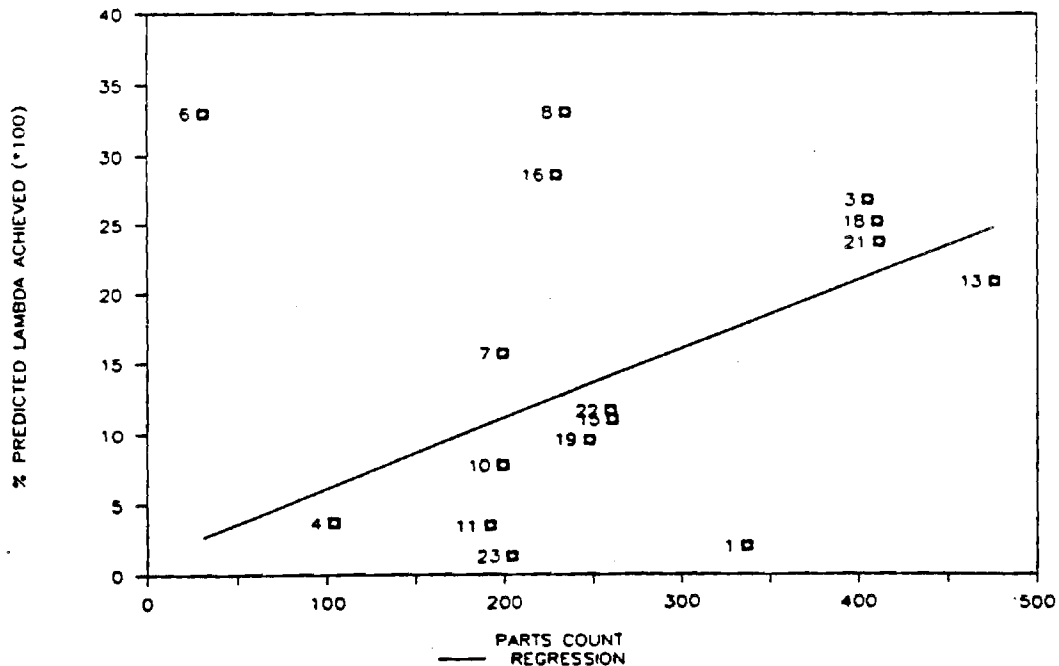
Figure 46. Power Supply Complexity vs Predicted Lambda Achieved

Although the regression line failed the test for correlation, it barely did so.

In an attempt to eliminate the scatter, the sub-SRAs were grouped to form functional power supplies and the graph was replotted as Figure 47. The scatter was reduced and a regression line with a much better fit than the one of Figure VI-4 was obtained. The equation of the regression line is:

$$\text{REG,} \qquad y = .033x + .05$$

In this case, the regression line did pass the test for correlation.
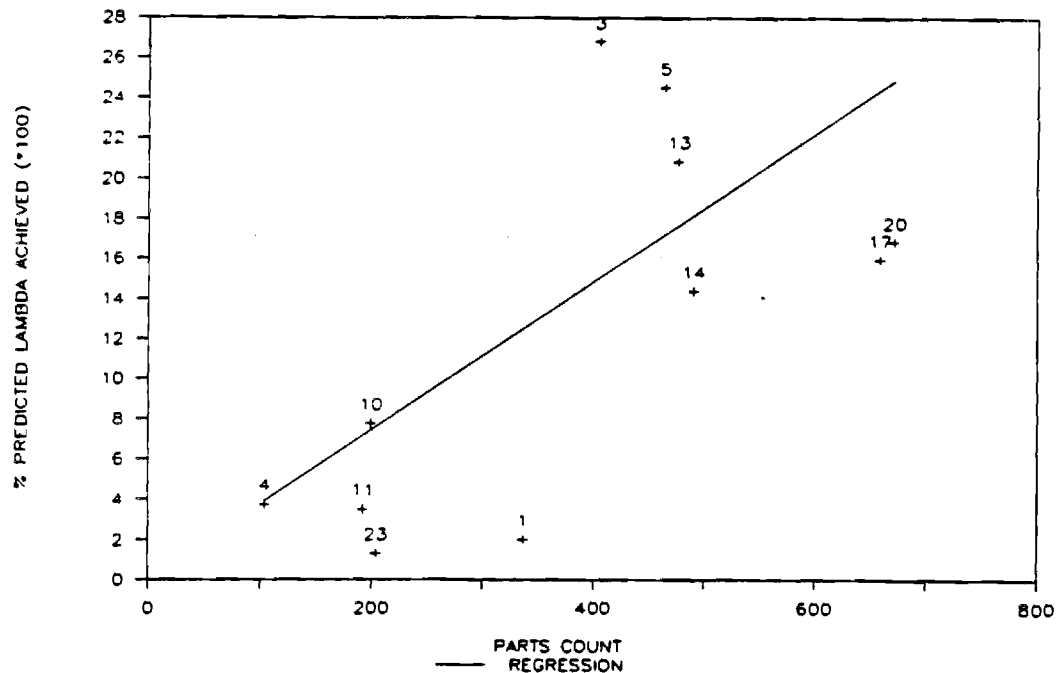
Figure 47.

Power Supply Complexity vs Predicted Lambda Achieved (Grouped)

Finally, the graph was plotted one more time (as Figure 48) with the power supplies for a given box grouped together to form one "power supply", ie., the high voltage units were thrown in with the low voltage units. This provided a good visual fit (regression line REG-ALL) with only one data point significantly out of the main group. However, due to the small

sample size, the line REG-ALL failed the correlation test. With that data point removed, the best fit of all was obtained with regression line REG-OTH. The line REG-OTH passed the correlation test. The equations of these lines are:

$$REG\text{-}ALL, \quad y = .023x - .93$$
$$REG\text{-}OTH, \quad y = .026x - 4.46$$

As illustrated in the last three graphs, the more complex power supplies have consistently proven to perform worse (with respect to their predicted rate) than more simple units.
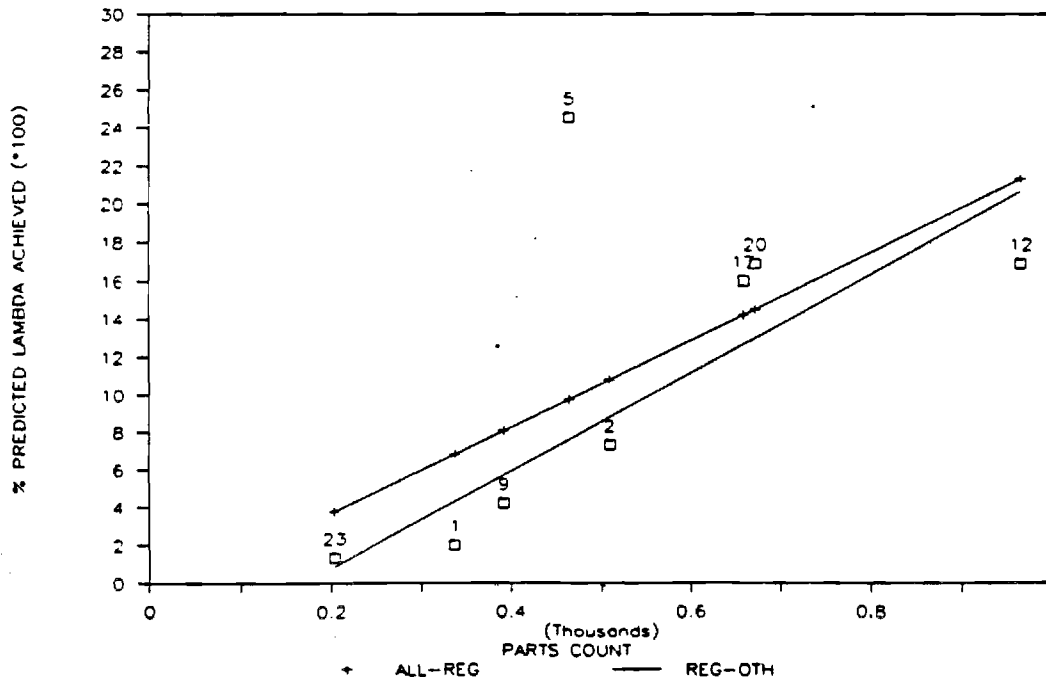
Figure 48.

Power Supply Complexity vs Predicted Lambda Achieved (WRA)

Protection Component Replacement vs % Total Parts are Protection

To determine if protection circuity is deserving of having adjustment factors applied to the predicted failure rate of individual components, the following analyses were initiated to quantify the frequency at which the

protective components failed with respect to their expected failure rate.

The first step of this process was to identify which parts on each power supply are associated with transient protection circuitry. For this purpose, all parts associated with sensing overvoltages or overcurrents, comparing the voltages, clamping voltages or diverting currents are considered transient protection circuitry. The components necessary to bias and filter these protection components were also included. These components were identified from the power supply schematics.

The second step of the process was to determine how many of these parts actually were replaced during the time period in question. The H through Z records in the Navy's 3-M data base contain information on every part removed from the individual circuit cards. A detailed list of the replaced parts sorted by work unit code and part number was obtained from this data base. From this list, the number of replaced protection parts, identified by their reference designator, were tallied for each power supply.

Once the parts were identified and tallied, the ratio of protection components replaced to the total number of parts replaced for a given power supply was calculated (Ratio A). Next, the ratio of protection parts to total parts was calculated (Ratio B). These two ratios were then plotted (Ratio A on the y-axis and Ratio B on the x-axis) for all of the power supplies except the MDI high voltage power supply and the ARC-182 power supply (piece part information for these two units was not available from the 3-M data base). As Figure 49 illustrates, the protection components of all power supplies in the study, with the exception of two, were replaced at a lower rate than would be expected. The expected replacement rate is the replacement rate achieved when the percentage of replaced protection parts equals the percentage of protection parts in the circuit. The X-Y line is the expected replacement rate. The regression line for these data points is represented by the equation:

$$REG, \qquad y = .42x$$

This implies the actual failure rate of protection components is 42% of the expected failure rate. The test for correlation failed, however.
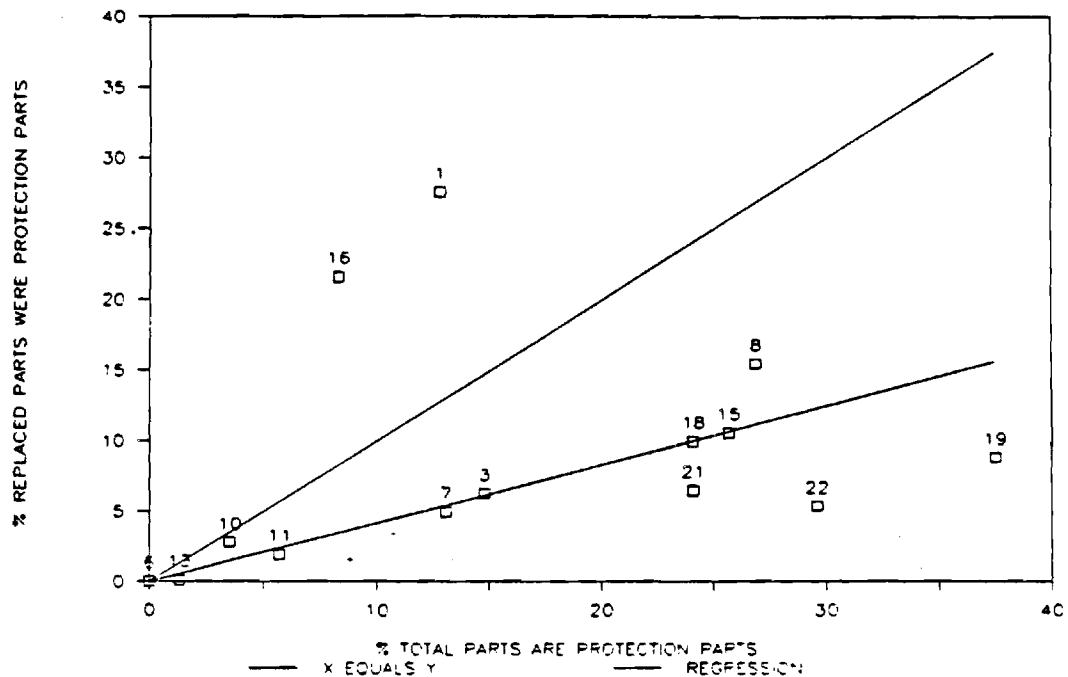
Figure 49.   Protection Complexity vs Replaced Protection Parts (I)

Upon closer examination of the two data points (1 and 16), it was discov-
ered that the values were being driven by one component in one case and a
class of components in the other case. For data point 1, a very large
percentage of the replaced protection components were fusistors - a resis-
tor designed to fuse open at a given current level to protect output
drivers on the power supply. In the other case (data point 16), the .
majority of protection component replacements were caused by two parallel
resistors which were used as start-up current in-rush limiters. In both
cases, the components are either being subjected to conditions far in
excess of the design specification, being subjected to maintenance induced
failures far above the norm, or have been misapplied or some combination of
the above. Therefore, failures of these components were disregarded and
the graph was replotted as Figure 50. With the fusistors and in-rush
resistors removed, the two power supplies fell into line with the other
power supplies. The regression line for this graph had the equation:

REG,   y - .35x

This implies the protection components have a failure rate 35% of the

73

expected failure rate. The correlation test for this regression line
passed.
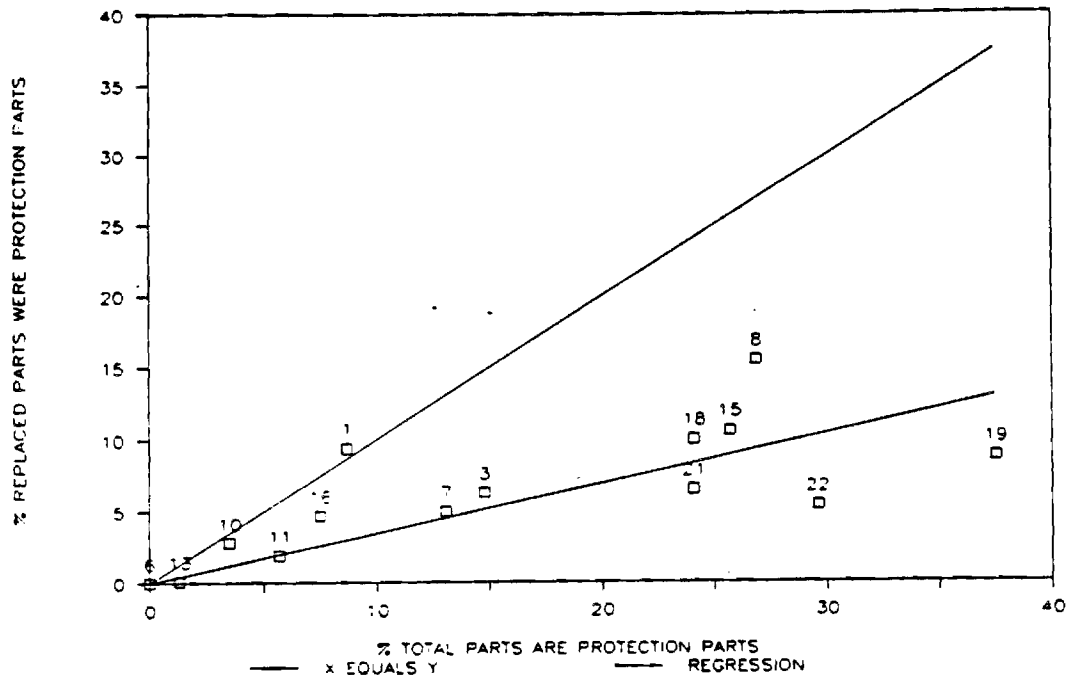
Figure 50. __Protection Complexity vs Replaced Protection Parts (II)__

Protection Complexity vs Achieved Reliability

This set of analyses was initiated to determine if the complexity of the
protection circuity (as determined by the percent of total power supply
parts which are related to protection-circuitry) had any influence on the
achieved failure rate of the power supply. The achieved failure rate is
defined as the ratio of the operational failure rate to the predicted
failure rate. The level of achieved failure rate would be expected to
decline with increasingly complex protection strategies and subsequently
increase with little or no protection.

Figure 51 was developed by comparing the achieved failure rates of all
power supply SRAs (y-axis) to the protection complexity (x-axis). As
illustrated, the data on the chart is very noisy and there appears to be
zero correlation of achieved reliability to the amount of protection

incorporated. A regression line was fit to the data, but the fit was very poor. The equation of the regression line is:

$$REG, \qquad y = .07x + 15.03$$

Figure 52 is identical to 51 except that the SRAs were grouped together to eliminate some of the scatter. However, the data is still very noisy and, as expected, the correlation test failed. The regression line has the equation:

$$REG, \qquad y = .40x + 7.27$$
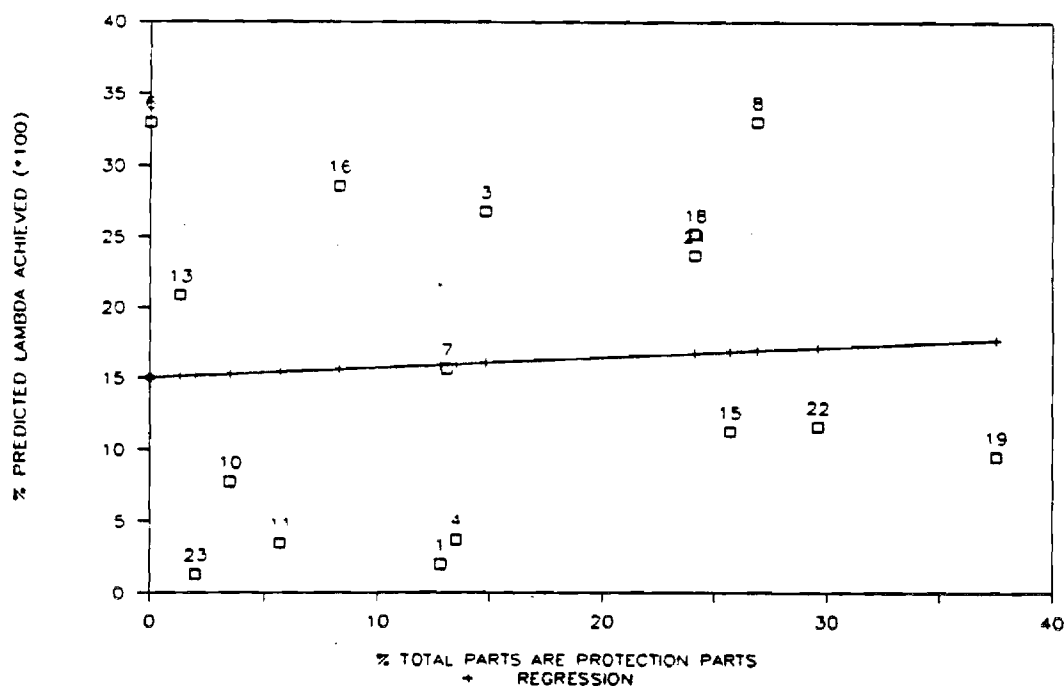
Figure 51. Protection Complexity vs Predicted Lambda Achieved

A different method of looking at the achieved reliability as a function of protection complexity was developed. Instead of determining the protection circuit complexity on the basis of parts count, the complexity was determined by the number of different types of protection offered. Overall, five types of protection were identified. They are input overvoltage,
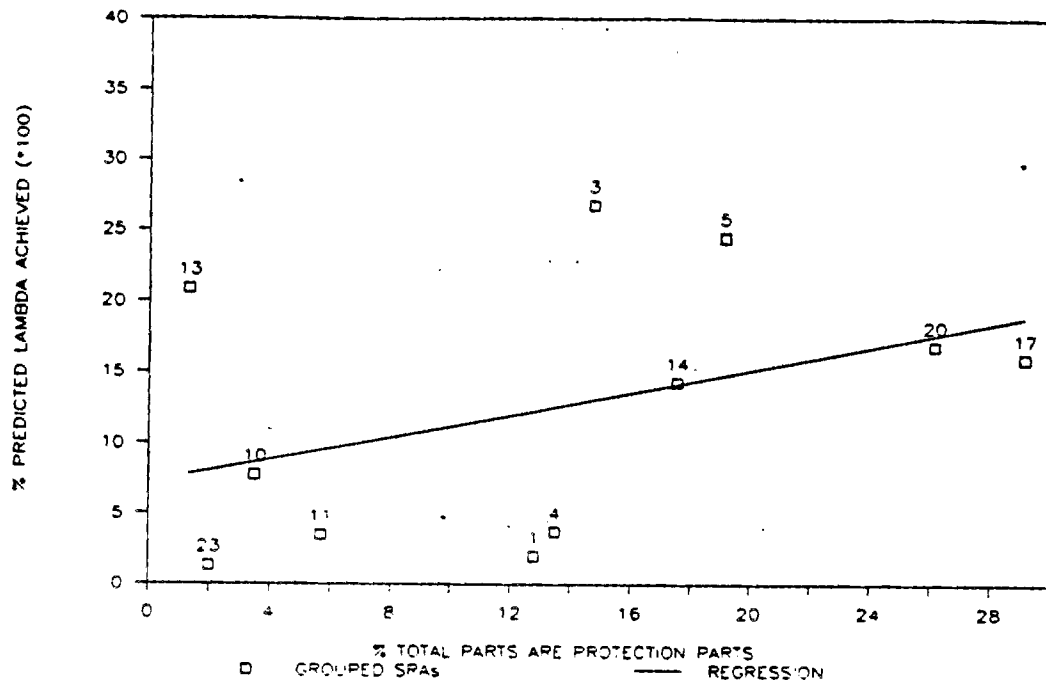
Figure 52.

Protection Complexity vs Predicted Lambda Achieved (Grouped)

output overvoltage, in-rush current limiting, normal current limiting and snubbing of transistors and inductors.

To start this analysis, each power supply was assessed to determine which types of protection they incorporate. Next, the power supplies were ranked according to the total number of protection types offered. The achieved failure rate of each power supply with the same number of protection types were summed together and an average value was obtained. The average values for each level of protection complexity were then plotted in Figure 53. For this plot, all of the power supply SRAs for a given electronic box were grouped together. This was done because, in many cases, one SRA of a given power supply would provide input protection while another SRA would provide the ouptut protection. While the electronic boxes with three and five types of protection only represent a sample of one box, the general trend indicates (again) that electronic boxes with more complex protection perform more poorly than those with less. The regression line has the equation:

$$\text{REG,} \qquad y = 3.2x + .61$$

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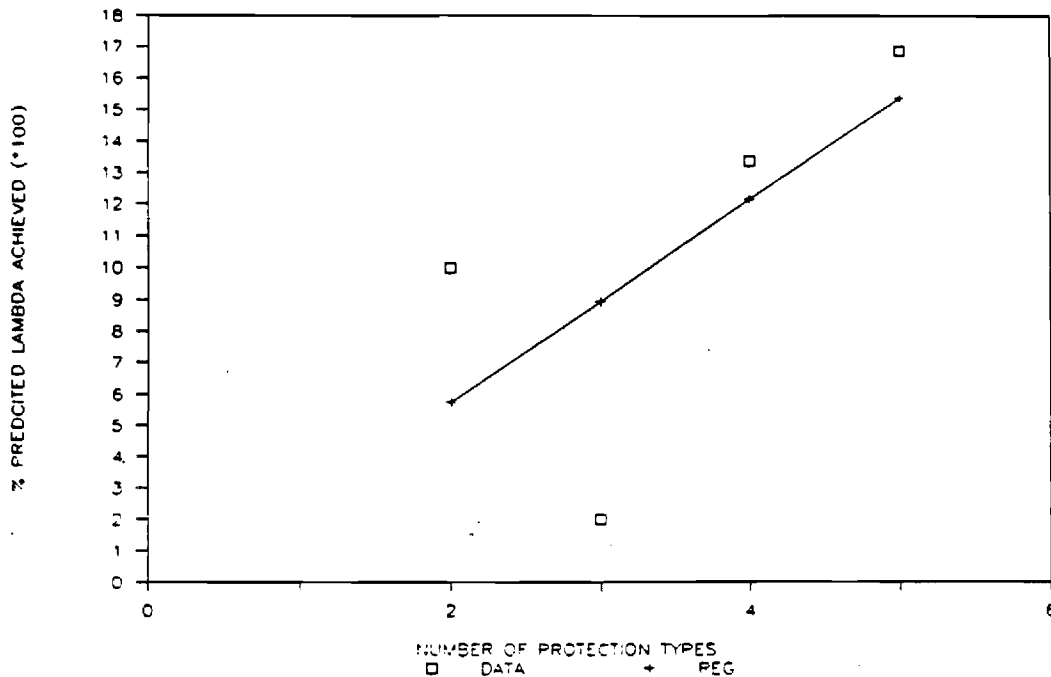
Figure 53.   Number of Protection Parts vs Predicted Lambda Achieved

A correlation analysis was not performed since the sample size was suffi-
ciently small that failure was guaranteed.

Three additional charts were plotted using the same analyses as used for
Figures 51 and 52 except that these charts were plotted based on the type
of power supply they were, ie., a switching supply, a linear supply or a
combination there of. The chart for the combination power supply is
plotted as Figure 54, the linear type. as Figure 55 and the switching type
as Figure 56.

Figures 51 through 56 are not encouraging. Any firm conclusions would be
difficult to make based on what appears in some cases to be random noise.
However, if one were to use the regression lines as an indicator, five of
the six plots indicated that increasing protection circuit complexity will
cause the failure rate to increase - the exact opposite result of what is
expected!   The one plot which did not show an increase had only three data
points on which to base the regression and must be discounted.

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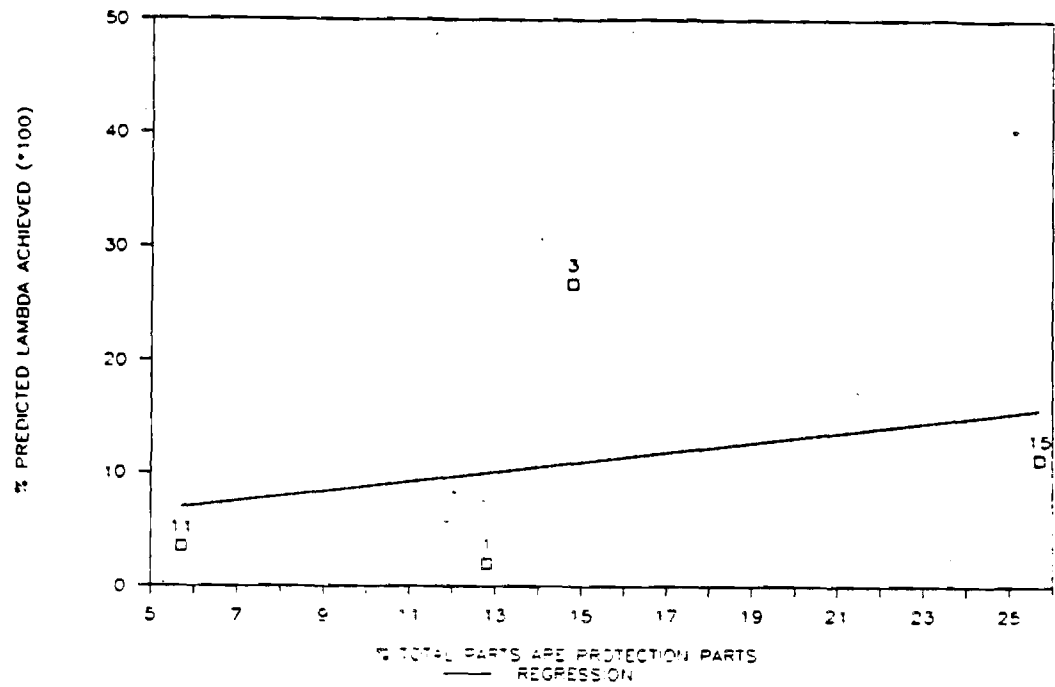
Figure 54. Protection Complexity vs Predicted Lambda Achieved
(Combined Linear and Switching)
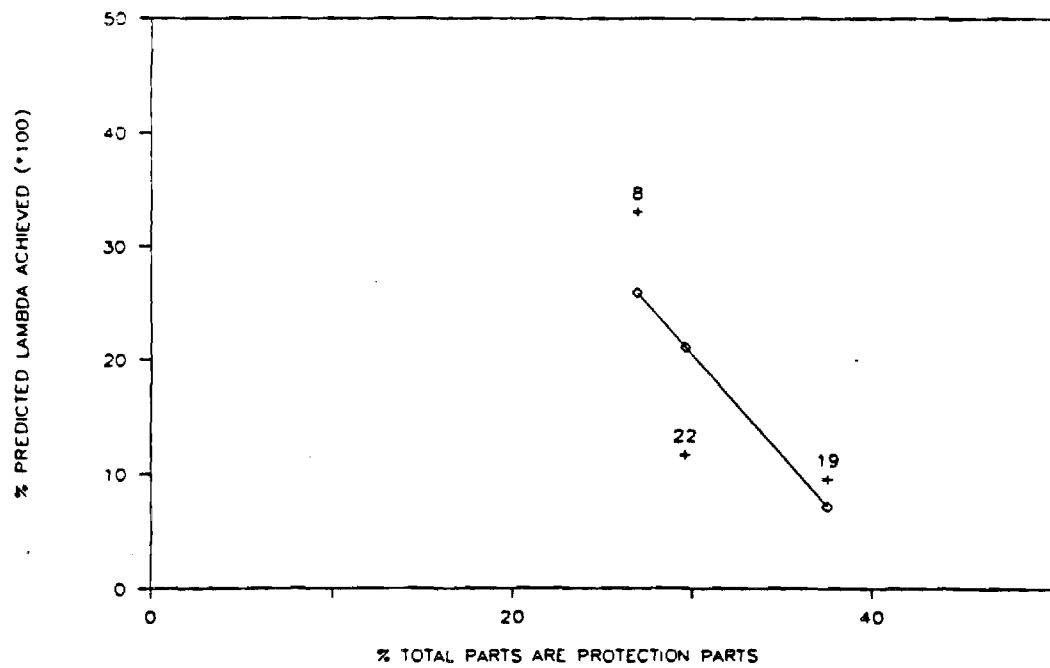
Figure 55. Protection Complexity vs Predicted Lambda Achieved (Linear)
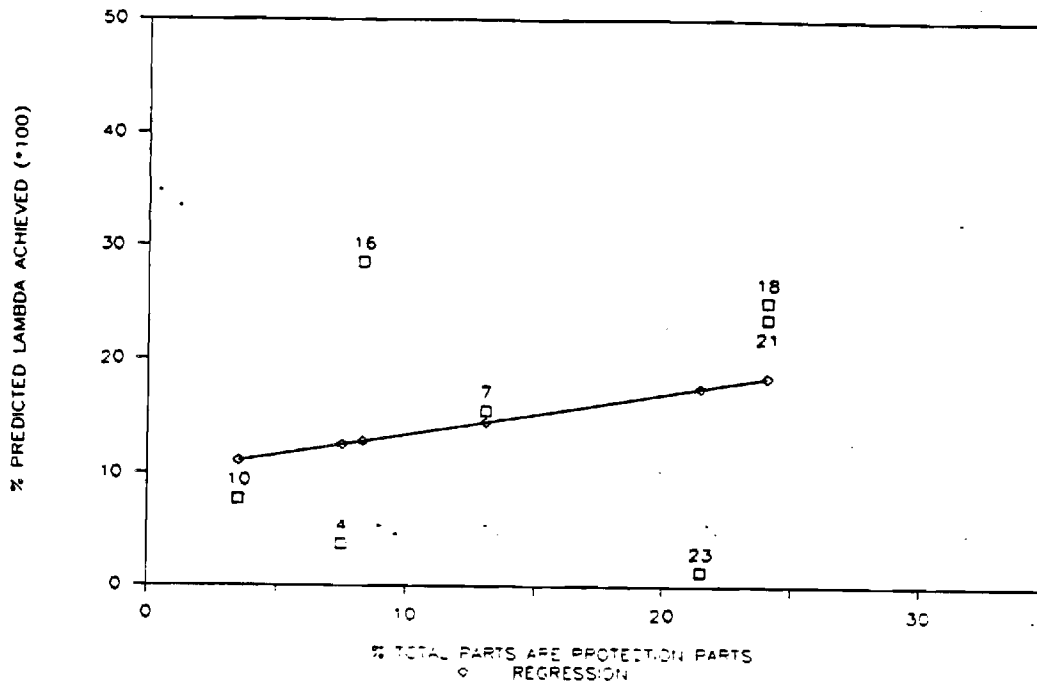
Figure 56. Protection Complexity vs Predicted Lambda Achieved (Switching)

Power Supply Type vs Achieved Reliability

   The last analysis performed compared the achieved failure rate (with
respect to the predicted failure rate) with the power supply type, ie.,
switching regulator, linear regulator or a combination of the two. This
analyis was performed on the individual SRAs of Table 4. The average value
of the achieved failure rate of each type is illustrated in Figure 57. For
the sample of this study, the supplies which were a combination of linear
and switching regulators performed best with switching regualtors coming in
second. Linear regulators performed the worst, supporting the argument
made by many (if not all) power supply designers. The relationship between
the complexity of the various types of power supplies and the achieved
failure rate can be seen in Figures 54 through 56.

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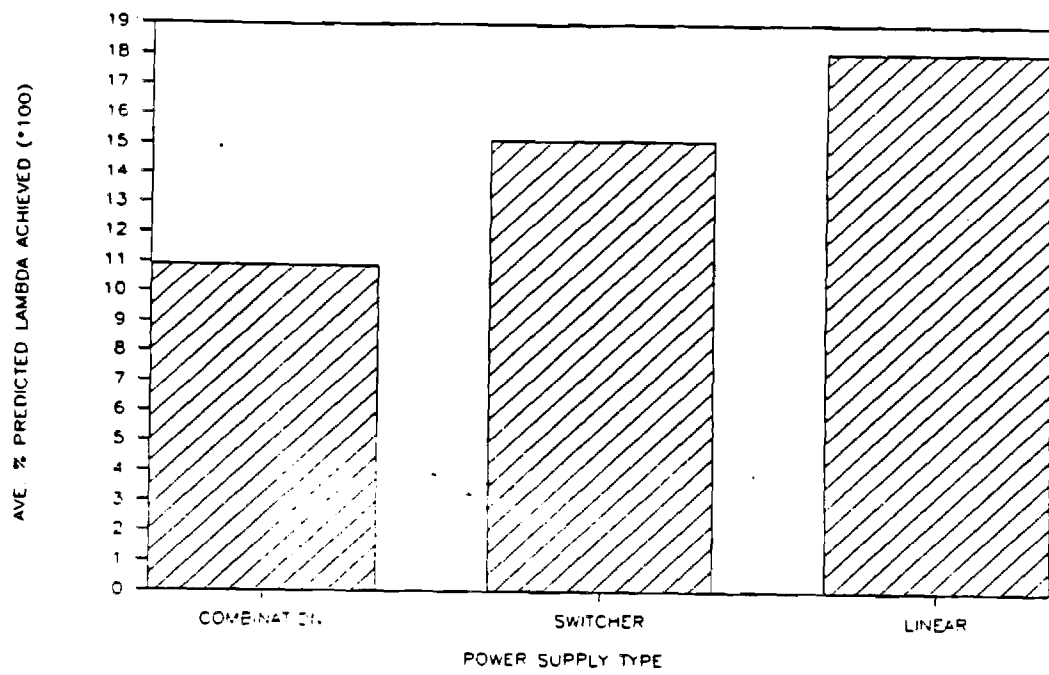
Figure 57. Power Supply Type vs Predicted Lambda Achieved

Chapter VII
Conclusions and Recommendations

Task VII of the statement of work required MCAIR to summarize the results of this effort and, if possible, develop adjustment factors to be applied to power supplies as a function of the transient protection incorporated. The conclusions and recommendations are as follows:

1) Conclusion: Present specifications inadequately define the electrical environment power supplies must survive in.

   Recommendation: Procurement specifications must clearly define the transients that power supplies are expected to survive, ie., shorted outputs, voltage transients on the input or output, or in-rush current. The waveform, peak voltages and currents, duration, source impedance, transient application point and the performance requirements during the transient must be precisely defined. Without clear direction, the protection incorporated will vary widely from one manufacturer to another. Additionally, the procurement specification should require snubbing of switching transistors to protect them from transients which are undefinable until the design is complete and actual measurements are available.

2) Conclusion: Qualification and reliability testing does not adequately verify the ability of a power supply to survive electrical transients.

   Recommendation: Qualification and reliability development test requirements should be expanded to include subjecting power supplies to specified transient conditions and verifying they can survive.

3) Conclusion: Purely analytical techniques are not adequate for derating and worst case analyses.

Recommendation: Portions of these analyses must be confirmed with measured data. Specifically, dissipation of the power transistors during steady state operation, dissipation of the power transistors during transient conditions, peak voltages at the input and output during steady state and transient conditions, and peak in-rush currents must be measured and compared to the analytical values. The derating analyses should be updated to reflect these measured parameters and design changes should be made to rectify any problems.

4) Conclusion: There is a more than adequate selection of components, in both discrete and integrated circuits, available to the designer to implement transient protection simply and effectively.

Recommendation: None

5) Conclusion: The data analyses indicate more complex protection schemes are associated with power supplies which perform progressively worse with respect to their predicted failure rate. However, the correlation tests for the regression lines all failed and adjustment factors could not be determined with confidence.

Recommendation: It is difficult to believe that power supplies with more complex protection circuitry perform more poorly as a result of the circuitry. It is more likely a function of some other unidentified parameter. A controlled laboratory test is recommended, using a "standard" power supply to which varying levels of transient protection are attached and to which standard transients are to, would provide an unbiased evaluation of the effect protection complexity has on reliability.

6) Conclusion: The analyses also have shown more complex power supplies perform worse with respect to their predicted rates than less complex power supplies.

Recommendation: None

7) Conclusion: Transient protection parts fail at a much lower rate than the remaining components in a power supply.

Recommendation: According to the analyses of Chapter VI, the relationship between replacement rates of transient protection parts and the remaining electronics does correlate. The data suggests the predicted failure rate of transient protection components could be adjusted downward by 65%, or, the adjusted predicted failure rate θ_a is related to the original prediction θ_o by the following equation:

$$\theta_a = .35\theta_o$$

8. Conclusion: The analyses confirmed the notion that power supplies fail more often than other assemblies within a piece of avionics.

Recommendation: None

9. Conclusion: Power supplies fail at a rate much higher than those rates obtained from the predictions.

Recommendation: Correlation analyses performed on the regression lines failed; therefore, adjustment factors can not be applied with confidence. However, the laboratory test mentioned in recommendation number 5 could be used to determine a reasonable adjustment factor to relate predictions to operational failure rates of power supplies.

10) Conclusion: Switching power supplies performed better than linear power supplies as compared to their predictions.

Recommendation: The use of switching power supplies is preferred whenever possible. Use linear supplies only when necessary performance parameters require them.

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Appendix A

Surveyed Companies

A-1 thru A-3

OPT Industries, Inc.
300 Red School Lane
Phillipsburg, NJ 08865

Pacific Electro Dynamics
11465 Willows Rd N.E.
Redmond, WA 98052

Powercube Corp.
8 Suburban Park Drive
Billerica, MA 01821

Power Functions Eng., Inc.
3831 Cavialier
Garland, TX 75042

Power Supply Concepts, Inc.
33 County Rte. 1
Warwick, NY 10990

Power Jen, Inc.
486 Mercury
Sunnyvale, CA 94086

Rantec Power Systems
9401 Oso Ave.
Chatsworth, CA 91311

RO Associates, Inc.
246 Caspian
Sunnyvale, CA 94089

Technipower/A Penril Co.
14 Commerce Drive
Danbury, CT 06810

Tri-Mag, Inc.
8210 W. Doe Ave.
Visalia, CA 93291

Trio Laboratories
#80 Duport Street
Plainview, NY 11803

Westcar Corp.
485-100 Alberta Way
Los Gatos, CA 95032

Acme Electronics
20 Water Street
Cuba, NY 14727

Arnold Magnetics Corp.
4000 Via Pescador
Camarillo, CA 93010

Abbott Transistor Labs
2727 South La Cienega
Los Angeles, CA 90034

Applied Power Conversion/Tech Dyn.
100 School Street
Bergenfield, NJ 07621

ATC Power Systems
472 Amherst St.
Nashua, NH 03063

CEAG Electric Corp.
1324 Motor Parkway
Hauppauge, NY 11788

Custom Power Systems, Inc.
33 Comac Loop
Ronkonkoma, NY 11779

EG and G Almond Instruments
1330 E. Cypress Street
Covina, CA 91724

Kepco, Inc.
131-38 Sanford Ave.
Flushing, NY 11352

Lamba Electronics
515 Broad Hollow Rd
Melville, NY 11747

Logitek
101 Christopher
Ronkonkoma, NY 11779

Modular Devices
Roned Rd, Brookhaven R&D Plaza
Shirley, NY 11967

North Hills Electronics, Inc.
1 Alexander Place
Glen Cove, NY 11542

OECO Corp.
4607 S.E. International Way
Milwaukie, OR 97222

Abbott Technologies, Inc.
8203 Vineland Ave.
Burbank, CA 91352

Advance Power Systems
32111 Aurora Rd
Solon, OH 44139

AT&T Microelectronics
2 Oak Way
Berkeley Heights, NJ 07922

Converter Concepts, Inc.
Industrial Parkway
Pardeeville, WI 53954

Elpac Power Systems
3131 S. Standard Ave.
Santa Ana, CA 92705

Integrated Power Designs, Inc.
9C Princess Rd
Lawrencville, NJ 08648

Kaiser Systems, Inc.
126 Sohier Rd
Beverly, MA 01915

Modern Power Conversion, Inc.
7100 Warden Ave., Unit #3
Markham, ONT, Canada L3R8B5

Marata Erie North America, Inc.
6338 Viscount Rd
Mississauga, ONT, Canada L4V183

Onan Power/Electronics
4801 W. 81st St. Suite 114
Minneapolis, MN 55437

Power Electronics Corp.
30 Industrial Dr.
Londonderry, NH 03053

Power Systems, Inc.
45 Griffin Rd South
Bloomfield, CT 06002

Shindengen America, Inc.
5999 New Wilke Rd
Rolling Meadows, IL 60008

Spellman High Voltage Elec. Corp.
7 Fairchild Ave.
Plainview, NY 11803

Switching Systems International
500 Porter Way
Placentia, CA 92670

Toko America, Inc.
1250 Feehanville Dr.
Mt. Prospect, IL 60056

Conver, Inc.
916 W. Maude Ave.
Sunnyvale, CA 94086

ORAM High Voltage
Klemp Rd
Dayton, TX 77535

General Electric Power Supply
1635 Broadway
Fort Wayne, IN 46802

Joule Power, Inc.
Summer Road, Joyce Industrial
Boxboro, MA 01719

Mil Electronics
1 Mill Street
Dracut, MA 01826

Modular Devices, Inc.
4115 Spencer
Torrance, CA 90503

NCR Power Systems
3200 Lake Emma Rd
Lake Mary, FL 32746

Panasonic Industrial Co.
Two Panasonic Way
Secaucus, NJ 07094

Power General Corp.
152 Will Drive
Canton, MA 02021

Powertec, Inc.
20550 Nordhoff St.
Chatsworth, CA 91311

Sola, Unit of General Signal, Inc.
1717 Busse Rd
Elk Grove, IL 60007

Switching Power, Inc.
3601 Veterans Highway
Ronkonkoma, NY 11779

Taltronics Corp.
404 Armour
Davidson, NC 28036

Tower Electronics
281 S. Commerce Circle
Fridley, MN 55432

Zenith Electronics Corp.
1000 Milwaukee Ave.
Glenview, IL 60025

Appendix B

Survey

B-1 thru B-4

POWER SUPPLY QUESTIONNAIRE

1. What are the transient levels you normally design for? Please identify the peak voltage, peak current, volts per second rise, current per second rise and the transient duration. If a specification is used, please identify the source, i.e., MIL-STD-704, IEEE, etc.

2. Several different power supply rectifier and regulator topologies are illustrated in Figure 1. For those topologies utilized in your designs, please indicate where transient protection is incorporated, what type of transient it absorbs or diverts and what type of device(s) are used. Schematic representation is preferred, but block diagrams may be substituted if proprietary designs are involved. An example follows.
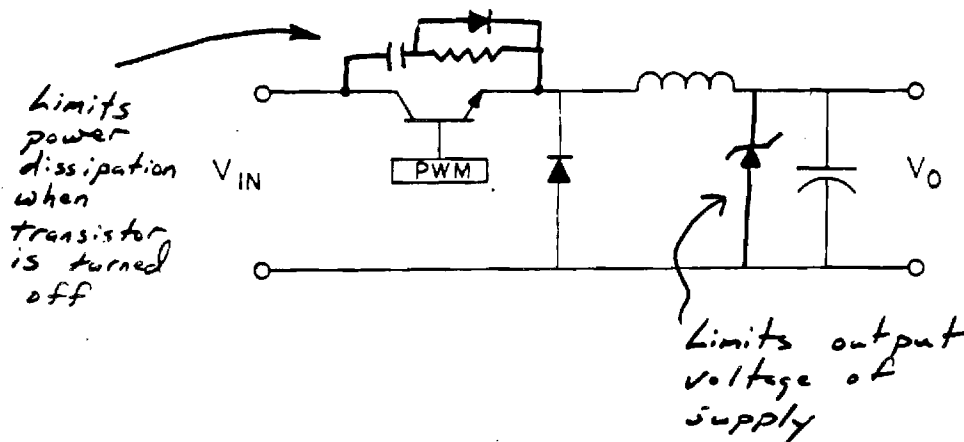
3. Please describe any transient protection properties which are inherent to your design.

POWER SUPPLY QUESTIONNAIRE

4. In your opinion, what percent of operational failures in protected and unprotected power supplies are a result of transient conditions?

5. For power supplies with protective circuitry, approximate the percentage of operational failures that occur in the protective circuitry.

6. In your opinion, what are the trade-offs of added protection in terms of increased production costs, increased power dissipation and decreased operational failure rates?

7. In your experiences, what are the real world limitations of the various protection schemes?
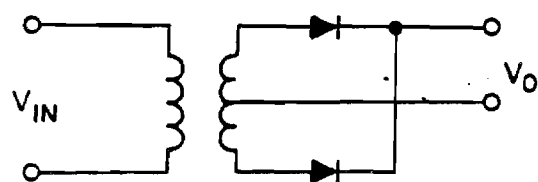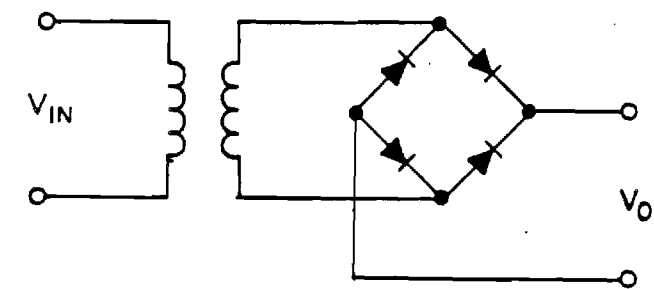
Linear Regulator
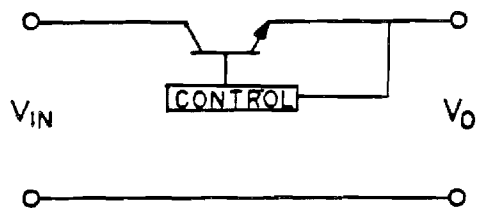
Switching Regulators
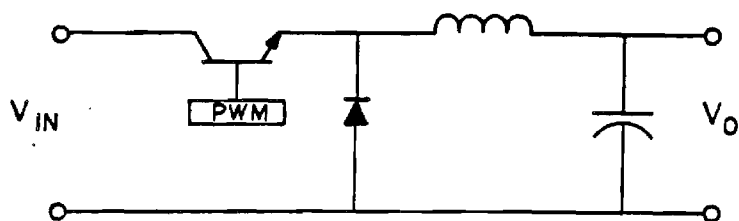
Figure 1

Switching Regulators (con't)
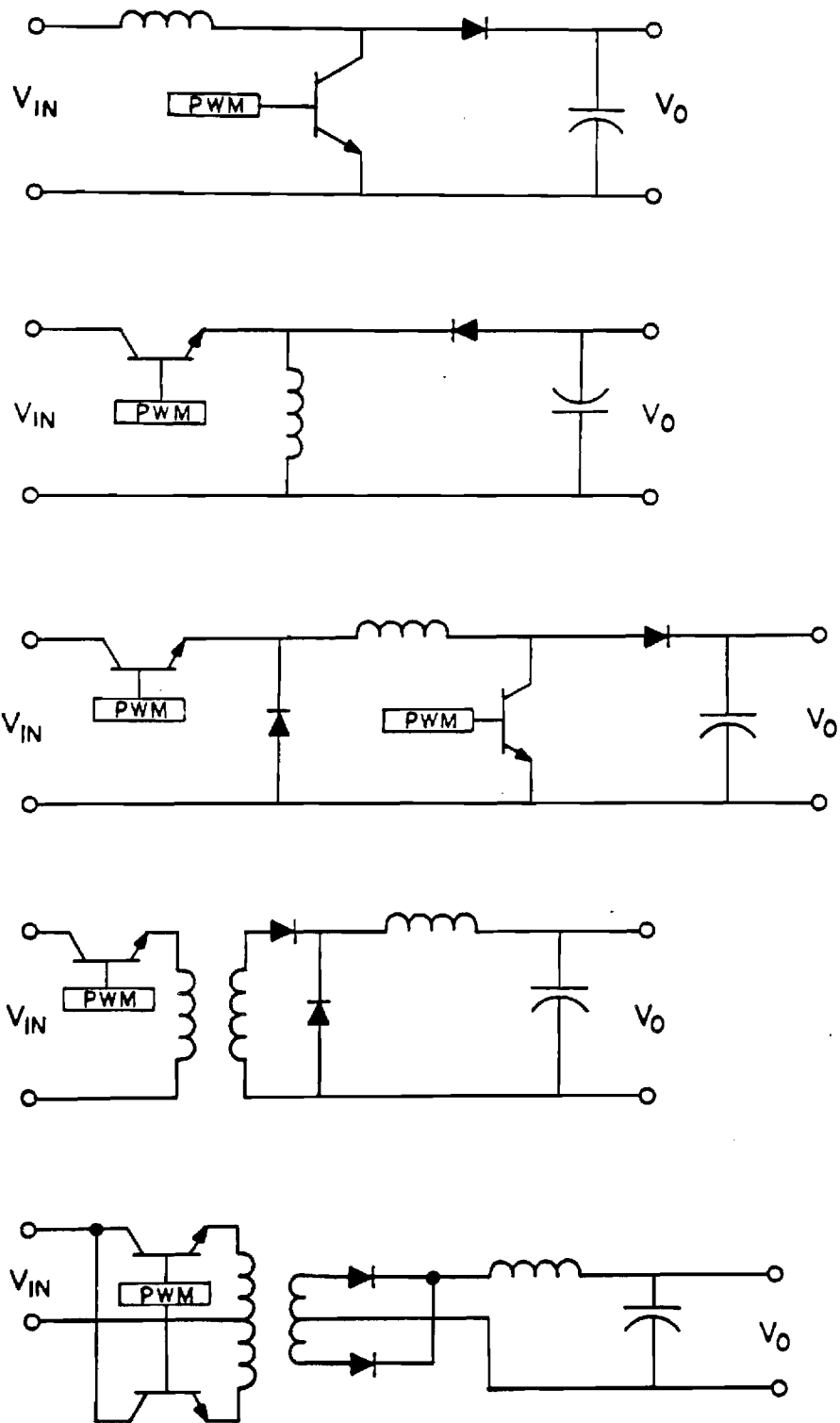
Figure 1
B-4

Appendix C

Returned Surveys

C-1 thru C-23

Murata
Erie

POWER SUPPLY QUESTIONNAIRE

1. What are the transient levels you normally design for? Please identify
the peak voltage, peak current, volts per second rise, current per second
rise and the transient duration. If a specification is used, please
identify the source, i.e., MIL-STD-704, IEEE, etc.

<u>Input Transients:</u> If not specified by customer, a rectangular pulse of 100% microsec
is often used, with unlimited energy (ie. zero inpedance). In other words, a pulse of
10KV could occur for 1 usec, or 1000 volts for 10 usecs, or 100 volts for 100 usec.
<u>Output Transients:</u> If not specified by customer, values used would be, typically
1.5KV for 1000 usecs. pulse power level. There would also be reverse polarity protec
ub to rated curents.
<u>Internal Transients:</u> 100's maybe 1000's of volts, tens of amps, kilovolts per microsec, tens of amps per mi

2. Several different power supply rectifier and regulator topologies are
illustrated in Figure 1. For those topologies utilized in your designs,
please indicate where transient protection is incorporated, what type of
transient it absorbs or diverts and what type of device(s) are used.
Schematic representation is preferred, but block diagrams may be
substituted if proprietary designs are involved. An example follows.

Limits power dissipation when transistor is turned off

Limits output voltage of supply

3. Please describe any transient protection properties which are inherent
to your design.

a) In half-bridge MOSFET designs, integral diodes can be exploited to clamp voltage
spikes generated by transformer leakage inductance.

b) Schottky rectifiers often possess sufficient self capacitance/stored energy to
provide the required snubbing for the devices.

c) Resonant topologies can be arranged to exhibit parasitic capcitances/inductances
in order to limit voltage/current excursions within required limits.

d) Often, solid clamping provided by rectifiers and free wheel diodes eliminate
the need for snubbing circuitry. Infact, modern day MOSFETS can be allowed to
self-zener without problems, in many circuits.

POWER SUPPLY QUESTIONNAIRE

4. In your opinion, what percent of operational failures in protected and unprotected power supplies are a result of transient conditions?

With otherwise well designed power supplies:

10% unprotected
1% protected

5. For power supplies with protective circuitry, approximate the percentage of operational failures that occur in the protective circuitry.

1%

6. In your opinion, what are the trade-offs of added protection in terms of increased production costs, increased power dissipation and decreased operational failure rates?

Production Costs: 10% increase
Power Dissipation: 4% increase
Decreased Failure Rate: Factor of ten

7. In your experiences, what are the real world limitations of the various protection schemes?

Input Transients: Nearby lightning strikes and EMP's can be tough to deal with. Also "illegal" use of input voltage can be a problem.

Output Transients: If coming from PSU, can be adequately dealt with using simple circuitry. (Crowbars, transorbs, etc.) For externally induced disturbances, same comments as for Input Transients apply.

Internal Transients: Voltage/current relationships for switching components can be difficult to define for all possible modes of PSU operation (OVP trip, output shorts, input/output transients).

Rectifiers
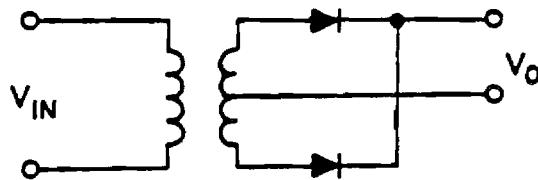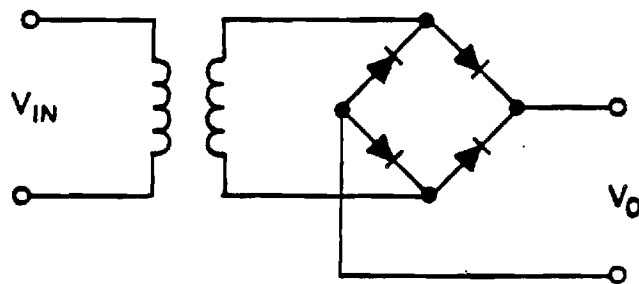
Capacitor across secondary
may be needed to deal with
leakage inductance. It also
helps with incoming transien

Two secondary capacitors may
be needed if the winding is
done hifilar. Otherwise
as above.

Linear Regulator
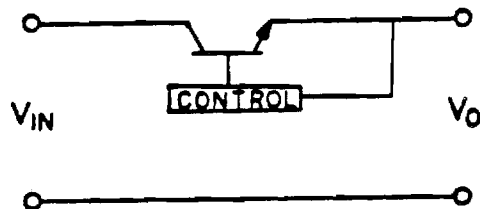
OVP and/or transzorb circuit
could not only take care of
problems with control logic,
but also incoming, fast
transients.

Switching Regulators
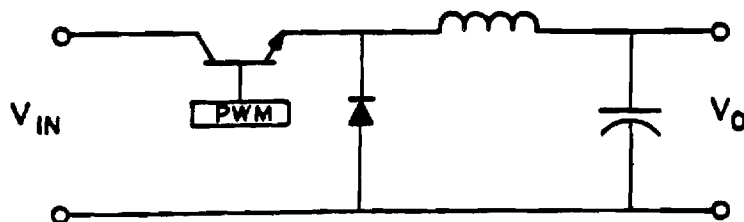
This circuit has some inher(
immunity to incoming transi(
Also, positive clamping eli-
minates the need for snubbi
circuitry, except maybe as
expedient for switching los:
or reducing collector curre
to zero before Vcex (maximu
is reached, as with circuit
shown in paragraph 2.

Figure 1
C-3

Switching Regulators (con't)
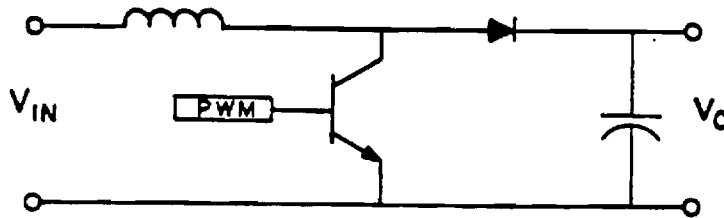
Same comments as for previous circuit.
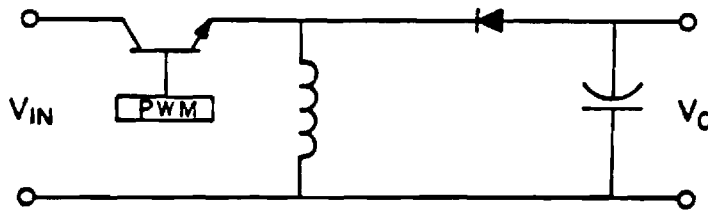
This circuit possisses positive clamping, but no protection against input transients. This could be added using surgistors (MoV's) combined with line filter transformers and capacitors.
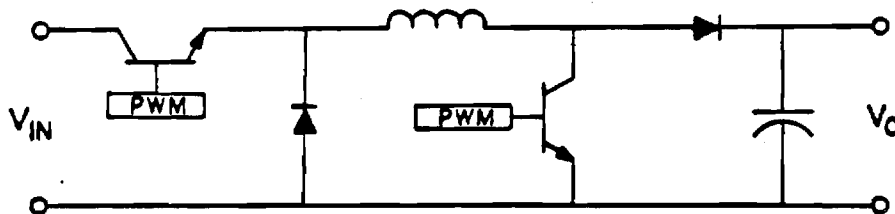
Same comments as for previous circuit.
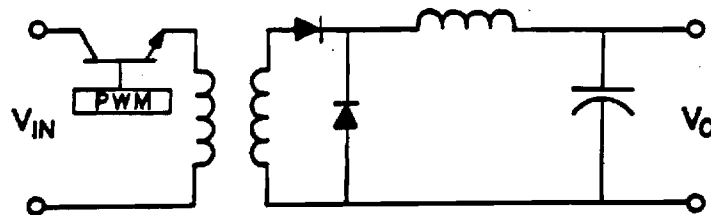
Snubbing is needed around transformer since there is no positive clamping. In fact a de-magnetisation winding may need adding since this is a forward converter. Protection against input transients needed.
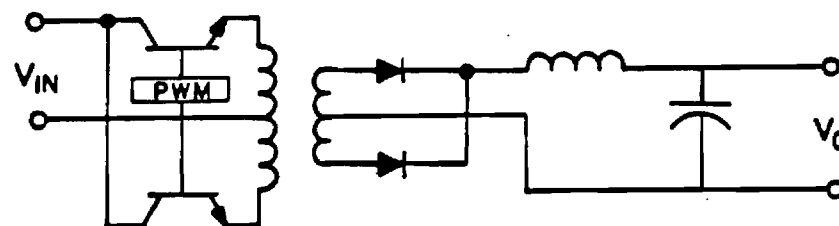
Snubbing needed to conteract leakage inductance. No demagnetisation winding needed. Protection against input transients required.

Figure 1
C-4

Powercube

May 4, 1989

David A. Followell
McDonnell Aircraft Company
P.O. Box 516
St. Louis, Mo. 63166-0516
D.346/32/2/MC 0341300

Dear Mr. Followell:

The following is a response to your questionnaire addressed to Mr. Roger LaFontaine. I hope that you will find it of use. We look forward to receiving a copy of the results of this survey.

1. We design to Mil-STD-704, DOD-STD-1399, and specific customer requirements. I have seen peak voltage requirements as high as 2500 volts. The wave shapes are usually diagramed in the published specifications.

2. Transient Considerations as a function of topology are as follows.

Rectifier Transient Protection

The first circuit of figure 1 is never used as is but rather with an output filter capacitor. Turn on inrush current is a big problem. To mitigate this problem an extra source resistor is added to both limit inrush and increase the conduction angle of the diodes. The value of the resistor added is not usually enough to protect the diodes and may contribute unacceptable system losses. Sometimes the inrush current limiting resistors are shunted after start up in which case no further transient protection is afforded at all. Another solution to the problem is to use an inductor in the output filter, but this adds weight, volume and expense.

1

Linear Regulator Transient Protection

Linear regulators utilizing common collector transistor pass elements are least affected by transients. Do not use the so called low drop regulator (usually consisting of a pnp series pass transistor in the common emitter configuration). A control system not using input voltage feed forward techniques requires infinite bandwidth to suppress input transients from its output. This can be demonstrated by looking at the small signal transistor model and making the observation that in the face of a transient condition control of the base current and therefore control of the collector current is not achieved.

Switching Regulator Transient Protection

The buck converter needs an input filter to keep switching currents off the power bus. All semiconductor switches need load shaping "snubbers." The nature of these snubbers is determined at the product brass board level of product development since it is the non ideal and uncontrolled character of parts and layout which contributes to their necessity. This problem is best explored in the time domain by observing current and voltage waveforms with an oscilloscope. Every switching topology shown in figure 1 requires this same careful consideration. The turn off snubber shown in the example is one tool most of us use. The objective is to look at current and voltage waveforms on every switch and with the addition of external parts make each switch as ideal as possible, meaning voltage and current aren't present at the same time. In order to achieve this end it is only necessary to recall that current

2

doesn't change in an inductor instantly, voltage doesn't change on a capacitor instantly, and only resistors dump energy out of an otherwise ideal system. If an effect is needed on only one edge a diode may be used, the example of the turn off snubber being a case in point. Many other considerations come to the designers attention when load line shaping is being considered, such as is the device already quite good enough to support the non-ideal character and can the application tolerate the added weight, volume, and expense?

The most major caution that I might add is that the addition of "protection" should not cause failure propagation. In your example the output voltage clamping zener, in the absence of current limiting, would only cause the transistor to fail instead of the output capacitor. This would do little good in a real application except during a catastrophic condition in which the load would be protected and then only if the zener didn't fail in a nonconducting condition. It is better to put decision making functions in the control circuit.

3. Transient protection is never inherent and if present is part of the design process. Line input filters will do much to protect a load from its source and a source from its load. Any system should have the ability to recover from a non failure mode induced self produced transient, and a switching power supply has them hundreds of thousands of times per second. This was the consideration explored in question 2 above. No exploration of transient protection can be started without knowledge of input port

3

and output port impedances. This needs to be known as a function of frequency. Only then can one conclude an answer to the basic question, which is "how much energy of a given time distribution can this system absorb at a given port without causing a failure?" If the power conditioner input port looks like a well controlled current sink, and the output port looks like a voltage source with current limiting and capacitive impedance then transients on the line and load will have the best chance of being tolerated. This is obviously qualitative and may be easily quantitatively analyzed by any engineer skilled in the art of power supply design.

4. In my opinion over half of switching power supply failures not due to misapplication or user error are due to either external or internal transients. Of these failures most seem to occur at turn on.

5. I don't recall any cases where well designed protective circuitry failed or caused failure. A scenario may be imagined which would propagate failure, but I have not seen it happen. I have been working with power processors for over ten years.

6. In my opinion added protection circuits in both the control processor and power processor sections of a power supply are of great benefit, however I would not be in favor of mandating their use in every application. The product of lowest long term cost is the one that should win out in the marketplace. A power supply that damages even one of its loads during its useful life could be expensive indeed, or merely inconvenient.

7. The biggest problem I see is that transient source impedance is not specified, and the levels boarder on the ridiculous. In order to build protection into a circuit we must have devices able to support the voltages, currents, and time limits corresponding to the transients. We must also have generators able to put out the proper levels and waveshapes which themselves have the proper output impedances. Only qualification and acceptance testing will guarantee the required ruggedness.

Please feel free to call me if questions should arise regarding this questionnaire as this is a subject that should be of great interest to us all.

Richard Kroeger
Senior Staff Engineer
Powercube Corp.
Eight Suburban Park Drive
Billerica, Ma. 01821
(508)667-9500 X363

cc   Tony Vaudo
      Steve Wood
      Roger LaFontaine

R.O. Associates
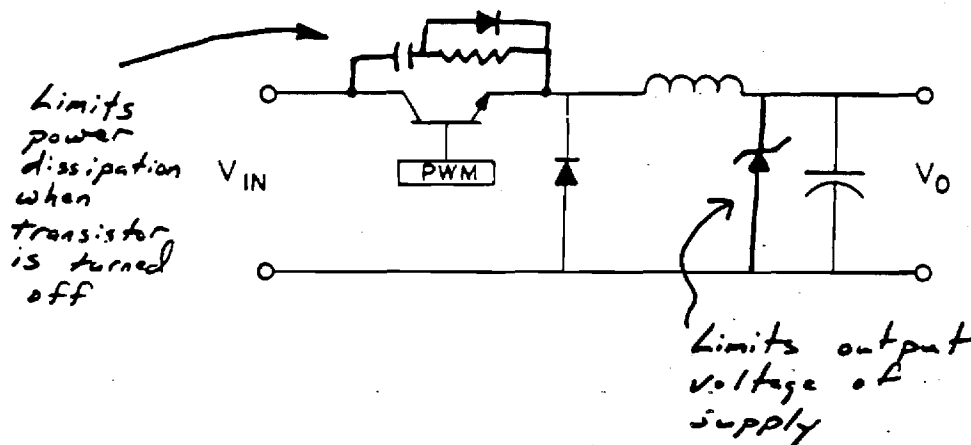
POWER SUPPLY QUESTIONNAIRE

1. What are the transient levels you normally design for? Please identify the peak voltage, peak current, volts per second rise, current per second rise and the transient duration. If a specification is used, please identify the source, i.e., MIL-STD-704, IEEE, etc.

IEEE 586

2. Several different power supply rectifier and regulator topologies are illustrated in Figure 1. For those topologies utilized in your designs, please indicate where transient protection is incorporated, what type of transient it absorbs or diverts and what type of device(s) are used. Schematic representation is preferred, but block diagrams may be substituted if proprietary designs are involved. An example follows.

Limits power dissipation when transistor is turned off

V_{IN} PWM V_O

Limits output voltage
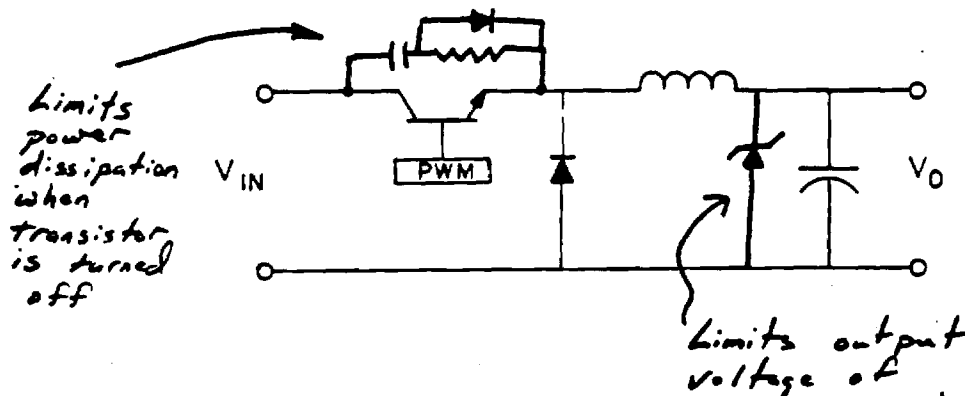
These snubbers and breakdown diodes are to relieve stresses during normal operation. They in general won't protect against input transients. This type of component should be included in MTBF calc. Probably not the overvoltage protection device

3. Please describe any transient protection properties which are inherent to your design.

Transients across input differentially. This does not protect against common mode Transients and not against differential mode that are clamped and result in common mode Transients

C-10

POWER SUPPLY QUESTIONNAIRE

4. In your opinion, what percent of operational failures in protected and unprotected power supplies are a result of transient conditions?

75 - 95 %

5. For power supplies with protective circuitry, approximate the percentage of operational failures that occur in the protective circuitry.
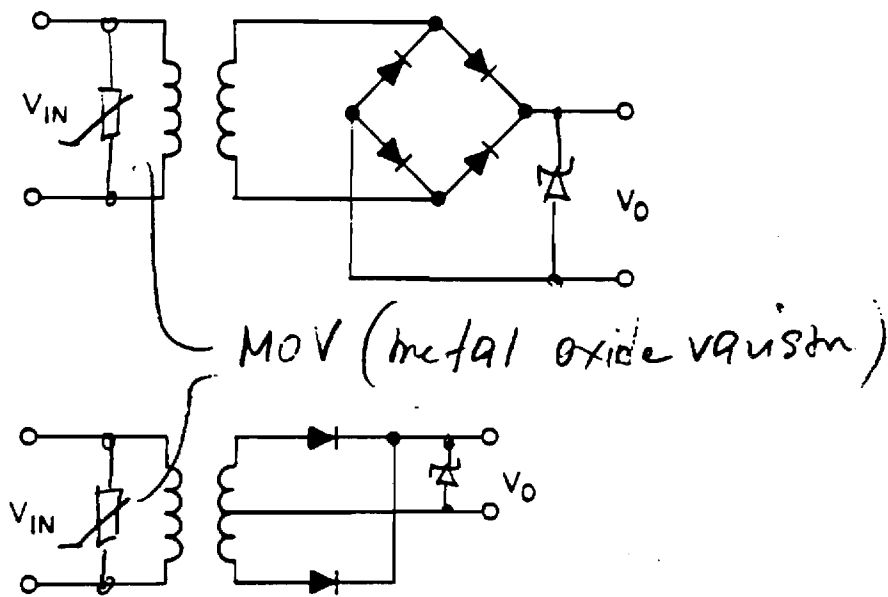
1-2 % due to non-
input transients

6. In your opinion, what are the trade-offs of added protection in terms of increased production costs, increased power dissipation and decreased operational failure rates?
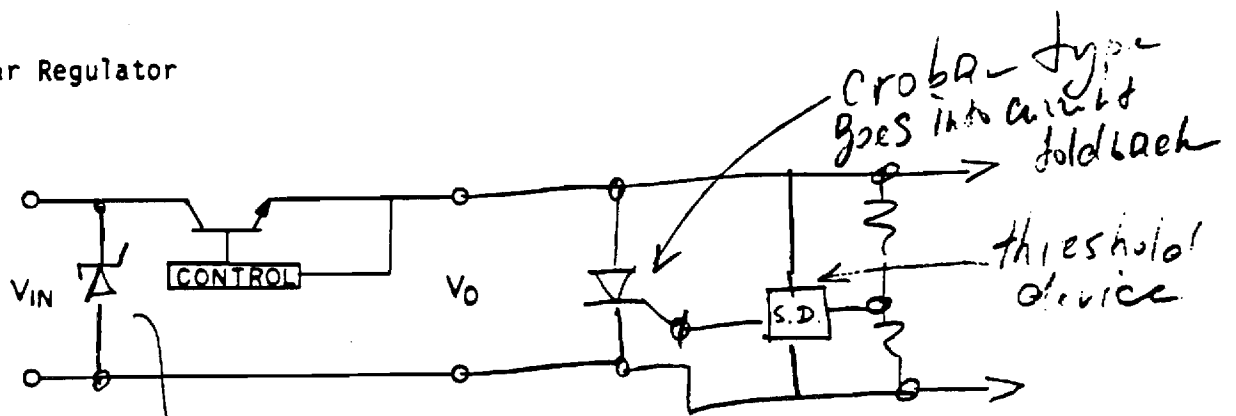
Input protection devices (such as MOV's common
differentially low common mode wise) are the
cheapest protection one can achieve.

7. In your experiences, what are the real world limitations of the various protection schemes?

With MOV's connected differentially and common
mode wise we are achieving 15 to 30 year
(directed MTBFS) in a 50,000 unit plus
worldwide installation over a period of 12 years
(Our experience shows that passing the IEEE
587 spec and the VDE safety spec assure
[this type of] MTBF if a correctly designed and tested
supply. power supply is used.)
There is little difference between input tra
protection and simplify to relieve stress in entire

C-11

North Hills (handwritten)
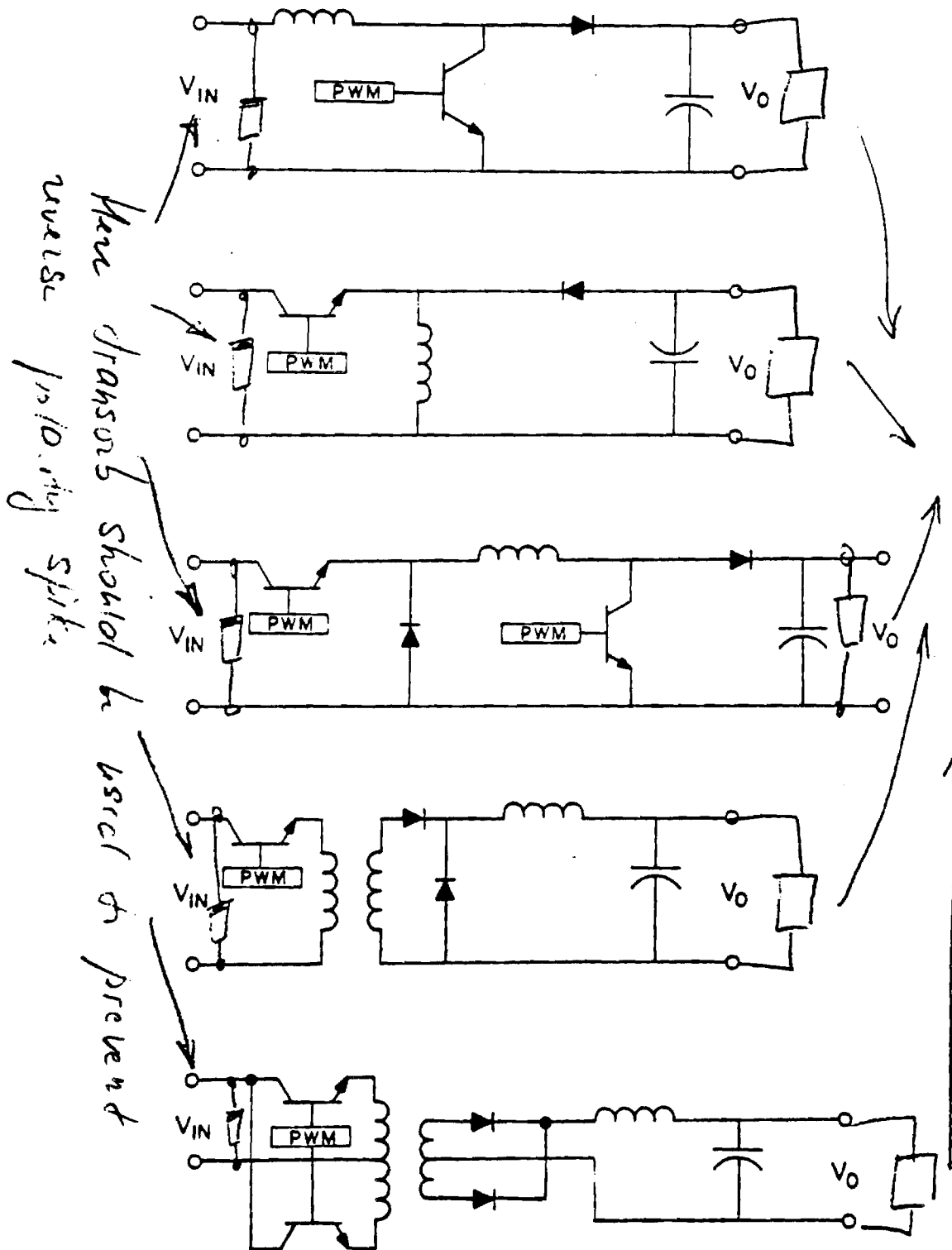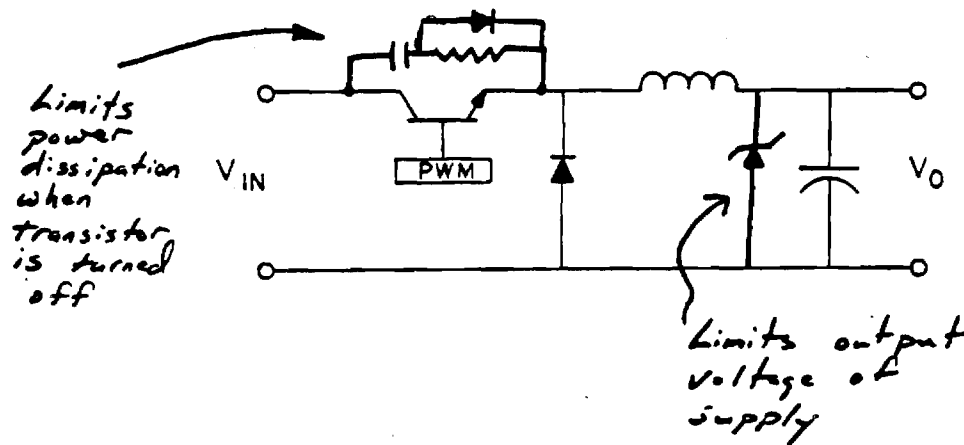
POWER SUPPLY QUESTIONNAIRE

1. What are the transient levels you normally design for? Please identify the peak voltage, peak current, volts per second rise, current per second rise and the transient duration. If a specification is used, please identify the source, i.e., MIL-STD-704, IEEE, etc.

6000 V open circuit, 200 Amp peak into low impedance load, 0.5 sec. rise time with 100 kHz exponentially decreasing ring (for current) Or it can be specified as 1.6 Jouls energy into 1000 V clamp (normally designed for 1.68 Jouls). IEEE Std. 587.

2. Several different power supply rectifier and regulator topologies are illustrated in Figure 1. For those topologies utilized in your designs, please indicate where transient protection is incorporated, what type of transient it absorbs or diverts and what type of device(s) are used. Schematic representation is preferred, but block diagrams may be substituted if proprietary designs are involved. An example follows.

Limits power dissipation when transistor is turned off (handwritten)

Limits output voltage of supply (handwritten)

3. Please describe any transient protection properties which are inherent to your design.

* Input protection is done by using MOV (AC side) absorbing certain amount of energy above specified AC voltage.

* Output protection in switchers is done via inverter shut down mechanism - inverter stops operating and stays this way till input power is removed.

* Output protection in linears is done via crobar type device (SCR) forcing the output to go into current limit (usually foldback type). The operation is restored after input power is removed.

POWER SUPPLY QUESTIONNAIRE

4.   In your opinion, what percent of operational failures in protected and unprotected power supplies are a result of transient conditions?

15%

5.   For power supplies with protective circuitry, approximate the percentage of operational failures that occur in the protective circuitry.

1%

6.   In your opinion, what are the trade-offs of added protection in terms of increased production costs, increased power dissipation and decreased operational failure rates?

Increased production cost

7.   In your experiences, what are the real world limitations of the various protection schemes?

Transient spike power

MOV (metal oxide varistor)

Linear Regulator

crobar-type
goes into current
foldback

threshold
device

transorb (power zener diode)

Switching Regulators

inverter
shuts down

optically
coupled
SCR

TL431
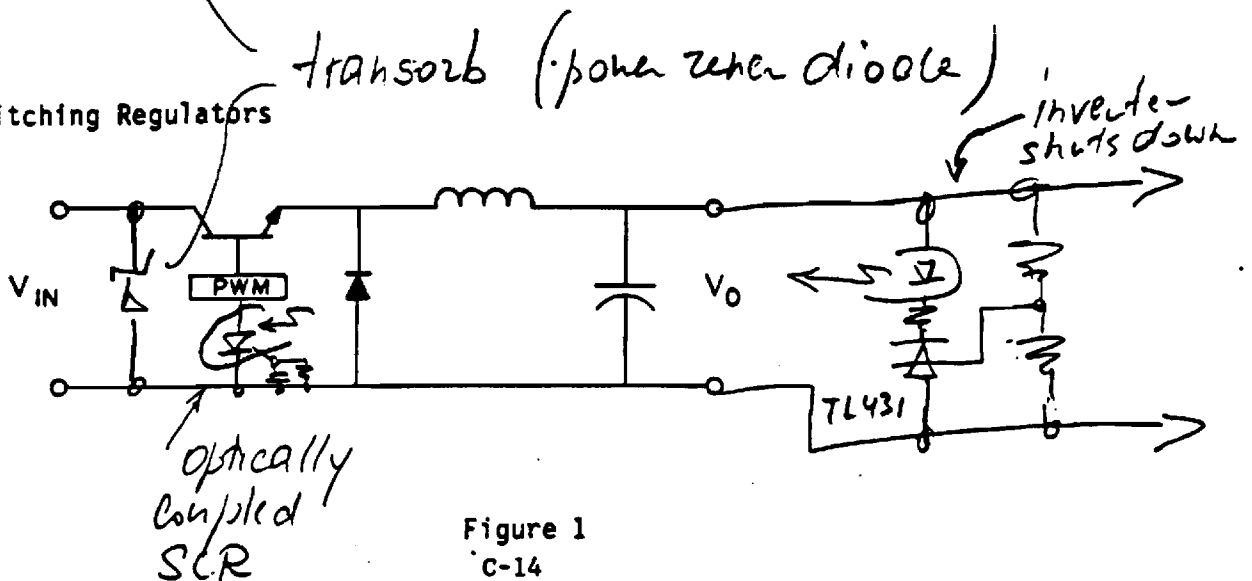
Figure 1
C-14

Switching Regulators (con't)

Here transors should be used to prevent

Here transors should be used to prevent reverse polarity spike

Inverter shut down mechanism. device should be utilized - see pg 3.

Figure 1
C-15

Switching Systems Int'
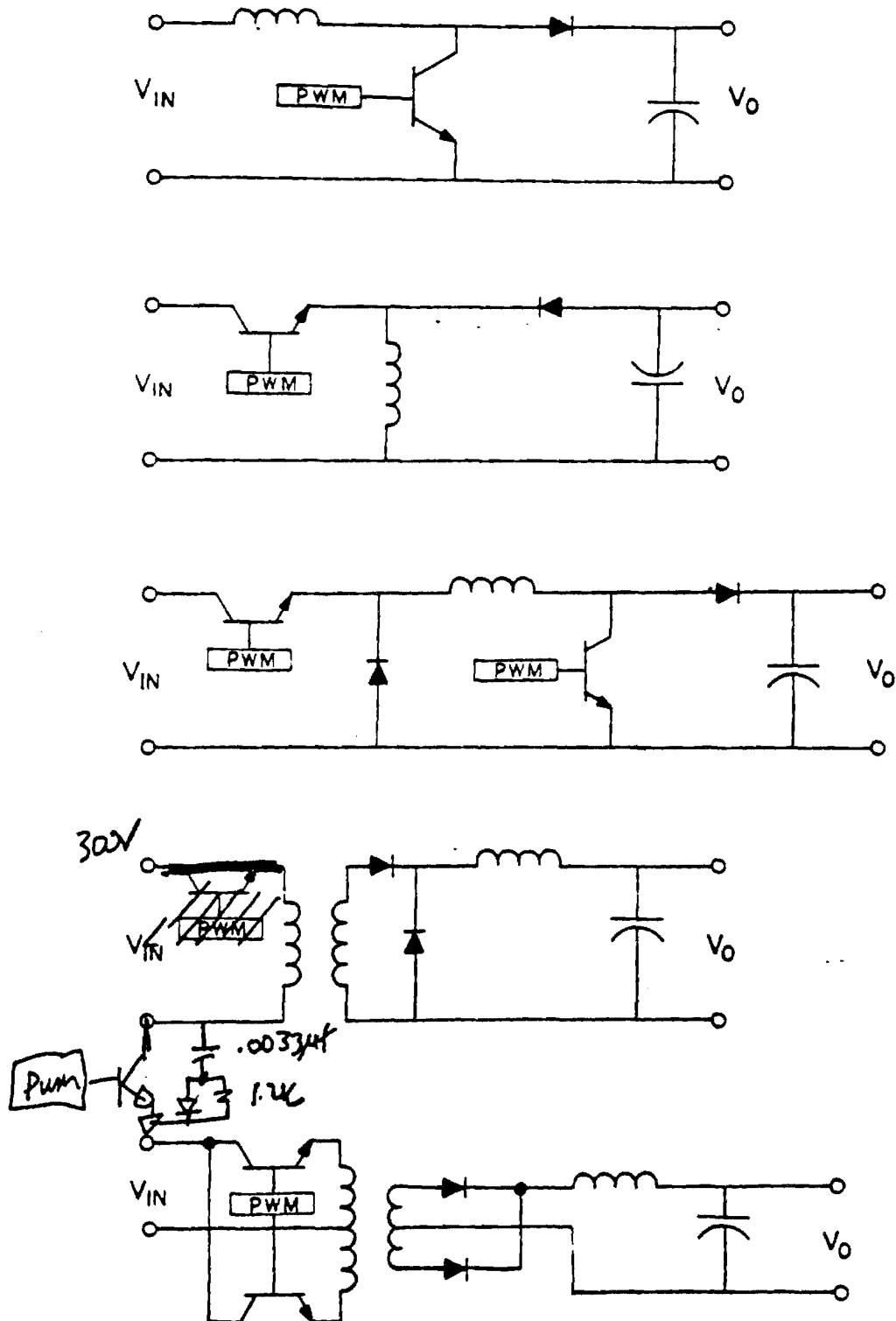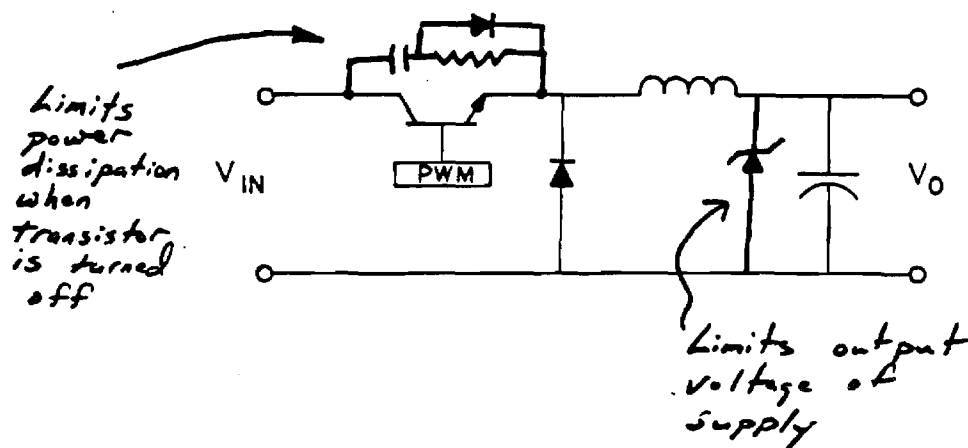
I

Attachment (1)
Page 1

POWER SUPPLY QUESTIONNAIRE

1. What are the transient levels you normally design for? Please identify the peak voltage, peak current, volts per second rise, current per second rise and the transient duration. If a specification is used, please identify the source, i.e., MIL-STD-704, IEEE, etc.

IEEE-587-1980

2. Several different power supply rectifier and regulator topologies are illustrated in Figure 1. For those topologies utilized in your designs, please indicate where transient protection is incorporated, what type of transient it absorbs or diverts and what type of device(s) are used. Schematic representation is preferred, but block diagrams may be substituted if proprietary designs are involved. An example follows.

Limits power dissipation when transistor is turned off

Limits output voltage of supply

3. Please describe any transient protection properties which are inherent to your design.

Spark gap devices across Input storage capacitors

C-16

POWER SUPPLY QUESTIONNAIRE

4. In your opinion, what percent of operational failures in protected and unprotected power supplies are a result of transient conditions?

2%

5. For power supplies with protective circuitry, approximate the percentage of operational failures that occur in the protective circuitry.

.01%

6. In your opinion, what are the trade-offs of added protection in terms of increased production costs, increased power dissipation and decreased operational failure rates?

Greatly needed to limit stress on switching devices

7. In your experiences, what are the real world limitations of the various protection schemes?

Power dissipation

Rectifiers
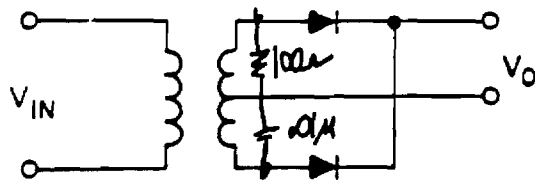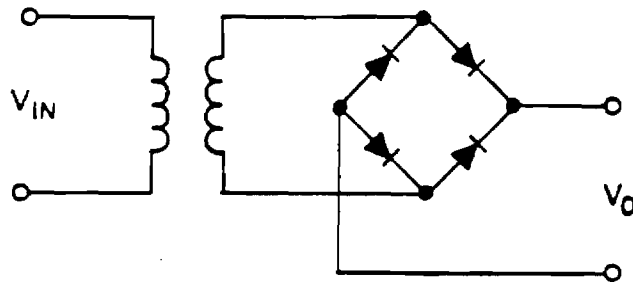
Linear Regulator
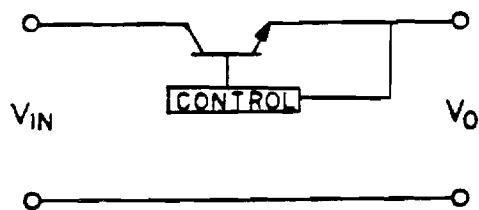
Switching Regulators
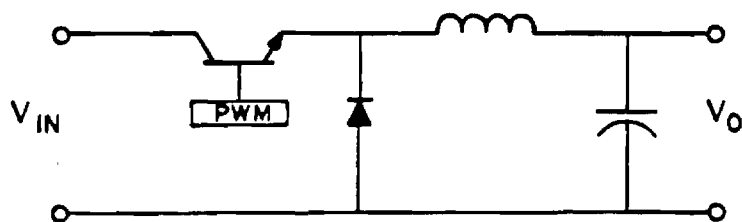
Figure 1
C-18

Switching Regulators (con't)

Figure 1

Tower Electronics

POWER SUPPLY QUESTIONNAIRE

1. What are the transient levels you normally design for? Please identify
the peak voltage, peak current, volts per second rise, current per second
rise and the transient duration. If a specification is used, please
identify the source, i.e., MIL-STD-704, IEEE, etc.

I presume that "transient" in this case is meant to be a high voltage transient
only - we also design for undervoltage transients which can be destructive to
the power supply if not considered in the design.
Our transient design criteria is too extensive to be discussed fully here
but in a nut shell, we design for ½ sine wave, 10µsec wide 2500V peak - this
is for single phase, 50/60Hz line powered equipment

2. Several different power supply rectifier and regulator topologies are
illustrated in Figure 1. For those topologies utilized in your designs,
please indicate where transient protection is incorporated, what type of
transient it absorbs or diverts and what type of device(s) are used.
Schematic representation is preferred, but block diagrams may be
substituted if proprietary designs are involved. An example follows.

Limits power dissipation when transistor is turned off

V_{IN}

PWM

V_O

Limits output voltage of supply

3. Please describe any transient protection properties which are inherent
to your design.

In order to meet EMI requirements of most customers (VDE 0871 class)
a filter is required which, when coupled with an inrush
current surge limiter, has provided all the transient protection
that we feel is necessary. In 11 years of business (design and
manufacturing power supplies) we have seen but one failure
due to transients and that was a massive lightning strike
(On our own main building which ruined 20 of several which can not be caused any

POWER SUPPLY QUESTIONNAIRE

4. In your opinion, what percent of operational failures in protected and unprotected power supplies are a result of transient conditions?

[handwritten] In our equipment — virtually zero

[handwritten] In other peoples equipment — ?

5. For power supplies with protective circuitry, approximate the percentage of operational failures that occur in the protective circuitry.

[handwritten] In our early days we had problems with output crowbars — after analyzing our problems and taking corrective action, we see little to no problems. Circuit layout and selection of appropriate components is critical to the prevention of nuisance trips of protective circuitry.

6. In your opinion, what are the trade-offs of added protection in terms of increased production costs, increased power dissipation and decreased operational failure rates? *[handwritten] Personally, I have a very basic and simple philosophy — Voltage dependent resistors (ie transorbs etc) have been of zero value — perhaps they are of value in other types of designs in extreme conditions which we have not been asked to meet. Output crowbars are essential when the equipment being powered is of sufficient dollar value and would be destroyed by an over voltage condition.*

7. In your experiences, what are the real world limitations of the various protection schemes?
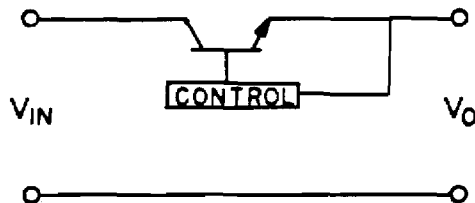
[handwritten] Transient suppressors (Transorbs etc.) are too poorly specified as to where there knee is and are too soft unless used with some series impedance & in which case just some capacitance used with that series impedance can work as well
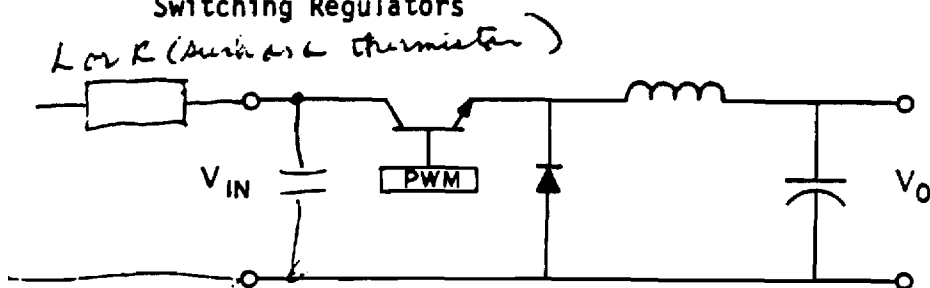
Linear Regulator

Switching Regulators

L or R (such as a thermistor)
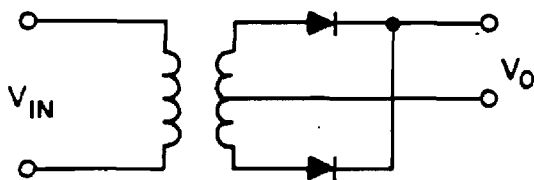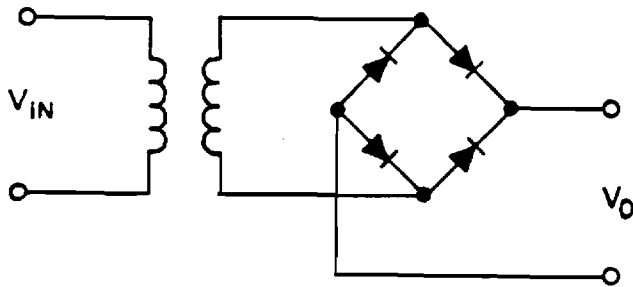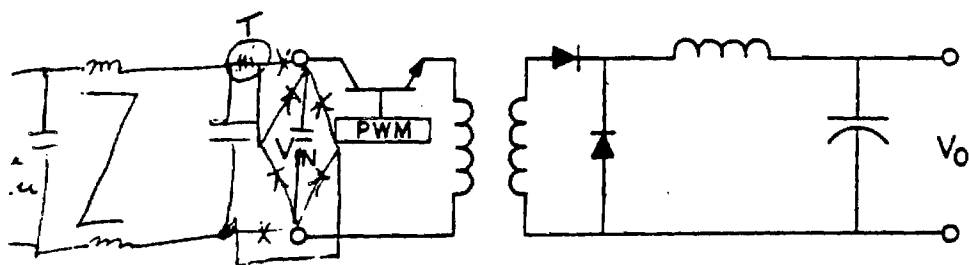

Figure 1
C-22

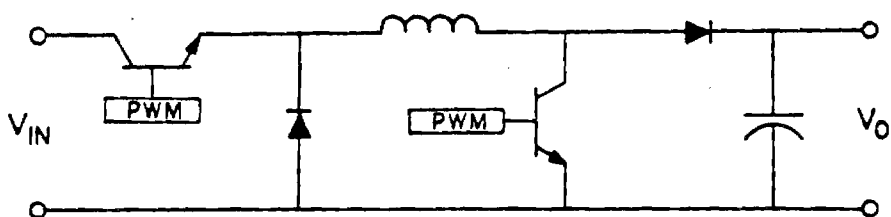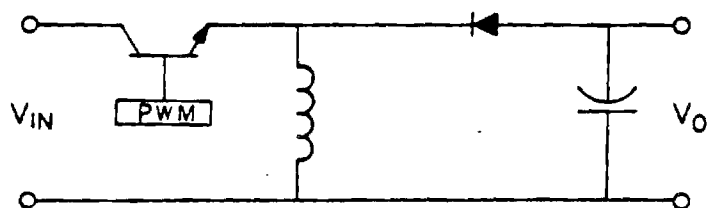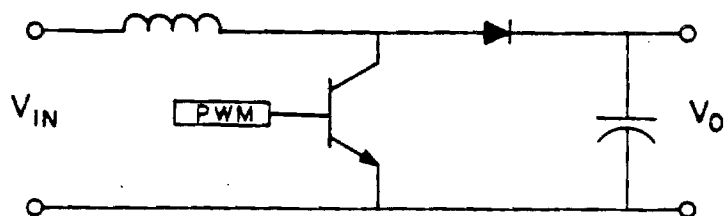Switching Regulators (con't)
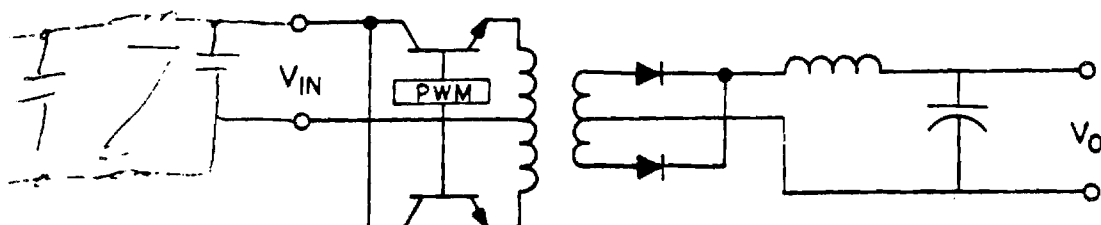
Figure 1
C-23

Appendix D

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D-1 thru D-7

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35. The Interpretation of Electrical Overstress in Power Transisitors; T. Lee, Motorola, Inc.
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36. Characterizing the SCR for Crowbar Applications; A. Pshaenich, Motorola Semiconductor Products Inc.; Application Note AN-789, 1978. Provides detailed instructions for the application of SCRs in crowbar circuitry. Provides design guidelines with respect to energy dissipation, current capacity, gate drive and SCR life testing.

37. Hardening Power Supplies to Line Voltage Transients; B. Roehr, General Semiconductor Industries, Inc. Discusses methods to integrate the rectifier and input filter capacitors with transient suppressors into an efficient protection scheme.

38. How to Prevent Circuit Zapping; R. Antinone, BDM Corp.; IEEE Spectrum, 4/87. Describes and defines transients and their sources. Provides explanations of the failure mechanisms of semiconductors.

39. Optimizing Line In-rush Design in Off-Line Converters; W. Hirschberg, ACDC Electronics Division of Emerson Electric Co.
    Discusses the problem of in-rush current during power up. Techniques for limiting this current are presented.

40. Transient Suppressors Compared; General Electric Co.; Solid State Power Conversion, 3/79.
    Compares the VI characteristics of various voltage suppressors. Also discusses the change in standby power of suppression devices as a function of applied steady state voltage.

41. Power Integrated Circuit Makes Board Level Overvoltage and Overtemperature Protection Simple and Inexpensive; D. Zaremba, J. Mansmann, Motorola Inc.; PCIM, 10/85.
    Discusses the application of Motorola's SMARTPOWER protection device.

42. Doing Surge Tests Properly; P.Richman, KeyTek Instrument Corp.; EMC Technology, 5/89.

Delineates the proper methods of testing equipment for immunity to transients. Discusses the common variations in testing approaches which supposedly have the same goal in mind.