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SUPERSEDES NAVSEA 0967-LP-597-1011

PARTS APPLICATION AND RELIABILITY INFORMATION MANUAL FOR NAVY ELECTRONIC EQUIPMENT

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COMMANDER, NAVAL SEA SYSTEMS COMMAND

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PARTS APPLICATION
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FOREWORD

The reliability achieved by military electronic systems and equipments is highly dependent upon the proper selection and application of the electrical and electronics parts used therein. Chapter I of this document provides requirements for three basic elements of a parts reliability program consisting of: (1) parts derating, (2) part quality, and (3) design for long life. Chapter II contains derating curves and part selection and application information on the ten most commonly used electrical and electronic parts. Appendices provide information on electrical subjects of interest pertaining to parts application and reliability.

The rapid technology of electronic part and device engineering may cause some of the information contained herein to become outdated. This is especially true of the information contained in sections 100 through 1000 of this document where new military specifications or revisions of those existing are constantly being generated for new parts and new part types. In view of the above, contract and military specifications and standards with their latest applicable revisions should be consulted for selections and applications of parts on a specific contract. In addition, this document will be updated annually in order to reflect the latest available information.

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LISTING OF SUBJECTS

This document covers the following topics:

CHAPTER I: REQUIREMENTS

- APPLICATION
- PARTS SELECTION
- DERATING
- DESIGN FOR LONG LIFE

CHAPTER II: PARTS APPLICATION INFORMATION

- RESISTORS
- CAPACITORS
- DISCRETE SEMICONDUCTORS
- MICROCIRCUITS
- CONNECTORS
- RELAYS
- CRYSTALS
- SWITCHES
- FILTERS
- MAGNETIC DEVICES

APPENDICES: PARTS INFORMATION ON SELECTED SUBJECTS

- THERMAL CONSIDERATIONS ON ELECTRONIC COMPONENT PARTS
- DESCRIPTION OF QUALITY/RELIABILITY SCREENING LEVELS OF STANDARD PARTS
- ELECTROSTATIC DISCHARGE (ESD) CONTROL
- FACTORS AFFECTING FAILURE RATES OF PARTS
- VARIABILITY ANALYSIS
- DERATING
- STANDARD ELECTRONIC MODULE PROGRAM
- TRANSIENT SUPPRESSORS
- APPLICABLE DOCUMENTS

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INTRODUCTION

All failures are due to stress. Reliable equipment must be designed to endure stress over time without failure. Parameters which stress a design must be identified and controlled. Parts and materials must be selected which can withstand these stresses. Derating is the selection and application of parts and materials so that applied stress is less than rated for a specific application. The derating criteria in this manual has been developed to provide designers the greatest flexibility possible in applying parts and materials compatible with the need for readiness.

Compliance with these guidelines is a necessary step for institutionalizing the reliability by design process and provides a most effective means of reducing life cycle cost and increasing readiness.

CHAPTER I

REQUIREMENTS

1. SCOPE

Chapter I of this document specifies derating (including verification testing), quality levels and variability analysis requirements pertinent to a parts control program. This document does not specify a complete parts control program.

Requirements for selecting standard parts, approving nonstandard parts, completing reliability predictions, and other requirements of MIL-STD-965 are not included in this document. All areas not specifically related to derating should be specified separately in the equipment procurement specification.

Chapter II contains part application guidelines for commonly used military part types. This document also contains appendices on general topics applicable to parts application and reliability to aid in understanding the requirements specified in Chapter II.

1.1 PURPOSE

The purpose of this document is to provide requirements for derating, quality levels, and variability analysis which can be imposed in equipment specifications by the acquiring activity. This can be accomplished by specifying all or part of this document in the purchase contract. Chapter I requires documentation such as analysis and the results of tests. Delivery of this documentation, if it is desired by the acquiring activity, must be specified in the contract DD 1423.

2. REFERENCED DOCUMENTS

The documents specified herein on the issue in effect on the date of invitation for bid or request for proposal form a part of the requirements of Section 3 to the extent they are specified. These documents and other documents used throughout this document are identified in Appendix I.

3. REQUIREMENTS

3.1 APPLICATION

The requirements of this Chapter are applicable as specified in the contract. When this document is cited in a contract any deviation from the requirements specified in Section 3 herein shall require approval of the acquiring activity.

3.2 PARTS SELECTION

3.2.1 Control Program

The contractor shall implement the requirements of MIL-STD-965 for the establishment of a parts control program.

3.2.2 Part Quality Levels

See Appendix B for an explanation of part quality/reliability levels.

3.2.2.1 Microcircuits

Microcircuits shall be MIL-M-38510 Class B as a minimum. Where MIL-M-38510 detailed specifications do not exist for a specific microcircuit or no qualified suppliers exist on the qualified products list for MIL-M-38510 Class B or S, the contractor shall justify the selection of this part to the acquiring activity. Such microcircuits shall be screened as a minimum to the screening requirements of MIL-STD-883, Method 5004, Class B requirements. Such parts are nonstandard and shall be marked with the contractor's part number and require nonstandard part approval from the acquiring activity.

3.2.2.2 Discrete Semiconductors

Discrete semiconductors shall be MIL-S-19500 Level JANTX as a minimum. Where MIL-S-19500 detailed specifications do not exist for a specific discrete semiconductor or no qualified suppliers exist on the qualified products list for MIL-S-19500 JANTX, JANTXV or JANS, the contractor shall justify the selection of this part to the acquiring activity. Such discrete semiconductors shall be screened as a minimum to the applicable JANTX screening requirements of MIL-STD-750. Such parts are nonstandard and shall be marked with the contractor's part number and require nonstandard part approval from the acquiring activity.

3.2.2.3 Passive Parts

Passive parts shall be selected from Established Reliability (ER) military specifications and shall meet, as a minimum, the ER failure rate level of P or higher (i.e., R, S, etc.). When military ER specifications do not exist or when no qualified suppliers exist for the ER level P or higher, the contractor shall use an ER level lower than P or other military parts as allowed by 3.2.1 in that order. The selection of other parts requires nonstandard part approval by the acquiring activity. See Appendix F for an explanation of part derating and Appendix A for thermal considerations.

3.3 DERATING

Parts identified in Table I and similar part types shall be derated electrically and thermally in accordance with Table I.

The derating criteria in Table I and other related sections are usually based on the temperature of the air surrounding the part. Often the contractor does a thermal analysis or design in a manner that case, part, or junction temperatures are more convenient to use than the air temperature. For these cases the contractor may convert the air temperature requirements of Table I or any of the derating curves to case, part, or junction temperature.

The conversion of a table or graph from air temperature to case, part, or junction temperature shall be done so that the actual derating parameters are not changed. If the contractor converts a table or graph it must be documented and supplied with any derating deliverable required by the contract DD 1423.

3.4 DESIGN FOR LONG LIFE

The contractor shall select parts based upon initial tolerance and tolerance drift due to age and environmental conditions. The contractor shall verify the adequacy of this tolerance selection by means of variability analyses.

The variability analysis shall be done on a worst case basis using a method from Appendix E or other method acceptable to the acquiring activity.

4. QUALITY ASSURANCE PROVISIONS

4.1 RESPONSIBILITY

When specified in the contract, the contractor shall be responsible for the performance of such analyses and tests as may be required to verify that the derating requirements of this contract have been met. The acquiring activity reserves the right to perform such tests and any analyses deemed necessary to ensure that the design meets the requirements set forth herein.

4.2 PARTS DERATING VERIFICATION TEST

Part thermal and electrical derating shall be verified through test by actual measurement of part stress levels and part ambient temperatures. These measurements shall be performed on at least 5 percent of the equipment parts. Fifty percent of the candidate parts shall be those having the highest power dissipation in the equipment. The other fifty percent of the candidate parts shall be randomly selected. Should the verification test demonstrate that the derating requirements are not met (i.e., all parts do not meet temperature and electrical derating requirements), corrective action shall be implemented and the test repeated on different parts (i.e., 50 percent of parts having the next highest power dissipation and 50 percent new randomly selected parts).

5. NOTES

5.1 INTENDED USE

This document is intended to facilitate the application of electrical and electronic parts in military systems and equipments in such a manner as to optimize reliability and life cycle costs.

5.2 DEFINITIONS

Terms used herein shall be interpreted in accordance with the definitions of MIL-STD-721 unless otherwise specified herein.

5.2.1 Derating

Derating is the application of electrical and electronic parts in such a manner that the actual worst case electrical and thermal stresses are less than the parts design maximum ratings

5.2.2 Electrical and Electronic Part

An electrical active or passive component, a microcircuit, or a discrete semiconductor.

5.2.3 Rated Stress

The maximum stress for which a part is specified to withstand. The ratings of most parts decrease as the operating temperature is increased.

5.2.4 Application

The method in which an electrical or electronic part is used, which influences its predicted failure rate as well as the effect of its possible failure modes.

5.2.5 Stress

Physical or electrical forces imposed on the electrical or electronic part, such as temperature, current, voltage, power dissipation, etc., which affect part failure rate.

5.2.6 Stress Ratio

The numeric ratio between the applied stress and the maximum rated stress for a given parameter, e.g., applied voltage divided by rated voltage.

TABLE I-I
PARTS DERATING REQUIREMENTS FOR RESISTORS

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Fixed				
Wirewound (Power Type)	MIL-R-26 (RW)	Power	See derating requirements on page 100-16.	See derating requirements on page 100-16.
Wirewound (Power Type Chassis Mounted)	MIL-R-18546 (RE)	Power	See derating requirements on page 100-17.	See derating requirements on page 100-17.
Variable				
Composition	MIL-R-94 (RV)	Power	See derating requirements on page 100-18.	See derating requirements on page 100-18.
Wirewound (Low Operating Temp)	MIL-R-19 (RA)	Power	See derating requirements on page 100-19.	See derating requirements on page 100-19.
Wirewound (Power Type)	MIL-R-22 (RP)	Power	See derating requirements on page 100-21.	See derating requirements on page 100-21.
Wirewound, Precision	MIL-R-12934 (RR)	Power	See derating requirements on page 100-22.	See derating requirements on page 100-22.

TABLE I-I
PARTS DERATING REQUIREMENTS FOR RESISTORS
(Continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Variable (continued)				
Wirewound, Semiprecision	MIL-R-39002 (RK)	Power	See derating requirements on page 100-23.	See derating requirements on page 100-23.
Wirewound (Adjustment Type)	MIL-R-27208 (RT)	Power	See derating requirements on page 100-24.	See derating requirements on page 100-24.
Nonwirewound (Adjustment Type)	MIL-R-22097 (RJ)	Power	See derating requirements on page 100-25.	See derating requirements on page 100-25.
Nonwirewound	MIL-R-23285 (RVC)	Power	See derating requirements on page 100-27.	See derating requirements on page 100-27.
Nonwirewound, Precision	MIL-R-39023 (RQ)	Power	See derating requirements on page 100-29.	See derating requirements on page 100-29.
Fixed, (ER)				
Composition, Insulated	MIL-R-39008 (RCR)	Power	See derating requirements on page 100-30.	See derating requirements on page 100-30.

TABLE I-I
PARTS DERATING REQUIREMENTS FOR RESISTORS
(Continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Fixed, (ER) (continued)				
Film	MIL-R-55182 (RNR)	Power	See derating requirements on page 100-31.	See derating requirements on page 100-31.
Wirewound (Accurate)	MIL-R-39005 (RBR)	Power	See derating requirements on page 100-32.	See derating requirements on page 100-32.
Wirewound (Power Type)	MIL-R-39007 (RWR)	Power	See derating requirements on page 100-33.	See derating requirements on page 100-33.
Film (Insulated)	MIL-R-39017 (RLR)	Power	See derating requirements on page 100-35.	See derating requirements on page 100-35.
Wirewound (Power Type, Chassis Mounted)	MIL-R-39009 (RER)	Power	See derating requirements on page 100-36.	See derating requirements on page 100-36.
Film, Chip	MIL-R-55342 (RM)	Power	See derating requirements on page 100-38.	See derating requirements on page 100-38.

TABLE I-I
PARTS DERATING REQUIREMENTS FOR RESISTORS
(Continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Variable, (ER)				
Wirewound (Lead Screw Actuated)	MIL-R-39015 (RTR)	Power	See derating requirements on page 100-40.	See derating requirements on page 100-40.
Nonwirewound (Lead Screw Actuated)	MIL-R-39035 (RJR)	Power	See derating requirements on page 100-42.	See derating requirements on page 100-42.
Special				
Networks, Fixed, Film	MIL-R-83401 (RZ)	Power	See derating requirements on page 100-43.	See derating requirements on page 100-43.

TABLE I-II
PARTS DERATING REQUIREMENTS FOR CAPACITORS

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Ceramic Dielectric				
Fixed, Temperature Compensating, ER	MIL-C-20 (CCR)	Voltage	See derating requirements on page 200-7.	See derating requirements on page 200-7.
Fixed, General Purpose	MIL-C-11015 (CK)	Voltage	See derating requirements on pages 200-8, 200-9, 200-10.	See derating requirements on pages 200-8, 200-9, 200-10.
Fixed, General Purpose, ER	MIL-C-39014 (CKR)	Voltage	See derating requirements on page 200-9.	See derating requirements on page 200-9.
Variable	MIL-C-81 (CV)	Voltage	See derating requirements on page 200-12.	See derating requirements on page 200-12.
Gas or Vacuum Dielectric				
Variable, Ceramic Envelope	MIL-C-23183 (CG)	Voltage	See derating requirements on page 200-13.	See derating requirements on page 200-13.

TABLE I-II
PARTS DERATING REQUIREMENTS FOR CAPACITORS
(continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
<u>Glass Dielectric</u>				
Variable (Piston Type, Tubular Trimmer)	MIL-C-14409 (PC)	Voltage	See derating requirements on page 200-14, 200-15.	See derating requirements on page 200-14, 200-15.
Fixed, ER	MIL-C-23269 (CYR)	Voltage	See derating requirements on page 200-17.	See derating requirements on page 200-17.
<u>Electrolytic</u>				
Fixed, Tantalum Solid Electrolyte, ER	MIL-C-39003 (CSR)	Voltage	See derating requirements on page 200-21.	See derating requirements on page 200-21.
		Series Impedance	≥3 ohms/volt	
		Reverse Voltage	≤2 of the maximum rated dc voltage.	
		Ripple Current	70	

TABLE I-II
PARTS DERATING REQUIREMENTS FOR CAPACITORS
(continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Electrolytic (continued)				
Fixed, Tantalum, Nonsolid Electrolyte, ER	MIL-C-39006 (CLR)	Voltage	See derating requirements on page 200-23.	See derating requirements on page 200-23.
		Reverse Voltage	≤2 of the maximum rated dc voltage	
		Ripple Current	70	
Fixed, Aluminum Oxide, Non ER, ER	MIL-C-39018 (CU/CUR)	Voltage	See derating requirements on page 200-25, 200-26, 200-27.	See derating requirements page 200-25, 200-26, 200-27.
		Reverse Voltage	≤2 of the maximum rated dc voltage	
		Surge Voltage	60	

TABLE I-II
PARTS DERATING REQUIREMENTS FOR CAPACITORS
(continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Mica Dielectric				
Fixed, Button Style	MIL-C-10950 (CB)	Voltage	See derating requirements on pages 200-29, 200-30.	See derating requirements on pages 200-29, 200-30.
Fixed	MIL-C-5 (CM)	Voltage	See derating requirements on pages 200-31, 200-32.	See derating requirements on pages 200-31, 200-32.
Fixed, ER	MIL-C-39001 (CMR)	Voltage	See derating requirements on pages 200-31, 200-32.	See derating requirements on pages 200-31, 200-32.
Paper, Plastic, Paper-Plastic Dielectric				
Fixed, ER	MIL-C-19978 (CQR)	Voltage	See derating requirements on page 200-35, 200-36.	See derating requirements on page 200-35, 200-36.

TABLE I-II
PARTS DERATING REQUIREMENTS FOR CAPACITORS
(continued)

PART TYPE	MIL-SPEC (STYLE)	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMP. (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Paper, Plastic, Paper-Plastic Dielectric (continued)				
Fixed, Metallized DC and AC, ER	MIL-C-39022 (CHR)	Voltage	See derating requirements on page 200-38.	See derating requirements on page 200-38.
Fixed, Supermetallized DC, AC, or DC and AC, ER	MIL-C-83421 (CRH)	Voltage	See derating requirements on page 200-39.	See derating requirements on page 200-39.

TABLE I-III
PARTS DERATING REQUIREMENTS FOR SEMICONDUCTORS

PART TYPE	MIL-SPEC	ELECTRICAL		MAXIMUM DERATED TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Diodes	MIL-S-19500	Power	See derating requirements on page 300-11.	See derating requirements on page 300-11.
		Forward Current (Continuous)	50	
		Current (Surge)	70	
		Inverse Voltage	65	
		Transient Voltage	80	
Transistors	MIL-S-19500	Power	See derating requirements on page 300-11.	See derating requirements on page 300-11.
		Forward Current (Continuous)	70	
		Forward Current (Surge)	75	
		Breakdown (Reverse Junction) Voltage	70	
Thyristors	MIL-S-19500	Power	See derating requirements on page 300-11.	See derating requirements on page 300-11.
		Current (Surge)	70	
		Turn-off Time	200 minimum	

TABLE I-IV
PARTS DERATING REQUIREMENTS FOR MICROCIRCUITS

PART TYPE	MIL-SPEC	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Linear				
Hermetically sealed micro-circuits except voltage regulators	MIL-M-38510	Power	See derating requirements on page 400-19.	See derating requirements on page 400-19.
		Current (Continuous)	70	
		Current (Surge)	60	
		Voltage (Signal)	75	
		Voltage (Surge)	80	
		Supply Voltage	Hold on to mfg. nominal rating	

TABLE I-IV
PARTS DERATING REQUIREMENTS FOR MICROCIRCUITS
(continued)

PART TYPE	MIL-SPEC	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Hermetically sealed voltage regulators	MIL-M-38510	Power	See derating requirements on page 400-19.	See derating requirements on page 400-19.
		Current (Continuous)	75	
		Current (Surge)	60	
		Voltage (Signal)	75	
		Voltage (Surge)	80	
		Supply Voltage	Hold on to mfg. nominal rating	

TABLE I-IV
PARTS DERATING REQUIREMENTS FOR MICROCIRCUITS
(continued)

PART TYPE	MIL-SPEC	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Nonhermetically sealed micro-circuits except voltage regulators	MIL-M-38510	Power	See derating requirements on page 400-19.	See derating requirements on page 400-19.
		Current (Continuous)	60	
		Current (Surge)	60	
		Voltage (Signal)	75	
		Voltage (Surge)	80	
		Supply Voltage	Hold on to mfg. nominal rating	

TABLE I-IV
PARTS DERATING REQUIREMENTS FOR MICROCIRCUITS
(continued)

PART TYPE	MIL-SPEC	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Nonhermetically sealed voltage regulators	MIL-M-38510	Power	See derating requirements on page 400-19.	See derating requirements on page 400-19.
		Current (Continuous)	65	
		Current (Surge)	60	
		Voltage (Signal)	75	
		Voltage (Surge)	80	
		Supply Voltage	Hold on to mfg nominal rating	

TABLE I-IV
PARTS DERATING REQUIREMENTS FOR MICROCIRCUITS
(continued)

PART TYPE	MIL-SPEC	ELECTRICAL		MAXIMUM DERATED AMBIENT TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Digital				
Hermetically sealed microcircuits	MIL-M-38510	Supply Voltage	Hold on to mfg. nominal rating	100
		Toggle Frequency	70	
		Set Up and Hold Time	200 minimum	
		Fanout	80	
Nonhermetically sealed microcircuits	MIL-M-38510	Supply Voltage	Hold on to mfg nominal rating	75
		Toggle Frequency	70	
		Set Up and Hold Time	200 minimum	
		Fanout	80	

TABLE I-V
DERATING REQUIREMENTS FOR CONNECTORS (With an ideal heat sink)

PART TYPE	MIL-STD	INSERT MATERIAL TYPE	CONTACT SIZE	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
				PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Connectors, General	All those listed in Mil-Std-1353	A	All those applicable	Pin Current Voltage	60 25 of the dielectric withstanding voltage	230
		B		Pin Current Voltage	60 25 of the dielectric withstanding voltage	170
		C		Pin Current Voltage	60 25 of the dielectric withstanding voltage	90
		D		Pin Current Voltage	60 25 of the dielectric withstanding voltage	90
Printed Circuit Board Connectors (PCBs)	All those listed in Mil-Std-1353	B	All those applicable	Pin Current Voltage	60 25 of the dielectric withstanding voltage	180

TABLE I-VI
DERATING REQUIREMENTS FOR CONNECTORS (Without an ideal heat sink)

PART TYPE	MIL-STD	INSERT MATERIAL TYPE	CONTACT SIZE	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
				PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Connectors, General	All those listed in MIL-STD-1353	A	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	200
		B	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	140
		C	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	60
		D	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	60
		A	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	190

TABLE I-VI
DERATING REQUIREMENTS FOR CONNECTORS (Without an ideal heat sink)
(continued)

PART TYPE	MIL-STD	INSERT MATERIAL TYPE	CONTACT SIZE	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
				PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Connectors, General	All those listed in MIL-STD-1353	B	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	130
		C	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		D	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		A	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	190
		B	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	130

TABLE I-VI
DERATING REQUIREMENTS FOR CONNECTORS (Without an ideal heat sink)
(continued)

PART TYPE	MIL-STD	INSERT MATERIAL TYPE	CONTACT SIZE	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
				PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Connectors, General	All those listed in MIL-STD-1353	C	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		D	16 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	50
		A	12 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	195
		B	12 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	135
		C	12 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	55

TABLE I-VI
DERATING REQUIREMENTS FOR CONNECTORS (Without an ideal heat sink)
(*continued*)

PART TYPE	MIL-STD	INSERT MATERIAL TYPE	CONTACT SIZE	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
				PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Connectors, General	All those listed in MIL-STD-1353	D	12 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	55
Printed Circuit Board Connectors (PCBs)	All those listed in MIL-STD-1353	B	26 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	165
		B	22 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	170
		B	20 GA	Pin Current Voltage	60 25 of the dielectric withstanding voltage	175

TABLE I-VII
PARTS DERATING REQUIREMENTS FOR RELAYS

PART TYPE	MIL-STD	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Relays	All those listed in MIL-STD-1346	Contact Current (Continuous)	60- Capacitive load 60- Resistive load 40- Inductive load 20- Motor 10- Filament (Lamp)	Limit to 65°C when rated at 85°C or 100°C when rated at 125°C
		Contact Current (Surge)	80	
		Vibration	75 (including "Q" of mounting)	
		Coil Energize Voltage	110 maximum	
		Coil Dropout Voltage	90 minimum	

TABLE I-VIII
PARTS DERATING REQUIREMENTS FOR SWITCHES

PART TYPE	MIL-STD	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Switches	All those listed in MIL-STD-1132	Contact Current (Continuous)	60 - Capacitive load 60 - Resistive load 40 - Inductive load 20 - Motor 10 - Filament (Lamp)	Limit to 20°C - 25°C below the specified maximum rated temperature.
		Contact Current (Surge)	80	
		Vibration	75 (including "Q" of mounting)	

TABLE I-IX
PARTS DERATING REQUIREMENTS FOR FILTERS

PART TYPE	MIL-STD	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Filters	All those listed in MIL-STD-1395	Current Working Voltage	50 50	Limit to 20°C less than the specified maximum operating temperature.

TABLE I-X
PARTS DERATING REQUIREMENTS FOR MAGNETIC DEVICES

PART TYPE	MIL-STD	ELECTRICAL		MAX. DERATED TEMPERATURE (°C)
		PARAMETER	MAX. % OF RATED ELECTRICAL STRESS	
Transformers, Inductors and Coils	All those listed in MIL-STD-1286	Current Density	2mA per cir. mil.	Limit to 65% of the specified maximum hot spot temperature (operating).
		Current (Continuous)	70	
		Current (Surge)	80	
		Voltage (Continuous)	70 or 25 of the Insulation Breakdown, whichever is less	
		Voltage (Surge)	80	
RF Coils	All those listed in MIL-STD-1286	Current (dc)	50	Limit to 65% of the specified maximum hot spot temperature (operating)

CHAPTER II

PARTS APPLICATION INFORMATION

SECTION 100

RESISTORS

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100 RESISTORS

100.1 GENERAL INFORMATION

Standard resistors are specified in MIL-STD-199. MIL-STD-199 is the key overall specification for resistor selection. This standard presents detailed data for use in the design of military equipment. Data is presented on terminology, resistor selection, environmental effects on characteristics and life, applications, application data, failure rates, and aging.

Resistors are functionally classified as fixed and variable (adjustable). Resistor construction is of three general types: composition, film, or wirewound and consist of a resistive element mounted on a base (chassis) with environmental protective coating and external electrical leads to allow insertion into an electrical circuit. Composition resistors are made from a mixture of resistive material and a binder and are molded into a shape and a specific resistor value. Film resistors are composed of a resistive film deposited inside or outside an insulating cylinder or filament. The wirewound type is composed of resistive wire wound on an insulative body. These three basic types of resistors differ from each other in reliability, size, cost, resistance range, power rating, and general characteristics. No one type has all the best characteristics. The choice among them depends on initial and long-term operating requirements, the environment in which they must exist, and numerous other factors.

The first considerations in evaluating resistors are the power handling capacity and tolerance. The power handling capacity normally determines the size of the resistor. For example, if an application requires more than one watt, a two watt power wirewound resistor will be the likely choice. If the tolerance needed is ± 2 percent or tighter, the resistor should inevitably be a precision wirewound or film resistor. However, the selection of a resistor also depends on the other application and derating program requirements.

For example, in the design of an audio amplifier, where noise is a significant criterion, the probable choice is a metal-film resistor, though these resistors cost more than carbon resistors. On the other hand, in data processing equipment, the termination resistors are usually low cost composition resistors. Analog-to-digital and digital-to-analog circuits require precise ratio matching and temperature tracking, which will point towards precision-wirewound or precision-film resistors. Operational amplifiers requiring long-term stability also dictate the use of precision wirewound or film resistors.

Some of the principal use applications for the various types of resistors are provided in Table 100-I.

TABLE 100-1

USE APPLICATIONS OF RESISTOR TYPES

RESISTOR TYPE	MIL-SPEC NO.	APPLICATION
Fixed		
Fixed, wirewound, power type	MIL-R-26	Use where large power dissipation is required and where ac performance is relatively unimportant (i.e., when used as voltage divider, bleeder resistors in dc power supplies, or series dropping). They are generally satisfactory for use at frequencies up to 20 kHz even though the ac characteristics are not controlled. Neither the wattage rating nor the rated continuous working voltage may be exceeded.
Fixed, wirewound, power type, chassis mounted	MIL-R-18546	Use where power tolerance and relatively large power dissipation is required for a given unit size and where ac performance is non-critical (i.e., voltage divider, bleeder resistors in dc power supplies, or series-dropping circuits).
Variable		
Variable, composition	MIL-R-94	Use where initial setting stability is not critical and long term stability needs to be no better than ± 20 percent.
Variable, wirewound, low operating temperature	MIL-R-19	Use primarily for noncritical, low power, low frequency applications where characteristics of wirewound resistors are more desirable than those of composition resistors.

TABLE 100-1 (CONT'D)

RESISTOR TYPE	MIL-SPEC NO.	APPLICATION
Variable, wirewound, power type	MIL-R-22	Use in such applications as motor speed control, generator field control, lamp dimming, heater and oven control, potentiometer uses, and applications where variations of voltage and current are expected.
Variable, wirewound, precision	MIL-R-12934	Use in servo-mounting applications requiring precise electrical and mechanical output and performance. Used in computer, antenna, flight control, bomb-navigation systems, etc.
Variable, wirewound, semiprecision	MIL-R-39002	Use for matching, balancing, adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Variable, wirewound, adjustment type	MIL-R-27208	Use for matching, balancing, adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Variable, nonwirewound, adjustment type	MIL-R-22097	Use for matching, balancing, adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Variable, metal film, nonwirewound	MIL-R-23285	Use where initial setting stability is not critical and long term stability needs to be no better than ± 5 percent. RVC resistors have low noise and long life characteristics.
Variable, nonwirewound, precision	MIL-R-39023	Use in servo-mounting applications requiring precise electrical and mechanical output and performance. Used in computer, antenna, flight control, and bomb-navigation systems, etc.

TABLE 100-1 (CONT'D)

RESISTOR TYPE	MIL-SPEC NO.	APPLICATION
Fixed, Established Reliability		
Fixed, composition, insulated	MIL-R-39008	Use insulated resistors for general purpose resistor applications where initial tolerance needs to be no closer than ± 5 percent and long term stability needs to be no better than ± 15 percent under fully rated operating conditions.
Fixed, film high stability	MIL-R-55182	Use in circuits requiring higher stability than provided by composition resistors or film, insulated, resistors and where ac frequency requirements are critical. Operation is satisfactory from dc to 100 MHz. Metal films are characterized by low temperature coefficients and are usable for ambient temperatures of 125°C, or higher with small degradation.
Fixed, wire-wound, accurate	MIL-R-39005	Use in circuits requiring higher stability than provided by composition or film resistors, and where ac frequency performance is not critical. Operation is satisfactory from dc to 50 kHz.
Fixed, wire-wound, power type, chassis mounted	MIL-R-39007	Use where power tolerance and relatively larger power dissipation is required for a given unit size than is provided by MIL-R-26 resistors, and where ac performance is noncritical (i.e., voltage divider, bleeder resistors in dc power supplies, or series-dropping circuits).

TABLE 100-1 (CONT'D)

RESISTOR TYPE	MIL-SPEC NO.	APPLICATION
Fixed, film, insulated	MIL-R-39017	These film resistors have semi-precision characteristics and small sizes. Design parameter tolerances are loose, but good stability makes them desirable in most electronic circuits.
Fixed, wire-wound, power type, chassis mounted	MIL-R-39009	Use where power tolerance and relatively large power dissipation is required for a given unit size and where ac performance is noncritical (i.e., voltage divider, bleeder resistors in dc power supplies, or series-dropping circuits).
Fixed, film, chip	MIL-R-55342	Use these chip resistors in thin or thick film hybrid circuitry where micro circuitry is indicated.
Variable, Established Reliability		
Variable, wire-wound, lead screw actuated	MIL-R-39015	Use for matching, balancing, and adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Variable, non-wirewound, adjustment	MIL-R-39035	Use for matching, balancing, adjusting circuit variables in computers, telemetering equipment, and other critical applications.
Special		
Networks, fixed, film	MIL-R-83401	Use in critical circuitry where stability, long life, reliable operation, and accuracy are of prime importance. They are particularly desireable for use where miniaturization is important. They are also useful where a number of resistors of the same resistance values are required in the circuit.

Some of the typical performance characteristics of various types of resistors can be found in Table 100-II.

Commercial grade, military grade, and military established reliability (ER) grade resistors are physically and functionally identical except for failure rate levels. These failure rate levels vary in orders of magnitude. Whenever possible, an ER resistor, failure rate level of "P" or higher reliability, shall be used. Figure 100.1 represents a comparison of the predicted part operating failure rates for established reliability resistors. The part operating failure rates shown are developed from the part operating failure rate models from MIL-HDBK-217D. The part operating failure rates are representative of a given military environmental condition and stress level and are not necessarily in the same proportion for other environments or operating conditions.

100.2 APPLICATION CONSIDERATIONS

100.2.1 RESISTOR MOUNTING

Resistor mounting plays a critical role in resistor reliability. The mounting determines to a large extent how thermal stress, shock, and vibration are transmitted from the environment to the resistor. Mounting guidelines are presented below.

a. Large resistors should be provided with some adequate means of mounting other than the leads. Under conditions of vibration or shock, lead failure can occur, and the larger the mass supported by the leads the more probable leads will fatigue. Even when vibration or shock is not a serious problem, ease of assembly and replaceability suggest that large components be individually mounted. Resistors should be mounted in such a manner that the body of the resistor is restrained from movement with respect to the mounting base. It should be noted that the heat dissipating qualities of the resistor can be enhanced or retarded depending on whether the clamping material is a good or poor heat conductor.

b. Maintain lead lengths to a minimum. The lead contacts with the PCB act as a heat sink.

c. Where temperature variations are present, leads should be offset (bent slightly) to allow for thermal contraction and expansion (thermal stress relief).

d. Close tolerance and low-value resistors require special precautions (i.e., short leads and good soldering techniques) since the resistance of the leads and the wiring and a poor solder joint could be as much as several percent of the resistance of the resistor.

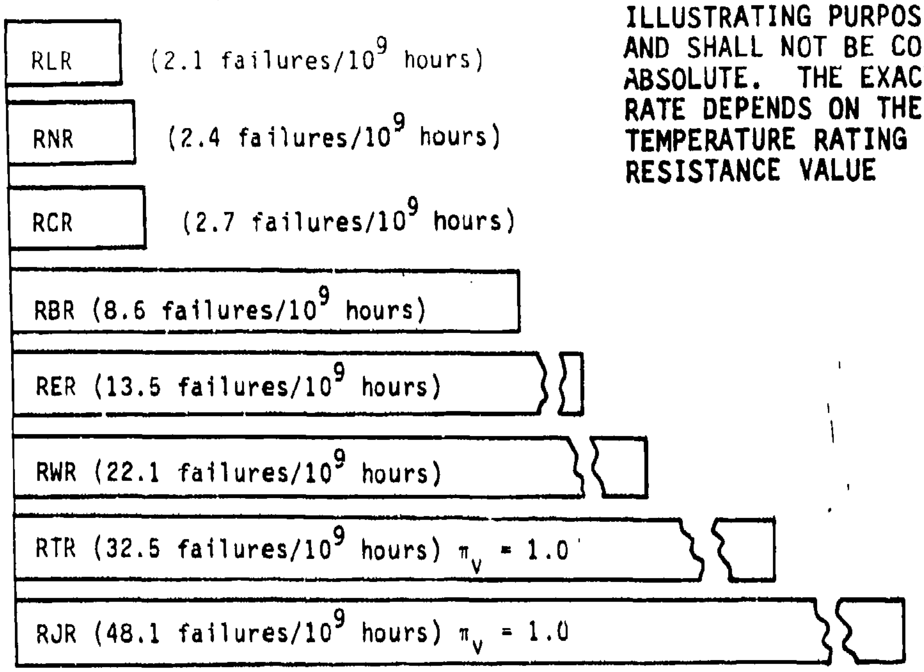
e. When resistors are mounted in rows or banks, they should be so spaced that, taking into consideration the restricted ventilation and heat dissipation of nearby resistors, no resistor in the row or bank exceeds its maximum permissible hot-spot temperature. An appropriate combination of resistor spacing and resistor power rating should be chosen if this is to be assured.

TABLE 100-II

TYPICAL PERFORMANCE CHARACTERISTICS OF VARIOUS RESISTOR TYPES

CHARACTERISTICS	CARBON COMPOSITION	CARBON FILM	METAL FILM	POWER WIREWOUNDS	PRECISION WIREWOUNDS
Resistance Range	2.7 Ω to 100 MΩ	10 Ω to 25 MΩ	10 Ω to 3 MΩ	0.1 Ω to 150 kΩ	0.1 Ω to 273 kΩ
Power rating (W)	1/8 to 2	1/10 to 2	1/20 to 2	5 to 225	1 to 15
Initial Tolerance	20% to 5%	10% to 2%	1% to 0.1%	10% to 5%	1% to 0.05%
Temperature coefficient resistance (TCR) (ppm/°C)	±200 to ±1500	±200 to ±500	100 typ	Less than ±260	±50 typ
Resistance change after over-voltage (2 1/2 times rated for 5 s)	0.5% typ	±1% typ	Figures not available	2%max	0.2% max
Noise (resistance below 1 MΩ)	Less than 6 Ω V/V[4]	Less than 10 Ω V/V	Less than 0.1 Ω V/V	Not applicable	Not applicable
Operating frequency	Up to 1 MHz	Up to 100 MHz	Up to 400 MHz	Limited to audio freq.	Limited to audio freq.
Stability per MIL specs	MIL-R-39008	MIL-R-55182	MIL-R-39017	MIL-R-39007	MIL-R-39005
Resistance changes from					
Moisture[1]	6% typ	0.3%	0.4%	0.5%	0.2%
High temp[2]	-2.0 to 10.1%	2.0%	0.5%	0.5%	0.5%
Load life[3]	-3.0% typ	0.5%	0.5%	3% max	0.5%
Relative cost	Least expensive	Moderately expensive	Moderately expensive	Moderately expensive	Most expensive

1. Temporary resistance change from nominal value @ 25°C when resistor is brought to 105°C.
2. 240 hours @ 95% relative humidity @ 40°C.
3. Load life is 1000 h @ rated voltage and ambient temperature.
4. Depends on manufacturing process. Hot-molded carbon composition resistors provide lower noise than other carbon composition resistors, but at a higher cost.



CAUTION: THESE VALUES ARE GIVEN FOR ILLUSTRATING PURPOSES ONLY AND SHALL NOT BE CONSIDERED ABSOLUTE. THE EXACT FAILURE RATE DEPENDS ON THE MAXIMUM TEMPERATURE RATING AND RESISTANCE VALUE

Note: For RTR and RJR resistors, $\pi_{TAPS} = 1.24$.

FIGURE 100.1

RELATIVE PART OPERATING FAILURE RATES FOR ER TYPE RESISTORS (PREDICTED)*

*Establishment of Ratios:
MIL-HDBK-217D Prediction Methods
Naval Sheltered environment
Ambient temperature (T_A) = 70°C
Stress ratio (S) = 0.1
Failure rate level = "P"
Resistance factor = 1
π_V = Voltage factor
$\pi TAPS$ = Potentiometer taps factor

f. For resistors mounted in series, consider the heat being conducted through the leads to the next resistor.

g. Large power resistors should be mounted to the metal chassis for heat dissipation.

h. Do not mount high-power resistors directly on terminal or printed circuit boards without heat sinks.

i. To provide for the most efficient operation and even heat distribution, power resistors should be mounted in a horizontal position.

j. Select mounting materials that will not char, and design mounts so they withstand strain due to thermal expansion and contraction.

k. Consider proximity to other heat sources as well as self heat.

l. A resistor that dissipates over two watts can char a terminal board. A charred board will have a lower insulation resistance than an uncharred board.

m. Supplementary insulation should be used if a resistor normally mounted directly onto a chassis is to be used at a higher potential above ground than is specified for the resistor. However, the mounting must be able to still dissipate the generated heat.

n. Assembly techniques can affect resistor reliability. Resistors should never be overheated by excessive soldering-iron heat, and the resistor leads should not be abraded by assembly tools. Normal soldering practice should include heat sinking to the extent that the resistor will not be physically damaged or its resistance value changed from the soldering operation.

o. When choosing a resistor, take care to ensure that the power rating of the unit will be sufficient to handle the higher current produced when the resistance is reduced, particularly if it is being used in series as a voltage-dropping resistor.

100.2.2 TEMPERATURE EFFECTS

Inadequate heat dissipation is the predominant cause of failure for any resistor type. Figure 100.2 depicts the manner in which heat is dissipated from fixed resistors in free air. The lowest possible resistor surface temperature should be maintained using radiation, conduction, and convection to the fullest extent to accomplish the necessary dissipation. Under normal atmospheric conditions (25°C, 30 in. Hg), resistors up to two watts dissipate heat in the following proportions: 10 percent radiation, 40 percent convection and 50 percent conduction through leads. Resistors with substantially larger wattage ratings, by virtue of increased surface area, dissipate heat in proportions of: 50 percent radiation, 25 percent convection and 25 percent conduction through leads.

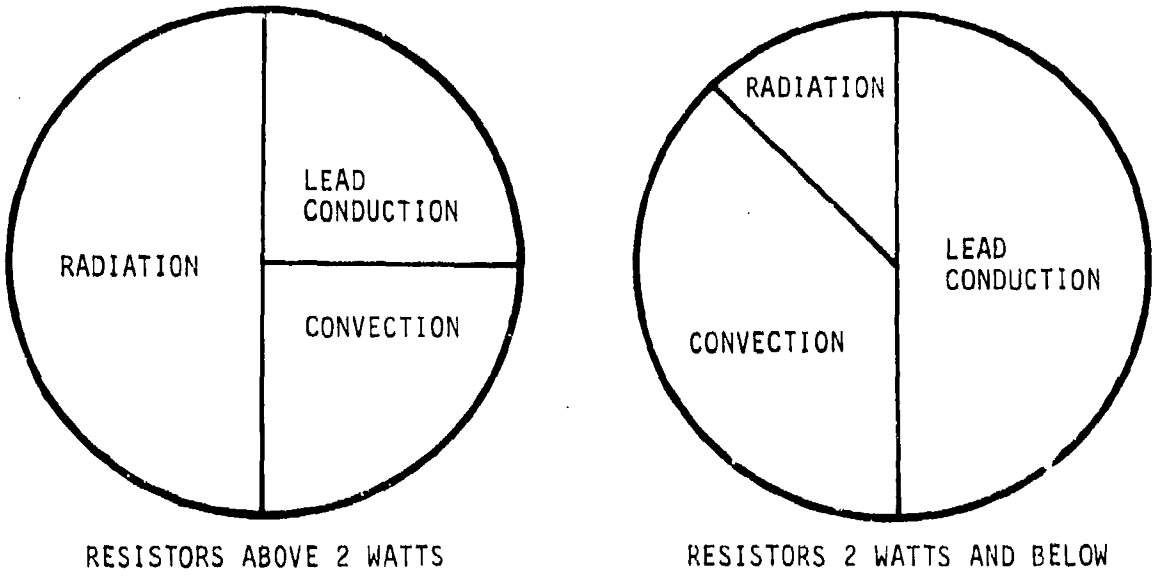


FIGURE 100.2

HEAT DISSIPATION OF RESISTORS UNDER ROOM CONDITIONS

Thermal dissipation considerations for the three methods of heat transfer include:

a. Radiation considerations:

(1) Maximize spacing between resistors that generate heat to reduce cross-radiation heating effects.

(2) Place resistors so that adjacent large metallic areas are located to absorb significant amounts of radiated heat.

(3) Use vented or similar types of body clamps on larger size resistors.

b. Conduction considerations:

(1) Use resistors with thick leads and minimum length.

(2) Terminate resistor leads at tiepoints of sufficient mass to perform the function of a heat sink.

(3) Mount large size resistors with body clamps to large metallic masses (such as the chassis).

c. Convection considerations:

(1) Maximize spacing between resistors that generate heat to allow reduced resistance to air flow.

(2) Orient resistors and provide baffles where needed for exposure to air flow by both natural and forced convection.

Power dissipation per unit of resistor area is specified in MIL-STD-199. The surface temperature rise of specific resistor types can usually be obtained from vendor resistor specifications.

100.2.3 FORM FACTORS AND PREFERRED RESISTANCE VALUE

For physical form and preferred resistance values of each resistor style, see MIL-STD-199 or the appropriate resistor detailed military specification.

100.2.4 VARIABLE RESISTORS

The use of variable resistors is not preferred for high reliability applications. These resistors are not hermetically sealed. Therefore, they are susceptible to degraded performance due to the ingestion of soldering flux, cleaning solvents, and conformal coatings during equipment fabrication. Variable resistors also contain moving parts that wear with use. The reliability of variable resistors is relatively low when compared to fixed resistors. When variable resistors must be used, the following precautions should be followed:

a. For variable resistors, enclosed units should be used to keep out as much dust and dirt as possible and to protect the mechanism from mechanical damage. The presence of lubrication oil can cause dust or wear particles to concentrate within the unit.

b. For variable resistors, it is necessary to provide some method of preventing movement of the wiper arm, other than those movements required during operation. For resistors which are not in continuous use, the short locked shaft with a slotted end is preferred. For continuous use, the high torque shaft will limit the amount of motion due to shock, vibration, and accidental movement. Where it is absolutely necessary to have a long shaft, a coupled extension is preferred to one long integral shaft. Regardless of the type of shaft, the use of oversize control knobs which permit high rotational torque will generally result in damage to the integral stop. Use the smallest size knob to reduce applied torque.

c. When a variable linear resistor is being used as a voltage divider, the output voltage through the wiper will not vary linearly if current is being drawn through it. This characteristic is usually called the "loading error." To reduce the loading error, the load resistance should be at least 10 to 100 times as great as the end-to-end potentiometer resistance.

d. In potentiometer applications it is necessary to bear in mind the fact that the load current as well as the "bleeder" current will be flowing through a part of the resistor and will contribute to the heating effect.

100.2.5 COMPOSITION RESISTOR APPLICATION CONSIDERATIONS

Composition resistors are small, inexpensive and have good reliability when properly used. They have poor resistance stability, high noise characteristic, and appreciable voltage and temperature coefficients. They do, however, have good high-frequency characteristics although this characteristic is not controlled by specification. Other application considerations of composition resistors include:

a. Exposure to humidity may have two effects on the resistance value: (1) Surface moisture can result in leakage paths which will lower the resistance values, or (2) absorption of moisture into the element may increase the resistance. These phenomena are more noticeable in higher resistance ranges. When exposed to humid atmosphere, operating at low power levels or during shelf storage, equipment nonoperating, and shipping, resistance values can change by as much as 15 percent.

b. Resistor characteristics can be permanently damaged by exposure to high operating temperatures.

c. The resistance-temperature characteristic for composition resistors is higher than for other resistor styles covered by military specifications.

d. Thermal agitation (Johnson noise) and resistance fluctuations (carbon noise), present only when current is flowing, are characteristic of carbon composition resistors. Use of these resistors, in low level high-resistance (1 megohm or more) circuits should be avoided. The expected noise level is approximately 3 to 10 microvolts per volt. A film or wirewound resistor will usually yield lower noise levels.

e. When used in high frequency circuits (1 MHz and above), the effective resistance will decrease as a result of dielectric losses and shunt capacity (both end-to-end and distributed capacity to mounting surface). High frequency characteristics of carbon composition resistors are not controlled by specification and hence are subject to change without notice.

f. Care should be taken in soldering resistors, since all properties of a composition resistor may be seriously affected when soldering irons are applied too closely to a resistor body or for too long a period. The length of lead left betwen the resistor body and the soldering point should not be less than 1/4 inch. Heat-dissipating clamps should be used, if necessary, when soldering resistors in close quarters. In general, if it is necessary to unsolder a resistor to make a circuit change or during maintenance, the resistor should be discarded and a new one used.

g. Fixed composition resistors exhibit little change in effective dc resistance up to 100 kHz. Resistance values above .3 megohms start to decrease in resistance at approximately 100 kHz. Above a frequency of 1 MHz, all resistance values exhibit decreased resistance. However, the resistor operates as a pure resistance free from a reactive component into the megacycle region.

h. Nominal minimum resistance tolerances available for fixed, composition resistors are ± 5 percent. Combined effects of climate and operation on unsealed types can raise this tolerance to ± 15 percent. These effects include aging, pressure, temperature, humidity and voltage gradient.

i. Composition elements of variable resistors can wear away after extended use, leaving particles of the element to permeate the mechanism. This can result in warmer operation and high resistance shorts within the variable resistor.

j. These variable resistors should not be used at potentials to ground or case greater than 500 volts peak, unless supplementary insulation is provided.

100.2.6 FILM RESISTOR, GENERAL APPLICATION CONSIDERATIONS

General application considerations are noted below:

a. Film-type resistors have the best high-frequency performance of all resistor types. The effective dc resistance for most resistance values remains fairly constant up to 100 MHz and decreases at higher frequencies. In general, the higher the resistance value the greater the effect of frequency.

b. Some lower power, tighter tolerance film resistors are quite susceptible to electrostatic damage (see Appendix C, DOD-STD-1686; DOD-HDBK-253).

c. Film resistors are recommended for use where high stability and close tolerance resistance values are required. That is, where the resistance value must be accurately maintained over a broad range of temperature or for long periods of equipment storage and operation. Regardless of the purchase tolerance (nominally ± 1 percent or less), the design should be able to tolerate a ± 2 percent shift in resistance to assure long life reliability in military applications.

d. Operation at radio frequencies above 100 MHz can produce inductive effects on spiral-cut types.

e. The resistance-temperature characteristic of film resistors is fairly low (+ 500 PPM/°C and + 200 PPM/°C) for thick film types (RLR) and very low (± 25 PPM/°C for metal film types (RNR)). Metal film resistors can experience temporary or permanent changes in resistance under operation in extreme temperatures.

f. Additionally, film resistors are capable of tight tolerance and high stability. Minimum resistance tolerance available is 0.1 percent.

g. Operation at reduced frequency may produce inductive effects on spiral-wound types; skin inductive effects are negligible.

h. Exposure to moisture can seriously affect this type of resistor if not protected by molded or ceramic casing or internal deposition of the resistance element.

i. Carbon-film resistance elements are susceptible to physical damage; hermetic seals are preferred for film-type resistors.

j. The noise level of variable film resistors is quite low compared to variable composition resistors.

k. The resistance values of variable film resistors are subject to change when they encounter shock, acceleration, and high frequency vibration force. Care should be taken to assure that the design can tolerate 6 percent variation in resistance at the contact arm when the shaft is unlocked.

l. Consideration should be given to temperature rise and ambient temperature of variable film resistors under operation in order to allow for the change in resistance due to resistance-temperature characteristic. The resistance-temperature characteristic is measured between the two end terminals. Whenever resistance-temperature characteristic is critical, variation due to the resistance of the movable contact should also be considered.

100.2.7 WIREWOUND RESISTOR, GENERAL APPLICATION CONSIDERATIONS

General application considerations are noted below:

Though some resistors are constructed using reverse Pi-winding, Ayrton-Perry or bifilar winding to reduce inductance, they are not designed for high frequency applications where ac performance is of critical importance. They are especially suited for use in dc amplifiers, electronic computers, meters, and laboratory test equipment. If used in high frequency circuits, adequate caution must be observed to ensure satisfacatory performance.

a. Wirewound resistors have inductive and capacitive effects and are normally unsuited for use above 50 kHz. Wirewound resistors usually exhibit an increase in resistance with high frequencies because of the "skin" effect.

b. Application of voltages in excess of the voltage rating can cause insulation breakdown in the thin coating of insulation between the windings.

c. The use of tapped resistors is to be avoided. Insertion of taps weakens the resistor mechanically, lowering the effective power ratings.

d. The presence of moisture may degrade coating or potting compounds used in these resistors.

e. Wirewound resistors employing a plastic or ceramic bobbin are susceptible to mechanical damage resulting from vibration, shock, and pressure.

f. Due to their size and weight, in applications where severe shock or high frequency forces are encountered, the bodies of these resistors should be constrained from movement.

g. Wirewound, power resistors have high stability, medium temperature coefficient, high reliability, negligible voltage coefficient, poor high-frequency characteristics, negligible noise, and are capable of dissipating considerable heat.

h. Wirewound, accurate resistors are physically large compared to composition types of the same power rating. They exhibit very high stability, negligible voltage coefficient, and high-frequency characteristics probably good to 50 kHz maximum. Operation above 50 kHz may produce inductive effects and intra-winding capacitive effects.

i. Wirewound resistors are used where high cost and size are not important and operational environment can be controlled.

j. Wirewound power variable resistors are generally not supplied in low tolerance, since most applications for this type do not require accurate resistance.

k. Fixed, wirewound, accurate resistors are physically the largest of all types for a given resistance and power rating, since they are very conservatively rated.

l. The variable wirewound resistors have the highest allowable noise specification for variable resistors. These wirewound resistors are subject to noise because of stepping of the contact from wire to wire.

m. The variable wirewound resistors have the lowest temperature coefficient and the most stable characteristic of any potentiometer.

100.3 DERATING FACTORS

For high reliability, resistors shall be derated according to the derating requirements specified herein. The resistor operating temperature range shall be compatible with anticipated equipment operating temperature, and hermetically sealed resistors shall be used in environments where anticipated relative humidity may exceed 80 percent.

In ac applications the rms (root-mean-square) values of voltage or current are used to determine the effective power used in reliability calculations. The resultant stress ratio is determined as follows:

$$S = \frac{P\ \text{applied}}{P\ \text{rated}}$$

101 RESISTORS, FIXED

101.1 MIL-R-26, RESISTORS, FIXED, WIREWOUND (POWER TYPE), (STYLE RW)

101.1.1 APPLICATION CONSIDERATIONS

101.1.1.1 Substitution

Use MIL-R-39007 style RWR resistors instead of MIL-R-26 style RW when applicable.

101.1.1.2 Operating Temperature

The maximum operating temperature is limited to 200°C. Above 200°C, the resistors are subject to "outgassing" of the volatile materials used in their fabrication.

101.1.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.3.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

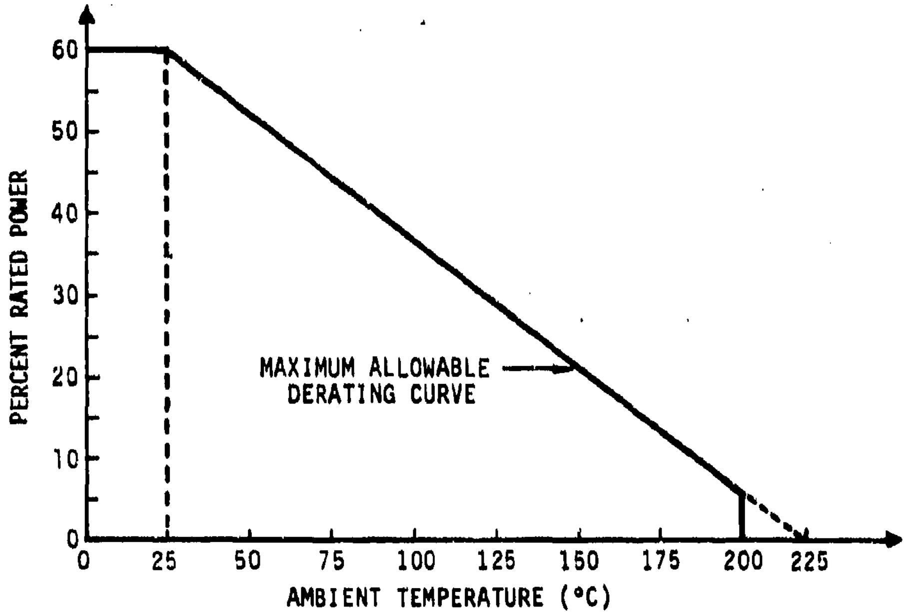


FIGURE 100.3

DERATING REQUIREMENTS FOR STYLES RW 29, 31, 33, 35, 37, 38, 47, 56

101.2 MIL-R-18546, RESISTORS, FIXED, WIREWOUND, (POWER TYPE, CHASSIS MOUNTED), (STYLE RE)

101.2.1 APPLICATION CONSIDERATIONS

101.2.1.1 Substitution

Use MIL-R-39009 style RER resistors instead of MIL-R-18546 style RE when applicable.

101.2.1.2 Operating Temperature

The maximum operating temperature is limited to 185°C, since above 185°C, the resistors may be subject to "outgassing" of the volatile materials used in their fabrication.

101.2.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.4.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.4.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specificaton (MIL-R-18546).

(3) Care shall be taken to insure that the instantaneous peak resistor body temperature does not exceed 210°C.

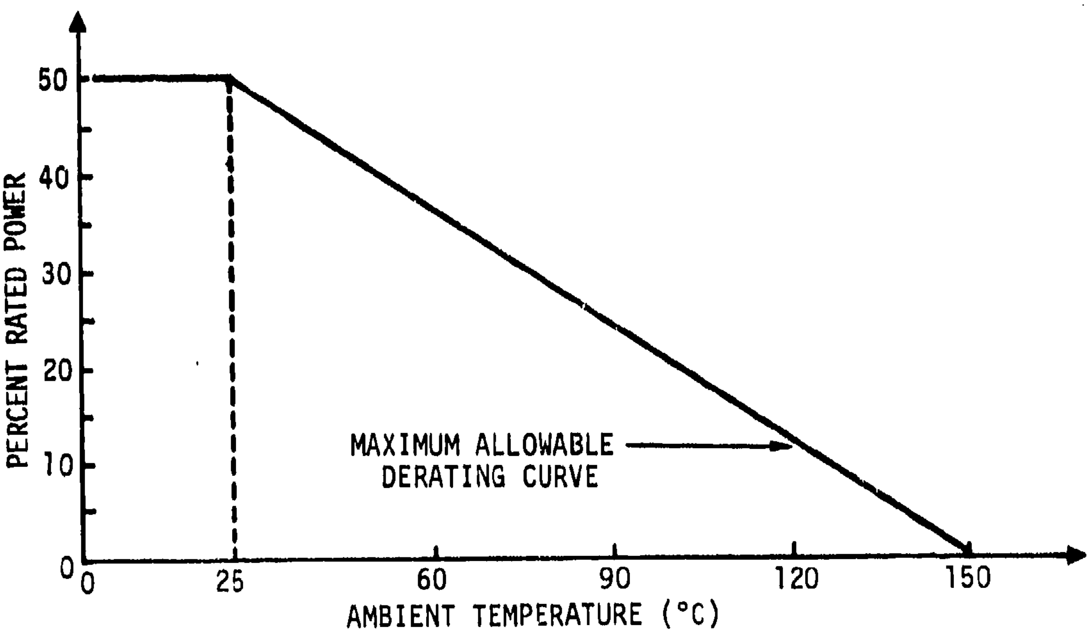


FIGURE 100.4

DERATING REQUIREMENTS FOR STYLES RE 77, 80

102 RESISTOR, VARIABLE

102.1 MIL-R-94, RESISTORS, VARIABLE, COMPOSITION, (STYLE RV)

102.1.1 APPLICATION CONSIDERATIONS

102.1.1.1 Selection of Bushing

Type S bushings have longer rotational life than Type T bushings. Hence, Type S bushings shall be used whenever possible to assure longer life.

102.1.1.2 Shelf Life

An average resistance change (ΔR) of 20 percent per year under normal storage conditions is estimated.

102.1.1.3 Temperature Characteristics

An average change ± 8 percent due to thermal cycling is estimated.

102.1.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.5.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

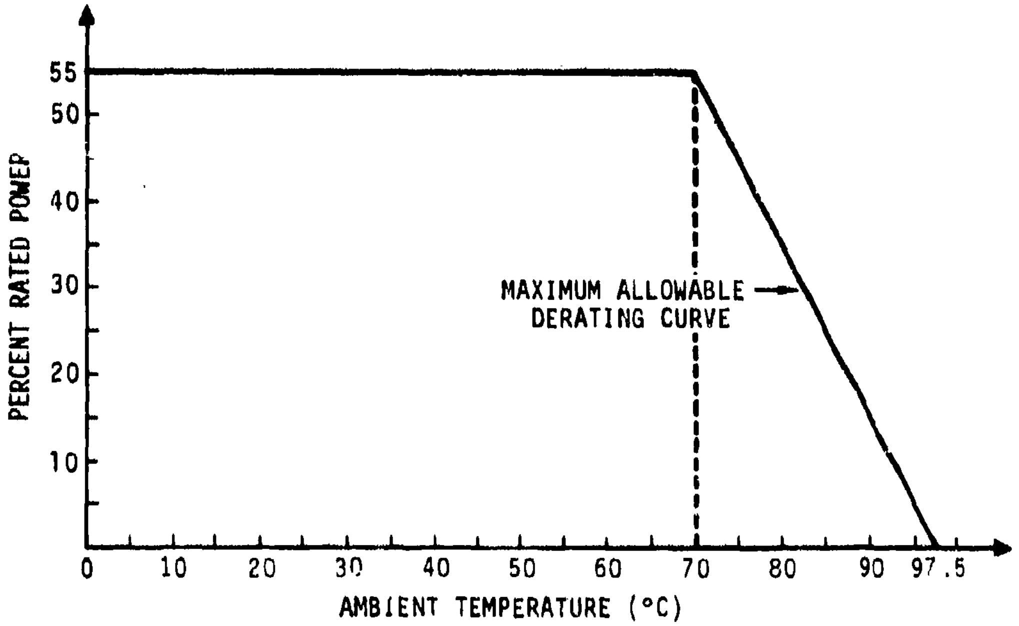


FIGURE 100.5

DERATING REQUIREMENTS FOR STYLES RV 04, 06

102.2 MIL-R-19, RESISTORS, VARIABLE, WIREWOUND (LOW OPERATING TEMPERATURE), (STYLE RA)

102.2.1 APPLICATION CONSIDERATIONS

102.2.1.1 Selection of a Safe Resistor Style

The wattage ratings of these resistors are based on operation at 40°C, mounted on a 16 gage steel plate, 4 inches square. This mounting technique should be taken into consideration when the wattage is applied during specific applications. For other types of mountings, the ratings must be properly modified.

102.2.1.2 Linear and Nonlinear Tapers

As shown in Figure 100.6, Taper A is a linear resistance taper, which is one having a constant change of resistance with angular rotation, while Taper C is a nonlinear resistance taper, which has a variation in the change of resistance with angular rotation.

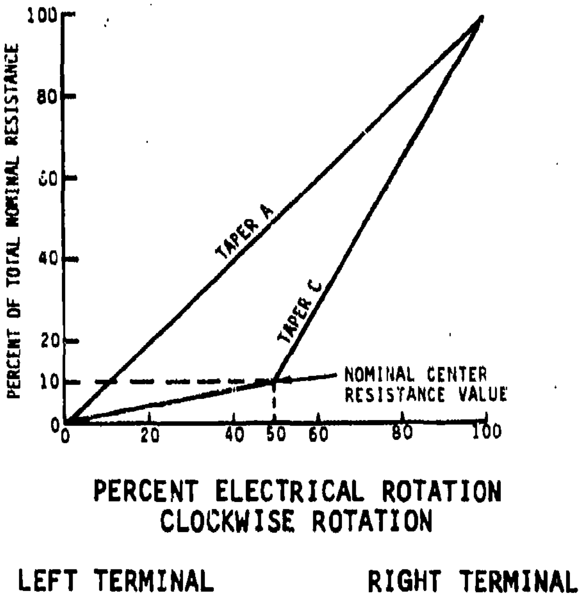


FIGURE 100.6

LINEAR AND NONLINEAR TAPERS FOR RA RESISTORS

102.2.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.7.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

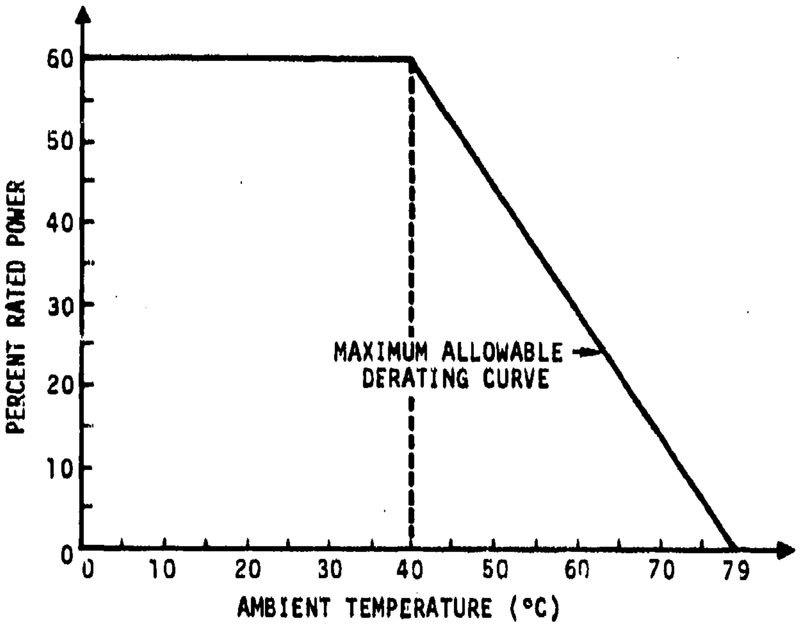


FIGURE 100.7

DERATING REQUIREMENTS FOR STYLES RA 20, 30

102.3 MIL-R-22, RESISTORS, VARIABLE, WIREWOUND (POWER TYPE), (STYLE RP) (UNENCLOSED)

102.3.1 APPLICATION CONSIDERATIONS

102.3.1.1 Selection of a Safe Resistor Style

The wattage ratings of these resistors are based on operation at 25°C, mounted on a 12 inch square steel panel, .063 inch thick (4 inch square x 0.050 inch for RP05 and RP06). This mounting technique should be taken into consideration when the wattage is applied during specific applications. For other types of mountings, the ratings should be properly modified.

102.3.1.2 Supplementary Insulation

These resistors should not be used at potentials above ground greater than 500 volts (250 volts for RP05 and RP06) unless supplementary insulation is used.

102.3.1.3 Electrical Off Position

Care should be exercised in specifying the electrical off position when resistors are required to break dc circuits having potentials in excess of 40 volts.

102.3.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figures 100.8A and 100.8B.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

NOTE: OPERATION OF THESE RESISTORS AT AMBIENT TEMPERATURES GREATER THAN 125°C CAN DAMAGE METAL PLATING, SHAFT LUBRICATION, INSULATION, ETC., OF THE RESISTORS.

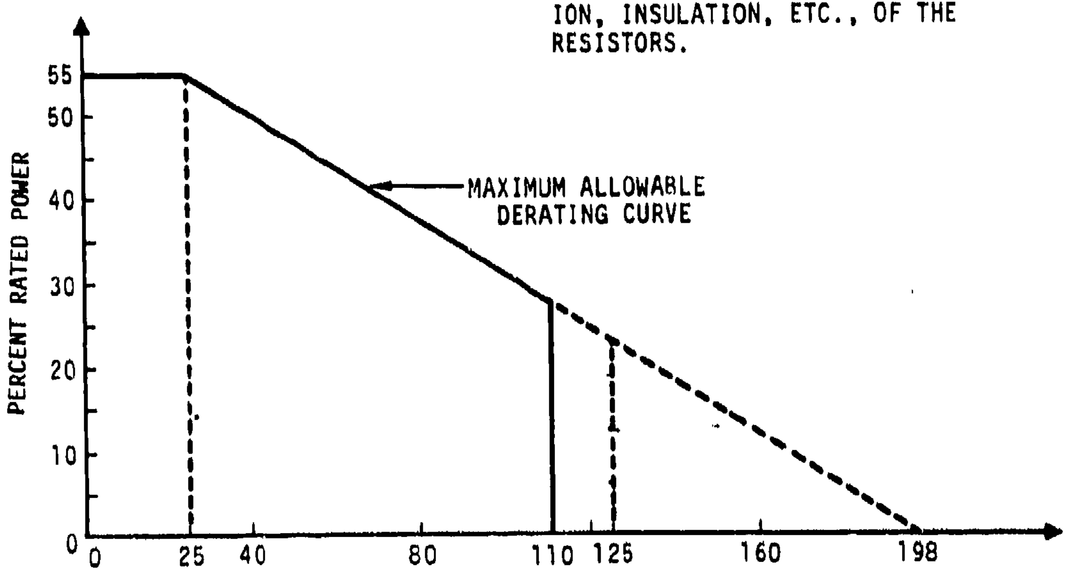


FIGURE 100.8A

DERATING REQUIREMENTS FOR STYLES RP 05, 06, 10, 15, 20, 25

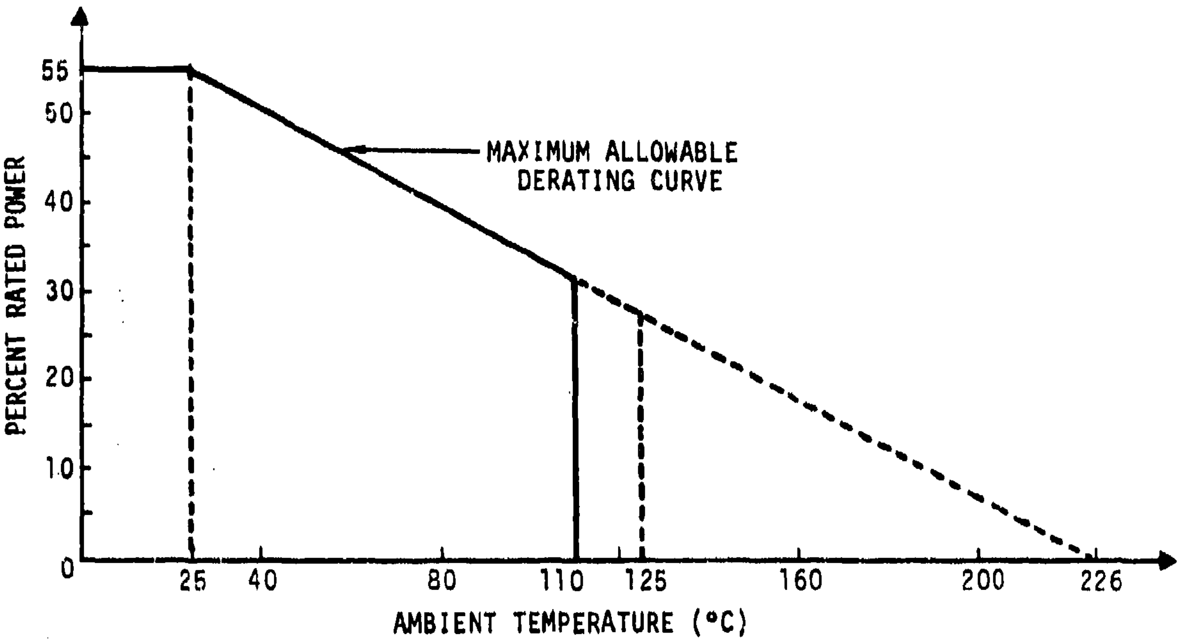


FIGURE 100.8B

DERATING REQUIREMENTS FOR STYLE RP30

102.4 MIL-R-12934, RESISTORS, VARIABLE, WIREWOUND, PRECISION, (STYLE RR)

102.4.1 APPLICATION CONSIDERATIONS

102.4.1.1 Selection of a Safe Resistor Style

The wattage rating of these resistors is based on operations at 85°C, mounted on a 4 inch square, 0.25 inch thick alloy aluminum panel. This mounting technique should be taken into consideration when a wattage is dissipated during specific applications. When other types of mountings are employed, the wattage ratings should be properly modified.

102.4.1.2 Bushings

A Type S bushing shall be used whenever possible to assure longer life.

102.4.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.9.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

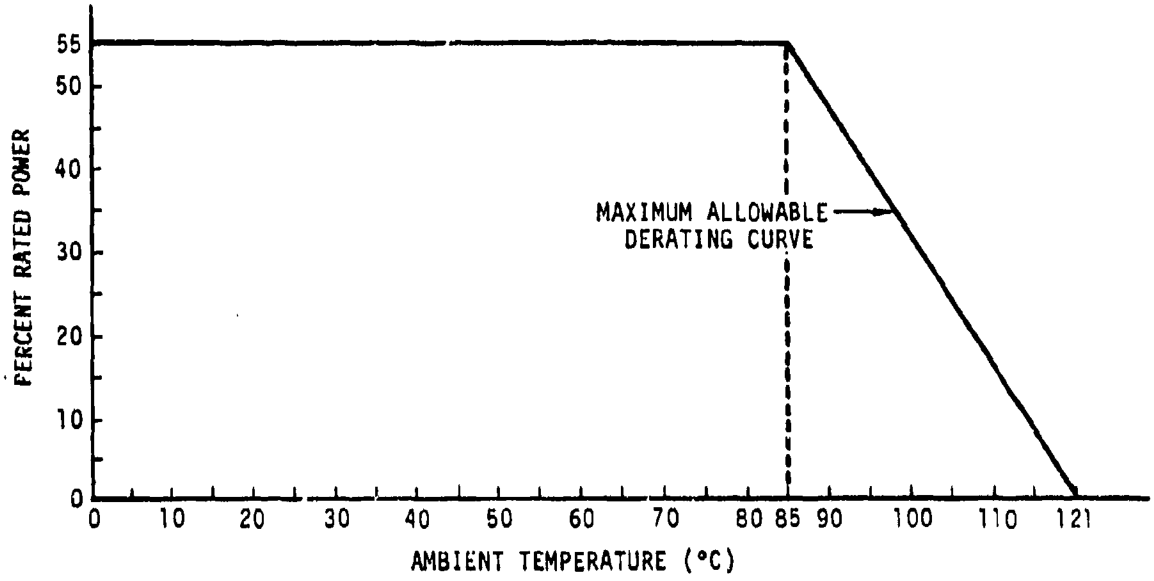


FIGURE 100.9

DERATING REQUIREMENTS FOR STYLES RR 0900, 1000, 1100, 1300, 1400, 2000, 2100, 3000, 3100, 3200, 3300, 3400, 3500, 3700, 3900, 4000, 4100

102.5 MIL-R-39002, RESISTORS, VARIABLE, WIREWOUND, SEMIPRECISION, (STYLE RK)

102.5.1 APPLICATION CONSIDERATIONS

102.5.1.1 Selection of a Safe Resistor Style

The wattage rating of these resistors is based on operation at 85°C, mounted on a 4 inch square, 0.050 inch thick, steel panel. This mounting technique should be taken into consideration when wattage is applied during specific applications. When using other types of mountings, the power rating must be properly modified.

102.5.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.10.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

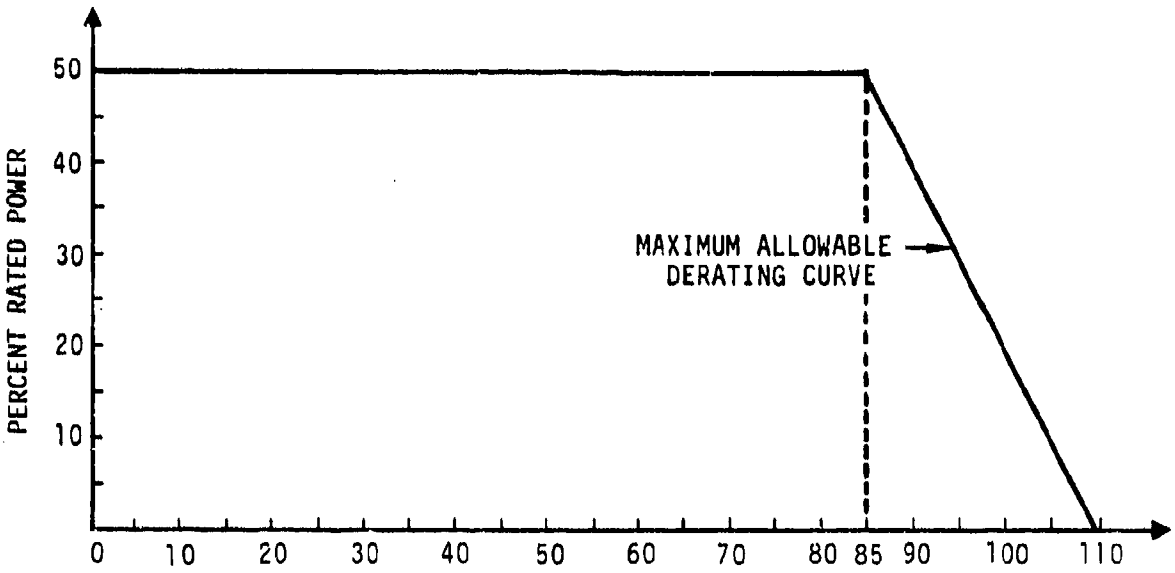


FIGURE 100.10

DERATING REQUIREMENTS FOR STYLE RK09

102.6 MIL-R-27208, RESISTORS, VARIABLE, WIREWOUND (ADJUSTMENT TYPE), (STYLE RT)

102.6.1 APPLICATION CONSIDERATIONS

102.6.1.1 Substitution

Use MIL-R-39015 style RTR resistors instead of MIL-R-27208 style RT, when applicable.

102.6.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.11.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

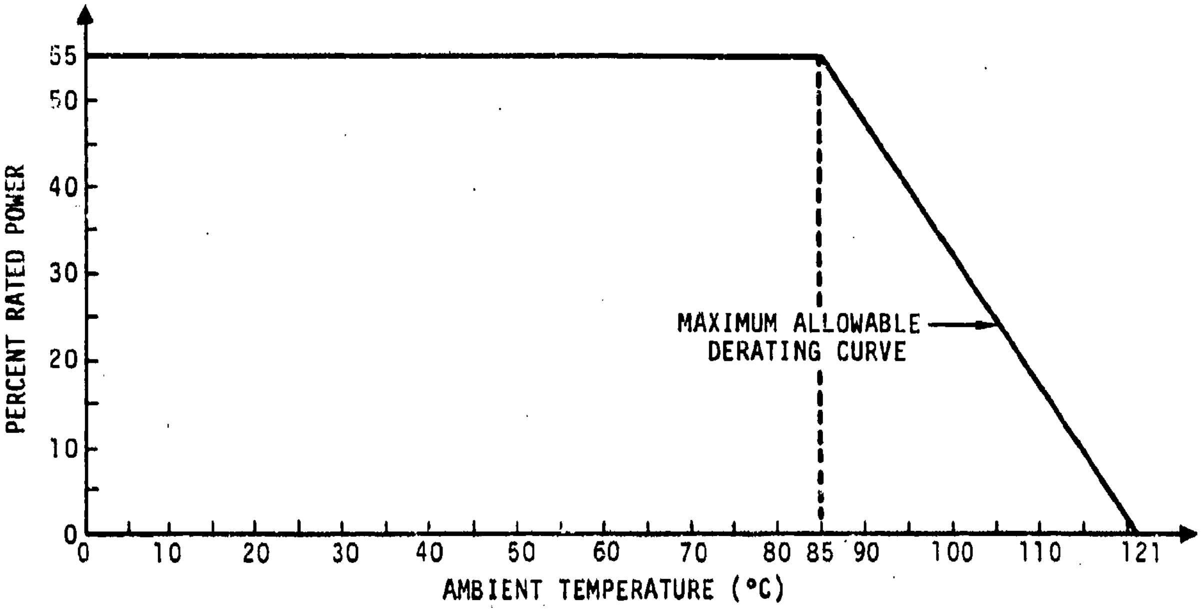


FIGURE 100.11

DERATING REQUIREMENTS FOR STYLE RT26

102.7 MIL-R-22097, RESISTORS, VARIABLE, NONWIREWOUND (ADJUSTMENT TYPE), (STYLE RJ)

102.7.1 APPLICATION CONSIDERATIONS

102.7.1.1 Substitution

Use MIL-R-39035 style RJR resistors instead of MIL-R-22097 style RJ, when applicable.

102.7.1.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.12.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

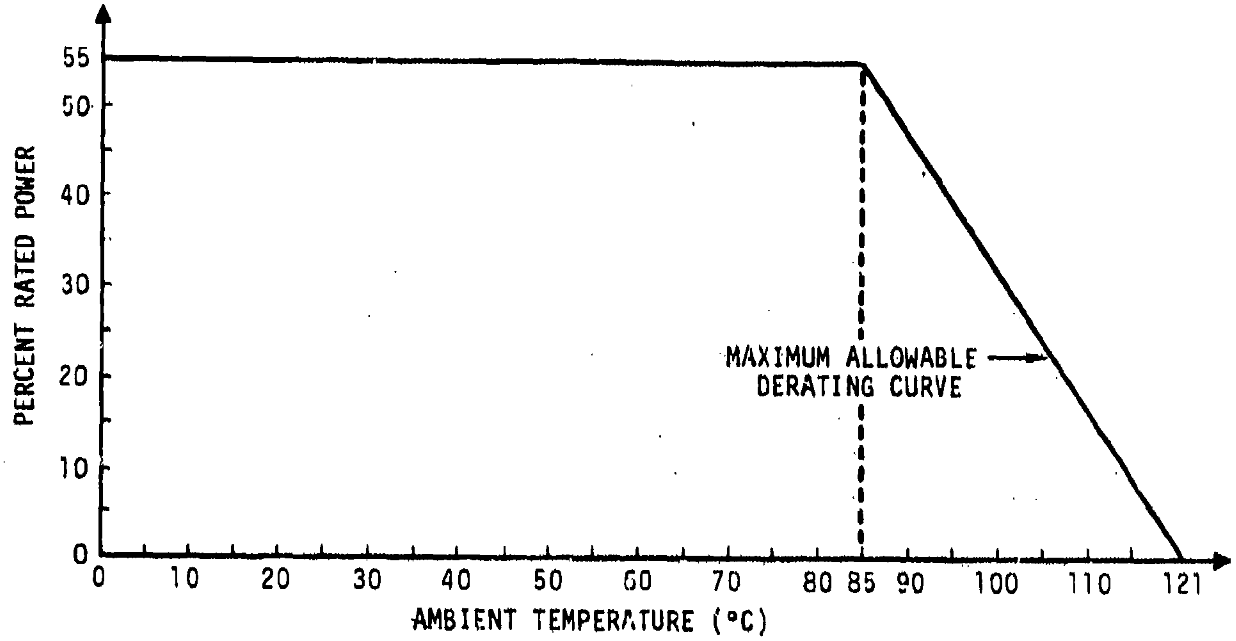


FIGURE 100.12

DERATING REQUIREMENTS FOR STYLES RJ 12, 50

102.8 MIL-R-23285, RESISTORS, VARIABLE, NONWIREWOUND, (STYLE RVC)

102.8.1 APPLICATION CONSIDERATIONS

These resistors are suitable for rheostat or potentiometer applications, where high precision is not required. They are capable of withstanding acceleration, shock, high frequency vibration, and 125°C operating temperature at rated load. They are most useful in circuitry where high resistance values and lower power dissipation are encountered in controlling volume, bias, tone voltage, and pulse-width.

102.8.1.1 Selection of Safe Resistors

The wattage ratings of these resistors are based on operation at 125°C, mounted on a 16-gage steel plate, 4 inch square. This mounting technique should be taken into consideration when the wattage is applied during specific applications. When using other types of mountings, the power ratings should be properly modified.

102.8.1.2 Linear and Nonlinear Tapers

As shown in Figure 100.13, Taper A is a linear resistance taper, which is one having a constant change of resistance with angular rotation, while Taper C is a nonlinear resistance taper, which has a variation or lack of constancy in the change of resistance with angular rotation.

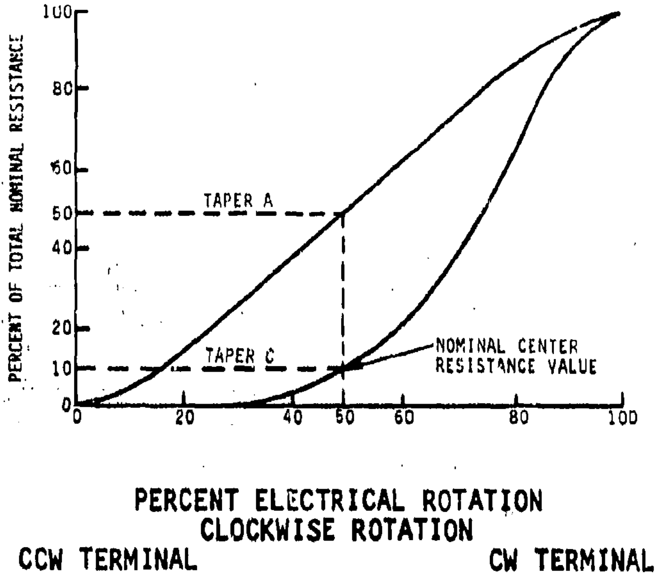


FIGURE 100.13

LINEAR AND NONLINEAR TAPERS FOR RVC RESISTORS

102.8.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.14.

b. Pulse condition - This resistor is suitable for pulsed circuits only if the voltage is limited to a value that will not cause the derated power dissipation to be exceeded.

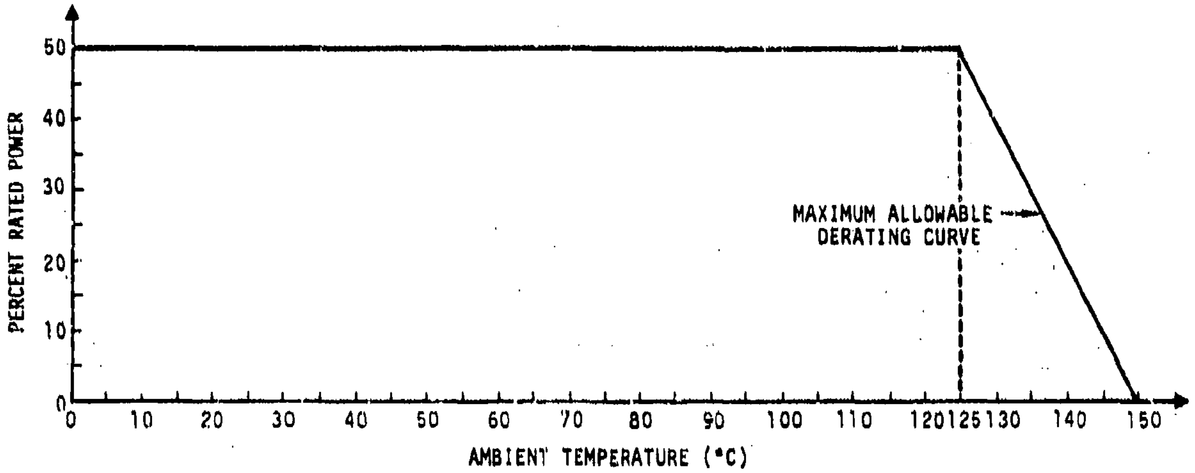


FIGURE 100.14

DERATING REQUIREMENTS FOR STYLE RVC06

102.9 MIL-R-39023, RESISTORS, VARIABLE, NONWIREWOUND, PRECISION, (STYLE RQ)

102.9.1 APPLICATION CONSIDERATIONS

102.9.1.1 Output

The output of these resistors (in terms of percent of applied voltage) is linear with respect to the angular position of the operating shaft.

102.9.1.2 Temperature Characteristics

An average resistance change of ± 10 percent due to temperature cycling is common.

102.9.1.3 Selection of Safe Resistors

The wattage rating of these resistors is based on operation at 70°C, mounted on a 4 inch square, 0.25 inch thick alloy aluminum panel. This mounting technique should be taken into consideration when a wattage is dissipated during specific applications. When using other types of mountings, the wattage ratings should be properly modified.

102.9.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.15.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

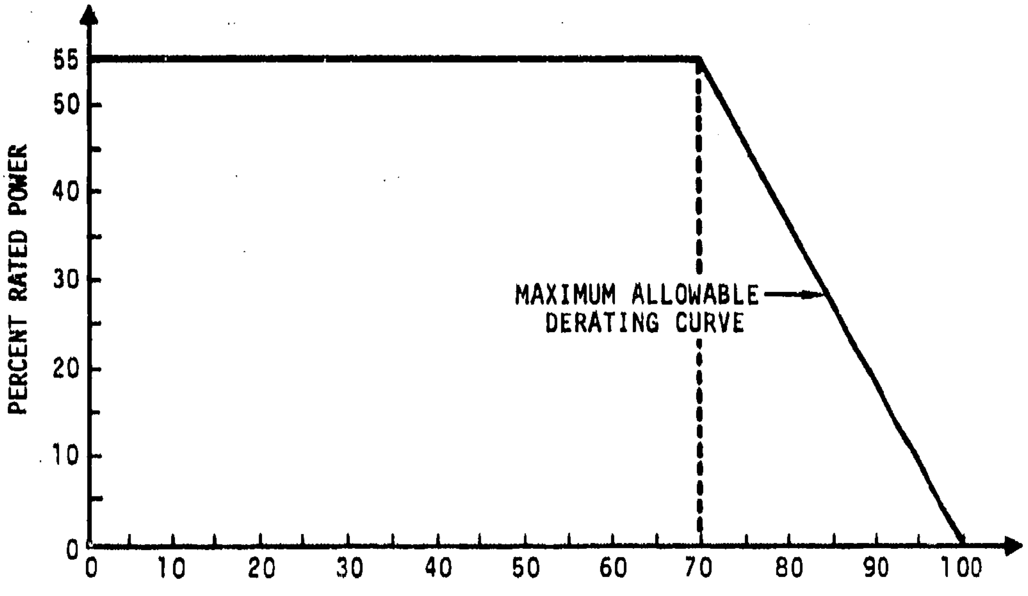


FIGURE 100.15

DERATING REQUIREMENTS FOR STYLES RQ 100, 110, 150, 160, 200, 210, 300 and RQ090

103 RESISTORS, FIXED, ESTABLISHED RELIABILITY

103.1 MIL-R-39008, RESISTORS, FIXED, COMPOSITION (INSULATED), ESTABLISHED RELIABILITY, (STYLE RCR)

103.1.1 APPLICATION CONSIDERATIONS

103.1.1.1 Voltage Coefficient

For resistance greater than 1,000 ohms, resistance values can change with the application of voltage, as follows:

RCR 05	0.05 percent/volt
RCR 07, RCR 20	0.035 percent/volt
RCR 32, RCR 42	0.02 percent/volt

The voltage coefficient for resistors below 1,000 ohms is not controlled by specifications and these resistors should not be used in circuits which are sensitive to this parameter.

103.1.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.16.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.16.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39008).

(3) Care shall be taken to insure that the instantaneous peak resistor body temperature does not exceed 115°C.

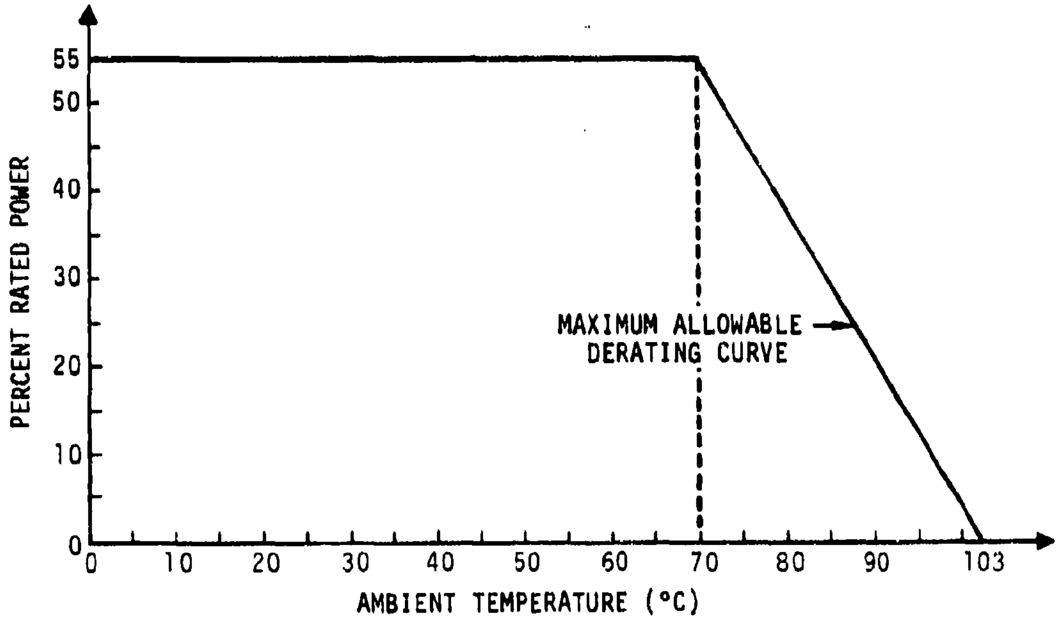


FIGURE 100.16

DERATING REQUIREMENTS FOR STYLES RCR 05, 07, 20, 32, 42

103.1.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

103.2 MIL-R-55182, RESISTORS, FIXED, FILM, ESTABLISHED RELIABILITY, (STYLE RNR)

103.2.1 APPLICATION CONSIDERATIONS

103.2.1.1 High Frequency Applications

When used in high frequency circuits (400 MHz and above), the effective resistance will decrease as a result of shunt capacity (both end-to-end and distributed capacitance to mounting surface). High frequency characteristics of metal film resistors are not controlled by specification and are subject to change without notice.

103.2.1.2 Noise

Noise output is controlled by the specification. In applications where noise is an important factor, fixed film resistors are superior to composition types. Where noise test screening is indicated, it is recommended that the noise test procedure of MIL-STD-202 be used.

103.2.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.17.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.17.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-55182).

(3) Care shall be taken to insure that the instantaneous peak resistor body temperature does not exceed 160°C.

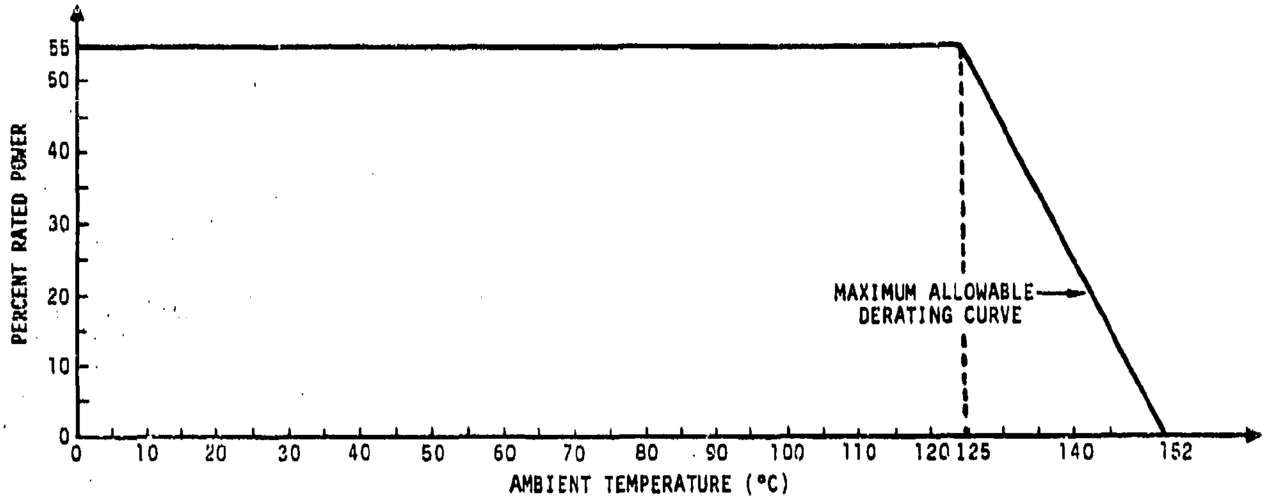


FIGURE 100.17

DERATING REQUIREMENTS FOR STYLES RNR 50, 55, 60, 65, 70, 75 AND RN090

103.2.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

103.3 MIL-R-39005, RESISTORS, FIXED, WIREWOUND (ACCURATE), ESTABLISHED RELIABILITY, (STYLE RBR)

103.3.1 APPLICATION CONSIDERATIONS

These resistors are intended for use where extremely close tolerances (± 1 percent to ± 0.01 percent), long life, and a high degree of temperature stability is required.

103.3.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.18.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.18.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specifiction (MIL-R-39005).

(3) Care shall be taken to insure that the instantaneous peak resistor body temperature does not exceed 135°C.

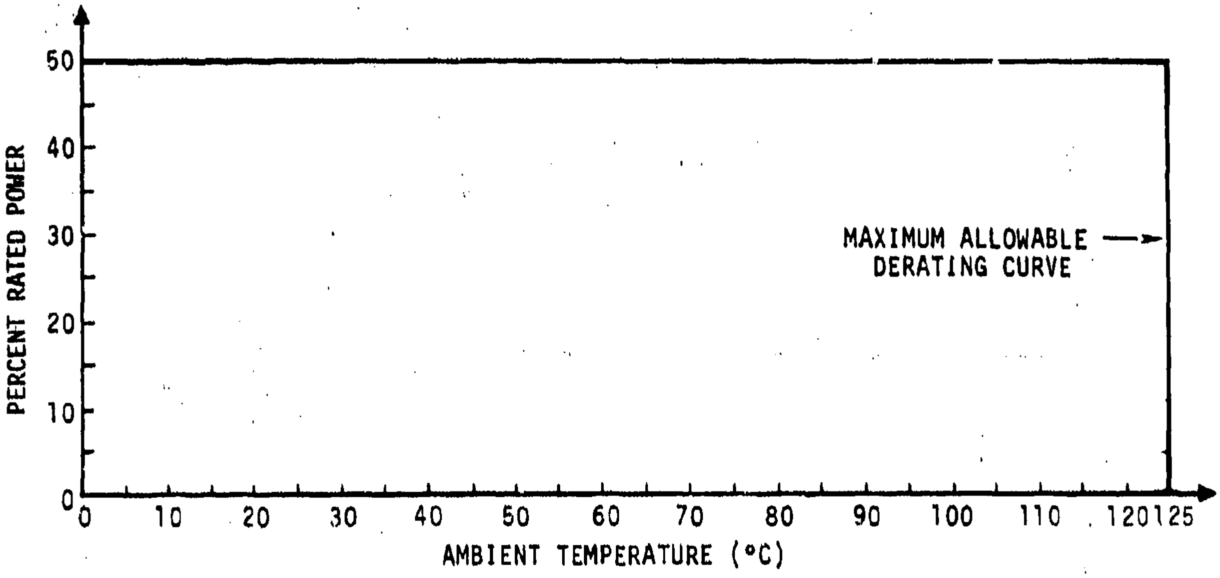


FIGURE 100.18

DERATING REQUIREMENTS FOR STYLES RBR 52, 53, 54, 55, 56, 57, 71, 75

103.3.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

103.4 MIL-R-39007, RESISTORS, FIXED, WIREWOUND (POWER TYPE), ESTABLISHED RELIABILITY, (STYLE RWR)

103.4.1 APPLICATION CONSIDERATIONS

These resistors are recommended for use where greater power handling capacity is required. The RWR resistors are available in very close tolerance (to ± 0.1 percent) and have tightly controlled temperature coefficients (± 20 ppm/°C for values of 10Ω or greater). Regardless of purchase tolerance, the design should tolerate a + 1 percent shift in resistance value to assure long life reliability in military applications.

103.4.2 DEPATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.19.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.19.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39007).

(3) Care shall be taken to insure that the instantaneous peak resistor body temperature shall not exceed 225°C.

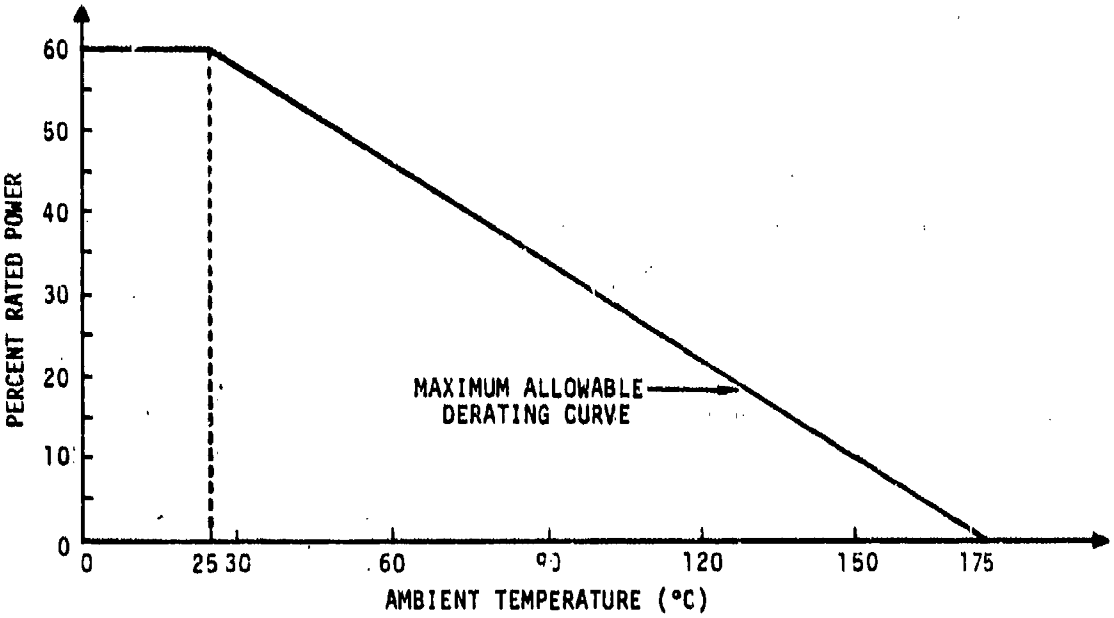


FIGURE 100.19

DERATING REQUIREMENTS FOR STYLES RWR 78, 80, 81, 82, 84, 89

103.4.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

103.5 MIL-R-39017, RESISTORS, FIXED, FILM (INSULATED), ESTABLISHED RELIABILITY, (STYLE RLR)

103.5.1 APPLICATION CONSIDERATIONS

103.5.1.1 Resistance Tolerance

These resistors are recommended for use where very close tolerances are not required, and where the composition type resistors do not provide the needed accuracy or stability. Regardless of the purchase tolerance (i.e., ± 1 percent or ± 2 percent), the design should tolerate an additional ± 5 percent shift in resistance value to assure long life reliability in military applications.

103.5.1.2 Operating Frequency

These resistors perform well in high frequency applications (up to about 100 MHz). The frequency characeristics are as shown in Figure 100.20.

103.5.1.3 Noise

The noise generated by these resistors is small.

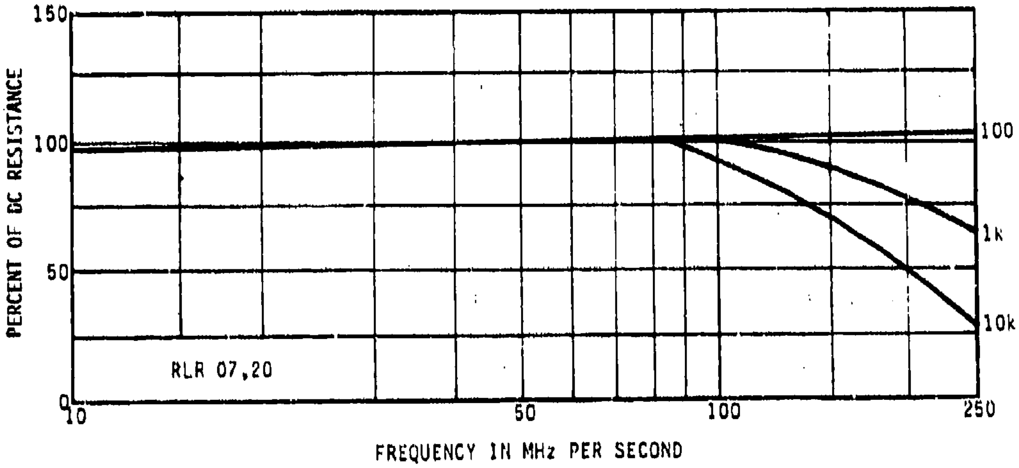


FIGURE 100.20

RESPONSE CURVE

103.5.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.21.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.21.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39017).

(3) Care shall be taken to insure that the instantaneous peak resistor body temperature shall not exceed 130°C.

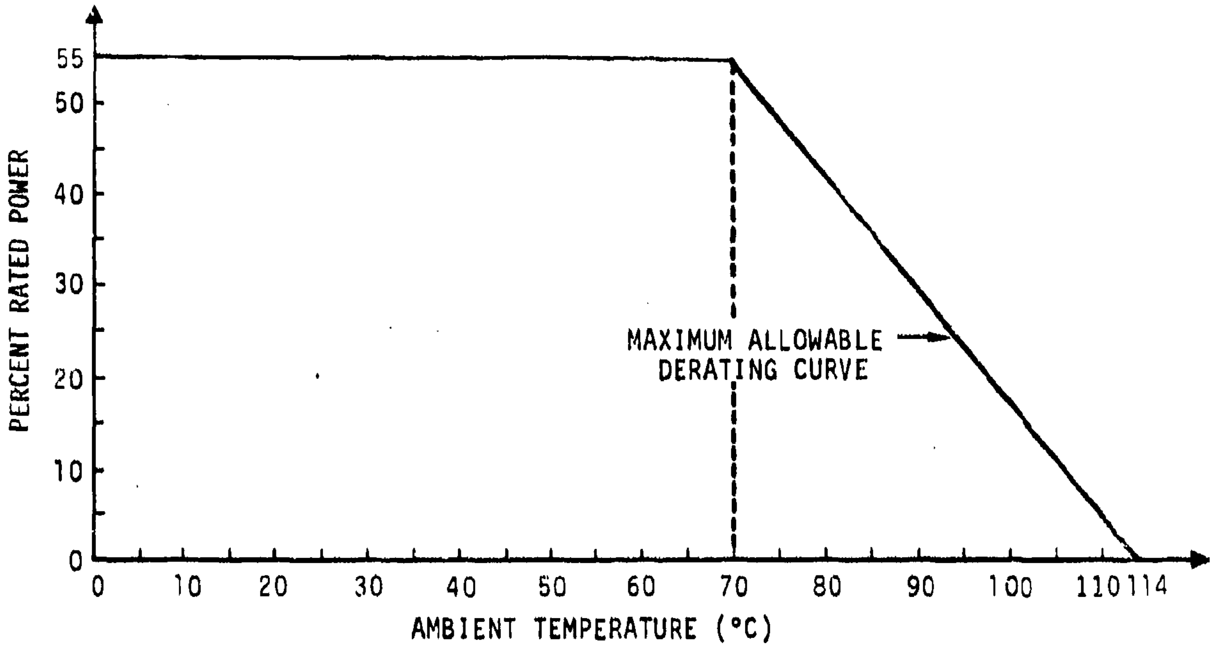


FIGURE 100.21

DERATING REQUIREMENTS FOR STYLES RLR 05, 07, 20, 32

103.5.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

103.6 MIL-R-39009, RESISTORS, FIXED, WIREWOUND (POWER TYPE, CHASSIS MOUNTED), ESTABLISHED RELIABILITY, (STYLE RER)

103.6.1 APPLICATION CONSIDERATIONS

103.6.1.1 Resistance Tolerance

Only one tolerance range (± 1 percent) is available. The temperature stability is very good (± 30 ppm/°C for values of 20 Ω or higher). The design should tolerate a ± 1.5 percent shift in resistance value to assure long life reliability in military applications.

103.6.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.22.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.22.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-39009).

(3) Care shall be taken to ensure that the instantaneous peak resistor body temperature shall not exceed 210°C.

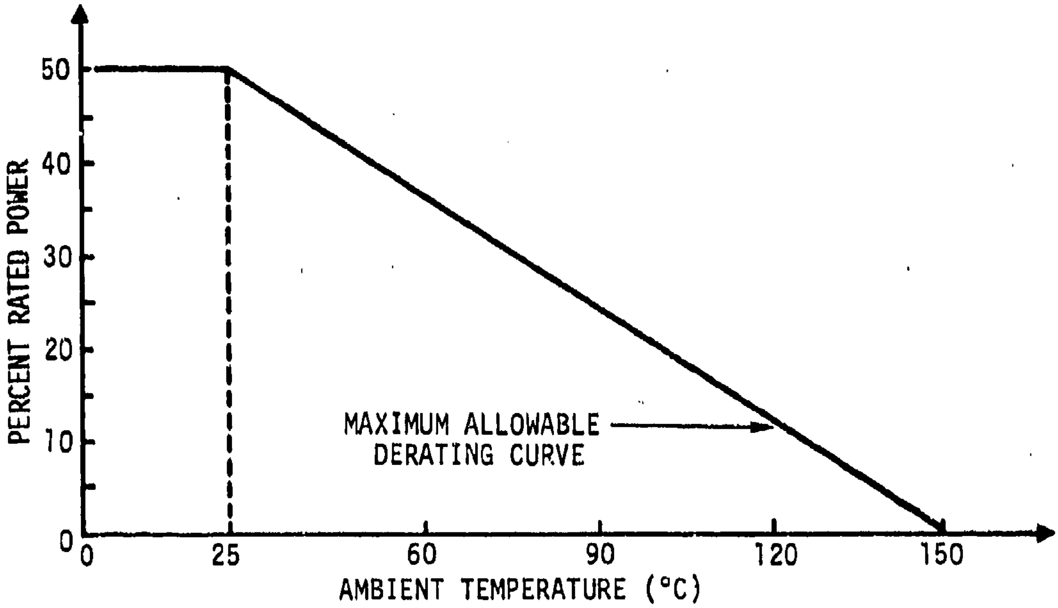


FIGURE 100.22

DERATING REQUIREMENTS FOR STYLES RER 40, 45, 50, 55, 60, 65, 70, 75

106.3.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

103.7 MIL-R-55342, RESISTORS, FIXED, FILM, CHIP, ESTABLISHED RELIABILITY, (STYLE RM)

103.7.1 APPLICATION CONSIDERATIONS

103.7.1.1 Use

These chip resistors are intended to be used in thin or thick film hybrid circuitry where micro circuitry is indicated.

103.7.1.2 Mounting

These resistors may be mounted individually on a substrate, usually 95 percent alumina, and connected to conductor areas by means of solder pre-forms, conductive cement, or wire bonding. They can also be directly connected to other components on the same substrate by means of wire bonding, using the substrate as a base or carrier for the resistor.

103.7.1.3 Stacking of Resistors

Stacking of resistors shall be avoided, since experience has shown that failure can occur due to electrolytic action in the bonding adhesive. When stacking the resistors, care shall be taken to compensate for the lower heat dissipation capabilities by properly derating the wattage rating. Stacking of resistors requires procuring activity approval.

103.7.1.4 Electrostatic Damage Sensitivity

Most types of film devices are found to be affected by electrostatic discharge (ESD).

103.7.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.23.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.23.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-55342).

(3) Care shall be taken to ensure that the instantaneous peak resistor body temperature does not exceed 110°C.

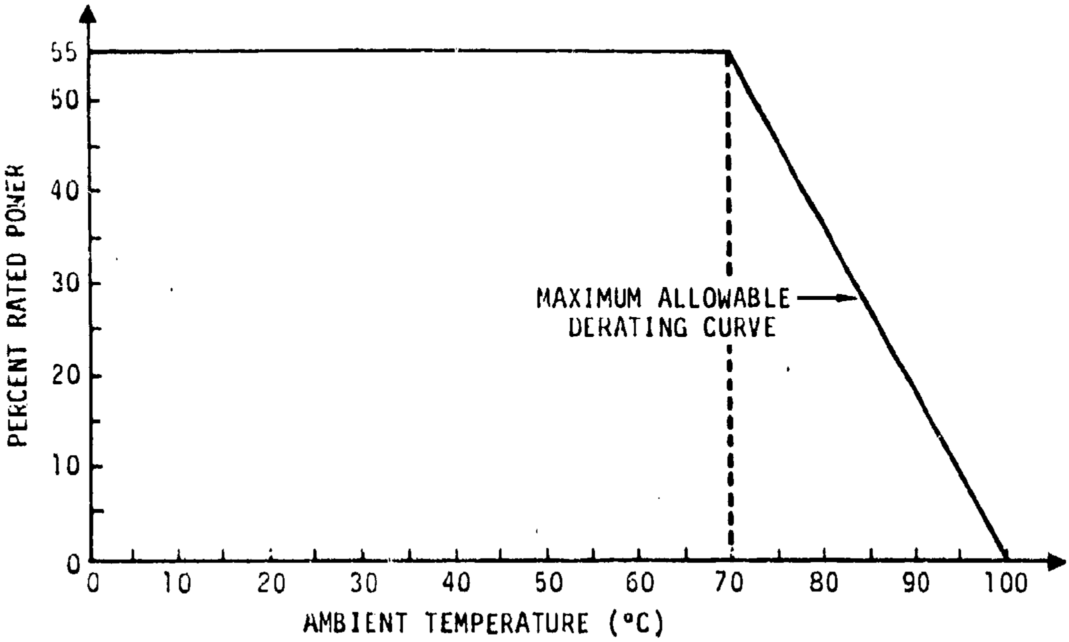


FIGURE 100.23

DERATING REQUIREMENTS FOR STYLES RMO 502, 505, 705 AND RM 1005, 1505, 2208

103.7.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

104 RESISTORS, VARIABLE, ESTABLISHED RELIABILITY

104.1 MIL-R-39015, RESISTORS, VARIABLE, WIREWOUND (LEAD SCREW ACTUATED), ESTABLISHED RELIABILITY, (STYLE RTR)

104.1.1 APPLICATION CONSIDERATIONS

104.1.1.1 Selection of a Safe Resistor Style

The wattage ratings of these resistors are based on operation at 85°C when mounted on a 1/16 inch thick, glass base, epoxy laminate. Therefore, the heat sink effect as provided by steel test plates in other specifications is not present. The wattage rating is applicable when the entire resistance element is engaged in the circuit. When only a portion is engaged, the wattage is reduced directly in the same proportion as the resistance.

104.1.1.2 Bushing

Type S bushings shall be used whenever possible to assure longer life.

104.1.1.3 Mounting

Resistors with terminal Type L should not be mounted by their flexible wire leads. Mounting hardware should be used. Printed-circuit types are frequently terminal mounted, although brackets may be necessary for a high-shock and vibration environment.

104.1.1.4 Environmental Conditions

Special care should be taken when using these resistors in highly humid conditions, since high humidity can cause turn-to-turn shorts. It is better to avoid the use of these resistors in high humidity environments.

104.1.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.24.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

CAUTION: REDUCE THE MAXIMUM ALLOWABLE DERATING CURVE IF THE ENTIRE ELEMENT IS NOT USED. SEE PARAGRAPH 104.1.1.1.

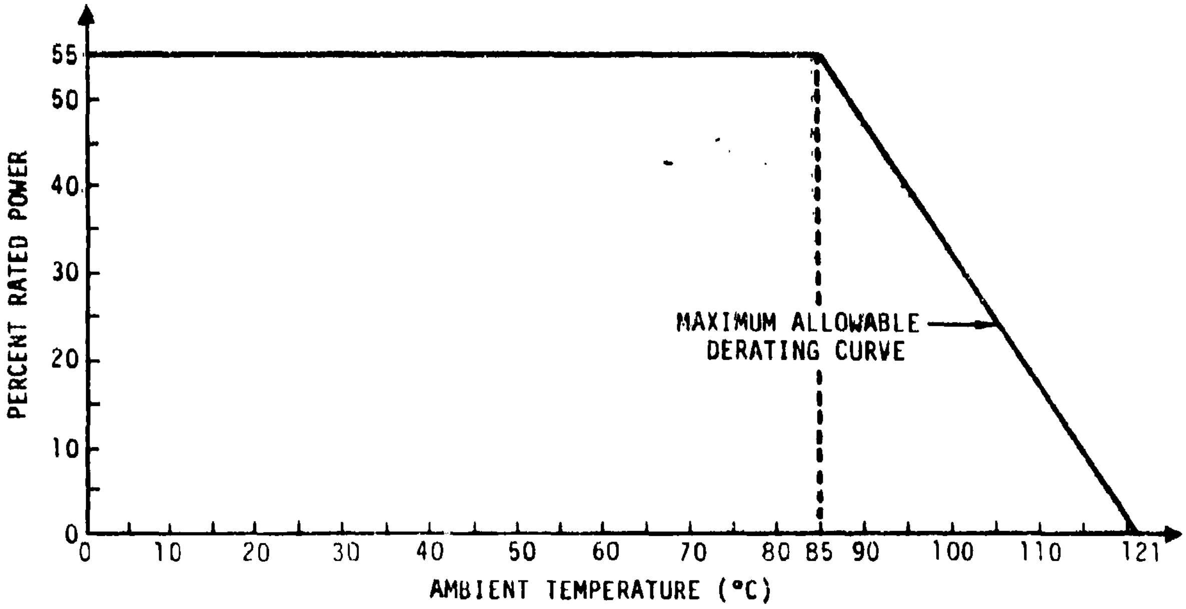


FIGURE 100.24

DERATING REQUIREMENTS FOR STYLES RTR 12, 22, 24

104.1.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

104.2 MIL-R-39035, RESISTORS, VARIABLE, NONWIREWOUND (LEAD-SCREW ACTUATED), ESTABLISHED RELIABILITY, (STYLE RJR)

104.2.1 APPLICATION CONSIDERATIONS

104.2.1.1 Tolerance

These resistors have a resistance tolerance of ± 10 percent. Regardless of the purchase tolerance, the design should be able to tolerate a ± 10 percent shift in resistance value to assure long life reliability in military applications.

104.2.1.2 Resolution

The resolution of style RJR resistors is very high (essentially infinite).

104.2.1.3 Noise

The noise level is not controlled by the resistor specification but it is normally relatively low.

104.2.1.4 Selection of Safe Resistors

The wattage ratings of these resistors are based on operation at 85°C when mounted on a 1/16 inch thick, glass base, epoxy laminate. Therefore, the heat sink effect as provided by steel test plates in other specifications is not present. The wattage rating is applicable when the entire resistance element is engaged in the circuit. When only a portion is engaged, the wattage is reduced directly in the same proportion as the resistance.

104.2.1.5 Bushing

A type S bushing shall be used whenever possible for longer life.

104.2.1.6 Secondary Insulation

Where voltages higher than 250 volts rms are present between the resistor circuit and grounded surface on which the resistor is mounted, or where the dc resistance is so high that the insulation resistance to the ground is an important factor, secondary insulation to withstand the conditions should be provided between the resistor and the mounting or between the mounting and ground.

104.2.1.7 Resistor Mounting

Resistors with terminal Type L should not be mounted by their flexible wire leads. Mounting hardware should be used. Printed-circuit types are frequently terminal mounted, although brackets may be necessary for a high-shock and vibration environment.

104.2.1.8 Variation

The contact resistance variation should not exceed 3 percent or 20 ohms for characteristic C, and 3 percent or 3 ohms for characteristics F and H, whichever is greater.

104.2.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.25.

b. Pulse condition - This resistor is not suitable for pulsed circuits.

CAUTION: REDUCE THE MAXIMUM ALLOWABLE DERATING CURVE IF THE ENTIRE ELEMENT IS NOT USED. SEE PARAGRAPH 104.2.1.4.

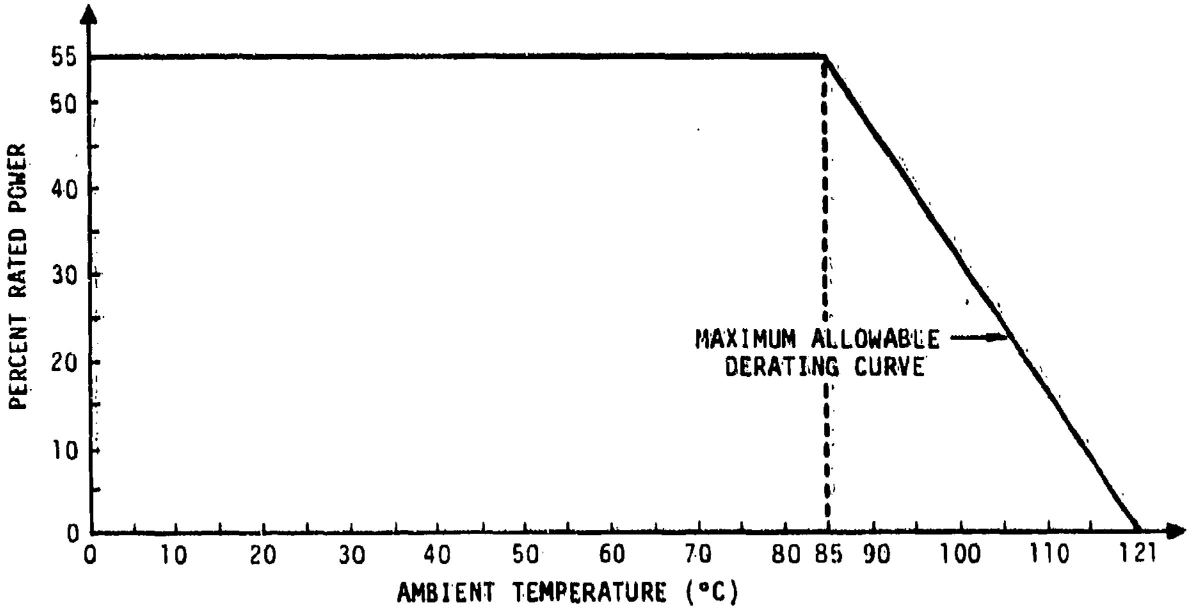


FIGURE 100.25

DERATING REQUIREMENTS FOR STYLES RJR 12, 24, 26, 28, 32, 50

104.2.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

105 SPECIAL

105.1 MIL-R-83401, RESISTOR NETWORKS, FIXED, FILM, (STYLE RZ)

105.1.1 APPLICATION CONSIDERATIONS

The RZ style resistors are in a resistor network configuration having a film resistance element and in a DIP or flat pack configuration. These resistors are stable with respect to time, temperature and humidity and are capable of full load operation at an ambient temperature up to 70°C after which they are derated to zero power at 125°C.

105.1.1.1 Use

These resistors are designed for use in critical circuitry where stability, long life, reliable operation and accuracy are of prime importance. They are particularly desirable for use where miniaturization is important. They are also useful where a number of resistors of the same resistance values are required in the circuit.

105.1.1.2 Operating Frequency

When used in high frequency circuits (200 MHz and above), the effective resistance will be reduced as a result of shunt capacity between resistance elements and connecting circuits. The high frequency characteristics of these networks are not controlled by specification.

105.1.1.3 Noise

The noise output is not controlled by specification, but it is typically very low for these resistors.

105.1.1.4 Resistance Tolerance

Operation of these resistor networks under military ambient conditions could cause permanent or temporary changes in resistance sufficient to exceed their initial tolerances. In particular, operation at extremely high or low ambient temperatures cause significant temporary changes in resistance. Care should be taken to assure that the circuit design will tolerate these changes.

105.1.1.5 Mounting

Under severe shock or vibration conditions (or a combination of both), the resistor network should be restrained from movement with respect to the mounting base. If clamps are used, certain electrical characteristics can be altered. The heat dissipating qualities will be enhanced or retarded depending on whether the clamping material is a good or poor conductor of heat. This phenomenon should be given due consideration.

105.1.1.6 Electrostatic Susceptibility

Most film resistors are found to be susceptible to electrostatic damage.

105.1.2 DERATING REQUIREMENTS

a. Steady-state conditions - When using these resistors under steady-state power conditions, derate according to the maximum allowable derating curve for power as shown in Figure 100.26.

b. Pulse conditions - When using these resistors under pulsed conditions, the following three conditions shall be met.

(1) The average power shall be less than or equal to the maximum allowable derating curve for power as shown in Figure 100.26.

(2) The peak voltage shall not exceed 70 percent of the dielectric breakdown voltage or the maximum short-time overload voltage, whichever is less as specified by the appropriate resistor military specification (MIL-R-83401).

(3) Care shall be taken to ensure that the instantaneous peak resistor body temperature does not exceed 110°C.

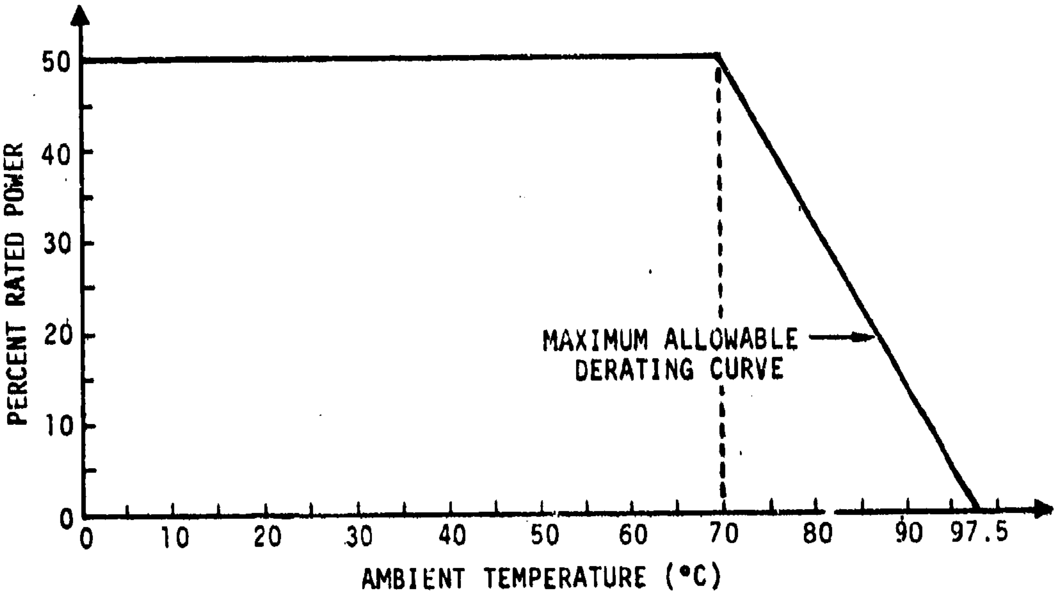


FIGURE 100.26

DERATING REQUIREMENTS FOR STYLES RZ 010, 020, 040, 050

SECTION 200

CAPACITORS

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200 CAPACITORS, GENERAL

200.1 GENERAL INFORMATION

Standard capacitors are specified in MIL-STD-198. This standard presents detailed data for use in the design of military equipment. Data is presented on terminology, capacitor selection, environmental effects on characteristics and life, applications, application data, failure rates and aging curves. In addition, detailed design data are presented for each capacitor type.

Capacitors can be broadly categorized into the following types according to the dielectric material used:

a. Ceramic dielectric
b. Glass dielectric
c. Aluminum dielectric
d. Solid tantalum dielectric
e. Non-solid tantalum dielectric
f. Mica dielectric
g. Paper, paper-plastic or plastic dielectric
h. Film; paper-plastic or plastic dielectric

200.2 APPLICATION CONSIDERATIONS

200.2.1 DIELECTRIC VERSUS VOLUME

In electrolytic capacitors, the dielectric is an almost negligible part of the volume of the capacitor. In other capacitors, such as mica, plastic, ceramic, and glass dielectrics, the dielectric comprises nearly the entire volume of the capacitor element. Theoretically, then, for all capacitors except electrolytic, where almost the entire volume of the unit (v) is an active dielectric, the volume (v) is directly proportional to CV^2 (where C is the capacitance and V is the maximum voltage rating). The proportionality constant depends on the dielectric constant of the material, its dielectric strength, and the life expected of the capacitors. For the electrolytic types, the volume has been found empirically to vary more nearly with CV than CV^2.

200.2.2 COMMERCIAL CAPACITORS

Conclusions can be made concerning the reliability expected from commercial capacitors by comparing them with similar military capacitors of the same dielectric and capacitance. The commercial unit is a short-life, less reliable part. Therefore, only military capacitors with an ER quality level "P" or higher shall be used without approval of the procuring activity.

200.2.3 VOLTAGE RATING AND LIFE

Since the catastrophic failure of capacitors is usually caused by dielectric failure, voltage ratings of non-electrolytic capacitors are based on a given life expectancy at a maximum ambient temperature and voltage stress. Dielectric failure is typically a chemical effect, and for well-sealed units, where atmospheric contamination of the dielectric does not contribute, is a function of time, temperature, and voltage. The time-temperature relationship affects the chemical activity or rate of degradation; that is, degradation proceeds at a doubled rate for each 10°C rise in temperature (e.g., a capacitor operating at 100°C will have half the life of a similar one operating at 90°C). Extensive studies have been made of certain organic dielectrics where it has been found that the deterioration is proportional to V^5 (fifth power of the voltage). For example, a capacitor operating at 20 Volts will last 32 times as long as a similar one operating at 40 Volts. The 10°C rule, of course, is applicable only over a temperature range where no significant changes of state occur to affect the dielectric. That is, no freezing, melting, boiling, condensing, loss or gain of water, crystallization or other change in stable crystal structure. The V^5 rule is also subject to modification by consideration that the dielectric will puncture suddenly if some particular voltage stress is exceeded, and that there are other electric fields (notably around the edges of the dielectric extending beyond the conducting plates) where breakdown can occur without failure of the principal dielectric.

200.2.4 RELIABILITY

Figure 200.1 represents a comparison of the predicted part operating failure rates for established reliability (ER) capacitors. The part operating failure rates shown are developed from the part operating failure rate models from MIL-HDBK-217D. The part operating failure rates are representative of a given military environmental condition and stress level and are not necessarily in the same proportion for other environments or operating conditions.

200.2.5 OPERATING FREQUENCY

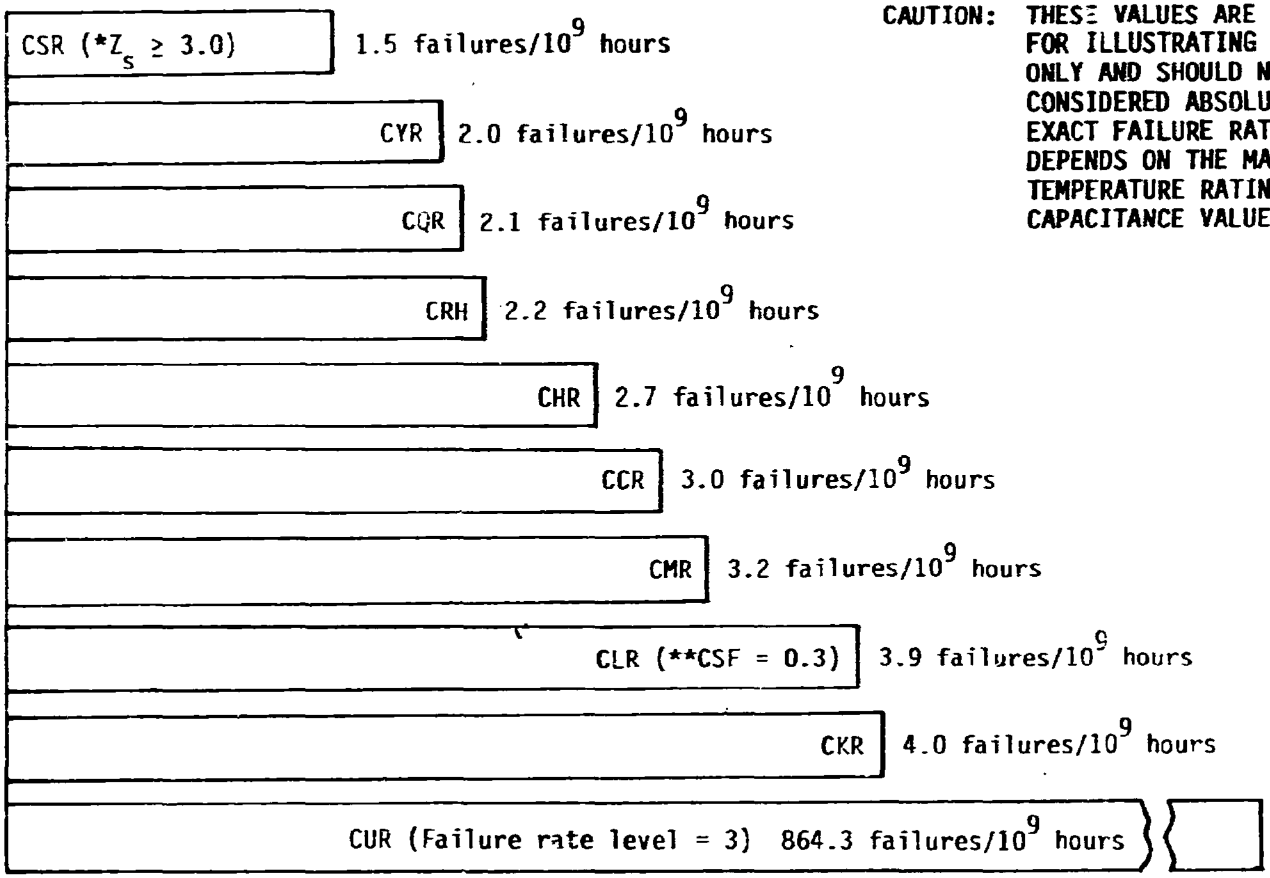
All capacitors have some operating frequency limitations due to the nature of the dielectric and other construction features. Figure 200.2 shows the operating frequency ranges for common types of capacitors except electrolytic. The frequency range for electrolytics is not readily described in this manner, because the effective capacitance of these type parts involves a complex relationship of voltage rating, case size, nominal capacitance value, and operating frequency.

200.2.6 CAPACITOR SELECTION FACTORS

Factors to be considered in capacitor selection are:

- Temperature
- Humidity
- Barometric pressure
- Applied voltage
  - Alternating/ripple current
  - Frequency
  - Dissipation factor
  - Equivalent series resistance
  - Reverse voltage levels

CAUTION: THESE VALUES ARE GIVEN FOR ILLUSTRATING PURPOSES ONLY AND SHOULD NOT BE CONSIDERED ABSOLUTE. THE EXACT FAILURE RATE DEPENDS ON THE MAXIMUM TEMPERATURE RATING AND CAPACITANCE VALUE.



***T_{MAX} = 125°C for these sample failure rates.

FIGURE 200.1

RELATIVE PART OPERATING FAILURE RATES FOR ESTABLISHED RELIABILITY CAPACITORS

ESTABLISHMENT OF PART OPERATING FAILURE RATES:

1. MIL-HDBK-217D part operating failure rate models; 2. Stress level (S) = 0.4; 3. Ambient temperature (T_A) = 70°C; 4. Naval Sheltered (N_S) environment; 5. Failure rate level = P; 6. Capacitance factor = 1.0;

* Z_S = Circuit series resistance in (ohms/applied volt)
** CSF = Construction factor
*** T_{MAX} = Maximum operating ambient temperature (°C)

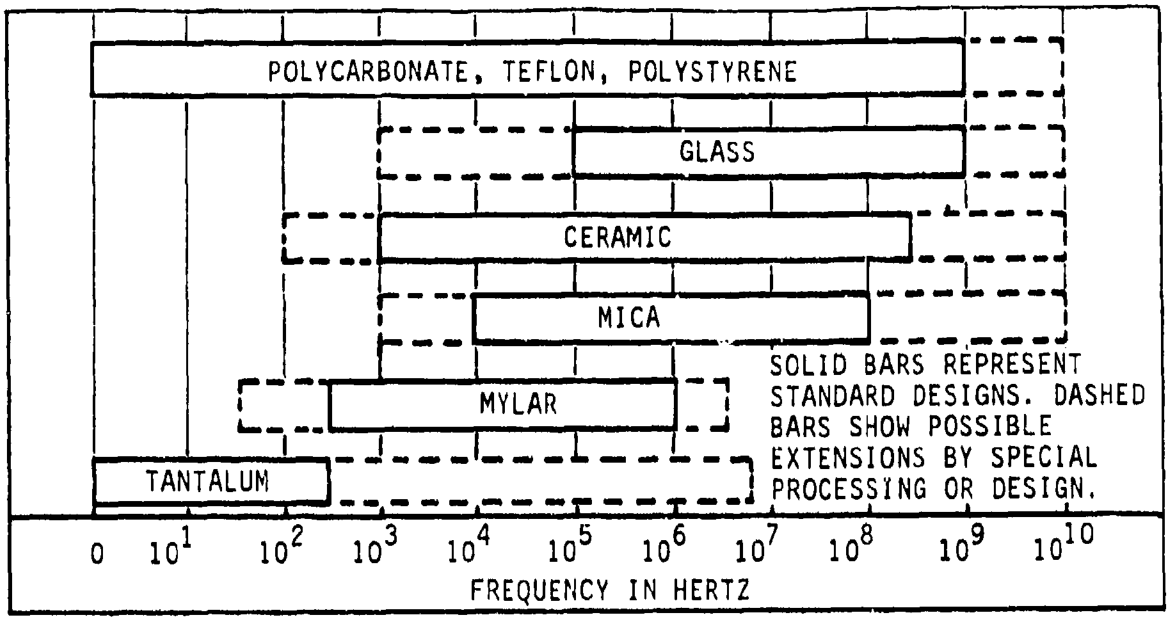


FIGURE 200.2

OPERATING FREQUENCY LIMITS OF CAPACITORS

- o Vibration
- o Current
- o Life
- o Stability
- o Retrace
- o Size
- o Volume
- o Mounting method
- o Cost

200.3 CAPACITOR PART TYPES

General information and derating requirements on capacitors are listed herein.

201 CAPACITORS, CERAMIC DIELECTRIC

201.1 APPLICATION CONSIDERATIONS

201.1.1 TEMPERATURE COMPENSATION APPLICATION

These capacitors are primarily used for compensation of reactive changes caused by temperature variations in other circuit parts and in precision type circuits where their characteristics are suitable. Ceramic capacitors are substantially smaller than paper or mica units of the same capacitance and voltage rating. They have tighter capacitance tolerances than mica or paper capacitors and their lead construction is highly suitable for printed-circuit use.

These units can be used to compensate frequency drift in radio frequency, oscillator, and intermediate frequency (IF) circuits caused by temperature variations. In IF stages where the frequency variation is uniform, satisfactory operation can be obtained by designing the temperature-compensating capacitor into the oscillator circuit. RF circuit reactive changes caused by temperature variations cannot be compensated for in the oscillator circuit; in these cases where most critical tuning accuracy is required, it is necessary that compensating capacitors be inserted directly into each circuit.

In RF circuits tuned by a variable capacitor, a shunt compensating capacitor of low value and high compensating characteristics can be used. In slug-tuned circuits, the total capacitance required can be provided by using a compensating capacitor having the desired temperature coefficient. In oscillator circuits, more linear tuning can be obtained by selecting capacitors with the proper temperature coefficients in both the series and the shunt capacitances of the tank circuit.

201.1.2 INSULATION RESISTANCE

The high insulation resistance of these capacitors is well suited to coupling applications between plate and grid circuits of electron tubes. Extremely low leakage and small physical size make them suitable for transistor circuit design. They are also used in filter and by-pass circuits.

201.1.3 TEMPERATURE COMPENSATION OF COILS

The temperature-time curve of the selected capacitor should be the exact opposite of the temperature-time curve of the coil or other part being compensated. Combinations of different capacitance values and temperature coefficients can give more precise compensation than can be obtained from a single capacitor. Full consideration should be given to the physical placement of compensating capacitors. Locations near hot operating parts could affect the designed-in circuit temperature compensation.

201.1.4 CAPACITANCE TO SIZE RATIO

These capacitors have the largest capacitance to size ratios of all high resistance dielectric capacitors.

201.1.5 CAPACITANCE VARIATION

Capacitance changes with variation in voltage, frequency, age and temperature should be determined from the detailed specifications.

201.1.6 HUMID OPERATING CONDITIONS

Ceramic materials are non-hygroscopic, effectively impermeable and have practically no moisture absorption even after considerable exposure to highly humid conditions. These capacitors are intended to operate, through their full temperature range, at relative humidities up to 95 percent. However, the terminal materials under high moisture conditions can be subject to ionic migration which can cause capacitor failure.

201.1.7 AC OPERATION

When ac operation is required, the peak ac voltage plus any dc bias shall not exceed the derated values established by the derating requirements.

201.1.8 MOUNTING

These capacitors are used to compensate circuit performance for temperature variations. Therefore, they should be mounted in close proximity to the part (or parts) they are intended to compensate, and isolated from parts that dissipate local heat. Otherwise thermal gradients will defeat the designed-in compensation capability.

201.1.9 FREQUENCY CONSIDERATIONS

Since the ceramic dielectric used is frequency sensitive, both capacitance and capacitance change with temperature will be different at different measuring frequencies. For extremely accurate compensation, the compensation characteristics should be measured at the proposed operating frequency.

201.1.10 DERATING FACTORS

Due to the low capacitive reactance, at high frequencies and with high capacitances, the continuous duty current will usually be reached at a voltage below the maximum rated voltage. Similarly, due to the high capacitive reactance at low frequencies and with low capacitances, the maximum voltage will often be reached before the rated current. Necessary care shall be taken to ensure that neither the current nor the voltage exceed the derated value established by the derating requirements specified for each capacitor type.

201.2 MIL-C-20, CAPACITORS, FIXED, CERAMIC DIELECTRIC (TEMPERATURE COMPENSATING), ESTABLISHED RELIABILITY, (STYLE CCR)

201.2.1 APPLICATION CONSIDERATIONS

201.2.1.1 Capacitance Tolerance

These capacitors come in tolerances of ±0.1 pf, ±.25 pf, ±.5 pf, ±1 percent, ±2 percent, ±5 percent, and ±10 percent. However, regardless of the purchase tolerance, the design should tolerate a ±1 percent absolute change in capacitance value to assure long life reliability in military applications. The temperature characteristics, however, are expected to remain virtually unchanged throughout the life of the capacitor.

201.2.1.2 Dielectric Strength

Where the capacitor body will normally contact parts with a potential difference of more than 750 volts, supplementary insulation shall be used.

201.2.1.3 Temperature Coefficient

These capacitors exhibit zero and negative temperature coefficients which can be used for temperature compensation.

201.2.1.4 Operating Frequency

These capacitors are suitable for operating frequencies ranging from 1 kHz to 300 MHz.

201.2.2 DERATING REQUIREMENTS FOR STYLES CCR 05, 06, 07, 08, 75, 76, 77, 78

The voltage shall be derated according to the derating curve shown in Figure 200.3. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.3.

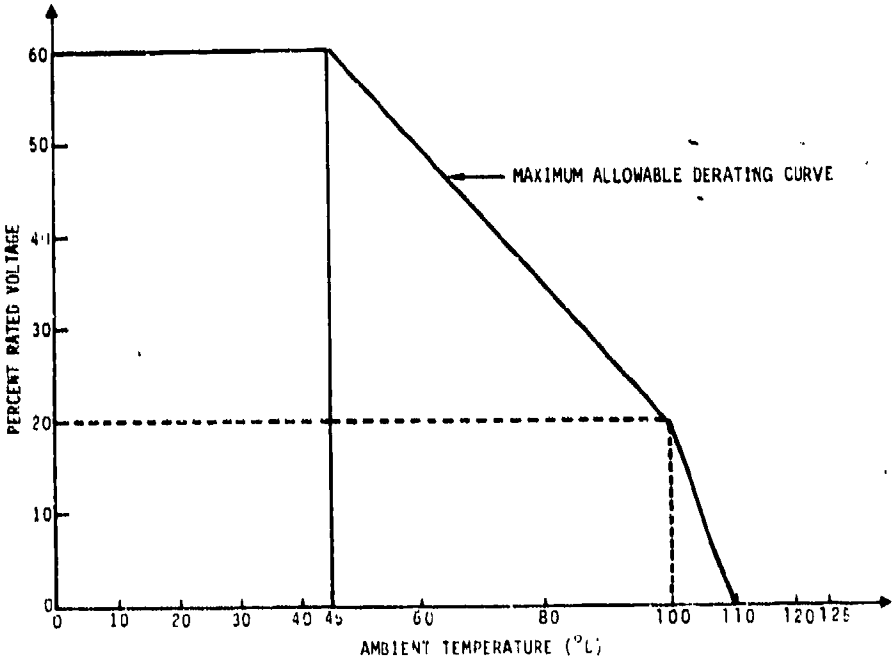


FIGURE 200.3

DERATING REQUIREMENTS FOR STYLES CCR 05, 06, 07, 08, 75, 76, 77, 78

201.2.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

201.3 MIL-C-11015, CAPACITORS, FIXED, CERAMIC DIELECTRIC (GENERAL PURPOSE), (STYLE CK)

AND

MIL-C-39014, CAPACITORS, FIXED, CERAMIC (GENERAL PURPOSE), ESTABLISHED RELIABILITY, (STYLE CKR)

201.3.1 APPLICATION CONSIDERATIONS

These capacitors are primarily designed for use where a small physical size with comparatively large electrical capacitance and high insulation resistance are required. Because of the cumulative effects of temperature, applied voltage, and aging, these capacitors are recommended for use only where broad variations in capacitance value can be tolerated. The dielectric constant usually decreases with increases in age, frequency, and temperature.

201.3.1.1 Humid Operating Conditions

Ceramic dielectric materials are nonhygroscopic, effectively impermeable, and have practically no moisture absorption even after considerable exposure to humid conditions. Thus, these units are intended to operate, through their full temperature range, at relative humidities up to 95 percent.

201.3.1.2 Soldering

Care should be used in soldering the leads. Excessive heat may damage the encapsulation and weaken the electrode to terminal lead contact. Sudden changes in temperature, such as those experienced in soldering, can crack the encapsulation or the ceramic dielectric. Leads should not be bent close to the case nor should any strain be imposed on the capacitor body to avoid fracturing the encapsulation or ceramic dielectric.

201.3.1.3 Capacitance Tolerance

These capacitors are available with initial tolerances of ±10 percent or ±20 percent. However, regardless of the purchase tolerance, the design should tolerate a ±20 percent change in capacitance value to assure long life reliability in military applications.

201.3.1.4 Operating Frequency

These capacitors are suitable for use as by-pass, filter, and non-critical coupling elements in high frequency circuits, with the typical operating frequency ranging from 1 kHz to 300 MHz.

201.3.2 DERATING REQUIREMENTS FOR STYLES CK 60, 62-70, 80

The voltage shall be derated according to the derating curve shown in Figure 200.4. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.4. These derating requirements only apply to those capacitors having a rated temperature range of -55°C to +85°C.

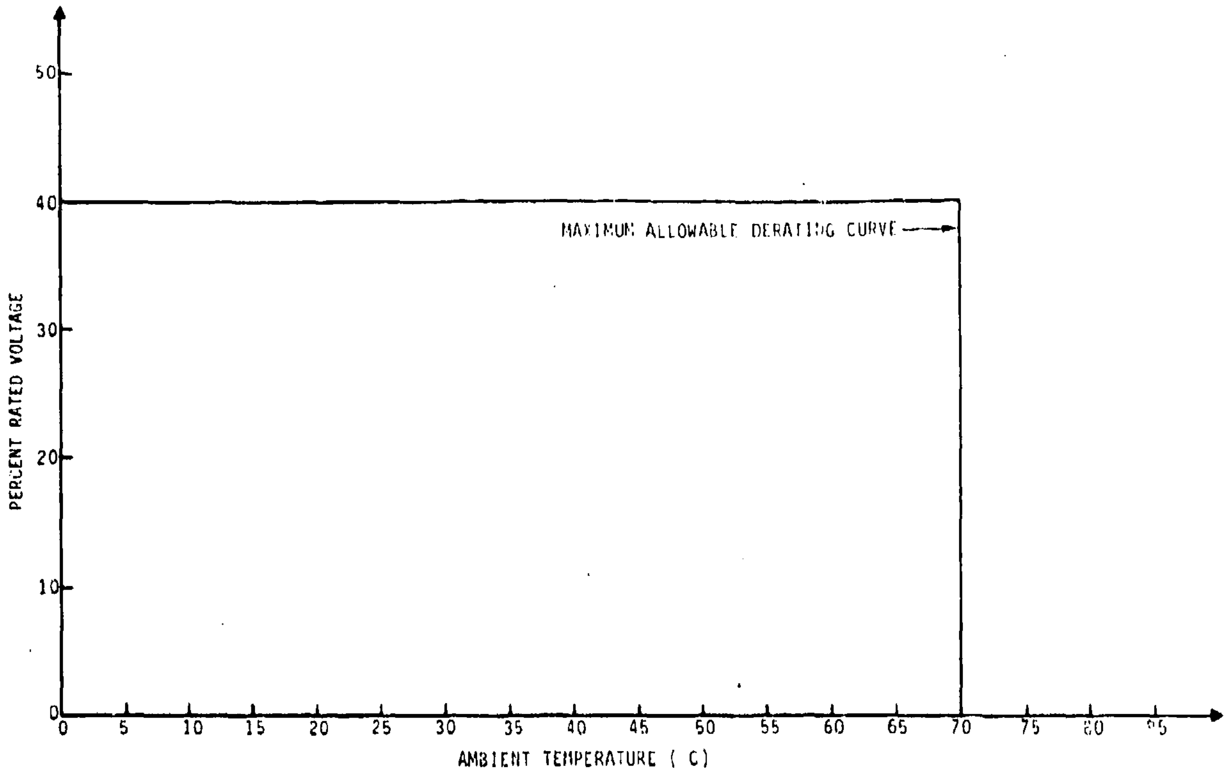


FIGURE 200.4

DERATING REQUIREMENTS FOR STYLES CK 60, 62-70, 80
WITH A RATED TEMPERATURE TO 85°C

201.3.3 DERATING REQUIREMENTS FOR STYLES CK 60, 62 AND CKR 05, 06, 11, 12, 14, 15

The voltage shall be derated according to the derating curve shown in Figure 200.5. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.5. These derating requirements only apply to those capacitors having a rated temperature range of -55°C to +125°C.

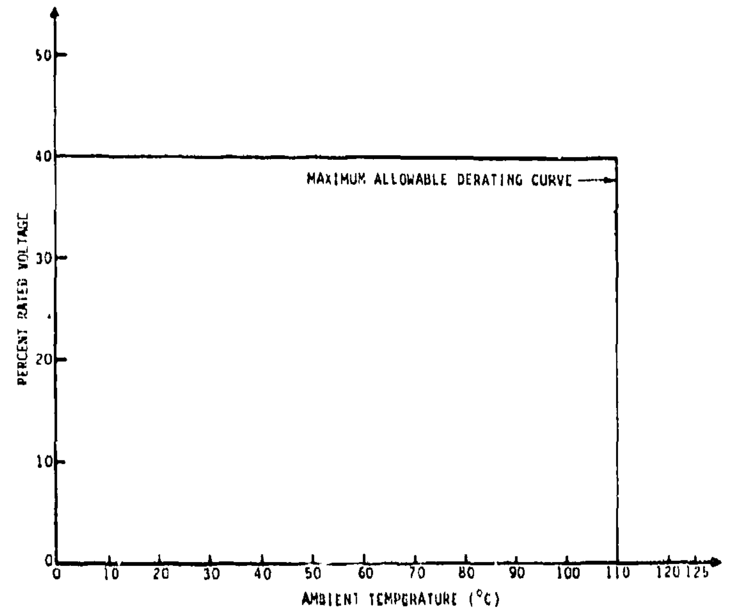


FIGURE 200.5

DERATING REQUIREMENTS FOR STYLES CK 60, 62 AND CKR 05, 06, 11, 12, 14, 15
WITH A RATED TEMPERATURE TO 125°C

201.3.4 DERATING REQUIREMENTS FOR STYLE CK63

The voltage shall be derated according to the derating curve shown in Figure 200.6. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.6. These derating requirements only apply to those capacitors having a rated temperature range of -55°C to +150°C.

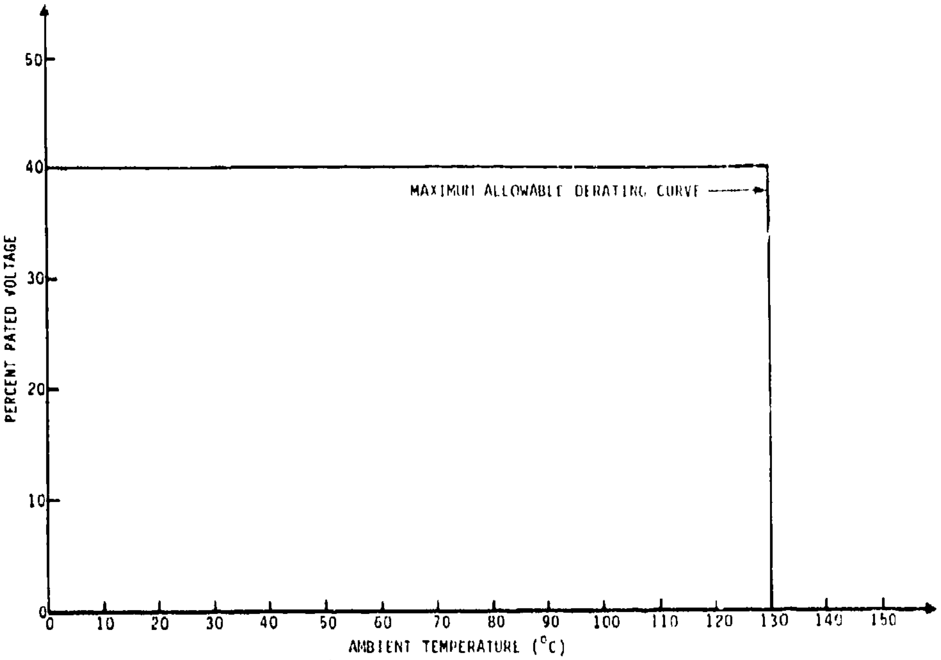


FIGURE 200.6

DERATING REQUIREMENTS FOR STYLE CK63
WITH A RATED TEMPERATURE TO 150°C

201.3.5 QUALITY LEVEL

Only ER level "P" or higher shall be used.

201.4 MIL-C-81, CAPACITORS, VARIABLE, CERAMIC DIELECTRIC, (STYLE CV)

201.4.1 APPLICATION CONSIDERATIONS

These capacitors are small-sized trimmer capacitors. They can be used for fine tuning, trimming, and coupling in such circuits as intermediate frequency, radio frequency, oscillator, phase shifter, and discriminator stages.

201.4.1.1 Temperature-Capacitance Characteristics

Changes in nominal capacitance from the values measured at +25°C may vary from -4.5 percent to +14 percent at -55°C or -10 percent to +2 percent at +85°C when measurements are made: (1) after the capacitors have reached thermal stability; (2) at a frequency range of 0.1 to 0.2 MHz and with the capacitor charged from 80 to 90 percent of maximum capacity.

201.4.1.2 Drift With Age

The capacitance drift over time is within 0.5 pf.

201.4.1.3 Mounting

These capacitors may be mounted close to a metal panel with little increase in capacitance. To avoid cracking or chipping of the ceramic mounting base, a resilient mounting (or mounting surface spacer) should be used.

201.4.1.4 Stability

Even though these capacitors are relatively stable against shock and vibration, air trimmers, due to their low mass, should be used where higher order or stability is required.

201.4.1.5 Temperature Sensitivity

These capacitors should not be designed into circuits as temperature compensating units since the temperature sensitivity is non-linear over the capacitance range and varies greatly between units.

201.4.2 DERATING REQUIREMENTS FOR STYLES CV 11, 21, 31

The voltage shall be derated according to the derating curve shown in Figure 200.7. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.7.

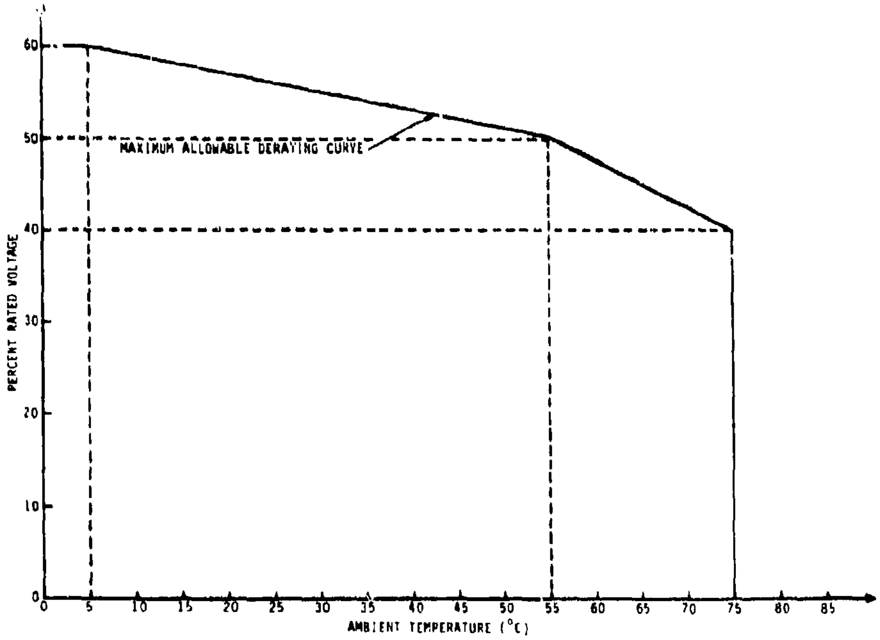


FIGURE 200.7

DERATING REQUIREMENTS FOR STYLES CV 11, 21, 31

202 CAPACITORS, GAS OR VACUUM DIELECTRIC

202.1 MIL-C-23183, CAPACITORS, VARIABLE, GAS OR VACCUM DIELECTRIC, CERAMIC ENVELOPE, (STYLE CG)

202.1.1 APPLICATION CONSIDERATIONS

202.1.1.1 Voltage Rating

The voltage rating is the 60 Hz test voltage, at maximum capacity. This is the absolute maximum voltage the unit can withstand before breakdown occurs. The breakdown voltage is greater at capacities less than maximum, becoming as much as 300 percent greater at minimum capacity for lower voltage units. The breakdown voltage at radio frequencies is the same as for low frequencies up to about 2.5 MHz, and becomes about 10 percent lower at 30 MHz. The continuous duty operating voltage is lower for higher frequencies. The continuous RF rating of a vacuum capacitor is arbitrarily defined as that voltage and current that will raise the temperature to a steady 85°C without cooling apparatus. This rating can be increased by additional cooling such as blowers, heat sinks, or water cooling.

202.1.1.2 Use of Large Conductors

When using large conductors for better heat dissipation, care should be taken to avoid excessive mechanical loading by these conductors.

202.1.2 DERATING REQUIREMENTS FOR STYLE CG60

The voltage shall be derated according to the derating curve shown in Figure 200.8. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.8.

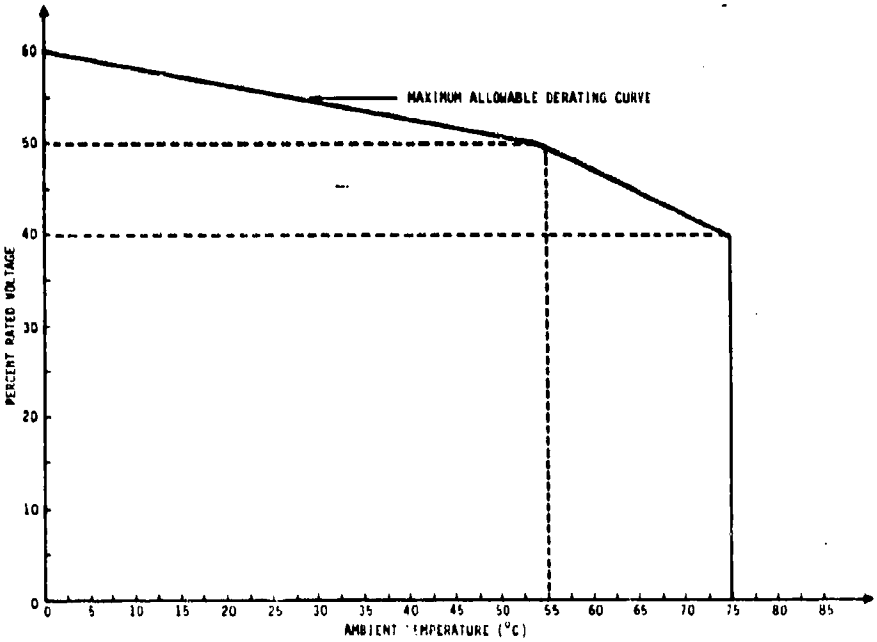


FIGURE 200.8

DERATING REQUIREMENTS FOR STYLE CG60

203 CAPACITORS, GLASS DIELECTRIC

203.1 MIL-C-14409, CAPACITORS, VARIABLE (PISTON TYPE, TUBULAR TRIMMER), (STYLE PC)

203.1.1 APPLICATION CONSIDERATIONS

These capacitors are small-sized, sealed, tubular trimmer, variable capacitors designed for fine tuning adjustments. They are normally used for trimming and coupling in such circuits as intermediate frequency, radio frequency, oscillator, phase shifter, and discriminator stages.

203.1.1.1 Stability

Because of their low mass, these capacitors are relatively stable against shock and vibration.

203.1.1.2 Linearity and Backlash

The capacitance change is linear with respect to rotation within +10 percent. Backlash is virtually non-existent except on Styles PC39 and PC43 which can have a backlash of 2 percent.

203.1.1.3 Torque

For styles PC25 and PC26 capacitors, the driving torque is between 0.5 and 6.0 ounce-inches throughout the temperature range (-55°C to +125°C); and 1 to 10 ounce-inches at all other temperatures within the operating temperature range.

203.1.1.4 AC Operation

In ac operation, the sum of the peak ac voltage and any dc bias shall not exceed the voltage derating value.

203.1.2 DERATING REQUIREMENTS FOR STYLES PC 25, 26, 39, 43, 48, 52

The voltage shall be derated according to the derating curve shown in Figure 200.9. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.9.

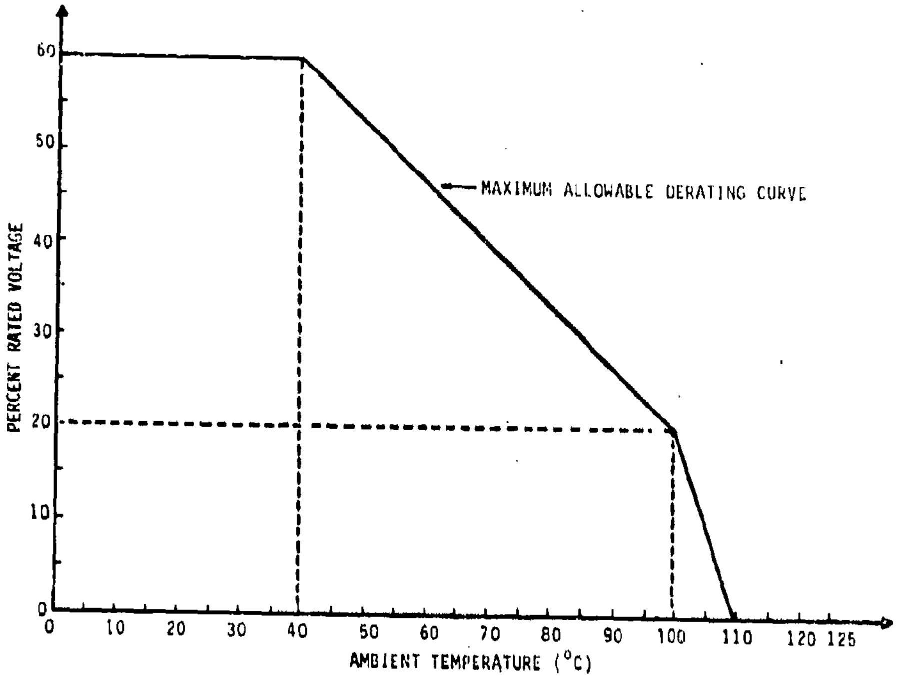


FIGURE 200.9

DERATING REQUIREMENTS FOR STYLES PC 25, 26, 39, 43, 48, 52

203.1.3 DERATING REQUIREMENTS FOR STYLES PC 38, 40, 42

The voltage shall be derated according to the derating curve shown in Figure 200.10. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.10.

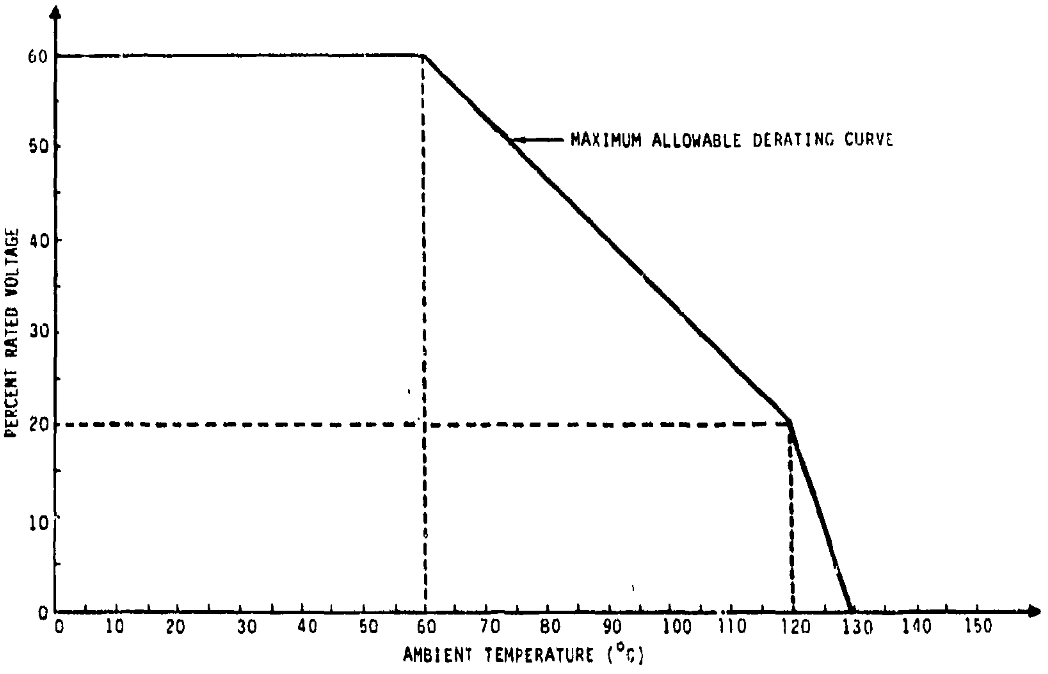


FIGURE 200.10

DERATING REQUIREMENTS FOR STYLES PC 38, 40, 42

203.1.4 Construction

Styles PC25 and PC26 capacitors are constructed with a series of concentric circular metal bands forming plates which interleave. The capacitance is varied by adjustment of the relative depth of engagement of the metal bands. All other style capacitors are constructed of glass or quartz dielectric cylinders and metal tuning pistons. A portion of the cylinder is plated with metal to form the stator. The metal piston, controlled by a tuning screw, acts as the rotor. Overlap of the stator and rotor determines the capacitance. The self-contained piston within the dielectric cylinder functions as a low inductance coaxial assembly.

203.2 MIL-C-23269, CAPACITORS, FIXED, GLASS DIELECTRIC, ESTABLISHED RELIABILITY, (STYLE CYR)

203.2.1 APPLICATION CONSIDERATIONS

These capacitors are intended for use where high insulation resistance, low dielectric absorption and fixed temperature coefficients are important circuit parameters. They are particularly useful in high frequency applications. They are capable of withstanding environmental conditions of shock, vibration, acceleration, extreme moisture, vacuum, extended life of 30,000 hours or greater, and high operating temperatures experienced in missile borne and space electronic equipment.

203.2.1.1 Capacitance Tolerance

These capacitors come with tolerances of ± 0.25 pf, ± 1 percent, ±2 percent, and ±5 percent. However, regardless of purchase tolerance, the design should be able to tolerate a ±1 percent change in capacitance value to assure long life reliability in military applications.

203.2.1.2 Operating Frequency

These capacitors perform very well at high frequencies up to 500 MHz with a typical operating frequency of 100 kHz to 1 GHz.

203.2.1.3 Temperature Coefficient and Capacitance Drift

These capacitors are available with three temperature coefficients. For the axial lead capacitors, the temperature coefficient is 140 ± 25 PPM/°C (for style CYR41). For the axial-radial lead capacitors, the temperature coefficient is 105 ± 25 PPM/°C. The capacitance drift is ± 0.1 percent or 0.1 pf, whichever is greater, for all capacitors.

203.2.1.4 AC Operation

When ac operation is required, the peak ac voltage plus any dc bias shall not exceed the value established by the derating requirements.

203.2.1.5 Shock

Although these capacitors are resistant to high acceleration loads during acceleration, they are susceptible to damage from mild mechanical shocks. Necessary care should be taken in such applications.

203.2.1.6 Quality Factor "Q"

These capacitors exhibit a much higher "Q" factor over a wider capacitance range than mica dielectric capacitors where "Q" is the ratio of reactance to effective resistance.

203.2.2 DERATING REQUIREMENTS FOR STYLES CYR 10, 13, 15, 17, 20, 22, 30, 32, 41, 51, 52, 53

The voltage shall be derated according to the derating curve shown in Figure 200.11. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.11.

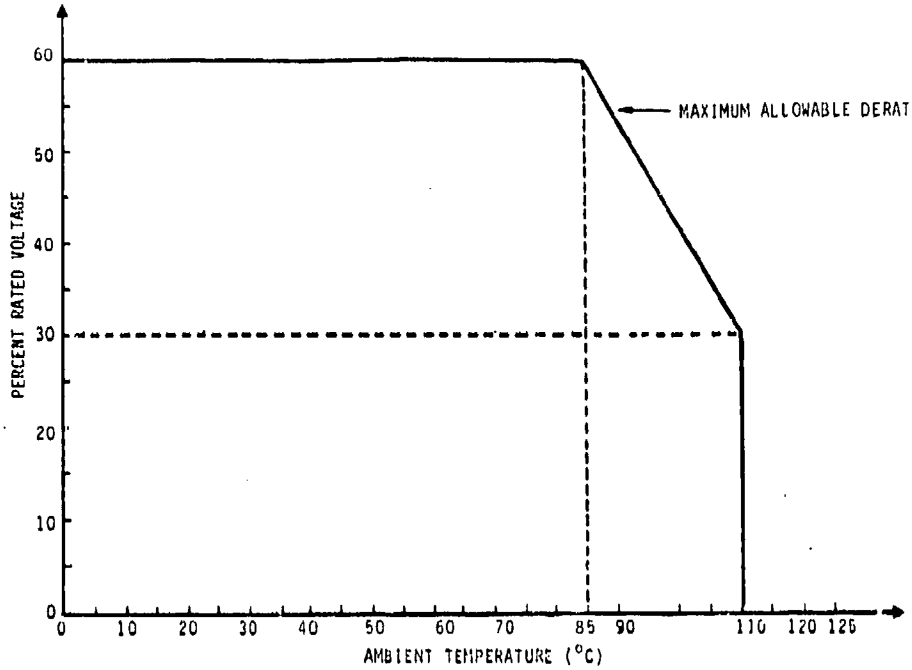


FIGURE 200.11

DERATING REQUIREMENTS FOR STYLES CYR 10, 13, 15, 17, 20, 22, 30, 32, 41, 51, 52, 53

203.2.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

204 CAPACITORS, ELECTROLYTIC

204.1 GENERAL INFORMATION

Electrolytic capacitors are smallest in size and cost for a specific capacitance and voltage rating. Although these capacitors are available with high capacitance values, the initial tolerances are large. These capacitors cannot be used where close tolerances are required.

204.2 APPLICATION CONSIDERATIONS

204.2.1 SHELF LIFE

Most tantalums have excellent shelf life characteristics. Shelf life of aluminum, however, is limited because the film dissolves in the electrolyte. Tantalum style CLR65 capacitors shall not be used without the approval of the procurement agency.

204.2.2 CASE

The largest possible case size should be used for a given capacitor voltage rating as this provides thicker oxide dielectric, lower equivalent series resistance, lower dissipation factor, better heat dissipation, and greater capacitance stability. Only hermetically sealed units shall be used since the penetration of moisture could affect the electrolyte.

204.2.3 USE

These capacitors are not suitable for application in low pressure high altitude environments. Many of these capacitors are polarized and shall not be subjected to reverse bias voltages beyond the limits specified in the derating section and the appropriate section of Table I.

204.2.4 OPERATING FREQUENCY

Generally, the filtering capability of these capacitors is limited to frequencies below 10 KHz. Above 10 KHz, the effective capacitance rapidly decreases until the capacitor becomes purely resistive.

204.2.5 OPERATION IN PARALLEL

When these capacitors are operated in parallel, the ripple or surge currents for each shall not exceed the recommended limit. The currents will not divide evenly due to the difference in internal impedances and this shall also be considered in parallel applications.

204.2.6 TANTALUM CAPACITOR CONSIDERATIONS

204.2.6.1 Series Impedance

These capacitors shall have a series impedance of at least 3 ohms/volt. This will allow the capacitor to self-heal due to its internal scintillation breakdowns. If the current is limited to 330 mA when the capacitor is momentarily shorted, this will also satisfy the requirement.

204.2.6.2 Assembly Considerations

When solid electrolytic capacitors are used in parallel banks, series limiting resistors should be installed with each capacitor to prevent discharge of the entire bank into a scintillation fault. When the capacitors are used in series, balancing resistors should be used to assure proper division of voltages. When they are used in banks, they should be assembled in easily removable modules to facilitate replacement and test.

204.2.6.3 Ripple Current

The ripple current in all capacitors shall be limited to values which do not bring the temperature above the derated rating. When capacitors are used in banks it is cautioned that the capacitor with the lowest equivalent series resistance will carry the largest ripple current. For foil and solid electrolytic capacitors, the allowable ripple current shall be derated to 70 percent of the manufacturer's maximum ripple current rating.

204.2.6.4 Reliability Considerations

a. For highest reliability, polarized capacitors shall be protected or applied so that voltage reversal never exceeds 2 percent of the maximum voltage rating. The combined ac and dc voltages shall be analyzed to insure that the worst case conditions do not cause voltage reversals beyond the specified value.

b. The applied voltage and operating temperature shall be limited to the derated values as specified by Table I and the appropriate derating section of this document.

204.2.7 ALUMINUM ELECTROLYTIC CONSIDERATIONS

Aluminum electrolytic capacitors are intended for use in filter, coupling and bypassing applications where large capacitance values are required in small cases, and where high capacitance tolerances can be tolerated.

Aluminum electrolytic capacitors have in the past experienced deterioration of the oxide film when operated at less than rated voltage for prolonged periods of time. The oxide film deformed to a lower voltage and the capacitor would be destroyed upon application of full rated voltage. This phenomena would also occur if the capacitors were stored for a long period of time, particularly at high temperature. If the capacitors have been in storage for longer than 5 years, however, it is recommended that the capacitors be checked for leakage prior to being used in the circuitry.

204.3 MIL-C-39003, CAPACITORS, FIXED, ELECTROLYTIC (SOLID ELECTROLYTE), TANTALUM, ESTABLISHED RELIABILITY, (STYLE CSR)

204.3.1 APPLICATION CONSIDERATIONS

These capacitors are intended for use where high capacitance in a small volume is required. Applications include low frequency filtering, bypassing, coupling, blocking and energy storage. They have excellent shelf life. These capacitors are hermetically sealed.

204.3.1.1 Temperature Coefficient

Because of their passive electrolyte being solid and dry, these capacitors have a lower capacitance-temperature characteristic than any of the other electrolytic capacitors.

204.3.1.2 Dielectric Absorption

These capacitors exhibit the characteristic of dielectric absorption whereby a voltage across them will reappear after they have been shorted. This should be considered in their use in RC timing circuits, triggering systems and phase-shift networks.

204.3.1.3 Reverse Voltage

These capacitors shall never be exposed to dc or peak ac voltages greater than 2 percent of their maximum rated dc voltage in the reverse of the normal polarization.

204.3.1.4 Mounting

Supplementary mounting means should be used where the application of these capacitors involves vibration frequencies above 55 Hz.

204.3.2 DERATING REQUIREMENTS FOR STYLES CSR 13, 21, 91

The voltage shall be derated according to the derating curve shown in Figure 200.12. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.12. For polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated dc voltage.

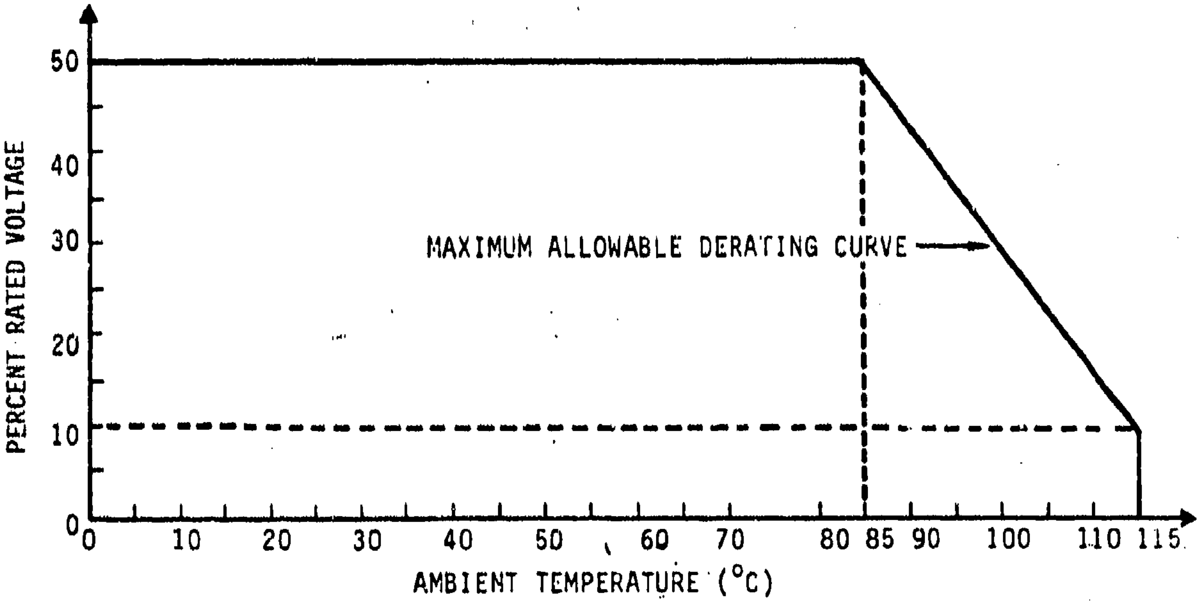


FIGURE 200.12

DERATING REQUIREMENTS FOR STYLES CSR 13, 21, 91

204.3.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

204.4 MIL-C-39006, CAPACITORS, FIXED, ELECTROLYTIC (NON-SOLID ELECTROLYTE) TANTALUM, ESTABLISHED RELIABILITY (STYLE CLR)

204.4.1 APPLICATION CONSIDERATIONS

These capacitors are recommended for use where high capacitance is required in a small volume, at medium to high voltages. The non-solid ("wet") electrolyte capacitors fall into three broad categories, which vary substantially in pertinent characteristics.

204.4.1.1 Plain Foil (Styles CLR35 and CLR37)

These capacitors are characterized by their high voltage ratings (up to 450 volts). They are comparatively larger than the sintered slug or etched foil styles for a given capacitance value and have only moderate purchase tolerances (±20 percent).

204.4.1.2 Etched Foil (Styles CLR25 and CLR27)

These capacitors provide substantial improvements in volumetric efficiency over the plain foil styles, and are available in higher voltage ratings than the sintered slug styles. They are characterized by extremely high capacitance values (up to 580 micro farads) but have broad purchase tolerances (+75 percent to -15 percent).

204.4.1.3 Sintered Slug (Type CLR79)

These styles utilize tantalum cases. The CLR79 does not require the silver plating and the tantalum case is impervious to attack by H_2SO_4.

204.4.1.4 Life Tolerance

As described above, these capacitors come with various tolerances from -15 percent to +75 percent. However, regardless of the purchase tolerance, the design should be able to tolerate an additional 10 percent reduction in capacitance as compared to the initial value, to compensate for the cumulative effects of temperature and aging over the life of these capacitors.

204.4.1.5 Polarization

CLR style capacitors are polarized except for styles CLR27 and CLR37. Non-polarized styles are primarily suitable for ac applications or where dc voltage reversals can occur. Examples of these uses are in:
(a) tuned low-frequency circuits; (b) phasing of low voltage ac motors;
(c) computer circuits and (d) servo systems.

204.4.1.6 Series Operation

Whenever these capacitors are connected in series for higher voltage operation, a resistor shall be in parallel across each unit. Unless a shunt resistor is used, the dc rated voltage can easily be exceeded on the capacitor in the series network depending upon the capacitance, the average dc leakage and the capacitor construction.

204.4.1.7 Parallel Operation

When these capacitors are operated in parallel, care shall be taken to assure that the sum of the peak voltage ripple and the applied dc voltage does not exceed the dc rated voltage. The connecting leads of the parallel network should be large enough to carry the combined currents without reducing the effective capacitance resulting from series lead resistance.

204.4.1.8 High Capacitance Series

It is not recommended to select the highest capacitance value available for a given voltage rating and case size. In some of the MIL-C-39006 detail specifications, these capacitors are flagged by an "*". Reasons for not selecting these capacitors are:

(a) They represent the ultimate in the capability of the manufacturing process, and are thus less predictable, and inherently less reliable.

(b) They are typically much more expensive than the lower capacitance values in the same voltage rating and case sizes.

(c) In the manufacture process, the "forming" voltage will generally be lower (as a ratio of the rated operating voltage) than for lower capacitance values, providing a lesser margin of safety.

(d) They will typically exhibit a greater decrease of capacitance at low temprature, and thus provide only an illusion of higher capacitance in the actual operating environment.

204.4.1.9 Hermetic Seal

Only hermetically sealed capacitors shall be used. The use of the liquid or gelled electrolyte absolutely precludes the use of non-hermetic types. The non-hermetic types have been proven unreliable because the electrolyte can escape, either in a liquid or gaseous form, reducing the capacitance and causing catastrophic failure under extended exposure to military service environments.

204.4.1.10 Restricted Use of Wet Slug Tantalum Capacitors

The order of preference for the selection of the types described above is as follows:

(a) Sintered Slug, Tantalum Case (Style CLR79)
(b) Plain Foil (Styles CLR35 and CLR37)
(c) Etched Foil (Styles CLR25 and CLR27)

Wet slug tantalum capacitance cannot be used on Naval Air Systems Command Programs without approval of the procuring agency. Wet slug capacitors other than MIL-C-39006/22 (CLR79) shall not be used on other programs without approval of the procuring agency.

204.4.2 DERATING REQUIREMENTS FOR STYLES CLR 25, 27, 35, 37, 79

The voltage shall be derated according to the derating curve shown in Figure 200.13. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.13. For polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated dc voltage.

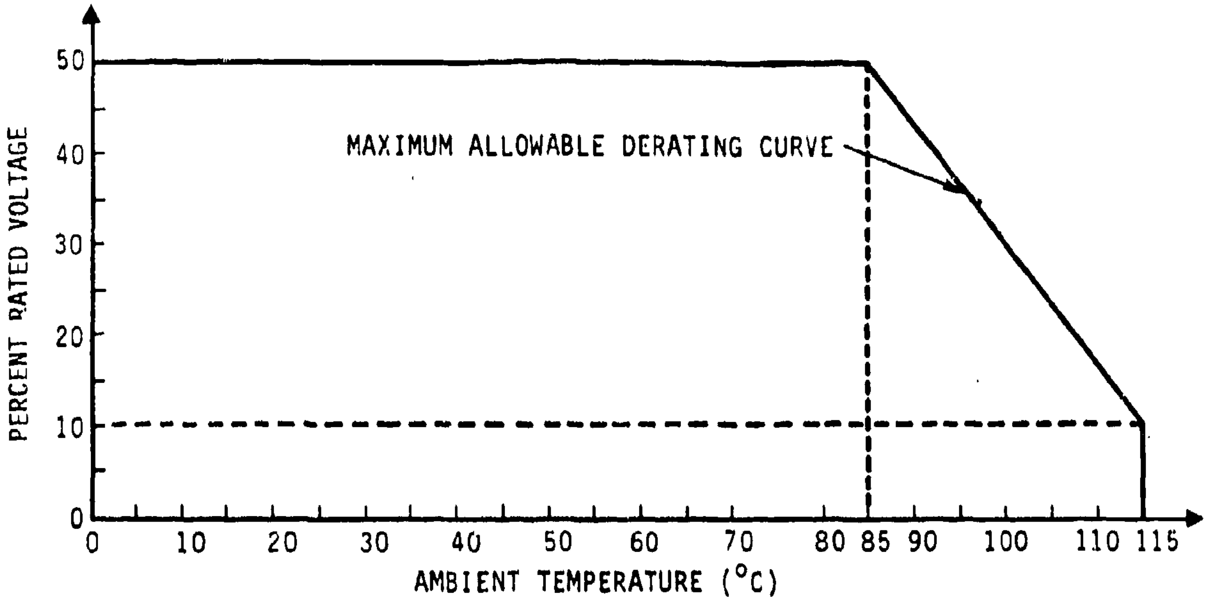


FIGURE 200.13

DERATING REQUIREMENTS FOR STYLES CLR 25, 27, 35, 37, 79

204.4.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

204.5 MIL-C-39018, CAPACITORS, FIXED, ELECTROLYTIC (ALUMINUM OXIDE), (STYLE CUR), ESTABLISHED RELIABILITY AND (STYLE CU), NONESTABLISHED RELIABILITY

204.5.1 APPLICATION CONSIDERATIONS

These capacitors are generally used for filtering low frequency, pulsating, dc signal components in B power supplies up to 400 Vdc. These capacitors are used at such points as plate and screen connections to B+, and as cathode bypass capacitors in self-biasing circuits. These capacitors are designed for applications where variations in capacitance are relatively unimportant.

204.5.1.1 Operating Frequency

These capacitors are recommended for use in the frequency range of 60 to 10,000 Hz.

204.5.1.2 Polarization

Styles (CUR13, CUR17, CUR19, CUR71 and CUR91) are polarized. In applications where reversal of polarity occurs, only CU15 shall be used. The polarized capacitors (CUR13, CUR17, CUR19, CUR71 and CUR91) shall be used only in dc circuits with polarity properly observed. Style CUR13 and CUR17 have a 3-volt reverse voltage limitation for units rated at 10 volts or greater. Styles CUR19, CUR71 and CUR91 have reverse voltage limitations of 1.5 volts. If ac components are present, the sum of the peak ac voltage plus the applied dc voltage shall not exceed the derated value. The proper polarity shall be maintained even on negative peaks, to avoid overheating and damage.

204.5.1.3 Seal

Even though these capacitors have vents designed to open at dangerous pressures, explosions can occur because of gas pressure build-up or a spark ignition of free oxygen and hydrogen liberated at the electrode. Provisions should be made to protect surrounding parts.

204.5.1.4 Environmental Conditions

These capacitors should not be subjected to low barometric pressures and low temperatures. Therefore they shall not be used for airborne applications without prior approval by the procuring activity.

204.5.1.5 Surge Voltage

The surge voltage is the maximum voltage to which the capacitor shall be subjected. This includes transients and peak ripple at the highest line voltage. For maximum reliability and long life, the dc working voltage should not be more than 60 percent of the full voltage rating so that surges can be kept within the full-rated working voltage. Surge-voltage application should not occur more than 30 seconds every 10 minutes.

204.5.1.6 Cleaning Solvents

Recommended solvents include those free of halogen or halogen groups, such as toluene, menthanol, methylcellosolve, alkinox and water, and naphtha. Chlorinated or fluroinated hydrocarbon solvents shall not be used for cleaning these capacitors.

204.5.2 DERATING REQUIREMENTS FOR STYLE CUR 71

The voltage shall be derated according to the derating curve shown in Figure 200.14. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.14. For the polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated dc voltage.

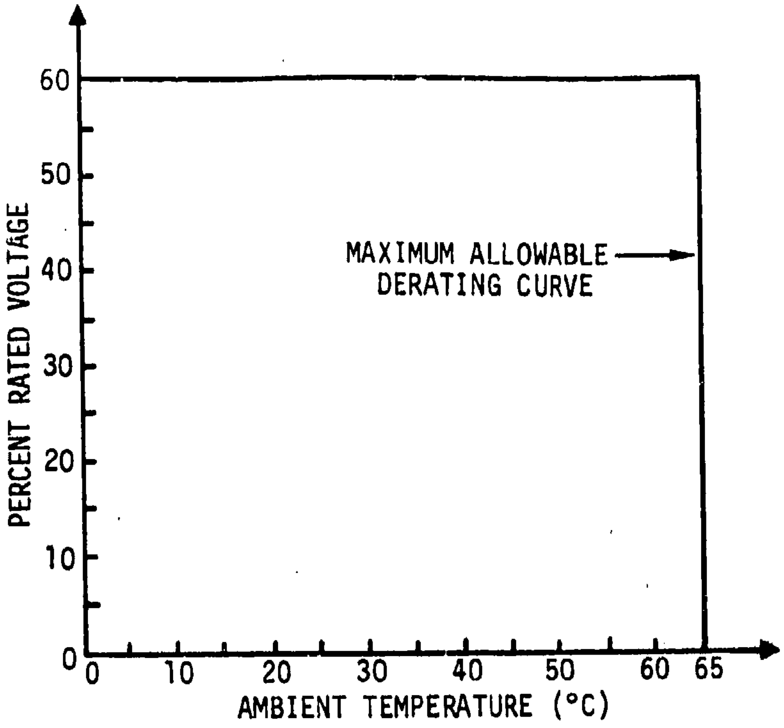


FIGURE 200.14

DERATING REQUIREMENTS FOR STYLE CUR 71

204.5.3 DERATING REQUIREMENTS FOR STYLES CUR 17, 19, 91

The voltage shall be derated according to the derating curve shown in Figure 200.15. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.15. For the polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated dc voltage.

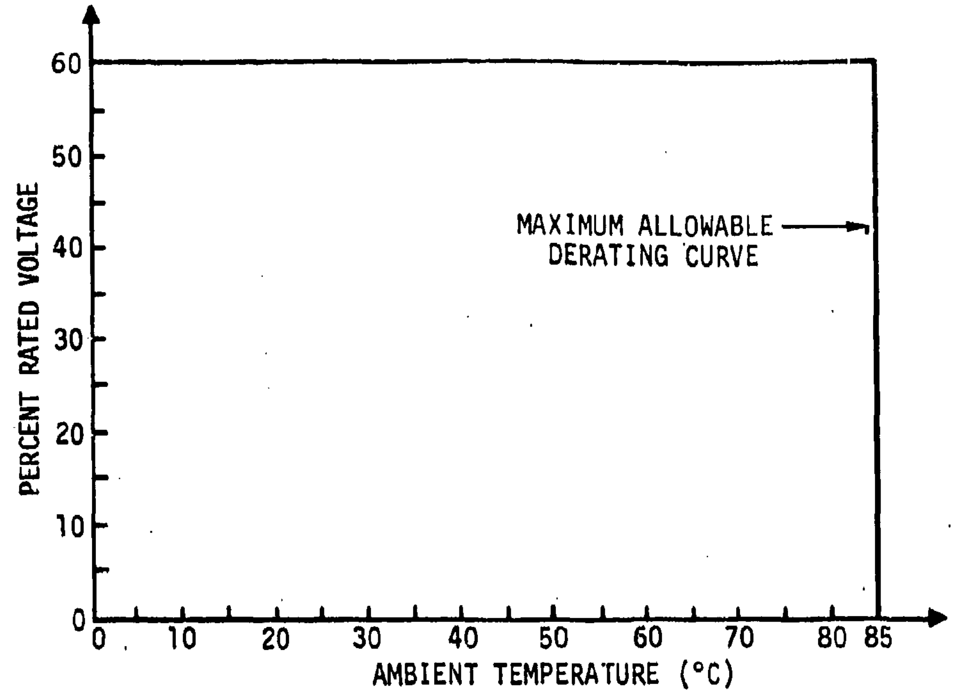


FIGURE 200.15

DERATING REQUIREMENTS FOR STYLES CUR 17, 19, 91

204.5.4 DERATING REQUIREMENTS FOR STYLES CUR13 AND CU15

The voltage shall be derated according to the derating curve shown in Figure 200.16. The ambient temperature shall be limited to the derated maximum values as shown in Figure 200.16. For polarized capacitors, the peak reverse voltage shall not exceed 2 percent of the maximum rated dc voltage.

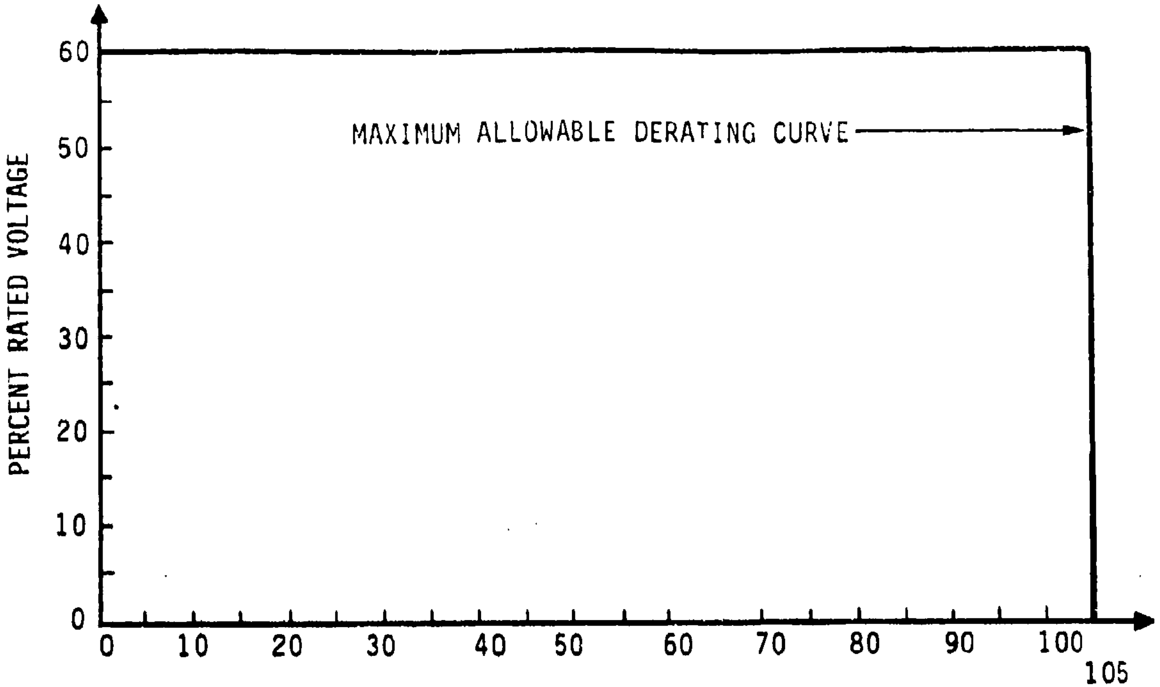


FIGURE 200.16

DERATING REQUIREMENTS FOR STYLES CUR13 AND CU15

204.5.5 QUALITY LEVEL

Only ER level "P" or higher shall be used.

205 CAPACITORS, MICA DIELECTRIC, FIXED

205.1 APPLICATION CONSIDERATIONS

205.1.1 CONSTRUCTION

Both glass and mica capacitors have high capacitance per unit volume or mass with the glass usually having a much higher capacitance to its volume/mass ratio than the mica. Bodies of these capacitors are often made of dielectric material and are capable of resisting moisture to a large degree. These capacitors are very brittle due to their construction and materials used and may be damaged by high shock or vibration.

205.1.2 OPERATING FREQUENCY

These capacitors perform well at high frequencies up to 500 MHz.

205.1.3 AC OPERATION

When ac operation is required, the peak ac voltage plus any dc bias shall not exceed the derated values obtained from derating guidelines. Where transients are encountered, the effects of these transients shall also be taken into consideration when selecting capacitors.

205.1.4 ENVIRONMENTAL CONSIDERATIONS

Silvered-mica capacitors should never be subjected to dc voltage stresses in combination with high humidity and high temperatures for extended periods due to silver-ion migration effects.

205.2 MIL-C-10950, CAPACITORS, FIXED, MICA DIELECTRIC, BUTTON STYLE, (STYLE CB)

205.2.1 APPLICATION CONSIDERATIONS

These capacitors are intended for use at frequencies up to 500 MHz. Their principal uses are in tuned circuits, and in coupling and bypassing applications in VHF and UHF circuits. These capacitors are small, are very stable over time and have high reliability in circuits where ambient conditions can be closely controlled to reduce failure from silver-ion migration.

205.2.2 DERATING REQUIREMENTS FOR STYLE CB50

The voltage shall be derated according to the derating curve shown in Figure 200.17. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.17.

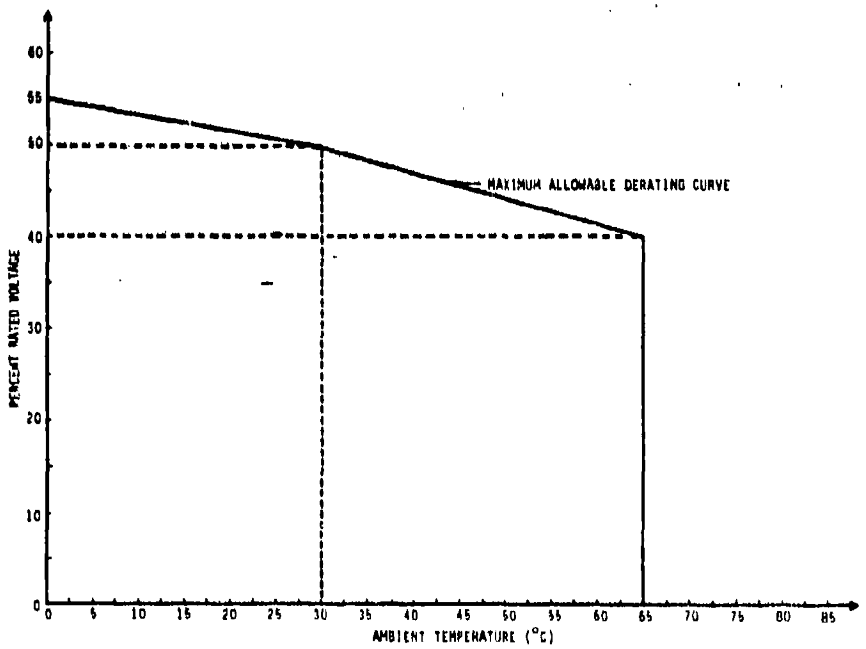


FIGURE 200.17

DERATING REQUIREMENTS FOR STYLE CB50

205.2.3 DERATING REQUIREMENTS FOR STYLES CB 55-57, 60-62, 65-67

The voltage shall be derated according to the derating curve shown in Figure 200.18. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.18.

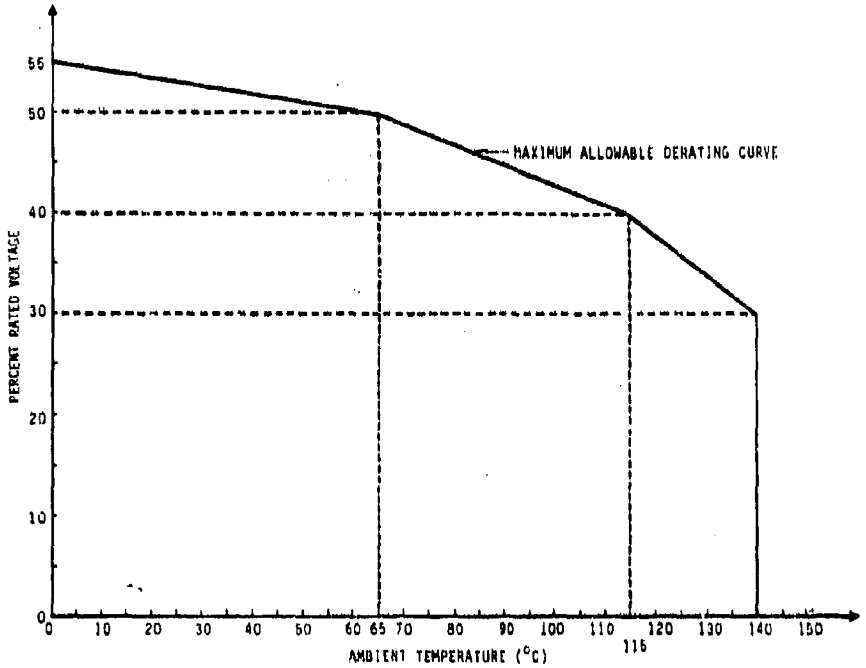


FIGURE 200.18

DERATING REQUIREMENTS FOR STYLES CB 55,
56, 57, 60, 61, 62, 65, 66, 67

205.2.4 CONSTRUCTION

These capacitors are hermetically sealed by glass except Style CB50 which is resin sealed.

205.3 MIL-C-5, CAPACITORS, FIXED, MICA DIELECTRIC, (STYLE CM)

AND

MIL-C-39001, CAPACITORS, FIXED, MICA DIELECTRIC, ESTABLISHED RELIABILITY, (STYLE CMR)

205.3.1 APPLICATION CONSIDERATIONS

These capacitors are designed for use in circuits requiring precise high frequency filtering, bypassing, and coupling. They are used where close impedance limits are essential with respect to temperature, frequency, and aging -- such as in tuned circuits which control frequency, reactance, or phase. These capacitors are also useful as padders in tuned circuits, as secondary capacitance standards, and as fixed-tuning capacitors at high frequencies. They can also be employed in delay lines and stable low-power networks.

Due to the inherent characteristics of the dielectric (i.e., high insulation resistance and high breakdown voltage, low power factor, low inductance, and low dielectric absorption), these mica capacitors are small, have good stability and high reliability.

205.3.1.1 Capacitance Tolerance

These capacitors come with tolerances of ±0.5 pf, ±1 percent, ±2 percent and ±5 percent. However, regardless of the purchase tolerance, the design should tolerate a ±0.5 percent change in capacitance value to assure long life reliability in military applications.

205.3.1.2 Operating Frequency

These capacitors perform very well at frequencies up to 500 MHz with a typical operating frequency range of 10 kHz to 500 MHz.

205.3.1.3 Insulation Resistance

These capacitors have very high insulation resistance and low dissipation factors.

205.3.2 DERATING REQUIREMENTS FOR STYLES CM35 AND CMR03

The voltage shall be derated according to the derating curve shown in Figure 200.19. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.19. These derating requirements only apply to those capacitors having a rated temperature range of -55°C to +125°C.

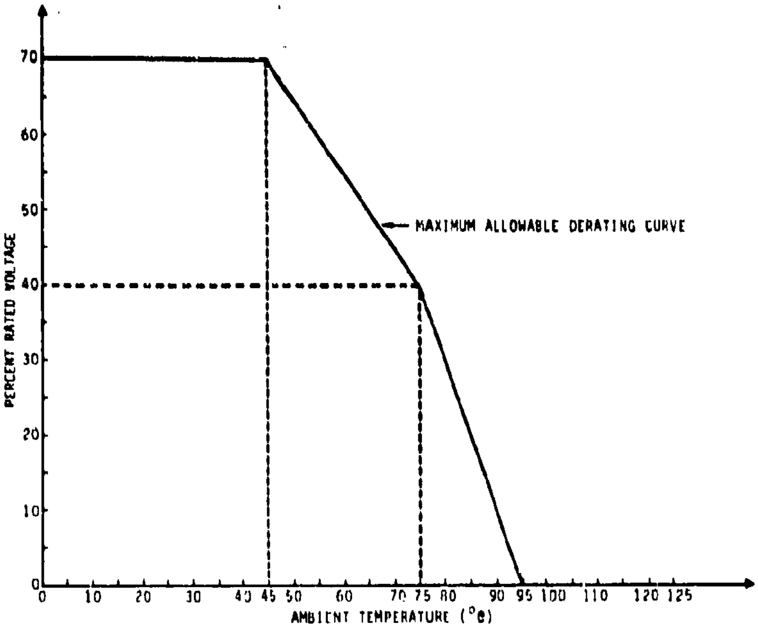


FIGURE 200.19

DERATING REQUIRMENTS FOR STYLES CM35 AND CMR03
WITH A RATED TEMPERATURE TO 125°C

205.3.3 CONSTRUCTION

These capacitors are fixed terminal capacitors; styles CM45 and CM50 employ the use of tin-lead foil.

205.3.4 DERATING REQUIREMENTS FOR STYLES CM 15, 20, 30, 35, 45, 50 AND CMR 04, 05, 06, 07, 08

The voltage shall be derated according to the derating curve shown in Figure 200.20. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.20. These derating requirements only apply to those capacitors having a rated temperature range of -55°C to +150°C.

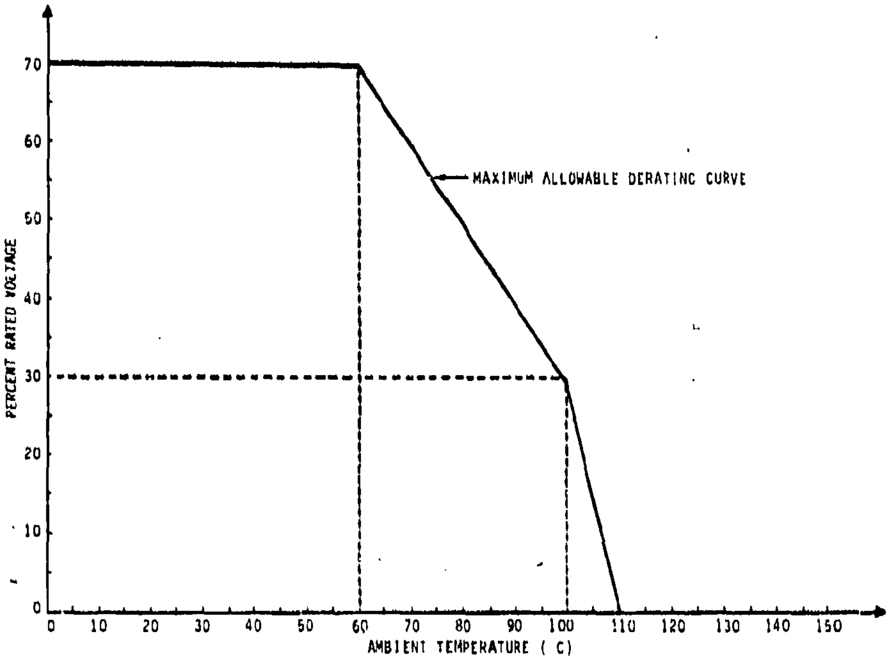


FIGURE 200.20

DERATING REQUIREMENTS FOR STYLES CM 15, 20, 30, 35, 45, 50 AND CMR 04, 05, 06, 07, 08 WITH A RATED TEMPERATURE TO 150°C

205.3.5 QUALITY LEVEL

Only ER level "P" or higher shall be used.

206 CAPACITORS, PAPER/PLASTIC/PAPER-PLASTIC DIELECTRIC

206.1 GENERAL INFORMATION

These capacitors can be used in applications that require high and stable dielectric resistance at high temperatures and good capacitance stability over a wide temperature range. This permits use in a wide range of applications ranging from computers to guided missiles. The relatively high dielectric strength of some of the plastic capacitors can lead to attractive small physical dimensions. These capacitors are of a small relative size for equivalent CV rating except for MIL-C-19978 polystyrene types which are medium to large size. Metallized paper capacitors have low dielectric resistance and are prone to dielectric breakdown. Plastic dielectric capacitors have superior moisture characteristics in that they are non-absorbent.

206.2 APPLICATION CONSIDERATIONS

206.2.1 SEAL

All units shall be hermetically sealed. Small amounts of moisture can increase the rate of chemical reactions within the capacitor materials.

206.2.2 MOUNTING

Capacitors with lengths of 1.375 or widths of 0.672 inches or greater should not be supported by their leads. These capacitors should be provided with a supplementary means for mounting, such as tangential brackets. To keep the inductance to a minimum, the capacitors should be installed close to the source so that the lead length is as short as possible. The output lead should be kept away from the input lead. In severe cases the input lead should be shielded. Good bonding is extremely important in the installation of capacitors.

206.2.3 AC OPERATION

When ac operation is required, care shall be taken to ensure that: (a) the sum of the dc voltage and the peak ac voltage does not exceed the dc voltage rating; and (b) the ac voltage does not exceed 20 percent of the dc voltage rating or the value calculated from the following equation whichever is smaller:

$$V_p(ac) = \sqrt{\frac{(T_{dc} - T)Ae}{(\pi)(f)(C)(D)}}$$

Where:

V_p ac = Peak value of ac component

f = Frequency in Hertz of ac component

D = 2 (maximum DF at applicable high test temperature)

C = Nominal capacitance in farads

A = Exposed capacitor case surface area in square centimeters $(cm)^2$, exclusive of portion occupied by terminal mountings

T_{dc} = Applicable high test temperature in degrees Celsius

T = Maximum ambient operating temperature expected within equipment containing capacitor

e = Convection coefficient in watts per $cm^2/°C$ (The value of "e" is approximately equal to 0.0006).

206.2.4 FAULTS OR "CLEARINGS"

For metallized paper and plastic capacitors with conducting plates having thicknesses in the micrometer or submicrometer range, a puncture of the dielectric can cause a relatively harmless vaporization of a small area of the plates known as "clearings". The clearings normally occur with voltage spikes and result in small reductions in capacitor values. These phenomena are not considered failures of the capacitor until enough of them occur to cause the capacitor value to be outside the specified tolerance.

206.3 MIL-C-19978, CAPACITORS, FIXED, PLASTIC (OR PAPER-PLASTIC), DIELECTRIC (HERMETICALLY SEALED IN METAL CASES), ESTABLISHED RELIABILITY, (STYLE CQR)

206.3.1 APPLICATION CONSIDERATIONS

206.3.1.1 Use

These capacitors are designed for use in circuit applications requiring high insulation resistance, low dielectric absorption, or low loss factor over wide temperature ranges, and where the ac component of the impressed voltage is small with respect to the dc voltage rating. These capacitors are broadly categorized into three characteristic groups as follows:

(a) Polyethylene terephthalate (characteristic M capacitors) - Characteristic M capacitors are intended for high temperature applications similar to those served by hermetically-sealed paper capacitors. These capacitors also exhibit high insulation resistance at the upper temperature limits.

(b) Paper and polyethylene terephthalate (characteristic K capacitors) - Characteristic K capacitors are intended for applications where high insulation resistance is necessary.

(c) Polycarbonate (characteristic Q capacitors) - Characteristic Q capacitors are intended for applications where minimum capacitance changes with temperature are required. These capacitors are especially suitable for use in tuned and precision timing circuits.

(d) Capacitance tolerance - These capacitors come with tolerances of ±2 percent, ±5 percent, ±10 percent. However, regardless of the purchase tolerance, designs using these capacitors should tolerate a ±2 percent change in capacitance value to assure long life reliability in military applications.

206.3.1.2 AC Operation

Whenever ac operation is required, care shall be taken to ensure that: (a) the sum of the dc voltage and the peak ac voltage does not exceed the dc voltage rating; or (b) the peak ac voltage does not exceed 20 percent of the dc voltage rating at 60 Hz, 15 percent at 120 Hz; or 1 percent at 10,000 Hz. Where heavy transient or pulse currents are encountered, the requirements of MIL-C-19978 are not sufficient to guarantee satisfactory performance. This should be considered in the selection of a capacitor.

206.3.1.3 Barometric Pressure (Flashover) for Metal-Cased Tubular Capacitors

The dc voltage that can be applied to metal-cased tubular capacitors at different altitudes can be obtained from Figure 200.21. The dc voltage shall not exceed the specified derating levels.

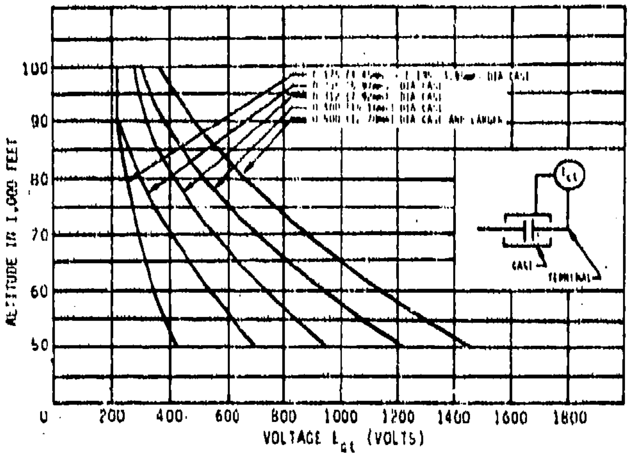


FIGURE 200.21

DC VOLTAGE AT DIFFERENT ALTITUDES FOR METAL CASE TUBULAR CAPACITORS

206.3.2 DERATING REQUIREMENTS FOR STYLES CQR 29, 32, 33

The voltage shall be derated according to the derating curve shown in Figure 200.22. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.22.

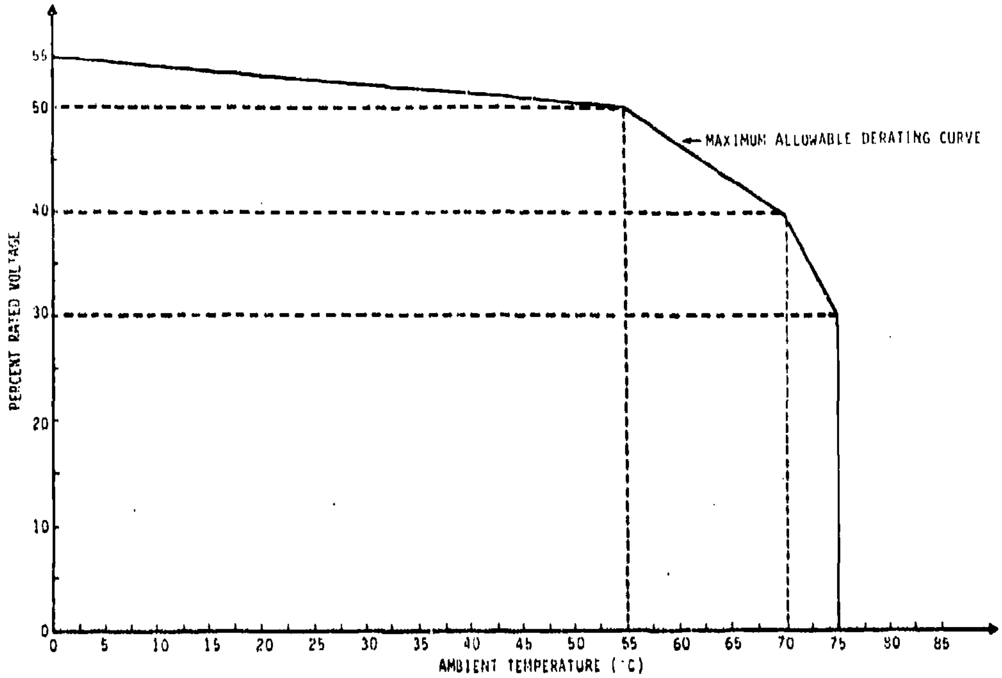


FIGURE 200.22

DERATING REQUIREMENTS FOR STYLES CQR 29, 32, 33

200.3.3 DERATING REQUIREMENTS FOR STYLES CQR 07, 09, 12, 13

The voltage shall be derated according to the derating curve shown in Figure 200.23. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.23.

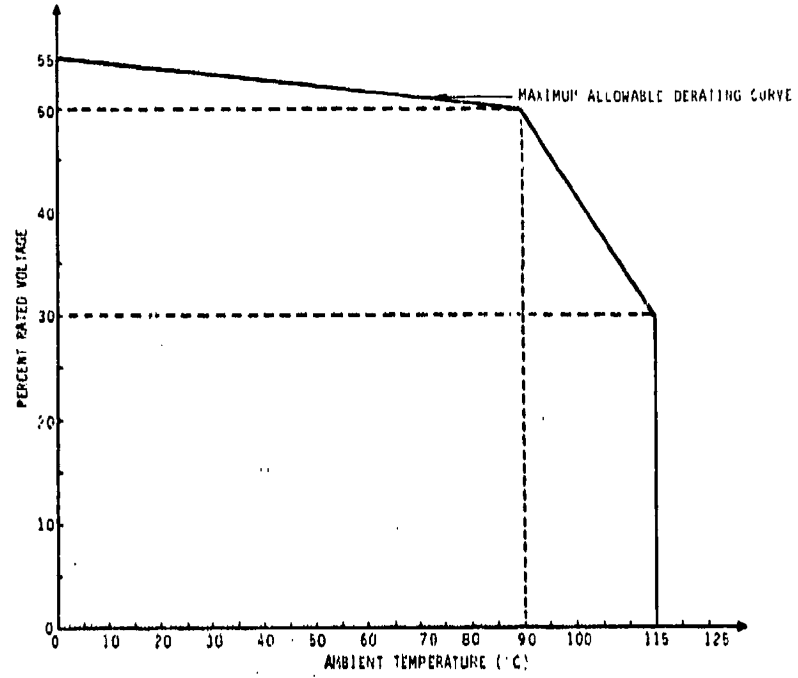


FIGURE 200.23

DERATING REQUIREMENTS FOR STYLES CQR 07, 09, 12, 13

206.3.4 QUALITY LEVEL

Only ER level "P" or higher shall be used.

206.4 MIL-C-39022, CAPACITORS, FIXED, METALLIZED, PAPER PLASTIC FILM OR PLASTIC FILM DIELECTRIC, DIRECT AND ALTERNATING CURRENT (HERMETICALLY SEALED IN METAL CASES), ESTABLISHED RELIABILITY, (STYLE CHR)

206.4.1 APPLICATION CONSIDERATIONS

These capacitors are primarily intended for use in power supply filter circuits, bypass applications, and other applications where: (a) the ac component of voltage is small with respect to the dc voltage rating, and (b) where occasional periods of low insulation and momentary breakdowns can be tolerated. These capacitors are available in a wide range of capacitance values and voltage ranges and offer low dielectric absorption.

206.4.1.1 Capacitance Tolerance

These capacitors come in tolerances of +5 percent and +10 percent. However, regardless of the purchase tolerance, the design should be able to tolerate a +2 percent change in capacitance value to assure long life reliability in military applications.

206.4.1.2 Capacitance-Temperature Characteristics

The capacitors with "Mylar" or polycarbonate dielectric offer very low (on the order of ±1 percent) capacitance change with temperature over the operating temperature range.

206.4.2 DERATING REQUIREMENTS FOR STYLES CHR 09, 49

The voltage shall be derated according to the derating curve shown in Figure 200.24. The ambient temperature shall be limited to the derated maximum value as shown in Figure 200.24.

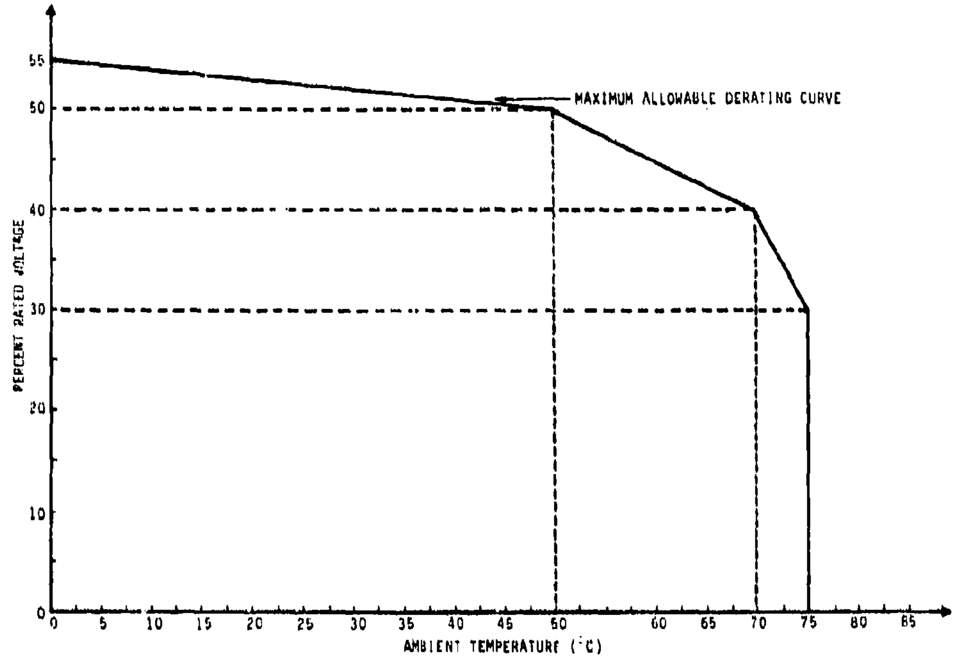


FIGURE 200.24

DERATING REQUIREMENTS FOR STYLES CHR 09, 49

206.4.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

207 FILM CAPACITORS, PLASTIC DIELECTRIC

207.1 MIL-C-83421 CAPACITORS, FIXED, SUPERMETALLIZED, PLASTIC FILM DIELECTRIC, (DC, AC, or DC and AC), HERMETICALLY SEALED IN METAL CASES, ESTABLISHED RELIABILITY, (STYLE CRH)

207.1.1 APPLICATION CONSIDERATIONS

207.1.1.1 Use

Capacitors covered by this specification are primarily intended for use in circuit applications which require non-polar behavior, relatively high insulation resistance, low dielectric absorption, low capacitance change with temperature, and low capacitance drift over the temperature range. Styles covered by this specification are rated for continuous operation under ac sinusoidal conditions in addition to continuous operation under dc conditions. These capacitors can exhibit periods of low insulation resistance and should only be used in circuits that can tolerate occasional momentary breakdowns. They should not be used in high impedance, low voltage applications.

207.1.1.2 Voltage Rating

DC ratings are 30 Vdc to 400 Vdc from -55°C to +100°C.

AC ratings are 22 Vrms to 240 Vrms at 400 Hz from -55°C to +10°C. Operation at frequencies above the below 40 kHz is permissable provided the rms voltage limit at 400 Hz or the rms current limit at 40 kHz is not exceeded.

The combined dc and ac peak voltage shall not exceed the dc rating of the capacitor.

207.1.2 DERATING REQUIREMENTS FOR STYLES CRH 01, 02, 03, 04, 05

The voltage shall be derated according to the derating curve shown in Figure 200.25. The ambient temperature shall be limited to the derated maximum value shown in Figure 200.25.

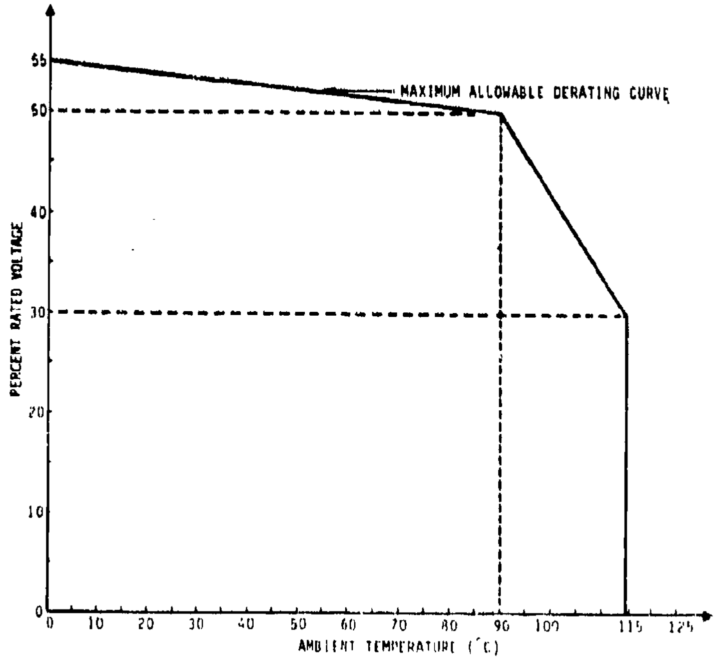


FIGURE 200.25

DERATING REQUIREMENTS FOR STYLES CRH 01, 02, 03, 04, 05

207.1.3 QUALITY LEVEL

Only ER level "P" or higher shall be used.

SECTION 300

DISCRETE SEMICONDUCTOR DEVICES

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300 DISCRETE SEMICONDUCTOR DEVICES

300.1 GENERAL INFORMATION

Standard semiconductor devices are those listed in MIL-STD-701. These devices are a subset of those meeting the general requirements of MIL-S-19500 and the detailed requirements of MIL-S-19500 slash sheets.

300.2 APPLICATION CONSIDERATIONS

300.2.1 GENERAL APPLICATION DATA

a. Device Parameter Drift - Semiconductor devices may exhibit change in parameter values over their life within specified limits. Therefore, for long life reliability the design should be able to tolerate a shift in the parameters as shown in Table 300-I:

TABLE 300-I

DEVICE PARAMETER TOLERANCE

Parameters	Diodes	Transistors	Thyristors
Gain			
Initial	--	±10%	--
Match	--	±20%	--
Leakage (off state) Current	+100%	+100%	+100%
Recovery, switching times	+20%	+20%	+20%
Junction voltage drop			
Forward, saturation	±10%	±10%	±10%
Forward, match	--	±50%	--
Zener - Regulator	±2%	--	--
- Reference	±1%	--	--

b. Sealing - Only hermetically sealed devices shall be used. No plastic (organic or polymeric) encapsulated or sealed devices shall be used without the approval of the procuring activity.

c. Uncontrolled Characteristics - Satisfactory equipment performance should not depend on a semiconductor device characteristic which is not controlled by the applicable MIL-S-19500 detail specification.

d. Electrostatic Damage Sensitivity - Most semiconductor devices are susceptible to electrostatic discharge (ESD) damage. Appropriate procedures compatible with DOD-STD-1686 and DOD-HDBK-263 shall be used when handling these parts, and selection of devices should include an analysis of the input protection circuitry.

e. Surge Current - Only devices rated by the vendor for surge currents shall be used in circuits where surge currents might logically occur.

300.2.2 DIODES

300.2.2.1 Rectifiers

a. Characteristics - Junction diodes designed for use as rectifiers should have I-V characteristics as close as possible to that of the ideal diode. The reverse current should be negligible, and the forward current should exhibit little voltage dependence. The reverse breakdown voltage should be large, and the offset voltage in the forward direction should be small.

b. Silicon vs Germanium - A rectifier made with a wide band gap material can be operated at higher temperatures. Thus Silicon (Si) is preferred over Germanium (Ge) for power rectifiers because of its wider band gap, lower leakage current, and higher breakdown voltage. In general, Ge semiconductors shall not be used in military applications without approval from the procuring agency.

c. High Reverse Bias Devices - Devices designed for use at high reverse bias should be of bevelled edge or guard ring construction.

d. Rectifier Junction Mounting - The mounting of a rectifier junction is critical to its ability to handle power. For diodes used in low-power circuits, glass or plastic encapsulation or a simple header mounting is adequate. However, high-current devices which must dissipate large amounts of heat require special mountings to transfer thermal energy away from the junction. Generally Si power rectifiers are mounted on molybdenum or tungsten disks to match the thermal expansion properties of the Si. This disk is fastened to a large stud of copper or other thermally conductive material that can be bolted to a heat sink.

e. Recovery Time - If the external voltage is suddenly reversed in a diode circuit which has been carrying current in the forward direction, the diode will not immediately fall to its steady-state reverse-voltage value until the excess minority carrier density has dropped nominally to zero. There is also a switching transient time (recovery time) when the voltage is switched from reverse to forward direction, because the depletion layer capacitance has to be discharged and diffusion capacitance has to be charged before the steady-state forward current is established.

The effect of a finite recovery time has very important implications on the uses and limitations of diodes for rectification and switching. When rectifying, it is obvious that if a high frequency voltage is to be rectified having a period of the same order of magnitude as the recovery time, there will not be any rectification. During the first, positive, half cycle, the diffusion capacitance will charge and during the second, negative, half cycle, the capacitance would discharge and the diode would operate as if it were a capacitor and not a rectifying element. Each diode has therefore an upper limit to the frequency at which it can be used for rectification (or for demodulation of RF waves in case of diodes intended for RF detection). The rectification efficiency of a diode, which usually operates as a line-frequency rectifier or as a low-frequency switch, may drop to 50 percent when the frequency is increased to a few kHz.

300.2.2.2 Zener and Reference Diodes

a. Temperature Coefficients of Zeners - For Zener diodes, the temperature coefficient is given as the percentage change in reference voltage per degree centigrade change in diode temperature. The temperature coefficients are supplied by the manufacturer. The temperature coefficient may be either positive or negative and will normally be in the range of +0.1%/°C. If the reference voltage is above 6V, where the physical mechanism involved is avalanche multiplication, the temperature coefficient is positive. However, below 6V, where true zener breakdown is involved, the temperature coefficient is negative.

b. Slope of V-I Curve - Another parameter of importance in connection with Zener diodes is the slope of the diode volt-ampere (V-I) curve in the operating range. If the reciprocal slope $\Delta V/\Delta I$ called the dynamic resistance is r, then a change ΔI in the operating current of the diode produces a change $\Delta V = r\Delta I$ in the operating voltage. Ideally, $r = 0$, corresponding to a volt-ampere curve which, in the breakdown region, is precisely vertical. The variation of r at various currents for a series of Avalanche diodes of fixed power dissipation rating and various voltages shows a rather broad minimum in the range of 10V. This minimum value of r is of the order of magnitude of a few ohms. However, for values of zener voltages, V_E, below 6V or above 10V, and particularly for small currents (approximately equal to 1 mA), r may be of the order of hundreds of ohms. Some manufacturers specify the minimum current below which the diode should not be used. Since this current is on the knee of the curve, where the dynamic resistance is large, for currents lower than this minimum current, the regulation will be poor. Some diodes exhibit a very sharp knee even down into the microampere region.

c. Transition Capacitance - The capacitance across a breakdown diode is the transition capacitance, C_T, and hence varies inversely with the voltage. Since C_T is proportional to the cross-sectional area of the diode, high-power Avalanche diodes have very large capacitances affecting the frequency response of the devices. Values of C_T from 10 to 10,000 pf are common.

d. Diodes in Series - Zener diodes are available with voltages as low as 2V. Below this voltage it is customary, for reference and regulating purposes, to use diodes in the forward direction. A number of forward biased diodes may be operated in series to reach higher voltages. Such series combinations, packaged as single units, are available with voltages up to about 5V, and may be selected over reverse biased Zener diodes, which at low voltages have very large values of dynamic resistance.

e. Temperature Coefficient - When it is important that a Zener diode operate with a low temperature coefficient, it may be feasible to operate an appropriate Zener diode at a current where the temperature coefficient is at or near zero. Frequently such operation is not convenient, particularly at higher voltages and when the diode must operate over a range of currents. Under these circumstances a temperature-compensated non-Zener Avalanche diode can be used in series with a Zener diode to achieve the desired results. Such circuits consist of a reverse-biased Zener diode with a positive temperature coefficient in series in a single package with a forward-biased non-Zener diode whose temperature coefficient is negative.

f. High Voltage Reference Application - Where a high-voltage reference is required, it is usually advantageous to use two or more diodes in series rather than a single diode. This combination will allow higher voltage, higher power dissipation, lower temperature coefficient, and lower dynamic resistance.

300.2.2.3 Tunnel Diodes

a. Applications - One application of the Tunnel diode is its use as a very high-speed switch. Since tunneling takes place at the speed of light, the transient response is limited only by total shunt capacitance (junction plus stray wiring capacitance) and peak driving current. Switching times of the order of a nanosecond are common, and switching times as low as 50 ps can be obtained. A second application of the tunnel diode is as a high-frequency (microwave) oscillator.

b. Types of Tunnel Diodes - The most common commercially available Tunnel diodes are made from Germanium (Ge) or Gallium Arsenide (GaAs). It is difficult to manufacture a Si tunnel diode with a high ratio of peak-to-valley current (I_p/I_v). GaAs has the highest ratio of I_p/I_v. The peak current I_p is determined by the impurity concentration (the resistivity) and the junction area. For computer applications, devices with I_p in the range of 1 to 100 mA are most common. The peak point (V_p, I_p), which is in the tunneling region, is not very sensitive to temperature. However, the valley point (V_v, I_v), which is affected by the injection current, is quite temperature-sensitive.

c. Characteristics - The advantage of the tunnel diode are low cost, low noise, simplicity, high speed, environmental immunity, and low power. The disadvantages of the diode are its low output-voltage swing and the fact that it is a two-terminal device. Because of the latter feature, there is no isolation between input and output, and this leads to serious circuit-design difficulties.

d. Recovery Time (See 300.2.2.1(e)) - When used as a switch, the diode must react quickly to fast pulses by going from conduction to cut-off, and the finite recovery time will limit the maximum pulse rate. Fast switching diodes must therefore have a very short recovery time. This is achieved by shortening the minority carriers' life time. Three orders of magnitude reduction (to less than 1 ns) can be obtained by inclusion of gold (Au) in Si. The "price" paid for the addition of the gold atoms is mostly an increase in reverse voltage leakage current with associated increased noise output and some reduction in the reverse breakdown voltage.

300.2.2.4 Varactors

a. Application - The Varactor diode is designed to exploit the voltage-variable properties of the junction capacitance. For example, a Varactor (or a set of Varactors) may be used in the tuning stage of a radio receiver to replace the bulky variable plate capacitor. The size of the resulting circuit can be greatly reduced, and its reliability is often improved. The series resistance and leakage current should be small so that the selectivity "Q" is high. In addition, the range of capacitance variation should be large. For some high-frequency applications, Varactors can be designed to exploit the forward-bias charge storage capacitance. The Step-Recovery diode is an example of this type of device.

300.2.2.5 Thyristors

A thyristor is a bistable semiconductor device that has three or more junctions (i.e., four or more semiconductor layers) and can be switched from a high impedance (OFF) state to a conducting (ON) state or vice versa. There are several types of thyristors which differ primarily in the number of electrode terminals and operating characteristics. Reverse-blocking triode thyristors, commonly called silicon controlled rectifiers (SCRs), bidirectional triode thyristors, referred to as triacs, are the most popular types. A triac can be considered as two parallel SCRs (p-n-p-n) oriented in opposite directions to provide symmetrical bidirectional characteristics.

Some features of thyristors are: (1) to initiate regeneration a gate triggered current is required, (2) to maintain regeneration latching current must be available, where latching current is the minimum principal current, (3) reduction of principal current flow results in turn-off at some level of current flow slightly greater than zero (defined as holding current (I_H)).

Triacs or SCRs when triggered by a gate signal, consists of two stages for turn-on time. These stages are a delay time (t_d) and a rise time (t_r). The delay time t_d is the time interval between the 50 percent point of the leading edge of the gate trigger voltage (V_{GT}) and the 10 percent point of the principal current for a resistive load. The rise time t_r is the time interval for the principal current to rise from 10 to 90 percent of its maximum value. The total turn-on time is ($t_d + t_r$).

For triacs a reverse voltage cannot be used to provide turn-off voltage because a reverse voltage applied to one-half of the triac would be a forward-bias voltage to the other half. SCR turn-off time, t_{off}, signifies the ability of the device to withstand re-application of a forward voltage t_{off} seconds after the anode current goes below the holding current. At this point the device is supposed to switch off. Due to the excess stored charge left over from the conduction period the device may turn on spontaneously if forward voltage is reapplied too quickly. One solution is the use of gold diffusion, which increases the number of recombination centers. This method shortens the device life time. Another method uses a momentary negative voltage pulse to the gate, sweeping out the charge. This is known as gate-assisted turn-off.

300.2.3 MICROWAVE SEMICONDUCTOR DEVICES

a. Characteristics - The microwave frequency range, i.e., from 1 GHz (10^9 Hz) up to 100 GHz and further, is becoming more and more common in present-day communication systems. Low power (up to a few watts) solid state microwave devices are becoming more and more available. The high-power microwave field is still dominated by vacuum tubes. The requirements relating to high power and high frequency semiconductor-device design are often contradictory.

Some specially designed high frequency transistors can provide amplification at the lower microwave frequencies; however, transient time and other effects limit the application of transistors beyond the 1 GHz range. Therefore, devices other than solid state semiconductors are required to perform electronic functions such as amplification and dc to microwave power conversion at higher frequencies.

Several high-frequency devices use the inherent instability characteristics which occur in semiconductors. One such instability is the acousto-electric effect involving the high-frequency interaction between electrons and the lattice vibrations of certain crystals. There are other types of instabilities, including "negative conductance". The most common negative conductance devices are: IMPact Avalanche Transit Time (IMPATT) diodes, which depend on a combination of impact ionization and transit time effects, and Gunn diodes which depend on the transfer of electrons from a high-mobility state to a low-mobility state. Each is a two-terminal device which can be operational in a negative conductance mode to provide amplification or oscillation at microwave frequencies.

b. Use of Si vs GaAs for Microwave Applications - As a semiconductor, GaAs is more attractive for microwave devices than Si, for two reasons:

o The electron mobility in GaAs is several times higher than in Si. This shortens transit times and increases the high-frequency capability of these devices.

o GaAs can withstand higher working temperatures due to its larger band gap. This is particularly important in the very small geometry devices used in microwaves that must dissipate a lot of power.

There are, however, serious drawbacks in using GaAs. GaAs technology is lagging behind that of Si. A complicated structure such as a bipolar transistor cannot be made to a high enough standard of quality and repeatability, especially as minority carrier life times are very short and base width must therefore be very narrow. A majority carrier device, however, similar to a JFET, where operation does not depend on surface effect and oxide can very well be made with present day technology and has the highest cut-off frequency "f_T" yet achieved in a transistor. This device is called a MESFET. This device cut-off frequency "f_T" is 35 GHz for a channel length of 1 μm. Such a device is a good small-signal microwave amplifier. If a wide enough channel and good heat sinking is used, it can also serve as a power amplifier; power outputs of several watts, at frequencies up to 15 GHz can be obtained.

c. The IMPATT Device - This device is commonly used for power generation at microwave frequencies because of their small size, reliability and output power. Calculation of the IMPATT device input impedance depends on the impurity profile, the knowledge of the ionization coefficients for holes and electrons and their dependence on the field. Efficiencies as high as 30 percent were achieved in GaAs devices. Output power as high as 10W (CW) at 10 GHz was also obtained. This is higher than any other semiconductor device can deliver today at this frequency. One important drawback is the noise inherent in the IMPATT ionization process which can interfere with the signal in some frequency ranges.

d. The Gunn of Transferred-Electron Device (TED) - Microwave devices which operate by the transferred electron mechanism are called Gunn diodes after J. B. Gunn, who first demonstrated one of the forms of oscillation. Basically, the device is made from a piece of N GaAs with N+ regions for contacts. In the transferred electron mechanism, the conduction electrons of some semiconductors are shifted from a state of high mobility to a state of low mobility by the influence of a strong electric field.

Gunn diodes and related devices are simple structures in principle, since they are basically homogeneous samples with ohmic contacts on each end. In practice, however, considerable care must be taken in fabricating and mounting workable devices. In addition to the obvious requirements on doping density, carrier mobility, and sample length, there are important considerations relating to contacts, heat sinking, and parasitic reactances of the packaged device.

Removal of heat is a very serious problem in these devices. The power dissipation may be 10^7 W/CM^3 or greater, resulting in considerable heating of the device. As the temperature increases, the device characteristics vary because of changes in carrier concentration and mobility. As a result of such heating effects, these devices seldom reach their theoretical maximum efficiency. Pulsed operation allows better control of heat dissipation than does continuous operation, and efficiencies near the theoretical limits can sometimes be achieved in the pulsed mode. The limited space charge accumulation (LSA) mode is particularly suitable for microwave power generation because of its relatively high efficiency and high operating frequencies. If the application does not require continuous operation, peak power of hundreds of watts can be achieved in pulses of microwave oscillation.

300.2.3.1 Other Microwave Devices

a. Detector Diode - A device which converts RF energy into dc or video output.

b. Mixer Diode - A microwave diode that combines RF signals at two frequencies to generate an RF signal at a third frequency.

300.2.4 PHOTOEMITTING DEVICES

a. Light Emitting Diode (LED) - A diode capable of emitting luminous energy resulting from the recombination of electrons and holes.

300.2.5 TRANSISTORS

300.2.5.1 Bipolar

a. Maximum Current Ratings - Maximum collector current is usually determined by junction heating considerations and the heat convection ability of the transistor and its mount. In large area power transistors there is the danger of non-uniform current distribution across the emitter area. Hot spots can form where current densities exceed the average. Special emitter structures are used to prevent this. Sometimes manufacturer's current limitations arise from the method and materials used for interconnecting the transistor chip to the encapsulation terminals.

A reason for recommending maximum operating current is the sharp drop in h_{FE} beyond that point. The base-emitter junction is especially vulnerable to overheating because of its much smaller area. Also this junction usually contains a smaller metal contact than the collector's contact which helps in heat removal.

b. Maximum Power Dissipation - The danger of collector junction overheating is most severe when both high-current and high-voltage conditions exist. The dissipated power that must be removed is approximately the product of the average values of I_C and V_{CE}. Transistor data sheets include the maximum collector dissipation rating, "P_D" maximum, at a given transistor case temperature, "T_C" or a given air ambient temperature, T_A. The P_{DMAX} can be calculated from one of the heat flow equations below:

$$T_{JMAX} = T_C + (\theta_{JC} \cdot P_{dMAX})$$

or

$$T_{JMAX} = T_A + (\theta_{JA} \cdot P_{dMAX})$$

where θ_{JA} = Thermal resistance from the collector junction to the air surrounding the transistor in °C/W

θ_{JC} = Thermal resistance from the collector junction to the transistor case in °C/W

T_{JMAX} = Maximum allowable junction temperature in °C

The thermal resistances are related by the following equation:

$$\theta_{JA} = \theta_{JC} + \theta_{CA}$$

where θ_{CA} = Thermal resistance from the transistor case to the surrounding air in °C/W

c. Maximum Voltages, First Breakdown - In some high-frequency alloy junction transistors, with narrow, low doped bases, punch-through breakdown can limit the maximum collector voltage. The collector junction depletion layer extends through the whole base, reaching the emitter junction on the other side when V_{CE} is high. Further increase of V_{CE} will forward bias the emitter junction, causing a sharp current increase which is limited only by the external circuit. If no overheating occurs, however, the transistor suffers no permanent damage.

Punch-through breakdown does not usually occur in planar type transistors because the base impurity density obtained by diffusion is higher everywhere except at the collector. This causes the depletion layer to extend mostly into the collector, by increasing the collector voltage junction fields to the point where avalanche multiplication starts before punch-through is reached. At this point, the current is then multiplied by a factor and increases very fast with the voltage. It is to be noted that high-voltage transistor operation necessitates the use of low collector doping densities in the transistor design since this increases BV_{CBO}. Reduced collector doping, however, increases its parasitic bulk resistance between the junction and the outside terminal. This is why the planar epitaxial transistor was developed. Here low-collector doping is maintained only near the collector junction, while the collector bulk needed for mechanical strength has high doping and low resistivity. Such a structure is essential for a switching transistor that must withstand high voltages in its "off" state and must present low saturation voltage in its "on" state.

Emitter-base junction breakdown occurs at rather low reverse voltage in planar transistors due to the relatively high doping densities on both sides of the junction. One should not apply more than a few volts of reverse voltage to it without an external series resistance high enough to protect against excessive current when breakdown occurs. Alloy junction transistors can withstand high reverse base voltages due to their lower base doping.

d. Secondary Breakdown - If a power transistor is allowed to reach and maintain high currents in the high-voltage avalanche zone (see Figure 300.1) the second breakdown phenomenon may occur. By "second breakdown" we refer to a destructive process that can occur even though the current and voltage separately are still below the maximum ratings.

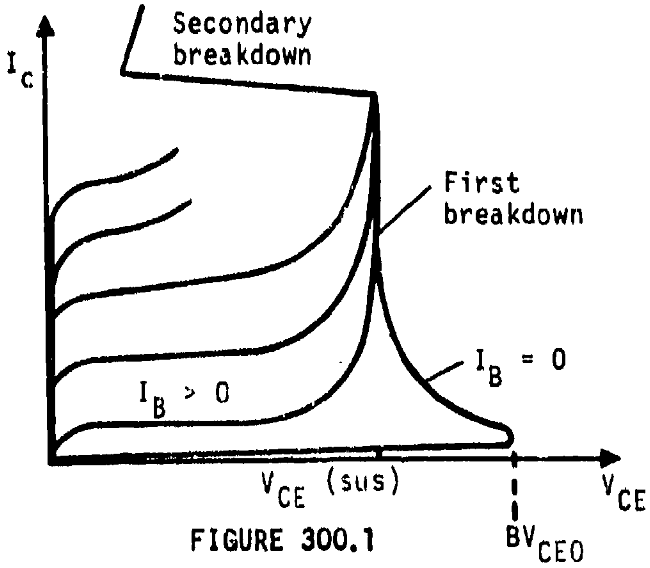
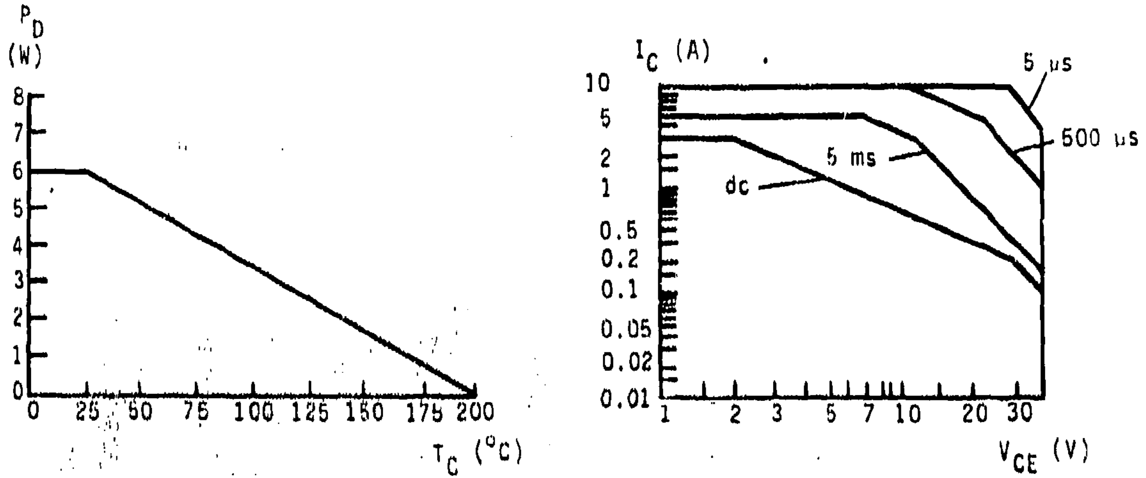


FIGURE 300.1

TRANSISTOR CHARACTERISTICS IN THE BREAKDOWN RANGE (COMMON EMITTER CONNECTON)

Secondary breakdown results from hot-spot formation in the semiconductor from non-uniform current density distribution and a positive feedback effect. Accidental crystal faults, doping fluctuation or other non-uniformities originated by processing may cause this current non-uniformity. At extreme operating conditions these spots overheat, reducing the necessary V_{BE} for a given current and increasing the local thermally generated carrier density resulting in more current concentration. Within a few microseconds local melting can occur with irreparable damage. This is shown in the characteristics by a sudden collector voltage drop followed by a sharp current increase.

A typical power-dissipation derating curve for a Si transistor based upon case temperature is given in Figure 300.2(a).



(a)

(b)

FIGURE 300.2

POWER SPECIFICATIONS FOR A TYPICAL Si TRANSISTOR (MOTOROLA 2N3719); (a) ALLOWED DISSIPATION DERATING CURVE VERSUS CASE TEMPERATURE; (b) SAFE OPERATING AREA MAP

Some manufacturers supply a chart of I_C - V_{CE} (see Figure 300.2(b)) that divides the active region into safe operating areas. The transistor is safe from secondary breakdown if it operates in that area for a limited time. For example, transistor 2N3719 can tolerate I_C = 10 A at V_{CE} = 30 V for only 5 μs but may tolerate 1 A at the same V_{CE} for 500 μs and 0.1 A for indefinite periods.

300.2.5.2 Unijunction Transistor

One of the most common applications of electronic devices is in switching, which requires the device to change from an "off" or blocking state to an "on " or conducting state. Transistors can be used in this application where base current drives the device from cut-off to saturation. Similarly, diodes and other devices can be used to serve as certain types of switches. There are a number of important switching applications that require a device to remain in the blocking state under forward bias until switched to the conducting state by an external signal. One device which fulfills this requirement is called the unijunction transistor (UJT). UJT is typified by a high impedance ("off" condition) under forward bias until a switching signal is applied; after switching a UJT exhibits low impedance ("on" condition). In this case the signal required for switching can be varied externally by changing an external voltage source. Therefore, these devices can be used to block or pass currents at predetermined levels. This device is useful in various switching applications, timing circuits, and for triggering other devices. Another advantage of the UJT is that its switching properties are relatively independent of temperature.

300.2.5.3 Field Effect Transistors

A Field Effect transistor is a transistor in which the conduction is due entirely to the flow of majority carriers through a conduction channel controlled by an electric field arising from a voltage applied between the gate and source terminals.

300.3 DERATING REQUIREMENTS

Generally, semiconductor devices are given two rating points; one for maximum permissible junction temperature (T_{JMAX} in Figure 300.3) and the other for the maximum case or ambient temperature at which 100 percent of the maximum power dissipation is allowed (T_S in Figure 300.3). Maximum case or ambient temperature is the temperature at which 100 percent of the rated load can be dissipated without the internal temperature rise causing the specified maximum junction temperature to be exceeded. As the ambient or case temperature rises above T_S value, the rated load must be decreased if the maximum junction temperature, T_{JMAX}, is not to be exceeded (see Figure 300.3). Figure 300.3 also includes a plot of the maximum allowable stress level. For discrete semiconductor applications the nominal stress level shall not exceed the maximum allowable stress level. The maximum allowable junction temperature is the maximum derated temperature (T_{DM}) which can be calculated using the following formula.

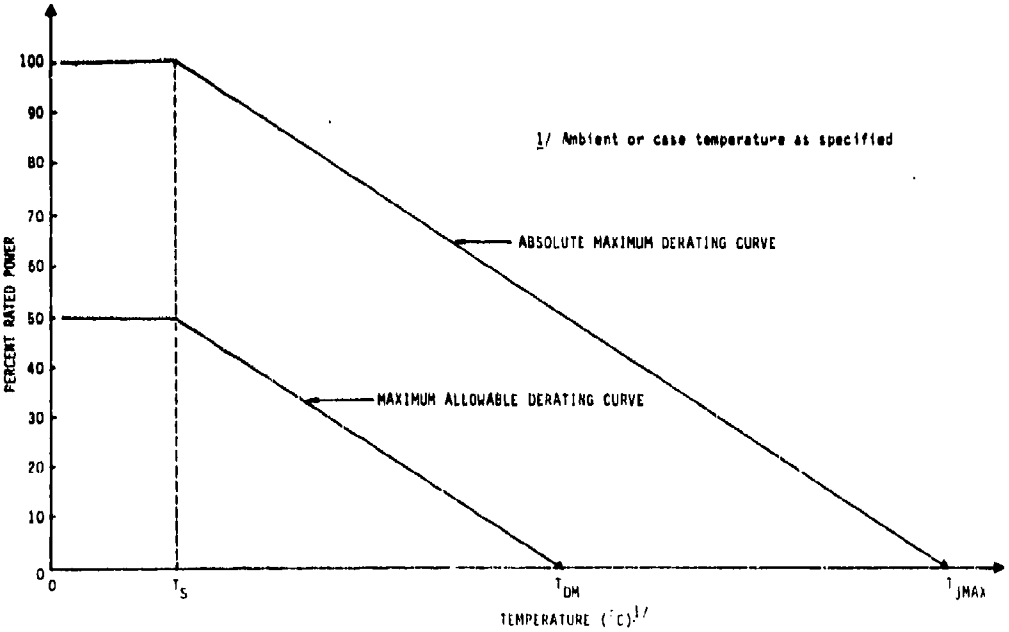


FIGURE 300.3

POWER DERATING CURVES

For maximum allowable derated temperature, $T_{DM} = \frac{T_S + T_{jMAX}}{2}$

Where:

T_{jMAX} = Maximum permissible junction temperature (°C)

T_{DM} = Maximum derated temperature (°C)

T_S = Temperature above which derating must occur (°C)

In addition to limitations of the above derating curve, the following parameters shall be limited to the values specified in Tables 300-II and 300-III for diodes and transistors, respectively.

TABLE 300-II

ADDITIONAL DIODE PARAMETERS

Parameter	Max. % of rated electrical values
Forward Continuous Current	50
Surge Current	70
Inverse Voltage	65
Transient Voltages	80

TABLE 300 III

ADDITIONAL TRANSISTOR PARAMETERS

Parameter	Max. % of rated electrical values
Forward Continuous Current	70
Forward Surge Current	75
Breakdown (Reverse Junction) Voltage	70

300.4 QUALITY LEVELS

Only JANTX or higher quality levels shall be used.

SECTION 400

MICROCIRCUITS

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400 MICROCIRCUITS

400.1 GENERAL INFORMATION

Standard microcircuits are those listed in MIL-STD-1562. These devices are a subset of those meeting the general requirements of MIL-M-38510 and the detailed requirements of MIL-M-38510 slash sheets.

Microcircuits, also known as Integrated Circuits (ICs), enable one to produce a large number of complete circuits on the same Silicon (Si) wafer. Each circuit may contain a large number of transistors, diodes, resistors and possibly some small capacitors, all interconnected by overlying thin aluminum (Al) lines, ending up at a small number of Al pads to which electrical connections from the outside are made.

The whole wafer is processed as a single unit. When the metallization interconnection is completed each circuit is electrically tested, marked if bad, and finally the wafer is cut up into individual dies, each comprising a single circuit. From this point on each circuit requires individual (and costly) handling. Each good circuit die (rectangular chip of the original wafer) is bonded on a header of Gold (Au) or Al. Wires are bonded to the Al pads on the die and to the header terminals, and the encapsulation is finished by sealing.

A semiconductor integrated circuit can be based on bipolar or MOS technology as shown in Figure 400.1. The steps in the processing of these two technologies are different in both number and sequence, and these two technologies are not usually designed into the same circuit (although this can be done by a more complex processing).

The circuits may also be classified according to their use: linear circuits for both small signal and low to high power use, and digital circuits for logic use.

The fast development in IC technology, since its beginning in the early 1960s, stems from several important causes:

a. Increased complexity of electronic circuitry;

b. The reliability problems associated with complicated circuits of discrete parts;

c. The need for reduction in the required operating power;

d. Physical size and weight constraints;

e. The economics of high cost discrete parts vs low cost ICs;

f. The ability of IC approaches to provide new and better solutions to systems problems (e.g., circuit speed).

400.1.1 LARGE SCALE INTEGRATION

Economic pressures to produce larger, more complex chips, aided by steady progress in reducing chip defects, have resulted in the production of large scale integrated (LSI) circuits. The principal technical distinction

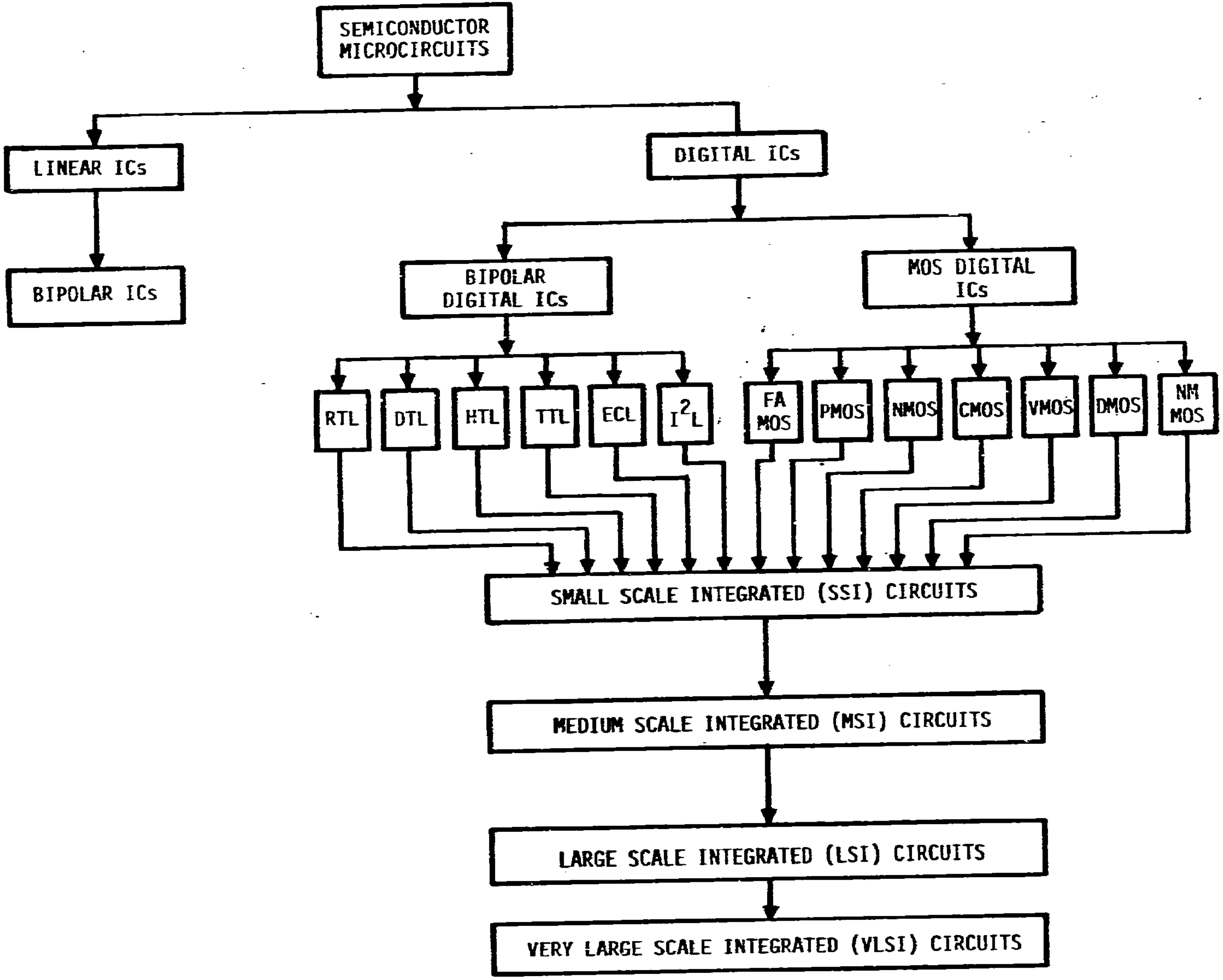
SEMICONDUCTOR MICROCIRCUITS
LINEAR ICs
DIGITAL ICs
BIPOLAR ICs
BIPOLAR DIGITAL ICs
MOS DIGITAL ICs
RTL
DTL
HTL
TTL
ECL
I^2L
FA MOS
PMOS
NMOS
CMOS
VMOS
DMOS
NM MOS
SMALL SCALE INTEGRATED (SSI) CIRCUITS
MEDIUM SCALE INTEGRATED (MSI) CIRCUITS
LARGE SCALE INTEGRATED (LSI) CIRCUITS
VERY LARGE SCALE INTEGRATED (VLSI) CIRCUITS

FIGURE 400.1

between LSI and conventional ICs is the use of multilevel interconnections for LSI. This permits the efficient interconnection of individual ICs on the same wafer to form very complex circuits. It also allows extensive circuit changes by changing only a single interconnection mask.

Like other ICs, LSI chips require a mass market to be economically feasible. Thus, LSI manufacturers follow the IC strategy of mass producing general-purpose circuits and limited special purpose consumer circuits. LSI circuits offer an additional advantage -- programmability -- by which a standard circuit can be made to fit an individual user's special needs. Semiconductor memories and microprocessors are two widely used types of programmable LSI circuits.

Read/write memories, often called random-access memories (RAMs), are used for temporary storage of programs or data; these memories are volatile, i.e., data is lost when power to the memory is interrupted. Non-volatile semiconductor memories include read-only memories (ROMs) and programmable read-only memories (PROMs). ROMs are usually mask-programmable, i.e., made to order by a semiconductor supplier using a custom interconnection mask. PROMs can be programmed electrically by the user or a programming service. These memories can be used not only for storage of data or programs, but also to replace logic gates.

Microprocessors provide the functional parts of a small general purpose computer in the form of a low cost LSI chip(s). Microprocessors are usually dedicated devices handling a variety of inputs and outputs in accordance with a fixed program. A microprocessor system design involves the programming of the processor's instruction ROMs as well as the physical interconnection to peripheral devices. Most processor programming is presently done in assembly language, although machine language and higher level languages are also used. The relatively high cost of programming makes the provision of higher language capability very probable in future microprocessor operations.

Custom designed LSI ICs provide the opportunity for maximum LSI performance to the user when a market for the product is large enough to recover the design costs.

400.1.2 PRODUCTION FALLOUT

Results of extensive screening tests indicate that while products of a well developed technology, such as simple TTL logic gates, had production fallout on the order of 1 percent of units tested, many newer and more complex devices had an alarmingly high fallout rate (5 percent to 19 percent). High device fallout rates become more significant when hundreds of devices are assembled into a completed assembly that is difficult and expensive to repair. Fallout rates of today's state-of-the-art devices will no doubt decrease and stabilize as their technologies mature. This is accounted for in the IC learning factor of MIL-HDBK-217 IC failure rate prediction method. In the meantime, it seems necessary for any serious user of complex ICs or LSI products to be prepared to perform comprehensive device screening in an attempt to find marginal devices before they require high maintenance and repair/rework costs in the field.

400.1.3 DIGITAL ICs

Digital ICs are the most commonly used ICs. They comprise the functional building blocks of logic and computer systems. Principal characteristics of common digital logic families are summarized in Table 400-I. The comparisons given are for functions of the same complexity for units specified in the same operating temperature range. ICs of a given type are usually available in several specified temperaure ranges, the most common being the industrial range of 0° to 70°C and the military (MIL-M-38510) range of -55°C to 125°C. The military temperature range ICs can cost several times more than the industrial range because of the need for more careful selection and testing. It is also worth noting that the most expensive IC lines (HTL, ECL, I^2L, CMOS) are also the least mature.

Some of the families shown in Table 400-I (RTL, high-threshold PMOS) are approaching obsolescence, the last stage in the life cycle of typical manufactured products. These families shall not be used in new designs. Families which have the notation "LSI" in the "number of functions" row are generally available only in the form of memories and complex processing circuits.

Advantages and disadvantages of different families of digital ICs are summarized in Table 400-II.

400.1.4 LINEAR ICs

The linear line of integrated circuits can be indexed by functional applications such as:

- Voltage Regulator
- Voltage Reference
- Operational Amplifier
- Instrumentation Amplifier
- Voltage Comparator
- Analog Switch
- Sample and Hold Amplifier
- Analog to Digital Converter (A-D)
- Industrial/Automotive/Functional Blocks
- Audio, Radio and TV Devices
- Transistor Arrays

The absolute maximum ratings specified for these devices are similar to those of discrete transistors.

TABLE 400-I

COMPARISON OF MAJOR IC LOGIC FAMILIES

PARAMETER	RTL	HTL	TTL	ECL	I^2L	P, NMOS	CMOS
Power Supply Voltage (±10%), Volt	3 to 3.6	15	5	-5.2	1.5 to 15	-27 to -13 (PMOS), 5.0 (NMOS)	1.5 to 16
Gate delay, ns	10 to 25	80 to 100	3 to 15	0.5 to 2	10 to 50	1 to 10	10 to 50
Power Dissipation per gate, mw	2 to 15	50	10 to 25	25 to 50	0.05 approx.	0.1 to 1	50 nW freq. dep.
Fan out	4 to 5	10	10	10 to 25	1	25 1 TTL gate	50
Noise Immunity	Poor	Excellent	Very Good	Good	Fair	Fair/Good	Very Good
Number of Functions	High	Low	High/Very High	High	Low	Medium/High	Medium
Cost Per Function	Getting Higher	Medium	Low/Medium	Medium	Low	Low	Medium

TABLE 400-II

ADVANTAGES AND DISADVANTAGES OF DIFFERENT FAMILIES OF DIGITAL ICs

FAMILY	ADVANTAGES	DISADVANTAGES
RTL	1. Low supply voltage, low power dissipation 2. Relatively low noise generation 3. Most functions capable of implied "AND" connection	1. Low voltage-noise immunity 2. Low fanout 3. Obsolete (circuits will become scarcer and expensive)
DTL	1. Relatively low cost 2. Good fanout 3. Easily mixed with TTL	1. Relatively poor noise immunity despite large voltage-noise margins 2. Lower speed capabilities than other logic families 3. Declining market share - poor rate of new function introduction
HTL	1. Best voltage and energy noise immunity 2. Largest logic swing 3. Interfaces well with electromechanical components 4. Compatible with discrete power control devices such as silicon controlled rectifiers (SCRs)	1. Relatively expensive logic form 2. Large gate delays 3. Relatively high power dissipation 4. Fewer functions available at present than other forms
TTL	1. Highest speed of saturating logic forms 2. Good immunity to energy noise 3. Active pull-ups provide excellent drive capability 4. Good fanout 5. Wide and expanding variety of available functions 6. Readily available from many sources; medium speed TTL is very cost competitive with other logic forms	1. High voltage and current switching rates require careful layout to avoid cross talk 2. Internal current transients require well bypassed supplies 3. Active pull-up prevents implied "AND" connection in most forms 4. All forms except medium speed are relatively expensive

TABLE 400-II (CONT'D)

ADVANTAGES AND DISADVANTAGES OF DIFFERENT FAMILIES OF DIGITAL ICs

FAMILY	ADVANTAGES	DISADVANTAGES
ECL	1. Highest speed logic available 2. Compatible with transmission line interconnection 3. Low levels of noise generation 4. Good fanout capability 5. Implied "OR" capability 6. Complementary outputs	1. Supply and logic levels require interfacing circuits to saturating logic types 2. Power dissipation higher than some families 3. Low external noise immunity 4. High speed versions relatively high in cost
I^2L	1. Lowest (best) delay time-power product 2. Operates on very low supply currents per gate 3. Simple, high density structure promises low cost, high complexity 4. Low internal noise generation 5. Compatible with TTL drivers	1. Low external noise immunity 2. Not available in a broad range of functions 3. Unable to drive capacitive loads or transmission lines 4. Higher gate delays than TTL or ECL
MOS	1. Low power dissipation (especially CMOS and single channel dynamic logic) 2. NMOS gives lowest cost per bit in large memories and shift registers 3. High device densities (especially single-channel) 4. Excellent fanout 5. CMOS has excellent noise immunity 6. Excellent for large scale integration and very large scale integration 7. CMOS has very wide power supply range	1. Inherently slower than most bipolar logic 2. CMOS expensive, PMOS is becoming obsolete 3. Poor driving capability 4. Vulnerable to damage from static electricity 5. High output impedance 6. Single channel low threshold circuits have relatively poor noise immunity 7. Requires interfacing circuits to operate with bipolar families

400.2 APPLICATION CONSIDERATIONS

400.2.1 USE OF A MINIMUM NUMBER OF STANDARD ICs

Standard ICs included in MIL-STD-1562 shall be used to the fullest extent practicable. Attempts should be made to minimize the required number of IC packages. A single MSI (medium scale integration, defined to have more than 12, but less than 100 gates per chip) can be used in place of a number of SSI (small scale integration, defined to have less than 12 gates (≅100 components)). Similarly, an LSI (large scale integration, containing in excess of 100 gates (≅1,000 components)) can be used in the system to replace several MSI chips. Thus a system should be defined in terms of standard MSI and LSI packages, if not VLSI (very large scale integration, with over 10,000 elements per chip) packages. Discrete gates (SSI) should be used only for "interfaces" (also called the "glue") as required between the subsystem ICs.

400.2.2 IC PACKAGE TYPE

There are three basic types of IC packages: TO-5 (metal can), flat-packs, and dual-in-line (DIP). There is a further division in that the DIP packages are available in both ceramic and plastic.

In some cases, only one style is available for a particular IC. For example, where the IC operates at high power, and dissipates considerable heat, the TO-5 metal can is required, because it permits the use of heat sinks or mounting directly on a metal chassis. Where there is a choice of package styles, where cost is a factor, or where a large volume of ICs is required, the DIP is generally the best choice. DIPs are ideally suited for mounting on printed circuit (PC) boards, since there is more spacing between the leads (typically 0.1 inch) than with other package types. During production, DIPs can be inserted (manually or automatically) into mounting holes on PC boards, and soldered by various mass production techniques.

The real weak spot in any IC package is at the seals where the leads enter the case or body. These seals are usually of glass or plastic and can be easily broken exposing the chip and unplated metal inside the package. This can occur if the leads are bent or twisted during production or repair. Also, broken seals can result in moisture and other undesired elements entering the IC package. While this may not cause immediate failure, it will shorten the life of the IC. The exposed bare metal under the seal can also corrode, and affect the IC performance.

If reliability is the major factor, the ceramic flat-pack is generally the best choice. Ceramic ICs are hermetically sealed to protect the silicon chip. Flat-packs also have an excellent history of reliability. Flat-packs are smaller and lighter than DIPs, with all other factors being equal. Ceramic flat-packs are usually the choice for many military applications, except where high power is involved (there a metal can is preferred for heat dissipation).

400.2.3 MOUNTING AND CONNECTIONS

Once the package type has been selected, the IC must be mounted and electrically connected to other parts. The selection of a particular method of mounting and connection of ICs depends upon: the type of IC package, the equipment available for mounting and interconnection, the connection method used (soldering, welding, crimping, etc.), the size, shape and weight of the overall equipment package, the degree of reliability, the ease of replacement in the field, and the cost factor. The following sections summarize mounting and connection methods for the three basic package types.

400.2.3.1 Breadboard Mounting and Connection

During the breadboard stage of design, the IC packages can be mounted in commercially available sockets. This will eliminate soldering and unsoldering the leads during design and test. Such sockets are generally made of Teflon or similar material, and are usually designed for mounting on a PC board. Other IC sockets are designed for metal chassis mounting. In other cases, the IC can be soldered to the socket that is in the form of a plug-in PC card. The card can then be plugged into or out of the circuit during testing.

400.2.3.2 Ceramic Flat-Pack Mounting and Connection

There are a number of methods for making solder connections to flat packs. The notch in one end of the package which is used as a reference point to identify the lead numbering is generally nearest to lead number 1. Always consult the manufacturer's data regarding IC lead numbering.

Some common soldering techniques use in-line lead and pad arrangements. Although such arrangements simplify lead forming, they result in very close spacing between leads (typically .032 inches) and require the use of high precision production techniques in both board manufacture and the assembly of ICs on the board, particularly when the leads must be inserted through holes in the PC board. Another disadvantage of the in-line arrangement is the limited space available for routing circuit conductors between adjacent solder pads.

Some of these disadvantages as referred to earlier can be overcome by the use of a staggered lead arrangement. In these staggered arrangements the lead holes and terminal pads for adjacent leads on the same edge of a flat package are offset by some convenient distance from the in-line axis. Although a staggered lead arrangement requires somewhat more PC board area per IC than the in-line arrangement, staggered leads provide several advantages: (1) tolerances are far less critical; (2) larger terminal pads can be used; (3) more space is available for routing circuit conductors between adjacent terminal connections; and (4) larger lead holes can be used to simplify lead insertion.

400.2.3.3 TO-5 Style Package Mounting and Connection

The most commonly used method for soldering TO-5 style packages is the one where leads are inserted in the properly plated-through holes in the PC board and connection is completed by dip soldering.

400.2.3.4 Dual-in-Line Package Mounting and Connection

Because the package configurations are very similar, the mounting arrangements and terminal sorting techniques used for these circuits are much the same as those used in the in-line method (400.2.3.2) for the flat-pack

ICs. The DIP terminal leads are larger than those of the flat-pack; the larger sized terminals are more rigid and more easily inserted in PCB or IC socket mounting holes.

Another significant feature of the DIP is the sharp step increase in width of the terminals near the package end. This step forms a shoulder upon which the package rests when mounted on the board. Thus, the DIP package is not mounted flush against the board and as a result, allows printed circuit wiring directly under the package. Also, convection cooling of the package is increased, and the circuit can be easily removed if replacement is required.

400.2.4 CONSIDERATIONS IN THE LAYOUT OF ICs

Different parameters should be considered in layout of each type of IC. For example, most linear ICs have high gain, and are thus subject to oscillation if feedback is not controlled by circuit layout. On the other hand, digital ICs rarely oscillate due to low gain, but are subject to noise signals. Proper circuit layout can minimize the generation and pick up of such noise. The following paragraphs describe those circuit layout problems that IC users must face at one time or another.

400.2.4.1 Layout of Digital ICs

All logic circuits are subject to noise. Therefore, it is recommended that noise and grounding problems be considered from the very beginning of design layout.

Wherever dc distribution lines run an appreciable distance from the supply to a logic chassis (or a PC board), both lines (positive and negative) should be bypassed to ground with a capacitor, at the point at which the wires enter the chassis.

Use 1 to 10 μF capacitors for power-line bypass. If the logic circuits operate at higher speeds (above 10 MHz), add a 0.01 μF capacitor in parallel with each 1 to 10 μF capacitor. Note that even though the system may operate at low speeds, there are higher frequency harmonics generated. These high frequency signals may produce noise on the power line and connecting wiring. If the digital ICs are particularly sensitive to noise, as is the case with the TTL logic form, use at least one additional bypass capacitor for each 12 IC packages.

The dc lines and ground return lines should have cross sections sufficiently large to minimize noise pickup and dc voltage drop. Unless otherwise recommended by the IC manufacturer, use AWG No. 20 or larger wire for all digital IC power and ground lines.

Keep all leads as short as possible to minimize noise pick up. Typically, present day logic circuits operate at speeds high enough so that the propagation time through long wire or cable can be comparable to the delay time through a logic element.

The problem of noise can be minimized if ground planes are used, that is, if the circuit board has solid metal sides. Such ground planes surround the active elements on the board with a noise shield. If it is not practical to use boards with built-in ground planes, a wire should be run around the outside edge of the board with both ends of the wire connected to a common or "equipment" ground.

Do not run logic signal lines near a clock line for more than 7 inches because of the possibility of cross talk.

Some digital IC manufacturers specify that a resistor (typically 1 kΩ) be connected between the gate input and the power supply (or ground, depending upon the type of logic), where long lines are involved. Always check the IC data sheet for such notes.

400.2.4.2 Layout of Linear ICs

The main problem with layout of linear ICs is undesired oscillation due to feedback. Since the ICs are physically small, the input and output terminals are close, creating ideal conditions for undesired feedback. To make matters worse, most linear ICs are capable of passing frequencies higher than those specified on the data sheet.

For example, an operational amplifier used in the audio range (i.e., up to 20 kHz with a power gain of 20 dB) could possibly pass a 10 MHz signal with some slight gain. This higher frequency signal could be a harmonic of signals in the normal operating range and, with sufficient gain, could feedback to the input and produce undesired oscillation. Therefore, always consider linear ICs as being RF, in laying out circuits, even though the IC is not rated for RF operation and the circuit is not normally used with RF. Also, the use of a capacitor to bypass IC power supply terminals to ground will aid in providing a path for any RF.

Keep IC input and output leads as short as possible. Use shielded leads wherever practical. Use one common tie point near the IC for all grounds. Resonant circuits can also be formed by poor grounding or by ground loops in general.

ICs mounted on PC boards (particularly with ground planes) tend to oscillate less than when conventional wiring is used. For that reason, an IC may oscillate in the breadboard stage, but not when mounted in final layout form.

Once all of the leads have been connected to an IC and power is applied, monitor all IC terminals for oscillation with an oscilloscope before signals are applied.

400.2.5 POWER DISSIPATION IN ICs

The maximum allowable power dissipation, "P_D" for an IC is a function of the temperature above which derating must occur "T_S", the maximum ambient temperature "T_A", and the thermal resistance from the semiconductor chip to ambient "θ_{JA}". The relationship is:

$$P_D = \frac{T_A - T_S}{\theta_{JA}}$$

IC data sheets do not necessarily list all of these parameters. It is quite common to list only the maximum power dissipation for a given ambient temperature and a maximum power decrease for a given increase in temperature.

For example, a typical IC might show a maximum power dissipation of 110 mW at 25°C, with a decreasing power rating of 1 mW/°C for each degree above 25°C. If this IC is operated at 100°C, the maximum power dissipation would be: (100 mW - (100°C-25°C)(1 mW/°C)) = 35 mW. Note that the decreasing power rating is the inverse of θ_{PC}.

In the absence of specific data sheet information, the following typical temperature characteristics can be applied to the basic IC package types:

a. Ceramic flat pack:

Thermal resistance = 140°C/W
Maximum storage temperature = 175°C
Maximum ambient temperature = 125°C

b. TO-5 style package:

Thermal resistance = 140°C/W
Maximum storage temperature = 200°C
Maximum ambient temperature = 125°C

c. Dual-in-Line (ceramic):

Thermal resistance = 70°C/W
Maximum storage temperature = 175°C
Maximum ambient temperature = 125°C

As previously stated, power ICs usually use the TO-5 style package. The package is metal and is typically used with some type of heat sink (either an external heat sink or the metal chassis). The data sheets for power ICs usually list sufficient information to select the proper heat sink. Also, the data sheets or other literature often provide recommendations for mounting power ICs. Always follow the IC manufacturer's recommendations. In the absence of such data and to make the reader more familiar with the terms used, the following sections summarize considerations for power ICs.

400.2.5.1 Power ICs

400.2.5.1.1 Maximum Power Dissipation

If the power supply voltages, input signals, output loads, and IC ambient temperature are at their recommended levels, the power dissipation will be well within the capabilities of the IC. With the possible exception of the data required to select or design heat sinks, the user need only follow the data sheet recommendations. The rated power decrease with increase in temperature must be considered in the determination of the allowable power dissipation (see the derating requirements).

400.2.5.1.2 Thermal Resistance

Thermal resistance can be defined as the increase in temperature of the semiconductor material (transistor junctions), with regard to some reference divided by the power dissipated.

Power IC data sheets often specify thermal resistance at a given temperature. The IC characteristics can change with ambient temperature and with the variation in power dissipation. Most ICs incorporate circuits to compensate for the effects of temperature. In power ICs, thermal resistance is normally measured from the semiconductor chip (or pellet) to the case. This results in the term θ_{PC}.

400.2.5.1.3 Thermal Runaway

When current passes through a transistor junction, heat will be generated. If this heat is not dissipated at the case, the junction temperature will increase. This temperature increase causes more current to flow through the junction, even though the voltage and other circuit values may remain constant. With a corresponding increase in current flow the junction temperature increases even further until the transistor burns out. This is known as thermal runaway.

Temperature compensation circuits have been developed by IC manufacturers, the most common places a diode in the reverse bias circuit for one or more transistors in the IC.

400.2.5.1.4 Operating ICs With and Without Heat Sinks

If a power IC is not mounted on a heat sink, the thermal resistance from case to ambient would be so large the allowable power dissipation would be minimal. In general 1 watt is the maximum power dissipation for an IC operating without a heat sink. After about 1 watt (or less) it becomes impractical to increase the size of the case to make the case to ambient air thermal resistance term comparable to the junction to case term.

To properly design a heat sink for a given application, the thermal resistance of both the IC and heat sink must be known. Commercial fin-type heat sinks can be used with TO-5 style ICs. Such heat sinks are especially useful when the ICs are mounted in Teflon sockets, which provide little thermal conduction to the chassis or PCB. Commercial heat sinks are rated by the manufacturer in terms of thermal resistance, usually in °C/W. For example, if the heat sink temperature rises from 25°C to 100°C when 25 W are dissipated, the thermal resistance is 75/25 = 3. This would be listed on the data sheet as an θ_{SA} of 3°C/W. With all other factors being equal, the heat sink with the lowest thermal resistance (°C/W) is best.

Practical heat sink considerations are as follows:

a. When ICs are to be mounted on heat sinks, some form of electrical insulation is usually required between the case and heat sink since most IC cases are not at electrical ground.

b. Because good electrical insulators usually are also good thermal insulators, it is difficult to provide electrical insulation without introducing some thermal resistance between case and heat sink. The best materials for this application are mica and beryllium oxide (Beryllia), with typical °C/W ratings of 0.4 and 0.25, respectively.

c. The use of a zinc oxide filled silicon compound between the washer and chassis, together with a moderate amount of pressure from the top of the IC helps to decrease thermal resistance. If the IC is mounted within a fin-type heat sink, an insulated cap should be used between the case and heat sink.

d. When a washer is added between the IC case and heat sink a certain amount of capacitance is introduced. In general, this capacitance will have no effect on operation of ICs unless the frequency is above 100 MHz. Rarely, if ever, do power ICs operate above the audio range. Thus, few such problems should be encountered.

400.2.5.2 Effects of Temperature Extremes on ICs

The effects of temperature extremes, either high or low, will vary with the type of IC involved, case style and fabrication techniques of the manufacturer. The following general rules can be applied to most ICs:

a. In some instances, the IC will fail to operate at temperature extremes, but will return to normal when the operating temperature is returned to the "normal" range.

b. In other cases, the IC will fail to operate properly once it has been subjected to a temperature extreme. In effect, the IC is destroyed once it is operated at an extremely high temperature primarily because of thermal runaway.

c. In general, high temperatures cause the IC characteristics to change. An increased operating temperature also produces increased leakage currents, increased sensitivity to noise, increased unbalance in balanced circuits, increased "switching spikes" or transient voltages for transistors in digital ICs, and an increase in burn-out.

d. If the power supply voltages, input signals, output loads, and ambient temperatures specified on the data sheet are observed, there should be no danger of failure for any IC. However, as a final check, multiply the rated thermal resistance by the maximum device dissipation and add the ambient temperature. If the result is less than 125°C, the IC should be safe.

e. When an IC is operated at its low temperature extreme, the IC is likely to "underperform". Usually at low temperatures, gain and power output will be different for operational amplifiers and other linear ICs; operating speed will be reduced for digital ICs; and the drive or output load capabilities of digital ICs will be reduced.

f. In no event should the IC be operated below the rated low storage temperature. As a general rule, the low storage temperature limit is 10°C to 20°C below the operating limit.

400.2.6 POWER SUPPLIES FOR ICs

All IC power supply voltages should be referenced to a common or ground, which may or may not be earth or equipment ground.

As in the case of discrete transistors, manufacturers do not agree on power supply labeling for ICs. Some manufacturers use V+ to indicate the positive voltage and V- to indicate the negative voltage, whereas another manufacturer might use the symbols V_{EE} and V_{CC} to represent negative and positive respectively. Thus, the IC data sheet must be studied carefully before connecting any power source. Typically, digital IC power supplies must be kept within ± 5 to ± 10 percent, whereas linear ICs will generally operate satisfactorily with power sources of ± 20 percent. Power supply ripple and regulation are also important. Solid state power supplies with filtering and voltage regulation are recommended. Ripple and any other power supply noise must be kept below 1 percent for noise sensitive circuits.

Proper value capacitors are used with power supply circuits to provide decoupling of the power supply (signal bypass). Usually, disc ceramic capacitors are used for this purpose. The capacitors should always be connected as close to the IC terminals as is practical, not at the power supply terminals. For linear IC power supply decoupling capacitors use capacitance values between .1 and .001 μF.

400.2.7 CALCULATION OF CURRENT REQUIRED FOR LINEAR ICs

The specification sheets for linear ICs usually specify a nominal and possibly a maximum operating voltage, as well as a "total device dissipation", which is defined as the dc power dissipated by the IC itself with output at zero and no load. The required current is obtained by dividing the power by the voltage.

400.2.8 CALCULATION OF POWER REQUIRED FOR DIGITAL ICs

Digital ICs operate with pulses. Thus, current is maximum in either of two states, but not in both states. Most digital IC data sheets list the current drain for the maximum condition. Manufacturers list I_{PDL}, the current drain when the logic signals are low, or I_{PDH}, the "high-state" current drain. If both I_{PDL} and I_{PDH} are listed, it is obvious that the higher of the two indicates the maximum current drain state. Thus current drains should be averaged to calculate power. The current requirements for digital ICs are also affected by the operating speed of the logic circuits and the type of loads into which the IC must operate.

A digital IC will require more current as the operating speed is increased. Generally, the data sheet will list a "nominal operating speed", a "maximum operating speed", and the current drain at the "nominal speed". Of course, the IC should never be operated beyond the maximum speed limit. When operating between the nominal and maximum speeds, the additional current can be approximated by adding 0.5 to 1 mA for each 1 MHz of speed increase.

400.2.9 APPLICATION DATA FOR COMMONLY USED LINEAR ICs

400.2.9.1 Operational Amplifiers

The source of signal error in the op-amp is due to the non-ideal parameters of the device. However, in many applications, the difference between ideal and actual parameters are close to negligible in terms of overall performance. The two parameters affecting signal output error are: finite open-loop gain and finite input resistance. These two non-ideal parameters produce: offset voltage at input; offset current at output; input noise; frequency instability and limited bandwidth.

a. Offset Voltage Error - In applications where a source of error due to input offset voltage is undesirable, select devices with minimum offset voltage characteristics and configure the circuit for offset voltage nulling.

b. Offset Current - If use of an op-amp with high input resistance and low bias current is required then the FET input op-amp should be considered. FET input op-amp features initial (room temperature) bias currents in the 10^{-12} ampere region, however, they have relatively high positive temperature coefficients in terms of change in input bias current versus change in temperature. This characteristic must be considered.

c. Input Noise - In choosing an op-amp, the requirement will often dictate a certain source resistance from which the amplifier must operate. This will dictate the noise performance specification of the device. In general, low input current amplifiers, such as FET input op-amps or low bias current bipolar type op-amps will have lower noise factor with impedances above 10 kΩ. Below 10 kΩ source impedance, the bipolar input op-amp has the lower noise factor. Another consideration is that the noninverting configuration has only half the noise gain as the inverting configuration for equal signal gain, therefore, it offers a lower signal-to-noise ratio. In addition, optimum noise performance may be obtained by the use of transformer coupling.

d. Frequency Instability and Limited Bandwidth - Frequency compensation and slew rate considerations are the most important for optimum ac performance in terms of stability. Frequency compensation is obtained by external circuitry or by selection of devices with internal compensation.

e. Latch-up - Latch-up occurs most often in voltage follower stages where the output voltage swing is equal to the input, and the op-amp output is driven to high levels. Methods to eliminate this failure mode must be considered.

f. Output Short Circuit Protection - Devices with limiting at the output should be considered in the design. If this protection is not internal to the chip, external protective circuitry must be provided.

g. Supply Voltage Protection - Protection circuitry against damage to devices during reversal of power supply voltage or power supply over-voltage should be considered.

400.2.9.2 Voltage Regulators

Voltage regulators consist of a reference voltage and sense error amplifier and a pass power transistor in series with a load or in shunt with load to control voltage across load. Regulation to 0.01 percent can be achieved. When a specific degree of output voltage regulation must be provided, the various error sources that influence the total performance must be separated and analyzed. This includes those source errors mentioned above under op-amps. Other error sources include temperature drifts, wiring voltage drops, power supply induced noise, drift and quality of the reference source. Application considerations are as follows:

a. Voltage Drift Due to Temperature - Temperature compensated devices should be considered to minimize errors due to changes of temperature above or below the designed optimum.

b. Offset Voltage Drift - Circuitry can be provided to initially adjust offset voltage to minimize null offset voltage errors.

c. Wire Size - One of the principal sources of error in high current and extremely close regulation tolerance is the wire size used between regulator terminal and load resistance. Wiring voltage drop must be considered.

d. Noise Characteristics - Because of inherent noise characteristics of zener and reference diodes, filtering must be provided.

e. Input-Output Voltage Differential - The input-output voltage differential should be limited such that proper voltage regulation is assured.

400.2.10 APPLICATION DATA FOR COMMONLY USED DIGITAL ICs

400.2.10.1 TTL Devices

The TTL microcircuit families provide general purpose logic with medium to high speed signal propagation, good noise immunity, and a high degree of economical logic flexibility. The switching speeds, especially associated with the very fast rise and fall of the circuits, are in the RF range and good high frequency circuit layout techniques have to be used.

Fanout capability is determined and specified by the device manufacturer. The voltage and current conditions needed for medium power TTL devices are normalized to a fanin or a fanout of a certain number of TTL loads. One TTL load being current-sinking 1.6 mA to ground. For applications requiring the device to drive more than the specified TTL load a buffer device shall be used. Types of TTL devices are:

a. Standard - Intended for use in implementing logic functions where speed and power requirements are not critical. This family offers a full spectrum of logic functions in various packages. Typical gate power dissipation is 10 mW with a typical propagation delay time of 10 ns. These devices exhibit a fanout of 10 when driving other standard TTL devices and are usually used to perform general purpose switching and logic functions.

b. Low Power - Employed in logic design where low power dissipation is a primary concern. These devices have a typical gate power dissipation of 1 mW with a typical propagation delay time of 30 ns. Typically, these devices will drive only one standard TTL device but exhibit a fanout of 10 when driving other low power devices. Low power generates less heat and therefore allows for greater board densities. Lower current levels also introduce less noise and reduce constraints on power supplies.

c. High Speed - Used to implement high speed logic functions in digital systems. These devices employ a Darlington output configuration to achieve a typical propagation delay time of 6 ns. The typical gate power dissipation is 23 mW. These devices can drive up to 12 standard TTL devices and exhibit a fanout of 10 when driving other high speed devices. These devices are used in high speed memories and central processor units.

d. Schottky - Used when ultra-high speeds are desired. These devices employ shallow diffusions and smaller geometries which lowers internal capacitance to reduce delay time and sensitivity to temperature variation. Typical delay time is 3 ns and power dissipation is 19 mW per gate. However, this power dissipation increases with frequency. These devices can drive 12 standard TTL devices and up to 10 Schottky devices. Noise margin is typically 0.3 volt. A ground plane is recommended for interconnections over 6 inches long and twisted-pair lines for distances of 10 inches.

400.2.10.2 ECL Devices

The general application data for ECL microcircuits are the same as that for TTL type. The ECL type microcircuits are intended for use in digital systems requiring high switching speeds and moderate power dissipation. Typical propagation delay time is 2 ns and typical power dissipation is 25 mW. The logic levels (-0.9V and -1.7V) are not as easily detected as those of TTL devices. Intended for use in high speed systems such as central processors, memory controllers, peripheral equipment, instrumentation and digital communications. Typical fanout is 25 when driving ECL devices.

400.2.10.3 CMOS Devices

The Complementary Metal Oxide Semiconductor (CMOS) microcircuits provide a general purpose logic family with low power, medium propagation speeds, good noise immunity, and reasonable degree of logic flexibility.

The CMOS devices are intended for use in applications where low power is extremely desirable and high speeds are not essential. The typical power dissipation is 10 mW and increases with frequency. Typical delay time is 50 ns. A typical fanout for a CMOS gate is 50 CMOS loads or 1 TTL unit load. Noise immunity is typically 2.25 volts for CMOS compared to 0.4V for standard TTL devices when powered by a 5 volt supply. This makes these devices useful in high noise environments. These devices are highly tolerant of power supply variation and operate anywhere in the range of 3 to 15 volts. Characteristics are as follows:

a. Input Source - The input requires a minimal current (typically 10 pico amps) voltage source in the low or high logic state. The voltage source has to be less than the device operating power supply voltage range.

b. Output Load - The fanout or output loading factor is defined by the current or sink capability of the device or the number of logic gates that can be controlled. The output of CMOS digital microcircuits generally satisfies the input source requirements for other CMOS devices.

400.2.11 ELECTROSTATIC DISCHARGE SUSCEPTIBILITY

Almost all integrated circuits are found to be susceptible to damage by electrostatic discharge. ESD handling precautions compatible with DOD-STD-1686 and DOD-HDBK-263 shall be observed.

401 MIL-M-38510, MICROCIRCUITS

401.1 DERATING REQUIREMENTS

When using linear microcircuits, power shall be derated according to the maximum allowable derating curve as shown in Figures 400.2, 400.3, 400.4, 400.5, 400.6 and 400.7.

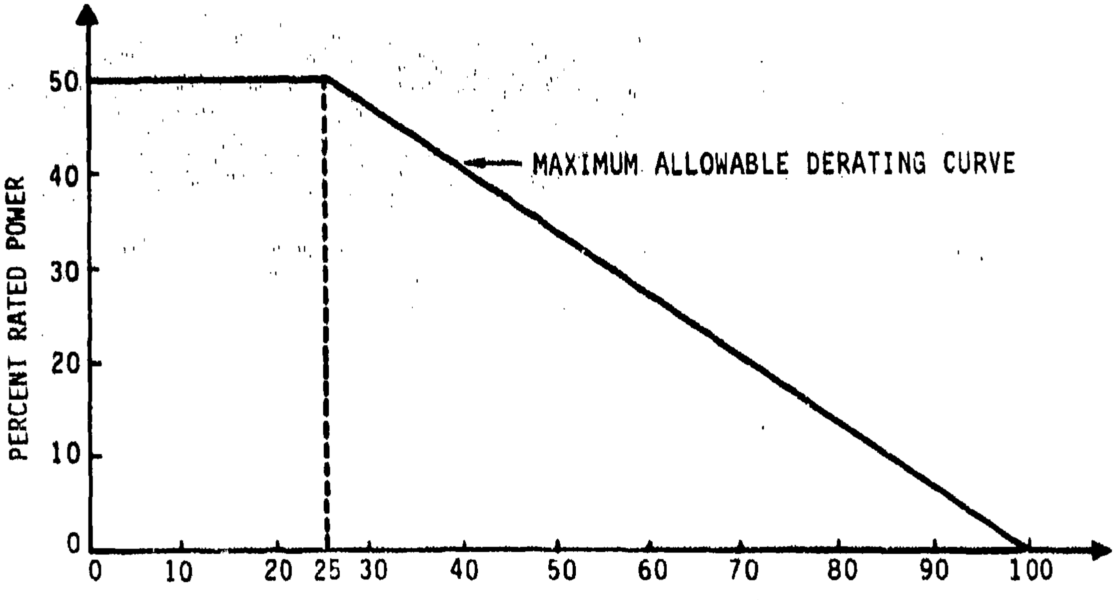

FIGURE 400.2

DERATING REQUIREMENTS FOR ALL HERMETICALLY SEALED MICROCIRCUITS, EXCEPT VOLTAGE REGULATORS, AT $T_S = 25°C$

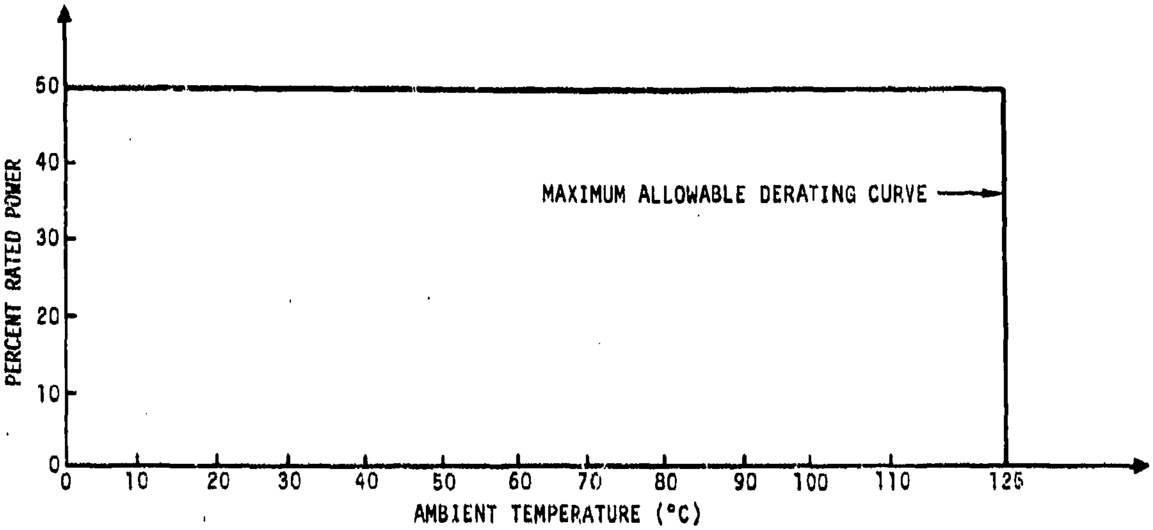

FIGURE 400.3

DERATING REQUIREMENTS FOR ALL HERMETICALLY SEALED MICROCIRCUITS, EXCEPT VOLTAGE REGULATORS, AT T_S = 125°C

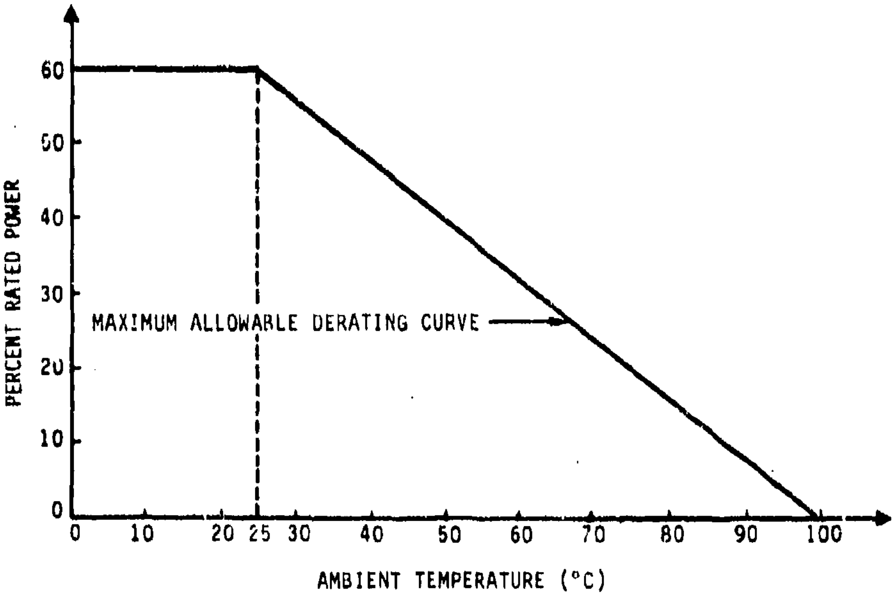

FIGURE 400.4

DERATING REQUIREMENTS FOR HERMETICALLY SEALED VOLTAGE REGULATORS AT T_S = 25°C

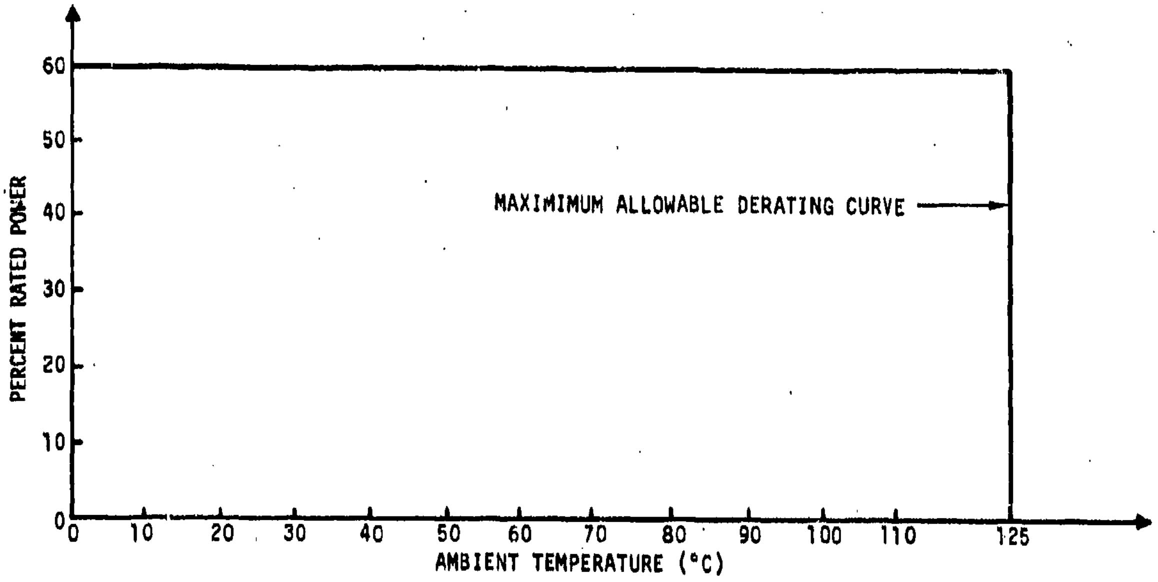

FIGURE 400.5

DERATING REQUIREMENTS FOR HERMETICALLY SEALED VOLTAGE REGULATORS AT T_S = 125°C

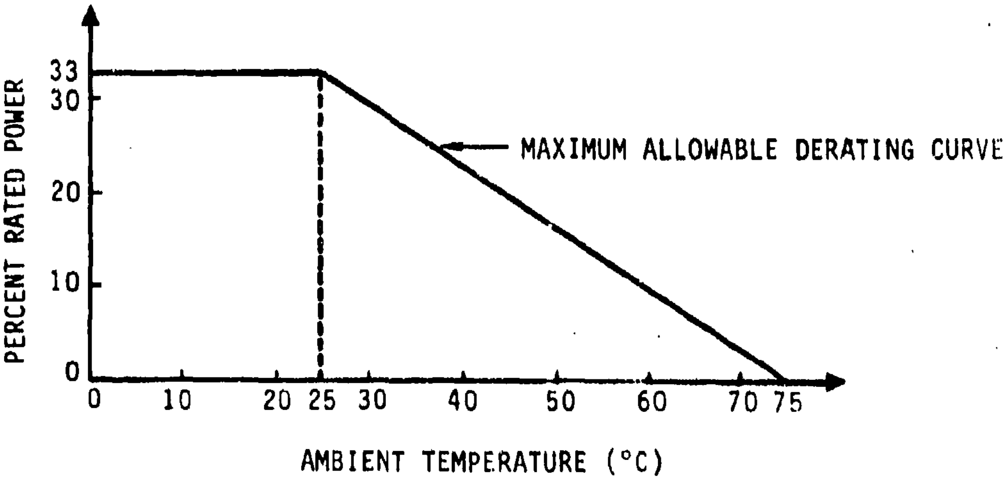

FIGURE 400.6

DERATING REQUIREMENTS FOR ALL NONHERMETICALLY SEALED MICROCIRCUITS, EXCEPT VOLTAGE REGULATORS, AT T_S = 25°C

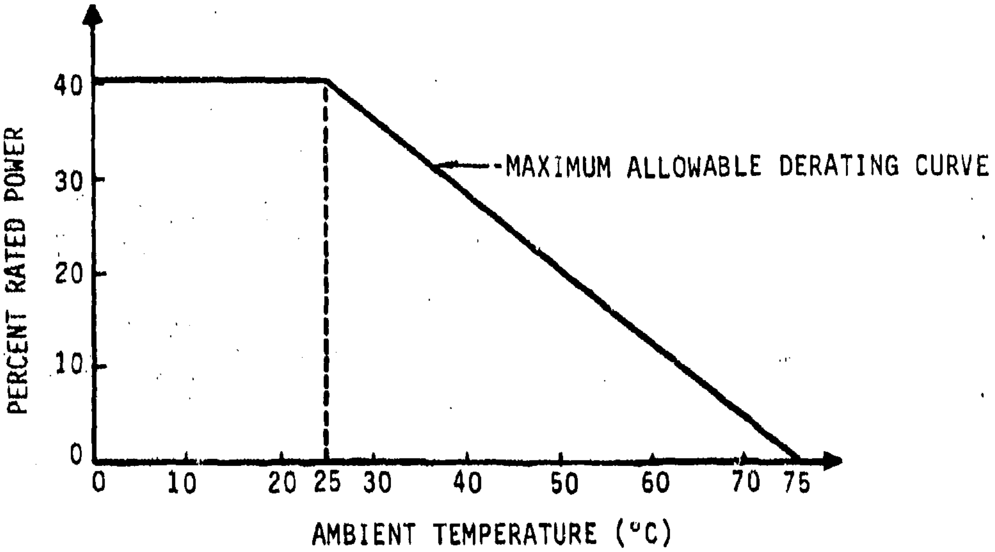

FIGURE 400.7

DERATING REQUIREMENTS FOR NONHERMETICALLY SEALED VOLTAGE REGULATORS AT $T_S = 25°C$

Note: Nonhermetically sealed microcircuits shall not be used without approval from the procuring activity.

In addition to limitations of the above derating curves, the following parameters shall be limited as follows:

Table 400-IIIA provides derating parameters for linear hermetically sealed microcircuits except Voltage Regulators.

Table 400-IIIB provides derating parameters for linear hermetically sealed Voltage Regulators.

Table 400-IIIC provides derating parameters for linear nonhermetically sealed microcircuits except Voltage Regulators.

Table 400-IIID provides derating parameters for linear nonhermetically sealed Voltage Regulators.

Table 400-IVA provides derating parameters for digital hermetically sealed microcircuits.

Table 400-IVB provides derating parameters for digital nonhermetically sealed microcircuits.

TABLE 400-IIIA*

Parameter	Max. % of the rated value
Current (continuous)	70
Current (surge)	60
Voltage (signal)	75
Voltage (surge)	80
Supply voltage	Hold on to mfg. nominal rating

TABLE 400-IIIB*

Parameter	Max. % of the rated value
Current (continuous)	75
Current (surge)	60
Voltage (signal)	75
Voltage (surge)	80
Supply voltage	Hold on to mfg. nominal rating

*Combination of ac and dc loads is not recommended for linear microcircuits.

TABLE 400-IIIC*

Parameter	Max. % of the rated value
Current (continuous)	60
Current (surge)	60
Voltage (signal)	75
Voltage (surge)	80
Supply voltage	Hold on to mfg. nominal rating

TABLE 400-IIID*

Parameter	Max. % of the rated value
Current (continuous)	65
Current (surge)	60
Voltage (signal)	75
Voltage (surge)	80
Supply voltage	Hold on to mfg. nominal rating

*Combination of ac and dc loads is not recommended for linear microcircuits.

TABLE 400-IVA

Parameter	Max. % of the rated value
Junction temps.	*100°C max.
Supply voltage	Hold on to mfg. nominal rating
Toggle frequency	70
Set up & hold time	200 min.
Fanout	80

TABLE 400-IVB

Parameter	Max. % of the rated value
Junction temps.	*75°C max.
Supply voltage	Hold on to mfg. nominal rating
Toggle frequency	70
Set up & hold time	200 min.
Fanout	80

*These values represent the actual temperature and not a percentage.

401.2 QUALITY LEVEL

Only MIL-M-38510 Class B or higher quality levels shall be used.

SECTION 500

ELECTRICAL CONNECTORS

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500 ELECTRICAL CONNECTORS

500.1 GENERAL INFORMATION

Standard connectors are specified in MIL-STD-1353.

500.2 APPLICATION CONSIDERATIONS

500.2.1 TYPICAL ELECTRICAL CHARACTERISTICS TO BE CONSIDERED IN THE SELECTION OF CONNECTORS

1. Voltage and current requirements - low current and high voltage situations, for example, require a plating that will not oxidize because the current may not be able to penetrate an oxide coating.

2. Resistance - becomes a critical factor if the connectors are in series and the impedances involved are low.

3. Maximum current - determined by the connector and the size of wires attached to it.

4. Maximum voltage - depends on the spacing between contacts and insulating material used.

5. Intercontact capacitance - becomes very important when high frequencies are involved.

Other key electrical parameters include surge current, characteristic impedance, insertion loss, and EMI leakage attenuation.

500.2.2 TYPICAL MECHANICAL CHARACTERISTICS TO BE CONSIDERED IN THE SELECTION OF CONNECTORS

1. The space available for the connectors.

2. The number of necessary spare contacts.

3. The type of termination required (i.e., crimp or solder).

4. The type of connector required: environmental, nonenvironmental, threaded, bayonet or push-pull.

5. Size of contacts (determined by the operating voltages and currents.

6. The type of wire characteristics required: that is, whether contacts for shielded wire are required; whether RFI protection is required; and also the wire materials construction and diameter.

7. If crimped removable contacts are used, the direction of removal (i.e., front release-rear removable or rear release-rear removable).

8. The type of receptacle to be employed (i.e., square flange mount or single hole mount).

9. The type of support hardware (clamps, caps, etc.) required and mounting provisions to be made.

500.2.3 ENVIRONMENTAL CONDITIONS

500.2.3.1 Mechanical Effects

Achieving good electrical contact in a connector is a function of contact surface films, surface roughness, contact area, plastic deformation of the contacting materials, and load applied. Since even the best machined, polished, and coated surfaces look rough and uneven when viewed microscopically, the common concept of a flat, smooth contact is grossly oversimplified. In reality, the connector interface is basically an insulating barrier with a few widely scattered points of microscopic contact. The performance of the connector is dependent upon the chemical, thermal and mechanical behavior at these contact points.

500.2.3.2 Electrical Effects

Current flow between mating materials is constricted at the interface to the small points on the contact surfaces which are in electrical contact. This flow pattern causes differences of potential to exist along the contact interface, and causes current bunching at points of lower resistance. As a result, contact resistance and capacitance are introduced into the circuit, and certain chemical effects evolve (see 500.2.3.4 on chemical effects).

500.2.3.3 Thermal Effects

Since the total contact resistance in a good connector may be small (micro-ohms) and is achieved by the paralleling along the interface of many higher resistance point conducting paths, a series of localized hot spots can develop. When high currents are conducted through multiple pins, the cumulative heat rise in the connector can be appreciable.

a. High Temperature Effects - Excessive temperature can cause failure of connectors by breakdown of insulation or by breakdown in the conductivity of the conductors. Either malfunction can be partial or complete. A typical breakdown caused by excessive temperature occurs progressively. As operating temperature increases, insulation tends to become more conductive, and simultaneously, the resistance of conductors increases. Higher resistance causes the temperature of the conductor and of its insulation to rise further. This pyramiding effect can raise conductors and connector contacts beyond maximum conductor operating temperatures, with resultant damage to contacts and conductive platings. Complete failure will occur if the operating temperature reaches the point where the conductor melts, breaking electrical conductivity, or where the insulation fails, causing a short.

Maximum operating temperatures are the sum of ambient temperature and conductor temperature rise caused by the passage of current. For example, maximum conductor operating temperature of 125°C is based on an ambient temperature of 100°C, plus a rise of 25°C, due to the conductor carrying current. A graph of service life versus hot spot temperature is given in Figure 500.1.

b. Low Temperature Effects - Metals and nonmetals tend to become brittle and shrink at different rates. How important each characteristic is depends on the application. Most high performance connectors will operate down to -55°C. Operation at lower temperature may require special materials.

Ambient temperatures below "normal" are not usually the cause of trouble in interconnection systems, so far as conductivity is concerned. The lower the temperature, the more current can be carried by a given conductor. However, extremely low ambient temperatures do produce mechanical failures, mostly occurring in the nonmetallic portions of connectors, wires and cables. The coefficient of expansion of most plastics and elastomers are so different from those of the metals used in structural members that they will shrink enough at extremely low temperatures to open seals. An open seal may not cause a malfunction unless moisture and contaminants enter through the opening. If a seal opens after the temperature of a connector falls below the freezing point of the contaminants present, and then seals itself before the melting point of the contaminants is reached, foreign matter will never enter. However, if a connector seal opens at a temperature where liquid or gaseous contaminants have not been frozen, they can enter and contaminate the connector.

500.2.3.4 Chemical Effects

Most contact failures of connectors are induced by the growth of films at points of contact. These films can cause increased contact resistance or open circuit. Contact resistance gives rise, as explained above, to interfaces at higher temperatures than the surroundings, thus increasing the chemical activity. Ions in impurities or contamination in the surface pores of contacts will migrate to the points of highest potential, which are frequently the localized hot spots. Ions interfacing with electrons and other constituents at the points of high chemical activity usually generate nonconducting films. There is also a continuous supply of material for the growth of insulating films from environments where there are corrosive elements such as hydrogen sulfide, water vapor, oxygen, ozone, hydrocarbons and various dusts.

500.2.3.5 Cycling Effects

The connector plugged to its mate during much of its operational life is characterized by a typical catastrophic failure rate based on the factors described. Many connectors, particularly of the cable type that are repeatedly plugged and unplugged continuously expose the contacts to a fresh supply of local corrosive contaminants. These cycling effects also create the problem of physical wear on the connecting interfaces. Surface contact points become worn making unsymmetrical contacts and sometimes substituting nonconducting films to replace conducting points in the physical interface. The result is increased interface resistance, higher contact temperature and degradation of the connection. Hence, there is an added failure rate relation between cycling rate of connector contacts (see Figure 500.1).

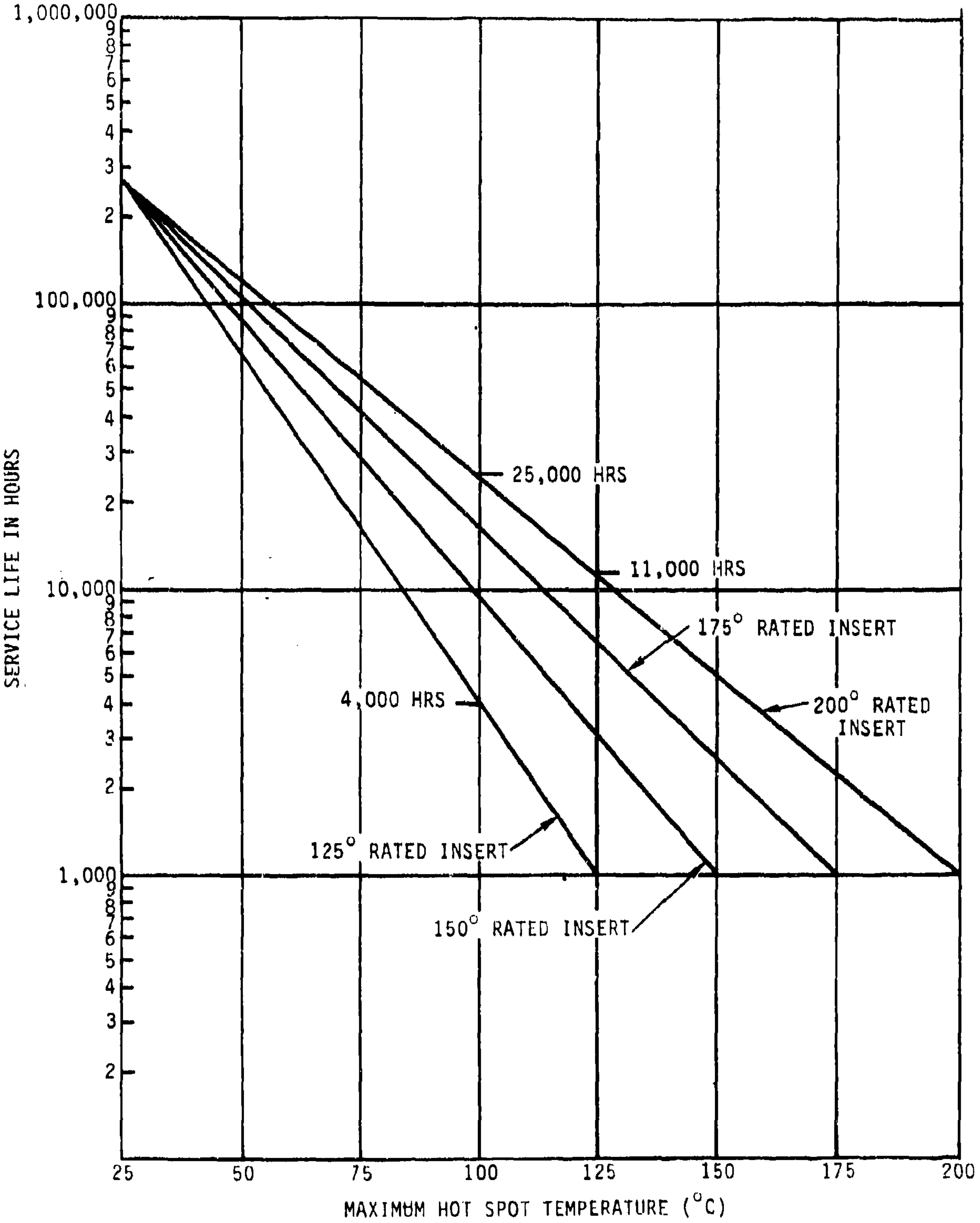


FIGURE 500.1

SERVICE LIFE VERSUS HOT SPOT TEMPERATURE

500.2.3.6 Operation in Parallel

When pins are connected in parallel at the connector to increase the current capacity, allow for at least a 25 percent surplus of pins over that required to meet the 60 percent derating for each pin assuming equal current in each. This results, since the currents will not divide equally due to differences, in contact resistance. For example, it would take five pins, each rated at one amp, to conduct two amps.

500.2.3.7 Protective Measures

All unmated connectors, during shipment, storage or operation, should be kept covered with moisture proof or vapor proof caps. Protective caps specified by military specifications or military standards and designed for mating with specific connectors should be used. Where such protective caps are not available, disposable plastic or metallic caps designed for purpose should be used.

501 CONNECTORS, CYLINDRICAL, GENERAL DUTY

501.1 MIL-C-5015, CONNECTORS, ELECTRICAL, CIRCULAR THREADED, "AN" TYPE

501.1.1 APPLICATION CONSIDERATIONS

501.1.1.1 Insulation Resistance

The insulation resistance limits vary with the temperature as shown in Figure 500.2.

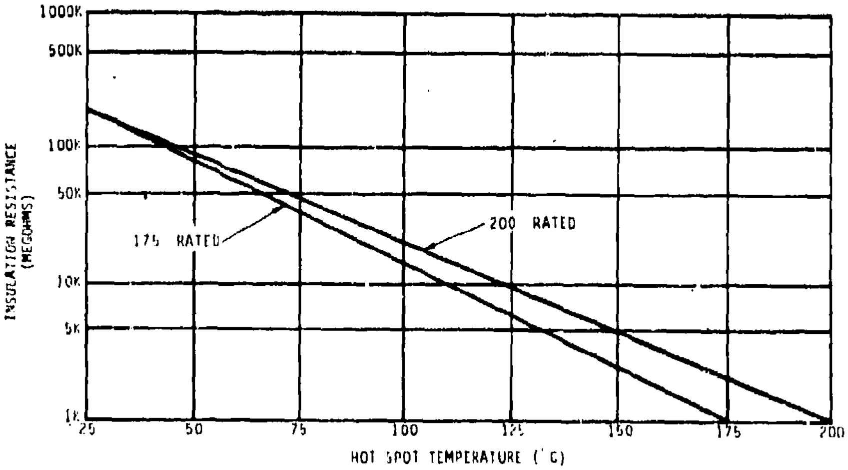


FIGURE 500.2

INSULATION RESISTANCE VERSUS TEMPERATURE

501.1.1.2 Service Life

The service life of these connectors varies with temperature as shown in Figure 500.3.

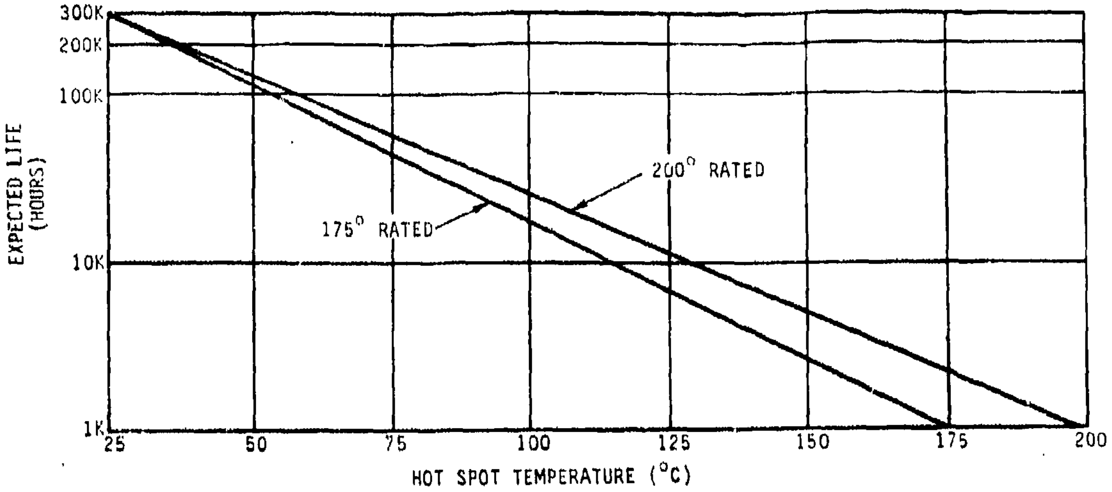


FIGURE 500.3

SERVICE LIFE VERSUS TEMPERATURE

501.1.1.3 Durability (Required by the Specification):

a. With Coupling Rings - Counterpart connectors are required to be capable of mating and unmating 100 times at a maximum of 10 cycles per hour with coupling rings attached.

b. Without Coupling Rings - Counterpart connectors are required to be capable of mating and unmating 500 times at a maximum rate of 600 cycles per hour with the coupling rings removed.

501.1.2 APPLICATION RESTRICTIONS ACCORDING TO MIL-STD-1353

a. Type MS3400s shall be used only for shipboard jacketed cable applications.

b. Type MS3450s shall not be used for shipboard jacketed cable applications and classes W and K are only acceptable for hookup wire applications.

501.2 MIL-C-38999, CONNECTORS, ELECTRICAL, CIRCULAR, MINIATURE, HIGH DENSITY, QUICK DISCONNECT, ENVIRONMENT RESISTANT, REMOVABLE CRIMP CONTACTS

501.2.1 APPLICATION CONSIDERATIONS

501.2.1.1 Intended Use

The various configurations of series III and series IV connectors are intended for use as follows:

a. Class F (environment resisting) - conductive plating.

b. Class K (environment resisting) - corrosion resistant steel with firewall barrier.

c. Class W (environment resisting) - corrosion resistant plating.

d. Class Y (hermetically sealed) - corrosion resistant steel, passivated.

501.2.1.2 Application Restriction According to MIL-STD-1353

Series III and IV connectors shall not be used in Navy shipboard jacketed cable applications. Series III with finish "W" are acceptable for hook-up wire applications.

501.2.1.3 Sealing Plugs

Sealing plugs should be installed in all grommet holes of E and T connectors which do not contain wires.

501.2.1.4 Performance

The tests of mated connectors covered in the dielectric withstanding voltage at altitude tests are overstress tests intended to demonstrate the sealing capabilities of mated connectors. They are not to be taken as indicative of recommended service usage. Operating voltages shall be based upon the applicable test voltages for unmated connectors with suitable allowances for transients, switching surges, and safety factors appropriate to the particular circuit in which the connector is to be used.

501.2.1.5 Contact Size

Connectors containing size 22 contacts shall not be used for equipment designed for military applications, unless specifically approved by the procuring activity.

501.3 MIL-C-28840, CONNECTORS, CIRCULAR THREADED, HIGH DENSITY, HIGH SHOCK SHIPBOARD, CLASS D

501.3.1 APPLICATION CONSIDERATIONS

501.3.1.1 Application Restriction According to MIL-STD-1353

These connectors are for use with jacket cable in shipboard applications.

502 CONNECTORS, CYLINDRICAL, HEAVY DUTY

502.1 MIL-C-22992, CONNECTORS, CYLINDRICAL, HEAVY DUTY

502.1.1 APPLICATION CONSIDERATIONS

502.1.1.1 Intended Use of Class C Connectors

Connectors are intended for heavy duty (rough service) applications for external electrical interconnection of equipments such as shelters, vans, buildings, missile/space launch sites.

502.1.1.2 Intended Use of Class R Connectors

Connectors are intended for heavy duty (rough service) applications in protected enclosures where water-proofing (unmated) or pressurization is not required.

502.2 MIL-C-22992, CONNECTORS, CYLINDRICAL, HEAVY DUTY

502.2.1 APPLICATION CONSIDERATIONS

502.2.1.1 Intended Use of Class L Connectors

Connectors are intended to be used for power connections in the current range of 60 to 200 amperes and will be used only with the heavy duty jacketed cables specified on the applicable insert standard. Reference MIL-STD-255.

503 CONNECTOR, RACK AND PANEL

503.1 MIL-C-24308, CONNECTORS, ELECTRIC, RECTANGULAR, MINIATURE POLARIZED SHELL, RACK AND PANEL (AND ASSOCIATED ACCESSORIES)

503.1.1 APPLICATION CONSIDERATIONS

503.1.1.1 Intended Use

Class G connectors are intended for use in nonenvironment resisting applications where the operating temperature range of -55°C to 125°C is experienced.

Class N connectors are intended for use in applications where presence of residual magnetism must be held to low levels to avoid interference with nearby sensitive instrumentation.

Class H connectors are intended for use in application where atmospheric pressures must be contained by the connectors across the wall or panels they are mounted on.

503.2 MIL-C-28731, CONNECTORS, ELECTRICAL, RECTANGULAR, REMOVABLE CONTACT, FORMED BLADE, FORK TYPE (FOR RACK AND PANEL AND OTHER APPLICATIONS)

503.2.1 APPLICATION CONSIDERATIONS

503.2.1.1 Intended Use

These connectors are intended for use in electronic and electrical equipment.

503.3 MIL-C-28748, CONNECTORS, ELECTRICAL, RECTANGULAR, RACK AND PANEL, SOLDER TYPE AND CRIMP TYPE CONTACTS

503.3.1 APPLICATION CONSIDERATIONS

503.3.1.1 Intended Use

These connectors are intended for use in nonenvironmental applications only.

503.4 MIL-C-28804, CONNECTORS, ELECTRIC, RECTANGULAR, HIGH DENSITY, POLARIZED CENTER JACKSCREW

503.4.1 APPLICATION CONSIDERATIONS

503.4.1.1 Intended Use

Class G connectors are intended for use in nonenvironment resisting applications where the operating temperature range of -55°C to 125°C is experienced.

Class E connectors are intended for use in environmental resisting applications. Provisions are made for sealing around wire at rear of connectors.

503.5 MIL-C-81659, CONNECTORS, ELECTRICAL, RECTANGULAR, ENVIRONMENT RESISTANT, CRIMP CONTACTS

503.5.1 APPLICATION CONSIDERATIONS

503.5.1.1 Intended Use

MIL-C-81659 covers environment resisting rectangular connectors with one to four inserts per connector.

503.6 MIL-C-83733, CONNECTORS, ELECTRICAL, MINIATURE, RECTANGULAR TYPE, BACK TO PANEL, ENVIRONMENTAL RESISTING, 200°C TOTAL CONTINUOUS OPERATING TEMPERATURE

503.6.1 APPLICATION CONSIDERATIONS

503.6.1.1 Intended Use

MIL-C-83733 covers miniature environmental resisting, 200°C rectangular connectors. All the types and classes are intermatable under the same shell size.

504 CONNECTORS, PRINTED WIRING BOARD

504.1 MIL-C-21097, CONNECTORS, ELECTRICAL, PRINTED WIRING BOARD, GENERAL PURPOSE

504.1.1 APPLICATION CONSIDERATIONS

All characteristics are applicable and no restrictions apply.

504.2 MIL-C-55302, CONNECTORS, PRINTED CIRCUIT SUBASSEMBLY AND ACCESSORIES

504.2.1 APPLICATION CONSIDERATIONS

All characteristics are applicable and no restrictions apply.

505 CONNECTORS, TEST POINT

505.1 MIL-C-39024, CONNECTORS, ELECTRICAL; JACKS, TIP (TEST POINT, PANEL OR PRINTED WIRING TYPE)

505.1.1 APPLICATION CONSIDERATIONS

All characteristics are applicable and no restrictions apply.

506 CONNECTORS, POWER, GENERAL DUTY

506.1 WC-596, CONNECTORS, PLUG, RECEPTACLES AND CABLE OUTLET, ELECTRICAL POWER

506.1.1 APPLICATION CONSIDERATIONS

All connectors are of the grounding type and of non-armored, dead front construction.

507 CONNECTORS, RADIO FREQUENCY, COAXIAL

507.1 MIL-C-39012, CONNECTORS, RADIO FREQUENCY, COAXIAL

507.1.1 APPLICATION CONSIDERATIONS

507.1.1.1 Intended Use

MIL-C-39012 covers radiofrequency connectors used with flexible RF cables and certain other types of coaxial transmission lines.

508 SOCKETS, PLUG-IN

508.1 MIL-S-83502, SOCKET, PLUG-IN, ELECTRIC COMPONENTS, ROUND STYLE

508.1.1 APPLICATION CONSIDERATIONS

508.1.1.1 Intended Use

Intended for use on panel boards, printed circuit boards, and microelectronic components.

508.2 MIL-S-83505, SOCKET (LEAD, ELECTRONIC COMPONENTS)

508.2.1 APPLICATION CONSIDERATIONS

508.2.1.1 Intended Use

Intended use for insertion through mounting boards or panels.

508.3 MIL-S-83734, SOCKET, PLUG-IN, ELECTRONIC COMPONENTS

508.3.1 APPLICATION CONSIDERATIONS

508.3.1.2 Intended Use

Intended for use on panel boards, printed circuit boards, and microelectronic components.

508.4 MIL-S-12883 SOCKET, PLUG-IN, ELECTRONIC COMPONENTS

508.4.1 APPLICATION CONSIDERATIONS

508.4.1.1 Intended Use

Intended for plug-in electronic components, such as electron tubes and related electronic devices, plug-in related electronic devices, plug-in capacitors, crystal units, batteries, vibrators, relays, coils, etc.

509 DERATING REQUIREMENTS

When using connectors, current and operating temperature shall be derated according to the maximum allowable derating curves as shown in Figures 500.4 through 500.27.

The voltage between the contacts shall not exceed 25 percent of the dielectric withstanding voltage.

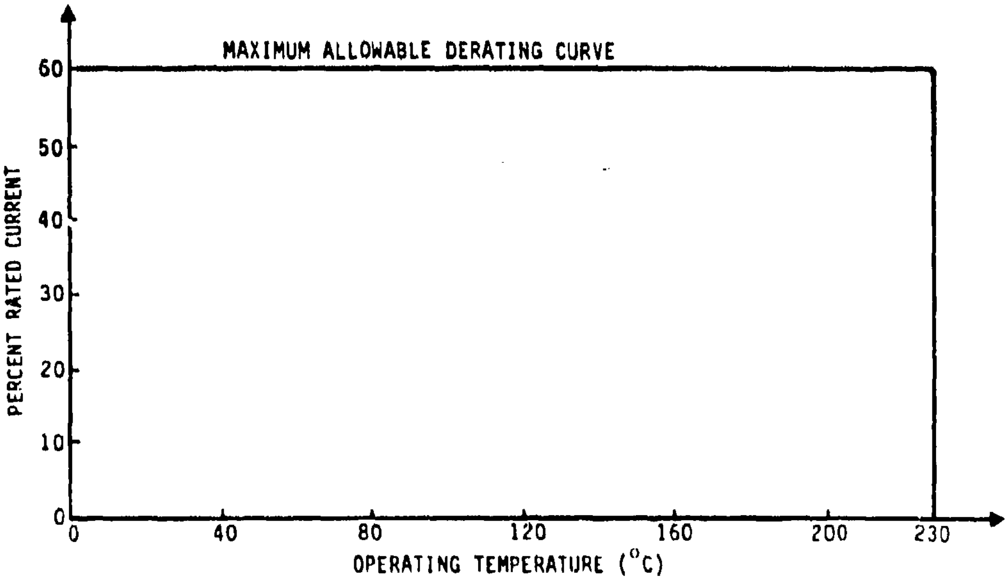


FIGURE 500.4

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS
(MOUNTED ON AN IDEAL HEAT SINK),
INSERT MATERIAL A

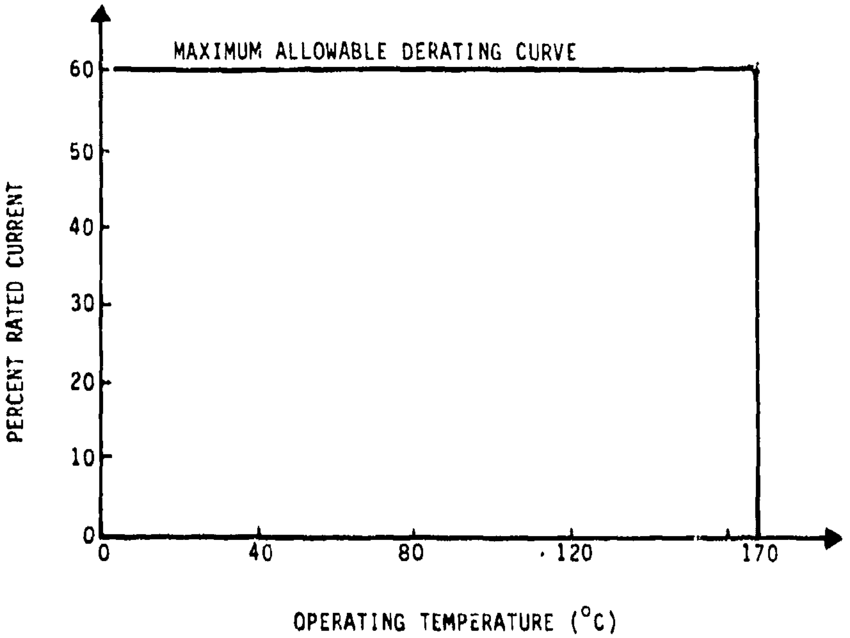


FIGURE 500.5

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS
(MOUNTED ON AN IDEAL HEAT SINK),
INSERT MATERIAL B

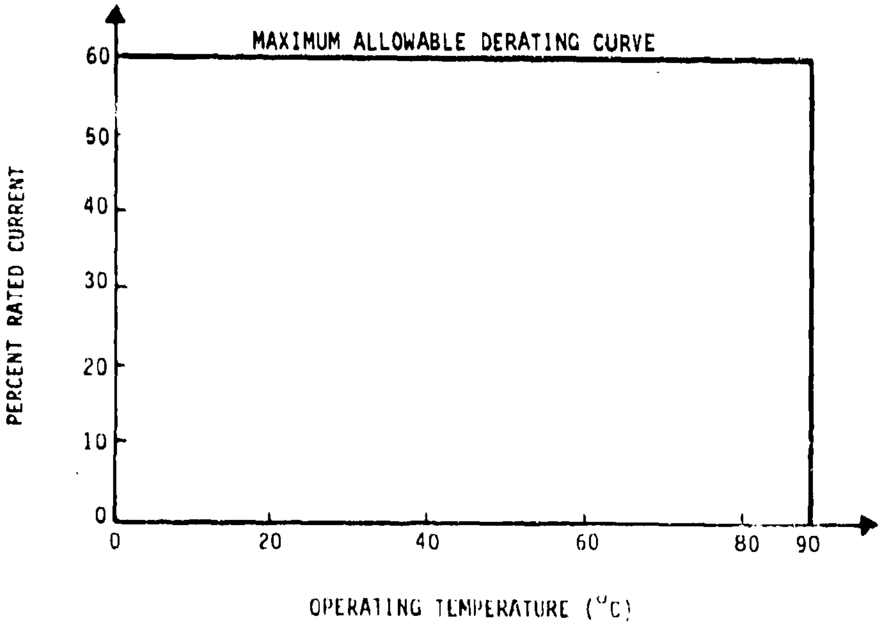


FIGURE 500.6

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS
(MOUNTED ON AN IDEAL HEAT SINK),
INSERT MATERIAL C

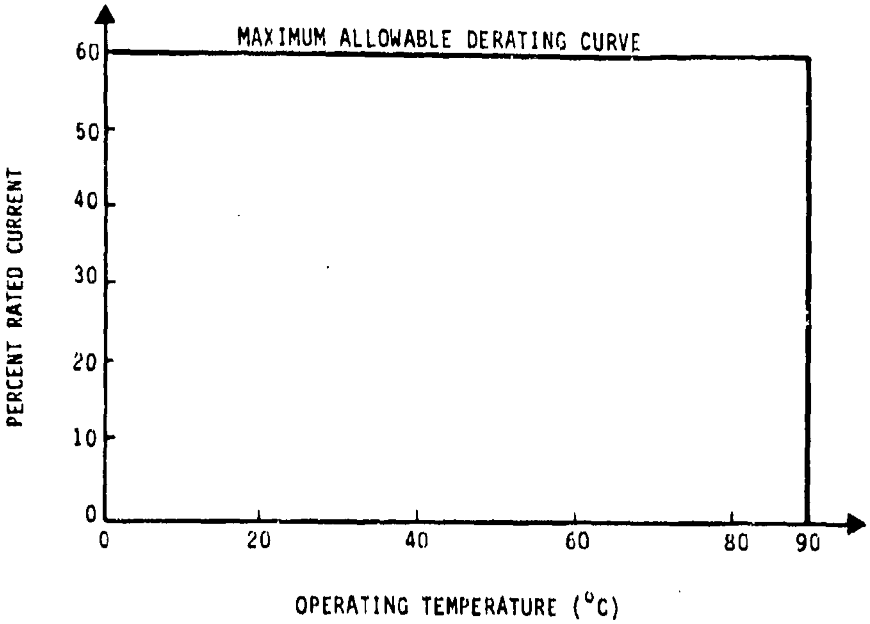


FIGURE 500.7

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS (MOUNTED ON AN IDEAL HEAT SINK), INSERT MATERIAL D

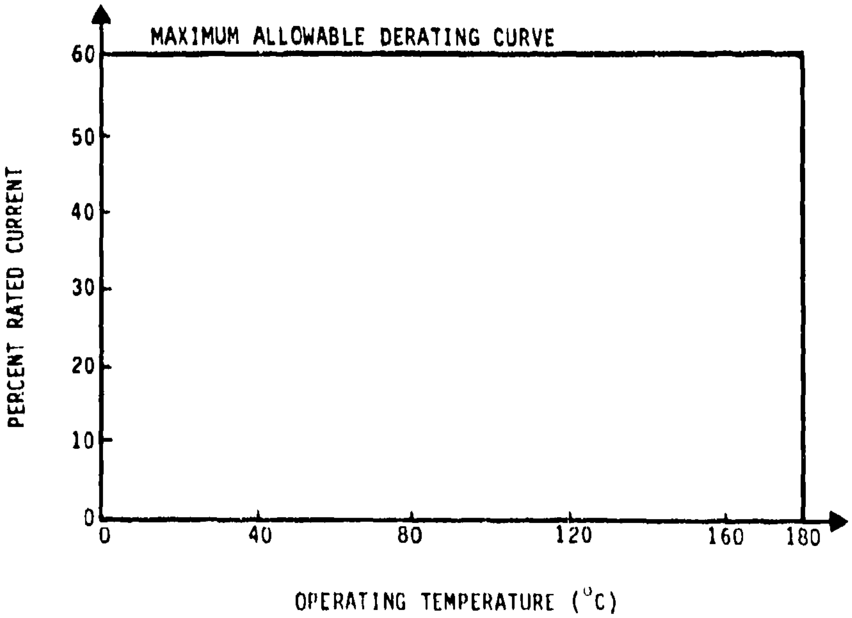


FIGURE 500.8

FOR PRINTED CIRCUIT BOARD CONNECTORS (MOUNTED ON AN IDEAL HEAT SINK)

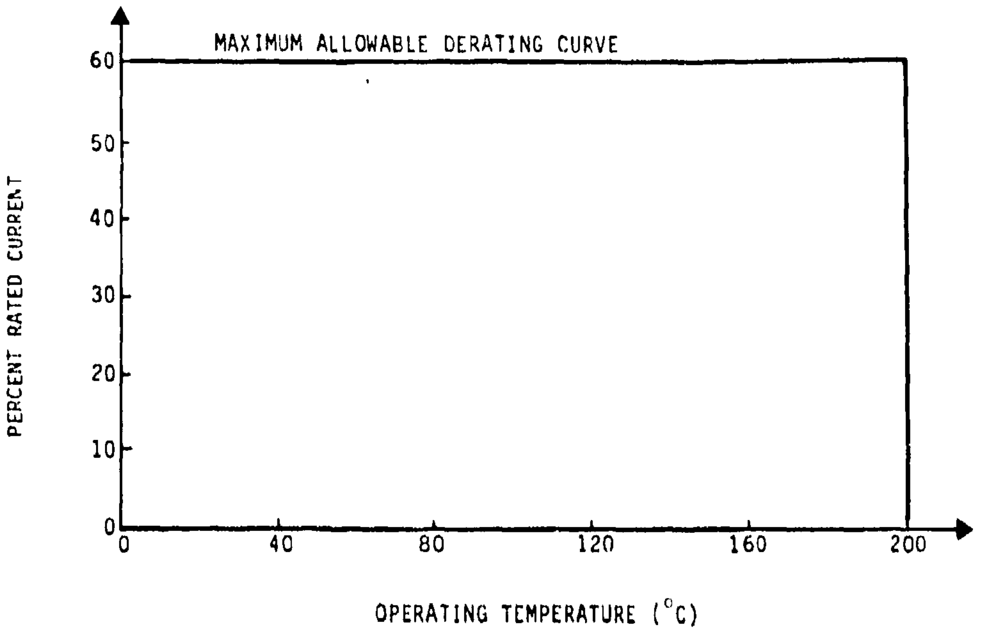


FIGURE 500.9

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL A, 22 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

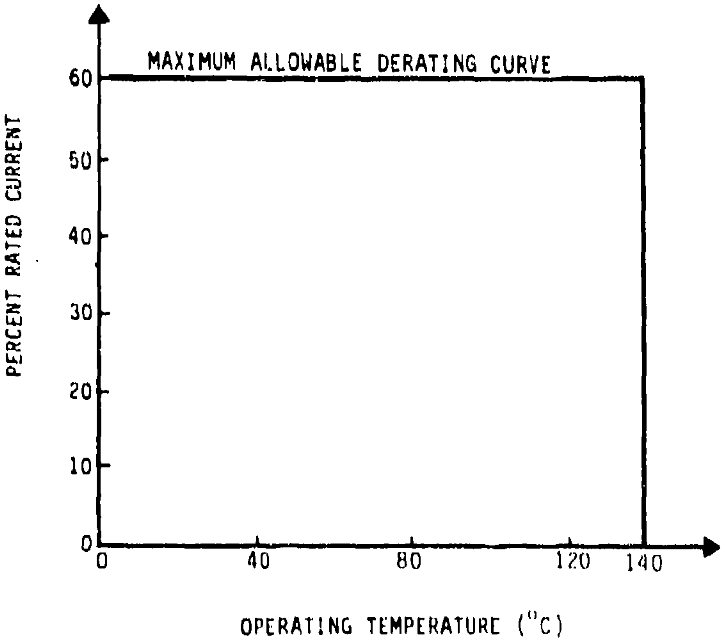


FIGURE 500.10

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL B, 22 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

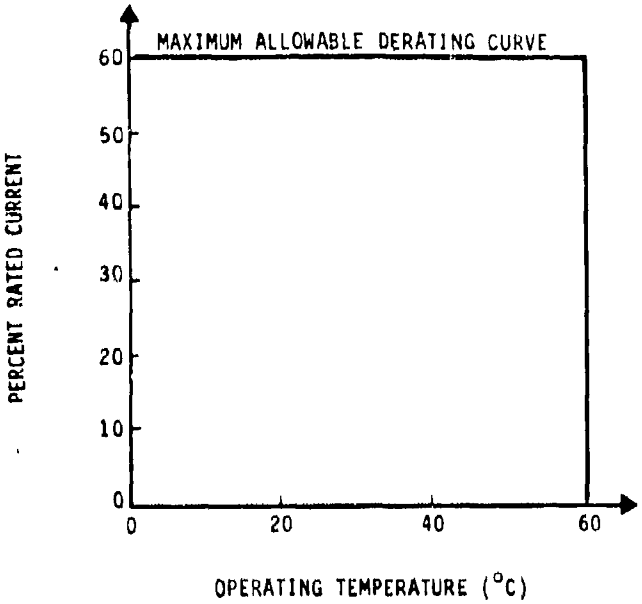


FIGURE 500.11

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL C, 22 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

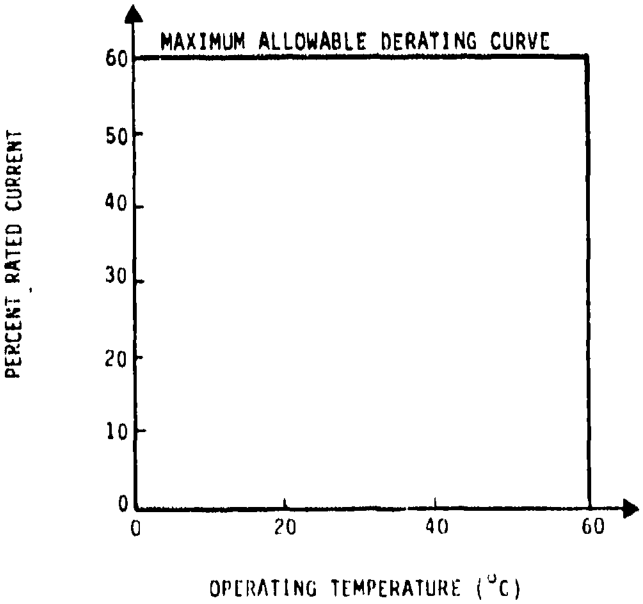


FIGURE 500.12

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL D, 22 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

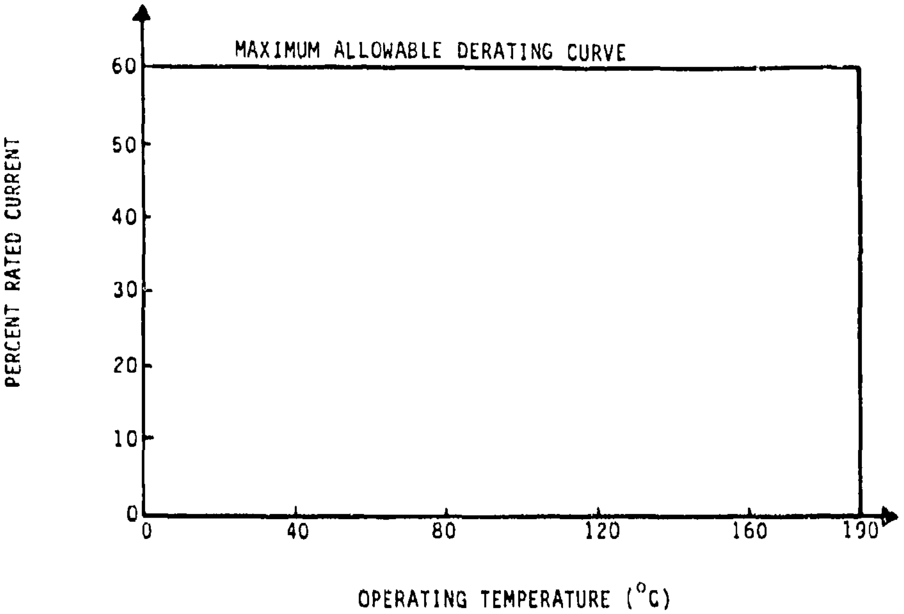


FIGURE 500.13

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL A, 20 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

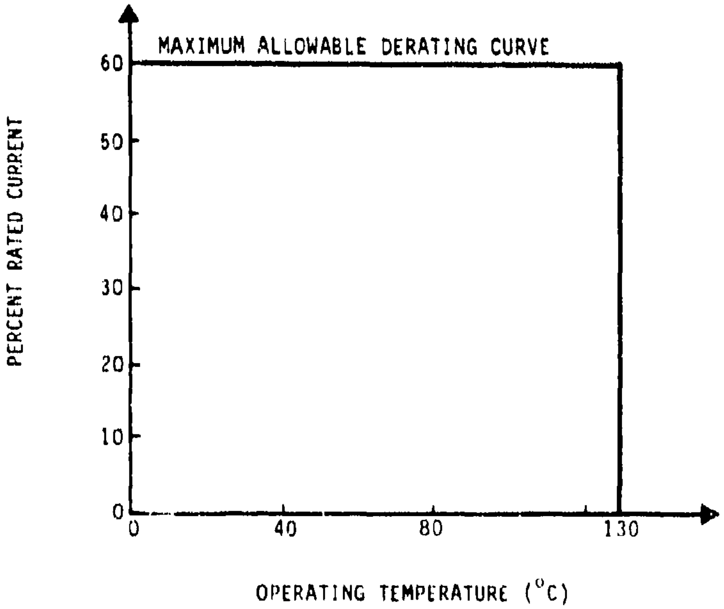


FIGURE 500.14

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL B, 20 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

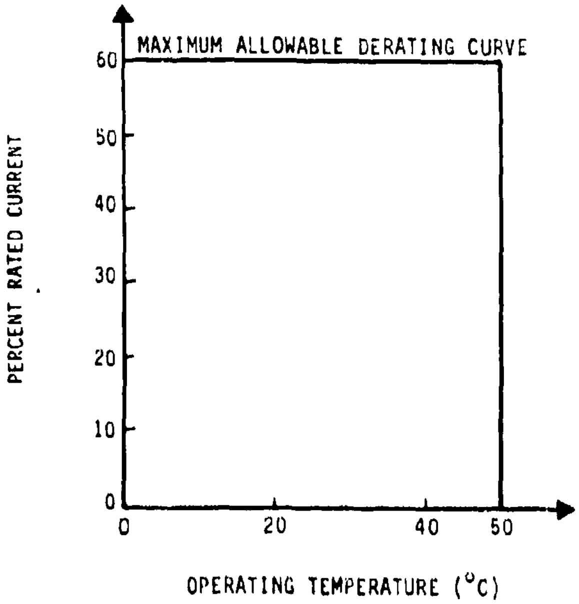


FIGURE 500.15

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL C, 20 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

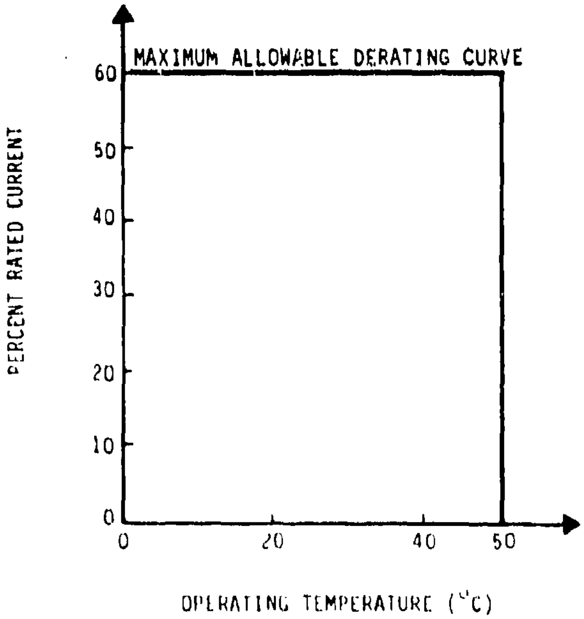
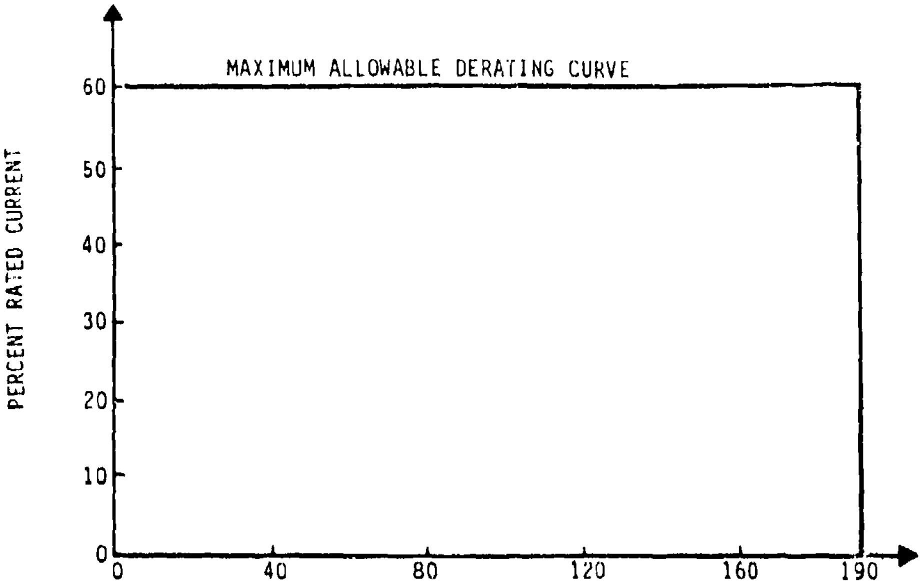


FIGURE 500.16

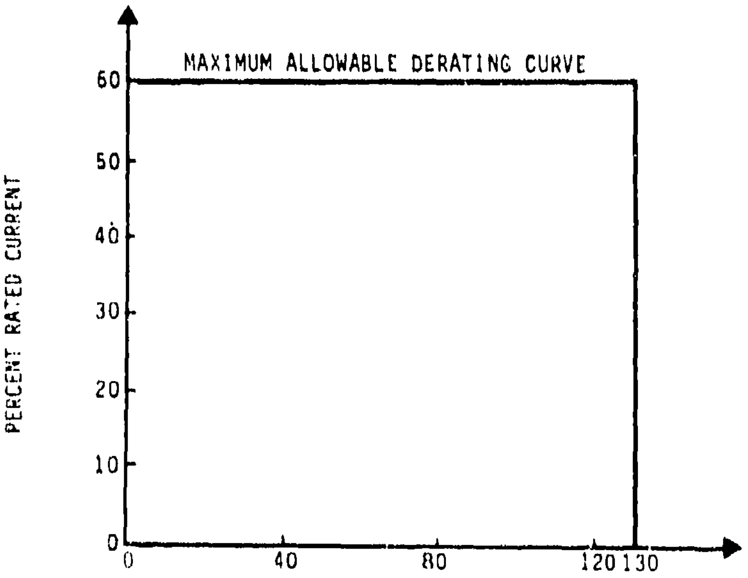
FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL D, 20 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)



OPERATING TEMPERATURE (°C)

FIGURE 500.17

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL A, 16 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)



OPERATING TEMPERATURE (°C)

FIGURE 500.18

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL B, 16 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

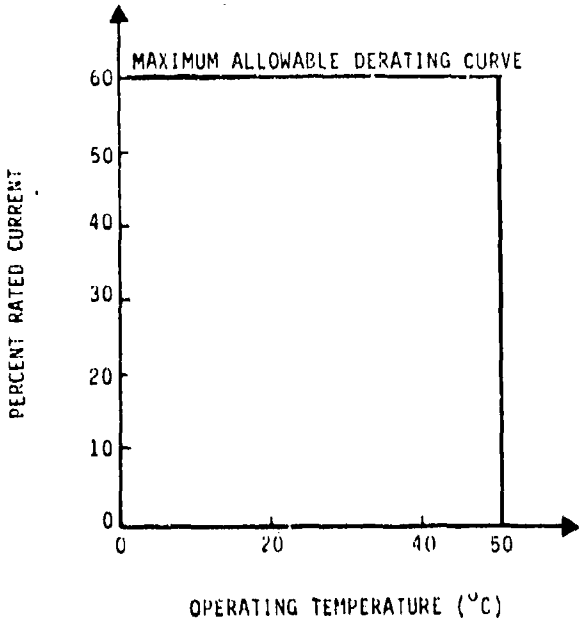


FIGURE 500.19

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL C, 16 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

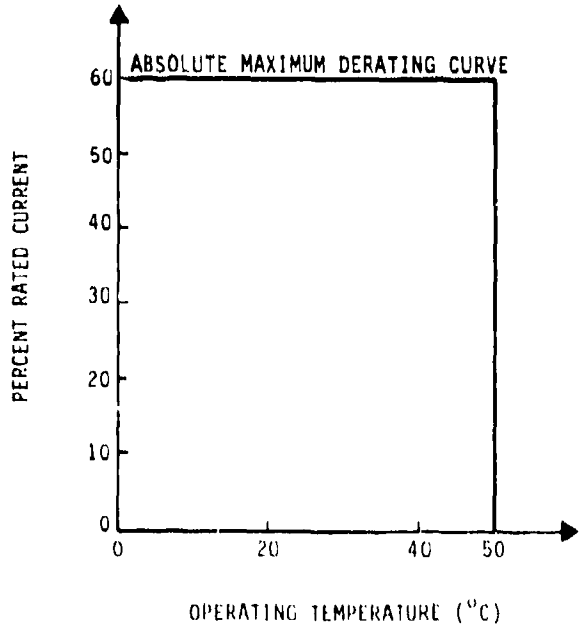


FIGURE 500.20

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL D, 16 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

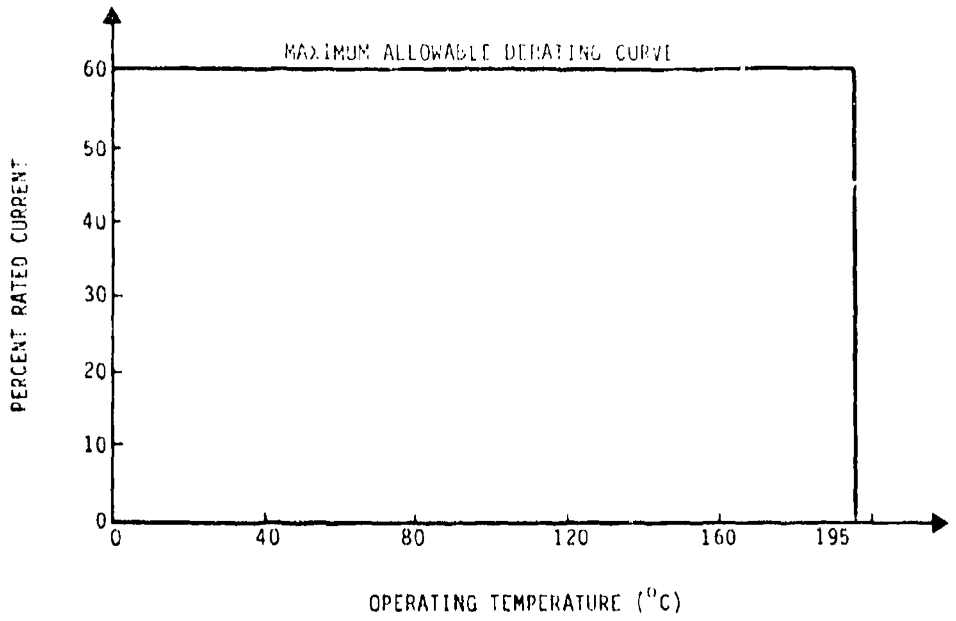


FIGURE 500.21

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL A, 12 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

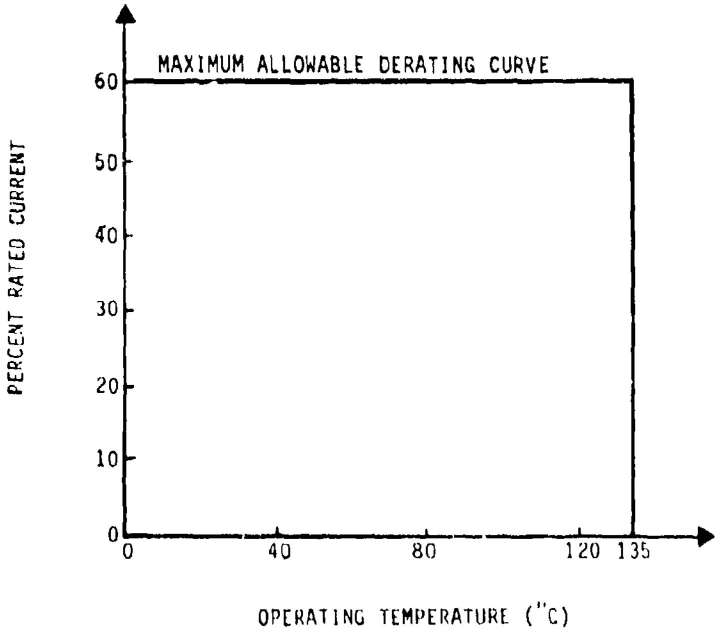


FIGURE 500.22

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL B, 12 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

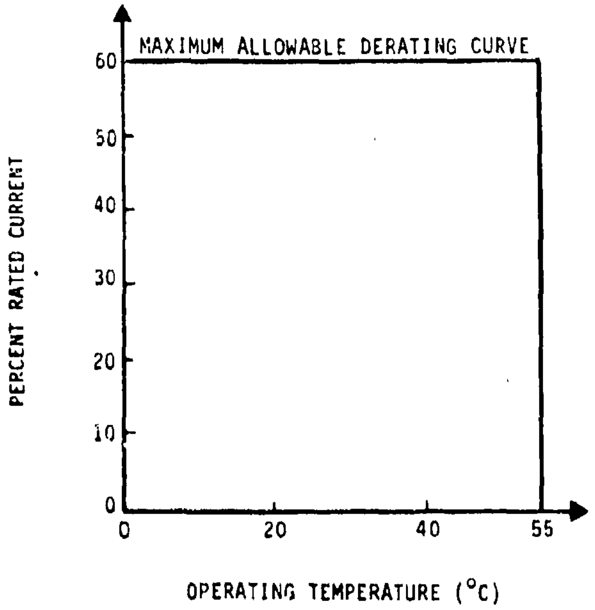


FIGURE 500.23

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL C, 12 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

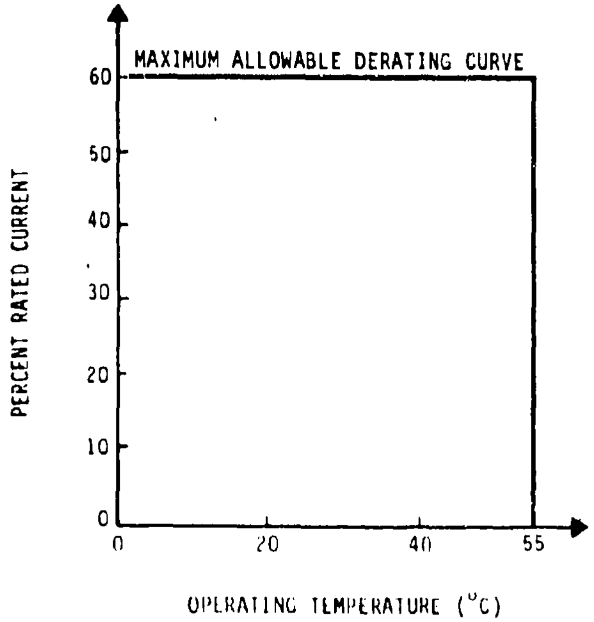


FIGURE 500.24

FOR ALL CONNECTORS EXCEPT PRINTED CIRCUIT BOARD CONNECTORS, INSERT MATERIAL D, 12 GA (TEMPERATURE RISE OF INSERT MATERIAL INCLUDED)

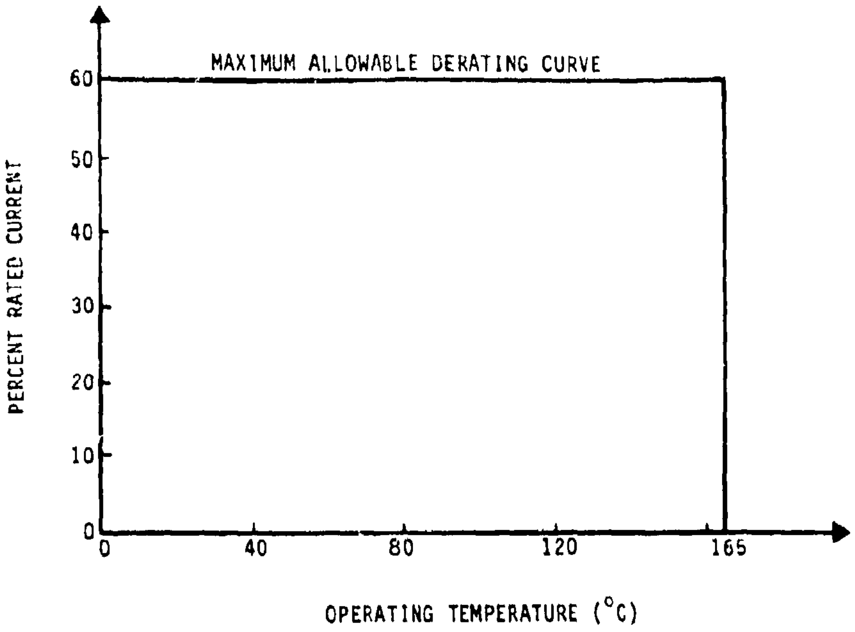


FIGURE 500.25

PRINTED CIRCUIT BOARD CONNECTORS, 26 GA
(TEMPERATURE RISE OF CONTACT INCLUDED)

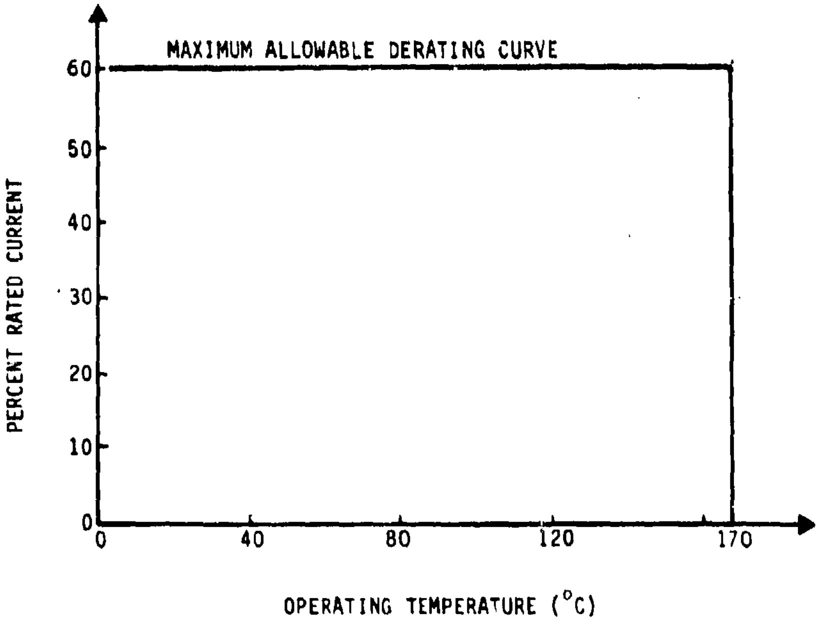


FIGURE 500.26

PRINTED CIRCUIT BOARD CONNECTORS, 22 GA
(TEMPERATURE RISE OF CONTACT INCLUDED)

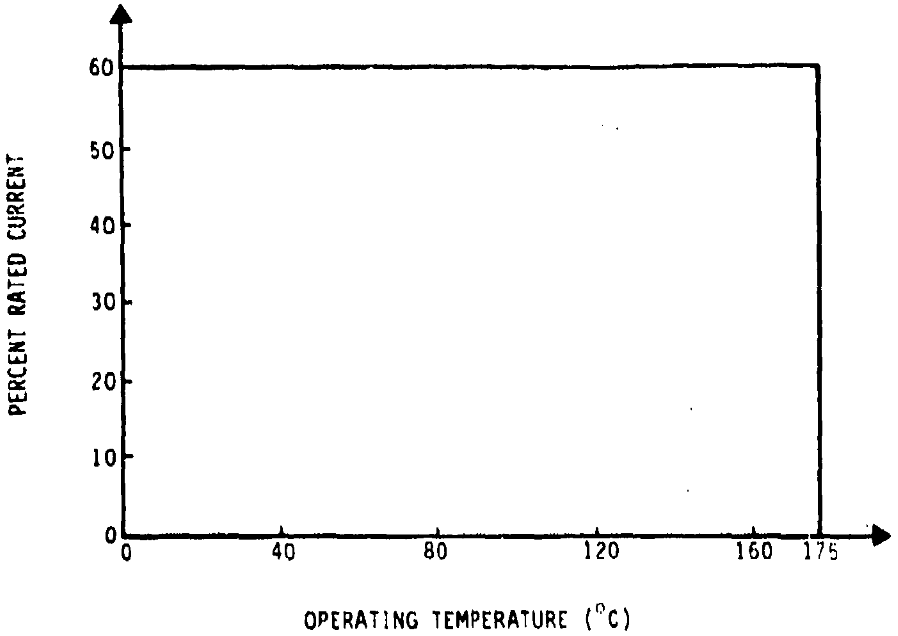


FIGURE 500.27

PRINTED CIRCUIT BOARD CONNECTORS, 20 GA
(TEMPERATURE RISE OF CONTACT INCLUDED)

SECTION 600

RELAYS

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

600 RELAYS

600.1 GENERAL INFORMATION

Standard relays are specified in MIL-STD-1346. Relays should be selected based upon the function to be performed. Table 600-I summarizes the relay types applicable to different functions. Where more than one type of relay can be used in a given application, consideration should be given to cost and availability.

In general, relays are used to:

a. Obtain isolation between input and output circuits.

b. Invert the signal sense (from open to closed and vice versa)

c. Increase the number of output circuits (so as to switch more than one load or to switch loads from different sources)

d. Repeat signals

e. Switch loads of different voltage or current ratings

f. Retain an input signal

g. Interlock circuits

h. Provide remote control

600.2 APPLICATION CONSIDERATIONS

600.2.1 SWITCHING

Circuits to be switched shall be designed to minimize stresses on the relay contacts.

600.2.2 ARC SUPPRESSORS

Arc suppression techniques should be used to protect relay contacts. Arc suppression circuitry (e.g., diodes) should be mounted externally to the relay package.

TABLE 600-I

RELAY APPLICATION DATA

Relay Function	Application Specification MIL-R-					
	5757	6106	28750	39016	83726	28776
For Electronic and Communication Type Equipment, General Purpose						
DC Operated	X			X		
AC Operated	X					
Sensitive	X			X		
Hybrid						X
General Purpose						
DC Operated		X				
AC Operated		X				
AC/DC Operated	No standard part has been established.					
Electromagnetic, ER				X		
Latching						
DC Operated	X	X		X		
AC Operated		X				
AC/DC Operated		X				
Reed Type						
Dry Reed	X					
Time Delay Type						
Electric and Electronic					X	
Solid State	No standard part has been established.					
Telegraph Relays, Passive, Solid State	No standard part has been established.					
Solid State			X			
Vacuum, High Voltage (DC Coil Operated)	No standard part has been established.					

All the specifications give the part number to M - specification number - slash sheet number.

In addition, MIL-R-6106 relays have "MS" numbers, and MIL-R-83726 relays have dash numbers.

600.2.3 CONSTRUCTION

Solid state relays are preferred over electromechanical relays. Redundant configurations should be used when high reliability is required. Contacts should be operated in parallel for redundancy only and never to increase the current rating of the relay contacts.

600.2.4 MISAPPLICATIONS

Misapplication of relays will result in reduced reliability. The following is a listing of typical relay misapplications:

a. Improperly using existing military specifications or using the incorrect relay military specification.

b. Paralleling contacts to increase capacity. Contacts will not make or break simultaneously and one contact carries all the load under the worst conditions. Contacts can be paralleled for redundancy in the low level or minimum current (contamination test current) areas.

c. Circuit transient surges. Circuit designers shall be careful not to expect relays to handle circuit transient surges in excess of their ratings. It should be noted that surge currents greater than ten times the steady state currents can result when switching inductive, capacitive and lamp loads. Protection devices (such as transient suppression diodes) should be used to limit these surges or a relay rated higher than the surge current should be used.

d. Using relays under load conditions for which ratings have not been established. Contact ratings should be established for each type of load. Many relays will work from low level to rated load. However, relays shall not be used at low level loads after having been tested or used for a short period of time at high level loads. A cold filament lamp draws very high currents until warmed up. When a filament lamp fails a current surge of 35 times steady-state occurs. Contacts switching lamps shall be able to take the current surges.

e. Using relays at higher voltages than those for which they were designed, for example, switching 300 volt power supplies with relays only rated 115 volts maximum.

f. Contact ratings with grounded case. Some relays employing a grounded case have small internal spacing, or lack arc barriers. In such cases, contact ratings shall be derated more than in the ungrounded case mode of operation when switching in excess of 40 volts ac or dc. Typically, the maximum ac rating of a nominally rated 28 Vdc, 2 amp resistive relay, is of the order of 0.150 ampere. Switching high voltage with the relay case ungrounded results in a potential personnel hazard.

g. Transferring loads between unsynchronized power supplies with inadequately rated contacts. When a load is switched, the voltages can range from being in phase to 180° out of phase, therefore, the relay contact voltage can vary from zero volts to two times peak voltage and maximum current.

h. Switching polyphase circuits with relays tested and rated for single phase only. A typical misapplication is the use of small multipole relays (whose individual contacts are rated for 115 volts single phase ac) in 115/200 volts three phase ac applications. Phase to phase shorting at rated loads is a strong possibility in these instances with potentially catastrophic results.

i. Using relays with no established motor ratings to switch motor loads. In addition, caution should be used in applying relays to reverse motors, particularly where the motor can be reversed while running, commonly called "plugging." This results in a condition where both voltage and current greatly exceed normal. Only power relays rated for "plugging" and reversing service should be utilized in these applications.

j. Using relays with no established minimum current (contamination test current) capabilities. It should not be assumed that because a relay is used in an application considerably below its rated contact load that the consideration of minimum current (contamination test current) capability can be ignored; this is especially true if there is no established level of minimum current (contamination test current) for the relay.

k. Using relays rated for 115 Vac only on 28 Vdc or higher voltage dc applications. If contacts in these devices are of the single break form A type, it may be necessary to derate severely for use on dc applications, at 28 volts or higher.

l. Effects of ambient temperature on coil overdrive. Many users do not realize that more power is required to operate a relay at elevated temperatures. A coil operated relay is a current device (ampere-turns). Temperature increases the coil resistance at the rate of 0.004 ohm/ohm/°C due to the temperature coefficient of copper. Therefore, with a given voltage applied to a relay coil, overdrive decreases at elevated temperatures; if this is not taken into account, misapplication occurs. When rated voltage is specified, an ambient temperature is usually also specified, the user should consider the maximum ambient temperature condition and the effect upon the voltage that is supplied.

m. Relay race involves conditions where one relay must operate prior to another in separate drive circuits. Relay race circuits should be avoided, but where they must be used ambient temperature drive power, operate and release times, coil suppression circuitry, and wear consideration shall be carefully considered.

n. A problem is encountered when a relay coil is operated from a slowly rising current. When conditions are right, the relay operates at some point during the increasing drive current. Back electromotive forces (EMFs) are produced when the armature closes to the pole face. This voltage being opposite in polarity to the driving voltage causes the relay to release and then reoperate. This condition prevails until a sufficient amount of drive current is available to overcome the back EMFs.

o. Relays rated for 400 Hz only, shall not be used at 60 Hz.

p. Using relays to switch inductive loads. While ac inductive circuit requirements and relay capabilities can be properly matched in terms of current, voltage, frequency, and power factor, no such positive comparison method exists for dc inductive circuits. Thus, special care should be exercised in selecting relays to switch dc inductive loads.

q. Using coil transient suppression relays where suppression is not required. Suppressing coil transients can affect load switching capability and relay life. Using maximum possible suppression will increase relay drop-out time. Increased drop-out time can reduce the amount of current that can be switched and the relay life. Increased drop-out time can also adversely offset relay logic circuits.

r. Relays should be located and mounted to minimize the probability of contact chatter due to shock and vibration. The shock from pyrotechnic sources is a significant problem to relays; this can be avoided by the use of solid-state relays.

s. Contacts shall never be operated in series to "increase voltage rating."

t. Relays which are not designed specifically for load transfer applications should not be used for that purpose.

600.3 DERATING

Relays shall be derated according to Table 600-II.

600.4 SYMBOLS

Symbols used in the ordering of relays are:

600.4.1 TEMPERATURE CLASS

The temperature class is identified by a single letter according to Table 600-III.

TABLE 600-II

DERATING FACTORS

Parameter	Max. % of the Rated Value
Contact Current (continuous)	60 - Capacitive load 60 - Resistive load 40 - Inductive load 20 - Motor 10 - Filament (Lamp)
Contact Current (surge)	80
Coil Energize Voltage	110 maximum
Coil Dropout Voltage	90 minimum
Vibration	75 (including Q of mounting)
Maximum Derated Ambient Temperature	Limit to 65°C when rated @ 85°C 100°C when rated @ 125°C

TABLE 600-III

TEMPERATURE CLASS

Symbol	Operating Ambient Temperature Range (°C)
A	-55 to + 85
B	-65 to +125
C	-65 to +200
D	-55 to + 71
E	-65 to + 85
F	0 to + 70
G	-70 to +125
H	-70 to +200

600.4.2 SHOCK

Shock is identified by a single digit according to Table 600-IV.

TABLE 600-IV

SHOCK

Symbol	Test Conditions	Applicable Test Methods of MIL-STD-202
1	A (50G)	213
2	B (75G)	213
3	C (100G)	213
5	--	207 (high-impact)
6	(200G)	213 (5 ±1 ms pulse duration)
7	D (500G)	213

Note: Symbols 1, 2, and 3 replace 15, 30, and 50G of Methods 202 and 205 of MIL-STD-202.

600.4.3 VIBRATION CHARACTERISTICS

Vibration characteristics are identified by a single digit according to Table 600-V.

TABLE 600-V

VIBRATION CHARACTERISTICS

Symbol	Acceleration Value	Vibration Condition (Hertz)
1	02 (G)	10 - 500
2	".060 dbl amptd"	10 - 55
3	10 (G)	10 - 500
4	10 (G)	10 - 1,500
5	15 (G)	10 - 2,000
6	20 (G)	10 - 2,000
7	20 (G)	10 - 3,000
8	30 (G)	10 - 2,000
9	30 (G)	10 - 3,000
10	50 (G)	10 - 3,000

Note: Use .060 double amplitude whenever it is less than the curve "G" level.

600.4.4 TERMINAL

The style of the terminal is identified by a single or double letter according to Table 600-VI.

TABLE 600-VI

TERMINAL

Symbol	Style of Terminal
L	Lug (solder)
PW [1/]	Pin (printed wiring)
PI	Pin (plug-in)
S	Stud or screw
W	Wire leads (straight)
C	Wire leads (crimp)

1/ PW is preferred (PC is used in some specifications)

600.4.5 FAILURE RATE LEVEL

The specified failure rate level is identified by a single letter according to Table 600-VII. Only ER level "P" or higher shall be used.

TABLE 600-VII

FAILURE RATE LEVEL (ESTABLISHED AT 90% CONFIDENCE LEVEL FOR QUALIFICATION AND A 60% CONFIDENCE LEVEL FOR MAINTENANCE OF QUALIFICATION)

Symbol	Failure Rate Level (% 10,000 Operations)
L	3.0
M	1.0
P	0.1
R	0.01
S	0.001

601 RELAYS, ELECTRICAL, FOR ELECTRONIC AND COMMUNICATION TYPE EQUIPMENT

601.1 DC OPERATED

This section covers relays with dc voltage rated coils and contacts nominally rated up to and including 10 amperes. The applicable military specifications for these relays are MIL-R-5757 and MIL-R-39016 having the following characteristics:

a. Duty Cycle - Continuous

b. Altitude - Up to 70,000 feet

c. Enclosure - Hermetically sealed

For standard part numbers and individual relay characteristics see MIL-STD-1346.

601.2 AC OPERATED

This section covers relays with ac voltage rated coils and contacts nominally rated up to and including 10 amperes. The applicable military specification for these relays is MIL-R-5757 having the following characteristics:

a. Duty Cycle - Continuous

b. Altitude - Up to 70,000 feet

c. Enclosure - Hermetically sealed

d. Pickup Voltage - 90 Vac(max) over specified temperature range

e. Dropout Voltage - 30 Vac(max) over specified temperature range

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

601.3 SENSITIVE

This section covers relays designed to operate with an input coil power of 100 milliwatts or less. The applicable military specifications for these relays are MIL-R-5757 and MIL-R-39016 having the following characteristics:

a. Duty Cycle - Continuous

b. Altitude - Up to 70,000 feet

c. Enclosure - Hermetically sealed

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

601.4 HYBRID

This section covers relays that use a combination of solid state circuitry and an electromechanical relay to perform the switching function. The applicable military specification for these relays is MIL-R-28776 having the following characteristics:

a. Duty Cycle - Continuous

b. Altitude - Up to 70,000 feet

c. Enclosure - Hermetically sealed

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

601.5 MIL-R-5757, RELAYS, ELECTRICAL (FOR ELECTRONIC AND COMMUNICATION TYPE EQUIPMENT)

601.6 MIL-R-28776, RELAYS, ELECTRICAL FOR ELECTRONIC AND COMMUNICATION TYPE EQUIPMENT, HYBRID

601.7 MIL-R-39016, RELAY, ELECTROMAGNETIC, ESTABLISHED RELIABILITY

601.7.1 QUALITY LEVEL

Only ER Level "P" or higher shall be used

602 RELAYS, ELECTRIC, GENERAL PURPOSE

602.1 DC OPERATED

This section covers dc voltage rated relays nominally rated for 5 amperes and up. The relays are capable of meeting the electrical and environmental requirements when mounted directly to a structure. The applicable military specification for these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle - Continuous

b. Rated Coil Voltage - 28 Vdc

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

602.2 AC OPERATED

This section covers ac voltage rated relays nominally rated for 5 amperes and up. The relays are capable of meeting the electrical and environmental requirements when mounted directly to a structure. The applicable military specification for these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle - Continuous

b. Rated Coil Voltage - 115 Vac, 400 Hz

c. Enclosure - Hermetically sealed

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

602.3 AC/DC OPERATED

This section covers relays with ac and dc voltage rated coils and contacts rated 5 amperes and up. These relays are capable of meeting the electrical and environmental requirements when mounted directly to the structure.

Note: At this time, no military specifications are established.

602.4 MIL-R-6106, RELAYS, ELECTROMAGNETIC

603 RELAYS, LATCHING

603.1 DC OPERATED

This section covers relays with dc voltage rated coils and contacts that latch in the energized or deenergized position, or both positions, until reset electrically. The military specifications covering these relays are MIL-R-5757, MIL-R-6106 and MIL-R-39016 having the following characteristics:

a. Duty Cycle - Continuous

b. Enclosure - Hermetically sealed

c. Operating Temperature Range - -65°C to 125°C

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

603.2 AC OPERATED

This section covers relays with ac voltage rated coils and contacts that latch in the energized or deenergized position, or both positions, until reset electrically. The military specification covering these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle - Continuous

b. Enclosure - Hermetically sealed

c. Rated Coil Voltage - 115 Vac, 400 Hz

d. Operating Temperature Range - -65°C to 125°C

e. Shock - 3 (see Table 600-IV)

f. Vibration - 4 (see Table 600-V)

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

603.3 AC/DC OPERATED

This section covers relays with ac/dc voltage rated coils and contacts that latch in the energized (dc) or deenergized (ac) position, or both positions, until reset electrically. The military specification covering these relays is MIL-R-6106 having the following characteristics:

a. Duty Cycle - Continuous

b. Enclosure - Hermetically sealed

c. Operating Temperature Range - -65°C to 125°C

d. Shock - 3 (see Table 600-IV)

e. Vibration - 4 (see Table 600-V)

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

604 RELAYS, REED (DRY) TYPE

604.1 DRY REED

This section covers relays consisting of one or more reed switch capsules and one or more coils. The military specification for these relays is MIL-R-5757 having the following characteristics:

a. Duty Cycle - Continuous

b. Enclosure - Sealed

c. Shock - 3 (see Table 600-IV)

For standard relays and individual relay characteristics, see MIL-STD-1346.

605 RELAYS, TIME DELAY

605.1 ELECTRIC AND ELECTRONIC

This section covers time delay relays in which the specified time delay interval is obtained through the use of electric or electronic circuitry. The military specification for these relays is MIL-R-83726 having the following characteristics:

a. Duty Cycle - Continuous

For standard part numbers and individual relay characteristics, see MIL-STD-1346.

605.2 SOLID STATE

This section covers time delay relays in which the specified time delay interval is obtained through the use of solid state electronic circuitry.

Note: At this time, no military specifications are established for these relays.

605.3 MIL-R-83726, RELAYS, TIME DELAY, HYBRID AND SOLID STATE

605.3.1 CLASSIFICATION

Time delay relays covered by this section consist of the following types and classes:

a. Type - The type is identified as follows:

I - Time delay on operate.

IIA - Time delay on release (separate control and power terminals).

IIB - Time delay on release (true).

III - Interval timer.

IV - Repeat cycle timer.

V - Time sequence as specified.

b. Class - The class is identified as follows:

A - Hybrid (integral electromagnetic relay qualified to MIL-R-5757 or MIL-R-39016).

B - Hybrid (integral electromagnetic relay qualified to MIL-R-6106).

C - Solid state.

D - Hybrid (integral electromagnetic relay not qualified with contact ratings 5 amperes or lower).

E - Hybrid (integral electromagnetic relay not qualified with contact ratings 5 amperes or higher).

605.3.2 RATINGS

Time delay relays with electromechanical relay output and with contact ratings 10 amperes or greater shall be class B or class E.

606 RELAYS, TELEGRAPH

606.1 PASSIVE, SOLID STATE

This section covers solid state polar relays for use in telegraph circuits and associated equipment.

Note: At this time, no military specifications are established for these relays.

607 RELAY, SOLID STATE

607.1 SOLID STATE

This section covers relays utilizing only semiconductor and electrical passive circuit devices. The military specification covering these relays is MIL-R-28750.

607.2 MIL-R-28750, RELAY, SOLID STATE

608 RELAYS, VACUUM, HIGH VOLTAGE

608.1 DC COIL OPERATED

This section covers relays, vacuum, high voltage dc coil operated.

Note: At this time, no military specifications are established for high voltage, vacuum, relays.

SECTION 700

CRYSTAL UNITS (QUARTZ)
AND
CRYSTAL HOLDERS (ENCLOSURES)

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700 CRYSTAL UNITS (QUARTZ) AND CRYSTAL HOLDERS (ENCLOSURES)

700.1 GENERAL INFORMATION

Standard Crystal Units and Holders are specified in MIL-STD-683.

700.2 APPLICATION CONSIDERATIONS

700.2.1 ESD SENSITIVITY

Some crystal units, especially tight tolerance units, are found to be susceptible to electrostatic discharge (ESD) in the static voltage range of >4,000 to ≤15,000 volts. Surface acoustic wave (SAW) devices can fail from ESD, in the static voltage range of <1,000 volts. ESD damage often results in operational degradation rather than catastrophic failure. These units shall be handled according to the requirements of DOD-STD-1686 and DOD-HDBK-263.

700.2.2 FAILURE MODES

Electrical parameters of piezoelectric crystals are deteriorated by excessive driving current or from high voltages which cause mechanical stress and movement to be generated in the crystal plate. When the voltage is excessive, mechanical forces cause motion in excess of the elastic limit of the crystal and crystal fracture can occur. The fracture can occur as a lifted platelet as has been experienced in lithium niobate SAW delay lines. Such fractures, when occurring in sufficient number, will cause enough change to the operating electrical characteristics, for example, frequency shift, for the crystal to be out of specification.

700.3 DERATING FACTORS

The specified maximum and minimum parameters of the crystal units are limiting factors beyond which the reliability of the crystal unit will be impaired from the viewpoint of reliability, life and performance. The designer shall ascertain that the crystal unit will be operated under conditions that are within the limits specified for the particular unit type required.

701.1 MIL-C-3098, CRYSTAL UNITS, QUARTZ

701.1.1 APPLICATION DATA

Refer to MIL-STD-683 for characteristics of crystal styles covered by MIL-C-3098.

701.2 MIL-H-10056, HOLDERS (ENCLOSURES), CRYSTAL

701.2.1 APPLICATION DATA

For Holders to be used with standard crystal units, see MIL-STD-683.

SECTION 800

SWITCHES

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800 SWITCHES

800.1 GENERAL INFORMATION

Standard switches shall be selected from MIL-STD-1132. To effectively and properly select switches and associated hardware, the designer shall know the advantages and disadvantages of different types of switches, their behavior under various environmental conditions, switch construction, the effect of the switch upon the circuit, and the effect of the circuit upon the switch.

800.1.1 CHOICE OF SWITCH TYPES AND ASSOCIATED HARDWARE

The designer should consider the following characteristics and parameters in choosing the most suitable switch design and associated hardware:

a. Application (type of switch)

b. Flexibility of circuitry

c. Type of action

d. Electrical data (contact ratings, etc.)

e. Type of contacts

f. Environmental capabilities such as shock and vibration

g. Mechanical data and safety features

h. Panel layout

i. Quality and reliability

j. Economics

800.1.2 SWITCH TYPES

Switches can be grouped into three general types: rotary, nonrotary, and sensing. These types differ from each other in size, cost, actuation, construction, and general mechanical and electrical characteristics.

800.1.3 SWITCH SELECTION FACTORS

Selection factors are noted below:

a. Design and construction

  (1) Open or enclosed construction

  (2) Sealed (hermetically, environmentally resilient, dust-tight, water-tight, explosion-proof)

(3) Mounting (bushing, multihole, mounting bracket, mounting plate)

(4) Illuminated or nonilluminated

b. Operating characteristics

(1) Actuation - pushbutton, toggle, rotary, sensing

(2) Switching action - momentary action, maintained action, alternate action, snap action

c. Contacts

(1) Type of contacts and contact arrangement

(2) Contact ratings - resistive, inductive, lamp, motor, capacitive, and frequency

(3) Contact bounce time

(4) Contact resistance

(5) Make-before-break, break-before-make, shorting or nonshorting contact

d. Environmental considerations

(1) Temperature range

(2) Moisture

(3) Altitude

(4) Shock and vibration

(5) Acceleration

(6) Sand and dust

(7) Explosion

e. Insulation requirements

(1) Insulation resistance

(2) Breakdown voltage

f. Switching speed

(1) Actuation speed

g. Life

    (1) Mechanical

    (2) Electrical at elevated temperature

h. Terminals

    (1) Solder

    (2) Screw

    (3) Wire

    (4) Plug-in termination

    (5) Integrated wire termination

    (6) Printed-circuit board terminations

800.2 APPLICATION CONSIDERATIONS

Application considerations in the selection of switches include the following.

800.2.1 ENCLOSURES

Many types of enclosures are used to protect switches from varying external conditions, particularly high humidity and dirt. Accordingly, switches may be classified based on the degree of protection offered by the enclosure. Such classifications include the following: open, sealed, enclosed, environmetally (resilient), and hermetically sealed. With the open construction switch, no effort is made to protect the switch or its parts from atmospheric conditions. The enclosed switch is one in which the contacts are enclosed in a case made of plastic or metal and plastic. The environmentally (resilient) sealed switch contains a completely sealed case where any portion of the seal is resilient material such as a gasket or a seal. The hermetically sealed switch is made air tight by a sealing process which involves fusing or soldering and does not use gaskets. The hermetically sealed enclosure offers the greatest protection because it insulates against such elements as moisture, harmful gases, and dirt. It also eliminates the increased arcing caused by low atmospheric pressures at high altitudes.

800.2.2 CONTACTS

The switch electrical contacts can be classified by function, current carrying capacity, and application. The contact arrangements vary in complexity from a simple make or break, through make-before-break, break-before-make, make-make, break-break, etc.; from a single-throw to multiple-throw, single pole to multipole; and various combinations of these features.

800.2.2.1 Contact Ratings

Contacts are usually given multiple ratings dependent on the type of load being switched. These ratings consist of resistive, capacitive, lamp, motor, or inductive loads. Most switches are given the resistive load rating and in most instances at least one additional rating mentioned above. Extra care should be used in selecting switches for motor, inductive, or lamp loads. Also, see section 800.3 on derating.

800.2.2.2 Contact Operate and Bounce Times

In many instances, critical operate and bounce times of the contact are important. Operate time in a double-throw switch is defined as the time it takes the moving contact to separate from the normally closed contact, travel to the normally open contact and make the circuit, not including bounce time. Bounce time is the interval between first make of the contact until the uncontrolled making and breaking of the contact ceases. In many electronic circuits, a millisecond is a long time and operate and bounce times become critical parameters.

800.2.2.3 Contact Resistance

Contact resistance is the resistance between two mating closed electrical contacts measured at their external terminals. Contact resistance can be used to measure the voltage drag and the dissipation across the contacts. Contact resistance includes the resistance of the contact material, oxide or other film on the surface of the contacts, and the resistance of the elements on which the contacts are mounted (e.g., springs, mounting, and the external terminals and their connections).

800.2.3 LOW-LEVEL (DRY CIRCUIT) APPLICATIONS

Dry circuit applications require switch contact resistance ratings based on testing, using an open circuit voltage of 30 millivolts maximum and a test current of 10 milliamperes maximum (e.g., Method 311 or MIL-STD-202). In order to achieve low-level load capability, suppliers use contact materials such as gold, platinum, palladium (or their alloys) to minimize formation of insulating films on the contacts. They also design the switch contacts so that they wipe across each other to remove such films. Other considerations are: to provide internal designs which do not allow rubbing of insulated parts against metal that generates dust particles internally; and to adequately seal the switch contacts from external dust and foreign matter since foreign particles being deposited on the switch contacts increases contact resistance. Proper test and performance requirements before and after life tests should be the basis for selection of these switches.

800.2.4 INSULATION RESISTANCE

Insulation resistance is important in high impedance circuits. Low insulation resistance in a high voltage circuit can result in excessive dissipation within the dielectric leading to failure. For applications where arc-over is a problem, switches shall be selected which have a high insulation resistance (1,000 megohms or more and 5 megohms or more as measured immediately after the moisture resistance test). Rated insulating materials, furthermore, will not form a conducting surface film buildup after repeated arcs on making and breaking of contacts.

800.2.5 LIFE OPERATIONS FOR TOTAL LIFE

A careful analysis of the required life of the switch or total number of operations should be made. In some equipment applications, the operational life of the switch can be comparatively short.

800.2.6 ENVIRONMENTAL CONSIDERATIONS

800.2.6.1 Temperature

a. Variations in temperature shall be considered, as moisture condensation within the switch could develop. In choosing a switch for a wide range of temperature, the entire temperature range must be considered rather than only one extreme.

b. Exposure to low temperature may cause certain materials of a switch to contract, causing case cracking or opening. Such failure could result in moisture or other foreign matter entering the switch causing short circuit, voltage breakdown, or corona.

c. Chemical action of switch materials are accelerated by high temperatures. Insulation resistance between the switch contacts and ground decreases as the temperature increases. High temperature can also affect the insulation from the standpoint of voltage breakdown due to a change in dielectric strength. Also, the increased speed of corrosion of contacts and switching mechanism is affected by high temperatures.

800.2.6.2 Moisture

Moisture in the dielectric will decrease the dielectric strength, life, and insulation resistance and could cause corrosion by increasing the galvanic action between dissimilar metals in the switch. Switches which operate in high humidities shall be hermetically sealed, or if this is not applicable, the use of boots, "O" rings, or diaphragms placed over switch openings, is recommended to decrease moisture entry.

800.2.6.3 Altitude

With a decrease of atmospheric pressure, the spacings required to prevent flashover increase substantially. Small switches, because of their very close contact spacing, are partially susceptible to malfunction at high altitudes. Contact life decreases substantially with continued arc-over.

800.2.6.4 Shock and Vibration

Switches should be selected that will operate under expected shock and vibration. Those with contact chatter requirements will cover low frequency vibration and shock applications. High frequency vibration will determine the effects of fatigue and resonance on the mechanical construction of the switch contact elements. Contact bounce due to shock or vibration causes arcing which shortens contact life and could generate electrical noise.

800.2.6.5 Acceleration

Some switches are sensitive to acceleration forces arising from use in high speed vehicles or aircraft. Failures are usually due to internal construction which allows normally closed contacts to open and normally open contacts to close under acceleration conditions.

800.2.6.6 Sand and Dust

A combination of dust and small amounts of moisture will increase the possibility of voltage breakdown of the insulation between closely space terminals. Where low insulation resistance or high leakage currents can cause circuit malfunction, the switch should be capable of passing sand and dust test requirements.

800.2.6.7 Explosion

Explosion resistance requires that switches operate in a volatile atmosphere without causing explosion. Wherever possible, switches to be used in an explosive atmosphere shall be sealed.

800.2.7 PRECAUTIONS

a. Switch contacts shall be operated in parallel for redundancy only and never to "increase the current rating."

b. Switch applications in digital circuits must be carefully reviewed to assure that contact bounce or chatter will not be interpreted as a circuit interruption which will produce logic errors.

c. Switches are subject to contact chatter in high shock and vibration environments, and these environments may dictate the use of solid state devices. The mounting of switches shall be designed to minimize vibration and shock amplification or to provide necessary isolation.

800.3 DERATING

Switches shall be derated according to Table 800-I.

TABLE 800-I

Derating Requirements

Derating Parameter	Max. % of Rated Value
Contact Current (continuous)	60 - Capacitive load 60 - Resistive load 40 - Inductive load 20 - Motor 10 - Filament (Lamp)
Vibration	75 (including "Q" of mounting)
Contact Current (surge)	80
Maximum Derated Ambient Temperature	Limit to 20°C - 25°C below the specified maximum

800.4 QUALITY LEVEL

Only ER level "P" or higher shall be used.

800.5 USE APPLICATIONS OF SWITCHES

The principal applications of various types of switches are provided in Table 800-II.

TABLE 800-II

SWITCH APPLICATIONS

Switch Type	MIL-SPEC No.	Application
Switch, Push-Button Illuminated	Mil-S-22885	Used as panel displays and switching devices in ac and dc applications. Panel displays include various combinations of colors and legends.
Switches and Switch Assemblies, Sensitive and Push (Snap Action)	MIL-S-8805	Used in ac and dc applications, where predetermined small and accurately controlled characteristics are required. Various means of actuation by toggle levers, push-buttons,

TABLE 800-II (CONTINUED)

SWITCH APPLICATIONS

Switch Type	MIL-SPEC No.	Application
MIL-S-8805 (cont'd)		cams, and other light pressure devices. These switches have snap-action which eliminates teasing.
Switches, Multi-Station, Push-Button (Illuminated and Nonilluminated)	MIL-S-23417	Used as panel displays and switching devices in ac and dc applications.
Switches, Pressure	MIL-S-9395	Used primarly to detect changes in pressure, liquid and gas applications.
Switches, Rotary	MIL-S-3786	Used primarily for low power, alternating current (ac) or direct current (dc) switching applications (capable of making and breaking a resistive load of 2 amperes or less). Includes both manually and solenoid actuated switches.
Switches, Rotary Selector Power	MIL-S-6807	Used in power circuits capable of making, arraying, and breaking electrical loads of 10 amperes or less.
Switches, Rotary (Printed Circuit), (Thumbwheel, Inline, and Push-Button)	MIL-S-22710	Used primarily for low power ac or dc switching applications. Thumbwheel switches provides a numerical or other legend readout tied to a particular switch position. Also provided for is logic circuitry for computer operation.
Switches, Thermostatic (Metallic and Bimetallic)	MIL-S-24236	Used primarily in ac and dc applications where temperature protection or accurate temperature control or an enclosure is required.
Switches, Thermostatic (Volative Liquid), Hermetically Sealed	MIL-S-28827	Used primarily in ac and dc applications that require rapid temperature response.

TABLE 800-II (CONTINUED)

SWITCH APPLICATIONS

Switch Type	MIL-SPEC No.	Application
Switches, Toggle Environmentally Sealed	MIL-S-3950	Used where simple make-and-break actions are required and are suitable for use on ac and dc circuits.
Switches, Toggle, Positive Break	MIL-S-8834	Used in ac and dc circuits where a positive make-and-break action is required. Positive break actuation causes minimum contact "tease".
Switches, Air and Liquid Flow	MIL-S-28788	
Boots, Dust and Water Seal	MIL-B-5423	Used on toggle, push-button and rotary switches to protect the switch actuating mechanism from sand, dust, water, and other contaminants, and to seal the panel on which the switches are mounted.
Switches, Reed	MIL-S-55433*	
Switches, Snap Action	MIL-S-15291*	
Guards	MIL-G-7703*	

*Standard switches are to be established for these specifications.

SECTION 900

FILTERS

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900 FILTERS

900.1 GENERAL INFORMATION

Standard filters shall be selected from MIL-STD-1395. The variety of filter and network types used in any particular equipment should be the minimum necessary to obtain satisfactory performance. Where more than one type filter or network can be used in a given application (i.e., L-C, R-C, L-R, electro-mechanical, piezo-electric crystal, etc.) consideration should be given to cost and availability (use of strategic materials, multiple sources, etc.). The filters and networks identified herein meet all the criteria for standard types as identified in MIL-STD-1395.

900.2 APPLICATION CONSIDERATIONS

900.2.1 ITEM IDENTIFICATION

Part numbers used to identify the filters and networks listed herein are as specified in the individual filter or network specification. Type designations can be constructed as indicated in examples given in applicable sections of this manual.

900.2.2 INSULATION RESISTANCE

Careful consideration shall be given to the insulation resistance of filters. The value of insulation resistance varies with temperature, and it is necessary to apply a correction factor to measurements made at temperatures other than 25°C. Table 900-I gives correction factors for measurements made at temperatures between 20°C and 35°C. The required value of insulation resistance shall be multiplied by the correction factor to determine the new value required at the new temperature.

TABLE 900-I

CORRECTION FACTORS

Degrees Centigrade	Correction Factor	Degrees Centigrade	Correction Factor
20	1.42	28	0.82
21	1.33	29	0.76
22	1.24	30	0.71
23	1.16	31	0.67
24	1.08	32	0.63
25	1.00	33	0.59
26	0.94	34	0.55
27	0.87	35	0.51

900.2.3 INSERTION-LOSS AND DISCRIMINATION

The design engineer should give consideration to insertion-loss and discrimination characteristics of the filter for its application. This will provide transmission of desirable frequencies through the filter at acceptable levels, while providing the necessary attenuation of undesirable frequencies.

900.3 DERATING REQUIREMENTS

Filters shall be derated according to Table 900-II.

TABLE 900-II

DERATING FACTORS

Derating Parameter	Max. % of the Rated Value
Current	50
Working Voltage	50
Operating Temperature	20°C less than the specified maximum

901 FILTERS, RADIO INTERFERENCE

901.1 MIL-F-15733, FILTERS, RADIO INTERFERENCE

901.1.1 APPLICATION CONSIDERATIONS

901.1.1.1 Use

These filters are current carrying filters, ac and dc, and are used primarily for the reduction of broadband radio interference. They are also applicable to shielded room and power factor applications.

901.1.1.2 Rated Frequency

These filters are applicable for use in equipment requiring frequency ratings up to 1,000 MHz.

901.1.1.3 Construction

These filters consist of discrete component parts (inductors and capacitors) arranged in the popular circuit configurations such as "Pi", "L", and "T". They are enclosed in hermetically sealed metallic enclosures, with all exposed metallic surfaces protected against corrosion by plating, lead alloy coating, or other means.

901.1.1.4 Voltage Rating

The filters covered by this section are of two types: those rated for direct current use, and those rated for both alternating current and direct current use. The direct current types are rated at 100 volts dc, and the ac-dc types are rated at 125 volts ac and 400 volts dc.

901.1.1.5 Current Rating

These filters are available in seven current ratings from 1 ampere to 30 amperes.

902 FILTERS, BAND PASS

902.1 MIL-F-18327, FILTERS, HIGH PASS, LOW PASS, BAND PASS, BAND SUPPRESSION AND DUAL FUNCTIONING

902.1.1 APPLICATION CONSIDERATIONS

902.1.1.1 Use

These filters are designed for use in applications with a wide range of source and load impedances ranging from a few ohms to several megohms.

902.1.1.2 Terminals

These filters are equipped with solder lug and pin type terminals. They are provided with external mounting studs, lock nut or flat washer, lock washer, and nut.

902.1.1.3 Construction

The filters covered by this section are composed of combinations of inductors, capacitors, resistors, piezo-electric crystals, electro-mechanical and other electronic components arranged in electrical configurations which provide insertion-loss and discrimination characteristics required in a particular filter.

903 QUALITY LEVEL

Only ER level "P" or higher shall be used.

SECTION 1000

MAGNETIC DEVICES

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1000 MAGNETIC DEVICES

1000.1 GENERAL INFORMATION

Standard transformers, inductors and coils are specified in MIL-STD-1286. The selection of a transformer, inductor, or coil should consider such factors as circuit function, construction, circuit application, operating temperature, altitude, type of mounting, environmental conditions, size, weight, life expectancy, and reliability. These factors are described herein. After the preliminary selection of a transformer, inductor or coil, the appropriate military specifications and MS drawings should be examined to verify that the item parameters important to the new application are controlled to the degree necessary.

1000.2 APPLICATION CONSIDERATIONS

Application considerations are as follows:

1000.2.1 POWER TRANSFORMERS AND INDUCTORS

1000.2.1.1 Frequency

Power transformers and inductors are designed to operate efficiently over a limited frequency range. Operation outside this range, particularly at lower frequencies, will result in overheating.

1000.2.1.2 Capacitive Loads

Transformers that drive rectifier circuits with capacitive filters require special consideration since the external load current is the average of the pulsed current from the transformer and the dissipation in the transformer is proportional to the average value of I^2. The result is that small changes in load current result in inordinately large changes in transformer dissipation.

1000.2.1.3 Saturation

Power inductors used as filters usually carry a large direct current component. If this component exceeds the value specified, the inductance can be reduced because of core saturation.

1000.2.2 AUDIO TRANSFORMERS

1000.2.2.1 Saturation

Audio transformers are not normally designed to accommodate any direct current. Small amounts of direct current can cause core saturation significant performance degradation, especially at low frequencies.

1000.2.2.2 Resistance Change With Temperature

The temperature coefficient of resistance for copper windings is approximately 0.4%/°C. This change in resistance can be significant in some applications. Most military equipment is required to operate over a large temperature range. An analysis should be performed to ensure that the resistance variations are compatible with the design requirements.

1000.2.2.3 Shielding

Electrostatic or electromagnetic shielding may be required in low level circuits to avoid noise or hum pickup.

1000.3 DERATING REQUIREMENTS

Transformers, inductors, coils, and RF coils shall be derated according to the parameters shown in Table 1000-I. The current limitations for wire size used in transformers, inductors and coils are provided in Table 1000-II.

TABLE 1000-I

DERATING REQUIREMENTS FOR TRANSFORMERS, INDUCTORS, COILS, AND RF COILS

Part Type	Derating Parameters	Max. % of Rated Value
Transformers, Inductors and Coils:		
	Current Density	2mA per cir. mil.
	Current (Continuous)	70
	Current (Surge)	80
	Voltage (Continuous)	70 or 25 of the Insulation Breakdown, whichever is less
	Voltage (Surge) Insulation Breakdown	80
	Hot Spot Temperature (Operating)	Limit to 65 of specified maximum
RF Coils:	Current (dc)	50
	Hot Spot Temperature (Operating)	Limit to 65 of specified maximum

TABLE 1000-II

CURRENT DERATING FOR WIRE SIZE USED IN CONSTRUCTION OF TRANSFORMERS, INDUCTORS, AND COILS

AWG No.	Max. Amps	AWG No.	Max. Amps.
42	.010	20	2.40
40	.025	18	4.40
38	.040	16	5.50
36	.060	14	9.00
34	.100	12	11.0
32	.153	10	15.0
30	.250	8	21.0
28	.400	6	28.0
26	.635	4	38.0
24	1.02	2	52.0
22	1.45		

1001 TRANSFORMERS/INDUCTORS

1001.1 MIL-T-27, TRANSFORMERS AND INDUCTORS, POWER, AUDIO FREQUENCY, HIGH POWER PULSE

1001.1.1 APPLICATION CONSIDERATIONS

The MIL-T-27 transformers and inductors shall be applied according to Table 1000-III.

TABLE 1000-III

APPLICATION OF MIL-T-27, TRANSFORMERS AND INDUCTORS

Application	Grade Required*	Temperature Class
Shipboard, transportable and ground-mobile	4 or 5	R, S, V or T
Ground-fixed	4 or 5	Q, R, S or V
Aircraft and missile	4 or 5	R, S, T or U

* Grade 6 transformers and inductors may be used in hermetically sealed or encapsulated assemblies only.

1001.2 MIL-T-21038, TRANSFORMERS, PULSE, LOW POWER

1001.2.1 APPLICATION CONSIDERATIONS

MIL-T-21038 transformers shall be applied according to Table 1000-IV.

TABLE 1000-IV

APPLICATION OF MIL-T-21038, TRANSFORMERS

Application	Grade	Temperature Class	Life Expectancy
Shipboard, transportable and ground-mobile	4 or 5	R, S, T or U	X
Ground-fixed	4 or 5	Q, R, S or T	X
Aircraft and missile	4, 5, 6, or 7	R, S, U or V	X

1002 COILS, RADIO FREQUENCY

1002.1 MIL-C-15305, COILS, RADIO FREQUENCY

MIL-C-15305 covers radiofrequency coils, fixed and variable, for use as simple inductive elements in radiofrequency circuits.

1002.2 MIL-C-39010, COILS, FIXED, RADIO FREQUENCY, ESTABLISHED RELIABILITY

MIL-C-39010 covers radiofrequency, molded coils which have a specified reliability for use in equipment where reliability, long life, and continuity of operation are necessary.

1002.2.1 QUALITY LEVELS

Only ER level "P" or higher shall be used.

1002.3 MIL-C-83446, COILS, RADIO FREQUENCY, FIXED OR VARIABLE

MIL-C-83446 covers fixed or variable chip radiofrequency coils intended for incorporation into hybrid microelectronic circuits.

APPENDICES

APPENDIX A

THERMAL CONSIDERATIONS ON ELECTRONIC COMPONENT PARTS

I. GENERAL

The electrical power dissipated in an electronic part causes a temperature increase which can affect its performance and reliability. The effect can be a gradual change in part characteristics, reduction in useful life, or a catastrophic failure.

Part failure rates are known to increase exponentially with temperature. A thermally caused failure may not always occur so rapidly as to be considered catastrophic. However, there is always a slow, progressive deterioration of dielectrics, cathode coatings, transistor junctions, and many other materials which accelerate with temperature, leading eventually to failure. These effects are cumulative so that failure rate depends, to some extent, on the entire thermal history of the part. Thermal failure is, therefore, insidious since it is usually impossible to determine the percentage of life remaining in a part. This has a direct bearing on the effects of temperature cycling specified in nearly all specifications for testing electronic parts and equipment. Additionally, temperature cycling can occur during the normal operation of equipments or as a result of equipment on-off cycling. There are indications that temperature cycling has an adverse effect on reliability, but there exists little quantitative data and no accurate model at this time by which the effect can be accurately estimated. However, temperature cycling in excess of +15°C has been found to significantly reduce part life and reliability. Steady state ambient temperatures can also have a significant effect on part failure rate. Failure rate increases as large as 46 to 1 occur for glass capacitors, with an ambient operating temperature differential of 95°C (i.e., 25°C and 120°C). This is shown in Table A-I which has been reconstructed from MIL-HDBK-217 to portray a few extreme examples of the effect of ambient temperature on part failure rate.

It is emphasized that adequate thermal design alone, including effective cooling of parts, is not a cure for all electrical overstress. Many parts are thermal sensitive, however, others are voltage or energy sensitive. Adequate thermal design requires control of part temperatures or using parts with higher ambient temperature ratings. This is also true for energy sensitive parts. Voltage sensitive parts, however, require control of part voltage ratings in addition to thermal constraints. Thus, thermal design must be closely coordinated with the electrical design during new equipment development to achieve the required reliability.

II. THERMAL RATINGS OF PARTS

For today's densely packaged equipment, the local air temperature (ambient) surrounding a part is related to the part's power dissipation and the temperature rise caused by radiation, convection or conduction effects to or from nearby parts. These latter effects are significant and can lead to the overheating of parts, even though the part temperature rating appears not to be exceeded based upon the power dissipation of that part. Typical of the problems that can develop is the example of wirewound power resistors which are generally allowed to have a hot spot temperature rise of 330°C when operating at full power. Most other electronic parts would be destroyed if mounted in a close proximity to this hot spot.

TABLE A-I

FAILURE RATES

Part Description	λ_b Failures Per Million Hours Base Failure Rate		ΔT°C	Ratio of High to Low Failure Rate
	High Temperature	Low Temperature		
PNP Silicon Transistors	0.0092 at 130°C and 0.3 stress	0.0014 at 25°C and 0.3 stress	105	6.5:1
NPN Silicon Transistors	0.0048 at 130°C and 0.3 stress	0.00094 at 25°C and 0.3 stress	105	5:1
Glass Capacitors	0.012 at 120°C and 0.5 stress	0.0026 at 25°C and 0.5 stress	95	46:1
Transformers and Coils MIL-T-27 Class Q	.0267 at 85°C	.0008 at 25°C	60	33:1
Resistors Carbon Comp.	.0065 at 100°C and 0.5 stress	.003 at 25°C and 0.5 stress	75	21.5:1

Electronic parts developed in recent years, such as semiconductor devices, are rated in terms of external surface or case temperatures, and the internal thermal resistances from this case to the most temperature sensitive internal element. This rating method is accurate; it determines the thermal state of the internal elements and it minimizes the problems discussed above.

A. Thermal Ratings of Solid State Parts

The methods of rating solid state parts under steady-state conditions are indicated by the following definition of thermal resistance (θ). "Thermal Resistance is the ratio of the temperature difference to the heat generated through internal power dissipation under steady-state conditions", i.e.:

$\theta = \frac{\Delta T}{P_D}$ where the temperature difference (ΔT) is measured between the region of heat generation and some reference point, and P_D is the internal power dissipation.

The overall thermal resistance of an assembled part is usually expressed as the rise in junction temperature above the case temperature per unit of power dissipated. It should be noted that thermal resistance is defined for steady-state conditions. If a uniform temperature over the entire semiconductor junction is assumed, the power dissipation required to raise the junction temperature to a value consistent with reliable operation, can be determined. However, under conditions of intermittent loads such a design may be unnecessarily conservative and expensive.

For example, under pulsed operation, with pulse width τ and pulse repetition rate $1/T$, the dissipation rating may be increased with respect to continuous operation. This is possible because the part cools somewhat between pulses. The allowed increase depends on the duty cycle τ/T and on the part thermal time constant, which is the product of its thermal resistance and thermal capacitance (J/°C). This time constant must be much longer than τ if the dissipation ratings are to be increased, i.e., the part should not be allowed to reach steady-state temperature during the pulse. Although both thermal resistance and thermal capacitance vary with temperature, the variation over the operating range of most solid state parts is small enough so that it may usually be neglected in thermal calculations. Section III-B of this appendix discusses calculations related to pulsed operation of discrete semiconductor devices.

B. Thermal Cycling Effects on Solid State Devices

Significant temperature variations occur in solid state devices because of changes in ambient temperature and in power dissipation during operation. These variations result in cyclic mechanical stresses due to the difference in the coefficient of thermal expansion of the semiconductor and metallic materials. Table A-II gives typical examples of the thermal cycling that a transistor may be required to withstand in some applications. The table shows that even for some very common applications the thermal cycling requirements can be very severe.

Thermal cycling rating charts have been developed to show the number of thermal cycles that a device is rated to withstand. Figure A.1 shows a typical chart for power transistors as a function of the total transistor power dissipation (P_D) and the change in case temperature (ΔT_C). The designer may use this rating to define the limiting value to which the case temperature must be restricted to assure reliable operation over the number of thermal cycles required in a given application. Conversely, if the power dissipation (P_D) and the change in case temperature (ΔT_C) are known, the designer may use this rating to determine whether the thermal cycling capability of the transistor is adequate for the application.

III. THERMAL EVALUATION AND DESIGN FOR HEAT TRANSFER

There are three basic processes of heat transfer: Conduction, Convection and Radiation. These processes are used, singly or in combination, in the removal of heat from electronic parts.

Conduction is considered to be caused through molecular oscillations in solids, and elastic impact in liquids and gases. The thermal resistance of a material which is attributed to conduction is given by:[2]

$$\theta_{COND} = \frac{d}{4.186\,KA} \quad (°C/WATT)$$

where d = length of thermal path in cm

K = thermal conductivity in cal/(sec)(cm)(°C)

A = area perpendicular to thermal path in cm^2

4.186 = conversion factor in (WATT)(sec)/cal

TABLE A-II

THERMAL CYCLING REQUIREMENTS FOR TYPICAL APPLICATIONS OF TRANSISTORS (Adapted from Ref. 2)

Application	Circuit	P_D (W)	ΔT_C (°C)	Minimum Equipment Life Required (years)	Typical Thermal Cycling Rating Required (Cycles)
Auto radio audio output	Class A	8	75	5	5,000
	Class AB	2	45	5	5,000
Power supply	Series regulator	50	65	5	5,000
	Switching regulator	15	65	5	5,000
Hi-Fi audio amplifier	Class AB	35	50	5	5,000
Computer power supply	Series regulator	50	65	10	10,000
Computer peripheral equip.	Solenoid regulator	5	5	10	1.3×10^8
Television	Vertical output	10	75	5	5,000
	Audio output	8	75	5	5,000
Sonar modulator	Linear amplifier	100	55	10	144×10^3

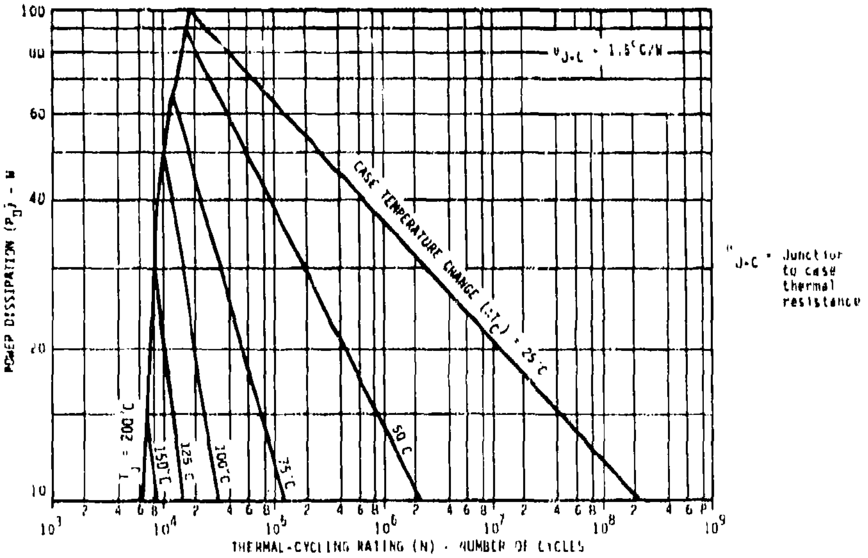

FIGURE A.1

THERMAL CYCLING RATING CHART (Adapted from Ref. 2)

Convection is the process of heat transfer from the surface of a solid to moving masses of fluids, either gaseous or liquid. The convective thermal resistance is given by:

$$\theta_{CONV.} = \frac{1}{Ah} \; (^\circ C/WATT)$$

where A = total exposed area in m^2

h = convective heat transfer coefficient in WATT/($m^2 \cdot {}^\circ C$)

Radiation is the emission of thermal energy from a surface in the form of electromagnetic waves ranging in wavelength from the long infared, to the short ultraviolet. The rate of emission can be found from Stefan's law, and the radiation thermal resistance is given by:[2]

$$\theta_{RAD.} = \frac{1763 \times 10^8}{AE(T_s^4 - T_{amb}^4)} (T_s - T_{amb})$$

where 1763×10^8 = inverse of Stefan Boltzmann's constant in $cm^2 \cdot {}^\circ C^4$ per WATT

E = emissivity of the surface (a function of the surface finish)

A = total exposed area in cm^2

T_s = surface temperature in °C

T_{amp} = ambient temperature in °C

A. Heat Exchanger Performance

Convection methods (natural or forced) are the most widely used methods of heat transfer from electronic parts due to their simplicity in design and cost effectiveness.

The selection of a heat exchanger to maintain a part at a desired operating temperature using convection requires knowledge of:

1. The available volume of space to be occupied.
2. The maximum allowable part temperature.
3. The power dissipated by the part.
4. The part configuration.
5. Ambient conditions (temperatures, air flow).

Table A-III shows heat exchanger properties of various metals.[3]

TABLE A-III

HEAT EXCHANGER PROPERTIES

MATERIAL	HEAT STORAGE CAPACITY (JOULE/in.^{3})	HEAT STORAGE CAPACITY (JOULE/ POUND)	THERMAL CONDUCTIVITY (W/in.-°C)	DENSITY (POUND/ in.^{3})	THERMAL CONDUCTIVITY DENSITY (W-in.^{2}/°C-lb.)
Aluminum (6061)	40.5	413	4.35	0.098	44.4
Brass	50.5	165	2.94	0.306	9.6
Copper	57.5	178	9.93	0.323	32.4
Gold	41.3	59	7.48	0.698	10.7
Lead	24.2	59	0.88	0.41	2.15
Molybdenum	45.5	123	3.71	0.369	10.1
Nickel	67.0	208	1.54	0.322	4.8
Silver	40.5	107	10.55	0.380	27.8
Steel, Carbon	62.0	209	1.14	0.283	4.0
Steel, Stainless	65.0	224	0.413	0.29	1.4
Tin	28.6	110	1.54	0.261	5.9
Zinc	47.5	184	2.84	0.258	10.6

Figure A.2 is a nomograph of thermal resistance as a function of heat exchanger dimensions for natural convection.

Thermal resistance versus heat exchanger volume for natural and forced convection are compared in Figure A.3. Natural convection cooling is based on a 50°C exchanger temperature rise above ambient. Force convection cooling is shown at air velocities of 250, 500 and 1,000 feet per minute.

B. Heat Sink Calculations for Semiconductor Devices

1. Steady-State Operation

The steady-state power dissipated (P_D) by a semiconductor device is given by:

$$P_D = \frac{T_j - T_{amb.}}{\theta_{JA}} \quad \text{(WATTS)}$$

where T_j = maximum permissible junction temperature (°C) given in the manufacturer's specifications

$T_{amb.}$ = maximum ambient temperature (°C)

θ_{JA} = junction to ambient thermal resistance in °C/W

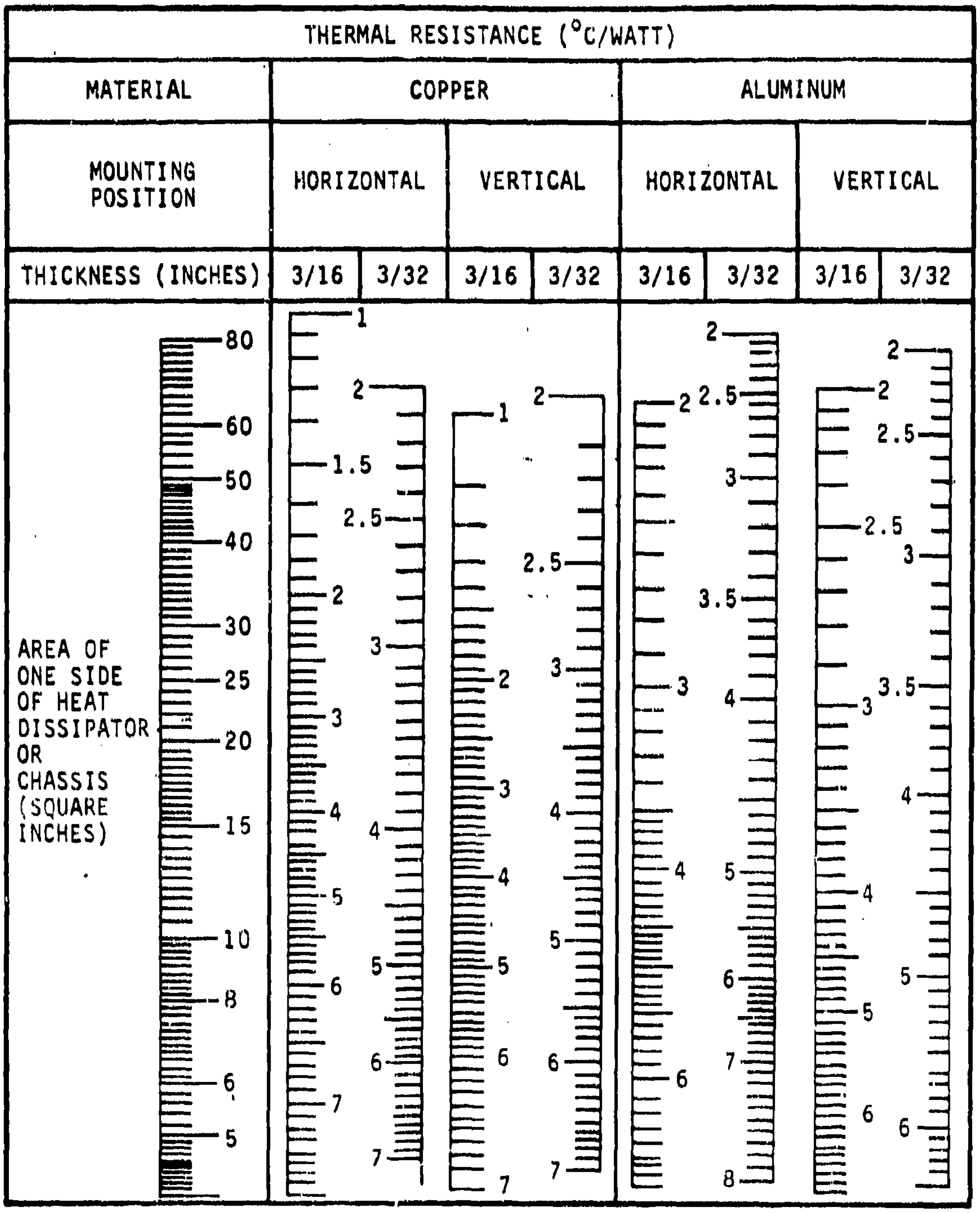

FIGURE A.2

THERMAL RESISTANCE OF FLAT FIN HEAT EXCHANGER[4]

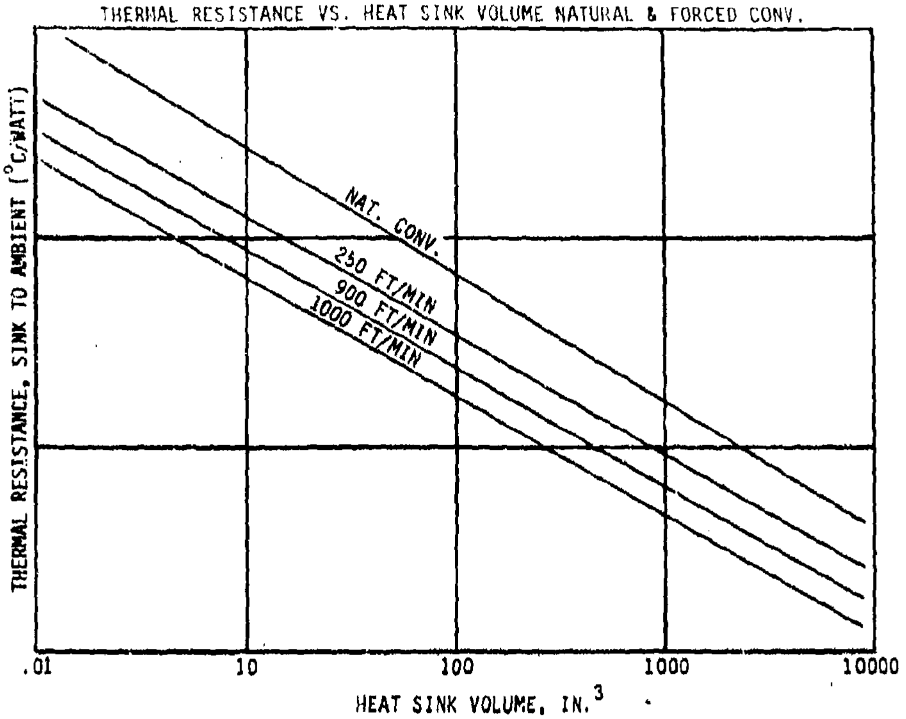

FIGURE A.3

THERMAL RESISTANCE VS. HEAT EXCHANGER VOLUME[5]

From the electrical equivalent shown in Figure A.4 θ_{JA} can be calculated as:

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$$

where θ_{JC} = junction to case thermal resistance (°C/W)

θ_{CS} = case to heat sink thermal resistance (°C/W)

θ_{SA} = heat sink to ambient thermal resistance (°C/W)

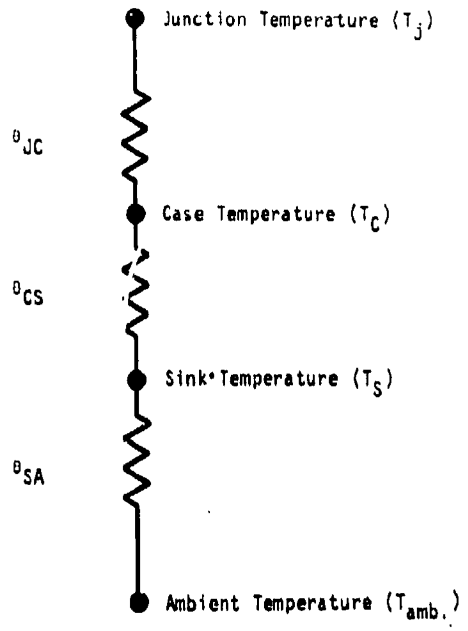

FIGURE A.4

EQUIVALENT CIRCUIT FOR HEAT SINK CALCULATION

Junction to case thermal resistance (θ_{JC}) depends on the style of the case with some common values shown in Table A-IV.[2]

Case to heat sink thermal resistance (θ_{CS}) depends on the method of mounting the device. Table A-V shows typical values with and without the use of thermally conductive compound.

As an example of a heat sink calculation, consider a 2N3055 power transistor for which $\theta_{JC} = 1.5$ °C/W and $T_j = 200°C$. It is desireable to keep the case temperature of the device below $T_C = 130°C$, with assumed values of $T_{amb.} = 50°C$ and $\theta_{CS} = 0.4°C/W$.

TABLE A-IV

JUNCTION TO CASE THERMAL RESISTANCE

CASE	θ_{JC}(°C/W)
TO-3	1.5
TO-5	30.00
TO-66	4.00
TO-220	4.00

TABLE A-V

COMPARISON OF INSULATING WASHERS USED FOR ISOLATION

Material	θ_{CS} (°C/W)	
	With No Compound	With Compound
None	0.2	0.1
Beryllium Oxide	0.4	0.2
Anodize Aluminum	0.5	0.3
Mica	0.8	0.4

From the power curve of the device, we find $P_D \cong 40$ WATTS @ $T_C = 130°C$, thus:

$$\theta_{JA} = \frac{T_J - T_{amb}}{P_D} = \frac{200 - 50}{40} = 3.75°C/\text{WATT}$$

From the equivalent circuit of Figure A.4:

$$\theta_{SA} = \theta_{JA} - \theta_{JC} - \theta_{CS} = 3.75 - 1.5 - 0.4$$

$$\theta_{SA} = 1.85°C/\text{WATT}$$

i.e., a heat sink with thermal resistance $\theta_{SA} \leq 1.85°C$/WATT will be capable of maintaining the case temperature of the device to below $T_C = 130°C$.

2. Single Pulse Operation

The maximum allowable power dissipation P_{SP}(max) in operation under a single nonrepetitive short duration pulse, is substantially greater than the steady-state dissipation capability of a device. A quantity defined as Transient Thermal Resistance[6] must be known before the dissipation capability of the device under pulsed operation can be determined. This quantity is usually obtained from the safe-operating-area curves or the Thermal Response curves of the device in the form of a normalized multiplier (M) at a given case temperature (T_C), usually 25°C, and at a given pulse duration. At higher case temperatures this multiplier must be linearly derated with the following derating factor:

$$DF = 1 - \frac{T_C - 25°C}{T_J - 25°C}$$

The maximum allowable dissipation $P_{SP}(max)$ under single pulse operation can now be calculated as:

$$P_{SP}(max) = M(DF)\, P_D(max)$$

where $P_D(max)$ = maximum steady-state power dissipation

As an example, consider again the 2N3055 Power Transistor which has safe-operating-area curves shown in Figure A.5 (manufacturer's specification).

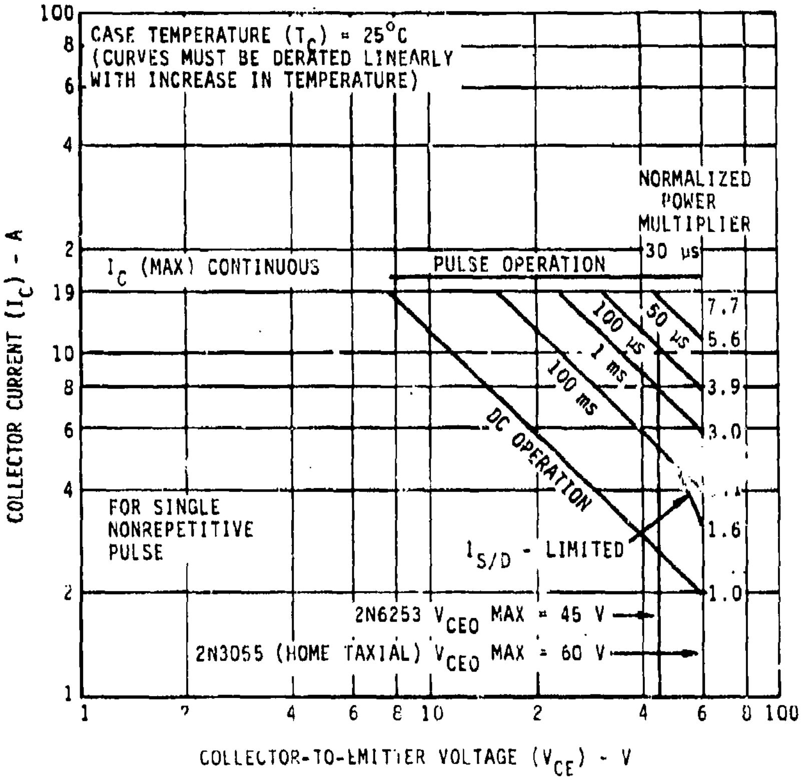

FIGURE A.5

SAFE-OPERATING-AREAS OF 2N3055 AND 2N6253

If we select a 1 millisecond pulse, the power multiplier M is shown as M = 3 at T_C = 25°C. The derating factor (DF) will then be:

$$(DF) = 1 - \frac{T_C - 25°C}{T_j - 25°C} = 1 - \frac{50 - 25}{200 - 25} = 0.857$$

where T_j = maximum junction temperature = 200°C

The case temperature (T_C) was considered to be essentially the ambient temperature ($T_{amb.}$ = 50°C) for this example, since no appreciable change in case temperature occurs because of the short duration of the pulse (1 millisecond).

Finally, the maximum allowable power dissipation $P_{SP}(max)$ under a single 1 millisecond pulse is calculated as:

$P_{SP}(max) = M(DF)\ P_D(max) = 295.7$ WATTS with

$P_D(max) = 115$ WATTS = maximum steady-state power dissipation

3. Repetitive Pulse Operation

In the repetitive pulse mode the rise in case temperature caused by the average power dissipation in the device, must also be taken into account. With pulse duty cycle (d), the maximum allowable power dissipation ($P_{RP}(max)$) of the device can be determined by:

$$P_{RP}(max) = M \frac{(T_j - T_{amb.})}{(\theta_{JC} + Md\ \theta_{CA})}$$

Consider, as an example, a pulse train with 1 millisecond pulse width and 100 Hz repetition rate, i.e., duty cycle d = 0.1 = 10 percent. For the 2N3055 power transistor with:

$T_j = 200°C$, $T_{amb.} = 50°C$, $\theta_{JC} = 1.5°C/W$

$\theta_{CA} = \theta_{JA} - \theta_{JC} = 3.75 - 1.5 = 2.25$ °C/W, M = 3, the maximum allowable power dissipation is calculted as:

$$P_{RP}(max) = M \frac{(T_j - T_{amb.})}{(\theta_{JC} + Md\ \theta_{CA})} = 3 \frac{(200 - 50)}{(1.5 + (3)(0.1)(2.25))}$$

$$= 206.9 \text{ WATTS}$$

It can be seen that under repetitive pulsing with a 10 percent duty cycle, the maximum power capability ($P_{RP}(max)$) of the device is reduced to about 60 percent of the single pulse maximum power capability ($P_{SP}(max)$), but it is still about 50 percent above the steady-state maximum power capability ($P_D(max)$).

REFERENCES

[1]"General Derating Guidelines," Evaluation Research Corporation.

[2]"Solid State Power Circuits," Designer's Handbook, RCA, 1971.

[3]"SCR Applications Handbook," International Rectifier, 1977.

[4]*Electronic Design*, August 1961.

[5]"Semiconductor Heat Sinks For Thermal Dissipation," volumes 1 and 2 EG & G Wakefield Engineering, 1979.

[6]"Introduction to Solid State Power Electronics," Westinghouse Electric Corporation, 1977.

APPENDIX B

DESCRIPTION OF QUALITY/RELIABILITY SCREENING LEVELS OF STANDARD PARTS

I. GENERAL

Reliability Screening is a testing process designed to remove from a group of parts those having inferior reliability. Such screening is accomplished by subjecting a delivered lot of parts to various electrical, thermal and environmental stresses for the purpose of making the weak ones fail. The screening process must be designed to meet the following criteria:

o Test and stress levels must be carefully selected to fail inferior parts;

o Tests must be nondestructive and nondegrading to good parts;

o Testing must be adequate to screen out all potential failure mechanisms of the parts to be screened.

An effective screening program requires a detailed understanding of the materials, fabrication and packaging techniques, electrical and thermal characteristics, and manufacturing tests performed on the parts to be screened. In addition, to limit costs to a reasonable level, screening should be based upon the least amount of testing required to provide a meaningful screen.

Much cost and effort has been expended by DoD agencies and industry in developing reliability screening processes and requirements for the major types of parts used in military equipment. These requirements have been detailed in the military specifications for these parts.

There are three different ways in which the reliability screening levels (also referred to as quality or product assurance levels) are specified for three distinct categories of military parts: (1) screened military grade active and passive electrical parts (e.g., relays, coils, connectors, resistors and capacitors) are procureable to Established Reliability (ER) Military Specifications categorized as to ER failure rate level (L through T); (2) screened military grade semiconductor devices are procureable to MIL-S-19500 and its detailed slash sheets and are categorized as JAN, JANTX, JANTXV and JANS screening levels; (3) screened military grade microcircuits are procureable to MIL-M-38510, are labeled JAN, and categorized as to screening class (i.e., S, B or C).

Commercial grade, military grade and military ER and JAN grade parts are generally physically and functionally interchangeable with the basic difference being the failure rate levels which can vary in the order of magnitudes. ER and JAN parts have been screened per Military Test Standards as required by the specific parts/military specifications and are certified to these specifications by government inspectors. These inspectors monitor and periodically survey and requalify these manufacturers to assure that the high reliability levels of the parts are maintained from lot to lot.

In addition to the military grade ER and JAN parts there are various so-called "vendor equivalents". These parts have been subjected to similar screening tests as those required by the ER or JAN military specifications, but do not meet the full requirements of the ER or JAN military specifications. Such vendor equivalents exhibit lower failure rates than their commercial counterparts, and sometimes those of standard military parts. The screening requirements and failure rate levels of ER passive parts and JAN semiconductors and microcircuits are discussed in detail below.

A. Established Reliability (ER) Active/Passive Electrical Components

ER passive electrical parts are procureable in accordance with ER Military Specifications to various failure rate levels from manufacturers qualified and certified to those levels by government inspectors. Such manufacturers are listed on Qualified Parts Lists (QPLs). ER specifications presently exist for many types of capacitors, resistors, relays, and RF coils and are presently being developed for other part types.

ER parts procured to these ER military specifications exhibit failure rates demonstrated under the controlled test conditions specified in these specifications. These failure rates are expressed as percent failures per thousand hours (percent/1,000 hours). The failure rate levels usually* provided for by these ER military specifications are:

MIL Symbol	Failure Rate (% Failures/1,000 hrs)
L	2.0
M	1.0
P	0.1
R	0.01
S	0.001
T	0.0001

Parts procured to ER military specifications are also subjected to special process controls, lot acceptance testing, screening, and extended life tests.

Manufacturers of ER parts must establish and implement a reliability assurance program in accordance with MIL-STD-790 that is evaluated and monitored by a government qualifying activity. This reliability assurance program requires an approved program plan; test, calibration, and failure analysis facilities; training program; failure reporting, analysis and corrective action system; maintenance of material, process, and failure analysis records; traceability; controlled storage; and reporting of test results to maintain listing on the QPL.

ER components are 100 percent screened in accordance with the requirements of the individual ER and military specification which imposes applicable test methods and conditions of MIL-STD-202. A listing of these tests is provided in Table B-I. Not all of these tests are required for each part type.

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* Failure rate levels vary for different parts and different ER specifications; e.g., "L" level failure rate for MIL-C-39022 capacitors is 5.0 percent per 1,000 hours.

TABLE B-I

LISTING OF MIL-STD-202 TEST METHODS

Method No.	Title
	Environmental Tests (100 Class)
101D	Salt spray (corrosion)
103B	Humidity (steady-state)
104A	Immersion
105C	Barometric pressure (reduced)
106E	Moisture resistance
107E	Thermal shock
108A	Life (at elevated ambient temperature)
109D	Explosion
110A	Sand and dust
111A	Flammability (external flame)
112D	Seal
	Physical Characteristics Tests (200 Class)
201A	Vibration
202D	Shock (specimens weighing not more than 4 pounds) (Superseded by Method 213)
203B	Random drop
204D	Vibration, high frequency
205E	Shock, medium impact (Superseded by Method 213)
206	Life (rotational)
207A	High-impact shock
208D	Solderability
209	Radiographic inspection
210A	Resistance to soldering heat
211A	Terminal strength
212A	Acceleration
213B	Shock (specified pulse)
214	Random vibration
215C	Resistance to solvents
217	Particle impact noise detection (PIND)
	Electrical Characteristics Tests (300 Class)
301	Electric withstanding voltage
302	Insulation resistance
303	DC resistance
304	Resistance-temperature characteristic
305	Capacitance
306	Quality factor (Q)
307	Contact resistance
308	Current-noise test for fixed resistors
309	Voltage coefficient of resistance determination procedure
310	Contact-chatter monitoring
311	Life, low level switching
312	Intermediate current switching

Failure rates and failure rate levels of ER parts are statistically established during life testing at 60 percent or 90 percent confidence levels (as required in the ER part military specifications) and in accordance with failure rate sampling plans and procedures of MIL-STD-690. These failure rates are established for laboratory conditions at rated electrical stress. Failure rate levels at derated application stress levels, and actual equipment environments can be estimated using MIL-HDBK-217. Parts with failure rate levels of P or better (i.e., R, S, or T) should be used in the design of military equipment when available.

B. JAN, JANTX, JANTXV, and JANS Semiconductors

Military grade high reliability screened semiconductors are procureable in accordance with MIL-S-19500 and designated as JAN, JANTX, JANTXV and JANS quality levels depending upon the type and amount of screening performed on the semiconductor. The prefix JAN of a semiconductor type designation refers to the military standardization program for semiconductors. These semiconductors have been tested to and have passed the minimum qualification tests specified by MIL-S-19500. The TX suffix to JAN designates "Testing Extra". JANTX parts, in addition to JAN processing, undergo specific process and power conditioning tests on a 100 percent basis (depending upon the detail specification) in addition to the JAN sampling tests, to enable further elimination of defective parts. JANTXV quality level semiconductors require all testing performed on JANTX semiconductor devices plus an internal visual PRECAP inspection which further eliminates defective parts and provides greater reliability in the surviving lot. JANS quality level semiconductors, while requiring all the tests performed on JANTXV parts, also requires Particle Impact Noise Detection (PIND) Testing, Failure Analysis, Serialization and traceability to a wafer lot. A diagram depicting the processing and screening for the JAN, JANTX, JANTXV and JANS are shown in Figures B.1, B.2 and B.3.

The sampling procedure and acceptance requirement for JAN testing is in accordance with the Lot Tolerance Percent Defective (LTPD) as defined in MIL-STD-105 and as specified in the semiconductor detailed specification. Test methods used in screening of semiconductors are in accordance with MIL-STD-750 for tests specified in the detail specification. A listing of these tests is provided in Table B-II.

Failure rates for semiconductors are determined in accordance with the procedures of MIL-HDBK-217.

Relative failure rate (FR) multipliers for various types of semiconductors for a given temperature and electrical stress level and based upon JAN as 1.0 are shown in Table B-III (JANS being the most reliable, and "commercial" being the least reliable).

These FR multipliers are used in the formulation of semiconductor failure rates per MIL-HDBK-217. JANTX, JANTXV or JANS level semiconductors are recommended for use in the design of military equipment.

C. Quality/Reliability Levels of Microcircuits

High quality level microcircuits should be procured per MIL-M-38510. This specification establishes the design, quality, reliability assurance and vendor qualification and certification requirements for

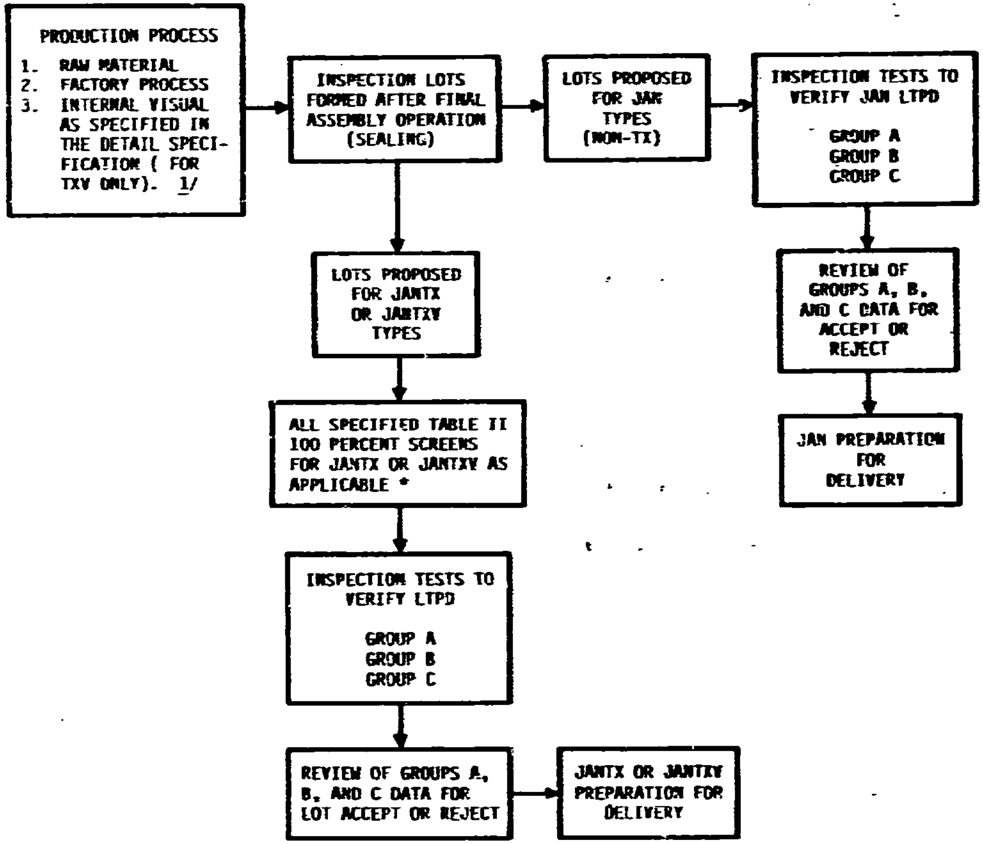


FIGURE B.1

ORDER OF PROCEDURE DIAGRAM FOR JAN (NON-TX), JANTX, AND JANTXV DEVICE TYPES

*Order of the tests shall be performed as specified in MIL-S-19500, Table II.

1/All products to be proposed for JANTXV processing must have been subjected to and passed JANTXV internal visual 100 percent screening at this step (except for clear glass JANTXV diodes which shall be subjected to internal visual inspecton prior to painting or marking).

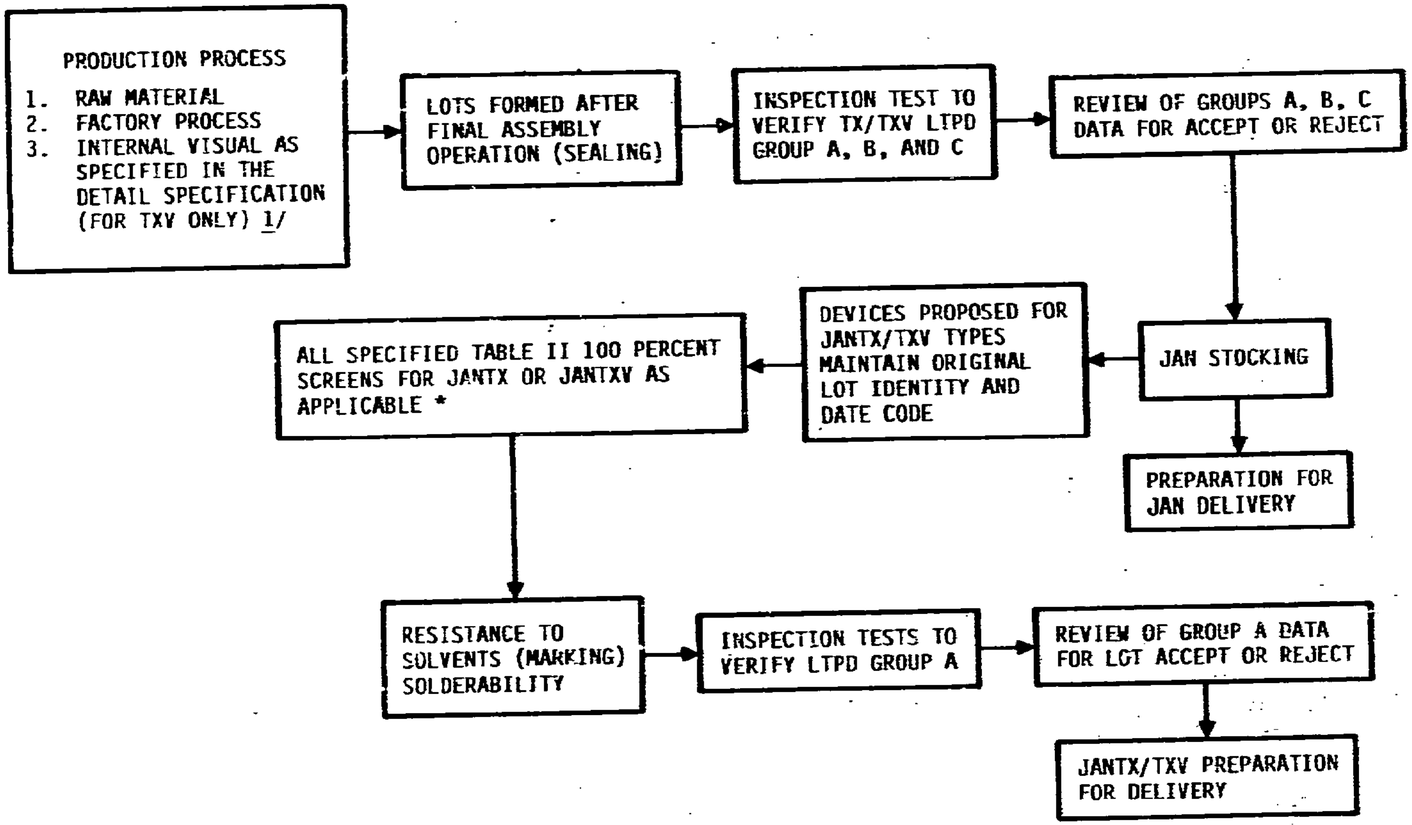


FIGURE B.2

ALTERNATE ORDER OF PROCEDURE DIAGRAM FOR JAN (NON-TX), JANTX, AND JANTXV TYPES

*Order of the tests in the blocks shall be performed as specified in MIL-S-19500.

1/See footnote 1/ from Figure B.1.

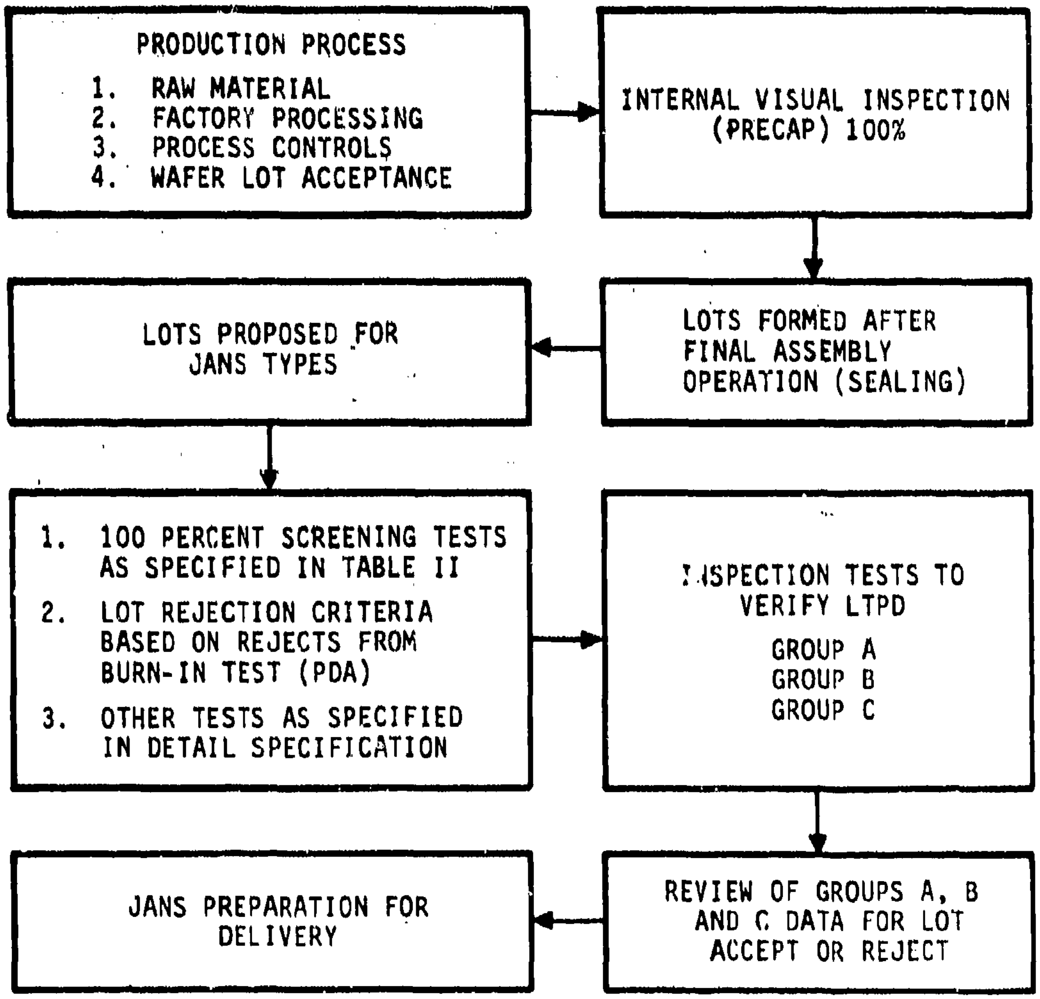


FIGURE B.3

ORDER OF PROCEDURE DIAGRAM FOR CLASS JANS

TABLE B-II

MIL-STD-750 TEST METHODS FOR SEMICONDUCTOR DEVICES

Method No.	Title
	Environmental Tests (1000 Class)
1001.1	Barometric pressure (reduced)
1011	Immersion
1015	Steady-state primary photocurrent irradiation procedure (electron beam)
1016	Insulation resistance
1017	Neutron irradiation
1019	Steady-state total dose irradiation procedure
1021.1	Moisture resistance
1022.1	Resistance to solvents
1026.3	Steady-state operation life
1027.1	Steady-state operation life (LTPD)
1031.4	High temperature life (nonoperating)
1032.1	High temperature (nonoperating) life (LTPD)
1036.3	Intermittent operation life
1037	Intermittent operation life (LTPD)
1038	Burn-in (for diodes and rectifiers)
1039	Burn-in (for transistors)
1040	Burn-in (for thyristors (controlled rectifiers))
1041.1	Salt atmosphere (corrosion)
1046.2	Salt spray (corrosion)
1051.2	Thermal shock (temperature cycling)
1056.1	Thermal shock (glass strain)
1061.1	Temperature measurement, case and stud
1066.1	Dew point
1071.2	Hermetic seal
	Mechanical Characteristics Tests (2000 Class)
2005	Axial lead tensile test
2006	Constant acceleration
2016.2	Shock
2017	Die shear strength
2026.4	Solderability
2031.1	Soldering heat
2036.3	Terminal strength
2037	Bond strength
2046.1	Vibration fatigue
2051.1	Vibration noise
2052	Particle impact noise detection test
2056	Vibration, variable frequency
2057.1	Vibration, variable frequency (monitored)
2066	Physical dimensions
2071	Visual and mechanical examination
2072.2	Internal visual transistor (precap) inspection
2073	Visual inspection for die (semiconductor diode)
2074	Internal visual inspection (discrete semiconductor diodes)
2075	Decap internal visual design verification

TABLE B-II (CONTINUED)

MIL-STD-750 TEST METHODS FOR SEMICONDUCTOR DEVICES

Method No.	Title
	Environmental Tests (1000 Class)(Continued)
2076.1	Radiography
2077	Scanning electron microscope (SEM) inspection of metallization
2081	Forward instability, shock (FIST)
2082	Backward instability, vibration (BIST)
	Electrical Characteristics Tests (for Transistors) (3000 Class)
3001.1	Breakdown voltage, collector to base
3005.1	Burnout by pulsing
3011.1	Breakdown voltage, collector to emitter
3015	Drift
3020	Floating potential
3026.1	Breakdown voltage, emitter to base
3030	Collector to emitter voltage
3036.1	Collector to base cutoff current
3041.1	Collector to emitter cutoff current
3051	Safe operating area (continuous dc)
3052	Safe operating area (pulsed)
3053	Safe operating area (switching)
3061.1	Emitter to base cutoff current
3066.1	Base emitter voltage (saturated or nonsaturated)
3071	Saturation voltage and resistance
3076.1	Forward current transfer ratio
3086.1	Static input resistance
3092.1	Static transconductance
	Circuit Performance and Thermal Resistance Measurements (3100 Series)
3126	Thermal resistance (collector-cutoff-current method)
3131.1	Thermal resistance (emitter to base forward voltage, emitter-only switching method)
3132	Thermal resistance (dc forward voltage drop, emitter base, continuous method)
3136	Thermal resistance (forward voltage drop, collector to base, diode method)
3141	Thermal response time
3146.1	Thermal time constant
3151	Thermal resistance, general
3181	Thermal resistance for thyristors
	Low Frequency Tests (3200 Series)
3201.1	Small-signal short-circuit input impedance
3206.1	Small-signal short-circuit forward-current transfer ratio
3211	Small-signal open-circuit reverse-voltage transfer ratio

TABLE B-II (CONTINUED)

MIL-STD-750 TEST METHODS FOR SEMICONDUCTOR DEVICES

Method No.	Title
	Low Frequency Tests (3200 Series) (Continued)
3216	Small-signal open-circuit output admittance
3221	Small-signal short-circuit input admittance
3231	Small-signal short-circuit output admittance
3236	Open circuit output capacitance
3240.1	Input capacitance (output open-circuited or short-circuited)
3241	Direct interterminal capacitance
3246.1	Noise figure
3251.1	Pulse response
3255	Large-signal power gain
3256	Small-signal power gain
3261.1	Extrapolated unity gain frequency
3266	Real part of small-signal short-circuit input impedance
	High Frequency Tests (3300 Series)
3301	Small-signal short-circuit forward-current transfer-ratio cutoff frequency
3306.2	Small-signal short-circuit forward-current transfer ratio
3311	Maximum frequency of oscillation
3320	Power output, RF power gain, and collector efficiency
	Electrical Characteristics Tests (for Field Effect Transistors) (3400 Series)
3401	Breakdown voltage, gate to source
3403	Gate to source voltage or current
3404	Mosfet threshold voltage
3405	Drain to source on-state voltage
3407	Breakdown voltage, drain to source
3411	Gate reverse current
3413	Drain current
3415	Drain reverse-current
3421	Static drain to source on-state resistance
3423	Small-signal drain to source on-state resistance
3431	Small-signal, common-source, short-circuit, input capacitance
3433	Small-signal, common-source, short-circuit, reverse-transfer capacitance
3453	Small-signal, common-source, short-circuit, output admittance
3455	Small-signal, common-source, short-circuit, forward transadmittance
3457	Small-signal, common-source, short-circuit, reverse transfer admittance
3459	Pulse response (FET)
3461	Small-signal, common-source, short-circuit, input admittance

TABLE B-II (CONTINUED)

MIL-STD-750 TEST METHODS FOR SEMICONDUCTOR DEVICES

Method No.	Title
	Electrical Characteristics Tests (for Diodes) (4000 Class)
4000.1	Capacitance
4011.4	Forward voltage
4016.3	Reverse current leakage
4021.2	Breakdown voltage (diodes)
4022	Breakdown voltage (voltage regulators and voltage reference diodes)
4026.2	Forward recovery voltage and time
4031.1	Reverse recovery time
4036.1	"Q" for voltage variable capacitance diodes
4041.2	Rectification efficiency
4046.1	Reverse current, average
4051.3	Small-signal reverse breakdown impedance
4056.2	Small-signal forward impedance
4061.1	Stored charge
4066.2	Surge current
4071.1	Temperature coefficient of breakdown voltage
4076.1	Saturation current
4081.2	Thermal resistance of lead mounted diodes (forward voltage, switching method)
	Electrical Characteristics Tests (for Microwave Diodes) (4100 Series)
4101.3	Conversion loss
4102	Microwave diode capacitance
4106	Detector power deficiency
4111.1	Figure of merit (current sensitivity)
4116.1	Intermediate frequency (IF) impedance
4121.2	Output noise ratio
4126.2	Overall noise figure and noise figure of the IF amplifier
4131.1	Video resistance
4136.1	Standing wave ratio
4141.1	Burnout by repetitive pulsing
4146.1	Burnout by single pulse
4151	Rectified microwave diode current
	Electrical Characteristics Tests (for Thyristors (Controlled Rectifiers)) (4200 Series)
4201.2	Holding current
4206.1	Forward blocking current
4211.1	Reverse blocking current
4216	Pulse response
4219	Reverse gate current
4221.1	Gate-trigger voltage or gate-trigger current
4223	Gate-controlled turn-on time
4224	Circuit-commutated turn-off time

TABLE B-II (CONTINUED)

MIL-STD-750 TEST METHODS FOR SEMICONDUCTOR DEVICES

Method No.	Title
	Electrical Characteristics Tests for Thyristors (Controlled Rectifiers) (4200 Series)(Continued)
4225	Gate-controlled turn-off time
4226.1	Forward "on" voltage
4231.2	Exponential rate of voltage rise
	Electrical Characteristics Tests (for Tunnel Diodes) (4300 Series)
4301	Junction capacitance
4306.1	Static characteristics of tunnel diodes
4316	Series inductance
4321	Negative resistance
4326	Series resistance
4331	Switching time
	High Reliability Space Application Tests (5000 Class)
5001	Wafer lot acceptance testing.

TABLE B-III

RELATIVE FAILURE RATE DIFFERENCES

Screening Level	All Semiconductors Except Microwave	Microwave Detectors and Mixers (Si & Ge)
JANS	.05	.05
JANTXV	.1	.1
JANTX	.2	.3
JAN	1.0	1.0
Lower*	5.0	5.0

monolithic, multichip and hybrid microcircuits. There are three (3) classes of screening provided for military JAN microcircuits: MIL-M-38510 JAN Classes S, B and C with S being the highest quality level and C the lowest quality level. Only microcircuits procured per MIL-M-38510 may have the "JAN" designation. The MIL-M-38510 Class S, B and C microcircuits require screening tests in accordance with Method 5004.6 (for monolithic) or Method 5008.2 (for hybrid) of MIL-STD-883 Class S, B and C respectively (except for interim electrical parameter testing). Manufacturers of microcircuits per Classes S, B and C of MIL-M-38510 must meet specific qualification requirements to acquire and maintain listing on the QPL. This qualification requires a manufacturer certification (including a government approved Product Assurance Program Plan), production line certification, and qualification and quality conformance inspection testing per Method 5005.8 (for monolithic) or Method 5008.2 (for hybrid microcircuits) of MIL-STD-883.

Many microcircuits are procured to MIL-STD-883 Class S, B or C screening. These devices may have been subjected to the tests of MIL-STD-883 Method 5004.6 (for monolithic) or Method 5008.2 (for hybrid microcircuits) but have not had the in-process controls required by MIL-M-38510 and generally exhibit higher failure rates than MIL-M-38510. Besides the MIL-M-38510 Class S, B and C of MIL-STD-883 Method 5004.6 (for monolithic) or Method 5008.2 (for hybrid) screened microcircuits, there are various vendor equivalents, "vendor classes", and lower grade commercial parts which exhibit much higher failure rates than both the MIL-M-38510 and MIL-STD-883 Method 5004.6 (for monolithic) or Method 5008.2 (for hybrid) screened microcircuits. A listing of the product assurance qualification, inspection and screening requirements tests required by MIL-M-38510 and MIL-STD-883 Method 5004.6 (for monolithic) or Method 5008.2 (for hybrid) are shown in Table B-IV. MIL-M-38510 Class B quality levels are recommended for all microcircuits used in the design of military equipment.

Relative failure rate multiplying factors also called "Quality Factors" (π_Q) for various quality grades of microcircuits are listed in Tables B-VA and B-VB. In addition to quality factor failure rate multipliers, it has been found that an independent quality factor based upon the length of continuous production has significant effects on microcircuit failure rates. These independent quality factors are called "Learning Factors (π_L)." Information on microcircuit Learning Factor rate multipliers is provided in Table B-VI. The use of these factors and the formulation of failure rates for microcircuit devices is presented in a later section.

Electrical performance tests for testing various types of microcircuits are specified in the detailed microcircuit military specification and are performed in accordance with the applicable test methods of MIL-STD-883. A listing of MIL-STD-883 test methods is provided in Table B-VII.

II. NONSTANDARD PART SELECTION

This manual calls for the use of standard electronic and electromechanical parts listed in applicable military standards. However, there may be cases where the application of standard parts is not feasible or there may not be any suitable standard parts established. Such cases dictate the use of nonstandard parts.

The requirements given herein are based upon the ratings of military standard (both ER and non-ER) parts. Manufacturers' catalog ratings for nonstandard parts should be carefully scrutinized until it has been demonstrated that the ratings are compatible with those assigned to similar military standard parts.

TABLE B-IV

Microcircuits Product Assurance Level

Requirement	Class S	Class B	Class C	Hybrid
	Monolithic and Multichip			
Qualification				
a. General	Required	Required	Required	Required
b. Class B certification	Required	Required	Required	Required
c. Class S certification	Required	---	---	---
Qualification (Groups A, B, C and D of Method 5005.8 or 5008.2 for applicable device class)	Required	Required	Required	Required
Wafer lot acceptance (per Method 5007.5)	Required	---	---	---
Traceability	Required	Required	Required	Required
Inspection during manufacture	Required			
Screening (Per Method 5004.6 or 5008.2)				
a. Internal visual (monolithic)	Method 2010.7 Test Cond. A	Method 2010.7 Test Cond. B	Method 2010.7 Test Cond. B	Method 2017.3
b. Stabilization bake	Required	Required	Required	Required
c. Temperature cycling and/or thermal shock	Required	Required	Required	Required
d. Constant acceleration	Required	Required	Required	Required 1/
e. Particle impact noise detection	Required	---	---	---
f. Seal (fine and gross)	Optional	Required	Required	Required
g. Serialization	Required	---	---	---
h. Interim electrical	Required	---	---	Required
i. Burn-in	240 hours	160 hours	---	160 hours
j. Interim electrical	Required when reverse bias burn-in spec.	---	---	---
k. Reverse bias burn-in	72 hours	---	---	---
l. Interim electrical	Required	Required	Required	Required
m. Seal (fine and gross)	Required	---	---	---

1/ Mechanical shock is optional

TABLE B-IV (CONTINUED)

Microcircuits Product Assurance Level

	Monolithic and Multichip			
Requirement	**Class S**	**Class B**	**Class C**	**Hybrid**
Screening (Per Method 5004.6 or 5008.2) (contd.)				
n. Final electrical	Required	Required	Required	Required
p. Radiographic	Required	---	---	---
q. External visual	Required	Required	Required	Required
r. Nondestructive 100% bond pull test	Optional	---	---	---
Quality conformance inspection (per Method 5005.8 or 5008.2)	Required	Required	Required	Required
a. Group A (each lot and sublot)	Required	Required	Required	Required 2/
b. Group B (each lot)	Required	Required	Required	Required 2/
c. Group C (periodic, every 3 months) (die related)	---	Required	Required	Required 2/
d. Group D (periodic, every 6 months) (package related)	Required	Required	Required	Required 2/

2/ See Appendix G of MIL-M-38510

TABLE B-VA

QUALITY FACTORS/FAILURE RATE MULTIPLIERS FOR MONOLITHIC MICROCIRCUITS

Quality Level	Description	π_Q
S	Procured in full accordance with MIL-M-38510, Class S requirements.	0.5
B	Procured in full accordance with MIL-M-38510, Class B requirements.	1.0
B-0	Procured in full accordance with MIL-M-38510, Class B requirements except that device is not listed on Qualified Products List (QPL). The device shall be tested to all the electrical requirements (parameters, conditions and limits) of the applicable MIL-M-38510 slash sheet. No waivers are allowed except current and valid generic data* may be substituted for Groups C and D.	2.0
B-1	Procured to all the screening requirements of MIL-STD-883, Method 5004, Class B and in accordance with electrical requirements of MIL-M-38510, DESC drawings, or vendor/contractor electrical parameters. The device shall be tested to all the quality conformance requirements of MIL-STD-883, Method 5005, Class B. No waivers are allowed except current and valid generic data* may be substituted for Groups C and D. This category applies to DESC drawings and contractor prepared specification control drawings (SCDs) containing the above B-1 screening and quality conformance requirements.	3.0
B-2	Procured to vendor's equivalent of the screening requirements of MIL-STD-883, Method 5004, Class B, and in accordance with the vendor's electrical parameters and vendor's equivalent quality conformance requirements of MIL-STD-883, Method 5005, Class B. Applies to contractor prepared SCDs containing the above B-2 screening and quality conformance requirements.	6.5
D	Hermetically sealed part with no screening beyond the manufacturer's regular quality assurance practices; parts encapsulated with organic material. All encapsulated devices must be subjected to 160 hr. burn-in at 125°C., 10 temperature cycles (-55°C to 125°C) with end point electricals, and high temperature continuity test at 100°C.	17.5

TABLE B-VA (CONTINUED)

QUALITY FACTORS/FAILURE RATE MULTIPLIERS FOR MONOLITHIC MICROCIRCUITS

Quality Level	Description	π_Q
D-1	Commercial (or non-mil standard) part, encapsulated or sealed with organic materials (e.g., epoxy, silicone or phenolic).	35.0

* Group C generic data must be on date codes no more than 1 year old and on a die in the same microcircuit group (See appendix E of MIL-M-38510) with the same material, design and process, and from the same plant as the die represented. Group D generic data must be on date codes no more than 1 year old and on the same package type (see 3.1.3.12 of MIL-M-38510) and from the same plant as the package represented.

TABLE B-VB

QUALITY FACTORS/FAILURE RATE MULTIPLIERS FOR HYBRID MICROCIRCUITS

Quality Level	Description	π_Q
S	Procured to the Class S requirements of MIL-STD-883, Method 5008 and Appendix G of MIL-M-38510 or MIL-STD-883, Methods 5004 and 5005 and MIL-M-38510	0.5
B	Procured to the Class B requirements of MIL-STD-883, Method 5008 and Appendix G of MIL-M-38510 or MIL-STD-883, Methods 5004 and 5005 and MIL-M-38510	1.0
D	Commercial Part, hermetically sealed, with no screening beyond manufacturer's normal quality assurance practices.	60.0

TABLE B-VI

MICROCIRCUIT

LEARNING FACTORS/FAILURE RATE MULTIPLIERS

The learning factor π_L is 10 under any of the following conditions:

(1) New device in initial production.

(2) Where major changes in design or process have occurred.

(3) Where there has been an extended interruption in production or a change in line personnel (radical expansion).

(4) For all new and unproven technologies such as CMOS fabricated on sapphire substrates (CMOS/SOS).

The factor of 10 can be expected to apply until conditions and controls have stabilized. This period can extend for 4 months of continuous production.

π_L is equal to 1.0 under all production conditions not stated in (1), (2), (3) and (4) above.

A. Nonstandard Part Justification

Unless otherwise specified, the use of nonstandard parts should require justification in accordance with MIL-STD-965. In addition to the requirements of that Standard, justification for acceptance of the catalog ratings of the nonstandard part should be included, in at least the following detail:

1. Provision of data that substantiates that the ratings are compatible with the long life reliability assurance criteria of the application.

2. If the reason for the use of a nonstandard part is size, cost or weight, data to substantiate that there is no sacrifice of reliability in the long term deployment of the equipment should be provided.

3. In any event, the proposed nonstandard part should be compared to the most nearly equivalent standard part, and the advantages and disadvantages presented in sufficient detail to permit an objective evaluation of the trade-offs involved.

B. Nonstandard Application

When any part is proposed for an application such that the criteria herein does not apply, supplemental justification should be required. For example, if a tantalum capaciator is intended for use at a frequency not recommended by the applicable criteria, objective data should be presented to show that the capacitor will perform the desired circuit function without degradation of reliability over the expected life cycle mission of the system or equipment.

C. Nonstandard Parameters

When any part is proposed for an application such that circuit performance depends on a characteristic or parameter that is not controlled by the governing specificaton (military specification or program peculiar specification), justification for use of the part shall include substantial data to show that the essential parameter will be maintained. Such justification may include data that shows that interrelated parameters are controlled to the extent necessary to assure that the critical parameter will be consistently within established limits, or that supplementary parameter limits have been imposed by specification to provide the same assurance without prohibitive cost and availability factors.

III. PART BURN-IN

A. Introduction

The advent of complex equipments incorporating large numbers of circuit elements has emphasized the importance of part reliability programs. Product reliability can only be realized by combining the proper uses of compatible materials, processes and design practices. While it is not possible to test reliability into a product, testing can be instrumental in identifying and eliminating potential failures while not adversely affecting good parts.

Unfortunately, product reliability is often compromised by economic considerations. In some commercial applications the greatest profit may be achieved by producing equipment of the lowest quality level that will meet the required product specifications and warranty commitments. However, even this practice would require extensive knowledge of part quality, as well as the capability to predict the quality level throughout the warranty period.

A general approach for evaluating reliability involves concepts pertaining to failure rate as a function of age. In general, the total life of a large part population can be categorized into three distinct intervals defined as follows:

1. Infant Mortality Period

Initially, a population exhibits a high failure rate resulting primarily from part failures caused by process defects, marginal design and testing errors. The failure rate rapidly decreases, eventually stabilizing at some value at the end of this initial period.

2. Useful Life

After the infant mortality period, the population failure rate remains relatively constant, characterized by random failure. This useful life period extends until the effects of wearout spawn an increase in the failure rate.

TABLE B-VIII

MIL-STD-883 TEST METHODS FOR MICROCIRCUITS

Method No.	Title
	Environmental Tests
1001	Barometric pressure, reduced (altitude operation)
1002	Immersion
1003	Insulation resistance
1004.4	Moisture resistance
1005.4	Steady state life
1006	Intermittent life
1007	Agree life
1008.2	Stabilization bake
1009.4	Salt atmosphere (corrosion)
1010.5	Temperature cycling
1011.4	Thermal shock
1012.1	Thermal characteristics
1013	Dew point
1014.5	Seal
1015.4	Burn-in test
1016	Life/reliability characterization tests
1017.2	Neutron irradiation
1018.2	Internal water-vapor content
1019.2	Steady state total dose irradiation procedures
1020	Radiation induced latchup test procedure
1021	Dose rate threshold for upset of digital microcircuits
1022	Mosfet threshold voltage
1023	Dose rate response of linear microcircuits
1030	Preseal burn-in
1031	Thin film corrosion test
	Mechanical Tests
2001.2	Constant acceleration
2002.3	Mechanical shock
2003.3	Solderability
2004.4	Lead integrity
2005.1	Vibration fatigue
2006.1	Vibration noise
2007.1	Vibration, variable frequency
2008.1	Visual and mechanical
2009.4	External visual
2010.7	Internal visual (monolithic)
2011.4	Bond strength
2012.5	Radiography
2013.1	Internal visual
2014	Internal visual and mechanical
2015.4	Resistance to solvents
2016	Physical dimensions
2017.3	Internal visual (hybrid)

TABLE B-VIII (CONTINUED)

MIL-STD-883 TEST METHODS FOR MICROCIRCUITS

Method No.	Title
	Mechanical Tests (continued)
2018.1	Scanning electron microscope (SEM inspection of metallization)
2019.2	Die shear strength
2020.3	Particle impact noise detection test
2021.1	Glassivation layer integrity
2022	Meniscograph solderability
2023.1	Nondestructive bond pull
2024.2	Lid torque for glass frit sealed packages
2025.1	Adhesion of lead finish
2026	Random vibration
2027	Substrate attach strength
	Electrical Tests (Digital)
3001.1	Drive source, dynamic
3002.2	Lead conditions
3003.1	Delay measurements
3004.1	Transition time measurements
3005.1	Power supply current
3006.1	High level output voltage
3007.1	Low level output voltage
3008.1	Breakdown voltage, input or output
3009.1	Input current, low level
3010.1	Input current, high level
3011.1	Output short circuit current
3012.1	Terminal capacitance
3013.1	Noise margin measurements for digital microelectronic devices
3014	Functional testing
3015.2	Electrostatic discharge sensitivity classification
	Electrical Tests (Linear)
4001	Input offset voltage and current and bias current
4002	Phase margin and slew rate measurements
4003	Common mode input voltage range Common mode rejection ratio Supply voltage rejection ratio
4004	Open loop performance
4005	Output performance
4006	Power gain and noise figure
4007	Automatic gain control range

TABLE B-VIII (CONTINUED)

MIL-STD-883 TEST METHODS FOR MICROCIRCUITS

Method No.	Title
	Test Procedures
5001	Parameter mean value control
5002	Parameter distribution control
5003	Failure analysis procedures for microcircuits
5004.6	Screening procedures
5005.8	Qualification and quality conformance procedures
5006	Limit testing
5007.5	Wafer lot acceptance
5008.2	Test procedures for hybrid and multichip microcircuits
5009.1	Destructive physical analysis
5010	Test procedures for custom monolithic microcircuits

3. Wearout

The onset of the wearout period is characterized by a rapidly increasing failure rate resulting from the degenerative effects of fatigue and accumulated wear.

Optimizing product reliability involves special consideration applied to each of the three life intervals. Infant mortality failures should be eliminated from the part population by controlled screening and burn-in procedures. Adequate derating factors and design guidelines should be employed to minimize stress related failures during the normal operating lifetime of the product. Finally, the effects of part wearout should be eliminated by timely preventive maintenance.

B. Purpose of Burn-In

Screening is employed to eliminate infant mortality defects and to convert latent reliability defects into actual failures which can be identified by conventional detection methods. Subjecting a part population to screening stresses does not merely provide a time displacement along the continuous function "bathtub curve", but actually results in a hazard rate at the beginning of the useful life segment lower than that indicated by the continuous function curve (see Figure B.4(a)).

This lower hazard rate can be explained by considering that the continuous function hazard rate curve is actually comprised of many underlying distributions. An example of this is shown in Figure B.4(b). The irregular underlying distributions arise from the stress dependency variations of the multitude of failure mechanisms exhibited by the part population. The activating stresses which are typically experienced during the lifetime of the part include temperature, mechanical stress and strain, and electrical bias, all of which affect the positioning and shapes of these underlying distributions.

Temperature is considered to be the primary activating stress since it has the most pronounced effect upon a substantial number of failure mechanisms experienced in microcircuits. Associated with each of the underlying distributions is an activation energy which reflects the temperature dependence of a particular failure mechanism or group of mechanisms.

Several models have been developed to characterize failure mechanism temperature dependence and to provide an approximation of the relationship between stress (electrical and thermal), time, and failure rate. One model which is commonly used to depict the temperature relationships is the Arrhenius model. The Arrhenius model takes the following general form:

$$\lambda(T) = C_1 \exp\left(\frac{-E_a}{KT}\right)$$

where:

$\lambda(T)$ = part failure rate (temperature dependent)

T = absolute temperature (°K)

K = Boltzman's constant (8.63×10^{-5} eV/°K)

E_a = the activation energy of the individual part failure mechanism (eV)

C_1 = a constant

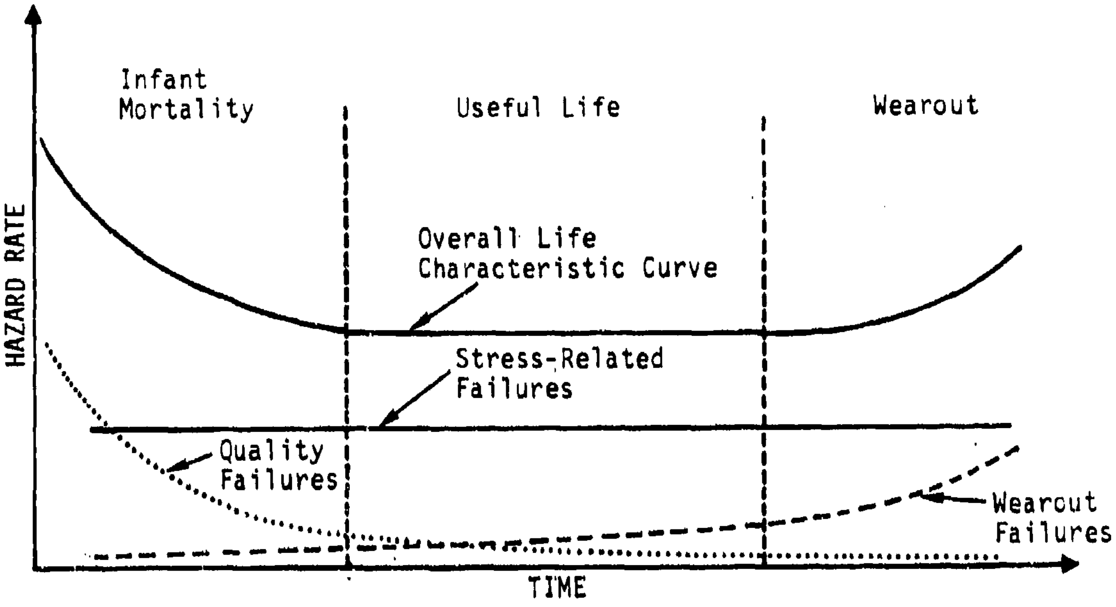
The identification of the activation energies associated with each of the known part failure mechanisms would permit accurate failure predictions and timely preventive maintenance actions. However, determining a realistic activation energy for any given failure mechanism is impractical since it is extremely difficult to isolate failure occurrences precipitated by any single mechanism. Therefore, it is more reasonable to consider representative activation energies associated with generic failure mode categories.

The experimental determination of activation energies requires extensive life testing at various temperatures and comprehensive failure analysis of all part failures.

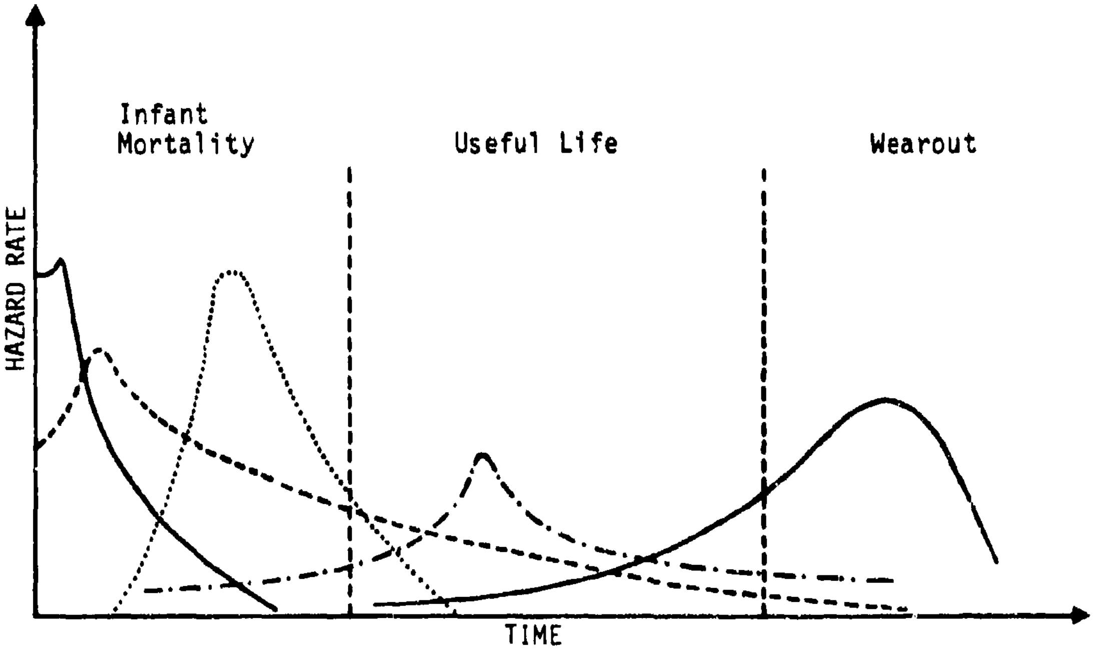
To assure satisfactory reliability of a part population during the early and useful life period, it is necessary to eliminate those underlying failure distributions whose activation energies place them within these two life periods. This can be best accomplished, prior to the early life period, by accelerating to the point of detection, those mechanisms associated with each of these underlying distributions. This is the primary objective of a screening program.

C. Burn-In Methods

There are several popular test configurations, each of which results in a variation in the burn-in stresses created. These various techniques can be grossly categorized as being either static or dynamic. Static burn-in configurations commonly consist of a DC voltage applied to the part at an elevated temperature.



(a) Typical Model



(b) Possible Underlying Distributions

FIGURE B.4

MODELING OF COMPONENT LIFE PERIODS

In the dynamic burn-in configurations the parts are actually operated at an elevated temperature. The burn-in technique provides both voltage and power stressing. The two most common types of dynamic burn-in configurations are parallel excitation, where all parts are connected in parallel and driven by the same source, and ring counter excitation, where the parts are connected in series, with the output of one part driving the input of the next.

D. Effects of Burn-In on Failure Mechanisms

Burn-in is considered to be one of the most effective methods for adequately screening a significant portion of the defects experienced in electronic parts. Burn-in screens often combine temperature with power and bias stresses which, in many cases, simulate worst case operating conditions. The accelerated stress test conditions are intended to activate the time temperature dependent failure mechanism to the point of detection in a relatively short period of time. The burn-in stresses may activate early life failures that have been only partially activated by previous screens or have been previously unaffected.

E. Particle Impact Noise Detection (PIND) Test

The PIND test is performed to detect the presence of loose foreign particles in open cavity type parts. While the test is capable of being performed on various types of parts, it is used primarily on discrete semiconductors and microcircuits. This test provides a nondestructive means of identifying parts containing particles of contamination of sufficient mass, which upon impact with the part case will excite the transducer used in the test. This transducer will convert the sound into an electrical signal that is suitable for audio and/or visual monitoring. The test procedure is given in MIL-STD-883, Method 2020.3.

F. Liquid Burn-in Systems

Yet another method of electronic part screening is the liquid burn-in. Usually, the liquid burn-in systems are designed for dynamic forward and reverse bias part level, board level and system level burn-in. Also liquid burn-in systems have other applications which include those that require power exercising electronic parts to complete black boxes in an inert nonconductive liquid at elevated temperatures. Advantages of liquid burn-in over conventional air burn-in include improved heat transfer, elimination of heat sinks for power type parts, increased part density loading and lack of oxidation. Liquid immersion burn-in is also suited for the thermal stressing of low or zero heat generating parts without thermal overstress of high heat generating parts.

APPENDIX C

ELECTROSTATIC DISCHARGE (ESD) CONTROL

I. INTRODUCTION

When two substances, solid, liquid or gases make contact, no matter how gentle, their surfaces are crushed on the atomic level and electrons pass back and forth between them. On separation, one substance always becomes negatively charged and the other positively charged. The polarity of the imparted charges depends to some degree on the relative position of the substances in the triboelectric series (DOD-HDBK-263). The magnitude of charge "Q" and the voltage level "V" that is developed, is dependent primarily on the relative humidity, the composition and the conductivity of the charged substances. Nonconductive materials such as common plastics can easily build up static voltages in excess of 20,000 volts but with low values of "Q". Electrostatic charges can also be induced on sections of objects (e.g., polarization) due to the proximity to a charged object. This is due to the electrostatic force field emanating from a charged body.

Static is brought into work areas by people and generated during their normal movements. Clothing and articles of common plastic such as cigarette and candy wrappers, styrofoam cups, part trays and bins, tool handles, packaging containers, finished or waxed floors, work surfaces, chairs, processing machinery, and numerous other articles are prime sources of static charges. These electrostatic charges can be high enough to damage or cause the malfunction of electronic parts, assemblies and equipment during discharge to ground or to an object at a lower potential.

The smaller the part, the less power it can dissipate or the lower the breakdown voltage, and the more likely it is to be damaged by an electrostatic discharge (ESD). Certain parts are considered highly susceptible and their chances for damage are great. These include Metal Oxide Semiconductor (MOS) parts with a direct access to the MOS junction, high frequency parts produced by the Schottky Barrier process, many bipolar and field effect microcircuits like RAMs, ROMs, PROMs utilizing small active area junctions, thin dielectrics, metallization crossovers, and N+ guard ring structures, precision film resistors and similar parts. A detailed list of electrostatic discharge sensitive (ESDS) parts and their voltage sensitivity ranges are provided in DOD-STD-1686 and DOD-HDBK-263.

II. ESDS PART FAILURE TYPE, FAILURE MODES AND FAILURE MECHANISMS

A. Types of ESD Failure

ESD can cause intermittent or upset failures as well as hard or catastrophic failures of electronics. Intermittent or upset failures of digital parts and equipment are usually characterized by a loss of information or temporary distortion of its functions. No apparent hardware damage occurs and proper operation resumes automatically after the ESD exposure. Such failures generally occur when the equipment is in operation.

Upset transients can be the result of an ESD spark in the vicinity of a part or equipment.

Parts that are very susceptible to ESD upset are any logic families that require small energies to switch states or small changes of voltage in high impedance lines. Examples of families that are sensitive would be NMOS, PMOS, CMOS, low power TTL and Schottky TTL. Linear circuits with high impedance and high gain inputs would also be highly susceptible along with RF amplifiers and other RF parts at the equipment level. These parts are very susceptible to erroneous signals generated by an ESD spark.

While upset failures occur when the equipment is in operation, catastrophic or hard failures can occur any time. Such failures are characterized by the degradation of electrical parameters beyond the manufacturer's specification limits. These hard failures can be the result of electrical overstress of parts caused by an ESD. Other failures may not be catastrophic but result in slight degradation of key electrical parameters such as increased leakage current, lower reverse breakdown voltages of P-N junctions or softening of the knee of the V-I curve of P-N junctions in the forward direction. Some ESDS part failures are more subtle and can remain latent until additional operating stress causes further degradation and ultimate catastrophic failure. For example, an ESD overstress can produce a dielectric breakdown of a self-healing nature. When this occurs the part can retest good, but contain a hole in the gate oxide. With use, metal will eventually migrate through the puncture resulting in a direct short through this oxide layer.

B. Failure Modes and Mechanisms

ESD related failure mechanisms typically include:

1. Thermal secondary breakdown
2. Metallization melt
3. Dielectric breakdown
4. Gaseous arc discharge
5. Surface breakdown
6. Bulk breakdown

The above failure mechanisms do not necessarily result in part damage. Unencapsulated chips and LSI MOS integrated circuits have exhibited temporary failure caused by positive charges deposited on the chip. Such charge deposits result in gaseous arc discharge within the package between the lid and the substrate.

1. Thermal Secondary Breakdown (avalanche degradation) - For very small active area junctions (e.g., emitter-base junction of a transistor), thermal time constants of semiconductor materials are generally large compared with transient times associated with an ESD pulse. There is little diffusion of heat from the areas of power dissipation and large temperature gradients can form in the parts resulting in a localized junction melting.

The ESDS part types that commonly fail due to avalanche breakdown are:

- Discrete MOS Field Effect Transistors (FETs)
- Diodes (PN, PIN, Schottky)
- Bipolar transistors
- Junction Field Effect Transistors (JFETs)
- Thyristors
- Bipolar ICS, digital and linear
- Input protection circuits on MOS ICs

Some common failure modes for these parts include high leakage current between gate to source and gate to drain for JFETs, degradation of beta and soft reverse characteristics for bipolar transistors, and no output or latch up of outputs for digital and analog circuits.

2. Metallization Melt - Failures can also occur when ESD pulses increase part temperature sufficiently to melt metal or fuse bond wires. This can occur where the metal strips have reduced cross sections as they cross oxide steps, or on nonuniform areas resulting in localized current crowding and subsequent hot spots in the metallization.

ESDS part type sensitive to metallization failure are:

- Hybrid ICs
- Monolithic ICs
- Multiple Finger Overlay Switching and High Frequency Transistors

Open circuit of a metallization stripe is a common failure mode for metallization melt type failures.

3. Dielectric Breakdown - When a potential difference is applied across a dielectric region in excess of the region's inherent breakdown characteristics, a puncture of the dielectric occurs. Depending on pulse energy, this can result in either total or limited degradation of the part.

ESDS part types utilizing MOS structures are most susceptible to dielectric breakdown. These are:

- MOS FET (Discrete)
- MOS ICs

- Semiconductor with metallization crossovers:

  Digital ICs (Bipolar and MOS)

  Linear ICs (Bipolar and MOS)

- MOS Capacitors

  Hybrids

  Linear ICs

Typical failure mode for these part types is an electrical short (high leakage) between gate and drain or gate and source.

4. Gaseous Arc Discharge - For parts with closely spaced unpassivated-thin electrodes, gaseous arc discharge can cause degraded performance. The arc discharge condition causes melting and fusing of electrode metal.

The ESDS part types affected by this failure mechanism are:

- Surface Acoustic Wave devices

- Thin metal unpassivated, unprotected semiconductors and microcircuits

5. Surface Breakdown - For perpendicular junctions the surface breakdown is explained as a localized avalanche multiplication process caused by narrowing of the junction space charge layer at the surface. The destruction mechanism of surface breakdown results in a high leakage path around the junction, nullifying the junction. Another mode of surface failure is the occurrence of an arc around the insulating material. This is similar to metallization to metallization gaseous discharge except in this case discharge is between metallization and semiconductor.

ESDS parts utilizing shallow junctions can be damaged as a result of surface breakdown.

6. Bulk Breakdown - Bulk breakdown results from changes in junction parameters due to high local temperature within the junction area. This effect is usually preceded by thermal secondary breakdown.

The ESDS part types that commonly fail from thermal secondary breakdown are also candidates for bulk breakdown failure.

7. Others - Film resistors (e.g., thick and thin film resistors of hybrid ICs, monolithic IC thin film resistors, encapsulated discrete film resistors) are noted to have failed as a result of dielectric breakdown, metallization melt or both. The failure is indicated by a shift in resistance, an increase in degree of instability and a change in the temperature coefficient.

A different type of failure mechanism is noticed for crystal oscillators. Crystal fracture occurs from mechanical forces when excessive voltage is applied as occurs during a high voltage ESD.

C. Approach to Corrective Actions

Based upon the problem caused by the lack of uniform and complete ESD controls, the Naval Sea Systems Command (NAVSEA), Department of the Navy, for the Department of Defense (DoD) has prepared DOD-STD-1686 to define the requirements for a standardized ESD control program. The intent of DOD-STD-1686 is to provide minimum requirements needed to provide an effective ESD control program.

DOD-STD-1686 contains the following basic requirements:

- ESDS item identification and classification
- ESD design protection
- ESD protected areas
- ESD handling procedures
- ESD protective covering
- ESDS equipment installation site
- ESD training
- ESD marking on documentation
- ESD marking on hardware
- Quality Assurance provisions, audits and reviews
- ESD packaging for delivery

DOD-HDBK-263 has also been prepared to provide guidance for establishing, implementing and monitoring elements of the DOD-STD-1686 ESD control program. This handbook includes guidance in: the identification of causes and effects of ESD on electronic parts, assemblies, and equipment; establishing and implementing ESD program controls; selection and application considerations for ESD protective materials and equipment; design and construction of ESD protected areas; design of protection networks; the preparation of ESD handling, packaging, and marking procedures; development of ESD personnel training programs; certification of ESD protected areas and monitoring of ESD control program requirements.

APPENDIX D

FACTORS AFFECTING FAILURE RATES OF PARTS*

I. GENERAL

The following tables give the factors affecting the failure rates of electrical/electronic parts. As given in MIL-HDBK-217 the part failure rate is a function of these factors (designated as "π" factors). An asterisk appearing in any column indicates that those factors do not contribute to the failure rate of the particular part type:

For example, the part failure rate λ_p for fixed resistors is given by:

$$\lambda_p = \lambda_b(\pi_E \times \pi_R \times \pi_Q)$$

Where λ_b = base failure rate (a function of temperature and stress)

π_E = Environmental factor

π_R = Resistance factor

π_Q = Quality factor

TABLE D-I
FACTORS AFFECTING FAILURE RATE

Device Type	Temperature	Environment	Quality Level	Stress** Ratio
Resistors	X	X	X	X
Capacitors	X	X	X	X
Semiconductors	X	X	X	X
Microcircuits	X	X	X	*
Relays	X	X	X	X
Connectors	X	X	*	*
Switches	X	X	*	X
Inductive Devices	X	X	X	*

* Due to a lack of statistical data MIL-HDBK-217 failure rates do not consider all the electrical parameters affecting part failure rate. Also

MIL-HDBK-217 does not consider the effect of transients on failure rate. For a more complete listing of factors which affect part reliability, see Table I of Chapter I

** Power for resistors
Voltage for capacitors
Power (current) for semiconductor devices
Power, current (continuous) for microcircuits
Contact current (continuous) for relays
Contact current and voltage for switches

II. FAILURE RATE FACTORS UNIQUE TO DIFFERENT DEVICES

TABLE D-II
(a) Resistors

Resistor Type	Resistance[1] Value	Number of Taps on Potentiometer	Voltage Factor	Construction	Number of Resistors in Use
Fixed	X				
Variable	X	X	X		
Variable (Styles RP and RR only)	X	X	X	X	
Resistor Network (Style RZ)					X

1/ The higher the resistance value, the higher the failure rate.

TABLE D-II
(b) Capacitors

Capacitance values - all styles except CV, PC, CT and CG. (The higher the capacitance value, the higher the failure rate)

Series circuit resistance - for type CSR and CLR. (The higher the series circuit resistance, the lower the failure rate)

Construction - for type CLR only.

Configuration - for type CG only.

TABLE D-II

(c) Relays, Switches and Connectors

Device Type	Number of Contacts	Time Rate of Actuation	Contact Load	Construction and Application
Relays	X	X	X	X
Switches	X	X	X	
Connectors	X	X		

TABLE D-III

III. ADDITIONAL FAILURE RATE FACTORS FOR SEMICONDUCTOR DEVICES

Semiconductor Device Type	Application	Device Rating	Voltage Stress	Circuit Complexity	Frequency and Peak Operating Power Factor	Type of Matching Network	Construction
Conventional Transistors	X	X	X	X			
Diodes, General Purpose	X	X	X				X
FET	X			X			
Zener/Avalanche	X						
Thyristors		X					
Microwave Transistors	X				X	X	
Opto-electronic Devices							

TABLE D-IV

IV. ADDITIONAL FAILURE RATE FACTORS FOR MONOLITHIC AND HYBRID MICROCIRCUITS

A. Monolithic Microcircuits

Package complexity.
Circuit complexity.
Learning factor.

B. Hybrid Microcircuits

Number of each particular component.
Failure rates of individual components.
Number of interconnections and density of interconnections.
Failure rate of Hybrid Package.
Circuit function (i.e., linear, digital, or linear-digital.

V. MIL-HDBK-217D FAILURE RATE CURVES

Figures D.1 and D.2 show base failue rate (in failures/10^9 hours) data plotted from MIL-HDBK-217D. The curves represent the failure rates for an ambient temperature (°C) range at various stress levels.

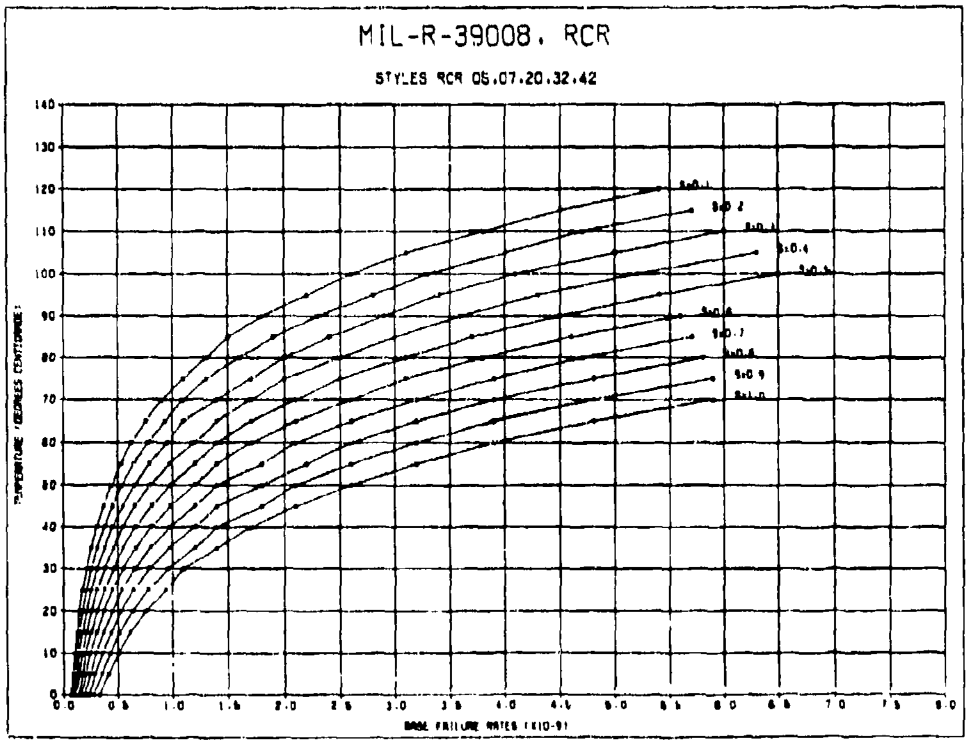


FIGURE D.1

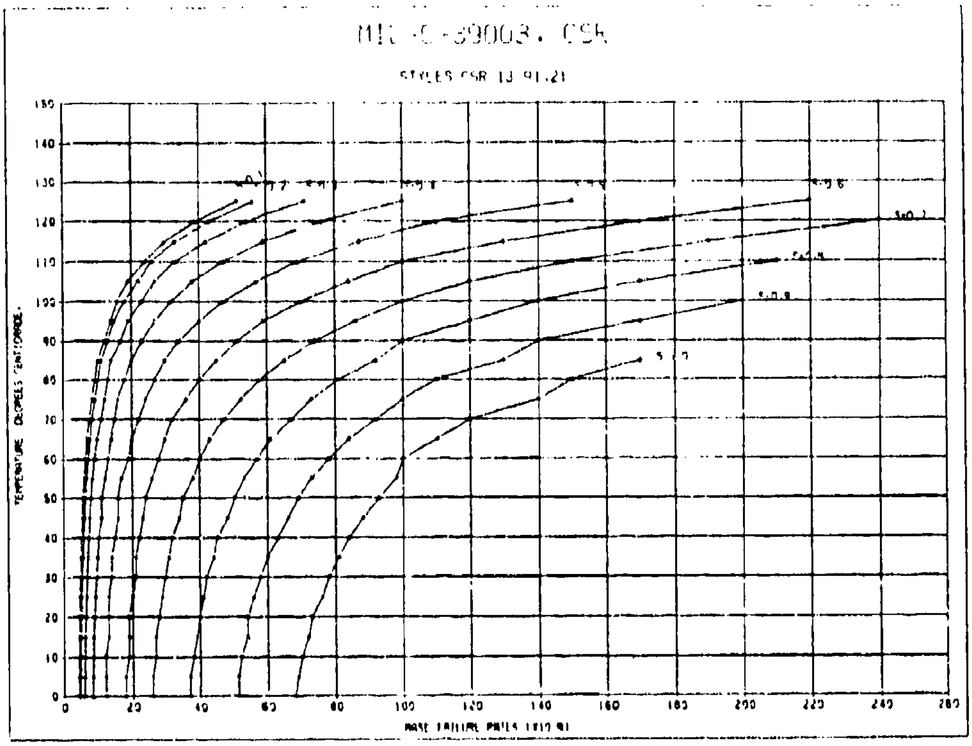

MIL-C-39003, CSR
STYLES CSR 13 91,21
TEMPERATURE DEGREES CENTIGRADE
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
BASE FAILURE RATES

FIGURE D.2

APPENDIX E

VARIABILITY ANALYSIS

I. GENERAL

All electronic components and devices (i.e., parts) are manufactured to have their important parameters lie between two extreme values called tolerance limits. Tolerance limits include initial tolerances, and drift due to age and environments. The parameters may vary and have any value between these two limits.

Variability analysis is a technique by which one can determine, to a very good aproximation, whether a system consisting of these parts will work within the specification limits, when the part parameters vary between their limits.

There are five primary methods of circuit variability analysis: the Worst Case, the Parameter Variation, the Moment, the Monte Carlo and the Empirical method. These methods are listed in Table E-I along with their pertinent characteristics.[1]

Next to the empirical method -- which is the direct approach of varying the part tolerances of a circuit breadboard -- the best known of these methods is the worst case. The parameter variation method is another version of the worst case method. The remaining two methods are more sophisticated and sometimes yield more information.

The following sections give an explanation of these analytical methods. One should not conclude that the empirical method cannot be used in high level variability analyses. In fact, a breadboard analysis (empirical method) can be an effective and accurate tool when properly organized and conducted.

II. VARIABILITY ANALYSIS METHODS

A. Worst Case Analysis

This method determines the circuit output failure criteria as a function of input parameter maxima or minima.

The analysis begins with the calculation of the partial derivatives in the form:

$$S_\Delta = \frac{\partial S_{out}}{\partial S_{in}} = \frac{\text{change in an output parameter}}{\text{change in an input parameter}}$$

where S_{out} and S_{in} are generalized output and input parameters, with all other input parameters held constant.

TABLE E-I

COMPARISON OF VARIABILITY ANALYSIS METHODS[1]

Method of Analysis	Type of Model	Class	Program Output	Objectives
Worst case	Mathematical	Nonstatistical	Worst case values for outputs with all parameters at cumulative worst case limits	Determine if failure is possible and under what conditions
Parameter variation	Mathematical	Nonstatistical	Range of variability data for schmoo plots	Establish realistic tolerance limits for parameters
Moment	Mathematical	Statistical	Mean values of outputs, indices of variability and redesign information	Reliability estimate Redesign if necessary
Monte-Carlo	Mathematical	Statistical	Output histograms	Reliability
Empirical	Breadboard	Statistical or Nonstatistical	Nominal (mean) and worst-case values of outputs, indices of variability, and redesign information	Determine if failure is possible Reliability estimate Redesign if necessary

By setting the input parameter at its extreme tolerance limit (maximum or minimum) the effect on the output parameters can be observed. The sign of the partial derivative will determine the setting of the input parameter. A plus sign indicates that the input parameter must be set to its maximum value and a minus sign to its minimum value. Consider, as an example, the circuit of Figure E.1.

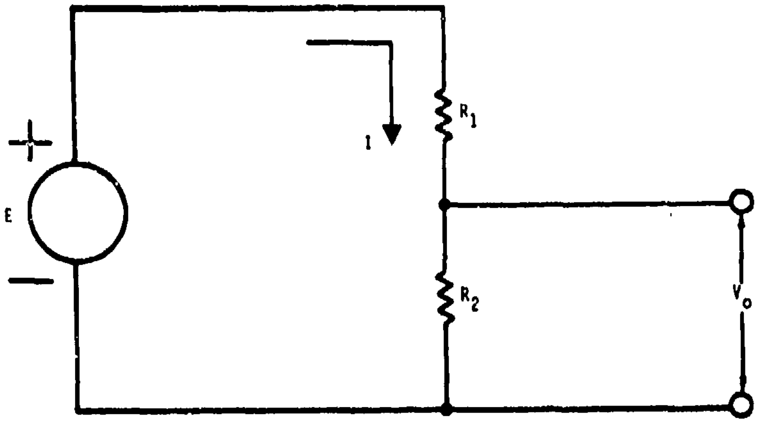


FIGURE E.1

VOLTAGE DIVIDER CIRCUIT

The minimum, nominal (mean) and maximum values of R_1, R_2 are given in Table E-II.

TABLE E-II

Parameter	Min.	Nom.	Max.
E (Volts)	9	10	11
R_1 (Ohms)	9	10	11
R_2 (Ohms)	9	10	11

The nominal values of I and V_O can be calculated as:

$$I_{(NOM)} = \frac{E_{(NOM)}}{R_{1(NOM)} + R_{2(NOM)}} = 0.5 \text{ Amps}$$

$$V_{o(NOM)} = \frac{E_{(NOM)} R_{2(NOM)}}{R_{1(NOM)} + R_{2(NOM)}} = 5 \text{ Volts}$$

If we select V_O as the output parameter, then the partial derivative of V_O with respect to the input parameter E will be:

$$\frac{\partial V_o}{\partial E} = \frac{R_2}{R_1 + R_2}$$

Similarly, with respect to the input parameters R_1, R_2 we can find:[2]

$$\frac{\partial V_o}{\partial R_1} = - \frac{ER_2}{(R_1 + R_2)^2}$$

$$\frac{\partial V_o}{\partial R_2} = + \frac{ER_1}{(R_1 + R_2)^2}$$

Therefore, in order to obtain $V_{O(max)}$ the following conditions must be met:

E set to its maximum value of 11 volts.

R_1 set to its minimum value of 9 ohms.

R_2 set to its maximum value of 11 ohms.

Thus:

$$V_{o(max)} = \frac{E_{(max)} R_{2(max)}}{R_{1(min)} + R_{2(max)}} = 6.05 \text{ volts}$$

Following the same approach for $I_{(max)}$ as an output parameter, we find:[2]

$$I_{(max)} = \frac{E_{(max)}}{R_{1(min)} + R_{2(min)}} = 0.61 \text{ amps}$$

It is evident from this example that the conditions for $I_{(max)}$ are different from those of $V_{o(max)}$. This result is generally true, i.e., worst case analysis cannot yield worst case values for all output parameters simultaneously. Note also that aging effects and drift in part values, which may alter the tolerance limits must be incorporated in the tolerance limits so that the analysis reflects the actual "Worst Case."

B. Parameter Variation Analysis

This method provides means for determining the maximum and minimum values for the input parameters of a circuit, which will result in satisfactory circuit operation. Input parameters, either one at a time or two at a time, are varied in steps from their maximum to minimum limits or vice versa, while all other input parameters are held at the nominal value. From this process data are generated for developing safe operating envelopes, known as Schmoo Plots[3], for the input parameters. If the values of the input parameters are maintained within the limits determined from the Schmoo Plots, the circuit will function successfully. The development of Schmoo Plots will be clarified by the use of the following simple example.

Consider the circuit shown in Figure E.2, with the given component tolerances.

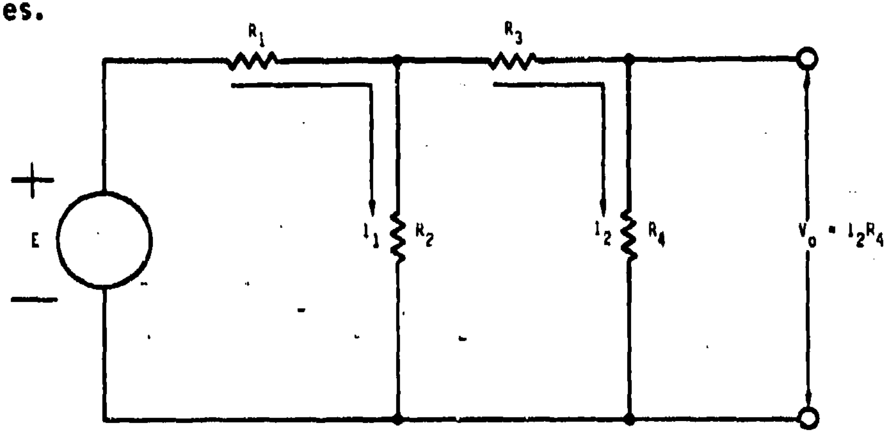


FIGURE E.2

First, a set of simultaneous equations describing the operation of the circuit must be set up. Using Loop analysis[4], we find:

$$E = (R_1 + R_2)\, I_1 - R_2\, I_2$$

$$0 = -R_2\, I_1 + (R_2 + R_3 + R_4)\, I_2$$

from where the unknowns I_1 and I_2 can be calculated as:

$$I_1 = \frac{\begin{vmatrix} E & -R_2 \\ 0 & (R_2 + R_3 + R_4) \end{vmatrix}}{\begin{vmatrix} (R_1 + R_2) & -R_2 \\ -R_2 & (R_2 + R_3 + R_4) \end{vmatrix}}$$

$$I_2 = \frac{\begin{vmatrix} (R_1 + R_2) & E \\ -R_2 & 0 \end{vmatrix}}{\begin{vmatrix} (R_1 + R_2) & -R_2 \\ -R_2 & (R_2 + R_3 + R_4) \end{vmatrix}}$$

With the given nominal values of the components, we can also calculate:

$I_{2(NOM)} = 0.217$ amps and $V_{O(NOM)} = 8.695$ volts

For the two at a time parameter variation, let R_1 and R_4 be the pair of parameters we want to vary, and V_o be the quantity which we want to observe. If R_1 and R_4 are set at their maximum values (11 ohms and 44 ohms) and the remaining parameters are held at their nominal value, we find:

$I_2 = 0.198$ amps and $V_o = I_2 R_4 = 8.71$ volts

Then R_1 and R_4 are set at their minimum values (9 ohms and 36 ohms) with the remaining parameters held at their nominal values. Substituting in the equation for I_2, we find:

$I_2 = 0.239$ amps and $V_o = 8.60$ volts

Next, the values of V_o are compared with the maximum and minimum allowable values of V_o. If the calculated values of V_o fall outside of these limits, the pair R_1, R_4 is designated as a "failure pair." Thus, if we were to assume ±0.05 volts tolerance on $V_{O(NOM)}$, we see that the pair $(R_1, R_4) = (9,36)$ is a "failure pair" because for that pair $V_o = 8.60$ volts, while allowable values of V_o are from 8.645 to 8.745 volts. Curves similar to the ones shown in Figure E.3 (Schmoo Plot) will be generated if the process is repeated until the safe area is reached by slightly increasing the values of the pair $(R_1, R_4) = (9,36)$. The circuit will function successfully as long as the value of the pair (R_1, R_4) is within the indicated safe area.

Similar calculations can be repeated for all possible combinations of two at a time parameters and Schmoo Plots can be generated for each combination. Such calculations give an indication of the relative importance of changes in individual or pairs of input parameters on the output parameters.

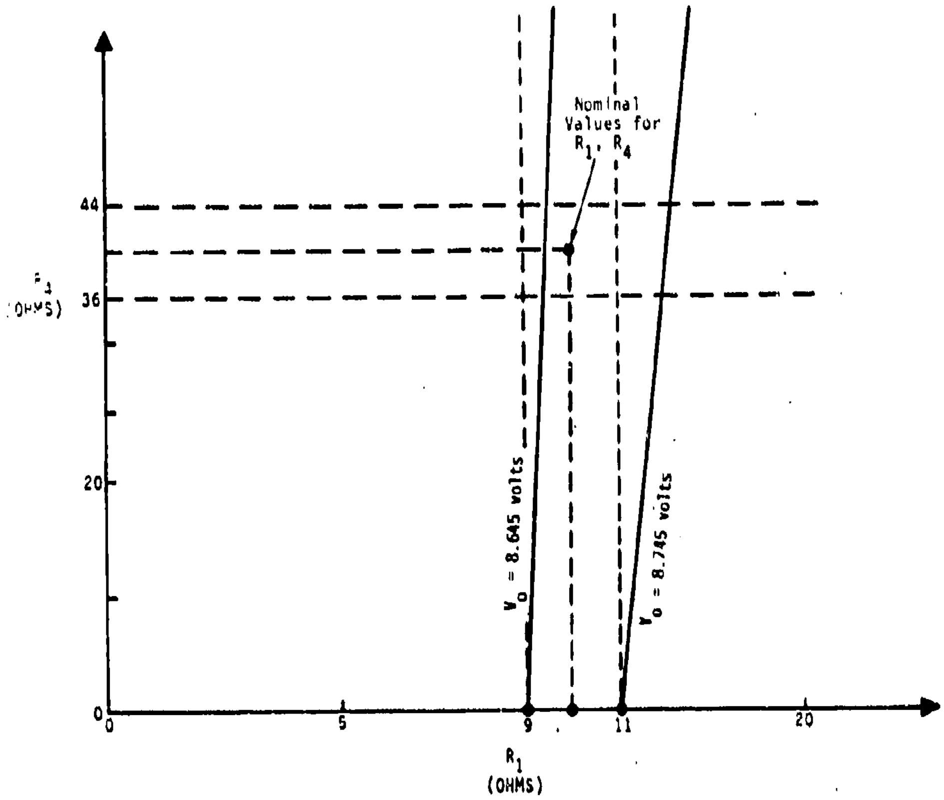


FIGURE E.3

SCHMOO PLOT OF THE PAIR (R_1, R_4)

C. Moment Analysis

This method computes the mean value $\overline{X}$ (first moment about the origin) and the variance σ^2 (second moment about the mean value) for each output parameter based upon mean values and variances of all input parameters. The mean value $\overline{X}$ is given by:

$$\overline{X} = \frac{\sum_{j=1}^{n} (X_j)}{n}$$

i.e., is the first moment about the zero origin.

The variance σ^2 is an approximation of the sample variance[5] (S_2) for large values of n, and is given by:

$$\sigma^2 = \frac{\sum_{j=1}^{n} (X_j - \overline{X})^2}{n}$$ i.e., is the second moment about the mean value $\overline{X}$

where n = size of the sample

X_j = random variable

Then, the Propagation of Variance Theorem[6,7] is used to compute the variance of each output parameter. This is performed in terms of the variances of the input parameters, correlation coefficients, and partial derivative of the output parameters with respect to the input parameters. The correlation coefficients relate input parameters and thus they are taken equal to zero if these parameters are independent. The partial derivatives are computed as in the Worst Case analysis. The method assumes that all output parameters will have Normal (Gaussian) distribution in order to make reliability predictions. This is because the mean value and the variance alone are not adequate to define the shape of other than the Normal distribution.

To apply the moment method, consider the circuit shown in Figure E.4.

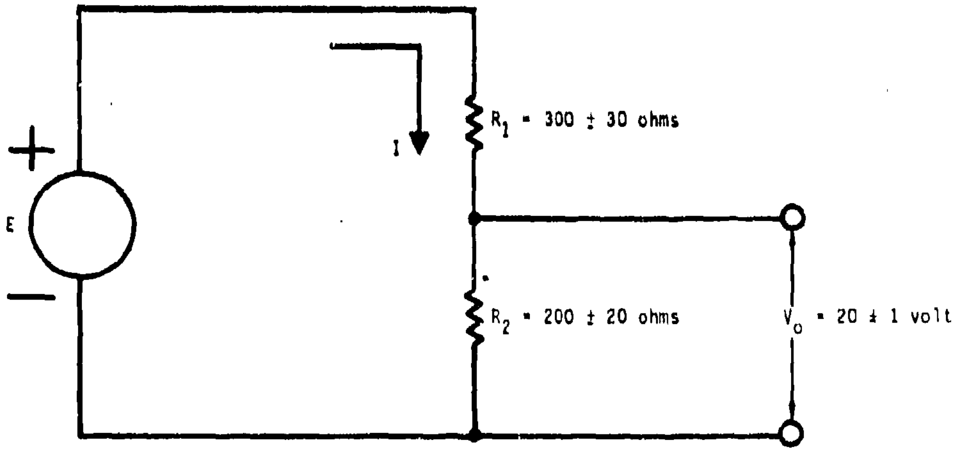


FIGURE E.4

VOLTAGE DIVIDER CIRCUIT

Statistical data needed to conduct moment analysis are given for samples $\overline{R}_1$ and $\overline{R}_2$ in the form of histograms (see Figure E.5 and Figure E.6). The mean values $\overline{R}_1$ and $\overline{R}_2$ are computed from these histograms by multiplying the midpoint values by their frequencies, summing them, and dividing by the total number of samples. The variances $\sigma_{R_1}^2$ and $\sigma_{R_2}^2$ are also computed from these histrograms as:

$$\sigma_{R_1}^2 = \frac{\sum_{j=1}^{12} (R_{1j} - \bar{R}_1)^2}{12} = 361.91 \qquad \text{and}$$

$$\sigma_{R_2}^2 = \frac{\sum_{j=1}^{10} (R_{2j} - \bar{R}_2)^2}{10} = 141.61 \qquad \text{and}$$

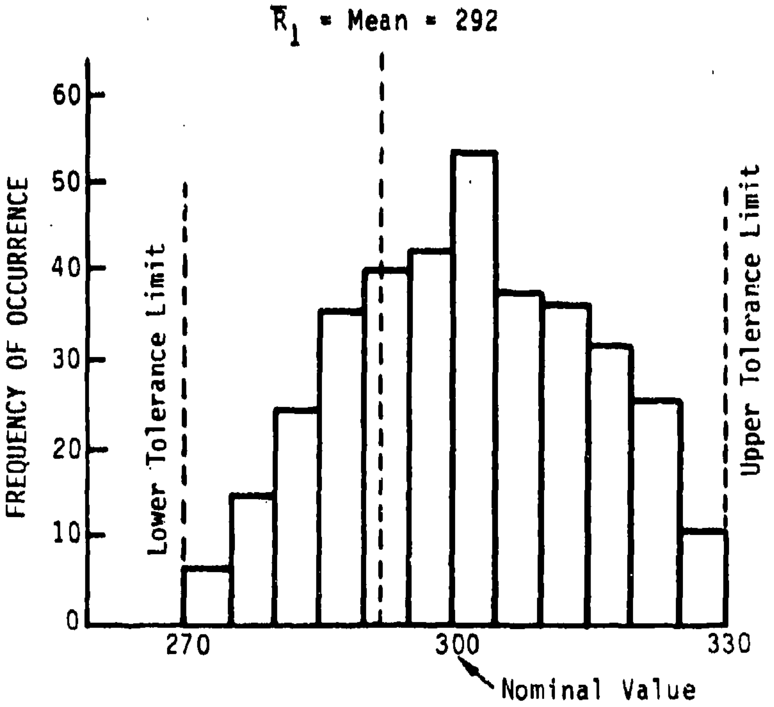


FIGURE E.5

FREQUENCY DISTRIBUTION OF R_1

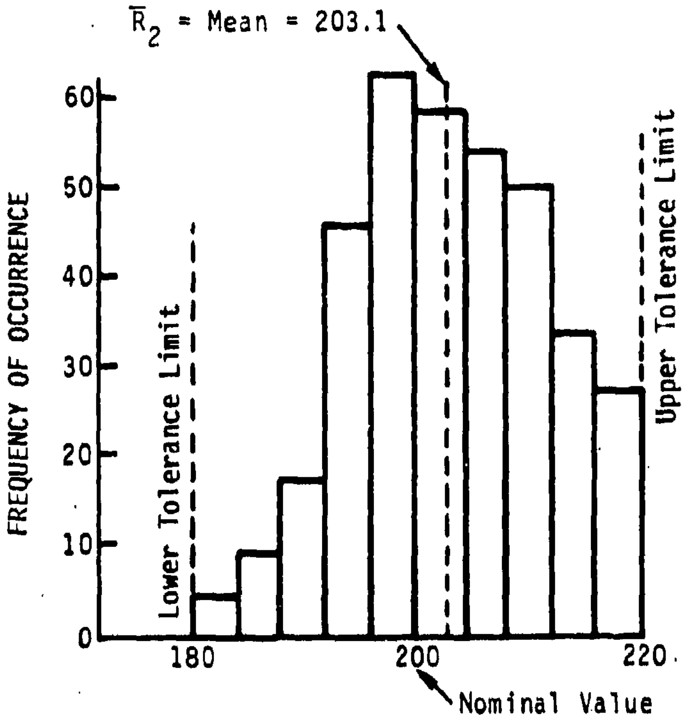


FIGURE E.6

FREQUENCY DISTRIBUTION OF R_2

The correlation coefficients for the input parameters are all equal to zero because the input parameters E, R_1, R_2 are independent. The output voltage V_o which, in this case, is the output parameter of interest has a nominal value of:

$$V_{o(NOM)} = \frac{E\,R_2}{R_1 + R_2} = \frac{50\ (200)}{300 + 200} = 20 \text{ volts}$$

The partial derivatives of the output parameter, with respect to the input parameters, will be:

$$\left(\frac{\partial V_o}{\partial R_1}\right)_{\overline{R}_1} = \frac{-\,E\,R_2}{(R_1 + R_2)^2} = -0.041 \text{ (evaluated at } \overline{R}_1)$$

$$\left(\frac{\partial V_o}{\partial R_2}\right)_{\bar{R_2}} = \frac{E\ R_1}{(R_1 + R_2)^2} = 0.0592 \text{ (evaluated at } \bar{R}_2)$$

Then, application of Propagation of Variance Theorem, will result in:

$$\sigma^2_{V_o} = \left(\frac{\partial V_o}{\partial R_1}\right)^2_{\bar{R}_1} \sigma^2_{R_1} + \left(\frac{\partial V_o}{\partial R_2}\right)^2_{\bar{R}_2} \sigma^2_{R_2}$$

$$= (-0.041)^2 (361.91) + (0.0592)^2 (141.61)$$

$\sigma^2_{V_o} = 1.104$, and the standard deviation of the output parameter is

$$\sigma_{V_o} = 1.05.$$

To evaluate these results, a Normal distribution of the output parameter V_o is assumed, and the failure probability is estimated by expressing the differences between the specification limits of V_o and the mean value of V_o in terms of the standard deviation. The mean value of V_o is:

$$\bar{V}_o = \frac{E\ \bar{R}_2}{\bar{R}_1 + \bar{R}_2}$$

$$\bar{V}_o = \frac{50\ (203.1)}{(292 + 203.1)}$$

$$\bar{V}_o = 20.51 \text{ volts}$$

Thus:

$$\text{Lower range} = \frac{V_{o(max)} - \bar{V}_o}{\sigma V_o} = \frac{21 - 20.51}{1.05} = 0.46\sigma$$

$$\text{Upper range} = \frac{\overline{V}_o - V_{o(min)}}{\sigma_{V_o}} = \frac{20.51 - 19}{1.05} = 1.43\,\sigma$$

Reference to standard tables of areas under the Normal curve[5] discloses that the area under the curve falling between 0.46σ and 1.43σ is:

$$0.4236 - 0.1772 = 0.3064 = 30.64 \text{ percent}$$

This represents the probability that the parameter V_O is within the specified limits of 20 ± 1 volts.

Thus, probability of success: P_S = 30.64 percent and

probability of failure: $P_F = 1 - P_S$ = 69.36 percent.

C. Monte-Carlo Analysis

The Monte-Carlo method[7] is essentially a computer simulation of the manual brute force method of variability analysis with randomly selected parts. This is accomplished by constructing many replicas of the circuit, selecting at random component parts values from representative bins of these parts. This process of random selection from bins is repeated until the supply of components is exhausted. Each time, measurements of the output parameters are obtained and tabulated. Statistical analysis of the tabulated data is then performed and the means and the variances of all output parameters computed.

To conduct a Monte-Carlo analysis, frequency distributions of each input parameter in the form of a histogram or a table are needed. A random number generator is then utilized to select a value for each input parameter from its frequency distribution. These values are inserted in the equations describing the circuit and the equations are solved for the output parameters of interest. The process is repeated usually more than 500 times (i.e., at least 500 values for each output parameter will be determined). This gives sufficient information to plot frequency distributions of each output parameter. By comparing the specifications of the output parameters with the ranges obtained on the corresponding histrograms, the probability of an output parameter being out of tolerance can be determined. In cases where there are multiparameter parts in the circuits, such as diodes and transistors, the random number generator can also select these values. However, the model must also take into account the correlation coefficients between two or more input parameters. Therefore, both correlation coefficients and frequency distributions must be known in order to perform the Monte Carlo analysis when multiparameter parts are used.

As an illustration of the Monte Carlo method, consider the circuit shown in Figure E.7.

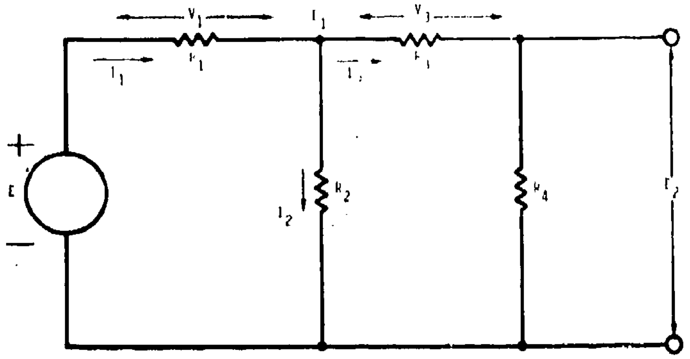


FIGURE E.7

Node analysis[4] of the circuit results in the following matrix equation:

$$\begin{bmatrix} \dfrac{E}{R_1} \\ \\ 0 \end{bmatrix} = \begin{bmatrix} \left(\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}\right) & -\dfrac{1}{R_3} \\ \\ \dfrac{1}{R_3} & -\left(\dfrac{1}{R_4} + \dfrac{1}{R_3}\right) \end{bmatrix} X \begin{bmatrix} E_1 \\ \\ E_2 \end{bmatrix}$$

The circuit has single parameter parts and all input parameters are independent. In this case, all correlation coefficients are zero. Table E-III presents the values of each input parameter (R_1, R_2, R_3, R_4, E) and the cumulative frequency distribution (C.F.D.) for each input parameter. The entries of the C.F.D. columns are calculated by the computer[2] from the given values of the input parameters. As an example, for parameter R_1, 1.0101 percent of the values do not exceed 510 ohms and no values exceed 661.3 ohms.

The output parameter data, as calculated by this computer simulation[2], consist of a complete frequency distribution of each output parameter from which histograms and continuous curves can be constructed. Table E-IV shows such a frequency distribution for the output parameter E_1; Figure E.8 is the corresponding histogram. Similar tabulations and histograms can be obtained for other output parameters such as voltages, currents, power, etc.

TABLE E-III

INPUT PARAMETER DISTRIBUTION DATA

SINGLE PARAMETER PARTS

PARAMETER		VALUE	C.F.D.
1	R1	0.5100E 03	1.0101
		0.5387E 03	3.0303
		0.5484E 03	6.0606
		0.5584E 03	10.1010
		0.5652E 03	15.1515
		0.5718E 03	21.2121
		0.5798E 03	30.3030
		0.5892E 03	42.4242
		0.6000E 03	58.5859
		0.6108E 03	70.7071
		0.6202E 03	79.7980
		0.6282E 03	85.8586
		0.6348E 03	90.9091
		0.6416E 03	94.9495
		0.6516E 03	97.9798
		0.6613E 03	100.0000
2	R2	0.6800E 03	1.0101
		0.7157E 03	3.0303
		0.7313E 03	6.0606
		0.7433E 03	10.1010
		0.7536E 03	15.1515
		0.7614E 03	21.2121
		0.7728E 03	30.3030
		0.7856E 03	42.4242
		0.8000E 03	58.5859
		0.8144E 03	70.7071
		0.8272E 03	79.7980
		0.8386E 03	85.8586
		0.8464E 03	90.9091
		0.8567E 03	94.9495
		0.8687E 03	97.9798
		0.8843E 03	100.0000

TABLE E-III (CONTINUED)

INPUT PARAMETER DISTRIBUTION DATA

SINGLE PARAMETER PARTS

PARAMETER		VALUE	C.F.D.
3	R3	0.2550E 03	1.0101
		0.2684E 03	3.0303
		0.2743E 03	6.0606
		0.2788E 03	10.1010
		0.2826E 03	15.1515
		0.2859E 03	21.2121
		0.2898E 03	30.3030
		0.2946E 03	42.4242
		0.3000E 03	58.5859
		0.3054E 03	70.7071
		0.3102E 03	79.7980
		0.3141E 03	85.8586
		0.3174E 03	90.9091
		0.3212E 03	94.9495
		0.3257E 03	97.9798
		0.3316E 03	100.0000
4	R4	0.4250E 03	1.0101
		0.4473E 03	3.0303
		0.4570E 03	6.0606
		0.4645E 03	10.1010
		0.4710E 03	15.1515
		0.4775E 03	21.2121
		0.4830E 03	30.3030
		0.4910E 03	42.4242
		0.5000E 03	58.5859
		0.5090E 03	70.7071
		0.5170E 03	79.7980
		0.5235E 03	85.8586
		0.5290E 03	90.9091
		0.5355E 03	94.9495
		0.5430E 03	97.9798
		0.5527E 03	100.0000

TABLE E-III (CONTINUED)

INPUT PARAMETER DISTRIBUTION DATA

SINGLE PARAMETER PARTS

PARAMETER		VALUE	C.F.D.
5	E	0.7000E 01	1.0101
		0.7900E 01	3.0303
		0.8300E 01	6.0606
		0.8600E 01	10.1010
		0.8800E 01	15.1515
		0.9100E 01	21.2121
		0.9300E 01	30.3030
		0.9600E 01	42.4242
		0.1000E 02	58.5859
		0.1040E 02	70.7071
		0.1070E 02	79.7980
		0.1090E 02	85.8586
		0.1120E 02	90.9091
		0.1140E 02	94.9495
		0.1170E 02	97.9798
		0.1210E 02	100.0000

TABLE E-IV

OUTPUT PARAMETER (E_1) DISTRIBUTION DATA

Mean = 3.9959 Standard Deviation = 0.23591

CELL LIMITS Lower	Upper	Frequency
3.2842	3.3703	2
3.3703	3.4563	1
3.4563	3.5424	10
3.5424	3.6284	15
3.6284	3.7145	35
3.7145	3.8005	50
3.8005	3.8866	52
3.8866	3.9726	85
3.9726	4.0587	59
4.0587	4.1447	60
4.1447	4.2308	50
4.2308	4.3168	24
4.3168	4.4029	27
4.4029	4.4889	13
4.4889	4.5750	10
4.5750	4.6610	3
4.6610	4.7471	2
4.7471	4.8331	1
4.8331	4.9192	0
4.9192	5.0052	1

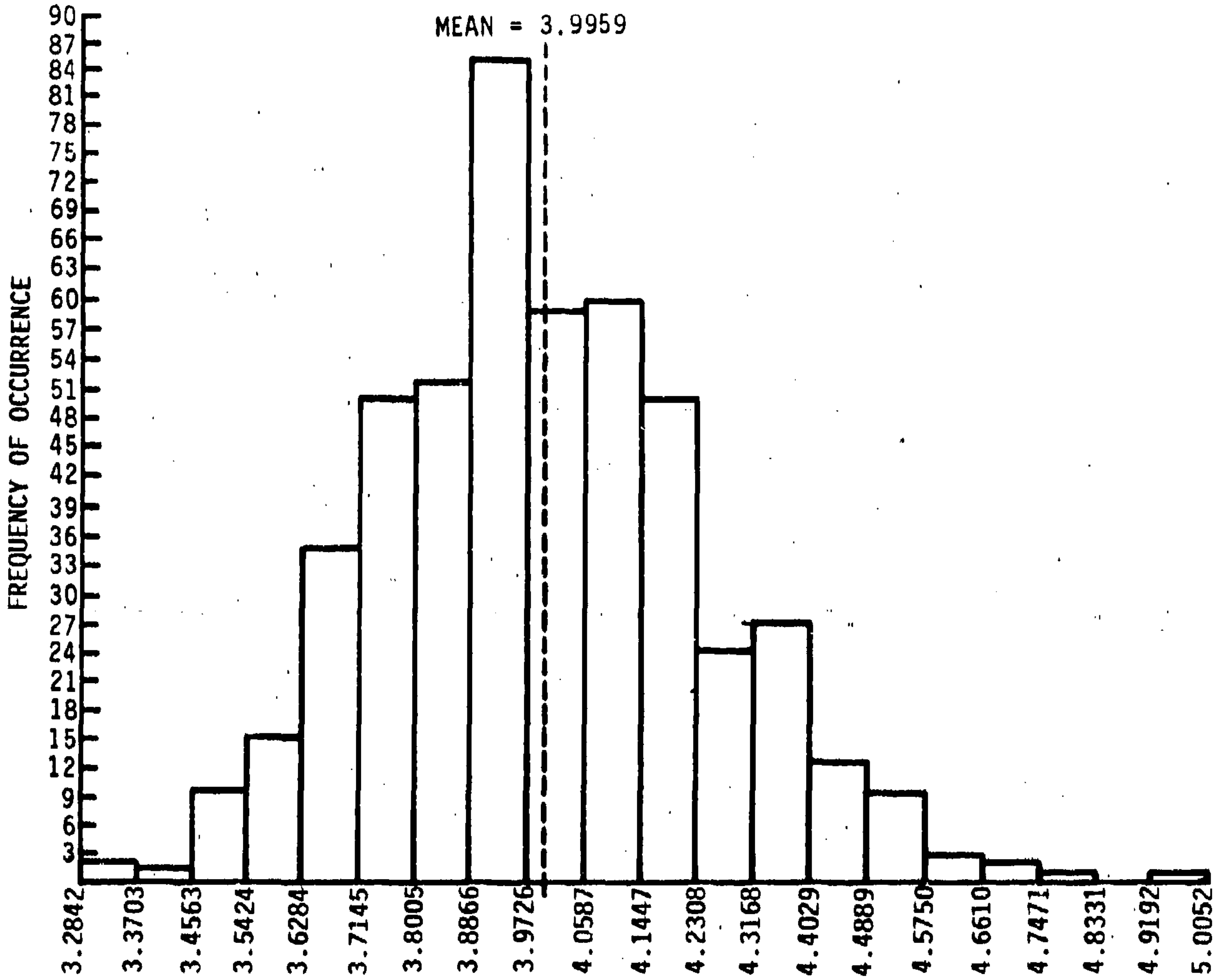


FIGURE E.8

HISTOGRAM OF OUTPUT PARAMETER E_1

Table E-IV shows upper and lower limits of each cell of the histogram, frequency of occurrence of each value, and the mean and standard deviation of the output parameter E_1. Based upon the given specifications for output parameter E_1, the probability of exceeding these limits (that is the probability of a circuit failure) can be determined. This probability will be the ratio of the area outside these limits to the total area of the histogram.

Assume, for example, that E_1 is given as $E_1 = 4 \pm 0.2$ volts. The area outside the bounds of $E_1 = 3.8$ and $E_1 = 4.2$ volts, A_O is computed from the histogram of Figure E.8 as:

$A_O \simeq 15.3$ and the total area of the histogram as:

$A_T \simeq 15.3 + 29.7 = 45$

Thus, the probability of failure (E_1 falling outside $E_1 = 4 \pm 0.2$ volts) is:

$P_F = \frac{15}{45} = 34$ percent and the probability of success

$P_S = 1 - P_F = 66$ percent.

Note that no restriction is imposed on the shape of the output parameter distribution curve, as in the case of the Moment analysis where Normal (Gaussian) distribution of all parameters was assumed.

III. CONCLUSIONS

The simple examples shown in the previous sections indicated that manually performing variability analysis can be an involved and time consuming process. For more complex circuits with multiparameter parts, a set of simultaneous equations is required to express the current and voltage relationships between the various branches of the circuit. As the order of this matrix equation increases, the only efficient way to solve it will be by means of a computer. The four analytical methods described in this appendix have been computer simulated.[2] This allows results of the same problem, solved by different methods, to be easily compared. The methods discussed herein are by no means the only ones existing. There are other specialized, computer oriented, methods (e.g., Vinil method[2], Optimization methods[4]) for particular variability analysis applications.

In selecting a suitable method for variability analysis, the advantages and limitations of each method should be considered:

A. The Worst Case analysis offers a quick check on tolerance selection, but it is impossible to obtain Worst Case values for all output parameters simultaneously. If a circuit passes the Worst Case analysis, it will never fail as long as the input parameters are maintained within the tolerance limits established by the analysis. In performing Worst Case analysis, any possible drift in part value over its life, due to aging or other environmental factors (e.g., temperature, humidity, vibration) must be taken into account, in addition to the initial tolerance. This will assure that the results obtained reflect the actual "worst case", but it also results in a very conservative analysis since the probability of the worst case build-up in tolerance for all parts in a circuit is very small.

B. The Parameter Variation method provides selection of part tolerances on pairs of parameters, but the process will become very elaborate if more than two parameters are varied simultaneously. Though it is possible to vary up to six parameters simultaneously, experience has shown that two at a time parameter variation furnishes sufficient data for all practical purposes.

C. The Moment method is the fastest of the four methods described in computer simulation. It is also a tool for the designer to generate circuits with desired reliabilities based upon total part tolerance. The accuracy of the results, however, depends upon the accuracy of the equivalent circuit used. This method assumes that the relations between input and output parameters are linear and the output parameters have Normal (Gaussian) distributions. That is, the Moment method makes no provisions for the effects of skewed distributions of input or output parameters.

D. The Monte-Carlo method provides complete and accurate frequency distributions of all output parameters, if adequate statistical data for all input parameters are given. The Monte-Carlo method assumes no restriction on the shape of the parameter distributions. However, there is no indication on what modifications should be made in the circuit parameters in case the circuit does not pass the test. For such cases analysis of Variance, using the Moment method, will be helpful in deciding what circuit parameters should be modified.

The largest single obstacle to overcome in performing either a Moment or a Monte-Carlo analysis is the frequent lack of adequate statistical data for all input parameters. Finally, the Monte-Carlo method requires more computer time than the Moment method due to the large number of circuit iterations required (usually more than 500). If, for example, one minute of computer time is required for the Moment method to perform analysis on a circuit with 17 input parameters and 23 output parameters, then the Monte-Carlo method will require about 4 minutes of computer time for the same circuit.[2]

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APPENDIX F

DERATING

I. GENERAL

This section explains the necessity for derating of electronic parts. An acceptable definition of derating is "the application of parts in such a manner that the actual stresses (failure forcing functions) are substantially less than the design maximum ratings". Design maximum ratings refer to the maximum capability of a part as established by the manufacturer. Derating, therefore, is the reduction of the impact of various kinds of stresses on a part in order to decrease the degradation rate and prolong the expected life of the part. It also allows added protection from system anomalies unforeseen by the designer such as combined transient stresses. Derating is a well known and commonly practiced procedure, and is one of the most powerful reliability tools available to the equipment designer.

II. PARTS DERATING GUIDELINES

Derating of electronic parts is analogous to the use of safety factors in structural design.

A part's strength of capability of handling a given stress varies from lot to lot and manufacturer to manufacturer. This variation for all parts of the same type can be represented by a statistical distribution of part strength. Similarly, the stress applied to a part changes from one point in time to another with instantaneous changes in temperature, electrical stresses and transients, vibration, shock and other deleterious environments. At a random point in time, the environmental effects can combine reaching stress levels beyond the part's strength, thus resulting in failure of the part. These failures are termed random failures and the rate at which they occur are the published random failure rates provided by MIL-HDBK-217.

This strength-stress relationship can be described graphically by two overlapping statistical probability density distributions as shown in Figure F.1. For parts following a given strength distribution that are used in an environment with an average stress equal to the mean of the stress distribution, the probability of failure is equal to the product of the areas of the two distributions where overlapping strength-stress occurs (i.e., the product of the probability of the stress being greater than the minimum strength times the probability of the strength being lower than the maximum stress). This probability of failure is represented by the solid area of Figure F.1.

In order to reduce the probability of part failure or the part's "random" failure rate, one of two approaches must be taken: (1) reduce the potential stress levels to a point where there is a very small probability of the stress exceeding the part's strength (shift stress distribution to the left), or increase the part's strength so that the probability of the combined stresses reaching or exceeding this strength is very small (shift strength distribution to the right). In most instances the stresses cannot be reduced

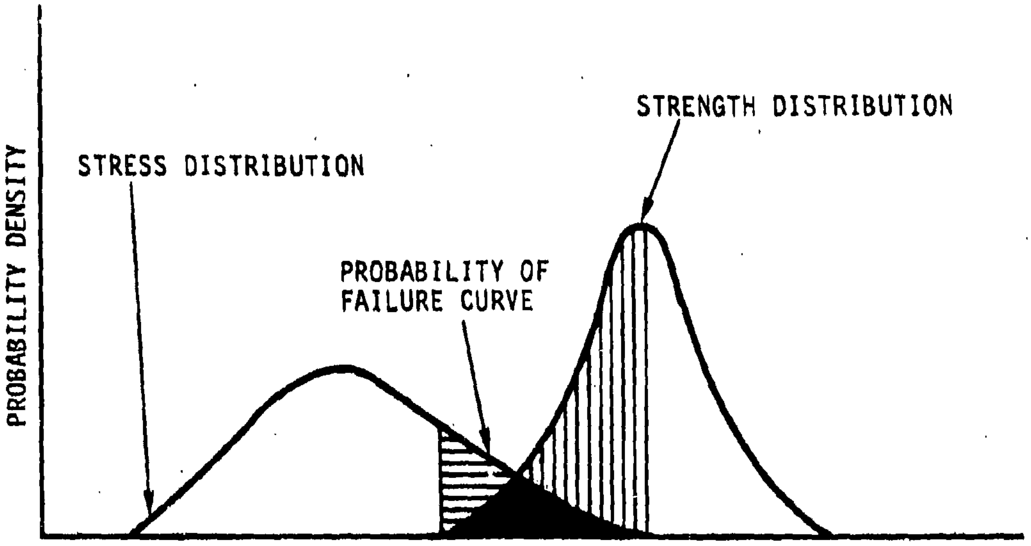

FIGURE F.1

STRENGTH-STRESS PARAMETER

and the only approach is to increase the part's strength. This is accomplished by using a larger or stronger part stressed to only a percentage of its capability. In other words, using high factors of safety. This is known as part derating.

Besides reducing part random failure, derating of parts reduces part internal operating temperatures, decreasing the rate of chemical time-temperature reaction which is the primary cause of part aging and parameter drift.

Different part types are failure sensitive to different kinds of environmental and electrical stresses such as temperature, power, voltage, current, humidity, shock, vibration, altitude, acceleration, etc. These are the stresses for which a particular part must be derated. A listing of the electrical stresses and the maximum percentage of rated stresses for high reliability application are provided in Table I of Chapter I. Protection from environments requires selection of parts capable of withstanding these environments or providing some type of environmental protection through design.

III. DERATING CURVE

Figure F.2 is a reproduction of the derating curve for a MIL-R-55182 resistor (style RNR). The absolute maximum rating is the curve of the steady state power rating of the resistor over its operating temperature range. For temperatures below 125°C the resistor is capable of operating at full wattage. For temperatures in excess of 125°C, the absolute maximum wattage rating is reduced linearly and reaches zero at 175°C. For example, in accordance with the absolute maximum rating curve shown in Figure F.2 a 1/8 (.125) watt resistor has an absolute maximum wattage rating of 73 percent of 1/8 watts or 0.092 watts at 140°C.

For reliability derating, this resistor should be derated within the maximum allowable derating curve (see derating curve of Figure F.2). This means that at 125°C, the 1/8 watt RNR resistor should be used at 11/20 watts and at 140°C at 0.051 watts.

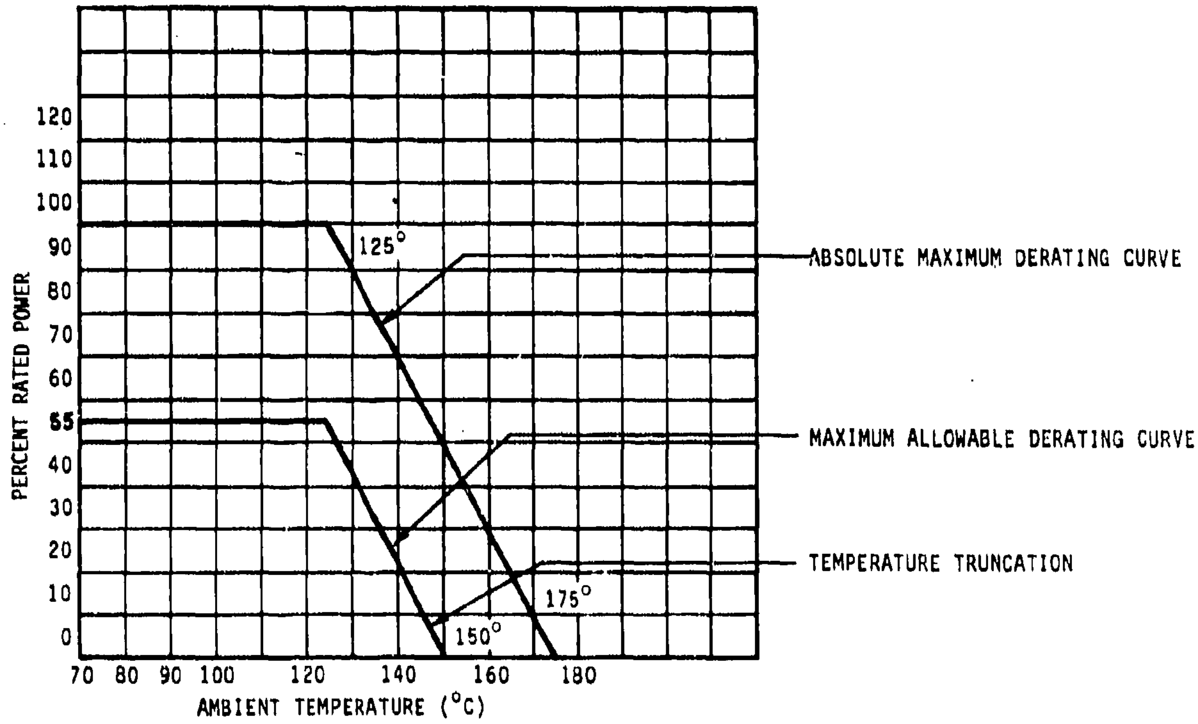

FIGURE F.2

DERATING CURVES FOR RNR STYLE RESISTORS

The derating curve of Figure F.2 also has a maximum temperature truncation point. That is, for reliability purposes, it is recommended that this style resistor not be used above 150°C ambient.

IV. TRADEOFF CONSIDERATIONS

There is a minimum stress level below which the advantages materialized by derating will be nullified by the increased circuit complexity required to achieve the desired performance. Where the space and weight are of major importance, derating may have to be traded off for savings in space and weight.

V. CIRCUIT/PART TOLERANCE

Although the time to achieve a given level of degradation is prolonged by derating the parts, failure rates in applications will vary widely depending on the tolerance of each circuit to part drift. To assure low failure rates, designers should strive to achieve the greatest circuit tolerance. Appendix E provides analytical methods for determining part tolerances needed to achieve required tolerances and includes basic part tolerances and tolerances due to drift from age and environment.

APPENDIX G

STANDARD ELECTRONIC MODULE PROGRAM

I. GENERAL

The Standard Electronic Module (SEM) program is an electronics module standardizaton program of common electronic functions. The program employs comprehensive quality assurance techniques, use of high quality parts, derating criteria and detailed thermal analysis and measurement.

The Standard Electronic Module (SEMP) program is sponsored by the Chief, Naval Material Command (CNM), managed by Naval Electronics Systems Command (NAVELEX), Washington, D.C., and operated by Naval Avionics Center (NAC), Indianapolis, Indiana and Naval Weapons Support Center (NWSC), Crane, Indiana. NAC is the SEMP Design Review Activity (DRA) whereas NWSC, Crane is the Quality Assurance Activity (QAA). The DRA responsibilities include: reviewing new modules and applicatons to a particular system, recommending methods of optimizing design, determining whether new modules should become "standard", assigning module key codes and drawing numbers and maintaining module data banks. The QAA responsibilities include: review of new module specifications, initial qualification design review and test, correlation of vendor test equipment with bench test setup of the module specifications, review of failure trends, performance of failure analysis, and the performance of production qualification and process audits of module vendors.

II. PROGRAM OBJECTIVES

The basic objectives of the SEMP are to:

A. Partition electronic functions in a manner to create building blocks that can be used in a majority of equipment applications.

B. Document modules with functional specifications to preclude dependence upon specific vendors' designs or technologies with the intent of cost savings through vendor innovation and competition.

C. Achieve high reliability through the use of high quality parts (MIL-M-38510 Class B microcircuits; JANTX semiconductors, and ER level M or better discrete passive parts), part derating (semiconductor junction temperature 105°C maximum, passive part hot spot temperature 20°C below maximum rated operating temperatures), and mandatory quality assurance requirements for module designs and their vendors.

D. Provide thermal design limits (e.g., 60°C Class I, 100°C Class II maximum fin temperature).

E. Achieve replace-upon-failure maintenance policy based on high reliability and low cost.

F. Ensure environmental compatibility with use environments.

G. Provide flexible mechanical packaging requirements which accommodate various circuit and packaging technologies.

H. Ease the logistics support burden on the congested supply system by extensive inter-system commonality of a limited number of module types.

There are approximately 350 standard modules presently in existence. To allow for maintaining packaging configuration, specially designed SEMs are allowed for use to perform special functions that are not available in the existing standard modules. These special SEMs are required to meet the same quality assurance requirements as the standard SEMs. Special modules which are expected to have common usage in future equipment can be added to the inventory of standard SEMs.

The quality assurance activity begins in the design phase and continues through design verification, production and use through auditing and failure analysis review. This process is outlined in Figure G.1.

The Military Specifications pertinent to the SEM program are shown in Figure G.2.

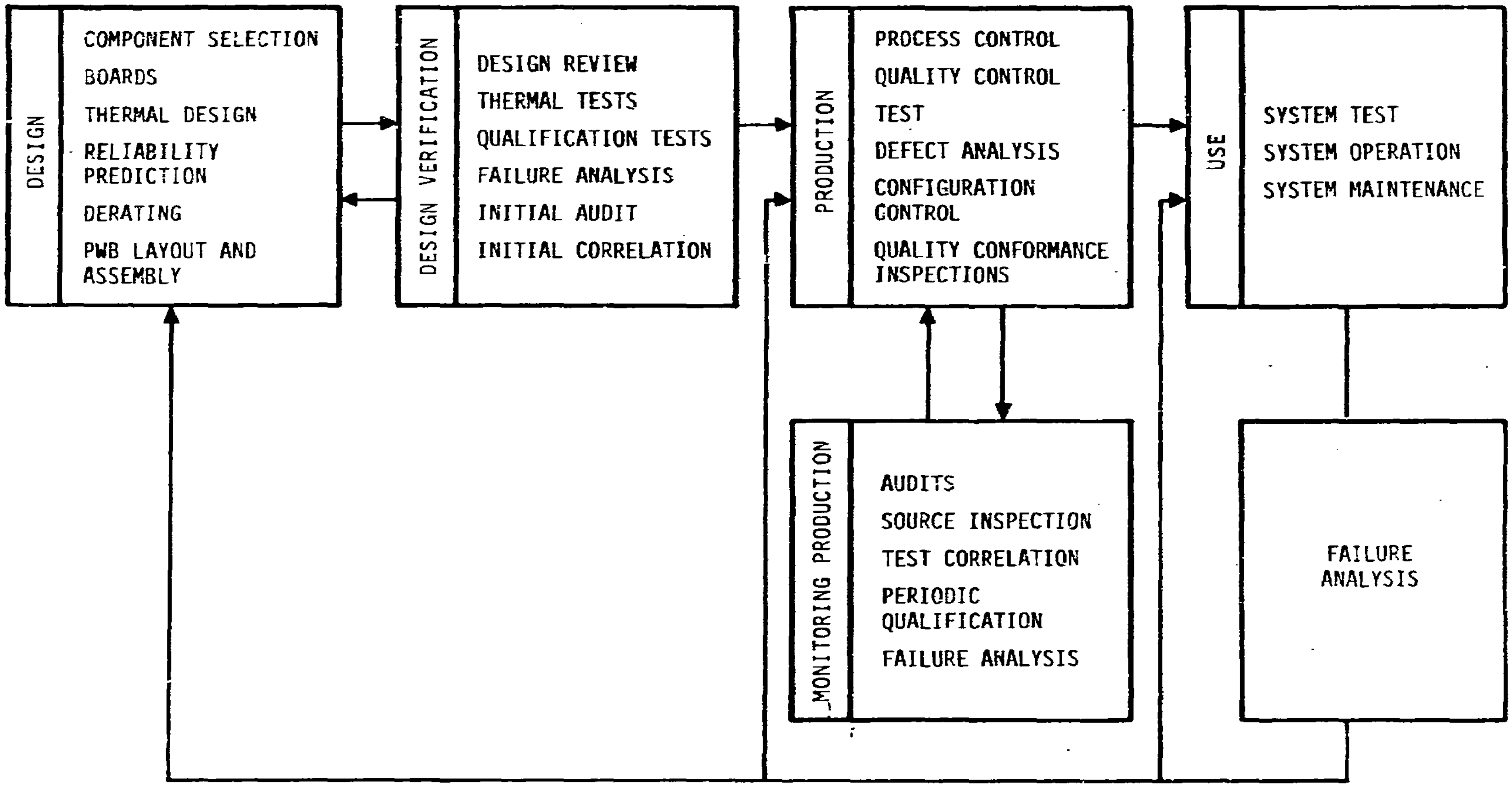

FIGURE G.1

QA PROCESS

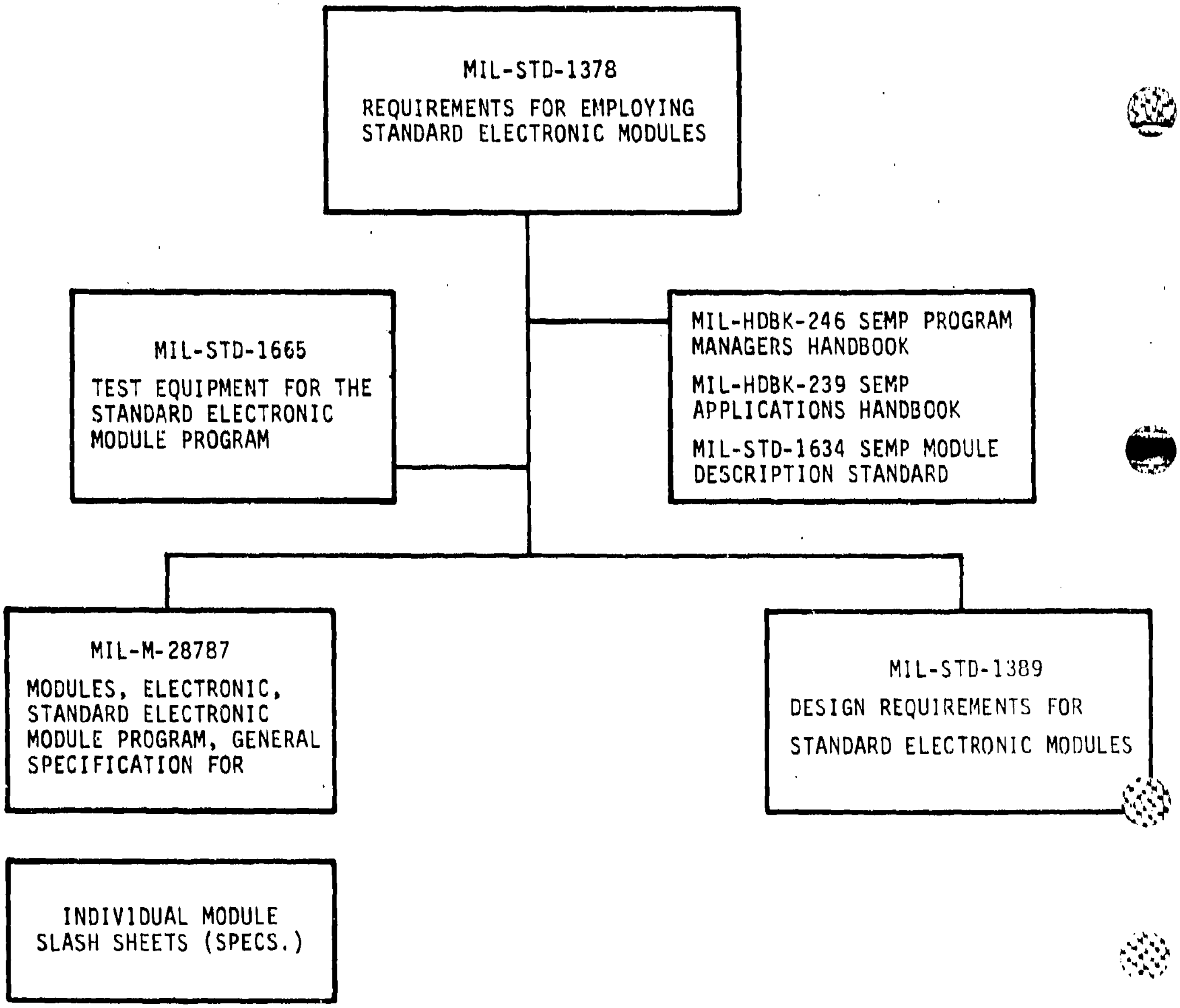

FIGURE G.2

MILITARY SPECIFICATIONS PERTINENT TO SEM PROGRAM

APPENDIX H

TRANSIENT SUPPRESSORS

I. GENERAL

A transient is a short duration high voltage pulse spike that can cause slow degradation, erratic operation or catastrophic failure in electrical and electronic parts, insulation dielectrics and electrical contacts such as those used in switches and relays.

Transient over-voltages originate from four major sources: lightning effects (not necessarily direct strikes), load switching transients, electromagnetic pulse and static discharge. Table H-I lists some sources of transient pulses.

TABLE H-I

TRANSIENT SOURCE[1/]

MAN-MADE
• Switching (mechanical and solid state) of reactive loads; opening and closing of switches and relays.
• Fuse and circuit breaker interruptions and resettings.
• Generator and motor operation (overspeed and hunting, startup, control and shutdown).
• Ignition system, arc welder, particle precipitator operation.
• Fluorescent light operation.
• Reflected waves.
• Electromagnetic pulse (EMP), e.g., from nuclear blasts, large chemical explosions.
• Current inrush.
• Thyristor switching power control.
NATURAL
• Lightning.
• Static charge on personnel, work surfaces, tools, etc.
• Static charges on long transmission lines.

Transients are commonly developed on shipboard power systems. As described in DOD-STD-1399 (NAVY), Section 300, shipboard power systems may encounter various types of voltage transients depending upon the type of power system.

A. Power System Types

The three different types of power systems used in shipboard applications are:

1. Type I - 400/115 volts rms, 30/10, 60 Hz, used mainly for ship's service power and lightning distribution system. Line to line voltage tolerance is ±5 percent.

2. Type II - 440/115 volts rms, 30/10, 400 Hz. Voltage tolerance is not as precise as that of Type III. For example, average voltage tolerance between line to line is ±5 percent.

3. Type III - Same as that of Type II except the average voltage tolerance between line to line is ± 1/2 percent.

B. Power System Transients

For Type I and Type II power - Voltage transient of 10 percent or less may occur several times an hour, and voltage transients of 10 to 16 percent may occur several times a day (percentage based on nominal user voltage). The time to reach the transient maximum may vary from 0.001 to 0.03 second, or to reach the transient minimum may vary from 0.001 to 0.06 second on Type I systems, depending on the rating of the generator and the type of regulator and excitation system employed.

For Type III power - Voltage transient of 5 percent or less may occur several times an hour. The time to reach the transient maximum may vary from 0.001 to 0.1 second.

C. Shipboard Equipment Transient Protection

Although some built-in system protection is normally incorporated in shipboard equipment, this protection will usually not prevent damage from high frequency (short pulse width) or extremely high voltage transients such as: (1) high voltage excursions of very short duration (spike voltage) which may occur under fault conditions or circuit switching surges when energizing/de-energizing low factor loads, from static discharge, lightning or high frequency electromagnetic pulses; (2) momentary interruption and restoration of power during transfer from normal to alternate or emergency supplies; (3) high voltage insulation resistance tests; (4) active ground detector tests (an active ground detector superimposes 500 volt direct current DC on the AC system).

II. DESCRIPTION OF COMMON SOURCES OF HIGH FREQUENCY TRANSIENT

A. Lightning

Lightning is one of the most fascinating phenomenon of nature. A single stroke can have a length of over 2 kilometers with peak currents up to 400 kiloamperes. Lightning usually occurs in multiple strokes. The number of return strokes can vary from one to about twelve with an average of two to three. The rise time to maximum for the first return stroke is about 1.5 microseconds with decay to 1/2 crest value of 40 microseconds.[2] Typically, the highest maximum peak current values (i.e., 400 kiloamperes) occur for the tropical regions of the world, because of the great height of the thundercloud. Maximum peak currents in the temperature zones are about 250 kiloamperes with the distribution of peak currents for first return strokes and subsequent return strokes occurring over a broad range.

Due to accumulation of charged atmospheric "cells" of various types, lightning strokes fall into the following general categories:

- Cloud to cloud
- Cloud to air
- Air to earth
- Cloud to earth
- Intra-cloud

The initial phase of a lightning discharge usually begins with what is called a downward moving stepped leader. This occurs when the electric field between the thundercloud and the earth is sufficient to cause dielectric breakdown of the intervening air space. The stepped leader lowers the charge from the cloud to the ground in incremental steps. This process ionizes a channel which becomes the path of the lightning stroke. After the ionized channel is generated, the return stroke travels from the ground up the base of the cloud. Although the stroke travels from earth to cloud, the charge transfer of electrons is normally from the cloud to the earth.

Lightning effects have not been measured directly, but transient recordings made during a lightning storm[3] on a utility pole provide sufficient correlation to yield data on the size of the voltage levels that can be produced, and the probable discharge mechanisms. The transient pulse from lightning affects electrical equipment as follows:

1. Voltages are induced in overhead lines by the magnetic field produced by a strike terminating on nearby objects.

2. Voltages injected in the secondary system as a result of the voltage produced by a primary arrester current discharge following a strike on a primary conductor.

3. Direct strikes on the secondary system.

Based upon measurements made on 120V ac power systems, Martzloff[4] has proposed a waveform which rises to peak in 500 nsec, and then subsequently decays in a sinusoidal waveform with a frequency of 100 kHz. The lightning stroke, which is usually reported with current rise times ranging from 1 to 3 μsec, has been more recently measured by Llewllyn[5] to be as low as 500 nsec. Transients on shipboard ac power systems have been defined by DOD-STD-1399 (Navy), Section 300, as having rise times of 1.5 μsec.

B. Load Switching Transients

1. Power Systems

Switching transients originating in power systems have been documented in the case of power factor correction capacitor switching.[6] These transients tend to have lower frequencies than the "spikes", which are of prime concern here; and their levels, at least in the case of restrike-fast switching operations, are generally less than twice normal voltage.

2. Electromechanical Switching

On the other hand, switching operations involving restrikes, such as those produced by air contactors or switches, can produce voltage escalations reaching several times the system voltage. The worst case is generally found on the load side of the switch and therefore involves only that device which is being switched. While this situation should certainly not be ignored, in such a case the prime responsibility for protection rests with the supplier or user of the component in question.

These switching transients can also be reflected on the line side of the switch and can affect other devices connected to the line. This situation has been identified as potentially harmful at a statistically significant level.[7]

3. Low/High Inductive Sources

The fast rise time voltage transients in circuitry wiring can be a source of high voltage secondary effects, due to what may appear to be virtually negligible inductance in the circuit. This secondary voltage transient is described by the relationship:

$$V(t) = L \frac{di}{dt}$$

Where L is inductance in henries and $\frac{di}{dt}$ is time rate change of current.

An example of such an induced voltage would be measured peak of 3,900 volts produced by a .4 ampere 30 volt inductive load.[8] Induced voltages have been recognized for a long time, but because of their short durations have not been a problem until the introduction and use of semiconductors. Many power semiconductors are relatively immune to most transients; however, small geometry semiconductors have been damaged with transient voltages of only 25 nsec duration.

The observed waveform of an induced voltage is usually oscillatory in nature. This is due to the switch gap alternately sparking over and extinguishing. This occurs as follows: When the switch opens and interrupts the line current, the current in the inductor continues by charging the capacitance in the line and interwinding capacitance of the inductor. The induced voltage then rises until the gap between the switch contacts spark over. When spark-over occurs, the induced voltage is discharged and when the spark-over extinguishes, the process then repeats itself. This oscillatory process then continues until there is insufficient stored energy remaining in the inductor to cause the spark-over. The stored energy in the coil is expressed by the following equation:

$$E = \frac{1}{2} LI^2$$

Where:

E = energy in joules

L = inductance in henries

I = current through the inductor in amperes

The maximum inductive switching transient for shipboard 110V ac systems is defined by DOD-STD-1399 (Navy), Section 300, having a peak voltage of 2,500V and a waveform as shown in Figure H.1.

This waveform has been adopted as the worst case switching transient which would be generated by a large inductive source. An example of such a worst case transient generator could be an elevator motor on an aircraft carrier.

Often power supplies act as a major transient generator since they are subjected to environmental conditions, such as lightning, auxiliary power equipment, and various large inductive loads.

C. Electromagnetic Pulse (EMP)

During a high altitude nuclear detonation, gamma rays are released which set into motion high speed electrons. These electrons subsequently are deflected by the electromagnetic belt surrounding the earth

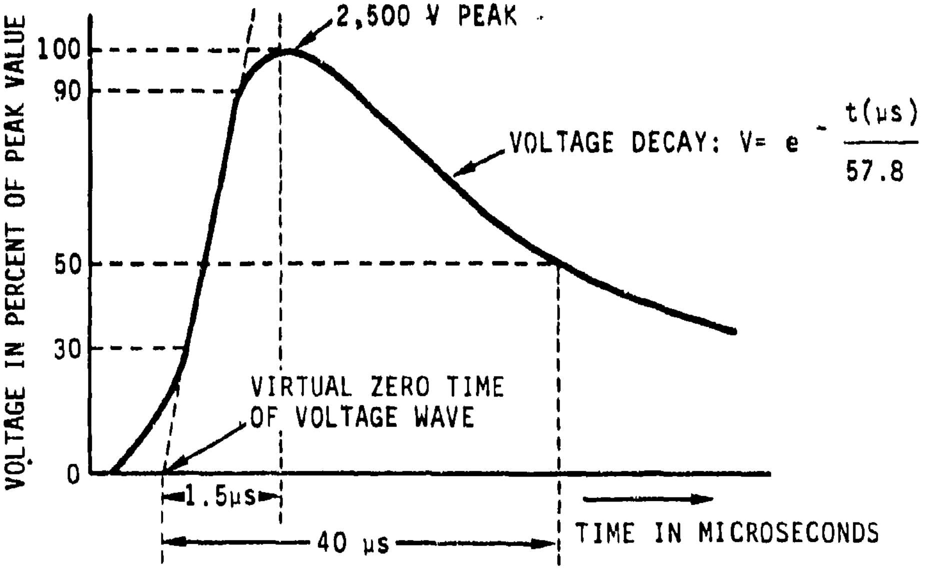

FIGURE H.1

DOD-STD-1399 WAVE FORM

and an electromagnetic pulse is created. This deflection can generate a voltage pulse of 50,000 volts per meter at a point 300 miles from the detonation, with a rise time of approximately 5,000 volts per nsec,[9] compared to lightning which can have a field density of 3 volts per meter, six miles from point of discharge, with a rise time of 600 volts per microsecond (see Table H-II). Because of the large magnitude of the voltage and frequency spectrum of an EMP, there are basically no "off-the-shelf" R-C or L-C filters that can effectively reduce or eliminate such an EMP.

TABLE H-II

COMPARISON OF EMP, LIGHTNING AND
STATIC DISCHARGE PULSES

EVENT	FIELD DENSITY OR MAGNITUDE	RISE TIME
EMP (from Nuclear Blast)	50 kv/m @500 km	5 kv/ns
Lightning	3 v/m @10 km	600 k/μs
Static Discharge (Human)	20 kv at impact	2 kv/ns

MOS circuits and small area geometry semiconductors are particularly vulnerable to the fast rise time transients of EMP origin. Because of the severe threat to sensitive electronic parts and equipment from EMP transients, effective suppression techniques and protective devices must be employed which provide protection from fast rise time transients exposure.

D. Static Discharge

One of the most unique aspects of ESD is its fast rise time, cresting in a matter of nsec as compared to the rise time of microseconds for induced lightning and inductive switching transients. Static discharges can have a rise time of 2 kilovolts per nanosecond, with voltage magnitudes in excess of 20,000 volts, from a normal body discharge (see Figure H.2).

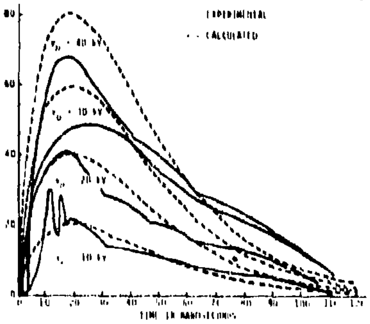

FIGURE H.2

WAVEFORM OF ESD FROM HAND-HELD METAL TOOL[10]

Peak values of ESD are a function of the environment and can range over several orders or magnitude as shown in Table H-III.

TABLE H-III

REPRESENTATIVE VALUES OF ELECTROSTATIC VOLTAGES

ACTION	RELATIVE HUMIDITY	
	LOW (10-20%)	HIGH (65-90%)
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Poly bag picked up from bench	20,000	1,200
Work chair padded with urethane foam	18,000	1,500

The new generations of VLSI and LSI bipolar and MOS semiconductor devices and circuits are confronted with unique transient voltage problems. Moreover, the steeper the wave front of the transient, the more vulnerable is a given device type. It has been reported that some CMOS types fail with energy levels of only a few microjoules when subjected to a 5 kv/nsec rise time transient.

III. REDUCING THE TRANSIENT PROBLEM

A. Capacitive Filters

Transients are normally associated with high frequency pulses which are several orders of magnitude above the steady-state voltage. The primary approach to protection from such transients is the use of a low pass filter. The simplest form of a filter is a capacitor that provides a lower impedance than the transient source, forming a voltage divider. A capacitor can be an effective filter as long as it:

- Does not load down the system and does not create any current "in-rush" problems. Sometimes a resistor in series will reduce the current "in-rush" problem, but it also reduced the effectiveness of the capacitor.
- Does not have any parasitic inductance which will spoil the high frequency admittance of the device.
- Does not degrade with time or ripple current.

If the transient has high dc current components of either polarity, the capacitor can become ineffective. Also, the inductance associated with filter resistance will reduce the effectivity of the filter.

In addition, transient oscillations or ringing can develop. When this happens the capacitor can have the effect of increasing the transient voltage if the transient source is inductive.

Filters are often used in conjunction with transient suppressors to be discussed in the next section. Figure H.3 shows a combination of transient suppressor (SA) and a low-pass filter.

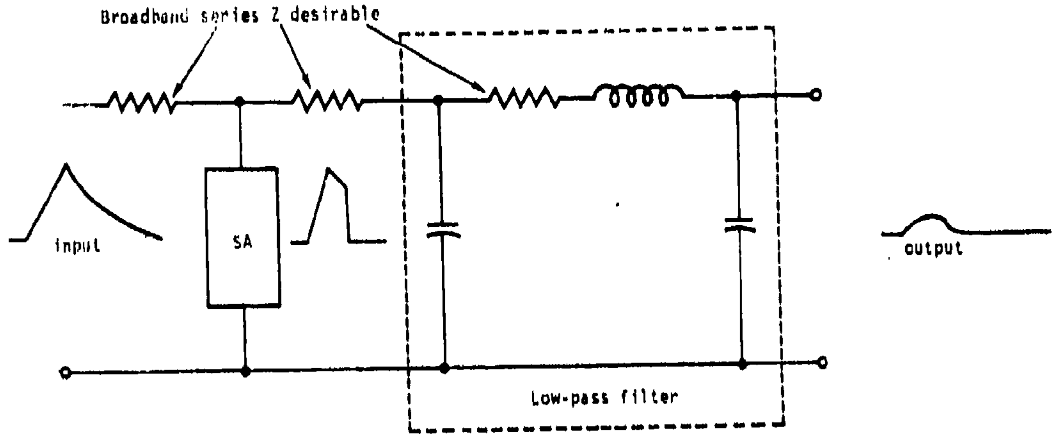

FIGURE H.3

HYBRID SURGE ARRESTER AND LOW-PASS FILTER[12]

B. <u>Transient Suppressors</u>

A second approach to the transient problem is the transient suppressors. To be effective, a transient suppressor must be fast in response and capable of high energy pulses. It must be able to clip the transient at some specified safe voltage level and dissipate the transient energy before any damage would occur within the equipment being protected. Since transient amplitude and duration are probabilistic, transient suppressor selection requires good engineering judgement based upon distributions of transient amplitudes and duration. The overall performance which includes power rating, maximum operating temperature, size, parasitic leakage and capacitance of the device should be considered.

1. <u>Basic Requirements of a Transient Suppressor</u> - Basic requirements of a transient suppressor are:

(a) The response time of the suppressor should be less than the rise time of the transient for effective suppression.

(b) The clamping voltage level should not interfere with the normal operation of the equipment and should be lower than the equipment can withstand.

(c) The suppressor should be self-restoring.

(d) The suppressor should be maintenance free.

To avoid interference with normal equipment operation, zener clamping voltages, gas arrester discharge voltages or varistor clamping voltages should be more than 20 percent higher than peak value of the normal equipment operating voltage. On the other hand, the surge protection voltage level (P) should be lower than the equipment withstanding voltage (W). The protective margin of the instrument is defined as:[13]

$$\left(\frac{W}{P} - 1\right) \times 100 \text{ percent}$$

and is generally recommended to be higher than 20 percent.

2. Types of Transient Suppressors - The different types of suppressors available are: semiconductors (Zener diodes, Avalanche diodes), varistors, spark gaps, and carbon blocks. Circuit breakers, fast fuses and thermistors are used for protection against extended overload conditions such as over-voltages or short circuits and are not intended as suppressors of fast transients. Thus they will not be described herein.

(a) Zener Diodes - Zener diodes are used in a transient suppressor protection circuit to clamp surge voltages to a specified value called the clamping voltage. Zener diodes for transient suppressors should have high transient current absorption and small thermal resistance between the junction and the case. The Zener diode is mostly used in reverse bias; however, its transient current absorption capability is larger in the forward bias condition. A single Zener can therefore clamp positive voltage surges to the zener voltage level and negative voltage surges to the zener forward voltage level. The allowable peak pulse power for a typical surge protection diode is a function of the pulse shape and duration. The shorter the decay time, the larger the peak surge power dissipation required by the Zener diode.

Therefore, in the protection of single polarity signal lines, a single reverse biased Zener diode with current limiting resistors can provide suitable transient suppression (see Figure H.4).

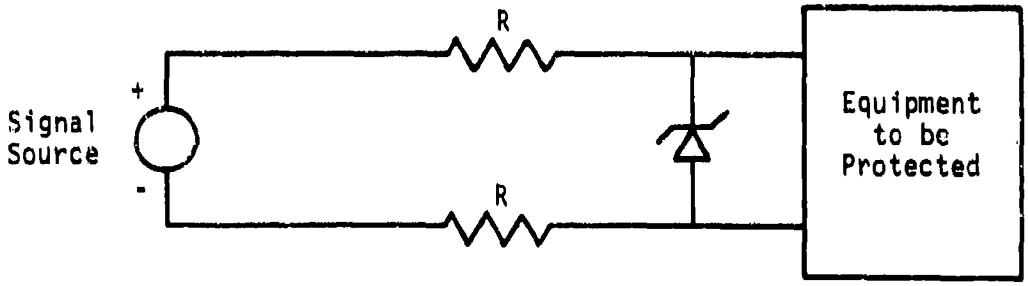

FIGURE H.4

PROTECTION USING ZENER DIODES

However, when the power or signal lines carry a bipolar signal or ac power, two Zener diodes connected back to back are needed to provide the necessary protection. Commonly used Zener diodes have a junction capacitance of 10 pf to 0.01 μf. This capacitance has the effect of decreasing the surge impedance, Z_D, of the diode, for high frequency pulses. A transient voltage pulse in excess of the zener voltage will develop a peak current, I_p, across the Zener as follows:

$$I_P = \frac{V_s - V_{mc}}{2R + Z_L + Z_D} = \frac{V_s - V_{mc}}{2\,R + Z_L}$$

Where:

V_s = the surge peak voltage

V_{mc} = the maximum clamping voltage of the Zener diode

R = the current limiting resistor

Z_D = the surge impedance of the diode is $<< 2\,R + Z_L$ for high frequency pulses

Z_L = steady-state impedance of the reverse biased diode

V_{mc} and the maximum allowable peak current I_P of a Zener diode are given in the Zener diode specification. Z_L depends on the type of cables and the cabling length to the equipment. The current limiting resistors, R, must be sized so the peak current through the Zener is smaller than the rating for the given surge waveform, that is, $I_P < I_P$ maximum for the Zener diode used. The Zener diode transient suppressor is usually effective as long as the expected surge voltage is smaller than the flash-over voltage of the conductors to or internal to the equipment.

(b) Silicon Avalanche Diode - Another type of semiconductor p-n junction transient suppressor is the silicon Avalanche diode. The Avalanche diode was developed for protecting telecommunictions circuits from induced lightning. This device provides transient suppression by limiting the peak voltages through avalanche breakdown and is especially effective for short term pulses in the order of 10 milliseconds. The Avalanche diode can absorb relatively large transients, due to its large area junction, and its fast heat dissipation provided by the incorporation of integral silver heat sinks which are metallurgically bonded to the silicon chip. The design and structure of this device provides inherently lower impedance compared to zener diodes having the same steady-state voltage ratings.

The clamping speed of the Avalanche diode is of the order of microseconds giving them the capability of protecting very sensitive devices such as integrated circuits, MOS devices, and other very voltage sensitive semiconductors and components from fast pulses. Avalanche diodes for transient suppression are available in special low inductance disc configuration and low inductance electrical connection to minimize the voltage generated by the L $\frac{di}{dt}$ effects for fast rise time transients. A discussion on the effects of the lead inductance in relation to limiting fast time transients is given in Section III-B-3 of this appendix.

Other limitations and disadvantages of these devices are as follows:

o Silicon Avalanche diodes have a proportionally larger capacitance over other protective devices due to their large area junction. When used on dc or low frequency (ac) signal lines the capacitance of these devices will not attenuate or alter the circuit conditions; however, if the frequency is quite high and insertion loss occurs, the capacitance must be reduced by adding a low capacitance diode as shown in Figure H.5. This compensation diode must have a reverse breakdown voltage greater than that of the suppressor, and must be capable of withstanding the maximum peak pulse current of the suppressor with the minimum voltage drop across it.

o The use of a low capacitance diode will reduce the response time of the suppressor by the very nature of its construction. Under pulse conditions the low capacitance diode, which is essentially a high voltage rectifier, will conduct in the forward conduction mode only. This mode is slower than the avalanche mode of conduction.

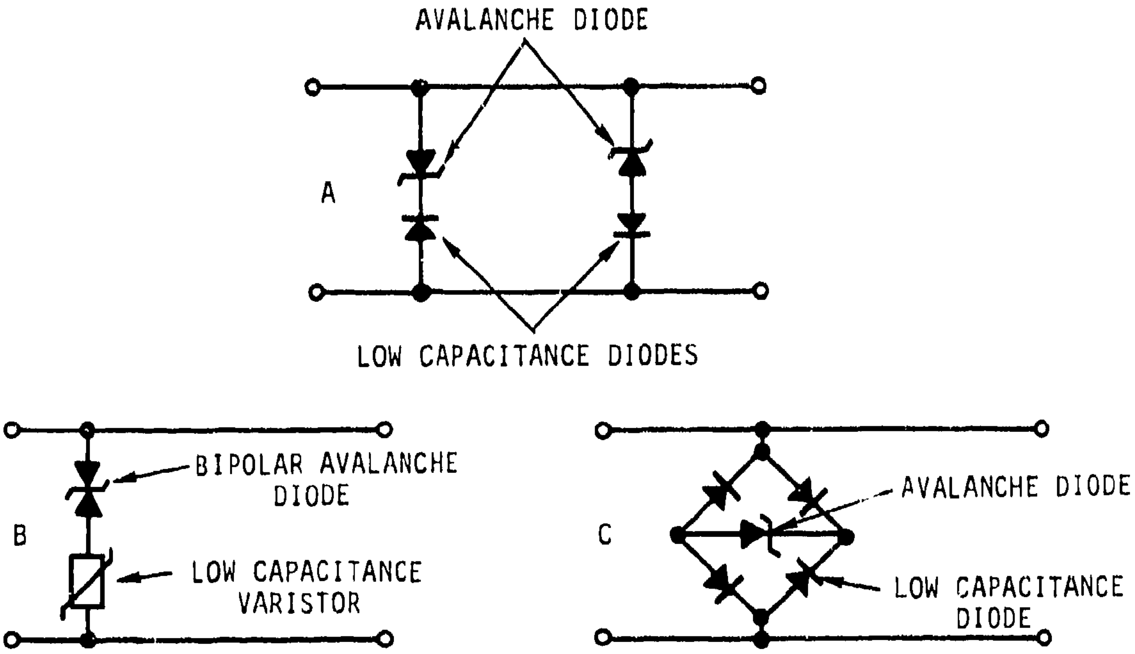

FIGURE H.5

LOW CAPACITANCE PROTECTORS

(c) Metal Oxide Varistors (MOV) - Metal Oxide Varistors (MOV) are devices consisting of a ceramic like material having small granules of zinc oxide suspended in a matrix of bismuth oxide. MOV are highly nonlinear devices. That is, when subjected to normal voltages, the MOV presents a very high resistance at its terminals; however, in the presence of a surge, its resistance diminishes by several orders of magnitude. At normal voltages (i.e., 115 volts), the varistor resistance is approximately 160 kΩ. This results in a steady-state current flow through the device (standby current) of less than 1 ma peak. Both the energy handling ability and the response of the varistor times are good. However, the device has a soft knee turn on, and consequently does not provide significant suppression until the transient voltage exceeds the power line voltage by approximately 100 volts. Once the transient subsides the devices returned to its off state. These devices will operate for a limited number of transient pulses.

Recent innovations made on this device provide low voltage nonlinear elements with: voltage-current characteristics comparable to Zener diodes, bipolar suppression capabilities, high energy dissipation and reduced size. These devices are presently designed for surge protection of ac power lines. However, lower voltage types of MOV should be available in the near future. The step response of an MOV is in the nanosecond range. Figure H.6 illustrates one method for assuming automatic voltage protection of motor starters, thyristors and diodes.

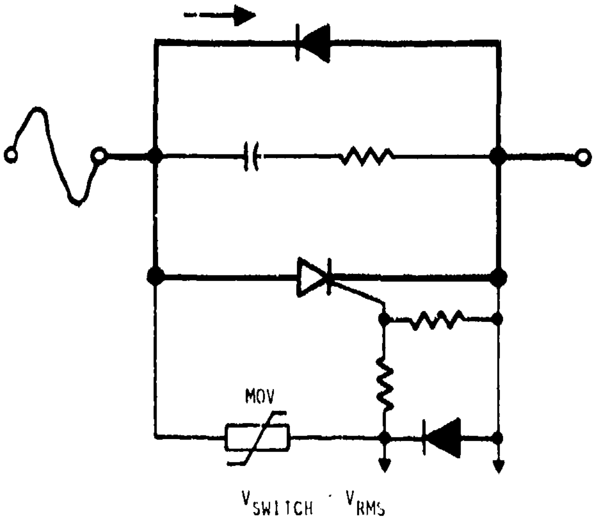

FIGURE H.6

PRIMARY METHOD FOR ASSURING AUTOMATIC VOLTAGE PROTECTION
OF MOTOR STARTER THYRISTORS AND DIODES

(d) Gas Arresters (Spark Gaps) - Gas Arresters are high energy suppression devices with high voltage hold-off capability. They consist of a low pressure gas filled tube with two or three electrodes. The pressure of the gas in the tube is controlled so that arcing between electrodes is achieved at a specified potential difference, provided the current flow is sufficient. The ionization and arcing of the gas in the gap (space between electrodes), for a given Gas Arrester, depends on the surge rise time and the peak value of the surge. Arcing or follow-on current will continue as long as the line voltage is higher than the discharge voltage and enough current flows through the arrester. After arcing, terminal voltages of Gas Arresters drop to 10V to 50V. In order to obtain a self-extinguishing arc, the normal equipment operating voltage must be lower than the discharge voltage or the circuit impedance should be high for limiting the follow-on current after surge.

The combined use of a Gas Arrester and a zener protector provides an efficient way of handling high voltage surges. A typical Gas Arrester-Zener diode protector circuit for an equipment connected to two signal or dc power supply lines is shown in Figure H.7.

As mentioned earlier a Gas Arrester sparks over at a higher voltage than its dc spark-over voltage if the surge wavefront is steep. In a typical case, the time before spark-over is 1 μs for a surge wavefront rise time of 600 v/μs. During that short period of time the Zener diode and the current limiting resistor absorb the surge energy, keeping the equipment line voltage less than the peak clamping voltage of the Zener. Once the Gas Arrester sparks over, it absorbs most of the surge. The Zener diode in Figure H.7 is used to limit the metallic (low voltage) surge (the potential between lines and ground may become high before the arrester arcs). Consequently, such circuits can be used with equipment incorporating good insulation between the electronic section and the case.

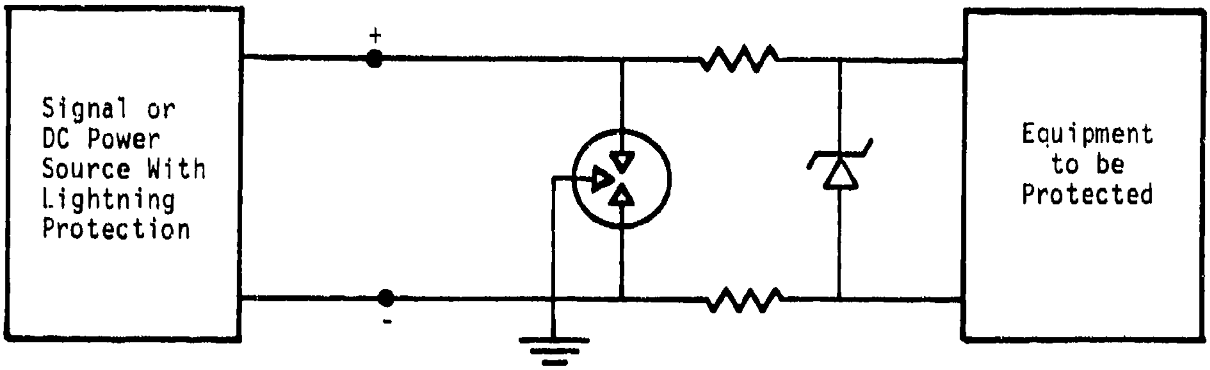

FIGURE H.7

PROTECTION USING GAS ARRESTER AND ZENER DIODE

The basic characteristics of gas discharge devices do not allow application in the less than 75 volt region. However for voltages above this level, gas discharge devices offer good characteristics for minimum interference with normal circuit operation while providing efficient transient protection.

The life time of these suppressors can be approximated in terms of cumulative charge, in coulombs, that can be passed through the device without changing its trip voltage by more than 10 percent.

It is important to note that, for some newer devices of this type, there will be no voltage overshoot, regardless of the particular trip voltage, when the transient is sufficiently fast so that the trip voltage is reached in less than 2 nanoseconds.

(e) Carbon Block - The Carbon Block operates similarly to the Spark Gap Gas Arrester in that it has two electrodes separated by a fixed distance. The major difference between the Carbon Block and the Spark Gap Gas Arrester is that the Carbon Block has only air between the electrodes, so that activation will not cause the conductivity of the path to change significantly. The Spark Gap Gas Arrester, on the other hand, contains easily ionizable Neon or a similar type of gas which when fired becomes a low impedance path until the next zero current crossing. The Carbon Block is normally set for a fixed breakdown voltage so that an over-voltage transient will cause breakdown of the air gap until the voltage drops below that fixed value. After the voltage transient subsides, the arc extinguishes and the power line is unaffected by the Carbon Block until another transient activates it. In most Carbon Blocks, the air gap can be manually set.

3. Suppressor Lead Inductive Effects on Fast Rise Time Transients - Inductive effects can be, and often are, a source of abnormally high peak clamping voltages nullifying the inherent capability of a transient voltage suppressor. These high clamping voltages can result in failure of vulnerable electronic parts. Therefore, transient voltage suppressors intended to provide adequate protection can be rendered ineffective due to inductive effects. To minimize the inductive effect, a zero inductance suppressor element can be used.

(a) Inductive Effects in Component Leads - The voltage developed across an inductor under a voltage step is expressed as:

$$V_{L(t)} = L \frac{di}{dt}$$

Where:

V_L = peak voltage in volts

L = inductance in henries

$\frac{di}{dt}$ = time rate of charge of current

The inductance contributed by the lead wires between the suppressor and the circuitry is usually overlooked when designing suppressors into a system. Although the inductance of such lead wires is quite low (about 1 μH/m), it has been shown that for fast rise time transients even a few centimeters of lead wire can drastically reduce the effectiveness of the suppressor by inducing a voltage overshoot across its leads. For example, assume 10 cm to be the total length of wire interconnecting the suppressor element to the circuit, and a voltage transient of 20 KV to be applied to the suppressor (see Figure H.8).

Then, the voltage at point A due to the inductance of the wires will be:

$$V_A = (10 \times 10^{-2}\ \text{m}) \times (1 \times 10^{-6}\ \frac{\text{H}}{\text{m}}) \times (4 \times 10^{9}\ \frac{\text{A}}{\text{sec}})$$

where:

$$\frac{di}{dt} = 4 \times 10^{9}\ (\frac{\text{A}}{\text{sec}})\ \text{(from Ref. 10)}$$

Thus:

$$V_A = 400\ \text{volts}$$

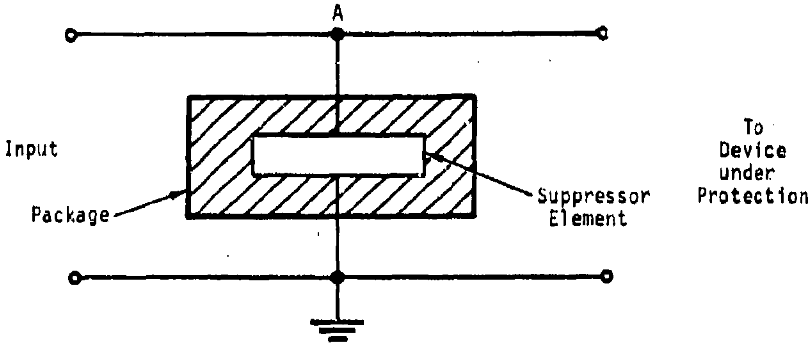

FIGURE H.8

TRANSIENT SUPPRESSORS WITH LEAD WIRE INDUCTANCE

Even if this voltage overshoot is not destructive for the circuit under protection, it could probably cause circuit upset. The effect of total lead length on peak clamping voltage is shown in Figure H.9 for an ICT-5 type Avalanche (TranZorb ®) suppressor. This device, which has been designed for protecting low voltage logic circuits, was pulsed at levels of 100A, 200A, 300A, 400A and 500A with a 1.2 x 50 μsec waveform. The voltage drop was measured across the 0.030 cm diameter straight wire leads at distances of zero, 1.0 cm and 2.0 cm from the body of the package. From Figure H.9 it is noted that the clamping voltages increase with both pulse current and with the lead length of the protective element (Avalanche suppressor). The increase in clamping voltage with pulse current results from the thermal effect on the semiconductor junctions. The increase in the clamping voltage with lead length results from the inductive effect as explained before.

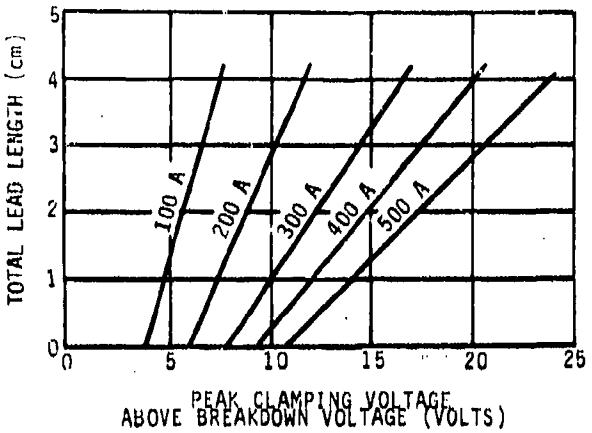

FIGURE H.9

EFFECTS OF LEAD LENGTH ON CLAMPING VOLTAGE[14]

For high rise time transients (such as electrostatic discharge transients, which have rise times in the order of 10 nanoseconds) lead lengths will present a real problem. Therefore, if the protector lead lengths could be reduced to virtually zero, more effective suppression would result.

(b) "Zero" Inductance Suppressor[15] - Reducing both internal and external lead lengths to virtually nothing would yield a "zero" inductance transient suppressor (Figure H.10).

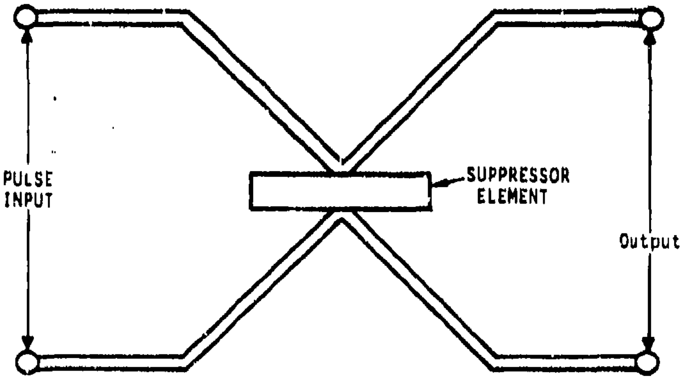

FIGURE H.10

"ZERO" INDUCTANCE TRANSIENT SUPPRESSOR

This suppressor has been designed using the same nanosecond clamping element as in the conventional avalanche transient suppressor, except it is provided with separate input and output terminals. This four terminal device offers low clamping voltage, of less than 10 volts, but power dissipation and Put-Thru current limitations may pose a problem to designers desiring to use the device for the dual purpose of regulation and suppression.

The current in the circuit protected by the "zero" inductance suppressor is limited by the steady-state current ratings of the device since the terminals of the device become a current carrying part of the circuit. This current should not exceed a few amperes as this device is designed to be used at the circuit board level.

The power dissipation is limited to about one Watt for the conventional four pin DIP package. The device can be fabricated in TO-3 package for more dissipation, but space and weight will increase to more than an order of magnitude.

IV. SELECTION AND APPLICATIONS OF TRANSIENT SUPPRESSORS

The intent of adding suppression elements is to improve reliability of the equipment, but the opposite effect can occur if the suppressor is not properly chosen. For example, adding a suppressor having marginal capability can be worse than no suppressor at all. Selection of the proper transient suppressor is, for most applications, a five step process:

- o Determine the necessary steady-state voltage ratings.
- o Establish the transient energy absorbed by the suppressor.
- o Calculate the peak transient current through the suppressor.
- o Determine any power dissipation requirements.
- o Select a device to provide the required voltage limiting characteristics.

Quite often adequate transient protection may not be attainable with only one type of suppressor. For example, high energy transient sources may require the use of spark gaps followed by semiconductor protective devices. A spark gap can divert the high current surge, and a varistor, Zener diode or Avalanche diode can then rapidly clamp the residual voltage.

Research on power line transients has shown excursions as high as 6 kv on 120V ac residential power lines. It is interesting to note that lower voltage lightning induced transients are frequently more destructive to terminal equipment located at either end of the affected line than higher magnitude pulses induced by direct hits or extremely close strikes. It should also be noted that load and distribution systems offer widely varying impedances to transients with frequencies from a few kHz to well into the VHF region of the spectrum.

A. Applications of Silicon Avalanche Suppressors

Silicon Avalanche suppressors have been proven to be effective EMP suppressors. However, each situation must be evaluated on its own particular set of boundary conditions such as circuit operating voltage and frequency, circuit destruct threshold, maximum peak current anticipated, etc. Integrated circuit protection can be provided by placing an Avalanche suppressor across the power line. The suppressor having a low "on" resistance will reduce unwanted transients within tolerance limit of the line while maintaining the circuit voltage level for continuous equipment operation. In case of abnormal transients (beyond the maximum current or power ratings of the suppressor), the suppressor will usually fail "short" tripping the system's circuit breakers or fuse, but protecting the equipment circuitry.

Typical applications of Avalanche transient suppressors are as follows:

1. The use of transient suppressors on power lines prevents IC failures caused by transients, power supply reversals, or during switching of the power supply to on or off (see Figure H.11).

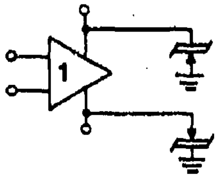

FIGURE H.11

2. The suppressor protects internal MOS FET devices from transients introduced on the power supply line (see Figure H.12).

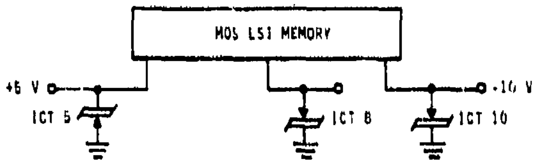

FIGURE H.12

3. A suppressor on the output of an operational amplifier will prevent a voltage transient, due to a short circuit or an inductive load, from being transmitted into the output stage (see Figure H.13). It will also reduce the effective capacity at the output.

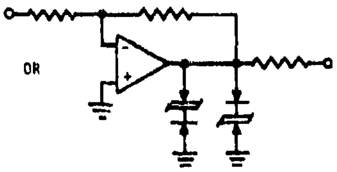

FIGURE H.13

4. Input stages of operational amplifiers are vulnerable to low energy, high voltage static discharges and EMP induced crosstalk transmitted on the signal wires. Limited protection is provided by the clamp diode or a diode input network within the IC substrate (see Figure H.14). The diode, however, must have a breakdown voltage greater than the supply voltage (V_{CC}). Note such diodes are limited in current capacity.

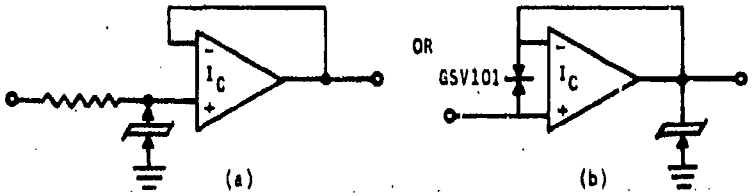

FIGURE H.14

5. Totem pole output circuits often generate current spikes requiring decoupling capacitors. While maintaining circuit continuity, the suppressor is capable of absorbing the energy pulse as well as eliminating noise spikes due to cross-talk, etc. A clamp diode in the IC substrate is limited in conduction current, <100 ma, providing a minimum protection (see Figure H.15).

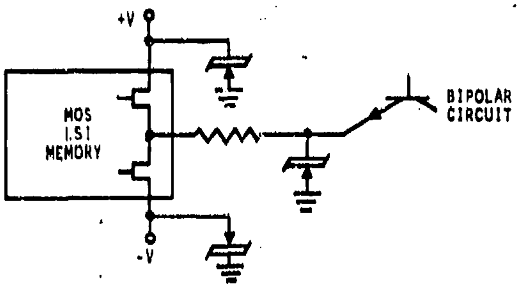

FIGURE H.15

6. Placing a silicon Avalanche diode across the output terminals of Schottky rectifiers provides protection for the Schottky devices from any load voltage transients and simultaneously provides effective protection from any secondary leakage inductance voltage "spikes" (see Figure H.16).

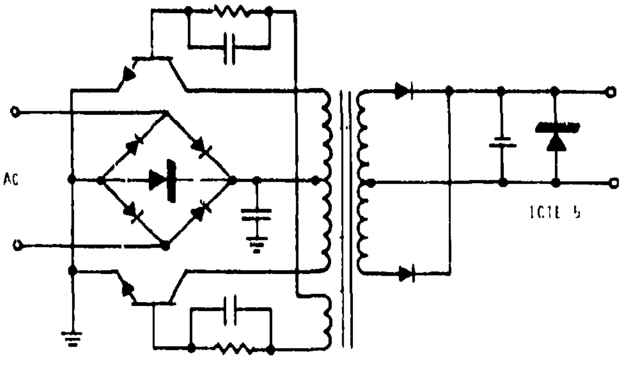

FIGURE H.16

B. Application of Metal Oxide Varistors (MOV)

MOVs offer a cost effective means of dealing with high, medium and low level transients. Most MOVs are electrically symmetrical, resembling back-to-back Zener diodes, and are thus useful elements in both ac and dc circuits. Unlike their silicon counterparts, MOVs are less effective in clamping highly repetitive spikes or pulses such as would occur in switching inverter circuits. This is due to a gradual deterioration in MOV characteristics that occurs each time a MOV conducts. As a consequence, pulse life derating curves identify the operating life of a MOV as a function of peak current, pulse width and mean number of pulses.

For example, assume a high power MOV is capable of suppressing 10^6 pulses, 20 ms wide at 50A peak. Operating at 10 kHz, the MOV can function for only 100 seconds. By that time the characteristics have deteriorated sufficiently so that rated protection specifications are no longer guaranteed.

However, when medium to high surge currents are expected on a dc power line on a random basis, and where maximum insulation resistance and minimum discharge voltage are not important, MOVs provide good protection together with small size, low cost and large energy handling capacity. MOVs are available with clamping voltages between 22 and 1,800 volts, peak surge capacities from 250 to 20,000 amperes and response times in the order of 50 ns. It is to be remembered that MOV ratings of energy, power dissipation capability, voltage and peak current are temperature dependent, so it is important to use derating curves when selecting MOVs.

Also, MOVs exhibit considerable shunt capacitance, ranging from low values of approximately 10 pf to a high of .02 μf. Most varistors are slightly inductive, so these parameters should be weighed carefully if the proposed application involves high frequency circuitry.

Table H-IV provides a general guide for comparison of various types of transient suppressors with ratings on their performance characteristics. The higher the rating number (e.g., 4), the better the device performance characteristics.

TABLE H-IV

Characteristics	Silicon Avalanche Suppressors	Zeners	MOVs	Spark Gap	R-C Filters
Voltage Capability	3	1	3	4	1
Peak Current Capability (non-repetitive)	2	1	2	4	3
Leakage Current	4	2	2	3	1*
Energy Absorption Capability (Repetitive)	4	2	2	2	3
Response Time	4	2	2	2	1
Operating Temperature	3	2	2	3	4
Life	3	2	1	3	4
Size	3	4	4	1	1
Cost	1	3	3	1	4

*Due to low network resistance.

NOTE: Ratings are based on a scale of one to four; the higher the number the better the rating.

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[9]DNA EMP Awareness Course Notes, Second Edition, IIT Research Institute, DNA Contract Number DASA01-69-0095, p. 1, August 1973.

[10]Tucker, T. J., "Spark Initiation Requirements of a Secondary Explosive," Annals of the New York Academy of Sciences, Volume 152, Article 1, pp. 643-653, 1968.

[11]Speakman, Thomas S., "A Model of Failure of Bipolar Silicon Integrated Circuits Subjected to Electrostatic Discharge", IEEE Proceedings, 12th Annual Reliability Physics, 1974.

[12]Ricketts, L. W., J. E. Bridges and J. Miletta, EMP Radiation and Protective Techniques, John Wiley & Sons, p. 203, 1976.

[13]Walsh, G. W., "A Review of Lightning Protection and Grounding Practices", IEEE Transactions on Industry, App., Volume IA-9, Number 2, March/April 1973.

[14]Clark, O. Melville, "Effects of Lead Wire Lengths on Protector Clamping Voltage", Report Number FAA-RD-79-6, U.S. Department of Transportation, FAA, Washington, DC 20590.

[15]Clark, O. Melville, "ESD Protection Using Silicon Transient Suppressors", General Semiconductor Industries, Inc.

APPENDIX I

APPLICABLE DOCUMENTS

The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this document. The cited documents shall not take precedence over this document, but should be consulted for supplemental information pertaining to the application of electronic and electromechanical parts.

SPECIFICATIONS

MILITARY

MIL-C-5	Capacitor, Fixed, Mica Dielectric, General Specification for
MIL-R-19	Resistor, Variable, Wirewound (Low-Operating Temperature), General Specification for
MIL-C-20	Capacitor, Fixed Ceramic Dielectric (Temperature Compensating), Established and Non-Established Reliability, General Specification for
MIL-R-22	Resistor, Variable (Wirewound Power Type), (Unenclosed), General Specification for
MIL-R-26	Resistor, Fixed, Wirewound (Power Type), General Specification for
MIL-T-27	Transformer and Inductor (Audio, Power and High-Power Pulse), General Specification for
MIL-C-62	Capacitors, Fixed, Electrolytic (DC, Aluminum, Dry Electrolyte, Polarized), General Specification for
MIL-C-81	Capacitor, Variable, Ceramic Dielectric, General Specification for
MIL-R-94	Resistor, Variable, Composition, General Specification for
MIL-C-3098	Crystal Units, Quartz, General Specification for
MIL-C-3432	Cable and Wire, Electrical (Power and Control; Flexible and Extraflexible, 300 and 600 Volts)
MIL-S-3786	Switch, Rotary (Circuit Selector, Low-Current Capacity), General Specification for
MIL-S-3950	Switch, Toggle, Environmentally Sealed, General Specification for

MIL-C-5015	Connector, Electrical, Circular Threaded, AN Type, General Specification for
MIL-B-5423	Boot, Dust and Water Seal, General Specification for
MIL-R-5757	Relay, Electrical (for Electronic and Communication Type Equipment), General Specification for
MIL-R-6106	Relay, Electromagnetic (including Established Reliability (AN) Types), General Specification for
MIL-S-6807	Switch, Rotary, Selector, Power, General Specification for
MIL-G-7703	Guard, Switch, General Specification for
MIL-S-8805	Switches and Switch Assemblies, Sensitive and Push (Snap Action), General Specification for
MIL-S-8834	Switch, Toggle, Positive Break, General Specification for
MIL-S-9395	Switches, Pressure (Absolute Gage and Differential), General Specification for
MIL-H-10056	Holder (Enclosures), Crystal, General Specification for
MIL-R-10509	Resistor, Fixed, Film (High Stability), General Specification for
MIL-C-10950	Capacitor, Fixed, Mica Dielectric, Button Style, General Specification for
MIL-C-11015	Capacitor, Fixed, Ceramic Dielectric (General Purpose), General Specification for
MIL-R-12934	Resistor, Variable, Wirewound (Piston Type, Tubular Trimmer), General Specification for
MIL-C-14409	Capacitor, Variable (Piston Type, Tubular Trimmer), General Specification for
MIL-S-15291	Switch, Rotary, Snap Action, General Specification for
MIL-C-15305	Coil, Fixed and Variable, Radio Frequency, General Specification for
MIL-F-15733	Filter, Radio Interference, General Specification for

MIL-F-18327	Filter, High Pass, Low Pass, Band Pass, Band Suppression and Dual Functioning, General Specification for
MIL-R-18546	Resistor, Fixed, Wirewound (Power Type, Chassis Mounted), General Specification for
MIL-S-19500	Semiconductor Device, General Specification for
MIL-C-19978	Capacitor, Fixed, Plastic (or Paper Plastic), Dielectric (Hermetically Sealed in Metal, Ceramic or Glass Cases), Established Reliability, General Specification for
MIL-T-21038	Transformer, Pulse, Low Power, General Specification for
MIL-C-21097	Connector, Electrical, Printed Wiring Board, General Purpose, General Specification for
MIL-R-22097	Resistor, Variable, Nonwirewound (Adjustment Type), General Specification for
MIL-S-22710	Switch, Rotary (Printed Circuit), (Thumbwheel, Inline and Push Button), General Specification for
MIL-S-22885	Switch, Push Button, Illuminated, General Specification for
MIL-C-22992	Connector, Plugs and Receptacles, Electrical, Water-Proof, Quick Disconnect, Heavy Duty Type, General Specification for
MIL-C-23183	Capacitor, Fixed or Variable, Vacuum Dielectric, General Specification for
MIL-C-23269	Capacitors, Fixed, Glass Dielectric, Established Reliability, General Specification for
MIL-R-23285	Resistor, Variable, Nonwirewound, General Specification for
MIL-S-24236	Switch, Thermostatic (Metallic and Bimetallic), General Specification for
MIL-C-24308	Connector, Electric, Rectangular, Miniature, Polarized Shell, Rack and Panel, General Specification for
MIL-S-24317	Switch, Multistation, Push Button (Illuminated and Nonilluminated), General Specification for
MIL-R-27208	Resistor, Variable, Wirewound (Adjustment Type), General Specification for

MIL-C-28731	Connector, Electrical, Rectangular, Removable Contact, Formed Blade, Fork Type (For Rack and Panel and Other Applications), General Specification for
MIL-C-28748	Connector, Electrical, Rectangular, Rack and Panel, Solder Type and Crimp Type Contacts, General Specification for
MIL-R-28750	Relay, Solid State, General Specification for
MIL-R-28776	Relays, Hybrid, Established Reliability, General Specification for
MIL-M-28787	Modules Standard Electronic
MIL-S-28788	Switches, Air and Liquid Flow Sensing, General Specification for
MIL-C-28804	Connector, Electric, Rectangular, High Density, Polarized Center, Jackscrew, General Specification for
MIL-S-28827	Switch, Thermostatic (Volatile Liquid), Hermetically Sealed, General Specification for
MIL-M-38510	Microcircuits, General Specification for
MIL-C-38999	Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect, Bayonet, Threaded and Breech Coupling, Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for
MIL-C-39001	Capacitor, Fixed, Mica Dielectric, Established Reliability, General Specification for
MIL-R-39002	Resistor, Variable, Wirewound, Semiprecision, General Specification for
MIL-C-39003	Capacitor, Fixed, Electrolytic (Solid Electrolyte), Tantalum, Established Reliability, General Specification for
MIL-R-39005	Resistor, Fixed, Wirewound (Accurate), Established Reliability, General Specification for
MIL-C-39006	Capacitor, Fixed, Electrolytic (Non-Solid Electrolyte) Tantalum, Established Reliability, General Specification for
MIL-R-39007	Resistor, Fixed, Wirewound (Power Type), Established Reliability, General Specification for

MIL-R-39008	Resistor, Fixed, Composition (Insulated), Established Reliability, General Specification for
MIL-R-39009	Resistor, Fixed, Wirewound (Power Type, Chassis Mounted), Established Reliability, General Specification for
MIL-C-39010	Coil, Fixed, Radio Frequency, Molded, Established Reliability, General Specification for
MIL-C-39012	Connector, Coaxial, Radio Frequency, General Specification for
MIL-C-39014	Capacitor, Fixed, Ceramic Dielectric (General Purpose), Established Reliability, General Specification for
MIL-R-39015	Resistor, Variable, Wirewound (Lead Screw-Actuated), Established Reliability, General Specification for
MIL-R-39016	Relay, Electromagnetic, Established Reliability, General Specification for
MIL-R-39017	Resistor, Fixed, Film (Insulated), Established Reliability, General Specification for
MIL-C-39018	Capacitor, Fixed, Electrolytic (Aluminum Oxide), Established Reliability and Non-Established Reliability, General Specification for
MIL-C-39022	Capacitor, Fixed, Metallized, Paper or Paper-Plastic, Film or Plastic Film Dielectric, DC and AC (Hermetically Sealed in Metal Cases), Established Reliability, General Specification for
MIL-R-39023	Resistor, Variable, Nonwirewound, Precision, General Specification for
MIL-C-39024	Connector, Electrical, Jacks, Tip (Test Point, Panel or Printed Wiring Type), General Specification for
MIL-C-39029	Contact, Electrical Connector, General Specification for
MIL-R-39035	Resistor, Variable, Nonwirewound (Adjustment Type), Established Reliability, General Specification for
MIL-C-55181	Connector, Plug and Receptacle, Intermediate (Electrical), (Water-Proof), General Specification for

MIL-R-55182	Resistor, Fixed, Film, Established Reliability, General Specification for
MIL-C-55302	Connector, Printed Circuit Subassembly and Accessories, General Specification for
MIL-R-55342	Resistor, Fixed, Film, Chip, Established Reliability, General Specification for
MIL-C-55365	Capacitor, Chip, Fixed, Tantalum, Established Reliability, General Specification for
MIL-S-55433	Switch, Capsules, Dry Reed Type, General Specification for
MIL-C-81659	Connector, Electrical, Rectangular, Crimp Contacts, General Specification for
MIL-C-83421	Capacitors, Fixed, Supermetallized, Plastic Film Dielectric, (DC, AC or DC and AC), Hermetically Sealed in Metal Cases, Established Reliability
MIL-C-83446	Coils, Radio Frequency, Fixed or Variable
MIL-R-83401	Resistor Networks, Fixed, Film, General Specification for
MIL-C-83502	Socket, Plug-In Electronic Components, Round Style, General Specification for
MIL-C-83505	Socket (Lead, Electronic Components), General Specification for
MIL-R-83726	Relay, Time Delay, Hybrid and Solid State, General Specification for
MIL-R-83733	Connector, Electrical, Miniature, Rectangular Type, Rack to Panel, Environmental Resisting, 200°C Total Continuous Operating Temperature, General Specification for
MIL-S-83734	Socket, Plug-In, Electronic Components, General Specification for

FEDERAL

WC-596	Connector, Plug, Receptacle and Cable Outlet, Electrical Power, General Specification for

STANDARDS

MILITARY

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-198	Capacitors, Selection and Use of
MIL-STD-199	Resistors, Selection and Use of
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-242 (NAVY)	Electronic Equipment Parts, Selected Standards
MIL-STD-255	Electric Voltages Alternating and Direct Current
MIL-STD-454	Standard General Requirements of Electronic Equipment
MIL-STD-683	Crystal Units (Quartz) and Crystal Holders (Enclosures), Selection of
MIL-STD-690	Failure Rate Sampling Plans and Procedures
MIL-STD-701	List of Standard Semiconductor Devices
MIL-STD-721	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety
MIL-STD-750	Test Methods for Semiconductor Devices
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production
MIL-STD-790	Reliability Assurance Program for Electronic Parts Specifications
MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-STD-965	Parts Control Program
MIL-STD-1132	Switches and Associated Hardware, Selection and Use of
MIL-STD-1286	Transformers, Inductors, and Coils, Selection and Use of
MIL-STD-1346	Relays, Selection and Application
MIL-STD-1353	Electrical Connectors, Plug-In Sockets and Associated Hardware, Selection and Use of

MIL-STD-1378	Requirements for Employing Standard Electronic Modules
MIL-STD-1389	Design Requirements for Standard Hardware Program Electronic Modules
MIL-STD-1395	Filters and Networks, Selection and Use of
DOD-STD-1399	Interface Standard for Shipboard Systems
MIL-STD-1531	Insert Arrangements for MIL-C-83733 Rack to Panel Connectors, Shell Size A
MIL-STD-1532	Insert Arrangements for MIL-C-83733 Rack to Panel Connectors, Shell Size B
MIL-STD-1554	Insert Arrangements for MIL-C-38723 Series 3 and MIL-C-26500 Environment Resisting, Circular, Electrical Connectors
MIL-STD-1560	Insert Arrangements for MIL-C-38999 and MIL-C-27599 Electrical, Circular Connectors
MIL-STD-1562	Lists of Standard Microcircuits
MIL-STD-1632	Insert Arrangements for MIL-C-28804, High Density, Rectangular, Electrical Connectors
MIL-STD-1634	Module Descriptions for the Standard Electronic Modules Program
MIL-STD-1651	Insert Arrangements for MIL-C-5015, MIL-C-22992 (Classes C, J and R) and MIL-C83723 (Series II) Electrical Connectors
MIL-STD-1665	Test Equipment for the Standard Electronic Modules Program
DOD-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)

HANDBOOKS

MILITARY

MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-239	Navy Standard Hardware Program Application Handbook
MIL-HDBK-246	Program Managers Guide for the Standard Electronic Modules Program

DOD-HDBK-263 Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)