Design for Electrical and Computer Engineers

Theory, Concepts, and Practice

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Part I - The Engineering Design Process

Appendix A

Component Failure Rate Data

This appendix contains failure rate data for selected electronic components in support of Chapter 8. The information was abstracted from the Military Handbook for Reliability Prediction [MIL-HDBK-217F] and contains information for devices that are relevant to this book. The information is a close facsimile to MIL-HDBK-217F, but in some instances comments are added to help interpret the information. Furthermore, MIL-HDBK-217F tends to present both empirical estimation formulas and tabular data computed from the formulas. The tabular data is generally not included here for simplicity of presentation, and is readily obtained from the formulas supplied. Data is presented for the following devices:

- Analog components: resistors and capacitors.
- Discrete semiconductors: diodes, bipolar transistors, and field effect transistors.
- Microcircuits: gate/logic arrays and microprocessors.

A.1 Environmental Use

All of the devices presented in this appendix have an environmental factor that is used to estimate the failure rate. The environmental factors are based on the 14 categories in Table A.1.

Table A.1: Environmental symbols and descriptions taken directly from MIL-HDBK-217F.

Environment	Description
G_B – Ground, Benign	Nonmobile, temperature and humidity controlled environments readily accessible to maintenance; includes laboratory instruments and test equipment, medical electronic equipment, business and scientific computer complexes, and missile and support equipment in ground silos.
G_F – Ground, Fixed	Moderately controlled environments such as installation in permanent racks with adequate cooling air and possible installation in unheated buildings; includes permanent installation of air traffic control radar and communication facilities.

Table A.1 – continued from previous page	
Environment	**Description**
G_M – Ground, Mobile	Equipment installed in wheeled or tracked vehicles and equipment manually transported; includes tactical missile ground support equipment, mobile communication equipment, tactical fire direction systems, handheld communications equipment, laser designations and range finders.
N_S– Naval, Sheltered	Includes sheltered or below deck conditions on surface ships and equipment installed in submarines.
N_U – Naval, Unsheltered	Unprotected surface shipborne equipment exposed to weather conditions and equipment immersed in salt water. Includes sonar equipment and equipment installed on hydrofoil vessels.
A_{IC}– Airborne, Inhabited Cargo	Typical conditions in cargo compartments that can be occupied by an aircrew. Environment extremes of pressure, temperature, shock, and vibration are minimal. Examples include long mission aircraft such as the C130, C5, B52, and C141. This category also applies to inhabited areas in lower performance smaller aircraft such as the T38.
A_{IF} – Airborne, Inhabited Fighter	Same as A_{IC} but installed on high performance aircraft such as fighters and interceptors. Examples include the F15, F16, F111, F/A 18 and A10 aircraft.
A_{UC} - Airborne, Uninhabited Cargo	Environmentally uncontrolled areas that cannot be inhabited by crew during flight. Environmental extremes of pressure, temperature, and shock may be severe. Examples include uninhabited areas of long aircraft such as the C130, C5, B52, and C141. This category also applies to uninhabited areas in lower performance smaller aircraft such as the T38.
A_{UF} - Airborne, Uninhabited Fighter	Same as A_{UC}but installed on high performance aircraft such as fighters and interceptors. Examples include the F15, F16, F111, and A10 aircraft.
A_{RW}– Airborne, Rotary Winged	Equipment installed on helicopters. Applies to both internally and externally mounted equipment such as laser designators, fire control systems, and communications equipment.
S_F – Space, Flight	Earth orbital. Approaches benign ground conditions. Vehicle neither under powered flight nor in atmospheric re-entry; includes satellites and shuttles.
M_F – Missile, Flight	Conditions related to powered flight of air breathing missiles, cruise missiles, and missiles in unpowered free flight.
M_L – Missile, Launch	Severe conditions related to missile launch (air, ground, and sea), space vehicle boost into orbit, and vehicle re-entry and landing by parachute. Also applies to solid rocket motor propulsion powered flight, and torpedo and missile launch from submarines.
C_L – Cannon, Launch	Extremely severe conditions related to cannon launching of 155 mm and 5 inch guided projectiles. Conditions apply to the projectile from launch to target impact.

A.2 Analog Components: Resistors and Capacitors

This section contains failure rate data for resistors and capacitors.

Resistors: Fixed Composition, Fixed Film, and Wirewound

The failure rate is given by the following relationship

$$\lambda = \lambda_b \pi_R \pi_Q \pi_E \frac{\text{failures}}{10^6\text{hours}}$$

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Table A.2: λ_b **- Base Failure Rate**

Resistor Type	λ_b (T = ambient temperatire in ° C, S = $\frac{\text{operating power}}{\text{device power rating}}$)
Fixed Composition	$\lambda_b = 4.5 * 10^{-9} exp[12(\frac{T+273}{343})] exp[\frac{S}{0.6}(\frac{T+273}{273})]$
Fixed Film	$\lambda_b = 3.25 * 10^{-4} exp[12(\frac{T+273}{343})^3] exp[S(\frac{T+273}{273})]$
Wirewound	$\lambda_b = 0.0031 exp[12(\frac{T+273}{343})^{10}] exp\{[S(\frac{T+273}{273})]^{1.5}\}$

Table A.3: **Resistance Factor -** π_R

Fixed Composition or Fixed Film Resistors		**Wirewound Resistors**	
Resistance Range	π_R	**Resistance Range**	π_R
$\leq 100k\Omega$	1.0	$\leq 10k\Omega$	1.0
$100k\Omega$ to $\leq 1M\Omega$	1.1	$10k\Omega$ to $\leq 100k\Omega$	1.7
$1M\Omega$ to $\leq 10M\Omega$	1.6	$100k\Omega$ to $\leq 1M\Omega$	3.0
$> 10M\Omega$	2.5	$> 1M\Omega$	5.0

Table A.4: **Quality Factor -** π_Q

Quality	π_Q
S	0.03
R	0.1
P	0.3
M	1.0
MIL-R	5.0
Lower	15

Table A.5: **Environmental factor -** π_E

Environment	π_E **Fixed Composition**	π_E **Fixed Film**	π_E **Wirewound**
G_B	1	1	1
G_F	3	2	2
G_M	8	8	11
N_S	5	4	5
N_U	13	14	18
A_{IC}	4	4	15
A_{IF}	5	8	18
A_{UC}	7	10	28
A_{UF}	11	18	35
A_{RW}	19	19	27
S_F	0.50	0.20	0.80
M_F	11	10	14
M_L	27	28	38
C_L	490	510	610

Capacitors: Fixed, Ceramic, and General Purpose

The failure rate is given by the following relationship

$$\lambda = \lambda b \pi_{CV} \pi_Q \pi_E \frac{\text{failures}}{10^6 \text{hours}}$$

For all factors T = ambient temperature (°C) and $S = \frac{\text{operating voltage}}{\text{rated voltage}}$, where the operating voltage is the sum of the DC and peak AC voltage.

Table A.6: **Base Failure Rate -** λ_b

$\lambda_b = 0.0003[(\frac{S}{0.3}^3) + 1]exp[\frac{T+273}{358}]$ for T=85°C max rated
$\lambda_b = 0.0003[(\frac{S}{0.3}^3) + 1]exp[\frac{T+273}{398}]$ for T=125°C max rated
$\lambda_b = 0.0003[(\frac{S}{0.3}^3) + 1]exp[\frac{T+273}{423}]$ for T=150°C max rated

Table A.7: **Capacitance Factor -** π_{CV}

$\pi_{CV} = 0.41 * C^{0.01}$
C = capacitance

Table A.8: **Quality Factor -** π_Q

Quality	π_Q
S	0.030
R	0.10
P	0.30
M	1.0
L	3.0
MIL	3.0
Lower	10

Table A.9: **Environmental Factor -** π_E

Environment	π_E
G_B	1
G_F	2
G_M	9
N_S	5
N_U	15
A_{IC}	4
A_{IF}	4
A_{UC}	8
A_{UF}	12
A_{RW}	20
S_F	0.40
M_F	13
M_L	34
C_L	610

A.3 Microelectronic Devices

For all microelectronic devices it is necessary to compute the junction temperature (T_j) of the silicon in order to determine the temperature factor. The junction temperature is determined as follows:

$T_j = T_A + \theta_{jA} P_D$

T_A = ambient temperature

θ_{jA} = junction to ambient thermal resistance (obtained from manufacture data sheet.)

P_D =power dissipated inm the device

Author's Note: The equations above are slightly different than those found in MIL-HDBK-217F. The junction to ambient thermal resistance is used here, instead of junction to case as in the original. In addition, the ambient temperature is used in place of the case temperature. This is more general and is consistent with the presentation in Chapter **??**. The junction to case resistance could be used, along with the case temperature. See Section **??** for more detailed coverage of this thermal model.

The part quality descriptors in Table A.10 are used to find the quality factors.

Table A.10: Part quality descriptors for microelectronic devices.

JANTXV	Full device testing as specified by the MIL-S-19500 specification, including Screening and Groups A, B, and C.
JANTX	Identical to JANTXV, except does not include the 100% precap visual inspection contained in Screening.
JAN	Testing as defined by MIL-S-19500, including Groups A, B, and C, but not including Screening.
Lower	All hermetically packaged devices.
Plastic	All devices encapsulated with organic materials.

Diodes: Low Frequency

The failure rate is given by the following relationship

$$\lambda = \lambda_b \pi_R \pi_Q \pi_E \frac{\text{failures}}{10^6 \text{hours}}$$

Table A.11: **Base Failure Rate -** λ_b

Diode Type/Application	λ_b
General purpose analog	0.0038
Switching	0.0010
Power rectifier, fast recovery	0.069
Power rectifier, Schottky power diode	0.0030
Power rectifier with high voltage stacks	0.0050/junction
Transient suppressor/varistor	0.0013
Current regulator	0.0034
Voltage regulator and voltage reference (avalanche and zener)	0.0020

Temperature Factor - π_T

For general purpose analog, switching, fast recovery, power rectifier, and transient suppressor applications

$$\pi_T = exp[-3091(\frac{1}{T_j + 273} - \frac{1}{298})].$$

For voltage regulator, voltage reference, and current regulator applications

$$\pi_T = exp[-1925(\frac{1}{T_j + 273} - \frac{1}{298})].$$

Table A.12: **Electrical Stress Factor -** π_S

$\pi_s = 0.054$	$V_S \leq 0.3$
$\pi_s = V_S^{2.43}$	$0.3 < V_S \leq 1$

$V_S =$ voltage stress ratio $= \frac{\text{applied voltage}}{\text{applied voltage}}$

Applied voltage is the diode reverse voltage

Table A.13: **Quality Factor -** π_Q

Quality	π_Q
JANTXV	0.7
JANTX	1.0
JAN	2.4
Lower	5.5
Plastic	8.0

Table A.14: **Contact Construction Factor -** π_C

Contact Construction	π_C
Metallurgically bonded	1.0
Non-metallurgically bonded and spring loaded contacts	2.0

Table A.15: **Environmental Factor -** π_E

Environment	π_E
G_B	1
G_F	6
G_M	9
N_S	9
N_U	19
A_{IC}	13
A_{IF}	29
A_{UC}	20
A_{UF}	43
A_{RW}	24
S_F	0.50
M_F	14
M_L	32
C_L	320

Diodes: High Frequency (microwave, RF)

The failure rate is given by the following relationship

$$\lambda = \lambda_b \pi_T \pi_A \pi_R \pi_Q \pi_E \frac{\text{failures}}{10^6 \text{hours}}$$

Table A.16: **Base Failure Rate -** λ_b

Diode Type	λ_b
Si IMPATT $\leq$ 35GHz)	0.22
Gunn/Bulk Effect	0.18
Tunnel and Back	0.0023
PIN	0.0081
Schottky Barrier	0.027
Varactor and Step Recovery	0.0025

Table A.17: **Application Factor -** π_A

Application	π_A
Varactor, voltage control	0.50
Varactor, multiplier	2.5
All other diodes	1.0

Table A.18: **Quality Factor -** π_Q

Quality	**Not Shottky**	**Shottky**
JANTXV	0.5	0.5
JANTX	1.0	1.0
JAN	5.0	1.8
Lower	25.0	2.5
Plastic	50.0	-

Table A.19: **Temperature Factor -** π_T

All types except IMPATT
$\pi_T = exp[-2100(\frac{1}{T_J+273} - \frac{1}{298})]$

and for IMPATT
$\pi_T = exp[-5260(\frac{1}{T_J+273} - \frac{1}{298})]$

Table A.20: **Power Rating Factor -** π_R

$\pi_R = 0.326 ln(P_R) - 0.25$ for PIN diodes
$\pi_R = 1.0$ for all other diodes

Table A.21: **Environmental Factor -** π_R

Environmental Factor -	π_E
G_B	1
G_F	2
G_M	5
N_S	4
N_U	11
A_{IC}	4
A_{IF}	5
A_{UC}	7
A_{UF}	12
A_{RW}	16
S_F	0.5
M_F	9
M_L	24
C_L	250

Transistors: Bipolar Junction, Low Frequency (≤ 200MHz)

The failure rate is given by the following relationship

$$\lambda = \lambda_b \pi_T \pi_A \pi_R \pi_S \pi_Q \pi_E \frac{\text{failures}}{10^6 \text{hours}}$$

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Table A.22: **Base Failure Rate -** λ_b

Type	λ_b
NPN or PNP	0.00074

Table A.23: **Temperature Factor -** π_T

$\pi_T = exp[-2114(\frac{1}{T_j+273} - \frac{1}{298})]$

Table A.24: **Application Factor -** π_A

Application	π_A
Linear Amplification	1.50
Switching	0.70

Table A.25: **Power Rating Factor -** π_R

$\pi_R = 0.043$	if $P_R \leq 0.1$W
$\pi_R = P_R^{0.37}$	if $P_R > 0.1$W
where P_R = rated power	

Table A.26: **Voltage Stress Factor -** π_S

$\pi_S = 0.045exp(3.1V_S)$	$0 \leq V_S \leq 1$
$V_S = \frac{\text{applied}V_{CE}}{\text{rated}V_{CEO}}$	
V_{CE} = voltage collector to emitter	
V_{CEO} = voltage collector to emitter, base open	

Table A.27: **Part Quality Factor -** π_R

Quality	π_Q
JANTXV	0.7
JANTX	1.0
JAN	2.4
Lower	5.5
Plastic	8.0

Transistors: Bipolar Junction, High Frequency ($>$ 200MHz), Low Noise (Power $\leq$ 1W

The failure rate is given by the following relationship

$$\lambda = \lambda_b \pi_T \pi_R \pi_S \pi_Q \pi_E \frac{\text{failures}}{10^6\text{hours}}$$

Table A.28: **Environmental Factor -** π_E

Environment	π_E
G_B	1
G_F	6
G_M	9
N_S	9
N_U	19
A_{IC}	13
A_{IF}	29
A_{UC}	20
A_{UF}	43
A_{RW}	24
S_F	0.50
M_F	14
M_L	32
C_L	320

Table A.29: **Base Failure Rate -** λ_b

Type	λ_b
All types	0.18

Table A.30: **Power Rating Factor -** π_R

$\pi_R = 0.43$ if $P_R \leq 0.1W$
$\pi_R = P_R^{0.37}$ if $P_R \leq 0.1W$
where P_R = rated power

Transistors: Field Effect, Low Frequency (≤ 400Hz)

The failure rate is given by the following relationship

$$\lambda = \lambda_b \pi_T \pi_A \pi_Q \pi_E \frac{\text{failures}}{10^6 \text{hours}}$$

Table A.31: **Part Quality Factor -** π_Q

Quality	π_Q
JANTXV	0.5
JANTX	1.0
JAN	2.0
Lower	5.0

Table A.32: **Temperature Factor -** π_T

$\pi_T = exp[-2114(\frac{1}{T_j+273} - \frac{1}{298})]$

Table A.33: **Voltage Stress Factor -** π_S

$\pi_S = 0.045exp(3/1V_S)$ $0 \leq V_S \leq 1$
$V_S = \frac{\text{applied}V_{CE}}{\text{rated}V_{CEO}}$
V_{CE} = voltage collector to emitter
V_{CEO} = voltage collector to emitter, base open

Transistors: Field Effect, High Frequency ($>$ 400MHz), Low Power ($\leq$ 300mW)

$$\lambda = \lambda_b \pi_T \pi_Q \pi_E \frac{\text{failures}}{10^6\text{hours}}$$

Table A.34: **Environmental Factor -** π_E

Environment	π_E
G_B	1
G_F	2
G_M	5
N_S	4
N_U	11
A_{IC}	4
A_{IF}	5
A_{UC}	7
A_{UF}	12
A_{RW}	16
S_F	0.50
M_F	9
M_L	24
C_L	250

Table A.35: **Base Failure Rate -** λ_b

Type	λ_b
MOSFET	0.012
JFET	0.0045

Table A.36: **Temperature Factor -** π_T

$\pi_T = exp[-1925(\frac{1}{T_j+273} - \frac{1}{298})]$

Microcircuits: Gate/Logic Arrays and Microprocessors

Includes the following devices:

1. Bipolar devices, Digital and Linear Gate/Logic Arrays
2. MOS Devices, Digital and Linear Gate/Logic Arrays
3. Field Programmable Logic Array (PLA) and Programmable Array Logic (PAL)
4. Microprocessors

The failure rate is given by the following relationship

$$\lambda = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L \frac{\text{failures}}{10^6\text{hours}}$$

Table A.37: **Application Factor -** pi_A

Application (P_R = rated output power)	π_A
Linear Amplification ($P_R < 2$W)	1.50
Small Signal Switching	0.70
Power FETs (Non-linear, $P_R < 2$W)	
$2 \leq P_R < 5$W	2.0
$5 \leq P_R < 50$W	4.0
$50 \leq P_R < 250$W	8.0
$P_R < 250$W	10.0

Table A.38: **Part Quality Factor -** π_Q

Quality	π_Q
JANTXV	0.7
JANTX	1.0
JAN	2.4
Lower	5.5
Plastic	8.0

Table A.39: **Environmental Factor -** π_E

Environment	π_E
G_B	1
G_F	6
G_M	9
N_S	9
N_U	19
A_{IC}	13
A_{IF}	29
A_{UC}	20
A_{UF}	43
A_{RW}	24
S_F	0.50
M_F	14
M_L	32
C_L	320

Table A.40: **Base Failure Rate -** λ_b

Type	λ_b
MOSFET	0.060
JFET	0.023

Table A.41: **Temperature Factor -** π_T

$\pi_T = exp[-1925(\frac{1}{T_j+273} - \frac{1}{298})]$

Table A.42: **Part Quality Factor -** pi_Q

Quality	π_Q
JANTXV	0.5
JANTX	1.0
JAN	2.0
Lower	5.0

Table A.43: **Environmental Factor -** π_E

Environment	π_E
G_B	1
G_F	2
G_M	5
N_S	4
N_U	11
A_{IC}	4
A_{IF}	5
A_{UC}	7
A_{UF}	12
A_{RW}	16
S_F	0.50
M_F	9
M_L	24
C_L	250

Table A.44: C_1 = **Complexity Failure Rate for Bipolar Devices (Digital and Linear Gate/Logic)**

Digital		**Linear**		**PLA/PAL**	
No. Gates	C_1	No. Transistors	C_1	No. Gates	C_1
1 to 100	0.0025	1 to 100	0.010	Up to 200	0.010
101 to 1,000	0.0050	101 to 300	0.020	201 to 1,000	0.021
1,001 to 3,000	0.010	301 to 1,000	0.040	1,001 to 5,000	0.042
3,001 to 10,000	0.020	1,001 to 10,000	0.060		
10,001 to 30,000	0.040				
30,001 to 60,000	0.080				

Table A.45: C_1 = **Complexity Failure Rate for MOS Devices (Digital and Linear Gate/Logic)**

Digital		**Linear**		**PLA/PAL**	
No. Gates	C_1	No. Transistors	C_1	No. Gates	C_1
1 to 100	0.010	1 to 100	0.010	Up to 500	0.00085
101 to 1,000	0.020	101 to 300	0.020	501 to 1,000	0.0017
1,001 to 3,000	0.040	301 to 100	0.040	1,001 to 5,000	0.0034
3,001 to 10,000	0.080	1,001 to 10,000	0.060	5,000 to 20,000	0.0068
10,001 to 30,000	0.16				
30,001 to 60,000	0.29				

Table A.46: C_1 = **Complexity Failure Rate for Microprocessors**

Number of Bits	**C_1 - Bipolar**	**C_1 - MOS**
Up to 8	0.060	0.14
Up to 16	0.12	0.28
Up to 32	0.24	0.56

Table A.47: C_2 = **Package Failure Rate for all microcircuits.**
N_p = **number of pins on package.**

$C_2 = 2.8x10^{-4}(N_p)^{1.08}$, Hermetic: DIPs with solder or weld seal, SMT
$C_2 = 9.0x10^{-5}(N_p)^{1.51}$, DIPs with glass seal
$C_2 = 3.0x10^{-5}(N_p)^{1.82}$, Flatpacks with axial leads on 50 mil centers
$C_2 = 2.8x10^{-4}(N_p)^{2.01}$, Cans
$C_2 = 3.0x10^{-5}(N_p)^{1.08}$,Nonhermetic: DIPs PGA, SMT (leaded and nonleaded)

Table A.48: **Temperature Factor -** π_T

$$\pi_T = 0.1exp[-\frac{E_a}{8.617x10^{-5}}(\frac{1}{T_j+273} - \frac{1}{298})]$$

Table A.49: The activation energy (E_a) for different technologies are given in the table below.

Technology	E_a
TTL, ASTLL, CML, HTTL, FTLL, DTL, ECL, ALSTTL	0.4
F, LTTL, STTL	0.45
BiCMOS LSTTL	0.5
Digital MOS, VHSIC CMOS	0.35
Linear (Bipolar and MOS)	0.65
Memories (Bipolar and MOS), NMOS 0.6	

Table A.50: **Learning Factor -** π_L

Years in Production	π_L
≤ 0.1	2.0
0.5	1.8
1.0	1.5
1.5	1.2
≥ 2.0	1.0

Table A.51: **Part Quality Factor -** π_Q

Quality	π_Q
S	0.25
B	1.0
B-1	2.0

Table A.52: **Environmental Factor -** π_E

Environment	π_E
G_B	0.50
G_F	2
G_M	4
N_S	4
N_U	6
A_{IC}	4
A_{IF}	5
A_{UC}	5
A_{UF}	8
A_{RW}	8
S_F	0.50
M_F	5
M_L	12
C_L	220