NOTICE

This ATM 605A revision replaces the original ATM 605 dated 1/6/67.

This ATM now includes failure rate data on Unitrode and Isofilm diodes and TTL integrated circuits. Also, the integrated circuit failure rate is now a function of temperature. A lunar standby K factor has been added and minor changes have been made to all failure rate charts. Appendix A, Reliability Mathematics and Methods has also been added. Other format changes have been made and are described in the introduction.

1.0 INTRODUCTION

The failure rate data presented in this ATM are applicable to piece-parts used on Flight Model Array E and subsequent hardware. The failure rate information contained herein is a compilation of data from numerous specifications, manuals, and handbooks. Failure rates for a specific generic part type may be obtained from this publication by applying part application and environmental conditions to modify a base failure rate.

The purpose of this ATM is to standardize failure rates, reliability prediction methods, and reliability design comparisons. Appendix A illustrates reliability prediction methods.

The revisions and changes herein reflect a consolidation of major points of other ATM's plus further updating with current vendor and user data.

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2.0 ARRAY E ENVIRONMENT AND K-FACTORS

Ref: ATM 274, ALSEP Reliability Mathematical Model and Prediction, Appendix C - "F" Factor Determination.

2.1 Assume for the Central Station, a thermally controlled environment for the electronic equipment of -20°C to +60°C.

2.2 Failure rate levels as obtained from this ATM are to be established on the basis of the part application and environment. The expected thermal profile for Array E Central Station is shown by the solid curve in Figure 2-1. For the purpose of establishing failure rates this solid curve is approximated by the dashed line in Figure 2-1.

The temperatures listed in Figure 2-1 are the thermal plate temperatures. The part's ambient temperature will be higher due to the power dissipation of the surrounding parts. In addition, the part itself will be above the ambient due to its own power dissipation. The failure rate is based on the actual internal temperature of the part in question.

Variation of the failure rate with temperature is not linear nor are the slopes similar for all electronic parts; therefore, it is postulated that the method herein is preferred over the weighted average temperature method for determining failure rates. The equivalent failure rate, λ_{EQ}, is defined by the equation

$$\lambda_{EQ} = .5\lambda_L + .5\lambda_H \qquad \text{Eq 1}$$

where

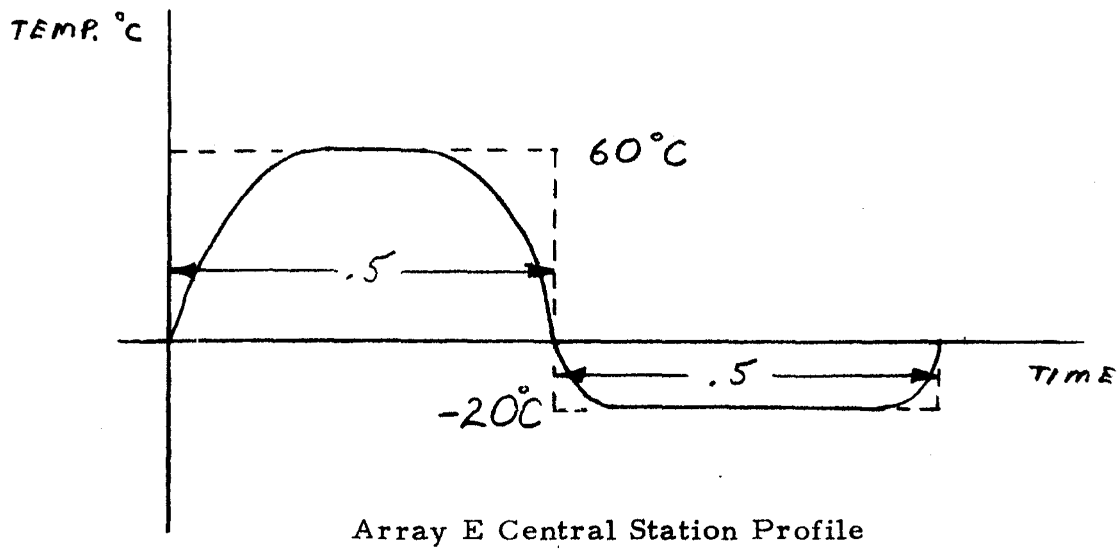
λ_{EQ} = equivalent failure rate

λ_L = failure rate established at the lower temperature

λ_H = failure rate established at the part's higher temperature

Equation 1 yields a conservative failure rate such that high confidence may be expected for the design to meet or exceed the reliability prediction.

Part temperature is determined from the appropriate entry in the Parts Application Analysis.



Array E Central Station Profile

Figure 2-1

2.3 Pre-deployment stresses experienced by ALSEP are primarily acceleration, vibration, and shock. These transit effects upon reliability are derived in ATM 274, Appendix C. The results are summarized below.

$$R_{PD} = e^{-\lambda F_B} \qquad \text{Eq 2}$$

where

F_{B_1} = 0.5200777 hours (electrical)

F_{B_2} = 5.20077 hours (electromechanical)

F_{B_3} = 52.0077 hours (mechanical)

Reliability predictions for ALSEP Array E must include both phases and is calculated by combining Equations 1 and 2 as shown below.

$$R = e^{-\lambda_{EQ}(t + F_B)} \qquad \text{Eq 3}$$

2.4 Storate failure rate K factor is .01 for the Lunar Power-Off standby condition.

3.0 ARRAY E, DERATING CRITERIA

All components used in Array E shall be derated according to ATM 241 (Rev E) as shown in Table 3-1 below.

TABLE 3-1

ALSEP ARRAY E DERATING LIMITS

Capacitors	
Ceramic	50% Voltage
Mica	50% Voltage
Paper/Plastic	50% Voltage
Electrolytic, Wet	60% Voltage
Solid	60% Voltage*
	*Requires series impedance of 3 ohms per volt
Resistors	
Film	50% Power
Wirewound	50% Power
Composition	50% Power, also ΔR = 25% allowable
Diodes, Silicon	50% Voltage, 50% current

TABLE 3-1 (CONT.)

Integrated Circuits

(1) Power supply voltages are derated as follows:

Derated minimum voltage = $V_{nom} - 0.6 (V_{nom} - V_{min})$

Derated maximum voltage = $V_{nom} + 0.6 (V_{max} - V_{nom})$

(2) For logic circuits, the derated fan-in and fan-out loading shall be 75% or less of the manufacturer's rating.

(3) For linear circuits the derated current loading shall be 75% or less of the manufacturer's rating.

It is recommended that all reasonable steps be taken to keep all I. C. silicon junction temperatures below 100°C. However, the maximum silicon junction temperature allowed is defined in Table 3-2.

TABLE 3-2

ARRAY E SILICON I. C. JUNCTION TEMPERATURE LIMITS

Manufacturers Rated Maximum Junction Temp.	ALSEP Derated Maximum Junction Temp.
200°C	140°C
175°C	130°C
150°C	120°C

Transistors, silicon	50% Voltage, 50% current Max. T_J = 140°C
Transformers and Coils	15°C rise

All derating shall be computed after recommended operating temperature derating has been made.

Any application exceeding the derating limits must be justified by reliability analysis or other system trade-offs.

4.0 FAILURE MODE APPORTIONMENT

TABLE 4-1

DISCRETE PARTS

Part	Mode of Failure		
	Short	Open	Drift
Capacitors			
Solid Tantalum*	.20	----	.80
Foil & Wet Slug Tantalum	.05	.05	.90
Paper Plastic	.95	.05	----
Mica, Glass, Ceramic	.90	----	.10
Variable	.70	----	.30
Diodes			
Rectifier (Glass Case)	.40	.20	.40
Rectifier (Metal Case)	.30	.15	.55
Switching	.30	.10	.60
Unitrode (UTR XXX)	.12	----	.88
Zener	.30	.10	.60
Resistors			
Composition	----	.05	.95
Film	----	.10	.90
Wirewound	.10	.20	.70
Transformers	.25	.25	.50
Transistors			
Diffused Junction (Si)			.65
Collector Emitter	----	----	----
Collector-Base	.125	----	----
Base-Emitter	.125	----	----
Collector		.025	
Emitter		.050	
Base		.025	

*Solid tantalum established with at least 3Ω/V series resistance

TABLE4-1(CONT.)

Part	Mode of Failure Short	Open	Drift
Transistors (Cont.)			
Mesa Planar			.70
Collector-Emitter	----	----	----
Collector-Base	.05	----	----
Base-Emitter	.05	----	----
Collector	----	----	----
Emitter		.10	
Base		.10	
Grown Junction (Si)			.60
Collector-Emitter	.20	----	----
Collector-Base	.05	----	----
Base Emitter	.05	----	----
Collector	----	----	----
Emitter		.05	
Base		.05	

TABLE 4-2

MICROCIRCUITS

(TTL with Mo-Au Metalization only)

Gates	
Output Low	.70
Output High	.30
Flip-Flops	
Output Low	.50
Output High	.50
Linear	
Output Inoperative	.65
Parameter Drift	.35

For other types of microcircuits use vendor or user data, or engineering judgement if such data is unavailable.

V COMPONENT FAILURE RATES

FAILURE RATE INDEX

Part	Table or Graph	Source
Resistors		
RNR	Table 5-1	MIL STD 1470A
RLR	Table 5-2	↓
RWR	Table 5-3	↓
RCR	Table 5-4	↓
RBR	Table 5-5	↓
Capacitors		
Solid Tantalum	Table 5-6	↓
Sintered Tantalum	Table 5-7	↓
Paper	Table 5-8	↓
Glass Dielectric	Table 5-9	↓
Ceramic	Table 5-10	↓
Foil Tantalum	Table 5-11	↓
Mica	Table 5-12	↓
Diodes		
Unitrode (UTRXXX)	Table 5-13	Unitrode
Isofilm	Table 5-13	Isofilm
IID 479-0684	Figure 5-1	North American Std. Parts Manual
All Others	Table 5-14	MIL STD 217A with Mod. Factor for screening

FAILURE RATE INDEX (CONT.)

Part	Table or Figure	Source
Transistors		
IID 472-0542-002	Figure 5-2	North American Parts Manual
IID 472-0544-002	Figure 5-3	↓
IID 472-0569-001	Figure 5-4	↓
All Others	Table 5-15	MIL HDBK-217A with Mod Factor for screening
Microcircuits		
TTL	Table 5-16	Texas Inst.
DTL	Table 5-16	Fairchild Semi.
Linear Bipolar	Table 5-16	National Semi.

MISCELLANEOUS

Inductors	See MIL HDBK 217A
Relays	See MIL HDBK 217A
Circuit Breakers	See MIL HDBK 217A

Failure Rates for MIL-R-55182 Fi[illegible] Resistors (Established Reliability
(Char C, D, E, [illegible]) RNR Type

Ambient Temperature °C	Stress Ratio (Operating/Rated Power)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.140	0.150	0.160	0.170	0.175	0.187	0.196	0.205	0.215	0.225
10	0.136	0.148	0.160	0.174	0.179	0.194	0.202	0.210	0.225	0.240
20	0.143	0.155	0.168	0.181	0.186	0.202	0.219	0.225	0.242	0.259
30	0.151	0.165	0.179	0.192	0.200	0.215	0.231	0.246	0.264	0.282
40	0.164	0.180	0.194	0.208	0.218	0.231	0.251	0.271	0.292	0.313
50	0.178	0.195	0.211	0.226	0.240	0.250	0.276	0.302	0.325	0.348
60	0.195	0.214	0.233	0.251	0.266	0.282	0.309	0.336	0.362	0.387
70	0.214	0.235	0.259	0.282	0.297	0.315	0.347	0.378	0.409	0.440
80	0.240	0.265	0.292	0.318	0.337	0.356	0.393	0.430	0.468	0.505
90	0.268	0.298	0.329	0.360	0.382	0.405	0.448	0.490	0.536	0.582
100	0.307	0.340	0.374	0.408	0.440	0.465	0.514	0.562	0.619	0.675
110	0.350	0.390	0.429	0.467	0.509	0.540	0.596	0.652	0.721	0.790
120	0.415	0.455	0.500	0.545	0.590	0.635	0.703	0.770	0.845	0.920
125	0.455	0.495	0.543	0.590	0.645	0.690	0.765	0.840	0.920	1.000

Note: Failure Rate Levels established at 100% stress and rated temp. Factors

Level	FR%/1000 hrs	Level	FR%/1000 hrs
M	1.0	R	0.01
P	0.1	S	0.001

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Table 5-1

Failure Rates for MIL-R-39017 [illegible]sistors (Established Reliability)
Type [illegible]R

Ambient Temperature °C	Stress Ratio (Operating/Rated Power)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.165	0.170	0.173	0.175	0.182	0.190	0.213	0.240	0.278	0.320
10	0.178	0.183	0.187	0.193	0.199	0.205	0.237	0.275	0.315	0.350
20	0.194	0.200	0.207	0.213	0.221	0.228	0.268	0.317	0.358	0.390
30	0.213	0.222	0.232	0.243	0.250	0.258	0.308	0.365	0.410	0.443
40	0.240	0.250	0.264	0.280	0.288	0.300	0.360	0.423	0.470	0.510
50	0.275	0.288	0.302	0.320	0.335	0.348	0.415	0.490	0.542	0.610
60	0.320	0.338	0.349	0.368	0.385	0.410	0.483	0.570	0.639	0.740
70	0.370	0.385	0.401	0.420	0.443	0.480	0.570	0.665	0.765	0.900
80	0.430	0.440	0.460	0.480	0.520	0.565	0.670	0.780	0.920	—
90	0.498	0.520	0.531	0.551	0.605	0.674	0.800	0.920	—	—
100	0.580	0.600	0.620	0.640	0.715	0.810	0.953	—	—	—
110	0.668	0.695	0.725	0.765	0.860	0.990	—	—	—	—
120	0.755	0.805	0.850	0.914	—	—	—	—	—	—
125	0.820	0.870	0.930	1.000	—	—	—	—	—	—

Note: Failure Rate Levels established at 100% stress and 70°C Factors

Level	FR%/1 khrs	Level	FR%/1khrs
M	1.0	R	0.01
P	0.1	S	0.001

ATM 605A
Table 5-2

Failure Rates for MIL-R-39007 Power Wirewound Resistors

Ambient Temperature °C	Stress Ratio (Operating/Rated Power)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.051	0.071	0.098	0.130	0.165	0.230	0.320	0.430	0.580	0.800
10	0.053	0.076	0.103	0.139	0.180	0.258	0.352	0.465	0.640	0.880
20	0.056	0.080	0.110	0.150	0.205	0.282	0.390	0.510	0.680	0.960
30	0.059	0.087	0.120	0.163	0.220	0.310	0.425	0.560	0.750	—
40	0.064	0.093	0.132	0.178	0.240	0.332	0.470	0.620	0.840	—
50	0.068	0.100	0.142	0.192	0.262	0.362	0.510	0.675	0.895	—
60	0.071	0.106	0.150	0.209	0.288	0.400	0.550	0.720	0.975	—
70	0.077	0.115	0.167	0.223	0.315	0.440	0.610	0.790	—	—
80	0.082	0.125	0.178	0.240	0.345	0.480	0.665	0.880	—	—
90	0.089	0.135	0.196	0.268	0.370	0.520	0.720	0.940	—	—
100	0.095	0.145	0.210	0.295	0.402	0.565	0.780	—	—	—
110	0.102	0.155	0.225	0.315	0.440	0.620	0.845	—	—	—
120	0.109	0.170	0.248	0.345	0.480	0.670	0.940	—	—	—
125	0.115	0.177	0.255	0.358	0.500	0.695	0.980	—	—	—

Note: Failure Rate Levels established at 100% stress and 25°C Factors

Level	FR%/1khrs	Level	FR%/1khrs
M	1.0	R	0.01
P	0.1	S	0.001

Failure Rates for MIL-R-39008 Composi[illegible]istor (Established Reliability)
Type RCR

Ambient Temperature °C	Stress Ratio (Operating/Rated Power)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
10								0.022	0.029	0.030
20							0.022	0.027	0.035	0.044
30					0.022	0.022	0.030	0.040	0.054	0.074
40				0.022	0.025	0.032	0.046	0.067	0.090	0.135
50			0.022	0.030	0.040	0.050	0.076	0.120	0.175	0.250
60	0.022	0.022	0.034	0.051	0.067	0.090	0.145	0.220	0.330	0.490
70	0.027	0.037	0.058	0.090	0.125	0.170	0.280	0.420	0.640	—
80	0.047	0.069	0.110	0.170	0.230	0.340	0.530	0.840	—	—
90	0.087	0.135	0.205	0.300	0.460	0.720	—	—	—	—
100	0.170	0.270	0.400	0.590	1.000	—	—	—	—	—

Note: Failure Rate Levels established at 50% stress and 70°C Factors

Level	FR%/1khrs	Level	FR%/1khrs
M	1.0	R	0.01
P	0.1	S	0.001

ATM 605A
Table 5-4

Failure Rates for MIL-R-39005 Accurate Wirewound Resistors (Established Reliability) (RBR Type)

Ambient Temperature °C	Stress Ratio (Operating/Rated Power)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.110	0.117	0.123	0.128	0.132	0.135	0.143	0.150	0.158	0.165
10	0.110	0.118	0.123	0.128	0.133	0.137	0.144	0.150	0.159	0.168
20	0.113	0.122	0.127	0.132	0.137	0.141	0.148	0.155	0.165	0.175
30	0.119	0.128	0.133	0.138	0.147	0.155	0.160	0.165	0.175	0.185
40	0.125	0.135	0.142	0.149	0.158	0.165	0.173	0.180	0.188	0.195
50	0.137	0.149	0.159	0.168	0.176	0.180	0.189	0.198	0.207	0.215
60	0.151	0.165	0.173	0.180	0.189	0.198	0.208	0.218	0.229	0.240
70	0.165	0.188	0.197	0.205	0.215	0.225	0.238	0.250	0.265	0.280
80	0.192	0.215	0.228	0.240	0.253	0.265	0.283	0.300	0.315	0.330
90	0.224	0.260	0.273	0.285	0.303	0.320	0.340	0.360	0.380	0.400
100	0.270	0.320	0.335	0.350	0.370	0.390	0.415	0.440	0.470	0.500
110	0.340	0.390	0.415	0.440	0.470	0.500	0.540	0.580	0.615	0.650
120	0.420	0.500	0.530	0.560	0.605	0.650	0.700	0.750	0.810	0.870
125	0.470	0.560	0.610	0.660	0.710	0.760	0.815	0.870	0.935	1.000

Note: Failure Rate Levels established at 100% stress and 125°C Factors

Level	FR%/1khrs	Level	FR%/1khrs
M	1.0	R	0.01
P	0.1	S	0.001

Failure Rates for MIL-C-39003 Solid Tanta[illegible]n [illegible]pacitors (Established Reliability)

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.00429	0.00572	0.00858	0.01430	0.02574	0.04719	0.09724	0.14147	0.17875	0.22880
10	0.00429	0.00620	0.00960	0.01573	0.02740	0.05148	0.10582	0.15434	0.19305	0.25400
20	0.00540	0.00680	0.01070	0.01716	0.03000	0.05600	0.12012	0.17160	0.21450	0.28700
30	0.00620	0.00780	0.01220	0.01980	0.03432	0.06400	0.13718	0.19305	0.24310	0.33500
40	0.00780	0.00858	0.01430	0.02288	0.04004	0.07400	0.16016	0.22880	0.28600	0.40040
50	0.00830	0.0108	0.01716	0.02574	0.04862	0.08866	0.19305	0.27170	0.34320	0.48000
60	0.00980	0.01287	0.02002	0.03300	0.05863	0.10725	0.23595	0.33000	0.41470	0.59345
70	0.01180	0.01573	0.02500	0.04004	0.07200	0.13146	0.29000	0.40040	0.50765	0.72000
80	0.01430	0.02002	0.03146	0.05005	0.09009	0.16505	0.35750	0.50050	0.63635	0.90090
90	0.01800	0.02574	0.04004	0.06292	0.11440	0.20735	0.44330	0.62000	0.80080	—
100	0.02340	0.03289	0.05148	0.0800	0.14290	0.26455	0.56000	0.90000	1.0000	—
110	0.03050	0.04200	0.06578	0.10300	0.18300	0.33605	0.70785	1.0000	—	—
120	0.04290	0.05577	0.08580	0.13400	0.23595	0.42900	0.86945	—	—	—
125	0.04862	0.06292	0.09581	0.15434	0.26455	0.48620	1.0000	—	—	—

Note: Failure Rate Levels established at 100% stress and 85°C Factors

Level	FR%/1khrs	Level	FR%/1khrs	Level	FR%/1khrs
L	5.0	P	0.1	S	0.001
M	1.0	R	0.01		

Failure Rates for MIL-C-39006 Sintered Tantalum Capacitors (Established Reliability)

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.00028	0.00028	0.00028	0.00028	0.00056	0.00084	0.00168	0.00224	0.00364	0.00560
10				0.00056	0.00084	0.00112	0.00196	0.00280	0.00420	0.00672
20				0.00056	0.00112	0.00140	0.00224	0.00336	0.00532	0.00812
30				0.00056	0.00112	0.00168	0.00280	0.00392	0.00644	0.01008
40			0.00028	0.00084	0.00140	0.00224	0.00336	0.00504	0.00812	0.01288
50			0.00056	0.00112	0.00196	0.00280	0.00420	0.00644	0.01008	0.1696
60			0.00056	0.00140	0.00252	0.00364	0.00560	0.00840	0.01344	0.02128
70			0.00084	0.00196	0.00336	0.00504	0.00784	0.01176	0.01876	0.02968
80		0.00028	0.00112	0.00280	0.00504	0.00756	0.01176	0.01764	0.02800	0.04424
90		0.00056	0.00168	0.00448	0.00812	0.01232	0.01876	0.02800	0.04480	—
100		0.00084	0.00280	0.00812	0.01456	0.02184	0.03332	0.03700	—	—
110		0.00140	0.00540	0.01596	0.02856	0.04340	0.06496	0.09240	—	—
120		0.00252	0.01036	0.03640	0.07000	0.10080	0.14840	—	—	—
125	0.00028	0.00364	0.01568	0.05880	0.11200	0.15680	—	—	—	—

Note: Failure Rate Levels established at 100% stress and 125°C Factors

Level	FR%/1khrs	Level	FR%/1khrs	Level	FR%/1khrs
L	2.0	P	0.1	S	0.001
M	1.0	R	0.01		

Failure Rate for MIL-C-14157D Paper (or [illegible]r Plastic) Capacitor (Esta. Reliability) (CPU Type)

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
10										
20										
30										
40										
50										0.040
60									0.040	0.040
70								0.040	0.053	0.078
80							0.040	0.050	0.082	0.120
90							0.048	0.082	0.130	0.195
100						0.040	0.074	0.130	0.205	0.320
110					0.040	0.064	0.118	0.210	0.330	0.500
120					0.048	0.100	0.180	0.340	0.510	0.780
125	0.040	0.040	0.040	0.040	0.064	0.130	0.230	0.420	0.640	1.000

Note: Failure Rates Levels Established at 100% stress and 125°C

Factors Level	FR%/1khrs	Level	FR%/1khrs
M	1.0	R	0.01
P	0.1	S	0.001

Failure Rates for MIL-C-23269A Glass Dielectric Capacitors (Established Reliability)

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.0004	0.0004	0.0004	0.0004	0.0004	0.0005	0.0007	0.0013	0.0028	0.0038
10					0.0004	0.0005	0.0016	0.0020	0.0036	0.0050
20					0.0005	0.0006	0.0018	0.0032	0.0057	0.0080
30				0.0004	0.0010	0.0019	0.0030	0.0051	0.0090	0.0125
40				0.0006	0.0016	0.0030	0.0047	0.0082	0.0140	0.0200
50			0.0004	0.0010	0.0025	0.0047	0.0055	0.0130	0.0220	0.0320
60			0.0005	0.0015	0.0040	0.0075	0.0120	0.0200	0.0350	0.0500
70			0.0008	0.0024	0.0065	0.0100	0.0200	0.0320	0.0630	0.0790
80			0.0012	0.0038	0.0100	0.0190	0.0300	0.0510	0.0900	0.1250
90		0.0004	0.0019	0.0060	0.0160	0.0300	0.0500	0.0820	0.1400	0.2000
100		0.0006	0.0030	0.0095	0.0250	0.0470	0.0800	0.1300	0.2200	0.3200
110		0.0009	0.0048	0.0150	0.0400	0.0750	0.1200	0.2100	0.3500	0.5000
120		0.0014	0.0075	0.0240	0.0640	0.1200	0.2000	0.3300	0.5500	0.7900
125	0.0004	0.0018	0.0095	0.0300	0.0800	0.1500	0.2500	0.4200	0.7000	1.0000

Note: Failure Rate Levels Established at 100% stress and 125°C

Factors	Level	FR%/1000 hrs	Level	FR%/1khrs
	M	1.0	R	0.01
	P	0.1	S	0.001

Failure Rate for MIL-C-39014 C[illegible] Capacitors (Established Reliability)
Temp. [illegible]ge "B"

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.009	0.013
10							0.006	0.009	0.013	0.017
20						0.005	0.008	0.013	0.018	0.025
30					0.005	0.008	0.013	0.018	0.025	0.025
40					0.006	0.011	0.018	0.027	0.038	0.052
50				0.005	0.009	0.015	0.025	0.037	0.052	0.071
60				0.007	0.013	0.023	0.037	0.054	0.075	0.103
70				0.009	0.018	0.031	0.049	0.072	0.103	0.145
80			0.005	0.014	0.026	0.045	0.072	0.107	0.150	0.210
90			0.007	0.019	0.036	0.062	0.099	0.145	0.210	0.285
100			0.011	0.028	0.054	0.094	0.150	0.215	0.310	0.420
110		0.0050	0.015	0.038	0.072	0.125	0.200	0.302	0.420	0.590
120		0.0084	0.021	0.054	0.102	0.180	0.290	0.420	0.600	0.840
125	0.005	0.010	0.025	0.066	0.125	0.215	0.345	0.510	0.740	1.000

Note: For temp. range A - subtract 40°C from the ambient temp. to obtain correct ambient, also for temp. range C - add 25°C to ambient temp.

Note: Failure Rate Levels Established at 100% stress at 85°C, 125°C, 150°C

Factors	Level	FR%/1khrs	Level	FR%/1khrs
	M	1.0	R	0.01
	P	0.1	S	0.001

ATM 605A
Table 5-10

Failure Rates for MIL-C-39006 Foil Tantalum Capacitors (Esta. Reliability)

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.011	0.012	0.014	0.016	0.020	0.025	0.031	0.038	0.060	0.108
10	0.011	0.013	0.016	0.018	0.021	0.024	0.032	0.040	0.064	0.116
20	0.012	0.014	0.017	0.020	0.023	0.026	0.034	0.042	0.068	0.124
30	0.013	0.016	0.019	0.022	0.025	0.028	0.037	0.046	0.074	0.134
40	0.015	0.018	0.021	0.024	0.028	0.032	0.041	0.050	0.082	0.148
50	0.018	0.021	0.024	0.026	0.031	0.036	0.046	0.056	0.092	0.168
60	0.021	0.024	0.027	0.030	0.035	0.040	0.052	0.064	0.104	0.190
70	0.025	0.028	0.032	0.036	0.042	0.048	0.061	0.074	0.122	0.220
80	0.031	0.034	0.038	0.042	0.049	0.056	0.072	0.088	0.146	0.260
90	0.038	0.042	0.047	0.052	0.061	0.070	0.090	0.110	0.182	0.330
100	0.050	0.054	0.061	0.068	0.081	0.094	0.118	0.142	0.240	0.430
110	0.065	0.073	0.084	0.094	0.111	0.128	0.160	0.192	0.320	0.588
120	0.090	0.102	0.117	0.132	0.156	0.180	0.225	0.270	0.458	0.820
125	0.109	0.124	0.142	0.160	0.190	0.220	0.275	0.330	0.560	1.000

Note: Failure Rate Levels Established at 100% stress and 125°C

Factors	Level	FR%/1000 hrs	Level	FR%/1000 hrs	Level	FR%/1000 hrs
	L	5.0	P	0.1	S	0.001
	M	1.0	R	0.01		

Failure Rates for MIL-C-39001 Mic[illegible]apacitors (Established Reliability)

Ambient Temperature °C	Stress Ratio (Operating/Rated Voltage)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.040	0.087	0.175
10							0.020	0.046	0.100	0.200
20							0.023	0.053	0.115	0.215
30							0.026	0.061	0.133	0.258
40							0.030	0.070	0.153	0.303
50							0.035	0.080	0.175	0.350
60						0.017	0.040	0.092	0.200	0.404
70						0.019	0.046	0.105	0.215	0.465
80						0.021	0.053	0.122	0.258	0.530
90						0.022	0.061	0.140	0.305	0.615
100						0.028	0.070	0.160	0.350	0.700
110						0.033	0.081	0.185	0.405	0.810
120						0.038	0.093	0.205	0.465	0.940
125	0.017	0.017	0.017	0.017	0.017	0.040	0.095	0.210	0.500	1.000

Notes: Failure Rate Levels Established at 100% stress and 125°C

Factors Level	FR%/1000 hrs	Level	FR%/1000 hrs	Level	FR%/1000 hrs
M	1.0	R	0.01	T	0.0001
P	0.1	S	0.001		

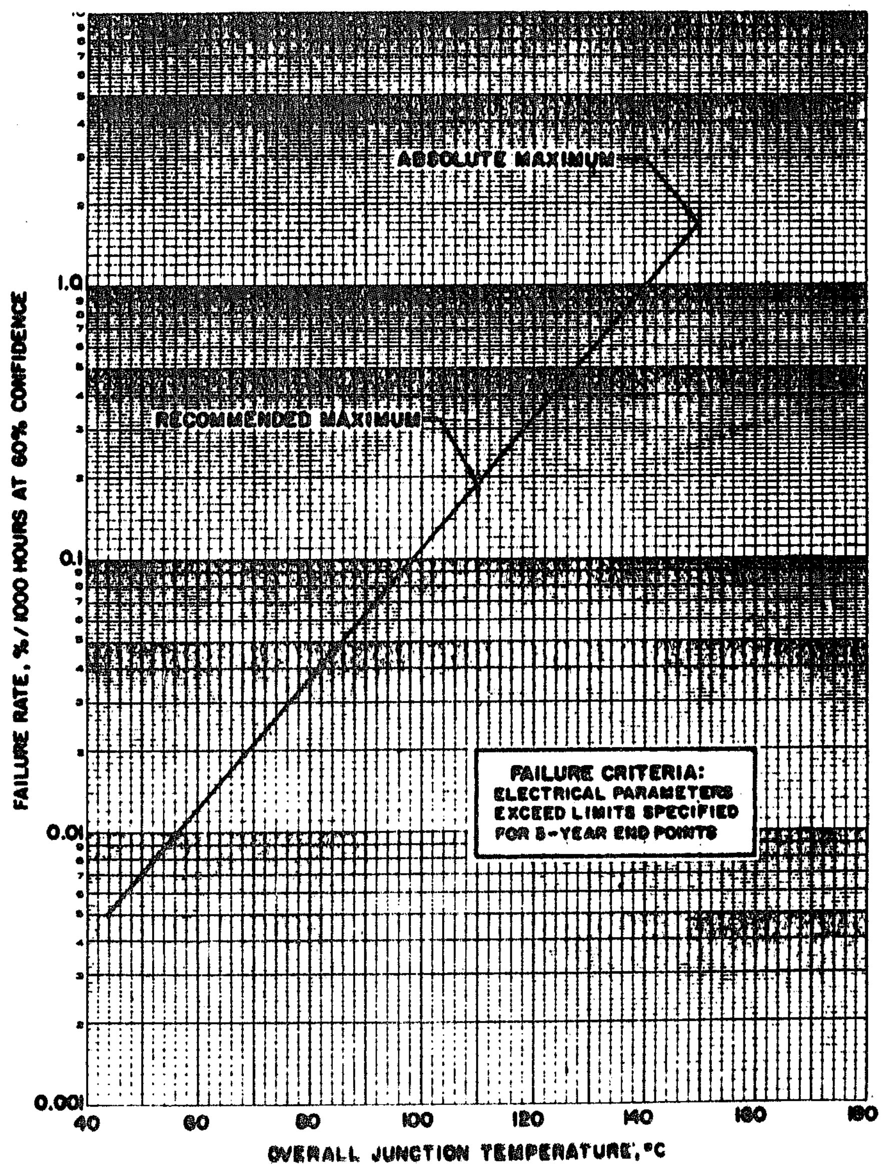
TABLE 5-13

FAILURE RATES (%/1000 HOURS) FOR UNITRODE AND ISOFILM DIODES

NORMALIZED JUNCTION TEMPERATURE	UNITRODE	ISOFILM
0.00	.00006	.00010
0.05	.00007	.00012
0.10	.00008	.00014
0.15	.00009	.00016
0.20	.00011	.00019
0.25	.00013	.00022
0.30	.00015	.00025
0.35	.00017	.00029
0.40	.00019	.00032
0.45	.00022	.00036
0.50	.00025	.00041
0.55	.00028	.00046
0.60	.00032	.00051
0.65	.00035	.00055
0.70	.00039	.00061
0.75	.00042	.00066
0.80	.00046	.00073
0.85	.00050	.00079
0.90	.00053	.00086
0.95	.00056	.00093
1.00	.00060	.00100

AUTONETICS A DIVISION OF NORTH AMERICAN AVIATION, INC WS-133B STANDARD PARTS MANUAL	MICRO-DIODE, SEMICONDUCTOR, HIGH POWER IID 479-0684- PART TYPE: P	TAB479 SECTION 1.9 PAGE 4
		ORIG DATE 6-17-66
		REV DATE
		REV NO.

Inherent Failure Rate = 0.005% per thousand hours at 50% of absolute maximum rated power and at Tc = 25°C.



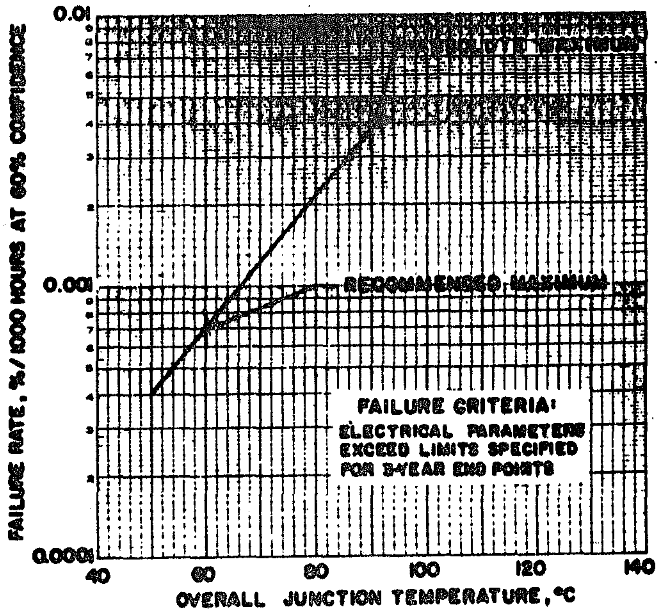
PREDICTED FAILURE RATES

Failure Rates (Failure/10^5 hours) for Diodes

Normalized Junction Temperature °C	Silicon Diodes (≤ 1 watt)	Silicon Power Diodes (> 1 watt)	Zener Diodes
0.00	.00050	.00050	.00150
0.05	.00059	.00065	.00127
0.10	.00070	.00080	.00210
0.15	.00082	.00109	.00247
0.20	.00097	.00140	.00290
0.25	.00111	.00170	.00335
0.30	.00127	.00215	.00385
0.35	.00145	.00257	.00435
0.40	.00162	.00310	.00490
0.45	.00182	.00375	.00560
0.50	.00205	.00450	.00625
0.55	.00230	.00525	.00700
0.60	.00255	.00615	.00770
0.65	.00275	.00715	.008500
0.70	.00305	.00920	.00925
0.75	.00330	.00940	.01010
0.80	.00365	.01075	.01110
0.85	.00395	.01240	.01200
0.90	.00430	.01350	.01300
0.95	.00465	.01530	.01400
1.00	.00500	.01750	.01500

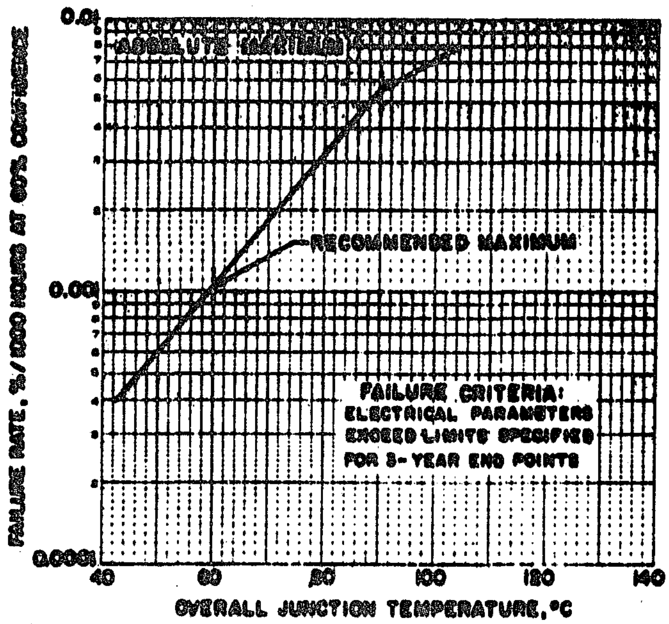
Note: The > 1 watt and ≤ 1 watt designations refer to the maximum rating for the diode, not actual power dissipation

AUTONETICS A DIVISION OF NORTH AMERICAN AVIATION, INC WS-133B STANDARD PARTS MANUAL	TRANSISTOR, SILICON, PNP, DUAL SWITCH, MATCHED PAIR IID 472-0542-002, -006 PART TYPE: P	TAB 472 SECTION 2.2 PAGE 3 ORIG DATE: 3-17-66 REV DATE: REV NO.:



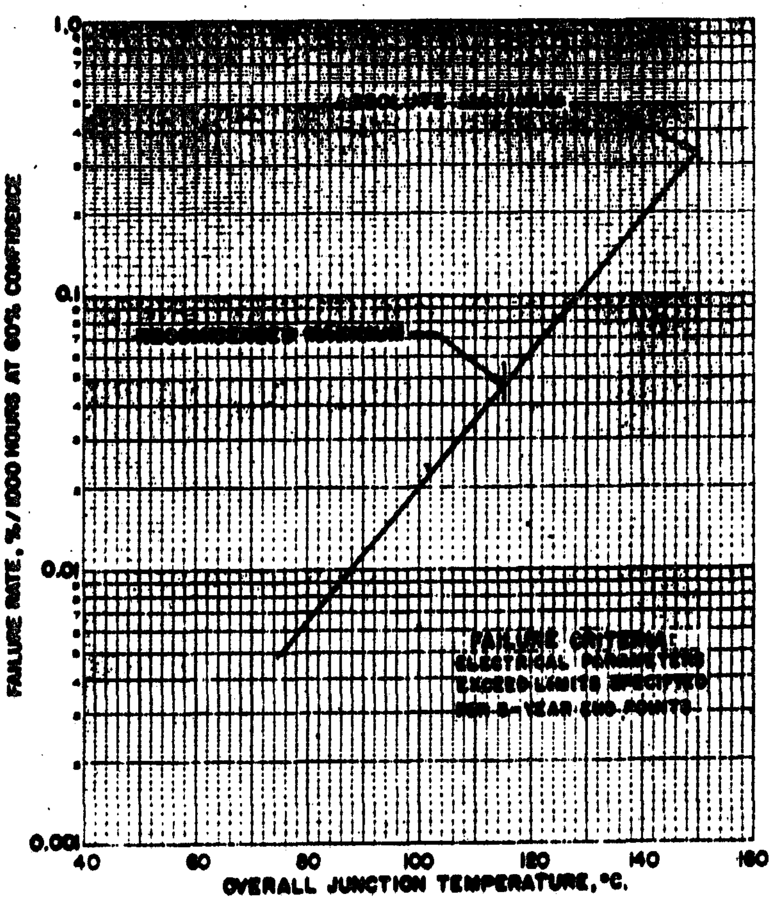
PREDICTED FAILURE RATES

AUTONETICS A DIVISION OF NORTH AMERICAN AVIATION, INC **WS-133B** **STANDARD PARTS MANUAL**	TRANSISTOR, SILICON, NPN, DUAL LOW LEVEL, MATCHED PAIR IID 472-0544-002 PART TYPE: P	TAB 472 SECTION 4.2 PAGE 3 ORIG DATE: 5-17-60 REV DATE: REV NO.:



PREDICTED FAILURE RATES

AUTONETICS A DIVISION OF NORTH AMERICAN AVIATION, INC WS-133B STANDARD PARTS MANUAL	TRANSISTOR, SILICON, NPN, POWER IID 472-0569-001 PART TYPE: P	TAB472 SECTION 8.1 PAGE 3 ORIG DATE 5-17-66 REV DATE REV NO.



PREDICTED FAILURE RATES

Failure Rates (Failures/10^5 hours) for Transistors

Normalized Junction Temperature °C	PNP		NPN	
	≤ 1 watt	> 1 watt	≤ 1 watt	> 1 watt
0.00	0.0020	0.0040	0.0010	0.0020
0.05	0.00246	0.00492	0.00118	0.00236
0.10	0.00305	0.00610	0.00140	0.00280
0.15	0.00380	0.00760	0.00165	0.00330
0.20	0.00470	0.00940	0.00195	0.00390
0.25	0.00560	0.01120	0.00222	0.00444
0.30	0.00670	0.01340	0.00255	0.00510
0.35	0.00780	0.01560	0.00290	0.00580
0.40	0.00920	0.01840	0.00325	0.00650
0.45	0.01070	0.02140	0.00365	0.00730
0.50	0.01250	0.02500	0.00410	0.00820
0.55	0.01430	0.02860	0.00460	0.00920
0.60	0.01650	0.03300	0.00510	0.01020
0.65	0.01850	0.0370	0.00550	0.01100
0.70	0.0210	0.0420	0.00610	0.01220
0.75	0.0230	0.0460	0.00660	0.01320
0.80	0.0265	0.0530	0.00730	0.01460
0.85	0.0295	0.0590	0.00790	0.01580
0.90	0.0320	0.0640	0.00860	0.01720
0.95	0.0360	0.0720	0.00930	0.01860
1.00	0.0400	0.0800	0.0100	0.02000

Note: The > 1 watt and ≤ 1 watt designations refer to the maximum rating of the transistor, not actual power dissipation

TABLE XX

MICROCIRCUIT FAILURE RATES

	Linear		Digital	
Temp. C	Nat. Semi.	Other	DTL	TTL
0	.0009	.0036	.0006	.0009
10	.0009	.0036	.0006	.0009
20	.0009	.0036	.0006	.0009
30	.0010	.0040	.0007	.0010
40	.0013	.0050	.0009	.0013
50	.0016	.0064	.0011	.0016
60	.0020	.0080	.0013	.0020
70	.0025	.0100	.0017	.0025
80	.0031	.0130	.0021	.0031
90	.0040	.0160	.0026	.0040
100	.0050	.0200	.0033	.0050
110	.0062	.0250	.0040	.0062
120	.0080	.0320	.0050	.0080
125	.009	.0360	.0057	.0090

Failure Rates are in %/1000 hrs.

This Appendix contains mathematical formulas and examples to be used in the calculation of reliability for complex systems.*

A-1 In general, reliability is calculated using the equation below. Note that the failure rate (λ) may be a function of time such as a bathtub curve.

$$R = e^{-\int_0^t \lambda(t)dt} \qquad (1)$$

A-2 Probability of System Success (P_s) For a system composed of critical parts having probabilities P_1, P_2, P_3 .... respectively and each part being capable of causing a system failure

$$P_s = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdots P_n \qquad (2)$$

Note: Equations 3 to 7 and 18 to 22 apply to an exponential failure distribution.

A-3 Probability of exactly n failures (P_n) In time t, of a single unit with at least n spares is

$$P_n = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \qquad (3)$$

A-4 When n = 0 the above equation reduces to

$$P_o = e^{-\lambda t} \qquad (4)$$

A-5 When the terms P_1, P_2, etc of equation 2 are each in the form of the right hand side of equation 4, then

$$\lambda_s t_s = \lambda_1 t_1 + \lambda_2 t_2 + \lambda_3 t_3 + \cdots \qquad (5)$$

*Reference: ("Reliability Handbook", the Bendix Corporation, ELIPSE-Pioneer Division, Teterboro, New Jersey.

A-6 When $t_1 = t_2 = t_3 = \cdots = t$

$$\lambda_s t = \lambda_1 t + \lambda_2 t + \lambda_3 t + \cdots \qquad (6)$$

A-7 By which

$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3 + \cdots \qquad (7)$$

A-8 Addition of Probabilities

When A, B, C, etc are mutually exclusive events (preclude each other) the probability of either A or B or C is

$$P(A \text{ or } B \text{ or } C \cdots) = P(A + B + C + \cdots) = P(A) + P(B) + P(C) \qquad (8)$$

A-9 The sum of the probabilities of all the mutually exclusive outcomes of an event is unity.

$$\sum_{i=1}^{n} P_i = 1 \qquad (9)$$

Where $P_1, P_2, \ldots P_n$ represent the probabilities of each of the mutually exclusive forms the event can take.

A-10 If an event can only succeed or fail the probability of success plus the probability of failure is unity.

$$P + Q = 1 \qquad (10)$$

A-11 Multiplication of Probabilities

When independent events A, B, C, etc are not mutually exclusive (can occur in the same trial or period), the probability of A and B and C etc all occurring is

$$P(A \text{ and } B \text{ and } C \cdots) = P(ABC \cdots) = P(A) \cdot P(B) \cdot P(C) \cdots \quad (11)$$

A-12 Conditional Probability

When event B is dependent on a prior event A, the single event B is designated P(B/A) and the compound event is designated P(AB), thus:

$$P(AB) = P(A) \,.\, P(B/A) \quad (12)$$

Where P(B/A) is the probability of B occurring, assuming that A has already occurred. Also:

$$P(B/A) = \frac{P(AB)}{P(A)} = \frac{P(A/B) \,.\, P(B)}{P(A)} \quad (13)$$

A-13 And/Or Probability

When independent events A and B are not mutually exclusive, the probability of A and/or B occurring is:

$$P(A + B) = P(A \text{ and/or } B) = P(A) + P(B) - P(AB) \quad (14)$$

This law is known as the "Addition Theorem".

A-14 The general form of equation 14 is:

P(A and/or B and/or C and/or D · · ·)

$$\sum P(A) - \sum P(AB) + \sum P(ABC) - \sum P(ABCD) \cdots \quad (15)$$

$$= 1 - P\text{ (not A and not B and not C and not D} \cdots \quad (16)$$

$$= 1 - [1 - P(A)]\ [1 - P(B)]\ [1 - P(C)]\ [1 - P(D)] \quad (17)$$

A-15 The probability of exactly x failures in period t of a single replaceable unit with x spares

$$P_x = \frac{(\lambda t)^x e^{-\lambda t}}{x!} \quad (18)$$

A-16 The probability of not more than x failures in period t of a single replaceable unit with x spares

$$P_{(0,\ 1 \cdots x)} = P_0 + P_1 + \cdots + P_x \quad (19)$$

Where P_0, P_1, etc are determined by equation (26). (See page 7.2.30 for graphical solution, letting n = 1).

A-17 The probability of exactly x failures in period t of a single replaceable unit with (x-1) spares

$$P_x = 1 - (P_0 + P_1 + \cdots + P_{x-1}) \quad (20)$$

Where P_0, $P_1 \cdots P_{x-1}$ are determined by equation (18).

A-18 The probability of exactly x failures in period t for n essential replaceable units in operation with x spares

$$P_x = \frac{(n\lambda t)^x e^{-n\lambda t}}{x!} \qquad (21)$$

Where λ = failure rate of a single unit.

A-19 The probability of not more than x failures in period t for n essential replaceable units in operation and at least x spares available.

$$P_{(0,\ 1,\ \cdots,\ x)} = P_0 + P_1 + P_2 + \cdots + P_x \qquad (22)$$

Where P_0, P_1, etc are determined by equation (30).

A-20 The probability of exactly x failures in period t for n units in operation and with no replacements.

$$P_x = C_x^n\, p^{n-x}\, q^x \qquad (23)$$

Where p = probability of 1 unit operating for period t without failure, q = 1 - p and C_x^n = combination of n things taken x at a time.

A-21 The probability of not more than x failures in period t for n units in operation and with no replacements

$$P_{(0,\ 1,\ \cdots,\ x)} = P_0 + P_1 + \cdots + P_x \qquad (24)$$

Where P_0, P_1, etc are determined by equation (23)

A-22 The reliability of a number of dissimilar elements in active redundancy with no replacements can be found by the following general method.

$$(P_1 + Q_1)\ (P_2 + Q_2)\ (P_3 + Q_3)\ (P_4 + Q_4) \cdots = 1 \qquad (25)$$

Where P_1 = probability element 1 will succeed, and Q_1 = probability element 1 will fail. Expansion of the left hand member presents all the possible combinations of the mutually exclusive results. For three units this becomes:

$$P_1P_2P_3 + P_1P_2Q_3 + P_1P_3Q_2 + P_2P_3Q_1$$

$$+ P_1Q_2Q_3 + P_2Q_1Q_3 + P_3Q_1Q_2 + Q_1Q_2Q_3 = 1$$

Where, for example, the second term represents the probability that both one and two succeed but three fails. By deleting those terms which are disallowed by the problem, the sum of retaining terms is the probability of success. Thus

$$R_0(t) = P_1P_2P_3 = \text{the probability of 0 failures}$$

$$R_{0,\ 1}(t) = P_1P_2P_3 + P_1P_2Q_3 + P_1P_3Q_2 + P_2P_3Q_1$$

$$= \text{probability of not more than 1 failure}$$

$$R_{0,\ 1,\ 2}(t) = P_1P_2P_3 + P_1P_2Q_3 + P_1P_3Q_2 + P_2P_3Q_1$$

$$+ P_1Q_2Q_3 + P_2Q_1Q_3 + P_3Q_1Q_2 = 1 - Q_1Q_2Q_3$$

$$= \text{probability of not more than 2 failures}$$

$$R_1(t) = P_1P_2Q_3 + P_1P_3Q_2 + P_2P_3Q_1$$

= probability of exactly one failure

$$R_2(t) = P_1Q_2Q_3 + P_2Q_1Q_3 + P_3Q_1Q_2$$

= probability of exactly two failures

$$R_3(t) = Q_1Q_2Q_3$$

= probability of exactly three failures

A-23 If a regular overhaul period is scheduled for T hours, some of the equipments will fail prior to T, requiring overhaul prior to schedule. The average overhaul period $\overline{T}$ for all (100%) of the equipment when the MTBF (m) is known is:

$$\overline{T} = m(1 - e^{-T/m}) \quad (26)$$

A-24 Approximate solutions of logarithmic equations
Note: Log indicates a logarithm to the base 10
Ln indicates a logarithm to the base e

A-25

$$\text{Log } n: \approx (n + \frac{1}{2}) \text{ Log } n - .43430\, n + .39909 \quad (27)$$

A-26 Solution of $P = e^{-\lambda t}$ for $1 > \lambda t > 0$

$$P = 1 - \lambda t + \frac{(\lambda t)^2}{2:} - \frac{(\lambda t)^3}{3:} + \cdots \quad (28)$$

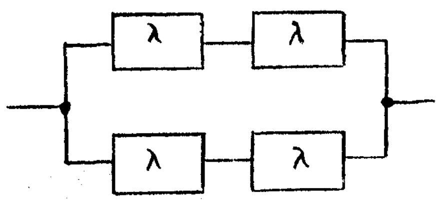
A-27 Equivalent Failure Rate of "Quads"

Let λ_s = the portion of λ attributable to shorts.
λ_o = the portion of λ attributable to opens.

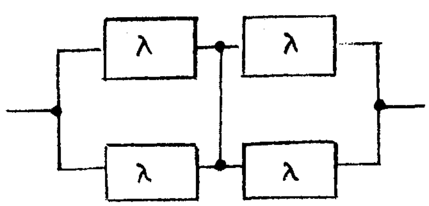
Assuming the element fails only by shorting or opening:

$$\lambda_s + \lambda_o = \lambda$$

For the following configurations



$$\lambda_e \approx 2\lambda_s^2 t + 4\lambda_o^2 t \qquad (29a)$$



$$\lambda_e \approx 4\lambda_s^2 t + 2\lambda_o^2 t \qquad (29b)$$

When $\lambda_s = \lambda_o = \lambda/2$, both configurations result in

$$\lambda_e \approx 3/2\, \lambda^2 t \qquad (29c)$$

From the above it is seen that configuration (a) is most suitable when the failure mode is to short, whereas configuration (b) is most suitable when the failure mode is to open.

Section IV of this ATM tabulates established percentages of λ_o and λ_s for various electrical parts.

A-28 MTBF, Active and with dependent elements:

For two dependent elements in parallel where each shares the load and where the failure rate increases when only one must carry the full load

$$\text{MTBF} = \frac{1}{\lambda_o} + \frac{1}{2\lambda_1} \qquad (29a)$$

λ_o = failure rate of an element when both elements share the load

λ_1 = failure rate of an element when it alone carries the load

For n elements in parallel, all sharing the load,

$$\text{MTBF} = \frac{1}{\lambda_o} + \frac{1}{2\lambda_1} + \frac{1}{3\lambda_2} + \cdots + \frac{1}{n\lambda_{n-1}} \qquad (29b)$$

Where

λ_o = failure rate of an element when all n elements are sharing the load

λ_1 = failure rate of an element when n-1 elements are sharing the load

λ_2 = failure rate of an element when n-2 elements are sharing the load

etc.

A-29 Reliability for two unlike elements in standby redundancy when λ_1 = failure rate of the operating element, λ_2 = failure rate of the standby element while idle and λ_3 = failure rate of the standby element when put into operation.

$$P = e^{-\lambda_1 t} + \frac{\lambda_1}{\lambda_1+\lambda_2-\lambda_3} \left(e^{-\lambda_3 t} - e^{-(\lambda_1+\lambda_2)t} \right) \qquad (30a)$$

The same as the above with switching reliability included.

$$P = e^{-\lambda_1 t} + R_{sw} \frac{\lambda_1}{\lambda_1+\lambda_2-\lambda_3} \left(e^{-\lambda_3 t} - e^{-(\lambda_1+\lambda_2)t} \right) \qquad (30b)$$

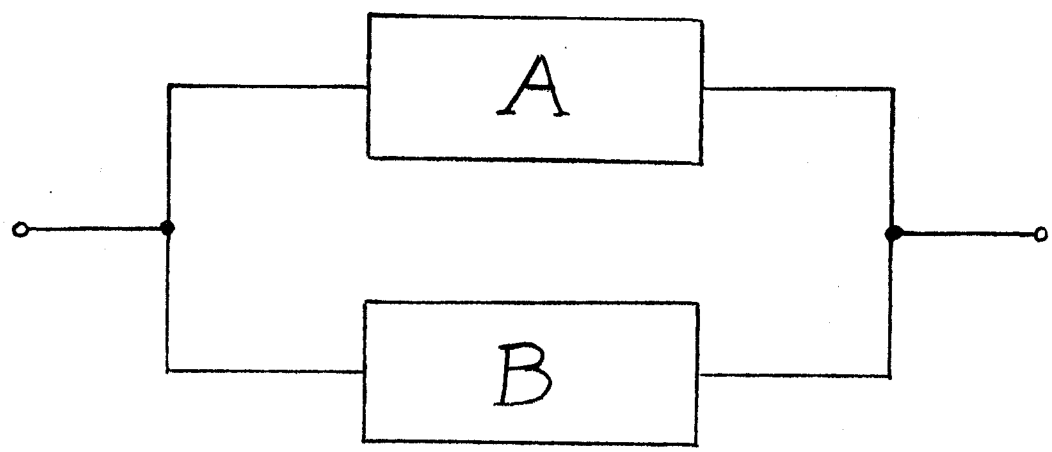
If the switch has failure modes of switching too soon (λ_T) or not switching (λ_s) then

$$P = \left(1 - \frac{\lambda_1\lambda_2 t^2}{2} - \frac{\lambda_1^2 t^2}{2}\right)\left(1 - \lambda_1\lambda_s t^2\right)\left(1 - \lambda_2\lambda_T t^2\right) \qquad (30c)$$

The formulas listed in this appendix are only formulas. Engineering judgment must be used as to which formula applies and when and where modifications to the formula might be needed. See the examples below.

Example 1 Ideal Redundancy

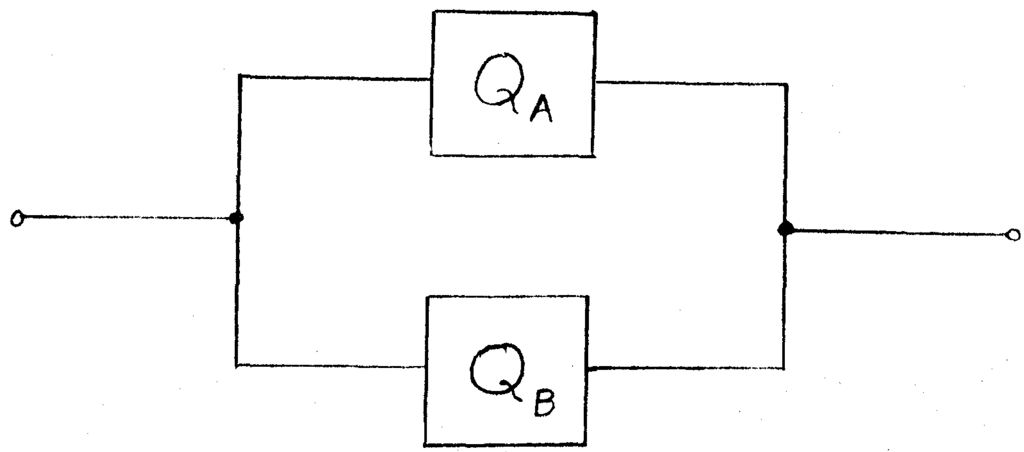
Consider the two subsystems "A" and "B" below which comprise an ideal redundant system: Either "A" or "B" need work to provide the system output and any failure in one will not affect the operation of the other.



Let

Q_A = .01 = Probability of failure of subsystem A

Q_B = .01 = Probability of failure of subsystem B



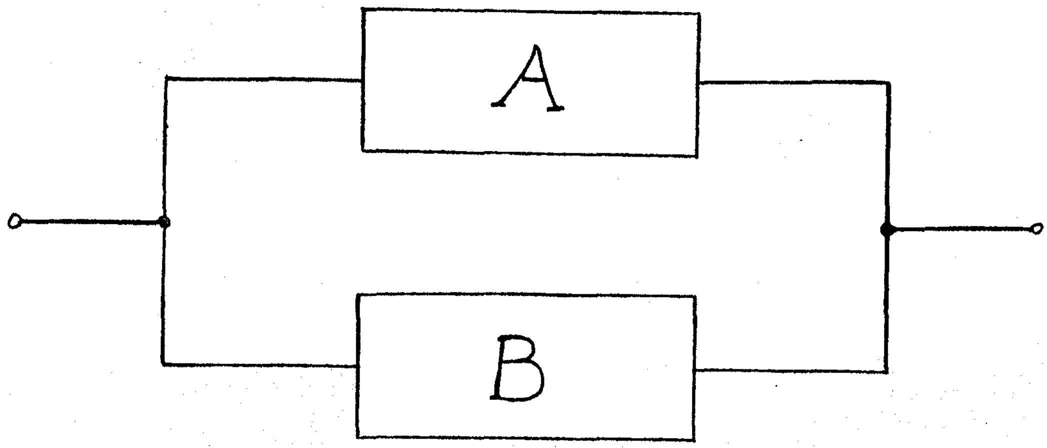
Reliability Block Diagram

Using Equation A 22 the reliability of the above ideal redundant system is:

$$R = 1 - Q_A Q_B = 1 - (.01)^2 = .9999$$

Example 2 Non-Ideal Redundancy

Most redundant systems contain failure modes in which a failure of one subsystem will affect the operation of the other. Such a failure mode would be termed a single point failure mode. An example is shown below. If the output of either subsystem fails low the system output will appear low.



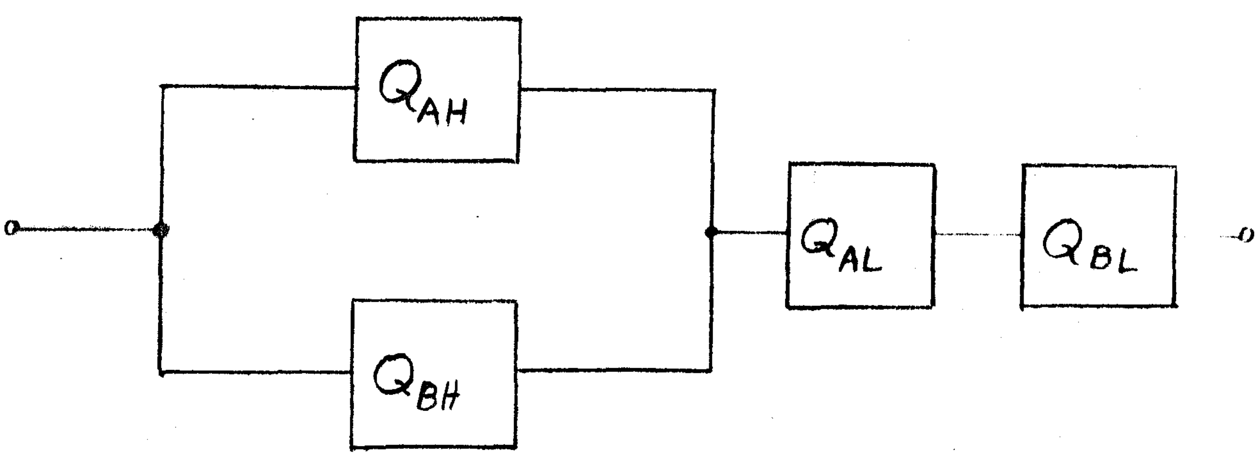
Q_{AL} = Probability that subsystem A will fail low

Q_{AH} = Probability that subsystem A will fail high

Q_{BL} = Probability that subsystem B will fail low

Q_{BH} = Probability that subsystem B will fail high

The reliability block diagram is shown below. Note that the single point failure modes are shown in series.



Since Q_{AL} and Q_{AH} are mutually exclusive

$$R = 1 - Q_{AL}(1-Q_{AH}) - Q_{BL}(1-Q_{BH}) - Q_{AH}Q_{BH}(1-Q_{AL})(1-Q_{BL})$$

Let

$$Q_{AL} = Q_{BL} = Q_{AH} = Q_{BH} = .005$$

$$R = 1 - (.005)(.995) - (.005)(.995) - .005)^2(.995)^2$$

$$R = .995$$

Note that $Q_{AL} + Q_{AH} = Q_A$ of Example 1 and compare this result with the result of Example 1. Each subsystem has the same over-all reliability in each example. The difference is caused by the effect of mode of failure