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Fluids and Combustion Facility Document

Reliability Verification Analysis on the Electrical Power Control Unit (EPCU)

Date: June 26, 2003

Approved by Robert Corban, FCF Deputy Project Manager, Microgravity Science Division, 6700

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Change Record

Rev.	Effective Date	Description
Initial Release	06/26/03	This is the first government release of this analysis. An initial Verification Analysis Report for Reliability Prediction of EPCU by Hamilton-Sundstrand on 2/2/02. Corrections were made throughout all major sections of the report. In particular, the CIR duty cycle was corrected. The MTBF and all reliability estimates associated with the correction in CIR duty cycle were re-calculated. Excel spreadsheets that were used to perform the analytical calculations were included in Appendix E. Appendix F was added to provide an explanation of Simpson's Rule.

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1.0 INTRODUCTION

1.1 Purpose

This Reliability Prediction Analysis is intended to provide an estimate of the reliability of the Electrical Power Control Unit (EPCU) contained in the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). The functions of the EPCU are to provide power control and protection for the power system within the CIR and FIR. The development of the EPCU is managed by NASA's Glenn Research Center (GRC) at Lewis Field. This reliability prediction analysis supports the detailed NASA review of the "Final Reliability Report, Reliability Failure Rate Prediction, Failure Modes and Effects Analysis and Critical Items List for the EPCU" performed by Hamilton Sundstrand.

This reliability prediction analysis is performed to provide the following:

- A verification (or check) of the EPCU reliability and Mean Time Before Failure (MTBF) estimate by Hamilton Sundstrand based on the parameters specified in Appendix C of FCF-SPEC-0010.
- An estimate of the reliability of the EPCU based on projected duty cycles for the EPCU as applied in the CIR and FIR during the on-orbit mission.
- An input to management to be used in conjunction with other types of design and operational data, to aid in upcoming program decisions.
- Recommendations, where applicable, to increase EPCU inherent reliability and effectively spare the EPCU to boost the rack-level operational availability.

1.2 Scope

This analysis is not intended to provide absolute overall reliability prediction values of the EPCU with a high degree of confidence, but a system-level estimate based upon the data obtained from Hamilton-Sundstrand. The theoretical model used in this analysis is based on the exponential distribution which assumes constant failure rates. This analysis is restricted to the EPCU and is not intended as an analysis of other Fluids and Combustion Facility (FCF) sub-systems or space station vehicle hardware of any type. This reliability estimate is not intended to analyze "structure" and does not include FCF software (code), software fault tolerance, or software design to initiate commands and control. It does not include human error, tubing, electrical wiring, electronic enclosures, or mechanical linkages such as power bolts, gears, and cranks.

1.3 Executive Summary

The calculations based upon analytical reliability modeling and Monte-Carlo Failure Simulations using Rapid Availability Prototyping for Testing Operation Readiness (RAPTOR), show that the predicted MTBF of the EPCU lies in the interval between 29, 397 hours and 32, 254 hours for the case of continuous operation. It appears from the results that the EPCU design by Hamilton-Sundstrand meets the reliability requirement as specified in FCF-SPEC-0010. However, the results do not agree with the projected MTBF by Hamilton-Sundstrand of 52, 565 hours for the case of a 100% duty cycle. It appears that Hamilton-Sundstrand "back-calculated" the MTBF from their predicted EPCU reliability as if the entire system could be described by a single exponential function.

A lesson learned is that it is difficult to calculate the MTBF for a unit that has extensive internal redundancy. In the future, reliability requirements for highly redundant subsystems should be set in terms of probability of mission success (Reliability) (R) or in terms of operational availability for restorable systems. It is believed that Hamilton-Sundstrand made their best effort to estimate the MTBF based on what they sincerely believed to be the correct method.

If the intended EPCU *duty cycle* for the CIR and FIR are taken into account, the predicted MTBF is 65, 654 hours for the CIR application and 60, 846 hours for the FIR application. The effective MTBF of the EPCU for the CIR and FIR application are higher because of the substantially lower operating time in these applications.

If a decision is made to operate the EPCU continuously (at a 100% duty cycle) throughout the 10-year mission of the FCF, calculations show that there is a very high probability of failure at 10 years of mission time. In addition, there is a substantial probability of failure at 10 years of mission time for the EPCU at the currently planned duty cycle for the FIR.

A minimum of one spare EPCU should be stored on-orbit to improve the overall FCF operational availability. However, it should be understood that this may not be possible due to constraints on stowage volume for spares and launch mass for spares.

The existing design features of the EPCU were incorporated to protect internal functions from Single Event Upsets (SEUs) and should not be reduced or eliminated in order to reduce the size, mass, or cost of the EPCU. Further design changes that are easy to accomplish, are within the development cost budget and can boost the reliability of the EPCU should be considered.

2.0 REFERENCES

2.1 Applicable Documents

Document Number	Document Title
FCF-DOC-003	Baseline Description Document (BSD) for the CIR, Appendix A
FCF-SPEC-0010	Electrical Power Control Unit Specification
RM-1097A	Electrical Power Control Unit Final EPCU Reliability Report by Hamilton-Sundstrand

2.2 Reference Documents

Document Number	Document Title
	Calculus and Analytic Geometry, Robert C. Fisher and Allen D. Ziebur, Prentice-Hall Inc., Copywrite 1965, Pg. 232.
	Reliability Engineering Handbook, D. Kececioglu, PTR Prentice Hall, 1991
	Reliability Analysis Center Reliability Toolkit: Commercial Practices Edition
	Reliability Analysis Center Manual: Design Reliability Training Course
EPRD 97	Reliability Analysis Center Parts Reliability Data
MIL-HDBK-217F Notice 2	Reliability Prediction of Electronic Equipment
MIL-HDBK-338B	Electronic Reliability Design Handbook - Sections 6.6.4 and 6.4.9.1
NASA/TP-200-207428	Reliability and Maintainability (RAM) Training – Chapter 4
NPRD 95	Reliability Analysis Center Non-Electronic Parts Reliability Data
T-70-48891-007	Handbook of Piece Part Failure Rates

2.3 Acronyms

Acronym	Definition
A/D	Analog-to-Digital
Ao	Availability(operational)
CDMS	Command Data Management System
CIL	Critical Items List
CIR	Combustion Integrated Rack
DOD	Department of Defense
EEE	Electrical, Electronics, Electrochemical
EM	Engineering Model
EPCU	Electrical Power Control Unit
EPS	Electrical Power System
FCF	Fluids and Combustion Facility
FIR	Fluids Integrated Rack
FMEA	Failure Modes and Effects Analysis
FOMA	Fuel-Oxidizer Management Assembly
FPGAs	Field Programmable Logic Arrays
FRPCs	Flexible Remote Power Controllers
GB	Ground Benign
GRC	Glenn Research Center
I.C.	Integrated Circuit
ISS	International Space Station
MDT	Mean Down Time
MM/OD	Micro Meteorite/Orbital Debris
MRDOC	Microgravity Research, Development, and Operations Contract
MRT	Mean Repair Time
MTBDE	Mean Time Between Down Events
MTBM	Mean Time Between Maintenance
MTBF	Mean Time Before Failure
MTTR	Mean Time To Repair
NSPARs	Non-Standard Parts Approval Requests
PCB	Printed Circuit Board
PRACA	Problem Reporting And Corrective Action
R	Reliability
RAC	(DOD) Reliability Analysis Center
RAM	Reliability and Maintainability

Acronym	Definition
RAPTOR	Rapid Availability Prototyping for Testing Operational Readiness
RBD	Reliability Block Diagram
RPC	Remote Power Controller
SAIC	Science Applications International Corporation
SEUs	Single Event Upsets
SF	Space Flight Environment
SPEL	Space Power Electronics Lab

3.0 EPCU SYSTEM DESCRIPTION AND RELIABILITY BLOCK DIAGRAMS

The purpose of the EPCU is to provide power control and protection for the CIR and FIR that includes voltage, current, and temperature protection. The EPCU monitors and conditions the 120Vdc input power (nominal value) that is received from two isolated power buses. Each EPCU in the FCF should provide an output of 3 kilowatts of power to the FCF. The outputs are to be controlled, fault-protected, isolated, and have priority coordinated load sharing.

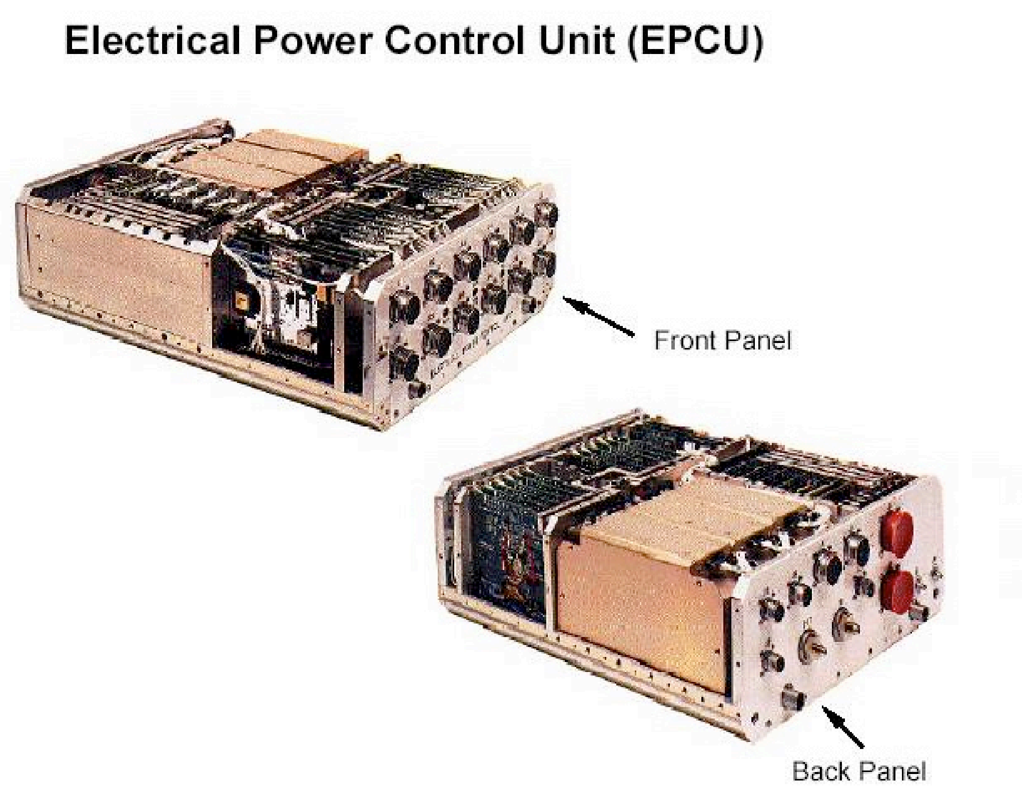


Figure 1 – EPCU System Photograph

The EPCU interfaces with the FCF Command Data Management System (CDMS) via a dual redundant 1553B-interface bus. The 1553 interface provides control and monitoring of the EPCU functions.

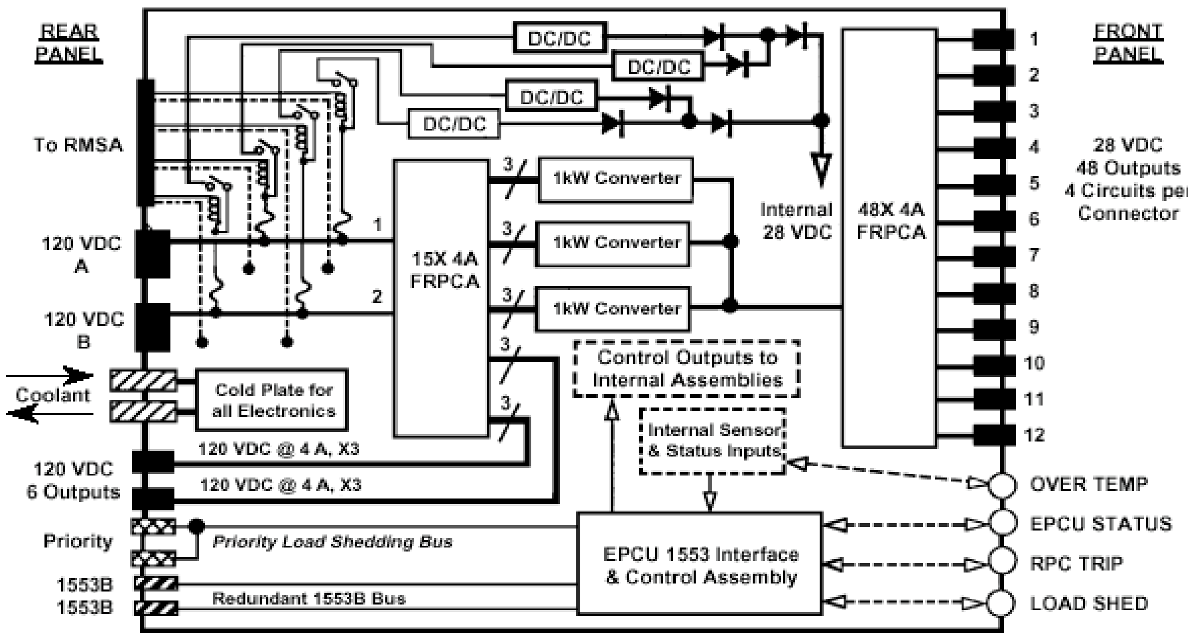


Figure 2 - Schematic – EPCU

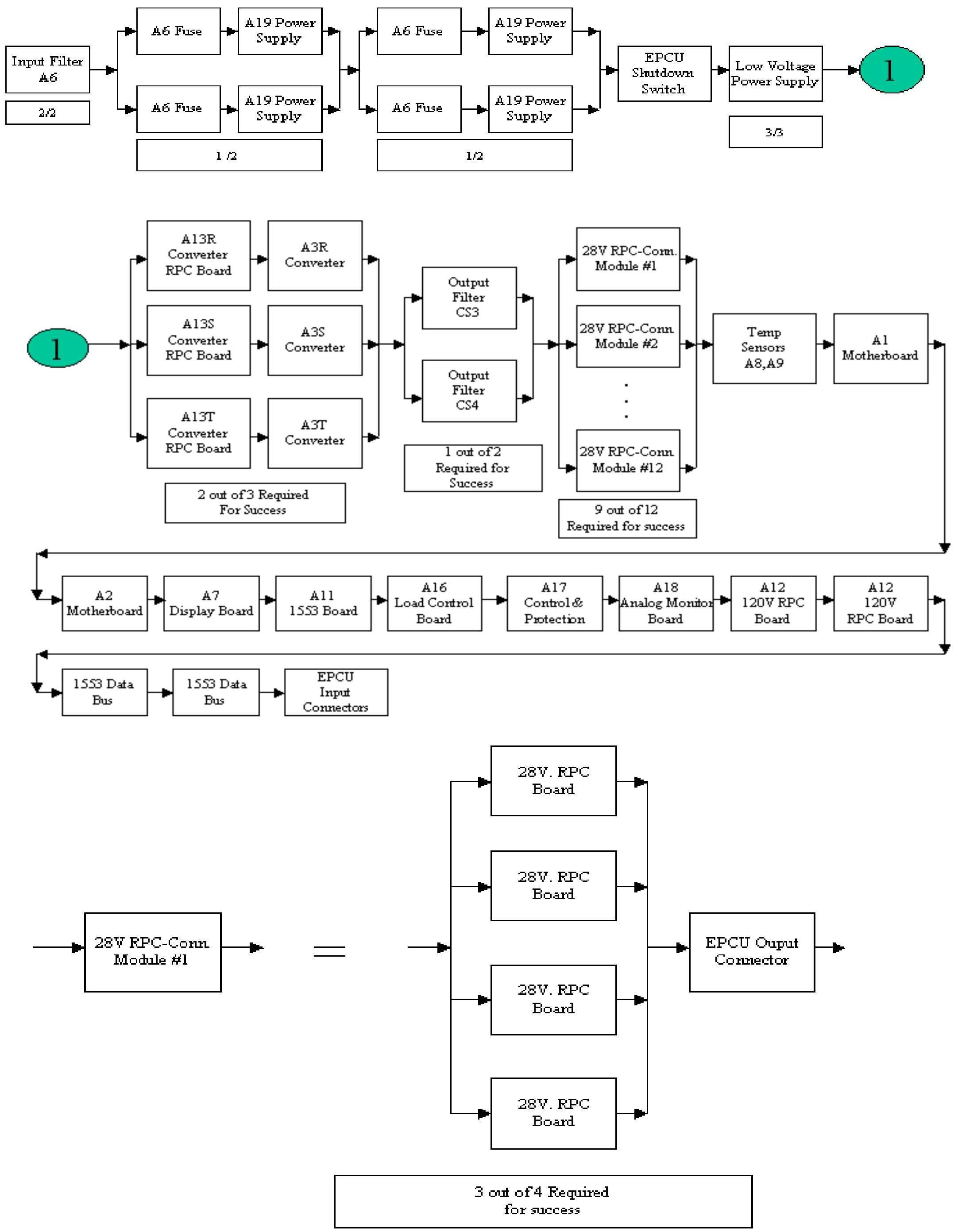


Figure 3 - Reliability Block Diagram

3.1 Functional Description of Major Components

The following table gives a brief functional description of the major components in Part 1 of the EPCU Reliability Block Diagram (RBD).

Block Designator	Title	Basic Function	Redundancy? {If Yes, then type and K out of N required for success}
A6	Input Filter	Filtering, and monitoring of 120Vdc input power from Bus A and B of the International Space Station (ISS)	No
A6	Fuse	Fusing: Overcurrent protection	Yes (active, 1 / 2)
A19	Power Supply	Converting 120Vdc to 28Vdc	Yes (active, 1 / 2)
	EPCU Shutdown Switch	Toggle-like switch to cut-off all power from the EPCU	No
A21	Low voltage Power Supply	Provide the EPCU with various levels of house-keeping power	No
A13R,S,T	Converter Remote Power Controller (RPC) Board	To provide input power to the three 120V to 28V Converters	Yes (active, 2 / 3)
A3R,S, & T	120V to 28V Converters	Provide parallel, 28Vdc @ 1 kW for load sharing	Yes (active, 2 / 3)
CS 3 & 4	Output Filter	Filtering the 28V output and monitoring the load currents supplied to the 28V Flexible Remote Power Controllers (FRPCs)	Yes (active, 1 / 2)
28V RPC-Conn. Modules	28V FRPC/Output Connector Modules	12 Modules: Each “module” is composed of 4 FRPCs tied to an output connector (48 FRPCs and 12 output connectors); the FRPCs provide the 28V, 4 amp EPCU output to J11 through J12 output connectors	Yes (active, 9/12)
A12	120V RPC boards	Provide switchable 120Vdc, 4 amp power outputs through alternate connectors J3 and J4	No
A17	Control & Protection	Control and protection for the 120Vdc input and 28Vdc output including component temperatures and load currents	No
A16	Load Control Board	Control of load allocation, sharing, and trip signal generation	No
A11	1553 I/O Board	Provide EPCU with data bus interface for control and monitoring of data acquisition	Yes, internally dual redundant but modeled as a single block

Block Designator	Title	Basic Function	Redundancy? {If Yes, then type and K out of N required for success}
A18	Analog Buffer Board	Analog-to-Digital Converter function to support monitoring of analog status in the EPCU. A/D conversion provides digital signals that can be transferred on the 1553 bus	No
A1 & A2	Motherboards	Signal command and control	No
A7	Display board	Electronics to support display data	No
1553	Data Bus	Transfer of command, control, and data signals	Yes, treated in the model as a composite non-redundant item
Input Connectors	Input Connectors	Transfer of power into the EPCU from the ISS Electrical Power System (EPS)	No

3.2 Mission Description

The mission of the EPCU is to accept the 120 volt DC input power from the solar array charged battery pack on board the ISS, condition and pass it on or down-convert it to 28 volt DC for use in both the CIR and FIR experimental programs to be executed on orbit aboard the ISS.

4.0 DISCUSSION OF MODELING APPROACH

4.1 Duty Cycles

EPCU Application	Projected Annual Operating Time	Duty Cycle (Operating Time)	Non-Operating Cycle
FCF-SPEC-0010	8, 766 hrs.	1.00000	0.00000
CIR *	2,700 hrs.	0.30801	0.69199
FIR	3,335 hrs.	0.38045	0.61955

* Previously was 864 hrs. but was corrected to account for powering functions other than experiments within the Fuel-Oxidizer Management Assembly (FOMA)

4.2 Methodology

Parts lists and failure rates obtained from MIL-HDBK 217F Notice 2 were totaled to arrive at major component (e.g. PCBs, converters, etc.) failure rates. These failure rates for major components were then converted to MTBFs.

Reliability block diagrams (RBDs) were constructed to represent the success paths for the complex internal redundancy of the EPCU. These RBDs were constructed manually and also by using Rapid Availability Prototyping for Testing and Operational Readiness (RAPTOR).

Two RBDs representing the EPCU design were constructed and evaluated by using RAPTOR. RAPTOR is a software program developed under the auspices of the U.S. Air Force that utilizes a Monte-Carlo failure simulation. It can be used to estimate the system reliability without repair when the mean-time-to-repair (MTTR) input is set at a very high number of hours. The MTTR was set to a value of 9,999,999 hours; this setting simulates a “virtually infinite” repair time that corresponds to a system without repair capability). RAPTOR assumes 100% duty cycle so there is no consideration of the non-operating time portion of the mission. The first RBD was a worst-case model that was constructed to take into account uncertainties. It was noted that the RBD generated by Hamilton-Sundstrand did not address the failure rates of several items. These failure rates could be found in MIL- HDBK-217F Notice 2. The components or parts addressed in MIL-HDBK-217F Notice 2 that were not addressed in the Hamilton-Sundstrand RBD include power connectors, data channel connectors, plated-through holes into which PCB connecting wires are soldered (the wires themselves are considered immune to failure), the motherboard female sockets (unpopulated when the EPCU is unassembled) and the EPCU shutdown switch (though not an integral part of the EPCU, it is essential to EPCU operation). Therefore, a GRC version of the EPCU RBD was generated to include input/output connectors, plated through-holes, unpopulated female connectors on the motherboards and the EPCU shutdown switch. Conservative failure rates per MIL-HDBK-217F Notice 2 were assigned to these items and “worst-case” EPCU reliability was then calculated. A second RBD was constructed that was based on the model developed by Hamilton-Sundstrand.

A modified method of modeling hybrid output A5 PCB reliability was also included. These A5 boards mount four hybrid output devices and associated driver circuitry all controlled by a single control Integrated Circuit (I.C.) called the firmware assembly. Based on the reasoning that total I.C. failure is more likely than partial, the firmware assembly was placed in the RBD separately from and ahead of the A5 board unit that Hamilton-Sundstrand used.

The reliability of the EPCU was also calculated utilizing analytical formulae (binomial expansions) to model the complex internal redundancy of the EPCU (Ref. EPCU Reliability Block Diagrams by Edward Zampino, August 8, 2001, Figure 3 and also Appendices C and E). Reliability at various elapsed mission times was calculated for the 100% duty cycle case as specified in FCF-SPEC-0010, the duty cycle expected for the CIR, and for the expected duty cycle of the FIR. The complex internal redundancy of the EPCU makes it difficult to compute the MTBF of the unit in a direct analytical fashion. It is difficult because the definite integral of the ***entire system reliability function*** from time zero to infinity must be found. However, it was realized that a good approximation of this definite integral could be found by using Simpson’s Rule. This methodology is shown in Appendix F.

4.3 Ground Rules and Assumptions

1. Maintenance procedures or availability of contingency or off-nominal crew (flight or ground) procedures shall not be considered as “unlike” redundancy or as a valid success path in the reliability block diagram of this analysis.
2. The system boundary of this analysis is the EPCU itself and will not extend beyond input/output connectors/connections of the EPCU.
3. This analysis shall not include a reliability function for micro-meteor/orbital debris (MM/OD) since the Space Station program has stipulated that MM/OD will not be included as a part of reliability models and will be a separate analysis for the ISS.
4. Software code and human action were not to be included as part of this analysis and should be covered by software product assurance and safety analyses.

5. The EPCU flight hardware will be tested on the ground prior to placement in storage to verify that it performs its intended functions. In particular, this refers to acceptance testing, where failures will be analyzed, fixed, and the fixes will be verified. All Problem Reporting and Corrective Action (PRACA) reports on the EPCU will be closed out.
6. Flight hardware will be subjected to at least 100 hours of burn-in testing. Controls will be implemented to protect the flight hardware during its storage phase (prior to launch) from contamination, chemical deterioration, and induced damage during handling. The storage environment will be temperature and humidity controlled. The EPCU will be inspected and tested following its extraction from storage to verify proper function. Any major defects or failures must be corrected, and the EPCU re-tested to confirm the fix. The flight hardware design will be qualified to survive launch and assent environment and to operate when called upon on-orbit. Therefore, it is assumed that reliability is one prior to the first usage of the EPCU on-orbit, since the effects of the launch and ascent environments are assumed to be negligible due to: a) proper protection and stowage and b) minimal exposure time to these environments when compared to the overall mission time on-orbit.
7. EPCU flight hardware components will operate over the useful life region of the “bathtub” failure rate curve but will eventually drift out of the specification.
8. The EPCU will be replaced as a unit on-orbit; spares will be lifted and stowed on-orbit.
9. Failed EPCUs will be returned from orbit for ground-based repair.
10. Applicable environments used in this analysis are derived from MIL-HDBK-217F, Notice 2
    - SF = Space Flight Environment (earth orbital, vehicle in space operations, includes satellites and shuttles/vehicles).
    - GB = Ground Benign (moderately controlled environment, and possible installation in uncontrolled areas). Other detailed assumptions and notes for individual components of the system, which were used to derive failure rates in the operating and non-operating environments, are provided in the applicable appendices.

5.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of Results

Table 1: EPCU Reliability Estimates Based on Analytical Model

Application and Duty Cycle	Predicted MTBF* (hours)	R(t) at t=1 year	R(t) at t=2 years	R(t) at t=3 years	R(t) at t=5 years	R(t) at t=10 years
FCF-SPEC-0010 Application (100% duty cycle)	29, 397	0.8434	0.6955	0.5428	0.2228	0.0019
CIR Application (2,700 hrs. per year)	65,654	0.9479	0.8964	0.8460	0.7483	0.4974
FIR Application (3,335 hrs. per year)	60,846	0.9368	0.8746	0.8141	0.6968	0.3796

*Based on Simpson’s Rule Approximation for the definite integral of the EPCU reliability function and a total mission time of 87, 660 hours or 10 years.

Table 2: RAPTOR Monte-Carlo Failure Simulation Results Using Worst-Case RBD

Number of Mission Simulation Runs RAPTOR treats duty cycle as 100% or continuous 24 hr. per day operation	MTBDE Mean-Time-Between Downing Events for EPCU ≈ MTBF *	Reliability R(t) where t = 19,872 hrs. as per FCF-SPEC- 0010	Reliability R(t) where t = 87, 660 hrs
1000 missions	31, 724 hrs.	0.6420	0.0240
10,000 missions	32, 254 hrs.	0.6589	0.0241
100,000 missions	32, 002 hrs.	0.6499	0.0221

* These estimates by RAPTOR based on a mission time of 87,660 hours or 10 years.

Table 3: RAPTOR Monte-Carlo Failure Simulation Results Using Hamilton-Sundstrand RBD

Number of Mission Simulation Runs RAPTOR treats duty cycle as 100% or continuous 24 hr. per day operation	MTBDE Mean-Time-Between Downing Events for EPCU ≈ MTBF *	Reliability R(t) where t = 19,872 hrs. as per FCF-SPEC- 0010	Reliability R(t) where t = 87, 660 hrs
1000 missions	33,400 hrs.	0.6630	0.0250
10,000 missions	34,010 hrs.	0.6803	0.0320
100,000 missions	34,023 hrs.	0 .6811	0.0286

* These estimates by RAPTOR based on a mission time of 87,660 hours or 10 years.

5.2 Conclusions

The calculations based upon analytical reliability modeling (Binomial expansions to describe redundancy and the exponential distribution) as well as Monte-Carlo Failure Simulations using RAPTOR, show that the predicted MTBF of the EPCU lies in the interval between 29, 397 hours and 32, 254 hours. This prediction is based on an assumed total mission time of 87, 600 hours or 10 years and also assumes a duty cycle of 100% (24 hours per day operation).

RAPTOR simulations utilizing the reliability block diagram by Hamilton-Sundstrand to describe the EPCU internal configuration (success paths) yields a predicted MTBF that lies in the interval between 33,400 hours and 34,023 hours. These results do not agree with the projected MTBF by Hamilton-Sundstrand of 52, 565 hours for the case of a 100% duty cycle.

It appears These results that the EPCU design by Hamilton-Sundstrand essentially meets the reliability prediction requirement (design target) as specified in FCF-SPEC-0010. When the intended duty cycles of the CIR and the FIR of the FCF are taken into account, the effective MTBF is somewhat higher than the value of 30,000 hours as specified in FCF-SPEC-0010. These effective MTBFs are higher because the required operating time (duty cycles) of the EPCU for actual application in the CIR and FIR is substantially lower than the 100% duty cycle case. If a decision is made to operate the EPCU with a

100% duty cycle, These calculations show that there is a very high probability of failure at 10 years of mission time. In addition, there is a substantial probability of failure at 10 years of mission time for the EPCU at the currently planned duty cycle for the FIR.

As a side note, RAPTOR simulations were also conducted using failure-terminated simulations rather than time-terminated. The block inter-dependency was also disabled for overall system operation. However, it was found that the results were very similar to those obtained with time-terminated simulations.

5.3 Recommendations

In the process of performing this study, it was learned that the EPCU system design contains particular features that support the current level of reliability. These are:

- The field programmable logic arrays (FPGAs) were designed with triple redundancy in all logic.
- The above redundancy was implemented on the qual unit to mitigate the effect of SEUs on logic gates within the FPGAs.
- The 1553 bus interface has dual redundancy.
- The design implements RAM checking (parity checks/memory checks) and can shift programming to other sections of memory if SEUs are detected.

It was learned that the following controls were implemented for Electrical, Electronic, Electrochemical (EEE) parts selection used in the design:

- EEE parts were, in general, selected from the Hamilton-Sundstrand Preferred Parts List or GSFC PPL-21.
- Parts selected that were not on GSFC PPL-21 were controlled by Non-Standard Parts Approval Requests (NSPARs).
- Parts/components on NSPARs were approved according to the following criteria:
  - manufacturer history of quality
  - technology and industry trends
  - package type and manufacturability
  - operating parameter ranges for the parts (temperature, voltage, current.
- The MAJORITY of the EEE parts selected for the EPCU are Mil-STD parts estimate is roughly about 80%). The EEE parts selected have been essentially at Grade 2.
- A de-rating analysis of electronic parts used in the EPCU was performed by Hamilton-Sundstrand.

It is recommended that all redundancy and other design features should be retained in the EPCU design to support the current level of reliability. Internal redundancy and other design features that were incorporated to protect the EPCU functions from SEUs should not be reduced or eliminated in order to reduce the size, mass, or cost of the EPCU. Further design changes that are easy to accomplish and are within the development cost budget but can boost the reliability of the EPCU should be implemented. It is imperative that the FCF system operational analysis and spares projection must include the EPCU. In particular, Northrop-Grumman/Hernandez Eng. Inc. should pay particular attention to how the reliability of the EPCU impacts their mitigation plan for FCF RISK 115. A minimum of one spare EPCU should be stored on-orbit because power is absolutely critical to the capability to conduct science.

APPENDIX A - RELIABILITY BLOCK DIAGRAMS (RBD) AND PREDICTION WORKSHEETS

The following RDBs were prepared by Hamilton-Sundstrand. The Raptor Models were developed by Science Applications International Corporation (SAIC).

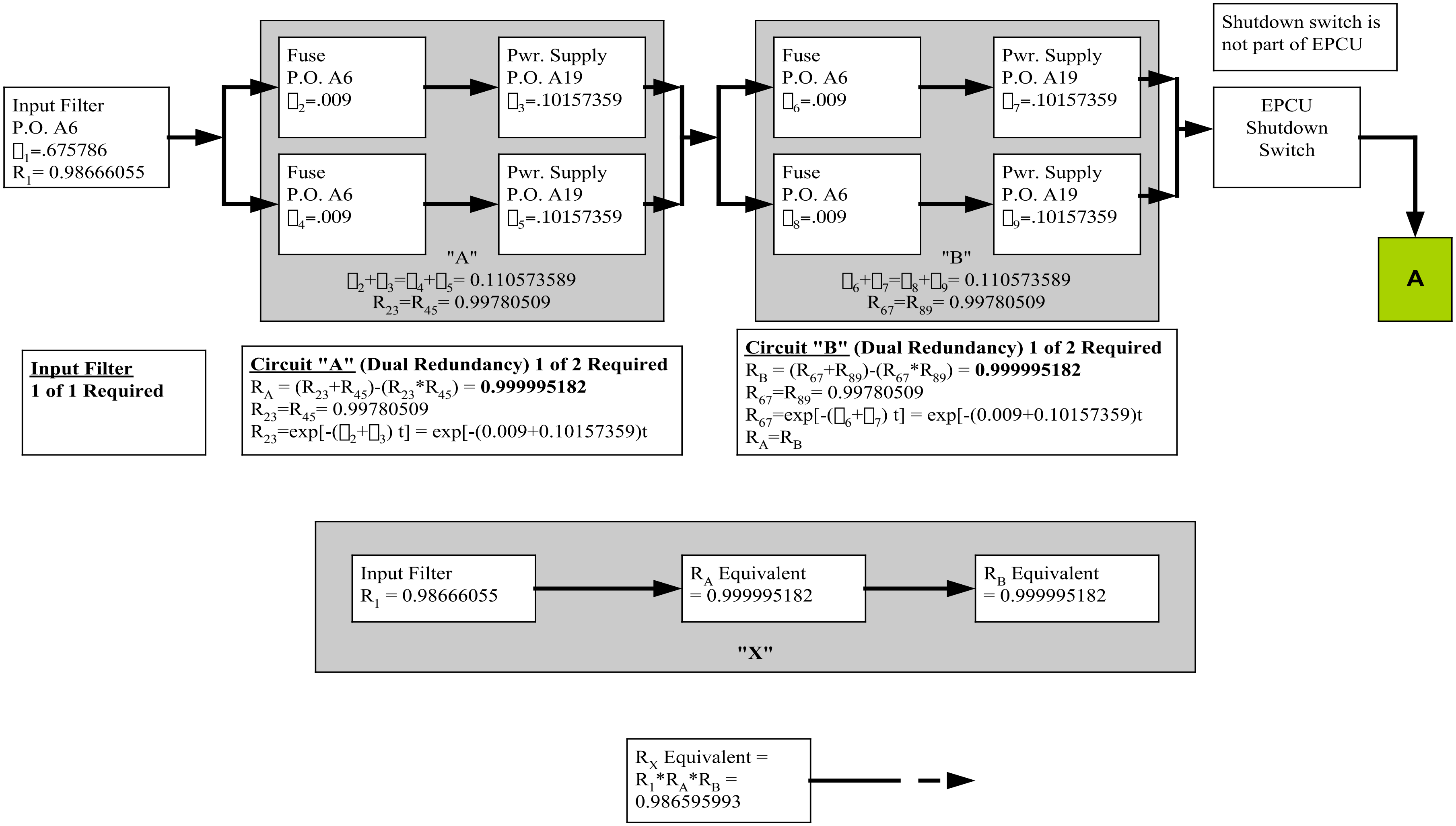


Figure 4 – Revised EPCU RDB – Page 1

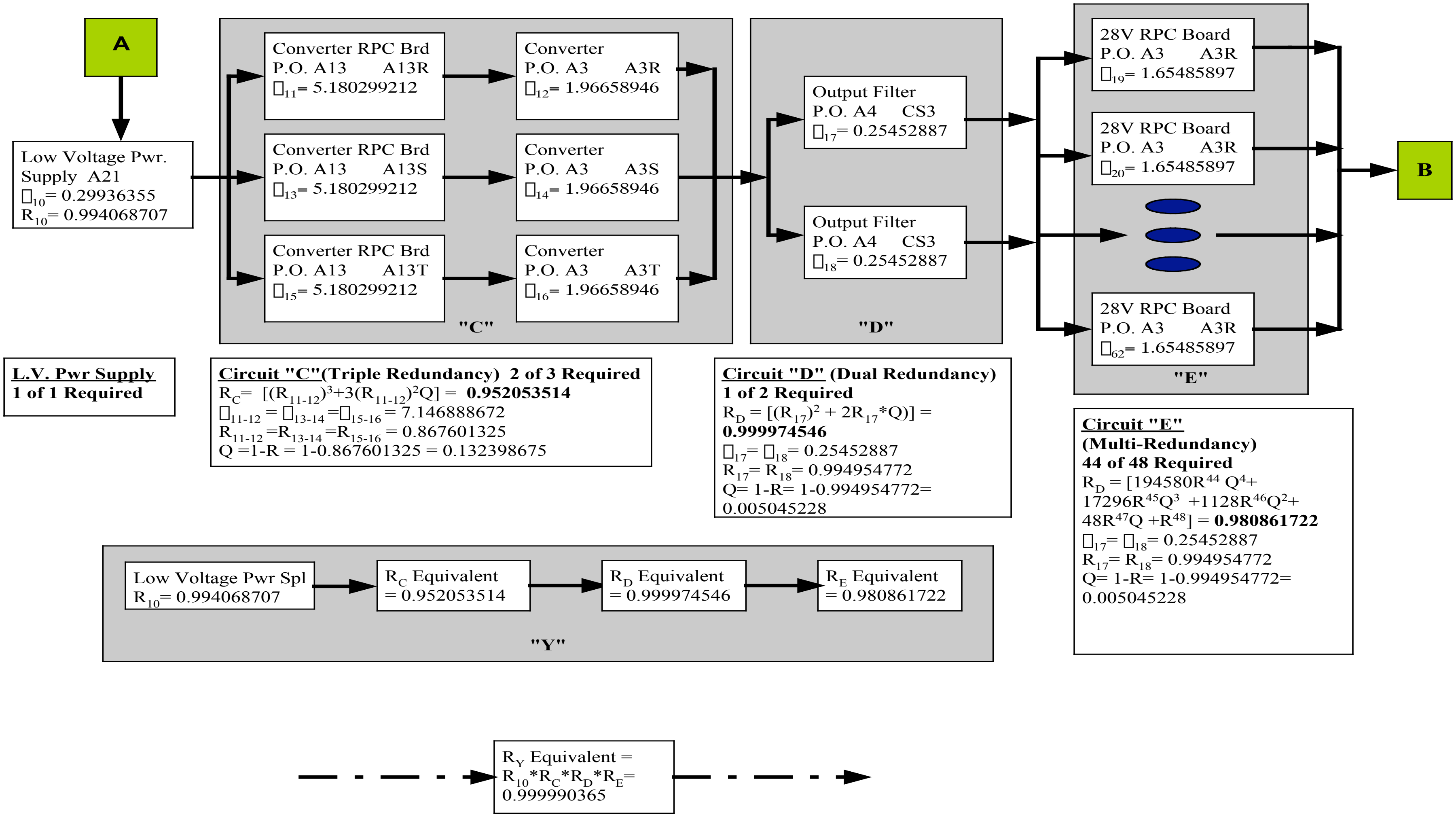


Figure 5 – Revised EPCU RDB – Page 2

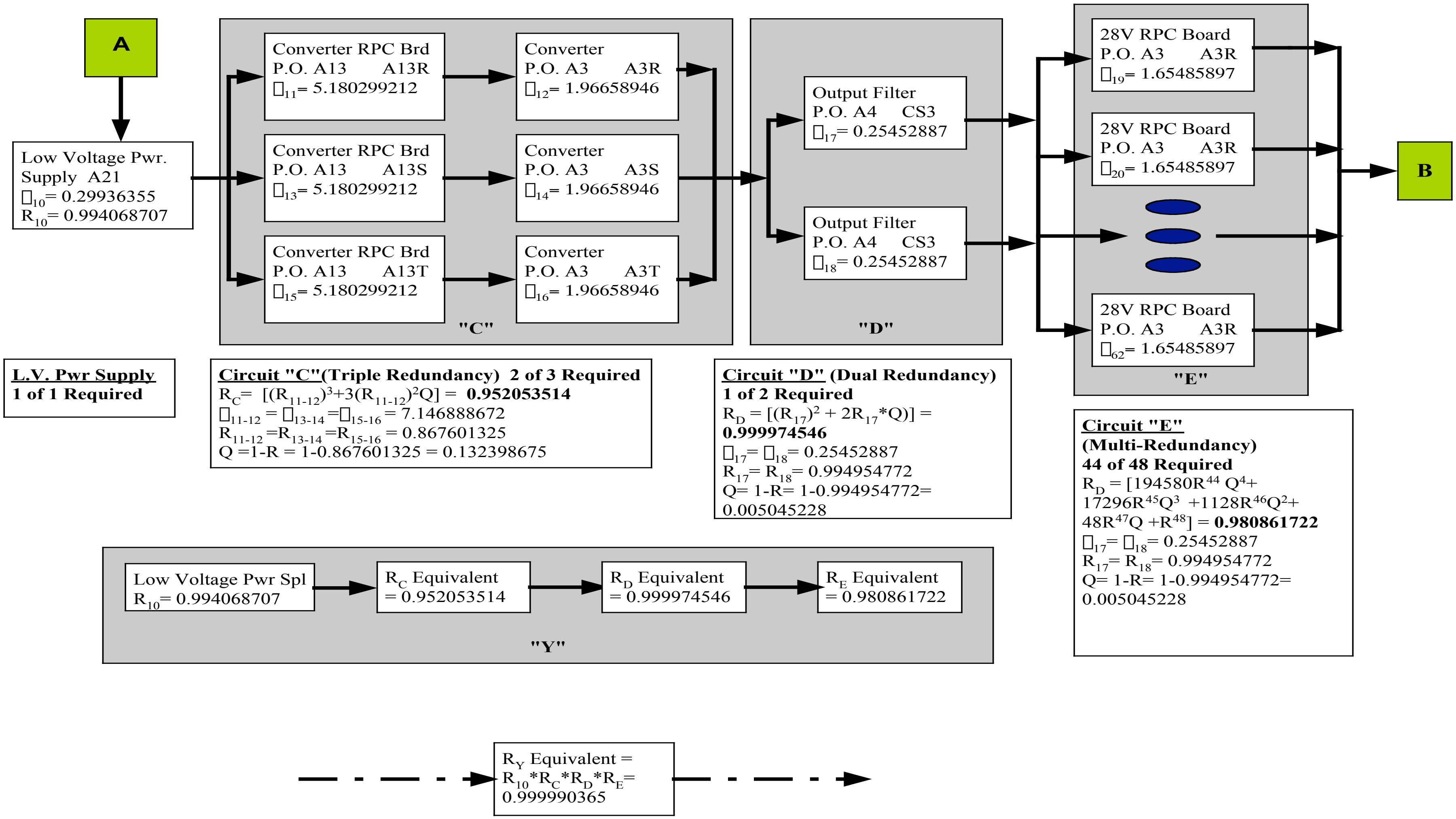


Figure 6 – Revised EPCU RDB – Page 3

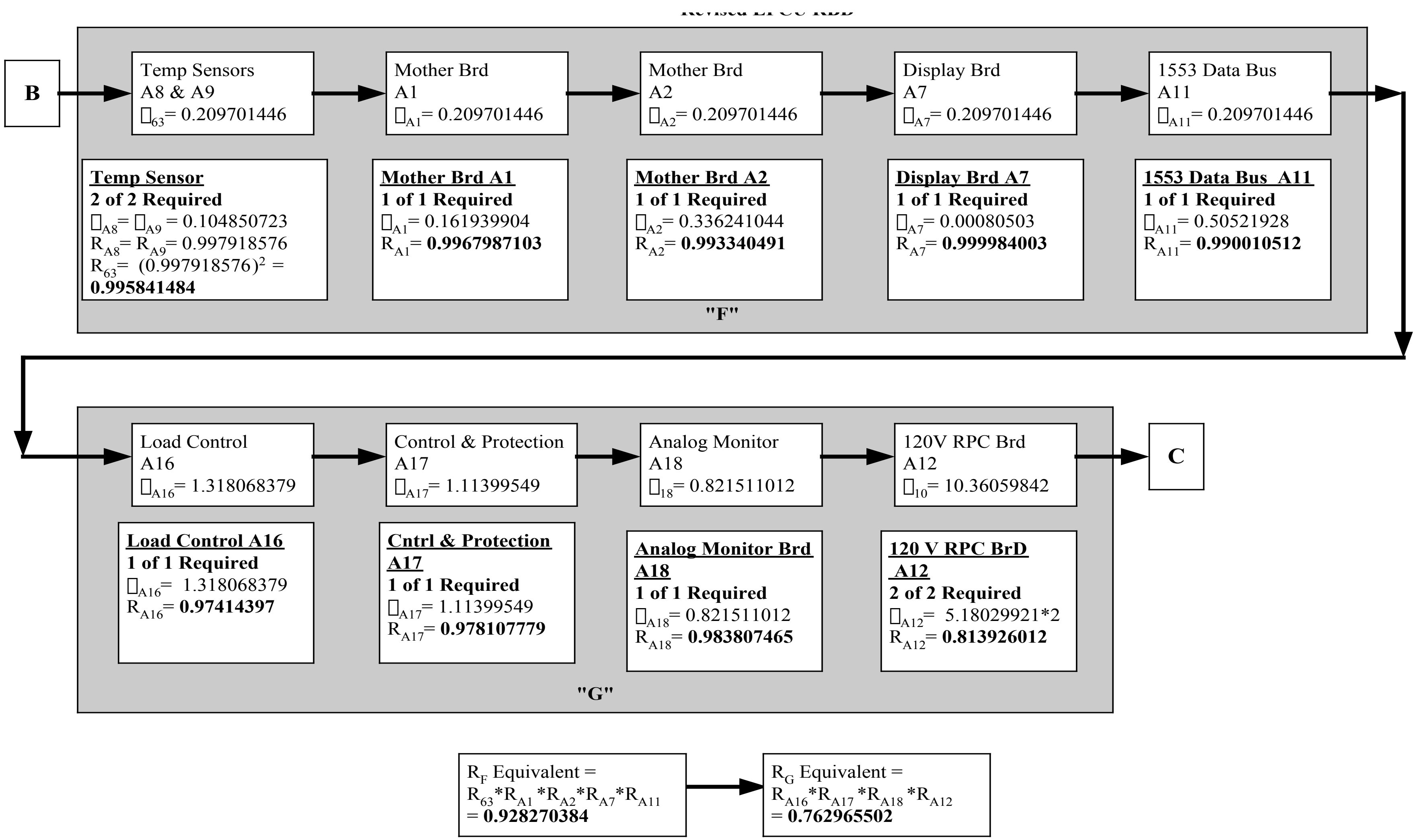


Figure 7 – Revised EPCU RDB – Page 4

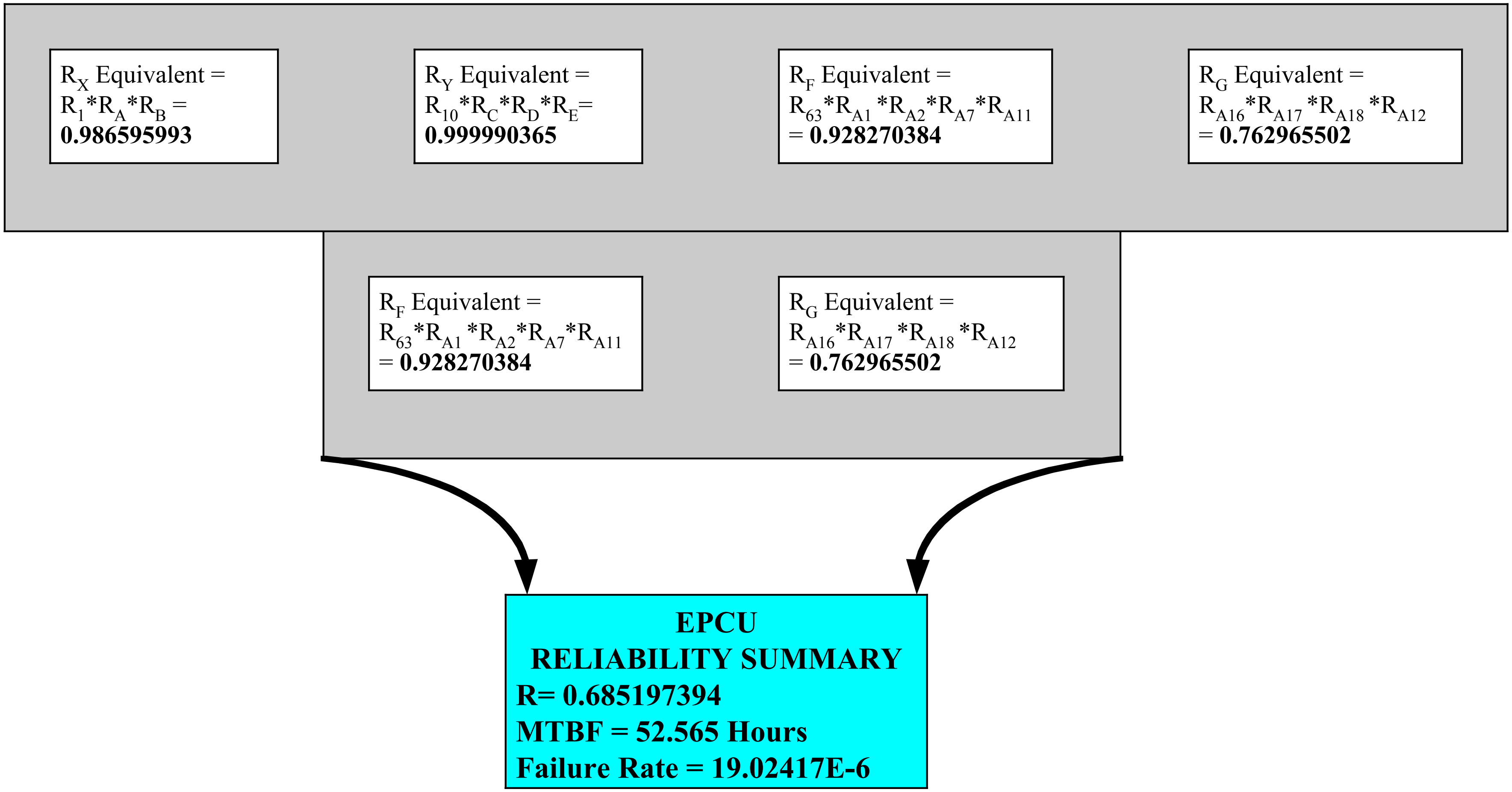


Figure 8 – Revised EPCU RDB – Page 5 (Summary)

Reliability Calculations Per H-S Revised RBD (Exponential Method)

Assy	Name	Failure Rate per Million Hr	Qty	Total F.R. per Million Hr	R = Mission Reliability	Q = 1 - Rel	Redundancy Level	EPCU Reliability	
A1	Mother Board	0.161939904	1	0.161939904	0.996787103	0.003212897	1	0.996787103	
A2	Mother Board	0.336241044	1	0.110573589	0.997805094	0.002194906	1	0.997805094	
A6	Input Filter	0.675786	1	0.675786	0.98666055	0.01333945	1	0.98666055	
A6	Fuses	0.009	4	0.036	0.999284864	0.000715136			
A19	Power Supply	0.406294358	1	0.406294358	0.991958625	0.008041375			
	1/4 A6 Fuses / A19	0.442294358	0.25	0.110573589	0.997805094	0.002194906	(1/2)*(1/2)	0.999990365	
A21	Power Supply	0.299363555	1	0.299363555	0.994068707	0.005931293	1	0.994068707	
A8/9	Temp Sensors	0.104850723	2	0.209701446	0.995841484	0.004158516	1	0.995841484	
A7	Display Board	0.00080503	1	0.00080503	0.999984003	1.59974E-05	1	0.999984003	
A11	1553 Board	0.505219281	1	0.505219281	0.990010512	0.009989488	1	0.990010512	
A16	Load Control Board	1.318068379	1	1.318068379	0.974147397	0.025852603	1	0.974147397	
A17	Control and Protection	1.113899549	1	1.113899549	0.978107779	0.021892221	1	0.978107779	
A18	Analog Monitor Board	0.821511012	1	0.821511012	0.983807465	0.016192535	1	0.983807465	
A12	120V RPC Board	5.180299212	2	10.36059842	0.813926012	0.186073988	1	0.813926012	
A3	Converter	1.96658946	3	5.899768379	0.889371543	0.110628457			
A13	Converter RPC Board	5.180299212	3	15.54089764	0.734306533	0.265693467			
	Conv / RPC	7.146888672	1	7.146888672	0.867601326	0.132398674	(2/3)	0.952053514	
A4	Output Filter	0.509057741	1	0.509057741	0.989934999	0.010065001			
	1/2 Output Filter	0.509057741	0.5	0.25452887	0.994954772	0.005045228	(1/2)	0.999974546	
A5	28V RPC Board	6.61943588	1	6.61943588	0.876742951	0.123257049			
	1/4 28V RPC Board	6.61943588	0.25	1.65485897	0.967649487	0.032350513	(44/48)	0.980861722	
						EPCU Reliability		0.685197394	
Mission Time		19872							
Redundancy Formulas:						**EPCU Failure Rate**		19.0241705	$(\times 10^{-6})$
(1/2)*(1/2)		$(1 - Q^2)^2$							
(2/3)		$R^3 + 3R^2Q$				**EPCU MTBF**		52564.70972	hours
(1/2)		$R^2 + 2RQ$							
(44/48)		$194580R^{44}Q^4 + 17296R^{45}Q^3 + 1128R^{46}Q^2 + 48R^{47}Q + R^{48}$							

Verification: Reliability Calculations for the EPCU Results

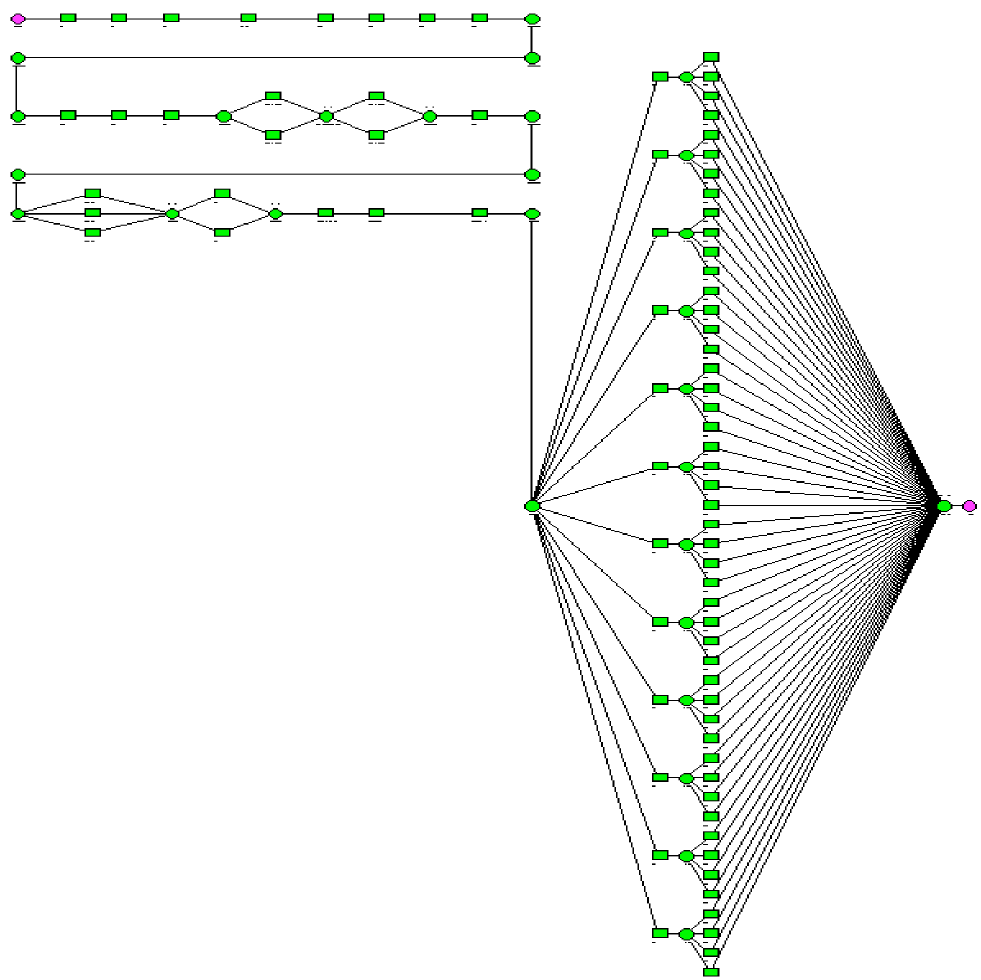
Note: Worst Case Calculations Per GRC Developed RBD

Results of Exponential Calculations Based on a Mission Time of 19,872 hrs as specified id FCF-SPC-0010
(Assumes that 44 out of 48 output channels must operate for success)

Assy.	Name	Failure Rate (xE-6hr)	Qty	Total F.R. (xE-6hr)	R=Mission Reliability	Q=1-Rel.	Redun-dancy	EPCU Reliability
A1	Motherboard	0.50506045	1	0.50506045	0.990013637	0.009986363	1	0.990013637
A2	Motherboard	1.2512262	1	1.2512262	0.975442205	0.024557795	1	0.975442205
A6	Input Filter	0.7027863	1	0.7027863	0.9861313	0.0138687	1	0.9861313
A6	Fuses	0.009	4	0.36	0.992871608	0.007128392		
A19	Power Supply	0.406294358	1	0.406294358	0.991958625	0.008041375		
(A6F/A19)(1/4)	A6 Fuses/A19(1/4="unit")	0.442294358	0.25	0.11057359	0.997805094	0.002194906	(1/2)*(1/2)	1
A21	Power Supply	0.299363555	1	0.299363555	0.994068707	0.005931293	1	0.994068707
A7	Display Board	0.00080503	1	0.00080503	0.999984003	1.59974E-05	1	0.999984003
A8/9	Temperature Sensors	0.104850723	2	0.209701446	0.995841484	0.004158516	1	0.995841484
A11	1553 Board	0.505219281	1	0.505219281	0.990010512	0.009989488	1	0.990010512
A16	Load Control Board	1.318068379	1	1.318068379	0.974147397	0.025852603	1	0.974147397
A17	Control and Protection	1.113899549	1	1.113899549	0.978107779	0.021892221	1	0.978107779
A18	Analog Motherboard	0.821511012	1	0.821511012	0.983807465	0.016192535	1	0.983807465
A12	120V RPC Board	5.180299212	2	10.36059842	0.813926012	0.186073988	1	0.813926012
A3	Converter	1.96658946	3	5.899768379	0.889371543	0.110628457		
A13	Converter RPC Board	5.180299212	3	15.54089764	0.734306533	0.265693467		
(A3/A13)	Converter/RPC "unit"	7.146888672	1	7.146888672	0.867601326	0.132398674	(2/3)	0.952053514
A4	Output Filter	0.509057741	1	0.509057741	0.989934999	0.010065001		
	1/2 Output Filter	0.509057741	0.5	0.25452887	0.994954772	0.005045228	(1/2)	0.999974546
A5(added)	28V RPC Bd Contr.Assy.	0.087809	12	1.053708	0.979278419	0.020721581		0.979278419
A5a	28V RPC Board	6.61943588	1	6.61943588	0.876742951	0.123257049		
	1/4 28vRPC Board	6.61943588	0.25	1.65485897	0.967649487	0.032350513	(44/48)	0.980861722
A20(added)	I/O Connectors (all)	0.054	1	0.054	0.998927488	0.001072512		0.998927488
A22(added)	EPCU Shutdown Sw.	0.05	1	0.05	0.999006893	0.000993107		0.999006893
A24(added)	Pltd.-Through Holes	0.16632	1	0.16632	0.996700345	0.003299655		0.996700345
Mission Time		19872 hrs				EPCU Reliability		0.647671371
Redundancy Formulas:								
(1/2)*(1/2)		(1-Q^2)^2				EPCU Failure Rate		21.85848709
(2/3)		R^3+3R^2Q						
(1/2)		R^2+2R^2				EPCU MTBF	(hrs)	45748.8204
(44/48)		194580^44Q^4+17296R^45Q^3+1128R^46Q^2+48R^47Q+R^48						

Results of RAPTOR Calculations

RAPTOR Worst-Case RBD



RAPTOR Results Using Worst-case RBD 19872 hr. mission time

The next three tables show, respectively, results from 1000, 10000, and 100000 mission repetitions

Mon Oct 01 14:50:48 2001 Results Table: Worst-case RBD/ 19872 hr. mission Results from 1000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	1583785.31	1923739.26	3300980.05	454835.89
Ao	0.000965321	0.81219352	1	0.303340568
MTBDE	19.182867	>16139.909642	>19872.000000	n/a
MDT(358runs)	19.351653	10424.8334	19852.81713	5632.771872
MTBM	19.182867	>10274.829976	>19872.000000	n/a
MRT(925runs)	0	0	0	0
%GreenTime	0.096532	36.196188	100	29.808959
%YellowTime	0	45.023164	99.782528	34.361884
%RedTime	0	18.780648	99.903468	30.334057
SystemFailures	0	0.358	1	0.479412
R(t=19872.000000)=0.642000				

Mon Oct 01 18:15:51 2001 Results Table: Worst-case RBD/ 19872 hr. mission Results from 10000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	1583785.31	1921125.39	3317452.68	461503.25
Ao	0.000071204	0.827278965	1	0.292353209
MTBDE	1.414976	>16439.687609	>19872.000000	n/a
MDT(3411runs)	10.802342	10062.48136	19870.58502	5677.53121
MTBM	1.414976	>10350.338222	>19872.000000	n/a
MRT(9136runs)	0	0	0	0
%GreenTime	0.00712	37.619898	100	30.896184
%YellowTime	0	45.107998	99.986214	34.536941
%RedTime	0	17.272103	99.99288	29.235321
SystemFailures	0	0.3411	1	0.474079
R(t=19872.000000)=0.658900				

Fri Oct 05 08:06:46 2001 Results Table: Worst-case RBD/ 19872 hr. mission Results from 100000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	1577257.25	1930666.85	3318350.5	469203.72
Ao	0.000002673	0.824309415	1	0.293815736
MTBDE	0.053125	>16380.676697	>19872.000000	n/a
MDT(35007runs)	0.888851	9973.214795	19871.94688	5721.593453
MTBM	0.053125	>10310.947698	>19872.000000	n/a
MRT(91198runs)	0	0	0	0
%GreenTime	0.000225	37.688301	100	31.001903
%YellowTime	0	44.74264	99.999775	34.697779
%RedTime	0	17.569058	99.999733	29.381574
SystemFailures	0	0.35007	1	0.476992
R(t=19872.000000)=0.649930				

RAPTOR Results Using Worst-case RBD 87660 hr. mission time

The next three tables show, respectively, results from 1000, 10000, and 100000 mission repetitions

Thu Nov 08 12:40:31 2001 Results Table: Worst-case RBD/ 87660 hr. mission Results from 1000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	7022834.71	9479078.62	13971401.68	1625557.97
Ao	0.000218832	0.361901207	1	0.25645116
MTBDE	19.182867	>31724.259851	>87660.000000	n/a
MDT(976runs)	1673.528038	57311.20917	87640.81713	20951.62743
MTBM	19.182867	8463.628608	40942.17654	5302.098335
MRT	0	0	0	0
%GreenTime	0.021883	8.873112	64.315832	8.666621
%YellowTime	0	27.317009	99.763775	24.446487
%RedTime	0	63.809879	99.978117	25.645116
SystemFailures	0	0.976	1	0.153049
R(t=87660.000000)=0.024000				

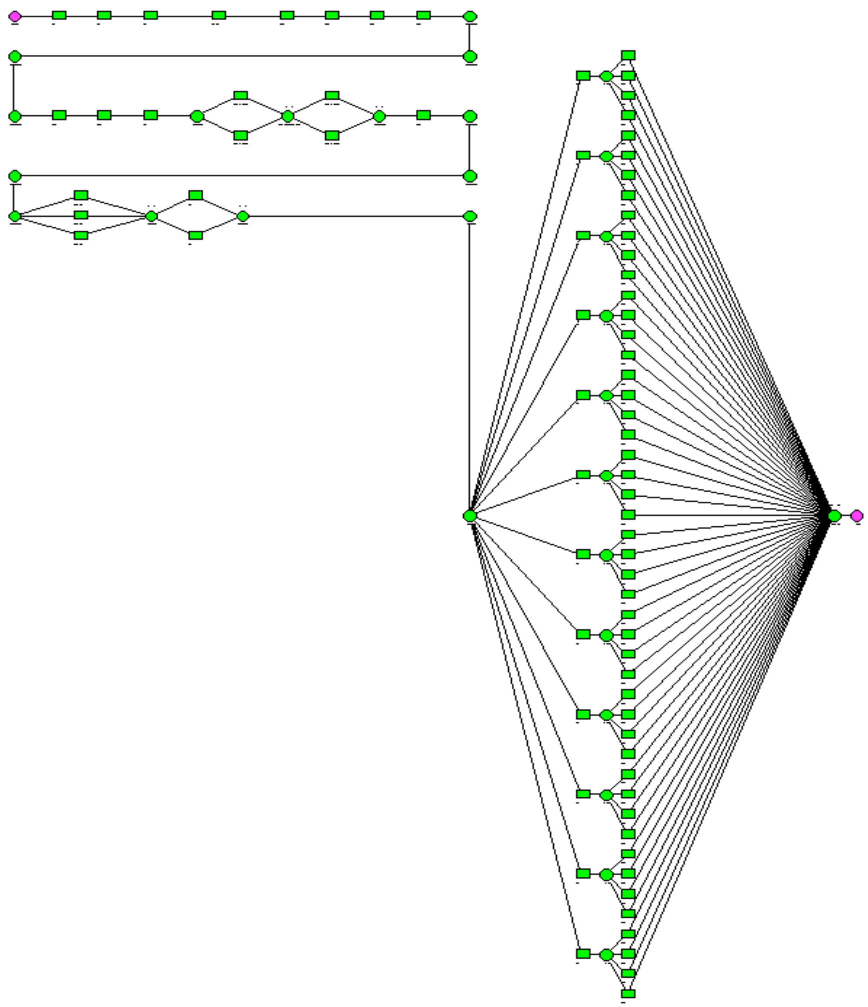
Mon Oct 01 17:31:06 2001 Results Table: Worst-case RBD/ 87660 hr. mission Results from 10000 run(s)

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	6987234.15	9515307.65	14398262.07	1591118.75
Ao	0.000016141	0.367944574	1	0.251430742
MTBDE	1.414976	>32254.021405	>87660.000000	n/a
MDT(9759runs)	4.145656	56774.23772	87658.58502	20496.20958
MTBM	1.414976	>8629.522692	>87660.000000	n/a
MRT(9999runs)	0	0	0	0
%GreenTime	0.001614	9.321614	100	9.243813
%YellowTime	0	27.472843	99.961544	23.538398
%RedTime	0	63.205543	99.998386	25.143074
SystemFailures	0	0.9759	1	0.15336
R(t=87660.000000)=0.024100				

Fri Oct 05 16:26:40 2001 Results Table: Worst-case RBD/ 87660 hr. mission Results from 100000 run(s)

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	6925463.9	9509824.48	14398262.07	1592306.56
Ao	0.000000606	0.365071305	1	0.250615079
MTBDE	0.053125	>32002.150604	>87660.000000	n/a
MDT(97787runs)	2.223151	56917.43217	87659.94688	20539.31658
MTBM	0.053125	>8586.461221	>87660.000000	n/a
MRT(99992runs)	0	0	0	0
%GreenTime	0.000051	9.369566	100	9.366438
%Yellow Time	0	27.137565	99.990819	23.385787
%Red Time	0	63.492869	99.999939	25.061508
R(t=87660.000000)=0.022130				

RAPTOR RBD Corresponding to H-S Proposed RBD



RAPTOR Results Using H-S RBD 19872 hr. mission time

The following RAPTOR Runs Were Executed To Verify H-S Exponential Calculations**.** The next three tables show, respectively, results from 1000, 10000, and 100,000 mission repetitions.

Mon Oct 01 15:25:32 2001 Results Table: H-S RBD/ 19872 hr. mission Results from 1000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	1530695.55	1857364.35	3164254.77	454794.58
Ao	0.000523557	0.834541195	1	0.286978063
MTBDE	10.404129	>16584.002646	>19872.000000	n/a
MDT(337runs)	58.788904	9756.668705	19861.59587	5778.624719
MTBM	10.404129	>10712.905651	>19872.000000	n/a
MRT(911runs)	0	0	0	0
%GreenTime	0.052356	37.862916	100	30.512012
%YellowTime	0	45.591204	99.923114	34.515542
%RedTime	0	16.54588	99.947644	28.697806
SystemFailures	0	0.337	1	0.472685
R(t=19872.000000)=0.663000				

Mon Oct 01 19:16:05 2001 Results Table: H-S RBD/19872 hr. mission Results from 10000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	1530695.55	1834204.37	3191368.71	435941.86
Ao	0.000079075	0.837462863	1	0.288666531
MTBDE	1.571388	>16642.062033	>19872.000000	n/a
MDT(3197runs)	0.010351	10103.02774	19870.42861	5786.963691
MTBM	1.571388	>10647.173925	>19872.000000	n/a
MRT(9057runs)	0	0	0	0
%GreenTime	0.007908	38.001503	100	31.219115
%YellowTime	0	45.744783	99.990357	34.799987
%RedTime	0	16.253714	99.992092	28.866653
SystemFailures	0	0.3197	1	0.46636
R(t=19872.000000)=0.680300				

Wed Oct 03 08:35:57 2001 Results Table: H-S RBD/ 19872 hr. mission Results from 100000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	1518871.01	1838919.22	3199038.03	441263.73
Ao	0.000068264	0.841319963	1	0.283975657
MTBDE	1.356547	>16718.710309	>19872.000000	n/a
MDT(31888runs)	0.010351	9888.640525	19870.64345	5767.377213
MTBM	1.356547	>10657.029398	>19872.000000	n/a
MRT(90466runs)	0	0	0	0
%GreenTime	0.000116	38.622143	100	31.419376
%YellowTime	0	45.509853	99.999884	34.765261
%RedTime	0	15.868004	99.993174	28.397566
SystemFailures	0	0.31888	1	0.466042
R(t=19872.000000)=0.681120				

RAPTOR Results Using H-S RBD   87660 hr. mission time

The next three tables show, respectively, results from 1000, 10000, and 100000 mission repetitions.

Mon Oct 01 14:00:36 2001   Results Table: H-S RBD/ 87660 hr. mission   Results from 1000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	6756429.53	9246252.26	13595888.76	1592194.34
Ao	0.000118687	0.381026584	1	0.259247885
MTBDE	10.404129	>33400.790361	>87660.000000	n/a
MDT(975runs)	63.314427	55650.47142	87649.59587	21266.73811
MTBM	10.404129	8792.596437	34340.20779	5158.235004
MRT	0	0	0	0
%GreenTime	0.011869	9.305272	70.323646	8.986112
%YellowTime	0	28.797386	99.922058	24.803663
%RedTime	0	61.897342	99.988131	25.924789
SystemFailures	0	0.975	1	0.156125
R(t=87660.000000)=0.025000				

Wed Oct 03 17:34:23 2001   Results Table: H-S RBD/ 87660 hr. mission   Results from 10000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	6724251.15	9240711.32	13672057.91	1574489.33
Ao	0.000017925	0.387974513	1	0.260018684
MTBDE	1.571388	>34009.845878	>87660.000000	n/a
MDT(9680runs)	63.314427	55423.71294	87658.42861	20938.22056
MTBM	1.571388	>8883.278357	>87660.000000	n/a
MRT(9999runs)	0	0	0	0
%GreenTime	0.001793	9.554467	100	9.70458
%YellowTime	0	29.242985	99.975541	24.377732
%RedTime	0	61.202549	99.998207	26.001868
SystemFailures	0	0.968	1	0.176
R(t=87660.000000)=0.032000				

Wed Oct 03 16:39:48 2001 Results Table: H-S RBD/87660 hr. mission Results from 100000 run(s):

Parameter	Minimum	Mean	Maximum	StandardDeviation
TotalCosts	6704669.49	9263401.51	13933383.81	1575739.36
Ao	0.000015475	0.388119677	1	0.258184365
MTBDE	1.356547	>34022.570967	>87660.000000	n/a
MDT(97140runs)	2.210991	55216.62449	87658.64345	20978.81278
MTBM	1.356547	>8920.572876	>87660.000000	n/a
MRT(99997runs)	0	0	0	0
%GreenTime	0.000026	9.683667	100	9.682881
%YellowTime	0	29.1283	99.99531	24.152354
%RedTime	0	61.188032	99.998452	25.818437
SystemFailures	0	0.9714	1	0.166679
R(t=87660.000000)=0.028600				

APPENDIX B - ENVIRONMENTAL AND NON-OPERATING FACTORS

There are environmental factors which are used to modify generic failure rates in order to reflect environmental conditions. These are known as π_E factors. The π_E factors can be found for the space flight operating state, and for the space flight non-operating state of a component. Since there will be a variety of components in the EPCU, the analysts have chosen to use an average π_E factor value. π_E factors extracted over a broad range of device types in MIL-HDBK-217 provided an average value of 0.5 for the space flight operating state environment. Technical consultation with the Department of Defense (DOD) Reliability Analysis Center (RAC), provided a ratio of 0.45.

Failure rate data was reviewed from Reliability Training, NASA/TP –2000-207428, Pg. 57, Ch. 4, "Using Failure Rate Data", Table 4.4 – Selected Listing – Approved Electronic Failure Rates For Launch Vehicle Application. Device failure rates are indicated for both the operating and non-operating states in space flight environment. Having computed the ratio of non-operating to operating failure rates yields an average value of about 33%. Data from the DOD RAC, who supplied extracts from "Reliability Toolkit: Commercial Practices Edition" shows an average conversion factor from the space (active-state) to space (inactive-state) of about 30%. This is close to the NASA/TP –2000-207428.

However, the NASA Johnson Space Center ISS reliability and maintainability leadership has directed the analysts to use a factor of (1/35) for the conversion of "operating state" failure rates to "non-operating state" failure rates.

Let λ be the ground-benign failure rate. Then,

$\lambda_{\text{space flight(operating)}} = \pi_{SF}\lambda = (0.45)\lambda$

$\lambda_{\text{space flight(non-operating)}} = (0.03^*)\pi_{SF}\lambda$

*(1/35 = 0.02857, here it has been rounded up to 0.03)

Some engineers are confused by the term "non-operating" failure rate, which is commonly used by reliability engineers. Non-operating failure rate is the contribution to the total failure rate from the non-operating (or in-active) state that is included as part of the reliability prediction when the non-operating time is significant.

APPENDIX C - RELIABILITY AND REDUNDANCY MODELING

Reliability Models

A great amount of reliability modeling background is included in this section, not all of which may be used in this actual report, but is being provided as reference.

Based on NASA/TP –2000-207428, Reliability and Maintainability (RAM) Training, Page 42, (section titled "Non-operating Failures")

1. $R(t) = \{\exp[-\lambda_{operating}\ t_{operating}]\}\ \{\exp[-\lambda_{non\text{-}operating}\ t_{non\text{-}operating}]\} = R_{operating}\ R_{non\text{-}operating}$ where $t_{operating}$ is the operating time of the device being analyzed, $t_{non\text{-}operating}$ is the non-operating time, $\lambda_{operating}$ is the failure rate which applies to the operating state, $\lambda_{non\text{-}operating}$ is the contribution to failure from the non-operating state, and R(t) is the reliability. If d is the duty cycle of the device, then we have:
   - $t_{operating} = dt$
   - $t_{non\text{-}operating} = (1-d)t$ where t is the mission time. The above reliability function in 1.) may be written as:

2. $R(t) = \exp[-\{\lambda_{operating}dt + \lambda_{non\text{-}operating}(1-d)t\}]$ Which agrees with the formula found in the RAC Manual, Design Reliability Training Course. Equation 1.) can be applied to components in series.

3. $$R(t) = \prod_{i=1}^{N} R_i(t)$$
   where $R_i(t)$ is the reliability function for the ith component in the series reliability block diagram, (i=1,2,3,…N), and R(t) is the reliability function for the series string.

   Then,

4. $$R(t) = \prod_{i=1}^{N} R_i^{(operating)}(t_{i,op})\ R_i^{(non\text{-}operating)}(t_{i,non\text{-}op})$$
   Where i=1,2,3,….N, is the particular component in the reliability block diagram, $Ri^{(operating)}(t_{i,op})$ is the reliability function evaluated for the operating state of the ith component and $Ri^{(non\text{-}operating)}(t_{i,non\text{-}op})$, is the reliability function evaluated for the non-operating state of the ith component. In reliability analysis it is necessary to multiply reliability functions for the operating and non-operating modes to obtain the complete reliability function.

   The right hand side of Equation 4.) can be expressed in terms of the exponential distribution.

5. $$R(t) = \prod_{i=1}^{N} \exp[-\lambda_{i,SF}^{(op)}(t_{i,SF})]\exp[-\lambda_{i,NSF}^{(non\text{-}op)}(t_{i,NSF})]$$

where,

$t_{i,NSF}$ = Projected hours of non-operating time to be accumulated on the ith component in the space flight environment.
$t_{i,SF}$ = Projected hours of operating time to be accumulated on the ith component in the space flight environment.
$\lambda_{i,SF}$ = Operating state failure rate of the ith component in the space flight environment.
$\lambda_{i,NSF}$ = Non-operating state failure rate of the ith component in the space flight environment.

Redundant configurations are modeled in the following ways:

Active redundancy (parallel configuration) of N identical units:

$$R(t) = \sum_{x=K}^{N} \{N!/x!(N-x)!\}p^{x} q^{N-x}$$

N = number of identical units

p = probability of individual unit success

q = 1-p = probability of failure for an individual unit

K = required number of successfully operating units in the redundant configuration

The values of p and q are time dependent:

Namely,

P = exp ($-\lambda t$), where λ is the total failure rate, and t is the mission time.

$\lambda = \lambda_{operating}d + \lambda_{non\text{-}operating}(1-d)$, d = duty cycle

q = 1-p = 1- exp($-\lambda t$),

R(t) = Reliability of the N identical items in active redundancy at mission time t.

(Reference: See MIL-HDBK-338B. para. 5.3.7.1.2, pgs. 5-21 to 5-22)

Standby Redundancy (involving identical units):

From D. Kececioglu, Reliability Engineering Handbook, PTR Prentice Hall, 1991, pg. 46, eqn. 3.6. Equation 3.6 allows an estimate of the reliability of a system with standby units. It is assumed that all units in the redundant configuration are identical and that switching is perfect.

If we have n identical units, and (n-1) are in standby,

$R_{sb}(t) = [\exp(-\lambda t)]\{1+\lambda t+\ldots..(\lambda t)^{n-1}/(n-1)!\}$

If n=2 (dual redundant units), then n-1=1, and

$R_{sb}(t) = [\exp(-\lambda t)]\{1+\lambda t\}$.

Standby Redundancy (involving non-identical units):

From D. Kececioglu, Reliability Engineering Handbook, PTR Prentice Hall, 1991, pg. 46, eqn. 3.4. Equation 3.4 allows an estimate of the reliability of a system with unlike standby units where the standby units have reliabilities of R_1 and R_2 . It is assumed that sensing and switching is perfect. Unit 1 is the primary (active unit) and unit 2 is the standby unit.

λ_1 is the active failure rate of the unit 1, λ_2 is the active or functioning failure rate of the second unit, $R_1 = \exp(-\lambda_1 t)$ and $R_2 = \exp(-\lambda_2 t)$. The reliability of this system with unit 2 on standby is

$R_{sb} = \exp(-\lambda_1 t) + [\lambda_1/(\lambda_1+\lambda_2)][\exp(-\lambda_2 t)-\exp(-\lambda_1 t)]$.

Redundancy Modeling Formulae For The EPCU

$$R_{sys}(t) = \sum_{x=K}^{N} \{N!/x!(N-x)!\}R^x Q^{N-x}$$

R = Reliability Function for the unit.
Q = Probability of Failure for the unit.

The dual redundant combination of the A6 fuse and the A19 Power Supply.

Active Redundancy, 1 out of 2 required for success.

$R_{sys} = 2RQ + R^2 = 2R(1-R) + R^2 = 2R - R^2$

A13R Converter RPC Board and A3R converter combination in triple redundant configuration.

Active redundancy with 2 out of 3 required for success.

$R_{sys} = 3R^2Q + R^3 = 3R^2(1\text{-}R) + R^3 = 3R^2–3R^3 + R^3 = 3R^2–2R^3$

Output filter CS-3 and CS4 – dual redundant.

Active redundancy with 1 out of 2 required for success

$R_{sys} = 2RQ + R^2 = 2R(1\text{-}R) + R^2 = 2R – R^2$

A5 RPC Boards: 4 per output connector.

Active redundancy with 3 out of 4 required for success

$R_{sys} = 4R^3 – 3R^4$.

Reliability of the RPC Board-Output Connector "module":

$R_{sys} = R_{con} (4R^3 – 3R^4)$

where R_{con} is the reliability of the output connector and R is the reliability of a single RPC board.

12 RPC Board-Output Connector "modules" : Active Redundancy - 9 out-of-12 modules required for success:

$R_{sys} = 220R^9(1– R)^3 + 66R^{10} – 120R^{11} +55R^{12}$

where R is the reliability of a single RPC-Output Connector module.

APPENDIX D - WORKSHEETS FOR ANALYTICAL CALCULATIONS

This model is based on the requirement in FCF-SPEC-0010: 37 out of 48 Output Channels must operate for success.

Based on RBD by E. Zampino and also includes duty cycles for FIR and CIR applications.

The following worksheets show the calculation of effective failure rates and MTBFs for major components that includes both the active and inactive states. Constant failure rates are used with the exponential distribution.

1. The "cells" in the Excel spreadsheet contain the formulae for computing the reliability of the system components at various mission times (from one to 10 years). The column called "Mission Time" is merely the set value of 8,766 hours per year. The effect of multiple years of mission time is then taken into account by the formulas contained in the cells for progressive years of mission time.

2. The spreadsheets were also designed to mathematically "accumulate" the reliabilities of the major components and to calculate the reliability of major parallel configurations within the reliability block diagram. Finally, all elements of the reliability block diagram (serial and parallel) were synthesized by multiplication. The spreadsheets approximate the 37 out of 44 output channels as 36 out of 44 output channels.

3. Finally, the "system" MTBF of the EPCU is approximated by using Simpson's Rule (See Appendix E).

Calculations for the 100% Duty Cycle Case (Sheet 1)

	A	B	C	D	E	F	G	H
1	Item	lambda operating	lambda operating x d	lambda non-op	duty-cycle	lambda non-op x(1-d)	lambda effective	Effective MTBF = 1
2	**EPCU Major Components**	failures/ 1e^6hr	failures/ 1e^6hr	failures/ 1e^6hr	dimension less	failures/ 1e^6hr	failures/ 1e^6hr	$\lambda_e = \lambda_{op} d + \lambda_{nop}(1-$
3	A6 Input Filter	0.7028	0.7028	0.020078996	1	0	0.7028	
4	A6 Fuse	0.009	0.009	0.00025713	1	0	0.009	
5	A19 Power Supply	0.4063	0.4063	0.011607991	1	0	0.4063	
6	EPCU Shutdown Switch	0.05	0.05	0.0014285	1	0	0.05	
7	A21 Low Voltage Power Supply	0.2994	0.2994	0.008553858	1	0	0.2994	
8	A13 Conv. RPC Bd.	5.1803	5.1803	0.148001171	1	0	5.1803	
9	A3 Converter	1.9666	1.9666	0.056185762	1	0	1.9666	
10	A4 Output Filter	0.5091	0.5091	0.014544987	1	0	0.5091	
11	A5 28V RPC Board	6.6194	6.6194	0.189116258	1	0	6.6194	
12	A8/9 Temp.Sensor	0.1049	0.1049	0.002996993	1	0	0.1049	
13	A1 Motherboard	0.1619	0.1619	0.004625483	1	0	0.1619	
14	A2 Motherboard	0.3362	0.3362	0.009605234	1	0	0.3362	
15	A7 Display Board	0.0008	0.0008	0.000022856	1	0	0.0008	
16	A11 1553 Board	0.5052	0.5052	0.014433564	1	0	0.5052	
17	A16 Load Control Board	1.3181	1.3181	0.037658117	1	0	1.3181	
18	A17 Control and Protection	1.1139	1.1139	0.031824123	1	0	1.1139	
19	A18 Analog Monitor Board	0.8215	0.8215	0.023470255	1	0	0.8215	
20	A12 120V RPC Board	5.1803	5.1803	0.148001171	1	0	5.1803	
21	1553 Data Bus	0.5052	0.5052	0.014433564	1	0	0.5052	
22	EPCU Input Connectors	0.0018	0.0018	0.000051426	1	0	0.0018	
23	EPCU Output Connectors	0.0018	0.0018	0.000051426	1	0	0.0018	
24	**EPCU Redundancy Calculations**							
25	A6 and A19 in series							
26	A6 & A19 (1/2 active redundancy)							
27	A13 & A3 in series							
28	A13 & A3 (2/3 active redundancy)							
29	A4 Output Filter (1/2 active Red.)							
30	28V.RPC Groups (3/4 active Red.)							
31	RPC Gp.-Connector (in Series)							
32	RPC-Conn. Mod.(10/12 active Red.)							
33	RPC-Conn. Mod.(9/12 active Red.)							
34	**EPCU R(t) based on line 33**							
35	**Assigned Duty Cycle** in Cell B35	1						
36	**MTBF by Simpson's Rule**	29397.32386						
37								
38								
39								

FOMA / Sheet2 / Sheet3

Calculations for the 100% Duty Cycle Case (Sheet 2)

	I	J	K	L	M	N	O	P	Q	
1	t/MTBF	exp (t/MTBF)	Mission time	Reliability	Probability of Failure	Reliability at t= 1 yr.	Reliability at t=2 yr.	Reliability at t=3 yr.	Reliability at t=4 yr.	Reliabili
2			Hours	dimension less	Q(t) @ t = 1 yr.	dimension less	dimension less	dimension less	dimension less	dimensi
3	0.006160745	1.006179761	8766		0.006141806	0.993858194	0.987754109	0.981687515	0.97565818	
4	0.000078894	1.000078897	8766		7.88909E-05	0.999921109	0.999842224	0.999763346	0.999684474	
5	0.003561626	1.003567976	8766		0.003555291	0.996444709	0.992902059	0.989372003	0.985854498	
6	0.0004383	1.000438396	8766		0.000438204	0.999561796	0.999123784	0.998685964	0.998248336	
7	0.00262454	1.002627988	8766		0.002621099	0.997378901	0.994764672	0.992157295	0.989556752	
8	0.04541051	1.046457353	8766		0.044394884	0.955605116	0.913181138	0.872640567	0.83389979	
9	0.017239216	1.017388668	8766		0.017091471	0.982908529	0.966109177	0.949596951	0.933366942	
10	0.004462771	1.004472744	8766		0.004452827	0.995547173	0.991114173	0.986700913	0.982307304	
11	0.05802566	1.059742189	8766		0.056374267	0.943625733	0.890429525	0.840232213	0.792864738	
12	0.000919553	1.000919976	8766		0.000919131	0.999080869	0.998162583	0.997245141	0.996328543	
13	0.001419215	1.001420223	8766		0.001418209	0.998581791	0.997165594	0.995751405	0.994339221	
14	0.002947129	1.002951476	8766		0.002942791	0.997057209	0.994123079	0.991197583	0.988280696	
15	7.0128E-06	1.000007013	8766		7.01278E-06	0.999992987	0.999985974	0.999978962	0.999971949	
16	0.004428583	1.004438404	8766		0.004418791	0.995581209	0.991181943	0.986802116	0.982441644	
17	0.011554465	1.011621475	8766		0.011487968	0.988512032	0.977156037	0.9659305	0.954833921	
18	0.009764447	1.009812275	8766		0.00971693	0.99028307	0.980660559	0.971131549	0.961695132	
19	0.007201269	1.00722726	8766		0.007175402	0.992824598	0.985700682	0.978627884	0.971605835	
20	0.04541051	1.046457353	8766		0.044394884	0.955605116	0.913181138	0.872640567	0.83389979	
21	0.004428583	1.004438404	8766		0.004418791	0.995581209	0.991181943	0.986802116	0.982441644	
22	1.57788E-05	1.000015779	8766		1.57787E-05	0.999984221	0.999968443	0.999952665	0.999936887	
23	1.57788E-05	1.000015779	8766		1.57787E-05	0.999984221	0.999968443	0.999952665	0.999936887	
24										
25						0.996366099	0.992745403	0.989137864	0.985543435	
26						0.999986795	0.999947371	0.999882014	0.999791008	
27						0.939272419	0.882232678	0.828656822	0.778334498	
28						0.98938439	0.961659237	0.921985298	0.874376548	
29						0.999980172	0.999921042	0.999823134	0.999686969	
30						0.982334638	0.938057208	0.87751637	0.808144513	
31						0.982319138	0.938027606	0.877474832	0.808093509	
32						0.998921191	0.965681778	0.825618825	0.587148922	
33						0.999956825	0.995123153	0.950417685	0.815627896	
34						0.843440301	0.695463409	0.542804674	0.376517843	
35										
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FOMA / Sheet2 / Sheet3

Calculations for the 100% Duty Cycle Case (Sheet 3)

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75%

	Q	R	S	T	U	V	W	X
1	Reliability at t=4 yr.	Reliability at t=5 yr.	Reliability @t=6yrs.	Reliability@ t=7yrs.	Reliability@t=8yrs.	Reliability@t=9yrs.	Reliability@t=10yrs.	
2	dimension less	dimension less						
3	0.97565818	0.969665877	0.963710377	0.957791454	0.951908884	0.946062444	0.940251912	
4	0.999684474	0.999605608	0.999526748	0.999447894	0.999369047	0.999290206	0.999211371	
5	0.985854498	0.982349499	0.978856961	0.97537684	0.971909091	0.968453672	0.965010538	
6	0.998248336	0.9978109	0.997373655	0.996936602	0.99649974	0.99606307	0.995626591	
7	0.989556752	0.986963025	0.984376097	0.98179595	0.979222565	0.976655925	0.974096013	
8	0.83389979	0.796878906	0.761501559	0.727694786	0.69538886	0.664517153	0.635015991	
9	0.933366942	0.917414329	0.901734369	0.886322402	0.871173849	0.856284207	0.841649051	
10	0.982307304	0.97793326	0.973578692	0.969243514	0.96492764	0.960630984	0.95635346	
11	0.792864738	0.74816757	0.705990172	0.666190494	0.628634493	0.593195685	0.559754713	
12	0.996328543	0.995412787	0.994497872	0.993583798	0.992670565	0.991758171	0.990846616	
13	0.994339221	0.992929041	0.99152086	0.990114676	0.988710487	0.987308289	0.98590808	
14	0.988280696	0.985372392	0.982472648	0.979581436	0.976698733	0.973824513	0.970958752	
15	0.999971949	0.999964937	0.999957924	0.999950912	0.999943899	0.999936887	0.999929874	
16	0.982441644	0.978100439	0.973778417	0.969475493	0.965191583	0.960926603	0.956680468	
17	0.954833921	0.943864819	0.93302173	0.922303206	0.911707817	0.901234146	0.890880797	
18	0.961695132	0.952350407	0.943096485	0.933932483	0.924857526	0.91587075	0.906971298	
19	0.971605835	0.964634173	0.957712535	0.950840562	0.944017899	0.937244191	0.930519087	
20	0.83389979	0.796878906	0.761501559	0.727694786	0.69538886	0.664517153	0.635015991	
21	0.982441644	0.978100439	0.973778417	0.969475493	0.965191583	0.960926603	0.956680468	
22	0.999936887	0.999921109	0.999905332	0.999889554	0.999873778	0.999858001	0.999842224	
23	0.999936887	0.999921109	0.999905332	0.999889554	0.999873778	0.999858001	0.999842224	
24								
25	0.985543435	0.981962068	0.978393715	0.974838329	0.971295862	0.967766269	0.964249502	
26	0.999791008	0.999674633	0.999533168	0.99936689	0.999176072	0.998960987	0.998721902	
27	0.778334498	0.731068127	0.686672128	0.644972191	0.60580459	0.569015543	0.534460606	
28	0.874376548	0.82192759	0.766998458	0.711364544	0.656338003	0.602865853	0.551609063	
29	0.999686969	0.999513059	0.999301914	0.999054039	0.99876993	0.998450081	0.99809498	
30	0.808144513	0.735185278	0.662250643	0.591746063	0.525193609	0.46347648	0.407023036	
31	0.808093509	0.735127278	0.662187949	0.591680708	0.525127318	0.463410666	0.406958818	
32	0.587148922	0.34603062	0.172722146	0.074951762	0.028943926	0.010140309	0.003273614	
33	0.815627896	0.602359317	0.380347101	0.208061265	0.100481753	0.043640171	0.017322161	
34	0.376517843	0.222759195	0.111849617	0.048352533	0.018356475	0.00623855	0.001930082	
35								
36								
37								
38								
39								

FOMA / Sheet2 / Sheet3

Calculations for the CIR Duty Cycle Application (Sheet 1)

	A	B	C	D	E	F	G	H
1	Item	lambda operating	lambda operating x d	lambda non-op	duty-cycle	lambda non-op x(1-d)	lambda effective	Effective MTBF = 1
2	**EPCU Major Components**	failures/ 1e^6hr	failures/ 1e^6hr	failures/ 1e^6hr	dimension less	failures/ 1e^6hr	failures/ 1e^6hr	$\lambda_e = \lambda_{op} d + \lambda_{nop}(1-$
3	A6 Input Filter	0.7028	0.216468172	0.020078996	0.308008214	0.0138945	0.230362673	
4	A6 Fuse	0.009	0.002772074	0.00025713	0.308008214	0.000177932	0.002950006	
5	A19 Power Supply	0.4063	0.125143737	0.011607991	0.308008214	0.008032634	0.133176372	
6	EPCU Shutdown Switch	0.05	0.015400411	0.0014285	0.308008214	0.00098851	0.016388921	
7	A21 Low Voltage Power Supply	0.2994	0.092217659	0.008553858	0.308008214	0.005919199	0.098136859	
8	A13 Conv. RPC Bd.	5.1803	1.595574949	0.148001171	0.308008214	0.102415595	1.697990543	
9	A3 Converter	1.9666	0.605728953	0.056185762	0.308008214	0.038880086	0.644609039	
10	A4 Output Filter	0.5091	0.156806982	0.014544987	0.308008214	0.010065012	0.166871993	
11	A5 28V RPC Board	6.6194	2.038829569	0.189116258	0.308008214	0.130866897	2.169696466	
12	A8/9 Temp.Sensor	0.1049	0.032310062	0.002996993	0.308008214	0.002073895	0.034383956	
13	A1 Motherboard	0.1619	0.04986653	0.004625483	0.308008214	0.003200796	0.053067326	
14	A2 Motherboard	0.3362	0.103552361	0.009605234	0.308008214	0.006646743	0.110199104	
15	A7 Display Board	0.0008	0.000246407	0.000022856	0.308008214	1.58162E-05	0.000262223	
16	A11 1553 Board	0.5052	0.155605749	0.014433564	0.308008214	0.009987908	0.165593657	
17	A16 Load Control Board	1.3181	0.405985626	0.037658117	0.308008214	0.026059108	0.432044734	
18	A17 Control and Protection	1.1139	0.343090349	0.031824123	0.308008214	0.022022032	0.365112381	
19	A18 Analog Monitor Board	0.8215	0.253028747	0.023470255	0.308008214	0.016241224	0.269269971	
20	A12 120V RPC Board	5.1803	1.595574949	0.148001171	0.308008214	0.102415595	1.697990543	
21	1553 Data Bus	0.5052	0.155605749	0.014433564	0.308008214	0.009987908	0.165593657	
22	EPCU Input Connectors	0.0018	0.000554415	0.000051426	0.308008214	3.55864E-05	0.000590001	
23	EPCU Output Connectors	0.0018	0.000554415	0.000051426	0.308008214	3.55864E-05	0.000590001	
24	**EPCU Redundancy Calculations**							
25	A6 and A19 in series							
26	A6 & A19 (1/2 active redundancy)							
27	A13 & A3 in series							
28	A13 & A3 (2/3 active redundancy)							
29	A4 Output Filter (1/2 active Red.)							
30	28V.RPC Groups (3/4 active Red.)							
31	RPC Gp.-Connector (in Series)							
32	RPC-Conn. Mod.(10/12 active Red.)							
33	RPC-Conn. Mod.(9/12 active Red.)							
34	**EPCU R(t) based on line 33**							
35	**Assigned Duty Cycle** in Cell B35	0.308008214						
36	**MTBF by Simpson's Rule**	65654.04219						
37								
38								
39								

FOMA / Sheet2 / Sheet3

Calculations for the CIR Duty Cycle Application (Sheet 2)

	H	I	J	K	L	M	N	O	P
1	Effective MTBF = 1 / lambda effectiv	t/MTBF	exp (t/MTBF)	Mission time	Reliability	Probability of Failure	Reliability at t= 1 yr.	Reliability at t=2 yr.	Reliability at t=3
2	$\lambda_e = \lambda_{op} d + \lambda_{nop}(1-d)$			Hours	dimension less	Q(t) @ t = 1 yr.	dimension less	dimension less	dimension less
3	4340981.062	0.002019359	1.002021399	8766		0.002017322	0.997982678	0.995969426	0.99396
4	338982387.8	2.58598E-05	1.00002586	8766		2.58594E-05	0.999974141	0.999948282	0.99992
5	7508839.504	0.001167424	1.001168106	8766		0.001166743	0.998833257	0.997667875	0.99650
6	61016829.81	0.000143665	1.000143676	8766		0.000143655	0.999856345	0.999712711	0.99956
7	10189851.34	0.000860268	1.000860638	8766		0.000859898	0.999140102	0.998280944	0.99742
8	588931.4307	0.014884585	1.014995912	8766		0.014774357	0.985225643	0.970669567	0.95632
9	1551327.921	0.005650643	1.005666638	8766		0.005634708	0.994365292	0.988762334	0.98319
10	5992617.345	0.0014628	1.00146387	8766		0.001461731	0.998538269	0.997078676	0.99562
11	460893.9617	0.019019559	1.019201583	8766		0.018839829	0.981160171	0.962675282	0.94453
12	29083331.65	0.00030141	1.000301455	8766		0.000301364	0.999698636	0.999397362	0.99909
13	18843986.97	0.000465188	1.000465296	8766		0.00046508	0.99953492	0.999070056	0.99860
14	9074483.909	0.000966005	1.000966472	8766		0.000965539	0.999034461	0.998069854	0.99710
15	3813551863	2.29864E-06	1.000002299	8766		2.29864E-06	0.999997701	0.999995403	0.99999
16	6038878.643	0.001451594	1.001452648	8766		0.001450541	0.998549459	0.997101022	0.99565
17	2314575.139	0.003787304	1.003794485	8766		0.003780141	0.996219859	0.992454007	0.9887
18	2738882.746	0.003200575	1.003205702	8766		0.003195459	0.996804541	0.993619293	0.99044
19	3713744.967	0.002360421	1.002363209	8766		0.002357637	0.997642363	0.995290285	0.99294
20	588931.4307	0.014884585	1.014995912	8766		0.014774357	0.985225643	0.970669567	0.95632
21	6038878.643	0.001451594	1.001452648	8766		0.001450541	0.998549459	0.997101022	0.99565
22	1694911939	5.17195E-06	1.000005172	8766		5.17194E-06	0.999994828	0.999989656	0.99998
23	1694911939	5.17195E-06	1.000005172	8766		5.17194E-06	0.999994828	0.999989656	0.99998
24									
25							0.998807428	0.997616278	0.99642
26							0.999998578	0.999994318	0.9999
27							0.979674184	0.959761507	0.94025
28							0.998777378	0.995272894	0.9897
29							0.999997863	0.999991466	0.99998
30							0.997923483	0.992051357	0.9828
31							0.997918322	0.992041095	0.9828
32							0.999998043	0.999894896	0.9990
33							0.999999991	0.999998113	0.99996
34							0.947896031	0.896439665	0.84597
35									
36									
37									
38									
39									

FOMA / Sheet2 / Sheet3

C.1 - Calculations for the CIR Duty Cycle Application (Sheet 3)

	P	Q	R	S	T	U	V	W
1	Reliability at t=3 yr.	Reliability at t=4 yr.	Reliability at t=5 yr.	Reliability @t=6yrs.	Reliability@ t=7yrs.	Reliability@t=8yrs.	Reliability@t=9yrs.	Reliability@t=10yrs.
2	dimension less	dimension less	dimension less					
3	0.993960236	0.991955098	0.989954006	0.98795695	0.985963923	0.983974917	0.981989923	0.980008933
4	0.999922424	0.999896566	0.99987071	0.999844854	0.999818998	0.999793143	0.999767289	0.999741436
5	0.996503854	0.99534119	0.994179883	0.99301993	0.991861331	0.990704084	0.989548187	0.988393639
6	0.999569097	0.999425504	0.999281932	0.99913838	0.998994849	0.998851338	0.998707848	0.998564379
7	0.997422524	0.996564843	0.995707899	0.994851692	0.993996221	0.993141486	0.992287486	0.99143422
8	0.956328548	0.942199409	0.928279018	0.914564292	0.901052193	0.887739726	0.874623942	0.861701935
9	0.983190947	0.977650953	0.972142175	0.966664438	0.961217566	0.955801386	0.950415724	0.945060409
10	0.995621215	0.994165885	0.992712683	0.991261604	0.989812647	0.988365808	0.986921083	0.98547847
11	0.944538644	0.926743698	0.909284006	0.892153251	0.875345236	0.858853882	0.842673222	0.826797403
12	0.999096179	0.998795087	0.998494086	0.998193176	0.997892356	0.997591627	0.997290988	0.99699044
13	0.998605409	0.998140977	0.997676762	0.997212763	0.996748979	0.996285411	0.995822058	0.995358921
14	0.997106179	0.996143434	0.995181619	0.994220732	0.993260774	0.992301742	0.991343636	0.990386455
15	0.999993104	0.999990805	0.999988507	0.999986208	0.99998391	0.999981611	0.999979312	0.999977014
16	0.995654686	0.994210448	0.992768305	0.991328254	0.989890292	0.988454416	0.987020622	0.985588908
17	0.98870239	0.984964956	0.981241649	0.977532417	0.973837206	0.970155964	0.966488637	0.962835173
18	0.990444224	0.9872793	0.98412449	0.980979761	0.97784508	0.974720417	0.971605738	0.968501012
19	0.992943751	0.99060275	0.988267269	0.985937293	0.983612811	0.981293809	0.978980275	0.976672195
20	0.956328548	0.942199409	0.928279018	0.914564292	0.901052193	0.887739726	0.874623942	0.861701935
21	0.995654686	0.994210448	0.992768305	0.991328254	0.989890292	0.988454416	0.987020622	0.985588908
22	0.999984484	0.999979312	0.999974141	0.999968969	0.999963797	0.999958625	0.999953454	0.999948282
23	0.999984484	0.999979312	0.999974141	0.999968969	0.999963797	0.999958625	0.999953454	0.999948282
24								
25	0.996426549	0.995238238	0.994051345	0.992865867	0.991681802	0.99049915	0.989317909	0.988138076
26	0.99998723	0.999977326	0.999964613	0.999949104	0.999930808	0.999909734	0.999885893	0.999859295
27	0.940253571	0.92114215	0.902419184	0.884076778	0.866107196	0.84850286	0.831256347	0.814360384
28	0.989717639	0.982325083	0.973292285	0.962801017	0.951018819	0.938099988	0.924186494	0.909408848
29	0.999980826	0.999965963	0.999946895	0.99992364	0.999896218	0.999864646	0.999828942	0.999789125
30	0.98288062	0.970859719	0.956392781	0.939843494	0.921538669	0.901771515	0.880804628	0.858872748
31	0.98286537	0.970839634	0.956368049	0.939814329	0.921505307	0.901734204	0.88076363	0.858828329
32	0.999014471	0.995523932	0.986416752	0.968176639	0.937771664	0.893525643	0.835566103	0.765778007
33	0.999961784	0.999703477	0.998647756	0.995610097	0.988754517	0.97581368	0.95452126	0.923112013
34	0.845975564	0.796652015	0.748294727	0.700347382	0.651976046	0.602326868	0.550832281	0.497440925
35								
36								
37								
38								
39								

Calculations for the FIR Duty Cycle Application (Sheet 1)

	A	B	C	D	E	F	G	H
1	Item	lambda operating	lambda operating x d	lambda non-op	duty-cycle	lambda non-op x(1-d)	lambda effective	Effective MTBF = 1
2	**EPCU Major Components**	failures/ 1e^6hr	failures/ 1e^6hr	failures/ 1e^6hr	dimension less	failures/ 1e^6hr	failures/ 1e^6hr	$\lambda_e = \lambda_{op} d + \lambda_{nop}(1-$
3	A6 Input Filter	0.7028	0.26737828	0.020078996	0.380447182	0.012439999	0.279818278	
4	A6 Fuse	0.009	0.003424025	0.00025713	0.380447182	0.000159306	0.00358333	
5	A19 Power Supply	0.4063	0.15457569	0.011607991	0.380447182	0.007191764	0.161767454	
6	EPCU Shutdown Switch	0.05	0.019022359	0.0014285	0.380447182	0.000885031	0.01990739	
7	A21 Low Voltage Power Supply	0.2994	0.113905886	0.008553858	0.380447182	0.005299567	0.119205453	
8	A13 Conv. RPC Bd.	5.1803	1.970830538	0.148001171	0.380447182	0.091694543	2.062525081	
9	A3 Converter	1.9666	0.748187429	0.056185762	0.380447182	0.034810047	0.782997476	
10	A4 Output Filter	0.5091	0.193685661	0.014544987	0.380447182	0.009011388	0.202697048	
11	A5 28V RPC Board	6.6194	2.518332078	0.189116258	0.380447182	0.117167511	2.635499589	
12	A8/9 Temp.Sensor	0.1049	0.039908909	0.002996993	0.380447182	0.001856795	0.041765705	
13	A1 Motherboard	0.1619	0.061594399	0.004625483	0.380447182	0.002865731	0.06446013	
14	A2 Motherboard	0.3362	0.127906343	0.009605234	0.380447182	0.00595095	0.133857292	
15	A7 Display Board	0.0008	0.000304358	0.000022856	0.380447182	1.41605E-05	0.000318518	
16	A11 1553 Board	0.5052	0.192201916	0.014433564	0.380447182	0.008942355	0.201144272	
17	A16 Load Control Board	1.3181	0.501467431	0.037658117	0.380447182	0.023331192	0.524798623	
18	A17 Control and Protection	1.1139	0.423780116	0.031824123	0.380447182	0.019716725	0.443496841	
19	A18 Analog Monitor Board	0.8215	0.31253736	0.023470255	0.380447182	0.01454063	0.327078423	
20	A12 120V RPC Board	5.1803	1.970830538	0.148001171	0.380447182	0.091694543	2.062525081	
21	1553 Data Bus	0.5052	0.192201916	0.014433564	0.380447182	0.008942355	0.201144272	
22	EPCU Input Connectors	0.0018	0.000684805	0.000051426	0.380447182	3.18611E-05	0.000716666	
23	EPCU Output Connectors	0.0018	0.000684805	0.000051426	0.380447182	3.18611E-05	0.000716666	
24	**EPCU Redundancy Calculations**							
25	A6 and A19 in series							
26	A6 & A19 (1/2 active redundancy)							
27	A13 & A3 in series							
28	A13 & A3 (2/3 active redundancy)							
29	A4 Output Filter (1/2 active Red.)							
30	28V.RPC Groups (3/4 active Red.)							
31	RPC Gp.-Connector (in Series)							
32	RPC-Conn. Mod.(10/12 active Red.)							
33	RPC-Conn. Mod.(9/12 active Red.)							
34	**EPCU R(t) based on line 33**							
35	**Assigned Duty Cycle** in Cell B35	0.380447182						
36	**MTBF by Simpson's Rule**	60845.64079						
37								
38								
39								

FOMA / Sheet2 / Sheet3

Calculations for the FIR Duty Cycle Application (Sheet 2)

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	H	I	J	K	L	M	N	O	P
1	Effective MTBF = 1 / lambda effective	t/MTBF	exp (t/MTBF)	Mission time	Reliability	Probability of Failure	Reliability at t= 1 yr.	Reliability at t=2 yr.	Reliability at
2	$\lambda_e = \lambda_{op} d + \lambda_{nop}(1-d)$			Hours	dimension less	Q(t) @ t = 1 yr.	dimension less	dimension less	dimension le
3	3573747.956	0.002452887	1.002455898	8766		0.002449881	0.997550119	0.99510624	0.99
4	279070007.1	3.14115E-05	1.000031412	8766		3.1411E-05	0.999968589	0.999937179	0.9
5	6181713.176	0.001418053	1.001419059	8766		0.001417049	0.998582951	0.997167911	0.99
6	50232601.27	0.000174508	1.000174523	8766		0.000174493	0.999825507	0.999651045	0.99
7	8388877.967	0.001044955	1.001045501	8766		0.001044409	0.998955591	0.997912272	0.99
8	484842.5889	0.018080095	1.018244529	8766		0.017917631	0.982082369	0.96448578	0.94
9	1277143.325	0.006863756	1.006887365	8766		0.006840254	0.993159746	0.986366281	0.97
10	4933470.956	0.001776842	1.001778422	8766		0.001775265	0.998224735	0.996452622	0.99
11	379434.7016	0.023102789	1.023371726	8766		0.022837963	0.977162037	0.954845646	0.93
12	23943089.26	0.000366118	1.000366185	8766		0.000366051	0.999633949	0.999268032	0.99
13	15513465.49	0.000565057	1.000565217	8766		0.000564898	0.999435102	0.998870523	0.99
14	7470642.664	0.001173393	1.001174082	8766		0.001172705	0.998827295	0.997655965	0.99
15	3139537579	2.79213E-06	1.000002792	8766		2.79213E-06	0.999997208	0.999994416	0.99
16	4971555.945	0.001763231	1.001764786	8766		0.001761677	0.998238323	0.996479749	0.99
17	1905492.803	0.004600385	1.004610983	8766		0.004589819	0.995410181	0.990841428	0.98
18	2254807.49	0.003887693	1.00389526	8766		0.003880146	0.996119854	0.992254764	0.9
19	3057370.741	0.002867169	1.002871284	8766		0.002863063	0.997136937	0.994282071	0.99
20	484842.5889	0.018080095	1.018244529	8766		0.017917631	0.982082369	0.96448578	0.94
21	4971555.945	0.001763231	1.001764786	8766		0.001761677	0.998238323	0.996479749	0.99
22	1395350035	6.28229E-06	1.000006282	8766		6.28227E-06	0.999993718	0.999987435	0.99
23	1395350035	6.28229E-06	1.000006282	8766		6.28227E-06	0.999993718	0.999987435	0.99
24									
25							0.998551585	0.997105268	0.99
26							0.999997902	0.999991621	0.99
27							0.975364677	0.951336252	0.92
28							0.998209205	0.993126006	0.98
29							0.999996848	0.999987416	0.99
30							0.996965042	0.988490562	0.9
31							0.996958779	0.988478142	0.97
32							0.999993938	0.999688723	0.9
33							0.999999958	0.999991898	0.99
34							0.936780662	0.874635708	0.81
35									
36									
37									
38									
39									

FOMA / Sheet2 / Sheet3

Calculations for the FIR Duty Cycle Application (Sheet 3)

Microsoft Excel - EPCU Rel FIR duty cycle

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U29 = =2*U10-U10^2

	P	Q	R	S	T	U	V	W
1	Reliability at t=3 yr.	Reliability at t=4 yr.	Reliability at t=5 yr.	Reliability @t=6yrs.	Reliability@ t=7yrs.	Reliability@t=8yrs.	Reliability@t=9yrs.	Reliability@t=10yrs.
2	dimension less	dimension less	dimension less					
3	0.992668348	0.990236428	0.987810467	0.985390448	0.982976359	0.980568184	0.978165908	0.975769518
4	0.99990577	0.999874362	0.999842955	0.999811549	0.999780144	0.99974874	0.999717337	0.999685935
5	0.995754876	0.994343843	0.992934809	0.991527772	0.990122729	0.988719677	0.987318614	0.985919535
6	0.999476612	0.999302211	0.99912784	0.998953499	0.998779189	0.998604909	0.998430659	0.99825644
7	0.996870044	0.995828903	0.99478885	0.993749884	0.992712002	0.991675205	0.99063949	0.989604857
8	0.947204481	0.930232821	0.913565253	0.897196328	0.881120696	0.865333101	0.849828382	0.834601471
9	0.979619285	0.97291844	0.966263431	0.959653943	0.953089666	0.946570291	0.94009551	0.933665017
10	0.994683655	0.992917828	0.991155136	0.989395574	0.987639135	0.985885814	0.984135606	0.982388504
11	0.933038916	0.911730208	0.890908147	0.870561619	0.850679765	0.831251972	0.81226787	0.793717326
12	0.998902248	0.998536599	0.998171084	0.997805702	0.997440454	0.99707534	0.996710359	0.996345512
13	0.998306263	0.997742322	0.9971787	0.996615396	0.99605241	0.995489742	0.994927392	0.994365359
14	0.996486009	0.995317425	0.994150212	0.992984367	0.99181989	0.990656777	0.989495029	0.988334644
15	0.999991624	0.999988832	0.999986039	0.999983247	0.999980455	0.999977663	0.999974871	0.999972079
16	0.994724274	0.992971891	0.991222595	0.989476381	0.987733243	0.985993176	0.984256174	0.982522233
17	0.986293645	0.981766736	0.977260604	0.972775154	0.968310292	0.963865923	0.959441953	0.955038288
18	0.98840467	0.984569516	0.980749242	0.976943792	0.973153107	0.969377131	0.965615806	0.961869076
19	0.991435379	0.988596837	0.985766422	0.98294411	0.980129879	0.977323706	0.974525566	0.971735438
20	0.947204481	0.930232821	0.913565253	0.897196328	0.881120696	0.865333101	0.849828382	0.834601471
21	0.994724274	0.992971891	0.991222595	0.989476381	0.987733243	0.985993176	0.984256174	0.982522233
22	0.999981153	0.999974871	0.999968589	0.999962307	0.999956025	0.999949743	0.999943461	0.999937179
23	0.999981153	0.999974871	0.999968589	0.999962307	0.999956025	0.999949743	0.999943461	0.999937179
24								
25	0.995661046	0.994218915	0.992778874	0.991340918	0.989905045	0.988471251	0.987039535	0.985609892
26	0.999981173	0.999966579	0.999947855	0.99992502	0.999898092	0.999867088	0.999832026	0.999792925
27	0.927899776	0.905040665	0.882744695	0.860997994	0.83978703	0.819098605	0.798919846	0.779238197
28	0.985154291	0.974660723	0.961977821	0.947406798	0.931220168	0.913664166	0.894960954	0.875310673
29	0.999971736	0.999949843	0.999921768	0.999887546	0.999847209	0.99980079	0.999748321	0.999689835
30	0.97543888	0.95857061	0.938555347	0.915981304	0.891363986	0.865153999	0.837744079	0.80947541
31	0.975420496	0.958546522	0.938525866	0.915946778	0.891324788	0.865110519	0.837696714	0.809424558
32	0.99723442	0.988176486	0.966387895	0.926472969	0.866017217	0.786525252	0.692885096	0.591905231
33	0.999845793	0.998882415	0.995262506	0.985754298	0.966279602	0.933080463	0.883952202	0.81900196
34	0.814080433	0.755083955	0.696820968	0.637835283	0.576683057	0.512696267	0.446430278	0.379601671
35								

FOMA / Sheet2 / Sheet3

Ready

APPENDIX E - SIMPSON'S RULE METHODOLOGY

1. DEFINITION OF SIMPSON'S RULE: An approximation rule that enables an estimate of the area under the curve of a function, y = f(x) , within the interval [x =a, x = b] . The exact area on the interval [a,b] under the curve defined by the function y=f(x), is the definite integral, A, where:

   A = $\int_a^b f(x)dx$

2. We can subdivide the interval [a,b] by dividing the interval width, (b-a), by an even integer called n. This gives smaller slices of area the curve, each slice with an interval width Δx, where x = (b-a)/n . Then, for each of these smaller intervals, i , where i = 0,1,2,...n , we can compute the value of the function y_i , given by y_i = f (a + i Δx). Simpson's rule allows an approximation of the definite integral, A, in the following way:

3. A ≈ (1/3) Δx ($y_0 + 4y_1 + 2y_2 + 4y_3 + ... + 2y_{n-2} + 4y_{n-1} + y_n$) .

4. Inside the parentheses the values y_0 and y_n are multiplied by one, whereas the other y's with even subscripts are multiplied by 2, and the y's with odd subscripts are multiplied by a factor of 4. Simpson's rule gives a much more accurate approximation of the integral than the Trapezoidal rule. Unlike the Trapezoidal rule, it is based on parabolas. As an example, if we are estimating the value of the integral,

   $$\int_2^3 \frac{1}{1+x}dx$$

   the Simpson's rule approximation, with n = 4, gives an answer of 0.2876831 as opposed to the exact area under the curve by direct integration which is 0.287682. So the technique is very accurate.

5. Application to Reliability calculations: Suppose that the independent variable is mission time t (rather than x) and that the function defining the curve is the reliability function, R(t), for a reliability block diagram model. Further, the interval [a,b] on the domain of mission time is defined as [0, ∞]. Then, A is the MTBF.

   MTBF = $\int_0 R(t)dt$

6. If the reliability function represents a system that has internal redundancy, R(t) could be very complicated and calculating the integral from zero to infinity could be very difficult. Another approach is to approximate the integral by truncating the infinite tail of the system model reliability function

for mission times $t > b$, that neglects only a small portion of area that would be acquired in the tail of the curve. Then, between the values $t=0$ and $t = b$, Simpson's rule could be applied to approximate the area under the curve. Then, we would have the following:

$$MTBF \approx (1/3)\,\Delta t\,(R_0 + 4R_1 + 2R_2 + 4R_3 + \ldots + 2R_{n-2} + 4R_{n-1} + R_n)$$

where, $\Delta t = (b-0)/n = b/n$, $R_i = R(0 + i\,\Delta t)$, $i = 0,1,2,3,\ldots,n$. The values R_0 through R_n are the values of the EPCU system reliability function at the mission times $i\,\Delta t$, where $i = 0,1,2,3,\ldots n$.