

aLIGO Electronics Reliability Calculations

Richard Abbott

21 January 2014

1. Overview

In order to set a reasonable policy for the number of spare electronics to have on hand, it is necessary to have a sense for the predicted failure rates associated with custom aLIGO electronics. There are many (perhaps hundreds) of different electronics designs in aLIGO, but in a broad sense the design practices are quite similar providing the possibility for simplifying a reliability analysis. By use of carefully selected reference designs ranging from relatively simple in terms of component count, to relatively complex, a range of failure rates can be calculated and applied accordingly to designs of similar complexity.

This note provides the background and sources for data used in the failure rate calculations. The calculation method is shown for one canonical design, and the results for other designs of differing complexity are presented. The accuracy of the failure analysis is compared to that obtained by use of a commercial reliability estimation software package using MIL-HDBK-217F. Bellcore TR-332 Issue 6, and Telcordia SR-332 Issue 1 are alternate methods of doing reliability analyses. The results from the MIL-HDBK-217F tend to be more pessimistic in terms of reliability, but comparisons of the results of each method was not significant enough to favor the other estimators over the pessimism and associated conservativeness of MIL-HDBK-217F.

These types of predictions are typically used in a qualitative manner to guide general design choices. An attempt was made to deliberately use pessimistic estimates, but a healthy degree of skepticism is reasonable in terms of absolute prediction accuracy.

2. Assumptions Common to all Parts

- a.** All linear operational amplifiers are assumed to fall in the category of Bipolar CMOS and to have a total transistor count of between 1 and 100. This is certainly true of common LIGO operational amplifiers.
- b.** Ambient air temperature is assumed to be 45C inside a sealed chassis.
- c.** Connectors are not included in the reliability prediction due to the highly variable nature of their usage. By design, an attempt is made to provide sufficient monitoring in aLIGO designs such that repetitive connector manipulation is minimized. Feedback will have to be made on a case by case basis as field experience is obtained.
- d.** Various parts such as: discrete diodes, inductors, LEDs, printed circuit board elements, solder joints, and wires are not included in the analysis as the probability of failure is not significant, or the parts are not critical to the continued operation of the device in question.
- e.** At time of writing, no attempt has been made to extend the scope of this analysis to commercial hardware. Items such as these are best analyzed in conjunction with manufacturer's field reliability data, if such data can be obtained.
- f.** The environment in the parlance of MIL-HDBK-217F is considered "Ground Benign" for all LIGO applications. The specific numerical

weighting of this assumption is detailed in the notes associated with each type of component.

3. Individual Component Assumptions

a. Operational Amplifiers (Opamps)

Parameter	Assumed Value	Comments
Power Dissipation	0.1 Watts	+/-15V at 5mA
Junction to Case Thermal Impedance	43 C/Watt	OP27 Datasheet
Junction to Ambient Thermal Impedance	158 C/Watt	OP27 Datasheet
Package Type	8 Lead SO Package	Common LIGO parts
Device Base Failure Rate (C1)	0.011 per 10 ⁶ hours	Texas Instruments OP27 Reliability Data
Package Failure Rate, 7 active pins (C2)	0.0023 per 10 ⁶ hours	MIL-HDBK-217, Section 5.9
Temperature Factor (π -T)	2	MIL-HDBK-217, Section 5.8, 65C Junction Temp.
Environment Factor (π -E)	0.5	Ground Benign
Quality Factor (π -Q)	1	Manufacturer's Failure Rate has Quality Factor Included
Learning Factor (π -L)	1	Part has been in production > 2years

General Form of Opamp Failure Rate (failures per 10⁶ hours)

$$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_E$$

b. Chip Resistors

Parameter	Assumed Value	Comments
Power Dissipation	0.05 Watts	500 Ω at 10mA
Package Type	3216 (1206)	Surface Mount Resistor
Device Base Failure Rate (λ_B)	0.0012 per 10 ⁶ hours	MIL-HDBK-217, Section 9.2, 0.4 stress level
Resistance Factor (π -R)	1	For resistors < 100k ohms per MIL-HDBK-217F, Section 9.1
Quality Factor (π -Q)	0.03	Low Failure Rate corresponding to type S
Environment Factor (π -E)	1	Ground Benign

General Form of Resistor Failure Rate (failures per 10⁶ hours)

$$\lambda_p = \lambda_B \pi_R \pi_Q \pi_E$$

c. Ceramic Capacitors

Parameter	Assumed Value	Comments
Package Type	3216 (1206)	Chip Capacitor
Device Base Failure Rate (λ_B)	0.0017 per 10 ⁶ hours	MIL-HDBK-217, Section 10.11, 50VDC rating, 15VDC usage, 85C max rated temperature
Capacitance Factor (π -CV)	3.1	MIL-HDBK-217, Section 10.11, formula
Quality Factor (π -Q)	1	Failure Rate corresponding to type M
Environment Factor (π -E)	1	Ground Benign

General Form of Ceramic Capacitor Failure Rate (failures per 10⁶ hours)

$$\lambda_p = \lambda_B \pi_{CV} \pi_Q \pi_E$$

d. Metalized Film Capacitors

Parameter	Assumed Value	Comments
Package Type	various	-
Device Base Failure Rate (λ_B)	0.0013 per 10 ⁶ hours	MIL-HDBK-217, Section 10.5, 50VDC rating, 10VDC usage, 85C max rated temperature
Capacitance Factor (π -CV)	1	MIL-HDBK-217, Section 10.5, 0.5uF
Quality Factor (π -Q)	0.1	Failure Rate estimate from general high reliability associated with these type parts
Environment Factor (π -E)	1	Ground Benign

General Form of Metalized Film Capacitor Failure Rate (failures per 10⁶ hours)

$$\lambda_p = \lambda_B \pi_{CV} \pi_Q \pi_E$$

e. Tantalum Capacitors

Parameter	Assumed Value	Comments
Package Type	SMT	Chip Capacitor
Device Base Failure Rate (λ_B)	0.016 per 10^6 hours	MIL-HDBK-217, Section 10.12, Stress Factor = 0.5
Capacitance Factor (π -CV)	1.4	MIL-HDBK-217, Section 10.12, 10uF
Series Resistance Factor (π -SR)	0.33	MIL-HDBK-217, Section 10.12, 0 to 0.1 ohms per volt
Quality Factor (π -Q)	1	Per AVX Inc. "Technical Summary and Application Guidelines" Section 3.1
Environment Factor (π -E)	1	Ground Benign

General Form of Metalized Film Capacitor Failure Rate (failures per 10^6 hours)

$$\lambda_p = \lambda_B \pi_{CV} \pi_{SR} \pi_Q \pi_E$$

4. Application Example

LIGO-D070081 is an Anti-aliasing board commonly found in aLIGO subsystems. By looking up the bill of materials associated with this board, a count of each component type can be made. The individual component type failure rates shown in the previous sections can be multiplied by the total number of each part to obtain part failure rates per chassis. As failure rates combine simply by addition, the total failure rate for a chassis is easily obtained.

AA Chassis Item	Failure Rate	Number of Parts	Total Failure Rate	MTBF
Opamps	0.03 per 10^6 hours	96	2.92 per 10^6 hours	3.43e5 (Hours)
Resistors	3.6e-5 per 10^6 hours	1376	0.05 per 10^6 hours	2.02 e7 (Hours)
Ceramic Capacitors	5.27e-3 per 10^6 hours	384	2.02 per 10^6 hours	4.94e5 (Hours)
Metalized Film Capacitors	1.3e-4 per 10^6 hours	288	0.04 per 10^6 hours	2.67e7 (Hours)
Tantalum Capacitors	7.4e-3 per 10^6 hours	16	0.12 per 10^6 hours	8.46e6 (Hours)
Total of all parts			5.15 per 10^6 hours	1.94e5 (Hours)

Without significant error, the results above can be extended to other aLIGO designs simply by tallying the part counts of the five categories of parts, and multiplying the item failure rate by the number of parts. Sum the failure rates for a total failure rate per chassis. MTBF tells the amount of time for ~63% of a population of parts to fail and relates to total failure rate by the following:

$$MTBF = \frac{1}{Total\ Failure\ Rate} \times 10^6$$

A collection of representative aLIGO design failure rates are shown below ranging in complexity from simple devices to complex. Given the coarse nature of these calculations, it is not unreasonable to simply compare a given design to these reference designs and round off to a “close” number. The error will be insignificant and conservatively covered by the rounding up intrinsic to the sparing policy.

Chassis Type	Total chassis Failure Rate per 10⁶ hours	MTBF (hours)	MTBF (years)
LSC RFPD	0.76	1.32e6	151
ISC QPD Amp	2.06	4.86e5	55.4
AA Chassis	5.15	1.94e5	22.2
ISC Whitening Filter	7.90	1.27e5	14.5

While it would be delightful if an in-vacuum RFPD would typically run for 151 years, there’s some room for skepticism. These estimates will best serve in setting a basis for the sparing analysis, and feedback from actual field experience will be the only reliable mechanism for the long run. These types of analyses are misleading in the sense that infant mortality and accelerated end of life failure mechanisms are poorly represented. For example, the Social Security Actuarial Life Table lists the death probability of a 20 year old male to be approximately 1.1e-3 yielding an MTBF of about 900 years. Obviously the underlying failure rate is not constant and the estimates are skewed at best. Use these methods as a starting point and pay close attention to field failures.