VIABILITY OF REUSING ELECTRONIC CIRCUITS IN PAYLOADS

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ABSTRACT

Due to high costs involved in project, manufacture and certification of onboard electronic equipments in sounding rockets' payloads, it is desirable that these devices should be reused. A procedure is presented to evaluate the possibility of using an item for up to five missions. In order to be reused, the item must have an acceptable reliability after each completed mission. A typical mission is considered to be composed of three phases: storage, tests and flight, each phase being subjected to different levels of degradation and duration. Mathematical models are used to estimate the failure rates for each phase for the different scenarios.

1. INTRODUCTION

A typical sounding rocket mission is composed of three phases: storage, tests and flight, each phase having peculiar environment and duration leading to different levels of degradation.

Typical storage phase can be modeled considering an environment under controlled temperature and humidity and duration estimated in about 8.700 hours (one year), under temperatures around 30°C, in absence of any worth considering vibration.

Typical tests phase encompasses all necessary tests before launching including flight simulation and can be considered to have duration of about 300 hours, with temperatures under 55°C, in absence of any worth considering vibration.

Typical flight phase period is considered to last one hour, the item being subjected to a conservative constant temperature of 70^{o}C and intense vibrations.

Mechanical shocks and air humidity are not presently considered.

Overall reliability is evaluated from the failure rates estimated for each phase.

1.1 Evaluating failure rates

To predict failure rates both traditional standards [1,2] and manufacturer's data [3-7] have widespread use. Failure rate data from traditional standards are generally pessimistic. Manufacturer's data are issued with 60% confidence level, 55°C environment temperature and failures considered with exponential distribution. They seem to be closer to field data.

Temperature, environment and dormancy adjustment coefficients taken from traditional standards are used to adjust manufacturer's failure data to the conditions defined for each phase.

All elements of the item chosen to illustrate following application are considered to be in series in reliability block diagram. Some items are put together in a block whose function is not essential to the success of the mission as only some specific failure modes, especially short-circuit, can jeopardize their operation.

2. MATHEMATICAL MODELING

2.1 Temperature failure rate variation

A coefficient of adjustment must be generated for each typical phase temperature. Table 1 shows temperature adjustment coefficients for some device types.

Table 1. Temperature adjustment coefficients.

Device type	Coeficient at 30°C	Coeficient at 70°C
Bipolar Junction Transistors (low frequency)	0.58	1.32
MOSFETs (low frequency)	0.61	1.28
Thyristors (SCR)	0.46	1.50
Diodes	0.61	1.28
Schottky Diodes	0.46	1.50
Resistors (metal film)	0.58	1.47
Capacitors (ceramics/ tantalum)	0.58	1.16
Inductors and transformers	0.73	1.20
Relays (mechanical)	0.56	1.33
Connectors (pair of connection)	0.67	1.21

Data for 90nm to 350nm and 0.8μm CMOS, for BiCMOS and for bipolar integrated circuits were taken from manufacturers' handbooks and web sites [3-7]. These coefficients and those taken from traditional standards differ in the former being greater for high temperatures and lower for low temperatures.

Fig. 1 and Tab. 2 show the adjustment coefficients variation for those items.

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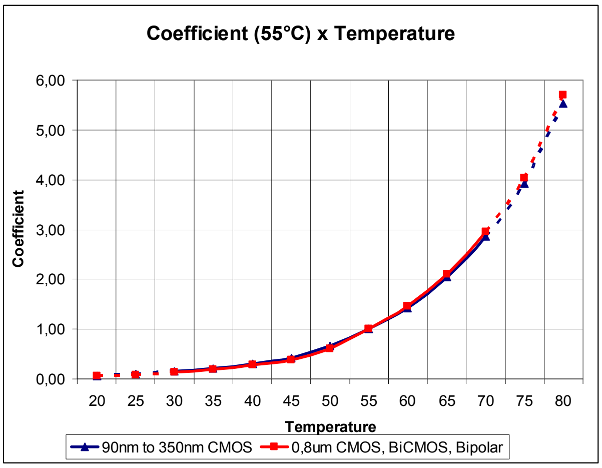

Fig 1. Behavior of temperature adjustment coefficients for specified integrated circuits

Table 2. Values of temperature adjustment coefficient for specified integrated circuits

Device type	Coefficient at 30°C	Coefficient at 70°C
90nm to 350nm CMOS	0.14	2.86
0.8µm CMOS, BiCMOS, Bipolar	0.13	2.95

2.2 Environment influence

For each element type and mission phase, a corresponding environment adjustment coefficient is used.

Ground Benign environment as considered in MIL HDBK 217 is used for storage phase. Mechanical vibration is considered negligible and temperature and humidity are considered controlled and constant.

Ground Fixed environment as considered in MIL HDBK 217 is used for tests phase. Mechanical vibration is considered negligible although the item is submitted to some vibration during transportation to launching site. Temperature is considered constant. Humidity is not considered.

Missile Launch environment as considered in MIL HDBK 217 is used for flight phase. Item is submitted to high levels vibrations and temperature and humidity show intense steep variations. A very good correlation is attained as Missile Launch comprises space vehicle boost into orbit, re-entry and landing by parachute being applied also to solid rocket motor propulsion powered flight.

Tab. 3 shows environment adjustment coefficients for selected miscellaneous devices.

2.3 Dormancy failure influence

During storage phase items are in non-operational state but nevertheless show some degradation that must be evaluated to be decided if it is worthy to be considered. Adjustment coefficients concerning dormancy state are shown in Tab. 4. [2]

Table 3. Environment adjustment coefficients for miscellaneous items

Device type	Storage	Tests	Flight
CMOS integrated circuits	0.5	2	12
Bipolar Junction Transistors (low frequency)	1	6	32
MOSFETs (low frequency)	1	6	32
Thyristors (SCR)	1	6	32
Diodes	1	6	32
Schottky Diodes	1	6	32
Resistors (metal film)	1	4	87
Capacitors (ceramics and tantalum)	1	10	50
Inductors and transformers	1	6	34
Quartz crystal	1	3	32
Fuses	1	2	21
Relays (mechanical)	1	2	66
Relays (solid state)	1	3	33
Switches	1	3	67
Connectors (pairs)	1	1	27
Printed circuit board (trough holes)	1	2	27

Items for which data are not found have adjustment coefficients taken from similar technology devices.

In cases for which similarity is not found the most conservative condition is used, for instance considering operational phase failure data during storage phase instead of dormancy failure data. This choice is supported by experience because most failures during non-operating periods were found to be of the same basic kind of those found in operating mode, however showing lower occurrence rate. [2,8]

Tab. 4 shows dormancy adjustment coefficients used for selected items.

Table 4. Dormancy adjustment coefficients for selected items

Device type	Coefficient
Integrated Circuits	0.08
Transistors	0.05
Diodes	0.04
Capacitors	0.10
Resistors	0.20
Transformers	0.20
Relays	0.20
Switches	0.40
Connectors	0.005
Printed Circuit Board	0.04

Some remarks seem worth-wile concerning similarities useful to items that are not found in Table 4.

Thyristors and solid-state relays show similarities with bipolar junction transistors allowing the use of their coefficients.

Mechanical switches are not found in temperature adjustment tables and coefficients for mechanical relays are used instead.

Quartz crystals and fuses are not found in dormancy adjustment tables nor in temperature tables. As they don't show any similarities with other items their adjusting coefficients are considered unitary.

Printed circuit boards are not found in temperature tables. As no similarity is found with other items their adjusting coefficients are considered unitary.

2.4 Mission phases adjustment coefficients

Using adjustment coefficients obtained as discussed and shown in Tables 1 to 4, a phase failure rate adjustment coefficient for each element can be evaluated considering the adjusting coefficients. Typical results are shown in Tab. 5.

Temperature, environment type and dormancy adjustments are considered. Relative humidity is not considered.

Table 5. Mission phases adjustment coefficients

Device type	Storage	Tests	Flight
CMOS integrate circuits	0.006	2	34
Bipolar Junction Transistors (low frequency)	0.029	6	42
MOSFETs (low frequency)	0.031	6	41
Thyristors (SCR)	0.023	6	48
Diodes	0.024	6	41
Schottky Diodes	0.018	6	48
Resistors (metal film)	0.116	4	128
Capacitors (ceramics and tantalum)	0.058	10	58
Inductors and transformers	0.146	6	41
Quartz crystal	1	3	32
Fuses	1	2	21
Relays (mechanical)	0.112	2	88
Relays (solid state)	0.029	3	44
Switches	0.400	3	89
Connectors (pair of connection)	0.003	1	33
Printed circuit board	0.040	2	27

3. DEFINING SCENARIOS

3.1 Phase scenarios

Three different scenarios are considered to evaluate degradation in failure rates when completing the phases of a mission.

Scenario 1 considers an optimistic hypothesis in which phase failure rates remain constant during all five missions showing no degradation at all.

Scenario 2 represents a more realistic hypothesis in which failure rate degrades in each phase of every mission. It represents a condition that shows increasing failure rate as phases of missions are completed or time proceeds.

Scenario 3 can be considered a pessimistic hypothesis that considers the same failure rate degradation of scenario 2 increased by 10%.

The main goal is to investigate whether overall reliability remains acceptable during at last five consecutive missions.

3.2 Exponential distribution

Exponential distribution is considered concerning failure distribution for all items.

4. MODELING FAILURE RATE DEGRADATION

Tab. 6 shows evolution of phase failure rate under scenario 1 until fifth mission is completed.

Table 6. Failure rates of five completed missions considering scenario 1 (x 10^{-6} f/h).

Phase	Mission				
	1	2	3	4	5
Storage	0.15	0.15	0.15	0.15	0.15
Tests	3.00	3.00	3.00	3.00	3.00
Flight	45.00	45.00	45.00	45.00	45.00

Under scenario 2 degradation produced by one flight hour shows to be equivalent to that produced by fifteen test hours or by three hundred storage hours, as shown in Tab. 7.

Table 7. Phases hours relative- degradation equivalences

Storage		Tests		Flight	
Tests	1/20	Storage	20	Storage	300
Flight	1/300	Flight	1/15	Tests	15

At the beginning of first mission storage item is considered to show basic failure rate and failure rate degradation is calculated in the usual way. Test phase time is converted into equivalent storage degradation time according to table 7. For flight phase the same procedure is used.

The adjusted failure rate of the item is evaluated by relation (1) that establishes FRET (Failure Rate considering Elapsed Time):

$$\text{FRET} = 1 / \text{MFET} \qquad (1)$$

Where MFET (Mean time to Failure minus the Elapsed Time) is obtained from MTTF (Mean Time To Failure) minus the elapsed time of the phase.

$$\text{MFET} = \text{MTTF} - \text{Elapsed Time} \qquad (2)$$

Failure rate and MTTF for an item already used in a preceding mission must be replaced by FRET and MFET respectively.

Calculation for scenarios 2 and 3 are showed in Tables 8 and 9 respectively.

Table 8. Failure rates of five completed missions considering scenario 2 (x 10^{-6} f/h).

Phase	Mission				
	1	2	3	4	5
Storage	0.150	0.150	0.151	0.152	0.153
Tests	3.004	3.008	3.012	3.016	3.020
Flight	45.182	45.366	45.551	45.738	45.926

Table 9. Failure rates of five completed missions considering scenario 3 (x 10^{-6} f/h).

Phase	Mission				
	1	2	3	4	5
Storage	0.150	0.165	0.183	0.203	0.226
Tests	3.304	3.640	4.011	4.420	4.872
Flight	49.700	54.915	60.705	67.141	74.302

5. FAILURE RATES EVALUATION

Consider an electronic circuit board used in payload of a sound rocket with a base failure rate of about 1.0 x 10^{-6} f.h^{-1} according to manufacturer's data without any adjustments. If the involved item's failure rates are adjusted for each mission the total failure rates for each phase of the mission and those shown in Tab. 10.

Table 10 Total failure rate for each mission phase

Mission Phase	Failure Rate x 10^{-6} f.h^{-1}
Storage	0.15
Tests	3.00
Flight	45.00

5.1 Storage phase behavior

Under scenario 1 no adjustments are made in failure rate at any phase and in a whole mission, shown in green. It considers that no degradation occurs due to previous periods.

Fig. 2 shows the behavior of reliability at this scenario during fifth mission.

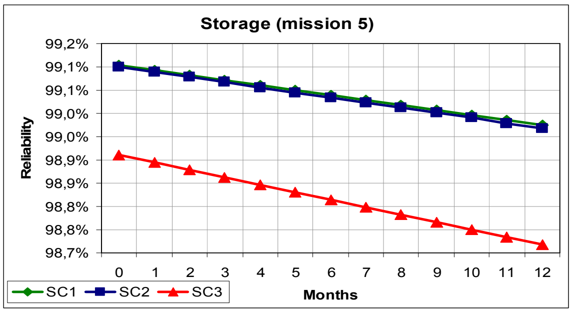

Figure 2. Reliability behavior during storage phase of fifth mission considering three scenarios

Under scenario 2 failure rate adjustment must be evaluated to show item degradation with storage time transferring a degraded failure rate to tests phase shown in blue.

Fig. 2 shows the behavior of reliability under scenario 2 during fifth mission.

Under scenario 3 failure rate can be obtained from results obtained under scenario 2 shown in red.

Fig. 2 shows the behavior of reliability under scenario 3 during fifth mission.

5.2 Tests phase behavior

Fig. 3 shows results for the behaviors under the three different scenarios.

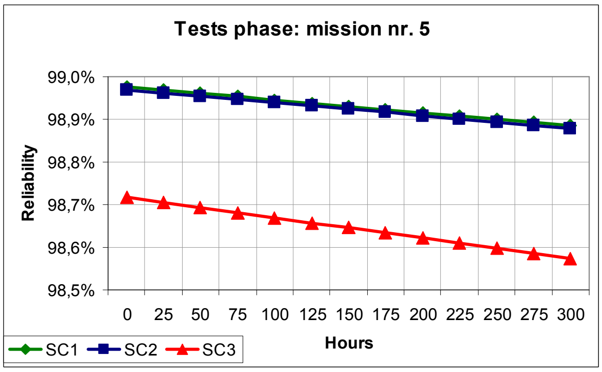

Figure 3. Reliability behavior during tests phase of fifth mission considering three scenarios

5.3 Flight phase behavior

Fig. 4 shows results for the behaviors under the three different scenarios.

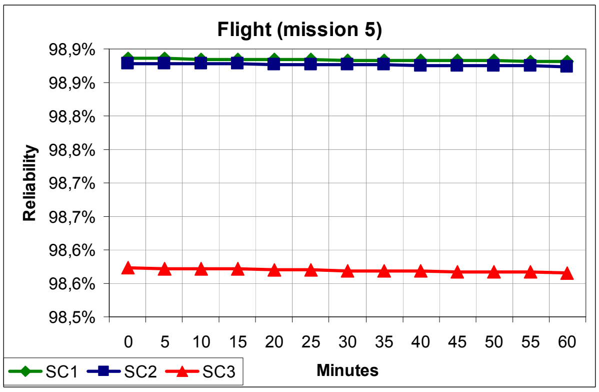

Figure 4. Reliability behavior during flight phase of fifth mission considering three scenarios

6. CONCLUSIONS

Figs. 2 to 4 show that results under scenarios 1 and 2 are negligibly different for the item chosen to illustrate the method.

Further degradation as used for scenario 3 could represent all non-considered or not fully-considered causes of degradation. Mechanical vibrations and shocks (storage, tests, transportation, assembling) an humidity are natural candidates to justify such practice.

Method flexibility allows for use in sensibility analysis concerning impacts of elements parameter variation or of architecture changes in the item.

Magnitude chosen to create scenario 3 can be different for mechanical, electrical, electronic or mixed type items.

7. REFERENCES

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