New FIDES models for emerging technologies

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New FIDES Models for Emerging Technologies

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SUMMARY & CONCLUSIONS

The purpose of this paper is to describe the PISTIS project, mainly focused on the reliability of emerging technologies involved in electronic systems. PISTIS is a French acronym, meaning faith, trust and confidence, from the Greek origin. Managing the reliability risk is a big challenge in rugged environments. PISTIS is linked to FIDES, a guide allowing reliability prediction of electronic systems.

Results from in-service study presented in this paper show the accordance between FIDES predictions and reliability observed.

This confirmed the interest to complete FIDES models by taking into account intrinsic wear-out effects limiting the operating lifetime. The PISTIS project started in 2015. Depending on the technologies and their main failure mechanisms, different long-term test processes are set up to evaluate the wear-out effects. To be able to construct reliability prediction models taking into account these effects, the stress level of reliability tests need to be close to the actual extreme use conditions and mission profiles in which electronic equipment are used.

1 FIDES GUIDE

During the previous RAMS congresses, some presentations [1] were about FIDES [2]. The methodology and details of the calculation models were described [3] and briefly presented (panel 2011).

1.1 Purpose of FIDES

FIDES is the result of a study driven by the French Ministry of Defense (MoD) and conducted by a consortium of companies involved in the defense, civil and aerospace fields: Airbus, MBDA, Thales, Nexter and Eurocopter. The objective of this study was to develop a new accurate method to evaluate the reliability of electronic components which takes into account the latest technologies. FIDES is an alternative to obsolete MIL HDBK 217 and IEC62380.

1.2 Use of FIDES

The FIDES guide became the French standard UTE C 80-811, available in English. It is cited as the best practice for reliability prediction in the European Defense Standards Reference System (EDSTAR) since 2011. The extension to an international IEC standard usable for international projects is in progress. FIDES guide and tools can be downloaded for free on www.fides-reliability.org. FIDES is used by various companies involved in large domains such as aerospace, defense, transportation, automotive, energy, etc).

1.3 Detailed methodology scope

The FIDES approach takes into account the three major contributors of the electronics item reliability, which are its technology, its process and its use. These contributors are considered throughout the life cycle, from the item manufacturing phase to the electronic system maintenance phase (*Figure 1*).

Technology includes electronic parts technology as well as equipment technology. *Process* takes into account all reliability engineering rules and the state of the art, from specification, the item manufacturing and integration to its removal from the final equipment. *Use* includes the life (mission) profile of the systems including COTS (Commercial-Off-The-Shelf) parts, sub-assemblies and high reliability electronic parts.

The model considers use physical stresses applied to one technology, taking into account all the process influences throughout the COTS life.

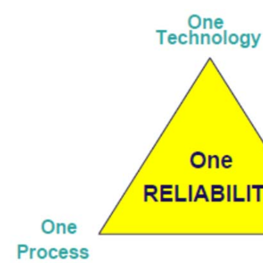

Figure 1 - FIDES methodology philosophy

FIDES methodology includes Physics of Failure (PoF) considerations, with expert knowledge, manufacturer's data and field returns coefficients (to skillfully adjust the models).

1.3.1 Generic model

The FIDES general model is used to calculate the failure rate of an electronic system before any redundancy or architectural consideration. The global failure rate of the electronic system (usually equipment) is obtained by

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summating all failure rates for each of its constituent items.

$$\lambda_{system} = \sum_{Item} \lambda_{Item} \tag{1}$$

The generic model consists in the product of three main terms, the first one being the contribution of physical stress factors and two acceleration factors Π representing the product quality and life cycle process contributions.

λ_{Item} is the predicted failure rate of the item (expressed in FIT (Failure In Time) with 1 FIT equal to 1 failure per 10^9 hours):

$$\lambda_{Item} = \lambda_{Physical} \Pi_{PM} \Pi_{Process} \tag{2}$$

where:

- $\lambda_{Physical}$ represents intrinsic reliability comprising the contribution of the technology of the item (die, package, …) and its sensitivity to physical stresses (temperature, humidity, …) described in the life profile (Table 1)
- $\Pi_{Part\_manufacturing}$ represents the quality grade and the manufacturing technical control of the item,
- $\Pi_{Process}$ represents the contribution of the system life cycle of the from the specification, the manufacturing and the use of the system. This factor is determined from an audit of about 300 questions and recommendations over all process (specification, design, manufacturing, integration, maintenance and support).

$\lambda_{physical}$ may be written :

$$\lambda_{Physical} = \left(\sum_{physical\_contributions} \lambda_0 \Pi_{acceleration} \right) \Pi_{induced} \tag{3}$$

where:

- λ_0 is the basic failure rate, depending on technological characteristics,
- Π*acceleration is* an environmental acceleration factor versus use conditions like ΠTH for thermal contribution (Arrhenius model) or ΠRH for humidity (Peck's model) (cf. equation (3)),
- Π*induced* is the overstress factor (Electrical OverStress, EOS, for example).

The use conditions include electrical, thermal, thermo-mechanical, mechanical, chemical and humidity stresses.

Π *induced* depends on the COTS sensitivity to the considered overstress (electric, thermal, mechanical), on the location of the COTS in the equipment, on the use conditions of the product and on the precautions taken to control the risk of overstress.

1.3.2 Calculation

In order to define all these conditions, the life profile has to be defined accurately. The life profile is split into n phases, according to the major constrain on the COTS. For each phase, the level of each environmental stress (electrical, thermal, thermo-mechanical, mechanical, chemical and humidity) is quantified.

The following Table 1 shows an example of FIDES life profile which can be used for medium range civil avionics systems. Each line describes each phase of the life profile of the product (generally at system level). Each column defines all operating parameters and the stress contributors' levels integrated in equation (4).

Table 1 - Medium range civil avionics, FIDES life profile description

Stress		Temperature and humidity			Temperature cycling			
Phases	Time by year (hours)	On /off	Ambient temp. (°C)	RH (%)	ΔT (°C)	# of cycles (/year)	Cycle duration (hours)	Max temp. (°C)
Ground operat. On/off	700	On	40	30	25	350	2	40
Ground operat. stopover	1400	On	55	30	15	700	2	55
Ground - taxi	630	On	40	10	-	2100	0.3	-
Flight climb/ descent	1050	On	40	10	-	1050	1	-
Flight- stable	3150	On	40	10	-	1050	3	-
Ground- storage	1830	Off	15	70	10	365	5	20

Then, the failure rate assessment may be done for all parts of the systems. For an integrated circuit, the complete model is:

$$\begin{aligned}\lambda_{Physical} = \sum_{i}^{Phases} \left(\frac{t_{annual\_phase}}{8760} \right)_i \Big(& \lambda_{0_{TH}} \Pi_{Thermal} \\ & + \lambda_{0_{TCy\_Package}} \Pi_{TCy\_Package} + \lambda_{0_{TCy_{solderjoints}}} \Pi_{TCy_{solderjoints}} \\ & + \lambda_{0_{RH}} * \Pi_{RH} \Big)_i \Pi_{induced-i}\end{aligned} \tag{4}$$

where λ_{0i} are generally defined from parts reliability manufacturers tests. Πacceleration factors derives from PoF models like Coffin-Manson for temperature cycling (Π_{TCy}). λ_{0i} failure rates are available in different tables in the guide as for acceleration factors. Depending on the life profile definition (Table 1), reliability can be calculated for a one year period, for all the life duration but also for a short mission period.

1.4 FIDES conclusion

FIDES Methodology provides a serious alternative to old methods because:

- It includes the state of the art of reliability contributors (intrinsic and extrinsic) including technology, usage and process; it takes into account induced constraints and process grade data collected through an audit.
- It includes Physics of Failures considerations (as Arrhenius, Coffin-Manson models),
- It takes into account a detailed life profile for all kind of application (automotive, space, industrial, military …).
- It has regular updates of the method (next one in 2019)

FIDES has been used on different projects which show accuracy of predictions on a wide range of harsh environments and applications (cf. example in §2). FIDES is a strong alternative to the obsolete MIL-HDBK-217F and is already used in all main French military programs. It has been used not only by defense and aeronautical industries but also by automotive and railway industries.

All studies done in Europe and in USA [1] have given a better perception of FIDES model richness and thus a good mastery of the sensitive parameters and their influence on the accuracy of estimated reliability prediction. Especially, an in-Service Feedback (of field return) study like “REX” (§2) was a good way to verify FIDES precision versus field returns. FIDES was confirmed as a real method of reliability construction and engineering, not exclusively intended to reliability engineers.

2 FIDES IN-SERVICE FEEDBACK.

2.1 *“REX” in-service feedback study*

Compliance between the in-service feedback observations and the predictions was confirmed by a complementary study called “REX” [4] meaning “in-service Feedback” in French, which was driven by the French MoD, for 42 months. The “REX” objectives were to process failure data from operational electronic equipment using COTS components for defense systems.

This study was based on collection of data, identification of failure occurrence, identification of the root cause, definition of action plans and comparisons between predicted and observed reliability. The scope of REX study addressed multiple air, land and sea domains. This exploitation of a large-scale of in-service feedback permitted the comparison between the reliabilities observed and those predicted from the FIDES and MIL-HDBK-217F methodologies.

This study combined at the same time theoretical aspects (definition of process of collection and analysis of data), and practices (collection of the failing components and the failure analysis). A consortium called “PEA REX” was established in 2008, it consisted of eight leading players in the defense sector: Thales the leader, Eurocopter and MBDA France.

2.2 *Method*

To obtain a reliable in-service feedback, the project "REX" was articulated around various tasks described below.

- Construction of a state of the art of the in service feedback and the practices implemented by the companies.
- Definition of a common process of in-service feedback:
  - Format definition of the collected data
  - Return of the declared failing sub-assembly,
  - Repair of the subassembly (if not No Fault Found).
  - Failure analysis of the defective components
- Definition of an exploitation methodology allowing the compilation of the operational reliability data observed on components used in various environments.
- Specification, design, and sharing of specific tools for data collection and exploitation.
- Failure analyses on a selection of representative COTS components.
- Comparison of the in-service/predicted reliabilities at the equipment level, Subassembly, component, Family group

2.3 *Results*

Summary is given in the following *Table 2*:

Table 2 - REX Key figures

“REX” Key figures	
Observation period (Months)	24
Number of equipment (ground/air/ sea)	14
Number of articles boards /modules	5200
Number of electronic components	28 900 000
Number of cumulated-hours.components	500 000 000 000
Number of customer returns	1325
Number of confirmed failures	438
Number of failure analyses	370

A confidence criterion was introduced to consider families presenting more than a significant number of failures (to be statistically significant) from low to good (*Table 3*).

For the contributions due to the overloads, the main phenomenon observed was Electrical Over Stress (EOS). Regarding the Quality of the component and its manufacturer, the analysis confirms the homogeneity of the Pi part manufacturing. All results were analyzed by the FIDES Working Group. The guide was updated following the findings. Table 3 summarizes the failure rates observed by components families, compared with the predictions done by FIDES (“λ_0”) A rating/ratio was introduced to be able to check the observed/predicted for all product families. The ratio at family component level presents satisfactory values. Generally, the ratio is within 1 to 3 at component level.

Ratio definition: observed/predicted Lambda, indicates the ratio between the value observed and predicted. When the ratio is below 1.00, a “–“sign is used to indicate that FIDES is optimistic. These ratios below 1 are inverted for a better reading.

A comparison between in-service reliability and MIL-HDBK and FIDES MTBF Predictions was performed. The *Table 4* summarizes the observed results:

Nota: “Total” from Table 4 are obtained from Weighting on Line replaceable Unit Number).

These results show the great difference between MIL-HDBK-217F and FIDES MTBF predictions versus Reliability observed. The results are very close to the prediction and good for FIDES (Failure rate observed/Failure rate predicted close to 1). Large dispersions between predicted reliability performed by MIL-HDBK-217F are caused by the different methods of calibration applied by companies, but are nevertheless very pessimistic (not adapted to the used components technologies). FIDES is designed to be used without any calibration by FIDES user companies. To take into account the evolution of technologies FIDES need to be updated periodically.

Table 3 - Summary of failures rates by families

Component Family	λ_O FIDES	Total Failures and Function Hours		"REX" Component Family			Confidence Criterion	λ Obs. / λ Predict.
		fail. Nb	Function hours	λ Min (10-9 déf/h) 90%	λ (10-9 déf/h) 50%	λ Max (10-9 déf/h) 90%		
ASIC	1,079	5	6 770 140 278	0,34	0,76	1,45	Low	-
IC microprocessor	0,668	10	5 259 289 715	1,17	2,03	3,23	Acceptable	3
IC Programmable	0,714	18	8 996 470 924	1,38	2,08	2,97	Acceptable	2,9
IC memory	0,283	21	18 280 081 074	0,82	1,19	1,65	Acceptable	4,2
IC numeric and interface	0,088	7	73 535 356 677	0,05	0,10	0,17	Low	-
IC analog and Power	0,427	36	92 891 204 763	0,29	0,39	0,51	Good	-1,1
Diode	4,089	11	403 449 296 199	0,02	0,03	0,05	Acceptable	-141,4
Transistor	0,047	18	114 623 050 835	0,11	0,16	0,23	Acceptable	3,4
Optoelectronic	0,031	3	6 210 373 834	0,22	0,59	1,25	Low	
Piezoelectric	4,765	4	5 309 012 509	0,37	0,88	1,72	Low	-5,4
Resistor fixed & variable	0,026	9	701 961 143 862	0,01	0,01	0,02	Low	-2
Potentiometer	0,413	4	2 038 431 429	0,97	2,29	4,49	Low	-
Capacitor	0,161	42	752 891 884 784	0,04	0,06	0,07	Good	-2,8
Fuse	0,143	5	1 052 053 578	2,48	5,39	9,99	Low	-
Inductive device & transformers	0,078	15	76 624 392 788	0,13	0,20	0,29	Acceptable	2,5
Relays	49,05	2	1 950 673 251	0,42	1,37	3,23	Low	-35,8
Switch	1,126	6	14 006 934 488	0,21	0,44	0,80	Low	-2,6
Connectors	0,677	31	19 121 842 067	1,22	1,66	2,19	Good	2,4
IC Microwave and RF	2,179	4	15 578 735 433	0,11	0,27	0,54	Low	-8,1
PCB	7	17	7 893 424 257	1,47	2,24	3,23	Acceptable	-3,1
COTS Board	212	15	45 782 015	219,21	342,23	504,50	Acceptable	1,6
Screen LCD (TFT, STN)	7547	16	127 574 351	84,91	130,65	190,49	Acceptable	-57,8
CRT monitor	3798	2	4 510 126	181,30	592,90	1365,00	Low	-6,4
Hard Disc	196	4	1 680 612	1172,00	2779,29	5446,00	Low	-
Voltage convertor	28,79	15	948 621 448	10,58	16,52	24,35	Acceptable	-1,7
Cell, Lithium et Nickel Batterie	0,306	2	2 104 817	388,49	1270,45	2991,00	Low	-
Fan	100	4	115 610 871	17,04	40,40	79,18	Low	-2,5
Tube	3798	3	535 586	2551,00	6856,16	14476,00	Low	-
Rotating device	100	0	5 560 158	9,23	124,66	538,79	Low	-
Lamp	0,409	1	6 734 178	52,77	249,228	704,446	Low	-
Electronic Filter	0,382	4	4 066 725 301	0,484	1,149	2,251	Low	-
Metter, panel	2,154	1	1 253 032 040	0,284	1,339	3,786	Low	-
Keyboard	12	0	4 628 151	11,083	149,768	647,285	Low	-
Passive RF HF Function	0,633	2	3 764 812 417	0,217	0,71	1,672	Low	-

3 The PISTIS PROJECT

It is fundamental to keep accuracy of reliability predictions. From this target, the PISTIS study is engaged for updating models, parameters associated and providing new models for Emerging technologies.

Depending on the technologies and their main failure mechanisms, different long-term test processes are set up to evaluate the wear-out effects. To be able to construct reliability prediction models taking into account these effects, the stress level of reliability tests need to be close to the actual extreme use conditions of mission profiles in which electronic equipment are used.

Entity	Equipment/ product	MTBF	
		Rate between Measured / Predicted values (adjusted MIL-HDBK 217F)	Rate between Measured / Predicted values (FIDES)
Company-1	Comp1-1	5.2	3.3
	Comp1-2	2.1	1.1
	Comp1-3	1.4	0.9
	Comp1-4	No information	4.2
	Comp1-5	1.4	1.0
	Comp1-6	0.6	0.5
	Total	7.1	1.0
Company-2	Comp2-1	12.4	2.2
Company-3	Comp3-1	2.4	0.7
	Comp3-2	4.1	0.8
	Total	3.0	0.7
Company-4	Comp4-1	2.5	1.3
	Comp4-2	1.4	0.6
	Comp4-3	1.3	0.3
	Comp4-4	0.5	0.2
	Total	1.1	0.4

Table 4 - Reliability predictions versus reliability observed.

3.1 Emerging Technologies

The increasing integration of embedded systems and the need to support new features requires high-performance and thermal-efficiency. To maintain competitiveness of the electronic systems, this trend pushes towards the use of components processed with the most advanced technologies such as technology nodes below 30nm. Some of these technologies may use new manufacturing processes and materials (such as hig-k gate oxides), sources of new concerns. Moreover, it is always difficult to evaluate reliability from emerging technologies, due to the lack of field experience in real conditions. Another goal of the study is to propose alternatives to existing procedures consisting in reliability qualification by using the PoF concept [5].

3.2 Purpose of PISTIS

The PISTIS project was launched for improving the methods to evaluate reliability from emerging technologies. This project is a collaborative study driven by the French MoD and is mainly focused on the reliability of leading edge technologies. Different product families and technologies are studied: Deep SubMicron (DSM) components used in digital components, power microwave GaN and power transistors (MOSFET and IGBT). The objective of this study is to construct new FIDES models, from random failures to the limit of operating lifetime, due to the beginning of wear-out effects. One of the fundamental steps before defining the long-term test conditions is to identify the most severe and typical life missions in which these technologies may be used. Another starting point is to collect reliability data from the different vendors of the component families to be evaluated.

The reliability data to be collected is not limited to the final packaged product level, as the results from High Temperature Operating Lifetime (HTOL). Results from Wafer Level Reliability (WLR) need to be analyzed. And for this level of information, the vendor could require a specific Non-Disclosure-Agreement (NDA). There is no major concern to sign this NDA when the user is a customer.

3.3 Deep Sub-Micron Technologies

Today, critical embedded computing systems need to use digital components processed with technology nodes between 30nm and 14nm. Higher reliability concerns have appeared with the down-scaling of CMOS device dimensions. The decreasing reliability is mainly due to intrinsic wear-out effects reducing operating lifetime. The main question if to evaluate the impact of wear-out effects on the lifetime. Another question is to define if the level of random failures remains constant or not as it is always assumed.

The study is based on long-term reliability tests, in severe conditions, for more than two years, with the purpose to evaluate the most critical failure mechanisms and the impact of critical drifts of electrical parameters. Among these mechanisms, Electromigration (EM), Hot Carriers Injection (HCI), Negative Bias Temperature Instability (NBTI) and Time Dependent Dielectric Breakdown (TDDB) are studied. Today, when considering Arrhenius model for one given mechanism, the basic approach is to consider constant activation energy in the full temperature range of the application. We need to determine the true acceleration as a function of temperature [6], voltage, frequency, etc, and to define the different acceleration factors specific to one failure mechanism and their area of use. Most of the simulation tools tend to simulate a single failure mechanism. The critical questions can be for instance, for this specific temperature and voltage, what is the major failure mechanism? Do we face to concurrent mechanisms?

Based on the PoF and the understanding of the mechanisms, the target is to construct reliability prediction models applicable to generic technologies and products. In the frame of the study, tests are performed on programmable FPGAs, SDRAM-DDR3 and Flash memories. The technology process nodes tested are summarized in the following *Table 5*:

Table 5 - Components and DSM technologies tested

Component family	*Technology process node*
FPGA	28nm
Flash #1	NAND MLC 20nm
Flash #2	NOR 65nm
SDRAM DDR3 #1	25nm
SDRAM DDR3 #2	20nm

3.4 Power Components

Power components are also concerned by the update of FIDES models in the frame of PISTIS. Considering the latest technologies available, there are some existing limitations to the FIDES guide, in the field of GaN technologies, GaAs power components and also for some emerging MOSFET products. Limitations in the application fields need to be investigated. The new GaN based technologies are forecast to enhance many military systems in the coming years. In particular, GaN properties are interesting for designs of power converters and RF amplifiers. But for applications in harsh environment, such as using electrical pulsed modes in radar systems, there is a need to increase the knowledge of failure mechanisms which could appear with any new technologies and processes. Therefore, reliability tests are performed on GaN products for pulsed applications, with different test conditions on Vds, Duty cycle and gain compression. Other long-term tests are also in progress on MOSFETs and IGBT technologies.

The following *Table 6* summarizes the technologies tested:

Table 6 - Power components tested

Technologies	*Characteristics*
Vendor #1, GaN-HEMT	15W, V_{DS}=30V
Vendor #2, GaN-HEMT	20W, V_{DS}=43.5V
Vendor #3, IGBT	600V field stop
Vendor #4, MOSFET	N Channel, $V_{(BR)DSS}$ 650V
Vendor #5, MOSFET	N Channel, $V_{(BR)DSS}$ 200V

3.5 Screening and aggravated Test Methods

With the objective to improve the reliability of electronic systems, the Environmental Stress Screening (ESS) and aggravated (Highly Accelerated Life Test, HALT) test methods are also addressed, in the frame of PISTIS, at the relevant level (components, boards or equipment for ESS; board or equipment for HALT). The study is first based on a benchmark of the different methods used in the industry and their efficiency for reliability growth. The next step is to provide recommendations and good practices in the next update of the FIDES guide.

4 PERSPECTIVES

The PISTIS study will allow a significant update of FIDES, by performing accelerated long duration tests, more than two years, on hundreds of components. For industrials designing systems to be used in rugged environments, this study will help to construct solutions to optimize the use of emerging technologies and to improve the intrinsic reliability and the operating lifetime.

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