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Innovative technologies : from the Commercial Electronics toward Space System applications. ESCCON 2013

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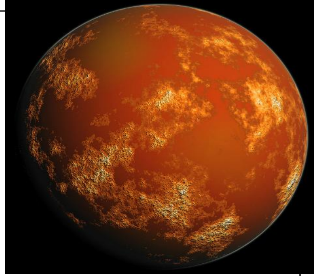
Outline



1. Context : High reliability system requirements for Space technologies. Constraints, checkpoints and cutoff points to use innovative products in these systems.
2. Why existing quality standards are inadequate to proceed with some innovative parts ?
3. Apparent inconsistency of GaAs processes reliability figures found in literature since decades.
4. How to reconciliate these reliability data.
5. Probabilistic-Design-for-Reliability (PDfr) : a powerful tool !
6. Discussion and recommendations
7. Conclusion

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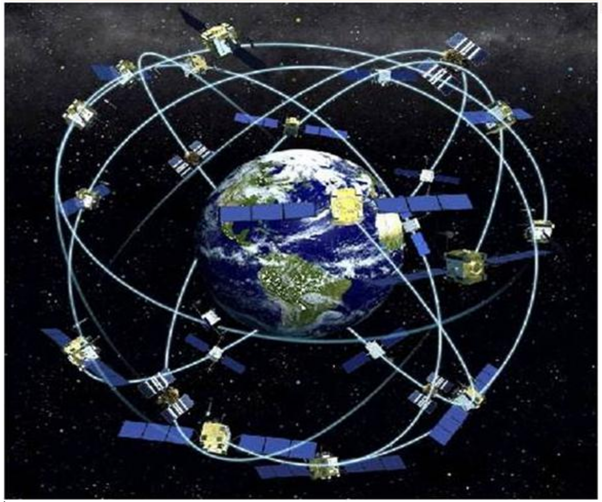
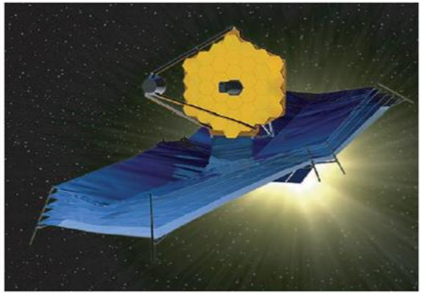
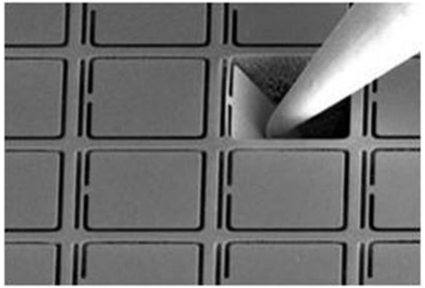
Space application

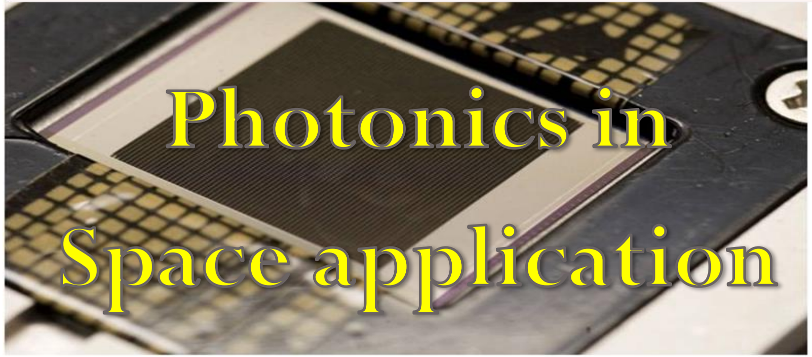
New system application for long term mission are requiring more **capacity**, more **flexibility** and greater **performances**.







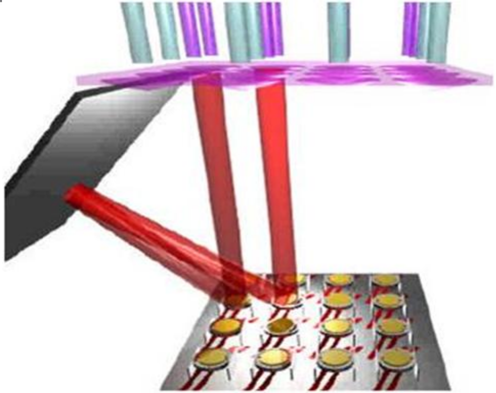
JWST (NASA) and Smart technologies and MOEMS for Extremely Large Telescope (ELT) instruments (NASA).



Micro-shutters manufactured by NASA/GSFC

http://www.nasa.gov/topics/technology/features/microshutters.html

The innovative technologies offering highly advanced electronic parts are appealing for designing new systems and functions found in aerospace and space system applications.



- *Advanced semiconductor processes*
- *Nanotechnologies*
- *MEMS Optoelectronics*
- *Photonics*

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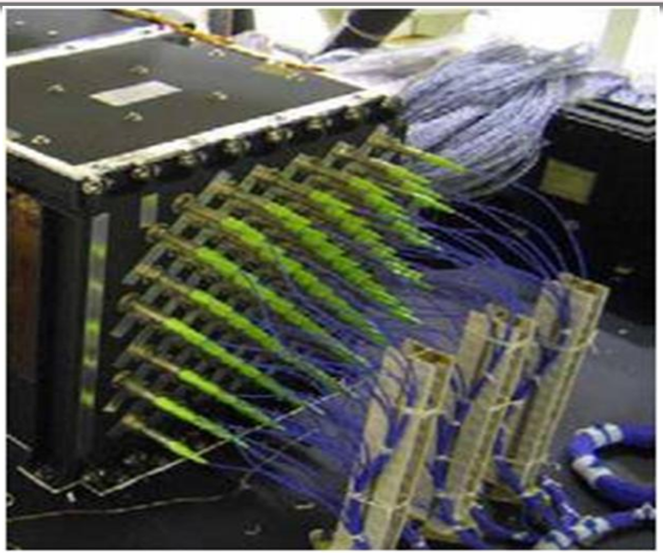
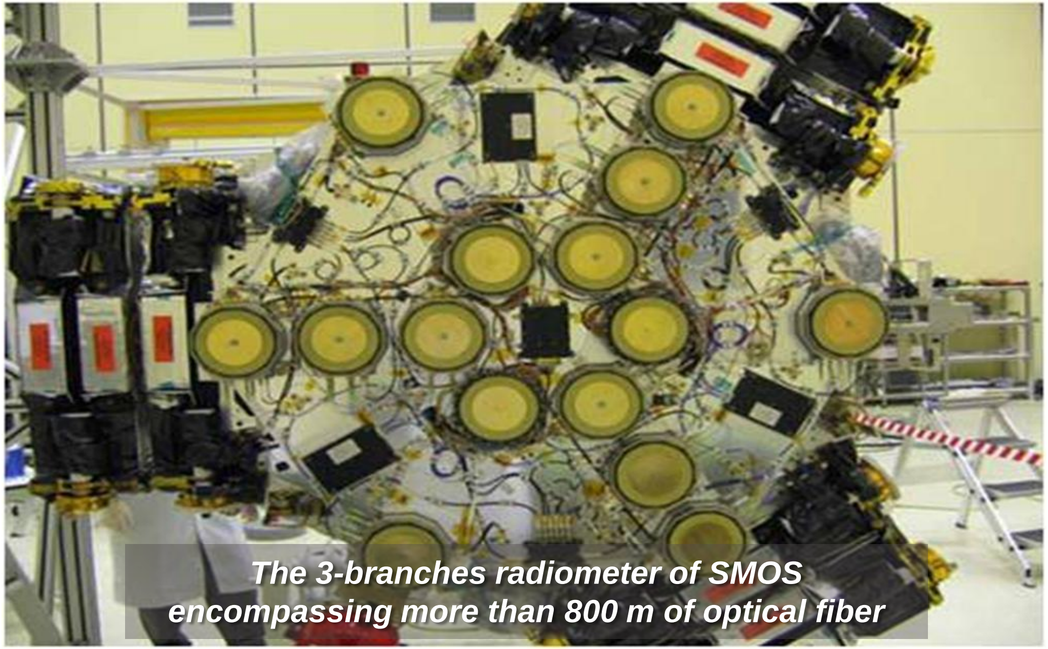
NASA courtesy

COTS Fibre Optic Components in SMOS/MOHA (ESA)

ESA's Soil Moisture and Ocean Salinity (SMOS) earth observation satellite using fibre optics.

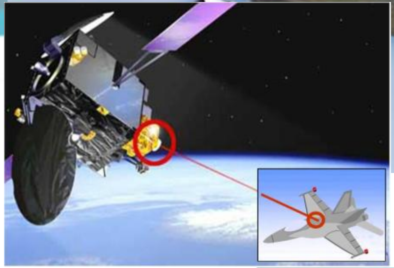


(courtesy of ESA)



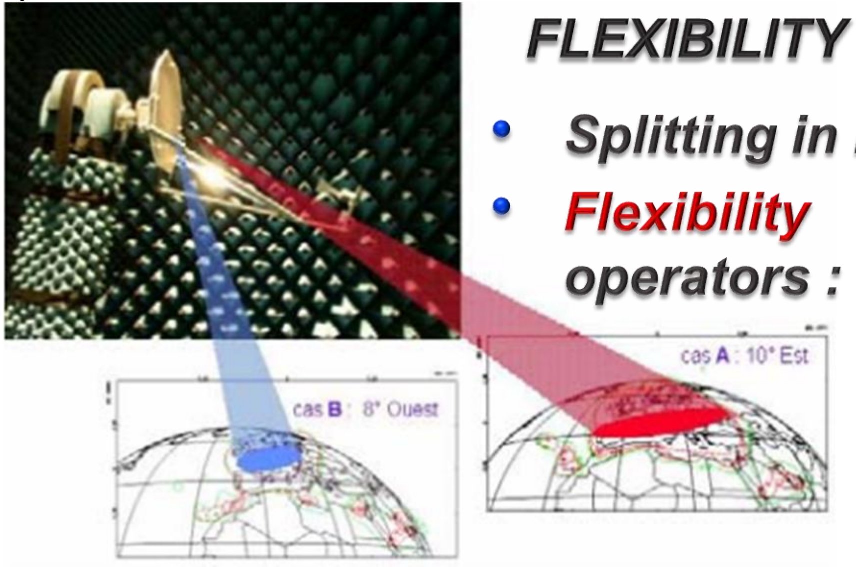
The 3-branches radiometer of SMOS encompassing more than 800 m of optical fiber

The optical fibre connection with the 72 detectors spread over the three arms of the satellite.



- Such pioneering devices from simple electronic parts to complex "System-on-a-Chip" are developed to operate on harsh environment.
- The application of compound semiconductor devices in high reliability systems requires a thorough understanding of the technology's reliability issues and well characterized failure mechanisms.
- The commercial focus of the semiconductor industry combined with the small market prospective of the space business makes the collection of reliability information a more difficult task.
- Evolution in device design and fabrication technology offers a constant challenge to understand the pertinent failure modes and mechanisms to be considered for system design optimization.
- For long term reliability mission, it is essential to establish an adequate understanding of the performance of compound semiconductor devices under mission stress condition and biasing.

FLEXIBILITY highly desirable for space application.

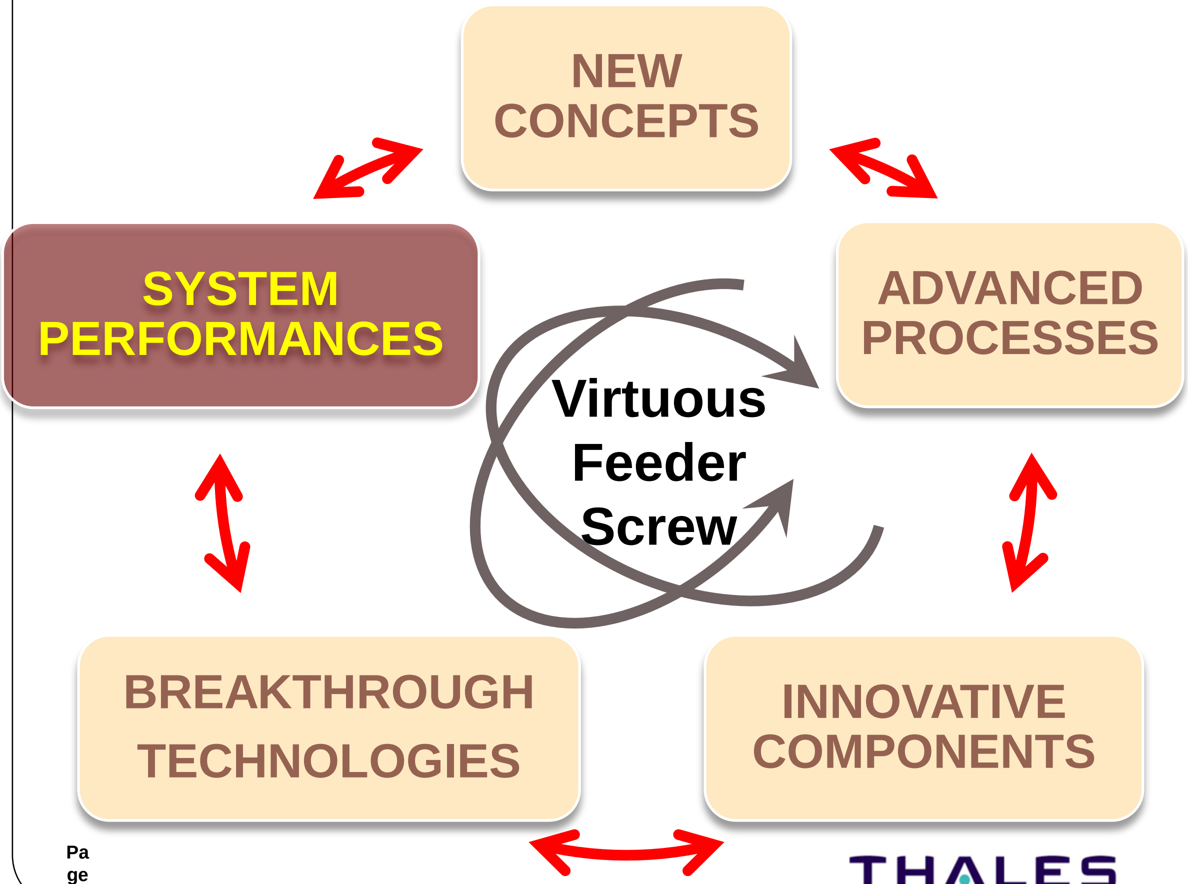


- *Splitting in multiple beams a global coverage*
- *Flexibility because of needs expressed by operators :*
  - ✓ *Capability to pursue market evolution*
  - ✓ *Flexibility in term of satellite fleet management*
  - ✓ *Flexibility in coverage, power, frequency plan, (sub)channels allocation of different beams, improving and assuring connectivity.*

Optical switching technologies:

- ✓ *Thermo-optic switch*
- ✓ *Electro-optic switch*
- ✓ *Optical Amplifier based switch*
- ✓ *MOEMS switch*

The innovative application paradigm.



New technologies paradigm in Space application

Innovative push technologies are strategic needs for space application:

- ***GaN Semiconductor***
- ***Nanotechnologies***
- ***Optoelectronics***
- ***Photonics***

The market is spurred by the growth of new system designs and new architectures in Space application

Existing Standards are crippling industry competitiveness	But requiring to lower development costs and to mitigate the risks

CONSTRAINTS

Photonic Devices (OEDs) will play an increasing role in Space.

But OEDs are often very complex products.	OED's Quality standards are yet available (TELCORDIA), but rather incomplete for Space.

CONSTRAINTS

Reliability

- of components, assemblies, and subsystems is not easy to assess.
- In the commercial sector, much of the network implementers demand and rely on 99.9999% link availability. Space is requiring few FIT level for a 20 years mission in operation.

Players for aerospace systems

- designers and users including industries, manufacturers, agencies, laboratories are more and more strongly demanding adequate strategies to procure, screen, and qualify new products.

Any new and innovative technology

- The same diagnostic applies for : optoelectronics and microwaves devices, micro-nano materials, Micro-systems (MEMS, MOEMS), GaN, microelectronic assembly processes, Graphene and nanotubes, ...

HOW and WHEN TO MANAGE THE INTRODUCTION OF SUCH DISCONTINUOUS INNOVATIONS ?

All is about risk : TRL concept and Valley of Death (TRL3-5) apply to discontinuous innovations

The products force the users to switch but customers want guarantees.

Reliability is imperative for EEE parts

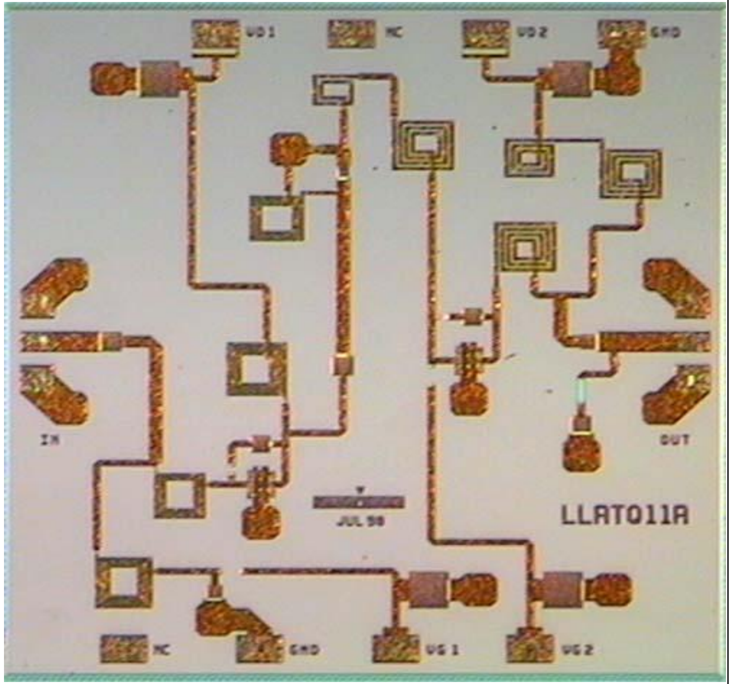
To bring such young innovative technologies to a satisfactory level of confidence, it is required :

A. TO CONDUCT long term, complex evaluation and qualification tests. They are resource and cost consuming test programs,

B. TO ESTABLISH AND APPLY adequate design rules for not exceeding safety factors (but they are not yet defined de facto),

C. TO BUILT system demonstrators (performance goal) for a time to market offering,

D. TO SATISFY customer requirements: high reliable application, availability, maintainability, performance, quality assurance, insurance targets and costs.



Proof of Concept with respect to Reliability Inside

- **Nowadays system studies are stimulated by growth of components development allowing to demonstrate proof-of-concept (TRL3/4).**
- **The next future challenge: to solve reliability concerns and uncertainties in order to make possible the introduction of such technologies in experimental and mission operations where *long term reliability is mandatory.***
- **To this purpose, in terms and in order to properly evaluate the risks of using new technologies in space missions, it is needed:**
  - **To manage the transition from fundamental R&D activities to industrialization phase.**
  - **To track the technology maturity progress along the TRL axis and properly target R&D and development funding to achieve the space qualification stage.**

What is the solution to solve these concerns now ?

To test AS YOU FLIGHT but also to test at DESIGN LIMITS and QUANTIFY.

The Change Vision approach should encompass the understanding of **how the product will stand under specific harsh environment.**

Change Vision is strongly motivated by use of tools like **Physics of Failure** (PoF), **Qualification Testing** (QT) and **Failure Oriented Acceleration Testing** (FOAT) : they are key catalyst to create the condition of change and to establish the right mathematics to model the devices under multiple severe environment conditions.

Predictive modeling (PM) in combination with FOAT is a powerful mean to carry out **Sensitivity Analyses (SA)**, to quantify and reduce or even **eliminate risk of failures** assuming the environment conditions are well characterized and known.

HIGH RELIABLE PRODUCT
TOO ROBUST - TOO EXPENSIVE ?

Commercial products found on markets are designed without compelling this adaptation.

It may be unrealistic to ask COTS' manufacturers to change their processes to include space needs and requirements ?

This situation may be solved. Do it yourself.

Designing RELIABILITY INSIDE is an option to develop ROBUST systems able to be quickly introduced into SPACE and AEROSPACE ENVIRONMENT.

When reliability is imperative for EEE parts, the Probabilistic Design for Reliability (PDfR) concept is the right tool.
It helps to quantify reliability and it can be a possible solution to solve this dilemma.

Do you want to calculate your chance to be the lucky winner at the lottery by return of experiments ?

(10 500 pers. each 11 bets = 115 500 grids).

(5 numbers out of 50 + 2 stars out of 11)

Mathematics allow to calculate it precisely and it represents

1 chance over more than 116 millions to win.

Burn-in and screening conditions are dealing with infant mortality removal.

Equipment design rules: maximum rating and derating rules (or safety factors) are the baseline of engineering design for high reliability space application.

Safe Operating Area: FAILURE ORIENTED ACCELERATION TESTING and QUALIFICATION TESTING are conducted in order to characterize the absolute maximum conditions of use of devices.

These key factors CAN be QUANTIFIED and must NOT ONLY based on space heritages or best practices.

PROBABILISTIC DESIGN for RELIABILITY (PDfR) CAN BE AN EVOLUTION TO QUANTIFY THE RISKS USING APPROPRIATE MATHEMATIC TOOLS.

BUT FOR SURE IT WILL BE A REVOLUTION IN OUR FIELD.

Literature heritage since decades demonstrate daily the following:

Wearout failure mechanisms are superposed and accelerated simultaneously when devices are submitted to multiple environment stress conditions.

For such mechanisms induced, activation energies may ranges from 0.6 eV up to 2 eV for given process or product.

Why this apparent data inconsistency?

Is there a possibility to built a model that settle them?

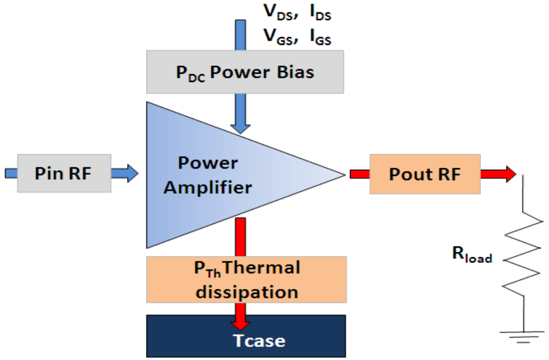
Have a look on the following example.

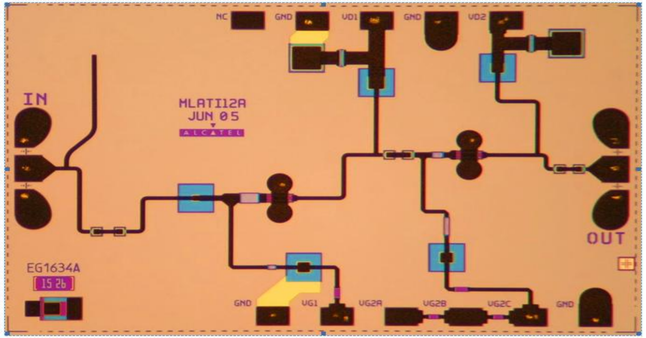
The Boltzmann-Arrhenius-Zhurkov (BAZ) model.

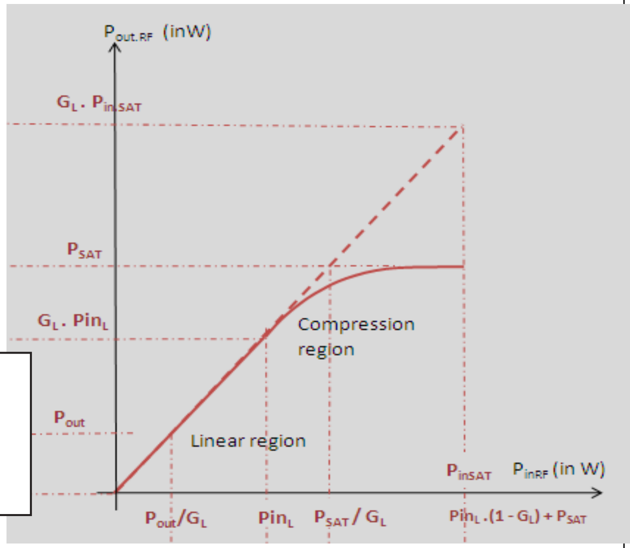
Ref: A. Bensoussan, E. Suhir, "Design-for-Reliability (DfR) of Aerospace Electronics: Attributes and Challenges", IEEE 2013 Aerospace Conference, Big Sky Montana.

Stress and constraints are modeled and adjusted to determine precisely the probability of failure of any component under multiple simultaneous stress conditions.

The Boltzmann-Arrhenius-Zhurkov (BAZ) model determines the lifetime τ for a material or a device experiencing combined action of an elevated temperature and external stresses :







S stresses (multiple and simultaneous) :

- **DC bias (voltages, currents, power dissipation)**
- **RF overdrive signal (high electric field)**
- **Package temperature (Tch, Ohmic contact)**
- **Package atmosphere content (Ionic contaminant due to glue, H2 outgassing)**
- **Radiation stress (Protons, electrons, gamma rays, ions)**

$$\tau = \tau_0 \exp \frac{(U_0 - \gamma S)}{kT}$$

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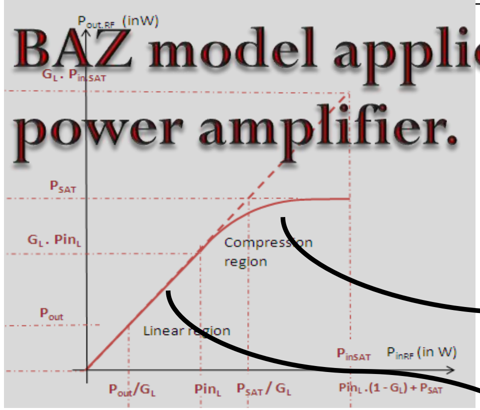
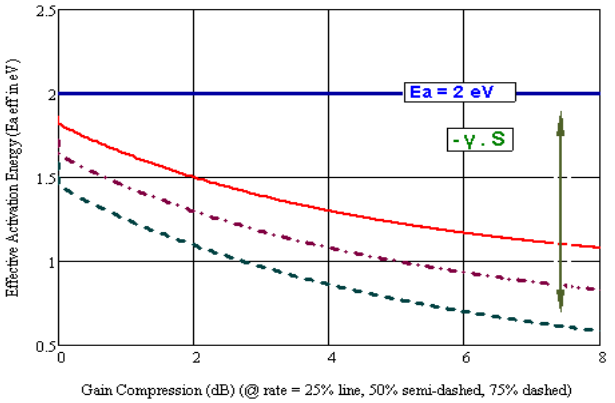
BAZ model applied to a GaAs MMIC RF power amplifier.



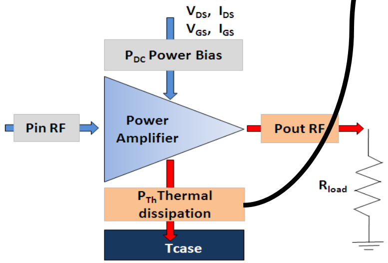
$$\tau = \tau_0 \exp \frac{(U_0 - \gamma S)}{kT}$$

CONDITION 1 : $\tau 1$ STRESS ACCELERATED (all multiple simultaneous stress conditions)

CONDITION 2 : $\tau 2$ REFERENCE (Nominal application)

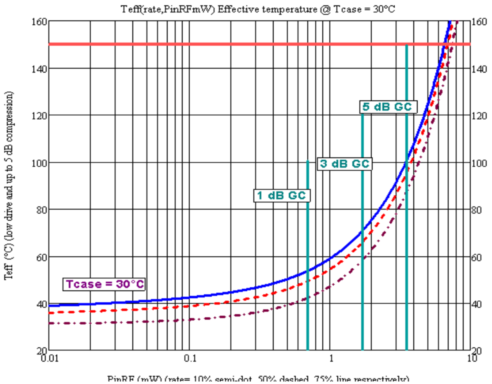


$$AF = \frac{\tau_1}{\tau_2} = \exp\left[\frac{\left(U_0 - \gamma_{DC}.P_{DC1} - \gamma_{Th}.P_{inRF1}(1-G_L) + \gamma_{Th}.a\log\left(\frac{P_{inRF1}}{P_{inL}}\right)^m - \gamma_{H2}.P_{H2-1}\right)}{k.\left(Rth_0.P_{Th1} + T_{c1}\right)} - \frac{\left(U_0 - \gamma_{DC}.P_{DC2} - \gamma_{Th}.P_{inRF2}.(1-G_L) + \gamma_{Th}.a\log\left(\frac{P_{inRF2}}{P_{inL}}\right)^m - \gamma_{H2}.P_{H2-2}\right)}{k.\left(Rth_0.P_{Th2} + T_{c2}\right)}\right]$$

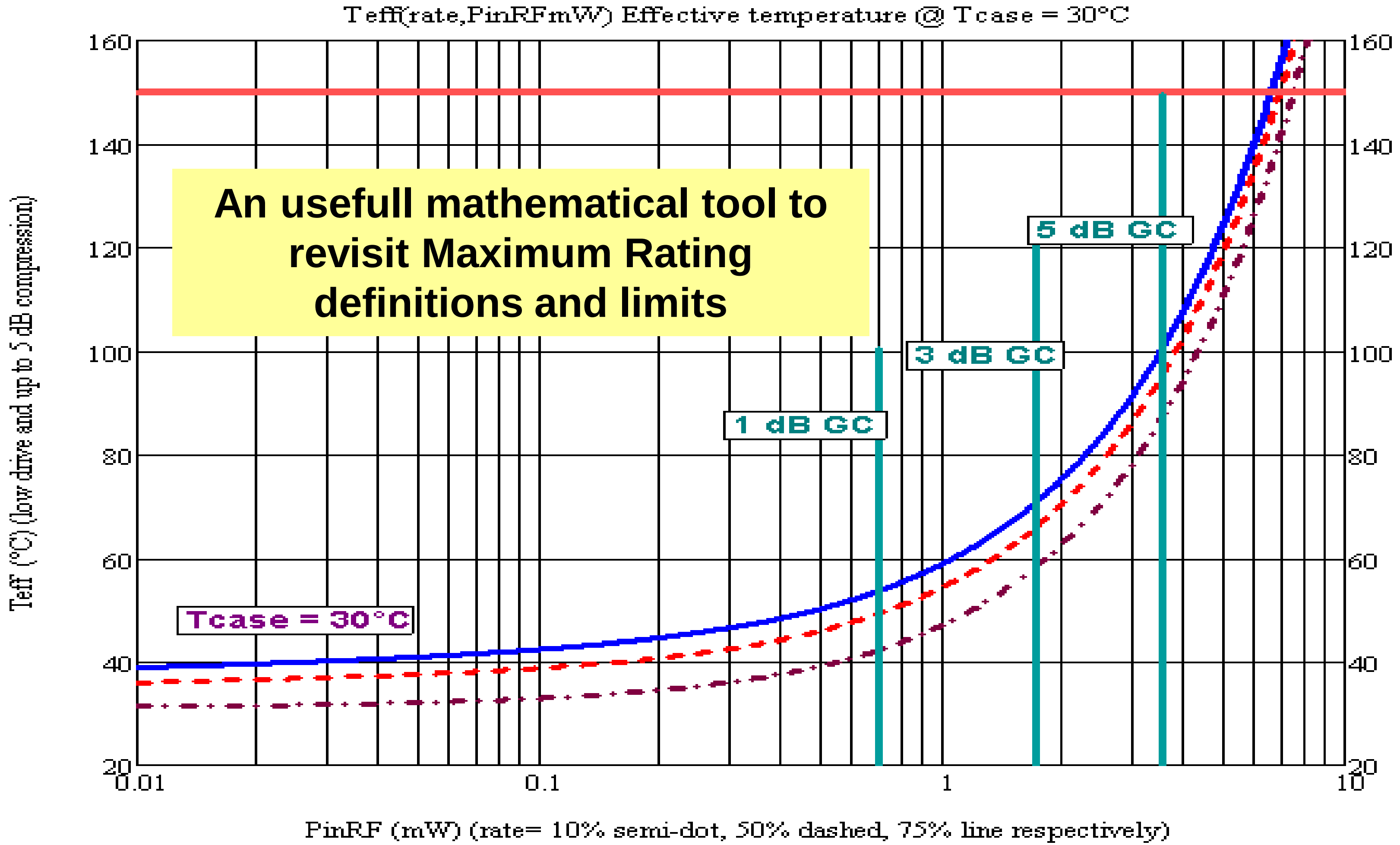


OTHER ENVIRONMENT INDUCING STRESSES:

- Ionic contaminant into package atmosphere are outgassed species from materials installed in hybrid modules: MIL-STD-883G, Method 5011.4 requirements for Specific Ion Analysis.
- Hydrogen poisoning on GaAs compound devices: H2 outgassed from KOVAR packaging materials.
- Radiation stresses (combined with or without bias and signal) : heavy ions, protons, electrons, gamma.

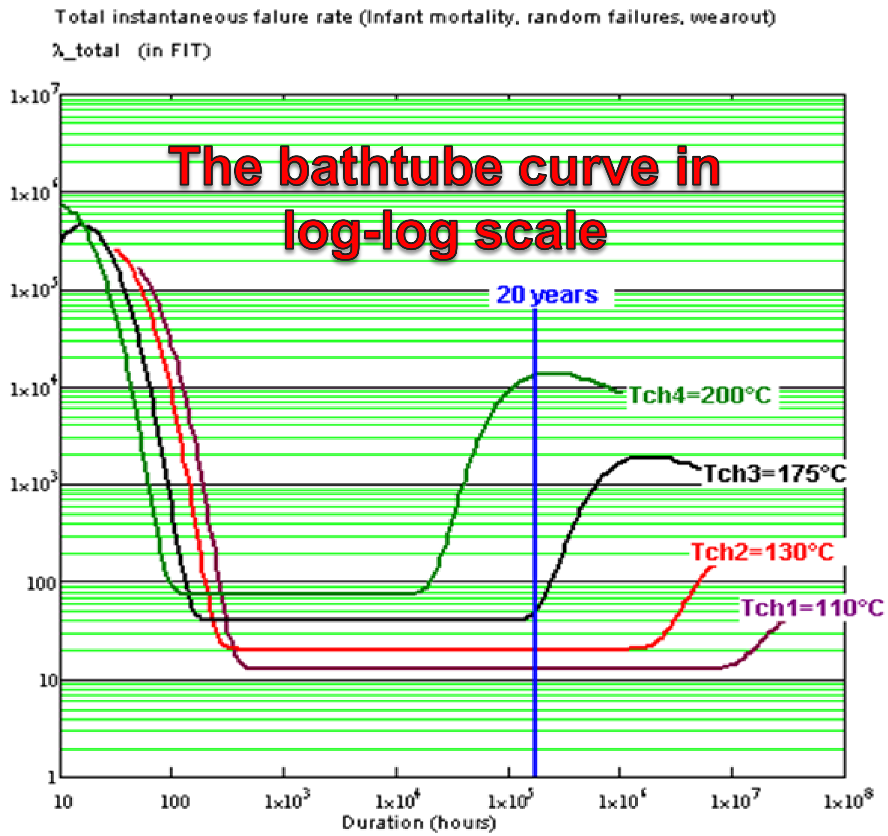


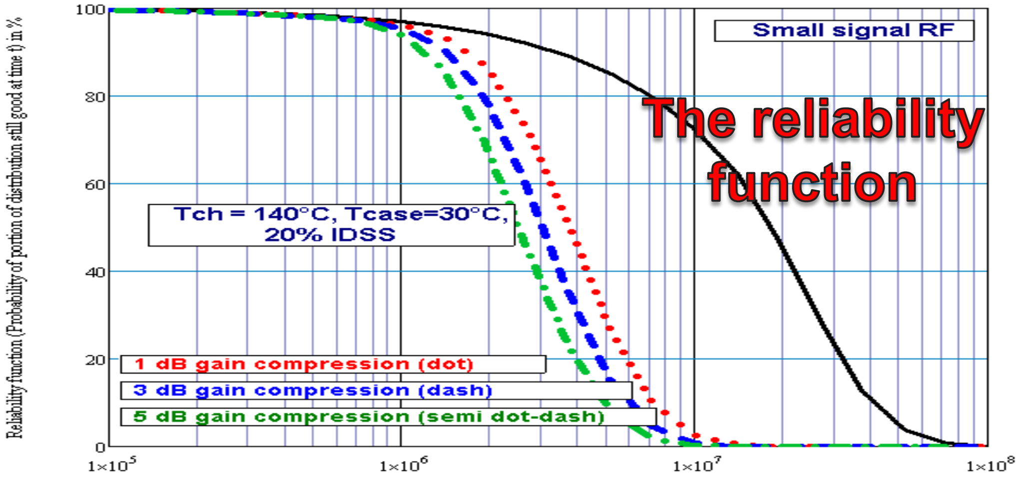
Effective channel temperature (in °C) for Tcase = 30°C calculated vs DC biasing and RF input power drive (showing 1dB GC, 3 dB GC and 5dB GC).



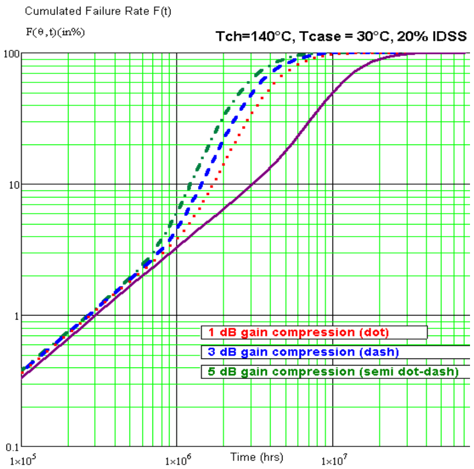
Effective channel temperature (in °C) for Tcase = 30°C calculated vs DC biasing and RF input power drive (showing 1dB GC, 3 dB GC and 5dB GC).

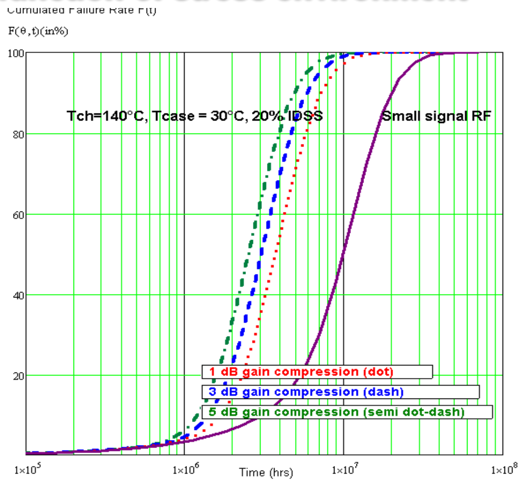
Probabilistic Design for Reliabillty from BAZ model applied to GaAs MMIC





Cumulative failure rate as function of stress environment





Total Cumulated Failure Rate (equ. 29) of the RF power amp. using BAZ model in log-log scale.

Advantages and drawbacks of BAZ model (1/2)

- Failure mechanisms and their associated activation energies may be modeled considering the adequate methodology defined by the BAZ model and taking into account all interaction effects due to stress conditions applied simultaneously.
- The well known Arrhenius model is modified in order to include multiple thermal and non thermal stress functions related effects due to applied electrical field, radiation, atmosphere or mechanical environments.
- The accelerating factor is expressed in a similar way as for thermal diffusion mechanisms.
- The BAZ model helps to separate the variables temperature T and stress S.
- The γi factors of loading which characterize the role of the stress level are the new parameters to be assessed : these set of parameters are process and stress dependant. They need to be extracted from relevant FOAT programs under controlled and careful referenced stress conditions.

Advantages and drawbacks of BAZ model (2/2)

- **Full equivalence between Arrhenius and BAZ models if considering equation :**

$$\tau = \tau_0 \exp \frac{(U_0 - \gamma S)}{kT}$$

- **All existing models (Black law, Eyring law or any other model published in the literature) may be expressed in term of BAZ model in a consistent and demonstrated mathematical re-writing.**
- **The methodology proposed may apply to any well known process and product as well as for new technologies and innovative devices. This could be the case in particular for GaN processes, Optoelectronic devices, MEMS and MOEMS based systems used in harsh environments and under any condition of use.**
- **The BAZ model allow to QUANTIFY the probability of failure.**
- **It is a new powerful tool to calculate the risk of failure of any system (Space or HiRel application) in order to prove Design for Reliability of equipments and to satisfy final customer's needs.**

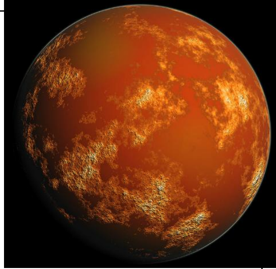
Recommendations (1/2)

- The complete BAZ model, in its simple application, is a superposition of complex mechanisms and is able to harmonize, unify and “bring to a common factor” activation energies of different cause and magnitude.
- It is consolidated in order to discriminate influences of various failure mechanisms and to model their effects occurring in microwave processes. It can be also applied to many innovative devices superposing failure mechanisms induced by electrical and optical overstresses as for example dark line induced defects and COD in laser diodes.

Recommendations (2/2)

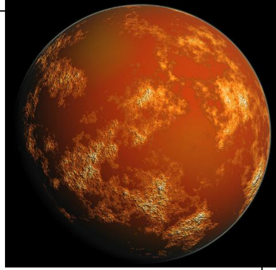
- The BAZ model can be employed in the PDfR approaches. The constructive aspect of BAZ model is to offer inputs for the definition of what are the maximum rating parameter values for temperatures, voltages, currents, RF inputs, or any other critical parameter to be under control for a Hi-Rel application. This enables Designers and Quality Assurance engineers to consolidate their equipment designs.
- It helps to promote a new approach considering a physically meaningful "mathematical" method to develop useful figures of merit and to quantify reliability minimizing the probability of failure for a 20 year long operation mission.

Conclusion (1/2)



- We have seen requirements in High reliability system for Space technologies that are imposing some constraints to use innovative products.
- The advantages and abilities of the today's Space qualification standards and testing practices have been shown.
- The use of built-in non qualified innovative technologies for space application might be used thanks to the concept of Probabilistic Design for Reliability as adequately implemented.
- The BAZ model has been presented to harmonize, consolidate and reconciliate reliability data accumulated since decades on a MMIC GaAs process.

Conclusion (2/2)



- **We have proposed some answers to the following questions**
  - **How to bring innovative technologies to a satisfactory level of confidence ?**
  - **How the today's qualification specs and testing practices (FOAT and QT) must be adapted to prepare design for reliability requirements?**
  - **How Probabilistic-design-for-reliability (PDfr) of Processes is a must tool to quantify reliability ?**
- **This approach can be generalized to any electronic parts for high reliability application.**
- **An optional vision has been proposed to revisit the absolute maximum rating limits methodology as described in existing Space Standards**

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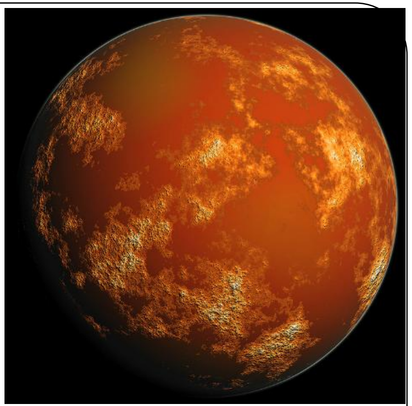
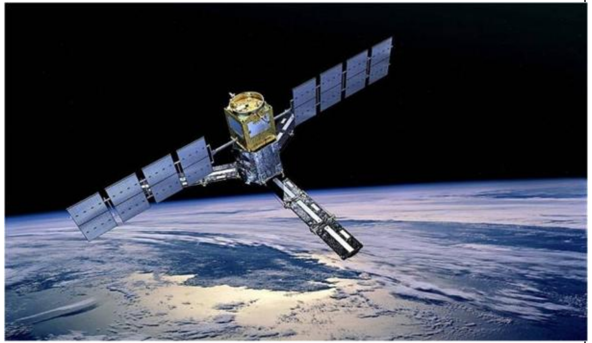



Thank you.

Any questions ?



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