Alén space

A GMV COMPANY

TURNKEY SOLUTIONS FOR SMALLSATS

Experience and lessons learned from HALT

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ACCEDE | ESCCON
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25 to 27th March
ALTER esa

Agenda

- Test description
- Test execution
- Failure analysis and root cause investigation
- Lessons learned

Alén Space: Who we are

Who we are

GMV group company (2023) founded in 2019 as spin-off from University of Vigo.

- Located in Nigrán, >80 employees
- End-to-end mall satellite missions
- COMMS product provider
  - Space segment: SDRs, OBC, RF frontends
  - Ground segment: Ground stations, SDR racks and MCS

Private initiatives: 5G IoT Constellation (Sateliot)

Design and manufacture of 4 6U CubeSat satellites, part of the first phase of this constellation.

ESA: LEO-PNT

Initial platforms and payload components for CubeSat technology demonstration.

Internal: SATMAR

Development of a satellite under the VDES standard to digitize maritime communications.

HALT: Test description

Objective

- Highly Accelerated Life Test Pilot Supporting Agile Space Engineering
- Accelerating the validation process of commercial electronic board
  - Characterization of all failure modes
  - Identification of environmental margins
  - Identification of weaknesses and possible improvements in the product design
- Product specification limits are exceeded
  - Failure analysis root cause investigation
  - Lessons learned

Project leader, analysis and climate tests

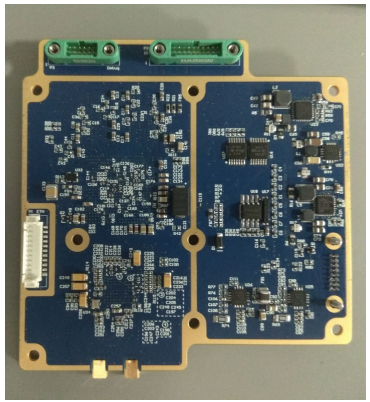
DUT responsible and analysis

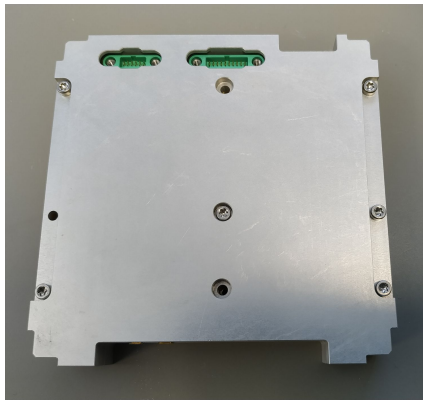
Vibration/TCY test + analysis

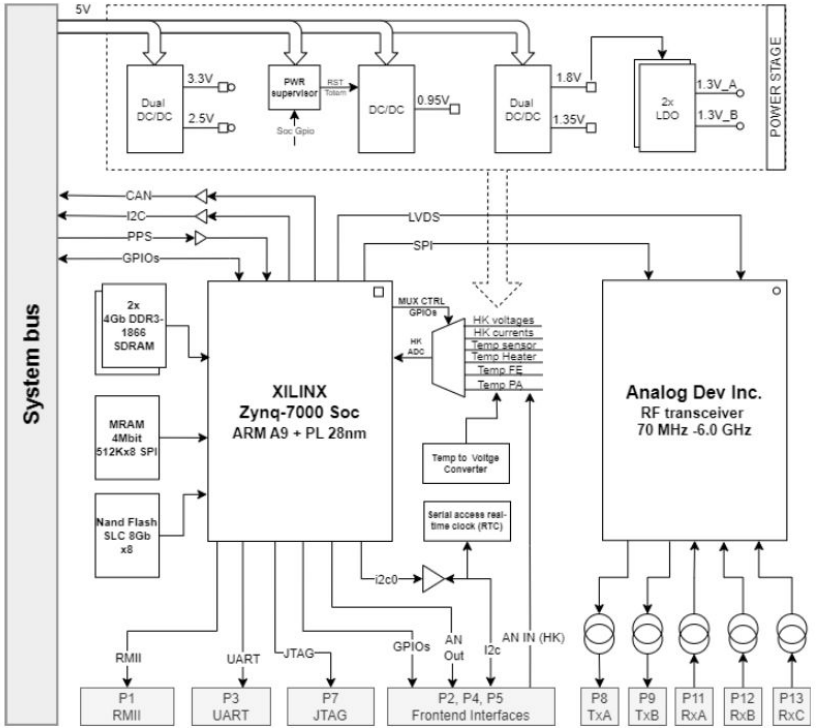
DUT: Description

TOTEM

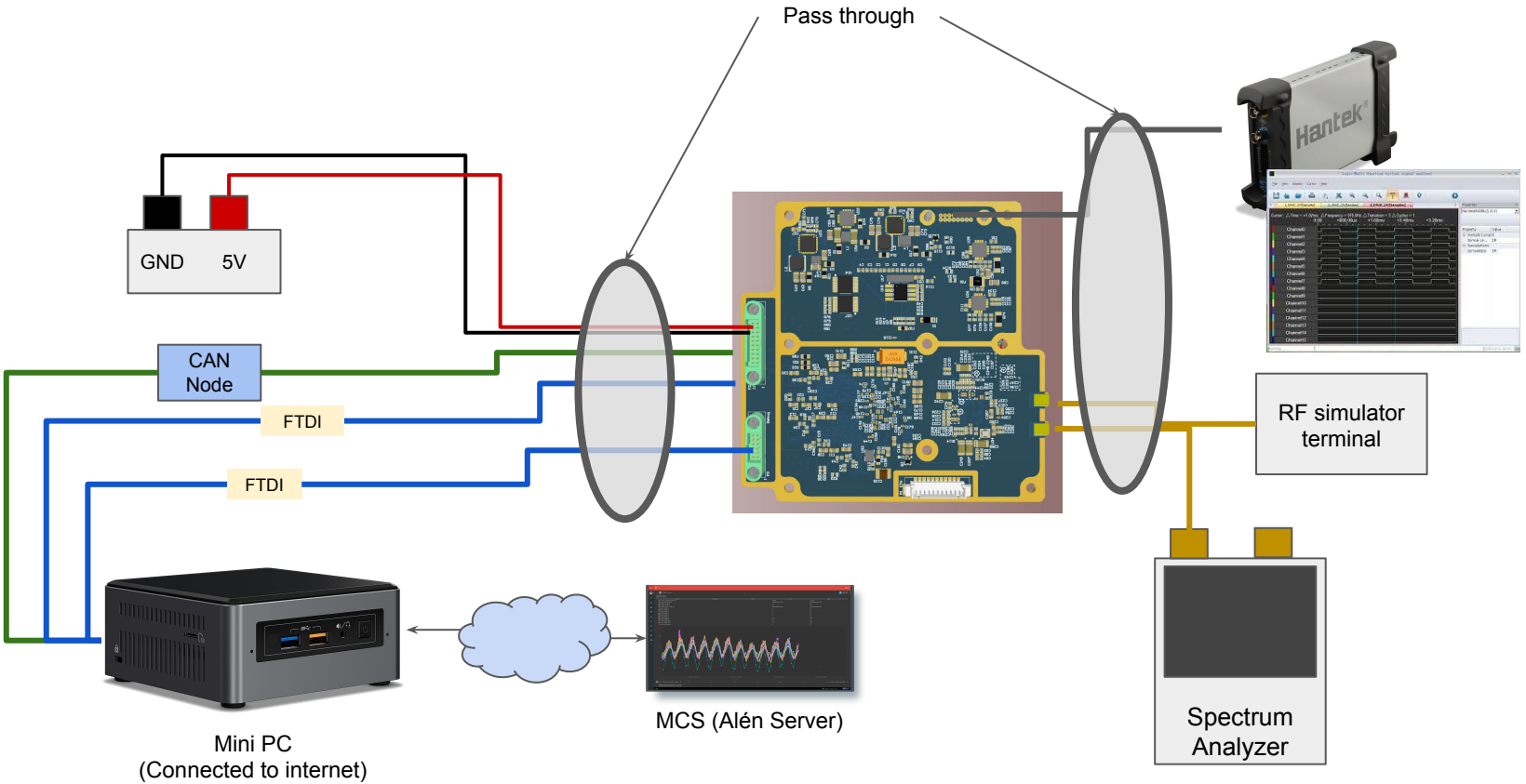
- Software defined radio developed by Alén Space (TRL9 - 2018)
- Core architecture based on SoC - TRX
  - Zynq-7000 SoC (28 nm) Xilinx, Linux OS
  - AD9364 Transceiver from Analog devices, 70MHz - 6 GHz
  - DDR3L 1GB, NAND Flash 1GB, 4Mb MRAM
  - PC104 form factor
  - 1TX and 1RX RF ports
  - Power consumption: 2.5W in TX mode





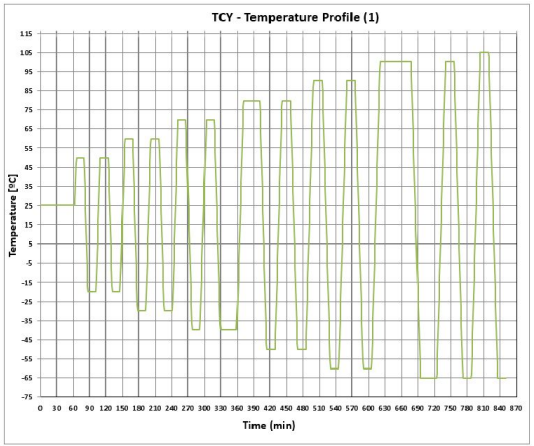


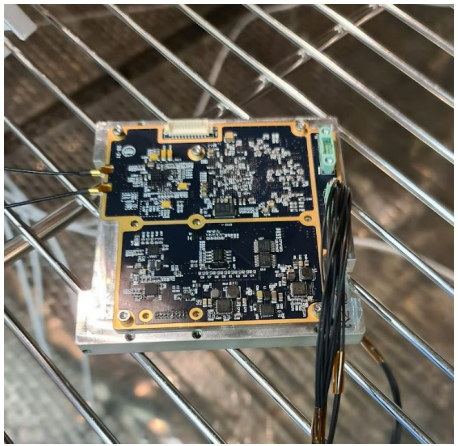
Test setup


Pass through
GND
5V
CAN Node
FTDI
FTDI
Hantek
RF simulator terminal
Mini PC
(Connected to internet)
MCS (Alén Server)
Spectrum Analyzer

HALT description - I

- Cold Step Stress (CSS): [+25ºC; -65ºC], Temp. Steps: 20ºC; Temp. ramp: 5ºC/min
- Hot Step Stress (HSS): [+25ºC; +120ºC], Temp. Steps: 20ºC; Temp. ramp: 5ºC/min
- Thermal Cycling (TCY): [-65ºC; +120ºC], Temp. ramp: 10ºC/min; ±10ºC every 2 cycles, until reaching max range
- Vibration Step Stress (VIB): [0 gRMS; 20 gRMS]. Vib Steps: 2.5 gRMS; Vib Time: 5min; Vib ramp: 5 gRMS/min
- Vibration Step Stress + Thermal Cycling (VIB+TCY)
- Functional checks at every step





HALT description – II

TID test

A Cobalt 60 source is used to produce the ionizing radiation with the possibility of fixing the dose rate which arrives on samples by adjusting the samples distance to the source.

Component No.:		Component Designation:		Irradiation Spec. No.:	
PCB TOTEM ALÉN SPACE		PCB TOTEM ALÉN SPACE		ESCC 22900 Issue 5	
Gen. Spec.:	N/A	Functional Assignment:		Project/Programme:	
Det. Spec.:	N/A	PCB TOTEM ALÉN SPACE		A2X	
Amend.:	N/A				
Family/Group:	Technology:			Package:	
99/01	--			PCB	
Manuf. Name: Address:	N/Av	Samples Size:	3	Level of Interest:	N/Av krad(Si)
		Irradiation Devices:	3	Max. Test Level:	20 krad(Si)
		Control Devices:	0	Radiation Source:	^{60}Co

EXPERIMENTAL STEPS	1	2	3	4	5	6	7	8	9	10	11
PROCESS	Irrad	Irrad	Irrad	Irrad	Irrad	Irrad	Irrad	Irrad	Irrad	Irrad	Ann
Dose [krad(Si)]	1	1	1	1	1	1	4	3	2	5	-
Cumulative Dose [krad(Si)]	1	2	3	4	5	6	10	13	15	20	-
Dose Rate [rad(Si)/h]	400	400	400	400	400	400	400	400	400	400	-
Exposure Time (Unit)	2.5 (h)	2.5 (h)	2.5 (h)	2.5 (h)	2.5 (h)	2.5 (h)	10 (h)	7.5 (h)	5 (h)	12.5 (h)	24 h
Temperature (°C)	25	25	25	25	25	25	25	25	25	25	25

Test description

During environmental test, several functionalities are checked in the DUT with **automatic test routines.**

Functionality	Verification method	Verification criteria
Total and internal consumption	Power supply (automation/operator observation) Current telemetry parameters in MCS (notification)	Range Range per parameter
Internal voltage generation	Voltage telemetry parameters in MCS (notification)	Range per parameter
Housekeeping collection	Telemetry parameters in MCS (notification)	Range per parameter
RF Transmission	Spectrum analyzer (automation/operator observation)	RF Output Power range / RF Frequency range
RF Reception	M2M/IoT telemetry parameters in MCS (Operator observation)	Number of received packets
UART bus transmission/reception	Events in MCS (notification)	Event is received.
GPIOs routine	Oscilloscope (Operator observation)	Voltage range / Oscillation frequency range
MCS Activitiy	Telemetry parameters in MCS (notification)	Range per parameter
Memories (Flash, RAM, MRAM)	Events in MCS (notification)	Event is received.

HALT: Test execution

Identification of failure modes

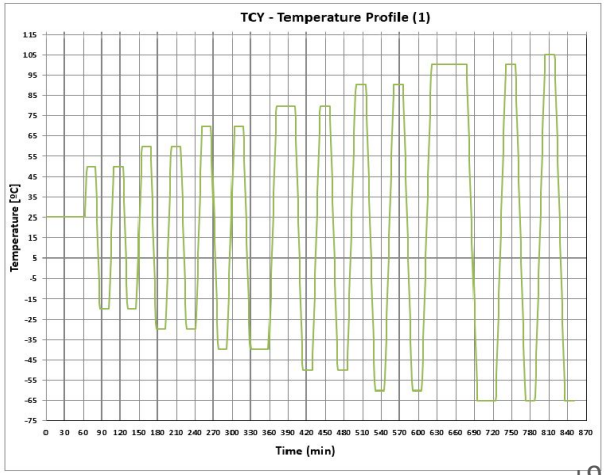
- Pre-work: for each functionality, identify possible failures (failure modes)
- Map each failure to each test
- This will be the first step in the anomaly investigation: what failed in which condition

Symptom	Problem	Action
No packets received	Transceiver/Oscillator is working out specification. Transceiver (RF part) is broken Defect in RF path soldering Failure in FPGA/Transceiver connection.	Test can continue to check if the error is recoverable. If normal operation is not recovered, test must be stopped.

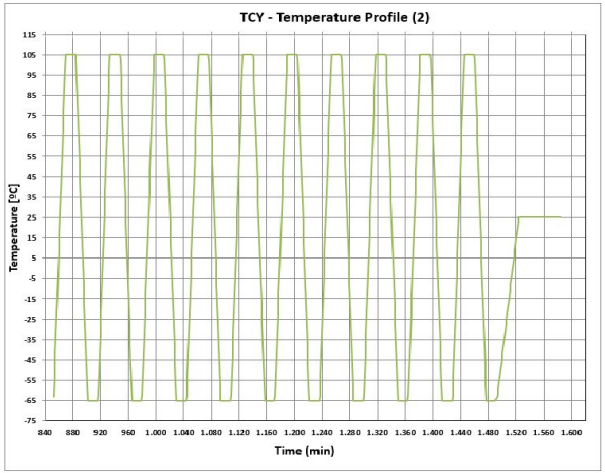
			HALT TESTS				
			CSS TEST	HSS TEST	TCY TEST	VIB TEST	VIB+TCY TEST
TOTAL & INTERNAL CONSUMPTION	Failure Mode 1	Current Parameter out of range		•	•		•
	Failure Mode 2	Voltage values out of range when the board is turned off and on					• (Destructive failure) (occurred to TOTEM003-008)
INTERNAL VOLTAGE GENERATION	Failure Mode 3	VCC_3V3 parameter out of range	• (just for TOTEM010)			• (just for TOTEM010)	• (just for TOTEM010)
	Failure Mode 4	VCC_2V5 parameter out of range	• (just for TOTEM010)				• (just for TOTEM010)
	Failure Mode 5	VCC_ODDR parameter out of range					• (just for TOTEM010)
	Failure Mode 6	VCC_AUX parameter out of range					• (just for TOTEM010)
	Failure Mode 7	VCC_BRAM parameter out of range					• (just for TOTEM010)
	Failure Mode 8	VCC_PAUX parameter out of range					• (just for TOTEM010)
HOUSEKEEPING COLLECTION	Failure Mode 9	MB Temperature stopped decreasing	•		•		• (This failure was not recorded for TOTEM007-008-009-010, just because the lowest temperature limit was changed from -65ºC to -45ºC)
	Failure Mode 10	FPGA Temperature oscillates in a wrong range	• (just for TOTEM010)	• (just for TOTEM010)	• (just for TOTEM010)	• (just for TOTEM010)	• (just for TOTEM010)
RF TRANSMISSION	Failure Mode 11	Tx frequency out of range	•	•	•		•
	Failure Mode 12	Tx frequency critically out of range	•	•	•		• (This failure was not recorded for TOTEM007-008-009-010, just because the lowest temperature limit was changed from -65ºC to -45ºC)
	Failure Mode 13	Tx Power out of range		• (just for TOTEM010)	• (just for TOTEM007-008-010)	• (just for TOTEM001-002-004-005-007)	•
	Failure Mode 14	Tx Power critically out of range				• (just for TOTEM002-004-005-007)	• (occurred to all the boards, except for TOTEM001-005)
RF RECEPTION	Failure Mode 15	TOTEM board temporarily stopped receiving packets from RF simulator					• (just for TOTEM001-006-008-009-010)
	Failure Mode 16	TOTEM board permanently stopped receiving packets from RF simulator			• (Destructive failure) (occurred to TOTEM004)	• (Destructive failure) (occurred to TOTEM004)	• (Destructive failure) (occurred to TOTEM001-003-006)* *This failure is classified as "likely" due to the fact that just 6 boards have been considered at all. In fact, for the remaining 4 boards (TOTEM007-008-009-010), the lowest temperature limit was changed from -65ºC to -45ºC
GPIOs ROUTINE	Failure Mode 17	GPIOs Pins stopped working		(Destructive failure)* (occurred to TOTEM001 at 120ºC). As only TOTEM001 reached the temperature of 120ºC, the occurrence of this failure could not be properly classified			
	Failure Mode 18	Not recurring commutation of GPIOs signal					• (just for TOTEM003-006-008-009-010)
	Failure Mode 19	FE_AN_IN0 parameter temporarily out of range				• (just for TOTEM007-010)	•
	Failure Mode 20	FE_AN_IN1 parameter out of range					• (just for TOTEM008)
MCS ACTIVITY	Failure Mode 21	Unavailability of telemetry data		• (just for TOTEM001 at 120ºC.) As only TOTEM001 reached the temperature of 120ºC, the occurrence of this failure could not be properly classified.			
MEMORIES (Flash, RAM, MRAM)			NO FAILURES	*Failure Mode 17 has then been related to a Flash Memory failure, according to the root cause investigation process	NO FAILURES	NO FAILURES	NO FAILURES
UART BUS TRANSMISSION & UART BUS RECEPTION			NO FAILURES	NO FAILURES	NO FAILURES	NO FAILURES	NO FAILURES

Test execution

- Perform the test plan
- Adaptation to new conditions and lessons learned
  - Temperature and vibration limits were modified based on the results
    - Maximum temperature was decreased from +120ºC to +105ºC
      - …too much
    - Minimum temperature was increased from -65ºC to -50ºC
      - After VIB + TCY, as all 4 boards failed destructively under -65ºC
      - +9 cycles added to remaining board with max range to find new failure modes
    - Maximum vibration was increased from 20 gRms to 22.5 gRms



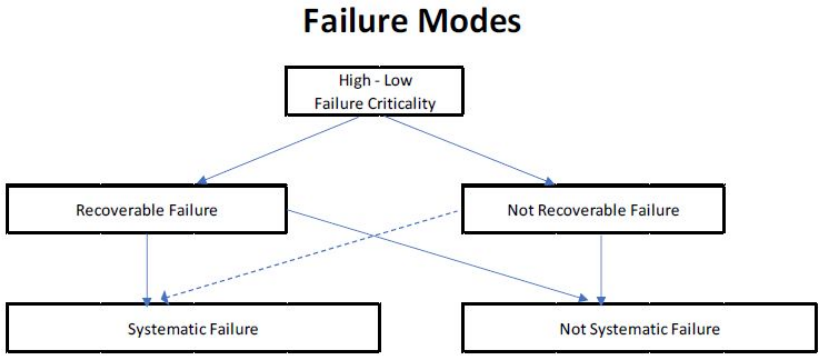
+9 cycles added



HALT: Failure analysis and root cause investigation

General

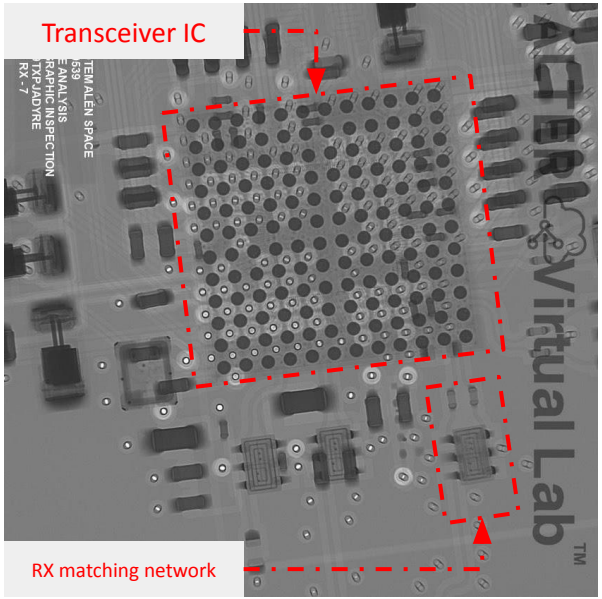
- Identification of failure mode at given test
- Functionality and failures dependency
- Destructive vs non-destructive
  - Failures that recover after removing the stress condition
- Likelihood of failure
  - Has it been produced to all boards? Systematics vs non systematic
- Is it expected?

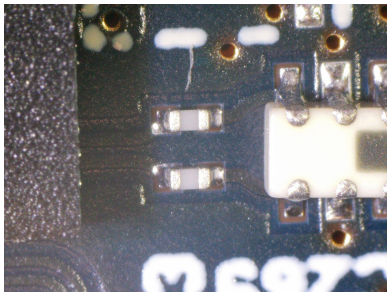


Root cause investigation – RF reception failure (I)

Failure description: The DUT does not receive packets under - 60 dBm, while the expected sensitivity level is -100 dBm **Test:** VIB + TCY and CSS test at -65ºC.

- Confirmation of the anomaly with test in the laboratory
  - Destructive anomaly. Neither removing stress condition no power cycle solves de anomaly
- Hypothesis
  - Component failure before the transceiver IC.
  - Failure of the transceiver IC
- Visual inspection
  - X-ray analysis: solder cracks in BGA pads, components…

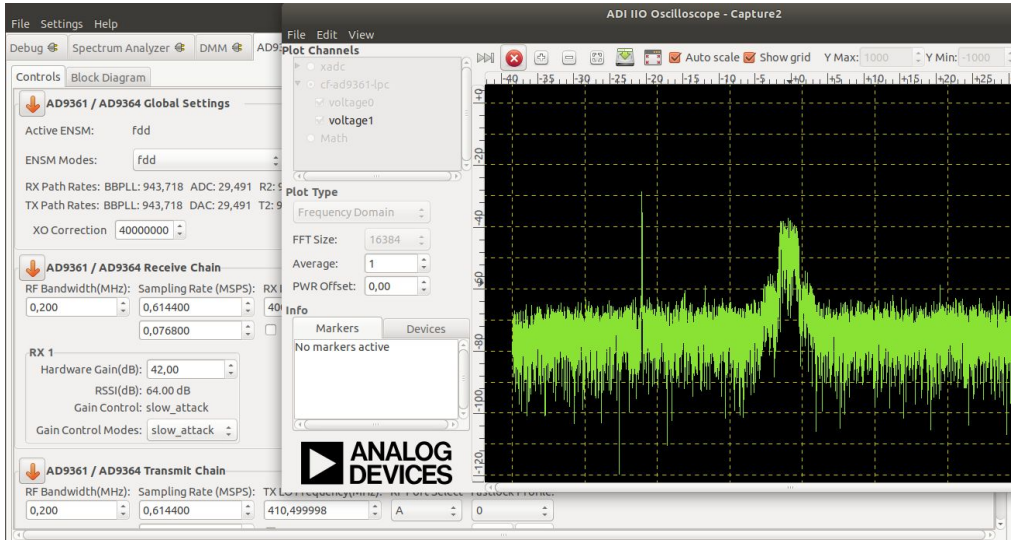




Root cause investigation – RF reception failure (II)

- Replace rx matching network ⟶ Replace of transceiver IC
  - Sensitivity level is restored.
    - **Anomaly solved**

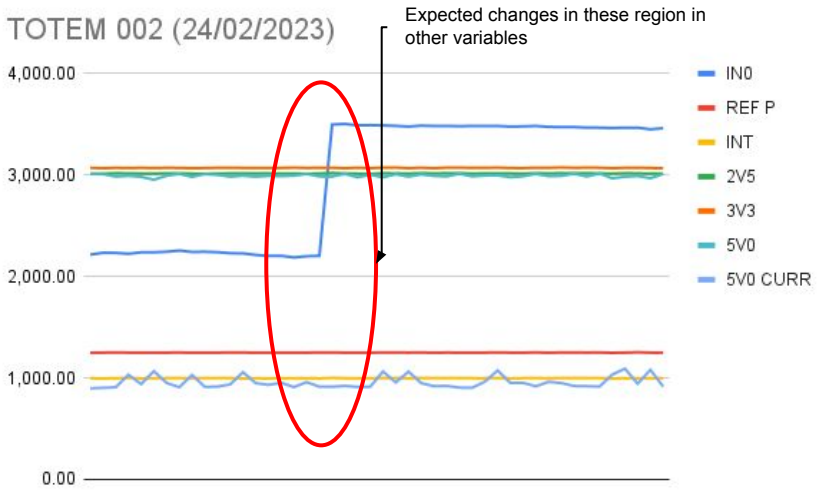
Conclusions: The transceiver IC brakes under such extreme conditions. Since this failure was systematic in multiple boards, the minimum temperature level for the test was increased from -65ºC to -50ºC.



Root cause investigation – Sensors failure

Failure description: FE_AN_IN0 outside of range while the rest of parameters are in range. Several boards affected.

1. Confirmation of the anomaly in the laboratory
   a. Non destructive anomaly that cannot be replicated in the laboratory
2. Investigation analysis
   a. Replication of set up
   b. Extend test operational time to make TOTEM heat up
   c. Exchange all data from the test with ALTER and try to correlate the out of range condition with other parameters
3. Conclusions
   a. The anomaly could not be replicated in the lab. Data analysis did not yield valuable insight.
   b. Possible causes
      i. Set up: this specific analog value was read with a loopback



HALT: Lessons learned

General process

- Test → failure → analysis → repair → test again
  - Intermittent process that lead to inefficient use of facilities, set ups, etc
- Carry on with the test if possible to check other failure modes
  - …tricky since previous failure could be the cause of new failure. Difficult to analyze
- “Live” adjustments. Not all boards were tested exactly the same
- More samples
- TID test only report failures at the end, when 20 Krads was reached…
  - And after power cycle de board (corruption of flash memory)...
  - … but we do not know if the memory was corrupted with TID of 10 Krads

Data acquisition process

Some failures (specially non-destructive) were difficult to find the root cause.

- Improve data acquisition system
  - Improve data correlation
  - Map each sensor data to internal process
- This would help to make assessments during failure analysis.
- Foresee future trends of critical parameters.
  - Could this deterministic data be used to predict failures?

Hardware improvements

- Housekeeping circuitry
  - Related with data acquisition system
  - Distributed architecture
- Power distribution network and start up
  - Some failures where related with the start up process. Identify key elements that should be considered as redundant for example
- Memories
  - Some test failed due to firmware corruption in flash memory.
  - Key element that may worth to upgrade
- Harness and connectors
  - Some connectors and harness were identified as possible cause of failures

Personal thoughts

- The 100% of destructive failures occurred beyond temperature operative range
  - How can we relate this to aging? Can we determine the amount of operating years in space like TID?
- New space “needs” to be agile, cheaper ... but also as reliable?
  - Redundant systems or features … makes them more complex and more expensive
  - Rely on rad-hard/tolerant or space grade key components -> Hybrid approach can be a good point to start with
- New space is also space
  - Customers and agencies are very happy to use COTS and agile methodologies at first. Cheap and fast, but…
    - Short development times face PA/QA typical processes. And you can’t have both worlds in 12 months missions from KO to launch, especially with projects with high R&D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