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The most important thing we build is trust

Investigation of Failure Mechanisms of Low Power Isolators and Circulators

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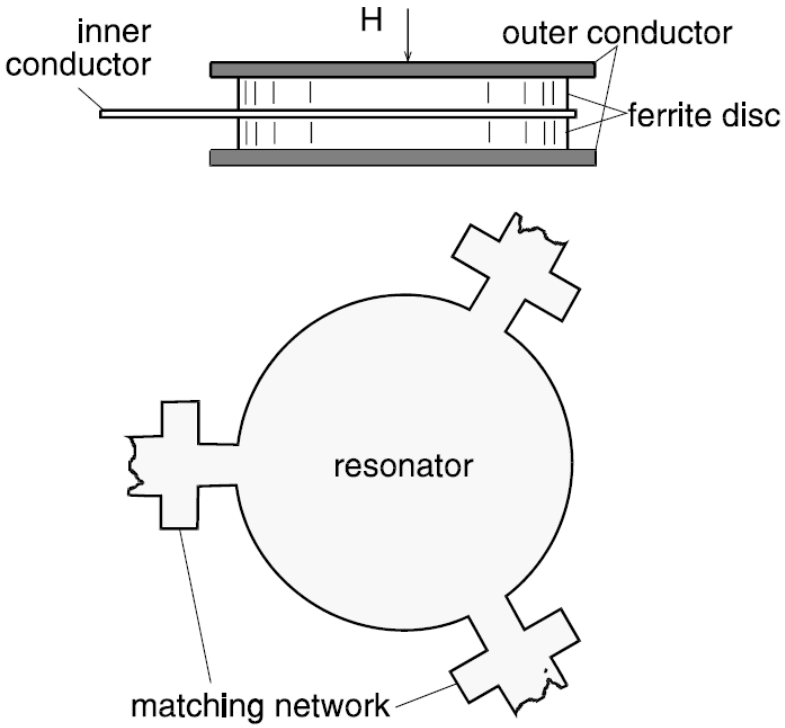
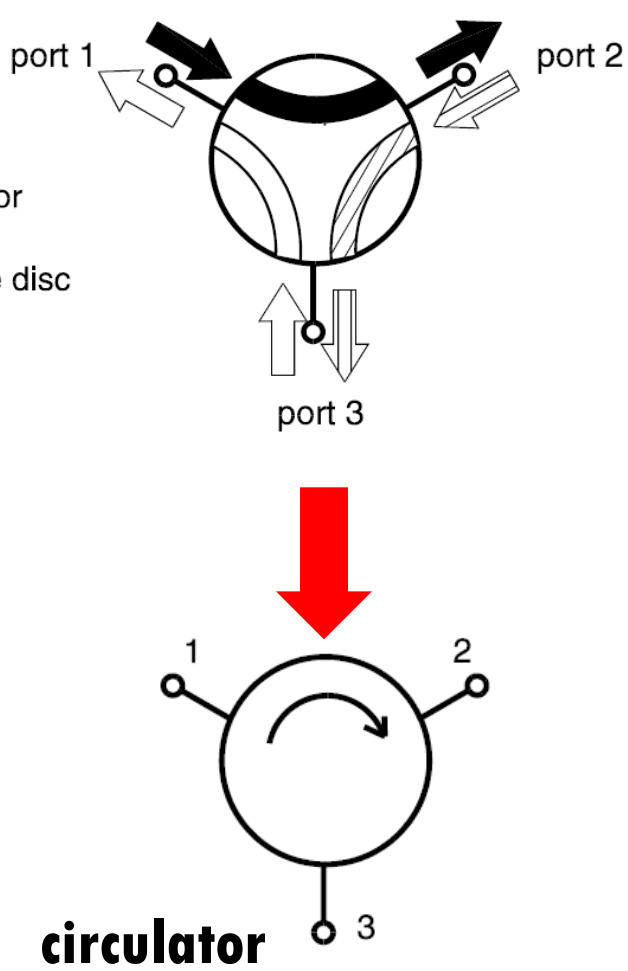
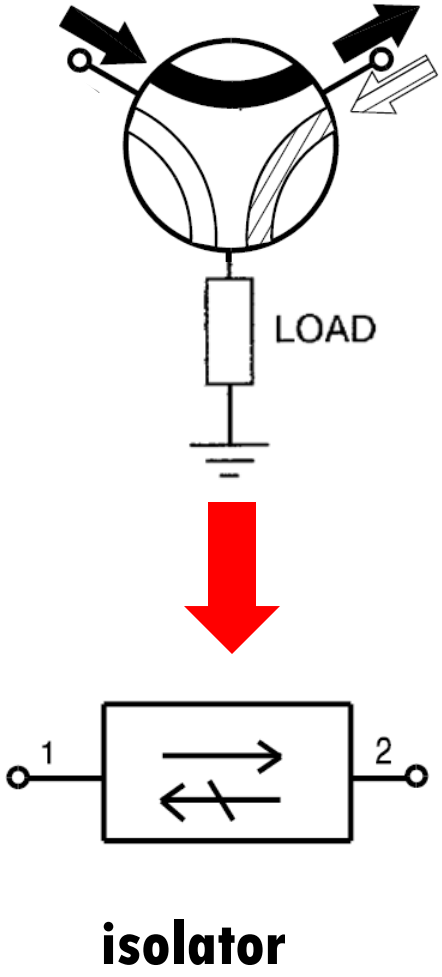
OUTLINE

- FERRITE CIRCULATORS AND ISOLATORS
- OBJECTIVES AND WORKPROGRAMME
- ESCC REQUIREMENTS
- MECHANICAL ANALYSIS
- EVALUATION TEST PLAN
- EVALUATION TEST RESULTS
- SUMMARY AND CONCLUSIONS

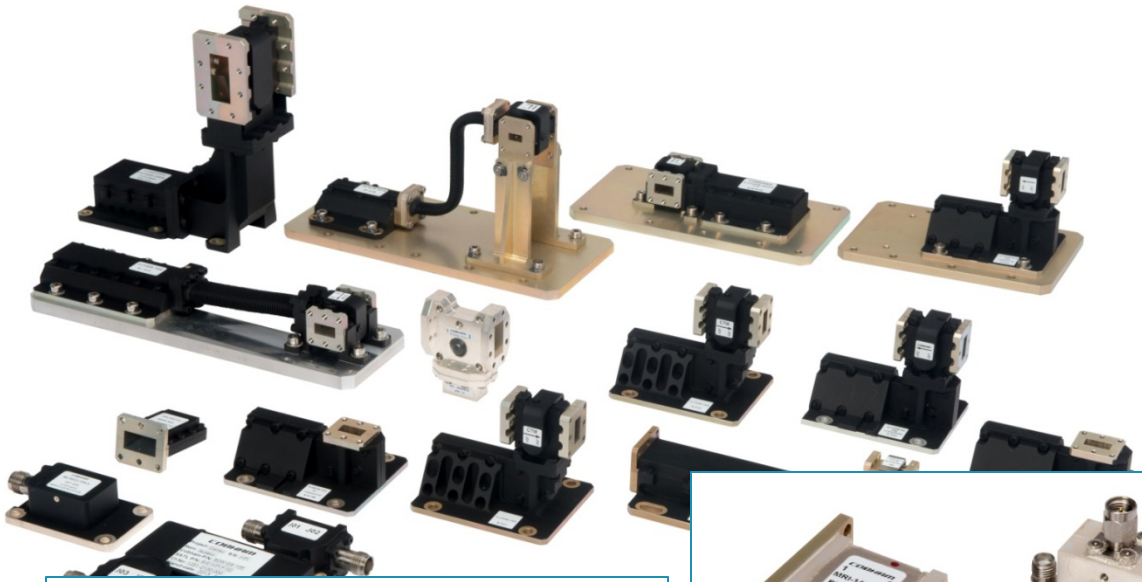
Ferrite Isolators and Circulators

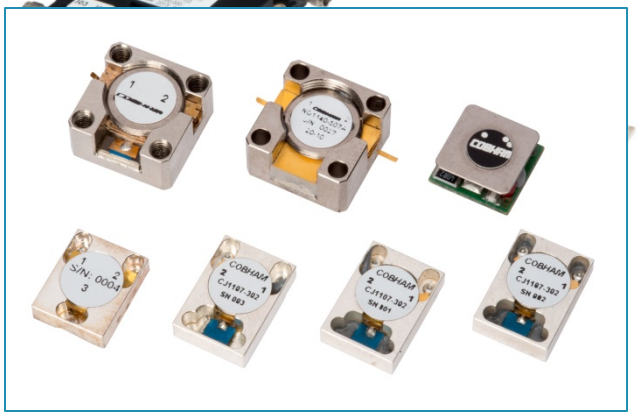






Ferrite Isolators and Circulators





Drop-in technology

EPPL Part 2

Coaxial technology

SCOPE

CTB RF PASSIVE WORKING GROUP

ESA TECHNOLOGY RESEARCH PROGRAMME (TRP)

BACKGROUND:

- Reliability aspects of ferrite devices are not well known
  - Lack of experimental evaluation and non reliable life prediction calculations
  - No available data to support derating rules and failure rate models
  - No ESCC qualified components
  - ESCC specifications to be updated
- High reliability devices (robust materials, simple constructions, wide margins of safety)
- Trend: frequency increase, power increase

OBJECTIVES:

- Reveal, describe and understand degradation and failure mechanisms
- Provide basis for
  - Update of current specifications (ESCC 3202, ECSS-S-ST-30-11C)
  - ESCC Qualification of circulators and isolators
- Low power devices as a first step

WORK PROGRAMME

- **WP1: Technology Analysis and Selection**
  - Description and classification of technologies
  - Review of materials and processes
  - Identification of applicable requirements
  - Review of failure mechanisms, degradation, fatigue
  - Technology selection and identification (Process Identification Doc, Detail Specification, FMECA)

- **WP2: Thermomechanical analysis and definition of Evaluation Test Plan (ETP)**
  - Implement geometries and materials data in Finite Element Analysis
  - Evaluate stress levels for vibration, shock and thermal environments
  - Prediction of maximum allowable levels, including fatigue aspects
  - Set evaluation levels accordingly (ETP definition)

- **WP3: Evaluation testing**
  - Manufacturing of test vehicles
  - Testing and analysis

Structure to be evaluated

- Drop-in Isolator
- 1.125-1.375 GHz
- Low power
- Space heritage

(as equipment)

- Copper alloy strip and ground planes
- Steel package
- Magnet
- Ferrite
- Stack and screw design
- Qualified platings
- Resistive chip load (AlN)
- SnPb and SnPbAg solders

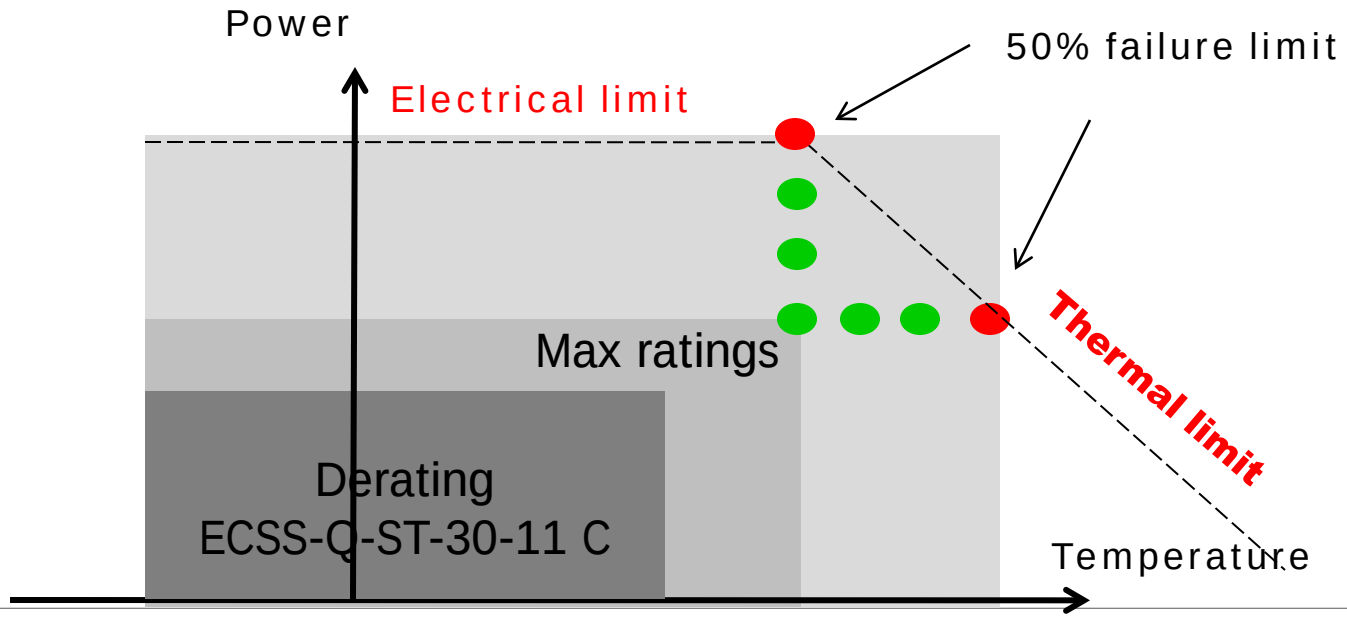
	Maximum ratings	Derating ECSS-Q-ST-30-11 C
Operating temperature	-20°C/+80°C	Hot spot 30°C below max
Storage temperature	-40°C/+85°C	NA
Input RF Power	10W	75%
Reverse RF Power	5W	75%

ESCC 3202 test levels (Issue 2 draft)

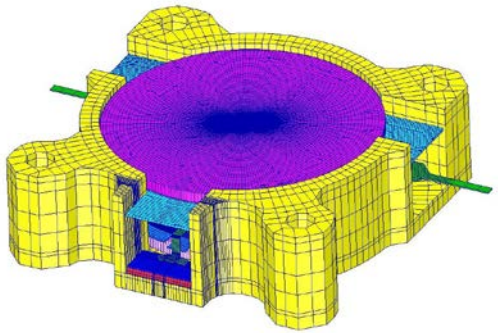
Test	Screening	Qualification
Non operating		
Vibration	Random 36 grms	Random 50 grms
Shocks	NA	1500 g, 0.3 ms
Thermal cycling	5 cycles Storage range	200 cycles Storage range
Operating		
Power Thermal test (high power only)	Max Power (forward, reverse and short circuit) Max op T, vacuum, 1H	Max Power (forward, reverse and short circuit) Max op T, vacuum, 6H
Operating life	NA	Max reverse Power, Max op T 1h on/ 1h off. 1000 H

ESCC Evaluation

- Un-screened components
- Destructive tests:
  - Temperature and power stress tests
  - Special test: Vibration, shock, thermal cycling
- Construction analysis
- Accelerated electrical endurance test

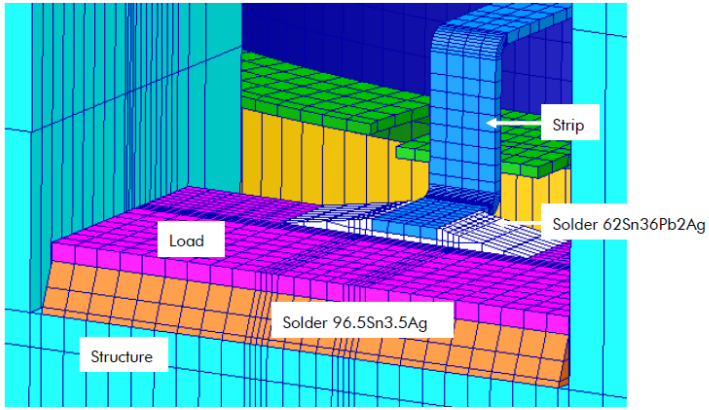


Mechanical analysis of isolator



Simulation of environment stresses:

- **Finite element analysis (geometry + materials data)**
- **Pre-load + vibration, shock, cyclic thermal loading**
- **Vibration: No structural mode below 2000 Hz**
- **Thermal cycling: thermoelastic analysis except for solders (creep phenomena and fatigue)**
- **Prediction of maximum allowable levels**



	Maximum allowable levels	Qualification levels
Vibration	63 to 94 grms (ferrite) 97 to 128 grms (magnet)	50 grms
Shocks	2040 to 3060 g (ferrite) 3100 to 4080 g (magnet)	1500 g
Thermal cycling	>30 000 cycles -55°C/+125°C	200 cycles -40°C/+85°C

Evaluation Test Plan

- ESCC detail specification N° 2263202 as guideline + recommendations of the CTB RF Passive Working Group
- Goal is to reach failures but evaluation levels are limited

	Evaluation level limit	Limiting factor
Power thermal	180 °C on load	Solder melt
Vibration	100 g rms	Equipment
Shock	4000 g	Equipment
Thermal cycling	500 cycles	Time / cost

Evaluation Test Plan

INSPECTION

Dimensions go-no-go	100%
Weight	100%
Electrical Parameters go-no-go	100%
External Visual Inspection	100%
Marking and Serialisation	100%

INITIAL MEASUREMENTS
N=25
100% Read and Record.
Table 2 and 3 of Detail Specification

GROUP 1
N=1
Control Group
Para 6.2

GROUP 2
N=21
Destructive Tests
Para 6.3

GROUP 3
N=3
Accelerated Electrical Endurance
Para 6.4

SUBGROUP 2A
N=9
Step-Stress Tests
Para 6.3.1

SUBGROUP 2B
N=4
Vibration Step-Stress
Para 6.3.2

SUBGROUP 2C
N=4
Shock Step-Stress
Para 6.3.3

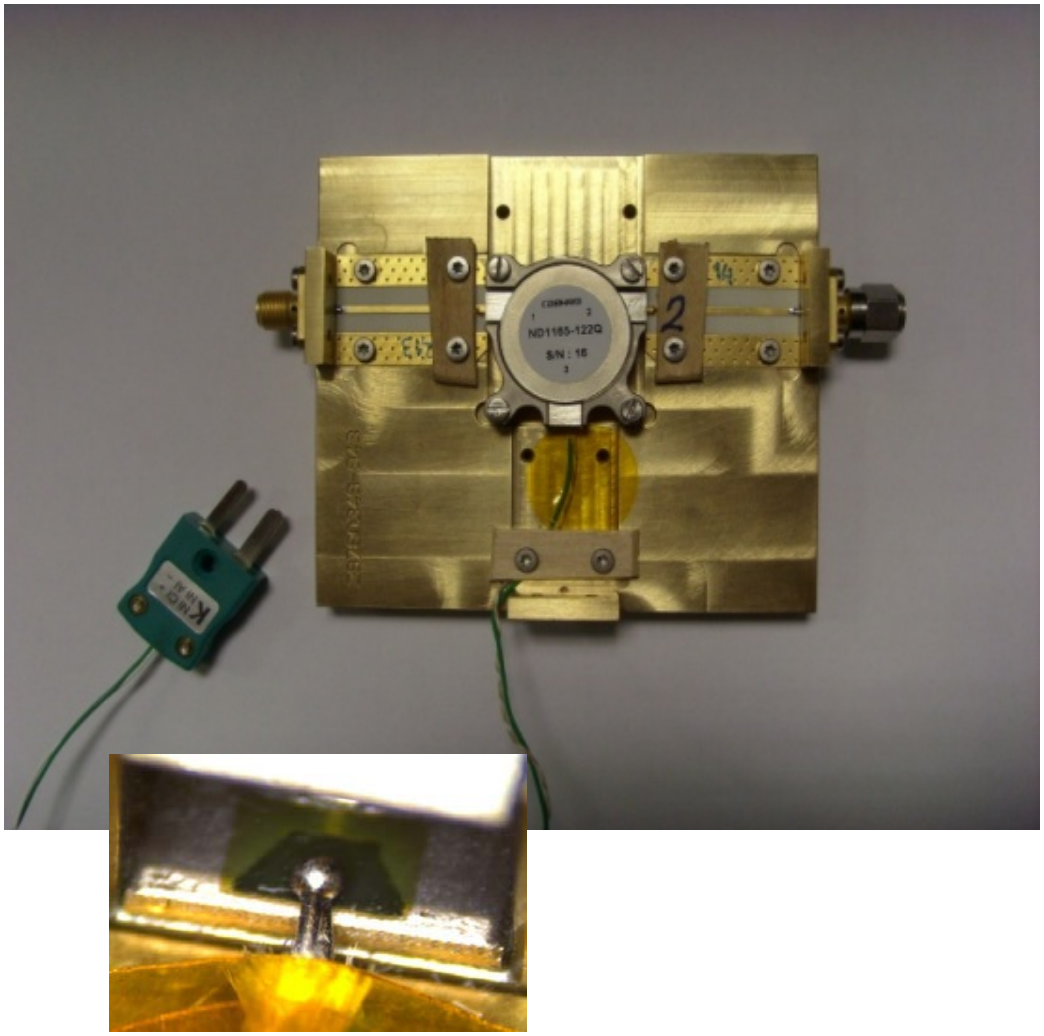
SUBGROUP 2D
N=4
Thermal Cycling Test
Para 6.3.4

SUBGROUP 2A(i)
N=4
Temperature Step-Stress Tests
Para 6.3.1.1

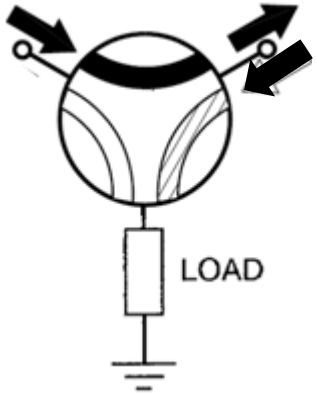
SUBGROUP 2A(ii)
N=4
Reverse Power Step-Stress Tests
Para 6.3.1.2

SUBGROUP 2A(iii)
N=1
Forward Power Step-Stress Tests
Para 6.3.1.3

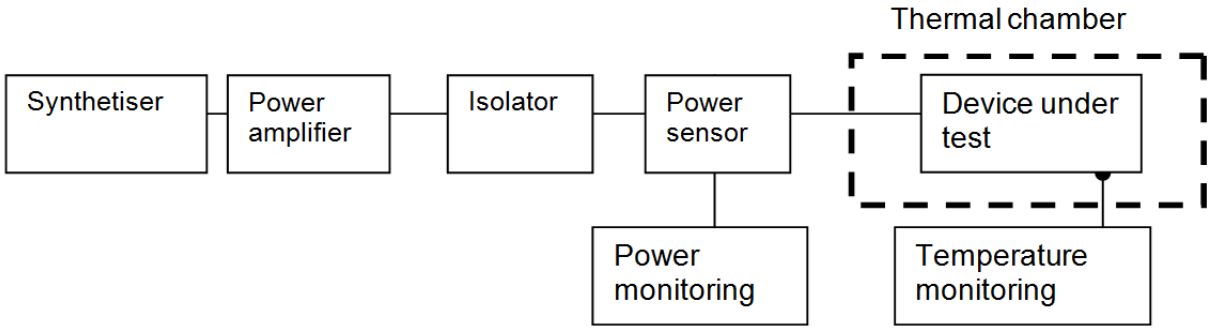
Power and temperature step stress

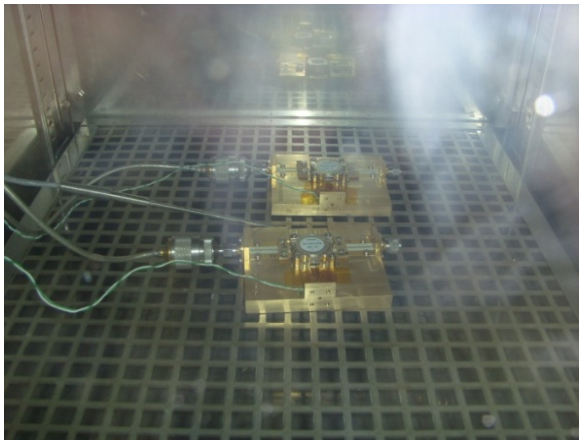


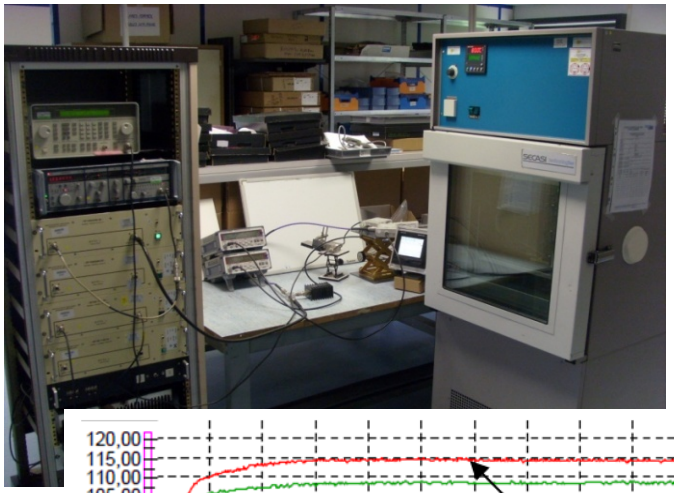
- Isolator on test jig
- Power input on port 1
- Short circuit on port 2
- Thermocouple on load



Power and temperature step stress

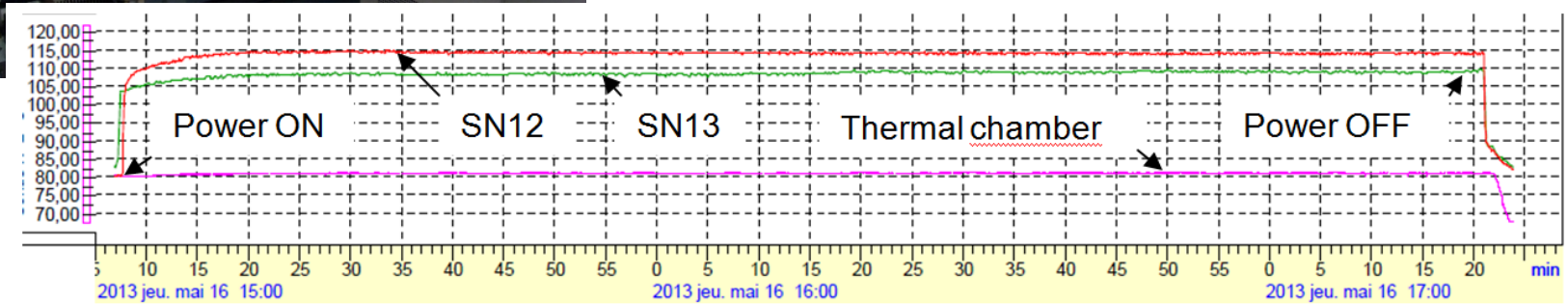






Monitoring of:

- **incident power**
- **return loss**
- **load temperature**



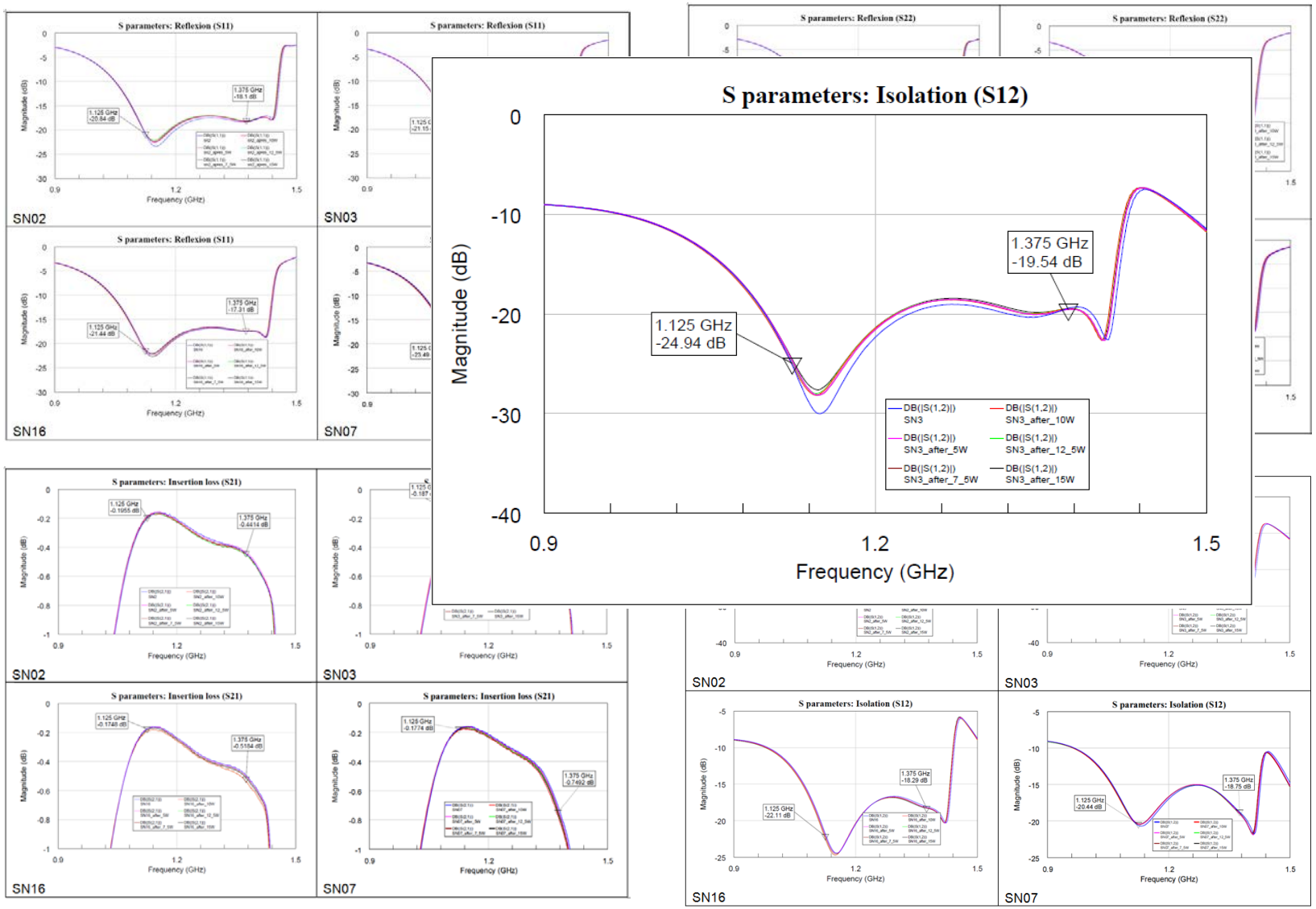
Power step stress

- 80°C / 4 units
- full reflected power (failure mode worst case)

	Time / level	Result	Load temperature
1st step	2H @ 5W	No failure	110°C
2nd step	2H @ 7.5 W	No failure	125°C
3rd step	2H @ 10 W	No failure	140°C
4th step	2H @ 12.5 W	No failure	155°C
5th step	2H @ 15 W	No failure	180°C

- No drift of temperature, no drift of return loss during each 2 hour step
- No drift of isolator S parameters after each step

Power step stress



Temperature step stress

- 5W / 4 units
- full reflected power (failure mode worst case)

	Time / level	Result	Load temperature
1st step	2H @ 85°C	No failure	115°C
2nd step	2H @ 100°C	No failure	135°C
3rd step	2H @ 135°C	No failure	155°C
4th step	2H @ 165°C	3 failures	185°C

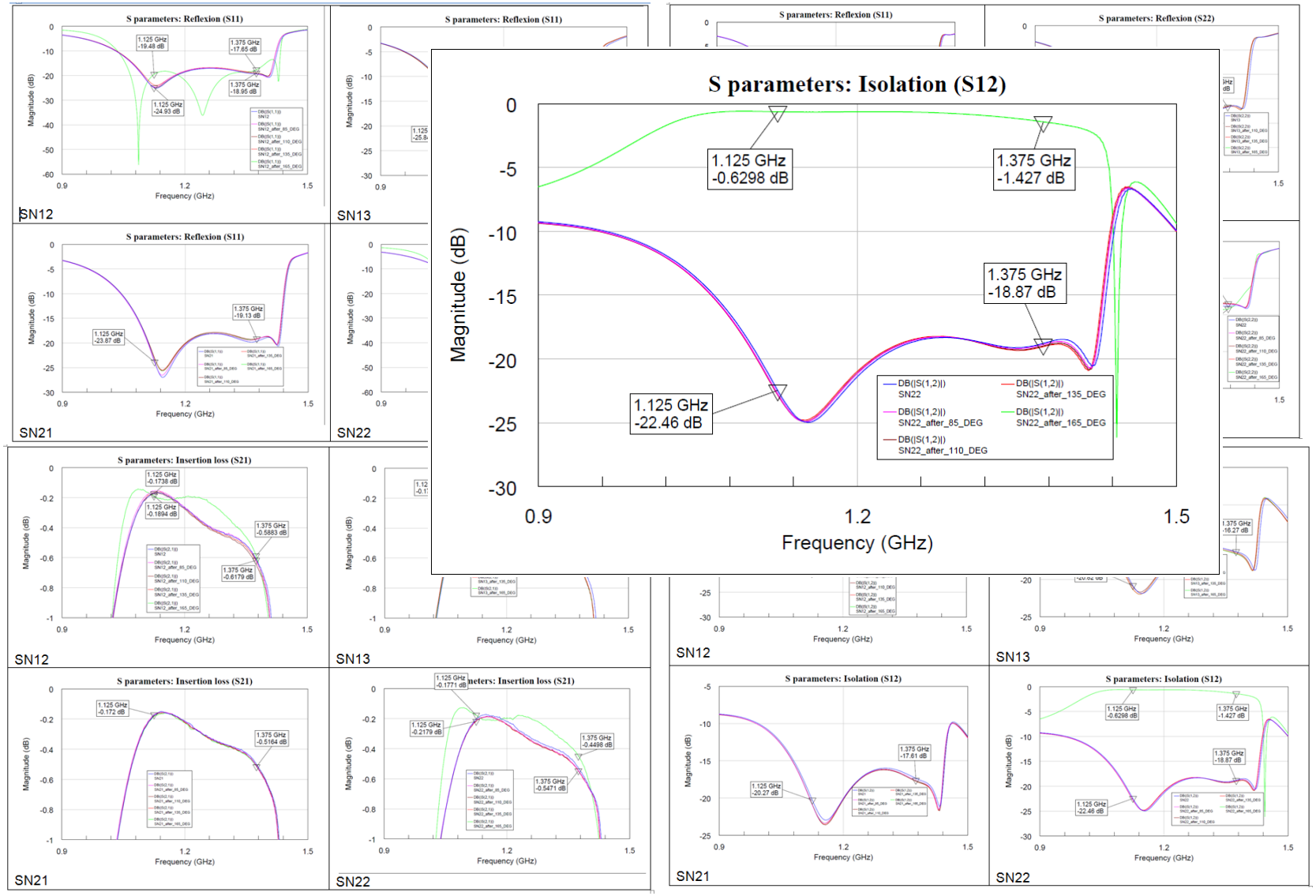
Up to 3rd step:

- No drift of temperature, no drift of return loss during each 2 hour step
- No drift of isolator S parameters between steps

4th step:

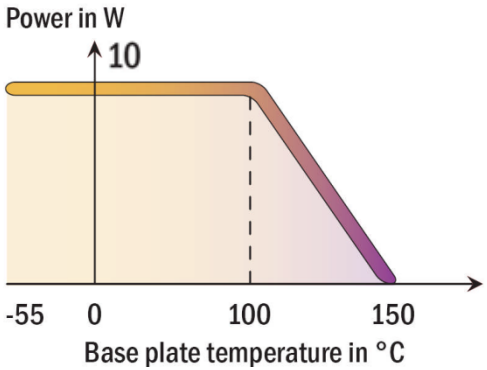
- Sudden increase of return loss when load temperature is reached
- Solder melting temperature reached. Open circuit (load to strip solder)

Temperature step stress



Operating life test

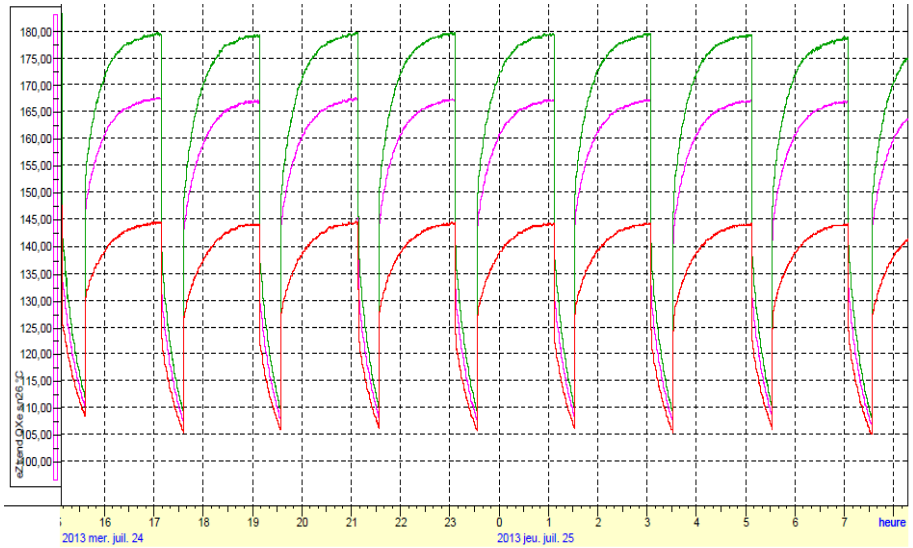
- 100°C, DC Power on load, 1.5H on/0.5H off
- 3 units, load temperature monitoring
  - 8.3 W: Tmax 180°C
  - 6.3 W: Tmax 167°C
  - 4.2 W: Tmax 144°C



load temperature derating

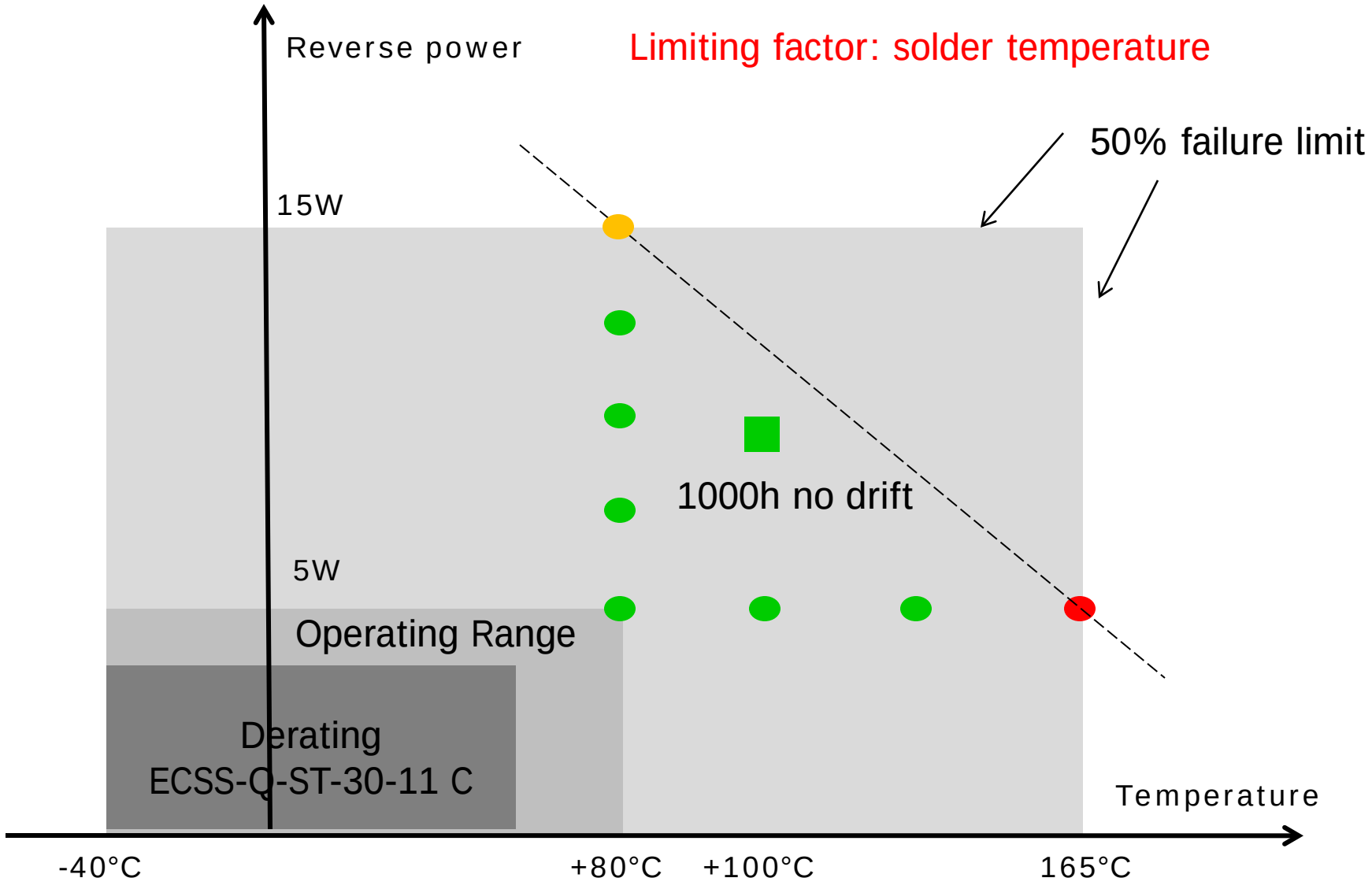
Time	Result
168 H	No failure
500 H	No failure
1000 H	No failure

180°C
167°C
144°C



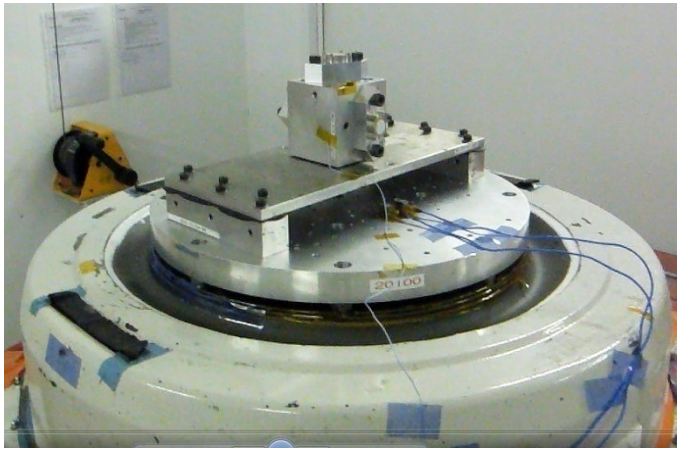
- No drift of isolator S parameters
- No drift of load DC resistance

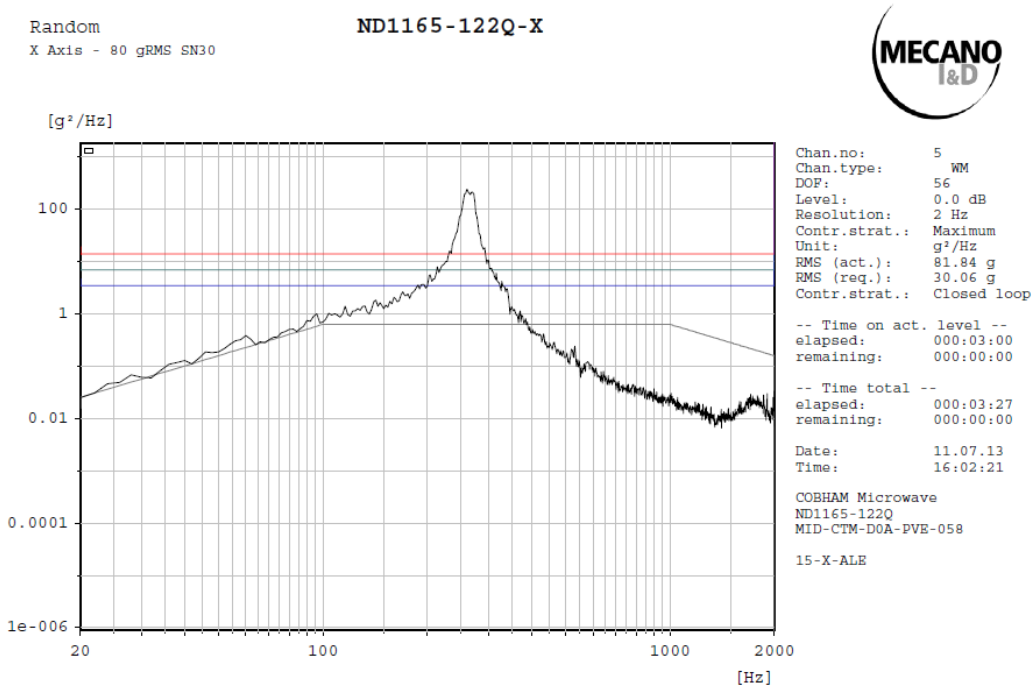
Operating margin



Vibration test

- **Random vibration**
- **Level amplification with trampoline**
- **4 units, 3 axes x 180s**





	Level	Result
1st step	50 g rms (qual)	No failure
2nd step	80 g rms	No failure
3rd step	100 g rms	No failure

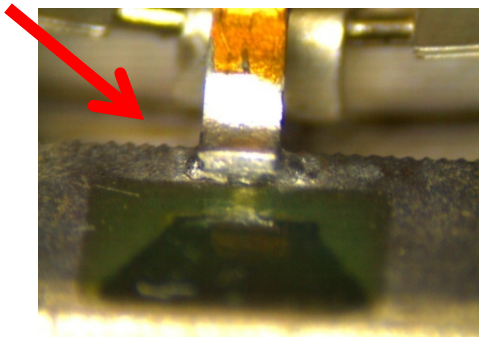
Shock test

- ½ sine, 0.3 ms
- Number of shocks at each step : 18 (3 x 2 directions x 3axis)
- 4 units

	Level	Result
1st step	1500 g (qual)	No failure
2nd step	3000 g	3 failures

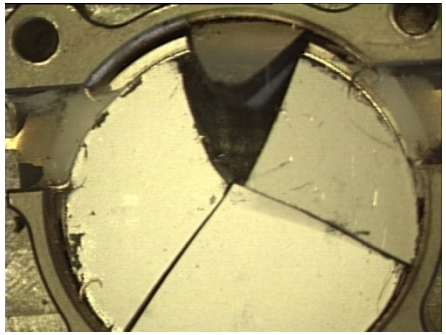
Open circuits (strip to load)

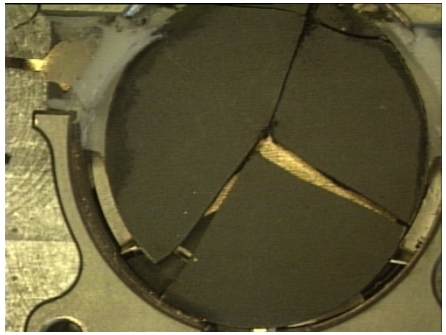
metal pad on AlN lifted off



As predicted by analysis:

Ferrite and magnet breaks (no effect on RF performance)

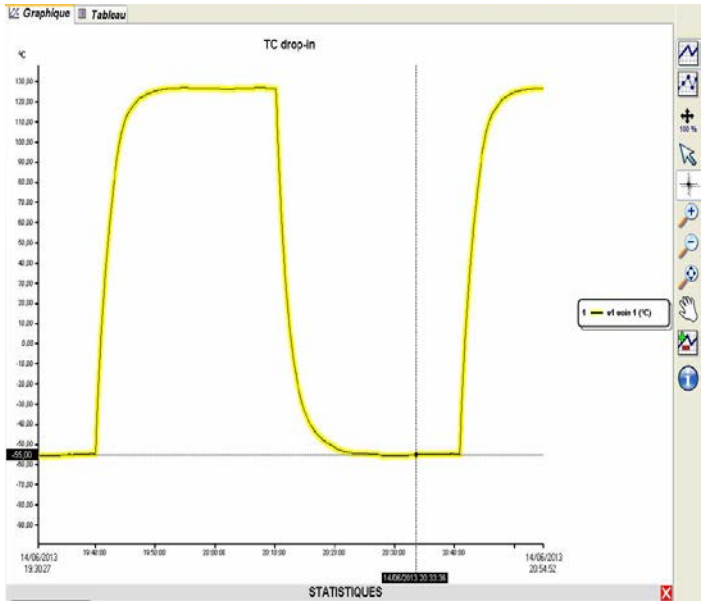




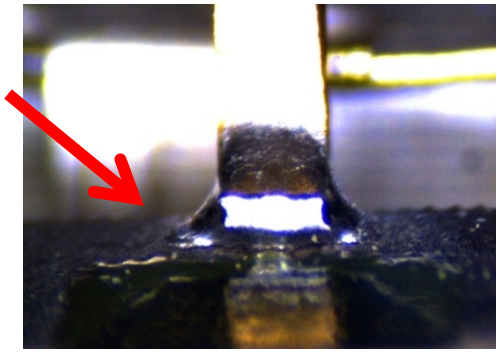
Thermal cycling test

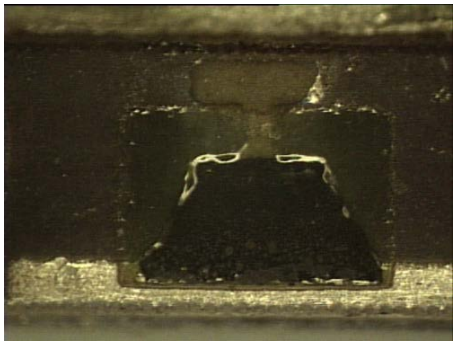
- Rapid change of temperature (2 chambers)
- -55°C/+125°C , 30 min. at each extreme
- 4 units

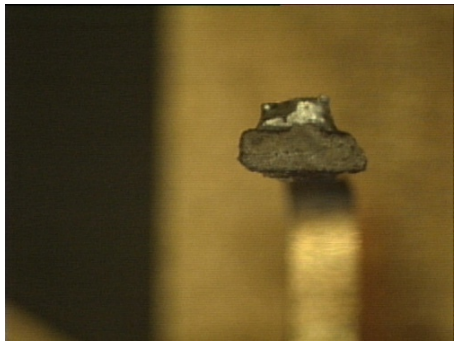
	Level	Result
1st step	20 cycles	No failure
2nd step	50 cycles	No failure
3rd step	100 cycles	No failure
4th step	200 cycles	3 failures



- Open circuit (strip to load): metal pad on AlN lifted off
- Ferrite and magnet are OK







Environmental margin

	Qual level	Limit
Vibration	50 grms	> 100 grms
Shock	1500 grms	3000 g
Thermal cycling	200 cycles -40°C/+85°C	200 cycles -55°C/+125°C

- **Coffin-Manson: Acceleration factor for thermal cycling $(\Delta Ta/\ \Delta Tu)^2$ # 2**
- **Limiting factor for this particular design: metal pad peel strength on AlN**

SUMMARY AND CONCLUSIONS

- Full ESCC evaluation performed on a ferrite isolator
- ESCC 3202 (Issue 2 draft) Qualification levels confirmed, margins quantified
  - Operating (power, thermal)
  - Environment (vibration, shock, thermal cycling)
- Some failures, never seen through all qualifications, detected at higher stress levels
  - Correlation with levels predicted by mechanical analysis
  - Weaker points and failure mechanisms identified
  - Improvements if needed: higher temperature solder, BeO load, stress relief
- Circulators have more margin (no load, no solder)

Next steps -> Evaluation / qualification of:

- Coaxial low power isolators (X-Ka bands)
- Coaxial high power isolators including vacuum aspects (L, S, C bands)

Thank you for your attention !