Testing of Power Converters for Industrial Use

Ghent 11 July 2019

(Summer school on wide-bandgap nitride devices)

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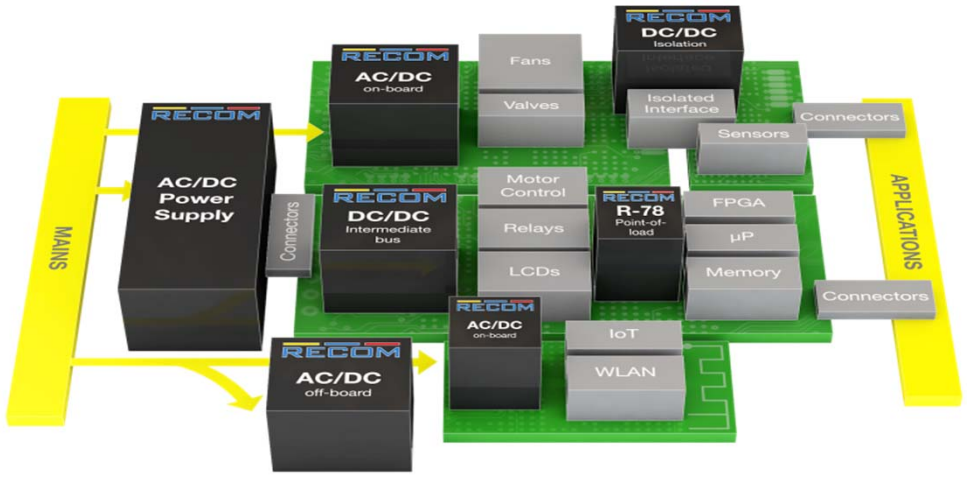
Agenda

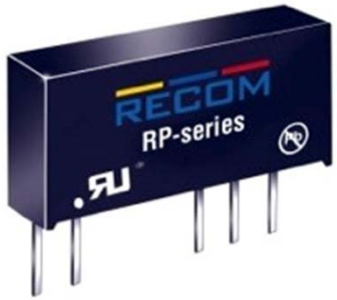
- RECOM – who we are
- Standard industrial test processes
- EMC issues
- Testing GaN – basic considerations
- GaNonCMOS efforts

- International corporation, which develops, manufactures and sells AC/DC & DC/DC converters as well as switching regulators and LED drivers around the globe.
- Founded in Germany in 1975, since 2003 headquarters in Gmunden, Austria
- Offices and plants in Singapore, US, Germany, Taiwan, Japan and China



Product Portfolio

DC/DC converters (0.25W – 240W)



Switching regulators

AC/DC converters (1W – 480W)

AC/DC and DC/DC LED drivers (3W – 150W)

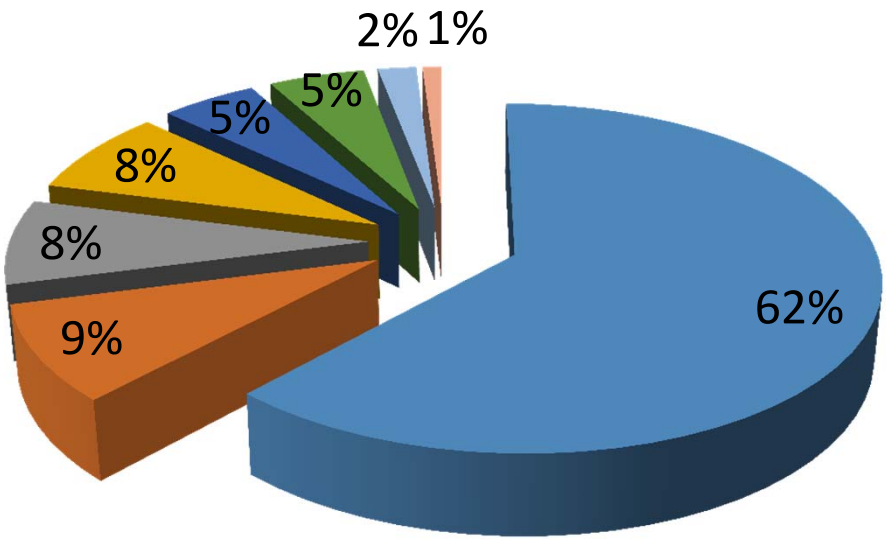
Medical DC/DC and AC/DC (1W – 150W)

Railway DC/DC (8W -240W)

Global Distributors

Digi-Key ELECTRONICS
MOUSER ELECTRONICS
RS
element14
ARROW
FUTURE ELECTRONICS
RUTRONIK ELECTRONICS WORLDWIDE
RichardsonRFPD An Arrow Company

Industries



- Industrial
- Transportation/Military/Aviation
- Medical
- Energy
- Test & Measurement
- Lighting
- Automotive
- Telecom

Standard test process *(for a new product)*

- Appearance Test Process
- Electrical Test Process
- Reliability & Environmental Test Process
- Special Test Process
- Release Test Process
- Quality Test Process
- Standard Operating Procedures
- Documentation Process
- Hardware Documentation
- Software Documentation
- Calibration Documentation

Appearance Test Process

process of testing mechanical specifications

1. Dimension check

2. Manufacturing quality check
   - Visual check, use of microscope, AOI in the production when possible
   - Operators are provided with descriptions of unacceptable product defects

3. Solderability test
   - To assess the solderability of a DUT termination and if the SMT products can withstand the heat of reflow soldering process
   - Parameters of DUT are measured before and after the test

Appearance Test Process

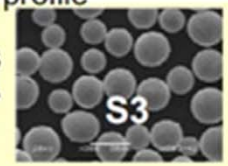
Manufacturing quality check

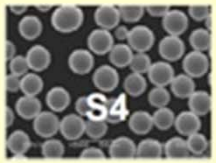
Defect

- Solder balls violate minimum electrical clearance.
- Solder balls are not entrapped in no-clean residue or encapsulated with conformal coating, or not attached (soldered) to a metal surface

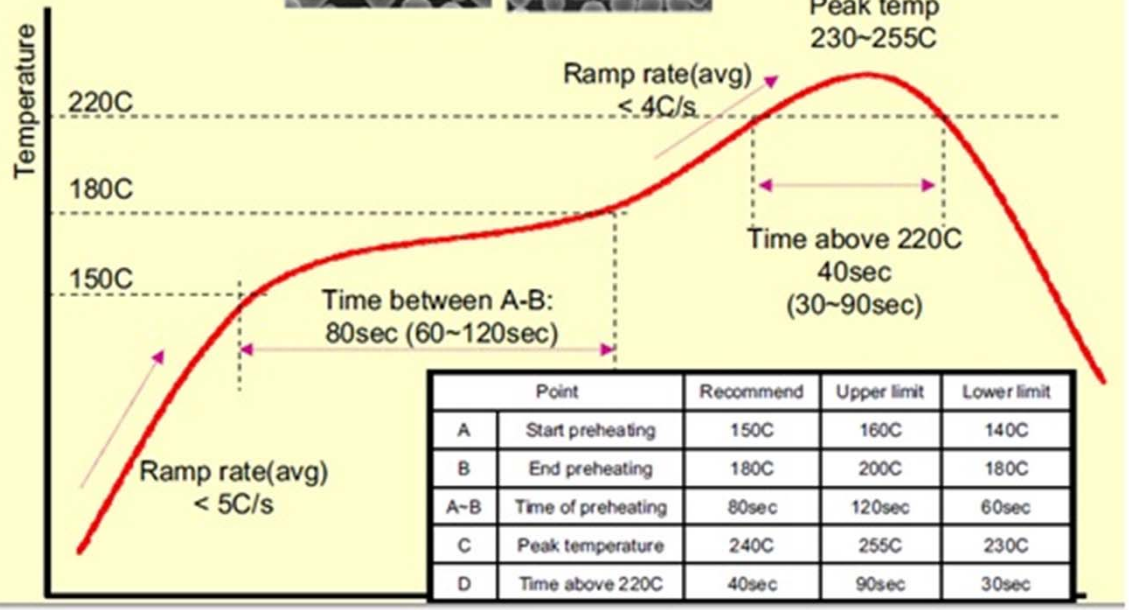
◆ Recommend reflow profile

For S101HF-S3: Type3
S101HF-S4: Type4





Adaptable reflow atmosphere
Air & Nitrogen

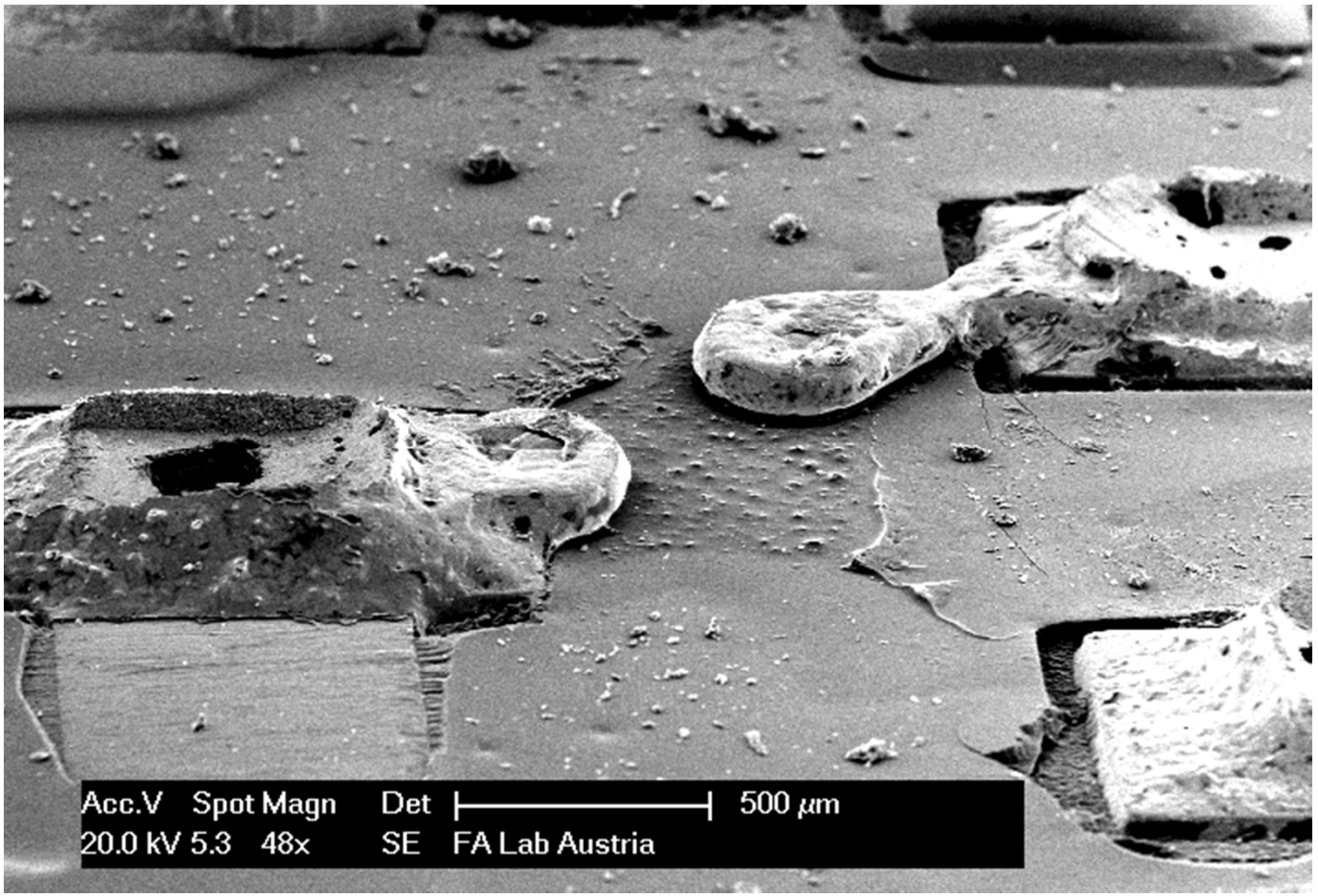


Point		Recommend	Upper limit	Lower limit
A	Start preheating	150C	160C	140C
B	End preheating	180C	200C	180C
A~B	Time of preheating	80sec	120sec	60sec
C	Peak temperature	240C	255C	230C
D	Time above 220C	40sec	90sec	30sec

Solderability test

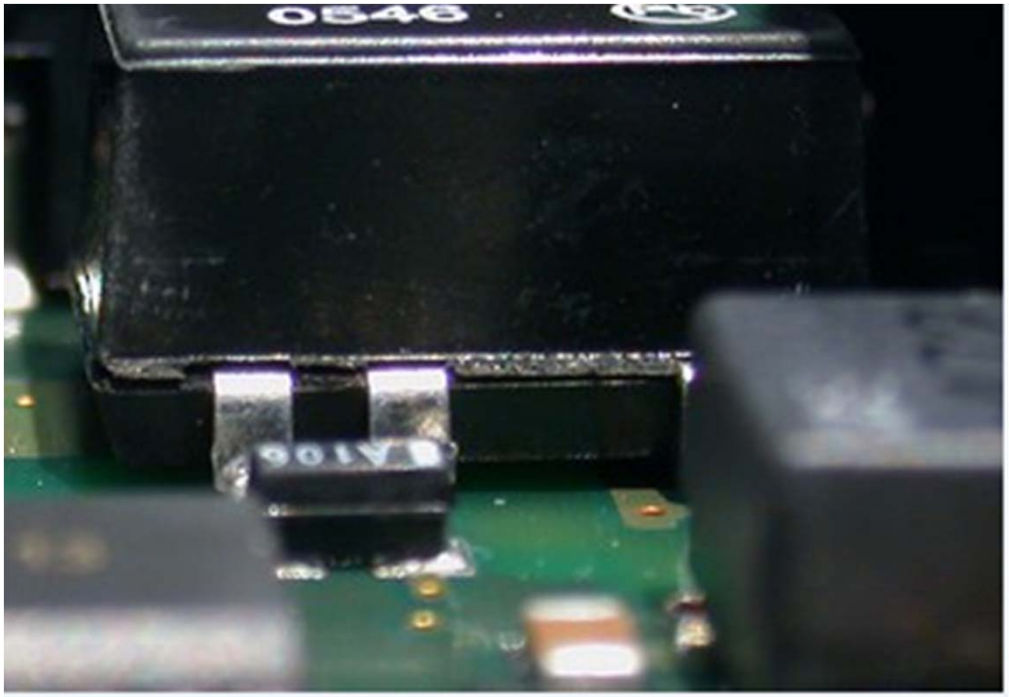
Appearance Test Process

Solderability test – solder pads with molten solder



Appearance Test Process

Solderability test – crack in the package



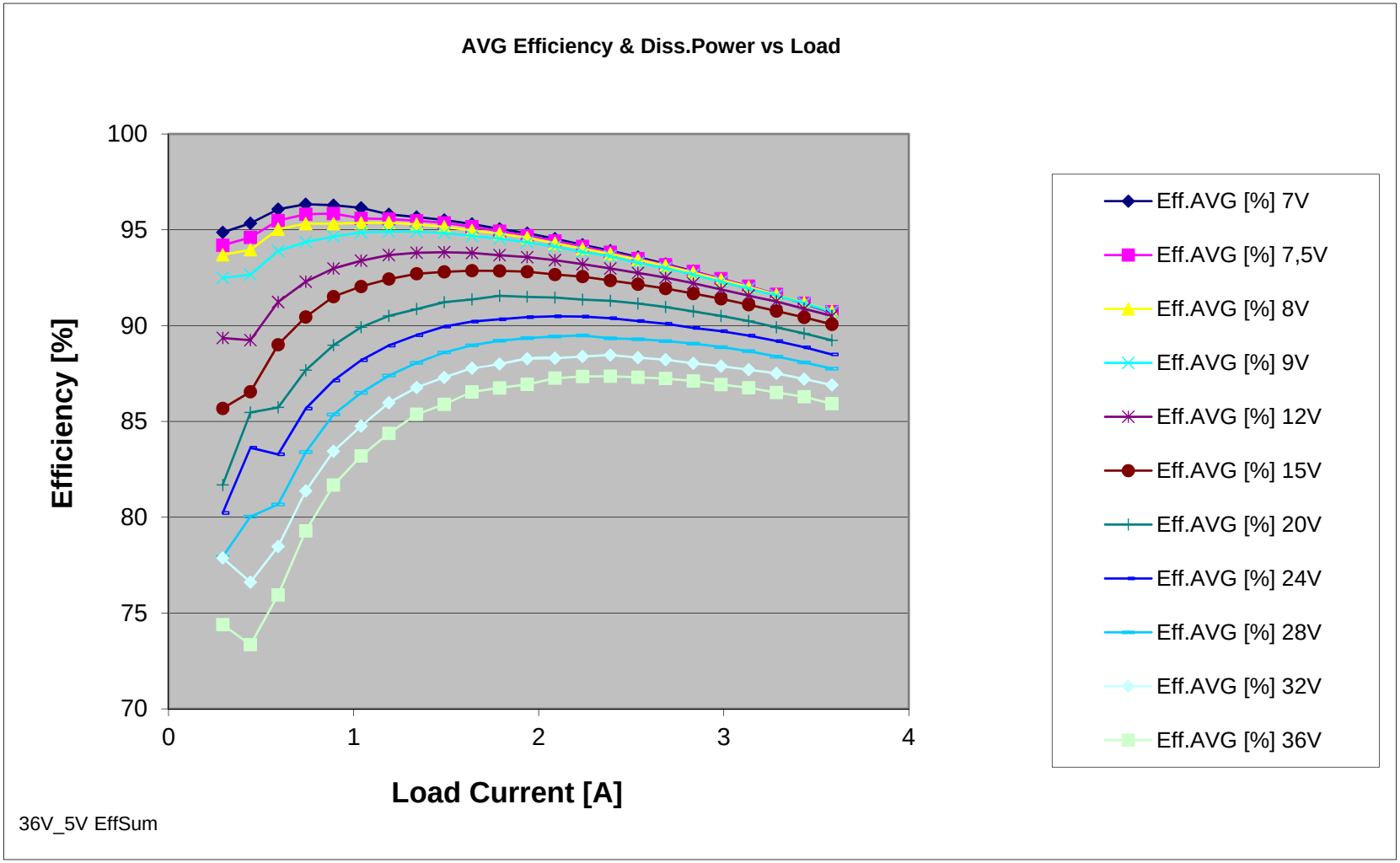
Electrical Test Process

process of testing electrical and thermal specifications of DUT

Efficiency Test
Ripple Noise
Back Ripple Current
No Load Power Consumption / Quiescent current
Operating Frequency
Start up Test
Hold up Test
Rise Time Test
Dynamic Load Stability
Hi Pot Test/Leakage Current
Over Current and Short circuit Protection Test
Over Load Protection
Over Voltage Protection Test
IR Test
Thermal Derating and Over – Temperature Protection Test
Airflow Test
Low Temperature Start up Test
Output Voltage Trim Function Test
Control Pin Test
Under Voltage Lockout Test

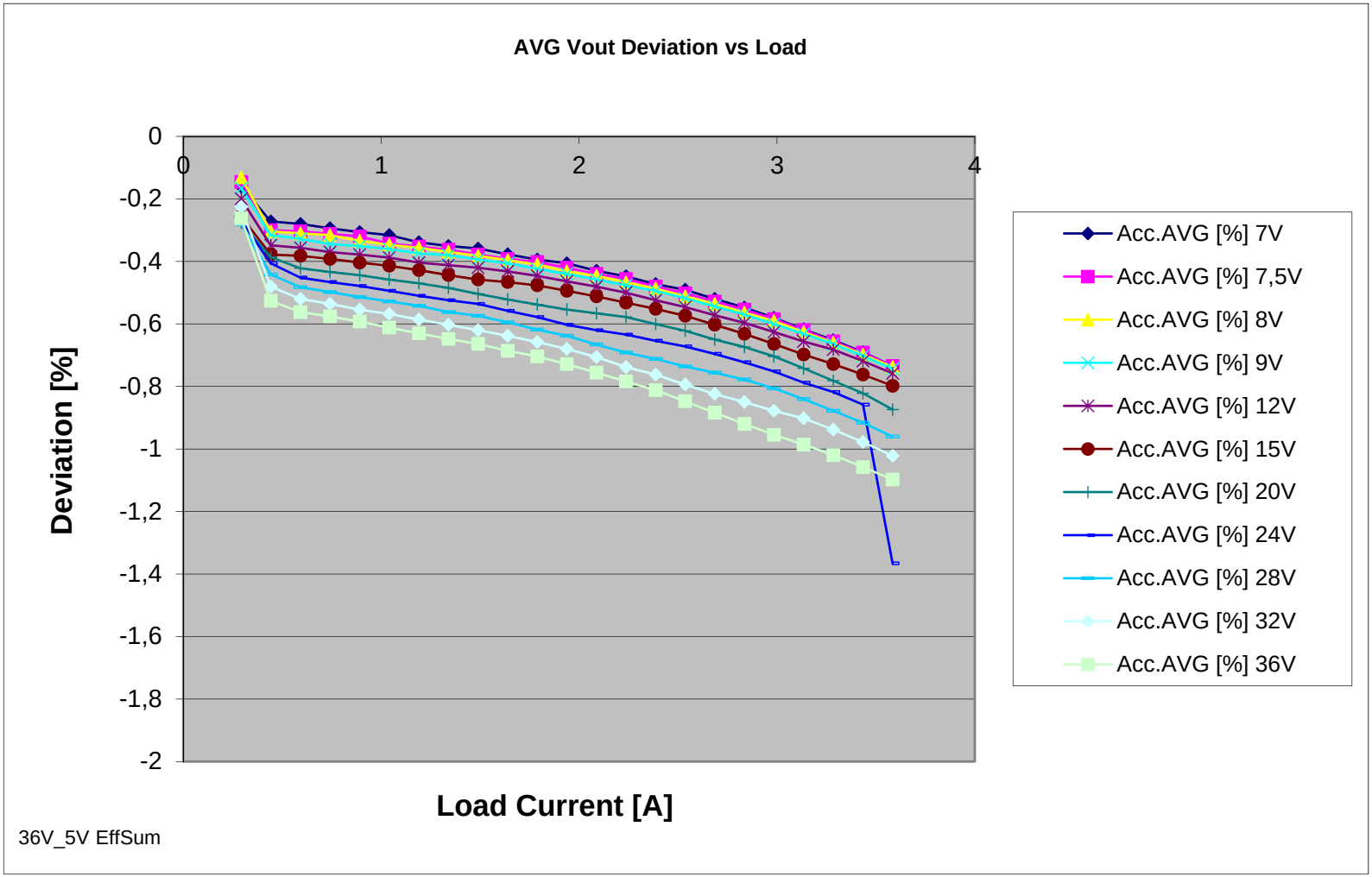
Electrical Test Process

Efficiency, Power Dissipation, Accuracy, Line and Load



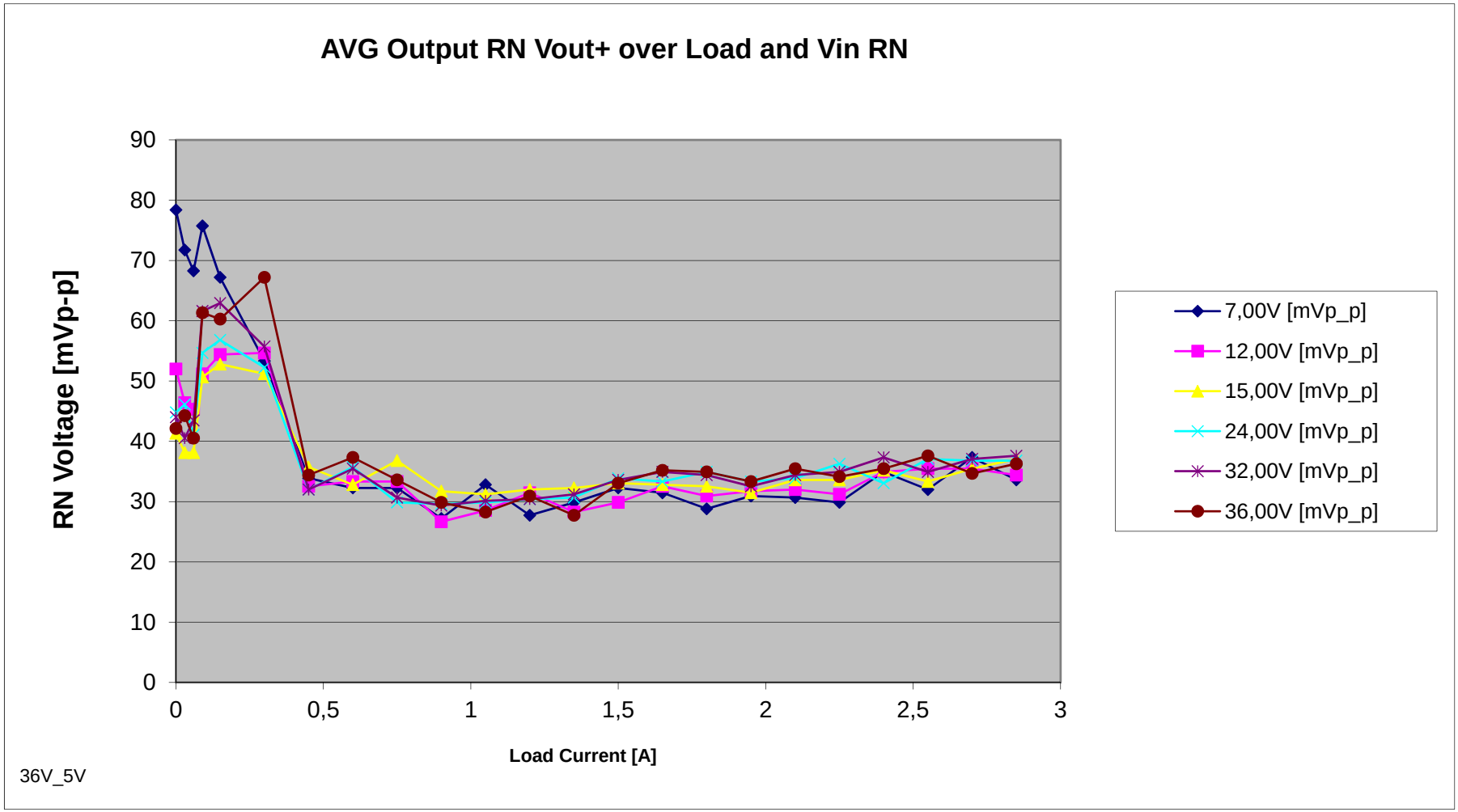
Electrical Test Process

Efficiency, Power Dissipation, Accuracy, Line and Load



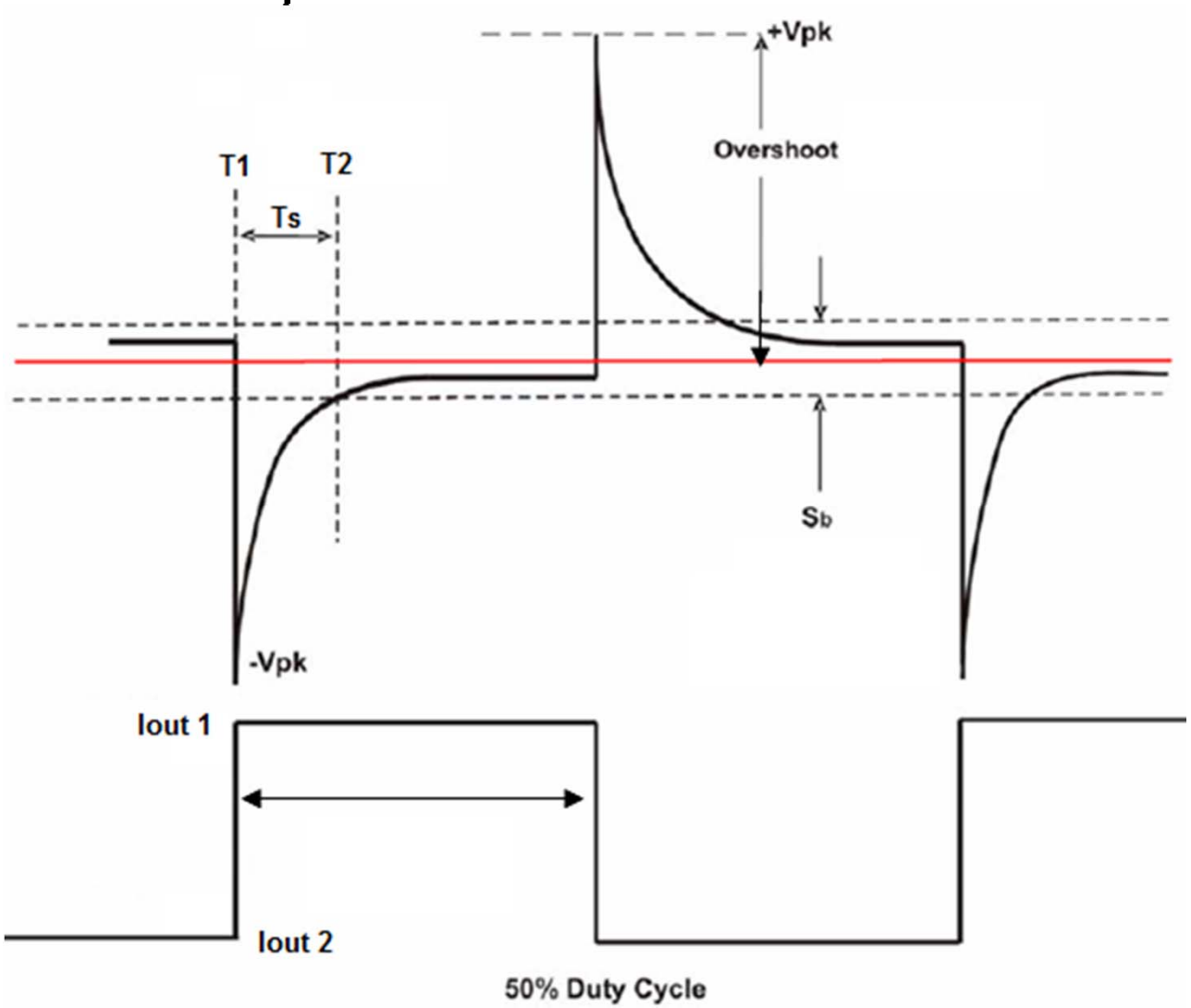
Electrical Test Process

Ripple Noise



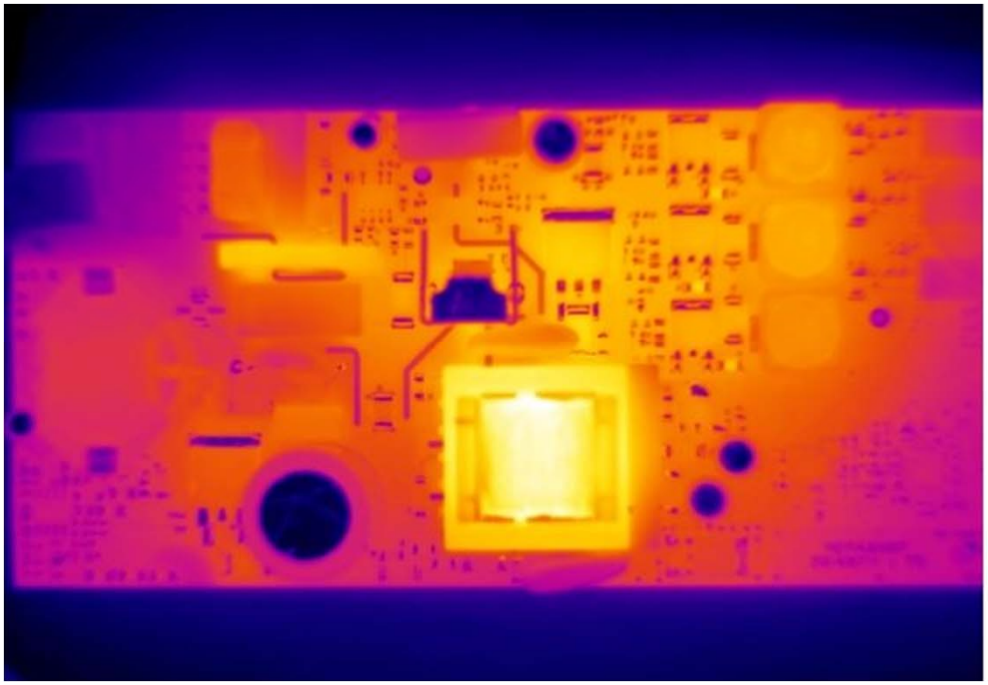
Electrical Test Process

Dynamic Load Response

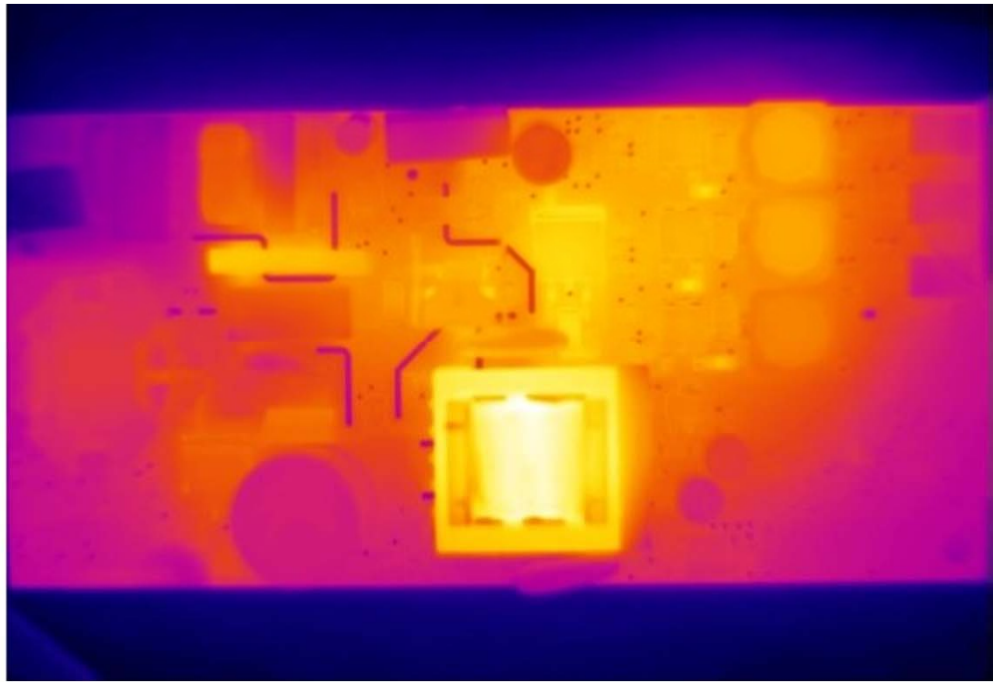


Electrical Test Process

Thermal IR test



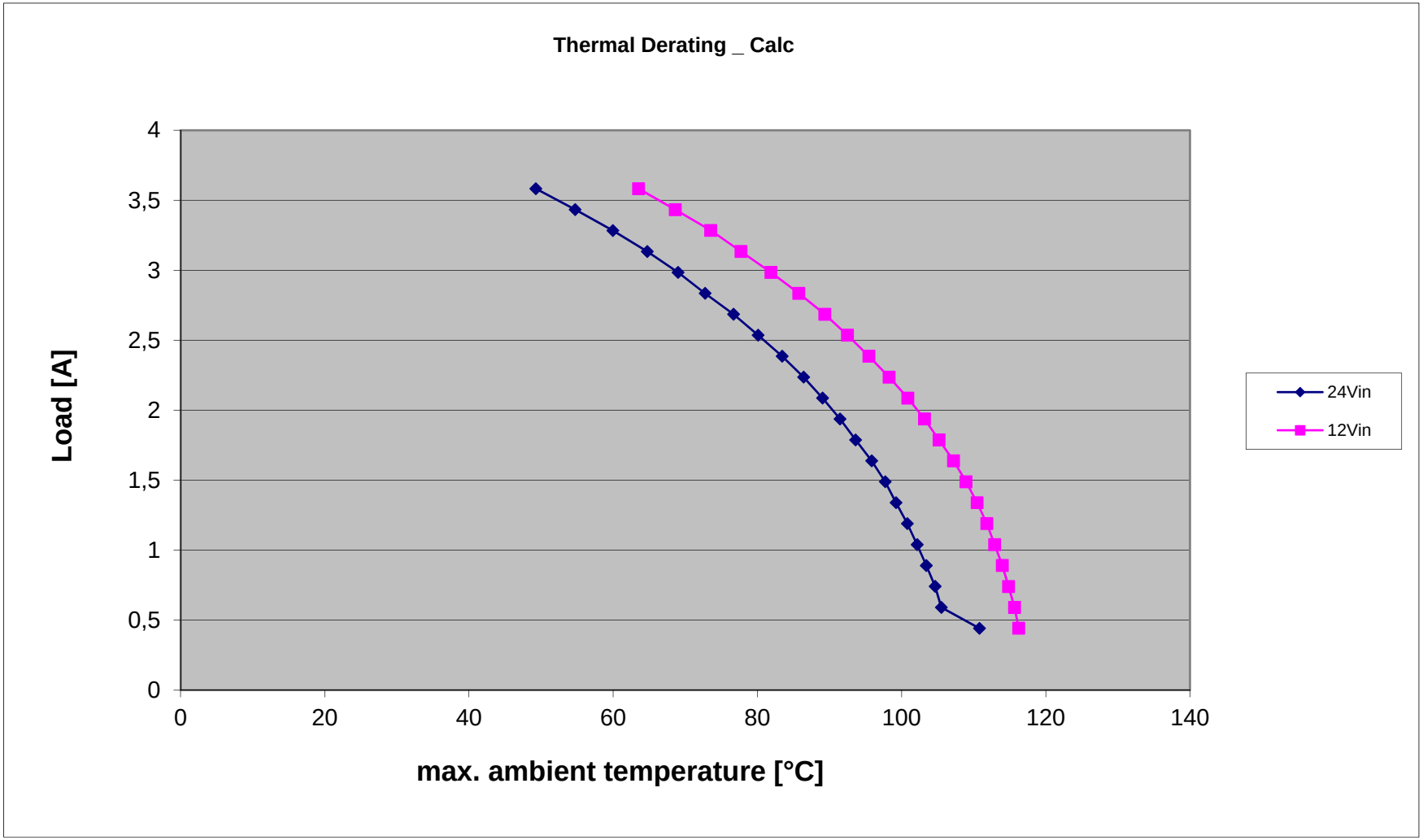
No homogenized surface



Homogenized surface

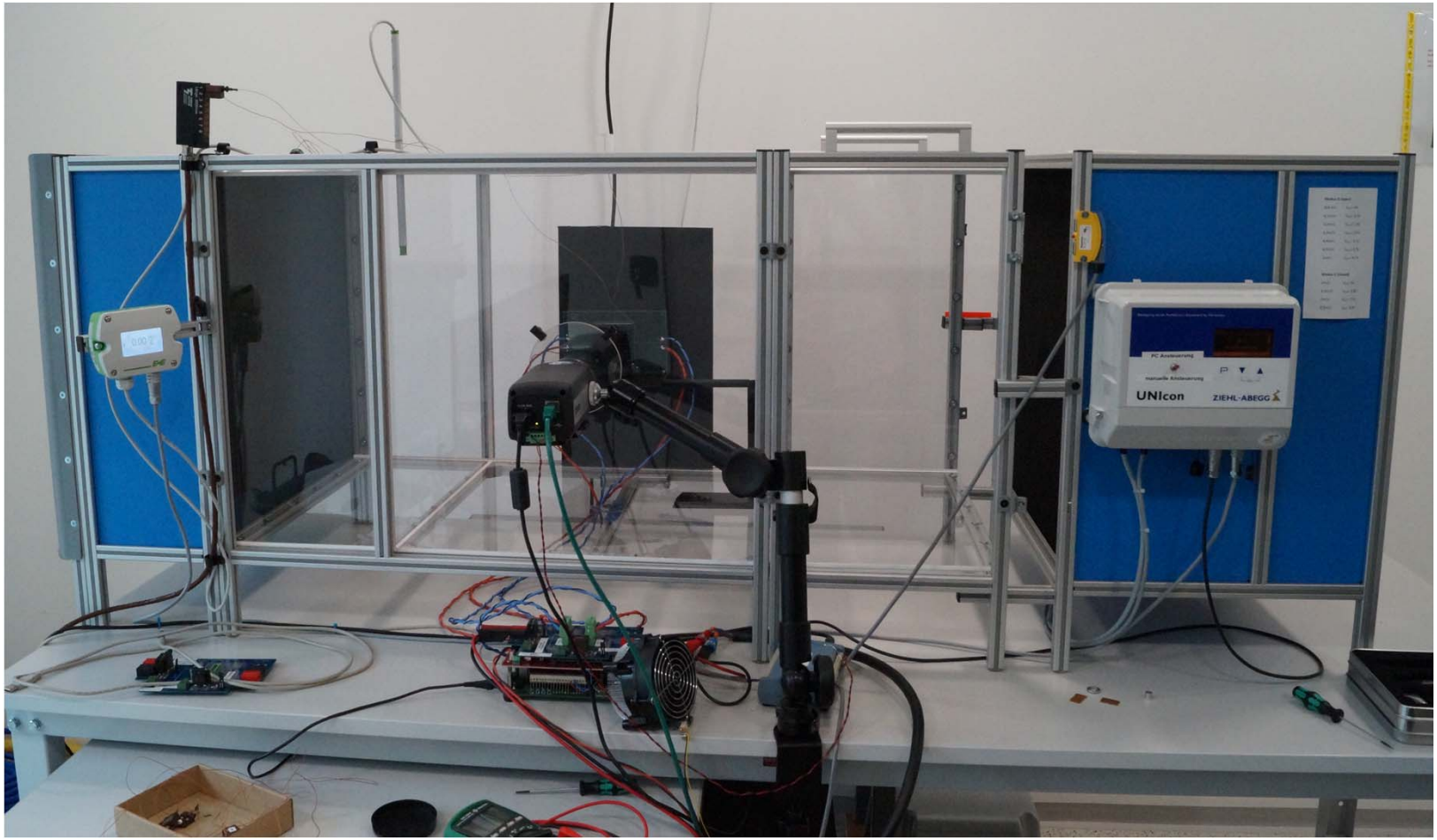
Electrical Test Process

Thermal derating



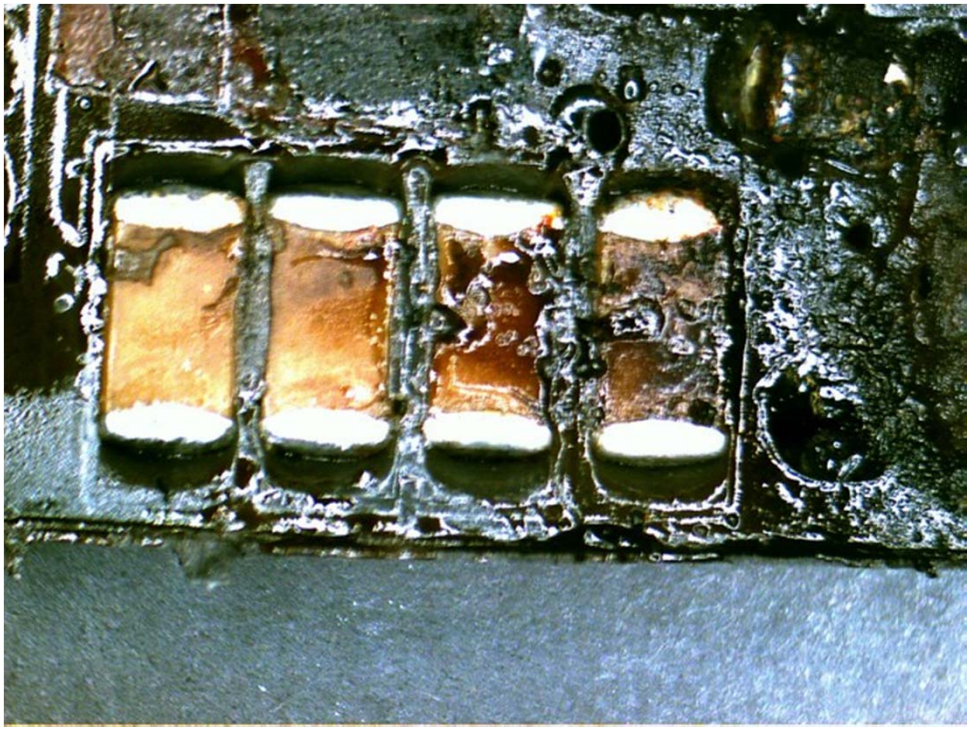
Electrical Test Process

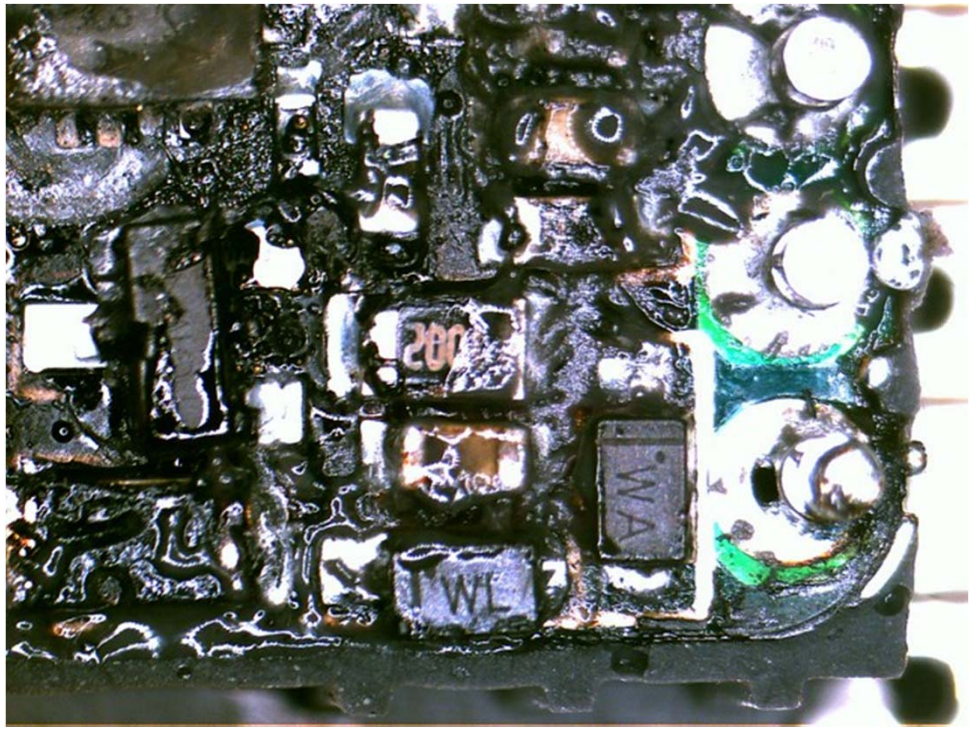
Airflow test



Electrical Test Process

Over temperature test – no OTP





Reliability & Environmental Test Process

process of testing reliability and environmental specifications of DUT

High Temperature Operating Life Test HTOL
Low Temperature Operating Life Test LTOL
Temperature Cycling Test TCy
High Temperature & High Humidity Test HTH
Powered Temperature & Humidity Test PTH
Power ON/OFF Cycling Test
High Vibration Random Noise Test HVN
Mechanical Shock
Temperature Shock Test
HALT

Reliability & Environmental Test Process

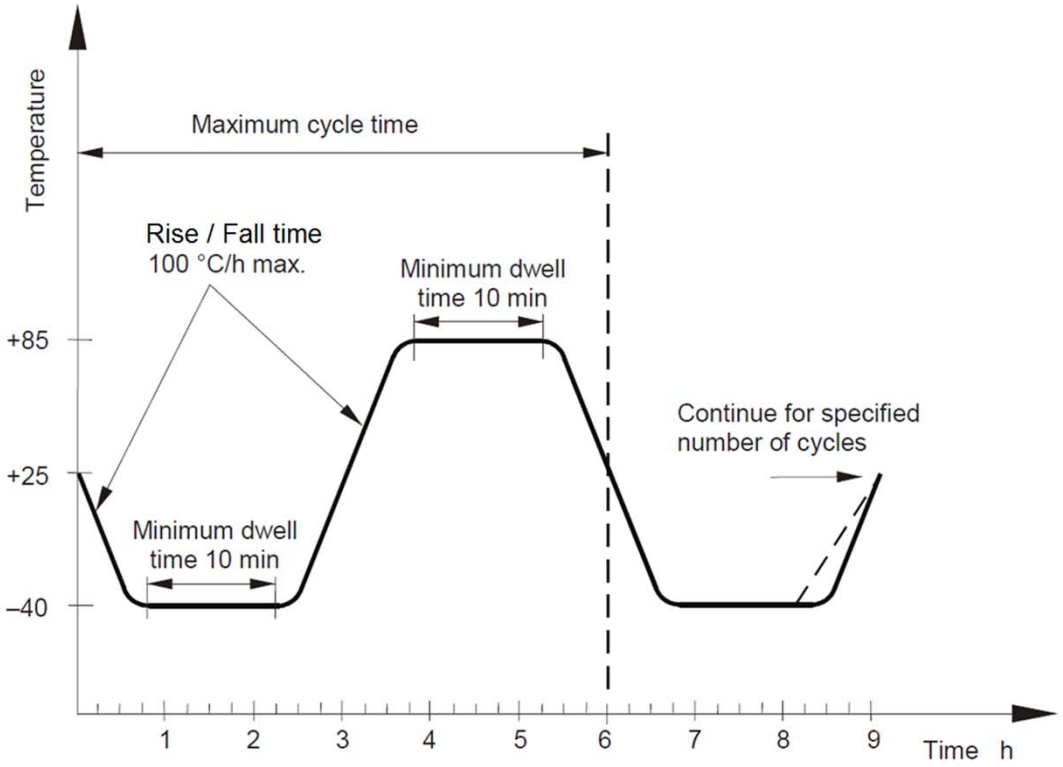
High (Low) Temperature Operating Life Test

- steady-state life test is performed to determine the reliability of devices under operation at high (low) temperature conditions over an extended period of time
- the temperature is at least 5°C above the maximum allowed ambient temperature (minimal specified temperature) at full load and nominal input for 1000 hours
- the chamber and accessories shall be constructed and arranged in such a manner as to avoid condensate dripping on the samples under test, and such that the samples shall be exposed to circulating air

Reliability & Environmental Test Process

Temperature Cycling Test

- cycling through two temperature extremes, typically at relatively high rates of change



$AF = (\Delta T_{test} / \Delta T_{use})^{m}$

AF = Acceleration Factor

ΔT_{test} = Test temperature difference (°C)

ΔT_{use} = Use temperature difference (°C)

m = Fatigue or Coffin-Manson exponent

Low temperature - 55°C
High temperature + 125°C
Dwell times 1 hour (depends on size)
Ramp Rate 3 to 5°C/min

Typical assumed Coffin-Manson exponent s for solder joints are 2.5 – 2.65.

Reliability & Environmental Test Process

Temperature Cycling Test

Example

Assume a product that undergoes 5 daily temperature transitions from 20 °C to 60 °C (ΔT_{use} = 40 °C) while it is normally being used. The following acceleration will occur if the product is temperature cycle tested using a high temperature of 100 °C and a low temperature of -20 °C (ΔT_{test} = 120 °C), assuming a typical Coffin-Manson exponent of 3:

$AF = (120 / 40)^3 = 27$

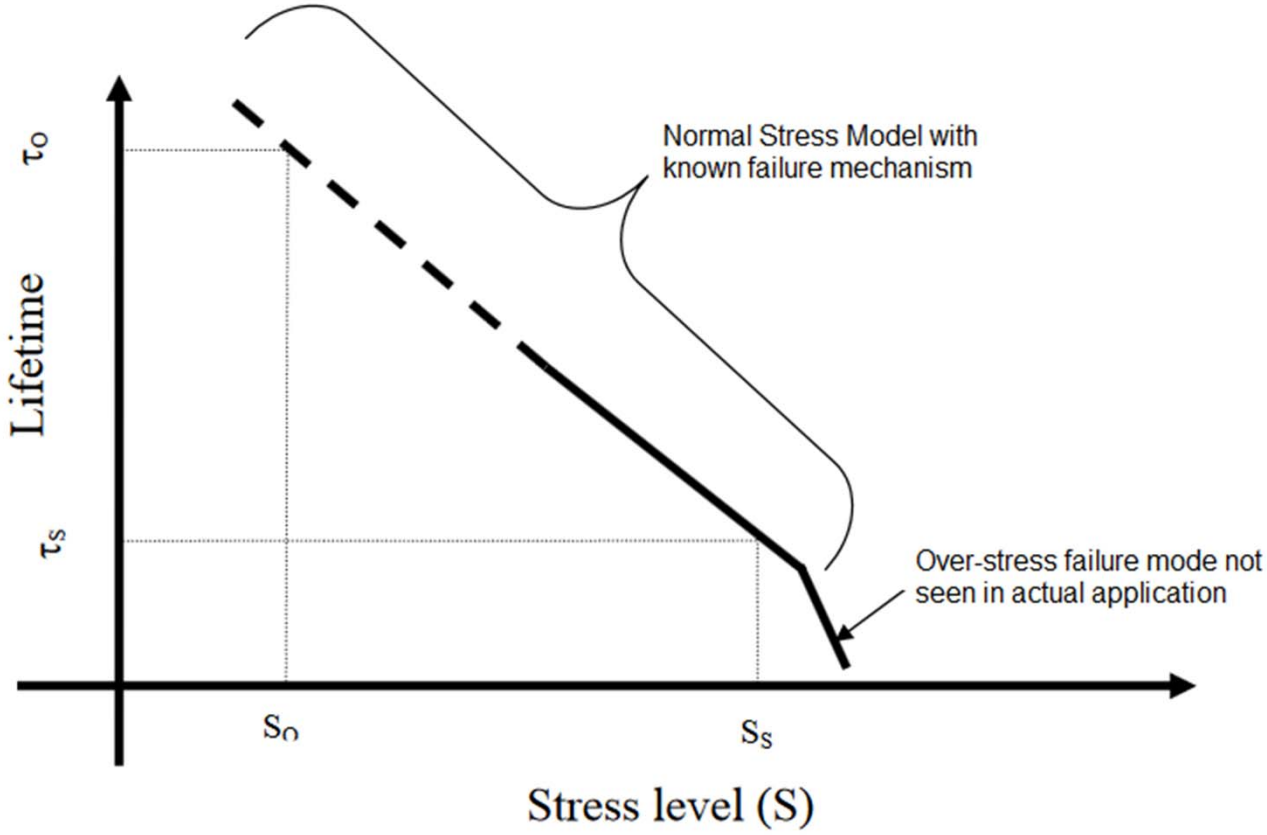
Testing this product for 1000 temperature cycles using the accelerated conditions would therefore be equal to 15 years of life based on the stated use conditions.

(27 X 1000 cycles) / ((5 cycles per day) (365 days per year)) = 14.8 years

Reliability & Environmental Test Process

High Temperature & High Humidity Test

- reliability test designed to accelerate metal corrosion
- 1000 hours at 85 deg C, 85% RH
- intermediate read points at 48H, 96H, 168H, and 500H are often used



High Temperature & High Humidity Test

Based on the Arrhenius model

- **Temperature Acceleration**

$$AF_T = \tau_o / \tau_s = e^{\frac{E_a}{k}\left(\frac{1}{T_o} - \frac{1}{T_s}\right)}$$

where E_A is the activation energy, k is the Boltzmann constant = 8.617×10^{-5} ev

- **Humidity Acceleration**

$AF_H = (RH_S / RH_O)^n$

where RH is the relative humidity

Plastic packages are considered non-hermetic. That means moisture gets into the package via a diffusion process through the plastic moulding compound or through the interface between the moulding compound and the lead frame.

Reliability & Environmental Test Process

High Temperature & High Humidity Test

Example

The total acceleration can be calculated as follows

$AF = AF_H \times AF_T$

What will the acceleration factor be when the temperature humidity test (1000h with 85°C and 85% relHum) is used based on the standard operation conditions of 40°C and 50% relHum.

$= (85/50)^3 \times \exp\{(0.7/8.617 \times 10^{-5}) \times [1/(273+40)-1/(273+85)]\} = 661$

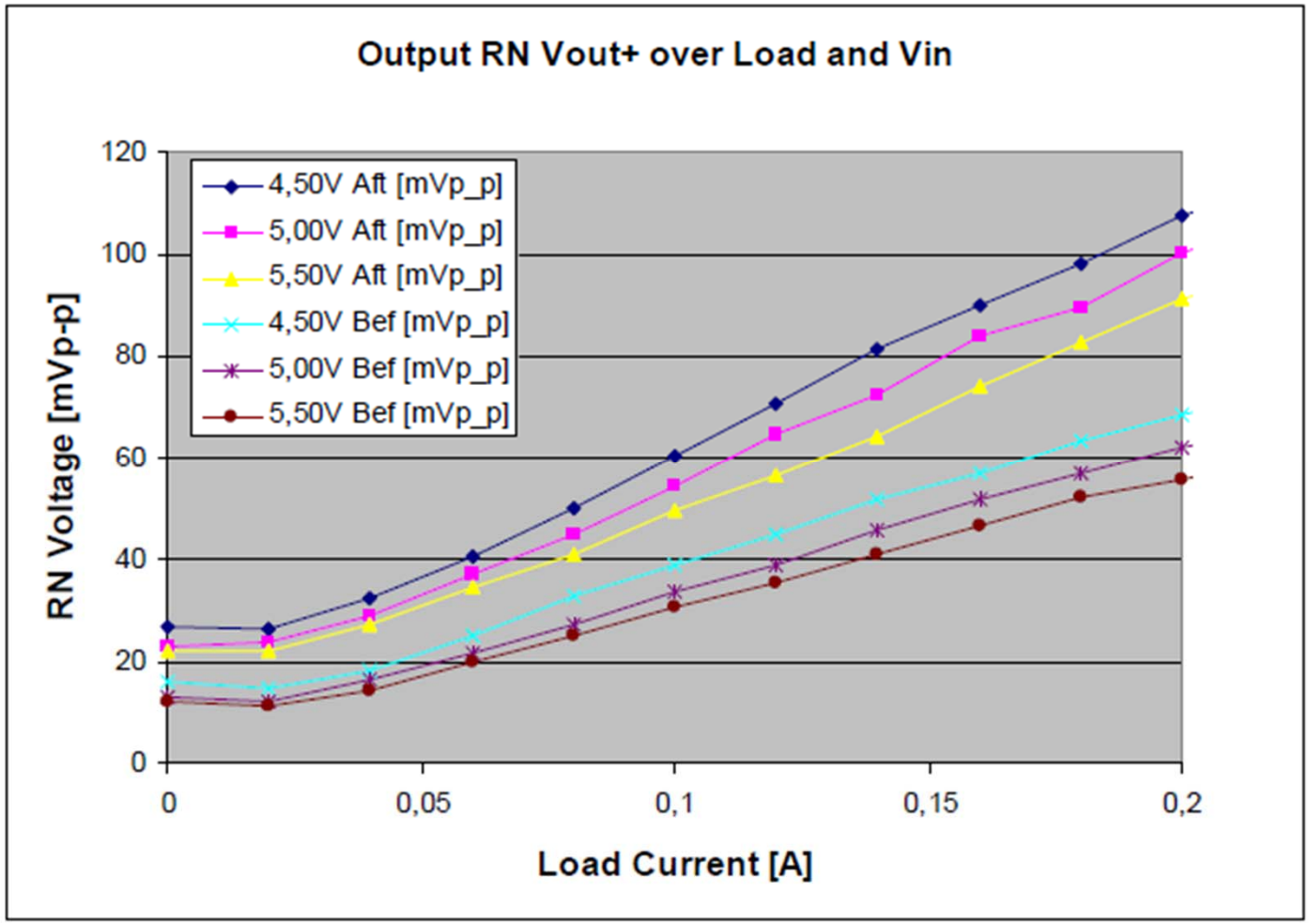
where n = 3
and E_a = 0.7 eV (most common for electronics)

$AF = AF_H \times AF_T \times$ testtime [h]

= ~12.8 years

Reliability & Environmental Test Process

High Temperature & High Humidity Test (96hrs@85C/85%RH)



Reliability & Environmental Test Process

Powered High Temperature & High Humidity Test

- designed to accelerate metal corrosion particularly that of the metallization's on the die surface of the device
- 1000 hours at 85 deg C, 85% RH
- bias is applied to the device

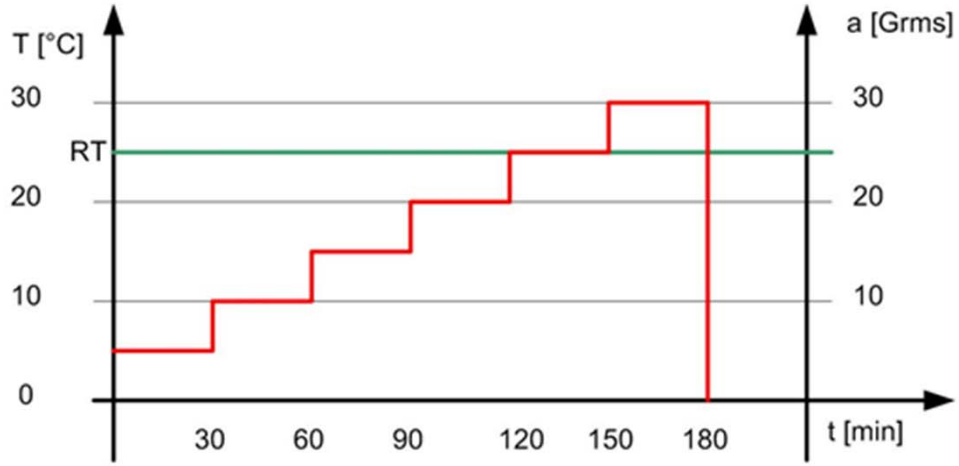
Power acceleration factor added $\mathbf{AF_P = P_S/P_O}$

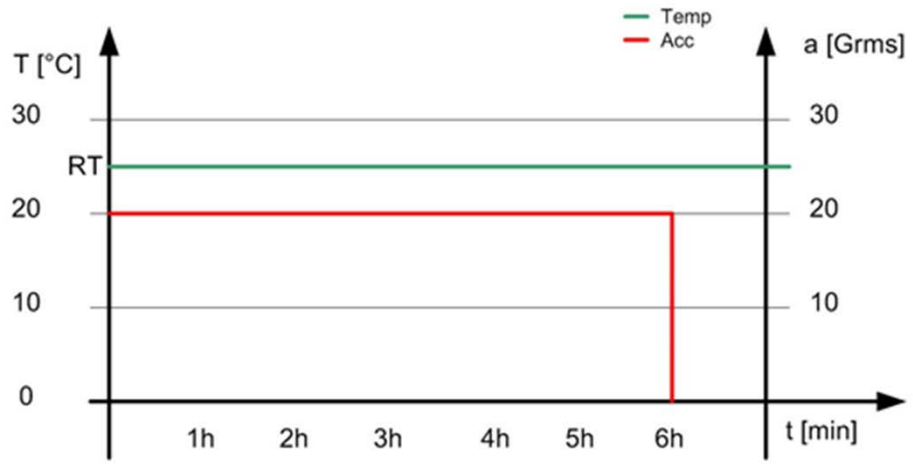
$$\mathbf{AF = AF_H \times AF_T \times AF_P}$$

Reliability & Environmental Test Process

High vibration random noise test

- Frequency range 5Hz to 5khz
- 6DOF (6 Degrees Of Freedom) Random distributed longitudinal and circular vibration
- vibration sweep test - 5 Grms 30min steps up to 30 Grms
- continuous vibration test - with a fixed vibration level over h hours.

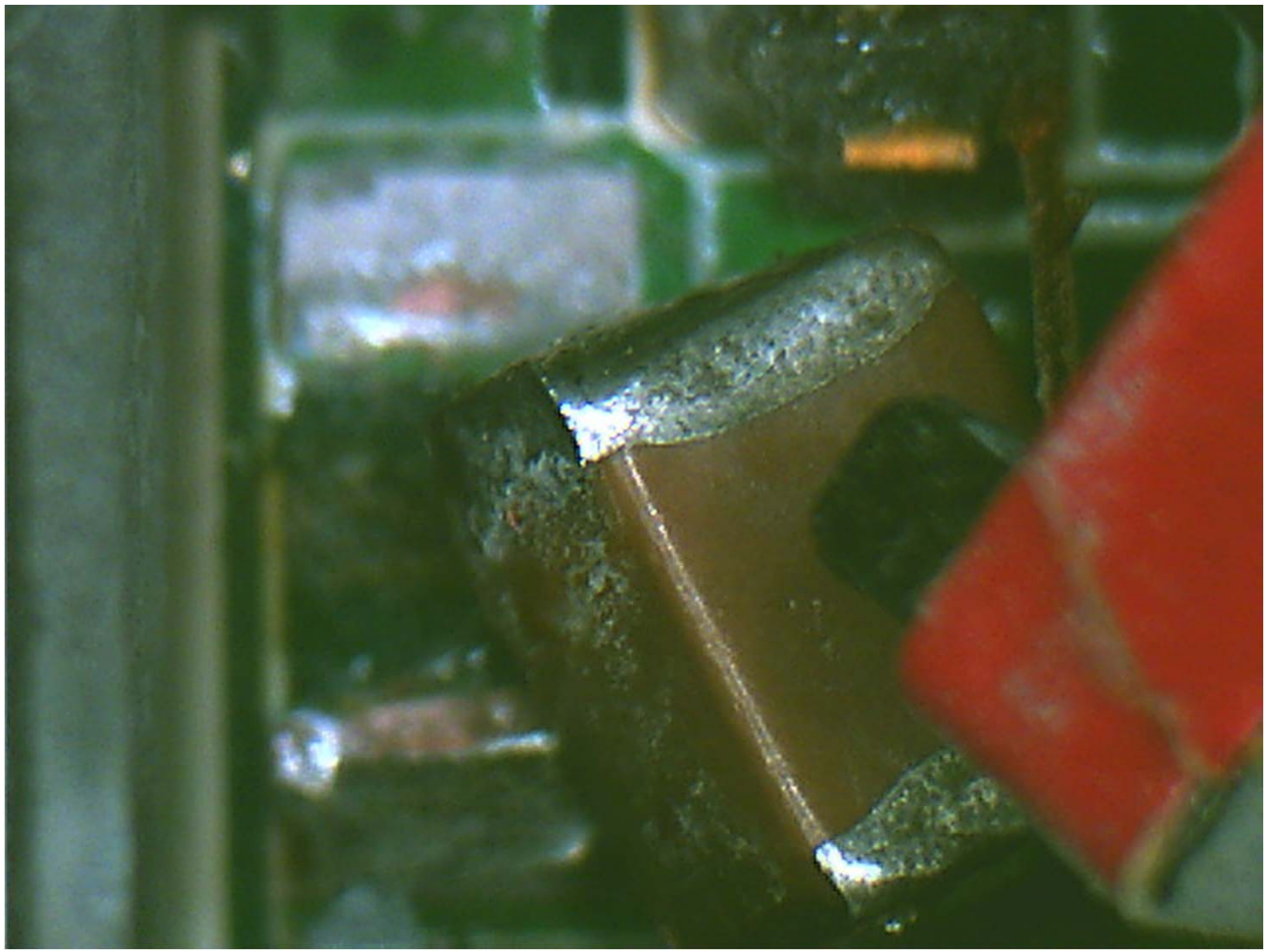




Reliability & Environmental Test Process

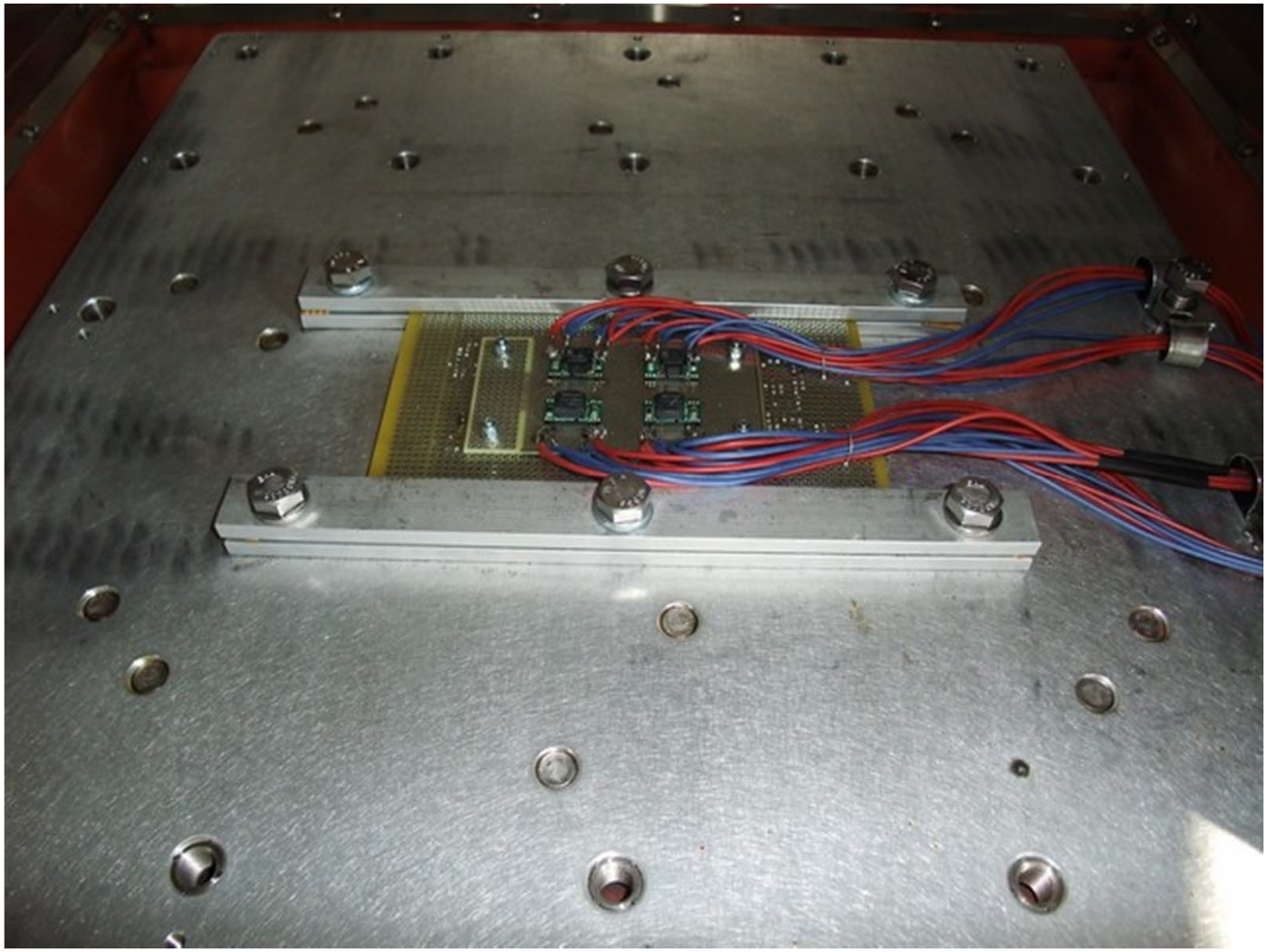
High vibration

random noise



Reliability & Environmental Test Process

High vibration random noise



Reliability & Environmental Test Process

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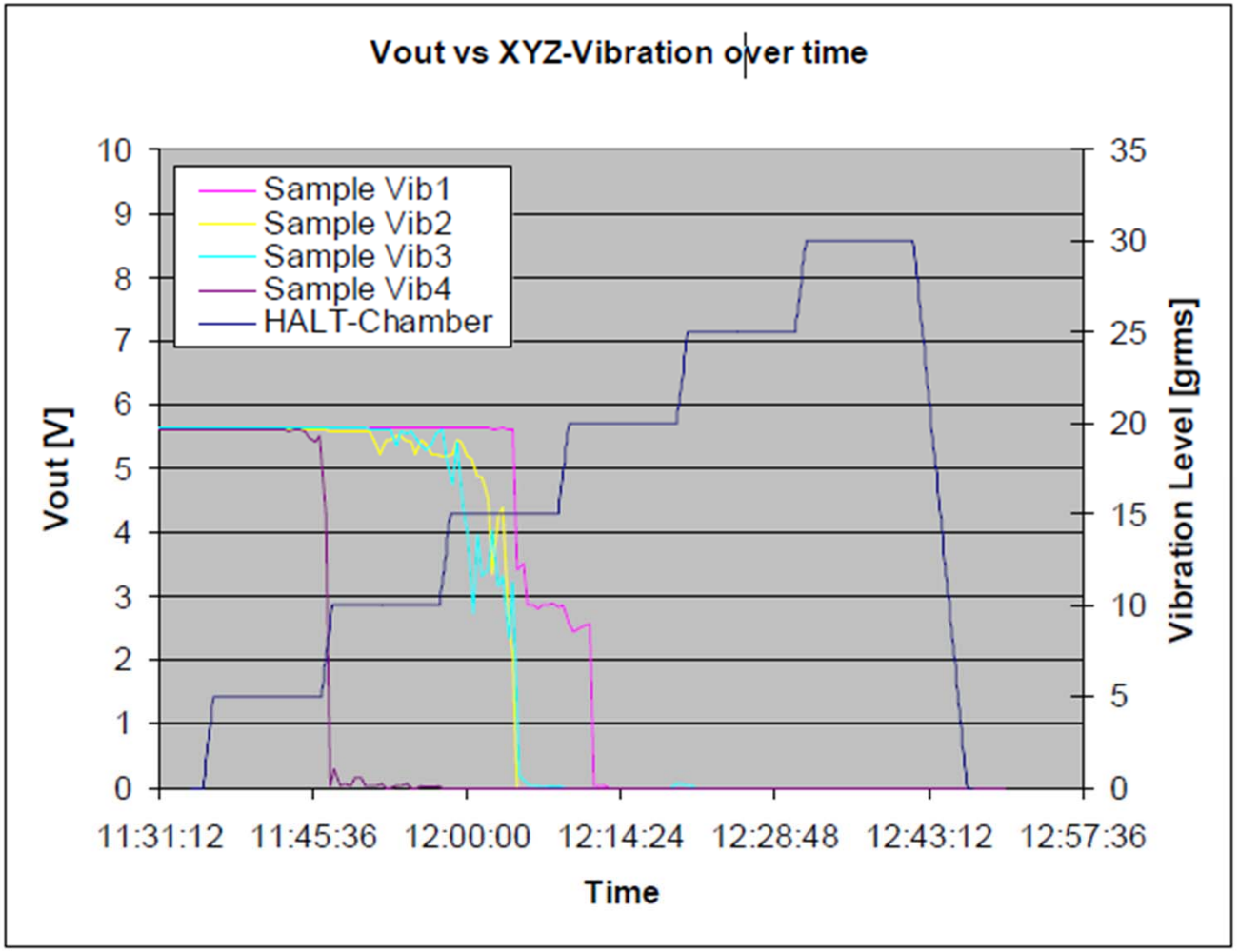


Reliability & Environmental Test Process

Mechanical Shock

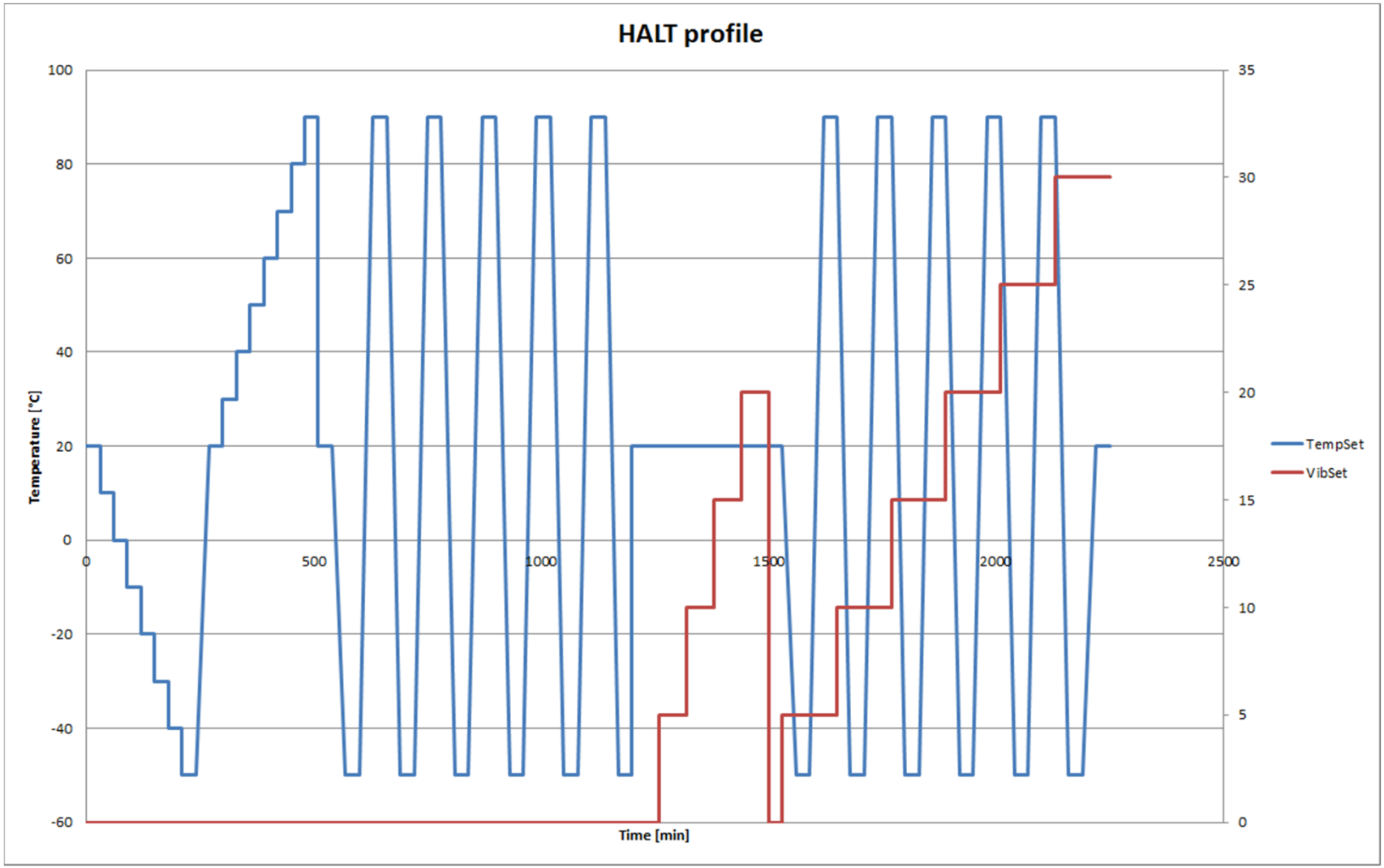
- DUT is subjected to 5 shock pulses along each axis both in a positive and negative direction (30 pulses in total) – peak and time must be defined.
- The default test condition for integrated circuits is test condition B (peak level of 1500 g and pulse duration of 0.5 ms)

Temperature Shock

- Temperature cycling with higher temperature change rate (15 °C per minute or more)

Reliability & Environmental Test Process

Highly Accelerated Life Test



Special Test Process

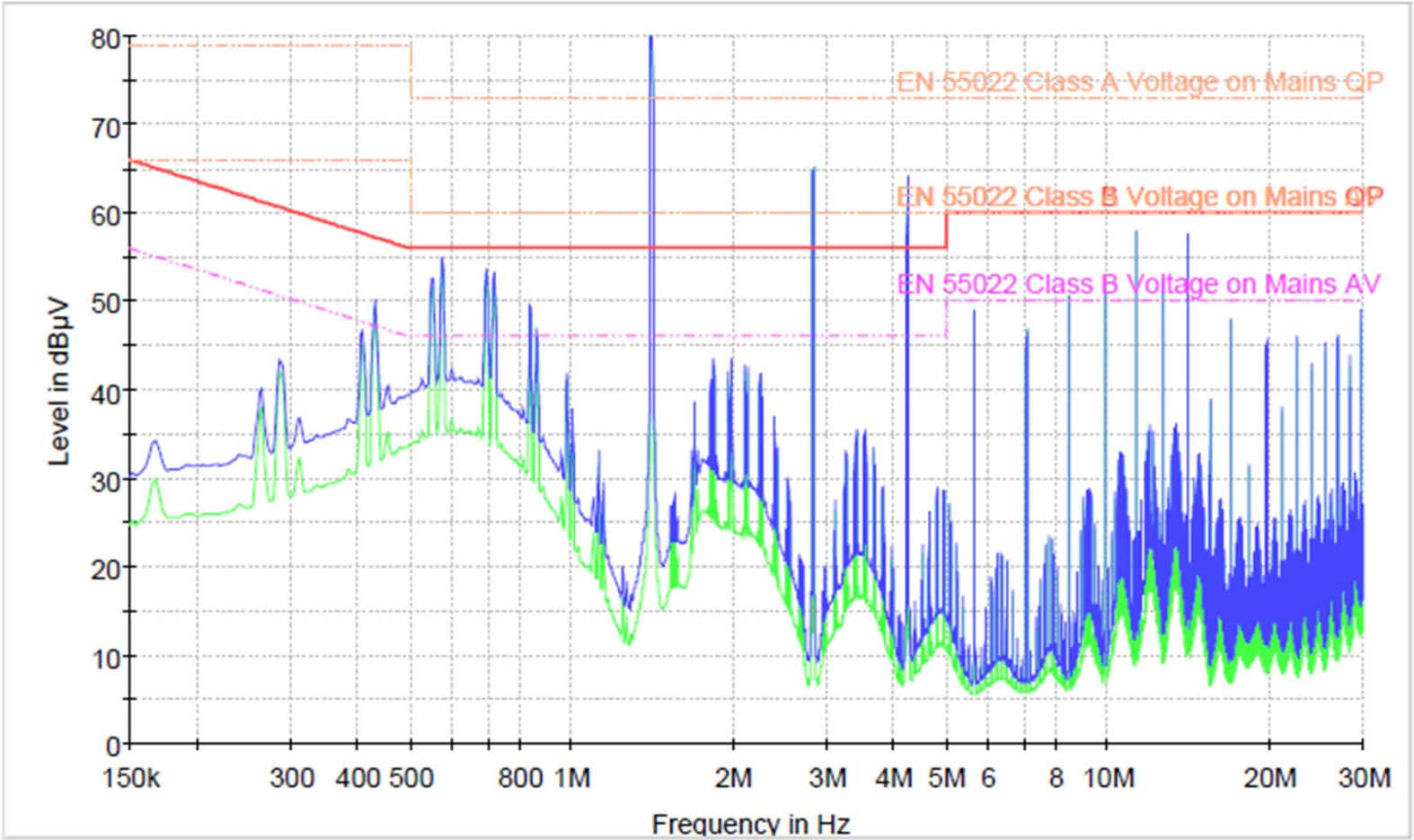
process of testing special specifications of DUT

Parallel Usage Test
Application Ciruit Test
Inrush Current
Overload Capability
Packaging
Isolation Test

EMC issues

faster switching, higher frequencies

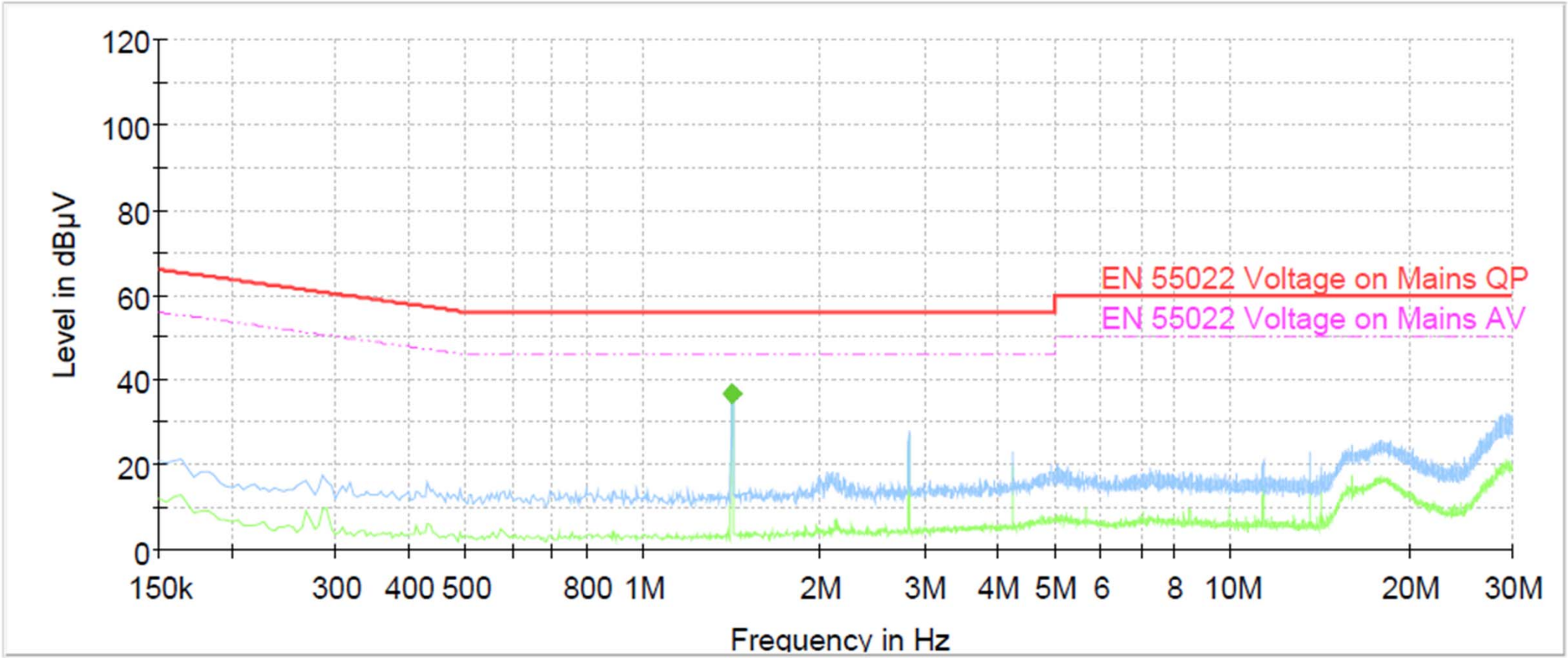
CE - no filter



EMC issues

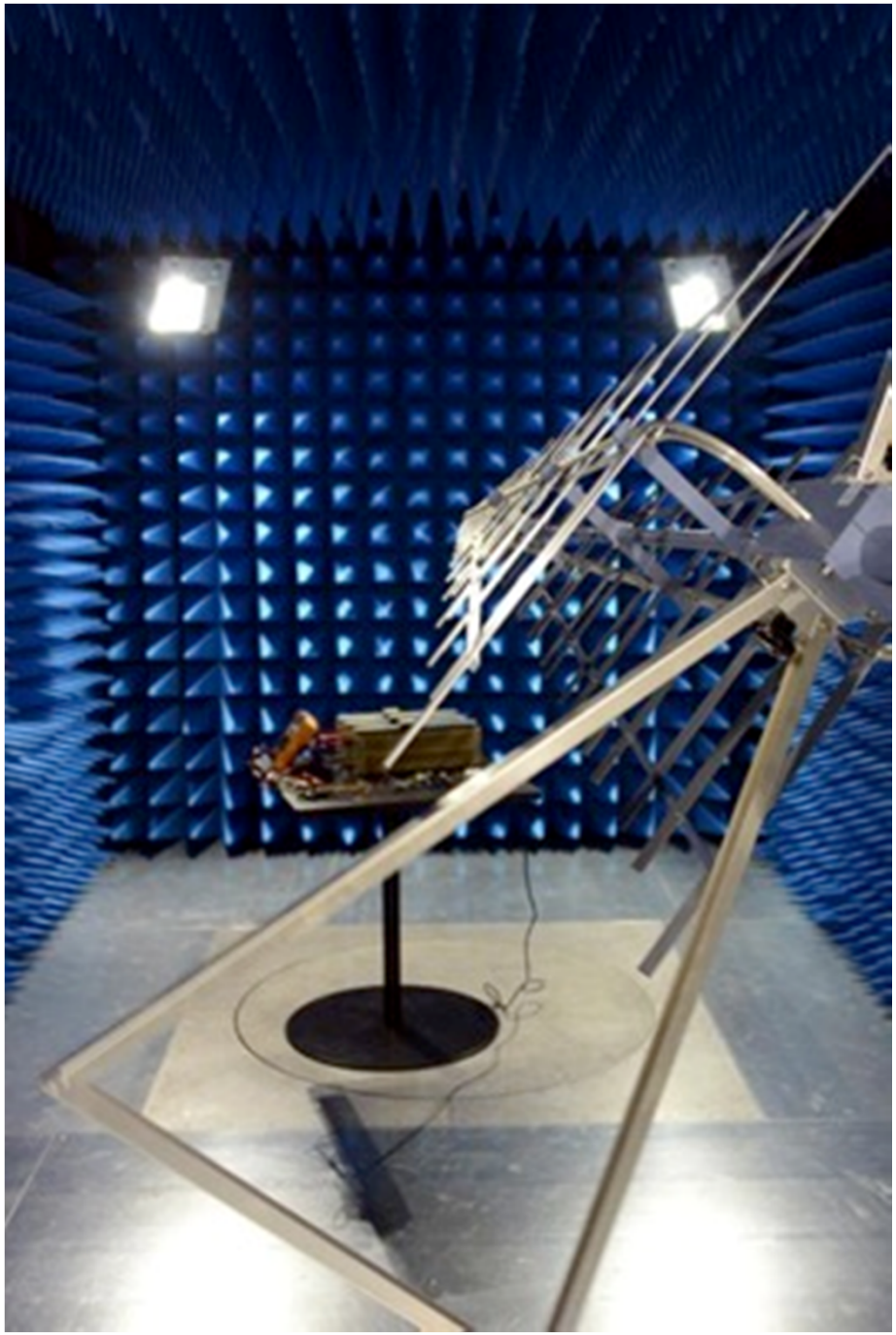
faster switching, higher frequencies

CE – with filter



EMC issues

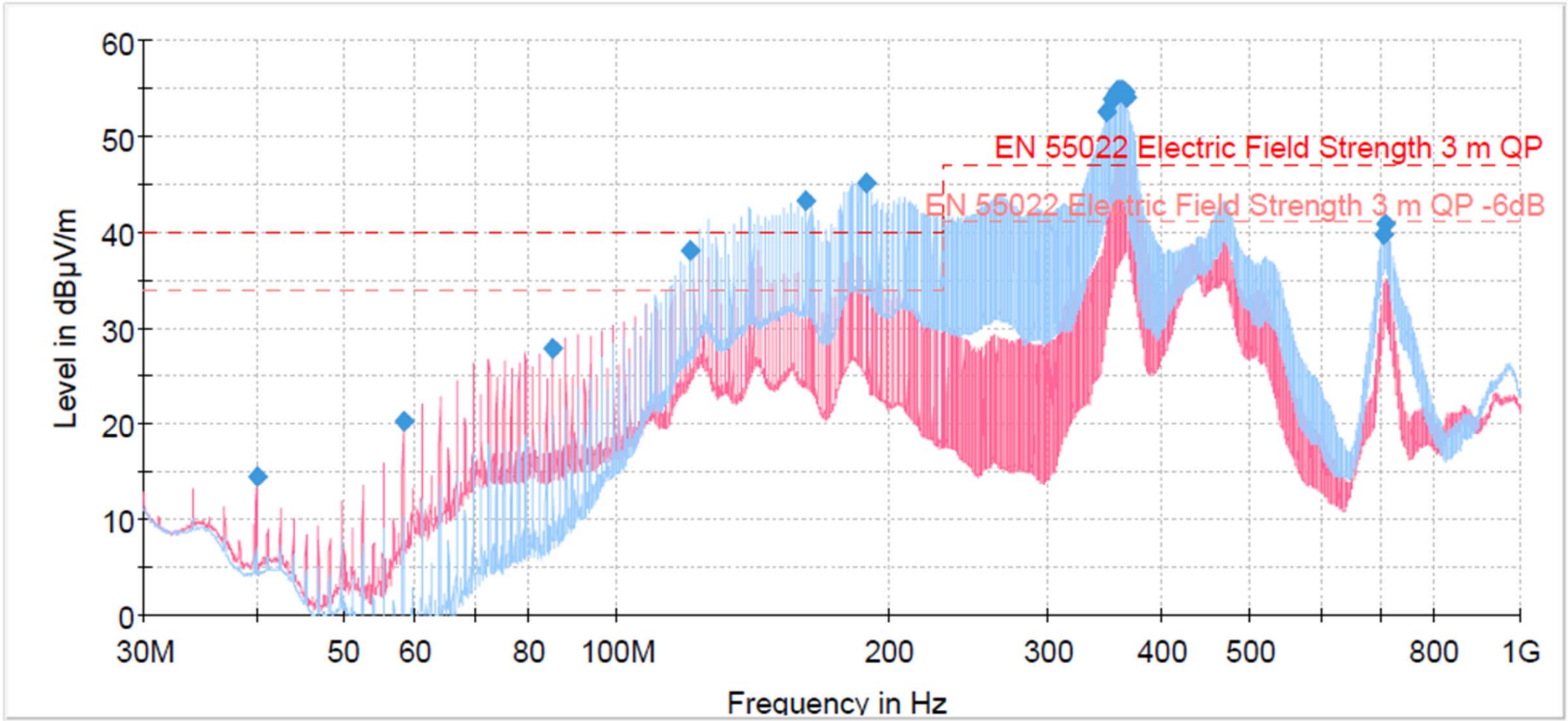
EMC chamber



EMC issues

faster switching, higher frequencies

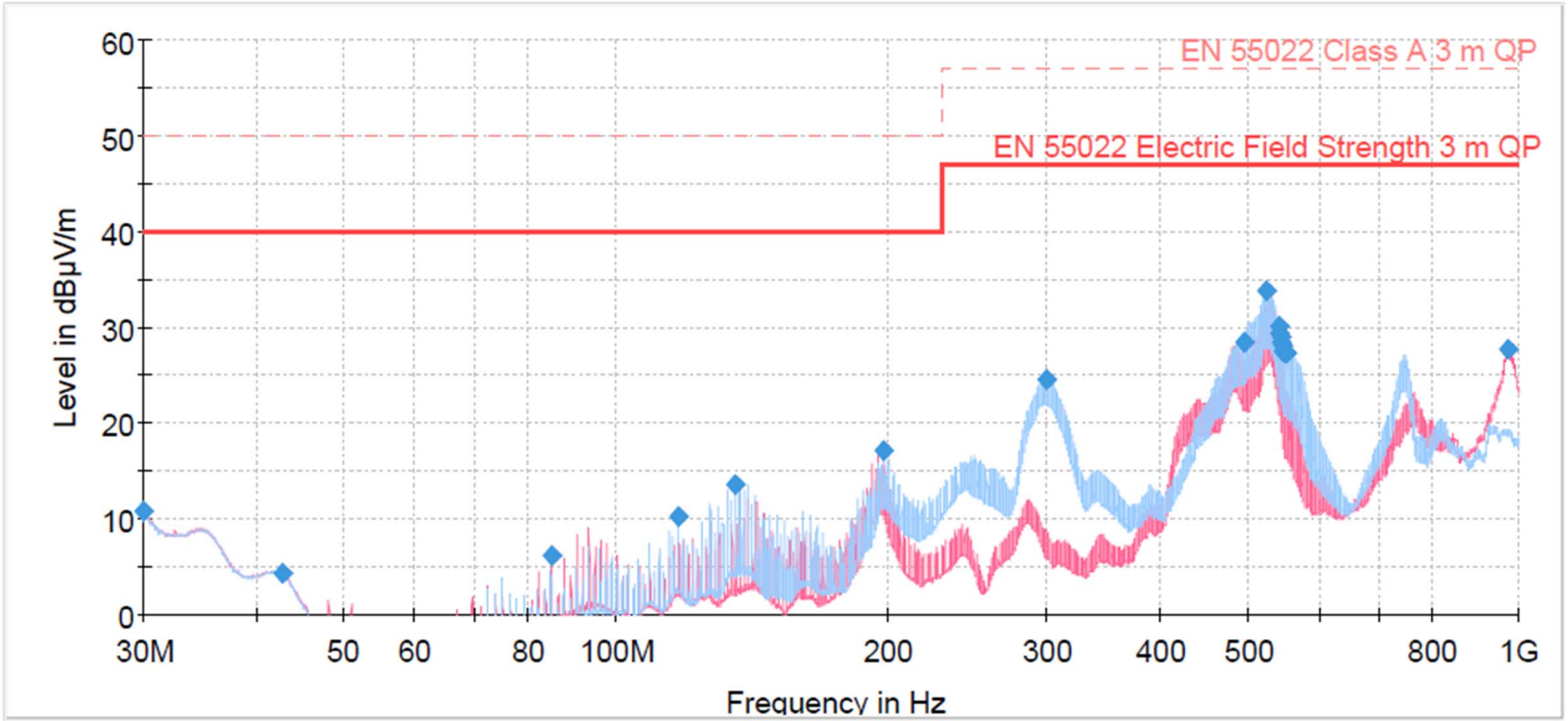
RE – no filter



EMC issues

faster switching, higher frequencies

RE – with filter



Testing GaN - general considerations

- There always be failures (do not underestimate the user!)

- What tests make sense for your device? To meet the application.
- What tests to select for qualification? To cover known failures and not to fail in the field completely.

- Testing cannot cover all possible stresses or their combinations.
- Higher the acceleration/stress, better. But it doesn't ensure failure detection.

Testing GaN - parts specific

- No long term experience with GaN, different failure modes than silicon.
- JEDEC and IEC standards are based on silicon. Does not cover GaN failure modes. Experience is needed (research and field).

- Some tests have to be modified due to a different nature of GaN (lateral device – gate bias).
- New tests have to be introduced (Frequency test – high frequency @max temp, voltage, current) – must be more severe then in the application

- What about application (power supply) testing? – more tests, more conservative design limits, aging, field failures …

Testing GaN *Example – EPC Reliability Reports*

These tests are being used:

- High temperature reverse bias (HTRB)

  the drain-source voltage at maximum rated temperature

- High temperature gate bias (HTGB)

  gate-source voltage at the maximum rated temperature

- High temperature storage (HTS)

  heat at the maximum rated temperature

- Temperature cycling (TC)

  alternating high- and low temperature extremes

- High temperature high humidity reverse bias (H3TRB)

  humidity under high temperature with a drain-source voltage applied

Testing GaN *Example – EPC Reliability Reports*

These tests are being used:

- Unbiased autoclave (AC or Pressure Cooker Test)

  pressure, humidity, and temperature under condensing conditions

- Moisture sensitivity level (MSL)

  moisture, temperature, and three cycles of reflow

- Electrostatic discharge (ESD)

  ESD under human body, machine, and charged device models

- Intermittent operating life (IOL)

  on/off cyclic DC power pulse which heats the device junction to a predefined temperature, and subsequently to an off state junction temperature (self heated temperature cycling)

Testing GaN *Example – EPC Reliability Reports*

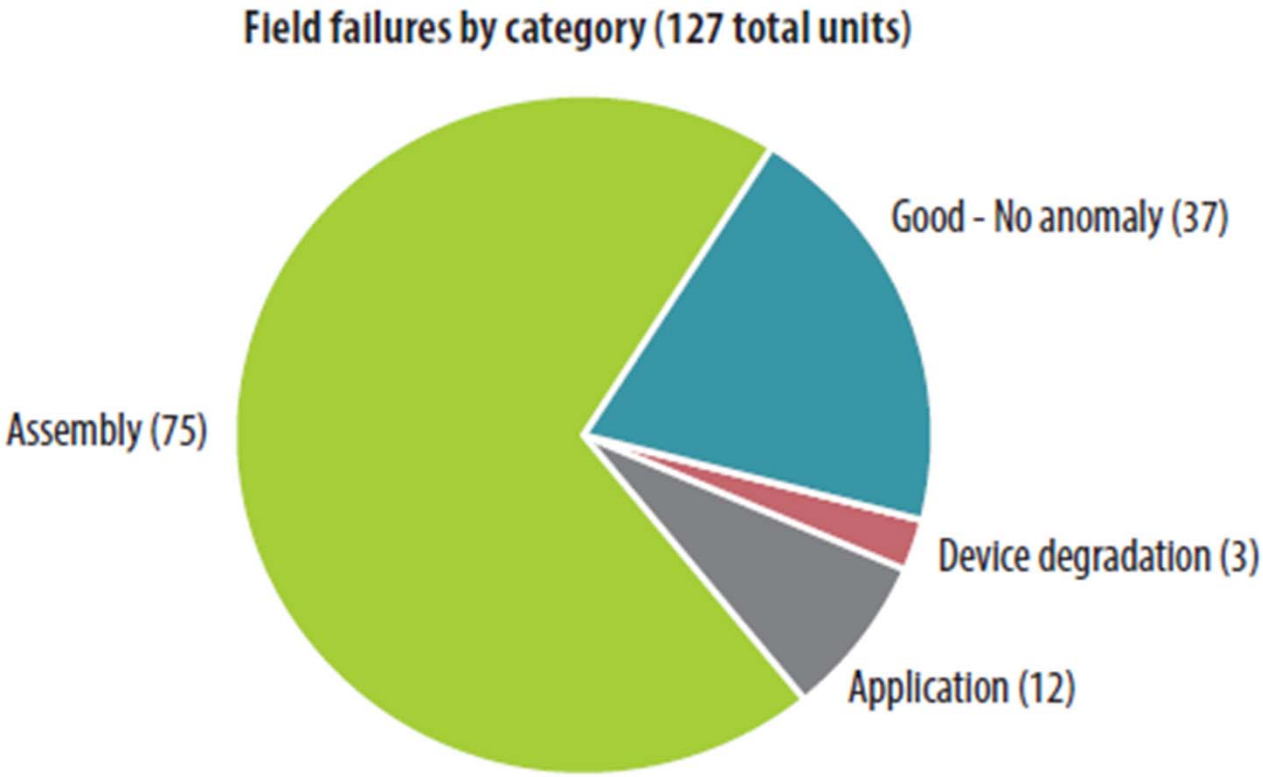
Intermittent operating life (IOL) - example

Stress Test	Part Number	Max V_{DS} (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)	Format
IOL	EPC2206	80	XL (6.05 x 2.3)	$\Delta Tj = 125°C; t_{ON} / t_{OFF} = 1\ min / 5\ min$	0	32 x 1	5000	PCB (Arlon 85NT)
IOL	EPC2202	80	M (2.11 x 1.63)	$\Delta Tj = 125°C; t_{ON} / t_{OFF} = 1\ min / 5\ min$	0	77 x 2	5000	PCB (Arlon 85NT)
IOL	EPC2203	80	S (0.95 x 0.95)	$\Delta Tj = 125°C; t_{ON} / t_{OFF} = 1\ min / 5\ min$	0	77 x 1	7500	PCB (Arlon 85NT)

Table 10. Intermittent Operating Life Tests (IOL)

Source: EPC Reliability Report Phase 10 (2019)

Testing GaN *Example – EPC Reliability Reports*



Source: EPC Reliability Report Phase 8 (2016)

GaNonCMOS efforts ***Overview***

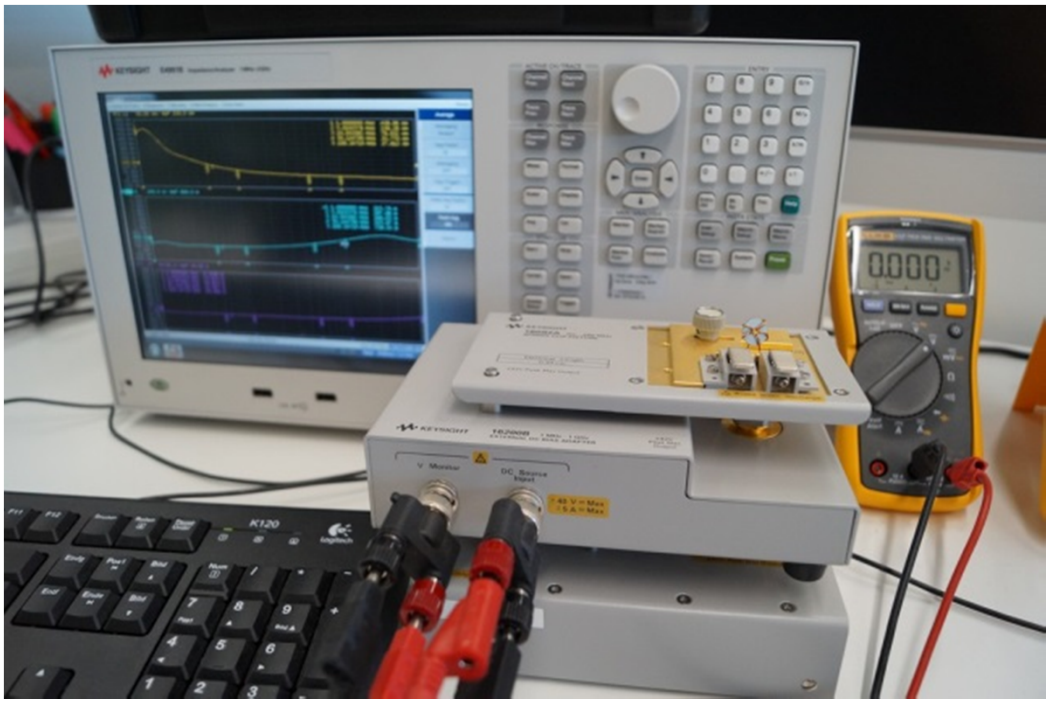
- Characterization of passive parts
  - Magnetic sheet material (with AT&S)
  - Embedded inductors (with AT&S)

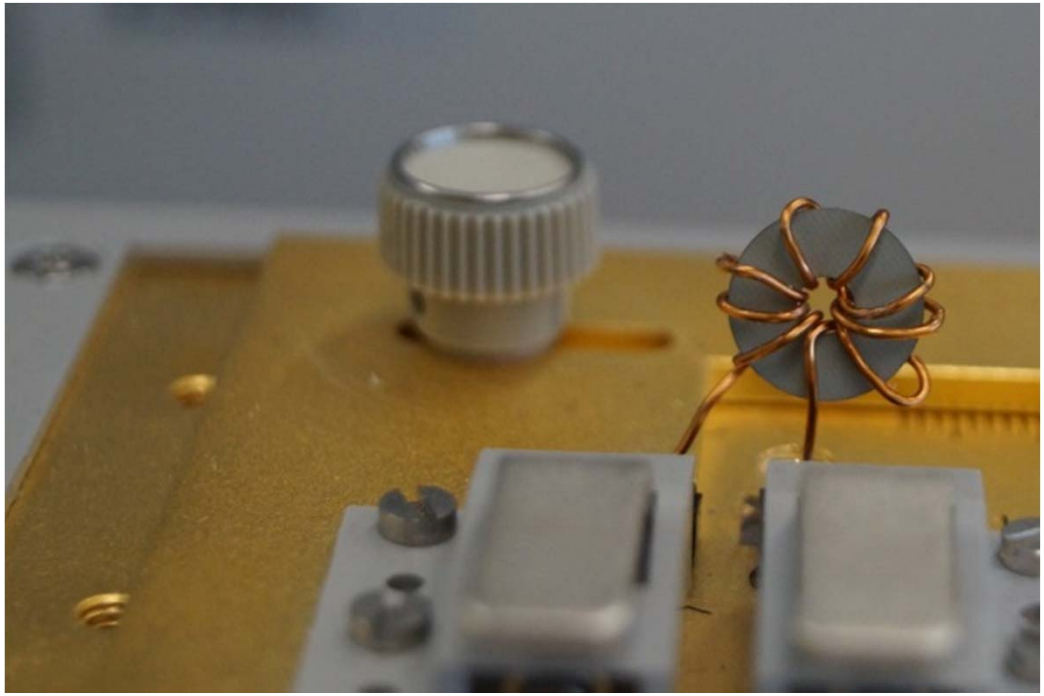
- Testing of the demonstrators
  - Test setup improvements
  - Test results

- Market segments/demonstrator definitions
  - High level demonstrator specification (IBM, Tyndall)
  - Market analysis (with PNO)

Characterization of passives

Measuring inductance of the magnetic sheet ring cores (1MHz up to 500MHz)

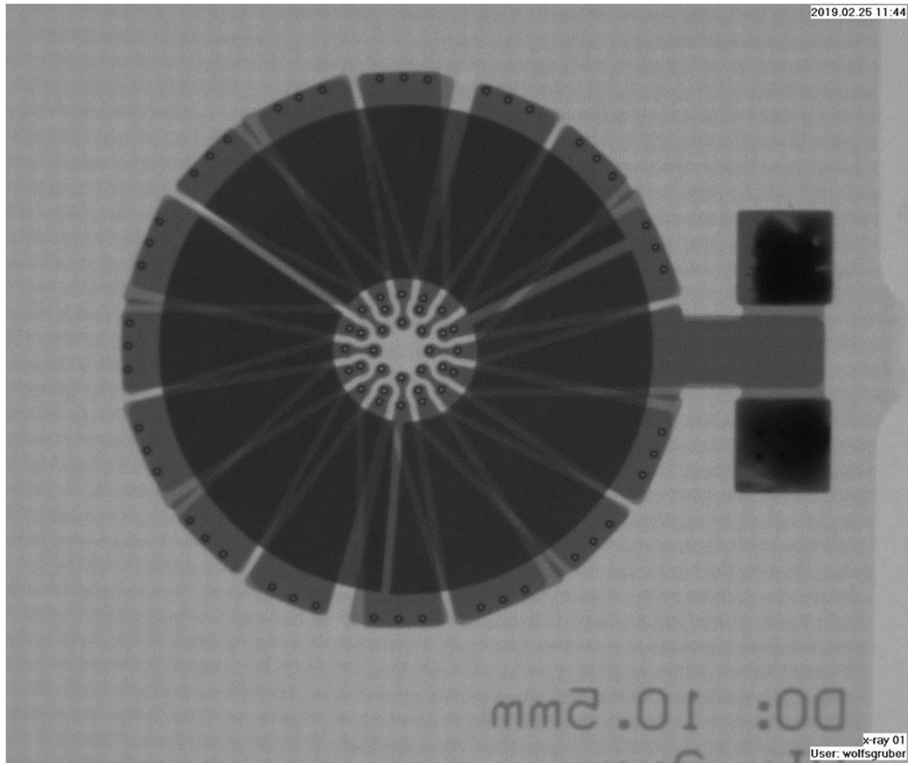


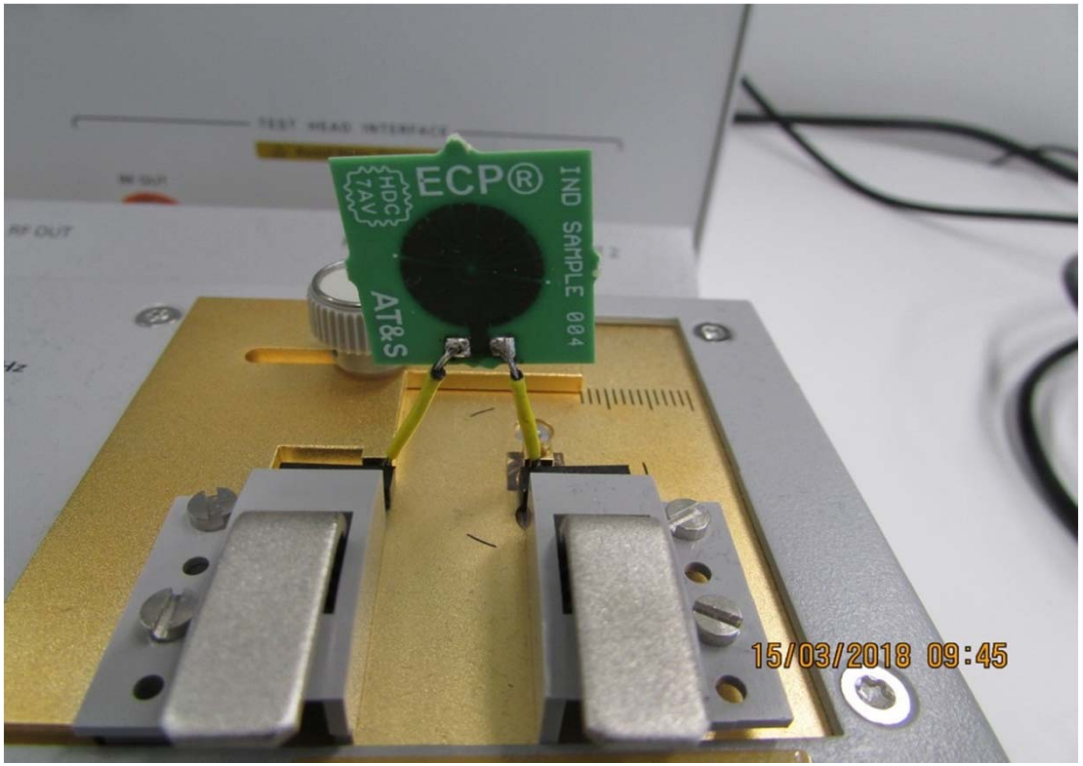


Characterization of passives

Measuring inductance of the embedded inductors (PCB inductors)

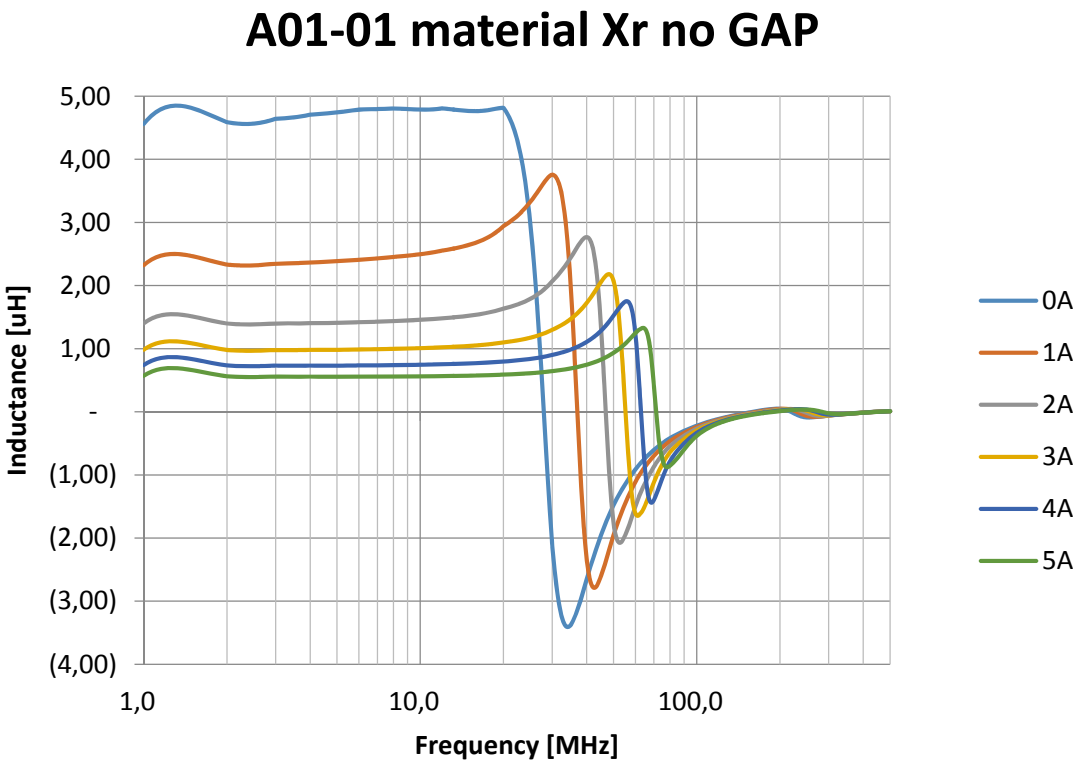
- Samples with different materials and construction (1GAP, 3GAP)
- outer/inner diameter of magnetic 10.5mm/3mm, 500µm thickness of the core and number of turns is 16

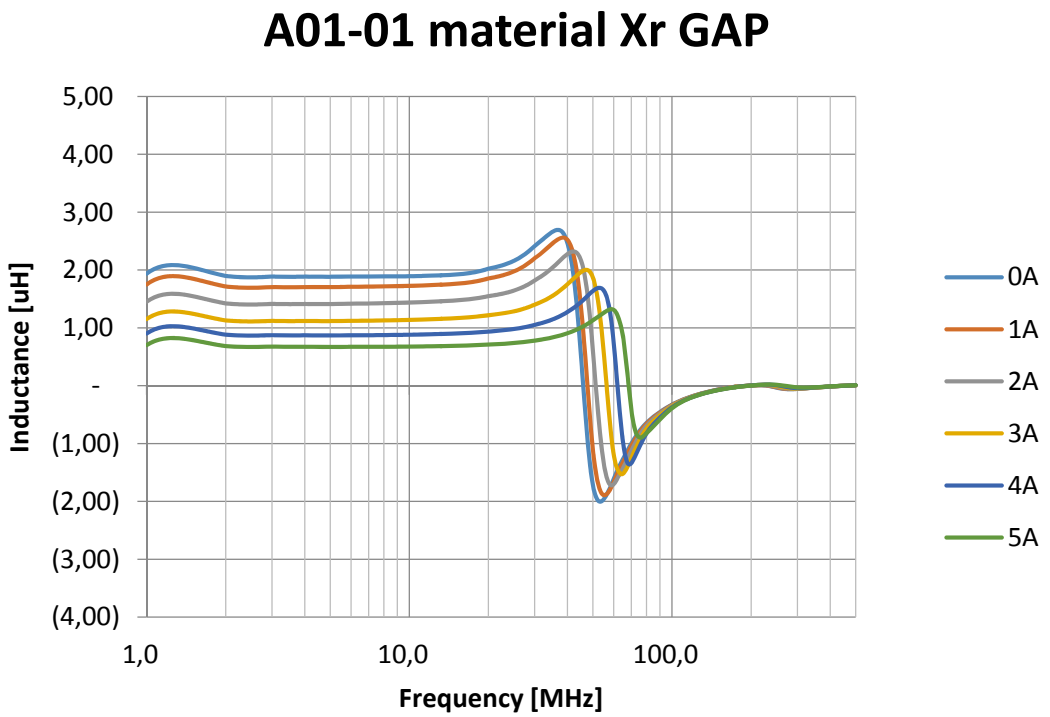




Characterization of passives

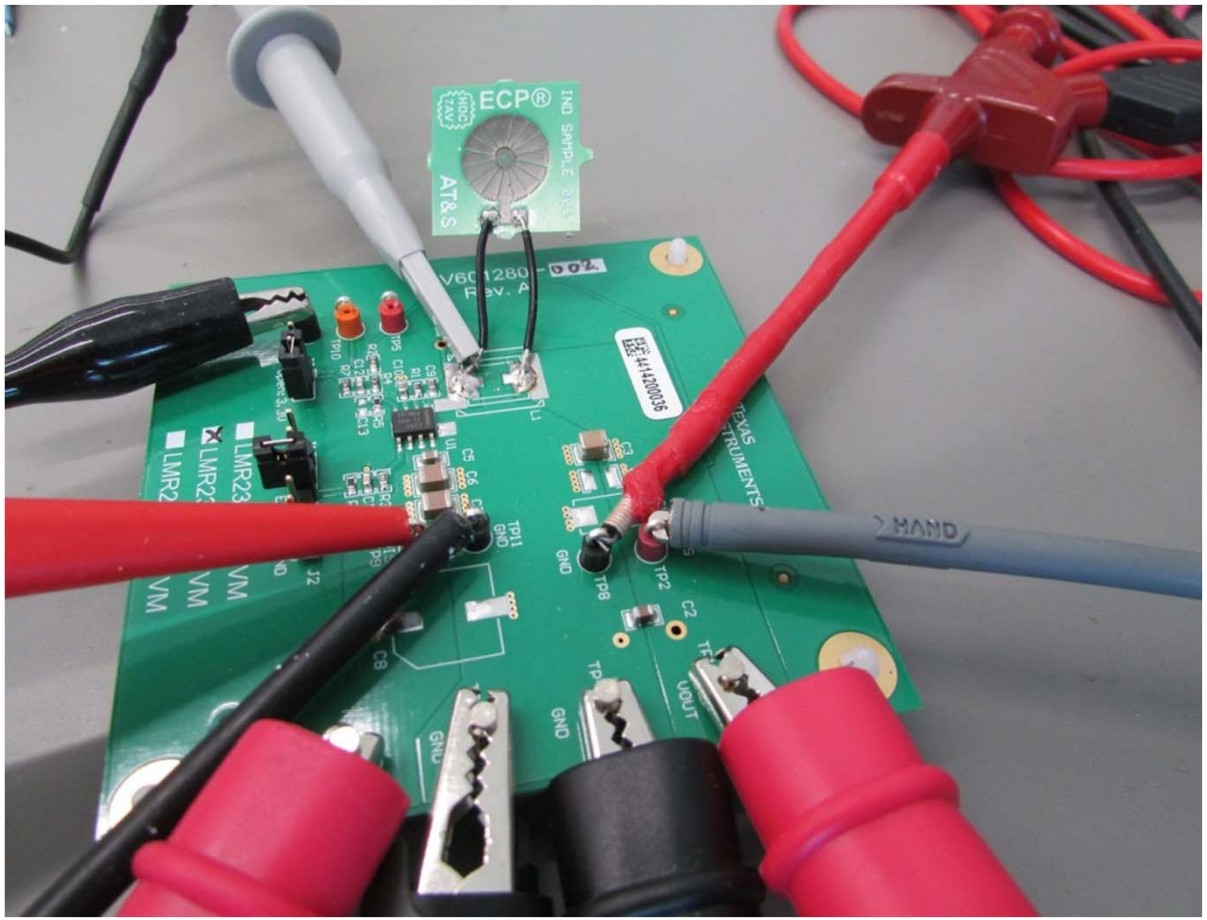
Measuring inductance of the embedded inductors (PCB inductors)





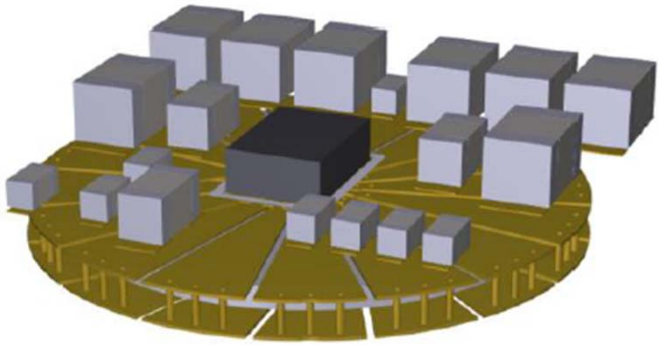
Characterization of passives

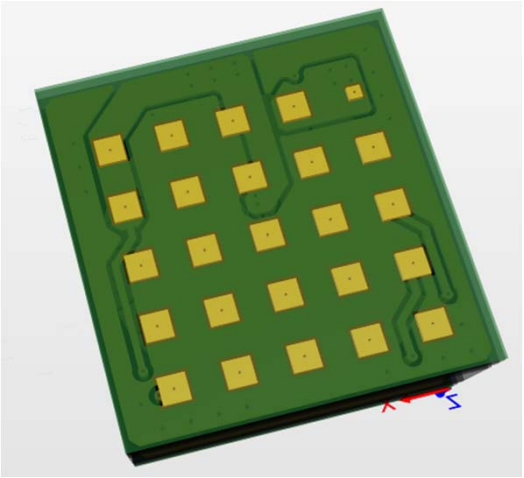
embedded inductor in a buck converter

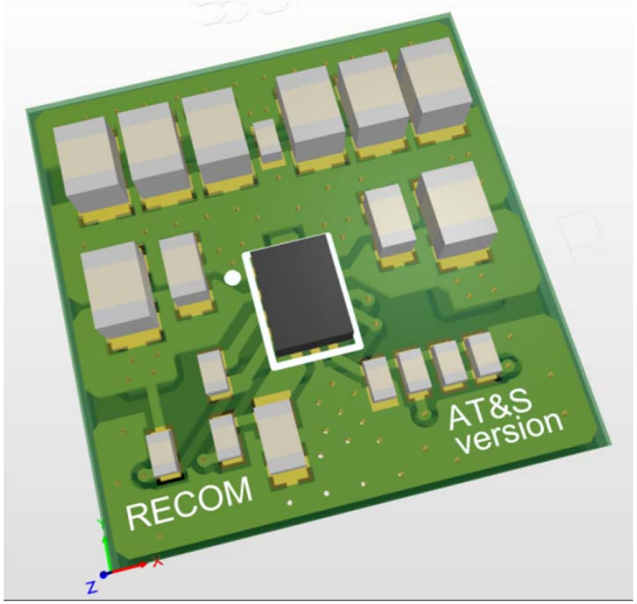


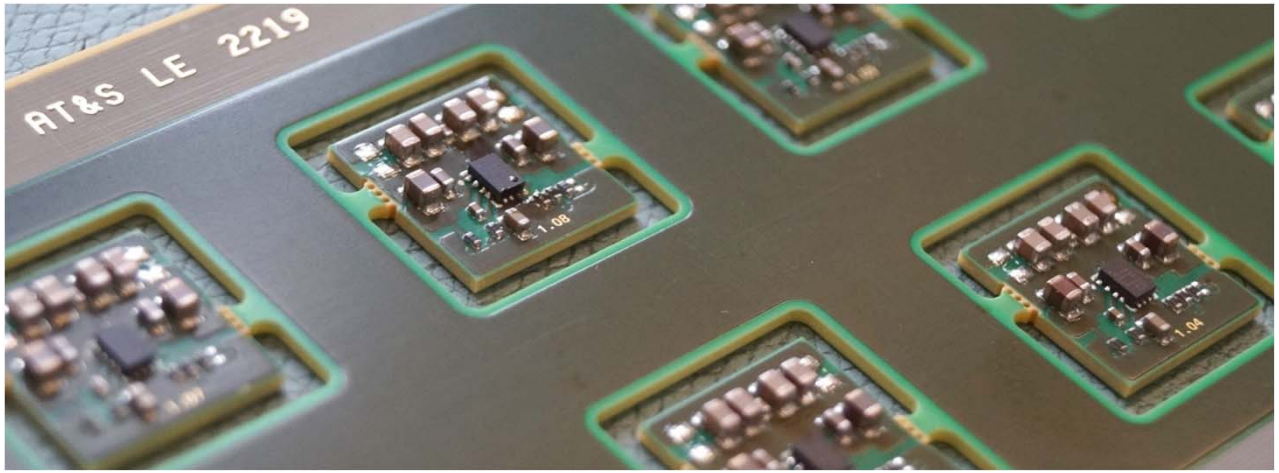
Characterization of passives

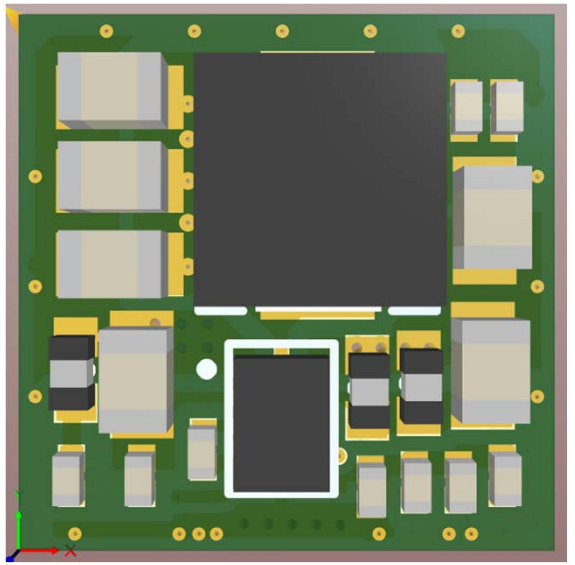
Measuring inductance of the embedded inductors in PCB DEMO 6









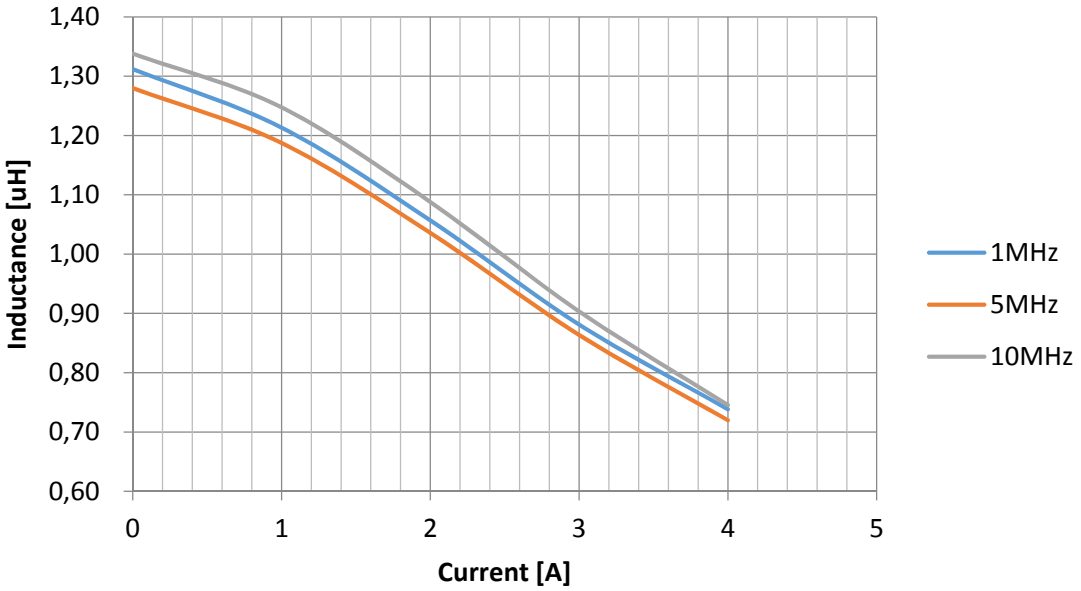


Characterization of passives

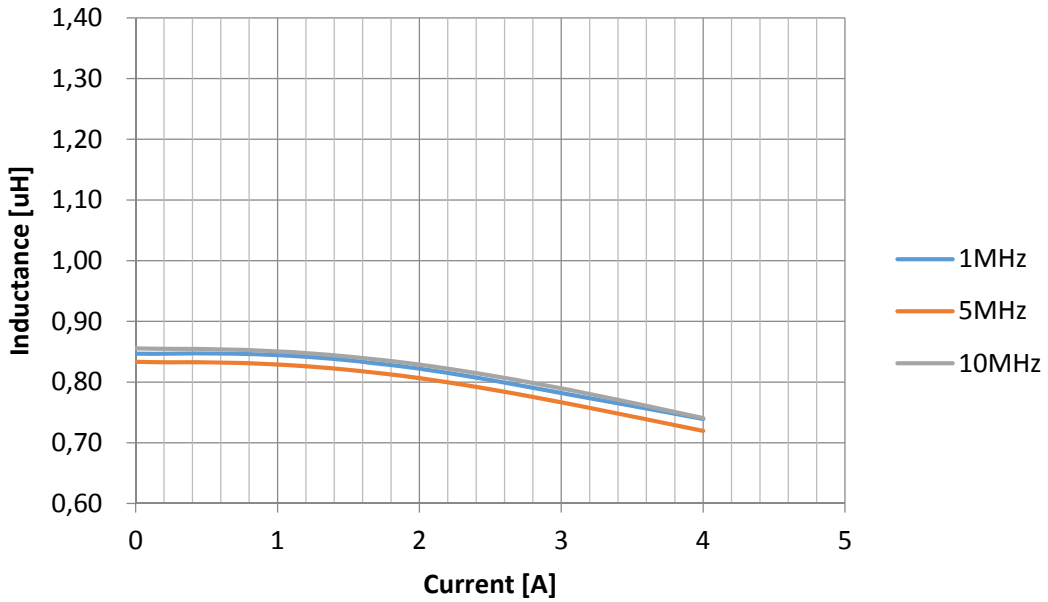
PCB DEMO 6 versions

- *Four different IC versions of the same family were used: switching frequency 1.4MHz or 2.1MHz and current limit 2A or 3A.*
- *Two different output voltage settings: 3.3V and 5V*
- *Embedded magnetic material with 1GAP or 3 GAP*

wire compensated ARRAY02_1.01 1 GAP



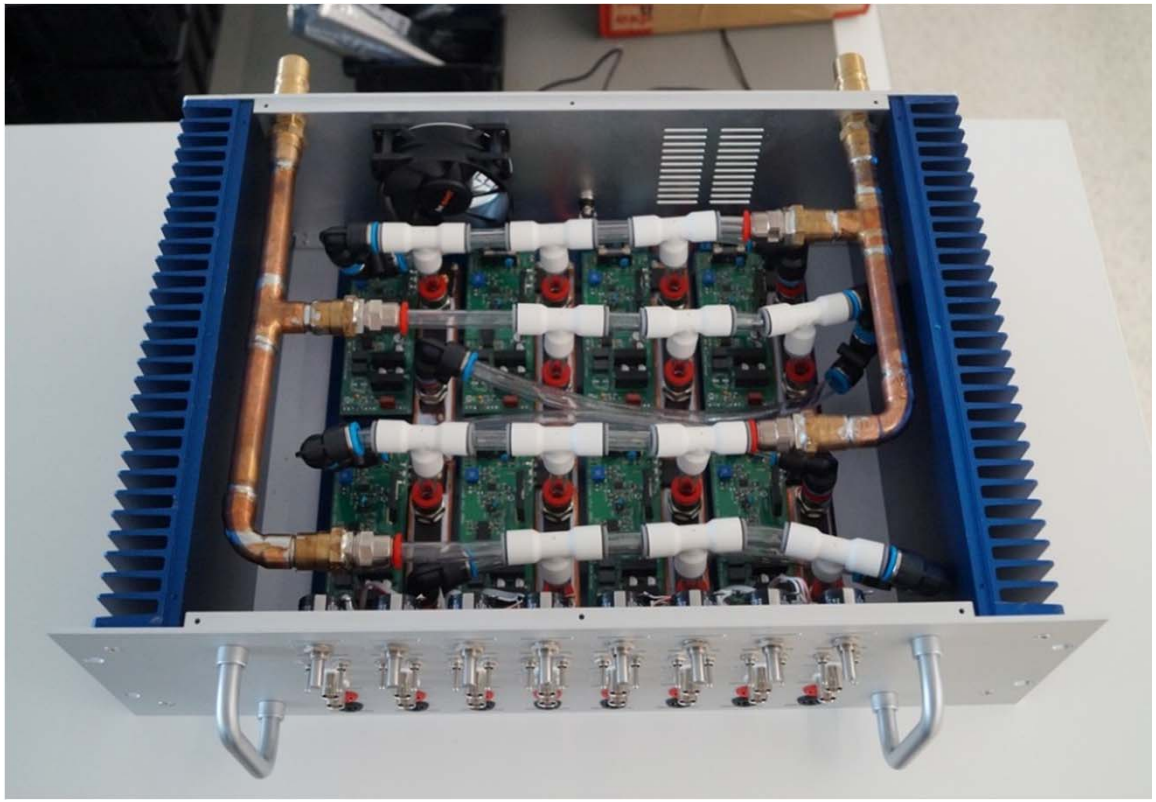
wire compensated ARRAY04_2.01 3 GAP



GaNonCMOS efforts ***Test setup***

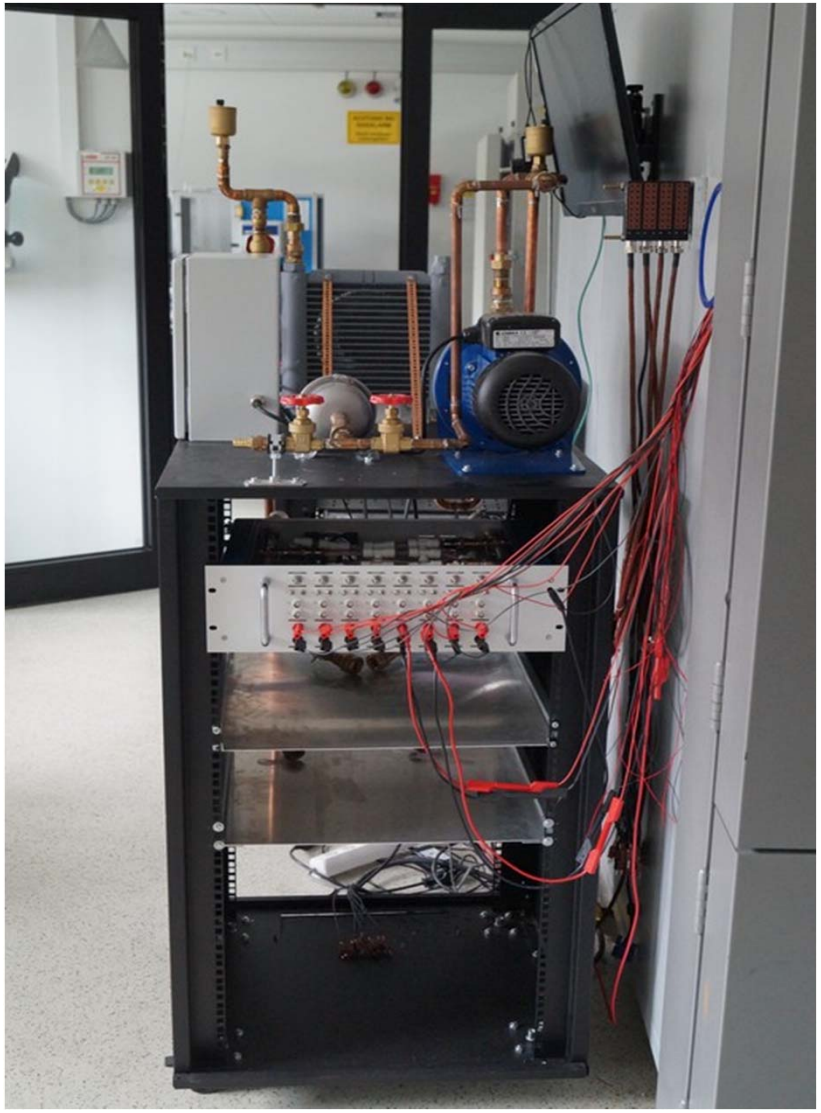
Self developed equipment

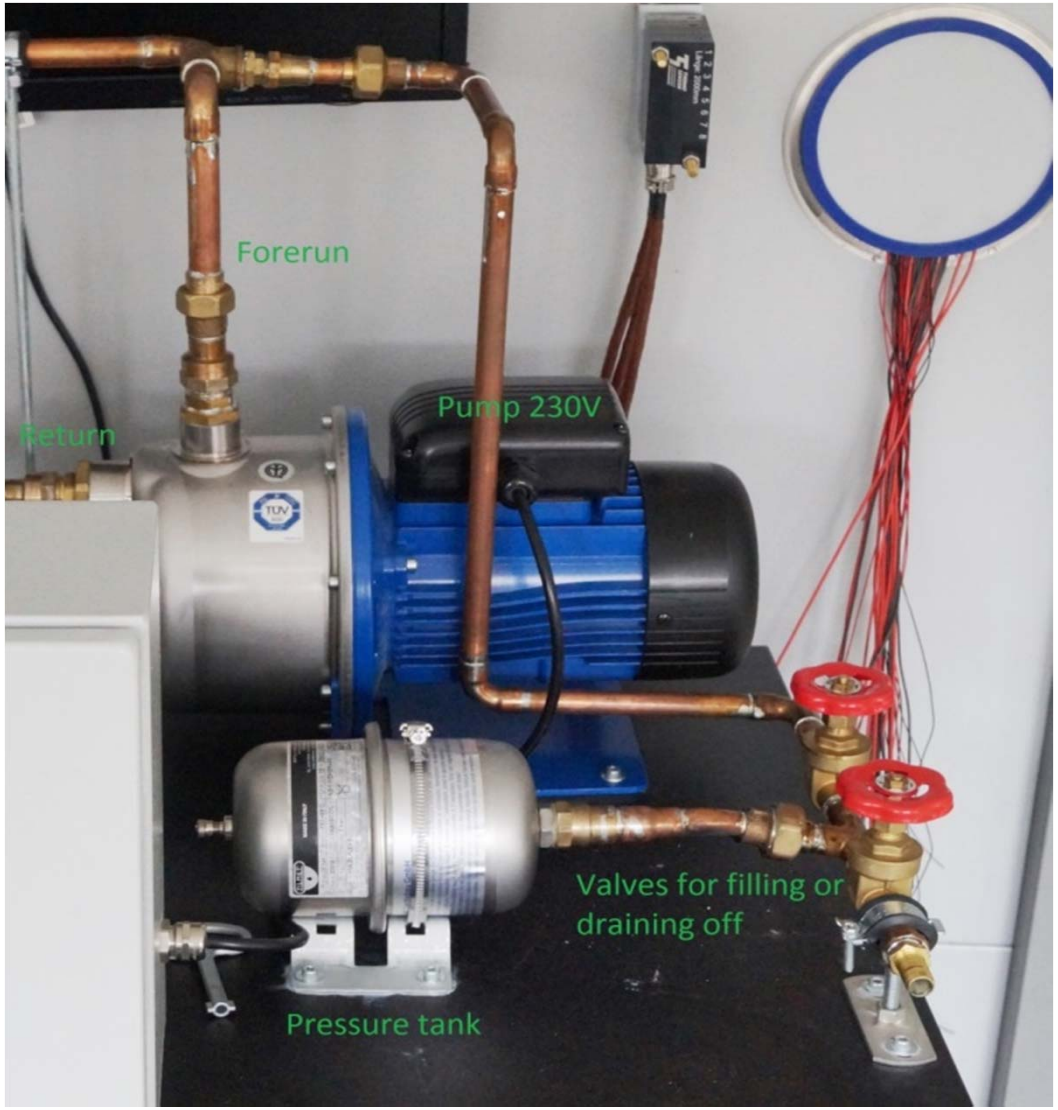
- measuring 32 DC/DC power supplies at one time
- contains 32 water cooled e-loads installed in four 19”-devices
- each e-load is capable of 10A
- water-cooler is connected via a thermal pad to the cooper-cooler



Test setup

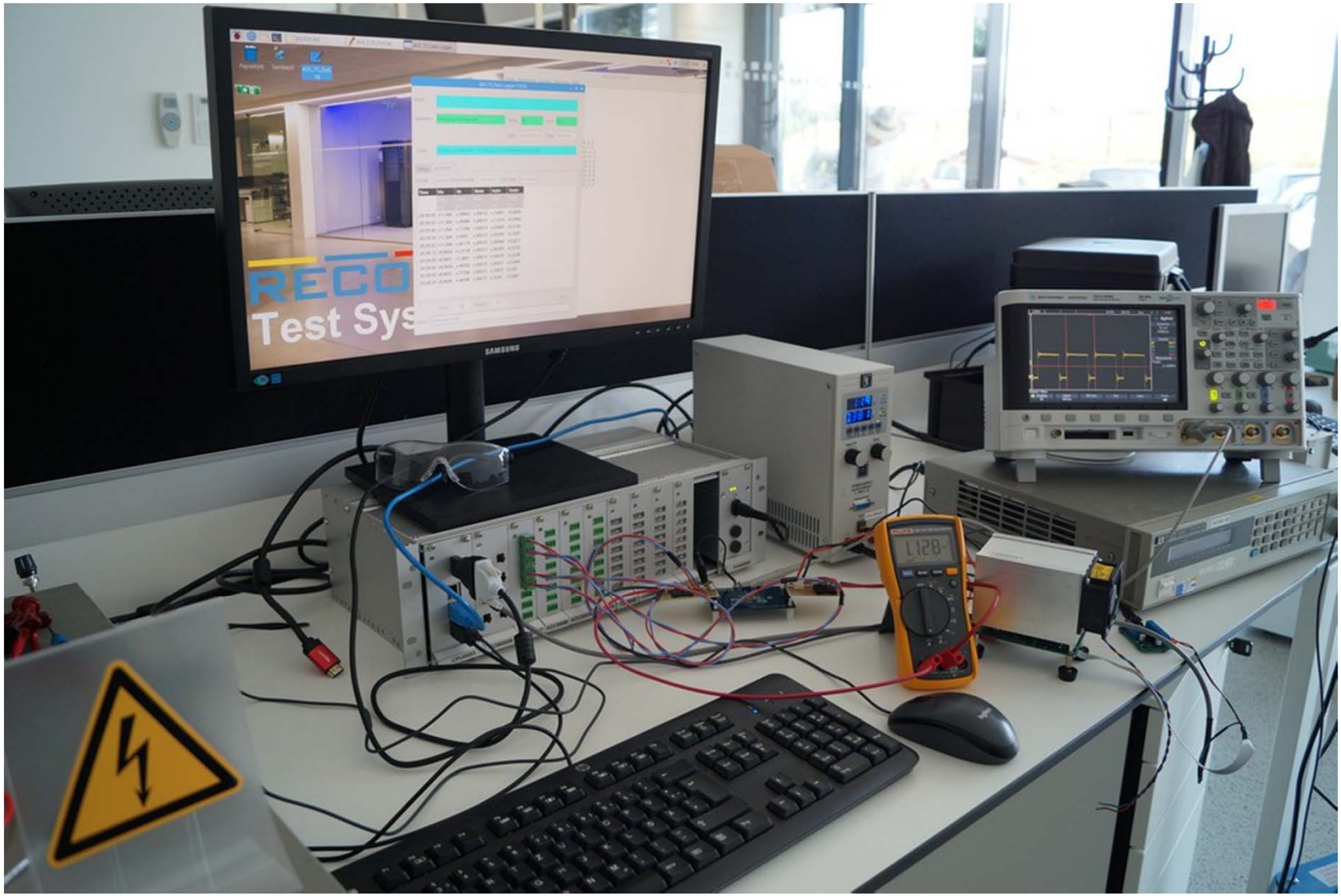
Self developed equipment





Test setup

Test setup with one PCB DEMO 6

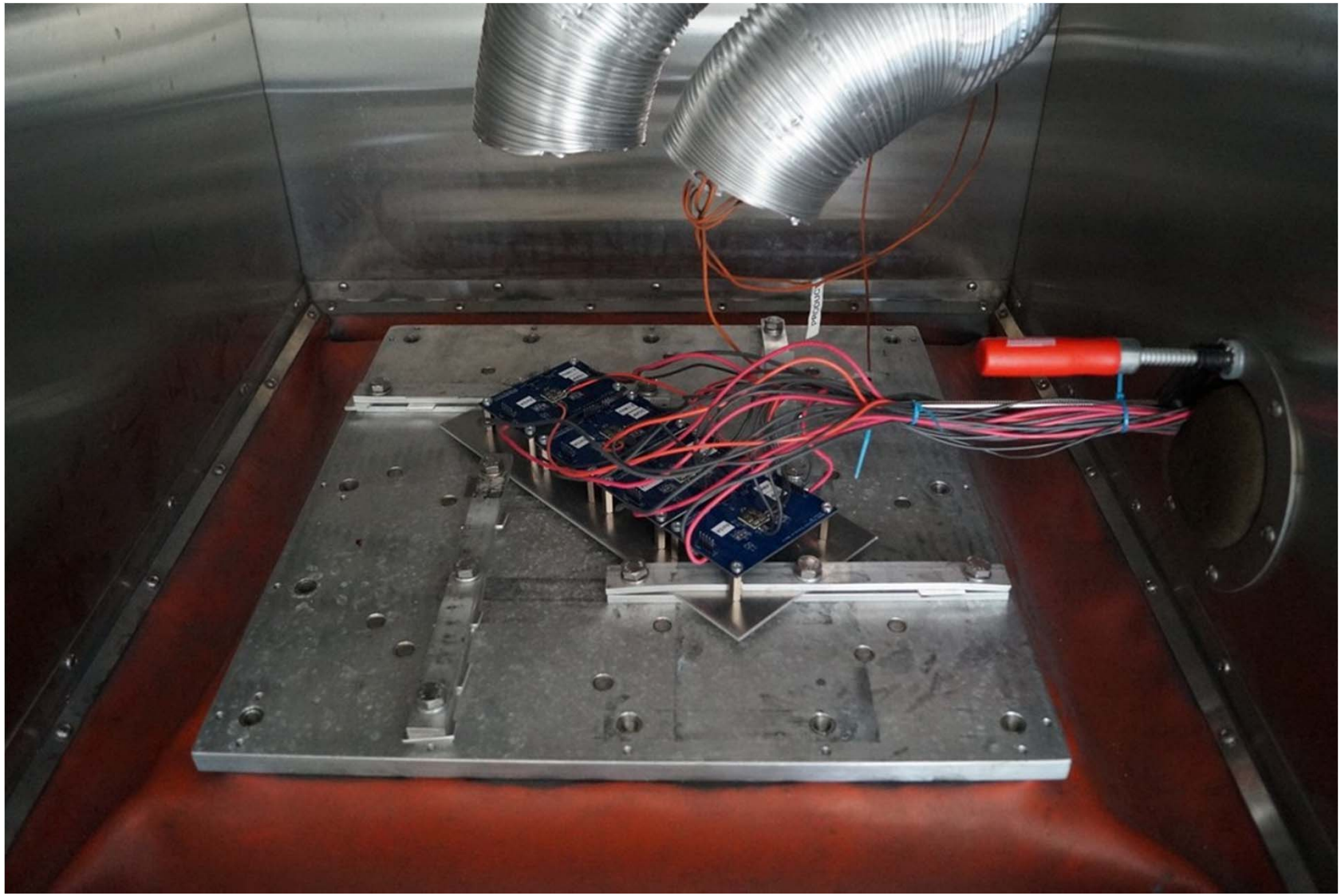


GaNonCMOS efforts Test setup

HALT test setup with four PCB DEMO 6

GaNonCMOS efforts Test setup

HALT test setup with four PCB DEMO 6



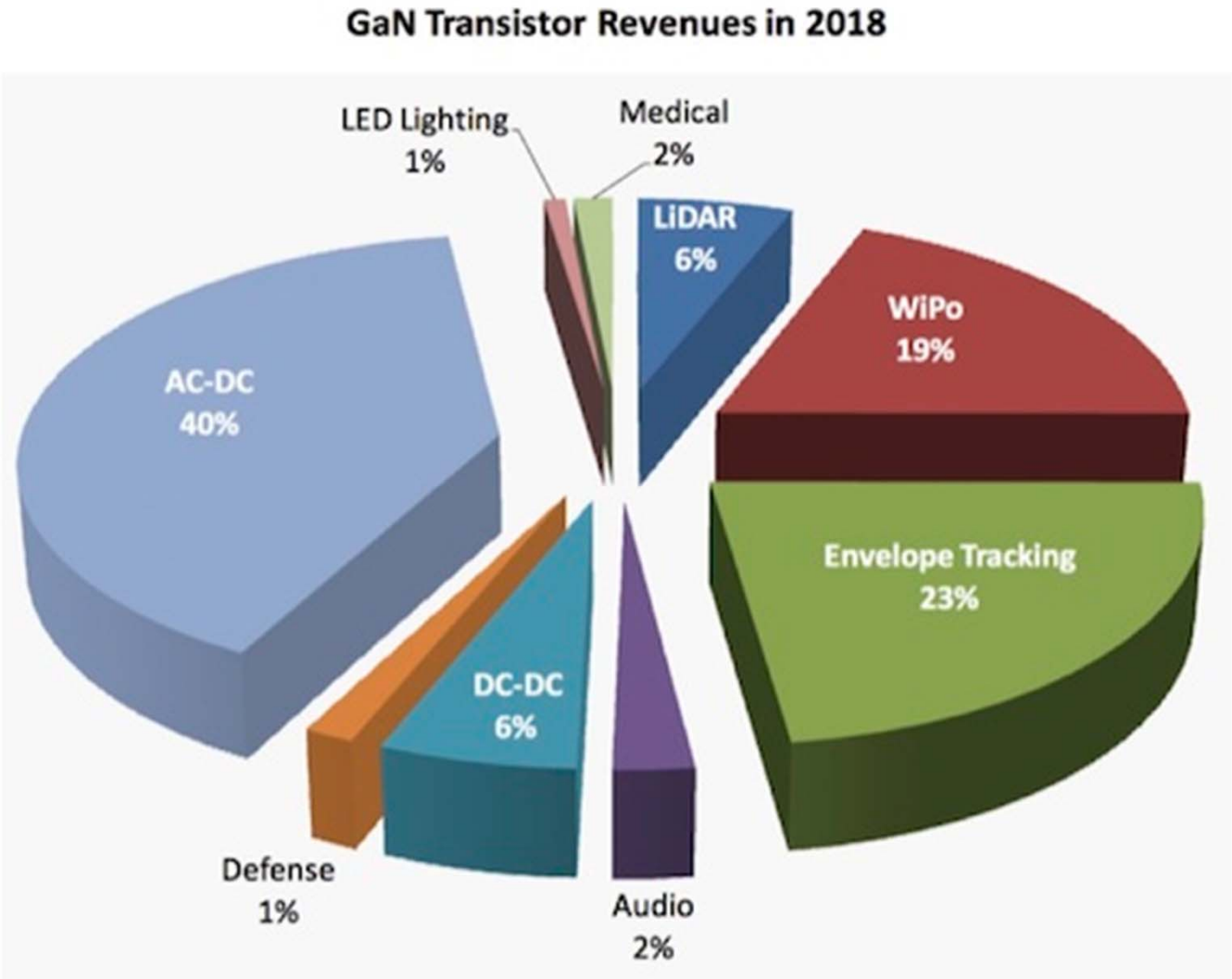
Market analysis

GaN currently on the market

Vendor	GaN Switch Category		
	<= 100V	100V<600V	>= 600V
EPC	x	x	
GaN Systems	x		x
Transphorm/Fujitsu			x
Infineon			x
Texas Instruments	x		x
Navitas			x
ExaGaN			x
Dialog			x
POWDEC			x
GanPower International			x
Freebird Semiconductor	x	x	
VisIC Technologies			x
Panasonic			x

Market analysis

Projected revenue by application in 2018 (Source: EPC)



General trend in the power supply industry

- Higher power density, 3D packaging – magnetics as the biggest component.
- Thermal management is the main issue – trade of between the size, switching frequency and acceptable power dissipation.
- GaN – proof of reliability, normally-off, high temp HF packages, drivers, magnetics, controllers

Industries

- Automotive – 48V battery systems ideal for 100V devices, AECQ required
- Aerospace – 28V/24V distribution bus, airworthiness non-critical applications such as various control units or entertainment systems
- Military/space – must be rad-hard, low volumes, custom designs
- Drones/UAV – maybe a good opportunity
- IT – data centers, 12V-to-POL, 48V-to-POL, high volume possible
- Industrial – higher power density modules, cost!

Questions