Towards package opening detection at power-up by monitoring thermal dissipation

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INTRODUCTION

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Observations:

- Package removal is ont considered a significant problem
- May be a legacy of smart-cards where the package is limited

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Countermeasures:

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Observations:

- Countermeasures focus on specific attacks
- Often, the attacks have already been carried out

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- Are temperature sensors exploitable to check IC package integrity?

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- Are temperature sensors exploitable to check IC package integrity?
- **Let us explore this with a common µcu**

THE DEVICE UNDER TEST

The device under test

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- Designed in a 90 nm bulk CMOS technology

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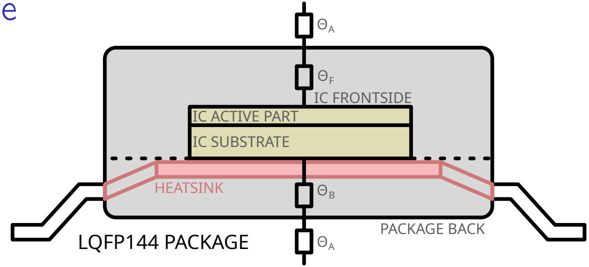
- Designed in a 90 nm bulk CMOS technology
- Embeds an ARM Cortex-M4 core and several cryptographic modules
- Embeds a temperature sensor: ± 1.5 °C between [-40 °C, 125 °C]
- Embeds calibration values to mitigate process variation: TS_CAL1, TS_CAL2:

$$T = \frac{80}{TS_{CAL1} - TS_{CAL2}} \cdot (TS - TS_{CAL1}) + 30 \quad ^{\circ}C \qquad (1)$$

The device package



Package characteristics:

- LQFP144

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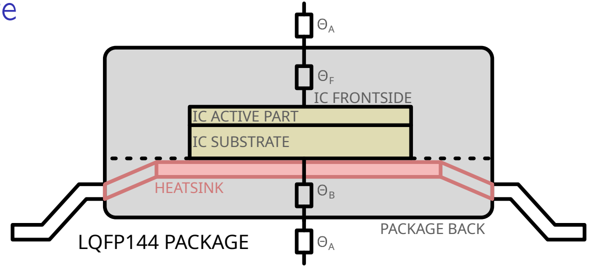

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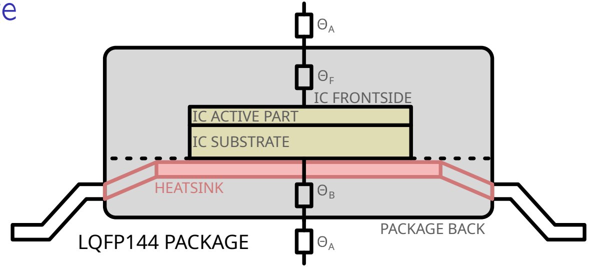

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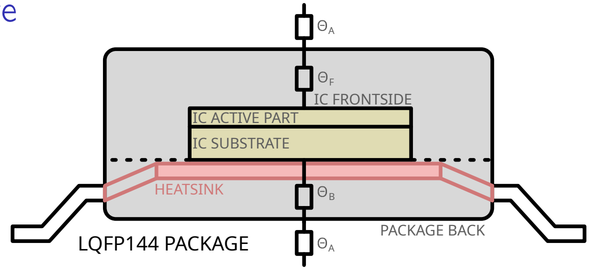

Package characteristics:

- LQFP144
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- Removing either frontside or backside changes θ_F or θ_B
- **What are the effects of the package on thermal dissipation?**

IC thermal behavior

First experiment

- Compare an intact IC with frontside and backside opened ones
- Periodic FLASH memory write operation and idle state (180 s each)

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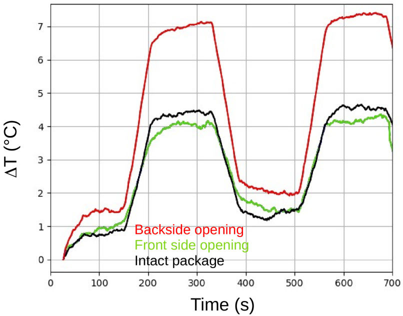

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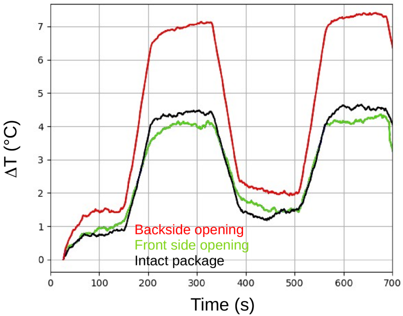
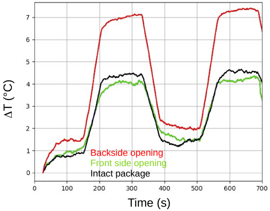


Conclusion:

Temperature changes:

- Are fast whatever the package
- Are limited with an intact or frontside opened IC
- Are faster and stronger with a backside opened IC

IC thermal behavior: power-up temperature transients



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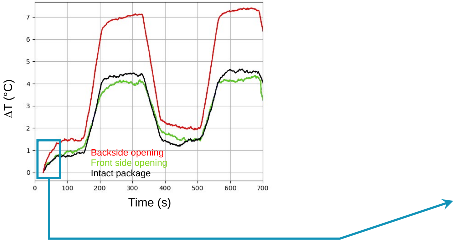

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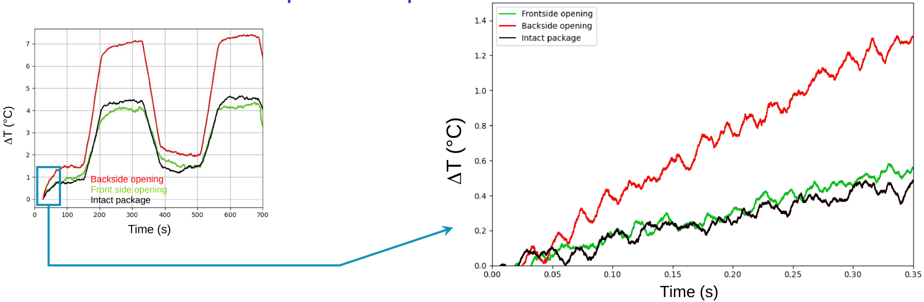

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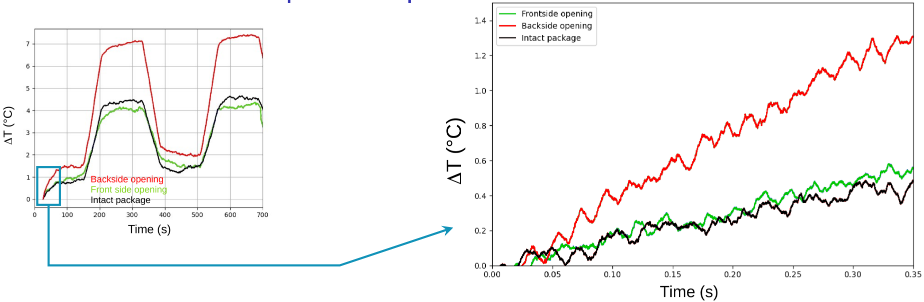

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- Higher slope for the backside opened IC

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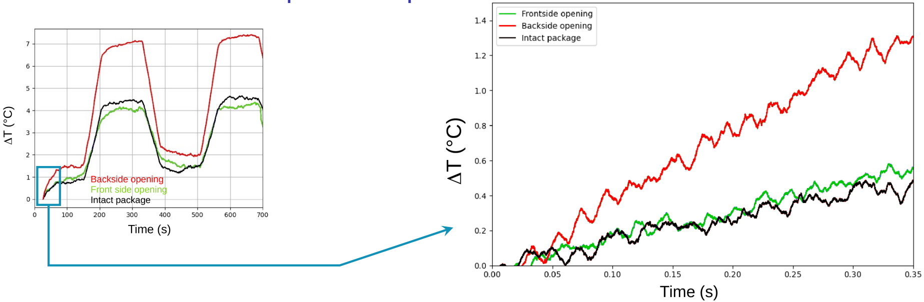

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Question?

Is it possible to check the backside package integrity by checking the value of β_1

PACKAGE REMOVAL EXPERIMENTAL RESULTS

β_1 measurements across 13 circuits

Package integrity verification process → 13 devices (all units in °C/s)

IC n°	$\bar{\beta_1}$	σ_{β_1}	$\bar{R^2}$	σ_{R^2}	Backside
25	0.931	0.229	0.011	0.005	Closed
3	1.405	0.145	0.060	0.015	Closed
12	1.819	0.204	0.180	0.085	Closed
6	2.183	0.191	0.080	0.012	Closed
2	2.503	0.322	0.174	0.146	Closed
26	2.970	0.160	0.057	0.006	Closed
1	3.433	0.159	0.093	0.08	Opened
9	3.965	0.167	0.336	0.021	Opened
10	4.341	0.193	0.144	0.100	Opened
7	4.567	0.137	0.278	0.023	Opened
8	4.843	0.222	0.232	0.086	Opened
4	6.351	0.149	0.437	0.078	Opened
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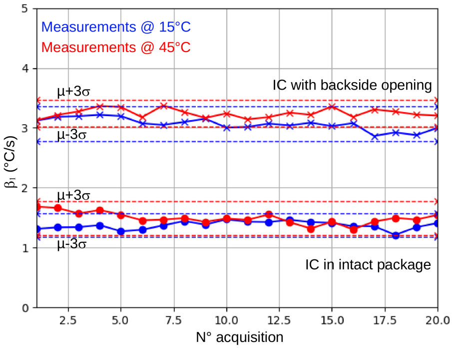
- σ_{β_1} ranges from 0.15 to 0.3 °C/s, with an average of 0.193 °C/s
- Is β_1 stable with room temperature and power supply voltage?

Experimental results at fixed temperatures



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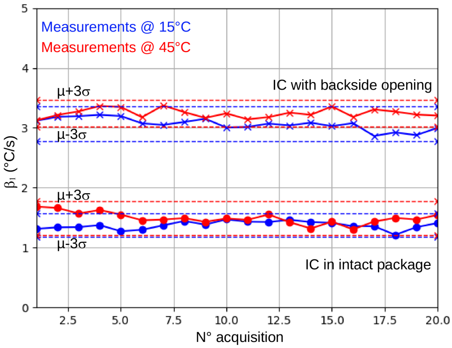

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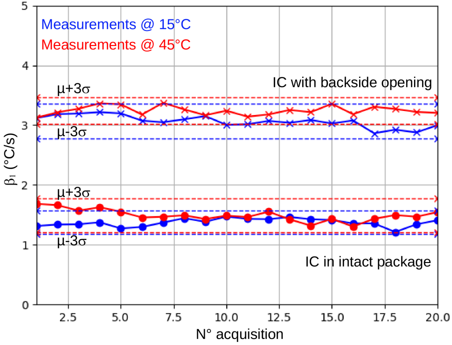

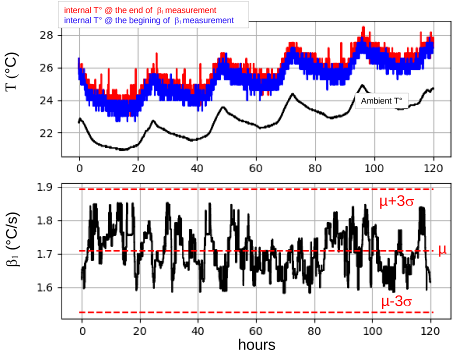

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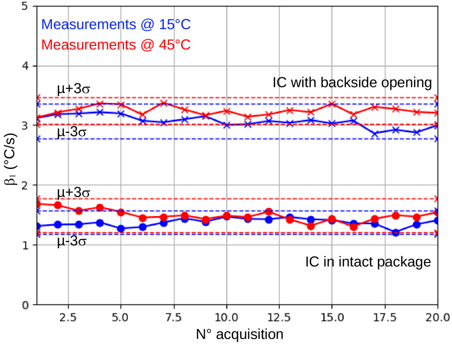

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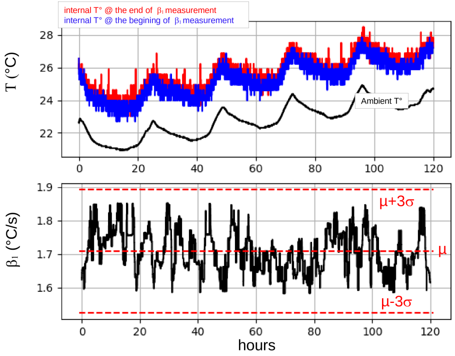
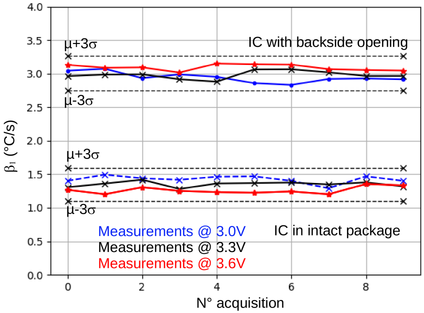


$$\rho_{T_{AMB},T_{IC}} = 96\ \%$$
$$\rho_{T_{AMB},\beta_1} = -22\ \%$$

Experimental results at different voltages



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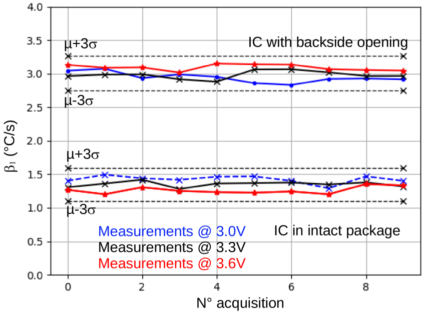

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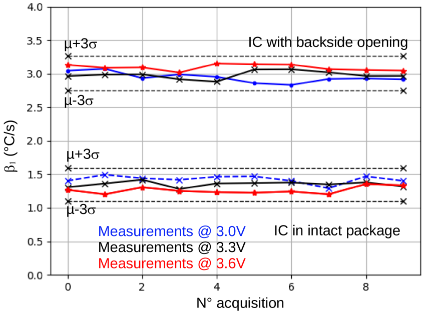

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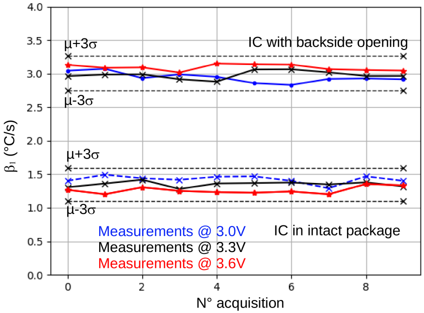

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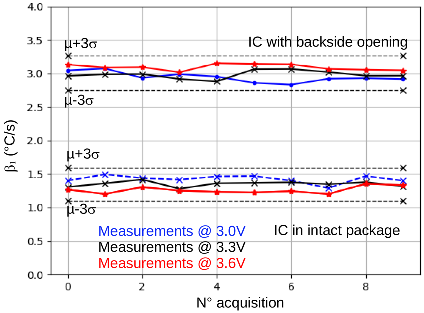

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Conclusion:

- β_1 seems temperature independent
- β_1 seems supply voltage independent
- β_1 is stable over time

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- Characterize the IC with the interval $\beta_1 \pm 3 \cdot \sigma_{\beta_1}$ after manufacturing
- Store its calibration value like for TS_CAL1 and TS_CAL2
- Check at every boot that β_1 is conform to the calibration value, i.e. ↴

$$\beta_1 \in [\overline{\beta_1} - 3 \cdot \sigma_{\beta_1}, \overline{\beta_1} + 3 \cdot \sigma_{\beta_1}] \tag{2}$$

Further validation: comparing identical ICs

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	Intact package		Backside opening		
IC №	$\overline{\beta_1}$	$\overline{\sigma_{\beta_1}}$	$\overline{\beta_1'}$	$\overline{\sigma_{\beta_1'}}$	$\overline{\beta_1'} - \overline{\beta_1}$
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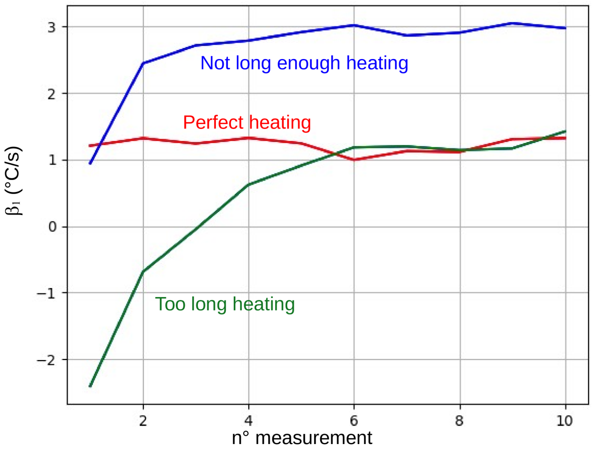
- β_1 distributions do not overlap

BYPASSING THE PACKAGE INTEGRITY VERIFICATION

Pre-heating the IC before power-up



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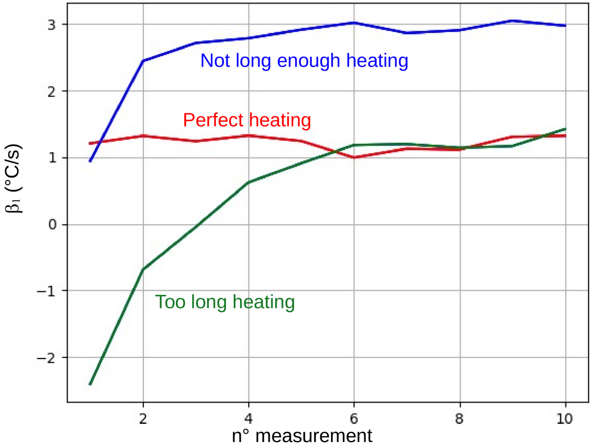
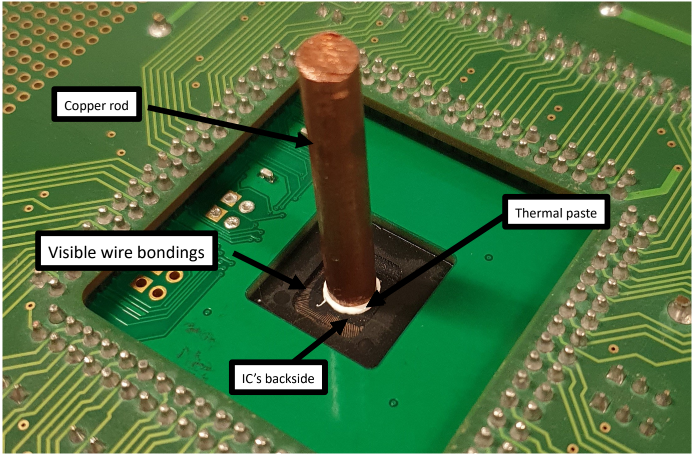


- Easy when unlimited boots are allowed
- Can be protected thanks to an initial temperature measurement

Removable heat-sink



Removable heat-sink results (units in °C·s^{-1})

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Average β_1 reduction of 5 °C·s^{-1}

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- Check package integrity against semi-invasive attacks

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- All of this with a sensor with a limited accuracy (± 1.5 °C)