Analysis of Circuits Effects in Analog Devices

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Équipe **RADIAC** « **RADIA**tion et **C**omposants »
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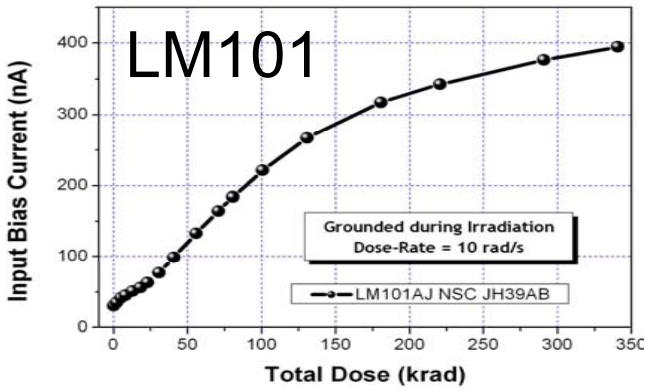
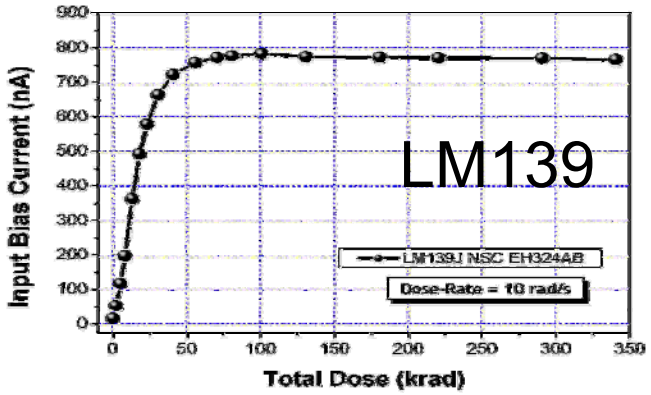
Introduction

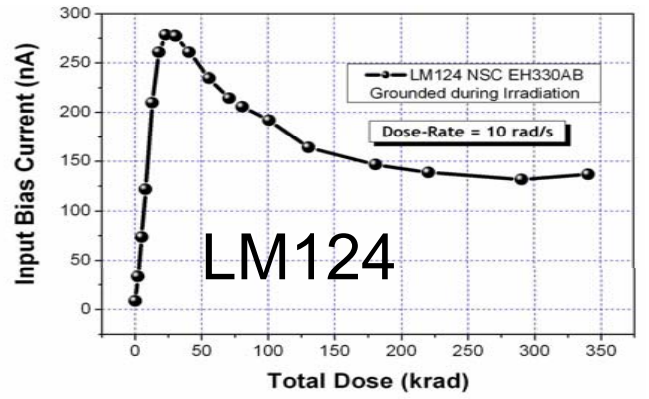
- **ICs** in **Bipolar** technology Exhibit degradation with TID
- Both **electrical** and **functional parameters** are impacted: Iin ↗ Icc ↘
- In Physics oriented studies, the **input bias current** is often used to evaluate the degradation
- Problem: The degradation curves exhibit a **variety of shapes**
- What are the root **causes**?
- What are the **consequences** for **RHA**?

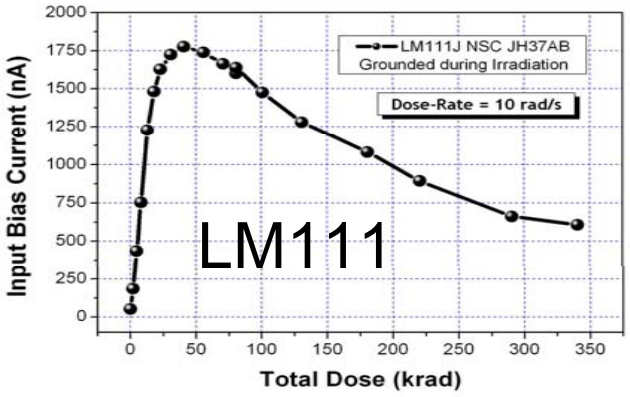
Starting point

4 ICs irradiated @ 11 rad/s➔4 different responses







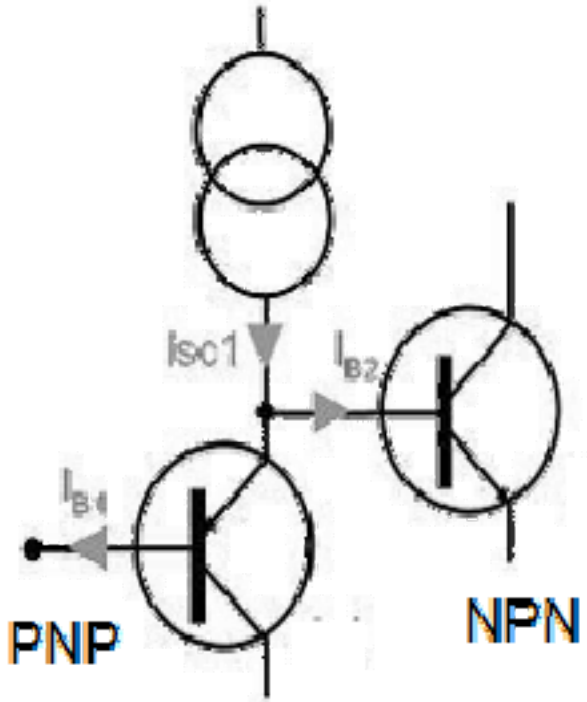


Compensation mechanisms

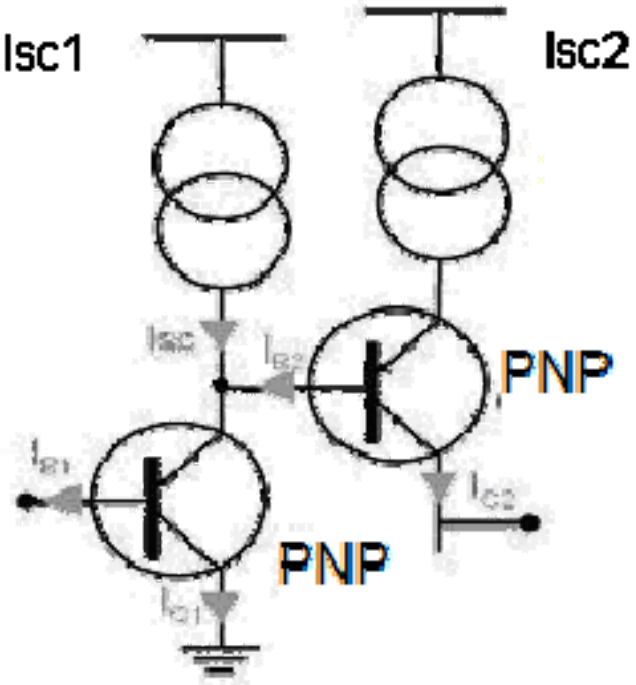
- In a bipolar Junction Transistor:
  - TID ➔ Ib ↗ & β ↘

$$I_b = \frac{I_c}{\beta}$$

- In a circuit, I_c is forced with a current source I_{sc}
- Connections at the collector node may **derive** or **add current**



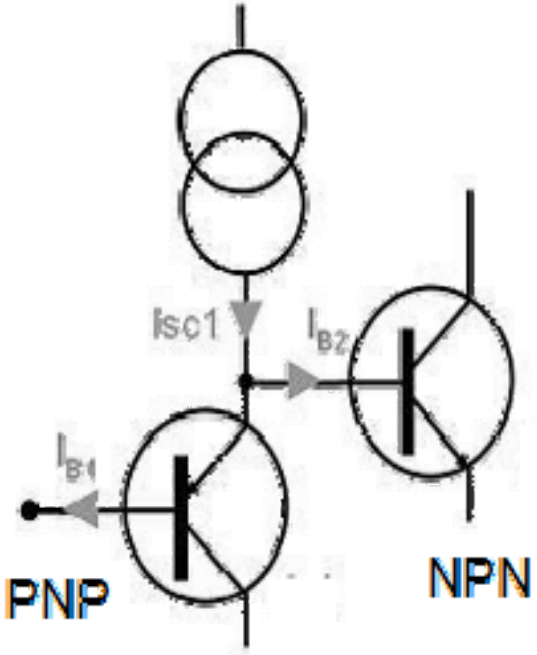
Compensation



Addition effect

$$I_{in} = \frac{I_{sc} \pm Ib2}{\beta}$$

Example of Circuit Effect and Compensation Mechanism in the LM111*

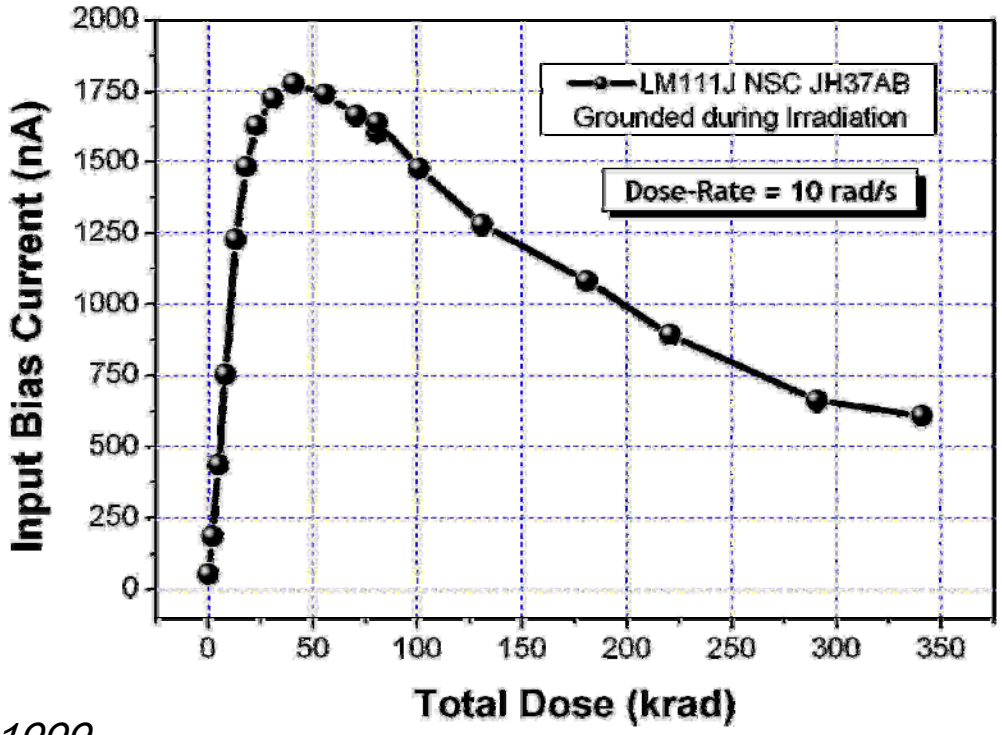


I_{sc} decreases +I_{b2} increases

⬇

Strong compensation mechanisms

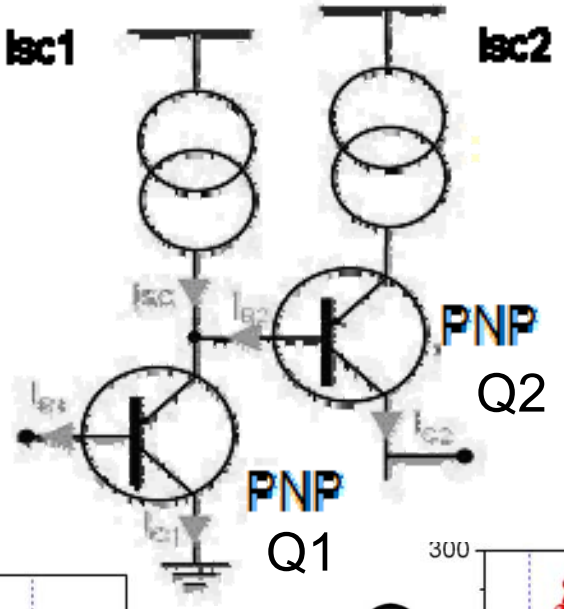
$$I_{in}(D) = \frac{I_{sc1}(D) - Ib2(D)}{\beta 1(D)}$$



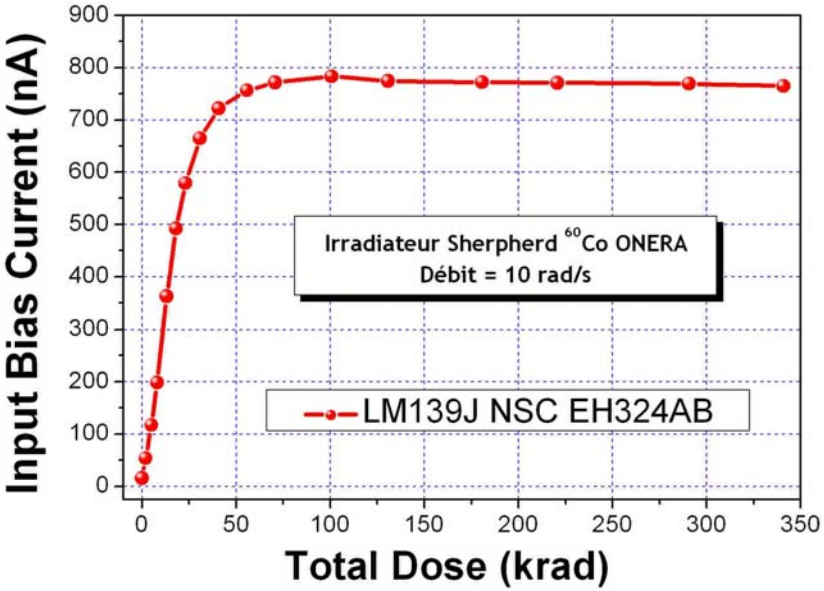
* *H. Barnaby et al. IEEE Trans. Nuc. Sci Dec 1999*

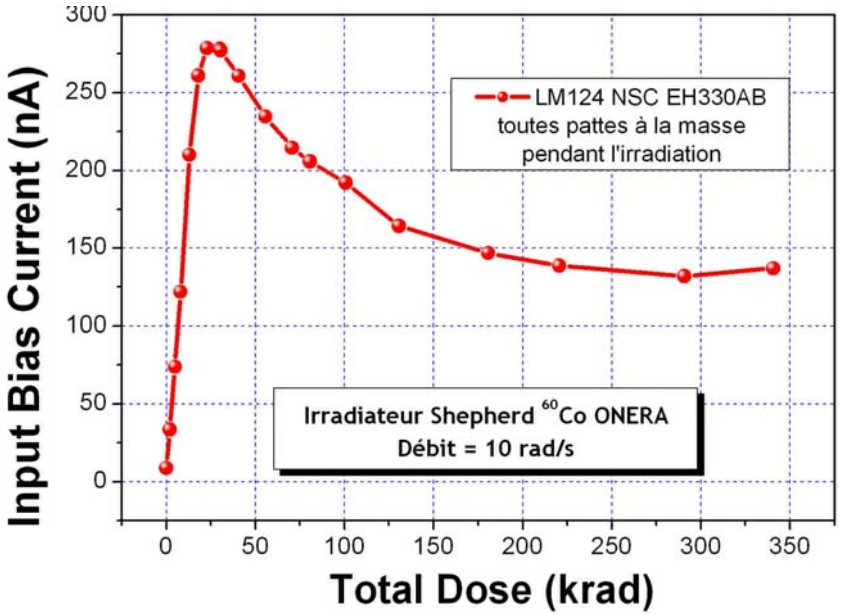
Same structure

LM139



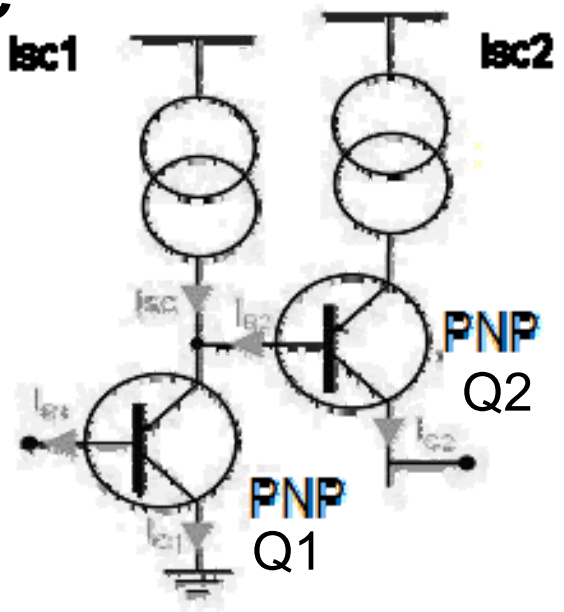
LM124



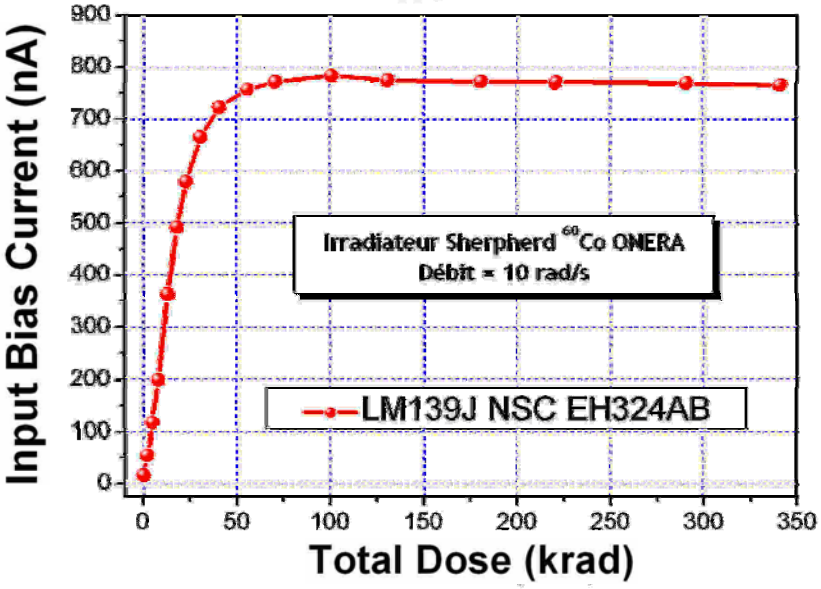


Same structure

- LM139
  - Isc2 = 100µA
  - Ib2 # µA ↗
  - Isc1↘ << Ib2
  - Ie1 ≈ Ib2



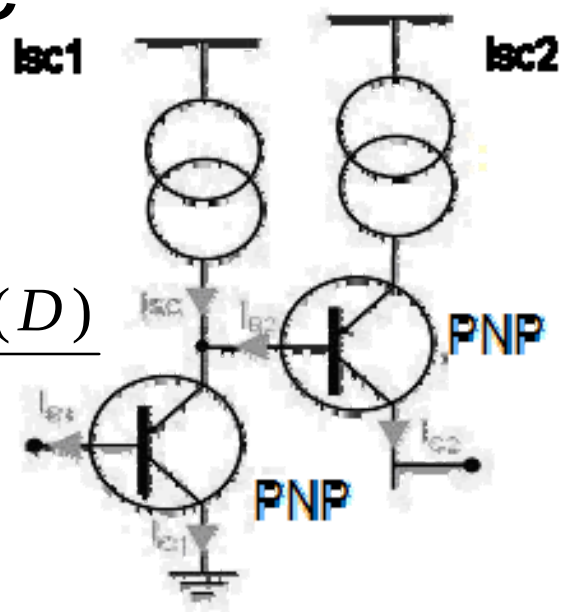
$$I_{in}(D) = \frac{I_{sc1}(D) + Ib2(D)}{\beta 1(D)} = \frac{Isc2}{\beta 1(D) \times \beta 2(D)}$$



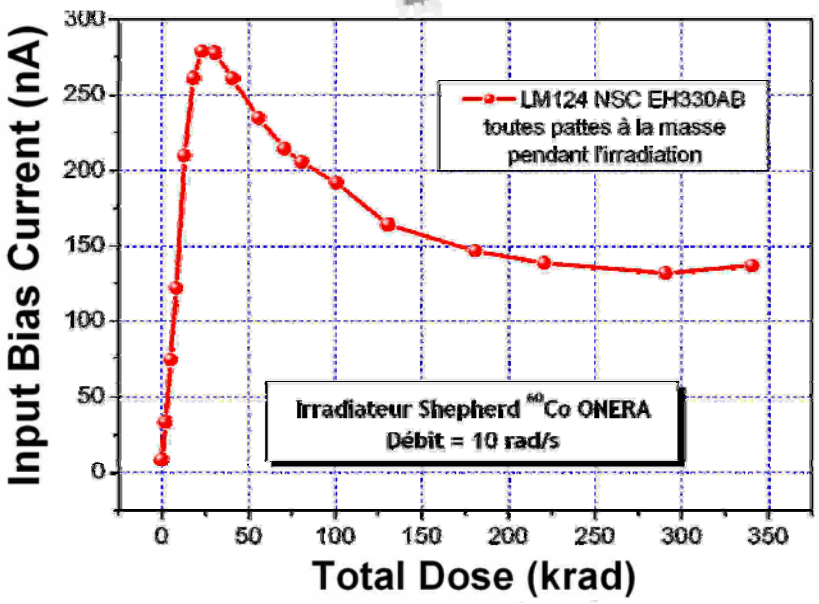
Same structure

- LM124
  - Isc2 = 3µA
  - Ib2 # nA <<Isc1
  - Ie1 ≈ Isc1

$$I_{in}(D) = \frac{I_{sc}(D) + Ib2(D)}{\beta 1(D)}$$

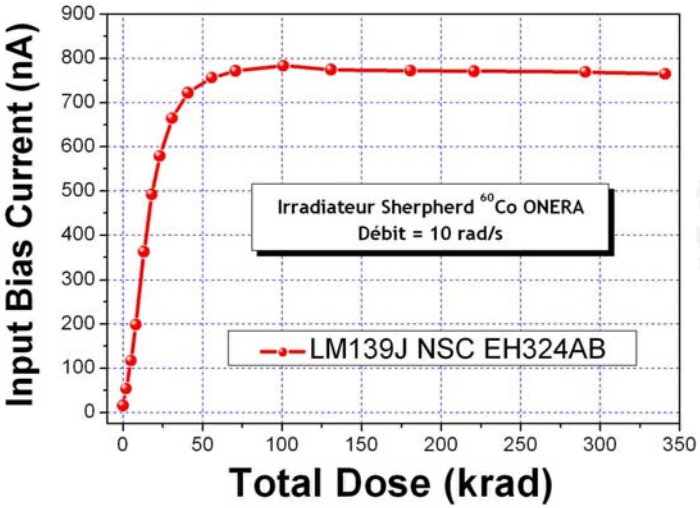


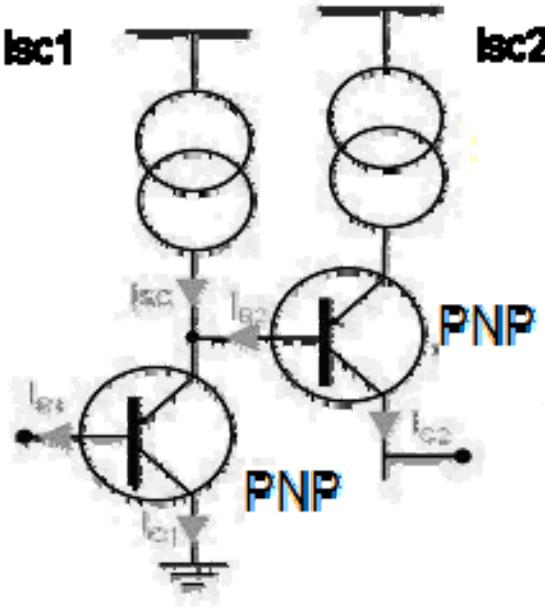
- **Two mechanisms are then to be considered**
  - β1 ↘; Ib1 ↗
  - Isc1 ↘; Ie1 ↘; Ib1 ↘



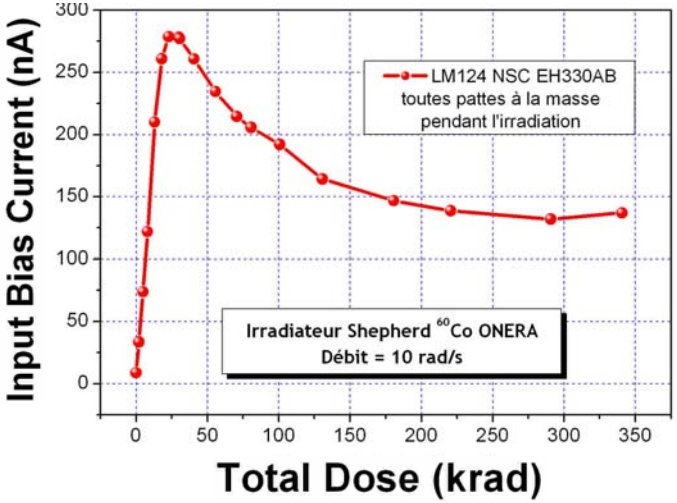
Same structure

LM139





LM124



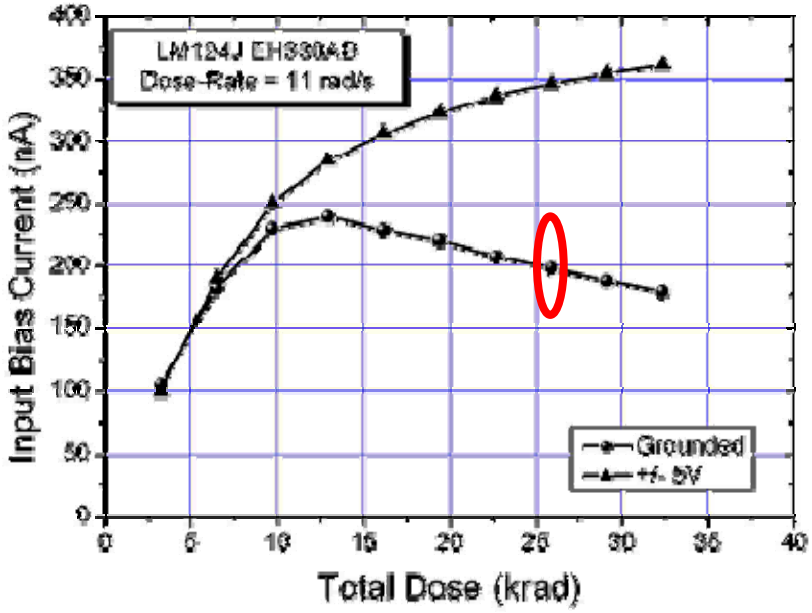
Different values of I_{sc}

Impact of bias conditions
Devices irradiated all pins **grounded**

- **Vbe = 0V** is a **worst case** for the degradation of **ALL** transistors

$$I_{in}(D) = \frac{I_{sc}(D)}{\beta(D)}$$

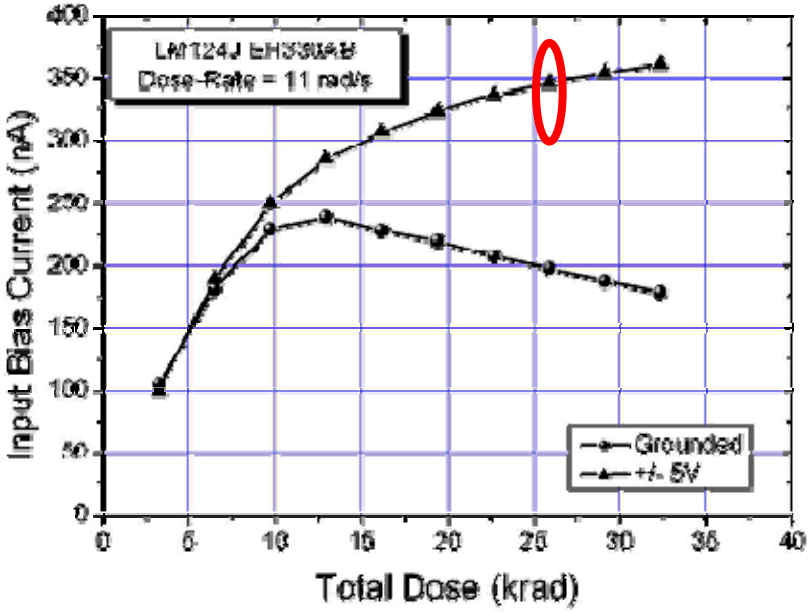
- The degradation of the current sources is maximum
- the compensation effect is maximum
- Iin+ exhibits a non monotonic shape



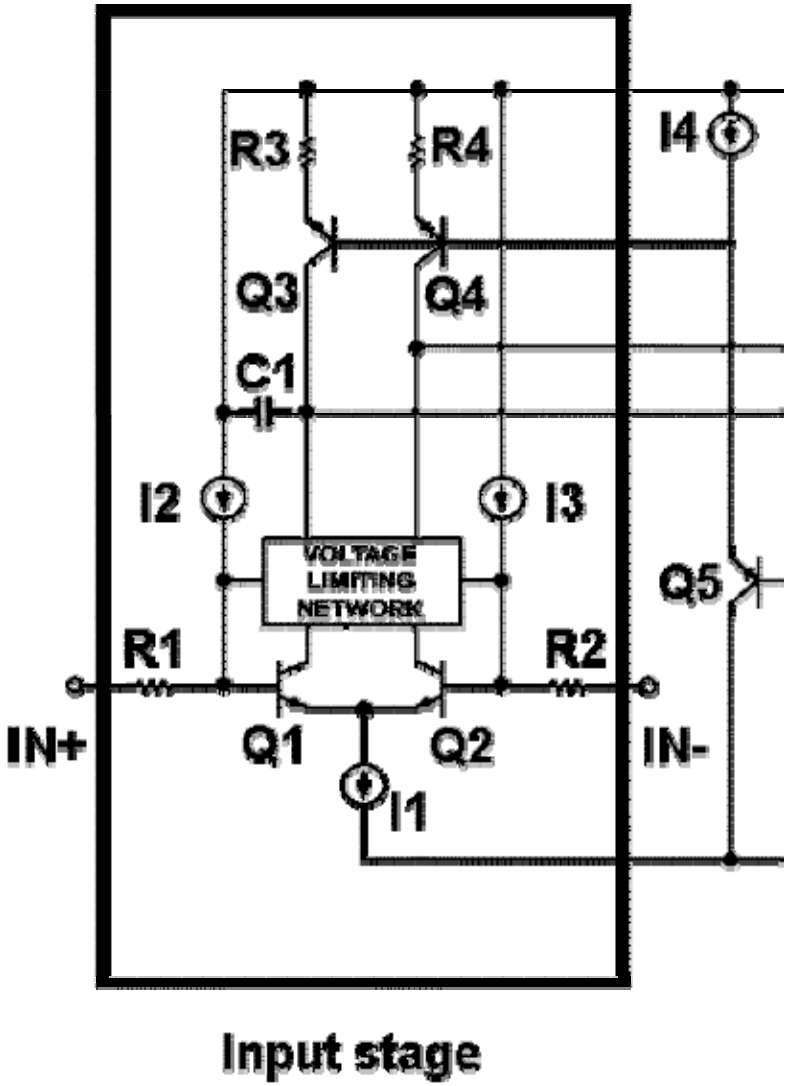
Impact of bias conditions Devices irradiated "**ON**"

- The degradation of the input transistor is the same
- Current sources irradiated biased exhibit less degradation
- Compensation mechanism is reduced
- The degradation of Iin+ is Monotonic

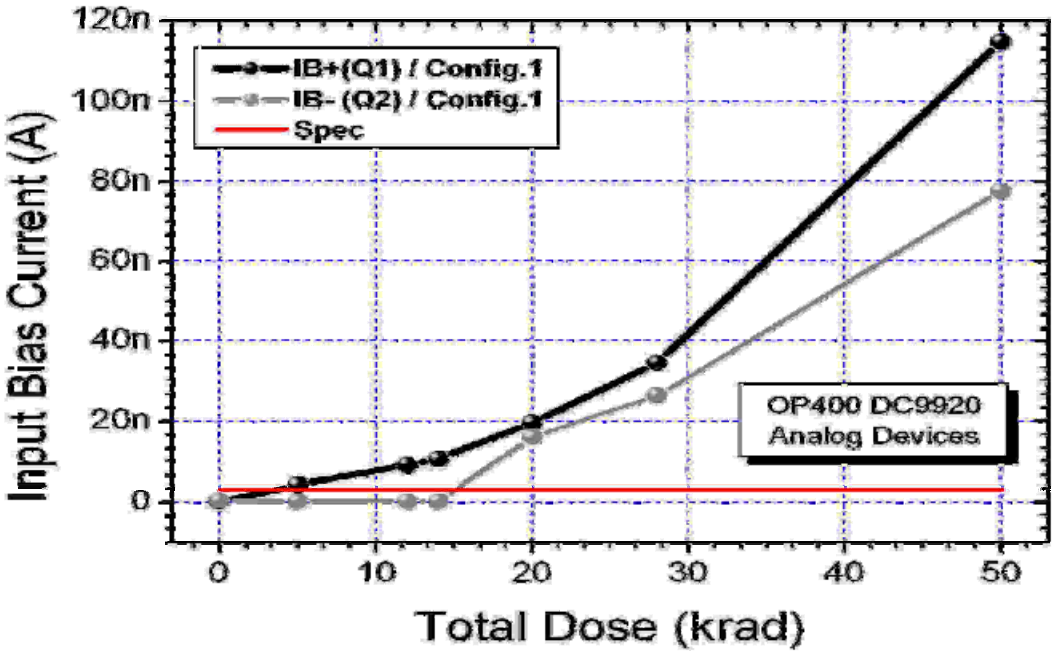
$$I_{in}(D) = \frac{I_{sc}(D)}{\beta(D)}$$



OP400 Input current canceling structures



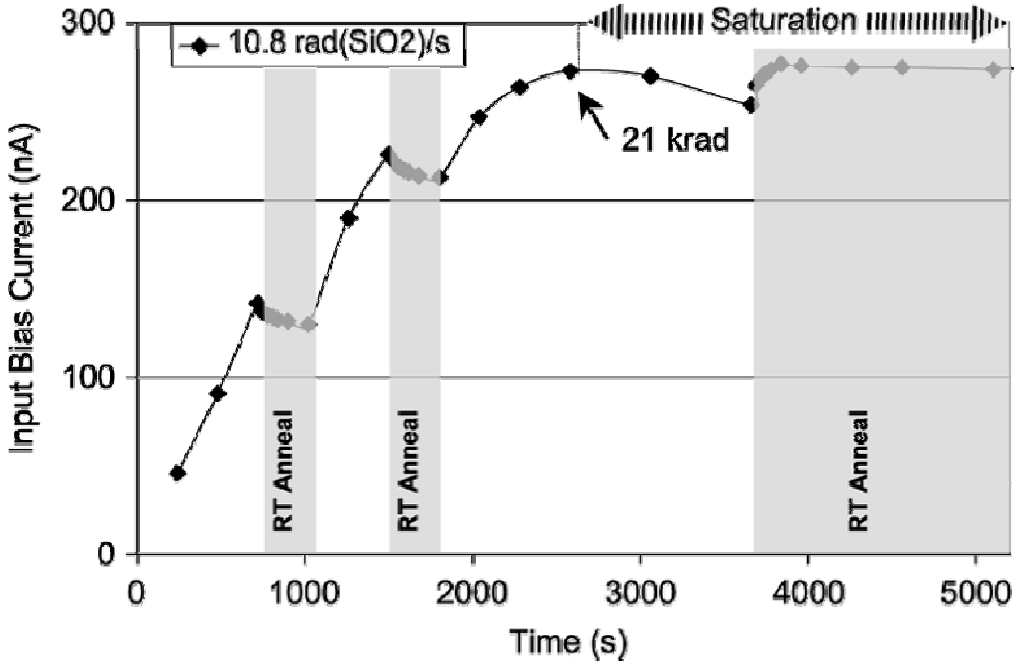
Input stage



- Current Feedback cancels the bias current at the input terminals
- If current mirrors degrade, Input current increases drastically

Annealing Effect

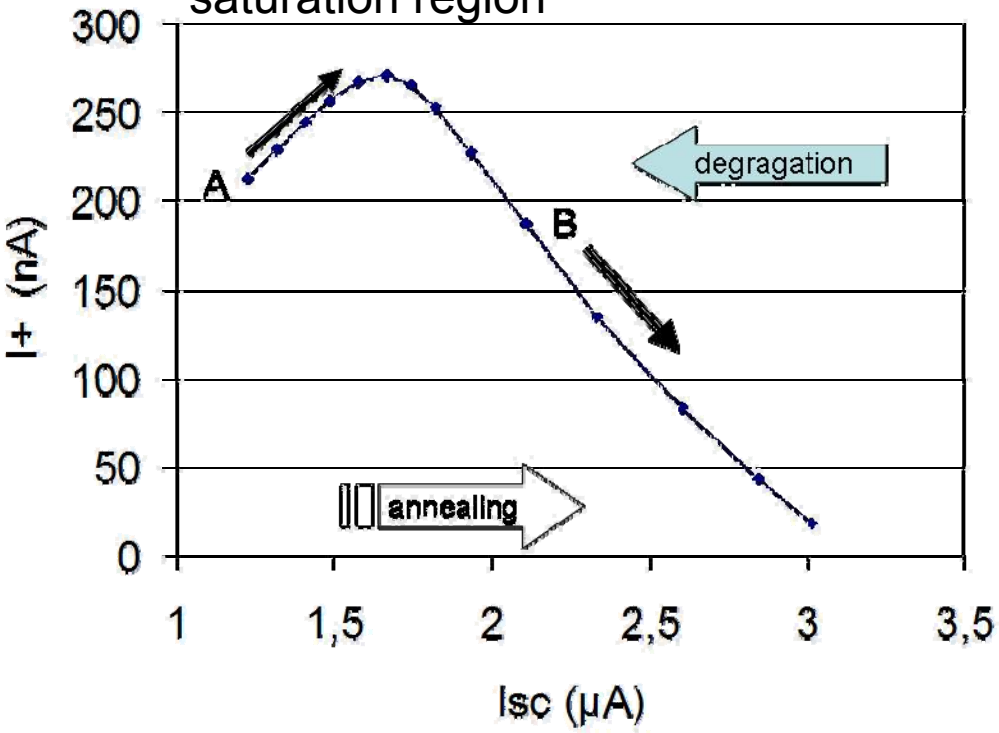
- Step-stress irradiation was followed by room temperature annealing
- Anealing before saturation
  - Iin ↘
- Annealing after saturation
  - In ↗



Annealing Effect

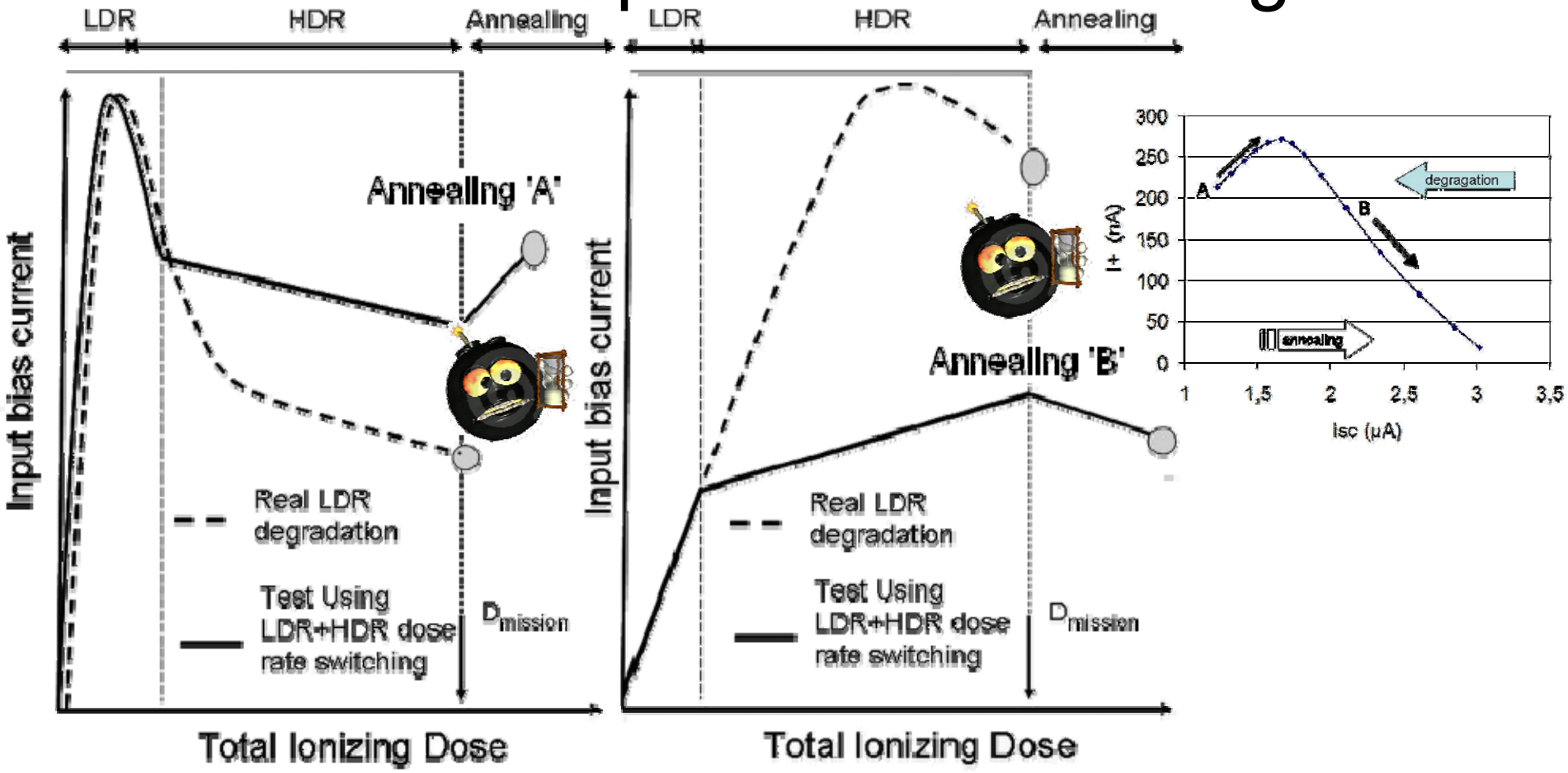
- Due to compensation mechanism
  - there is a direct relationship between Isc and Iin
- It is possible to calculate the impact of a recovery of Isc on Iin
- Depending on TID, this impact can be
  - either positive (degradation)
  - negative (recovery)

A : annealing is performed after the saturation region
B : annealing is performed before the saturation region



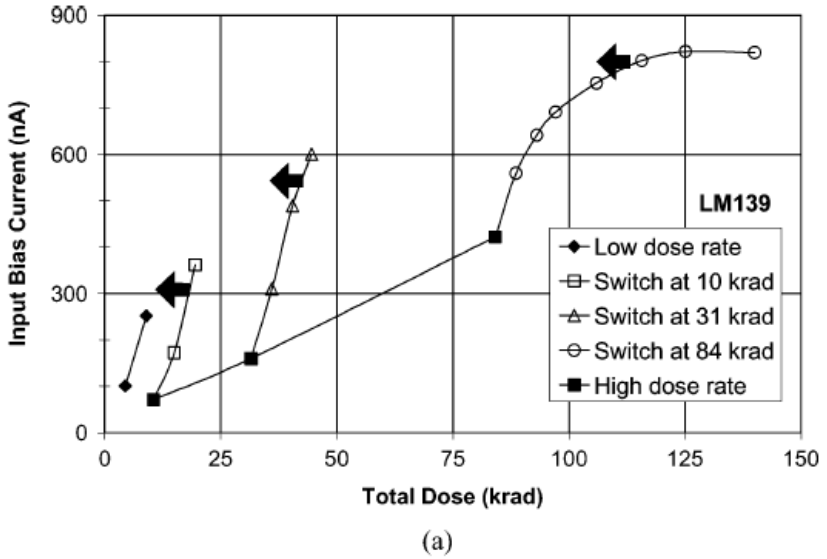
➔Annealing is not significant

Dangers of performing LDR HDR sequence + Annealing

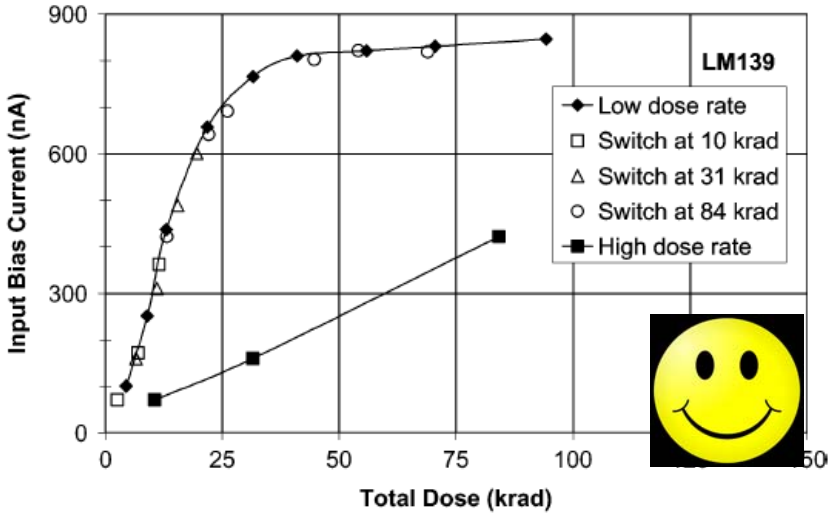


➔The result of LDR HDR sequence of irradiation is almost impossible to analyze

ELDRS and Dose rate switching



(a)



(b)

- **<u>HDR + n LDR</u>** irradiation
  - Reconstruction of the curve by translation
  - Accurate, time saving by a factor t/n
  - requires a large sample size (n)

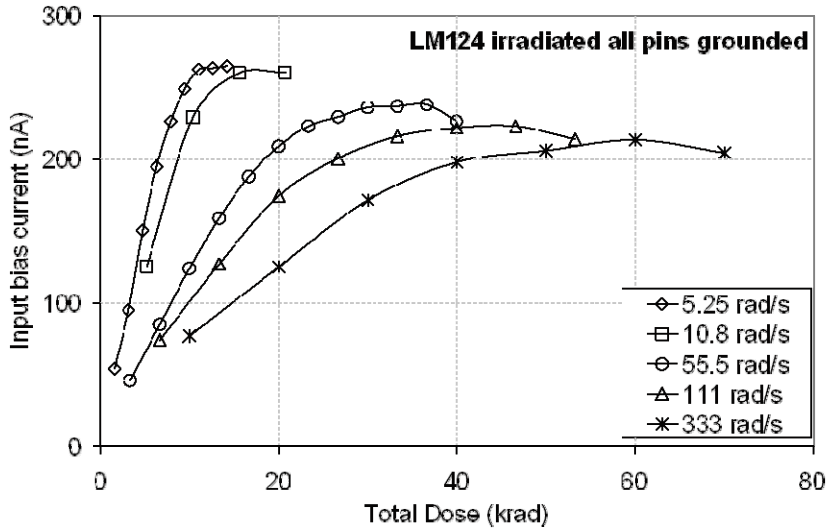
J. Boch et al. "Estimation of Low Dose Rate Degradation on Bipolar Linear Integrated Circuits Using Switch-ing Experiments", IEEE Trans. Nucl. Sci., vol. 52, pp. 2616-2621, 2005

Conclusion 1/2

- The variety of shapes observed is due to circuit effects in ICs
- Compensation or cumulative degradation depends on:
  - The architecture of the input stage
  - Bias
  - Dose rate
  - Annealing

Conclusion 2/2

- What are the risks ?
  - Missing the peak at low dose rate
    - Peak value has been reported before 5krad (LDR) in some devices
    - critical in the case of large irradiation steps
    - Step > ~~15 krad~~



Thanks for your attention