Design and Assessment of a Robust Voltage Amplifier with 2.5 GHz GBW and >100 kGy Total Dose Tolerance

Jens Verbeeck

TWEPP 2010

Institute for the Promotion of Innovation by Science and Technology in Flanders

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Outline

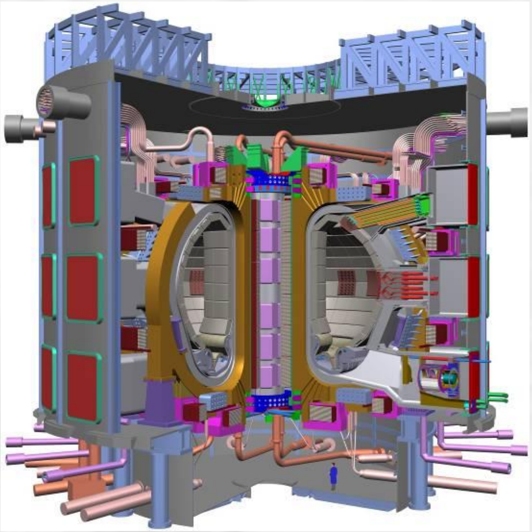
- Introduction
- Radiation and temperature effects
- Constant g_m amplifier
- Matching structure
- Conclusions

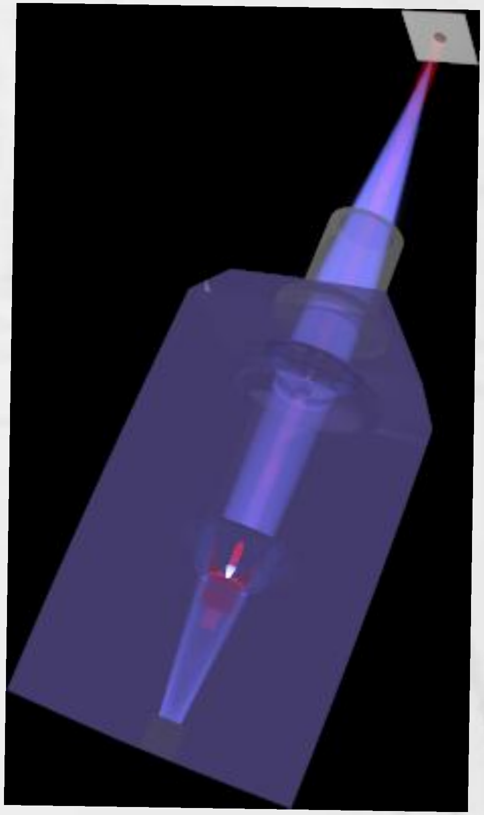
Outline

- **Introduction**
- Radiation and temperature effects
- Constant g_m amplifier
- Matching structure
- Conclusions

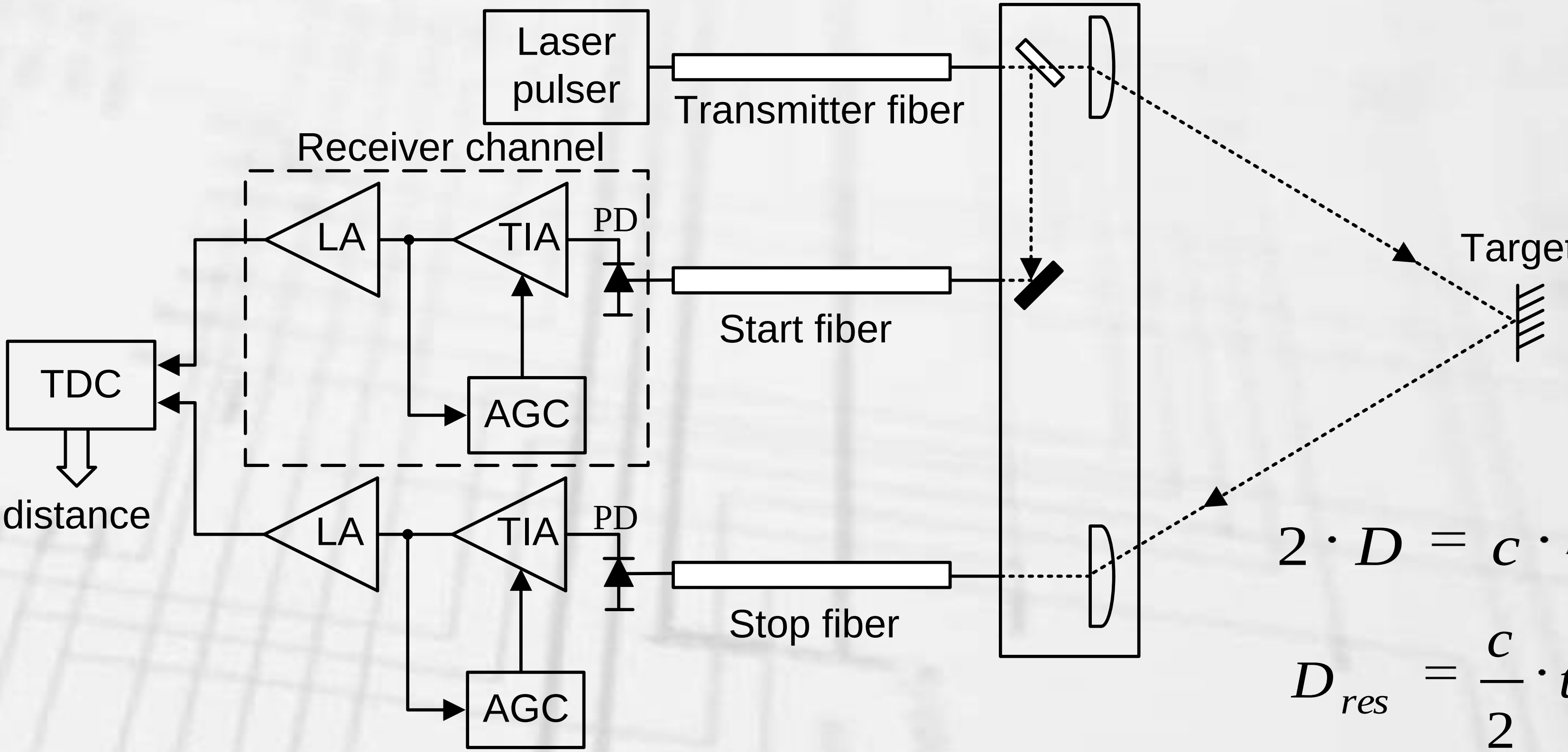
Introduction

- Development of optical instrumentation and communication for nuclear and high temperature environments
- Applicable for
  - MYRRHA
  - ITER
  - LHC
  - Space





Optical instrumentation



$$2 \cdot D = c \cdot \Delta t$$

$$D_{res} = \frac{c}{2} \cdot t_{res}$$

PD: Photo diode

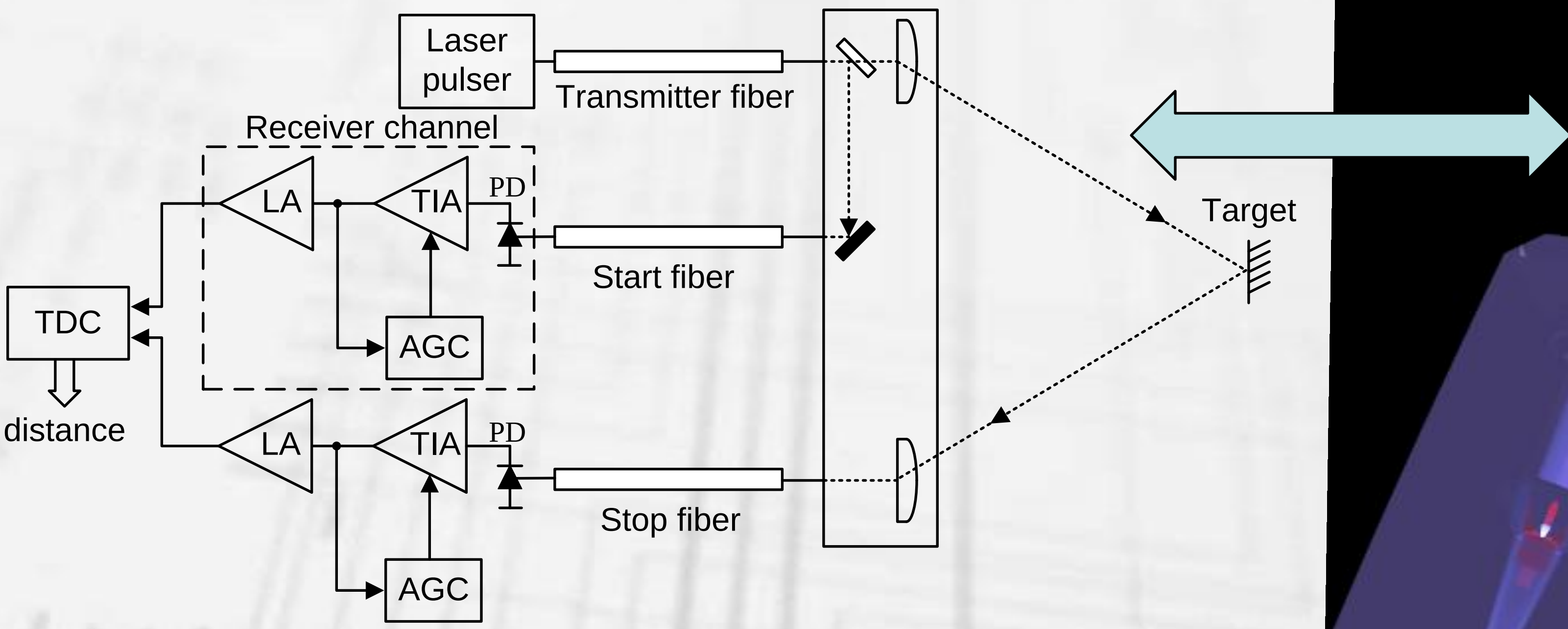
TIA: Transimpedance amplifier

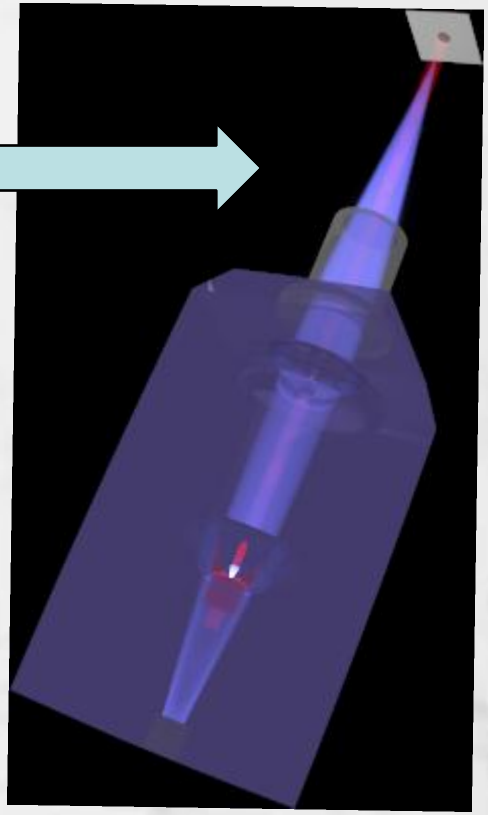
LA: Limiting amplifier

AGC: Automatic gain controller

TDC: Time to digital converter

Optical instrumentation



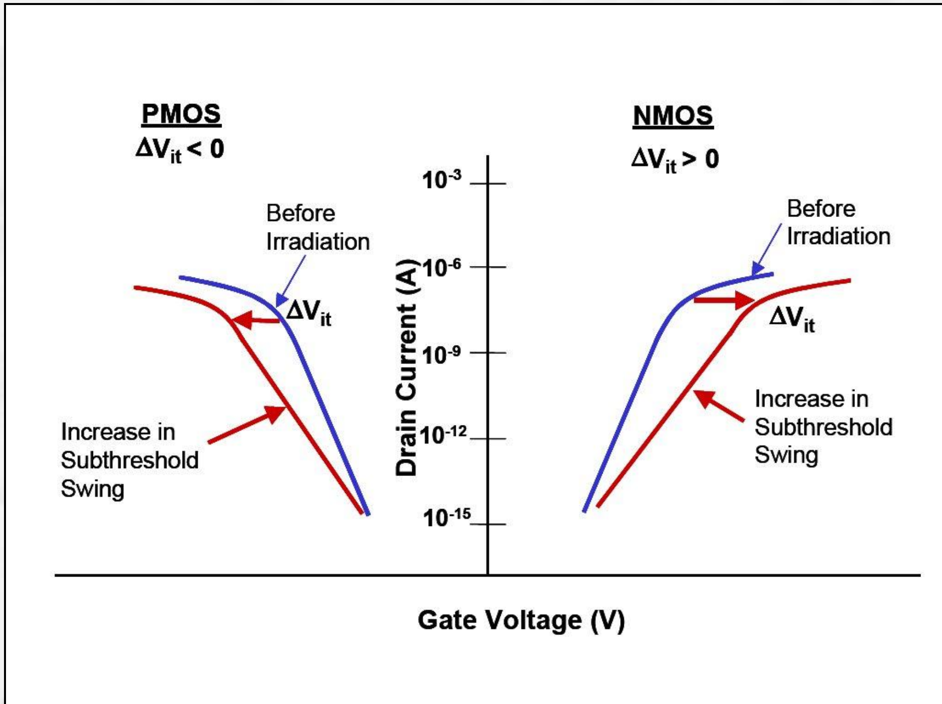


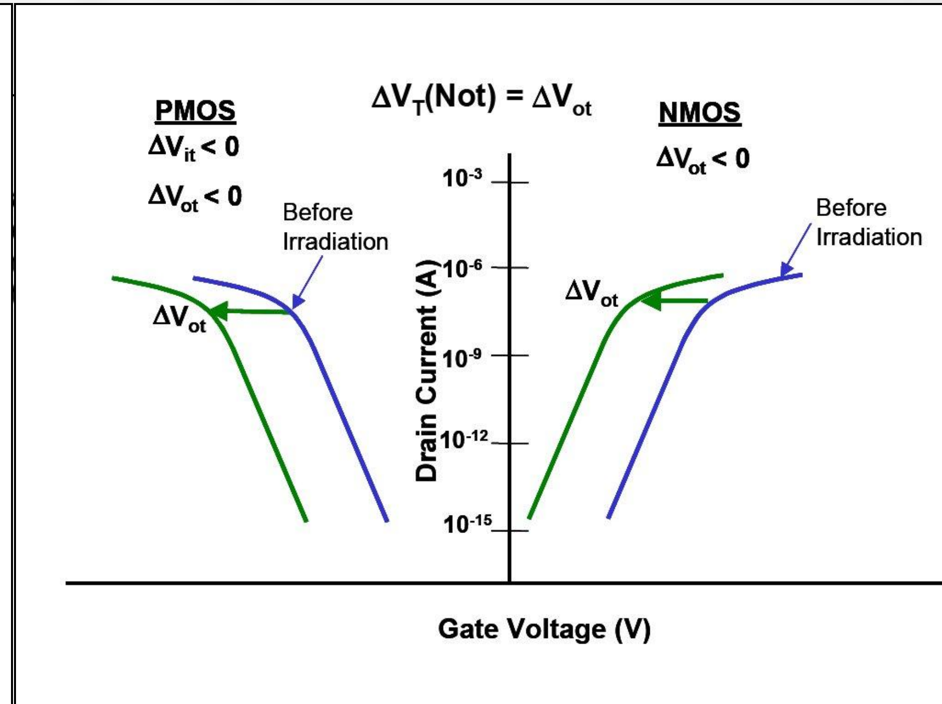
- Goal
  - LIDAR with ps accuracy, distance =10m
- Current status
  - TDC with ps resolution developed and irradiated up to 5MGy (Ying Cao)
  - November tape-out receiver channel

Outline

- Introduction
- **Radiation and temperature effects**
- Constant g_m amplifier
- Matching as a function of radiation dose
- Conclusions

Radiation : Introduction TID



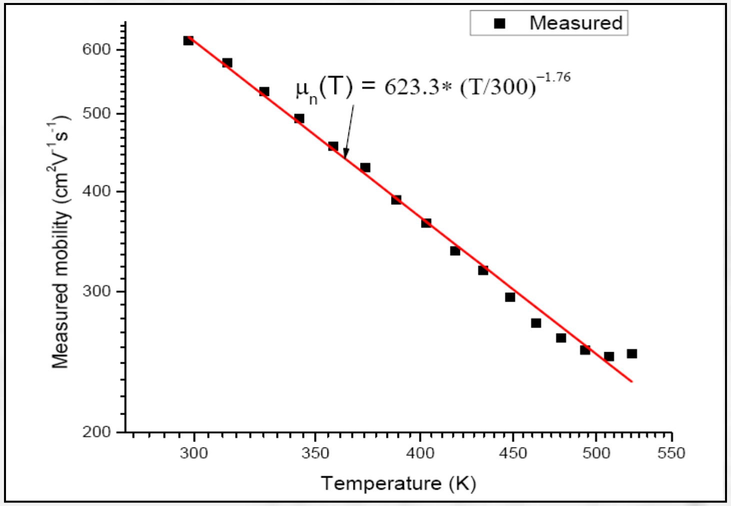


[Hugh J. Barnaby]

[Hugh J. Barnaby]

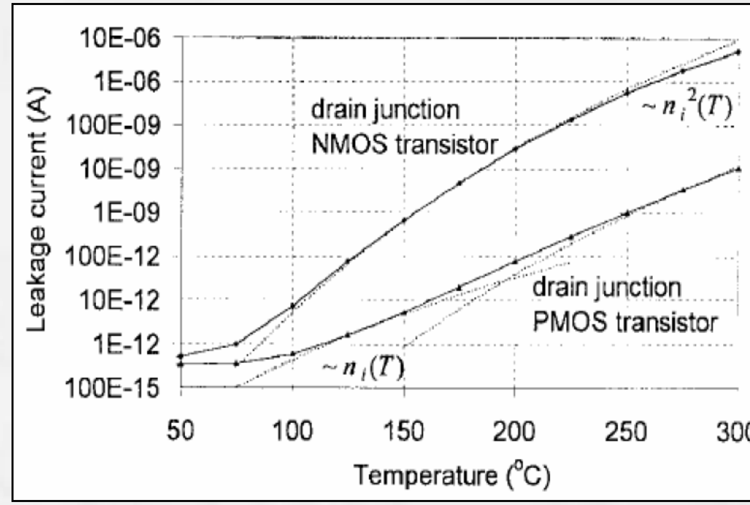
Temperature: effects

Decrease of mobility



[M. Willander]

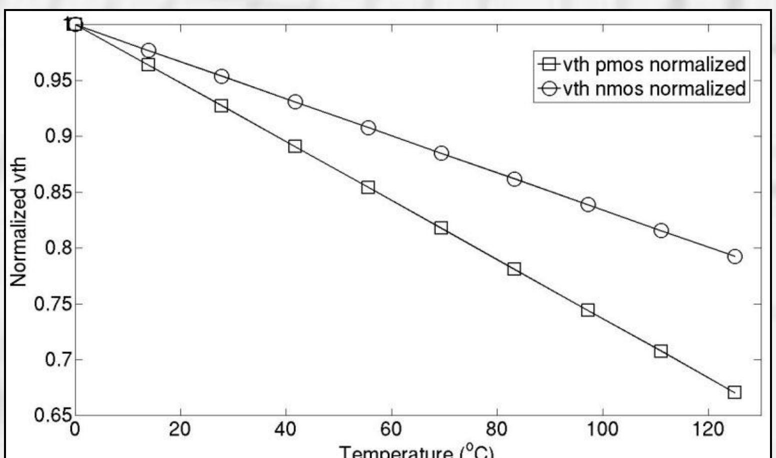
Increase of leakage current



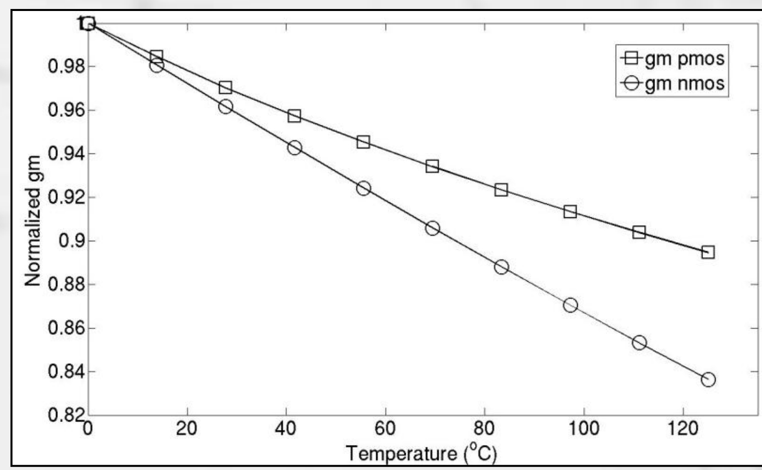
[P. C. de Jong et. al.]

T

Decrease of V_{TH}



Decrease of g_m

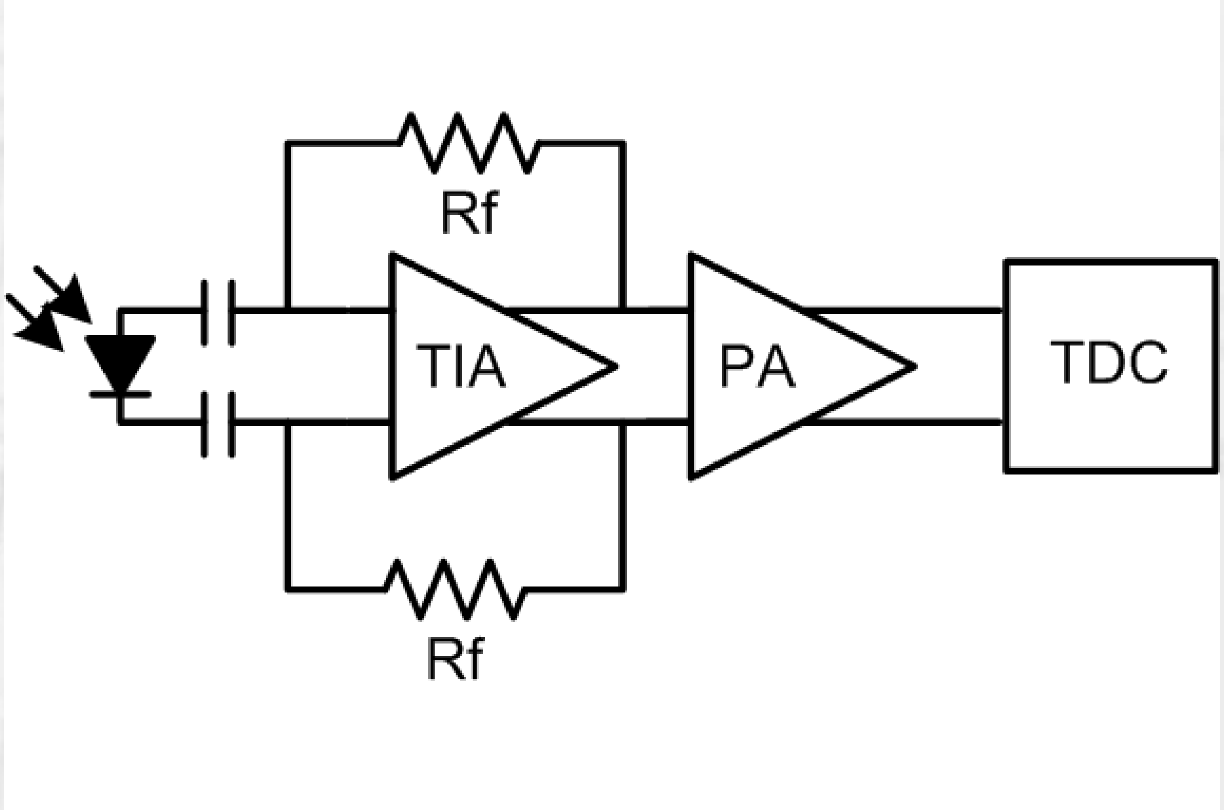


Outline

- Introduction
- Radiation and temperature effects
- Constant g_m amplifier
- Matching as structure
- Conclusions

Optical receiver

- Classical building blocks
  - Transimpedance amplifier (TIA)
  - Post amplifier (PA)
  - Time to digital convertor (TDC)

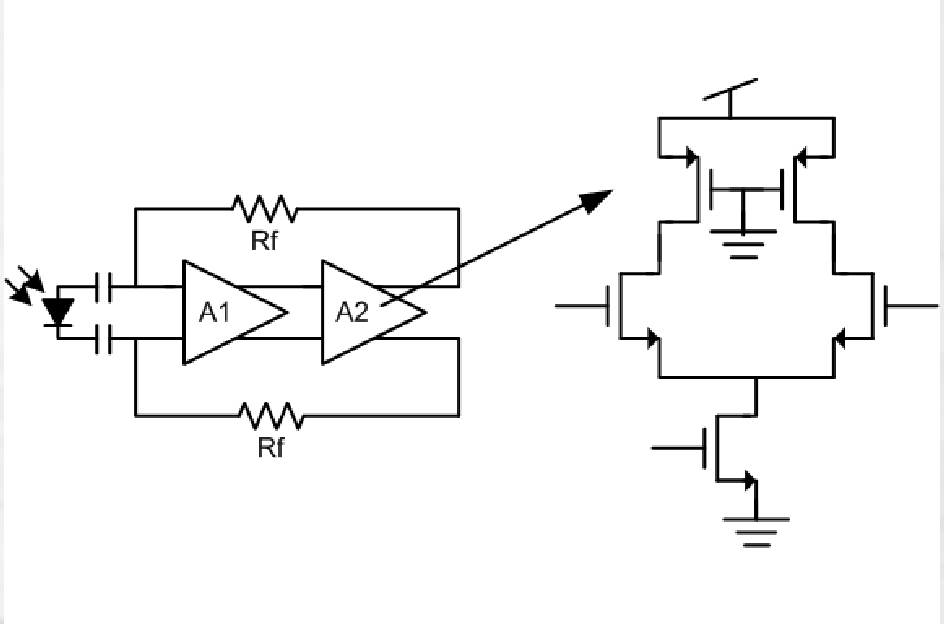


Constant g_m amplifier: Why?

Radiation/temperature causes variation in TIA parameters

$$Z_{TIA} = \frac{Rf \cdot A_0}{A_0 + 1} \qquad BW = \frac{A_0}{2 \cdot \pi \cdot R_f \cdot C_{in}}$$

$$f_{nd} = \frac{1}{2 \cdot \pi \cdot R_f \cdot C_{out}} \qquad GBW = \frac{A_0}{2 \cdot \pi \cdot C_{in}}$$



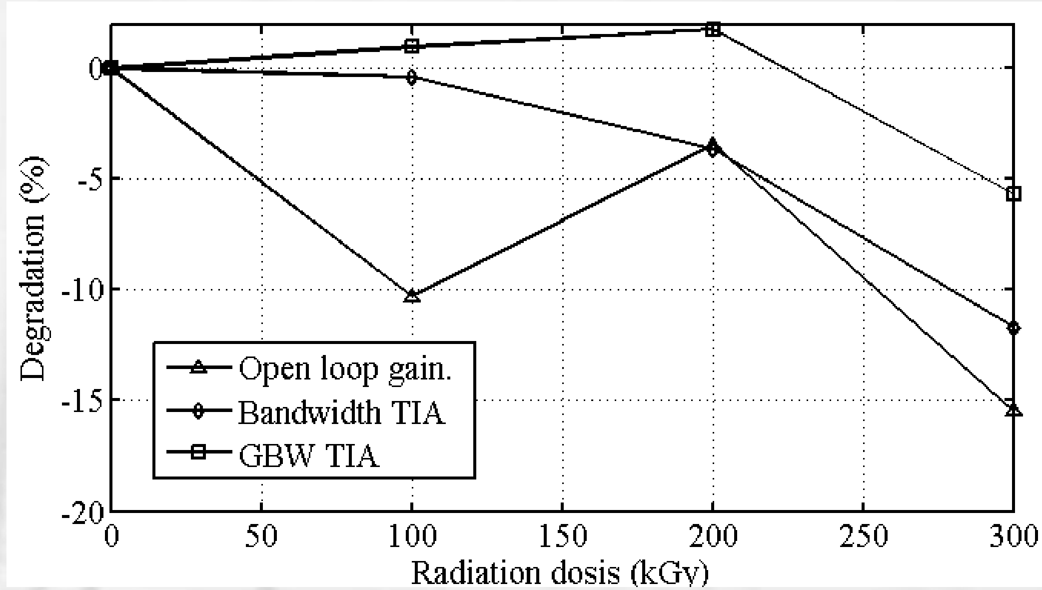
$$A_0 = g_{m1} \cdot r_{out1} \cdot g_{m2} \cdot r_{out2}$$

- g_m and r_{out} variable in formula A_0
  - Make gain independent of gm and r_{out}

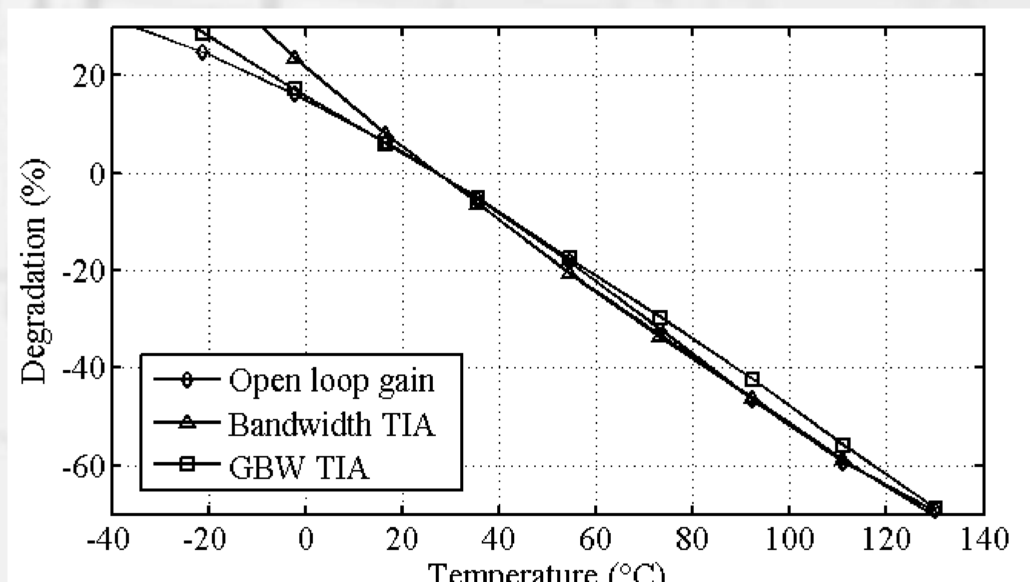
Constant g_m amplifier: Why?

Radiation
up to 300 kGy
(M. Manghisoni et al.)

0.18µm CMOS	100kGy	300kGy
NMOS	+7mV	+20mV
PMOS	-12mV	-60mV



Temperature
(-40 up to 130°C)



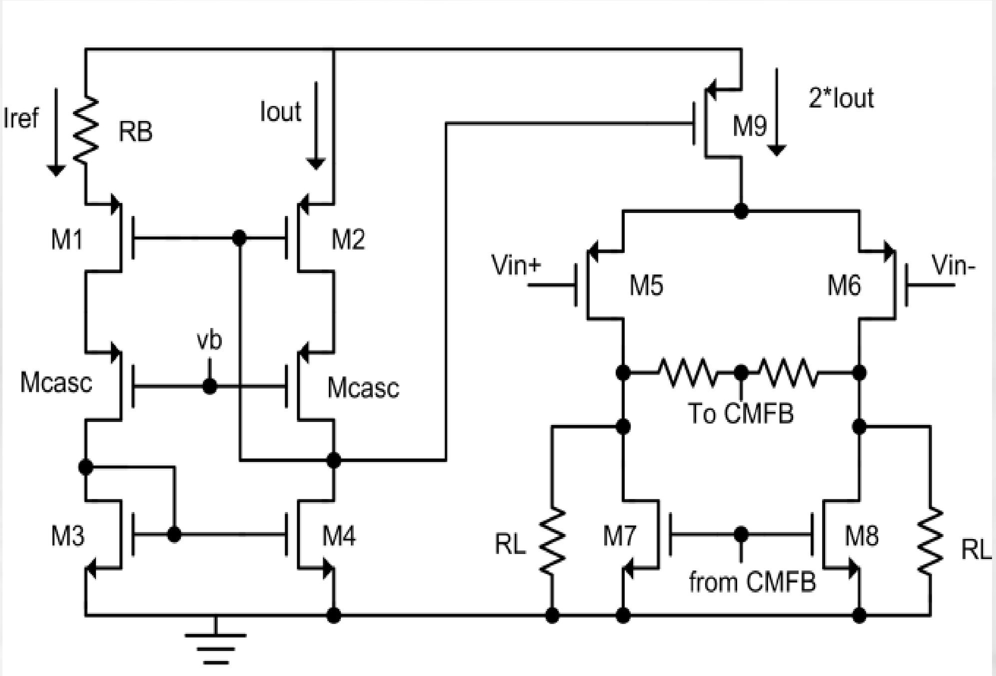
Constant g_m amplifier: Operation

$$I_{OUT} = I_{REF}$$
$$V_{GS2} = V_{GS1} + I_{OUT} * R_b$$

$$I_{OUT} = \frac{2}{\mu_n C_{ox} (\frac{W}{L})} \cdot \frac{1}{Rb^2} (1 - \frac{1}{\sqrt{B}})^2$$

$$g_m = \sqrt{2 \cdot \mu_n \cdot C_{ox} \cdot (W/L)_5 \cdot I_{D5}}$$

$$g_{mx} = \frac{2}{R_B} (1 - \frac{1}{\sqrt{B}}) \sqrt{\cdot \frac{(W/L)_5}{(W/L)_1} \frac{\mu_x}{\mu_n}}$$



$$A \approx 2 \frac{R_L}{R_B} (1 - \frac{1}{\sqrt{B}})$$

[B.Razavi]

[Sean Nicalson et al.]

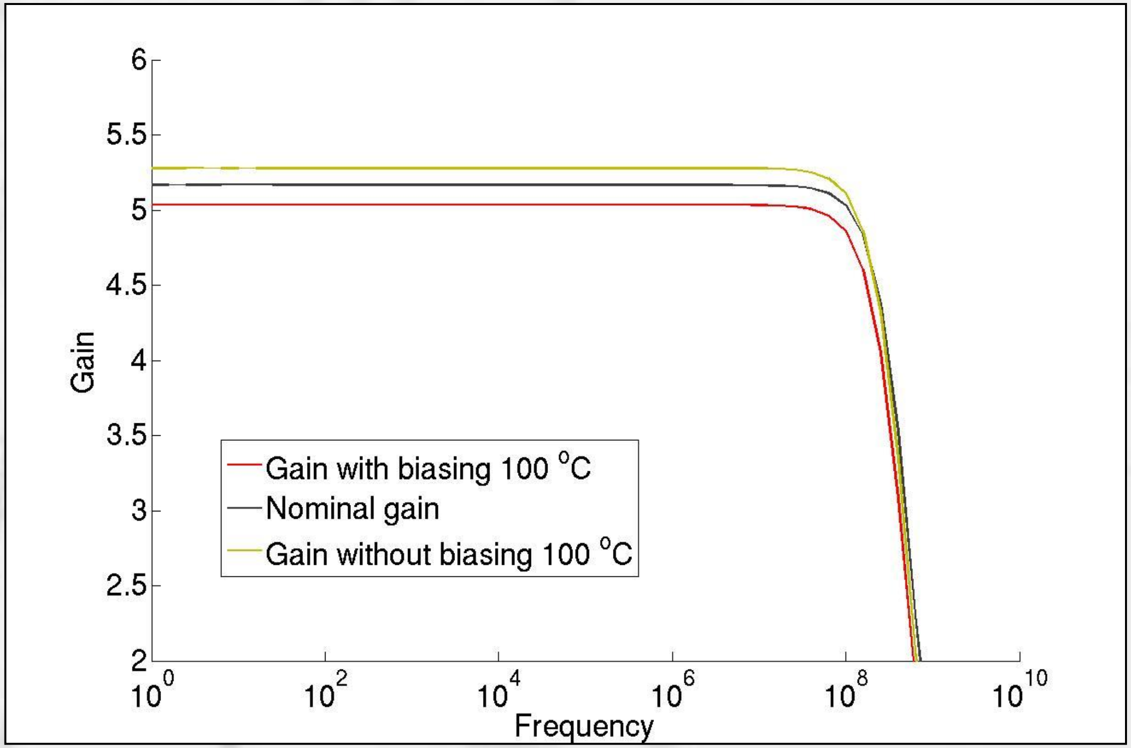
- R_{DSTOT} >> RL
  - Transistor length ↑
  - Trade-off: BB <=> temp/RAD tolerance

Temperature simulations

- Degradation with bias : 2.5 %

Temperature sweep from 0°C to 100°C

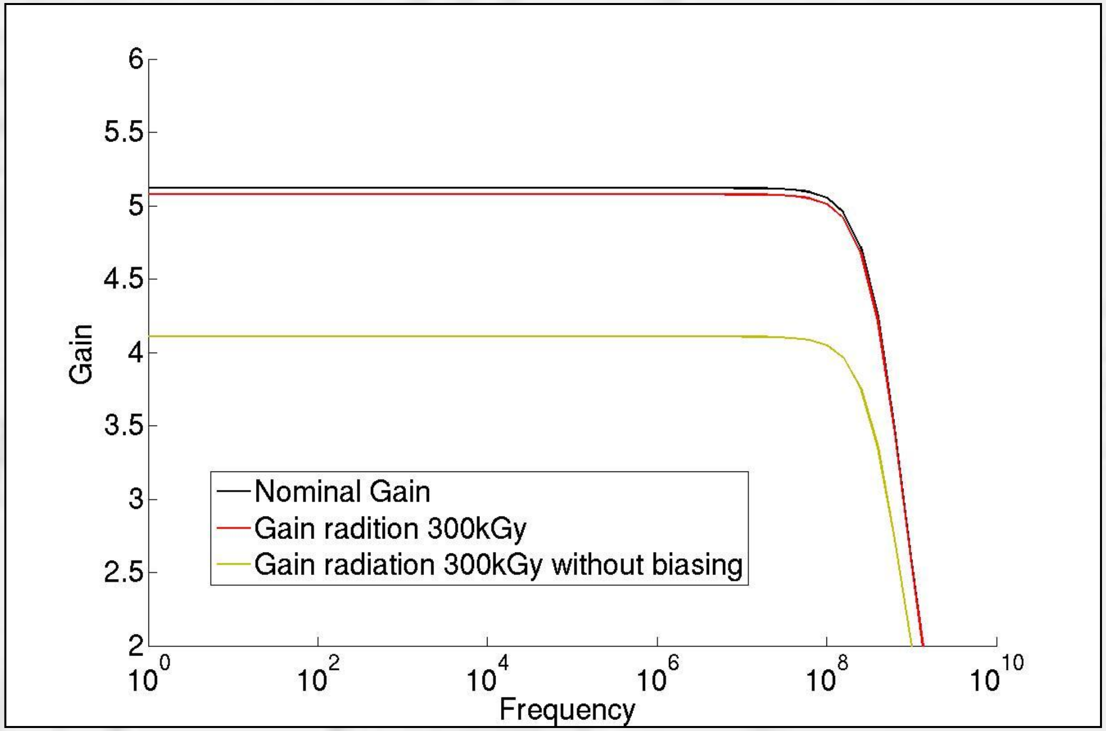
Gain =14dB
GBW = 2.5Ghz
BB = 500MHz



Radiation simulations

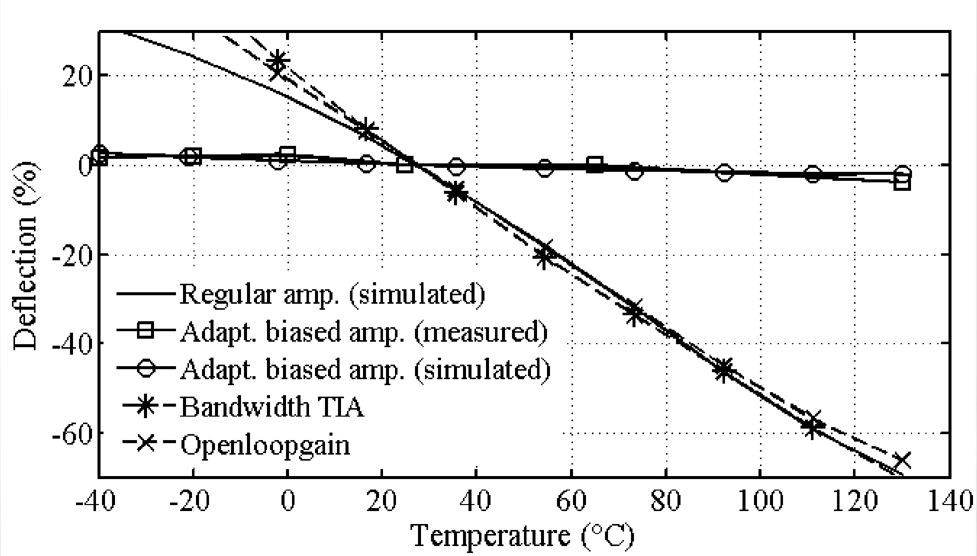
- Degradation with bias : 0.85 %

Amplifier irradiated up to 300kGy

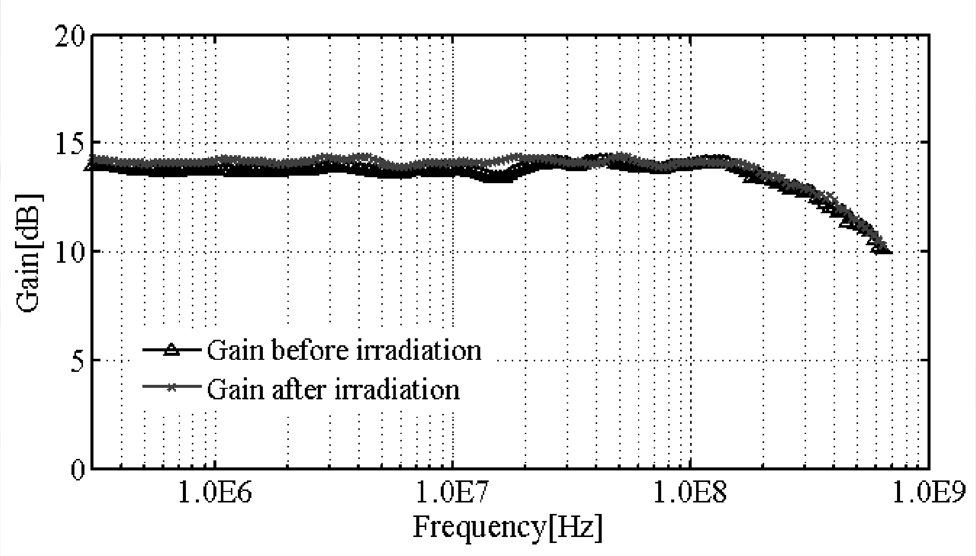


Results

Temperature drift 5.6 % or 343 ppm/°C



Radiation up to 100 kGy
Gain degradation 4.5%

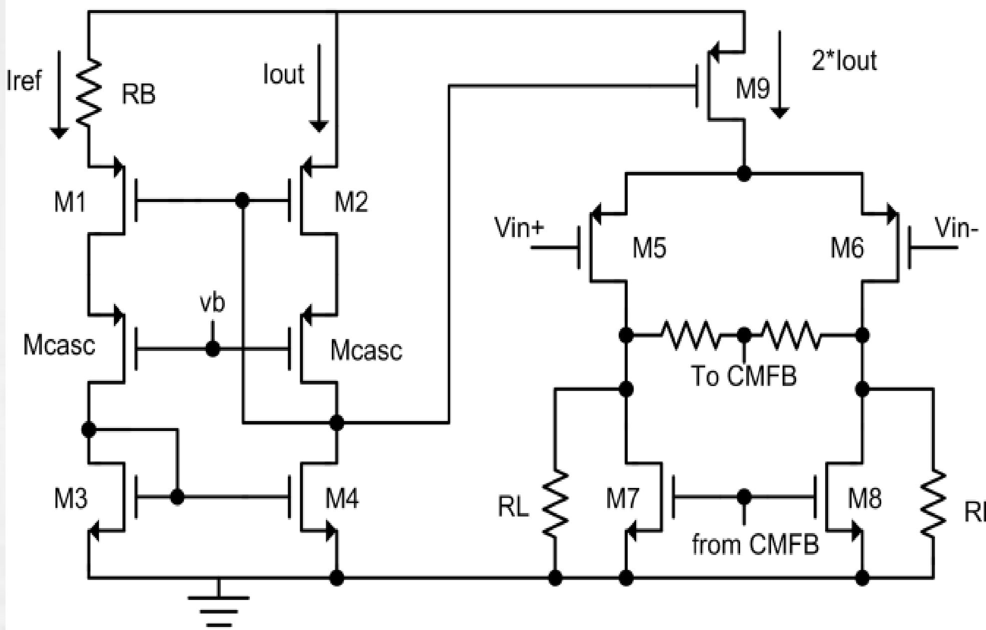


Results: Radiation

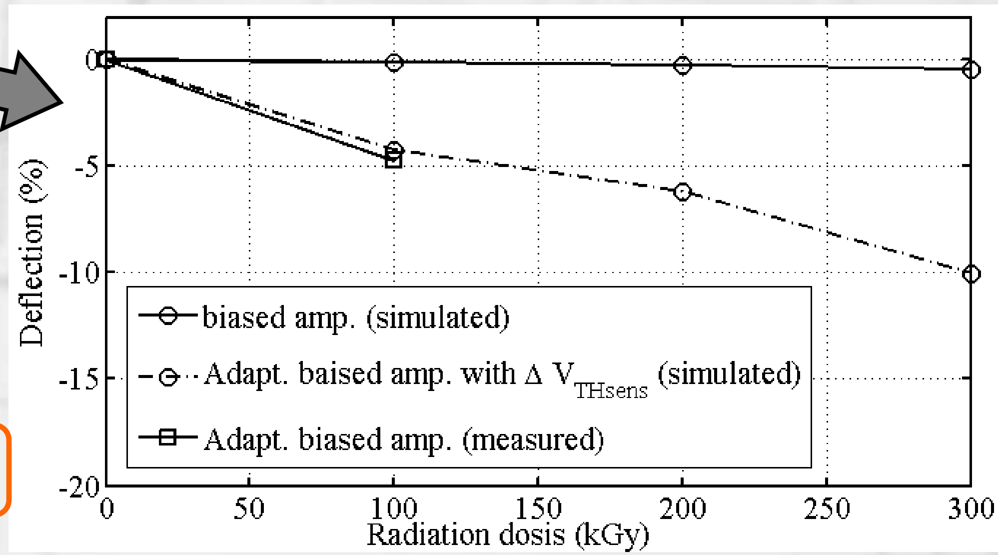
Cause degradation?

$$\frac{\Delta gm}{gm} = \frac{1}{V_{GSTH}\ (1 - \frac{1}{\sqrt{B}} + \frac{V_{THsens}}{V_{GSTH}})} \Delta V_{THsens}$$

- V_{THsens} = Standard deviation before radiation of M1 and M2
- ΔV_{THsens} = Variation of V_{THsens}



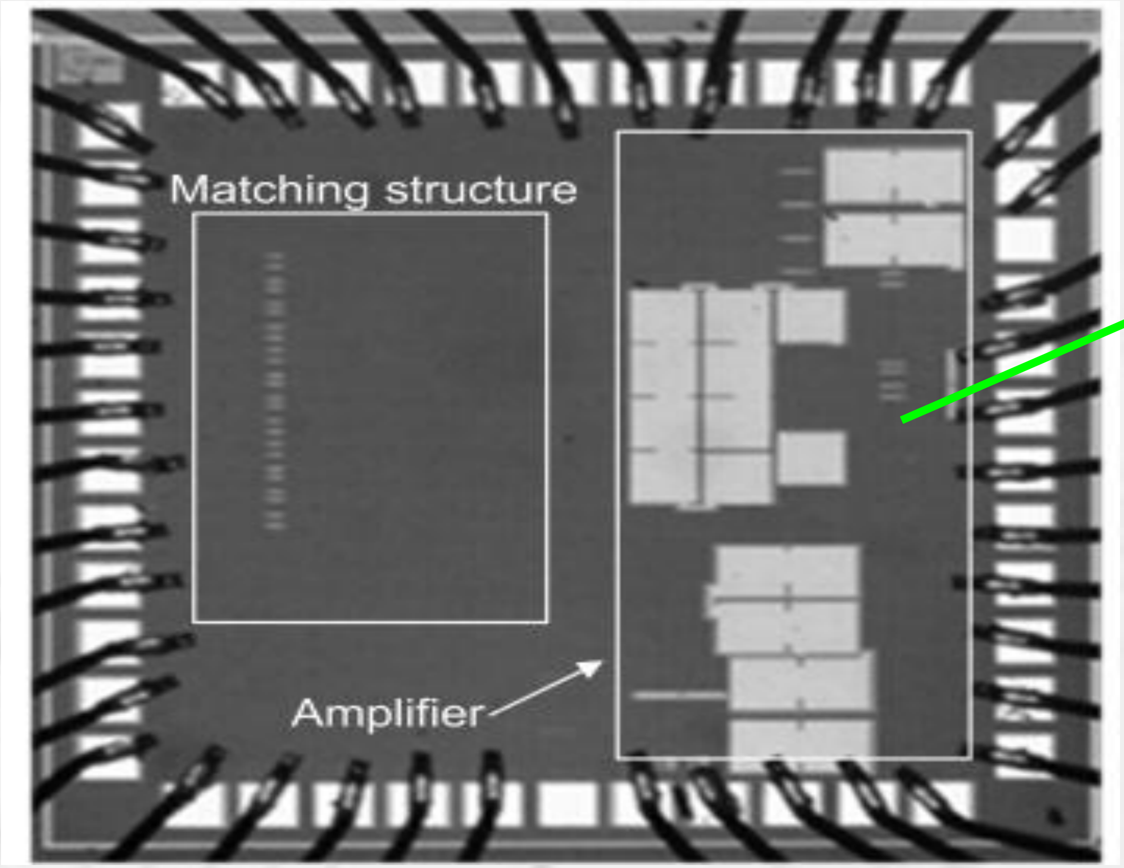
Impact of a ΔV_{THsens} of 10% on the gain of the amplifier.

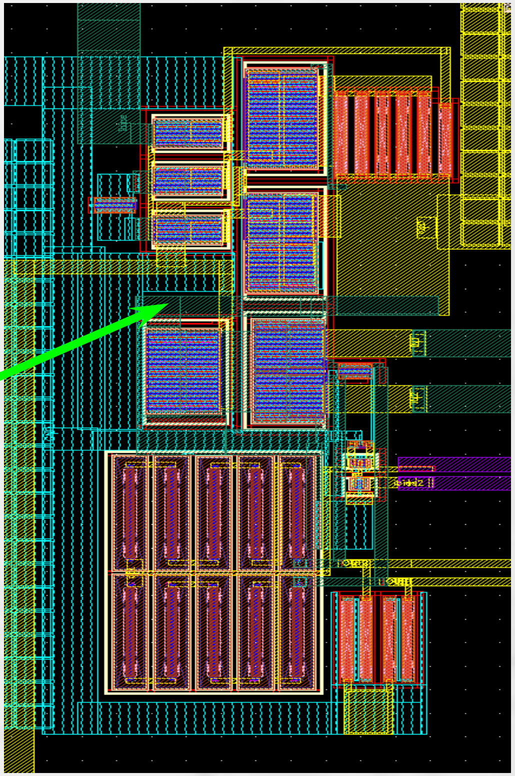


Large $V_{GS} - V_{TH}$ for high radiation tolerance

$g_m = 2 \cdot I_{DS}/(V_{GS}-V_{TH}) \Rightarrow I_{DS}\uparrow\uparrow$ & $V_{DSsat}\uparrow\uparrow$

Layout





Outline

- Introduction
- Radiation and temperature effects
- Constant g_m amplifier
- Matching structure
- Conclusions

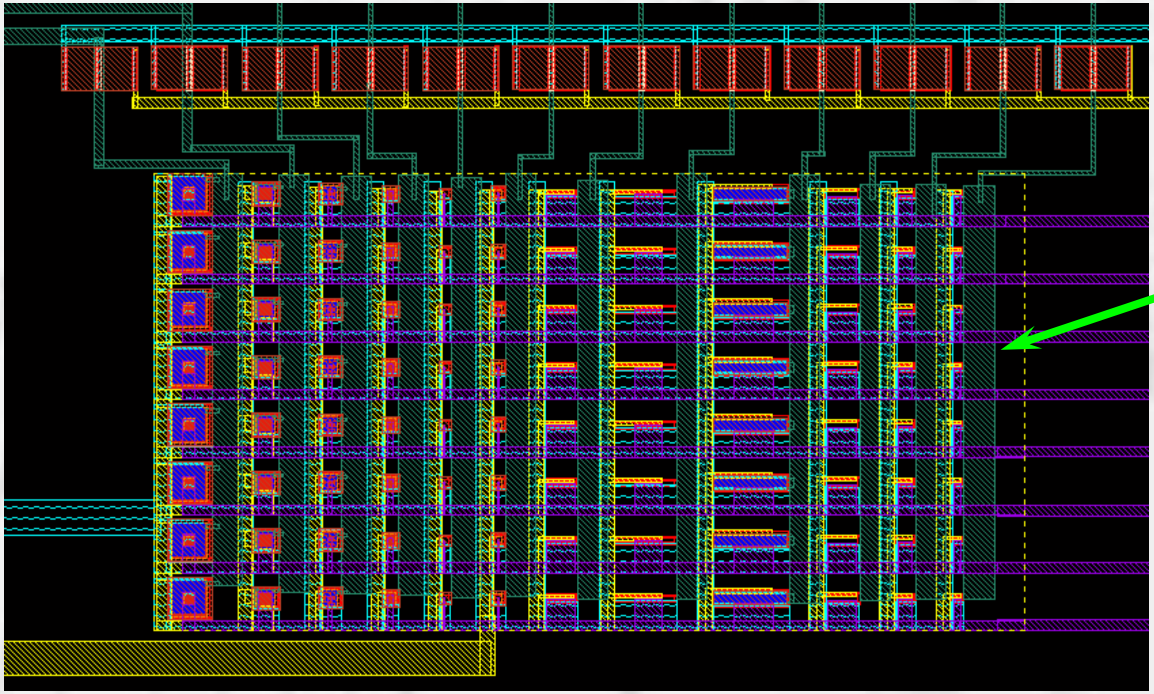
Matching

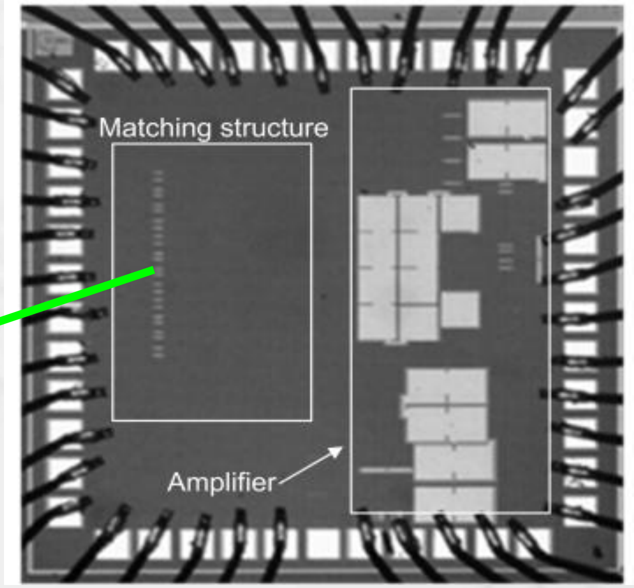
- Standard deviation between identical components fabricated on the same chip
  =>small statistic variations = MISMATCH
- Good matching
  - good PSRR, CMRR
  - Important for replica biasing
  - Reduces offset
- Matching of V_{th} depends strongly on area transistor

$$\sigma_{vth} = \frac{A_{vth}}{\sqrt{W * L}}$$

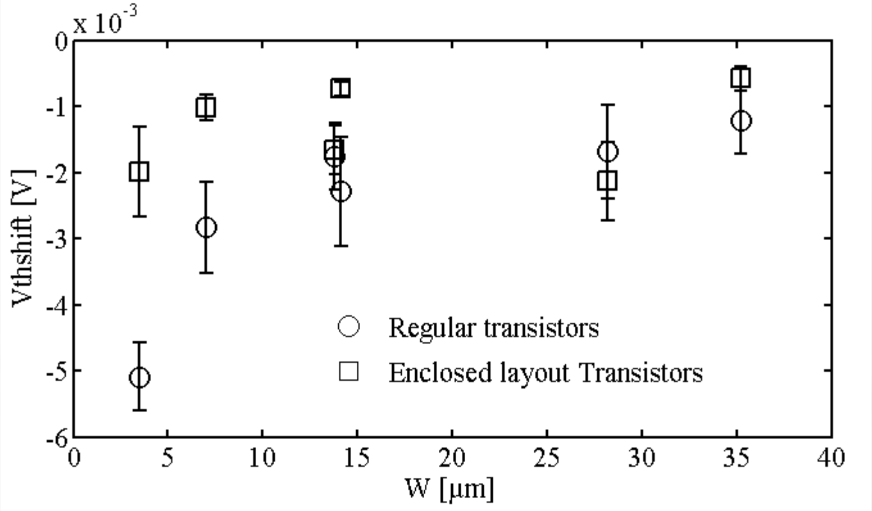
Matching

- Layout transistors on chip
  - Drains connected in each column
  - Gates connected in each row
  - Shared source and bulk
  - 6 regular transistors, 6 Enclosed layout transistors [G. Annelie et al.]





Radiation effects up to RD of 100kGy



Regular NMOS transistors

- Decrease of V_{TH}
  - Rebound effect
- RINCE effect [F. Faccio]
  - Different effect for large gates
  - Radiation Induced Narrow Channel Effect
- Standard deviation V_{TH} –shift! =>

$$\frac{\Delta gm}{gm} = \frac{1}{V_{GSTH}\left(1 - \frac{1}{\sqrt{B}} + \frac{V_{THsens}}{V_{GSTH}}\right)} \Delta V_{THsens}$$

ELT transistors

- No significant effects

Outline

- Introduction
- Radiation and temperature effects
- Constant g_m amplifier
- Transistor measurements
- **Conclusions**

Conclusions

- Effects of radiation and temperature
  - Change of transistor parameters
  - Varying gain
- Gain can be held stable with constant g_m amplifier
  - BW and GBW of optical receiver guaranteed
  - Open loop control
  - Generate bias voltages for whole chip with g_m biasing
  - Trade off: bandwidth ⇔ temperature tolerance
  - Trade off: current consumption & voltage headroom ⇔ rad. Tolerance
    - Larger V_{GS}-V_{TH} => V_{DSsat} ↑↑ ⇔ difficult to keep transistors in saturation at high temperatures.
- Matching results
  - Decrease of V_{TH}
  - V_{TH}-shift depending on transistor width
  - Standard deviation V_{TH} –shift

Questions

?

Acknowledgments to:

Institute for the Promotion of Innovation by Science and Technology in Flanders

SCK•CEN

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

References

1. M. Manghisoni, L. Ratti, V. Re and V. Speziali, "Radiation hardness perspectives for the design of analog detector readout circuits in the 0.18-µm CMOS Generation", Transactions on nuclear science, VOL. 49 NO. 6, December 2002
2. Hugh J. Barnaby, "Total-Dose Effects in Modern Integrated Circuit Technologies" IEEE NSREC, 2005
3. F. Faccio, G. Cervelli, "Radiation-Induced Edge effects in Deep Submicron CMOS transistors", Transactions on nuclear science, VOL. 52 NO. 6, December 2005
4. M. Willander and H. L. Hartnagel (eds.), High Temperature Electronics, Chapman & Hall, London, 1997.
5. P. C. de Jong, G. C. M. Meijer, and A. H. M. van Roermund, "A 300 °C dynamic feedback instrumentation amplifier," IEEE J. Solid-State Circuits, vol. 33, no.12, pp. 1999-2009, Dec. 1998.
6. Sean Nicalson and Khoman Phang, "Improvements in biasing and compensation of cmos opamps", ISCAS 2004
7. B. Razavi, "Design of analog integrated circuits"
8. G. Anelli et al.," Radiation tolerant VLSI circuits in standard deep submicron CMOS technologies for the LHC experiments: Practical design aspects," *IEEE Trans. Nucl. Sci*., vol. 46, no. 6, pp. 1690–1696, Dec.1999.