Impact of process variation on the circuit performance

(RO / LNA)

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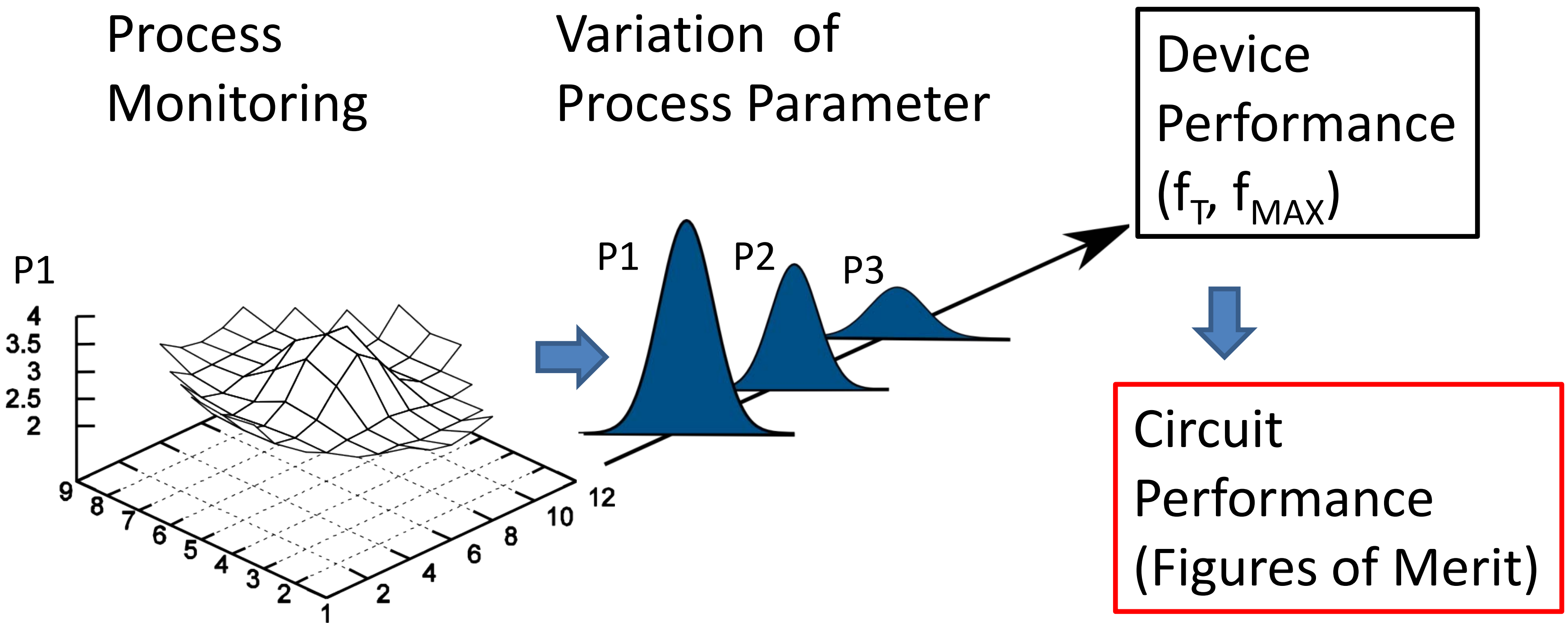
Overview

1. Introduction
2. Process Parameters
3. RO Investigations
4. LNA Investigations
5. Conclusion
6. Future Prospects

1. Introduction

→ Further device scaling increases the impact of process variations on the circuit performance



Process Monitoring

Variation of Process Parameter

Device Performance (f_T, f_{MAX})

Circuit Performance (Figures of Merit)

1. Introduction

- Methodology: The impact of 11 process parameters on 2 RF Designs is investigated
- Technology provided by ST Microelectronics → SiGe:C BiCMOS (B9MW)
- 1) Ring oscillator (RO) for 3.1GHz
  - Propagation delay 3.15ps
- 2) Low noise amplifier (LNA) for 94GHz

2. Process Parameters

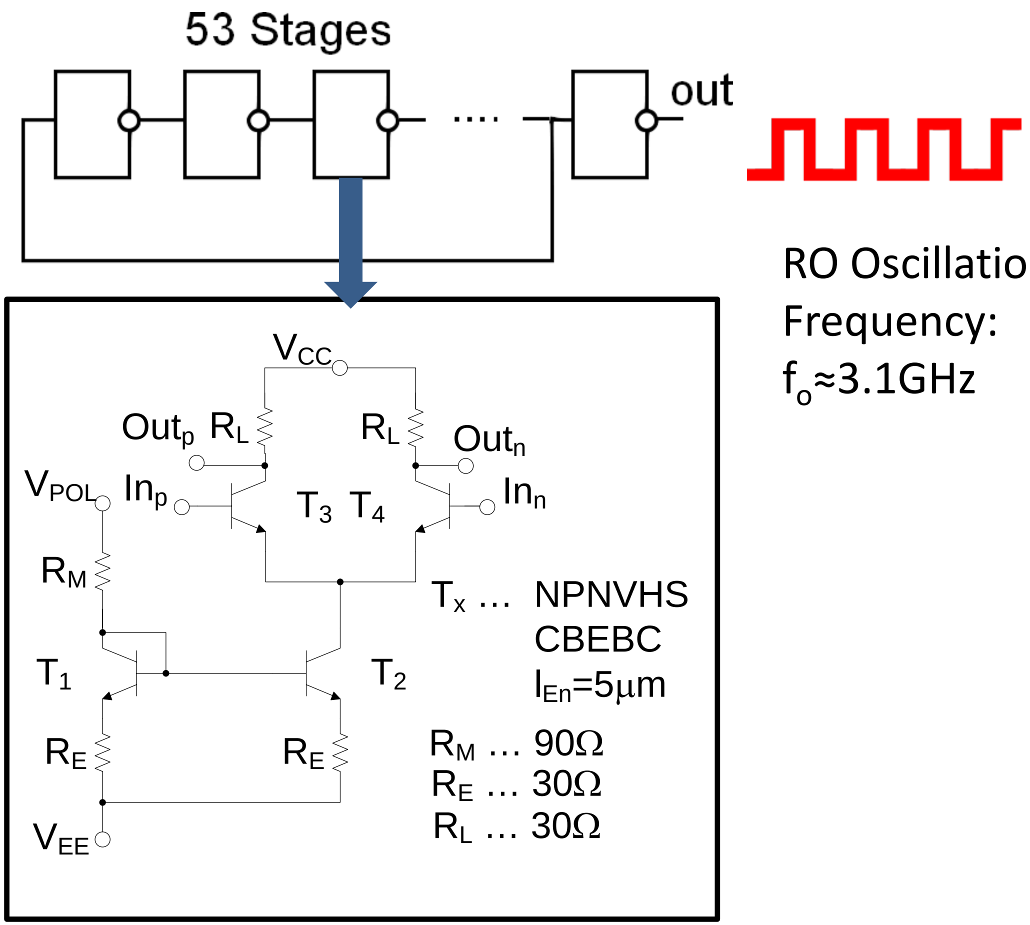
Name	Description	Determination
rsbx	Extrinsic base sheet resistance	PCM based parameter
rea	Emitter sheet resistance → Variation of emitter resistance	PCM based parameter
rsbl	Buried layer sheet resistance → Variation of buried layer resistance	PCM based parameter
rsbp	Pinch base sheet resistance → Variation of pinched base resistance	PCM based parameter
nepi	Epi layer doping parameter → Variation of SIC doping for BC capacitance variation	Fitting parameter

2. Process Parameters

Name	Description	Determination
nsub	Substrate doping level parameter → Variation of substrate doping level for CS capacitance variation	Fitting parameter
wepi	Thickness of epi layer → Variation of BC capacitance	Fitting parameter
rec	BE saturation current parameter → Base current is monitored and rec is fitted	Fitting parameter
deg	Impact of bandgap variation on Ic → Collector current is monitored and deg is fitted	Fitting parameter
irec	BE recombination saturation current parameter → Base current is monitored and irec is fitted	Fitting parameter
wctf	Tuning parameter for transit time → Monitoring of ft and wctf is fitted	Fitting parameter

3. RO Investigations

- CML differential inverter with a current mirror
- Biasing through V_{CC} and V_{POL}



T_x … NPNVHS CBEBC l_{En}=5μm

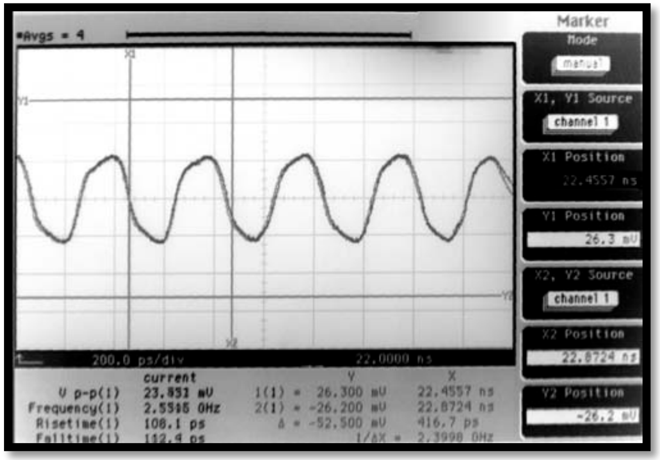
R_M … 90Ω

R_E … 30Ω

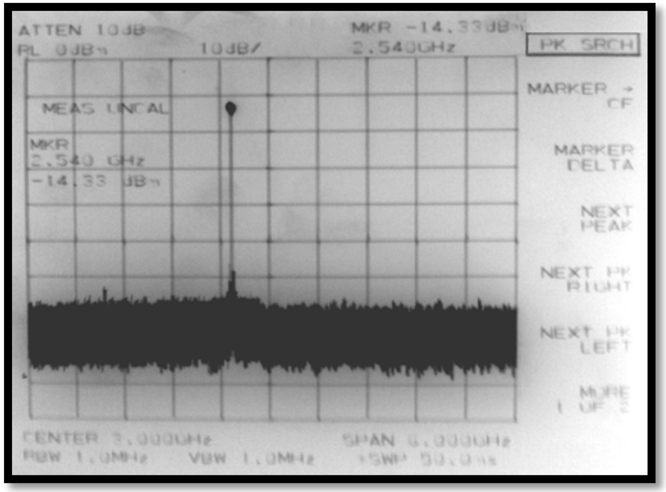
R_L … 30Ω

RO Oscillation Frequency: $f_o \approx 3.1\text{GHz}$

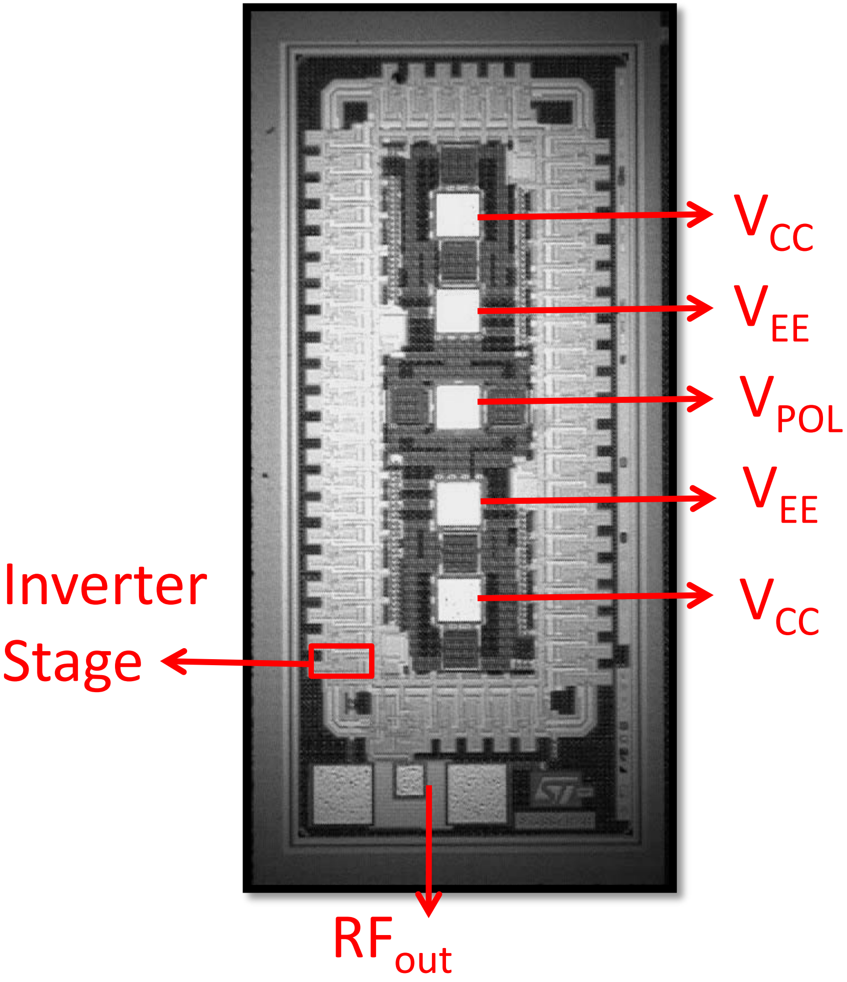
3. 2. RO: Measurements



```
22.4557 ns
26.3 mV
22.8724 ns
-26.2 mV
200.0 ps/div                     22.0000 ns
               current                   Y               X
     V p-p(1)  23.851 mV     1(1) =  26.300 mV   22.4557 ns
 Frequency(1)  2.5515 GHz    2(1) = -26.200 mV   22.8724 ns
  Risetime(1)  108.1 ps         Δ = -52.500 mV   416.7 ps
  Falltime(1)  112.4 ps                 1/ΔX =   2.3998 GHz
```

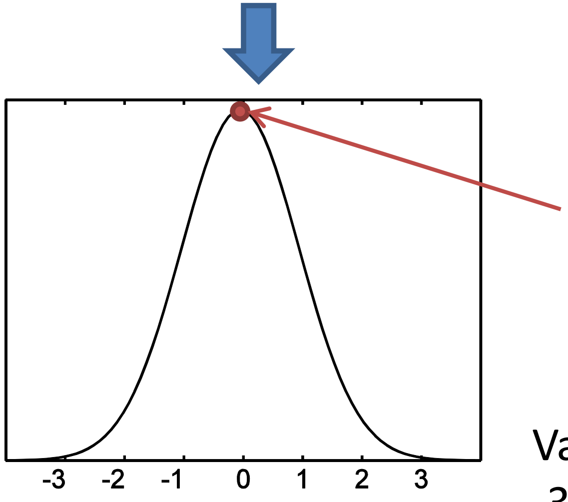


```
ATTEN 10dB                  MKR -14.33dBm
RL 0dBm       10dB/         2.540GHz
MKR
2.540 GHz
-14.33 dBm
CENTER 3.000GHz             SPAN 6.000GHz
RBW 1.0MHz    VBW 1.0MHz    SWP 50.0ms
```



3.3. RO: Impact of Process Parameters

Process Control Monitoring (PCM) of Extrinsic base sheet resistance

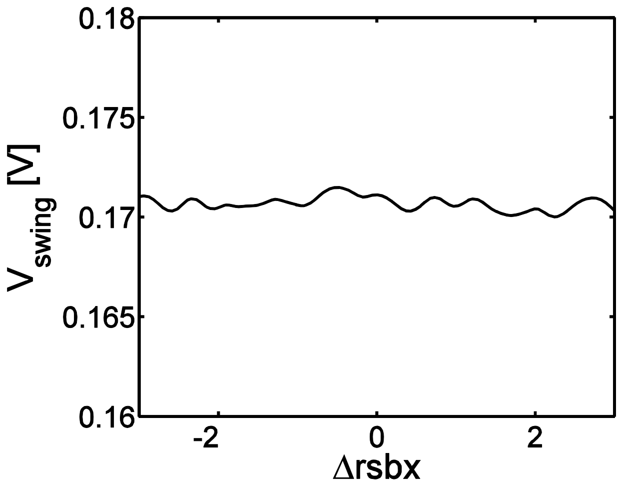


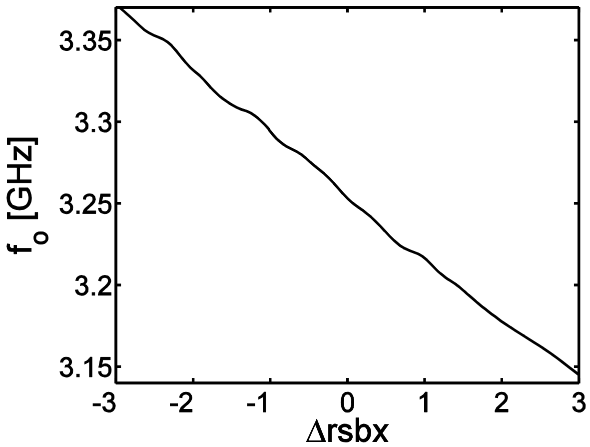
Typical Value

nsigma_rsbx

Variation between
-3σ and 3σ
= 50 simulations

→External Base Resistance: rbx=±10%
→RO Oscillation Frequency: f_o=±3%





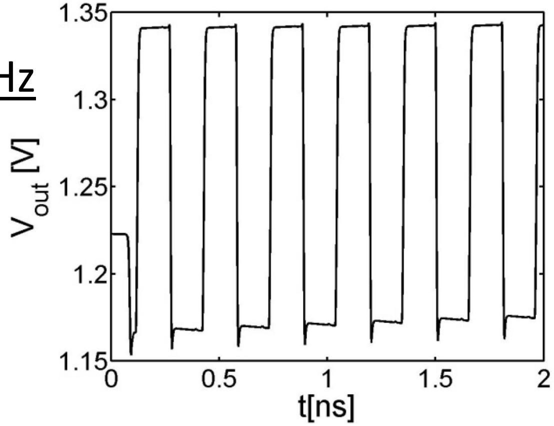
3.3. RO: Impact of Process Parameters

Optimized parameters:

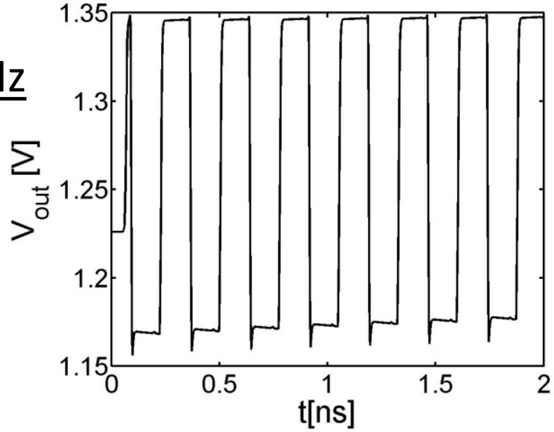
nsigma_rsbx=-3
nsigma_nepi=-3
nsigma_rsbp=3
nsigma_wctf=-3

For 99.7% of all devices the oscillation frequency can be differ:
$f_o=\pm11\%$

TYP:
f_o= 3.24 GHz

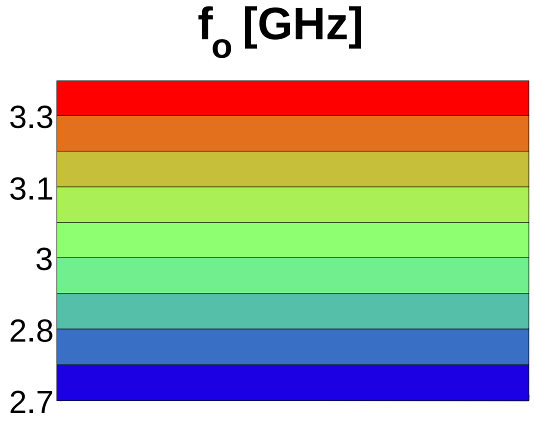


BEST CASE:
f_o= 3.62 GHz

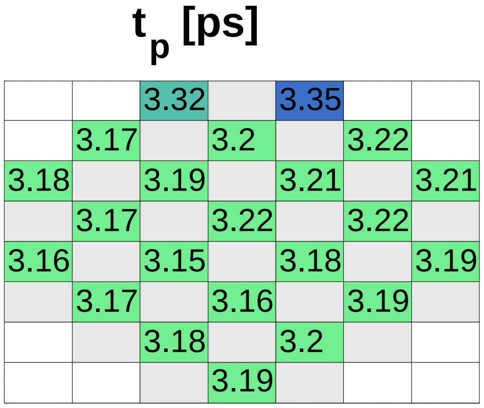


Biasing @ V_{cc}=3V and V_{pol}=1.9V

3.3 RO: Wafer Map: Propagation Delay



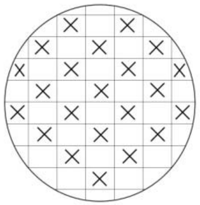
$$t_p = \frac{1}{2 \cdot 53 \cdot f_o}$$



		3.32		3.35		
	3.17		3.2		3.22	
3.18		3.19		3.21		3.21
	3.17		3.22		3.22	
3.16		3.15		3.18		3.19
	3.17		3.16		3.19	
		3.18		3.2		
			3.19			

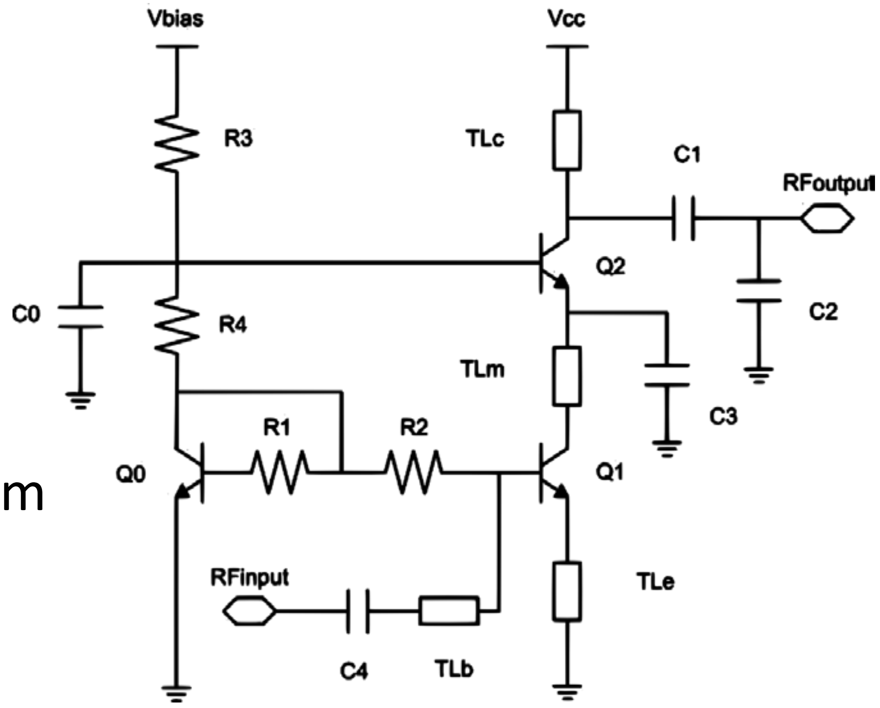
Biasing @ V_{cc}=3V and V_{pol}=1.9V

On one measured wafer the oscillation frequency differ: $f_o = \pm 3\%$



Crosses indicate measured devices

4. LNA Investigations



- Single cascode stage for 94.7 GHz

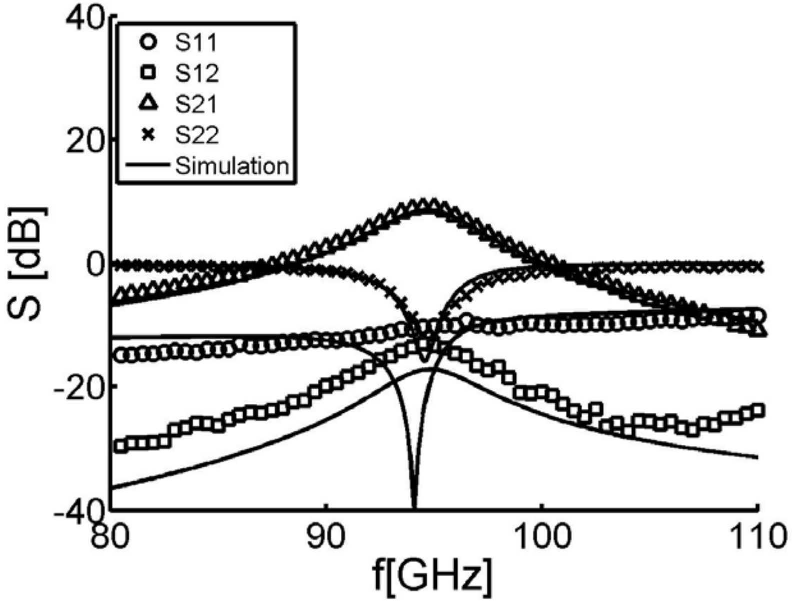
- Performance optimized through inter-stage matching inductor

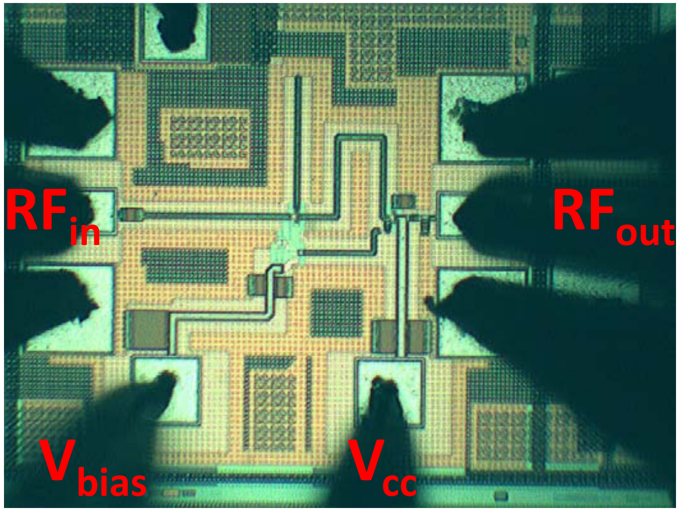
- 1µm emitter length in order to achieve current density for minimum noise figure (NF)

- Transistors Q1 and Q2 with five emitter fingers

Ref: R. R. Severino, J. B. Begueret, D. Belot, Y. Deval, and T. Taris, "A SiGe:C BiCMOS LNA for 94GHz band applications," presented at the BCTM, 2010.

4. LNA Investigations





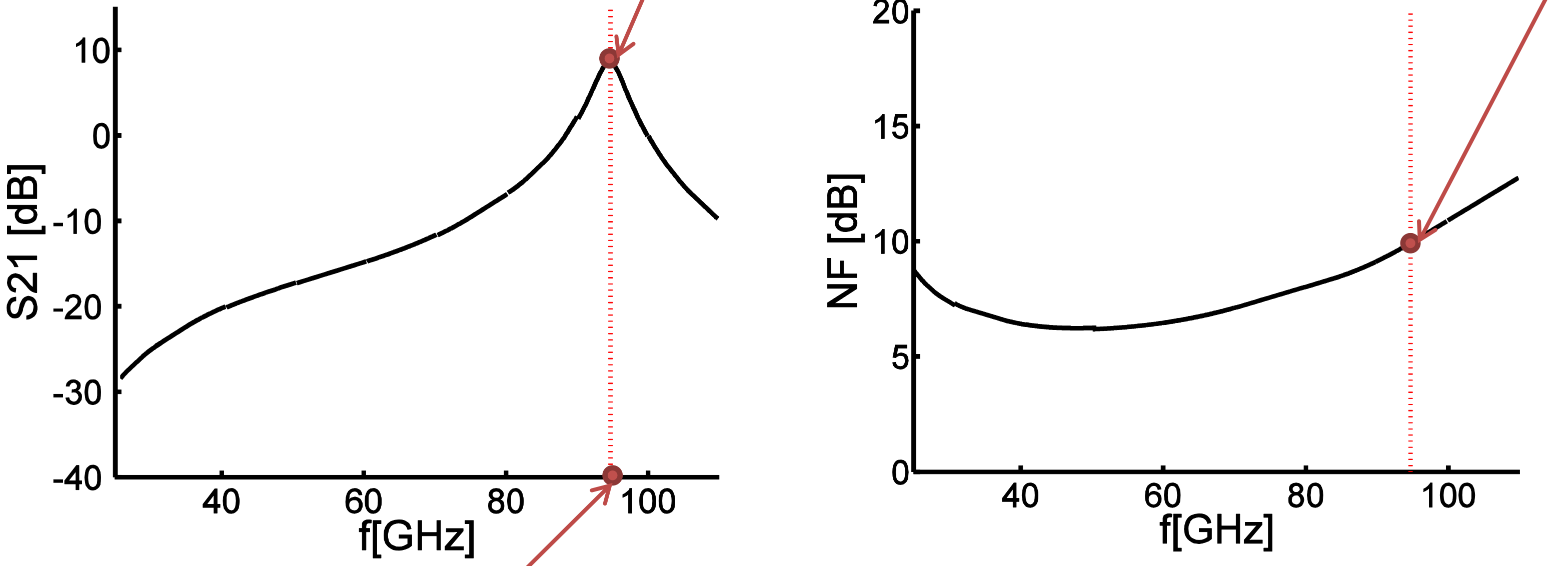
4.3. LNA: Figures of Merit

Maximum small signal gain

S_{21max}=8.625dB

Noise Figure

NF=9.265dB



Working Frequency

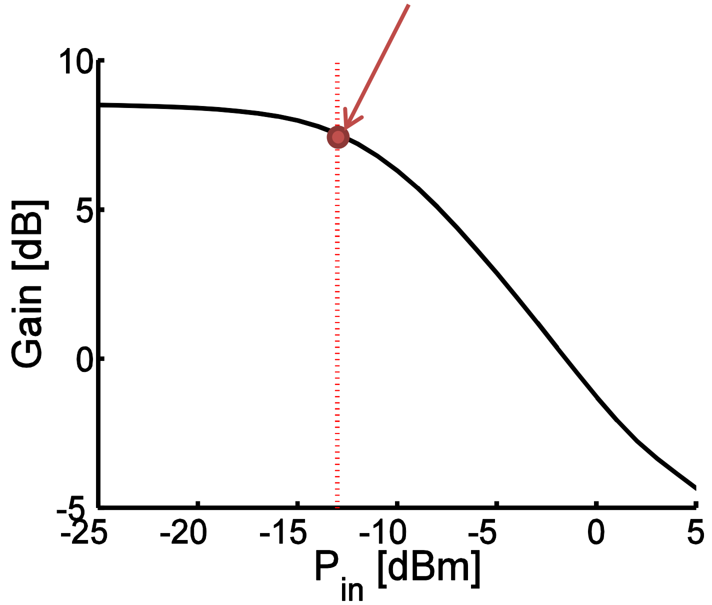
f_{LNA}=94.7GHz

4.3. LNA: Figures of Merit

1dB Compression Point

P_{in_1dB}=-13dBm

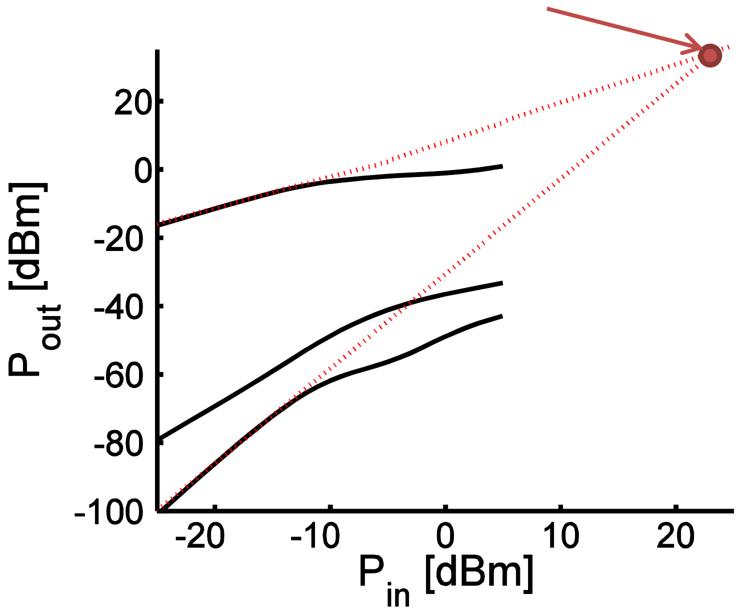
P_{out_1dB}=-5.43dBm



3rd Order Interception Point

IIP3=19.86dBm

OIP3=24.78dBm



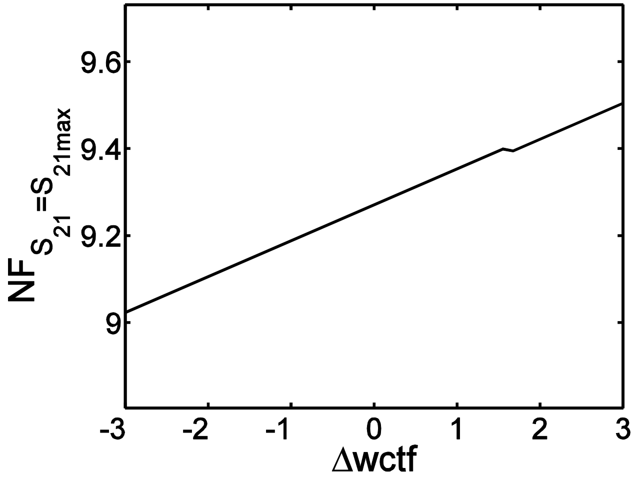
4.3. LNA: Impact of Process Parameters

nsigma_wctf

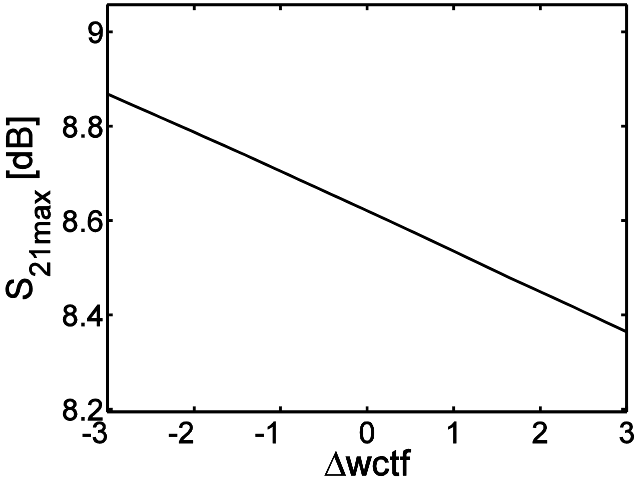
→Fitting parameter for the transit time

→ Changes the low-current forward transit time at V_{BC}=0V → t_0=±10%

Noise Figure

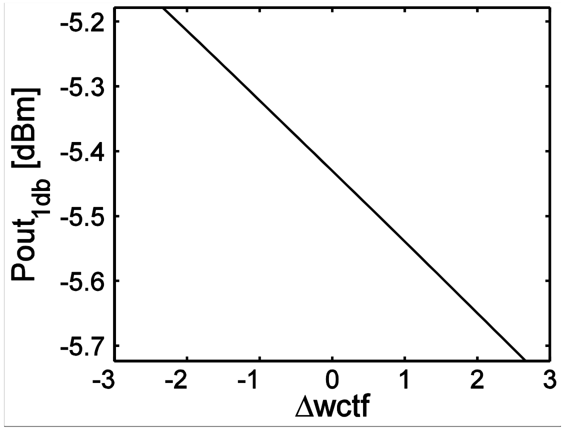


Maximum small signal gain

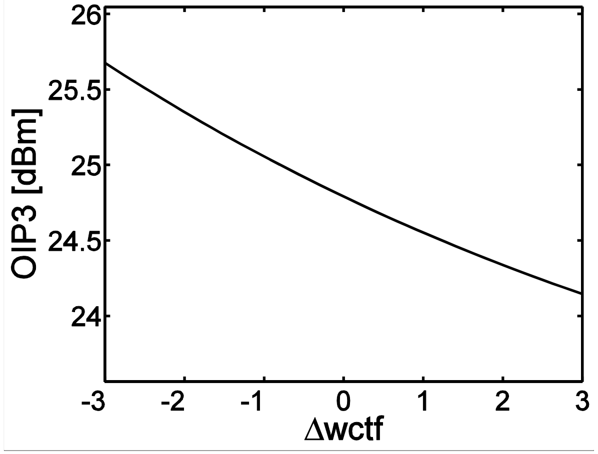


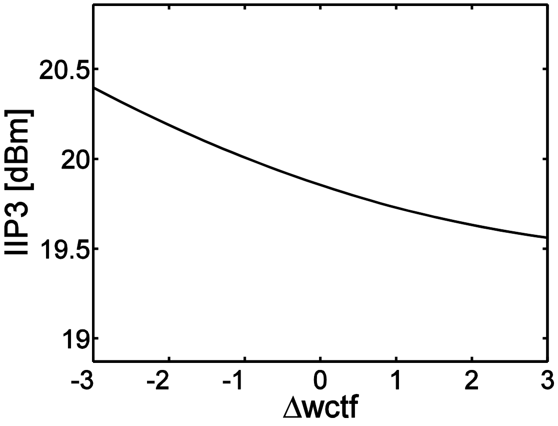
4.3. LNA: Impact of Process Parameters

1dB Compression Point



3rd Order Interception Point





→S_{21_max} =±2.94%
→NF =±2.62%
→$Pout_{1db}$=±2.36%
→IIP3 =±2.09%
→OIP3 =±3.08%

5. Discussion

Optimized parameters RO

nsigma_rsbx=-3
nsigma_nepi=-3
nsigma_rsbp=3
nsigma_wctf=-3

Can be influenced by the process engineers!?

Optimized parameters LNA

nsigma_rsbx=-3
nsigma_rsbp=3
nsigma_wctf=-3

Changed HICUM Parameters

nsigma_rsbx → rbx
nsigma_nepi → vdcx, rci0, cjci0, tr, vdci, cjcx0
nsigma_rsbp → qp0, vdei, cjep0, vdep, t0, tr, rbi0, cjei0
nsigma_wctf → t0

5. Conclusions

- Only 4 out of 11 process variation parameters affect Figures of Merit of the presented RO and LNA
- These 4 parameters enhance RO as well the LNA performance (in the same direction)
- nsigma_rsbx and nsigma_rsbp are PCM based parameters

6. Future Prospects

- Measurement of FOM variations of the LNA
- Apply the same methodology for Mixer and PA designed for B9MW technology
- Process optimization in order to increase circuit performance
- Improve robustness of circuit design due to process variations

Thank you for
your attention!

Acknowledgements: DOTFIVE, SIAM, Nano2012

Questions?

- E.g. What are the most important HiCuM parameters?

Process Parameter -> HICUM

Process Par.	Range	HICUM Par.	Rel. Change
nsigma_rsbx	[-3,3]	rbx	±10.33%
nsigma_rea	[-3,3]	re	±11.40%
nsigma_rsbl	[-3,3]	rcx	±9.25%
nsigma_rsbp	[-3,3]	qp0 vdei cjep0 vdep t0 tr rbi0 cjei0	±25.96% ±0.83% ±5.06% ±0.80% ±8.48% ±25.96% ±25.96% ±21.17%
nsigma_nepi	[-3,3]	vdcx rci0 cjci0 tr vdci cjcx0	±0.25% ±9.9% ±3.39% ±9.9% ±0. 37% ±6.87%

Process Parameter -> HICUM

Process Par.	Range	HICUM Par.	Rel. Change
nsigma_nsub	[-3,3]	cjs0 vds	±7.15e-6% ±2.31e-6 %
nsigma_wepi	[-3,3]	rci0 tr	±9.9% ±9.9%
nsigma_rec	[-3,3]	ibeis ibeps	±8% ±8%
nsigma_deg	[-3,3]	qp0 tr	±24.99% ±24.99%
nsigma_irec	[-3,3]	ireis ireps	±51% ±51%
nsigma_wctf	[-3,3]	t0	±10.5%

These values are valid for a device with CBEBC configuration, emitter length l_E=5 µm and emitter width w_E=0.27µm.