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Part 4
Design Methodology-Application to Low Noise Amplifier

"Scan me"

NEWCAS 2025

Sylvain Bourdel

https://github.com/ACMmodel/MOSFET_model
https://colab.research.google.com/drive/1s3PKF6pf3zIhlTj6jc-qhCLIcGfJ_UEE?usp=sharing#scrollTo=EMGo7aUzyukW

Agenda

- Overview of Design Methods for RFIC
- LNA Design Considerations
- Resistive Feedback LNA
- What we need in ACM-2
- Inversion Level Based Method for R-Feedback LNA with ACM-2

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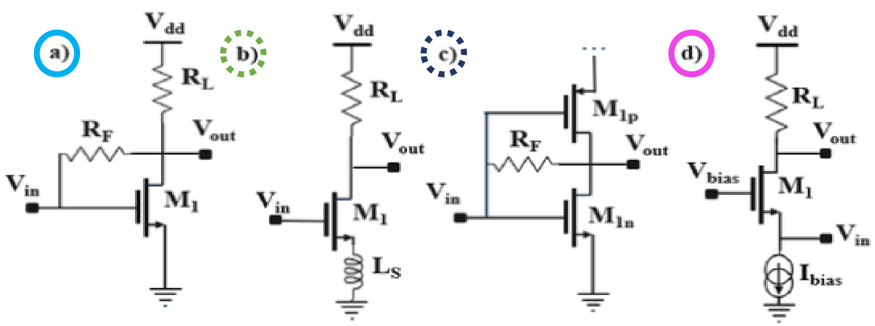
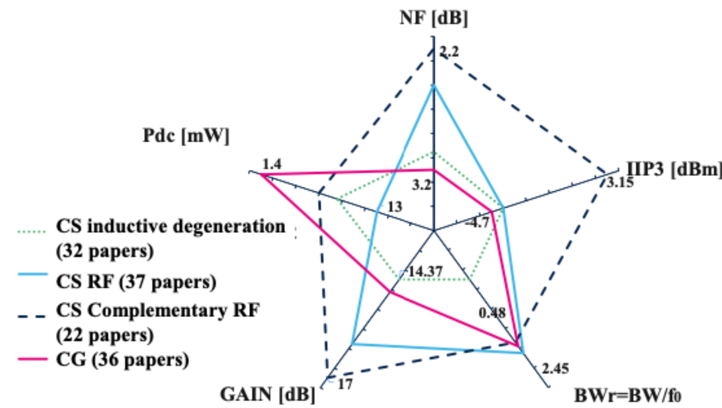
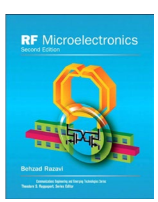
Overview of Design Methods for RFIC General Principle

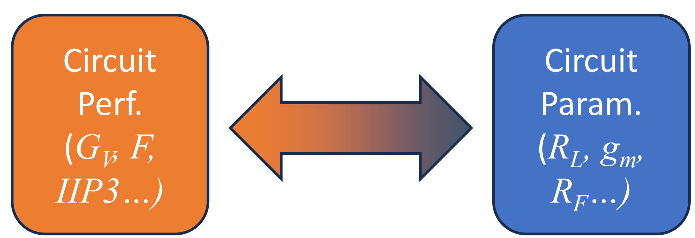
- 1st Step: Architecture Choice





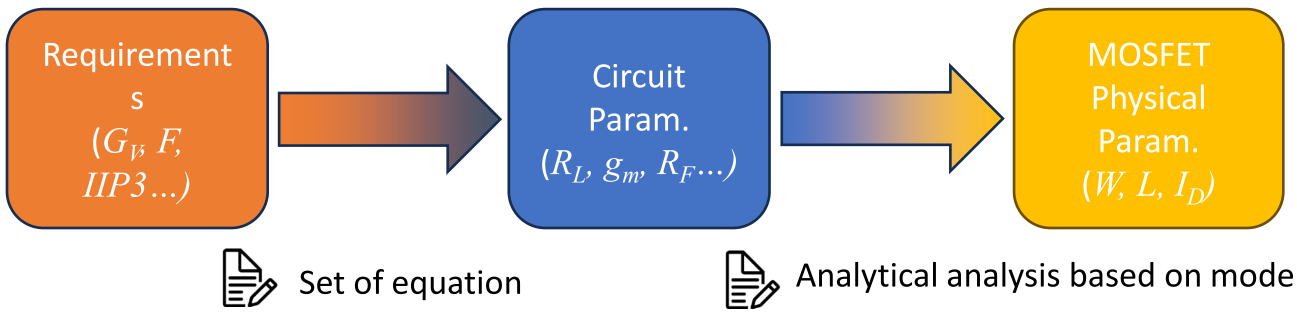
- 2nd Step: Circuit Analysis





$$|G_T| = |G_v| Q_{IN} = \frac{(G_m R_F - 1) R_O}{(R_O + R_F)} \sqrt{1 + Q_P^2}$$

- 3rd Step: Circuit Sizing



Overview of Design Methods for RFIC General Principle

- 3rd Step: Circuit Sizing

Requirements (G_V, F, $IIP3\ldots$) → Circuit Param. (R_L, g_m, $R_F\ldots$) → MOSFET Physical Param. (W, L, I_D)

Set of equation

Analytical analysis based on model

Region based model

sat. $$I_d = 2.K_n \frac{W}{L}\left[(V_{gs} - V_t)V_{ds} - \frac{V_{ds}^2}{2}\right]$$

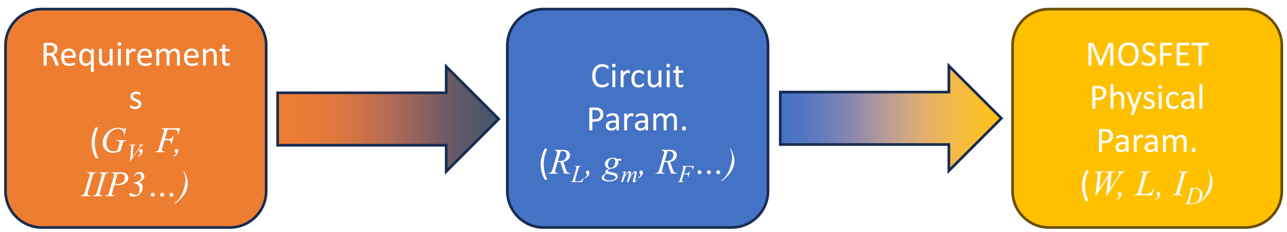
lin. $$I_d = K_n \frac{W}{L}(V_{gs} - V_t)^2\left(1 + \frac{k_{en}}{L}V_{ds}\right)$$

PROS: simple

CONS: Inaccurate with short channel MOS

Overview of Design Methods for RFIC General Principle

- 3rd Step: Circuit Sizing



Set of equation

Analytical analysis based on model

Electrical simulation based on model

BSIM3 / UTSOI compact model

PROS:

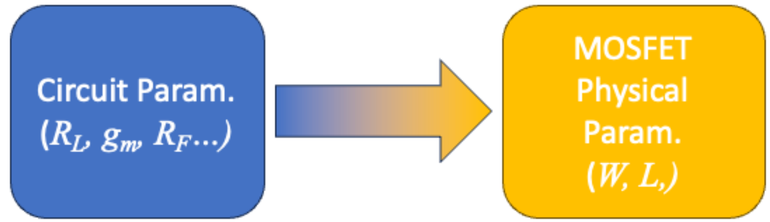
- *Accurate*
- *Direct relationship between requirements and physical parameters*

CONS:

- *Increases the gap between Physic and design*
- *Long optimization*

Overview of Design Methods for RFIC New Trends

- **Issue in the sizing step**



?
  - How to maintain simplicity **and** accuracy with the scaling and especially Short Channel Effects (SCE) at the sizing step.
?

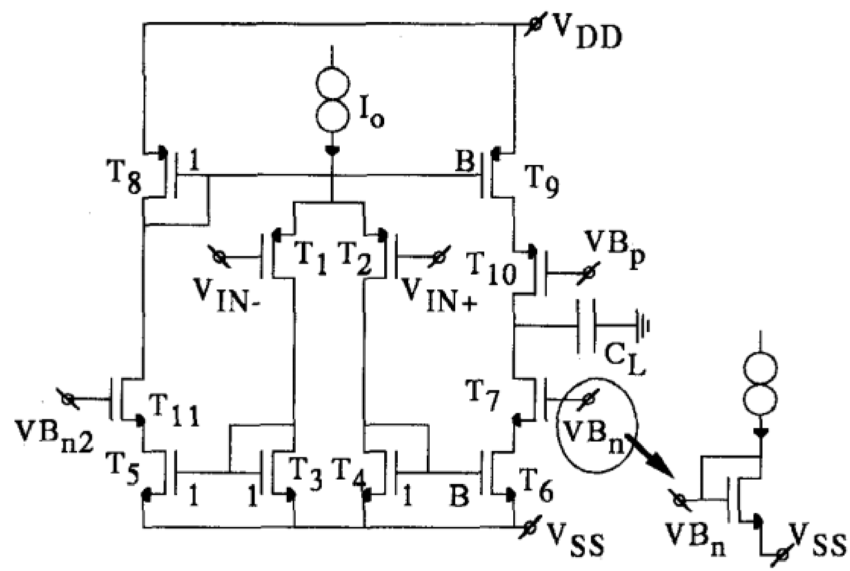
- **A possible solution**
  - g_m/Id design approaches
    - LUT based
    - ACM or EKV based

Overview of Design Methods for RFIC g_m/Id approach based on LUT

[Silveira, Flandre, Jespers – JSSC 1996]

General Principle

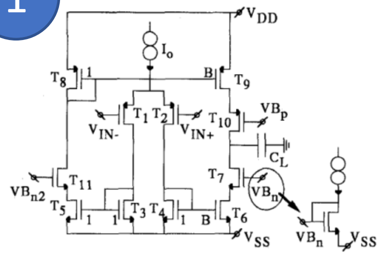
- For a given structure



Overview of Design Methods for RFIC g_m/Id approach based on LUT

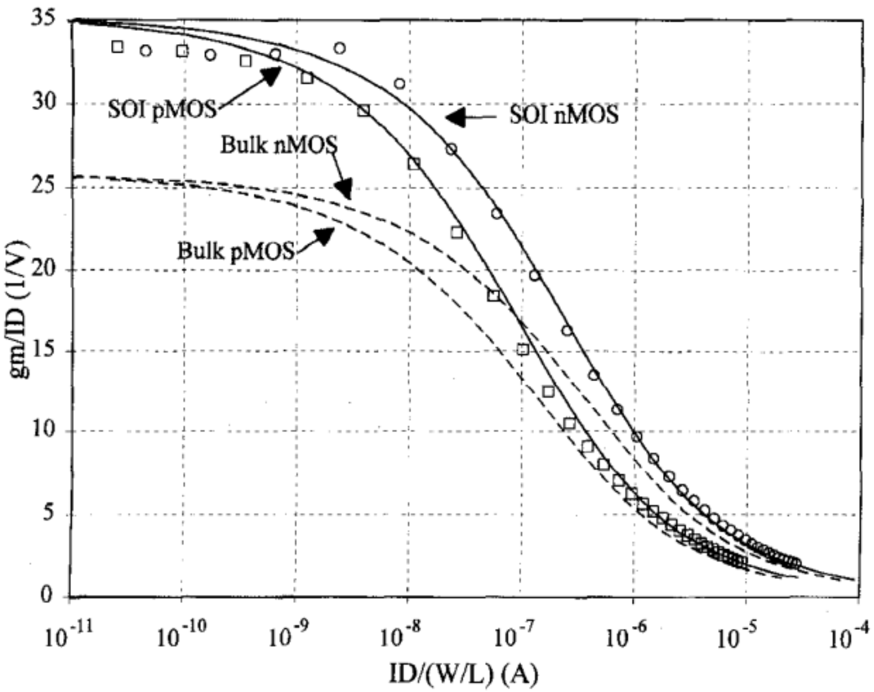
General Principle

1



- For a given structure

- Methods are based on
  ⇒ Extraction of MOS parameters (LUT)
    - $I_D/(W/L)$ vs g_m/I_D
    - g_m/I_D vs V_{gs0}

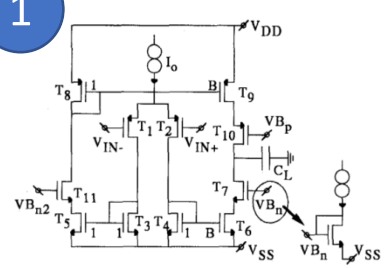


Overview of Design Methods for RFIC

g_m/Id approach based on LUT

General Principle

1



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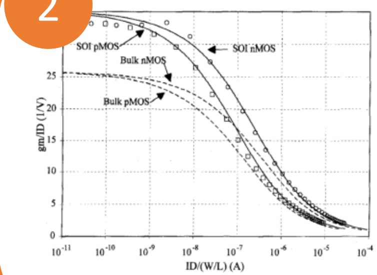


- For a given structure

- Methods are based on
  - $\Rightarrow$ Extraction of MOS parameters (LUT)
    - $I_D/(W/L)$ vs g_m/I_D
    - g_m/I_D vs V_{gs0}
  - $\Rightarrow$ Set of equations

$$SR = \frac{B \cdot I_{D1}}{C_L}$$

$$f_T = \frac{B \cdot g_{m1}}{2\Pi \cdot C_L} \quad (5)$$

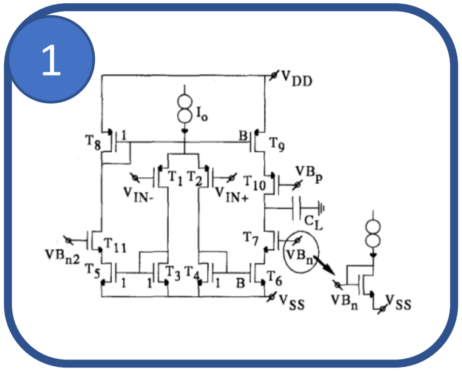
$$A_0 = \left(\frac{g_m}{I_D}\right)_1 \cdot \left(\frac{g_m}{I_D}\right)_2 \cdot \frac{1}{\frac{1}{V_{A6} \cdot V_{A7}} + \frac{1}{V_{A9} \cdot V_{A10}}} \quad (4)$$

Overview of Design Methods for RFIC

g_m/Id approach based on LUT

General Principle

1



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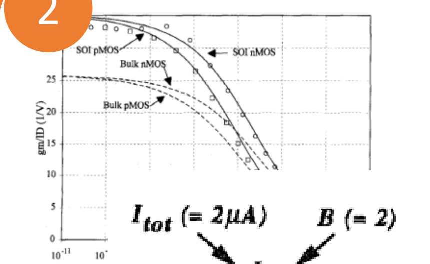


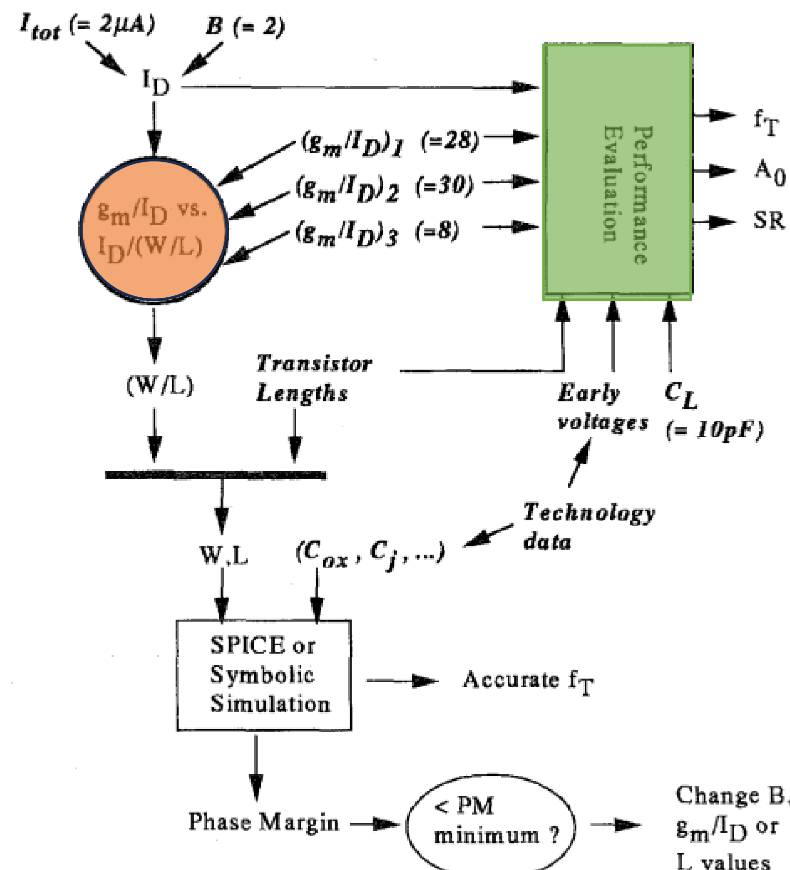
3

$$SR = \frac{B \cdot I_{D1}}{C_L}$$

$$f_T = \frac{B \cdot g_{m1}}{2\Pi \cdot C_L} \quad (5)$$

$$A_0 = \left(\frac{g_m}{I_D}\right)_1 \cdot \left(\frac{g_m}{I_D}\right)_2 \cdot \frac{1}{\frac{1}{V_{A6} \cdot V_{A7}} + \frac{1}{V_{A9} \cdot V_{A10}}} \quad (4)$$

- For a given structure
- Methods are based on
  - ⇒ Extraction of MOS parameters (LUT)
    - $I_D/(W/L)$ vs g_m/I_D
    - g_m/I_D vs V_{gs0}
  - ⇒ Set of equations
- Methods helps the designers in sizing the structure
- Quite used in low frequency domain



Overview of Design Methods for RFIC
g_m/Id approach based on LUT

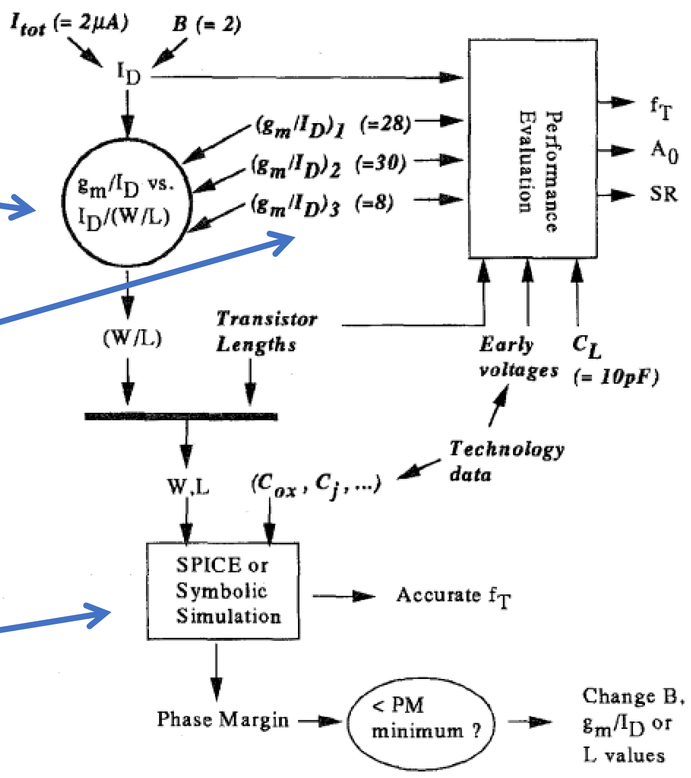
LIMITATIONS ?

- Time Consuming

- Lakes of precision (parametric set of characteristics)

- Long optimization sequence

Need for a model based approach

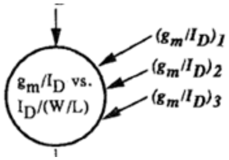


Overview of Design Methods for RFIC

g_m/Id approach based All Region Models (ACM/EKV)

All Region 3PM model

- EKV – [Enz, Krummenacher, Vittoz]
- ACM – [Schneider, Galup]



$$\frac{I_D}{(W/L)} = i_f I_{S0}$$

- With a 3PM model we have :

$$\frac{g_m}{I_D} = \frac{2}{n\phi_t\left(1+\sqrt{1+i_f}\right)} \qquad g_m = \frac{2I_S}{\phi_t}\left(\sqrt{1+i_f}-1\right) \qquad V_P - V_{S(D)} = \phi_t\left[\sqrt{1+i_{f(r)}}-2+\ln\left(\sqrt{1+i_{f(r)}}-1\right)\right]$$

$$V_P \cong \frac{V_G - V_{T0}}{n}$$

- PROS: The sizing is straightforward
- CONS: Inaccurate with SCE
  Non-linearities can't be captured
  gds effect can't be captured

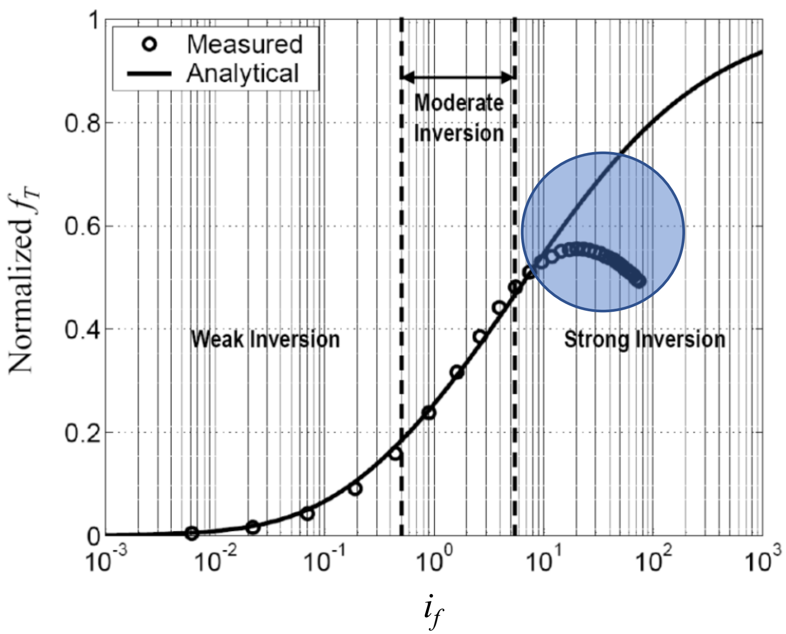
Can we design RFICs ?

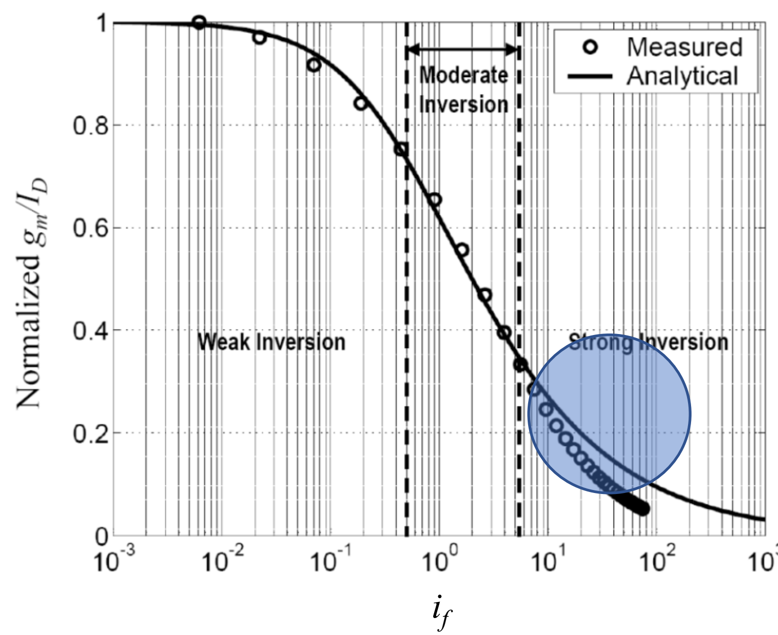
Overview of Design Methods for RFIC
g_m/Id in RFIC design

Design Regions

Year 2000 (RF-180nm)

- f_t grows with i_f





Overview of Design Methods for RFIC

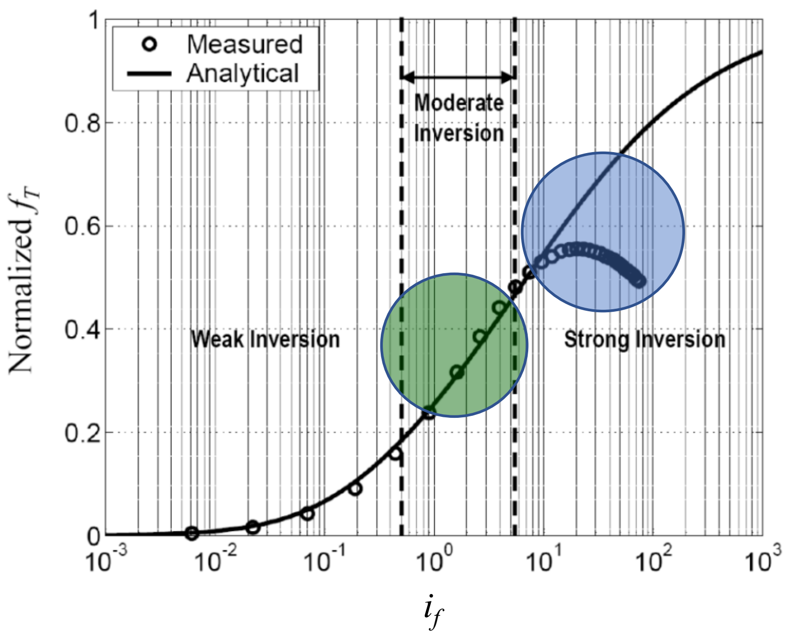
g_m/Id in RFIC design

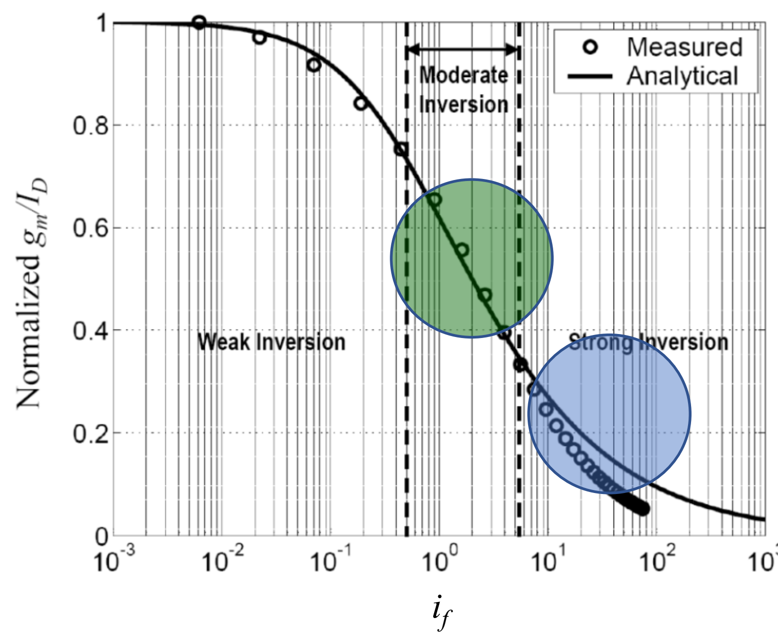
Design Regions

- f_t grows with i_f but g_m/I_D reduces with i_f

Year 2000 (RF-180nm)

Year 2016 (RF-22nm) up to now





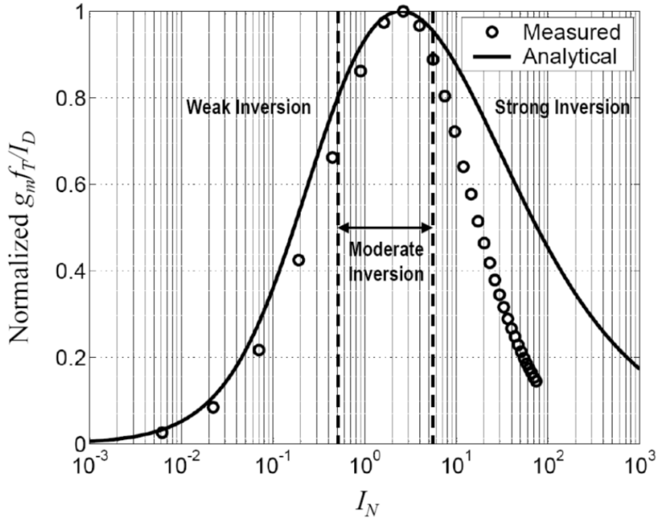
$g_m f_t/I_D$: A First Approach

A. Shameli et P. Heydari, « Ultra-Low Power RFIC Design Using Moderately Inverted MOSFETs: An Analytical/Experimental Study », *RFCI*, 2004.

- For RF design
- A FOM that maximize the gain bandwidth product

$$\frac{g_m f_T}{I_D}$$

- Gives the i_f that produces the best GBW product
- Not optimal :
  - the gain or the bandwidth might be oversized.
  - Do not depends on the topology



Overview of Design Methods for RFIC

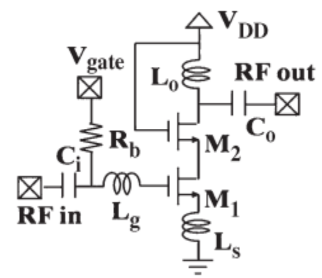
g_m/Id in RFIC design

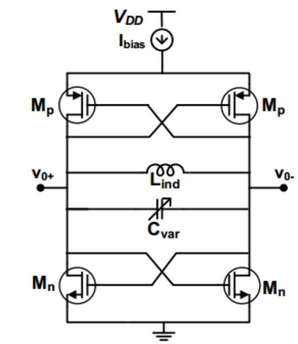
LNA

LO

Function Based FoM

- For a given Function
- Define a FoM for the function
- Find the i_f that maximizes the FoM



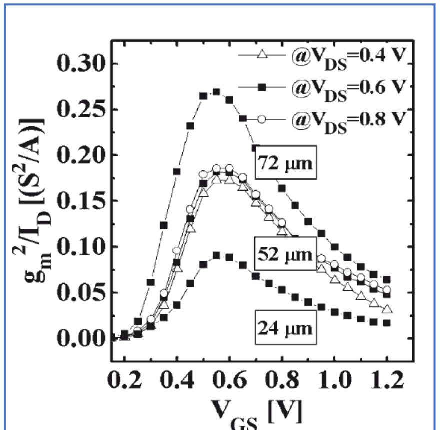


$$\mathrm{FoM}_{\mathrm{LNA}} = \frac{G}{(F-1)\cdot P} \propto \frac{g_m^2}{\left(\frac{I_D}{g_m^2}\right)\cdot I_D} \propto \left(\frac{g_m^2}{I_D}\right)^2$$

I. Song et B.-G. Park, « A Simple Figure of Merit of RF MOSFET for Low-Noise Amplifier Design », *Electron Device Lett. IEEE*, vol. 29(12), 2008.

$$PN(\Delta f) = 10log\left(\frac{k_B T \pi^2}{64Q^2}\frac{g_m}{I_D}\frac{1}{I_D}\frac{f_0}{(\Delta f)^2}\lambda\right)$$

R. Fioreli ; J. Núñez ; F. Silveira; "All-Rnversion region gm/ID methodology for RF circuits in FinFET technologies" *2018 NEWCAS*

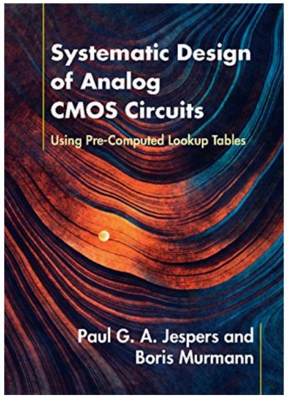


Overview of Design Methods for RFIC
g_m/Id in RFIC design

Circuit Based Method

Circuit Sizing Based on LUT

- For a given Circuit
- Similar to the one introduced by Silveira, Flandre, Jespers in 1996
- Capacitance and noise effects can be captured in LUT for bandwidth and noise analysis
- Well known and well referenced
- But …
    - Still complicated
    - The gap between physics and design remains
    - No analytical relationships to size « by hand »



Circuit Sizing Based on ACM

- Equations can be derived for a given circuit
- Quasi analytical approach
    - R-F LNA designed with 3PM-ACM [Bourdel - ICECS 2019]
- Gds and gm3 (NL) are taken into account
    - R-F LNA designed with 7PM-ACM [Bouchoucha – ISCAS 2023]
    - CG LNA designed with 5PM-ACM2[Alves Neto – ACCESS 2024]

RESEARCH ARTICLE

Resistive Feedback LNA design using a 7-parameter design-oriented model for advanced technologies

Mohamed Khalil Bouchoucha[1,2], Dayana A. Pinc… …lippe Cathelin[1], Jean-Michel Fournier[2], Manuel J. Barragan… …Bourdel[2]

[1]STMicroelectronics, 38920 Crolles, France, [2]TIMA I… …é Grenoble Alpes, 38000 Grenoble, France

All Ressources accessible for free

https://github.com/ACMmodel/MOSFET_model

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LNA Design considerations

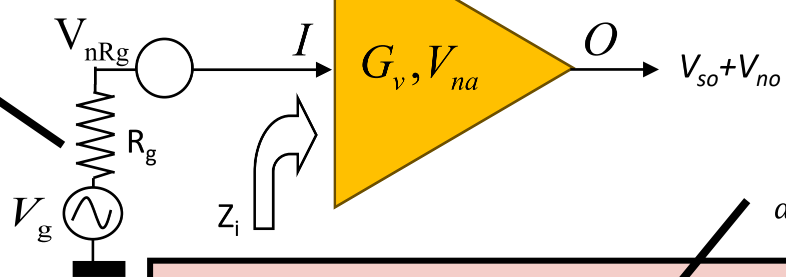
Noise Factor

- NF is the signal to noise ratio (SNR) degradation (Eq. 1)

$$F = \frac{(S/N)_i}{(S/N)_o} \quad (1)$$

$$\overline{v_{nRg}^2} = 4KTR_g$$

$$V_{RMS\_nRg} = \sqrt{4KTR_g \Delta f}$$



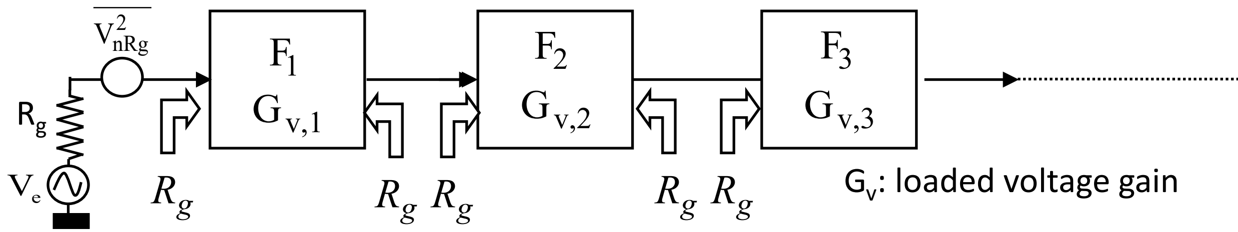
$$\alpha = \left\| \frac{Z_i}{Z_i + R_g} \right\|$$

$$F = \frac{V_{si}^2/V_{ni}^2}{V_{so}^2/V_{no}^2} = \frac{V_g^2/V_{nRg}^2}{V_{so}^2/V_{no}^2} = \frac{V_{no}^2}{\alpha^2 . G_v^2 . V_{nRg}^2} = \frac{\overline{v_{no}^2}}{\alpha^2 . G_v^2 . \overline{v_{nRg}^2}}$$

$$F = \frac{\text{total output noise}}{\text{total output noise of the ideal (no aditive noise) device}} \quad (2)$$

- NF also express the quantity of noise added by the stage regarding the noise delivered by the source (R_g) on Δf. (Eq. 2)

LNA Design considerations
Friss Formula



G_v: loaded voltage gain

$$F = F_1 + \frac{(F_2 - 1)}{G_{v,1}^2} + \frac{(F_3 - 1)}{G_{v,1}^2 . G_{v,2}^2} + \ldots\ldots$$

This formula is valid only for real impedances and in case of power matching: (Z_s=Z_e=R_g)

In RFIC, impedances are complex and never equal. This formula cannot be used as is. However, the following statements remain valid in RFIC.

The gain of the first stages reduces the NF of the following ones.

=> The receiver chain must start by amplifiers

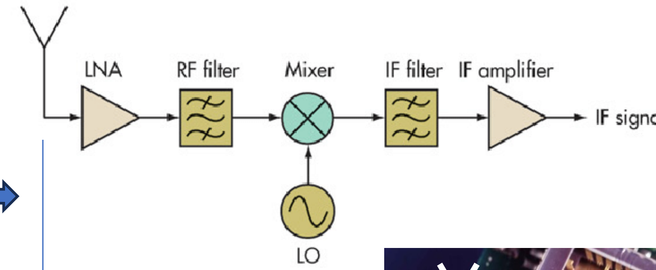
=> The NF of the first stage must be as low as possible

LNA

Note that lossy stages (G_v<1) increase the NF, especially when they are in front of the receiver chain ***(antenna filter, image rejection filter, antenna switch).***

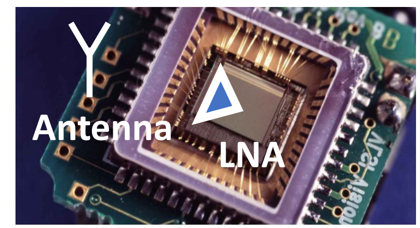
LNA Design considerations
Input patching

System point of vue



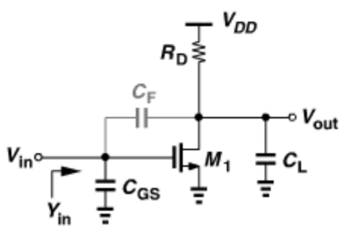
- LNA is the first device due to Friss formula
- Antenna is mainly 50 Ω.

$Z_{lna}=Z_g{}^*$



In CMOS

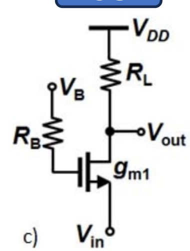
- Generally, the input impedance is capacitive Re (Y11) is very low
- For exemple : CS amplifier



$$\Re(Y_{in}) = R_D \| 1/g_m$$

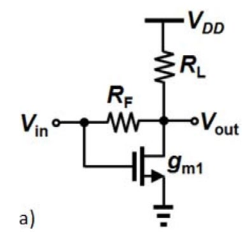
$$\Im(Y_{in}) = \frac{1}{C_{GS}C_F\omega}$$

CG



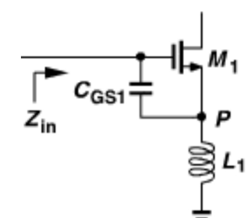
$$\Re(Z_{in}) = \frac{1}{g_{m1}}$$

R-Feedback



$$\Re(Z_{in}) = \frac{R_F}{1+|A_V|}$$

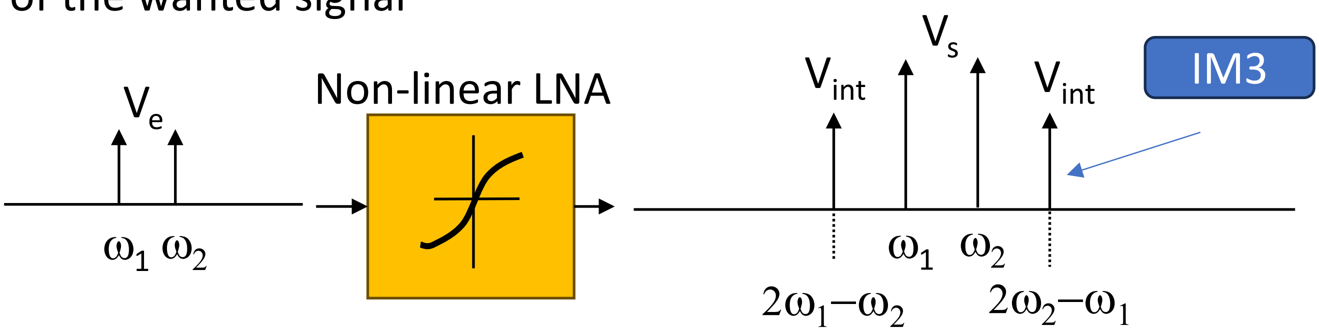
Inductive Degeneration

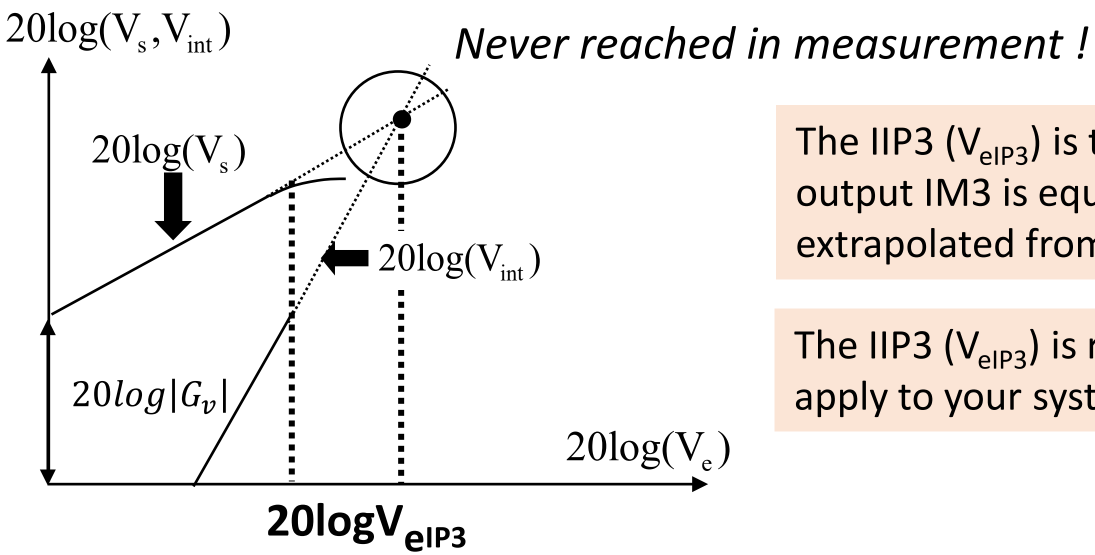


$$\Re(Z_{in}) = \frac{g_m L_1}{C_{GS}}$$

LNA Design considerations
Non-Linearities

ω_1 and ω_2 are 2 harmonics of the wanted signal





The IIP3 (V_{eIP3}) is the input signal level for which the output IM3 is equaling the fundamental harmonic (Vs) extrapolated from small signal (AC).

The IIP3 (V_{eIP3}) is related to the maximum power you can apply to your system

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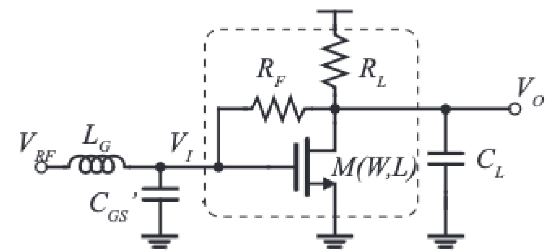
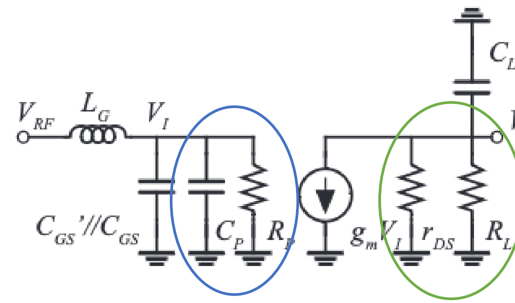
Resistive Feedback LNA

Topology

R-Feedback general considerations

- Simple
- Compact (No-inductors)
- Wideband
- RF allows to synthesize a real part in Zin
- LG and CGS’ will help in cancelling the imaginary part
- while controlling Qin





Input impedance

$$Z_{IN} = L_G s + \left(\frac{1}{(C_{GS} + C'_{GS})s} // Z_P \right)$$

$$\boxed{\Re(Zp) = R_P = \frac{R_O + R_F}{1 + G_m R_O},}$$

$$\boxed{C_P = \frac{R_O^2 C_L (G_m R_F - 1)}{(R_O + R_F)^2}}$$

$$\boxed{R_O = \frac{R_L r_{DS}}{R_L + r_{DS}}}$$

$$\Re(Z_{IN}) = R_S = \frac{R_P}{(1 + Q_P^2)} = 50\ \Omega \qquad Q_P = R_P C_T \omega_0 \qquad C_T = C_{GS} + C'_{GS} + C_P$$

$$\Im(Z_{IN}) = 0 = L_G s + \frac{Q_P^2}{C_T s (1 + Q_P)^2}$$

Note :

$$\begin{cases} \Re(Zp) = \dfrac{1 + \left(\frac{f}{f_c}\right)^2}{\frac{1 + G_m R_O}{R_O + R_F} + \frac{1}{R_F}\left(\frac{f}{f_c}\right)^2}, \\ \Im(Zp) = -\left(1 + \dfrac{R_F}{R_O}\right)^2 \dfrac{1 + \left(\frac{f}{f_c}\right)^2}{2\pi f C_L (G_m R_F - 1)} \end{cases}$$

Reduces For

$$\frac{f_c}{f} = N > 3$$

Resistive Feedback LNA

Topology

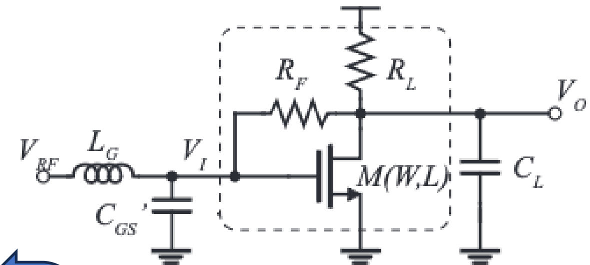
Voltage Gain

$$|G_o| = \left|\frac{V_O}{V_{RF}}\right| = \frac{|G_T|}{\sqrt{\left(1+\left(\frac{f_0}{f_c}\right)^2\right)}}$$

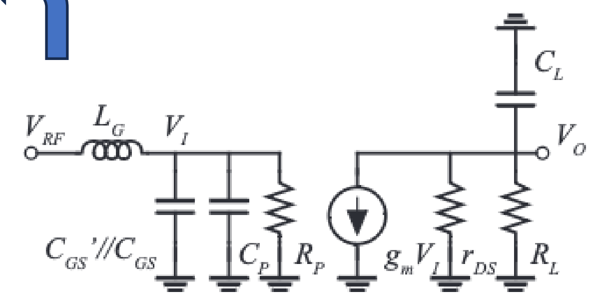
$$|G_T| = |G_v|Q_{IN} = \frac{(G_m R_F - 1)R_O}{(R_O + R_F)}\sqrt{1+Q_P^2}$$

$$\frac{f_c}{f_0} = N > 3$$

$$Q_{IN} = V_I/V_{RF} \qquad Q_{IN} = \sqrt{1+Q_P^2} = \sqrt{\frac{R_O + R_F}{R_S(1+G_m R_O)}}$$



R_S
(the source resistance seen
at the 50 Ω input)



BW

$$f_c = \frac{R_O + R_F}{2\pi R_O R_F C_L} = N f_0$$

Noise Figure

$$F = 1 + \frac{4\left(\frac{R_F}{Q_{IN}^2} + R_S\right)^2}{Q_{IN}^2 G_m R_S \left[\frac{R_F}{Q_{IN}^2} + R_S + \frac{G_m R_S R_F R_L)}{R_F + R_L}\right]^2}\left[\gamma + \frac{1}{G_m R_L} + \frac{\left(1 + \frac{Q_{IN}^2 G_m R_S R_F}{R_F + Q_{IN}^2 R_S}\right)^2}{G_m R_F}\right]$$

$$\left(F_{min} = 1 + \frac{(1+G_m\ )R_S{}^2 R_F}{R_S\,(1-G_m\ R_F)^2} + \frac{\gamma\, g_m\,(R_S + R_F)^2}{R_S\,(1-G_m\ R_F)^2} + \frac{(R_S + R_F)^2}{R_S\, R_L(1-G_m\ R_F)^2}\right)$$

IIP_3

$$V_{IIP3} = \frac{2}{Q_{IN}}\sqrt{\frac{2G_m}{G_{m3}}}$$

Agenda

- Overview of Design Methods for RFIC
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What we need in ACM-2

Small signal parameters

Small signal (AC) parameters

- G_T, NF, IIP3 vs (G_m, G_{m3}, G_{DS})

$$g_m = \frac{\partial I_D}{\partial V_G} = \frac{I_S}{\phi_t} g_G = \frac{I_S}{n\phi_t} \frac{2(q_s - q_d) - i_d\,\zeta\left(\frac{q_s}{1+q_s} - \frac{q_d}{1+q_d}\right)}{1 + \zeta\,(q_s - q_d)}$$

$$g_{ds} = \frac{I_S}{\phi_t} g_D = \frac{I_S}{n\phi_t} \frac{2(q_s\sigma - q_d(\sigma - n)) - i_d\zeta\left(\sigma\frac{q_s}{1+q_s} - (\sigma - n)\frac{q_d}{1+q_d}\right)}{1 + \zeta(q_s - q_d)}$$

$$g_{m3} = \frac{I_S}{(n\phi_t)^3} \left\{ \frac{\frac{2q_s}{(1+q_s)^3} - \frac{2q_d}{(1+q_d)^3} - \zeta n^2 g_{G2}\left(\frac{q_s}{1+q_s} - \frac{q_d}{1+q_d}\right) - \zeta\left[2ng_G\left(\frac{q_s}{(1+q_s)^3} - \frac{q_d}{(1+q_d)^3}\right) + i_d\left(\frac{q_d(1-2q_d)}{(1+q_d)^5} - \frac{q_d(1-2q_d)}{(1+q_d)^5}\right)\right]}{1 + \zeta\,(q_s - q_d)} \right\}$$

- Valid in all region (qs and qd shall be explored)

- We consider only saturation

$$q_{dsat} = q_s + 1 + \frac{1}{\zeta} - \sqrt{\left(1 + \frac{1}{\zeta}\right)^2 + \frac{2q_s}{\zeta}}$$

$$g_{msat} = \frac{2I_S}{n\phi_t} \frac{q_s}{1 + \zeta(q_s + 1)} \qquad g_{dsat} = \frac{\sigma}{n} \frac{2I_S}{\phi_t} \frac{q_s}{1 + \zeta(q_s + 1)} \qquad g_{msat3} = \frac{16 I_S}{(n\phi_t)^3} \frac{q_s}{(q_s + 1)^3} \frac{2 - 2\zeta q_s - 3\zeta q_s^2}{(q_s + 1)^4}$$

- It reduces the exploration to only qs.

What we need in ACM-2
Small signal parameters

Large signal (DC) parameters

- To compute the final voltages

$$V_T = V_{T0} - \sigma(V_{SB} + V_{DB})$$

$$V_P = \frac{V_{GB} - V_T}{n}$$

$$\frac{V_P - V_{S(D)B}}{\phi_t} = q_{s(d)} - 1 + \ln q_{s(d)}$$

- Sometime we'll use i_f in the code

$$i_d = i_f - i_r \Longleftrightarrow q_{S(D)} = \sqrt{1 + i_{f(r)}} - 1 \Longleftrightarrow i_d = \frac{(q_s + q_d + 2)}{1 + \zeta|q_s - q_d|}(q_s - q_d)$$

$$I_D = I_S . i_d$$

$$I_S = \frac{\mu C'_{ox} n (U_T)^2}{2} \frac{W}{L}$$

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Inversion Level Based Method for R-Feedback LNA with ACM-2

General Approach :

Requirements

- GT, NF, IIP3, IDC ← Possible Tradeoff
- fo, CL, BW ← No Tradeoff

Design parameters

- ACM parameters for a fixed L
- $V_{T0}, I_S, n, \sigma, \zeta$

Design Variables (parameters)

- W, qs are first order design variables (qs = inversion level sets the energy efficiency and the voltages)
- RL, RF are second order design variables

Approach :

- Explore the different tradeoff (the design space) on GT, NF, IIP3 and IDC by playing with W, qs.
- In saturation region (only qs is needed)

$$g_{msat} = \frac{2I_S}{n\phi_t} \frac{q_s}{1+\zeta(q_s+1)} \qquad g_{msat3} = \frac{16 I_S}{(n\phi_t)^3} \frac{q_s}{(q_s+1)^3} \frac{2-2\zeta q_s - 3\zeta q_s^2}{(\zeta q_s + 2)^4} \qquad g_{dsat} = \sigma \frac{2I_S}{n\phi_t} \frac{q_s}{1+\zeta(q_s+1)}$$

- Circuit equations depend on **G**m and ACM gives **g**m (normalized)…

Where we introduce W in the design space

$$|G_T| = \frac{(G_m R_F - 1)R_O}{(R_O + R_F)} \sqrt{\frac{R_O + R_F}{R_S(1 + G_m R_O)}} \qquad G_{[m;DS]x} = \mu C'_{ox} \frac{(U_T)^{2-x}}{2} \frac{W}{L} g_{[m;DS]x} \qquad I_S = \mu C'_{ox} n \frac{(U_T)^2}{2} \frac{W}{L} \qquad I_{SL} = \frac{I_S}{W} = \mu C'_{ox} n \frac{(U_T)^2}{2L}$$

Inversion Level Based Method for R-Feedback LNA with ACM-2

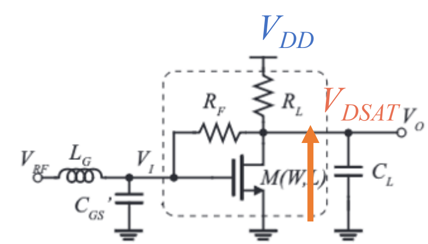
Reducing the variables :

Starting from : $|G_T| = \frac{(G_m R_F - 1)R_O}{(R_O + R_F)} \sqrt{\frac{R_O + R_F}{R_S(1 + G_m R_O)}}$ $\quad G_T(G_m; R_0; R_F; R_S) = G_T(W; q_S; I_D; V_{DSAT}; V_{T0}; I_S; n; \sigma; \zeta; f_c; C_L)$

variables parameters

$$G_{[m;DS]x} = \mu C'_{ox} \frac{(U_T)^{2-x}}{2} \frac{W}{L} g_{[m;DS]x} \rightarrow g_{msat} = \frac{2I_S}{n\phi_t} \frac{q_s}{1 + \zeta(q_s + 1)} \Rightarrow \boxed{G_m(q_S; W)}$$

$$\rightarrow g_{dsat} = \frac{\sigma}{n} \frac{2I_S}{\phi_t} \frac{q_s}{1 + \zeta(q_s + 1)} \Rightarrow \boxed{G_{DS}(q_S; W)}$$



$$R_O = \frac{R_L r_{DS}}{R_L + r_{DS}} \rightarrow G_{DS}(q_S; W)$$

$$R_L(I_D) = \frac{V_{DD} - V_{DSAT}}{I_D} \rightarrow V_{DSAT} = \phi_t(\sqrt{1 + i_f} + 3)$$

$$I_D = I_{SL} * W * i_f \qquad i_f = (1 + q_s)^2 \Rightarrow \boxed{R_0(q_S; W)}$$

$$R_F = \frac{R_0}{2\pi R_0 C_L f_c - 1} \Rightarrow \boxed{R_F(q_S; W)\Big|_{f_c}}$$

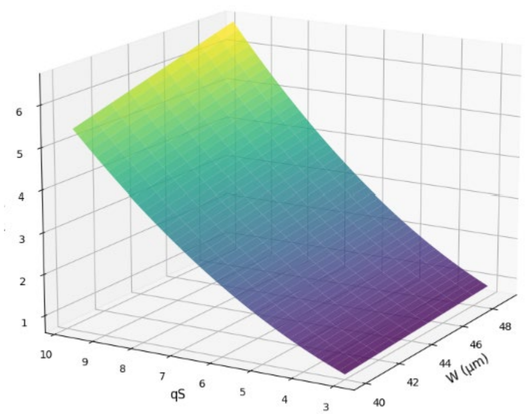
$$\left(f_c = \frac{R_O + R_F}{2\pi R_O R_F C_L} \right)$$

$$\Rightarrow \boxed{G_T(G_m; R_0; R_F; R_S) = G_T(W; q_S)}$$

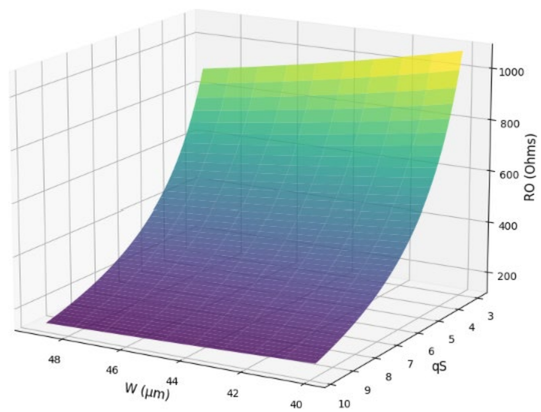
Inversion Level Based Method for R-Feedback LNA with ACM-2

Finally : $I_D(q_s;W)$; $R_F(q_s;W)$; $R_0(q_s;W)$; $G_T(q_s;W)$

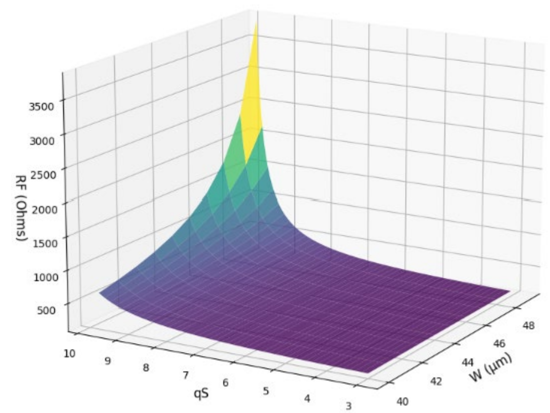
$I_D(q_s;W)$



$R_0(q_s;W)$



$R_F(q_s;W)$



Inversion Level Based Method for R-Feedback LNA with ACM-2

Computing GT, F and IIP3:

Finally : $|G_T| = \frac{(G_m R_F - 1)R_O}{(R_O + R_F)}\sqrt{\frac{R_O + R_F}{R_S(1 + G_m R_O)}}$

$\boxed{G_T(q_s; W)|_{f_c; C_L}}$

$$F = 1 + \frac{4\left(\frac{R_F}{Q_{IN}^2} + R_S\right)^2}{Q_{IN}^2 G_m R_S \left[\frac{R_F}{Q_{IN}^2} + R_S + \frac{G_m R_S R_F R_L)}{R_F + R_L}\right]^2}\left[\gamma + \frac{1}{G_m R_L} + \frac{\left(1 + \frac{Q_{IN}^2 G_m R_S R_F}{R_F + Q_{IN}^2 R_S}\right)^2}{G_m R_F}\right]$$

$\boxed{F(q_s; W)|_{f_c; C_L; R_S}}$

with $G_T(q_s; W)|_{f_c; C_L}$

$\boxed{F(G_T; W)}$

Remember :

$$Q_{IN} = V_I / V_{RF} = \sqrt{1 + Q_P^2} = \sqrt{\frac{R_O + R_F}{R_S(1 + G_m R_O)}}$$

$$V_{IIP3} = \frac{2}{Q_{IN}}\sqrt{\frac{2G_m}{G_{m3}}}$$

$\boxed{IIP_3(q_s; W)|_{f_c; C_L; R_S}}$

Inversion Level Based Method for R-Feedback LNA with ACM-2

Exploring the design space:

Setting GT (or NF, or IIP3) helps to build 2D plots.

For a particular G_T

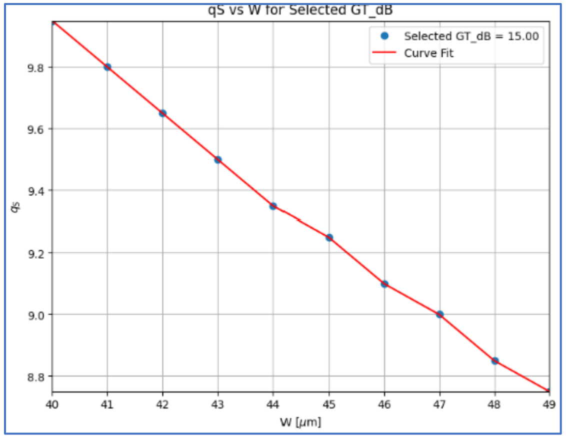
=> We get the relationship q_S<=>W

=> We plot $NF(W)$

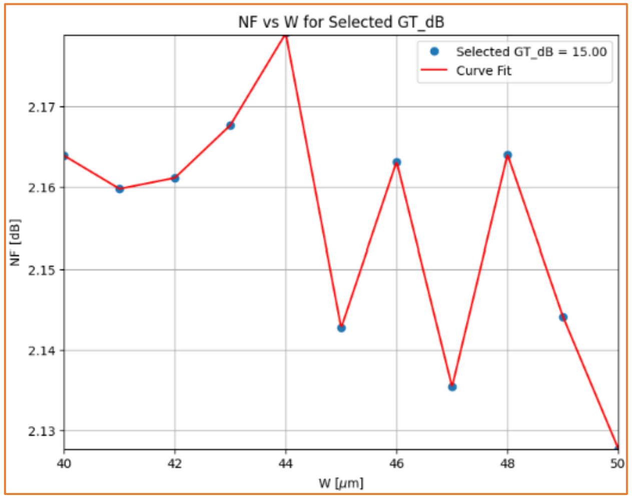
=> We plot $IIP3(W)$

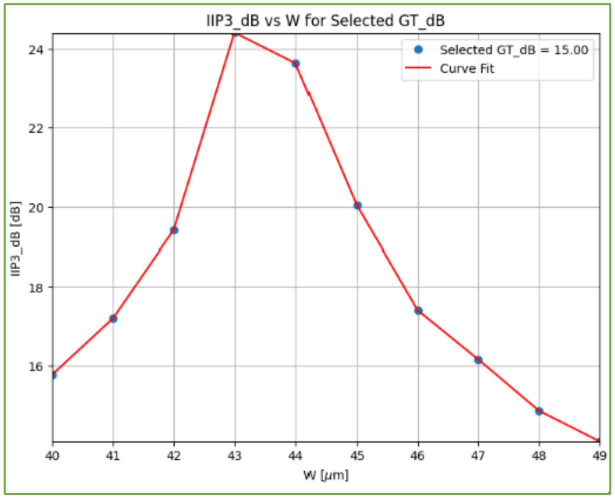
And We already have I_D

q_S



$W(\mu m)$





Inversion Level Based Method for R-Feedback LNA with ACM-2

Setting the final value:

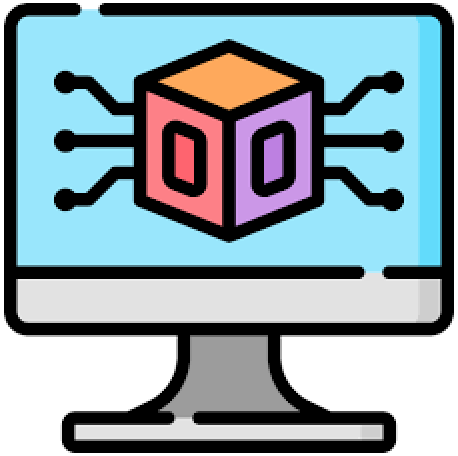
- We choose W, that gives q_S for a given G_T.
- $(W;q_S)$ gives R_0, R_L, I_D, G_m, V_{DSAT} and V_G

Input Matching

- *With R_0, R_F, G_m => R_P* $\qquad \Re(Zp) = R_P = \dfrac{R_O + R_F}{1 + G_m R_O},$
- *With R_S and R_P calculate Q_P* $\qquad \Re(Z_{IN}) = R_S = \dfrac{R_P}{(1 + Q_P^2)} = 50\,\Omega$
- *With Q_P calculate C_T and C_{GS}'* $\qquad Q_P = R_P C_T \omega_0 \qquad C_T = C_{GS} + C'_{GS} + C_P \qquad C_P = \dfrac{R_O^2 C_L (G_m R_F - 1)}{(R_O + R_F)^2}$
- *With C_T calculate L_G* $\qquad \Im(Z_{IN}) = 0 = L_G s + \dfrac{Q_P^2}{C_T s (1 + Q_P)^2}$

Validation

Now, let's simulate with a real PDK



Acknowledgments

SOIL

SOLIDIFY THE EUROPEAN FDSOI ECOSYSTEM ACCELERATING ITS INDUSTRIAL DEPLOYMENT

GRENOBLE INP UGA

UGA Université Grenoble Alpes

cnrs

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