LECTURE 6 – PARAMETER EXTRACTION

Topics:

- Model parameters
- Principles of parameter extraction
- Strong inversion extraction
- Influence of L
- Weak inversion extraction
- BJT parameter extraction
- Examples

What will I learn?

- How to use a simulator and simulator models to extract model parameters

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Device Model Parameters

What are model parameters?

- Model parameters are the constants in the equations that determine the voltage and currents of devices (transistors, etc.)
- The value of the model parameters depend upon the operating conditions of the devices

Where can you find these model parameters?

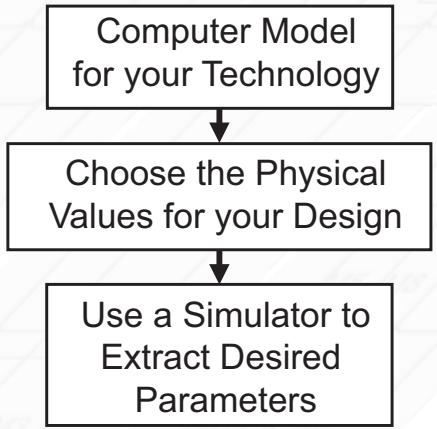
1. Process control documents (PCD)
2. Data sheets
3. Extraction

The problem with the first two approaches is the parameters may not correspond to the operating conditions of your design.

Principles of Parameter Extraction

Requirements

1. SPICE type simulator
2. Computer models for your devices (i.e. BSIM3v3)
3. Simple model equation
    1. Sah model
    2. Weak inversion model
    3. Gummel Poon model
4. Extraction procedure



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Strong Inversion MOSFET Extraction

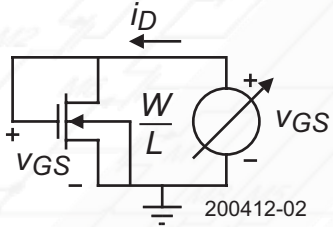
Procedure for K' and V_{T0}

1. Sah Model

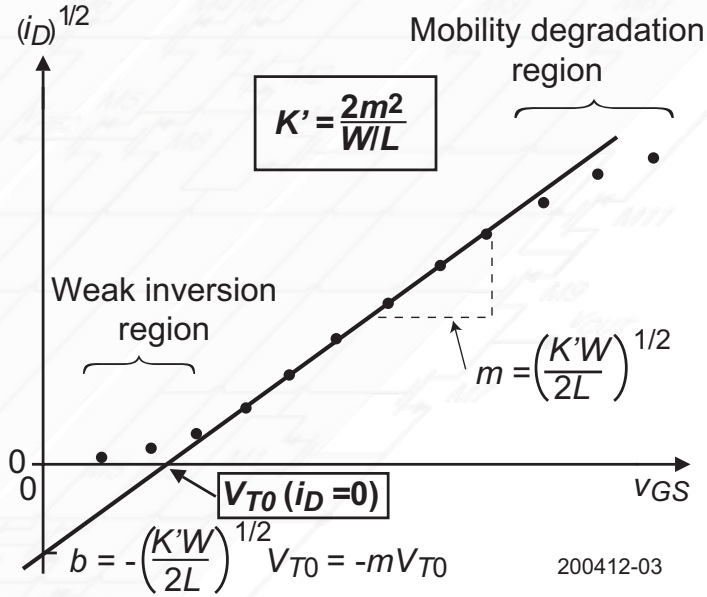
$$i_D = \frac{K'_N}{2}\frac{W}{L}(V_{GS} - V_{T0})^2(1 + \lambda V_{DS})$$

The model parameters are K_N', V_{T0}, and λ.

2. Choose W and L
3. Use the circuit shown to extract K_N' and V_{T0}

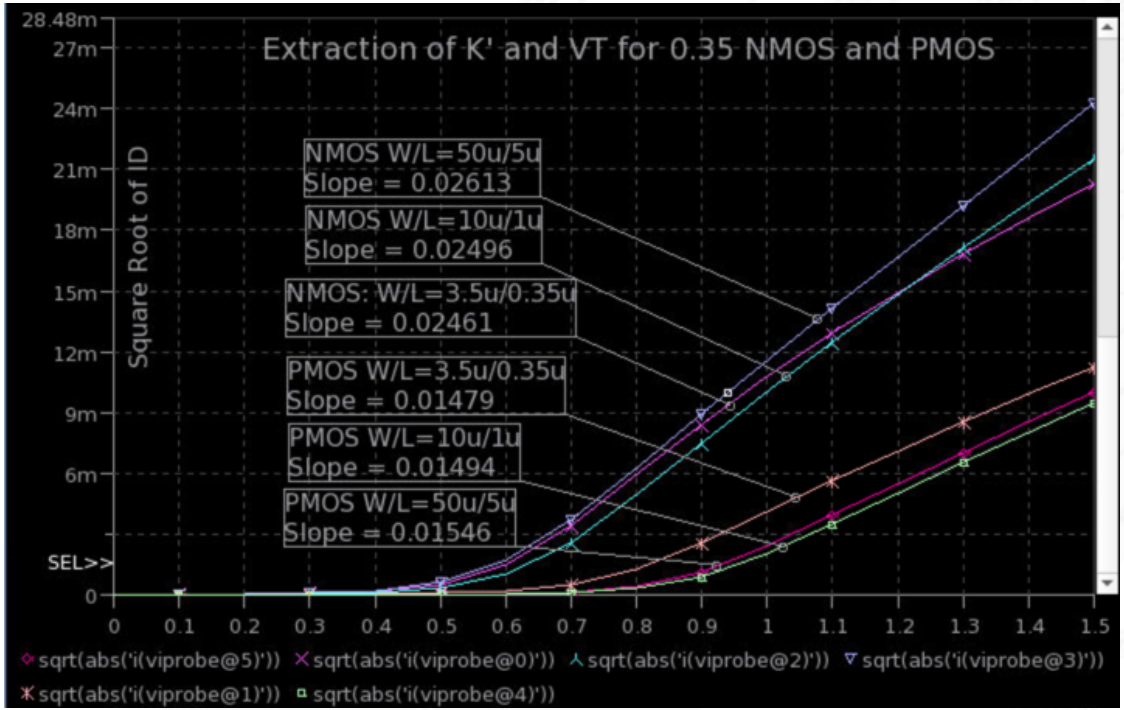


4. Plot the square root of i_D and extract K_N' and V_{T0} as illustrated.
5. Be careful of extreme regions



Strong Inversion MOSFET Extraction

Example for NMOS and PMOS *K'* and V_{T0} extraction



Parameter	L	NMOS	PMOS
V_T	0.35u	0.55V	-0.72V
V_T	1u	0.6V	-0.86V
V_T	5u	0.59V	-0.83V
K'	0.35u	121µA/V^2	44µA/V^2
K'	1u	125µA/V^2	45µA/V^2
K'	5u	137µA/V^2	48µA/V^2

Strong Inversion MOSFET Extraction

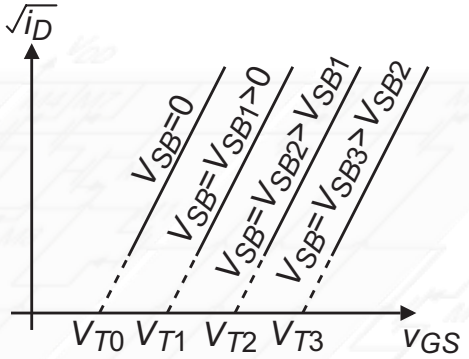
Procedure for extraction of γ and ϕ_F

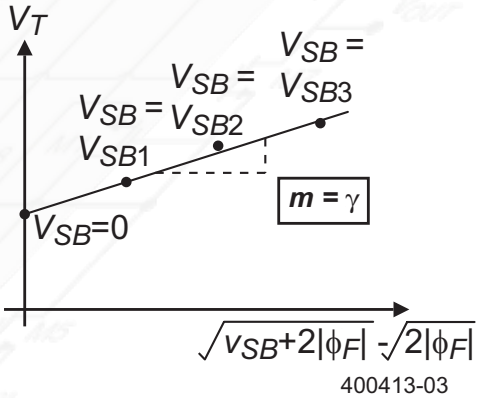
1. Sah Model

$$V_T(v_{SB}) = V_{T0} + \gamma\sqrt{2|\phi_F| + v_{SB}} - \sqrt{2|\phi_F|}$$

where γ and ϕ_F are model parameters.

2. Choose W and L
3. Pick a value of ϕ_F (≈0.6-0.8V)
4. Extract a value for γ using the following steps:
   a.) Extract V_T for various values of V_{SB}.
   b.) Extract γ from the plot of V_T versus $\sqrt{2|\phi_F| + v_{SB}} - \sqrt{2|\phi_F|}$
5. Calculate ϕ_F from $\phi_F = -\frac{kT}{q} ln\left(\frac{\gamma^2 C_{ox}^2}{2\epsilon_{si} q n_i}\right)$
6. Iterate ϕ_F until ϕ_F of step 2 agrees with ϕ_F of step 5.





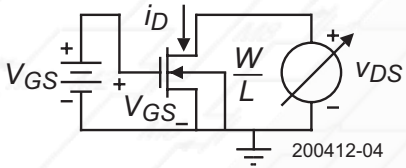
Strong Inversion MOSFET Extraction

Procedure for λ

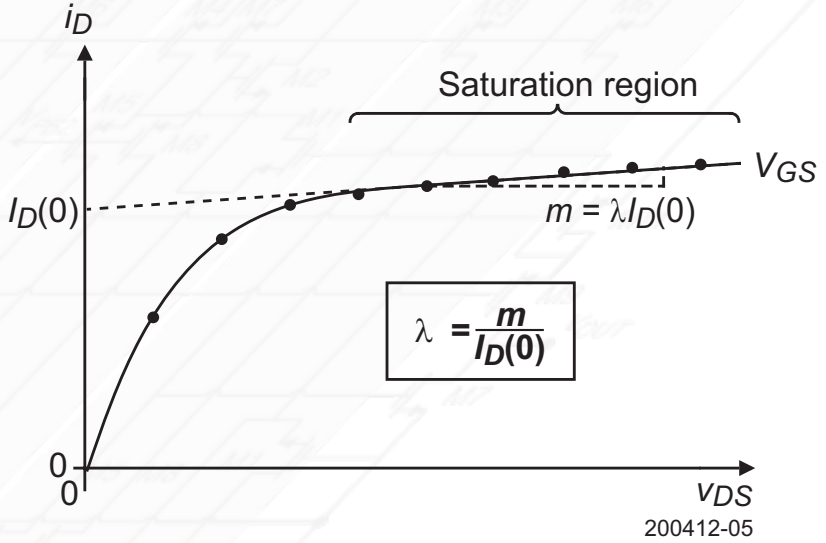
1. Sah Model

$$i_D = \frac{K'_N}{2}\frac{W}{L}(V_{GS} - V_{T0})^2(1 + \lambda V_{DS})$$

2. Choose W and L (λ is very sensitive to L)
3. Choose $V_{GS} > V_{DS}$(sat) and use the circuit shown to extract λ

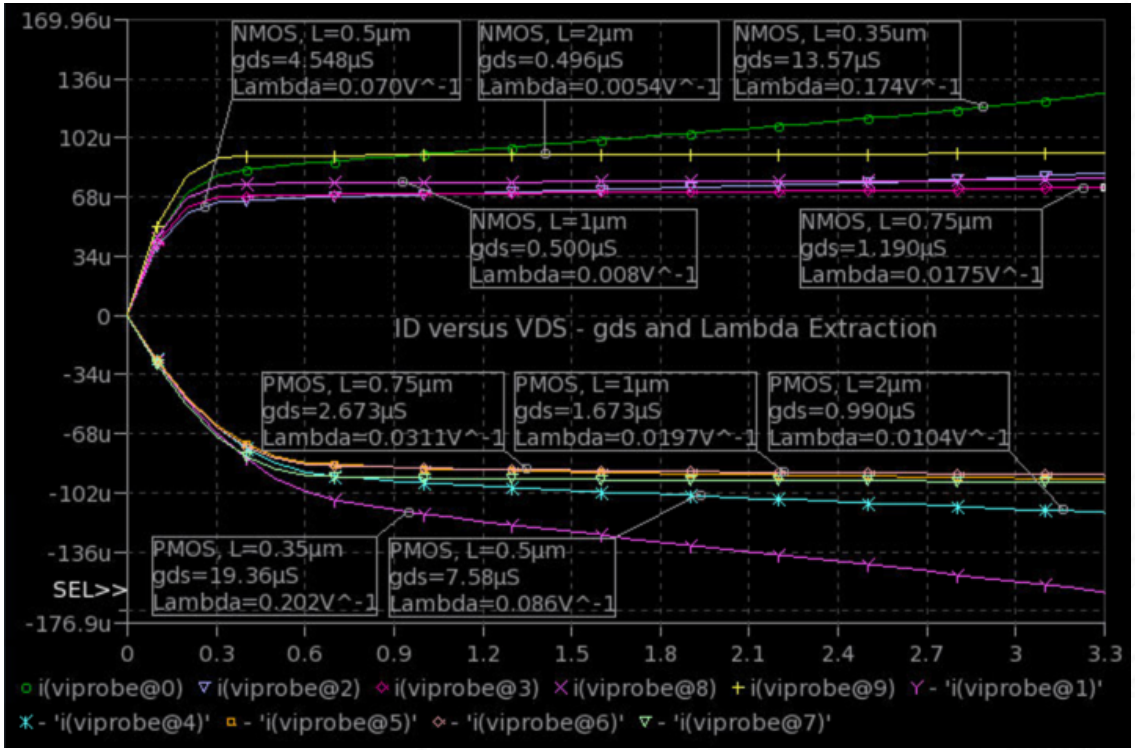


4. Plot the i_D versus v_{DS} and extract λ as illustrated.
5. Unfortunately, λ is a poor approximation to model the output of the MOSFET but is good enough for the simple model.



Strong Inversion MOSFET Extraction

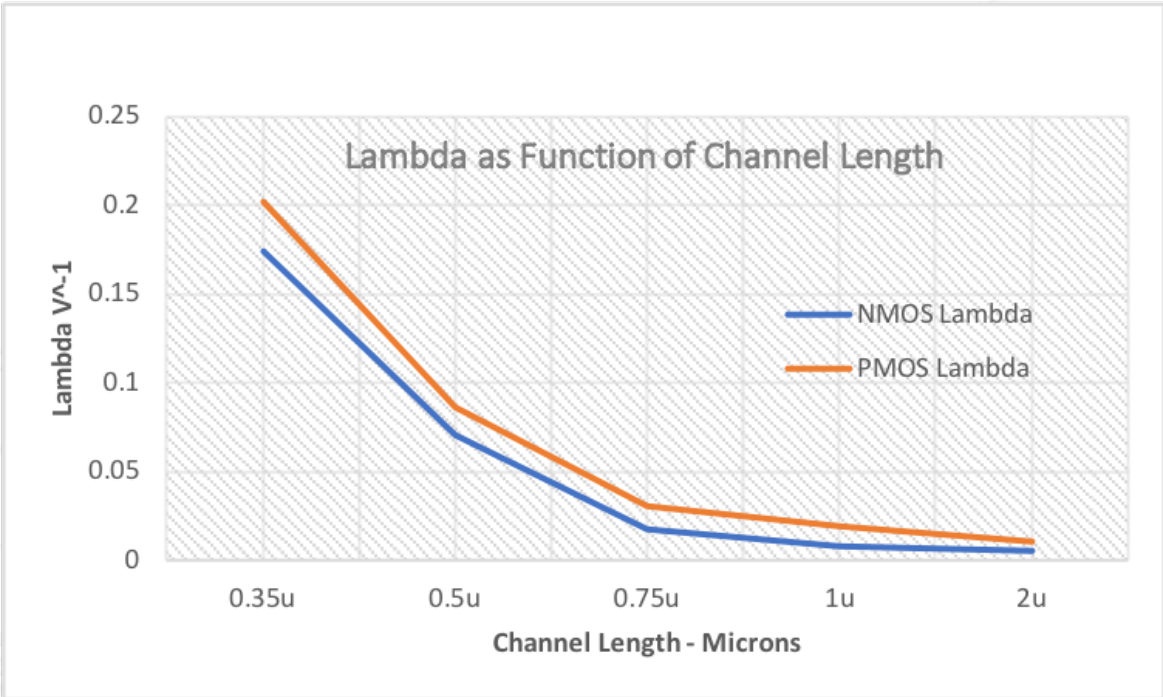
Example for NMOS and PMOS for λ Extraction



Parameter	L	NMOS	PMOS
g_{ds}	0.35u	13.57µS	19.36µS
g_{ds}	0.5u	4.548µS	7.58µS
g_{ds}	0.75u	1.190µS	2.673µS
g_{ds}	1u	0.500µS	1.673µS
g_{ds}	2u	0.496µS	0.990µS
λ	0.35u	$0.174V^{-1}$	$0.202V^{-1}$
λ	0.5u	$0.070V^{-1}$	$0.086V^{-1}$
λ	0.75u	$0.0175V^{-1}$	$0.0311V^{-1}$
λ	1u	$0.008V^{-1}$	$0.0197V^{-1}$
λ	2u	$0.0054V^{-1}$	$0.0104V^{-1}$

Strong Inversion MOSFET Extraction

Influence of *L* on λ



Weak Inversion MOSFET Extraction

Procedure for I_t and n extraction

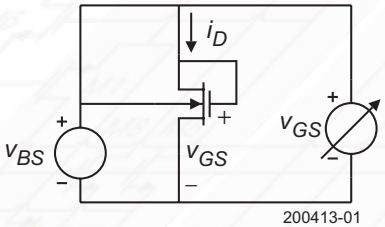
1.) Simple weak inversion model:

$$i_D = \boldsymbol{I_t}\left(\frac{W}{L}\right) exp\left(\frac{v_{GS}-V_T}{\boldsymbol{n}V_t}\right)(1+\boldsymbol{\lambda} v_{DS})$$

The model parameters are I_t, n, and λ. Note that V_T is the MOSFET threshold voltage and V_t is the thermal voltage (kT/q).

2.) Choose W and L.

3. Use the circuit shown to extract I_t and n.

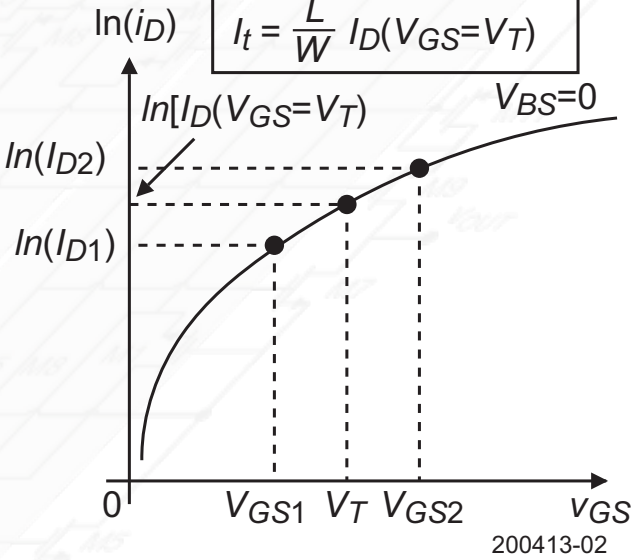


4.) Plot $ln(i_D)$ versus v_{GS} and extract I_t and n.

5.) λ can be extracted as shown for strong inversion.

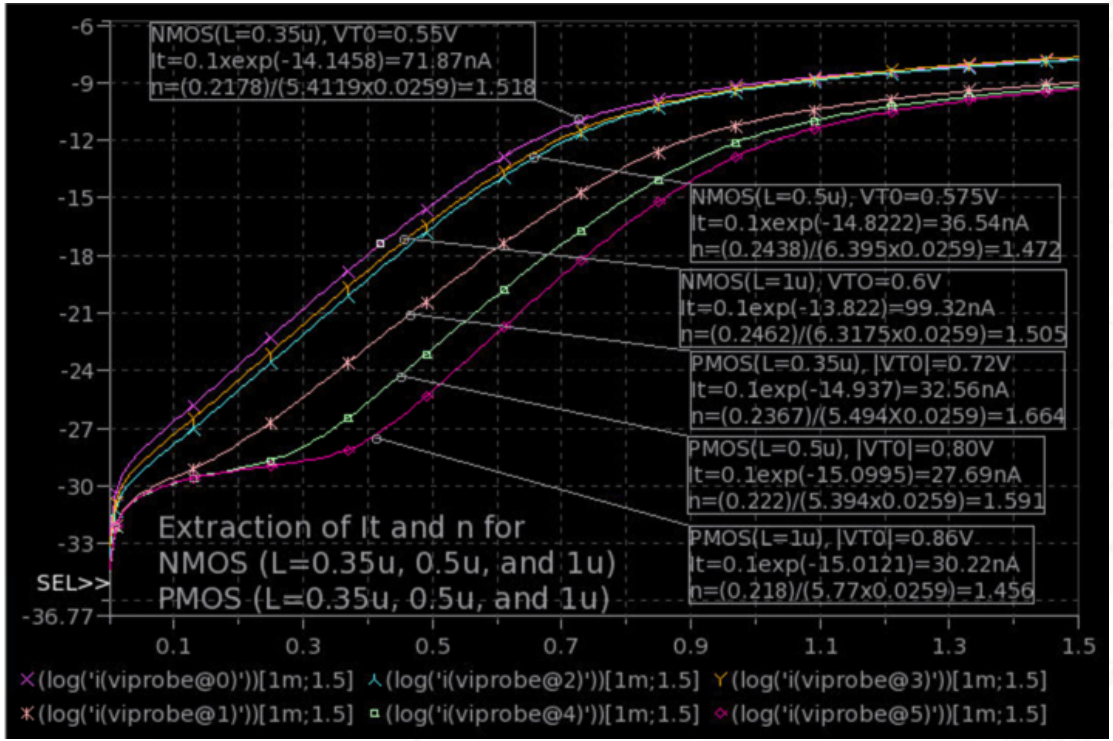
$$n = \frac{1}{V_t}\left(\frac{V_{GS2}-V_{GS1}}{ln(I_{D2})-ln(I_{D1})}\right)$$

$$I_t = \frac{L}{W} I_D(V_{GS}=V_T)$$



Weak Inversion MOSFET Extraction

Example



Parameter	L	NMOS	PMOS
I_t	0.35u	71.87nA	32.56nA
I_t	0.5u	36.54nA	27.69nA
I_t	1u	99.32nA	30.22nA
n	0.35u	1.518	1.664
n	0.5u	1.472	1.591
n	1u	1.505	1.456

BJT Parameter Extraction

Procedure for I_S , B_F, and n extraction

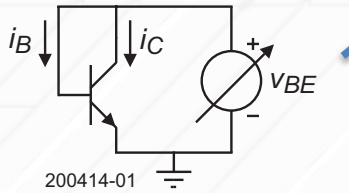
1.) Simple BJT model for forward active region:

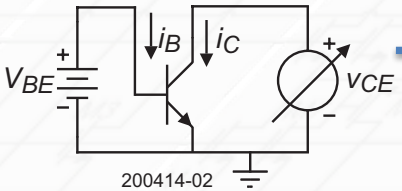
$$i_C = \boldsymbol{I_s \beta_F} exp\left(\frac{v_{BE}}{\boldsymbol{n} V_t}\right)\left(1 + \frac{v_{CE}}{\boldsymbol{V_A}}\right)$$

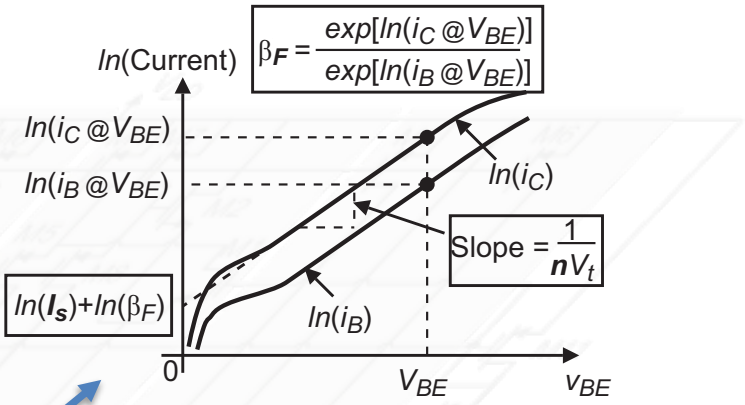
The model parameters are I_S, β_F, n, and V_A.

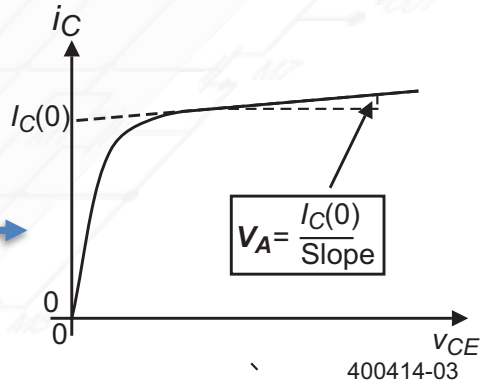
2.) Use the circuit shown to plot $ln(i_C)$ versus v_{BE} to extract I_S, β_F, and n

3.) Use the circuit shown to plot i_C versus v_{CE} to extract V_A.



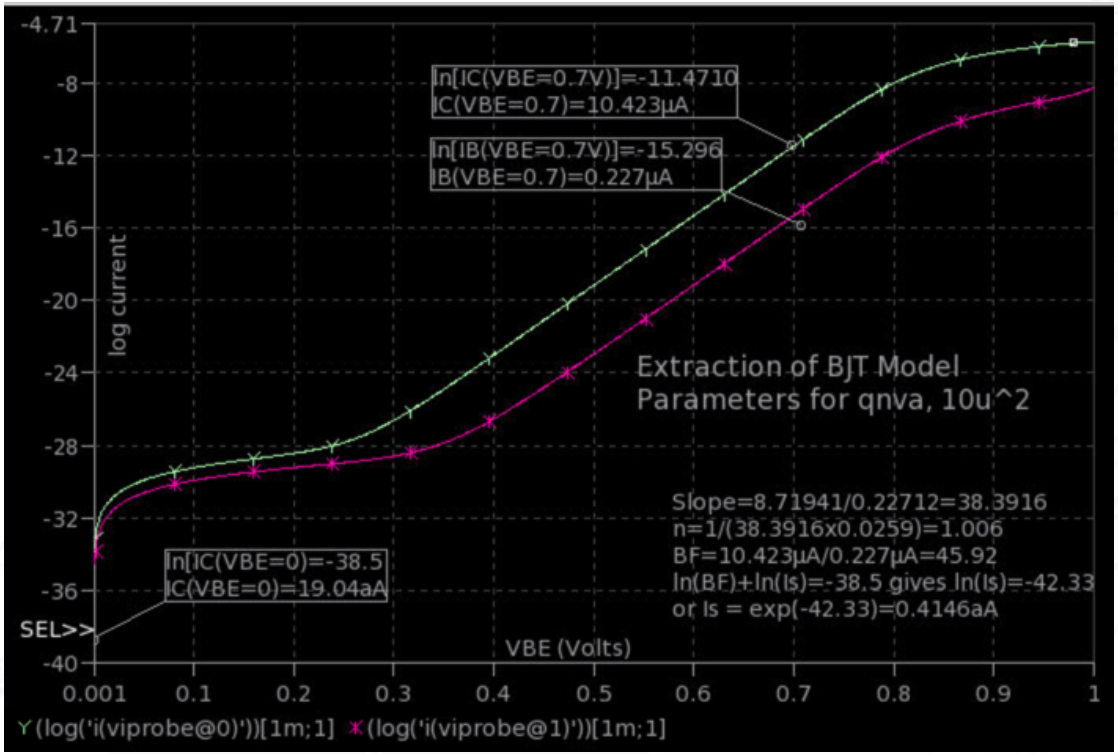






BJT Parameter Extraction

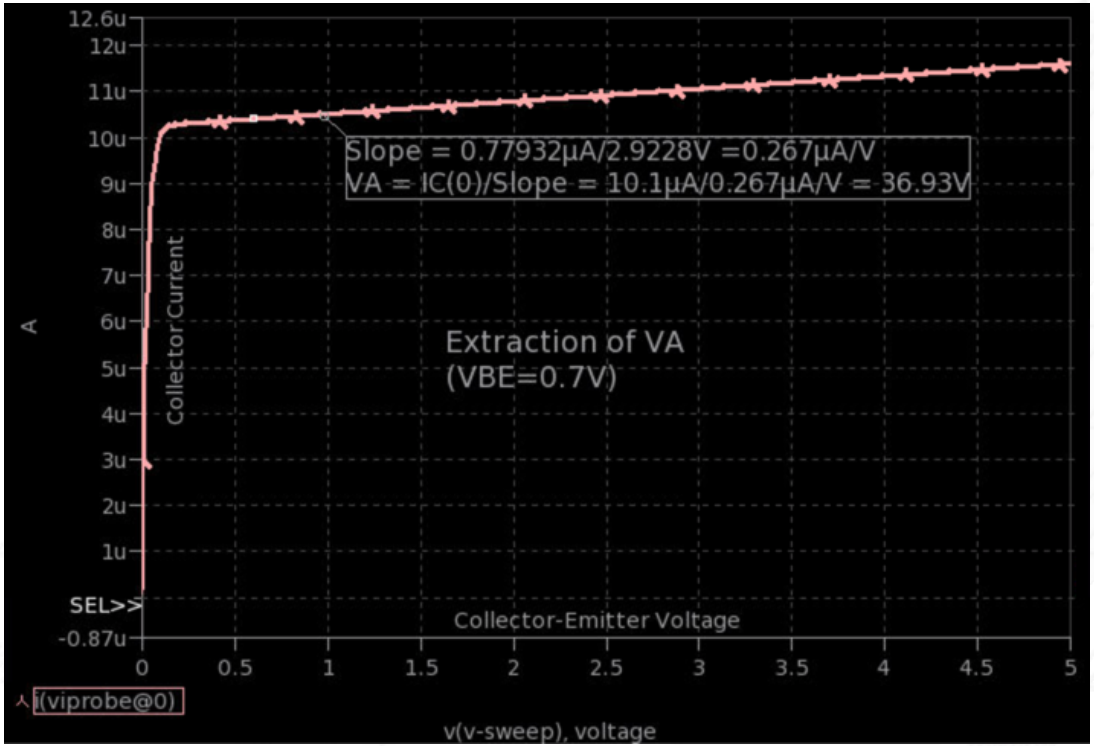
Example – I_S, β_F, and n



Parameter	Value
β_F	45.92
I_s	0.4146aA
n	1.006

BJT Parameter Extraction

Example – V_A



Parameter	Value
V_A	36.93V

SUMMARY

Illustrated Methods for Extraction of Model Parameters

- Extraction principles
- NMOS and PMOS parameter extraction in strong inversion
- NMOS and PMOS parameter extraction in weak inversion
- BJT parameter extraction for the forward active region
- Similar methods can be used to extract the parameters of passive components
- Do not expect the parameters to be that precise especially λ or V_A
- Be aware of the influence of channel length on λ

Change Tracking

Date	Slide No.	Correction or change
4/20/2020	10	Made correction on It formula for extraction
4/20/2020	11	Replaced figure with corrected extraction
4/20/2020	13	Replaced figure with corrected extraction and updated table entries