A Systematic Approach to MOST Circuit Design and Analysis:

Classification of 2VCCS Circuits

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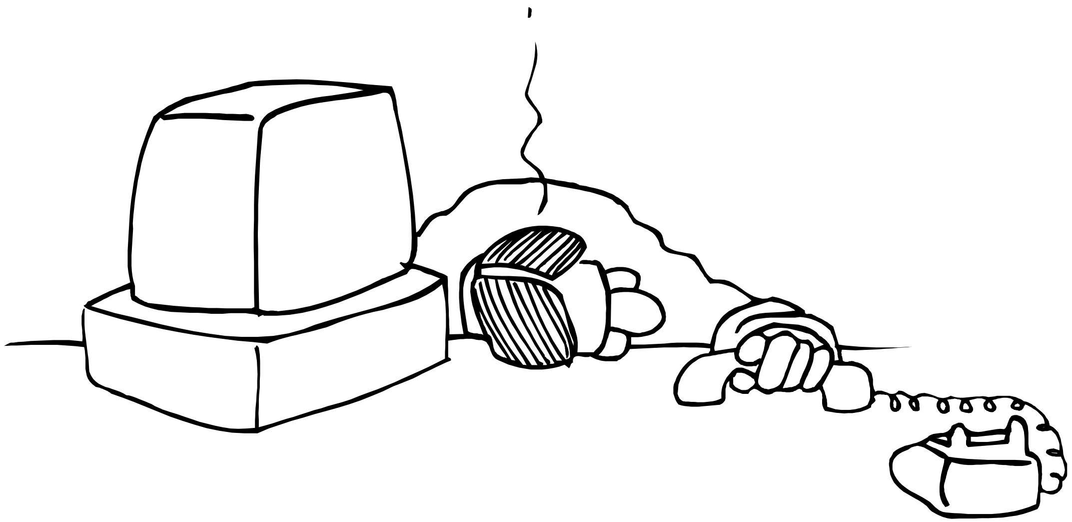
Contents

Introduction: Problem and Aim

Analog Computer Aided Design:

- **Analysis well developed, e.g. simulation, symbolic analysis**
- **Synthesis largely intuitive, especially for *transistor topology***

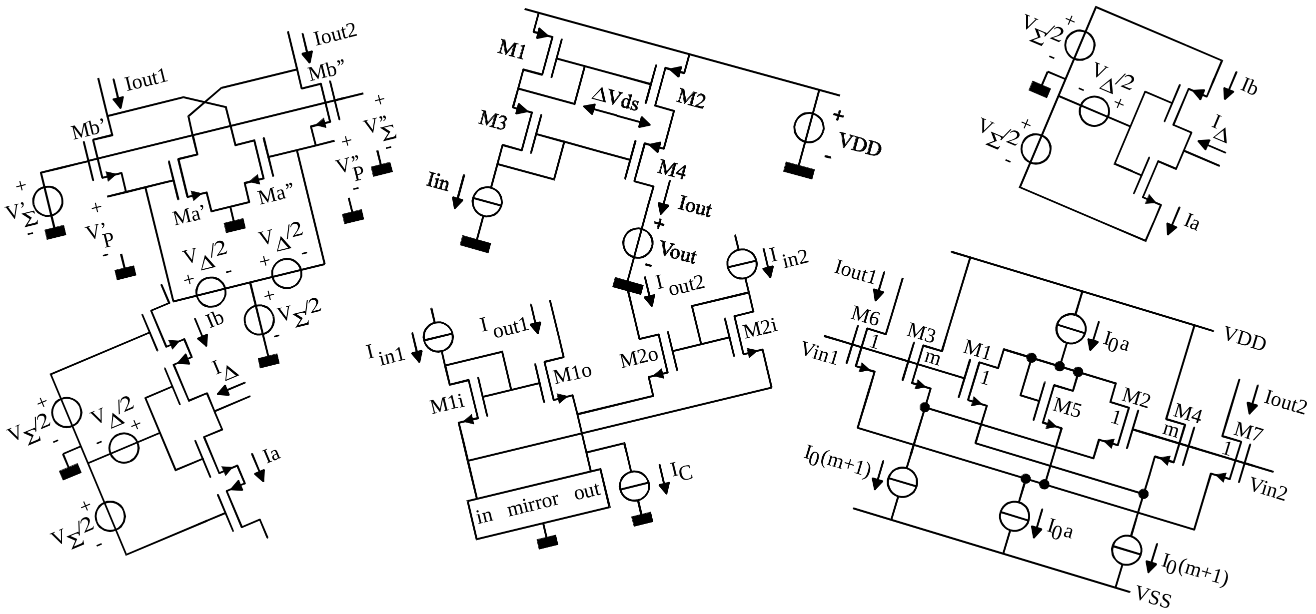


Teach intuition

to a computer??

AIM: Systematic approach

- **Literature: fragmentary, many circuit topologies!**



- **Questions: Variations on a theme? Relative merits?**

=> Aim: 1) *Create overview* of different possible topologies

2) *Predict* and *compare* circuit *performance*

A Design Philosophy for MOST Circuits

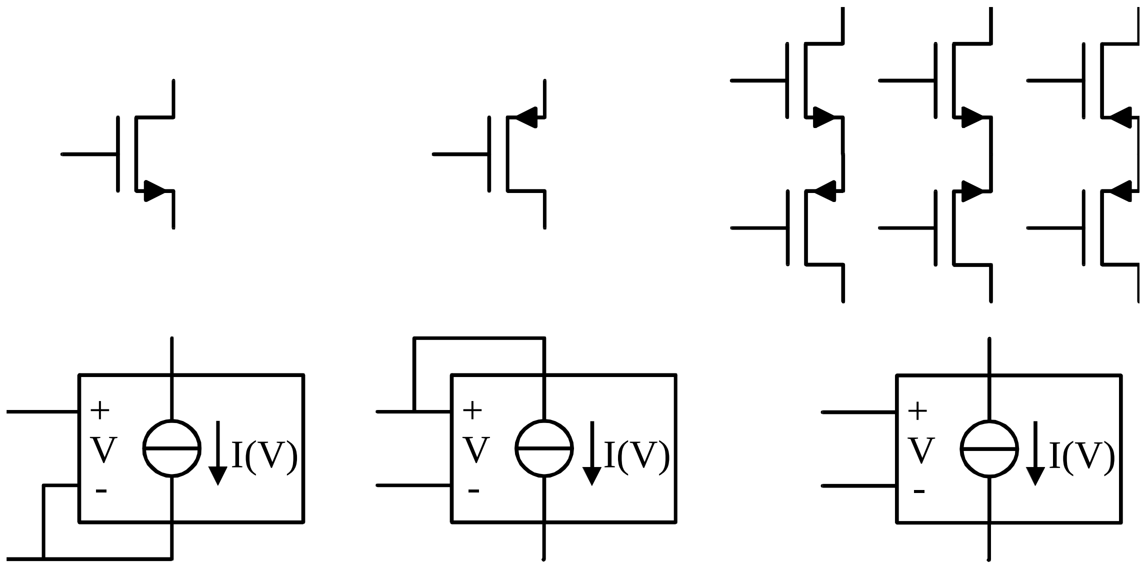
Classify on what? What is important during design?

MOST design experience:

- **Combine simple basic circuits (differential pair, mirror)**
  few components <=> HF, low noise, low current
- **Mainly MOSTs, saturated region (current output)**
- **Transconductance g_m of MOST is crucial:**
  - **Good model up to high frequencies**
  - **Matching of transconductance is good (< 1%)**
  - **Electronic variability (self-correction/adaptivity)**
  - **Large g_m-range: nS....S**

PhD Thesis: Transconductance Based CMOS Circuits

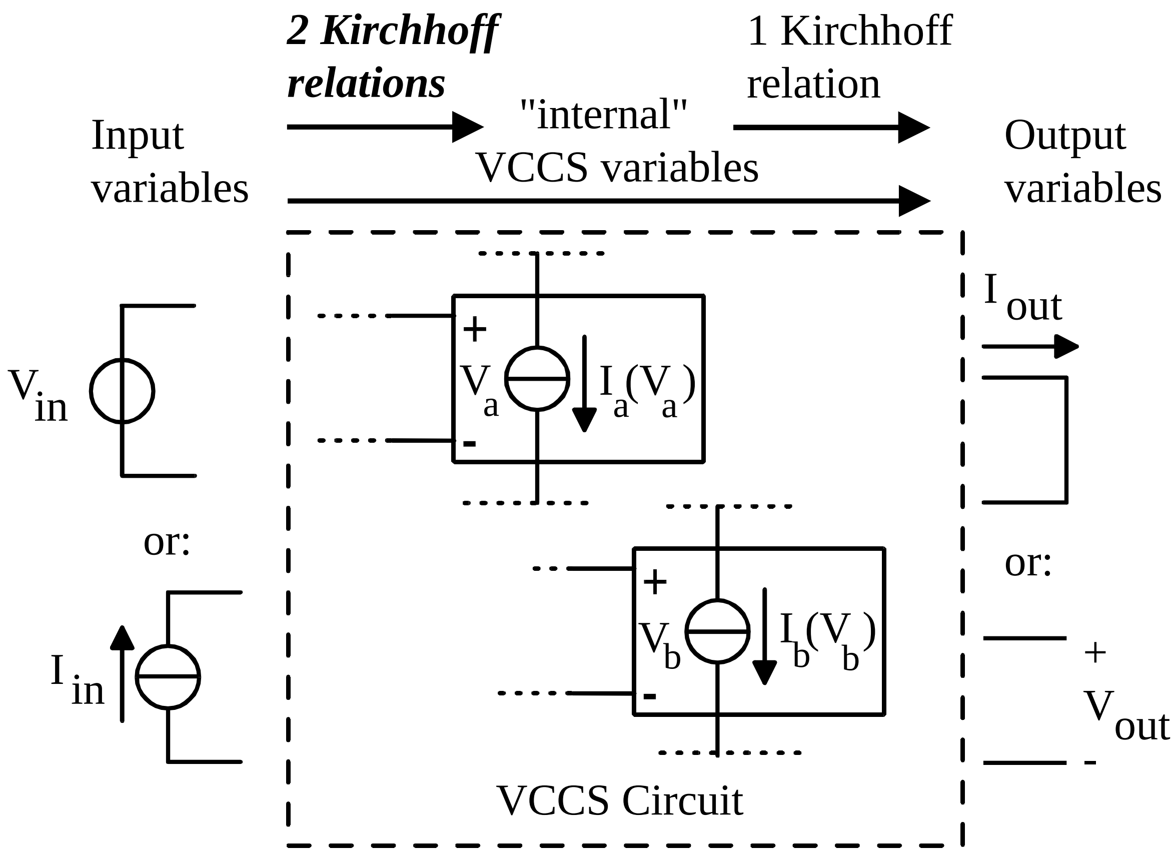
- **MOST = Voltage Controlled Current Source (VCCS)**



- **Synthesize linear two-ports with *only VCCSs***
- ***All* two-ports with *2 VCCSs* (Circuit Generation)**

=> 145 topologies, covering most needs => *2VCCS circuits*

Classification of 2VCCS Circuits



Analyse electrical behaviour:

- **Analyse two-port parameters**
- **VCCS variables are crucial!**
- **4 eqns needed (4 VCCS vars)**
- **$I_a=g_aV_a$ and $I_b=g_bV_b$ available**
- **2 additional topology related KVL/KCL relations needed!**

Non-linear case: square-law and exponential I(V) also 2 eqns.

Set of 2 independent Kirchhoff relations needed!

All classes of 2VCCS Circuits

- **Types of Kirchhoff relations:**

Kirchhoff relations
- voltage
  - primary V_P
  - secondary
    - Sum V_Σ
    - Difference V_Δ
- current
  - primary I_P
  - secondary
    - Sum I_Σ
    - Difference I_Δ

- **ALL Sets of 2 relations: 3 main classes and 14 subclasses:**

{V,V}	$\{V_P,V_\Sigma\}$
	$\{V_P,V_\Delta\}$
	$\{V_\Sigma,V_\Delta\}$

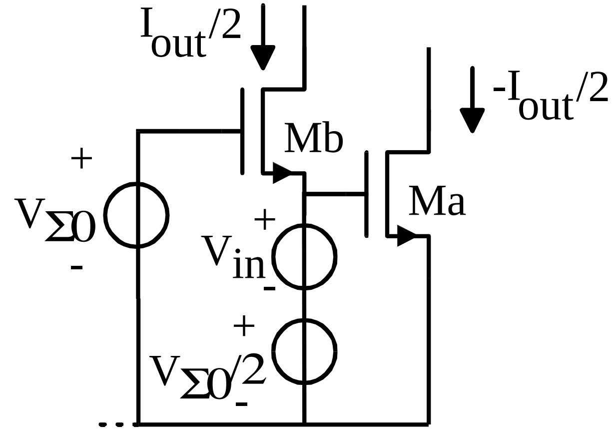
{I,I}	$\{I_P,I_\Sigma\}$
	$\{I_P,I_\Delta\}$
	$\{I_\Sigma,I_\Delta\}$

{V,I}	$\{V_P,I_\Sigma\}$
	$\{V_P,I_\Delta\}$
	$\{V_\Sigma,I_P\}$
	$\{V_\Delta,I_P\}$
	$\{V_\Sigma,I_\Sigma\}$
	$\{V_\Sigma,I_\Delta\}$
	$\{V_\Delta,I_\Sigma\}$
	$\{V_\Delta,I_\Delta\}$

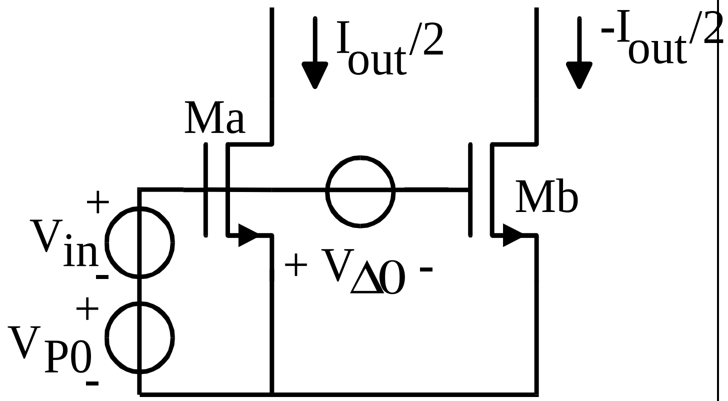
Application Examples

Recognise variations on a theme: 50 V-I Kernels in 4 classes

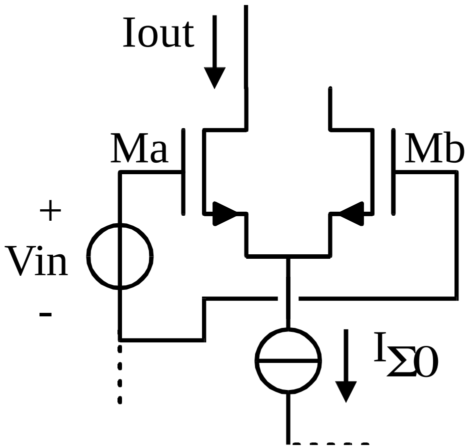
$\{V_P, V_\Sigma\}$,
constant V_Σ
(> 25 refs)



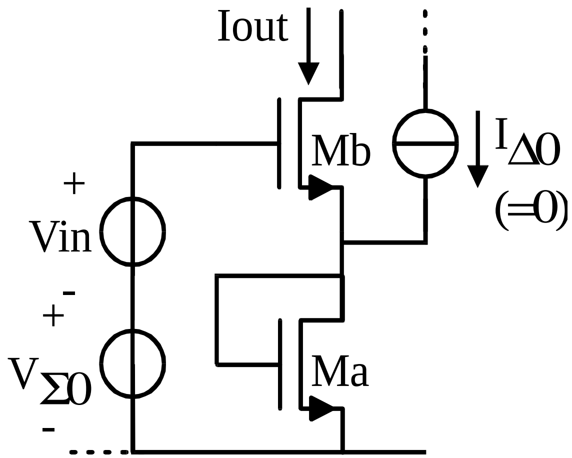
$\{V_P, V_\Delta\}$
constant V_Δ
(10 refs)



$\{V_\Delta, I_\Sigma\}$
constant I_Σ
(numerous refs)



$\{V_\Sigma, I_\Delta\}$,
constant I_Δ
(10 refs)



Generating *all* Classes of V-I kernels with 2 VCCSs

Required: ≥ 1 KVL relation. Result: 4 realy different classes

Class	Vin	1st order coeff.Ia,Ib	2nd order coeff.Ia,Ib	3rd order coeff.Ia,Ib
$\{V_P,V_\Sigma\}$	**V_P** V_Σ	**g_{1a}, $-g_{1b}$** 0, g_{1b}	**g_{2a}, g_{2b}** 0, g_{2b}	**g_{3a}, $-g_{3b}$** 0, g_{3b}
$\{V_P,V_\Delta\}$	**V_P**	**g_{1a}, g_{1b}**	**g_{2a}, g_{2b}**	**g_{3a}, g_{3b}**
	V_Δ	0, g_{1b}	0, g_{2b}	0, g_{3b}
$\{V_\Sigma,V_\Delta\}$	**V_Σ** **V_Δ**	**$g_{1a}/2$, $g_{1b}/2$** **$g_{1a}/2$,$-g_{1b}/2$**	**$g_{2a}/4$, $g_{2b}/4$** **$g_{2a}/4$, $g_{2b}/4$**	**$g_{3a}/8$, $g_{3b}/8$** **$g_{3a}/8$,$-g_{3b}/8$**
$\{V_\Sigma,I_P\}$	V_Σ	0, g_{1b}	0, g_{2b}	0, g_{3b}
$\{V_\Delta,I_P\}$	V_Δ	0, $-g_{1b}$	0, $-g_{2b}$	0, $-g_{3b}$
$\{V_P,I_\Sigma\}$	V_P	g_{1a},$-g_{1a}$	g_{2a}, $-g_{2a}$	g_{3a}, $-g_{3a}$
$\{V_P,I_\Delta\}$	V_P	g_{1a}, g_{1a}	g_{2a}, g_{2b}	g_{3a}, g_{3b}
$\{V_\Sigma,I_\Sigma\}$	V_Σ	no solution	no solution	no solution
$\{V_\Sigma,I_\Delta\}$@	**V_Σ**	**$g_1/2$, $g_1/2$**	**$g_2/4$, $g_2/4$**	**$g_3/8$, $g_3/8$**
$\{V_\Delta,I_\Sigma\}$@	**V_Δ**	**$g_1/2$, $-g_1/2$**	**0 , 0**	**$g_3/8-(g_2^2/4g_1)$**
$\{V_\Delta,I_\Delta\}$	V_Δ	no solution	no solution	no solution

@= equal g-coefficients for VCCSa and VCCSb ; **BOLD=different from 1VCCS**

Comparison of V-I Kernels: Figure of Merit NDR/ISS

- **DR=S/N depends on distortion and noise bandwidth NBW!**

  Assume dominant HD3:

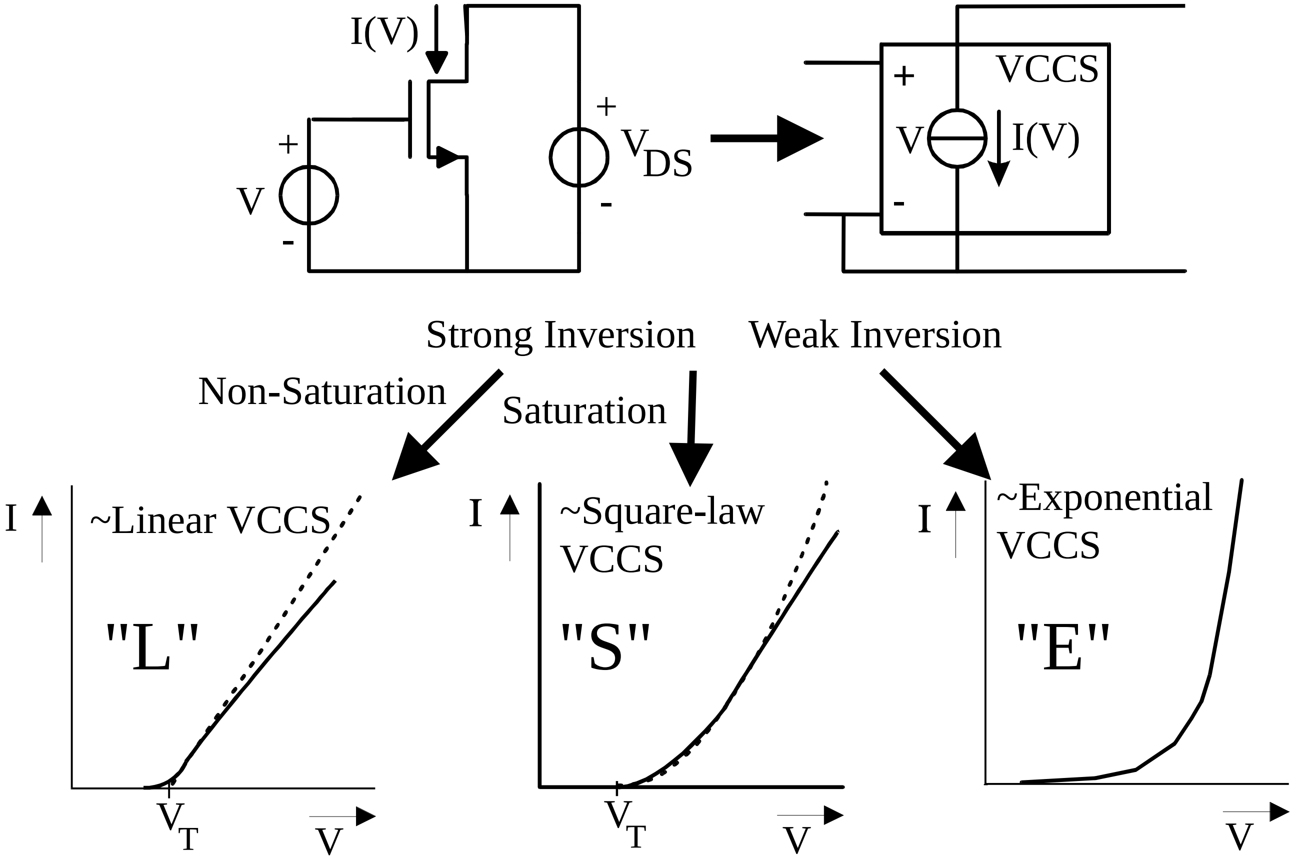
$$HD3 \approx \frac{g_3}{4g_1}\hat{V}_{in}^2 = \left(\frac{\hat{V}_{in}}{V_{IP3}}\right)^2$$

- **Normalise: HD3 = 100% and NBW =1Hz** ($NDR = \frac{NBW}{HD3} DR$)
- **Figure of Merit independent of scaling:**

$$\frac{NDR}{ISS} = \frac{S}{N \cdot ISS}\Bigg|_{\substack{HD3=100\% \\ NBW=1Hz}} = \frac{\frac{1}{2} G_m V_{IP3}^2}{4 \cdot k \cdot T \cdot NEF \cdot I_{SS}}$$

Model I(V) and noise of VCCS and analyse NDR/ISS!!!

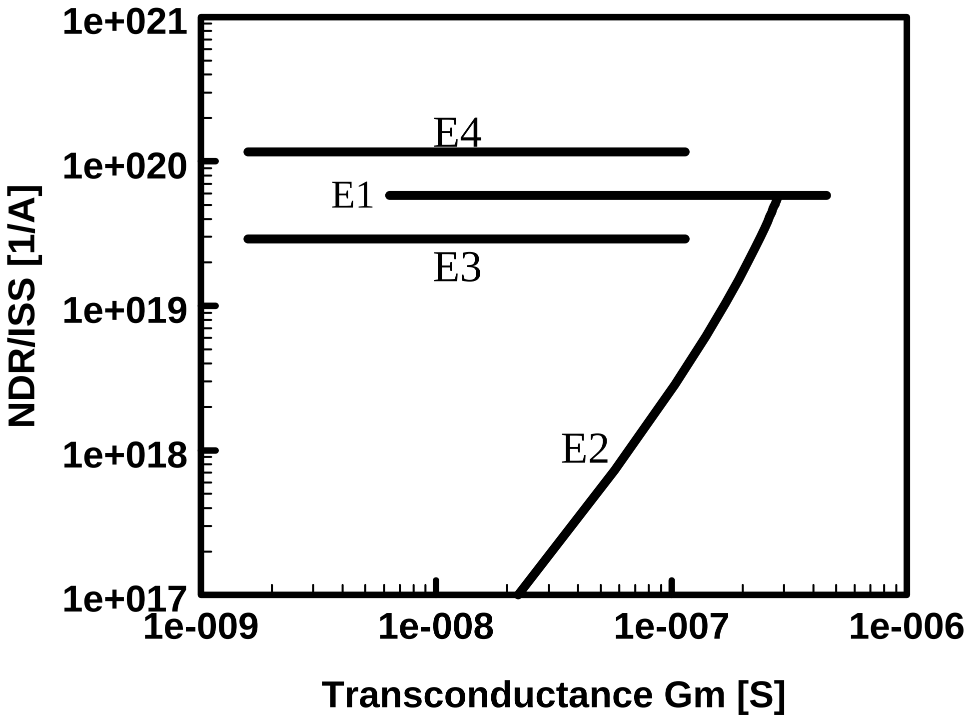
Compare MOST V-I Kernels: 3 Operating regions



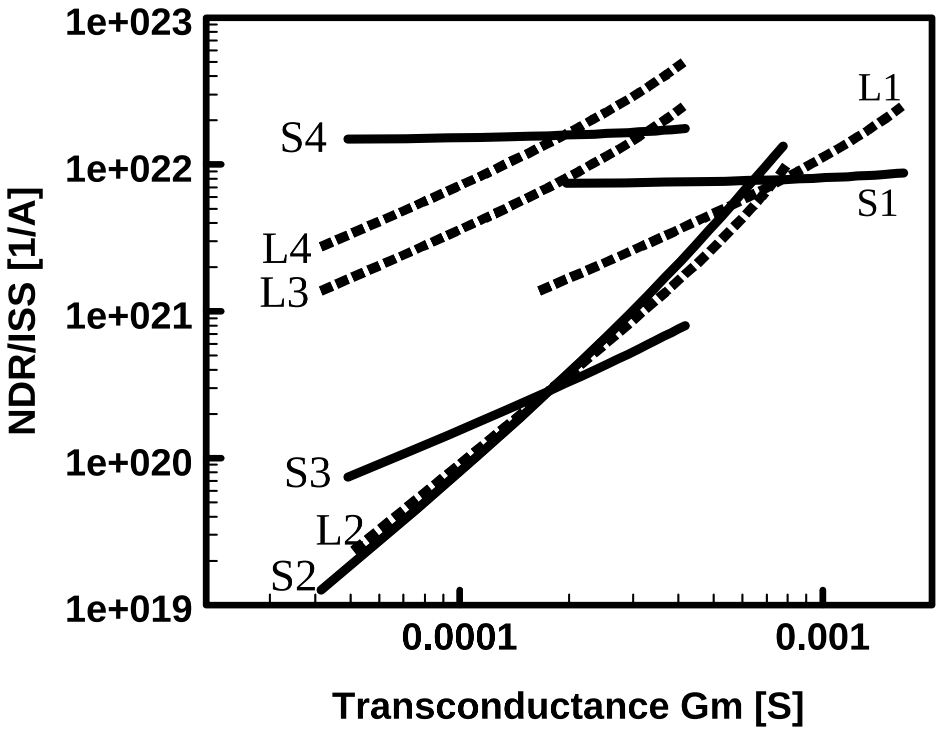
Assume mobility reduction:

$$\mu = \frac{\mu_o}{1 + \theta(V_{GS} - V_T)}$$

Draw General Conclusions on Relative Merits



Exponential cases

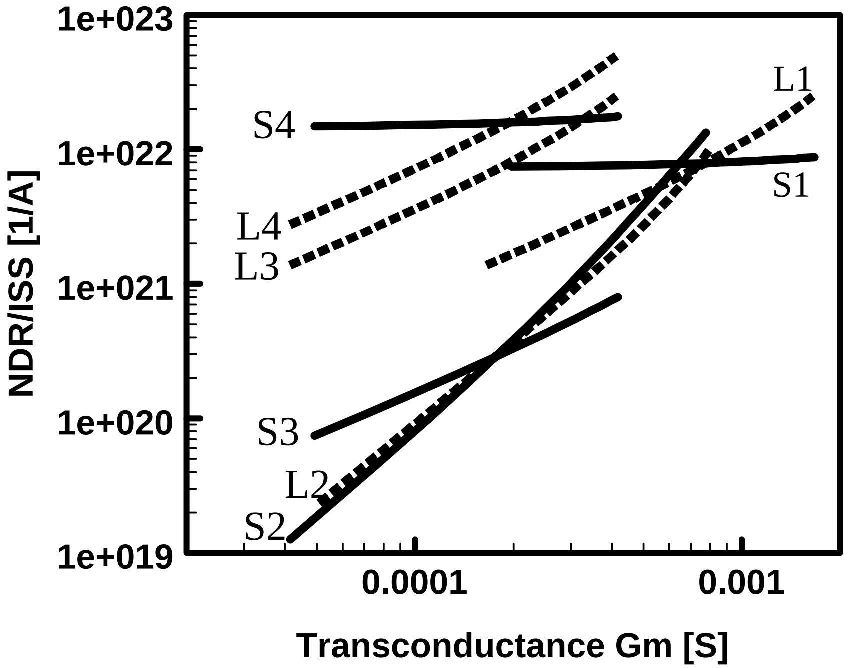


Square-law and Linear cases; θ*=0.1*

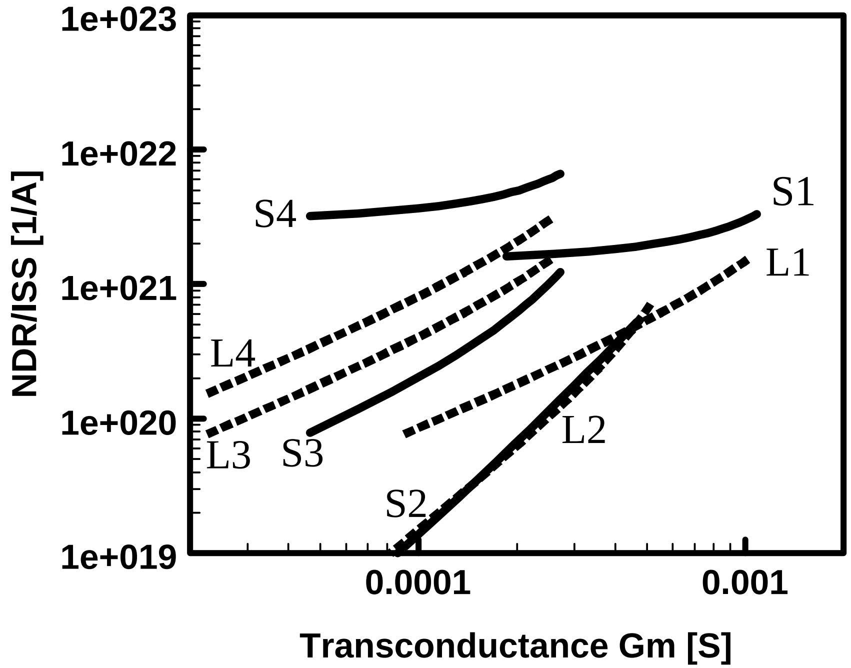
- **Exponential VCCS: worst result (different scales!)**
- **{V_Σ,I_Δ} Square-law or Linear VCCSs (S4 and L4) best!**

Assess Feasibility: e.g. effect of increased θ

- **Results are reference for circuits design (best achievable)**



$\theta = .1 V^{-1}$



$\theta = .5 V^{-1}$

- **Assess feasibility, e.g. in newer technology: higher θ**
  => worse NDR/ISS, except differential pair (S3)

Conclusions

Classification system proposed based on sets of 2 Kirchhoff relations establishing a solution for the variables of the VCCSs.

Usefulness shown:

- ***Overview of all possibilities*** **with 2 VCCSs**
- **Recognise variations on a theme: 50 Kernels, 4 classes**
- **Analyse classes of circuits in one run: general conclusions**
- **Guide designers in choosing and optimising circuits**
    - Select class with best DR/ISS
    - Use best achievable NDR/ISS as land-mark during design