Design of Transconductance Based CMOS Circuits: An Overview

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“Most circuits are MOST circuits”

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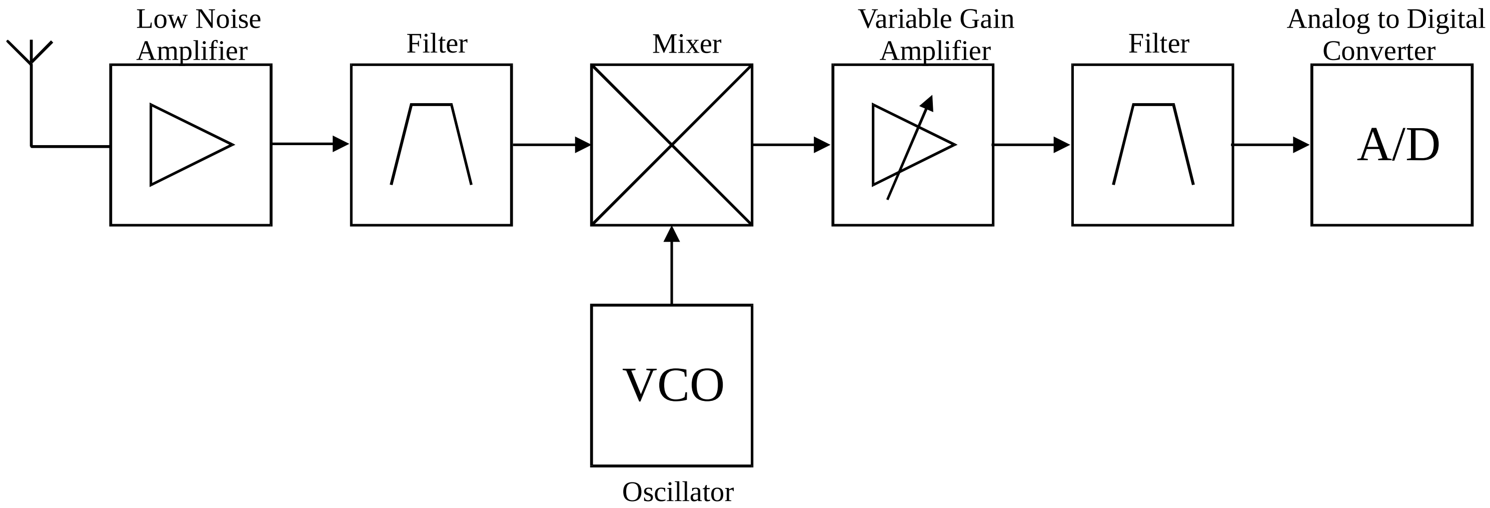
Contents

- Introduction on Transistor Level Circuit Design
- A Design Philosophy for Linear CMOS Circuits

  => “Transconductance Based CMOS Circuits”
- **Generation** of linear two-port circuits with 2 VCCSs
- **Classification** of 2VCCS Circuits
- Applications examples
- Conclusions

Introduction

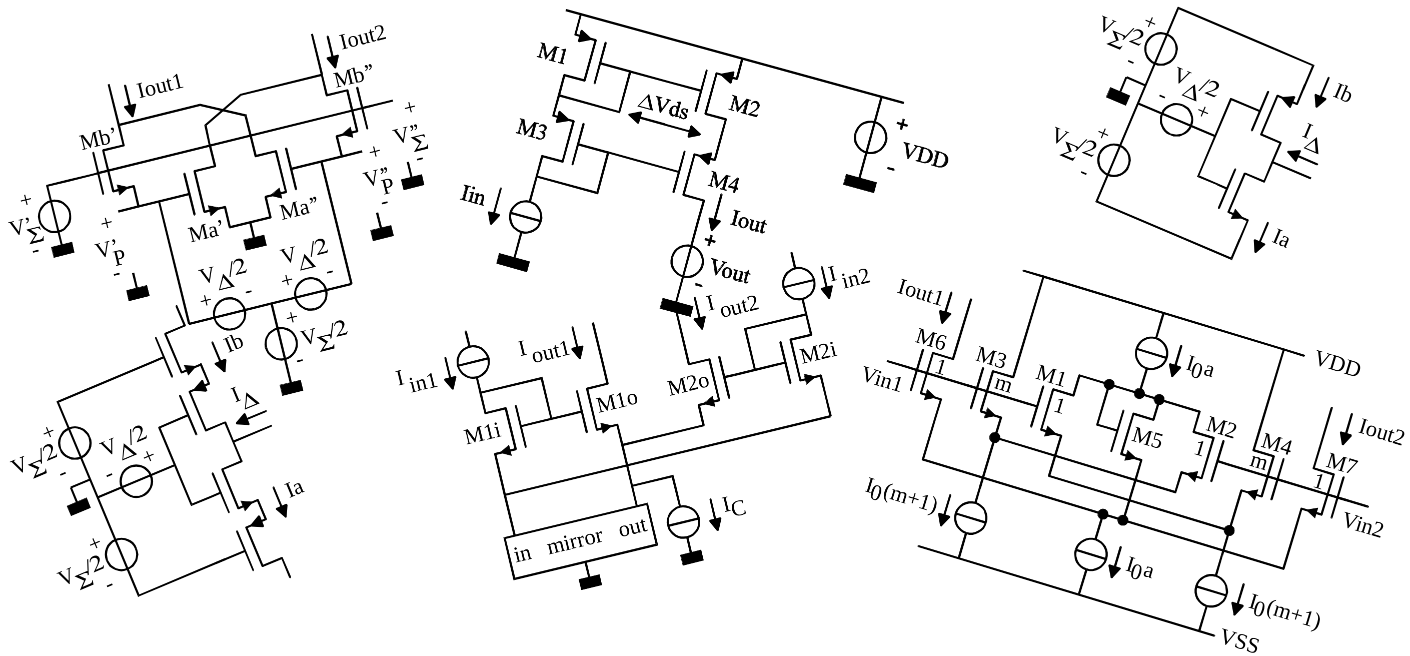
- Example of the analog section of a receiver IC:



- Use building blocks
- Linear blocks important: visible: amplifiers, filters
- “Invisible” (subblocks): V-I , I-V, buffers.
- At lowest level: Transistor level

How to design transistor level building blocks?

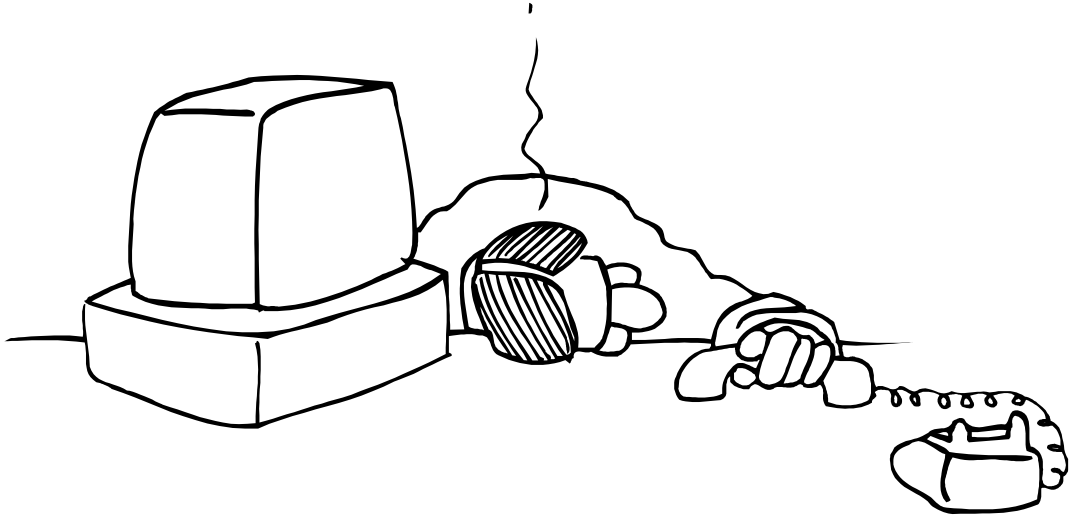
- Literature: fragmentary, many circuit topologies!



- Questions: Variations on a few themes? Relative merits?
- CAD: analysis and optimisation of GIVEN topology

Transistor level topology design??

- Huge number of possibilities!! => use heuristics, intuitions



Difficult to teach to students!

Teach intuition to a computer??

AIM: systematic methods:

- Less chance of overlooking possibilities => better designs
- Basis for education and CAD

A Design Philosophy for Linear MOS Circuits

Look at how most MOST Circuits are constructed:

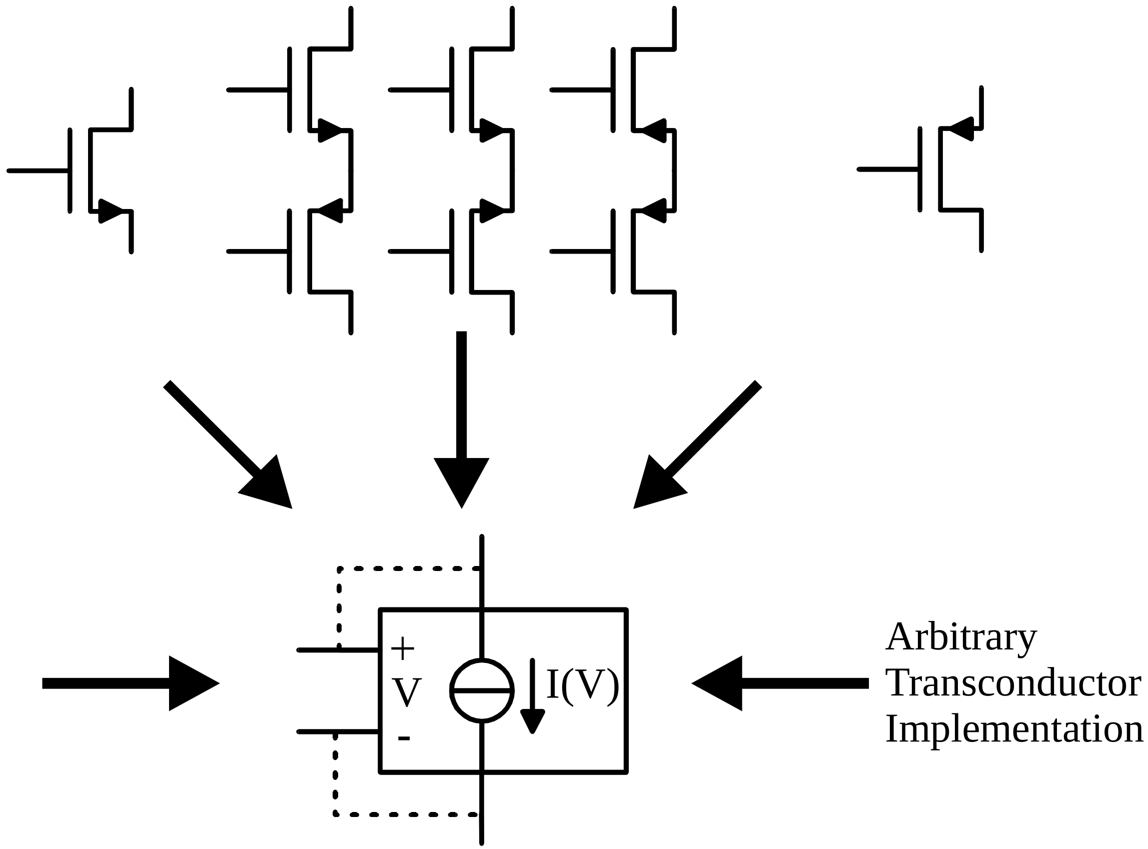
- Combine simple basic circuits (differential pair, mirror) few components <=> HF, low noise, low current
- Use mainly saturated MOSTs (current output)
- Transconductance g_m of MOST is crucial:
  - Good model up to high frequencies
  - Matching of transconductance is good (< 1%)
  - Electronic variability

    => Self-correction

    => Adaptive signal processing

PhD Thesis: Transconductance Based CMOS Circuits

Model components as Voltage Controlled Current Sources



Aim: Design linear circuit building blocks using VCCSs

Four main Questions:

What is needed for linear circuits?

=> REQUIREMENTS

What is possible with using VCCSs?

=> CIRCUIT GENERATION

Which are essentially different?

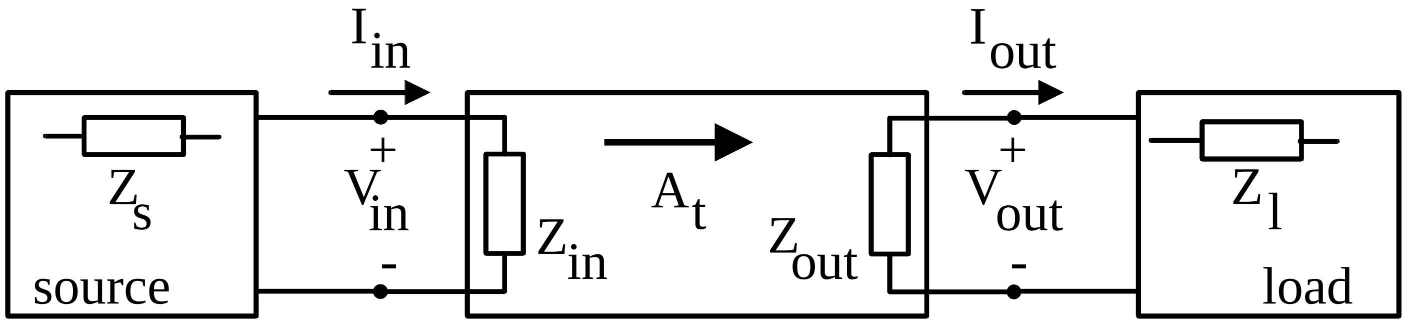
=> CLASSIFICATION

What are their properties?

=> ANALYSIS OF CLASSES

Requirements for linear circuit building blocks

Model building block as linear two-port



"useful linear transactor"

Adapt to source/load [Nordholt, Huijsing]

=> Z_{in} and Z_{out}: $\infty \vee 0 \vee Z_{exact}$: => 3 x 3 “Transactors”

Transfer function known or electronically controllable

=> Two-port parameters: accurate or controllable

V-V and I-I, apart from V-I and I-V Transfers => 2 VCCSs

Generation of 2VCCS Circuits

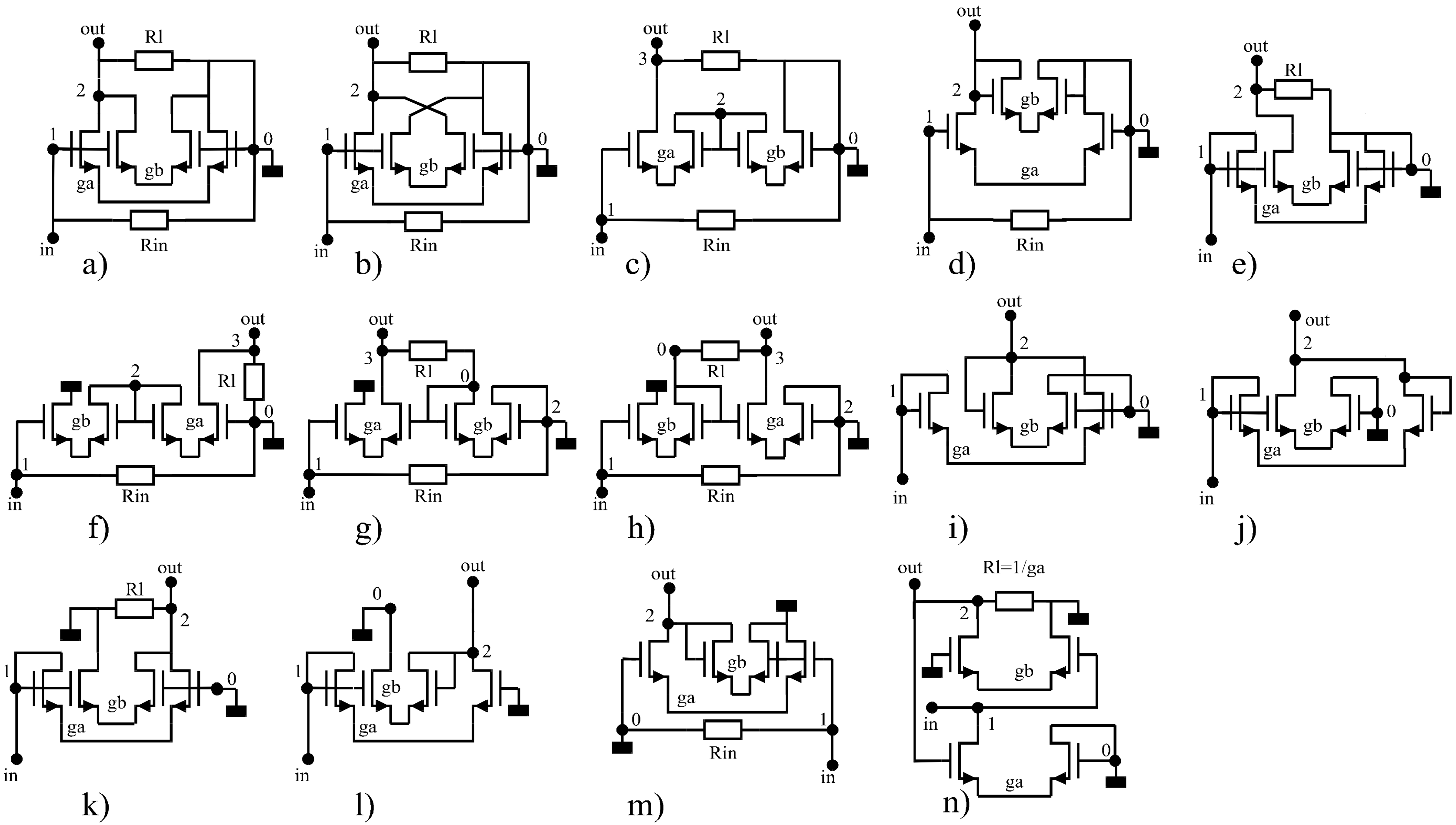
- All two-ports with 2 VCCSs generated using linear graphs
- Symbolic Analysis program to select useful ones:

  => 145 topologies with non-zero transfer function
- Each VCCS topology has several implementations
- All 3x3 transactors possible, directly or approximated

Application example:

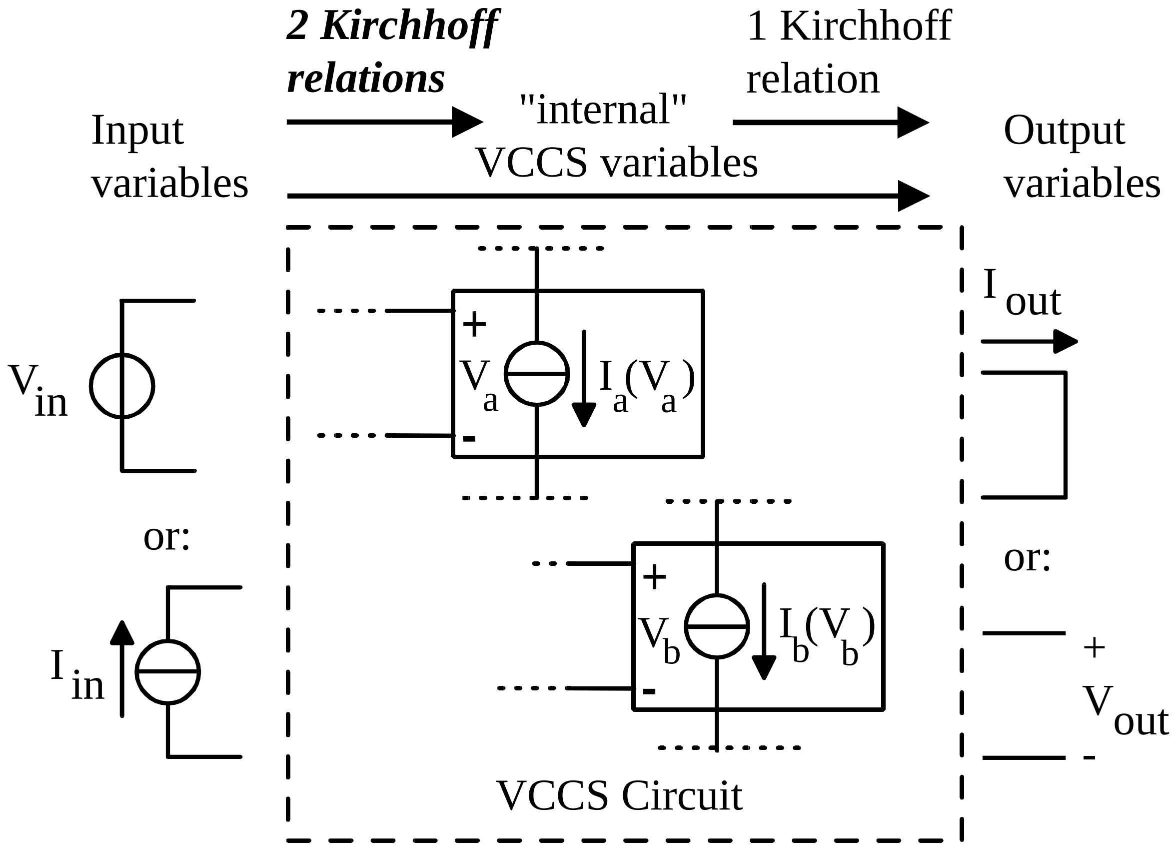
- Input Impedance matching Amplifier
- Implement all VCCS by differential pairs (simplicity)

Example: Voltage Amplifiers with Zin=Rin



Hard to find by in non-systematic way!

Classification of 2VCCS Circuits



Analyse electrical behaviour:

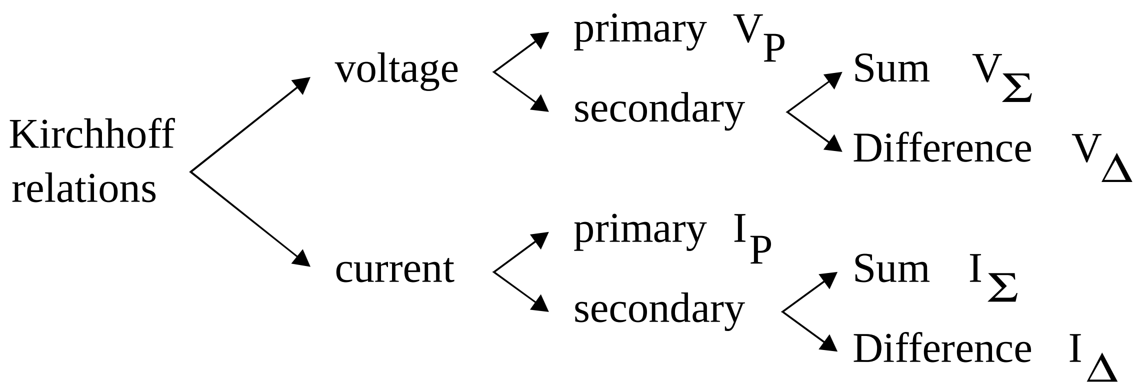
- **Two-port parameters**
- **Different possible solutions for the VCCS variables?**
- **4 eqns needed (linear VCCS)**
- **$I_a = g_a V_a$ and $I_b = g_b V_b$ available**
- **<u>2 additional</u> topology related <u>KVL/KCL</u> relations needed!**

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

Classification criterium: set of 2 independent Kirchhoff relations!

All classes of 2VCCS Circuits

- **Types of Kirchhoff relations:**



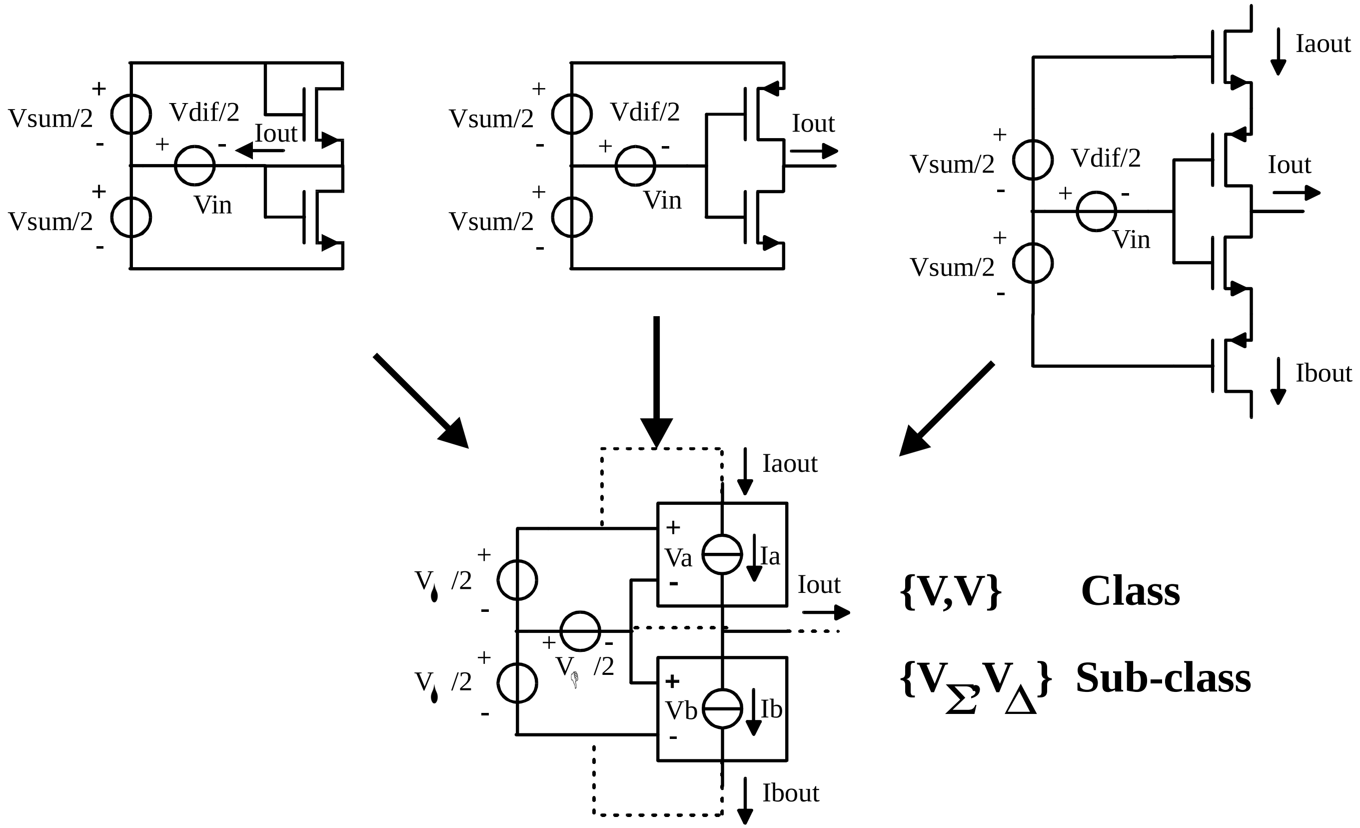
- **ALL Sets of 2 relations: 3 main classes and 14 subclasses:**

{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 of the Classification

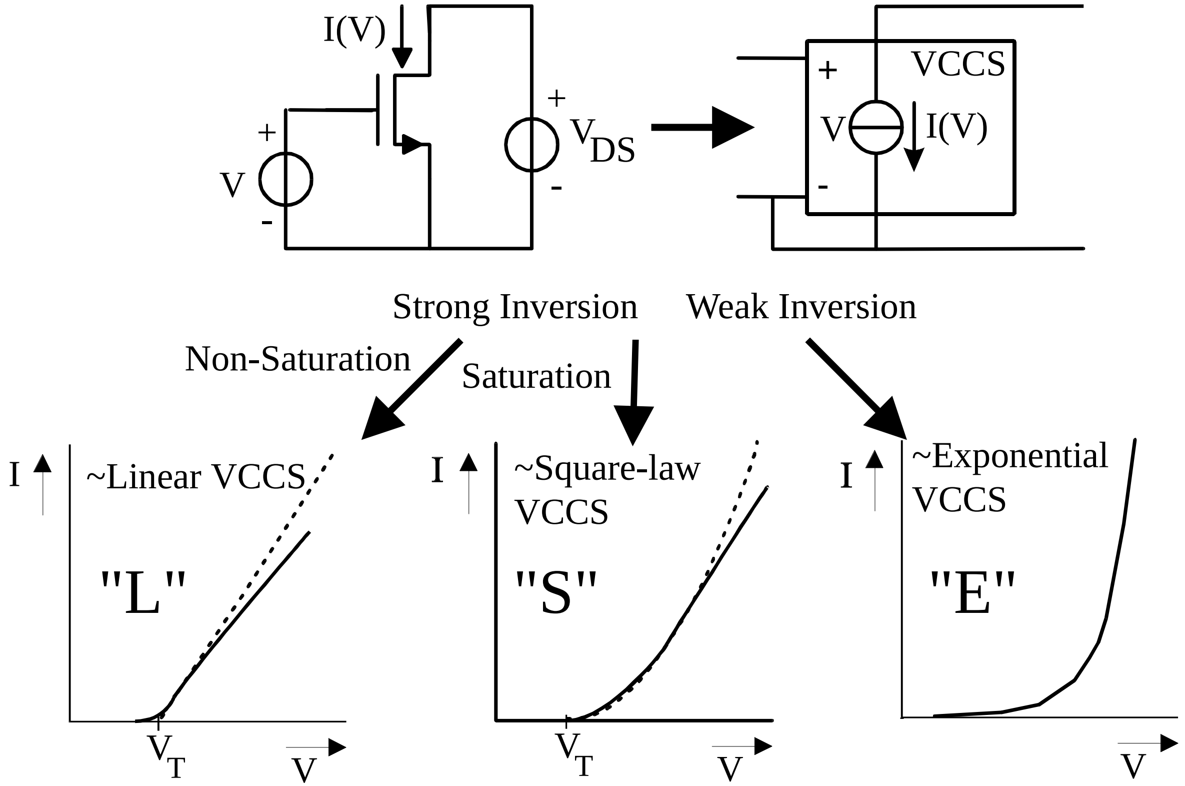


{V,V} Class

$\{V_\Sigma V_\Delta\}$ Sub-class

- Recognise circuits as variations on a theme:
- 50 Published V-I Kernels in 4 classes!

Analyse DR/ISS of the 4 Classes of V-I Kernels



Use MOST-VCCS:

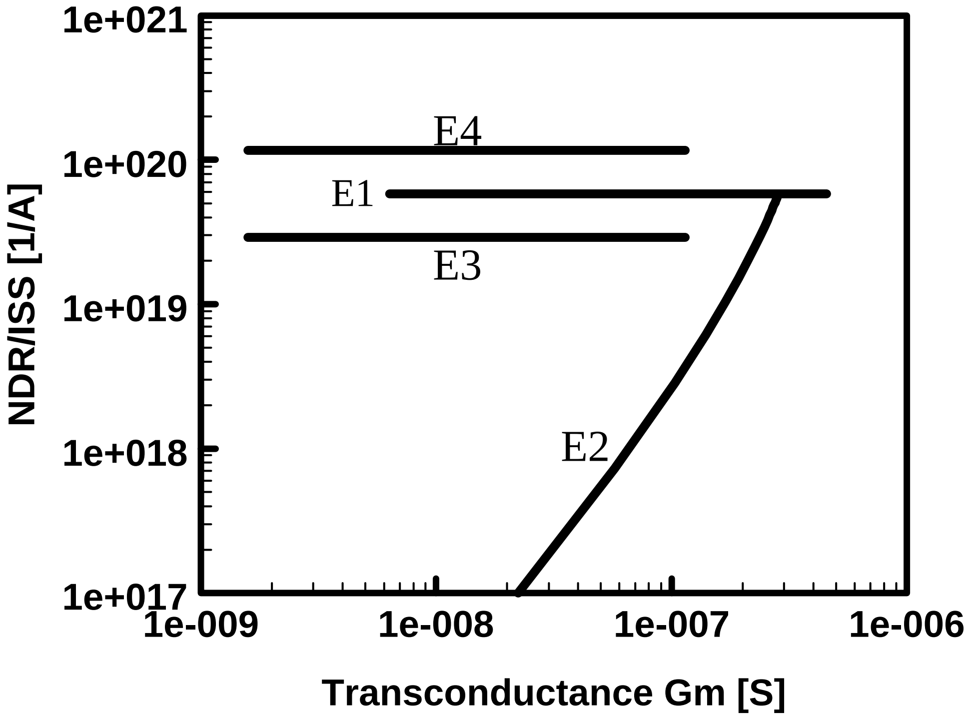
- **Compare DR/ISS**
- **Compare 3 regions**
- **Model for MOST:**
  1. **I(V) needed: I, Gm, Non-linearity**
  2. **Noise**

Assume mobility reduction:

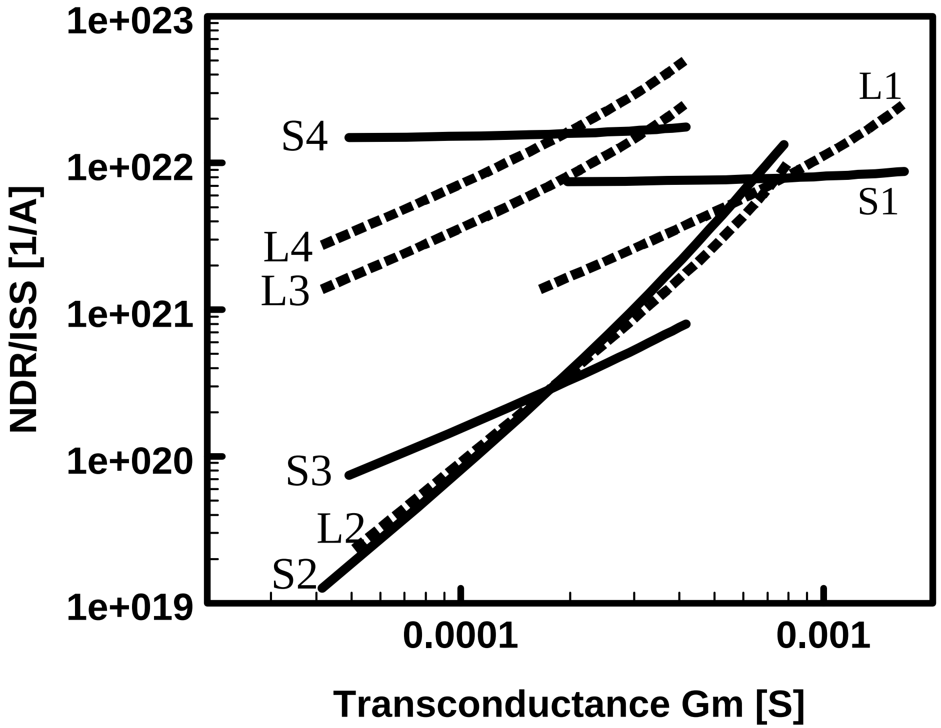
$$\mu = \frac{\mu_o}{1 + \theta\left(V_{GS} - V_T\right)}$$

Compare 4 Classes of Circuits in 3 regions

- NDR/ISS: Normalised to 100% HD3 (IP3), 1Hz NBW



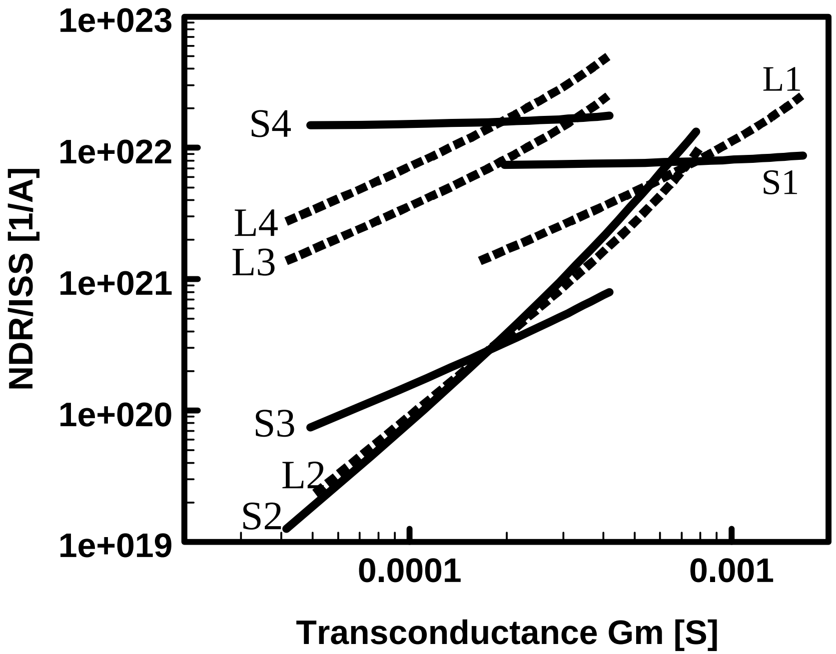
Exponential cases



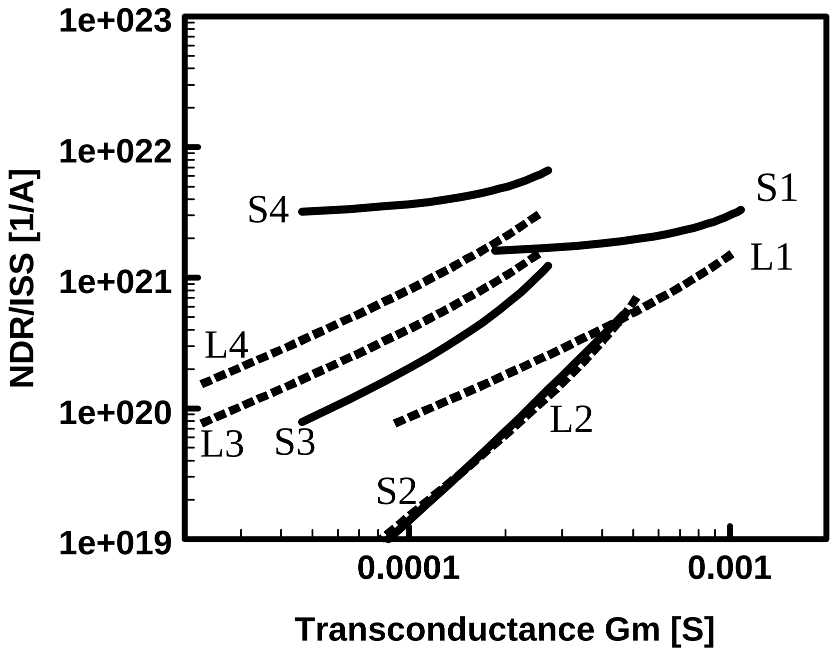
Square-law and Linear cases; θ*=0.1*

- **Weak inversion case much worse than strong inversion**

Design Clues: compare 1μCMOS with deep submicron



θ=.1V^{-1} (1uCMOS)

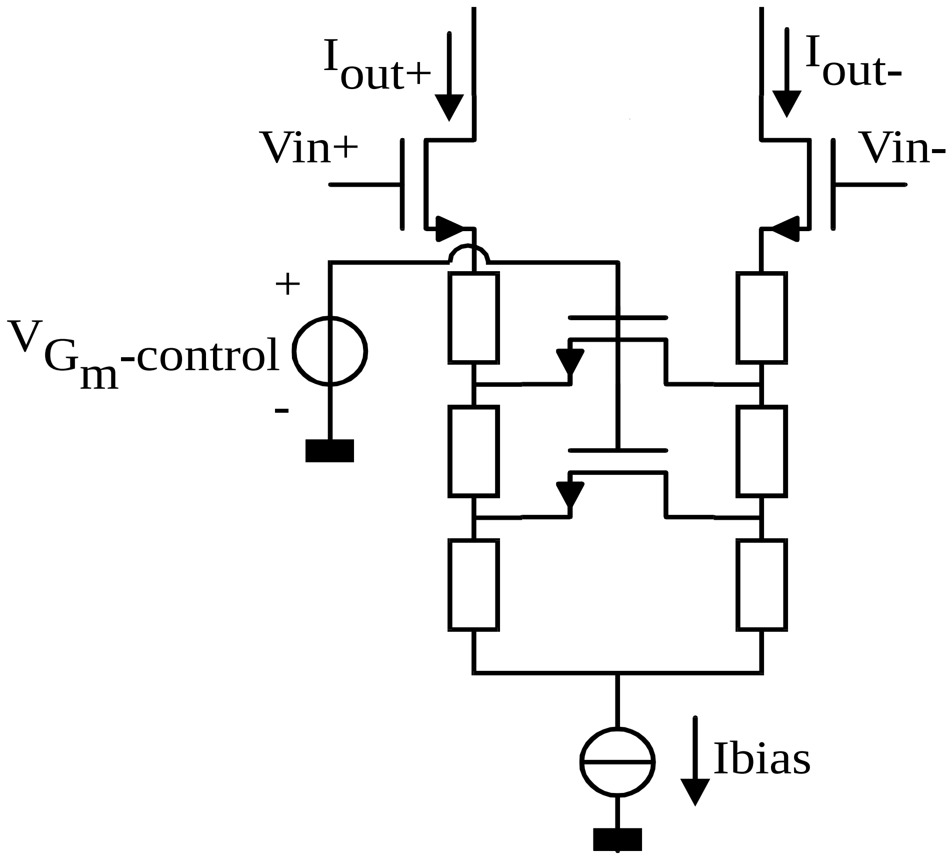


θ=.5V^{-1} (deep sub-micron)

- **=> worsened NDR/ISS, except differential pair (S3)**
- **MOST + Source resistance: maintains good NDR/ISS**
- **However: hardly any electronic variability**

Transconductor with "Soft-Switched" Resistors

PhD Mensink: Resistors + MOST Switches



- Body effect: different switching-level
- "gradually switched"
- Careful dimensioning

Conclusions

Systematic approach to transistor level circuit design:

Systematic Generation of circuits

- Hundreds of circuits based on only 2 VCCS

Classification of ALL 2VCCS Circuits

- Compact overview: 3 main classes and 14 subclasses
- Recognise variations on a theme

Analysis of classes of circuits

- General design clues, e.g. use strong inversion if “square-law conformance”, rely on resistors if not.

Many transistor level circuit topologies are yet to be explored!