EE-429
Fundamentals of VLSI Design

Spice Simulations

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Need for Circuit Simulations

- **Circuit simulators are important to**
  - Verify that our designs are properly working (verification)
  - Extract circuit parameters for high-level models for design and optimization
  - Fine tune parameters from an initial hand-crafted (model-based) starting point
  - Verify a circuit in different corners and in the presence of uncertainties
  - Track down hidden issues in a larger circuit (especially post-layout)

- **They should not serve as a basis for pure trial-and-error**
  - Analog simulation are too slow for extensive trial and error
  - At any stage, you need to have a good idea of "what to expect"
  - You should have a good (and well justified) starting point

The Original of Circuit Simulations

- **First circuit simulator was developed in the 1970s at Berkely:**
  - Started as a class project: CANCER="Computer Analysis for Non-linear Circuits Excluding Radiation" (under Prof. Ron Rohrer)
  - His successor (Prof. **Don Peterson**) **and** his student (**Larry Nagel**) **developed** this class project into **the first version of Spice**
  - **1972 Spice** was **released as "Public Domain"** (free SW), written in FORTRAN
  - **1975 Spice 2:** support for hierarchy, better stability and much less basic device models
  - **1989 Spice 3:** better UI, advanced MOSFET (BSIM1 models), written in C
  - **SPICE**: Bimulation **P**rogram with **I**ntegrated **C**ircuit **E**mphasis
- **Today, there are many versions of Spice**, including "famous" commercial simulators
  - **LTSpice, PSpice: public domain**
  - **HSpice:** today owned by Synopsys
  - **SPECTRE:** developed by CADENCE

Setting up a Simulation

- **For an analog (e.g., Spice) circuit information, we need**
  - A "Netlist" that describes our circuit
  - A "Testbench" to provide stimuli, supply voltages, and other inputs as well as external components that connect to our DUT (e.g., capacitive loads,...).
  - "Device models" for basic components: part of the simulator
  - "Model parameters": part of the PDK:
  - Initial conditions: The state of our circuit at the start of the simulation
  - Instructions what and how to simulate and simulation parameters (e.g., temperature)
  - Instructions what to record/save and plot

```
INVERTER TRANSIENT ANALYSIS
**********
• MODELS *
• **********
• .model NMOD NMOS (LEVEL=1, VTO=0.7 GAMMA=0 LAMBDA=0
  KP=73U)
• .model PMOD PMOS (LEVEL=1, VTO=-0.8 GAMMA=0 LAMBDA=0
  KP=21U)
• ***********
• * CIRCUIT *
• ***********
• VDD 3 0 DC 5
• VGS 1 0 PULSE(0,5,0,5n,5n,1u,2u)
• M1 2 1 0 0 NMOD L=2U W=10U
• M2 2 1 3 3 PMOD L=2U W=25U
• C1 2 0 0.047n
• .OP
• .TRAN 0.1U 3U
• .PLOT TRAN V(2)
• .PROBE
• .END
```

Types of Simulations

- **DC Analysis**
  - Find the **DC Operating Point**: circuit solution in steady state (all inputs fixed)
  - Solves a non-linear system of equations: usually through **linearization** and **Newton's method**
  - Iterative process that converges to a solution
  - The DC analysis is the **starting point for a Transient or AC Analysis**

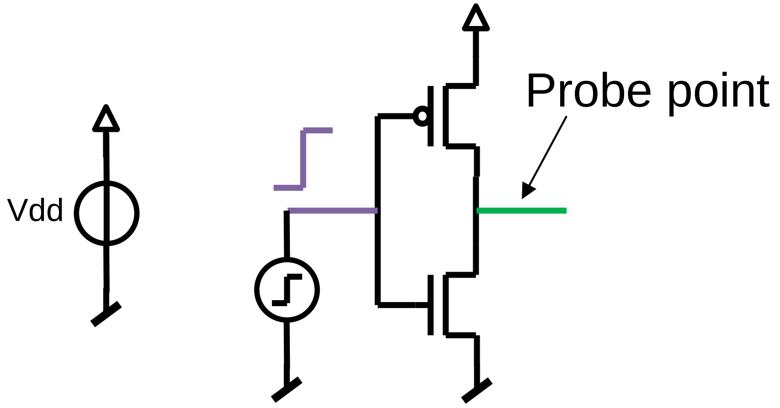
- **Transient Analysis**
  - Starts from operating point found in DC analysis (time-0)
  - **Solves** a set of **non-linear differential equations by discretizing time** usually with variable time steps

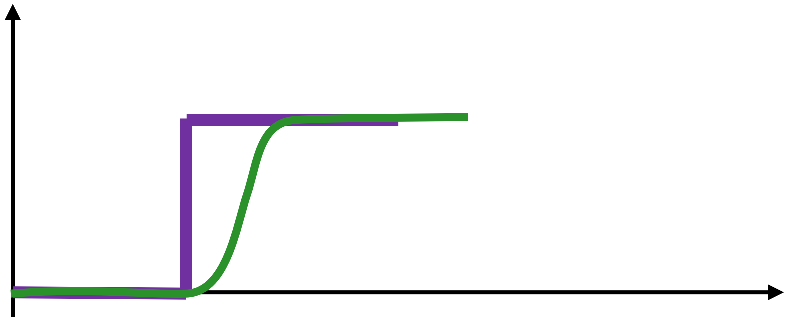
- **AC Analysis**
  - Used mostly for analog design
  - **Analyzes frequency domain behavior** / response of a circuit

Creating a Proper Testbench

- **A proper testbench (adapted to what we want to see) is critical to have meaningful results**

Example: delay (transient) simulation of an inverter





What is missing here?

Creating a Proper Testbench

- **A proper testbench (adapted to what we want to see) is critical to have meaningful results**

- **Must properly reflect not only the circuit, but also the boundary conditions**
  - Realistic input signals
  - Realistic electrical characteristics of the inputs and outputs

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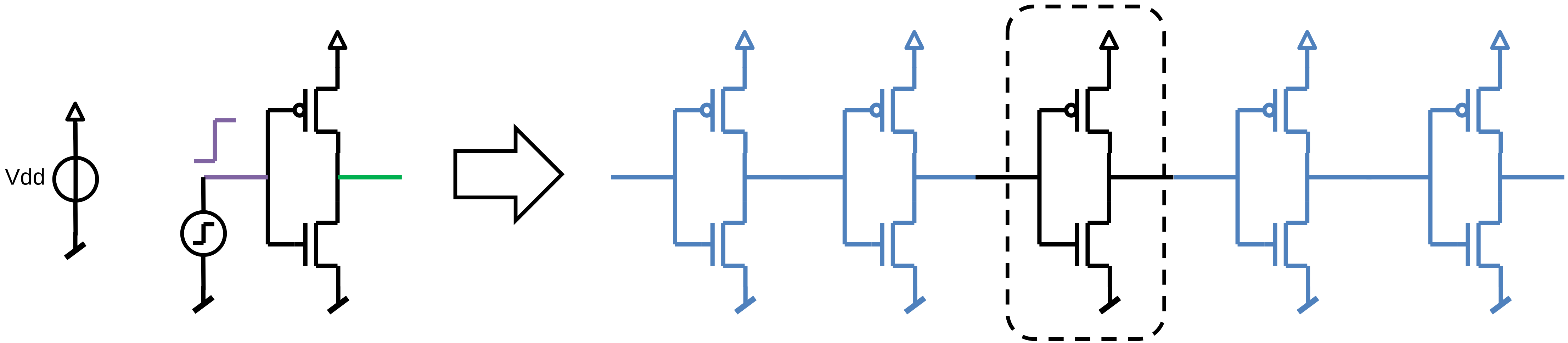

Creating a Proper Testbench

- **A proper testbench (adapted to what we want to see) is critical to have meaningful results**
- **Must properly reflect not only the circuit, but also the boundary conditions**
  - Realistic input signals
  - Realistic electrical characteristics of the inputs and outputs
- **Efficiently represent boundary conditions with a proper model**

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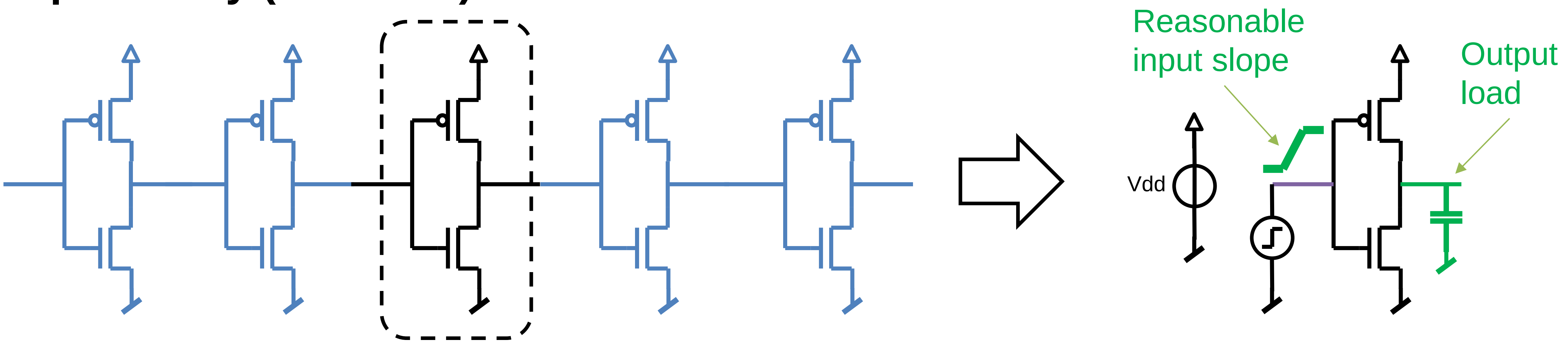
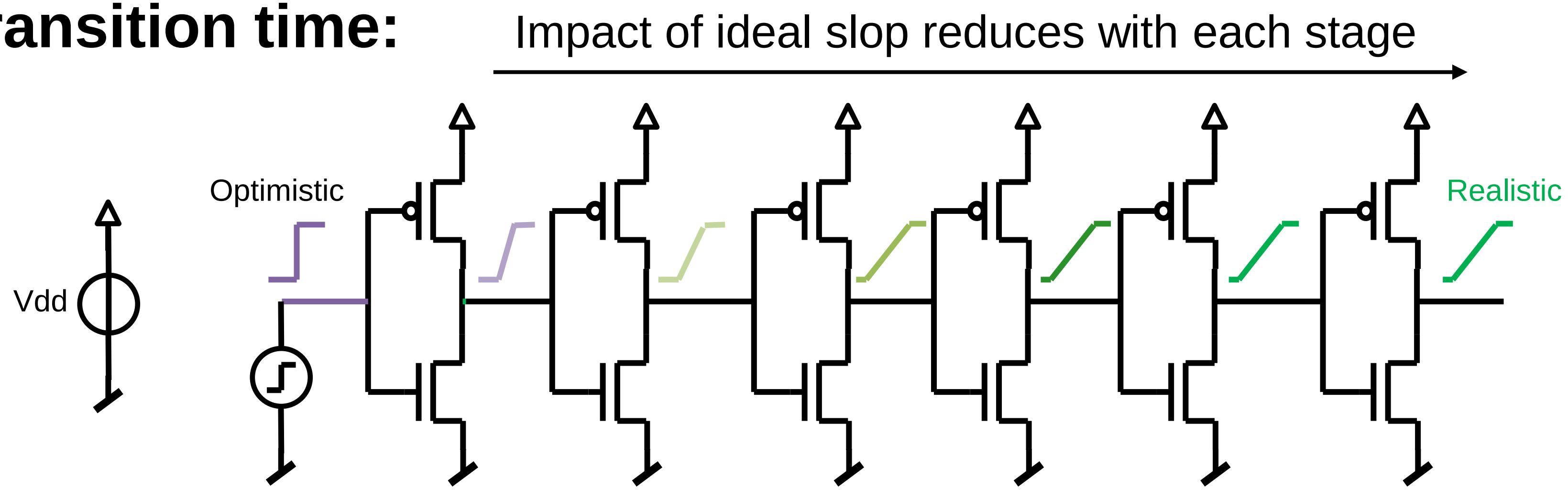


Creating a Proper Testbench

- **Using simulation to find proper values for transition time and output load:**
  - Build a testbench that allows to calculate the desired model parameters from known quantities

- **Input transition time:**



Creating a Proper Testbench

- **Using simulation to find proper values for transition time and output load:**
  - Build a testbench that allows to calculate the desired model parameters from known quantities

- **Load capacitance:**
  - Extract from RC model