A Simple Transistor Model

The variables that describe a transistor’s behavior are:
- $V_{gs}$—the gate-to-source voltage;
- $V_{ds}$—the drain-to-source voltage (remember that $V_{ds} = -V_{sd}$);
- $I_d$—the current flowing between the drain and source.

The constants that determine the magnitude of source-to-drain current in the transistor are:
- $V_t$—the transistor threshold voltage, which is positive for an n-type transistor and negative for a p-type transistor;
- $k'$—the transistor transconductance, which is positive for both types of transistors;
- $W/L$—the width-to-length ratio of the transistor.

Drain current characteristics

- Linear region ($V_{ds} < V_{gs} - V_t$):
  - $I_d = k' (W/L)[(V_{gs} - V_t) V_{ds} - 0.5 V_{ds}^2]$]
- Saturation region ($V_{ds} \geq V_{gs} - V_t$):
  - $I_d = 0.5k' (W/L)(V_{gs} - V_t)^2$

Drain current

<table>
<thead>
<tr>
<th>Type</th>
<th>$k'$</th>
<th>$V_t$</th>
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</thead>
<tbody>
<tr>
<td>n-type</td>
<td>$170 \mu A/\text{V}^2$</td>
<td>0.5 V</td>
</tr>
<tr>
<td>p-type</td>
<td>$-30 \mu A/\text{V}^2$</td>
<td>-0.5 V</td>
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</table>
A minimum-size transistor in the SCMOS rules is of size $L = 2\lambda$ and $W = 3\lambda$. Given this size of transistor and the 180 nm transistor characteristics, calculate the current through a minimum-sized n-type transistor at the boundary between the linear and saturation regions at $V_{gs} = 0.7V$

$$I_d = \frac{1}{2}\left(\frac{170\lambda I}{V^2}\right)\left(\frac{3\lambda}{2\lambda}\right)(0.7V - 0.5V)^2 = 5.1\mu A$$

Basic transistor parasitics

1. Gate to substrate, also gate to source/drain.
2. Source/drain capacitance, resistance.
3. Gate capacitance $C_g$. Determined by active area.
4. Source/drain overlap capacitances $C_{gs}$, $C_{gd}$. Determined by source/gate and drain/gate overlaps. Independent of transistor $L$. $C_{gs} = C_{gd} W$
5. Gate/bulk overlap capacitance.

Transistor parasitics cntd..

CMOS ICs have parasitic silicon-controlled rectifiers (SCRs).
- When powered up, SCRs can turn on, creating low-resistance path from power to ground. Current can destroy chip.
- Early CMOS problem. Can be solved with proper circuit/layout structures.

Latch-up (parasitics in IC)
Parasitic SCR

Diffusion wire capacitance

- Capacitances formed by p-n junctions:

Quiz

Calculate the current through a minimum-sized p-type transistor at saturation.