Lecture 14

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- Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET)
  - Extremely high impedance looking into the gate
    - $I_G \approx 0$
  - Body is often connected to the source or to ground (substrate)
  - Cutoff Region
    - $V_{GS} < V_{to}$
      - V_{to} is the threshold voltage (technology-dependent parameter: .3[V] (new) - 2[V] (older))
    - $I_D = 0$
  - Triode Region
    - $V_{GS} > V_{to}$ and $V_{DS} < V_{GS} - V_{to}$
    - Also called "linear region"
      - $I_D \propto V_{GS}$ when V_{DS} is small
      - Voltage-controlled resistance (between drain and source terminals)
  - Saturation Region
    - $V_{GS} > V_{to}$ and $V_{DS} > V_{GS} - V_{to}$
    - $I_D = K(V_{GS} - V_{to})^2$ (desired mode for amplifiers)
  - Drain-Source Current:

$$I_D = \left(\frac{W}{L}\right)\left(\frac{KP}{2}\right)\left[2(V_{GS} - V_{to})V_{DS} - V_{DS}^2\right]\left[1 + \lambda V_{DS}\right]$$

    - Parameters:
      - L is the channel length, W is the channel width
      - $KP = \mu_n C_{ox} = \mu_n(\varepsilon_{ox}/t_{ox})$
      - μ_n is the mobility of the electrons in the channel

- C_{ox} is the oxide capacitance per unit area
- $K = (W/L)(KP/2)$ has units of ampéres per square volt
- λ is the channel length modulation parameter ($\lambda = 0$ in many hand-based calculation estimates)

- Boundary between triode and saturation regions:

$$I = \left(\frac{W}{L}\right)\left(\frac{KP}{2}\right)V_{DS}^2$$

- Small Signal Analysis with MOSFETS

  - Hybrid-π small-signal model

    - Parasitic capacitors are excluded here

      - The model is only valid at low and midband frequencies

  - Parameters depend on the Q-point

$$g_m = \frac{2I_D}{V_{GSQ} - V_{to}} = KP\frac{W}{L}(V_{GSQ} - V_{to}) = \sqrt{2KP\frac{W}{L}I_D}$$

$$r_{ds} \approx \frac{1}{\lambda I_D} = \frac{|V_A|}{I_D}$$

- T-Model has the same structure, but with one addition:

$$r_{gs} = \frac{1}{g_m}$$

- MOSFETs in Triode Region

  - Simple Triode-Region Model

    - Parasitic capacitors are excluded here

      - The model is only valid at low and midband frequencies

$$r_{on} \approx \frac{1}{KP\frac{W}{L}(V_{GSQ} - V_{TH})}$$

  - For AC signals with small amplitudes

- Common-Source Amplifier Formulas

– Amplifier gain without load:

$$A_{vo} = \frac{v_o}{v_i} \approx -g_m(r_{ds}||R_D)$$

– Loaded voltage gain:

$$A_v = \frac{v_o}{v_i} \approx -g_m(r_{ds}||R_D||R_L)$$

– Gain from source to load:

$$A_{vs} = \frac{v_o}{v_{sig}} \approx -g_m \left[\frac{R_i}{R_{sig} + R_i}\right] (r_{ds}||R_D||R_L)$$