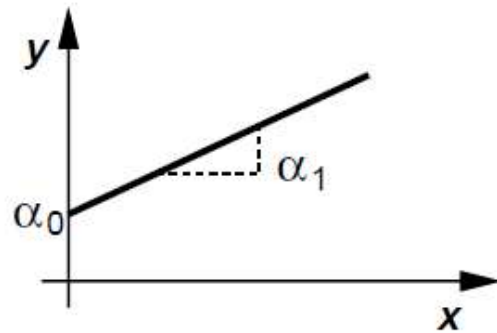
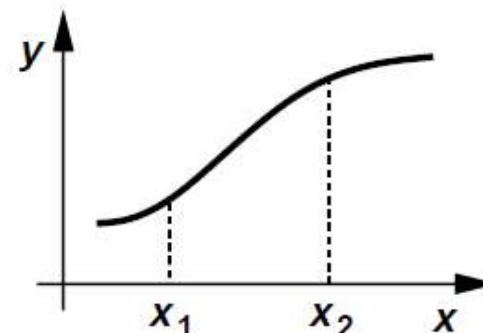


Ideal vs Non-ideal Amplifier



(a)



(b)

- **Ideal amplifier (Fig. a)**

$$y(t) = \alpha_0 + \alpha_1 x(t)$$

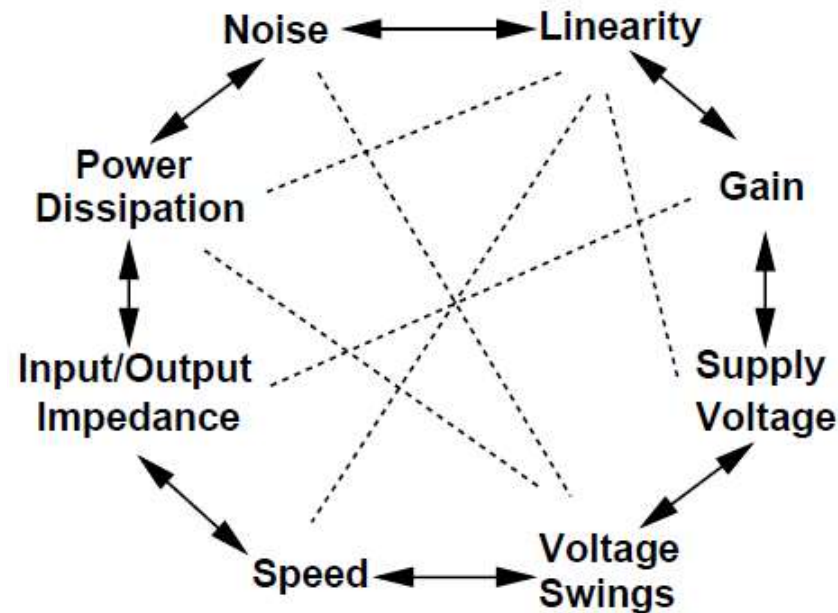
- Large-signal characteristic is a straight line
- α_1 is the “gain”, α_0 is the “dc bias”

- **Nonlinear amplifier (Fig. b)**

$$y(t) = \alpha_0 + \alpha_1 x(t) + \alpha_2 x^2(t) + \cdots + \alpha_n x^n(t)$$

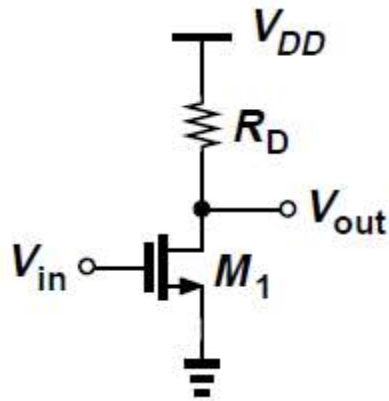
- Large signal excursions around bias point
- Varying “gain”, approximated by polynomial
- Causes distortion of signal of interest

Analog Design Tradeoff



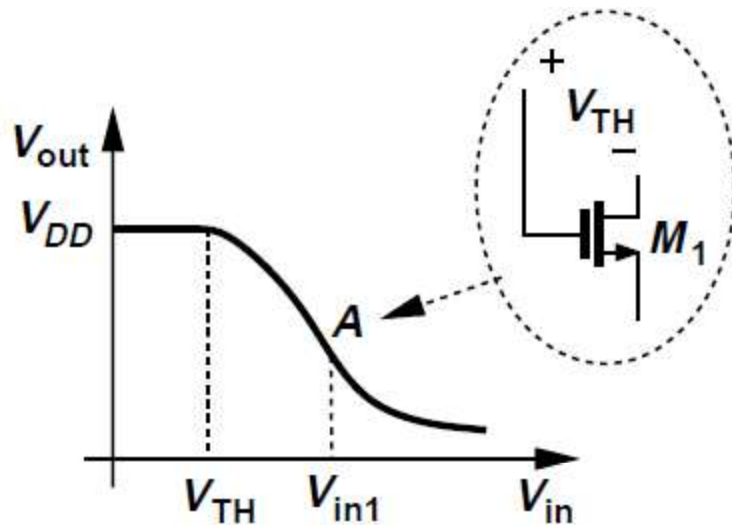
- Along with gain and speed, other parameters also important for amplifiers
- Input and output impedances decide interaction with preceding and subsequent stages
- Performance parameters trade with each other
 - Multi-dimensional optimization problem

Common-Source stage with resistive load



- Very high input impedance at low frequencies
- For $V_{in} < V_{TH}$, M_1 is off and $V_{out} = V_{DD}$

$$V_{out} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{TH})^2$$



- When $V_{in} > V_{TH}$, M_1 turns on in saturation region, V_{out} falls
- When $V_{in} > V_{in1}$, M_1 enters triode

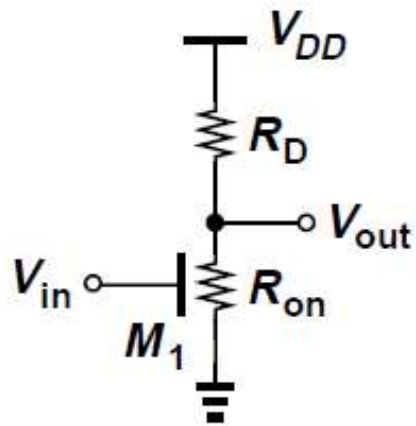
$$V_{in1} - V_{TH} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in1} - V_{TH})^2$$

- At point A, $V_{out} = V_{in1} - V_{TH}$

Common-Source stage with resistive load

- For $V_{in} > V_{in1}$,

$$V_{out} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \left[2(V_{in} - V_{TH})V_{out} - V_{out}^2 \right]$$



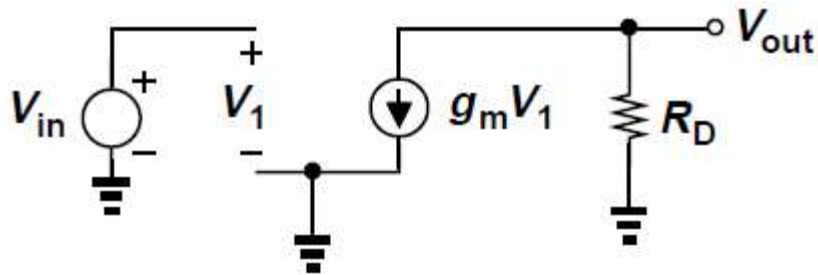
- If V_{in} is high enough to drive M_1 into deep triode region so that

$$\begin{aligned} V_{out} &= V_{DD} \frac{R_{on}}{R_{on} + R_D} \\ &= \frac{V_{DD}}{1 + \mu_n C_{ox} \frac{W}{L} R_D (V_{in} - V_{TH})} \end{aligned}$$

Common-Source stage with resistive load

$$\begin{aligned}
 A_v &= \frac{\partial V_{out}}{\partial V_{in}} \\
 &= -R_D \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{TH}) \\
 &= -g_m R_D.
 \end{aligned}$$

- Taking derivative of I_D equation in saturation region, small-signal gain is obtained



- Same result is obtained from small-signal equivalent circuit

$$V_{out} = -g_m V_1 R_D = -g_m V_{in} R_D$$

- g_m and A_v vary for large input signal swings according to

$$g_m = \mu_n C_{ox} (W/L) (V_{GS} - V_{TH}).$$

- This causes non-linearity