MIC511
Analysis and Design of Analog Integrated Circuits
Lecture 11

Examples

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March 4, 2012

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• Assumptions

1. Intrinsic gain of each device $\gg 1$

   \[ g_m r_o \gg 1 \implies 1/g_m \ll r_o \]

2. Intrinsic gain of devices similar in value

3. Output resistances of devices similar in value

   \[ r_{o1} \approx r_{o2} \]

• Note:

  – Assumption 1 is reasonable in practice
  – Assumptions 2 and 3 are invalid in practice

    * Used here only for pedagogical reasons
Replace Current Sources
Remove Non-Signal-Path Biasing Circuitry
Bipolar Modeling is similar to CMOS

**MOSFET**

**Key Small-Signal Parameters**

\[ g_m = \mu_n C_{ox}(W/L)(V_{GS} - V_{TH}) = \sqrt{2\mu_n C_{ox}(W/L)} I_D \]

\[ g_{mb} \ll g_m \]

\[ r_o = \frac{1}{\lambda I_D} \]

**Thevenin Resistances**

\[ R_{thd} = r_o (1 + g_m R_S) \]

\[ R_{thg} = \text{infinite} \]

\[ R_{ths} = \frac{1 + R_D / r_o}{g_m} \]

**General Thevenin Model**

\[ A_v = 1 \]

\[ \alpha = 1 \]

\[ g_{mb} \ll g_m \cdot g_m r_o \ll 1 \]

\[ R_d \ll R_{thd} \]

**BIPOLAR**

**Key Small-Signal Parameters**

\[ g_m = \frac{I_c}{V_i}, \quad V_i = \frac{kT}{q} \]

\[ V_i \approx 25 \text{ mV at room temp} \]

\[ r_x = \frac{\beta_o}{g_m}, \quad \beta_o \approx 100 \text{ to } 200 \]

\[ r_o = \frac{V_A}{I_c}, \quad V_A \approx 100 \text{ to } 200 \text{ V} \]

**Thevenin Resistances**

\[ R_{thd} = \text{approx} \]

\[ R_{thg} = \text{approx} \]

\[ R_{ths} = \text{approx} \]

**Thevenin Resistances**

\[ R_{thd} = r_o (1 + g_m (R_d || R_E)) \]

\[ R_{thg} = r_x + \beta_o R_E \]

\[ R_{ths} = 1/g_m + R_B/\beta_o \]

**General Thevenin Model**

\[ A_v = 1 \]

\[ \alpha = 1 \]

\[ R_c + R_E \ll r_o, R_B \ll r_x \]

\[ R_c + R_E \ll \beta_o r_o \]
Compute 2-port for Stage 3

\[ V_{out} = \frac{50}{50 + r_{\pi} + \beta_o 50} \]

\[ V_{out} = \frac{1}{g_{m25}} + \frac{(r_{\pi} + \beta_o 50)}{\beta_o} \approx \frac{1}{g_{m25}} \]

\[ r_{\pi} + \beta_o 50 \]

\[ r_{\pi} + \beta_o 50 \]

\[ (g_{m10} + r_{o10}) r_{o11} \]

\[ 50 \, \Omega \]

output resistance of Stage 2
Compute 2-port for Stage 2
Compute 2-port for Stage 1 (Step 1)

Calculate Thevenin resistances
Compute 2-port for Stage 1 (Step 2)

**Calculate short circuit current at output**

\[ i_{sc} \approx 2i_{s1} \approx \frac{V_{in} g_{m1}}{2} \]

**Calculate output resistance**

\[ i_t \approx \frac{V_t}{r_{o4}} + 2i_t = \frac{V_t}{r_{o4}} + 2 \frac{V_t}{2r_{o2}} \]

\[ V_t = r_{o2} || r_{o4} \]
Compute 2-port for Stage 1 (Final Step)
What is the overall input/output resistance of the amp?

What is the overall gain?

Which stage contributes the most gain?

What is the function of each stage?