

Collection of Formulas

Analogue IC-design ETIN25



***OBS!! Work in progress
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Preface

This collection of formulas is an unofficial formula sheet created by me, a student (Melker Rose E23), for the course Analogue IC-design (ETIN25) at LTH.

The primary purposes of creating this document were:

- To gather all relevant formulas in one convenient location for study and reference
- To enhance learning through the process of organizing and typesetting the material

Important notes:

- This is *not* an official document from the course administration, department, or faculty
- Although care has been taken to ensure accuracy and formulas are primarily sourced from official materials, the coursebook (**Gray, Hurst, Lewis, Meyer:** *Analysis and Design of Analog Integrated Circuits*, Fifth Edition. Wiley 2010.) and/or lecture slides, cross-referencing is recommended, as there may be errors or omissions
- This document is a work in progress and may be updated

I hope this collection of formulas proves useful.

Best of luck,

Melker Rose

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Active-Device Parameters

npn Bipolar Transistor Parameters

Large-Signal Forward-Active Operation

Collector current $I_C = I_S \exp\left(\frac{V_{be}}{V_T}\right)$ (1)

Small-Signal Forward-Active Operation

Transconductance $g_m = \frac{qI_C}{kT} = \frac{I_C}{V_T}$ (2)

Transconductance-to-current ratio $\frac{g_m}{I_C} = \frac{1}{V_T}$ (3)

Input resistance $r_\pi = \frac{\beta_0}{g_m}$ (4)

Output resistance $r_o = \frac{V_A}{I_C} = \frac{1}{\eta g_m}$ (5)

Collector-base resistance $r_\mu = \beta_0 r_o$ to $5\beta_0 r_o$ (6)

Base-charging capacitance $C_b = \tau_F g_m$ (7)

Base-emitter capacitance $C_\pi = C_b + C_{je}$ (8)

Emitter-base junction depletion capacitance $C_{je} \simeq 2C_{je0}$ (9)

Collector-base junction capacitance $C_\mu = \frac{C_{\mu 0}}{\left(1 - \frac{V_{BC}}{\psi_{0c}}\right)^{n_c}}$ (10)

Collector-substrate junction capacitance $C_{cs} = \frac{C_{cs0}}{\left(1 - \frac{V_{SC}}{\psi_{0s}}\right)^{n_s}}$ (11)

Transition frequency $f_T = \frac{1}{2\pi} \frac{g_m}{C_x + C_\mu}$ (12)

Effective transit time $\tau_T = \frac{1}{2\pi f_T} = \tau_F + \frac{C_{je}}{g_m} + \frac{C_\mu}{g_m}$ (13)

$$\begin{array}{ll} \text{Maximum} & g_m r_o = \frac{V_A}{V_T} = \frac{1}{\eta} \\ \text{gain} & \end{array} \quad (14)$$

NMOS Transistor Parameters

Large-Signal Operation

$$\begin{array}{ll} \text{Process transconduc-} & k' = \mu C_{ox} \\ \text{tance parameter} & \end{array} \quad (15)$$

$$\begin{array}{ll} \text{Drain current (active re-} & I_D = \frac{k'}{2} \frac{W}{L} (V_{GS} - V_t)^2 \\ \text{gion)} & \end{array} \quad (16)$$

$$\begin{array}{ll} \text{Early voltage} & V_A = \frac{I_D}{\delta I_D / \delta V_{DS}} = L_{eff} \left(\frac{\delta X_d}{\delta V_{DS}} \right)^{-1} \\ & \end{array} \quad (17)$$

$$\begin{array}{ll} \text{Reciprocal of the Early} & \lambda = \frac{1}{V_A} \\ \text{voltage} & \end{array} \quad (18)$$

$$\begin{array}{ll} \text{Drain current (active re-} & I_D = \frac{k'}{2} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS}) \\ \text{gion) better} & \end{array} \quad (19)$$

$$\begin{array}{ll} \text{Drain current (triode re-} & I_D = \frac{k'}{2} \frac{W}{L} [2(V_{GS} - V_t)V_{DS} - V_{DS}^2] \\ \text{gion)} & \end{array} \quad (20)$$

$$\begin{array}{ll} \text{Characteristic current} & I_t = q X D_n n_{po} \exp \left(\frac{k_2}{V_T} \right) \\ & \end{array} \quad (21)$$

$$\begin{array}{ll} \text{Drain current} & I_D = \frac{W}{L} I_t \exp \left(\frac{V_{GS} - V_t}{n V_T} \right) \left[1 - \exp \left(-\frac{V_{DS}}{V_T} \right) \right] \\ \text{(subthreshold region)} & \end{array} \quad (22)$$

$$\begin{array}{ll} \text{Threshold voltage} & V_t = V_{t0} + \gamma \left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f} \right] \\ & \end{array} \quad (23)$$

$$\begin{array}{ll} \text{Threshold voltage pa-} & \gamma = \frac{1}{C_{ox}} \sqrt{2q\epsilon N_A} \\ \text{rameter} & \end{array} \quad (24)$$

$$\begin{array}{ll} \text{Oxide capacitance} & C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 3.45 \text{ fF}/\mu\text{m}^2 \quad \text{for } t_{ox} = 100 \text{ \AA} \\ & \end{array} \quad (25)$$

Small-Signal Operation (Active Region)

$$\begin{array}{ll} \text{Top-gate} & g_m = \frac{\delta I_D}{\delta V_{GS}} = k' \frac{W}{L} (V_{GS} - V_t) = \sqrt{2I_D k' \frac{W}{L}} \\ \text{transconductance} & \end{array} \quad (26)$$

$$\begin{array}{ll} \text{Transconductance-to-} & \frac{g_m}{I_D} = \frac{2}{V_{GS} - V_t} \\ \text{current ratio} & \end{array} \quad (27)$$

Body-effect transconductance $g_{mb} = \frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} g_m = \chi g_m$ (28)

Channel-length modulation parameter $\lambda = \frac{1}{V_A} = \frac{1}{L_{\text{eff}}} \frac{dX_d}{dV_{DS}}$ (29)

Output resistance $r_o = \frac{1}{\lambda I_D} = \frac{L_{\text{eff}}}{I_D} \left(\frac{dX_d}{dV_{DS}} \right)^{-1}$ (30)

Effective channel length $L_{\text{eff}} = L_{\text{down}} - 2L_d - X_d$ (31)

Maximum gain $g_m r_o = \frac{1}{\lambda} \frac{2}{V_{GS} - V_i} = \frac{2V_A}{V_{GS} - V_i}$ (32)

Source-body depletion capacitance $C_{sb} = \frac{C_{s0}}{\left(1 + \frac{V_{SB}}{\psi_0}\right)^{0.5}}$ (33)

Drain-body depletion capacitance $C_{db} = \frac{C_{db0}}{\left(1 + \frac{V_{DB}}{\psi_0}\right)^{0.5}}$ (34)

Gate-source capacitance $C_{gs} = \frac{2}{3} W L C_{ox}$ (35)

Transition frequency $f_T = \frac{g_m}{2\pi(C_{gs} + C_{sd} + C_{gb})}$ (36)

Transconductance $G_m = \left. \frac{i_o}{v_i} \right|_{v_o=0}$ (37)

Input resistance (with test source) $R_i = \left. \frac{v_t}{i_t} \right|_{v_o=0}$ (38)

Output resistance (with test source) $R_o = \left. \frac{v_t}{i_t} \right|_{v_i=0}$ (39)

Maximum gain $|A_v|_{\text{max}} = G_m R_o$ (40)

Example $A = \frac{B}{C}$ (41)

example (42)

Example
example

$A = \frac{B}{C}$

(43)

(44)

Example
example

$A = \frac{B}{C}$

(45)

(46)

Example
example

$A = \frac{B}{C}$

(47)

(48)

Example
example

$A = \frac{B}{C}$

(49)

(50)