GATE 2027 EC, Section 4

Analog circuits

Diode circuits, BJT and MOSFET amplifiers, frequency response, current mirrors, differential amplifiers, op-amp circuits and oscillators.

45 formulas in 7 topics. Equations are numbered section.topic.formula, for example (4.1.1).

4.1 Diode circuits

Half-wave rectifier (4.1.1)

$V_{dc} = V_m/\pi$; $V_{rms} = V_m/2$; ripple factor 1.21; efficiency 40.6%; PIV $= V_m$

Full-wave rectifier (4.1.2)

$V_{dc} = 2V_m/\pi$; $V_{rms} = V_m/\sqrt{2}$; ripple factor 0.482; efficiency 81.2%

Peak inverse voltage (4.1.3)

Centre-tap: $2V_m$; bridge: V_m

Capacitor filter ripple (4.1.4)

$V_r(\text{p-p}) \approx I_{dc}/(fC)$ half-wave; $I_{dc}/(2fC)$ full-wave

Clipper / clamper (4.1.5)

Clipper limits output at $V_{ref} \pm$ diode drop; ideal clamper shifts DC level by $\pm V_m$

4.2 BJT amplifiers

Parameters (4.2.1)

$g_m = I_C/V_T$; $r_\pi = \beta/g_m$; $r_e = V_T/I_E \approx 1/g_m$

Divider bias (4.2.2)

$V_{Th} = V_{CC}\cdot R_2/(R_1 + R_2)$; $R_{Th} = R_1 \| R_2$; $I_B = (V_{Th} - V_{BE})/(R_{Th} + (\beta + 1)R_E)$

Common emitter (4.2.3)

$A_v \approx -g_m(R_C \| r_o \| R_L)$; $R_{in} = r_\pi$

CE with unbypassed R_E (4.2.4)

$A_v \approx -(R_C \| R_L)/(r_e + R_E)$; $R_{in} = r_\pi + (\beta + 1)R_E$

Common collector (4.2.5)

$A_v \approx 1$; $R_{out} \approx r_e + R_s/(\beta + 1)$

Common base (4.2.6)

$A_v \approx g_m(R_C \| R_L)$; $R_{in} \approx r_e$

Stability factor (4.2.7)

$S = \partial I_C/\partial I_{CO}$; fixed bias $S = 1 + \beta$

4.3 MOSFET amplifiers

Common source (4.3.1)

$A_v = -g_m(R_D \| r_o \| R_L)$

CS with source resistor (4.3.2)

$A_v \approx -g_m R_D/(1 + g_m R_S)$

Source follower (4.3.3)

$A_v = g_m R_S/(1 + g_m R_S) < 1$; $R_{out} \approx 1/g_m$

Common gate (4.3.4)

$A_v \approx g_m R_D$; $R_{in} \approx 1/g_m$

Cascode (4.3.5)

$R_{out} \approx g_m {r_o}^2$

4.4 Frequency response

Miller effect (4.4.1)

$C_{in} = C(1 - A_v)$; $C_{out} \approx C(1 - 1/A_v)$

Unity-gain frequency (4.4.2)

$f_T = g_m/(2\pi(C_\pi + C_\mu))$ (MOS: $g_m/(2\pi(C_{gs} + C_{gd}))$)

RC corner (4.4.3)

$f = 1/(2\pi R_{eq} C)$

n identical stages (4.4.4)

$f_H(n) = f_H\sqrt{(2^{1/n} - 1)}$; $f_L(n) = f_L/\sqrt{(2^{1/n} - 1)}$

4.5 Current mirrors and differential amplifiers

MOS mirror (4.5.1)

$I_{out} = I_{ref}\cdot(W/L)_2/(W/L)_1$

BJT mirror (4.5.2)

$I_{out} = I_{ref}/(1 + 2/\beta)$

Widlar source (4.5.3)

$V_T \ln(I_{ref}/I_o) = I_o R_E$

Differential gain (4.5.4)

$A_d = g_m R_D$ (differential out); $g_m R_D/2$ (single-ended)

Common-mode gain (4.5.5)

$A_{cm} \approx -R_D/(2R_{SS})$

CMRR (4.5.6)

$\text{CMRR} = |A_d/A_{cm}|$; $\text{dB} = 20 \log \text{CMRR}$

4.6 Op-amp circuits

Inverting (4.6.1)

$V_o = -(R_f/R_1)V_{in}$

Non-inverting (4.6.2)

$V_o = (1 + R_f/R_1)V_{in}$

Summer (4.6.3)

$V_o = -R_f(V_1/R_1 + V_2/R_2 + \ldots)$

Difference amplifier (4.6.4)

$V_o = (R_f/R_1)(V_2 - V_1)$ with matched ratios

Integrator / differentiator (4.6.5)

$V_o = -(1/RC)\int V_{in}\, dt$; $V_o = -RC\, dV_{in}/dt$

First-order active filter (4.6.6)

$f_c = 1/(2\pi RC)$

Negative feedback (4.6.7)

$A_f = A/(1 + A\beta)$; bandwidth and series-mixed input resistance $\times (1 + A\beta)$

Gain-bandwidth product (4.6.8)

Closed-loop gain $\times$ bandwidth $= f_T$ (single pole)

Slew rate (4.6.9)

Full-power bandwidth $f_{max} = SR/(2\pi V_p)$

Schmitt trigger (inverting) (4.6.10)

$\beta = R_1/(R_1 + R_2)$ (R_1 to ground); thresholds $\pm\beta V_{sat}$; hysteresis $2\beta V_{sat}$

4.7 Oscillators and stability

Barkhausen criterion (4.7.1)

$|A\beta| = 1$ and $\angle A\beta = 0°$ (or 360°)

RC phase shift (3 sections) (4.7.2)

$f = 1/(2\pi RC\sqrt{6})$; amplifier gain ≥ 29

Wien bridge (4.7.3)

$f = 1/(2\pi RC)$; gain ≥ 3

Colpitts (4.7.4)

$f = 1/(2\pi\sqrt{(LC_{eq})})$, $C_{eq} = C_1C_2/(C_1 + C_2)$

Hartley (4.7.5)

$f = 1/(2\pi\sqrt{((L_1 + L_2 + 2M)C)})$

555 astable (4.7.6)

$f \approx 1.44/((R_1 + 2R_2)C)$

Phase margin (4.7.7)

$\text{PM} = 180° + \angle A\beta$ at the frequency where $|A\beta| = 1$

Miller (dominant-pole) compensation (4.7.8)

Two-stage op-amp: $\omega_{p1} \approx 1/(g_{m2}R_1R_2C_c)$; unity-gain $\omega_u \approx g_{m1}/C_c$

My notes