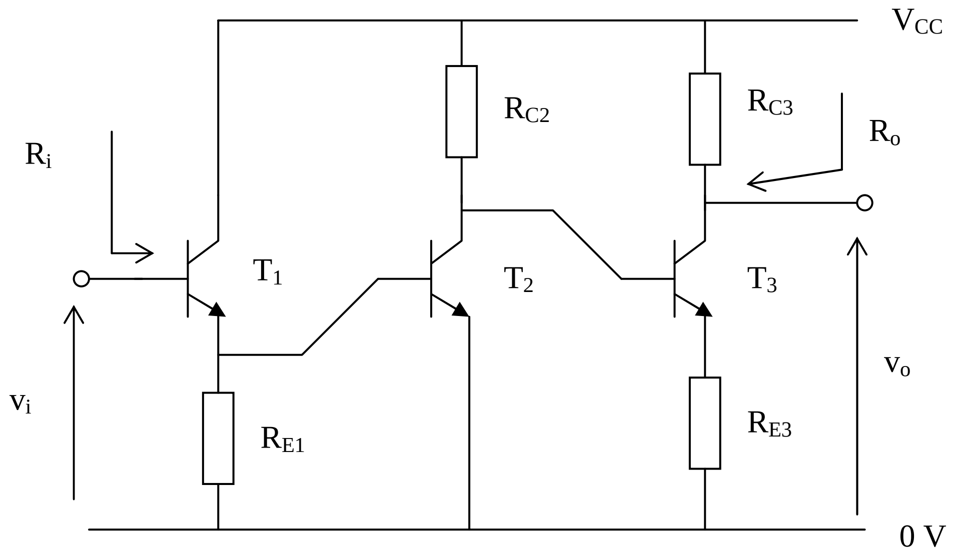
Example: 3 stage Amplifier

(Using the details of amplifier properties provided)

Question



In the circuit shown above, biasing components have been omitted. The collector currents in transistor T_1, T_2 and T_3 are 0.1 mA, 0.5 mA and 2 mA respectively. Calculate the transistor transconductance (g_m) and emitter-base resistance (r_{be}) of each transistor. (β_o = 100) Calculate the voltage gain v_o/v_i, the input resistance R_i, the output resistance, R_o. R_{E1} = 1 kΩ, R_{C2} = 10 kΩ, R_{C3} = 2 kΩ and R_{E3} = 200 Ω; assume r_{ce} and $r_{b'c}$ are infinite and $r_{bb'}$= 0.

Solution

Relationship between I_C and V_{BE}:

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$ where V_T is 25 mV @ room. Temp

g_m transistor transconductance

$$g_m = \frac{\Delta I_C}{\Delta V_{BE}} = \frac{I_S}{V_T}\exp\left(\frac{V_{BE}}{V_T}\right) = \frac{I_C}{V_T}$$

$\underline{g_m = 40\ I_C}$

$r_{b'e}$ *dynamic* resistance of the emitter-base junction

$$r_{b'e} = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{\Delta V_{BE}}{\Delta I_C}\frac{\Delta I_C}{\Delta I_B} = \frac{\beta_o}{g_m}$$

$\underline{r_{b'e} = \beta_o /(40\ I_C) = \beta_o/g_m}$

β_o = common-emitter a.c. current gain $\Delta I_C/ \Delta I_B$

g_{m1} = 40 x 0.1m = 4mA/V
g_{m2} = 40 x 0.5m = 20mA/V
g_{m3} = 40 x 2 m = 80mA/V

$r_{b'e1} = 100/g_{m1} = 25k\Omega$
$r_{b'e2} = 100/g_{m2} = 5k\Omega$
$r_{b'e3} = 100/g_{m3} = 1.25k\Omega$

Voltage gain:

$v_o/v_i = v_o/v_{i3} \times v_{i3}/v_{i2} \times v_{i2}/v_i$
$= v_o/v_{i3} \times v_{o2}/v_{i2} \times v_{o1}/v_i = A_{v1} A_{v2} A_{v3}$

[BEST TO START FROM THE LAST STAGE AND WORK BACK]

Third stage: common-emitter amplifier with emitter degradation

$$A_{v3} = -\frac{g_{m3}R_{C3}}{1 + g_{m3}R_{E3}}$$

= - 80m x 2k /(1 + 80m x0.2k) = -9.4 $\underline{A_{V3} = -9.4}$

Also will need R_{i3} to work out loading on second stage:

$$R_{i3} = r_{be3} + (1+\beta_o)R_{E3}$$
= 1.25k + 101 x 0.2k = 21.5k

$\underline{R_{i3} = 21.5k}$

Second stage: Common emitter

$$A_{v2} = -g_{m2} R_{C2} \;//\; R_{i3}$$
$$= -20\text{m} \times 6.83\text{k} = -136.5$$

$A_{V2} = -136.6$

Also need R_{i2} to work out loading on first stage

$$R_{i2} = r_{be2} = 5\ \text{k}$$

First stage: emitter follower

$$A_{v1} = \frac{g_{m1} R_{E1} \;//\; R_{i2}}{1 + g_{m1} R_{E1} \;//\; R_{i2}}$$

($R_{E1}//R_{i2}$ = 0.83 k)
A_{V1} = 4m x 0.83k / (1 + 4m x 0.83k) = 0.77

$A_{V1} = 0.77$

Total gain is 9.4 x 136.5 x 0.77 = 988

Overall gain = +988 (large)

Input resistance

is that of the first stage (emitter follower)

$$R_i = R_{i1} = r_{be1} + (1+\beta_o) R_{E1} \;//\; R_{i2}$$
$$= 25\text{k} + 101 \times 0.83\text{k} = 109\text{k}$$

R_i = 109 k (high)

Output resistance

Is that looking into 3rd stage (CE-ED)

$R_o = R_{C3}$ = 2k Ω

R_o = 2k