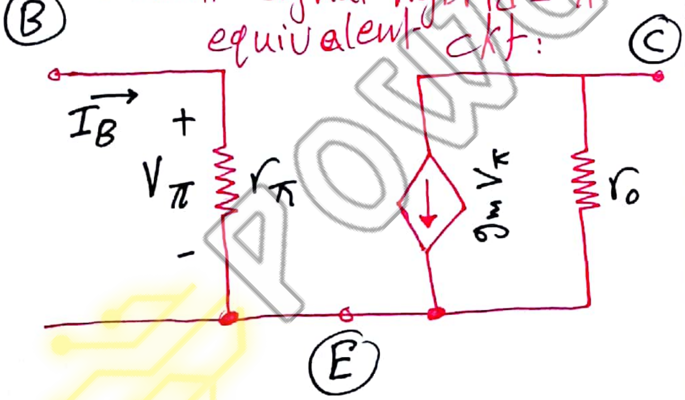
Chapter 6

* i_B, v_{BE} : total instantaneous values
* I_B, V_{BE} : DC values
* i_b, v_{be} : instantaneous AC values
* I_b, V_{be} : phasor values

---

* $r_\pi = \dfrac{V_T}{I_{BQ}} = \dfrac{\beta V_T}{I_{CQ}}$
* $g_m = \dfrac{I_{CQ}}{V_T}$
* $\beta = g_m r_\pi$
* $r_o = \dfrac{V_A}{I_{CQ}}$

- small signal hybrid-π equivalent ckt:



① common-emitter Amplifier

* without R_E :

$$A_v = -g_m (r_o \| R_C) \cdot \left(\frac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 \| r_\pi + R_S} \right)$$

* with R_E :

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E} \cdot \left(\frac{R_i}{R_i + R_S} \right)$$

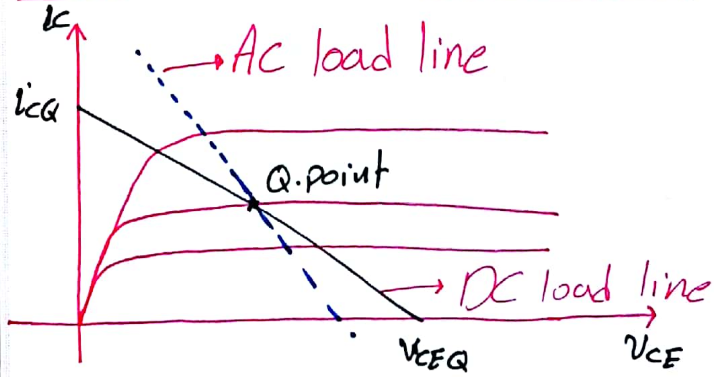
* $R_{ib} = r_\pi + (1+\beta) R_E$
* $R_i = R_1 \| R_2 \| R_{ib}$

* active load:

$$A_v = -g_m (r_o \| r_C)$$

---

* Ac & DC load line:



* DC: slope $= \dfrac{-1}{R_C + R_{E1} + R_{E2}}$

* AC: slope $= \dfrac{-1}{R_C + R_{E1}}$

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Chapter 6

② common-collector:

$$A_v = \frac{(1+\beta)(r_o \| R_E)}{r_\pi + (1+\beta)(r_o \| R_E)} \cdot \left(\frac{R_i}{R_i + R_s}\right)$$

* $R_{ib} = r_\pi + (1+\beta)(r_o \| R_E)$

* $R_o = \frac{r_\pi}{1+\beta} \| R_E \| r_o$ *without R_s

* $R_o = \left(\frac{r_\pi + R_1 \| R_2 \| R_s}{1+\beta}\right) \| R_E \| r_o$ with R_s

* $A_i = (1+\beta)\left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}}\right)\left(\frac{r_o}{r_o + R_E}\right)$

- $A_i \approx (1+\beta)$

③ common-Base Amplifier

$$A_v = g_m (R_C \| R_L)$$

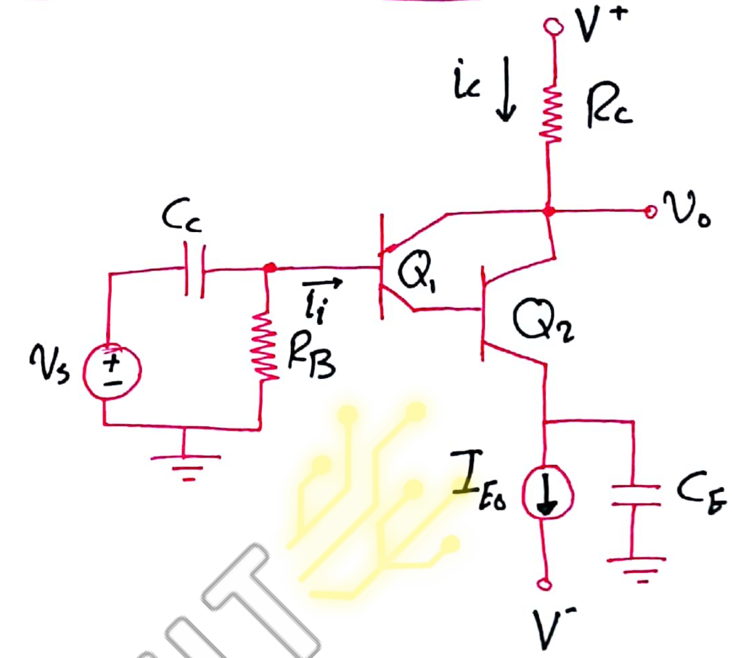
$$A_i = \frac{g_m r_\pi}{1+\beta} = \frac{\beta}{1+\beta} = \alpha$$

$$R_{ie} = \frac{r_\pi}{1+\beta} = r_e$$

* $R_{eq} = R_s \| R_E \| r_\pi$

$$R_{oc} = r_o(1 + g_m R_{eq}) + R_{eq}$$

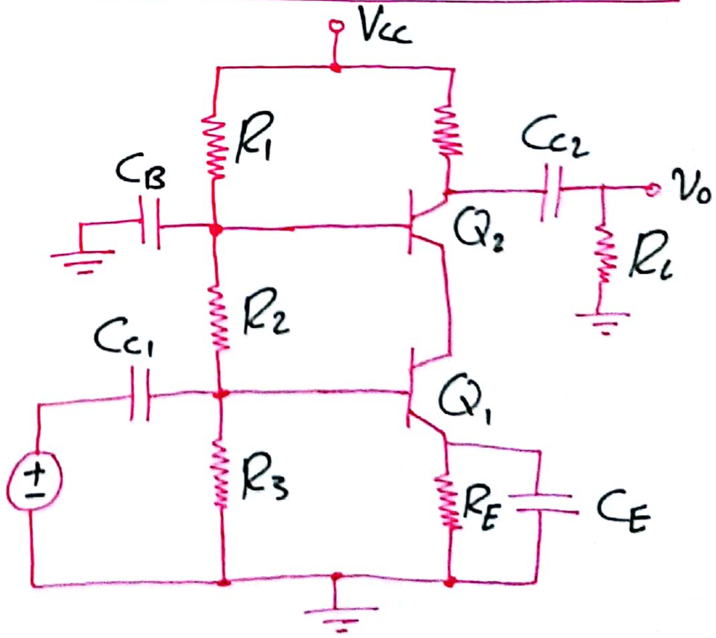
* Darlington pair Configuration



$$A_i = \beta_1 + \beta_2(1+\beta_1) \approx \beta_1 \beta_2$$

$$R_i \approx 2\beta_1 r_{\pi 2}$$

* Cascode Configuration:



$$A_v \approx -g_{m1}(R_C \| R_L)$$

Chapter 4

* $i_D = K_n(V_{GS} - V_{TN})^2$
* $g_m = 2K_n(V_{GS} - V_{TN})$
  $= 2\sqrt{K_n I_{DQ}}$
* $r_o = \dfrac{1}{\lambda I_{DQ}}$

* D: Drain
* S: Source
* G: gate
* $I_G = 0$

① Common-source Amplifier

$$A_v = -g_m(r_o \| R_D) \cdot \left(\frac{R_i}{R_i + R_{si}}\right)$$

$R_i = R_1 \| R_2$ # without R_s →

$$A_v = \frac{-g_m R_D}{1 + g_m R_s} \cdot \frac{R_i}{R_i + R_{si}} \quad \text{\# with } R_s$$

$$A_v \cong \frac{-g_m R_D}{1 + g_m R_s} \approx \frac{-R_D}{R_s}$$

② Common-Drain Amplifier:

$$A_v = \frac{g_m(R_s \| r_o)}{1 + g_m(R_s \| r_o)} \cdot \left(\frac{R_i}{R_i + R_{si}}\right)$$

* $R_o = \dfrac{1}{g_m} \| R_s \| r_o$

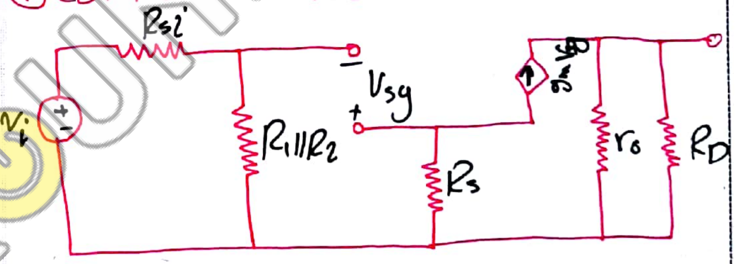
③ common-gate

$$A_v = \frac{g_m(R_D \| R_L)}{1 + g_m R_{si}}$$

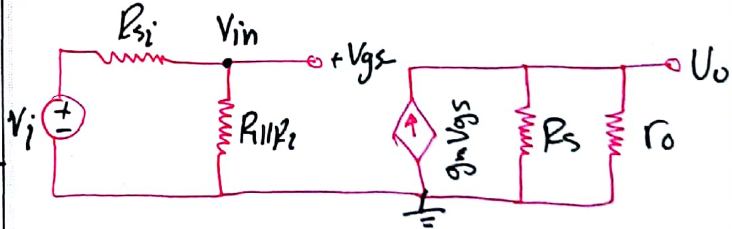
$$A_i = \left(\frac{R_D}{R_D + R_L}\right) \cdot \left(\frac{g_m R_{si}}{1 + g_m R_{si}}\right)$$

* $R_i = \dfrac{1}{g_m}$
* $R_o = R_D$

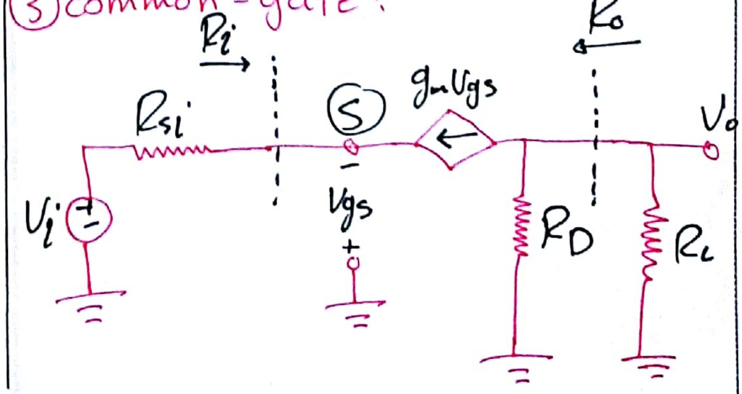
① common-source:



② common-Drain:



③ common-gate:



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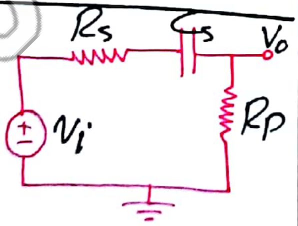
Chapter 7

* in low frequancy: external capacitances (bypass & coupling)
* in high frequncy: internal capacitors (C_μ & C_π)
* in midband range:
  external ⟶ short circuit
  internal ⟶ open circuit



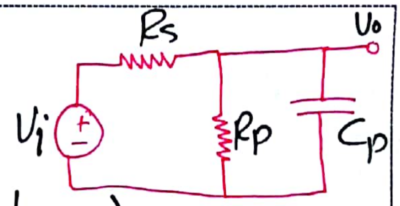
$$\frac{V_o(s)}{V_i(s)} = k\left(\frac{S\tau_s}{1+S\tau_s}\right)$$

where:

$$k = \frac{R_P}{R_S + R_P}$$

$$\tau_s = (R_s + R_P)\,C_s$$

⟶ time constant



$$\frac{V_o(s)}{V_i(s)} = k\left(\frac{1}{1+S\tau_p}\right)$$

where:

$$K = \frac{R_P}{R_P + R_S}$$

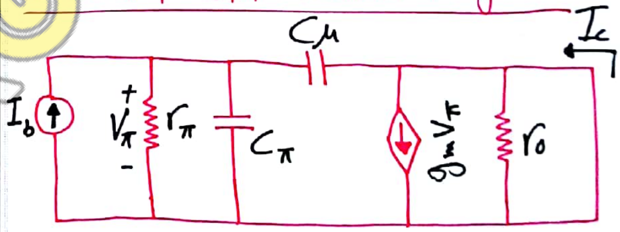
$$\tau_p = (R_S \parallel R_P)\,C_P$$

⟶ time constant

* $f_L = \dfrac{1}{2\pi\tau_s}$
* $f_H = \dfrac{1}{2\pi\tau_p}$

* BipolAR transistor:

short ckt current gain:



$$A_i = h_{fe} = \frac{(g_m - j\omega C_\mu)}{\left[\frac{1}{r_\pi} + j\omega(C_\pi + C_\mu)\right]}$$

$$h_{fe} \approx \frac{g_m r_\pi}{1 + j\omega r_\pi (C_\pi + C_\mu)}$$

$$f_\beta = \frac{1}{2\pi r_\pi (C_\mu + C_\pi)}$$ * beta cutoff freq.

$$h_{fe} = \frac{\beta_o}{1 + j\left(\frac{f}{f_\beta}\right)}$$

$$f_T = \beta_o f_\beta = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$ * unity-gain bandwidth.

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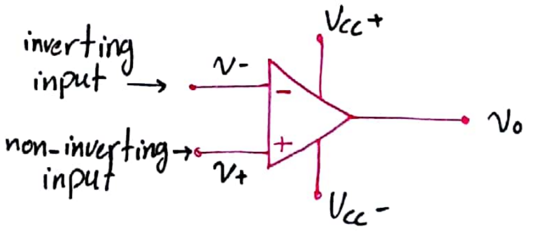
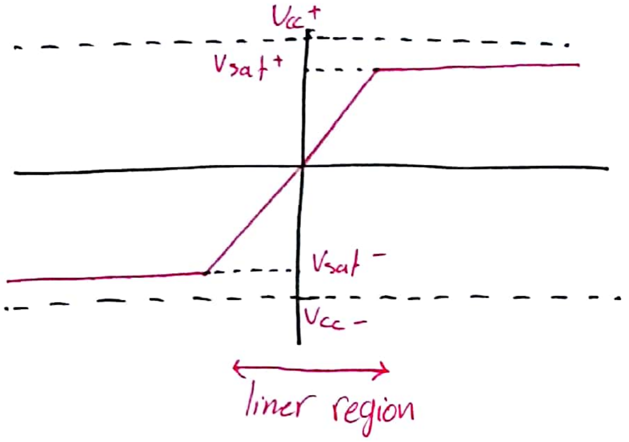
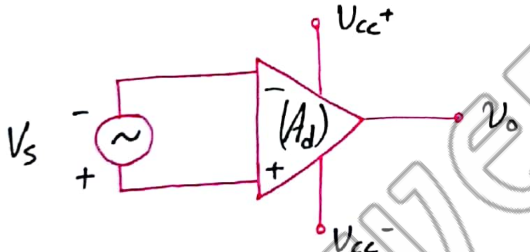
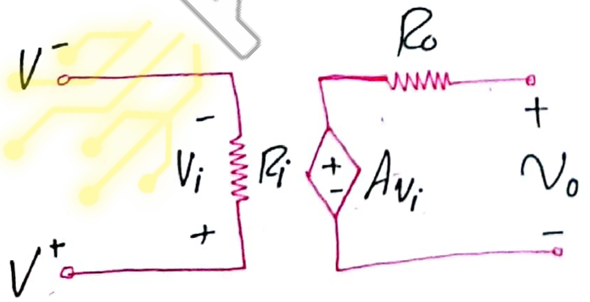
Chapter 9:





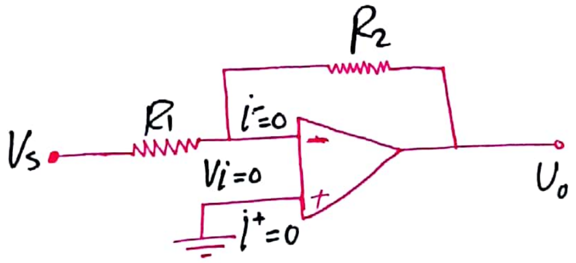


$$V_o = A_d(V^+ - V^-) = A_d V_s$$



(practical op-amp model)

① The Inverting Amplifier:

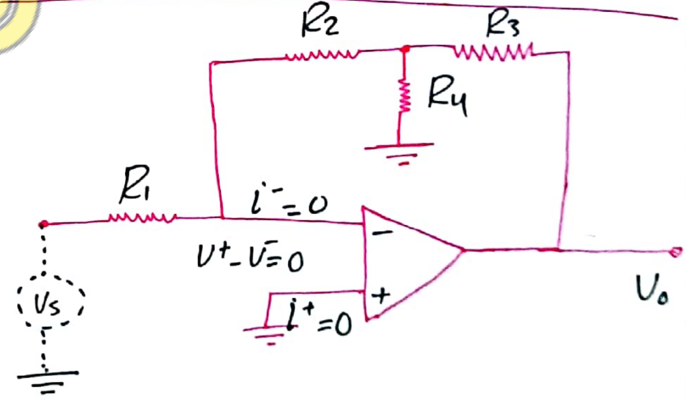


$$v^+ - v^- = 0$$
$$I^- = I^+ = 0$$

always

$$\frac{V_o}{V_s} = \frac{-R_2}{R_1}$$

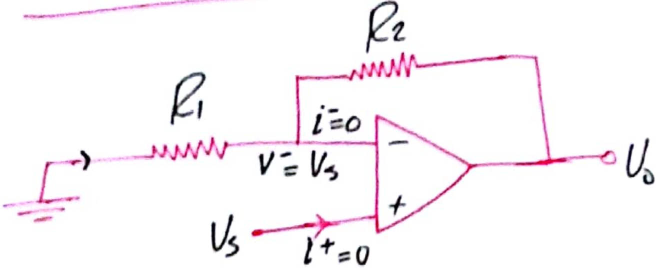
② the T-Network Amplifier



$$\frac{V_o}{V_s} = \frac{-R_2}{R_1} \cdot \left[1 + \frac{R_3}{R_2} + \frac{R_3}{R_4}\right]$$

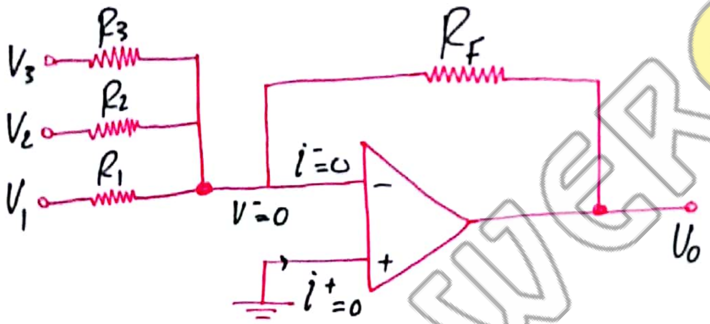
chapter 9

③ The non-inverting Amplifier



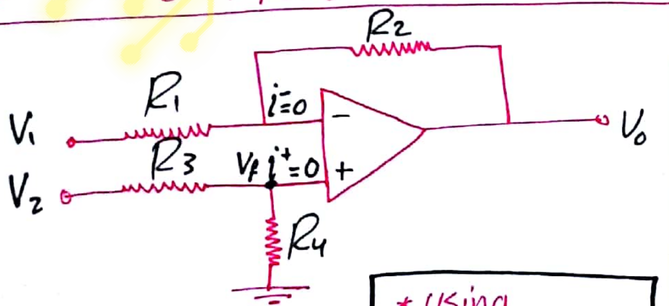
$$\frac{V_o}{V_s} = \left(1 + \frac{R_2}{R_1}\right) = \frac{R_1 + R_2}{R_1}$$

④ The summing Amplifier



$$V_o = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]$$

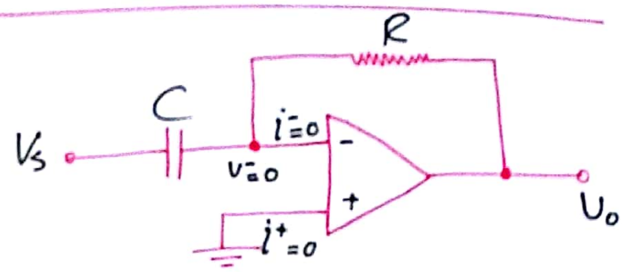
⑤ the Difference Amplifier



$$V_o = \frac{R_2}{R_1}(V_2 - V_1)$$

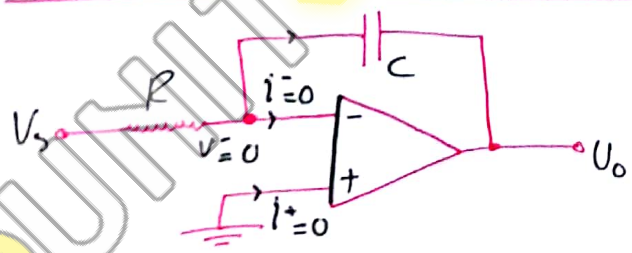
* using soperpostion

⑥ The Differentiator circuit



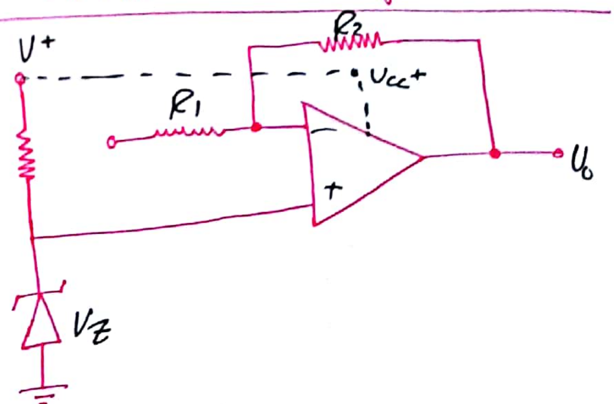
$$V_o = -RC \frac{d}{dt} V_s$$

⑦ the integrator circuit



$$V_o = \frac{-1}{RC} \int V_s \, dt$$

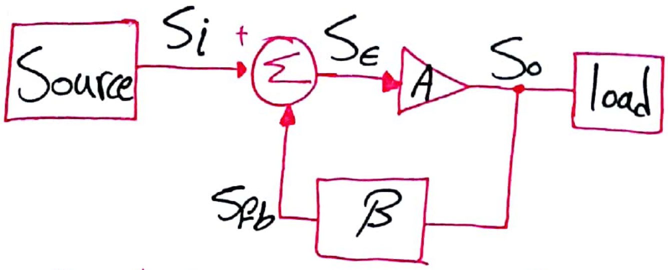
⑧ Reference voltage source



- Assuming the Zener is in Breakdown

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_Z$$

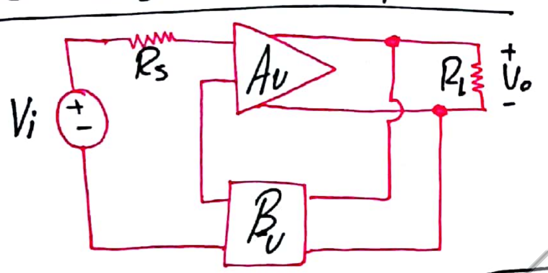
Chapter 12



closed-loop transfer function:

$$A_f = \frac{S_o}{S_i} = \frac{A}{(1+\beta A)}$$

① series – shunt:

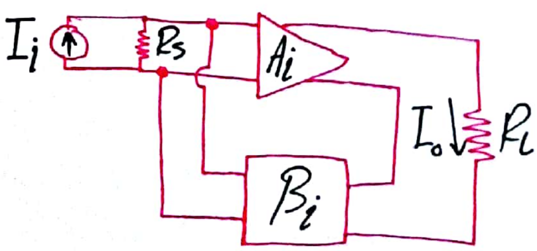


* $A_{vf} = \dfrac{A_v}{(1+\beta_v A_v)}$

Voltage Amplifier

* $R_{if} = R_i(1+\beta_v A_v)$
* $R_{of} = \dfrac{R_o}{(1+\beta_v A_v)}$

② shunt – series:

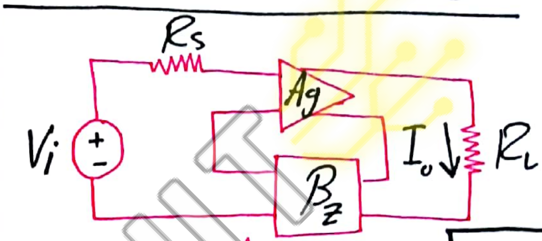


* $A_{if} = \dfrac{A_i}{(1+\beta_i A_i)}$

current Amplifier

* $R_{if} = \dfrac{R_i}{(1+\beta_i A_i)}$
* $R_{of} = R_o(1+\beta_i A_i)$

③ series – series:

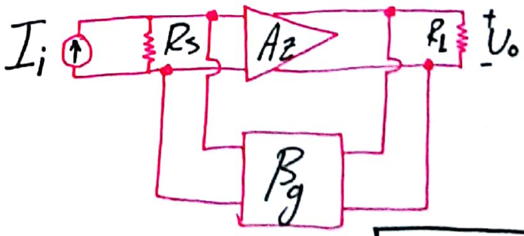


* $A_{gf} = \dfrac{A_g}{(1+\beta_z A_g)}$

transconductance Amplifier

* $R_i = R_i(1+\beta_z A_g)$
* $R_o = R_o(1+\beta_z A_g)$

④ shunt – shunt:



transresistance Amplifier

* $A_{zf} = \dfrac{A_z}{(1+\beta_g A_z)}$
* $R_i = \dfrac{R_i}{(1+\beta_g A_z)}$
* $R_o = \dfrac{R_o}{(1+\beta_g A_z)}$