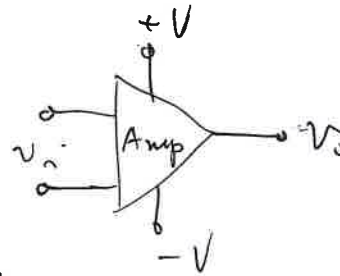


## Chapter 2 Voltage Amplification



" $v_i$ : modulates power transferred to output  $v_o \Rightarrow$  amplification"

### 2.1 Ideal Voltage Amplifiers

- Common-mode and differential-mode input
- Differential-mode and common-mode gain

### 2.2 Practical Voltage Amplifier

#### Figures of Merit

- CMRR

#### Finite Input Impedance

#### Error Modeling

- Zero error
- Input bias current
- Input offset current
- Thermal drift
- IZE and OZE
- Noise and interference

2.21 & 2.22

$$I_{ZE} = V_{i0} + \frac{\partial V_{i0}}{\partial T} (T - T_0) + \frac{\partial V_{i0}}{\partial t} \Delta t$$

$$+ I_p R_o - I_n R_o' + \left( \frac{\partial I_p}{\partial T} R_o - \frac{\partial I_n}{\partial T} R_o' \right) (T - T_0)$$

$$T = T_a + P_d (\theta_{jc} + \theta_{cs} + \theta_{ra})$$

Ex 2.3

2.24

#### Differential and single-ended amplifier

### 2.3 Building Blocks

#### Voltage-feedback Operational Amplifier

- Model
- Negative feedback
- Op amps with positive and negative feedback

$$V_o = A_d V_d + A_c V_c$$

$$A_d = A_{d0} \frac{f_a}{1 + jf/f_a} = \frac{f_T}{1 + jf/f_a} = G_{DB}$$

$$\begin{matrix} R_D \\ R_C' \end{matrix} \begin{cases} 1 \mu\Omega - 1 \text{ p}\Omega \\ 2 \text{ pF} - 10 \text{ pF} \end{cases} \quad (\text{layout parasitic: } 2 - 5 \text{ pF})$$

$$Z_o : 100 \Omega$$

$$V_{i0} : 1 \mu\text{V} - 1 \text{ mV}, \quad 0.01 \mu\text{V}/^\circ\text{C}$$

*Current-feedback Operational Amplifier*

*Difference Amplifier*

*Instrumentation Amplifier*

*Switched Capacitors*

*Voltage Buffer*

## **2.4 dc Amplifiers**

*Single-ended dc Amplifier*

- Inverting amplifier
- Noninverting amplifier

*Differential-input dc Amplifier*

*Fully Differential dc Amplifier*

## **2.5 ac Amplifiers**

*Single-ended ac Amplifier*

*Differential-input ac Amplifier*

*Fully Differential ac Amplifier*

## **2.6 Composite Amplifiers**

*Cascaded Amplifier*

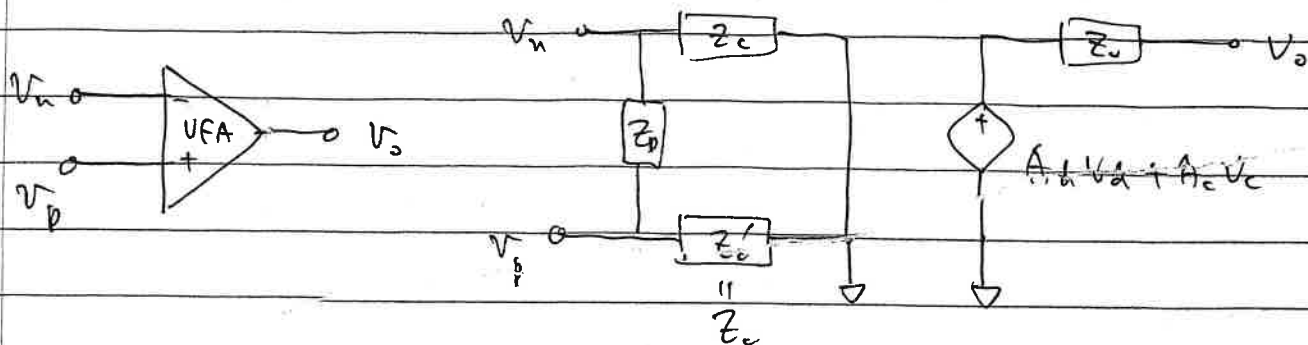
***Feedback Composite Amplifier***

***Parallel Amplifier***

**2.7 Programmable-gain Amplifiers**

## 2.3 Building Blocks for Voltage Amplifiers

### 2.3.1 Voltage-Feedback Op Amp



- Differential input / Single-ended output

$$G_{cd} = G_{cc} \Rightarrow$$

$$V_o = A_d V_d + A_c V_c$$

$$V_c = \frac{1}{2} (V_p + V_n), \quad V_d = V_p - V_n$$

$$A_d = G_D = G_{DD}, \quad A_c = G_c = G_{DC}$$

$$A_d = A_{d0} \frac{f_a}{j\omega + f_a} = \frac{f_T}{j\omega + f_a} = G_{DD}$$

$A_{d0}$  : differential dc gain :  $10^5 - 10^7$

unity-gain frequency  $\leftarrow f_T = A_{d0} f_a$  : gain-bandwidth product (GBD)

$f_a$  : open-loop gain cutoff freq :  $\sim 1 \text{ Hz} - 200$

$A_c = G_{DC}$  : not specified

CMRR : specified  $\Rightarrow |G_{DC}| = |G_{DD}| / \text{CMRR}$

$V_{io}$  :  $1 \mu\text{V} - 1 \text{ mV}$ ,  $0.01 \mu\text{V}/^\circ\text{C}$

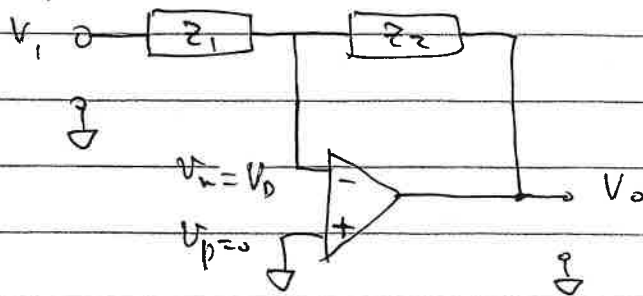
$I_b$  :  $10 \text{ fA} - 1 \text{ pA} - 10 \text{ nA}$ ,  $\times 2 / 10^\circ\text{C}$

CMRR :  $80 - 130 \text{ dB}$  until  $f_a$

PSRR :  $80 - 110 \text{ dB}$  at dc

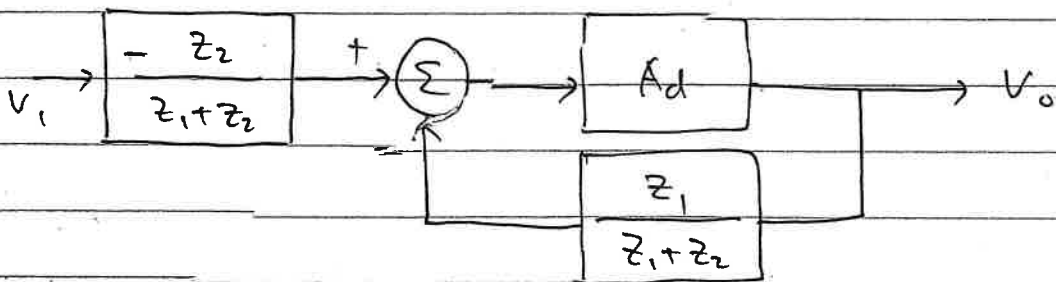
SR (slew rate) :  $0.1 \text{ V}/\mu\text{s} - 1000 \text{ V}/\mu\text{s}$   
 ( for sinusoidal signal with  $f$  and  $V_p$  )  
 $2\pi f V_p < \text{SR}$

\* Negative feedback



$$\frac{V_i - V_D}{z_1} = \frac{V_D - V_o}{z_2} \quad , \quad V_o = A_d V_d$$

$$V_o = - \left( V_i \frac{z_2}{z_1 + z_2} + V_o \frac{z_1}{z_1 + z_2} \right) A_d$$



$$\beta = \frac{z_1}{z_1 + z_2} \quad : \quad \text{feedback factor}$$

$$V_o = - V_i \frac{z_2/z_1}{1 + 1/A_d \beta} \quad \approx \quad - V_i \frac{z_2}{z_1} \quad (A_d \beta \gg 1)$$

$$-\frac{z_2}{z_1} \quad : \quad \text{closed-loop voltage gain}$$

$$\left. \begin{array}{l} z_D \rightarrow z_D (1 + A_d \beta) \\ z_O \rightarrow z_O / (1 + A_d \beta) \end{array} \right\}$$