4. Amplifiers

Operational Amplifier

Instrumentation Amplifier

Grounding

Isolation

Amplifier Properties

Operational Amp.

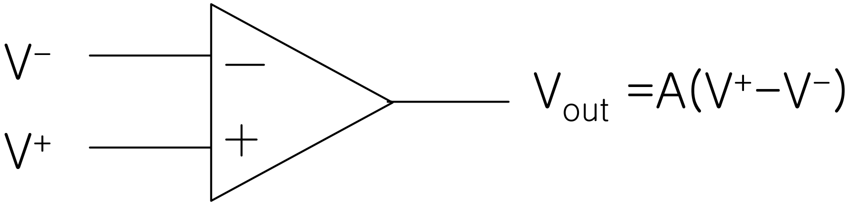
1947 – Ragazza : Diff. Equation Solver

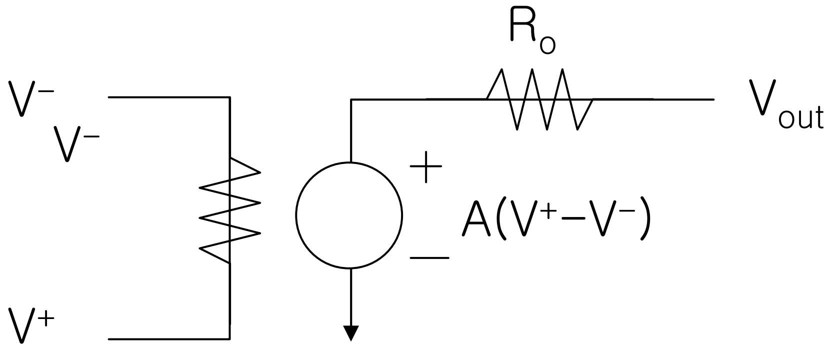
1962 – Module형 OP Amp.

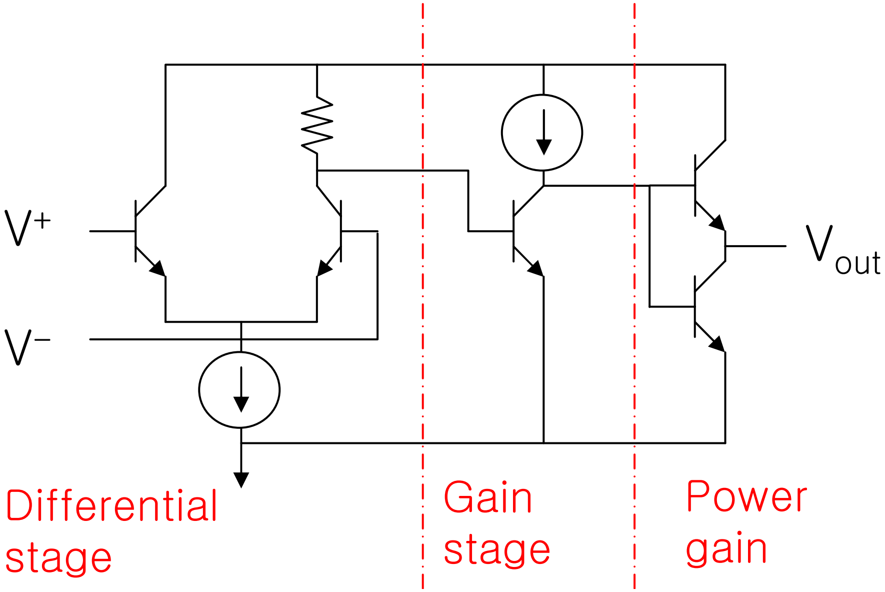
1970 – Chip

Ideal Op. Amp.	ideally	means
gain(open-loop)	∞	$\geq 10^4$
open-loop BW	∞	Dominant Pole at 10Hz
CMRR	∞	≥ 70dB
Ri	∞	≥ 10MΩ
Ro	0	< 500Ω
I B	0	< 0.5μA
Vos	0	< 10mV
Ios	0	< 0.2μA

How do we achieve these properties?







741인 경우

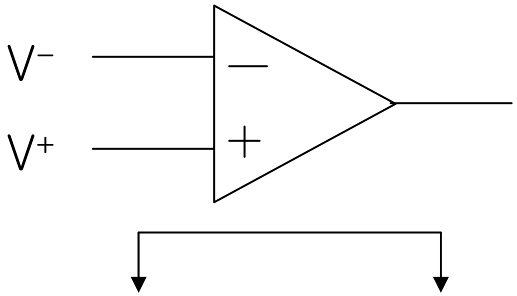
(Stage 1) R=1.6MΩ
Gain=1200

(Stage 2) V_{tg} gain=220

(Stage 3) Ro=60Ω
V_{tg} gain=1

Overall Gain=108dB

Two rules



$V_{out} = A(V^{+} - V^{-})$

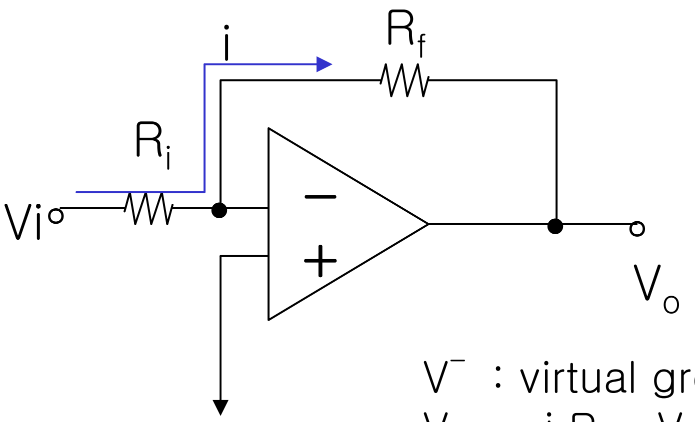
Rule 1: Op Amp의 output이 Linear Stage에 있을 때,

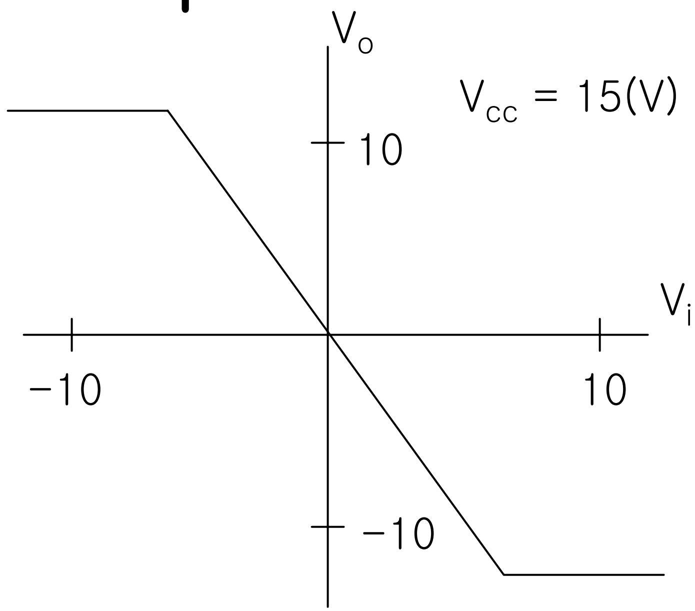
두 input은 동 전위에 있다. (Virtual Ground)

Rule 2: Op Amp의 input 단자에 입력되는 전류는 없다.

(infinite input impedance)

Inverting Amp.



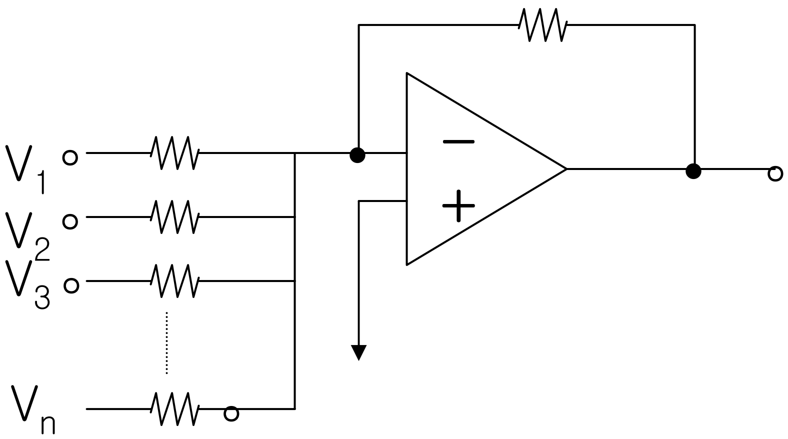


V^- : virtual ground

$V_o = -i R_f = V_i(R_f / R_i)$

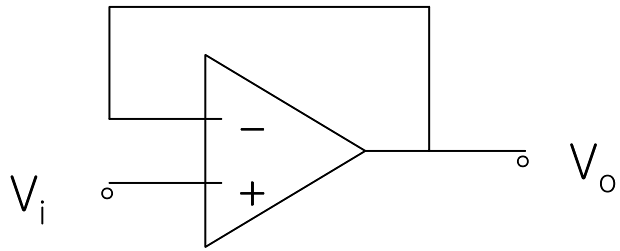
$A_v = -(R_f / R_i)$

- Summing



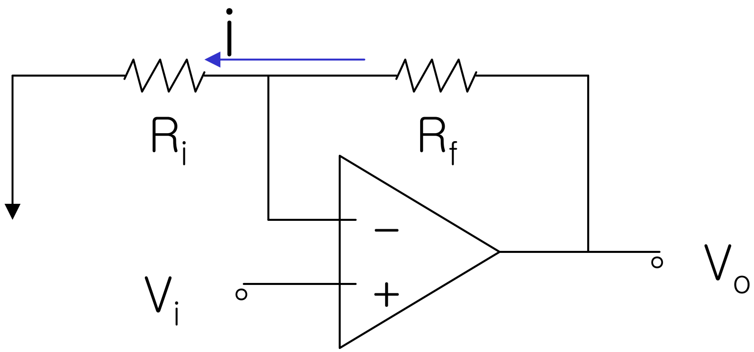
Non Inverting Amp.

- Follower



Buffer, Impedance Converter

- Non-inverting Amp.



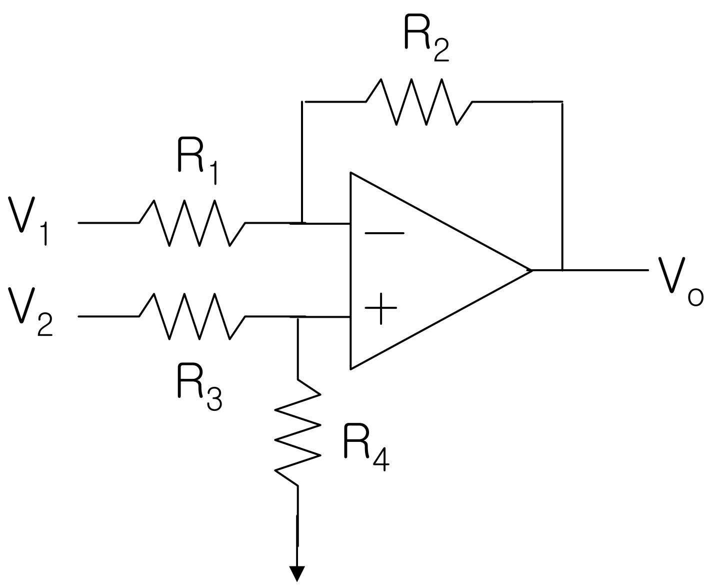
$$V_o = i \bullet (R_i + R_f)$$
$$V_i = i \bullet R_i$$
$$\rightarrow A_v = \frac{R_i + R_f}{R_i}$$

Instrumentation Amp

- High gain DC complied differential amp with single ended output.

  High Z_{in}, CMRR

  Used to Amplify small differential signals from transducer where there may be a large common signal.



$$V^{+} = V_2 \cdot \frac{R_4}{R_3 + R_4}, \quad V^{-} = (V_o - V_1)\frac{R_1}{R_1 + R_2} + V_1$$

$V^{+}=V^{-}$로부터

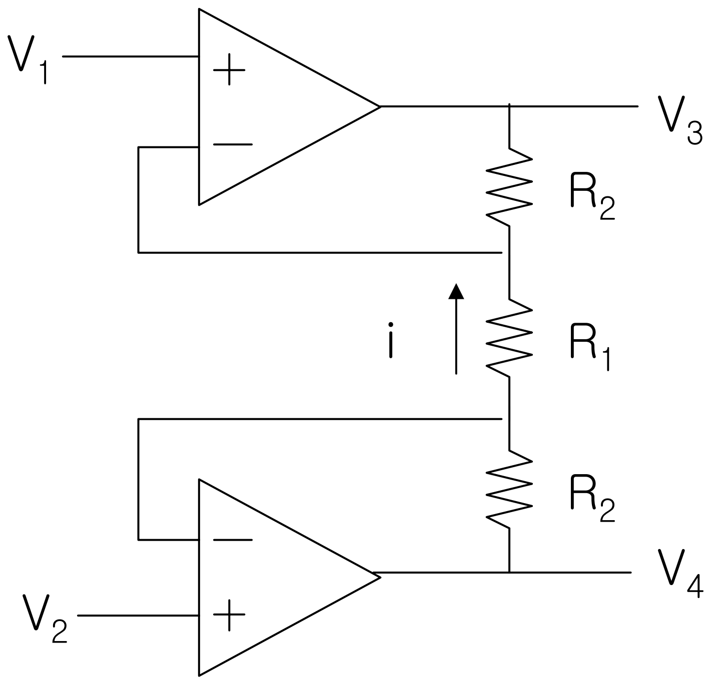
$$V_o = \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right)V_2 - \frac{R_2}{R_1}V_1$$

$$\textit{if} \quad \frac{R_3}{R_4} = \frac{R_1}{R_2} \quad \rightarrow \quad V_o = \frac{R_2}{R_1}(V_2 - V_1), \quad G_d = \frac{R_2}{R_1}$$

Common mode $V_1=V_2$ → $V_o=0$ → $G_c=0$

CMRR= G_d / G_c

For High Input Impedance



If $V_1 = V_2$ (CMG)

→ $i = 0$

→ $V_1 = V_2 = V_3 = V_4$

→ G_c (CMG) $= 0$

If $V_1 \neq V_2$ (DMG)

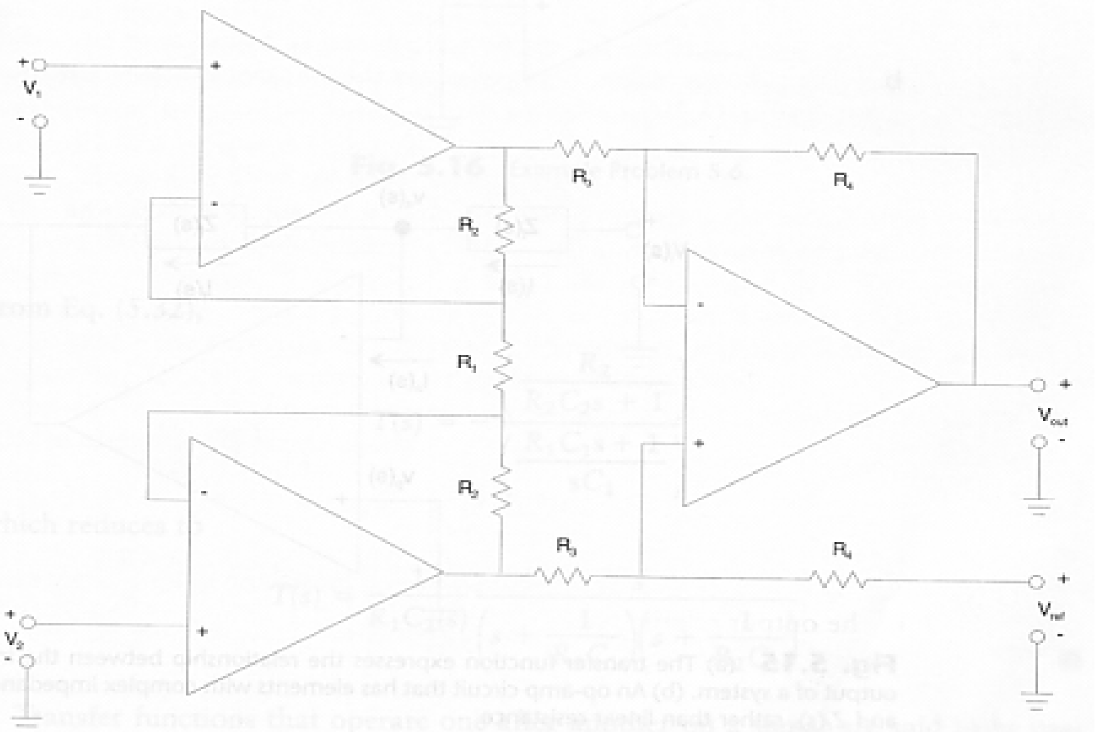
→ $i = (V_2 - V_1)/R_1$

$$\frac{V_4 - V_3}{V_2 - V_1} = \frac{R_1 + 2R_2}{R_1} = 1 + 2 \cdot \frac{R_2}{R_1}$$

Complete Design of Instrumentation Amp.

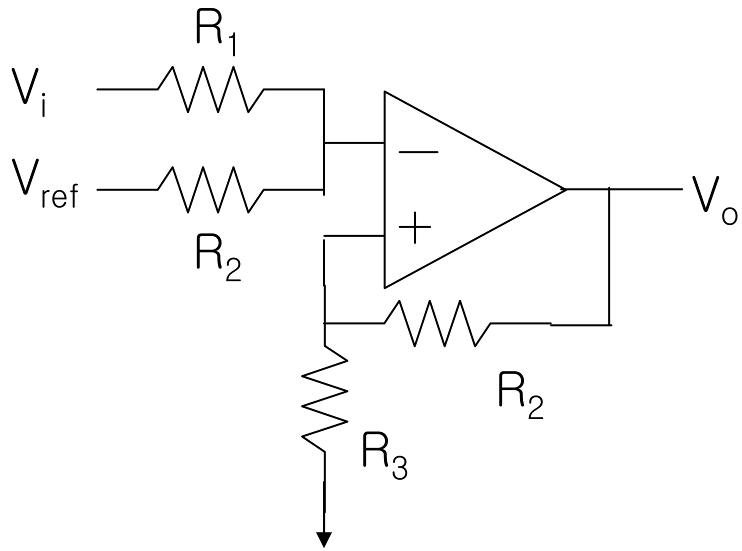
$$v_{out} - v_{ref} = G(v_2 - v_1)$$

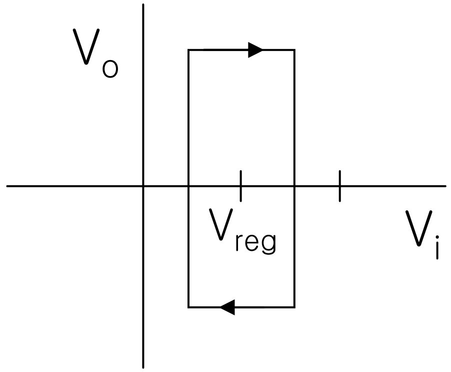
$$G = \frac{R_4}{R_3}\left(1 + 2\frac{R_2}{R_1}\right)$$



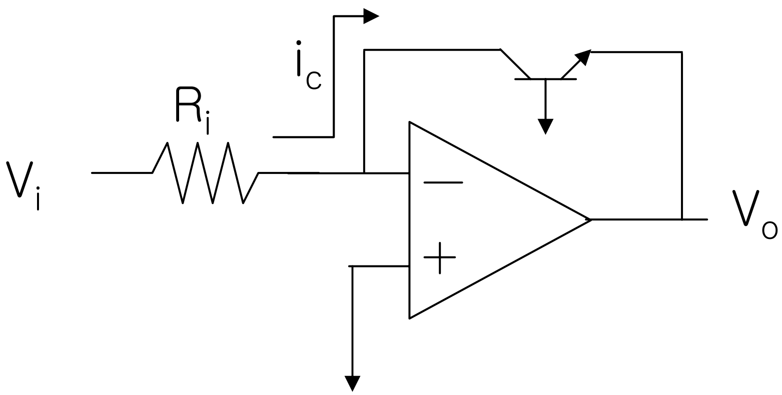
Circuits

<Comparator>





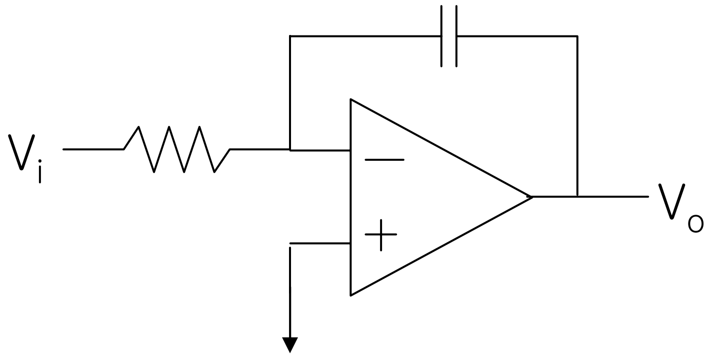
<Log Amp>



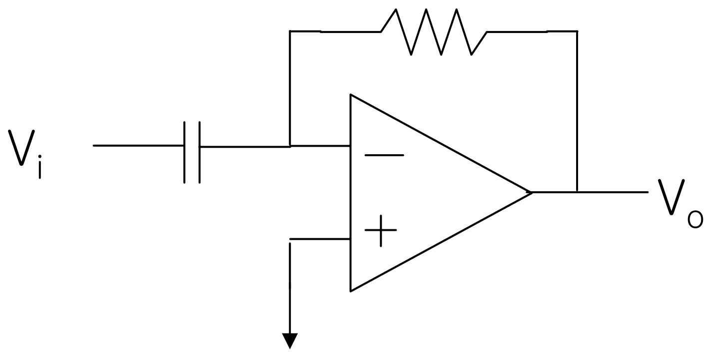
$$V_{BE} = 0.06\log\frac{I_c}{I_s},\ V_{BE} = -V_o$$

$$I_c = \frac{V_i}{R_i} \quad \rightarrow \quad V_o = -V_{BE} \propto -\log V_i$$

<Integrator>

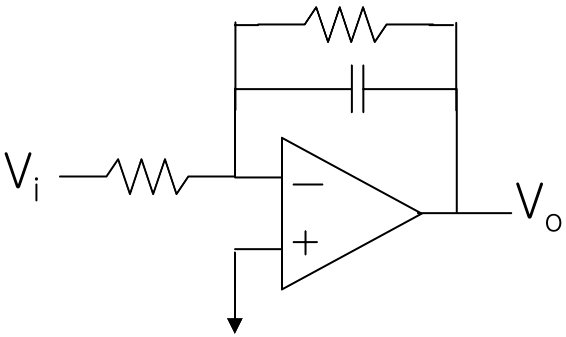


<Differentiator>

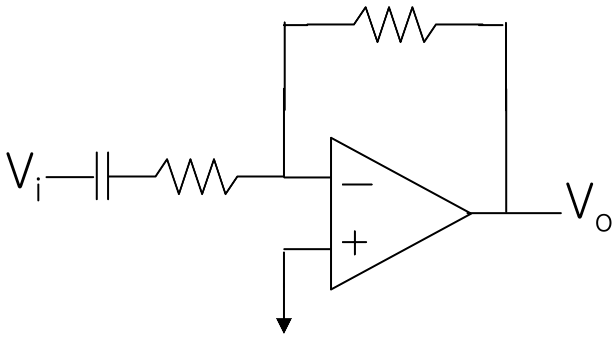


Slope detector (if cascaded by a comparator)

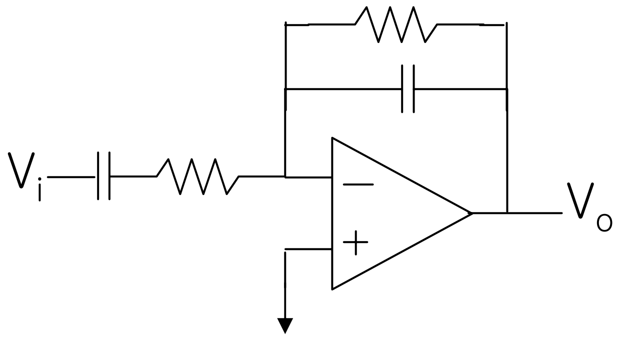
<Filter>



Low pass



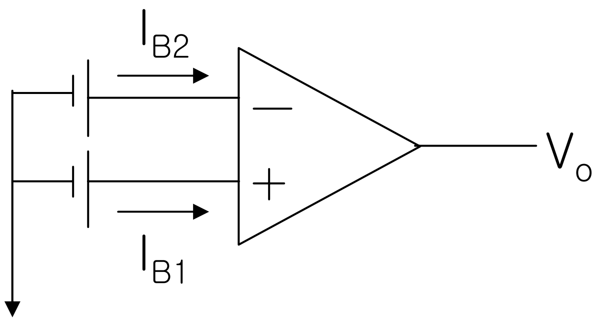
High pass

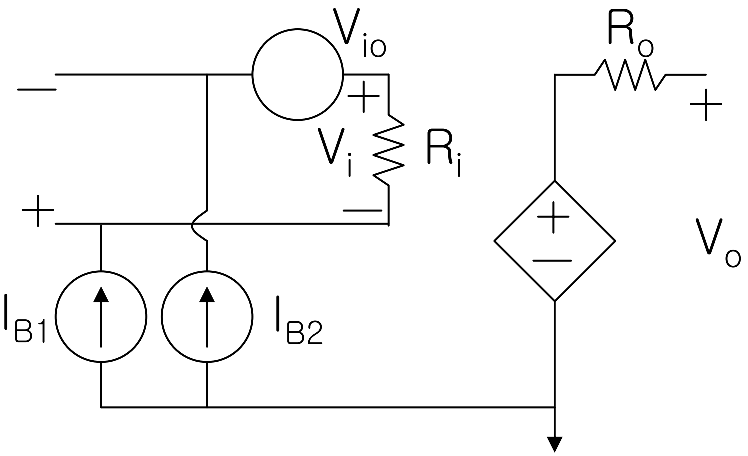


Band pass

Bias currents and Input current offset

– Input Bias Currents I_{B1},I_{B2} exist to bias the frontend transistors.





~20uA 741 30pA to JFET input

– Input offset current (I_{io})

$$I_{io}=I_{B1}-I_{B2}$$

Input and Ouput Voltage Offsets

-Input offset voltage (V_{io})

V_{be}의 작은 차이가 원인

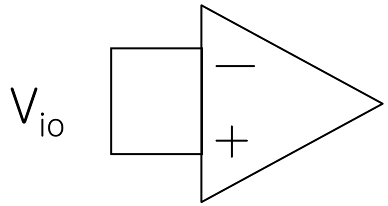
V_{io} is temperature dependent (-2.2mV/C)
This temperature dependency is too large to accept. Use differential configuration to compensate. (3.3uV/C)

- Output offset voltage (V_{os})

DC voltage present at two output terminals when two input terminals are grounded. This is independent of amplifier gain. Usually seen as a drift at unity gain.

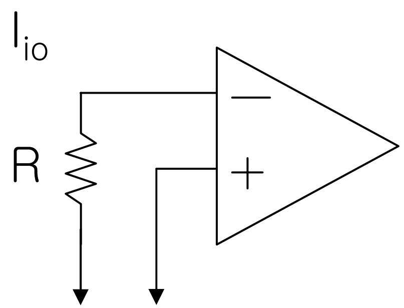
Measurements of Offsets

– Input offset voltage measurement



–Short input. (At high gain, the output offset voltage can be negligible compared to the input offset voltage multiplied by the gain.)

–Bias current measurement



Measure output divided by Gain This gives the input offset voltage.

– Short two inputs to GND, one through R

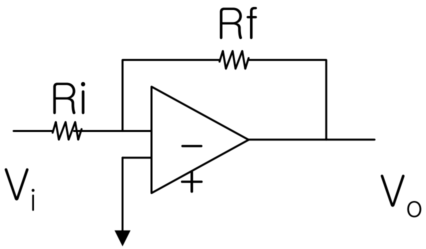
$$\left(\frac{V_{out}}{Gain} - V_{io}\right) \cdot \frac{1}{R} = I_{b1}$$

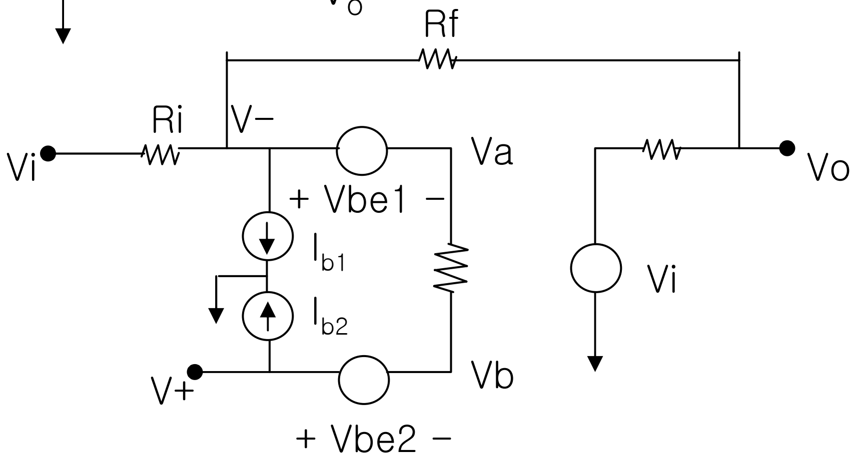
Repeat this for the other terminal for I_{b2}

$$I_{io} = I_{b1} - I_{b2}$$

$$I_b = \frac{1}{2}(I_{b1} + I_{b2})$$

Nulling the bias current





Assume

$V^+ = V^-$

$I_{b1} = I_{b2} = I_b$

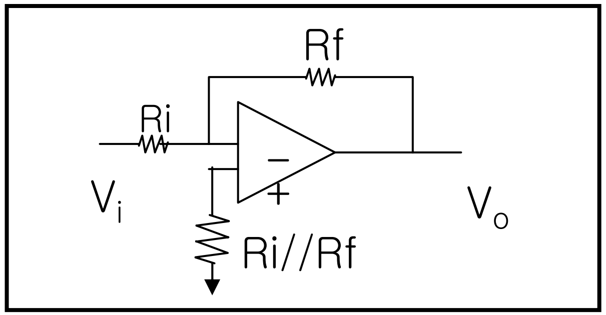
$$\frac{Vo - V^-}{Rf} + \frac{Vi - V^-}{Ri} = Ib \quad \text{(eq 1)}$$

Ideally we want, $Vo/Rf = -Vi/Ri$ (eq 2)

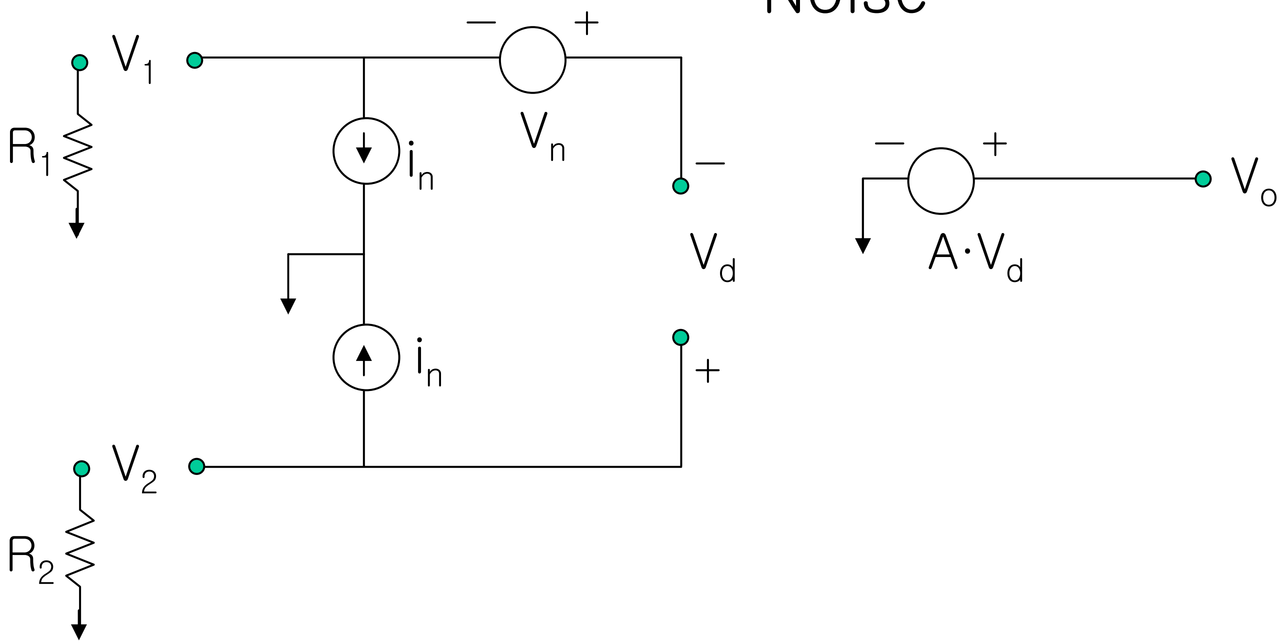
Comparing eq 1 and 2,

$$I_b + V^+/(Rf//Ri) = 0$$

This condition can be satisfied by the next circuit.



Noise



i_n: noise current sources in rms $A/\sqrt{Hz}$

V_n: noise voltage sources in rms $V/\sqrt{Hz}$

$$V_t \cong \sqrt{\left[V_n^{\ 2} + (i_n R_1)^2 + (i_n R_2)^2 + 4kTR_1 + 4kTR_2\right]BW}$$

i_n, V_n given by specs

- Bipolars
- FETs: smaller i_n—especially JFETs

Input Impedance

(1) The case of a Follower

$R_i = R_i$ (op amp) x A_{OL} :   very large

$2M\Omega x 10^5 = 100G\Omega$

But Bias currents can reduce Ri.

For this reason, OP amp with FET (especially JFET) input is preferred for applications where high input impedance is required, such as in single neural cell recordings.

(2) inverter

$R_i = R_i$ (op amp)

- output impedance

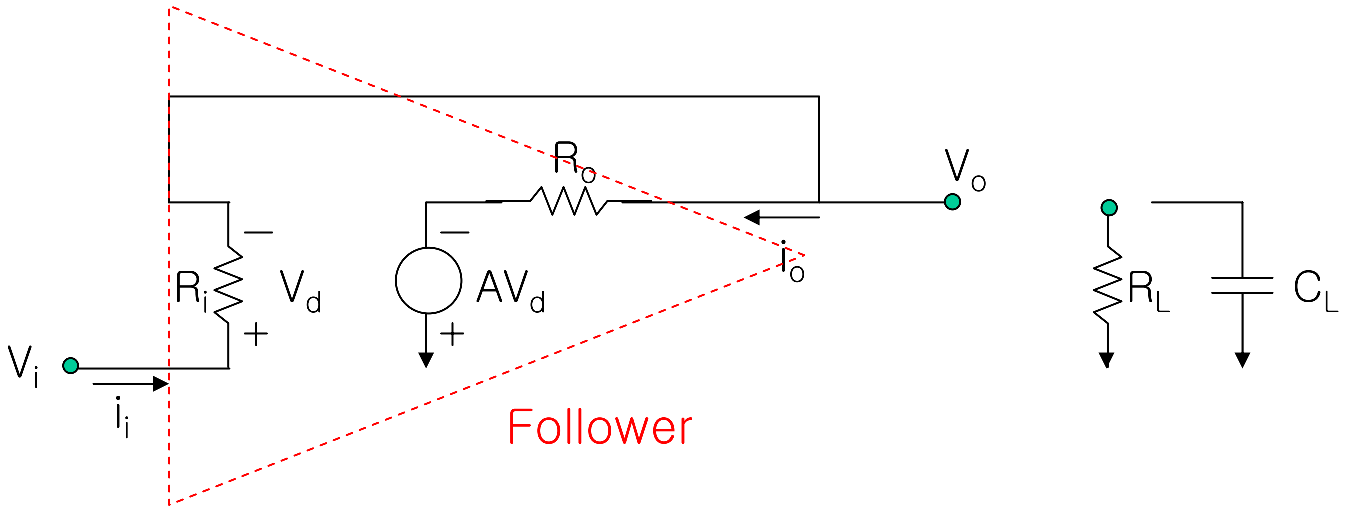
(1) Follower인 경우

$R_0 = R_o\ (\text{op amp}) / A_{OL}$

$40/10^5 = 0.4\text{m}\Omega$

(2) inverter인 경우

$R_o = R_o\ (\text{op amp})$



For R_i

$$\Delta V_o = AV_d = A(\Delta Vi - \Delta Vo)$$

$$\Delta V_o = \frac{A}{A+1}\Delta V_i$$

$$\Delta i_i = \frac{\Delta V_d}{R_i} = \frac{\Delta V_i - \Delta V_o}{R_i} = \frac{\Delta V_i}{(A+1)R_i}$$

$$\rightarrow R_i = \frac{\Delta V_i}{\Delta i_i} = (A+1)R_i = A \cdot R_i$$

For R_o

$$\Delta V_d = \Delta V_o = A\,\Delta V_d + \Delta\ i_o R_o$$

$$= -A\,\Delta V_o + \Delta\ i_o\ R_o$$

$$\rightarrow (A+1)\,\Delta V_o = \Delta i_o\ R_o$$

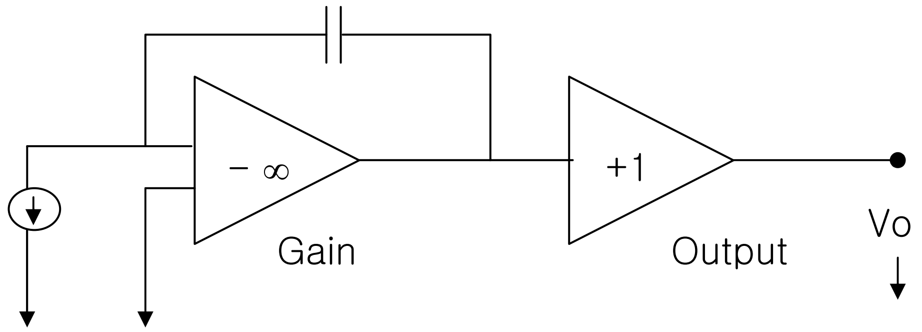
$$\rightarrow R_o = \frac{\Delta V_o}{\Delta\ i_o} = \frac{R_o}{A+1} = \frac{R_o}{A}$$

Slew Rate

- Maximum rate of output voltage change

741 model

Maximum current 19uA = $2 * I_c$

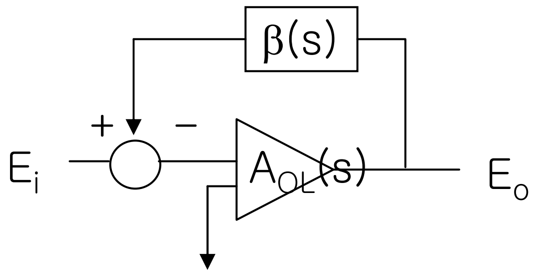


2*Ic charging Cc : Slew rate

= dVo/dt = 2Ic/Cc = 0.63V/us

Cc : freq. Compensation 을 위해 삽입된 Miller Cap.

Frequency Stability



$A_{CL}(S) = Eo/Ei = A_{OL}(S)/(1+ A_{OL}(s)\ \beta(s))$

$= A_{oL}(s)/(1+A_L(S))$

Instability : $A_L(s) = A_{OL}(s)B(s) = 1\angle 180 = -1$ 일때.

Critical condition : $A_{OL}(jw) = \{1/\ \beta(jw)\}\angle 180$

즉,

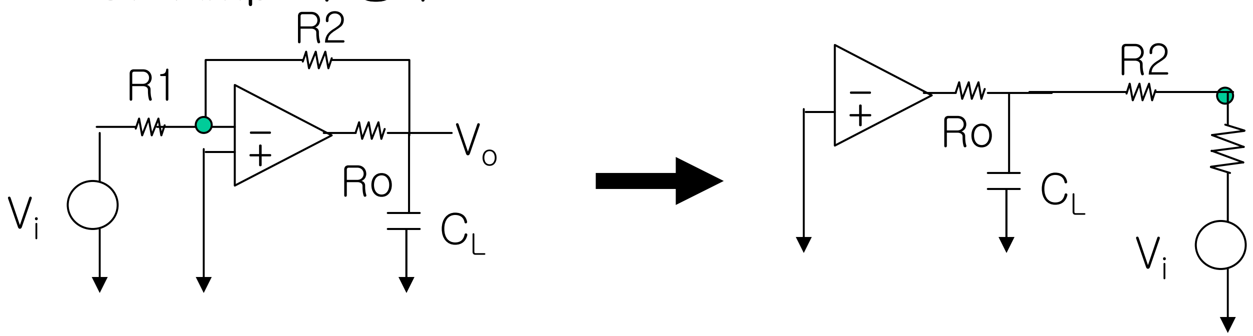
$|A_{oL}(jw)| = 1/|\ \beta(jw)|$이고 $\Phi_{OL} - \Phi_{CL} = 180°$

가 되는 freq.에서 oscillation

Frequency Stability

- 흔히 우리는 $|A_L(jw)| = |A_{oL}(jw)\beta(jw)| = 1$이 되는 w를 구하고 이 때의 $A_L(jw)$의 phase를 보아, 이것이 +180°로부터 떨어진 정도를 측정하며 이를 Φ_M (Phase margin) 이라고 한다.
  - $\Phi_M \sim 90°$ 정도일 때 stable system
  - Φ_M 은 크면 클수록 유리하다.

- OP Amp 의 경우



A_{oL}에feedback 되는 양

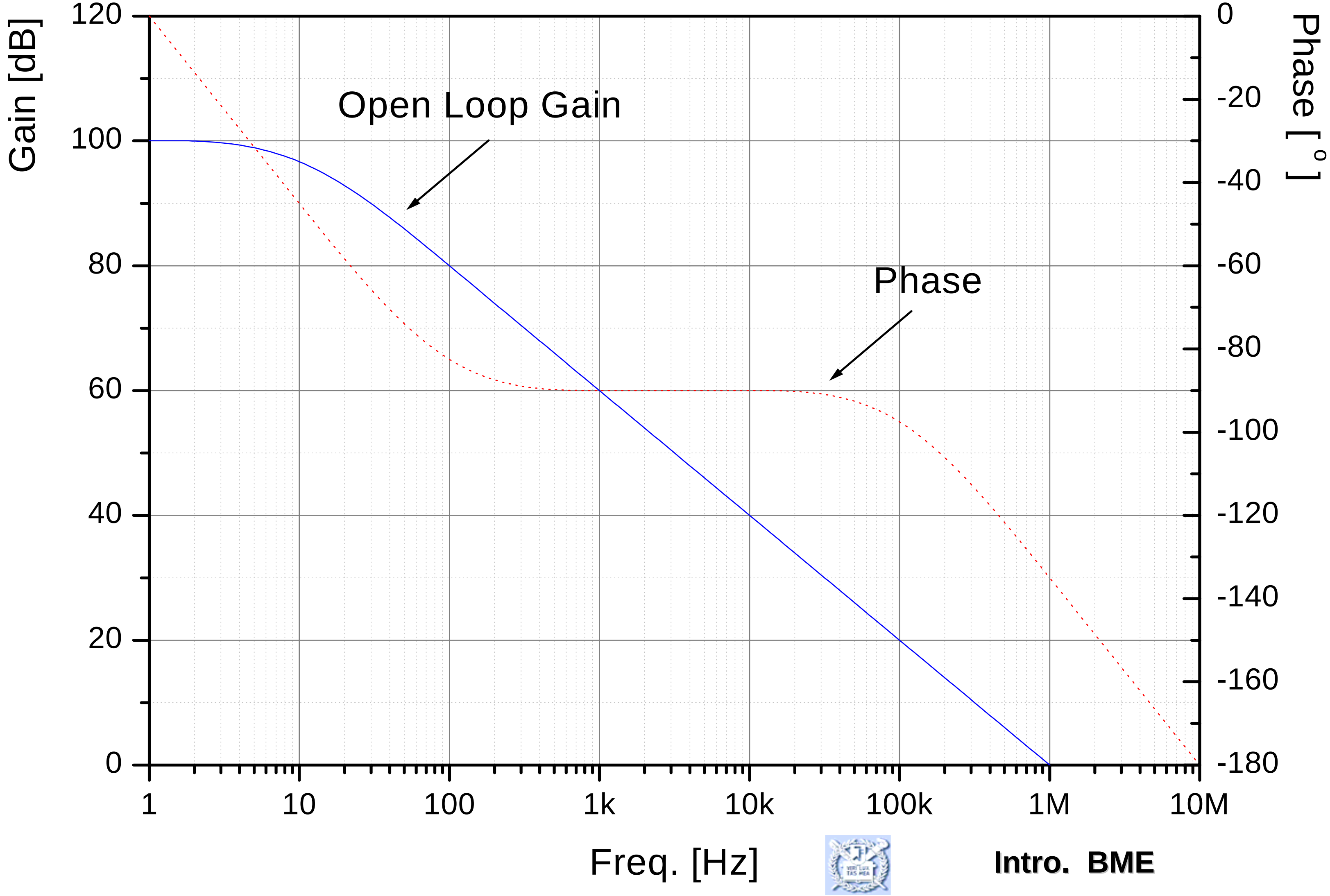
C_L=0, Vi 가 없을 때,

β = R1/(R0+R2+R1) ≈ R1/(R2+R1)

즉 $A_{oL}(jw)$에 β = R1/(R2+R1)을 곱해 $A_L(jw)$를 구하고

이의 Bode Diagram 에서 Φ_M을 구한다

Frequency Stability



Interference

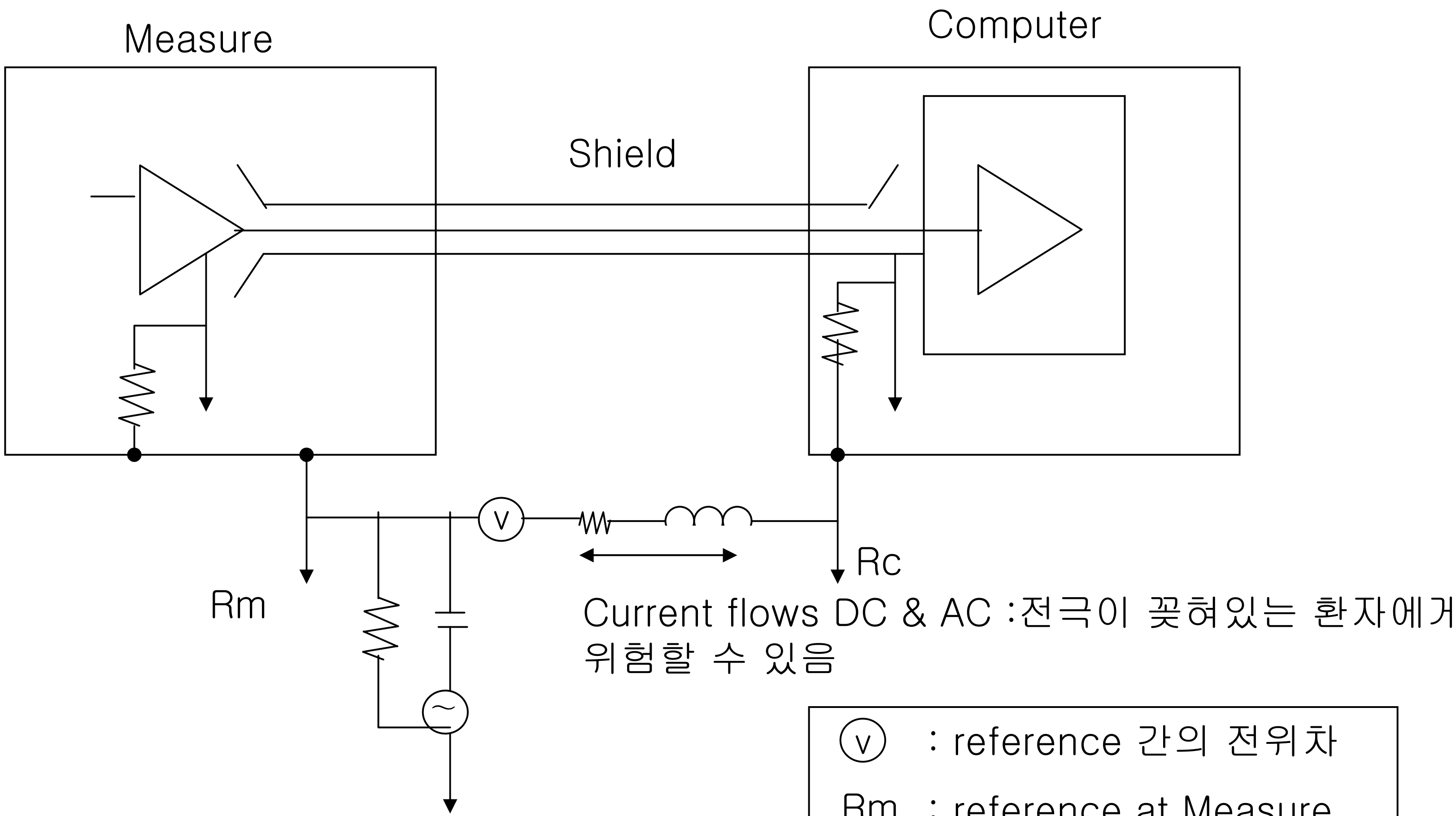
- Noise : random
- Interference : not random, comes from a known source

- Dominant interference : 60Hz
  - Thru. ① AC capacitive coupling
    ② AC inductive coupling
    ③ Ground loops
  - Solutions
    (1) Elimination at the source
      - Use of Instrumentation Amps and Isolation Amps.
      - Star Ground (one true ground)

    (2) (Adaptive) Filtering

Grounding & Instrumentation Amp.

- Ground Loop is a problem.

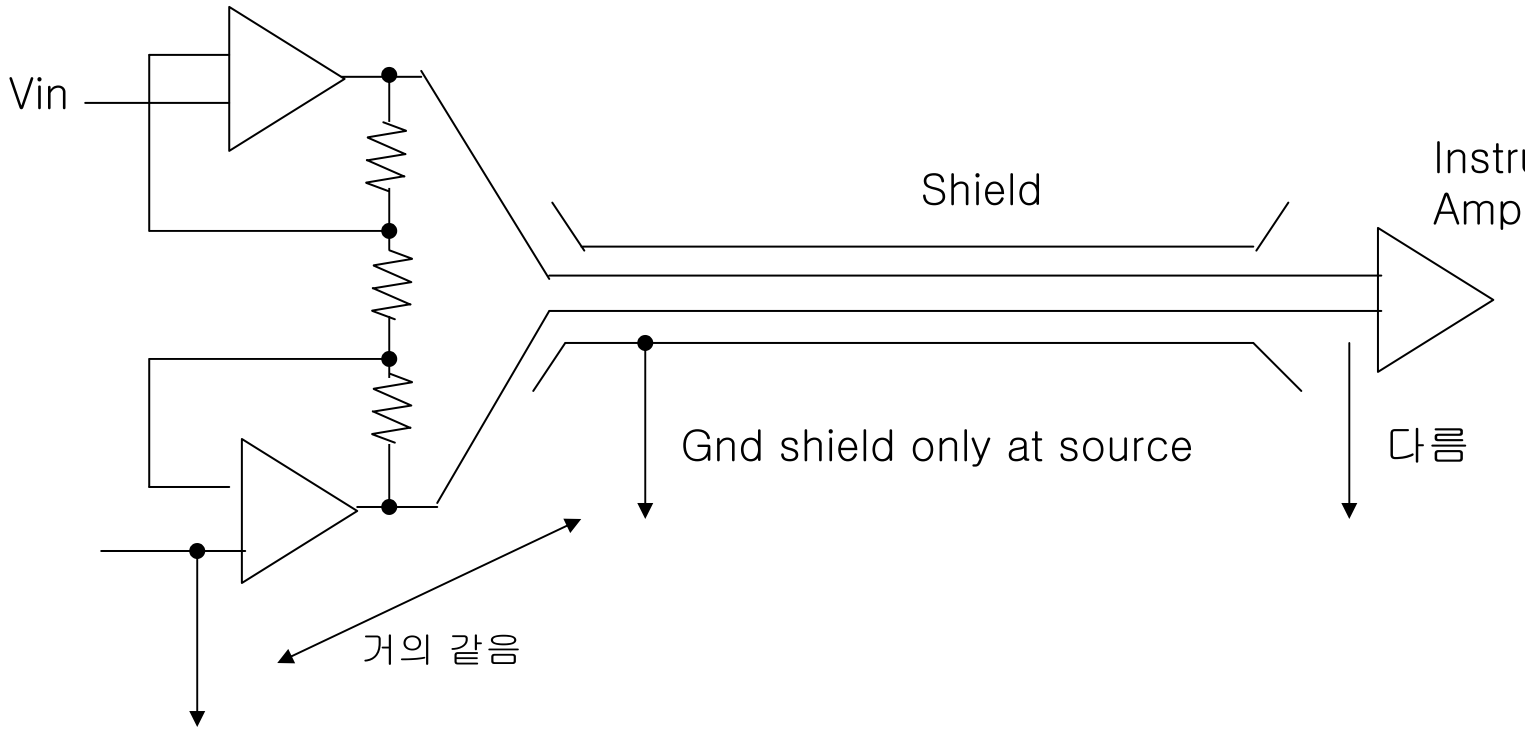


Current flows DC & AC :전극이 꽂혀있는 환자에게 위험할 수 있음

V	: reference 간의 전위차
Rm	: reference at Measure
Rc	: reference at Computer

Grounding & Instrumentation Amp.

- Solution(I) : Differential Transmission



모든 noise는 common mode로 처리

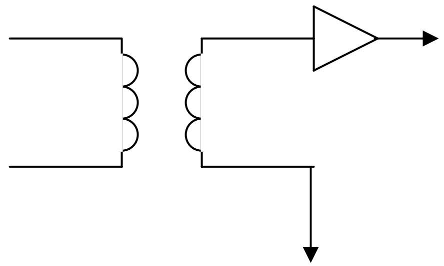
Grounding & Instrumentation Amp.

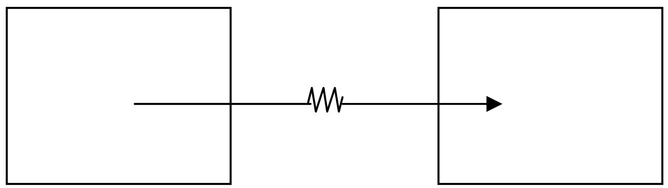
- Ground Loop => safety
  ECG 측정시 ground loop current는 전극이 꽂혀있는
  환자를 통하여 흐르게 되므로 위험

- Bias current => safety
  특별히 I_B가 작은 소자
  Ex) AD55L max I_B = 75fA
  AD00L max I_B = 10fA
- Ground Loop => SNR을 낮춤
- Careful grounding is needed

Grounding & Instrumentation Amp.

- Solution(II) : Isolation between Measure and Computer stations.
  - By transformer





Optics, RF ....

  - Optical coupling :optical isolator : (LED/LD)-PD 조합
  - Radio link
    - Signal – Modulator – Transmitter …– Receiver – Demodulator

ANALOG DEVICES

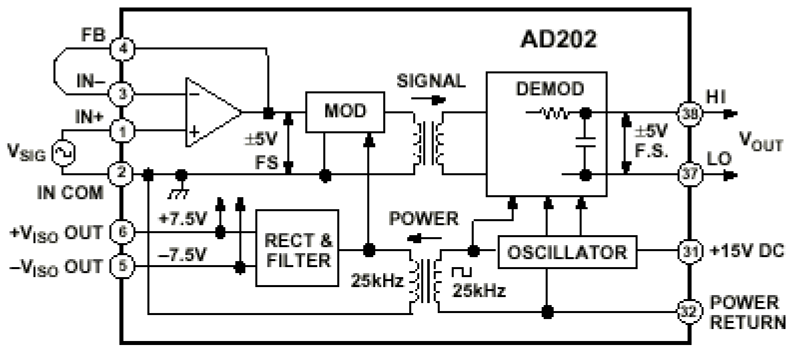
Low Cost, Miniature Isolation Amplifiers

AD202/AD204

FEATURES
- Small Size: 4 Channels/Inch
- Low Power: 35 mW (AD204)
- High Accuracy: ±0.025% max Nonlinearity (K Grade)
- High CMR: 130 dB (Gain = 100 V/V)
- Wide Bandwidth: 5 kHz Full-Power (AD204)
- High CMV Isolation: ±2000 V pk Continuous (K Grade) (Signal and Power)
- Isolated Power Outputs
- Uncommitted Input Amplifier

APPLICATIONS
- Multichannel Data Acquisition
- Current Shunt Measurements
- Motor Controls
- Process Signal Isolation
- High Voltage Instrumentation Amplifier

FUNCTIONAL BLOCK DIAGRAM



Isolation mode rejection ratio(IMRR);105dB@60Hx

GENERAL DESCRIPTION

The AD202 and AD204 are general purpose, two-port, transformer-coupled isolation amplifiers that may be used in a broad range of applications where input signals must be measured, These industry standard isolation amplifiers offer a complete isolation function, with both signal and power isolation provided

ing. For applications requiring a low profile, the DIP package provides a height of just 0.350".

High Accuracy: With a maximum nonlinearity of ±0.025% for the AD202K/AD204K (±0.05% for the AD202J/AD204J) and low drift over temperature, the AD202 and AD204 provide high isolation without loss of signal integrity.

Low Power: Power consumption of 35 mW (AD204) and 75 mW (AD202) over the full signal range makes these isolators power budgets.