Chương 5

Một số mạch khuếch đại đặc biệt

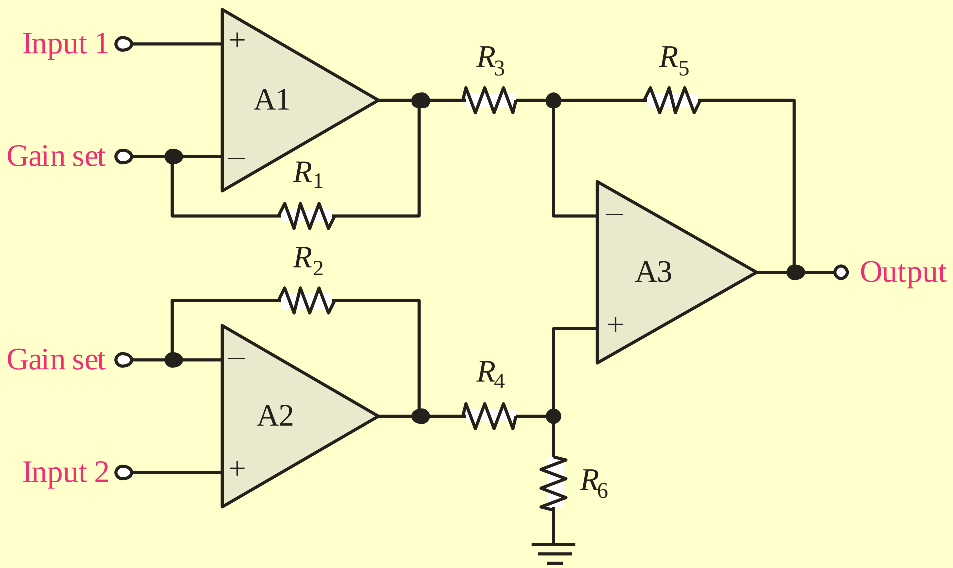
Instrumentation Amplifiers

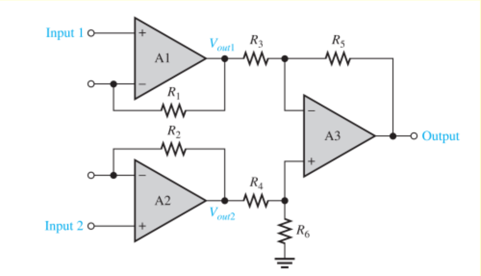
Khuếch đại máy đo

Khuếch đại máy đo **instrumentation amplifier** (IA) khuếch đại khác biệt điện thế giữa hai ngõ vào.

Ưu điểm của IA:

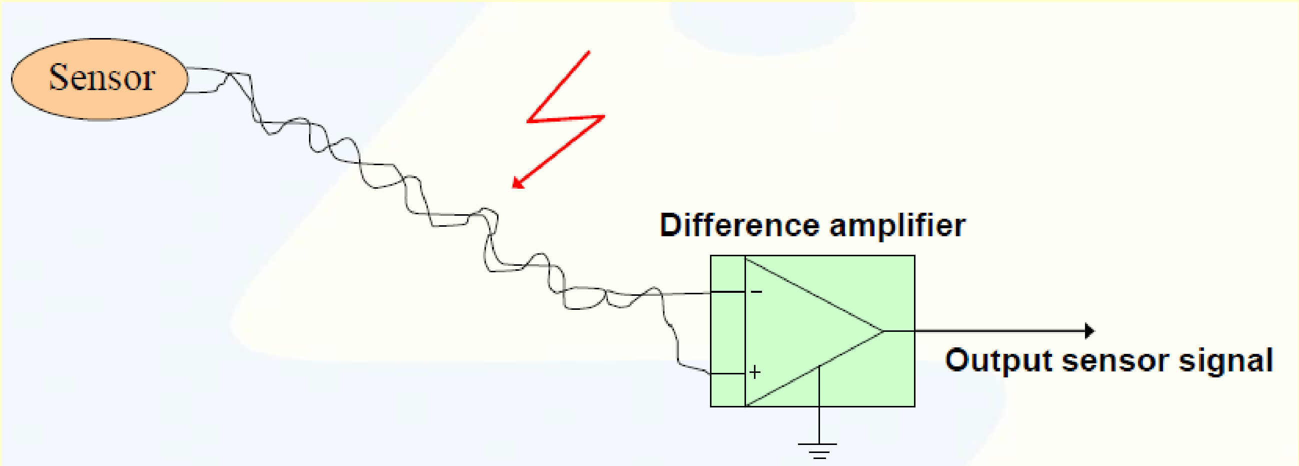
- Ultra-high input impedance
- Very-high CMRR
- Low output offset
- Low output impedance





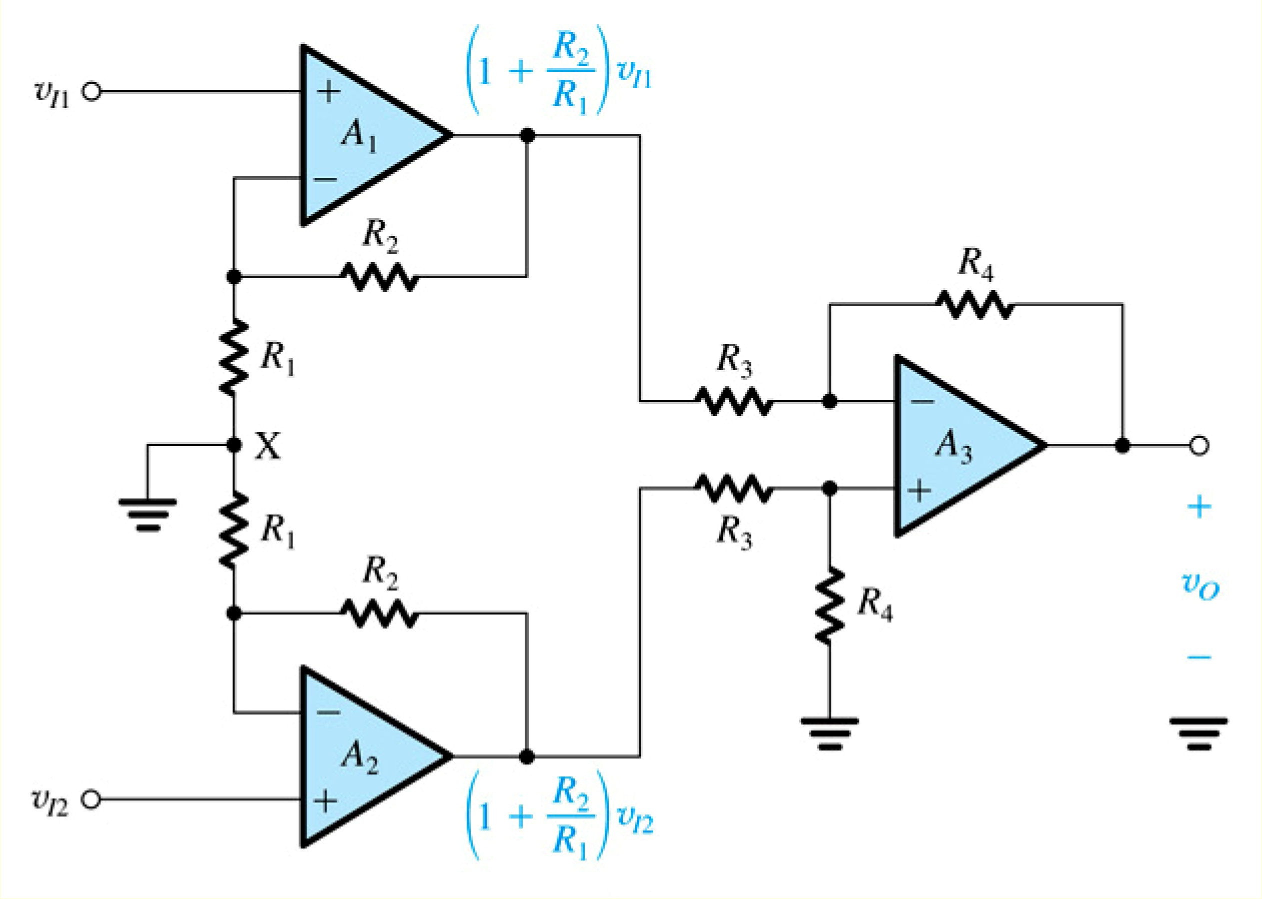
Ứng dụng của IA

Applications:



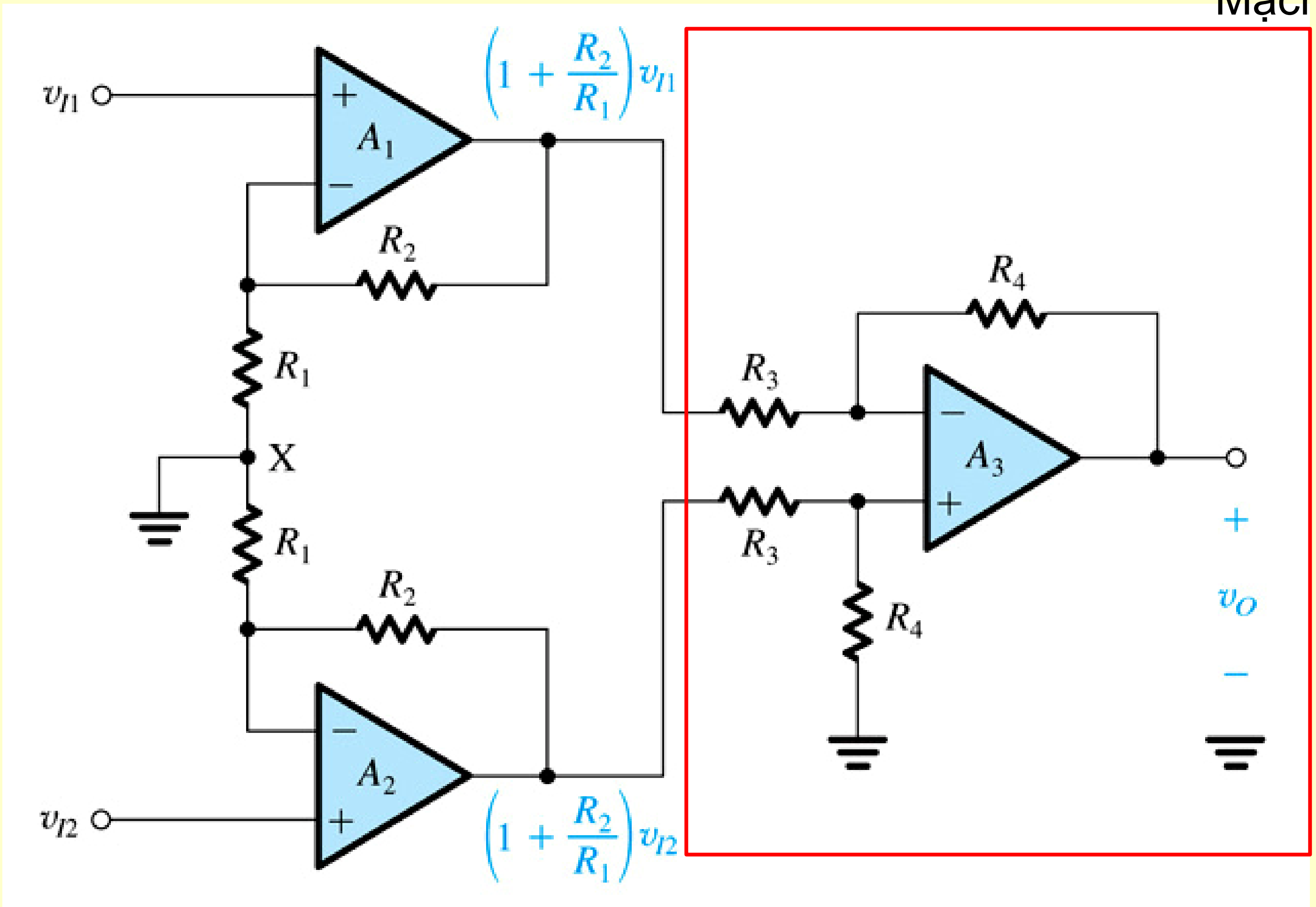
- Sử dụng hữu hiệu khi cần kết nối sensor (nhiệt độ, áp suất,…) ở khoảng cách xa → dây dẫn dài → nhiễu (tín hiệu chế độ chung, common-mode voltage) xuất hiện trên đường dây.
- IA được đặt ở ở cuối đường dậy để khuếch đại tín hiệu vi sai (sai biệt điện thế giữa hai dây) và loại bỏ tín hiệu chung (nhiễu)

Khuếch đại máy đo (mạch cơ bản)

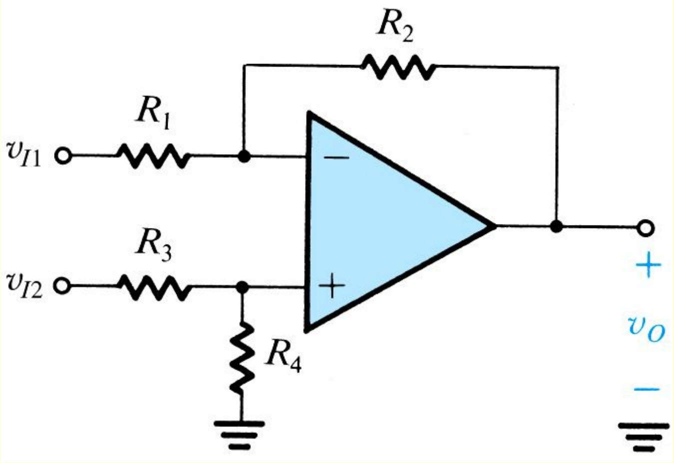


stage #1 stage #2

Mạch trừ



Mạch trừ (nhắc lại)

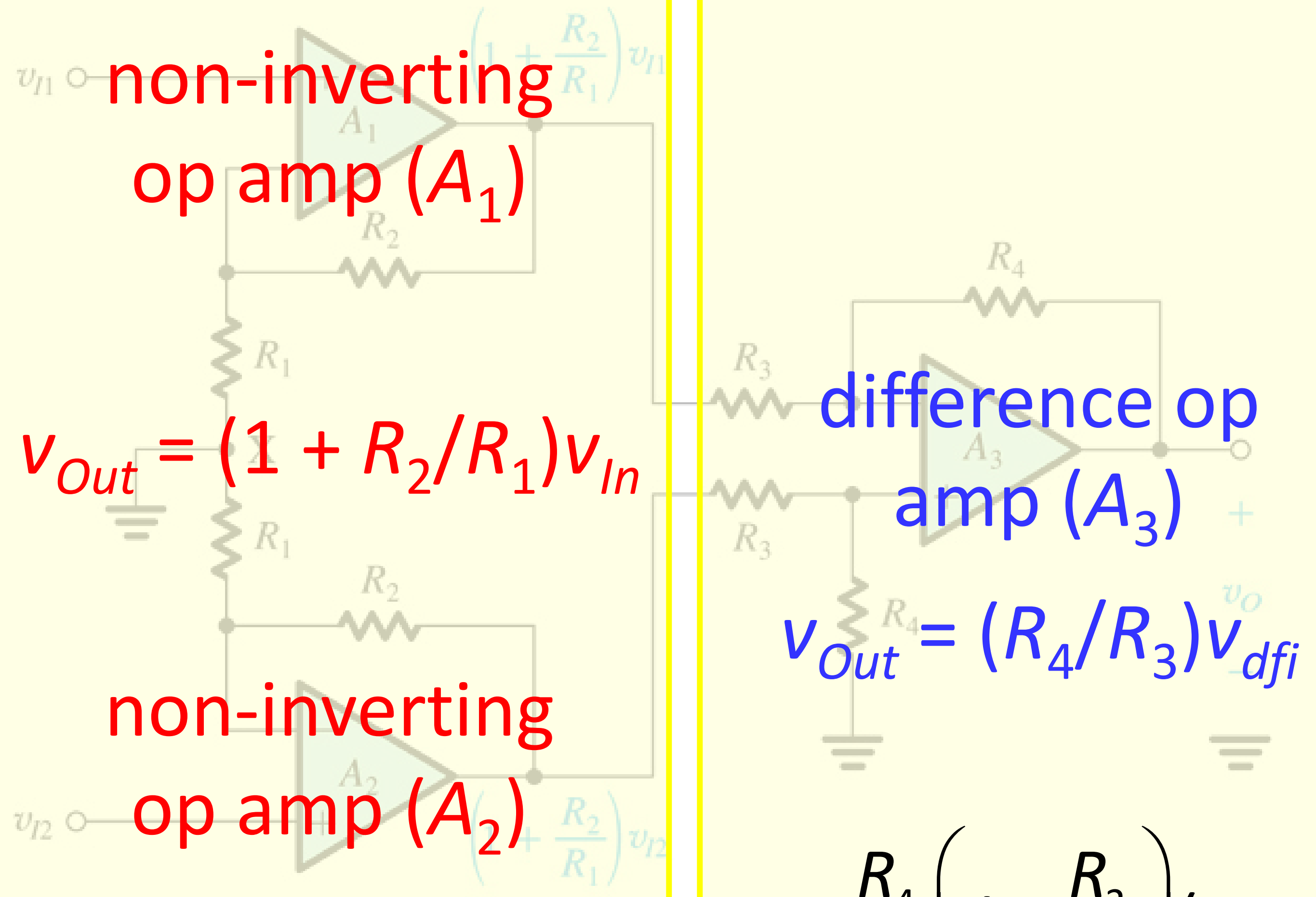


$$v_{Out} = \frac{(R_2 + R_1)R_4}{(R_4 + R_3)R_1} v_{In2} - \frac{R_2}{R_1} v_{In1}$$

but if $\begin{Bmatrix} R_1 = R_3 \\ R_2 = R_4 \end{Bmatrix}$ then $v_{Out} = \frac{R_2}{R_1}\left(v_{In2} - v_{In1}\right)$

stage #1

stage #2



non-inverting op amp (A_1)

$v_{Out} = (1 + R_2/R_1)v_{In}$

non-inverting op amp (A_2)

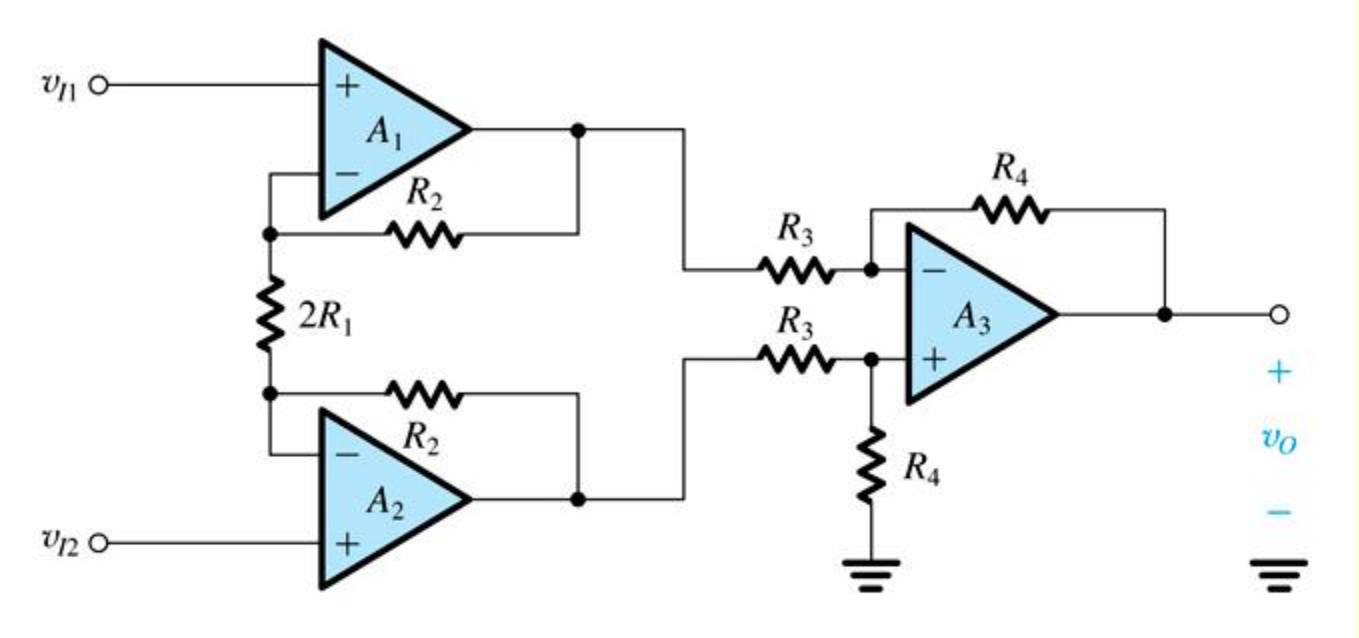
difference op amp (A_3)

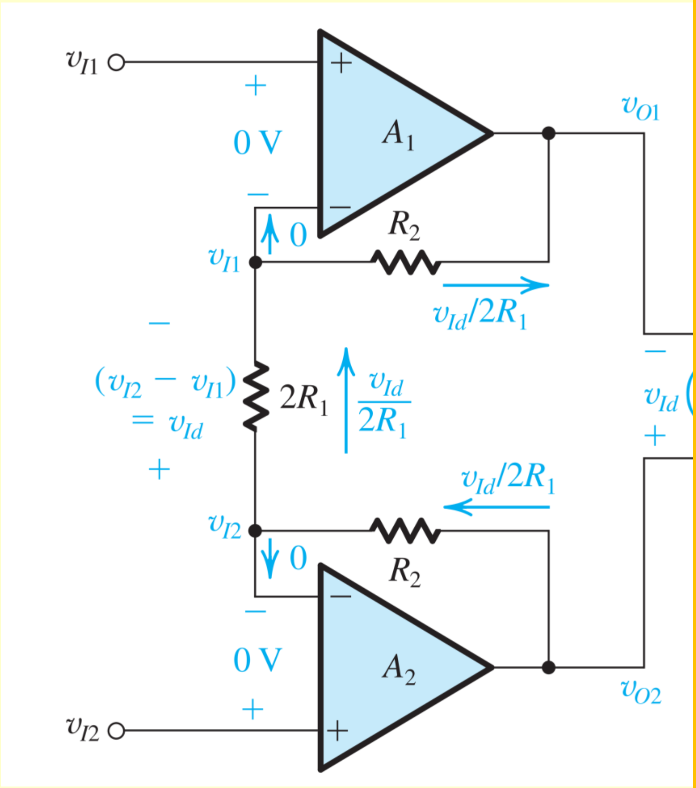
$v_{Out} = (R_4/R_3)v_{dfi}$

$$v_{Out} = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)(v_{i2} - v_{i1})$$

Mạch cải tiến

- Lý do cần cải tiến:
  - Ở mạch cơ bản độ lợi tín hiệu chung và tín hiệu vi sai bằng nhau →tín hiệu ra ở A1/A2 và A3 lớn có thể là có thể làm cho Opamp bão hòa, ngoài ra tầng thứ hai phải có CMRR lớn nếu muốn CMRR toàn thể lớn.
  - Các điện trở và OPAMP ở tầng 1 phải đối xứng → rất khó để thực hiện.





for both op amp A_1 and A_2

$$\overbrace{v_{(+)} - v_{(-)} = 0}$$

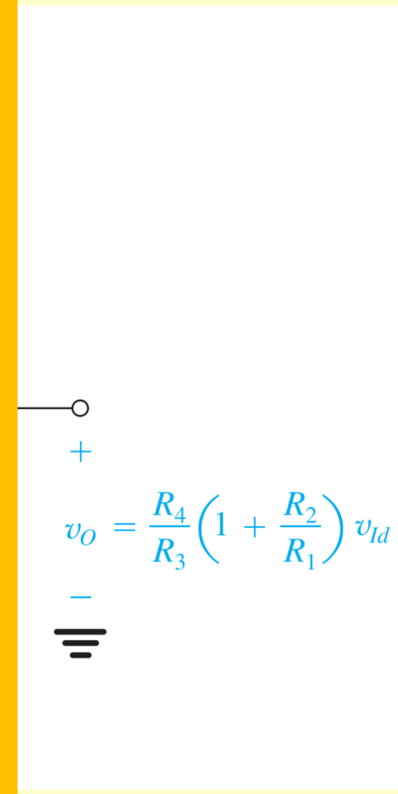
$$\Rightarrow \quad v_{(+)} = v_{(-)}$$

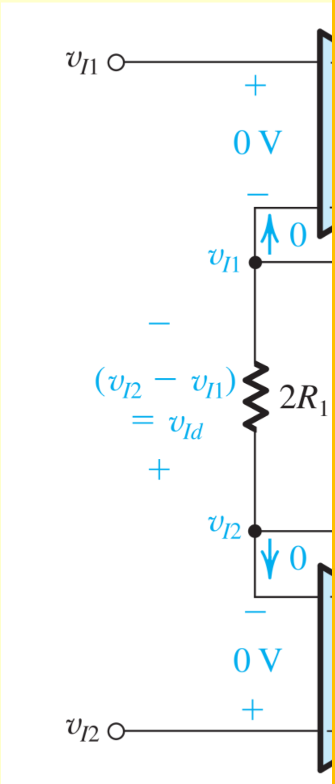
$$i_{R1} = \frac{\overbrace{v_{i2} - v_{i1}}^{v_{id}}}{2R_1}$$

all of iR_1 will flow across R_2

$$\overbrace{v_{o1} = v_{i1} - i_{R1}R_2}$$

$$v_{o2} = v_{i2} + i_{R1}R_2$$





$$\overbrace{v_{(+)} - v_{(-)} = 0}^{\text{for both op amp } A_1 \text{ and } A_2}$$

$$\Rightarrow \quad v_{(+)} = v_{(-)}$$

$$i_{R1} = \frac{\overbrace{v_{i2} - v_{i1}}^{v_{id}}}{2R_1}$$

all of iR_1 will flow across R_2

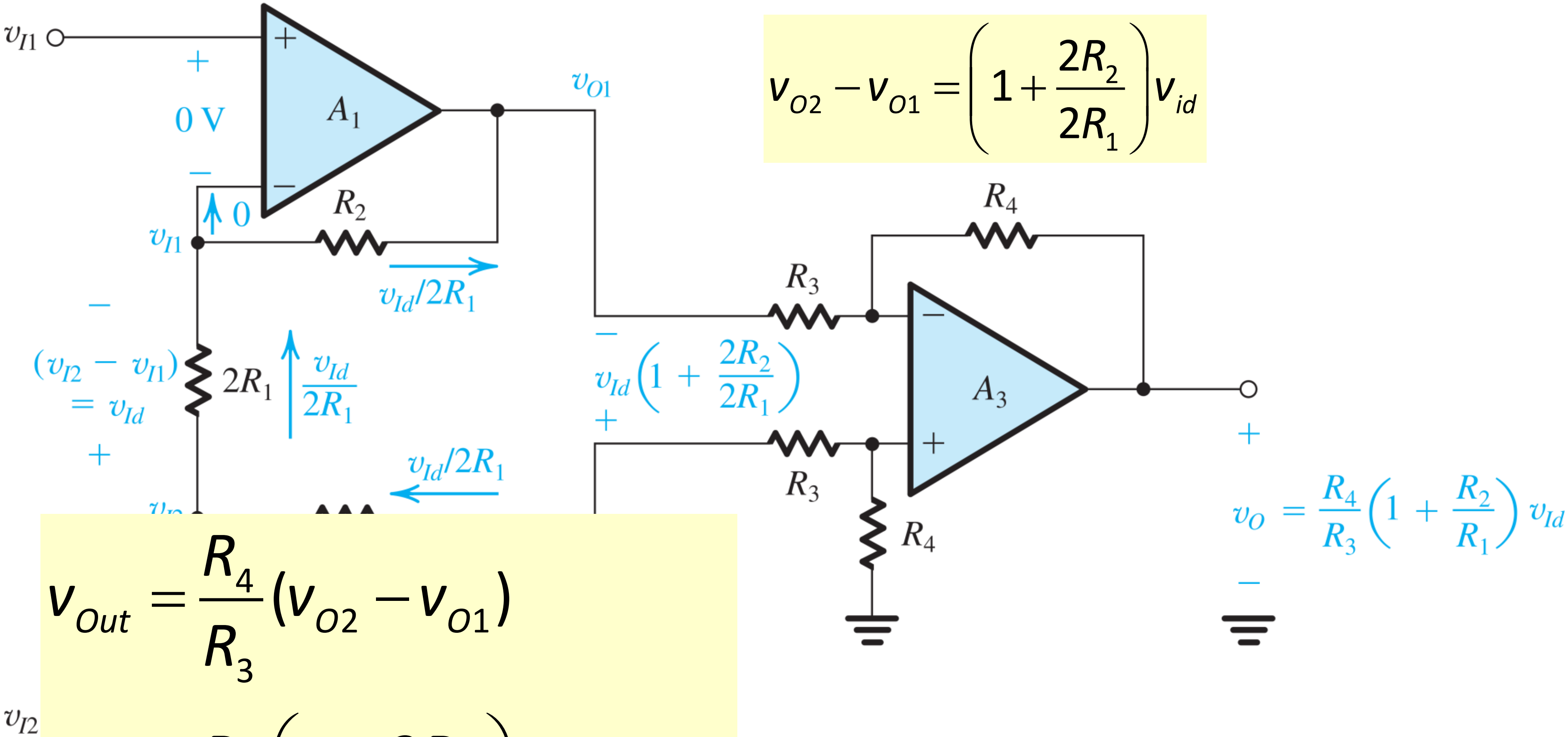
$$\overbrace{\begin{aligned} v_{o1} &= v_{i1} - i_{R1} R_2 \\ v_{o2} &= v_{i2} + i_{R1} R_2 \end{aligned}}^{\text{all of } iR_1 \text{ will flow across } R_2}$$

$$v_{o2} - v_{o1} = \underbrace{\left[v_{i2} + \left(\frac{v_{i2} - v_{i1}}{2R_1} \right) R_2 \right]}_{v_{O2} = v_{i2} + i_{R1} R_2} - \ldots$$

$$\ldots - \underbrace{\left[v_{In1} - \left(\frac{v_{In2} - v_{In1}}{2R_1} \right) R_2 \right]}_{v_{O1} = v_{i1} - i_{R1} R_2}$$

$$v_{O2} - v_{O1} = \underbrace{(v_{i2} - v_{i1})}_{v_{id}} + 2 \left(\frac{\overbrace{v_{i2} - v_{i1}}^{v_{id}}}{2R_1} \right) R_2$$

$$v_{O2} - v_{O1} = \left(1 + \frac{2R_2}{2R_1} \right) v_{id}$$



$$v_{O2} - v_{O1} = \left(1 + \frac{2R_2}{2R_1}\right) v_{id}$$

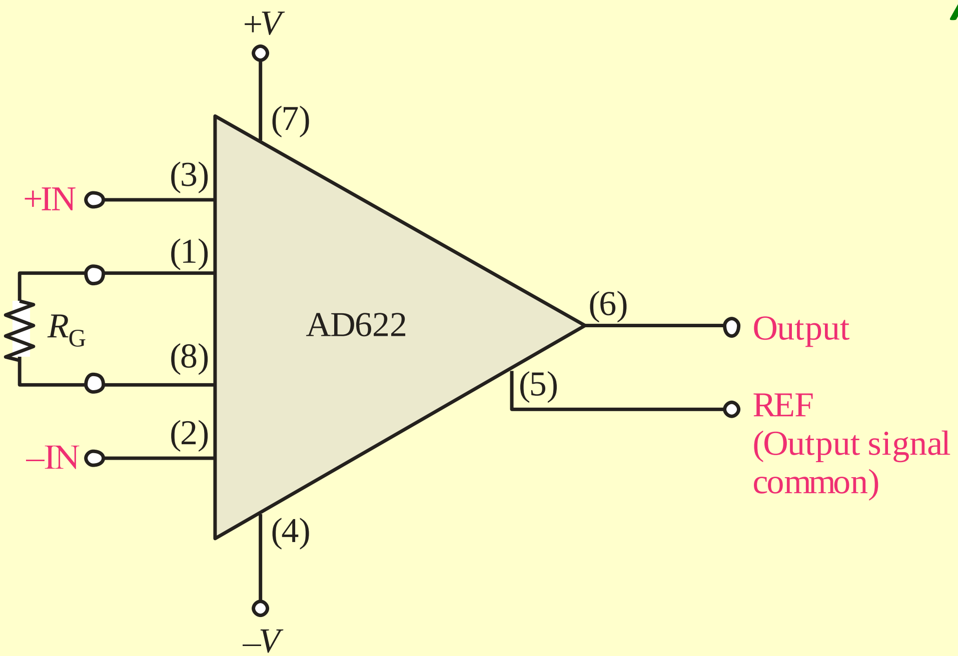
$$v_{Out} = \frac{R_4}{R_3}(v_{O2} - v_{O1})$$

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

$$\boxed{\frac{v_{Out}}{v_{id}} = A_v = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{2R_1}\right)}$$

solution

AD622



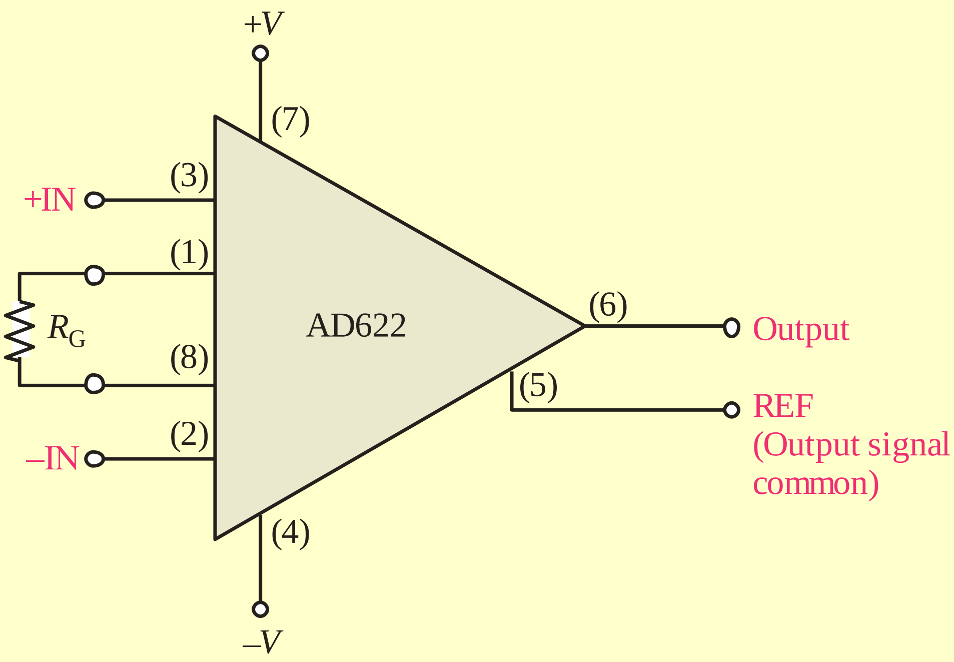
$$A_v = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{2R_1}\right)$$

Nếu $R_4 = R_3$
Và $R_1 = R_G$
Thì:

$$A_v = 1 + \frac{R_2}{R_G}$$

Trong AD622, R_G được chọn theo công thức:

$$R_G = \frac{50.5\ \text{k}\Omega}{A_v - 1}$$

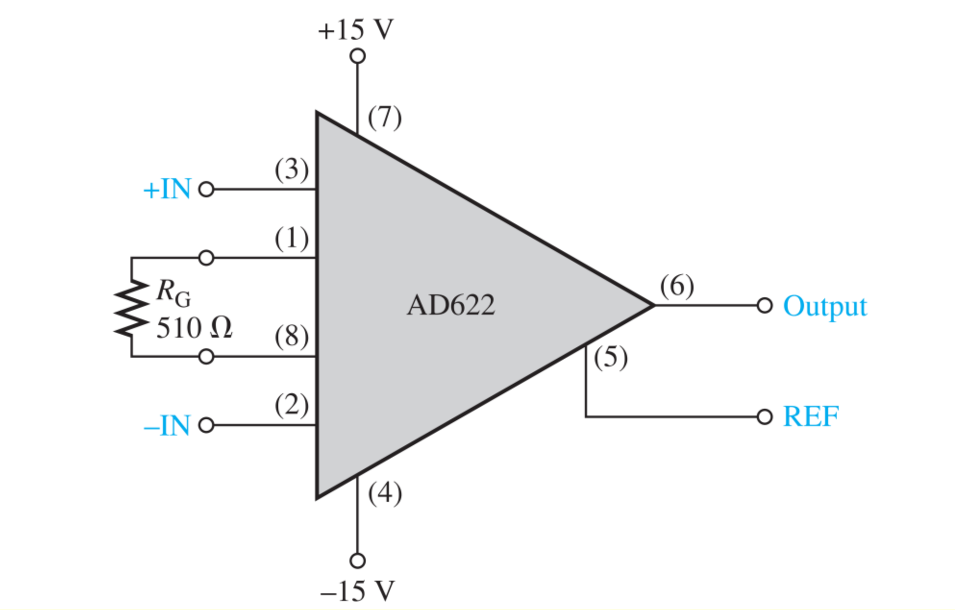


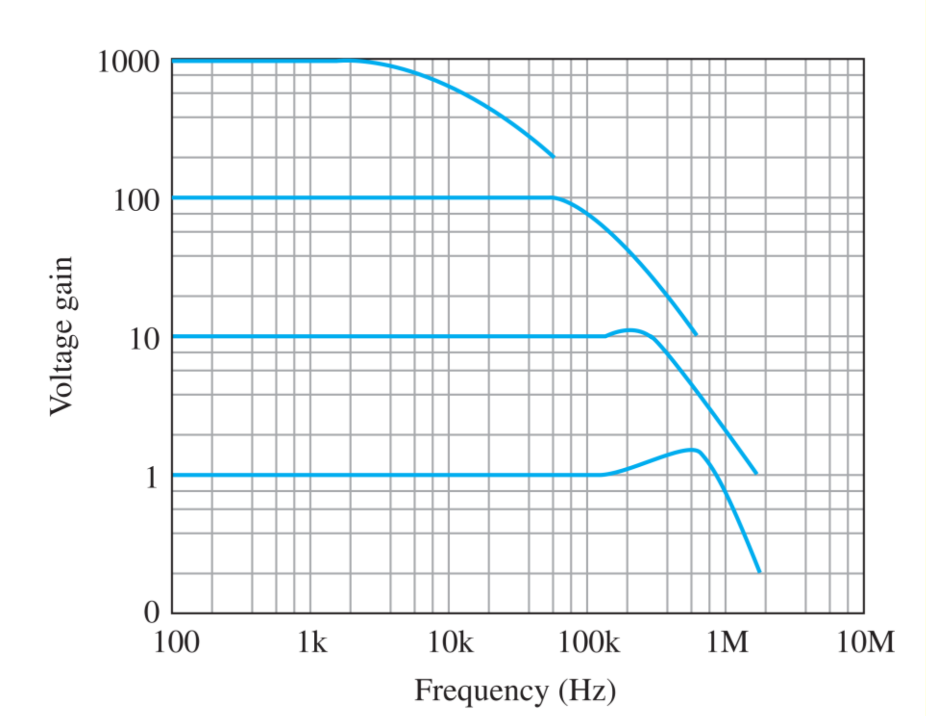
R_G bằng bao nhiêu để gain = 35?

$$R_G = \frac{50.5\ \text{k}\Omega}{A_v - 1} = \frac{50.5\ \text{k}\Omega}{35 - 1}$$

$= 1.5\ \text{k}\Omega$

VD: Hãy tìm băng thông của OPAMP





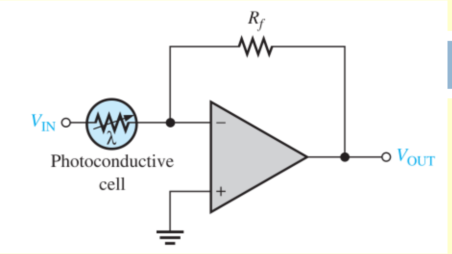
$$R_G = \frac{50.5\ \text{k}\Omega}{A_v - 1}$$

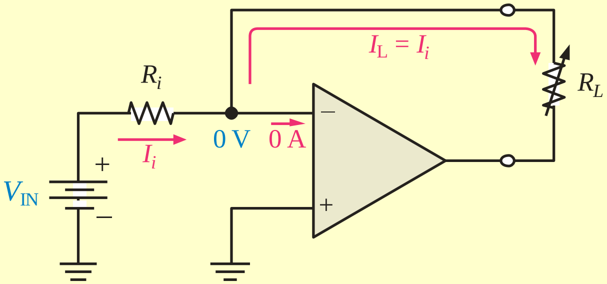
$$A_v - 1 = \frac{50.5\ \text{k}\Omega}{R_G}$$

$$A_v = \frac{50.5\ \text{k}\Omega}{510\ \Omega} + 1 = \mathbf{100}$$

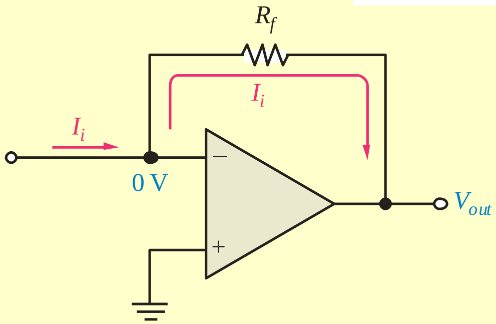
$$BW \cong \mathbf{60\ kHz}$$

Bài tập: hãy giải thích hoạt động của các mạch sau

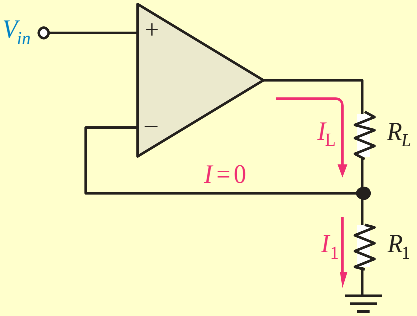




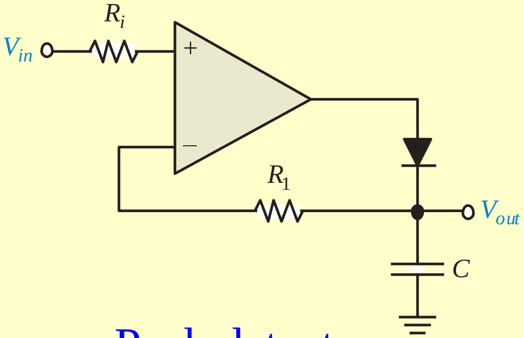
Constant-current source



Current-to-voltage converter



Voltage-to-current converter

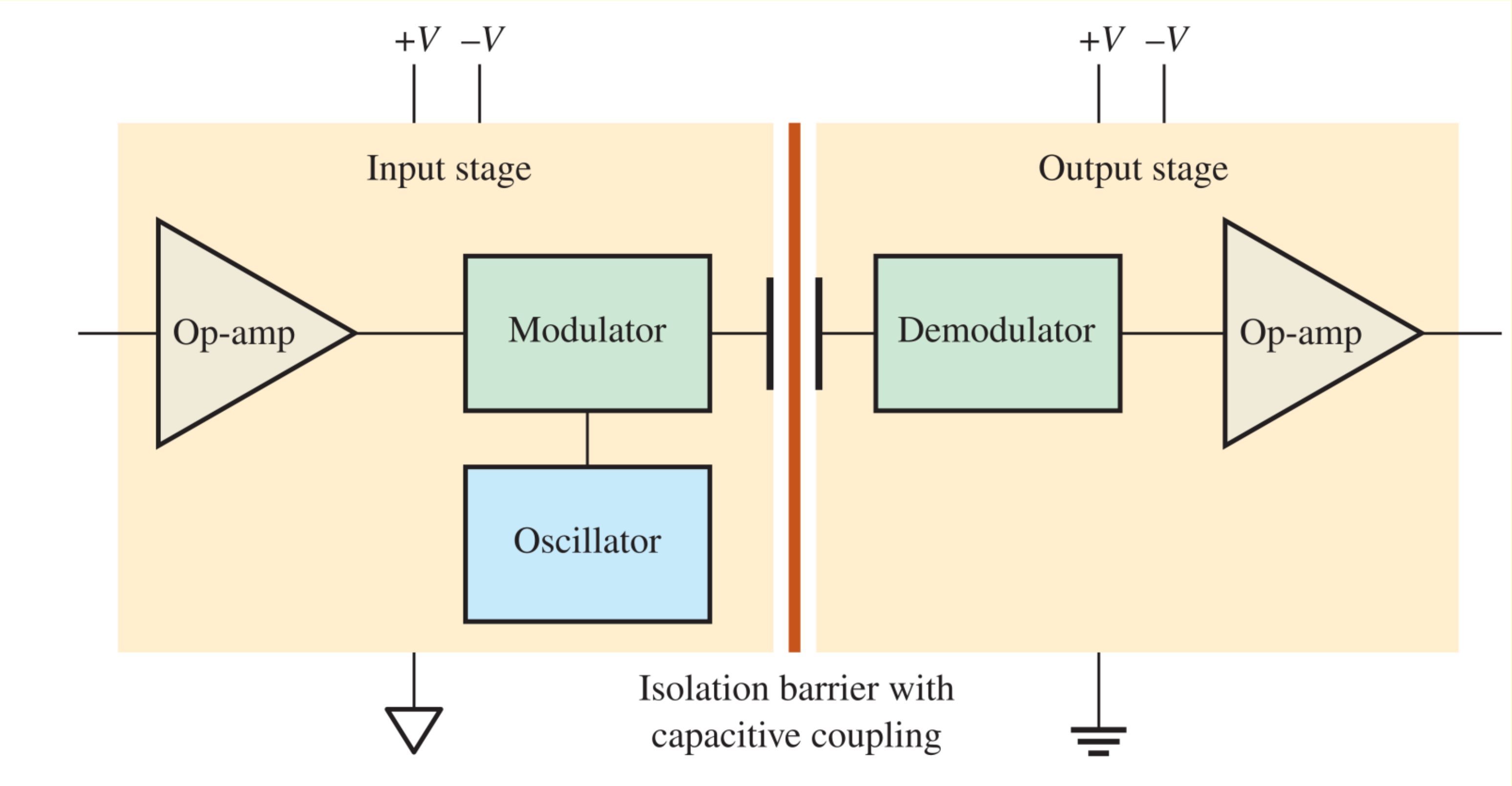


Peak detector

ISOLATION AMPLIFIERS

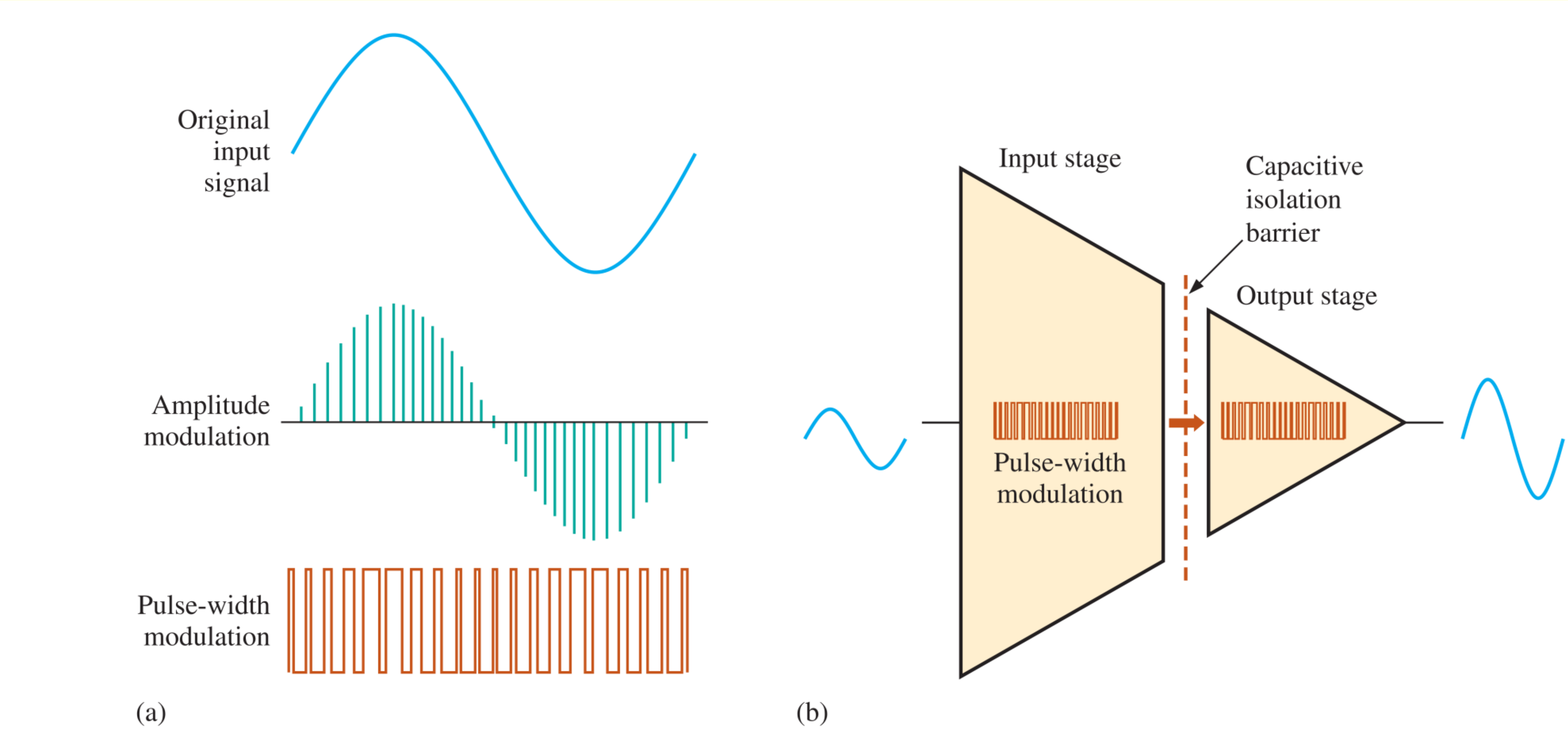
Dùng ghép nối điện cảm, điện dung hay quang giữa tầng ngõ vào và tầng ngõ ra.

Capacitor-Coupled Isolation Amplifier

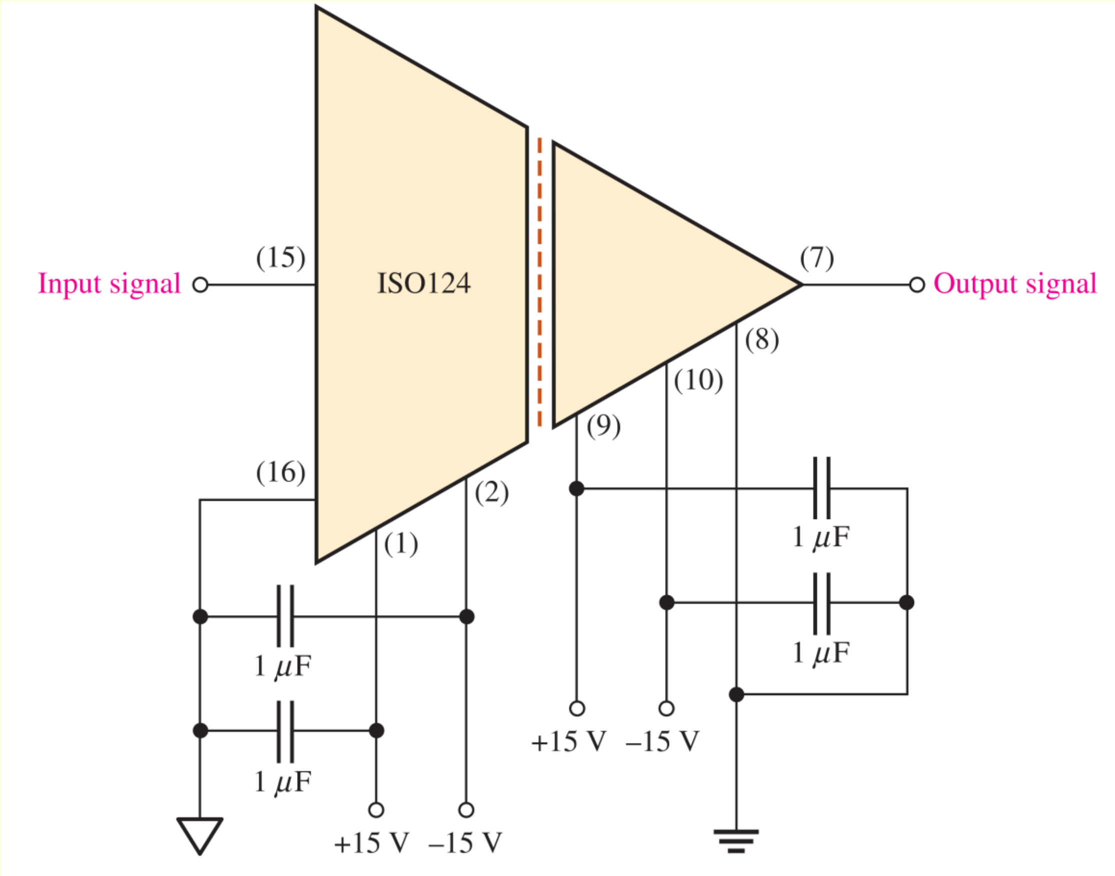


Tuy cấu trúc bên trong khá phức tạp nhưng cơ bản thì đây là một bộ khuếch đại với ngõ vào và ngõ ra cách ly điện thế với nhau.

Tại sao cần điều chế?

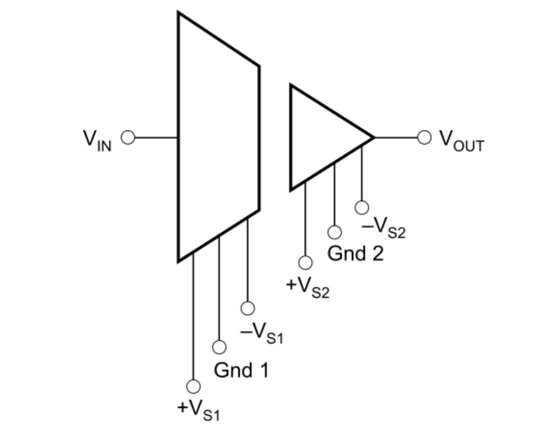


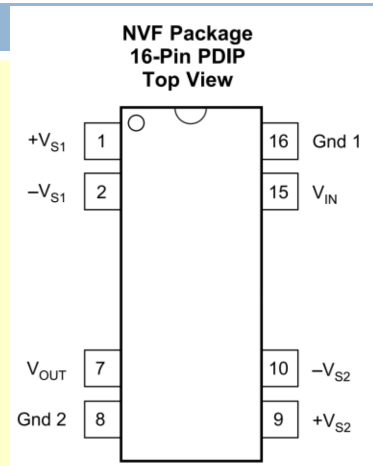
Ví dụ

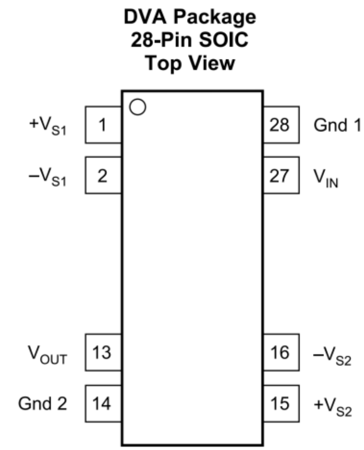


A_v =1 (cố định);
Dùng PWM có f = 500 kHz

ISO 124







6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)

	MIN	MAX	UNIT
Supply voltage		±18	V
Analog input voltage, V_{IN}		100	V
Continuous isolation voltage		1500	Vrms
Junction temperature		125	°C
Output short to common		Continuous	
Storage temperature, T_{stg}	–40	125	°C

6.3 Recommended Operating Conditions

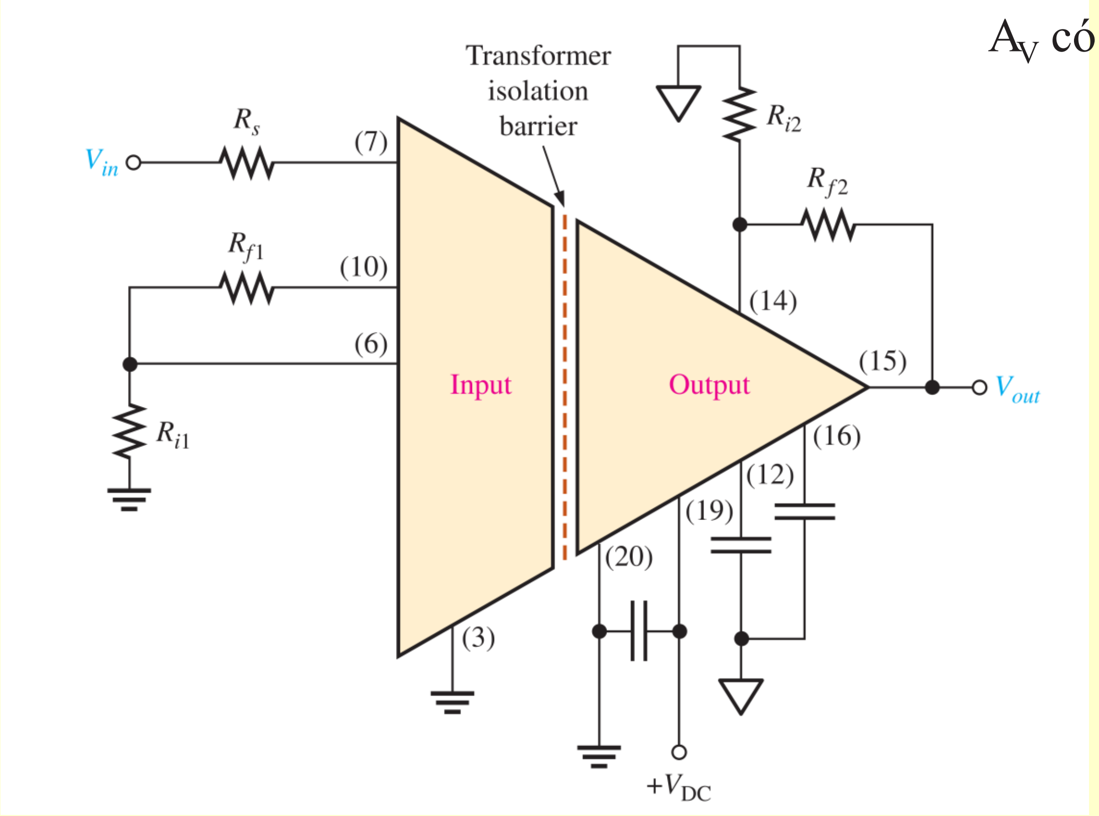
over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V_{S1}	High-side analog supply voltage ($\pm V_{S1}$ to GND1)	±4.5	±15	±18	V
V_{S2}	Low-side analog supply voltage ($\pm V_{S2}$ to GND2)	±4.5	±15	±18	V
V_{IN}	Analog input voltage		±10		V
T_A	Operating temperature	–25		85	°C

Transformer-Coupled Isolation Amplifier

Texas Instruments (Burr-Brown) 3656KG

A_V có thể thay đổi thông qua các điện trở

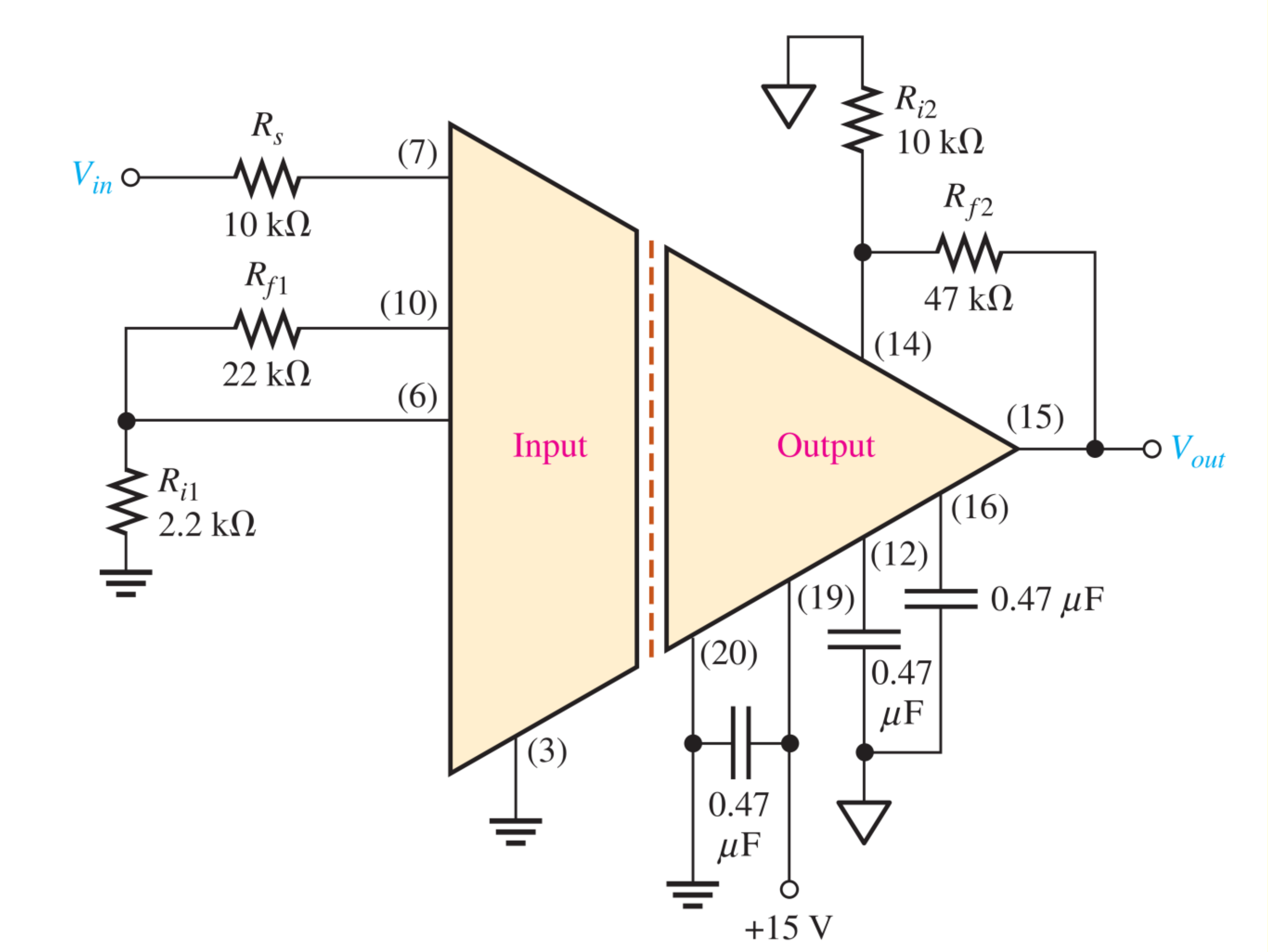


$$A_{v1} = \frac{R_{f1}}{R_{i1}} + 1$$

$$A_{v2} = \frac{R_{f2}}{R_{i2}} + 1$$

$$A_{v(tot)} = A_{v1}A_{v2}$$

VD: tìm độ lợi điện thế của mạch

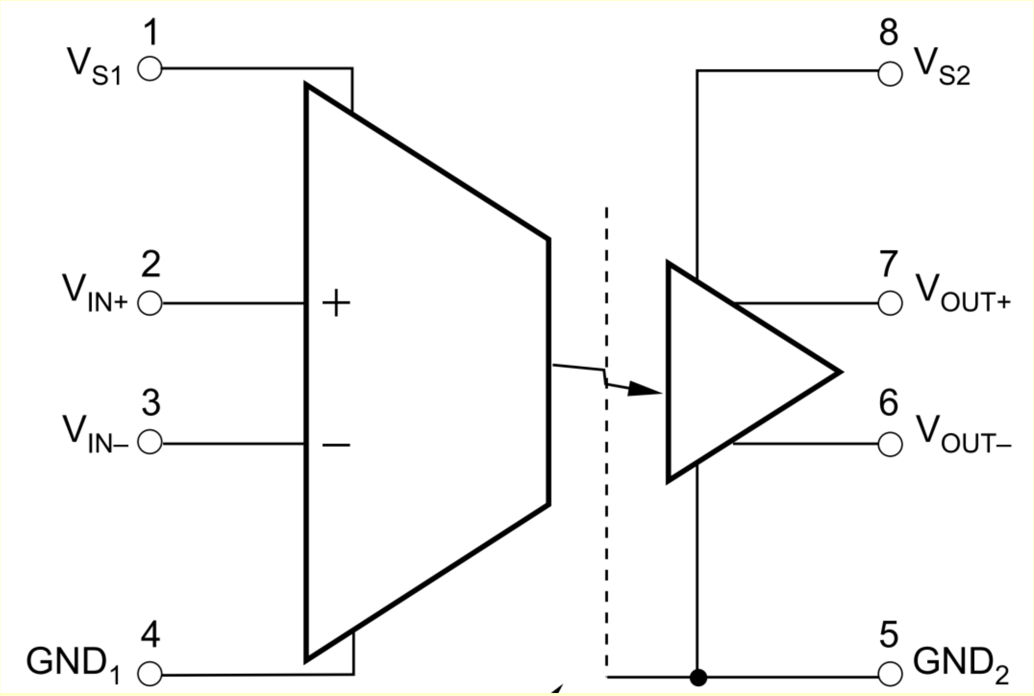


$$A_{v1} = \frac{R_{f1}}{R_{i1}} + 1 = \frac{22\ \mathrm{k}\Omega}{2.2\ \mathrm{k}\Omega} + 1 = 10 + 1 = 11$$

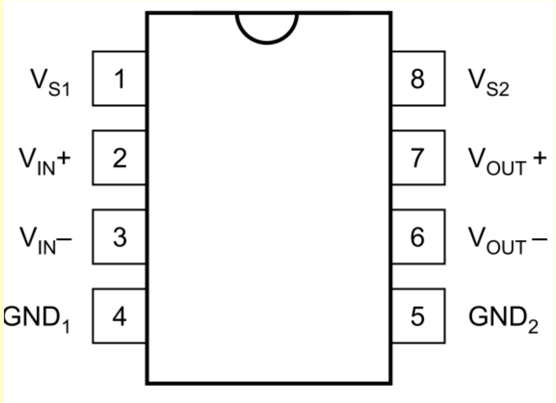
$$A_{v2} = \frac{R_{f2}}{R_{i2}} + 1 = \frac{47\ \mathrm{k}\Omega}{10\ \mathrm{k}\Omega} + 1 = 4.7 + 1 = 5.7$$

$$A_{v(tot)} = A_{v1}A_{v2} = (11)(5.7) = \mathbf{62.7}$$

Optically-Coupled Linear ISOLATION AMPLIFIERS



ISO130



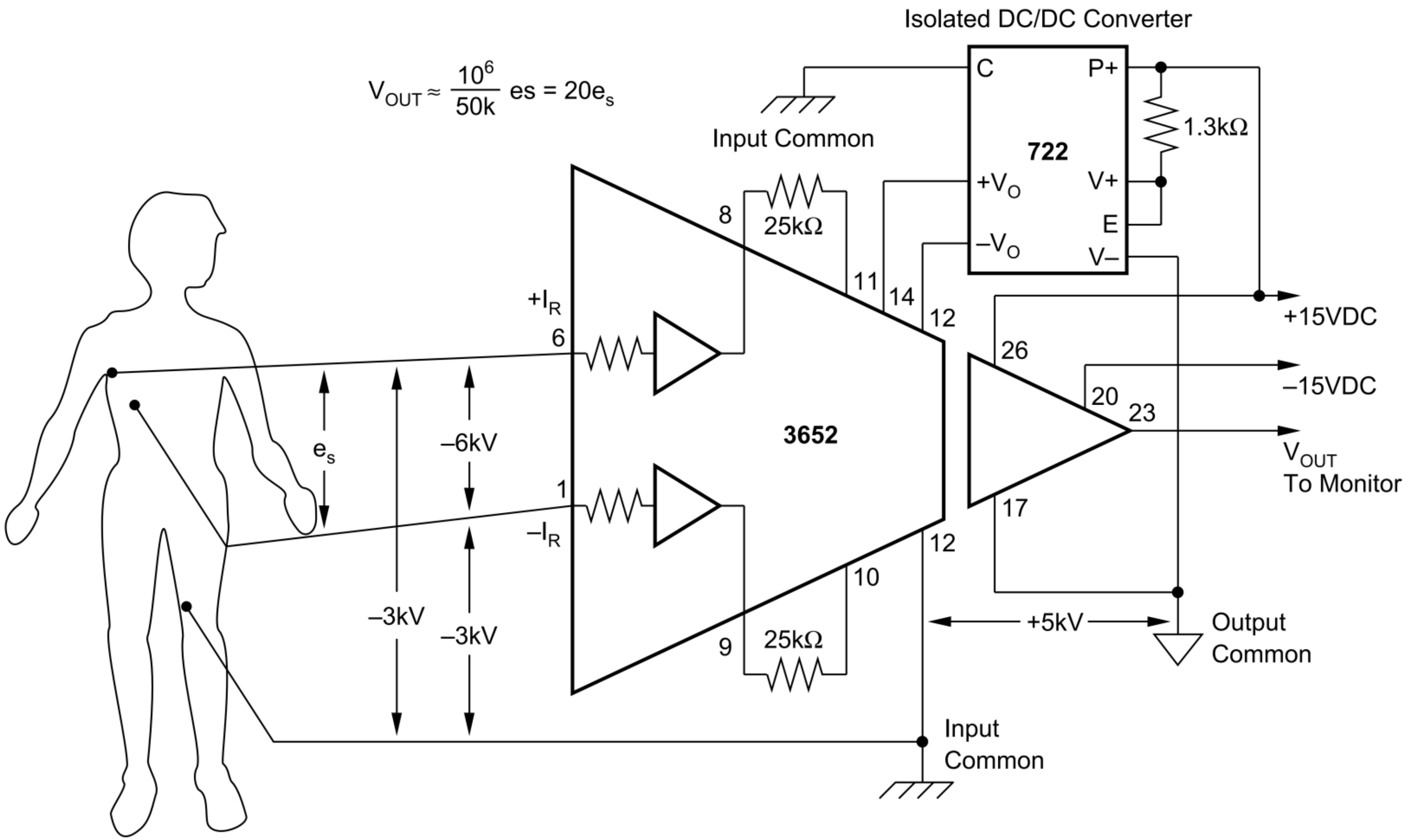
ELECTRICAL CHARACTERISTICS

ISOLATION SPECIFICATIONS

At $V_{IN}+$, $V_{IN}-$ = 0V, T_A = 25°C, V_{S1}, V_{S2} = 5.0V, unless otherwise noted.

PARAMETER	CONDITIONS	ISO130P, ISO130PB ISO130U, ISO130UP MIN	TYP	MAX	UNITS
ISOLATION					
Input-Output Surge Withstand Voltage(8, 9), (In accordance with UL1577)	t = 1_{MIN}, RH ≤ 50%	3750			Vrms
Barrier Impedance(9)					
Resistance	V_{ISO} = 500VDC		10^{13}		Ω
Capacitance	f = 1MHz		0.7		pF
Isolation Mode Voltage Errors					
Rising Edge Transient Immunity	V_{IM} = 1kV, ∂ V_{OUT} < 50mV	10	25		kV/µs
Falling Edge Transient Immunity	V_{IM} = 1kV, ∂ V_{OUT} < 50mV	10	15		kV/µs
Isolation Mode Rejection Ratio(2)			> 140		dB
Noise	0.1Hz to 100kHz		300		µVrms
Input Voltage Range		–200		200	mV
Maximum Input Voltage Range before Output Clipping			±300		mV
Initial Input Bias Current(3)			–670		nA
vs Temperature			3		nA/°C
Input Resistance(3)			530		kΩ
vs Temperature			0.38		%/°C
Common-Mode Rejection Ratio(4)			72		dB
GAIN(5)					
Initial Gain					
ISO130P/ISO130U	–200mV < $V_{IN}+$ < 200mV	7.61	8.00	8.40	V/V
ISO130PB/ISO130UB	–200mV < $V_{IN}+$ < 200mV	7.85	7.93	8.01	V/V
Gain vs Temperature			10		ppm/°C
Gain vs V_{S1}			2.1		ppm/mV
Gain vs V_{S2}			–0.6		ppm/mV
Gain Nonlinearity					
for –200mV < $V_{IN}+$ < 200mV			0.2	0.35	%
for –100mV < $V_{IN}+$ < 100mV			0.1	0.25	%
vs Temperature(6)	–200mV < $V_{IN}+$ < 200mV		–0.001		% pts/°C
vs V_{S1}(6)	–200mV < $V_{IN}+$ < 200mV		–0.005		% pts/V
vs V_{S2} (6)	–200mV < $V_{IN}+$ < 200mV		–0.007		% pts/V

Ví dụ: 3652 Used in Patient Monitoring Application (ECG, EMG Amplifier).



BURR - BROWN®

3650
3652

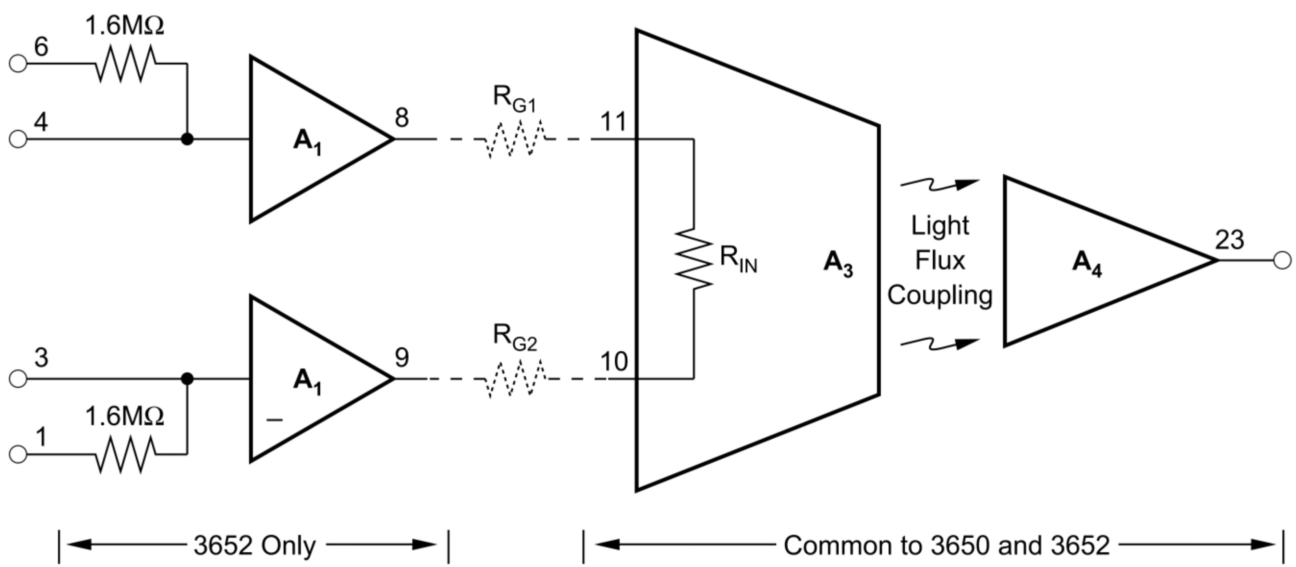
Optically-Coupled Linear ISOLATION AMPLIFIERS

FEATURES

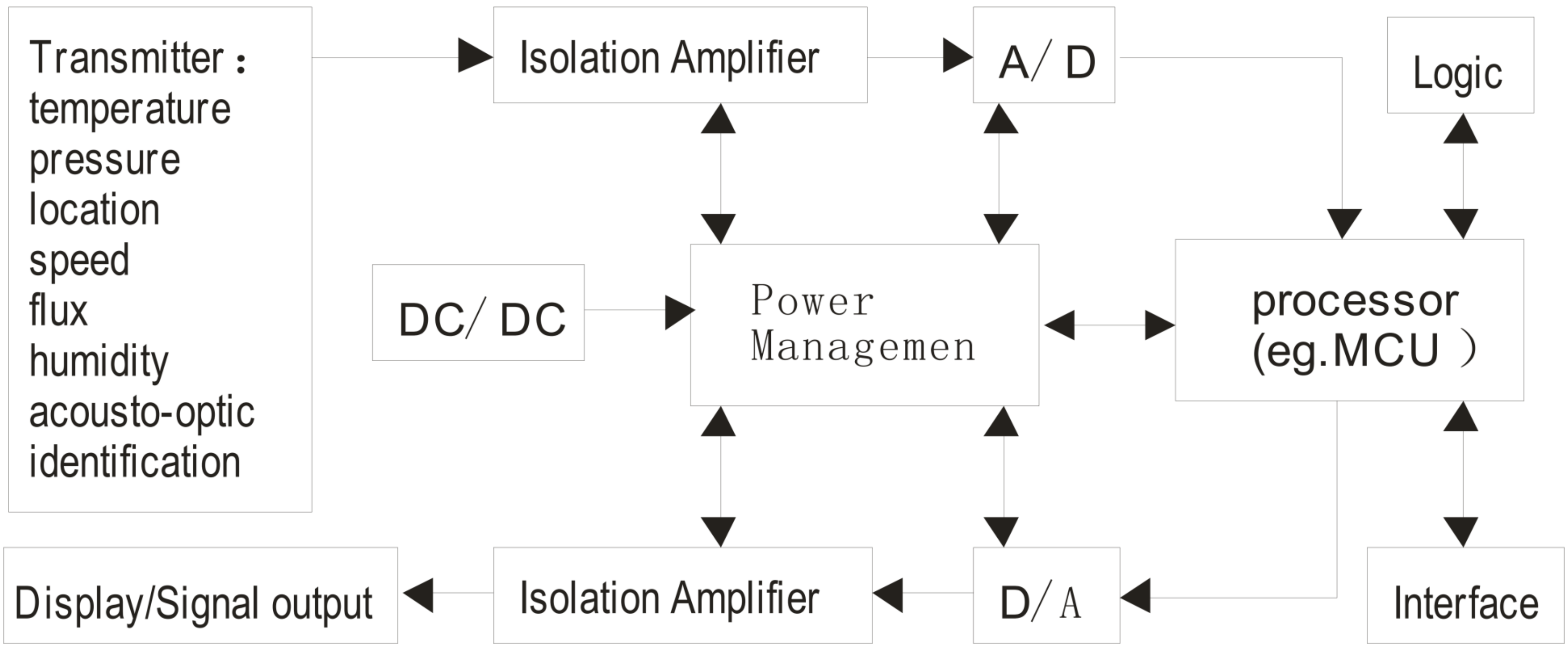
- BALANCED INPUT
- LARGE COMMON-MODE VOLTAGES:
  ±2000V Continuous
  140dB Rejection
- ULTRA LOW LEAKAGE:
  0.35µA max at 240V/60Hz
  1.8pF Leakage Capacitance
- EXCELLENT GAIN ACCURACY:
  0.05% Linearity
  0.05%/1000 Hrs Stability
- WIDE BANDWIDTH:
  15kHz ±3dB
  1.2V/µs Slew Rate

APPLICATIONS

- INDUSTRIAL PROCESS CONTROL
- DATA ACQUISITION
- INTERFACE ELEMENT
- BIOMEDICAL MEASUREMENTS
- PATIENT MONITORING
- TEST EQUIPMENT
- CURRENT SHUNT MEASUREMENT
- GROUND-LOOP ELIMINATION
- SCR CONTROLS



Một số ứng dụng

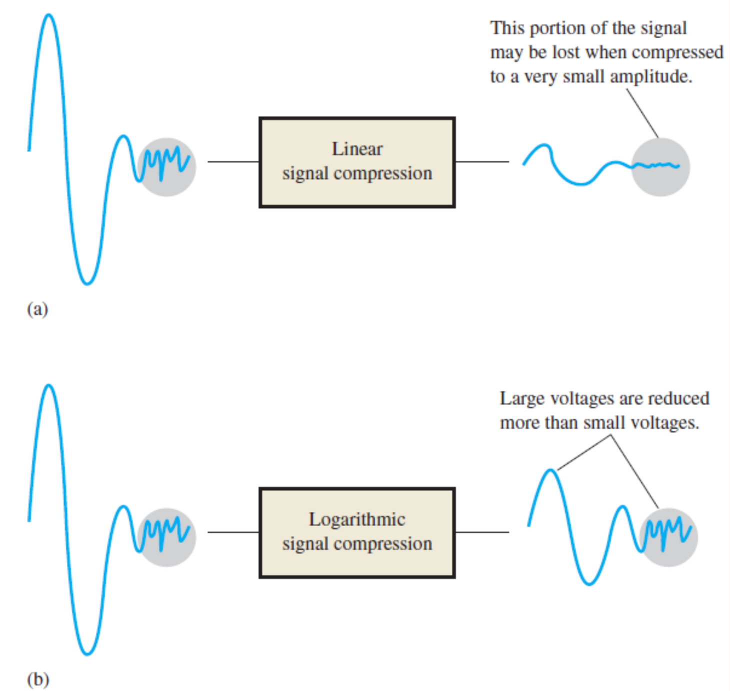


Khuếch đại logarit (logarithmic (log) amplifier)

Bộ khuếch đại logarit (logarithmic (log) amplifier) cho ngõ ra tỉ tệ với logarit của tín hiệu vào.

Bộ khuếch đại log và antilog được dùng trong những ứng dụng

- Nén dữ liệu analog.
- Tuyến tính hóa các cảm biến/bộ chuyển đổi (transducers) có ngõ ra là hàm mũ.
- Thực hiện phép nhân hay chia tín hiệu analog.

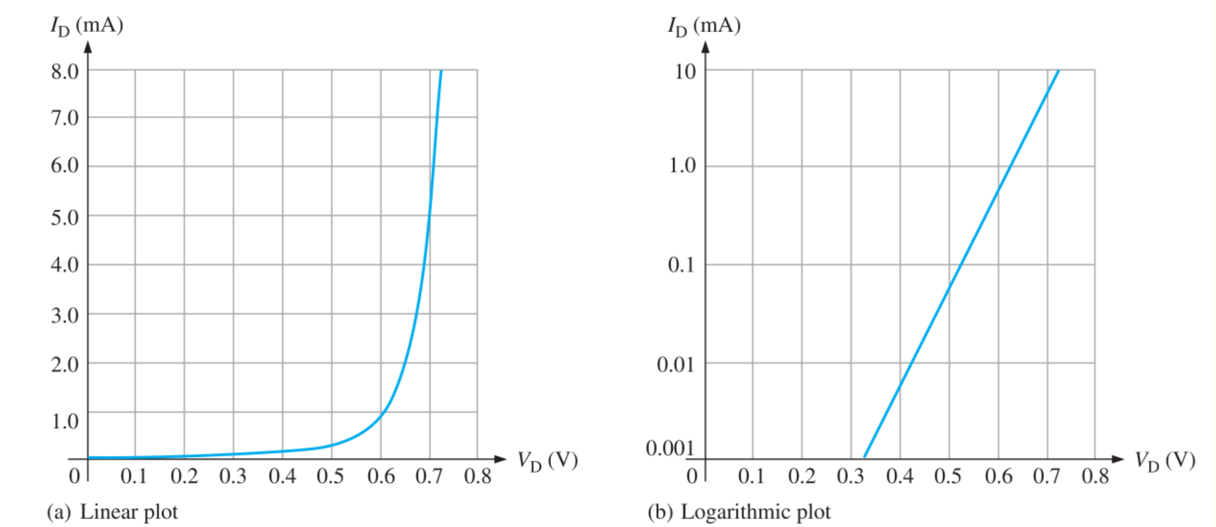


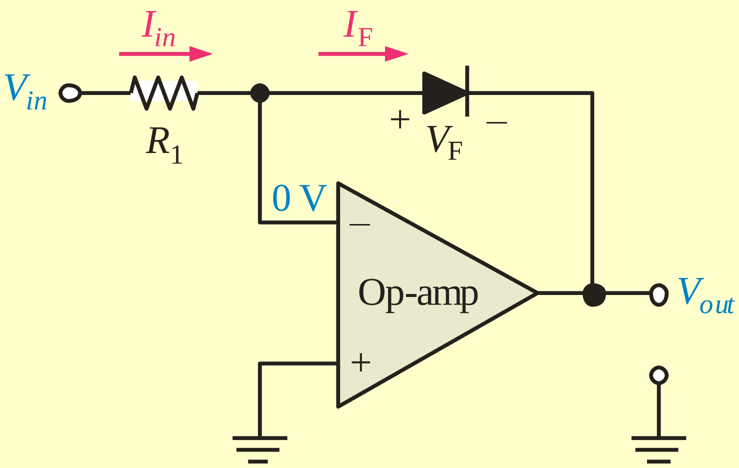
Thực hiện log amplifier

Diode

$$V_D = K \ln\left(\frac{I_D}{I_R}\right)$$

K: hằng số (=kT/q), ~ 25 mV ở 25 ^{0}C
I_R: dòng bão hòa ngược (dòng rò ngược)





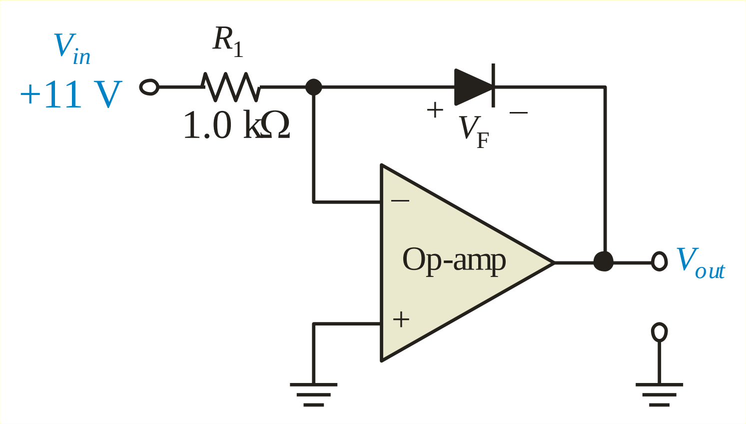
$$V_{out} = -V_F$$

$$I_F = I_{in} = \frac{V_{in}}{R_1}$$

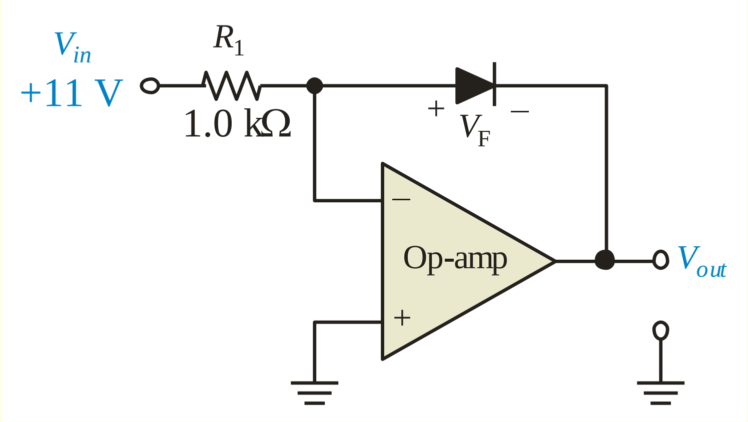
$$V_{out} = -\left(\frac{kT}{q}\right)\ln\left(\frac{V_{in}}{I_R R_1}\right)$$

$$V_{out} \cong -(0.025\ \text{V})\ln\left(\frac{V_{in}}{I_R R_1}\right)$$

What is V_{out}? (Assume I_R = 50 nA.)



What is V_{out}? (Assume I_R = 50 nA.)

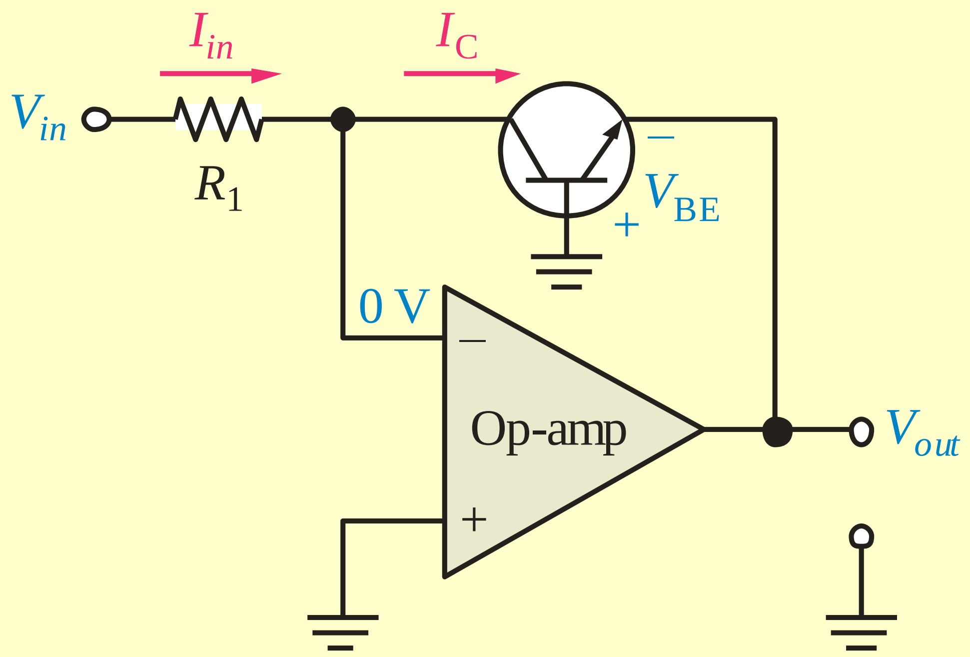


$$V_{out} \cong -(0.025\ \text{V})\ln\frac{V_{in}}{I_R R_1}$$

$$V_{out} \cong -(0.025\ \text{V})\ln\frac{11\ \text{V}}{(50\ \text{nA})(1.0\ \text{k}\Omega)}$$

= –307 mV

Khuếch đại log dùng BJT

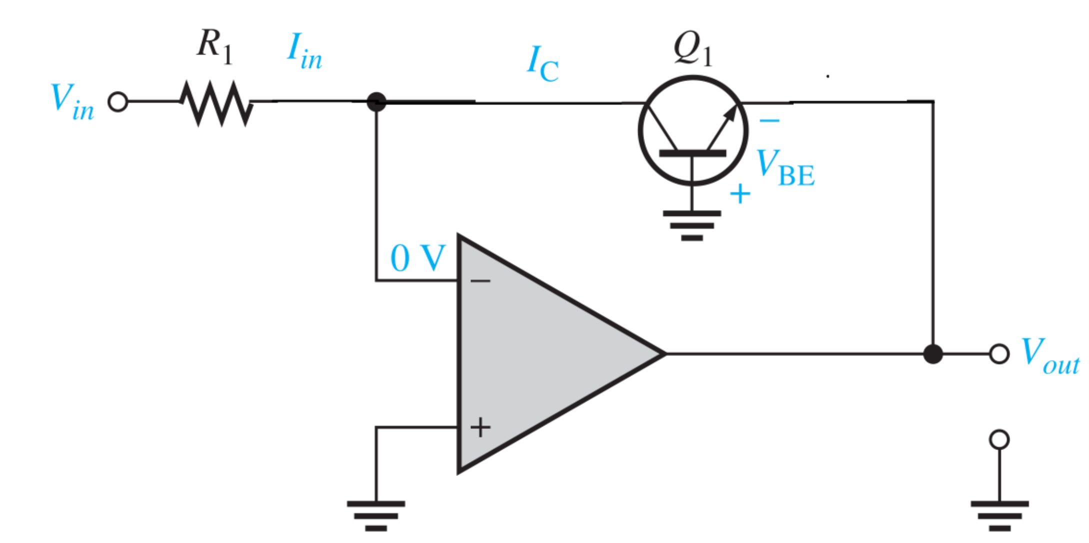


IC: MAX4206

$$V_{out} = -(0.025\ \text{V})\ln\left(\frac{V_{in}}{I_{EBO}R_1}\right)$$

I_{EBO} emitter-to-base leakage current

Ví dụ



V_{out} =? V_{in} = 3 V, R_1 = 68 kΩ?

Giả sử I_{EBO} = 40 nA

Solution

$$V_{out} = -(0.025\text{ V})\ln\left(\frac{V_{in}}{I_{\text{EBO}}R_1}\right)$$

$$V_{out} = -(0.025\text{ V})\ln\left(\frac{V_{in}}{I_{\text{EBO}}R_1}\right) = -(0.025\text{ V})\ln\left(\frac{3\text{ V}}{(40\text{ nA})(68\text{ k}\Omega)}\right)$$

$$= -(0.025\text{ V})\ln(1103) = \mathbf{-0.175\text{ V}}$$

Antilog

Định nghĩa: If log *x* = *y*, then antilog *y* = *x*.

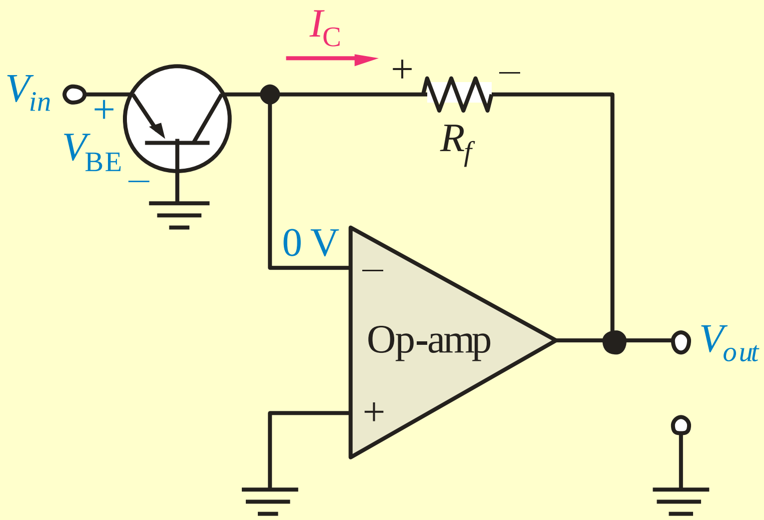
Mạch khuếch đại antilog tạo ra điện thế ở ngõ ra tỉ lệ với lũy thừa của điện thế ngõ vào. Nó là hàm đảo của hàm log.

$x = e^{\ln x}$ → $x = \text{antilog}_e (\ln x)$

Diode:

$$V_D = K \ln\left(\frac{I_D}{I_R}\right)$$

$$I_R = I_{EBO}$$



$$V_{in} = -K \ln\left(\frac{V_{out}}{I_{EBO} R_F}\right)$$

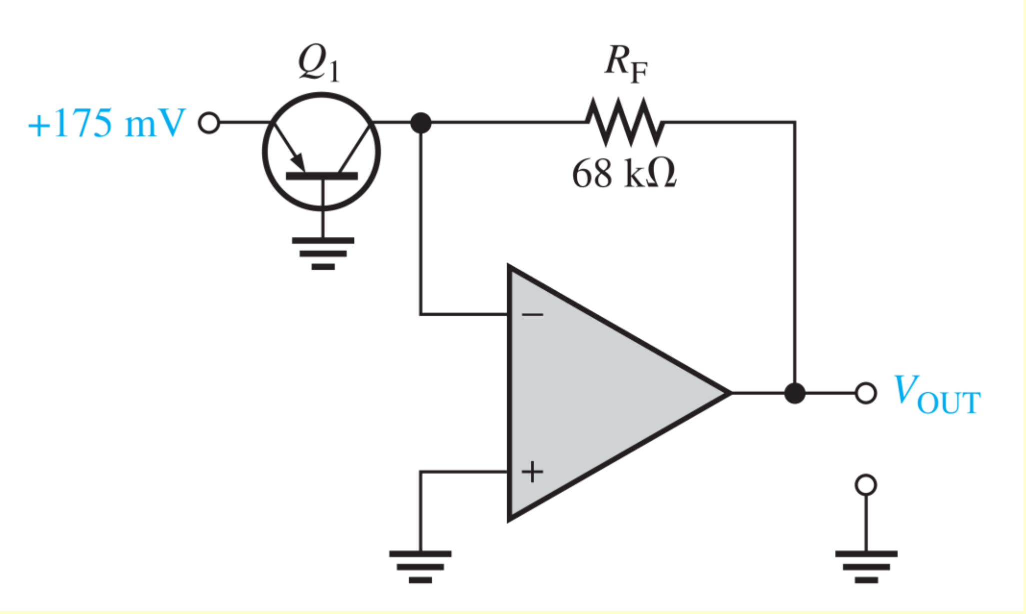
$$V_{out} = -I_{EBO} R_F e^{V_{in}/K}$$

$$V_{out} = -R_F I_{EBO} \text{antilog}_e \frac{V_{in}}{25 \text{ mV}}$$

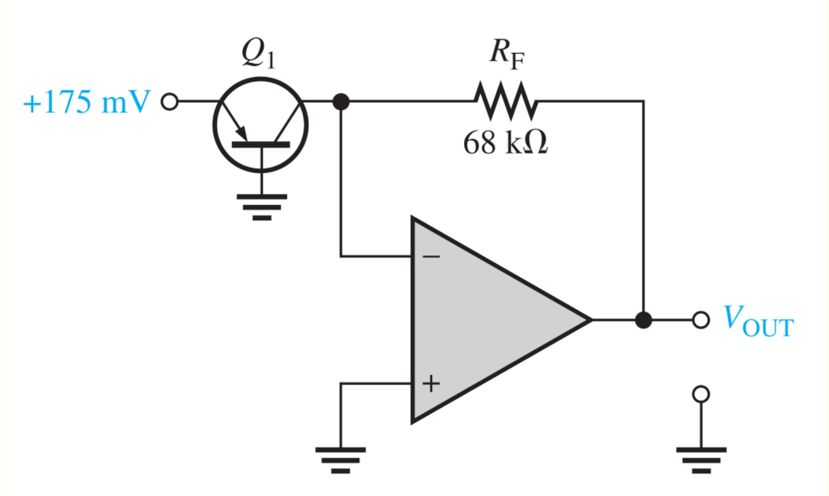
Ví dụ

LA-8048, LA-8049
Monolithic Log Amplifier
Monolithic Antilog Amplifier

Cho mạch antilog amplifier trong hình, tìm output voltage. Giả sử:
$I_{EBO} = 40$ nA.



Solution



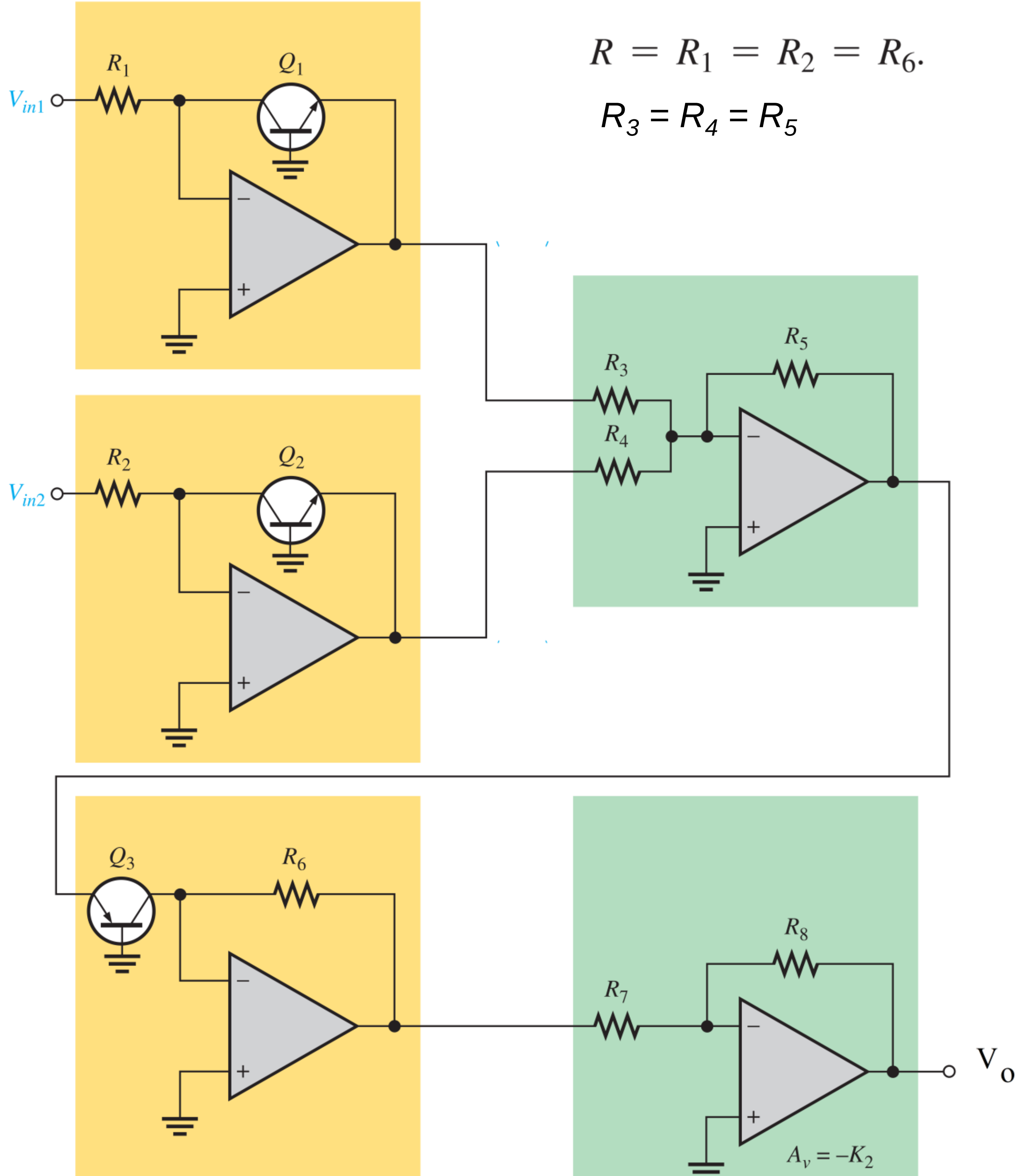
$$V_{OUT} \cong -I_{EBO}R_F \text{antilog}_e\left(\frac{V_{in}}{25\text{ mV}}\right) = -(40\text{ nA})(68\text{ k}\Omega)\text{antilog}_e\left(\frac{0.175\text{ V}}{25\text{ mV}}\right)$$

$$= -(40\text{ nA})(68\text{ k}\Omega)(1100) = \mathbf{-3\ V}$$

Bài tập: Tìm V_o

$R = R_1 = R_2 = R_6.$

$R_3 = R_4 = R_5$



$$\ln V_1 + \ln V_2 = \ln(V_1V_2)$$

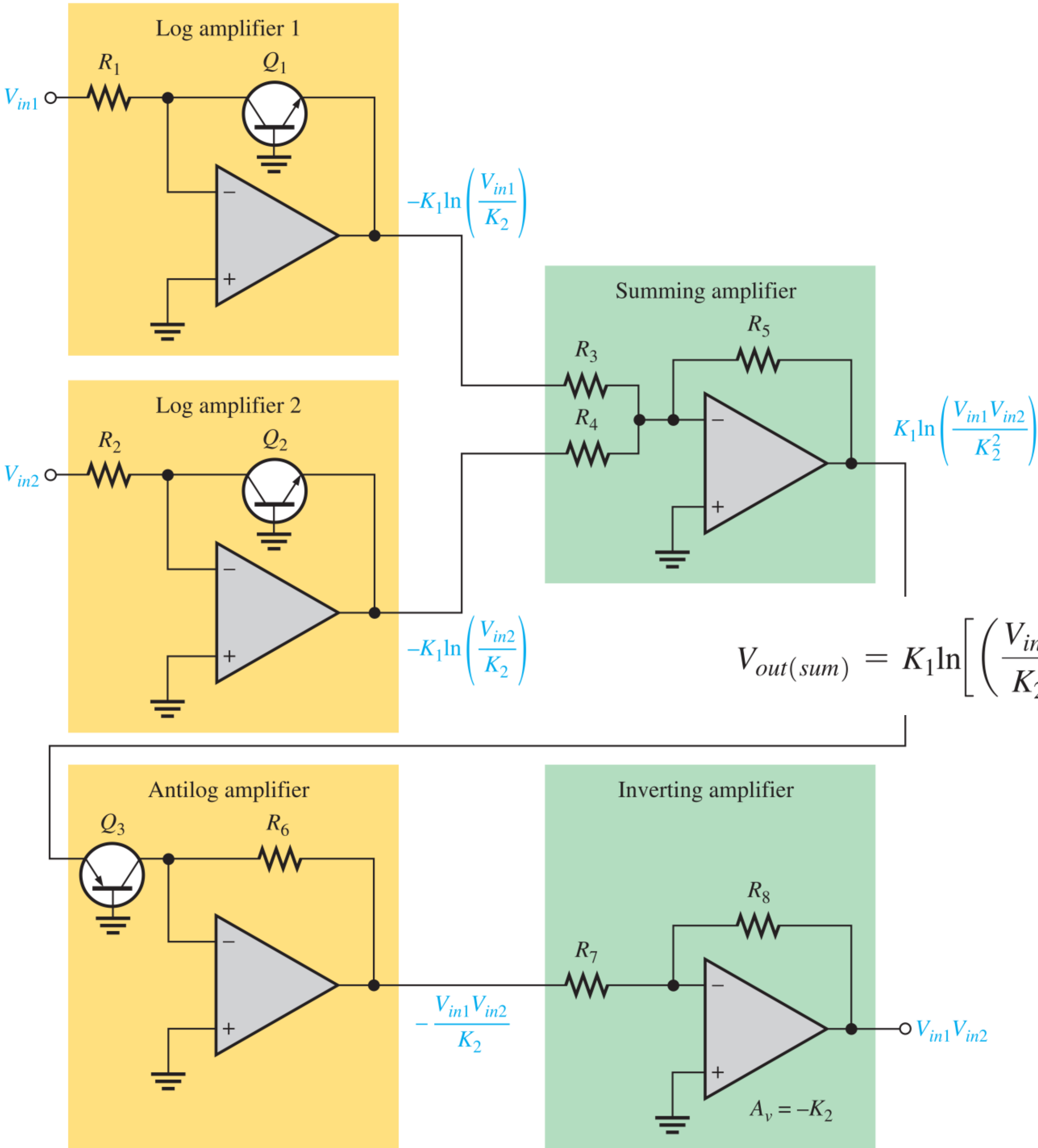
$$\text{antilog}_e[\ln(V_1V_2)] = V_1V_2$$

$$V_{out(log1)} = -K_1 \ln\left(\frac{V_{in1}}{K_2}\right)$$

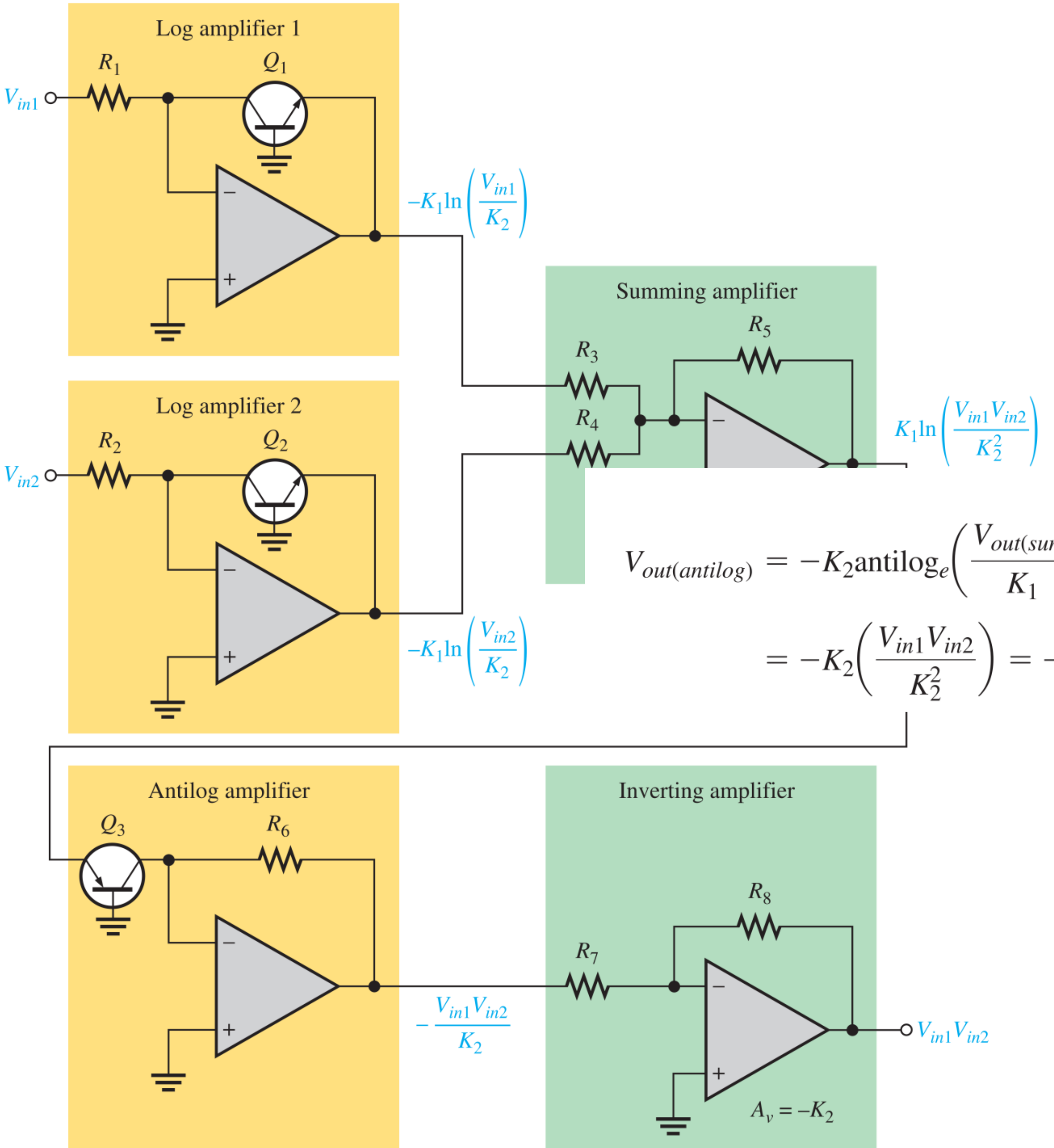
$$V_{out(log2)} = -K_1 \ln\left(\frac{V_{in2}}{K_2}\right)$$

$K_1 = 0.025$ V, $K_2 = RI_{EBO}$,

$R = R_1 = R_2 = R_6$.



$$V_{out(sum)} = K_1 \ln\left[\left(\frac{V_{in1}}{K_2}\right) + \ln\left(\frac{V_{in2}}{K_2}\right)\right] = K_1 \ln\left(\frac{V_{in1}V_{in2}}{K_2^2}\right)$$



$$V_{out(antilog)} = -K_2 \text{antilog}_e\left(\frac{V_{out(sum)}}{K_1}\right) = -K_2 \text{antilog}_e\left[\frac{K_1 \ln\left(\frac{V_{in1}V_{in2}}{K_2^2}\right)}{K_1}\right]$$

$$= -K_2\left(\frac{V_{in1}V_{in2}}{K_2^2}\right) = -\frac{V_{in1}V_{in2}}{K_2}$$

$$V_{out} = -K_2\left(-\frac{V_{in1}V_{in2}}{K_2}\right)$$

$$V_{out} = V_{in1}V_{in2}$$