

iTMO

Laboratory Work 2

Operational amplifiers circuits design and simulation

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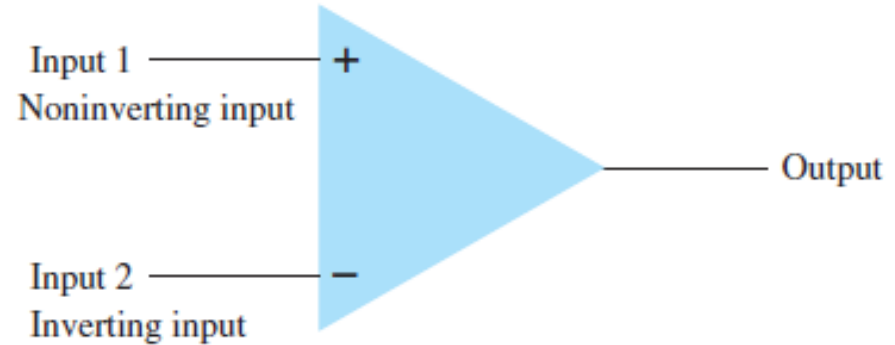
Arina Arbuzina

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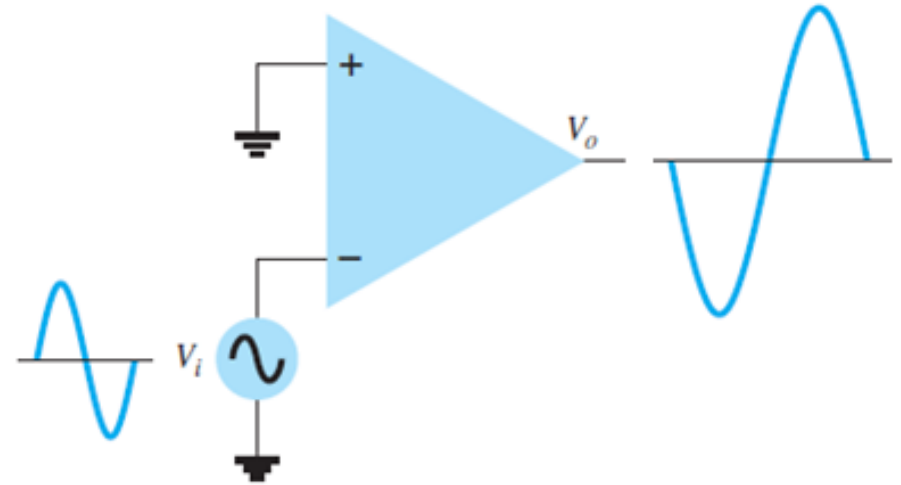
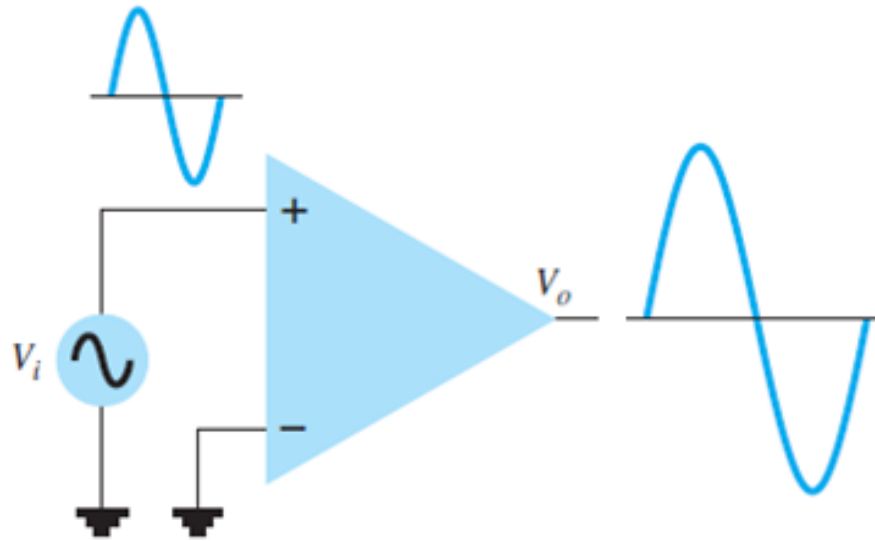
1. Operational amplifiers circuits theory review
2. Laboratory work 2: ideal and real amplifier comparison
3. Starting data analysis
4. Step 1: check of scheme gain
5. Step 2: check of scheme (time domain simulation)
6. Step 3: check of scheme (frequency domain simulation)
7. Results and conclusions
8. Uploading report

Double-ended input, Single-Ended output

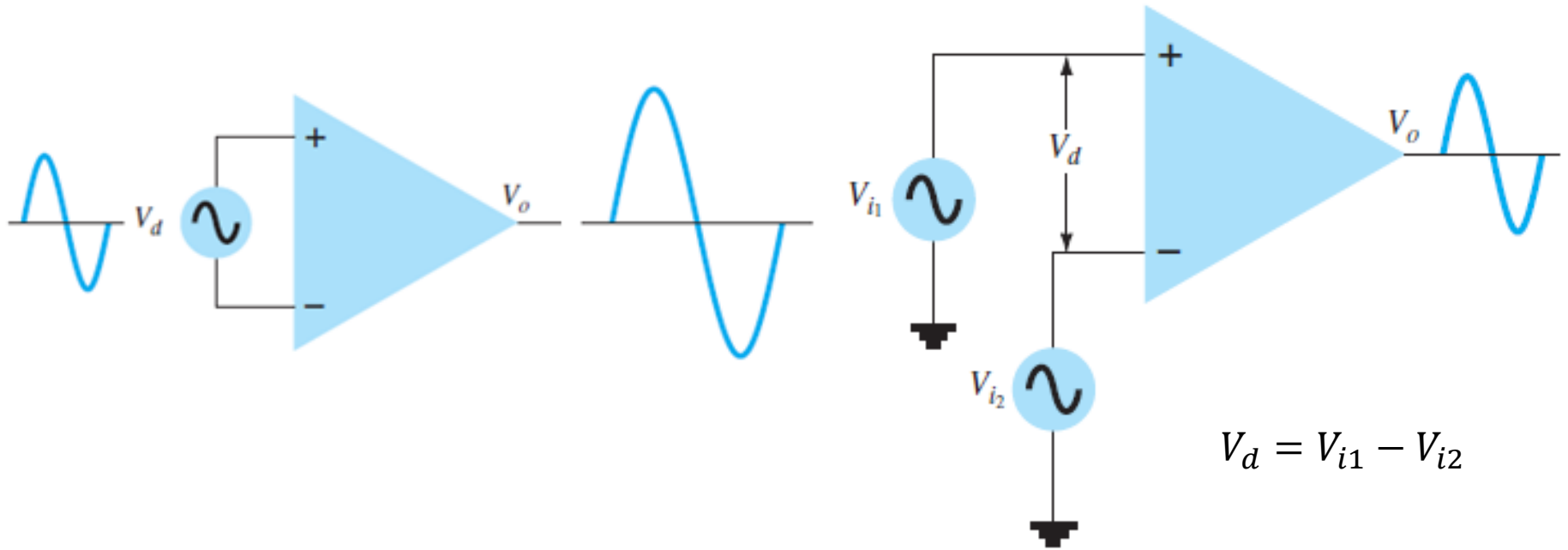
- ✓ Double-Ended (Differential) Input
- ✓ Common-Mode Operation



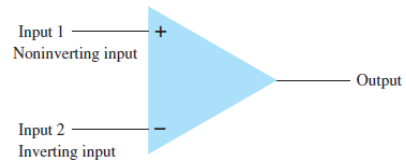
Single-Ended Input



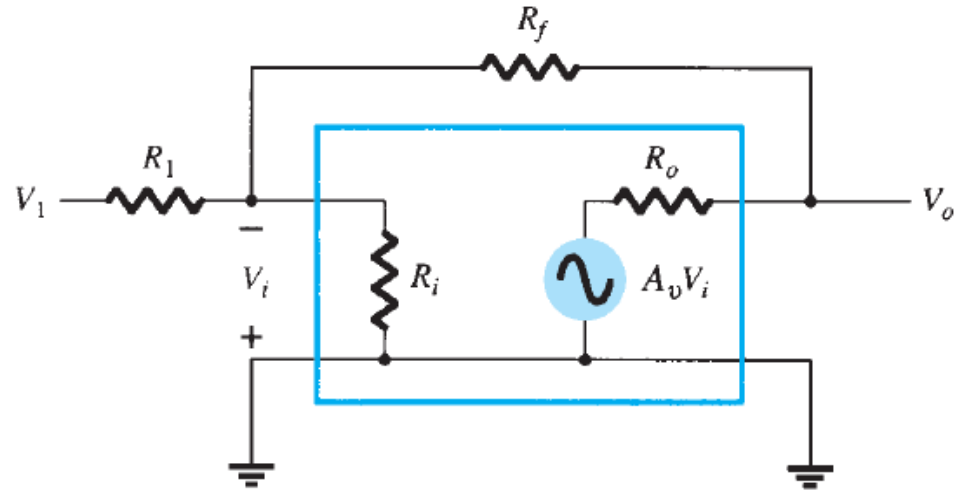
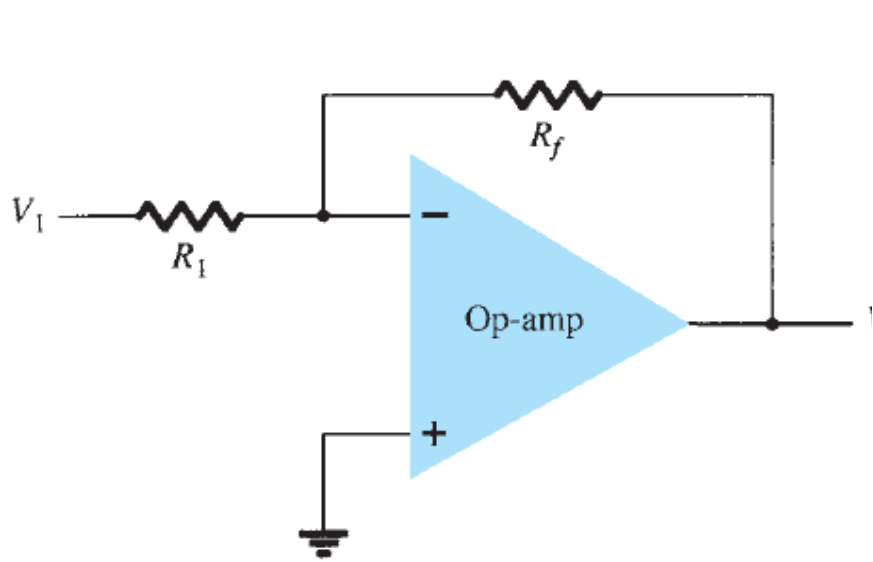
Double-Ended (Differential) Input



$$V_d = V_{i1} - V_{i2}$$

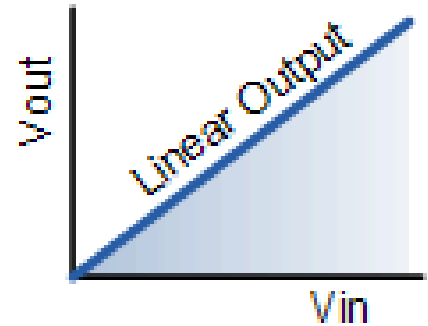


Inverting Amplifier

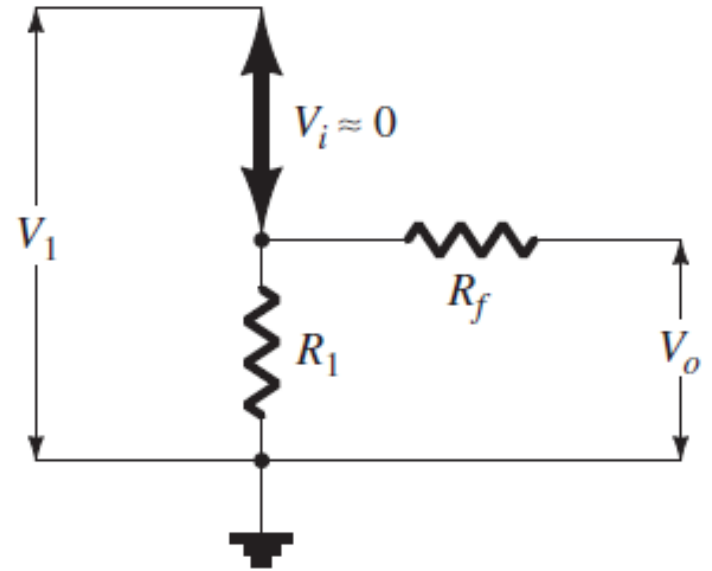
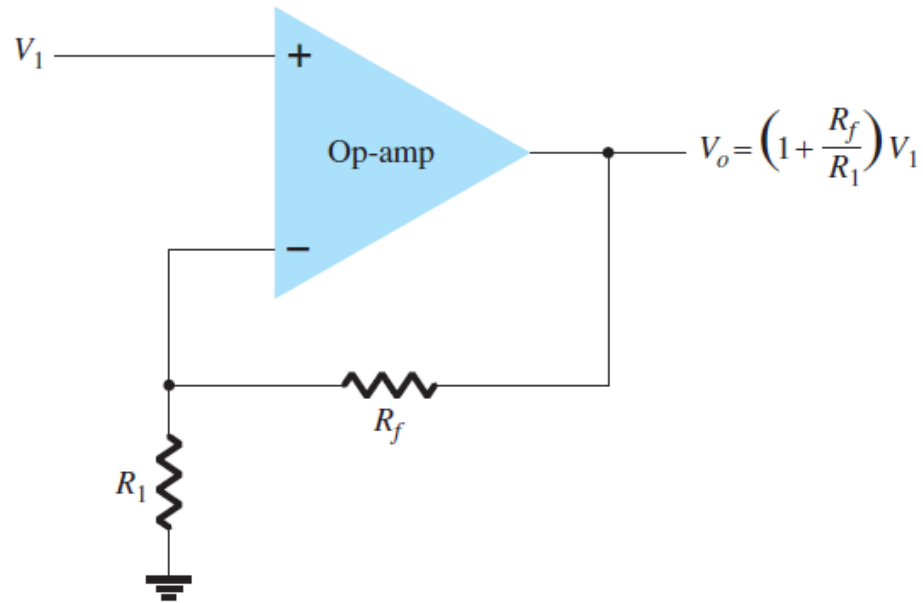


$$I_{R1} = I_{Rf} \Rightarrow V_o = -\frac{R_f}{R_1} V_i$$

$$A_d = \frac{V_o}{V_i} = -\frac{R_f}{R_1}$$



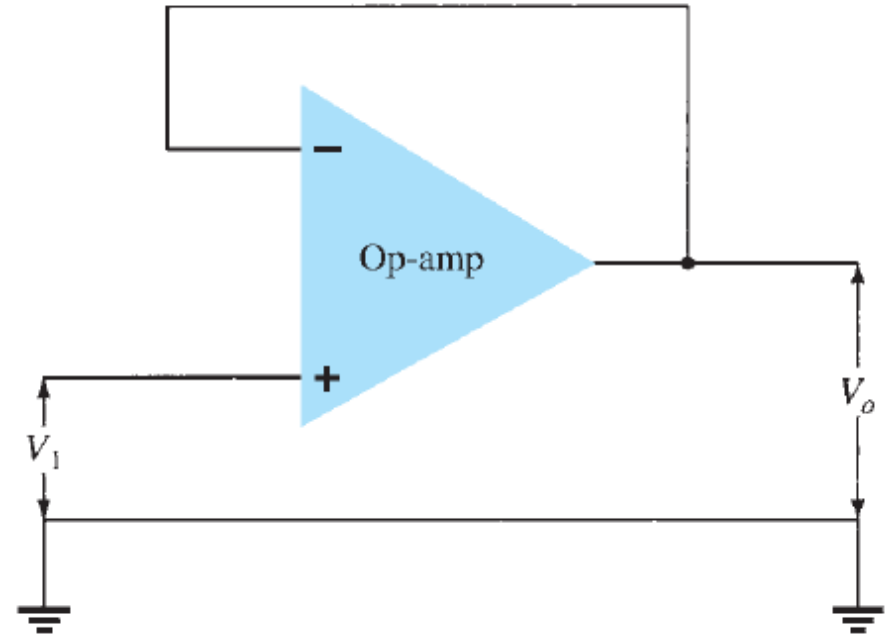
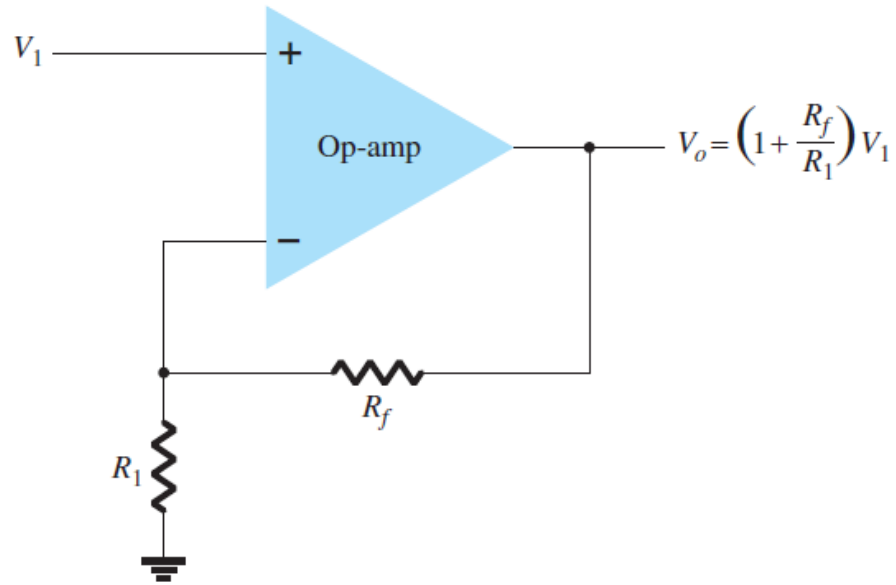
Noninverting Amplifier



$$\frac{V_o}{V_1} = \frac{R_1 + R_f}{R_1} = 1 + \frac{R_f}{R_1}$$

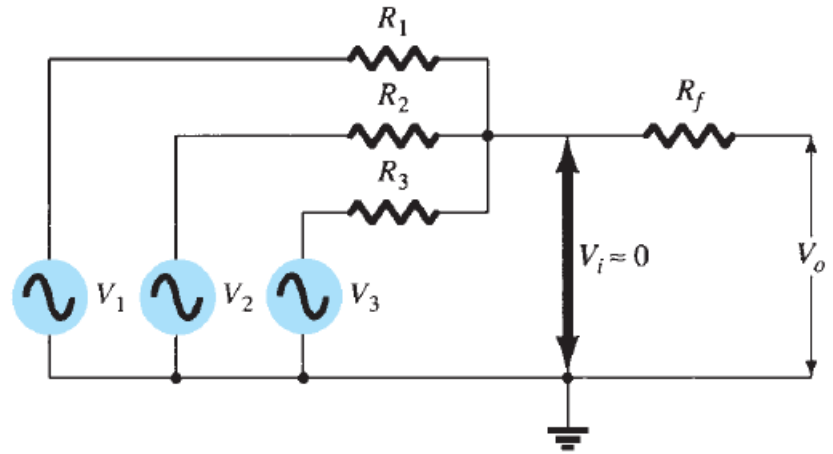
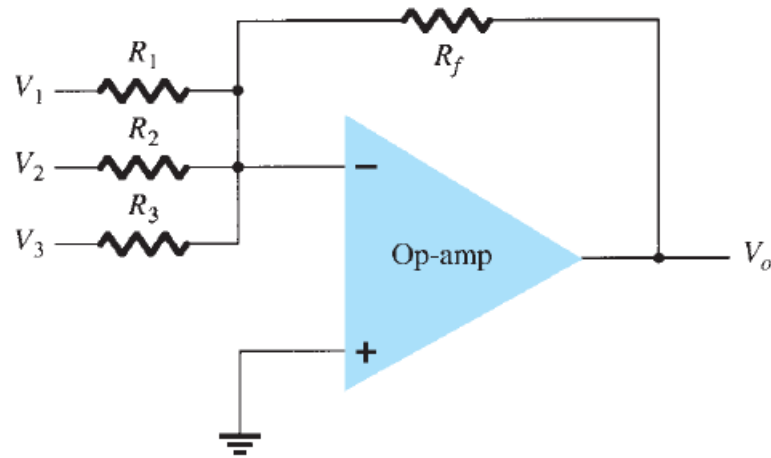
Inverting Amplifier	Non-inverting Amplifier
The feedback used in amplifier is voltage shunt or negative feedback	The type of feedback used in amplifier is voltage series or negative feedback
The output of this amplifier is inverted	The output of is in phase by the input signal
the reference voltage can be given to the inverting terminal	In this amplifier, the reference voltage can be given to the non-inverting terminal
The gain is $A_d = -\frac{R_f}{R_1}$	The gain is $A_d = 1 + \frac{R_f}{R_1}$
The voltage gain is $A_d \leq \geq 1$ (less than, greater than or equal)	The voltage gain is $A_d \geq 1$
The input impedance is R_1	The input impedance is very large

Unity Follower



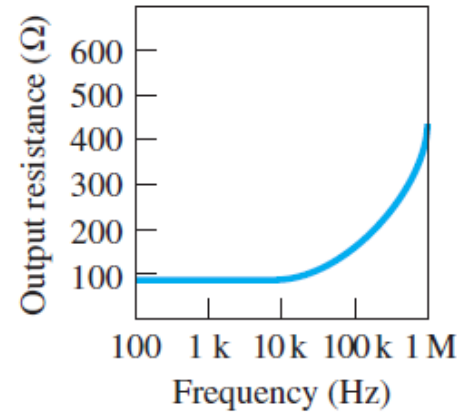
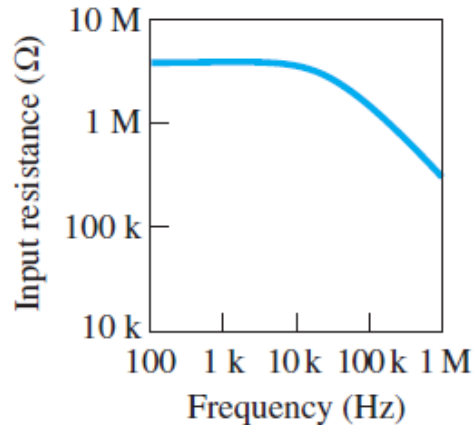
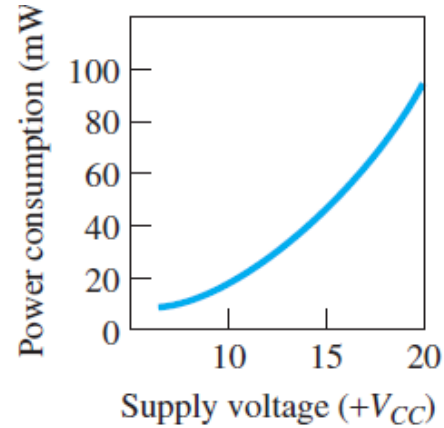
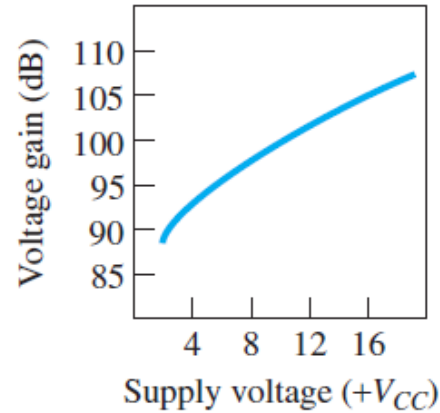
$$V_o = V_1$$

Summing Amplifier

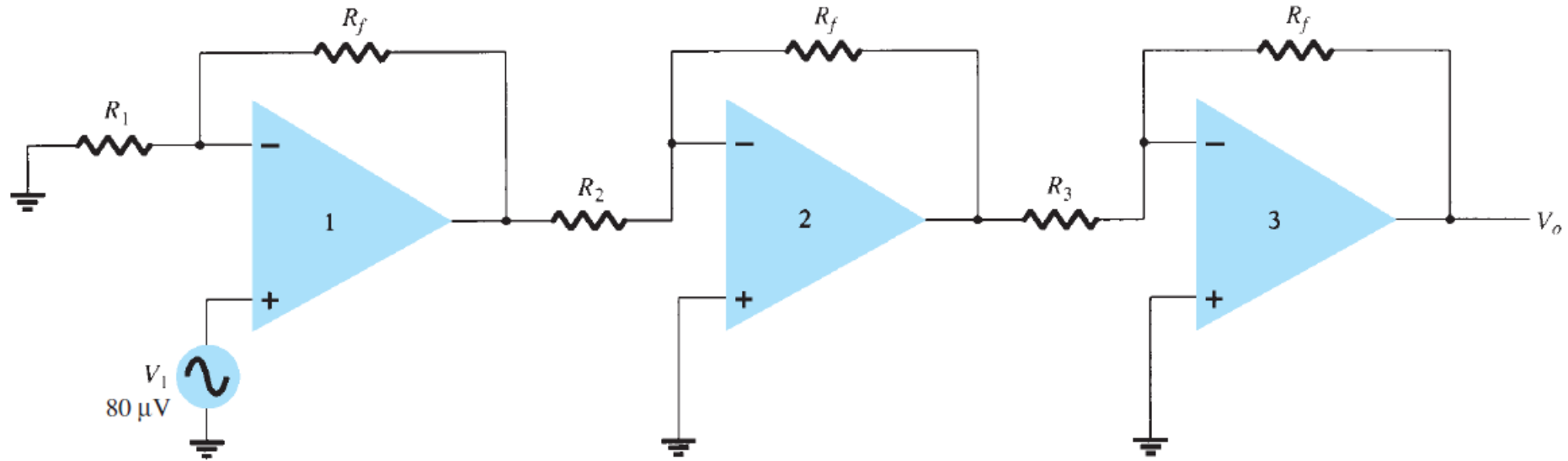


$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

Op-Amp Performance



Multiple-Stage Gains



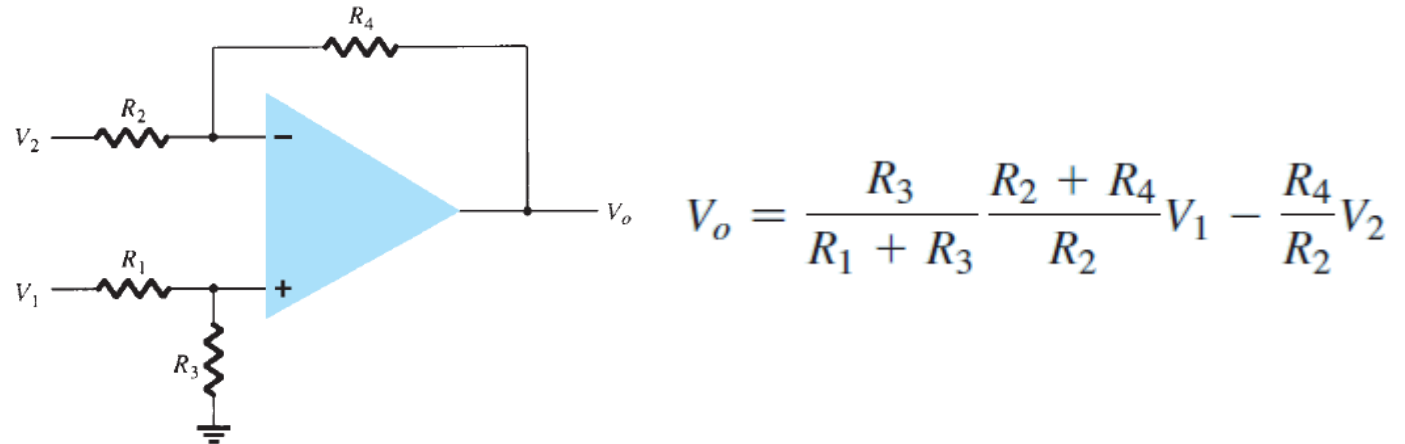
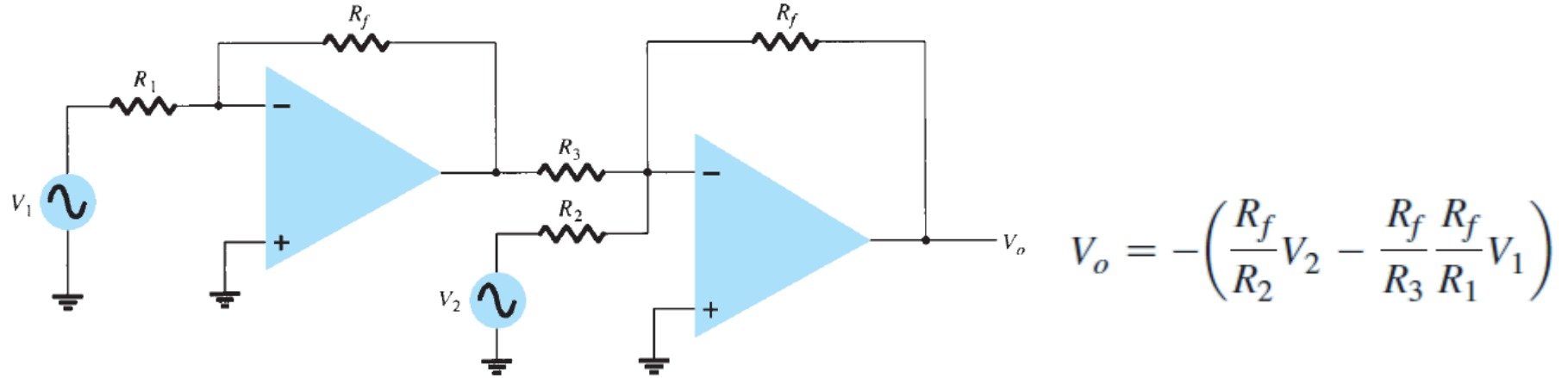
$$A_1 = 1 + \frac{R_f}{R_1}$$

$$A_2 = -\frac{R_f}{R_2}$$

$$A_3 = -\frac{R_f}{R_3}$$

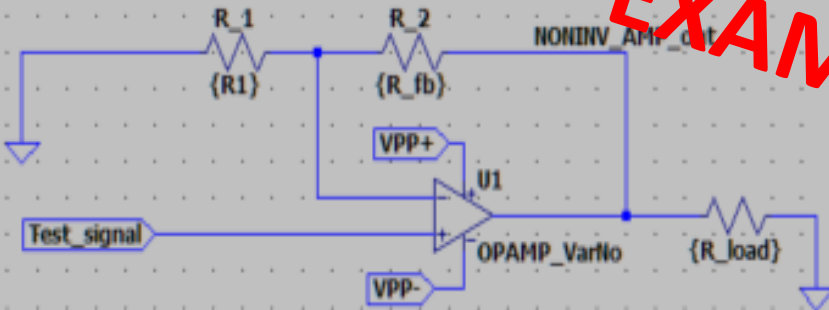
$$A = A_1 A_2 A_3$$

Voltage Subtractor

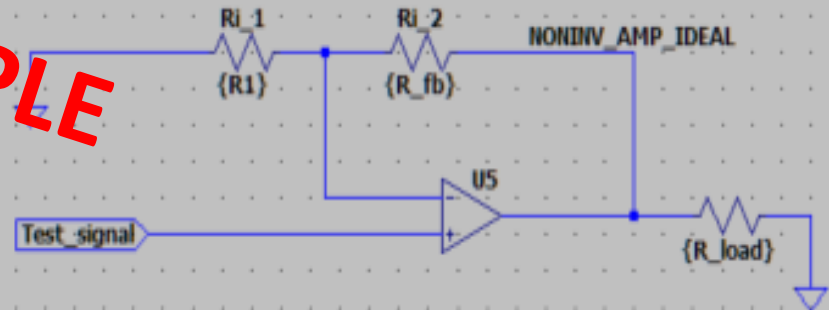


NON-INVERTING AMPLIFIER

REAL OPERATIONAL AMPLIFIER



IDEAL OPERATIONAL AMPLIFIER



EXAMPLE

Real operational amplifier:

- Limited by power supply (VPP+/VPP-)
- Limited real Operational amplifier open loop gain $K_{OL} \approx \frac{K_{NI}}{E_{NI}}$
- Limited frequency operation (unity gain frequency)

Ideal operational amplifier:

- Any output voltage
- Open loop gain $K_{OL} \rightarrow \infty$
- Good for circuit check

1. **Work purpose: to study parameters of Operational Amplifier and basis of Operational amplifiers circuits design**

Goals:

- 1) Design amplifier model on the basis of operational amplifier «Opamp_name»
- 2) Simulate amplifier scheme and analyze dependencies of output voltage from load and resistor values variation
- 3) Analyze time domain and frequency domain of amplifier
- 4) Simulate underpower state/power supply check

- **Required gain of amplifier** $K_{NI} = 4$
- **Required tolerance:** $\Delta K_{NIOPAMP} = 5\%$
- **Operational Amplifier :**
- **Voltage source power supply** $V_{PP+} = 3$ (V) / $V_{PP-} = 3$ (V)
- **Frequency for time domain simulation**

$$f_{test_1} = 500 \text{ (Hz)}$$

$$f_{test_2} = 5000 \text{ (Hz)}$$

$$f_{test_3} = 100000 \text{ (Hz)}$$

- **Test signal voltage magnitude**

$$V_{testAC} = V_{test} = 0,5 \text{ (V)}$$

- **Resistor parameters**

$$R_1 = 10000 \text{ } (\Omega)$$

$$R_{fb} = 10000 \text{ } (\Omega)$$

$$R_3 = 10000 \text{ } (\Omega)$$

$$R_4 = 10000 \text{ } (\Omega)$$

$$R_{Load} = 1\ 000\ 0000 \text{ } (\Omega)$$

- **Amplifier scheme:** Non-Inverting amplifier

- Required gain of amplifier $K_{NI} = 4$
- Required tolerance: $\Delta K_{NIOPAMP} = 5\%$
- Operational Amplifier :
- Voltage source power supply $V_{PP+} = 3$ (V) / $V_{PP-} = 3$ (V)
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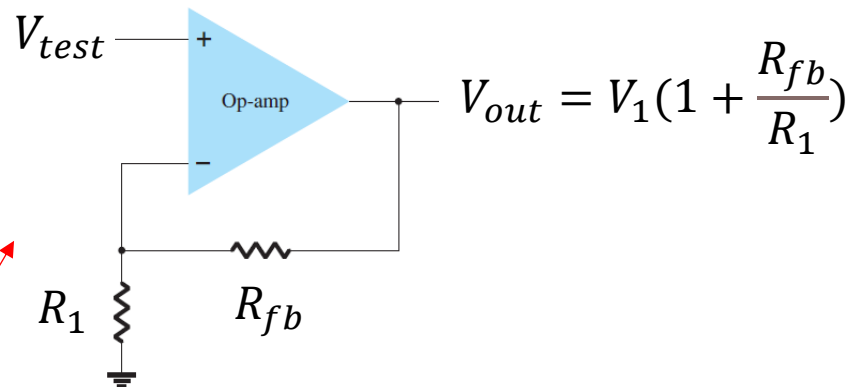
$$R_3 = 10000 \text{ (}\Omega\text{)}$$

$$R_4 = 10000 \text{ (}\Omega\text{)}$$

$$R_{Load} = 1\ 000\ 0000 \text{ (}\Omega\text{)}$$

- Amplifier scheme: Non-Inverting amplifier

Step 1: check of scheme gain



$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{10000}{10000} = 2$$

- Required gain of amplifier $K_{NI} = 4$
- Required tolerance: $\Delta K_{NIOPAMP} = 5\%$
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- Voltage source power supply $V_{PP+} = 3$ (V) / $V_{PP-} = 3$ (V)
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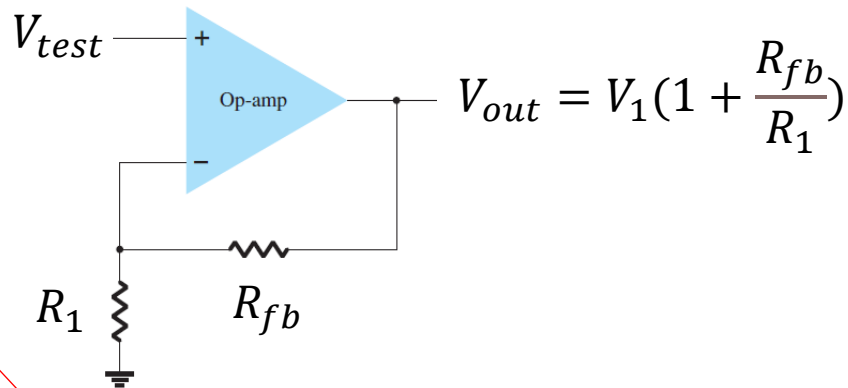
$$R_3 = 10000 \text{ } (\Omega)$$

$$R_4 = 10000 \text{ } (\Omega)$$

$$R_{Load} = 1\ 000\ 0000 \text{ } (\Omega)$$

- Amplifier scheme: Non-Inverting amplifier

Step 1: check of scheme gain



$$V_{out} = V_1 \left(1 + \frac{R_{fb}}{R_1} \right)$$

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{10000}{10000} = 2$$

Step 1: check of scheme gain

- Required gain of amplifier $K_{NI} = 4$
- Required tolerance: $\Delta K_{NIOPAMP} = 5\%$
- Operational Amplifier :
- Voltage source power supply $V_{PP+} = 3$ (V) / $V_{PP-} = 3$ (V)
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$$f_{test_3} = 100000 \text{ (Hz)}$$

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$$V_{test_AC} = V_{test} = 0,5 \text{ (V)}$$

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$$R_{fb} = 10000 \text{ (}\Omega\text{)}$$

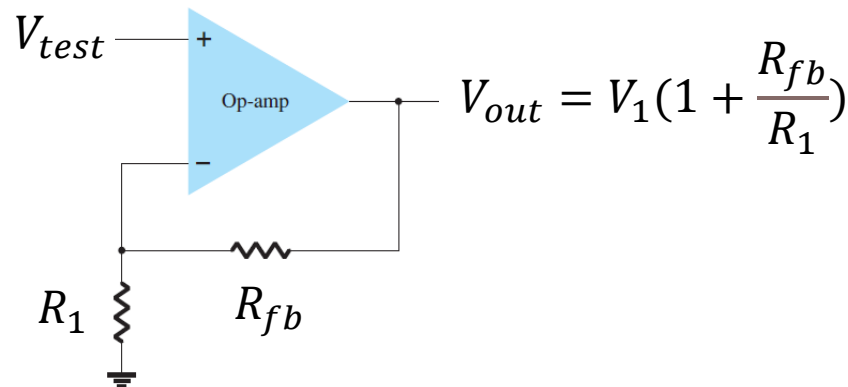
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$$R_{Load} = 1\,000\,0000 \text{ (}\Omega\text{)}$$

- Amplifier scheme: Non-Inverting amplifier

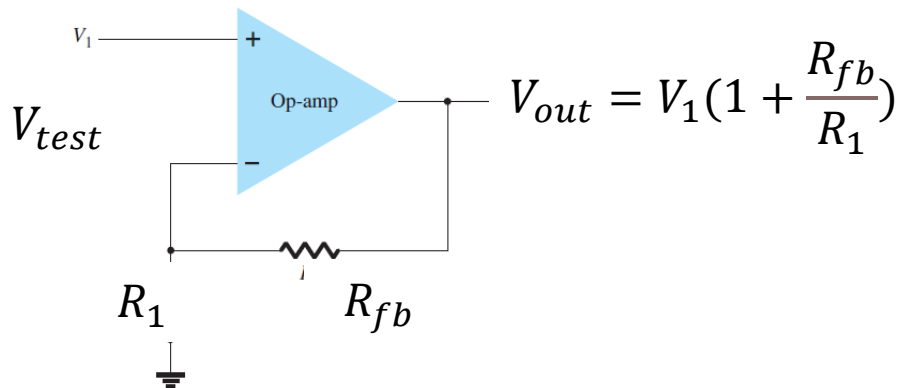
Step 1: check of scheme gain



New R_{fb} or/and new R_1 :

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

Step 1: check of scheme gain



$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

New R_{fb} or/and new R_1 with tolerance parameter:

- Required gain of amplifier $K_{NI} = 4$
- Required tolerance: $\Delta K_{NI_{OPAMP}} = 5\%$
- Operational Amplifier :
- Voltage source power supply $V_{PP+} = 3$ (V) / $V_{PP-} = 3$ (V)
- Frequency for time domain simulation

$$f_{test_1} = 500 \text{ (Hz)}$$

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- Test signal voltage magnitude

$$V_{test_AC} = V_{test} = 0,5 \text{ (V)}$$

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$$R_{Load} = 1\ 000\ 0000 \text{ } (\Omega)$$

- Amplifier scheme: Non-Inverting amplifier

Step 1: check of scheme gain

New R_{fb} or/and new R_1 :

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

New R_{fb} or/and new R_1 with tolerance parameter:

$$K_{NI_{max}} = 1 + \frac{R_{fb_{max}}}{R_{1_{min}}} = \frac{R_{fb}(1 + M)}{R_{1_{min}}(1 - M)} =$$

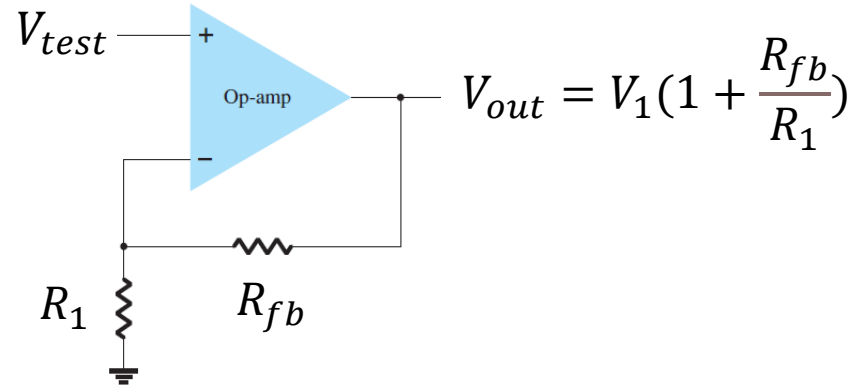
$$K_{NI_{min}} = 1 + \frac{R_{fb}(1 - M)}{R_{1_{min}}(1 + M)} =$$

Define maximum deviation from K_{NI} defined by resistance tolerance

$$E_{NI_{R+}} = \frac{K_{NI_{max}} - K_{NI}}{K_{NI}} =$$

$$E_{NI_{R-}} = \frac{K_{NI_{min}} - K_{NI}}{K_{NI}} =$$

Step 1: check of scheme gain



Step 1: check of scheme gain

New R_{fb} or/and new R_1 :

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

New R_{fb} or/and new R_1 with tolerance parameter:

$$K_{NI_{max}} = 1 + \frac{R_{fb_{max}}}{R_{1_{min}}} = \frac{R_{fb}(1 + M)}{R_{1_{min}}(1 - M)} =$$

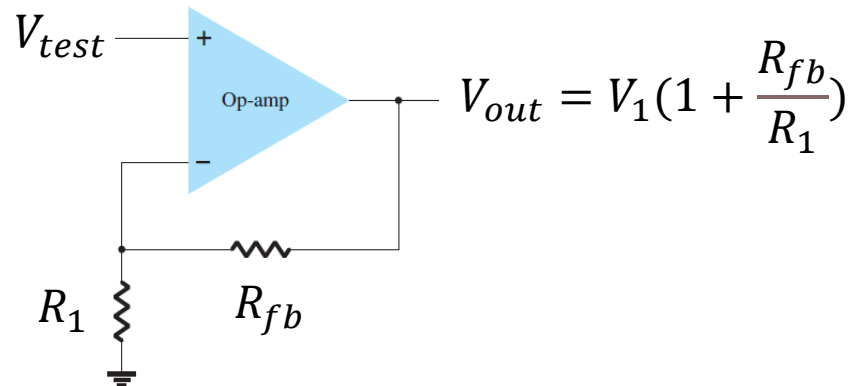
$$K_{NI_{min}} = 1 + \frac{R_{fb}(1 - M)}{R_{1_{min}}(1 + M)} =$$

Define maximum deviation from K_{NI} defined by resistance tolerance

$$E_{NI_{R+}} = \frac{K_{NI_{max}} - K_{NI}}{K_{NI}} =$$

$$E_{NI_{R-}} = \frac{K_{NI_{min}} - K_{NI}}{K_{NI}} =$$

Step 1: check of scheme gain



TECHNICAL SPECIFICATIONS						
DESCRIPTION	TNPW0201 e3	TNPW0402 e3	TNPW0603 e3	TNPW0805 e3	TNPW1206 e3	TNPW1210 e3
Imperial size	0201	0402	0603	0805	1206	1210
Metric size code	RR0603M	RR1005M	RR1608M	RR2012M	RR3216M	RR3225M
Resistance range	22 Ω to 40 kΩ	10 Ω to 100 kΩ	1 Ω to 332 kΩ	1 Ω to 1 MΩ	1 Ω to 2 MΩ	10 Ω to 3.01 MΩ
Resistance tolerance	± 0.5 %; ± 0.1 %					
Temperature coefficient	± 25 ppm/K; ± 50 ppm/K; ± 25 ppm/K; ± 15 ppm/K; ± 10 ppm/K					
Rated dissipation, $P_{70}^{(1)}$	0.075 W	0.100 W	0.125 W	0.200 W	0.400 W	0.500 W
Operating voltage, U_{max} AC/RMS or DC	25 V	50 V	75 V	150 V	200 V	200 V

$M = 0,01$ for 1%

Step 1: check of scheme gain

New R_{fb} or/and new R_1 with tolerance param:

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

TECHNICAL SPECIFICATIONS						
DESCRIPTION	TNPW0201 e3	TNPW0402 e3	TNPW0603 e3	TNPW0805 e3	TNPW1206 e3	TNPW1210 e3
Imperial size	0201	0402	0603	0805	1206	1210
Metric size code	RR0603M	RR1005M	RR1608M	RR2012M	RR3216M	RR3225M
Resistance range	22 Ω to 40 kΩ	10 Ω to 100 kΩ	1 Ω to 332 kΩ	1 Ω to 1 MΩ	1 Ω to 2 MΩ	10 Ω to 3.01 MΩ
Resistance tolerance	± 0.5 %; ± 0.1 %		± 1 %; ± 0.5 %; ± 0.1 %			
Temperature coefficient	± 25 ppm/K		± 50 ppm/K; ± 25 ppm/K; ± 15 ppm/K; ± 10 ppm/K			
Rated dissipation, $P_{70}^{(1)}$	0.075 W	0.100 W	0.125 W	0.200 W	0.400 W	0.500 W
Operating voltage, U_{max} , AC RMS or DC	25 V	50 V	75 V	150 V	200 V	200 V

$$M = 0,01 \text{ for } 1\%$$

New R_{fb} or/and new R_1 :

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

New R_{fb} or/and new R_1 with tolerance parameter:

$$K_{NI_{max}} = 1 + \frac{R_{fb_{max}}}{R_{1_{min}}} = \frac{R_{fb}(1 + M)}{R_{1_{min}}(1 - M)} =$$

$$K_{NI_{min}} = 1 + \frac{R_{fb_{min}}}{R_{1_{max}}} = 1 + \frac{R_{fb}(1 - M)}{R_{1_{min}}(1 + M)} =$$

Define maximum deviation from K_{NI} defined by resistance tolerance

$$E_{NI_{R+}} = \left| \frac{K_{NI_{max}} - K_{NI}}{K_{NI}} \right| =$$

$$E_{NI_{R-}} = \left| \frac{K_{NI_{min}} - K_{NI}}{K_{NI}} \right| =$$

- Required gain of amplifier $K_{NI} = 4$
 - Required tolerance: $\Delta K_{NIOPAMP} = 5\%$
 - Operational Amplifier :
 - Voltage source power supply $V_{PP+} = 3$ (V) / $V_{PP-} = 3$ (V)
 - Frequency for time domain simulation
- $f_{test_1} = 500$ (Hz)
 $f_{test_2} = 5000$ (Hz)
 $f_{test_3} = 100000$ (Hz)
- Test signal voltage magnitude
- $V_{testAC} = V_{test} = 0,5$ (V)
- Resistor parameters
- $R_1 = 10000$ (Ω)
 $R_{fb} = 10000$ (Ω)
 $R_3 = 10000$ (Ω)
 $R_4 = 10000$ (Ω)
 $R_{Load} = 1\ 000\ 0000$ (Ω)
- Amplifier scheme: Non-Inverting amplifier

$$K_{NI_{max}} = 1 + \frac{R_{fbmax}}{R_{1min}} = \frac{R_{fb}(1 + M)}{R_{1min}(1 - M)} =$$

$$K_{NI_{min}} = 1 + \frac{R_{fb}(1 - M)}{R_{1min}(1 + M)} =$$

Define maximum deviation from K_{NI} defined by resistance tolerance

$$E_{NI_{R+}} = \left| \frac{K_{NI_{max}} - K_{NI}}{K_{NI}} \right| = (\text{should be less then } 5\%)$$

$$E_{NI_{R-}} = \left| \frac{K_{NI_{min}} - K_{NI}}{K_{NI}} \right| = (\text{should be less then } 5\%)$$

$$\Delta K_{NIOPAMP} = \max \text{ of } E_{NI_{R+}} \text{ and } E_{NI_{R-}}$$

Step 1: check of scheme gain

New R_{fb} or/and new R_1 with tolerance param:

$$K_{NI} = 1 + \frac{R_{fb}}{R_1} = 1 + \frac{33000}{11000} = 4$$

- **Required tolerance** : $\Delta K_{NIOPAMP} = 5\%$

$$K_{NI_{max}} = 1 + \frac{R_{fb_{max}}}{R_{1_{min}}} =$$

$$K_{NI_{min}} = 1 + \frac{R_{fb_{min}}}{R_{1_{max}}} =$$

Define maximum deviation from K_{NI} defined by resistance tolerance

$$E_{NI_{R+}} = \left| \frac{K_{NI_{max}} - K_{NI}}{K_{NI}} \right| = \text{(should be less then 5\%)}$$

$$E_{NI_{R-}} = \left| \frac{K_{NI_{min}} - K_{NI}}{K_{NI}} \right| = \text{(should be less then 5\%)}$$

Real Operational amplifier open loop gain $K_{OL} \approx \frac{K_{NI}}{E_{NI}}$

Step 2: check of scheme (time domain simulation)

- Setting up resistor tolerance:
- Providing simulations:

$$f_{test_1} = 500 \text{ (Hz)}$$

$$f_{test_2} = 5000 \text{ (Hz)}$$

$$f_{test_3} = 100000 \text{ (Hz)}$$

Step 3: check of scheme (frequency domain simulation)

- setting up resistor tolerance R_{fb} and new R_1
- setting up resistor load resistance variation R_{load} **list:** 100, 1000, 10000, 100000 (Ω)

Step 4: Power supply check

- V_{pp+} and V_{pp-} should have enough values

	Ideal	VarNo	Ideal	VarNo	Ideal	VarNo
frequency, kHz	500		5000		50000	
$V_{\text{test}}, \text{V}$						
V_{out}, V						
$K_{\text{NI_exp}}$						
$\Delta K_{\text{NIOPAMP}}$						
$E_{\text{NI}_{\text{max}}}$						
$E_{\text{NI}_{\text{min}}}$						
$K_{\text{OL}} \approx \frac{K_{\text{NI}}}{\Delta K_{\text{NIOPAMP}}}$						

Real Operational amplifier open loop gain $K_{\text{OL}} \approx \frac{K_{\text{NI}}}{E_{\text{NI}}}$

Conclusions should contain:

- 1) Is it possible to realize amplifier with defined gain and gain tolerance?
- 2) In which range can be load resistance R_{Load} variated
- 3) How was operational amplifier power supply modified?

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<https://clck.ru/32eHHL>

1st deadline: 04.11.2023 10:00 (GMT +8)

Task	Deadline #1 (extra score)	Deadline #2 (No extra score)	Deadline #3 (No extra score)
	The results will be published before 15.11.2024	The results will be published before 20.11.2024	The results will be published with the results of the final test (final scores)
Lab 1, Practice 1	28.10.24 10:00	11.11.24 10:00	20.11.24 10:00
Practice 2	28.10.24 22:00	11.11.24 10:00	20.11.24 10:00
Lab 2	04.11.24 10:00	11.11.24 10:00	20.11.24 10:00
Practice 3	04.11.24 10:00	11.11.24 10:00	20.11.24 10:00
Lab 3	11.11.24 10:00	15.11.24 10:00	20.11.24 10:00
Practice 4	11.11.24 10:00	15.11.24 10:00	20.11.24 10:00





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