

1.5 Ideal operational amplifiers

Name: _____ Class: _____ Date: _____

Total: 21 marks

KEY WORDS operational amplifier

• negative feedback

• virtual short

• saturation

• ideal operational amplifier

• inverting amplifier

Objective

Analyse ideal op-amp circuits with negative feedback using the two golden rules, compute inverting and non-inverting gains, and recognise when saturation ends the linear story.

1 Key knowledge and worked examples

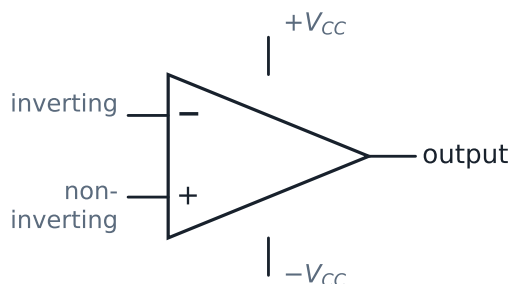
■ The ideal op-amp and its golden rules

An **operational amplifier** amplifies the difference between its + and – inputs. The **ideal operational amplifier** has infinite open-loop gain, infinite input resistance and zero output resistance. With **negative feedback** from output to the – input, two rules hold:

1. No current flows into either input.
2. The input difference is zero – a **virtual short** : the – input sits at whatever voltage the + input has.

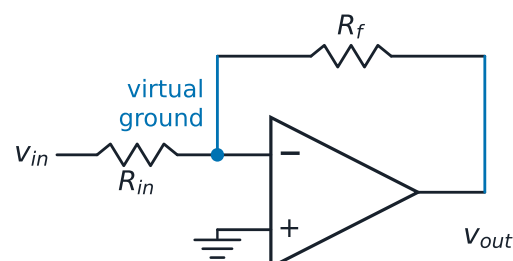
Saturation : the output cannot leave the supply rails (a ± 15 V op-amp stops near ± 13 – 14 V). Beyond that, rule 2 is false and linear answers are invalid.

Five terminals



ideal: infinite gain,
infinite input resistance

Inverting amplifier



the – node sits at 0 V, so
all of v_{in}/R_{in} flows through R_f

■ Worked example: the inverting amplifier

Input through R_{in} to the $-$ node, feedback through R_f , $+$ grounded. The $-$ node is at 0 V (virtual short), so the input current v_{in}/R_{in} flows entirely through R_f :

$$\frac{v_{out}}{v_{in}} = -\frac{R_f}{R_{in}}$$

With $R_{in} = 10k\Omega$ and $R_f = 100k\Omega$: gain -10 , and $v_{in} = 0.2V$ gives $v_{out} = -2V$ – inside ± 15 V, so the linear model stands. The feedback current $0.2/10k = 20\mu A$ is supplied by the output, not the input.

■ Worked example: non-inverting stage and a saturation trap

Signal at $+$; feedback divider R_f over R_{in} at $-$. The $-$ node must equal v_{in} , so $v_{out} = v_{in}(1 + R_f/R_{in})$ – always at least unity. With $R_{in} = 10k\Omega$, $R_f = 30k\Omega$: gain 4, and 0.5 V in gives 2 V out.

Now demand gain -100 ($R_f = 1M\Omega$, $R_{in} = 10k\Omega$) with $v_{in} = 0.3V$: the linear answer is -30 V, but ± 15 V rails stop the output near -14 V. The correct statement is “the output saturates”, not “the output is -30 V”.

2 Practice

2.1 An inverting amplifier has $R_{in} = 4.7k\Omega$ and $R_f = 47k\Omega$. State the gain, and the output for $v_{in} = +0.15V$. [3]

2.2 A non-inverting amplifier has $R_{in} = 10k\Omega$ (to ground) and $R_f = 30k\Omega$. State the gain and the output for $v_{in} = 0.5V$. [3]

2.3 An inverting amplifier with gain -100 receives $v_{in} = 0.3V$; the supplies are ± 15 V. Give the output the linear model predicts, the actual output, and the condition under which the linear model would be trustworthy. [3]

3 Exam-style questions

3.1 Design an inverting stage with gain -6 using $R_{in} = 10k\Omega$, stating the feedback resistor. For $v_{in} = 1.2V$ (peak), compute the output, check it against ± 15 V rails, and compute the feedback current. Then explain why the input source sees an input resistance of exactly R_{in} . [6]

3.2 Two cascaded inverting stages use ideal op-amps with ± 15 V supplies: stage 1 has $R_{in} = 10k\Omega$, $R_f = 20k\Omega$; stage 2 has $R_{in} = 15k\Omega$, $R_f = 45k\Omega$.

Compute each gain and the overall gain. For $v_{in} = 0.4V$, give the voltage at each stage output, verify neither stage saturates, and state why the virtual short applies to both stages. [6]
