4.2 The Non-inverting Amplifier

A non-inverting amplifier is shown in Fig 4.5 where an input signal V_{in} is applied directly to the non-inverting input (+). Negative feedback is applied by means of resistors R_f and R_1.

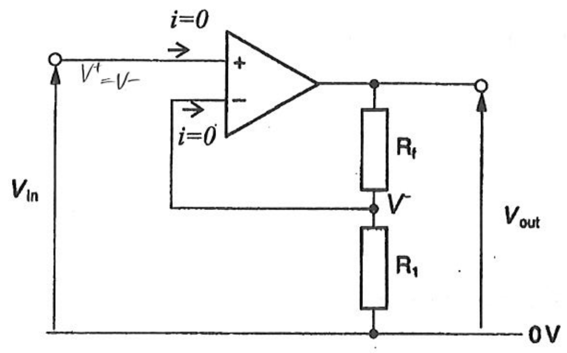


Fig 4.5

Using the same reasoning as the case of the inverting amplifier,

(i) the potential of $V^+ \approx V^-$ if the output is not saturated;

(ii) Little current flows through the amplifier.

The non-inverting input is equal to V_{in}:

$$V^+ = V_{in}$$

whereas the inverting input (-) is given by the potential divider formula

$$V^- = \frac{R_1}{R_1 + R_f} V_{out}$$

Equating $V^+ \approx V^-$ and rearranging,

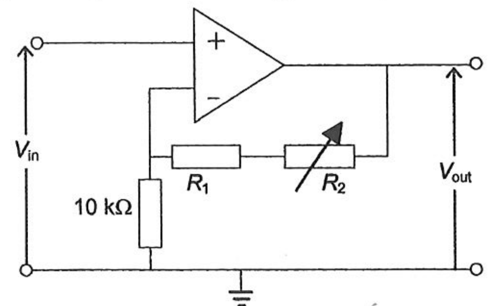
$$\boxed{\text{voltage gain} = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}}$$

Always positive as R always positive

Note that the non-inverting amplifier produces an output voltage which is *in phase* with the input voltage, hence the name non-inverting amplifier.

Example 6 [N85/III/6]

The figure below illustrates the circuit for a non-inverting voltage amplifier. What are the values of R_1 and R_2 such that the gain may be set at any value between 5 and 10?



$A = 1 + \frac{R_1 + R_2}{10}$

As R_2 increase, gain increase

Min gain, set $R_2 = 0$,

$5 = 1 + \frac{R_1}{10}$

$R_1 = 40\,k\Omega$

Max gain, set R_2 to full value

$10 = 1 + \frac{40 + R_2}{10}$

$R_2 = 50\,k\Omega$

5. Frequency response

Figure 5.1 shows a circuit which could be used to measure the open-loop gain of a real operational amplifier at a number of different frequencies. An oscilloscope could be used to measure the input and output voltages.

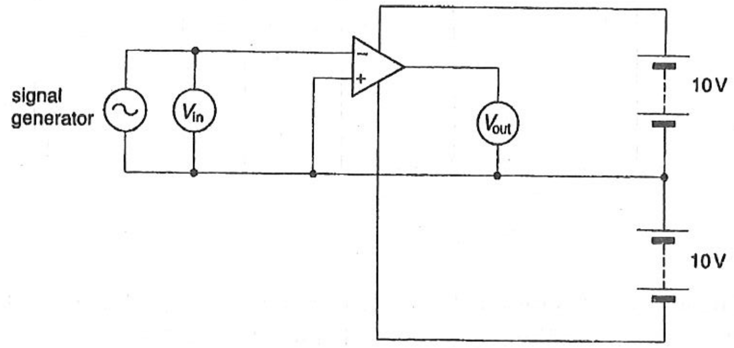
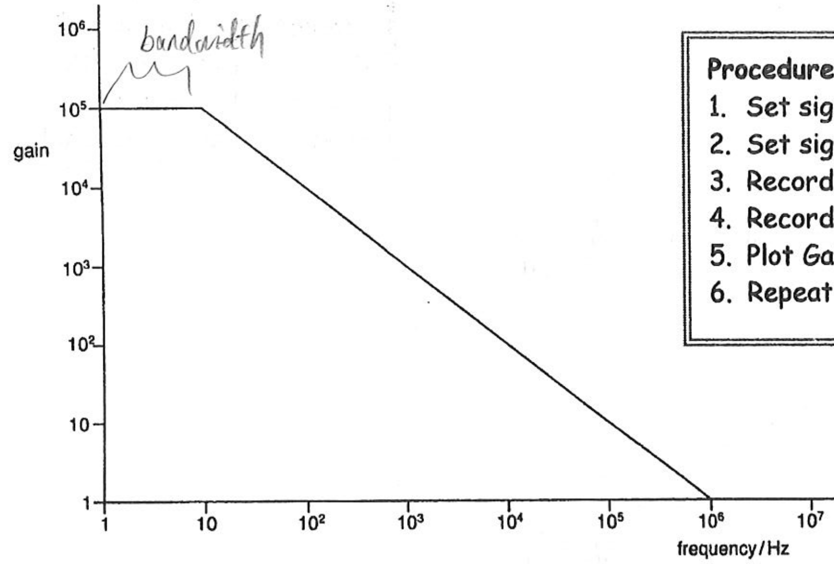


Fig 5.1

The signal generator would be set to the frequency required and then its output would have to be adjusted to an extremely low value. This is because the open loop gain of the op-amp might be as high as 10^5 and if it is not to saturate (the gain of an amplifier can only be measured if it is not saturated), then the input voltage must be less than the (maximum op-amp output voltage) $\div 10^5 \approx$ $10\text{ V} \div 10^5 \approx 0.1\text{ mV}$.

Figure 5.2 shows the variation with frequency of the open-loop gain for a typical op-amp. The graph is said to show the frequency response of the amplifier.



Procedure:

1. Set signal generator voltage = 0.1 mV.
2. Set signal generator frequency = 1 Hz.
3. Record op-amp peak Vin.
4. Record op-amp peak Vout.
5. Plot Gain = Vout / Vin.
6. Repeat 2-4, for other frequencies.

f/Hz	V_{in}/mV	V_{out}/V	$\frac{V_{out}}{V_{in}}$
1	0.1	10	10^5
10	0.1	10	10^5
100	0.1	1	10^4

Fig 5.2

This plot reveals that a real op-amp in open-loop mode does not amplify all frequencies equally. The range of frequencies for which the *gain is more or less constant* is known as the *bandwidth* of the amplifier. Thus, the bandwidth of an op-amp in open-loop mode is limited to the range from d.c. (i.e. extremely low frequency a.c.) to about 10 Hz.

> bandwidth, equipment is better as signal not distorted over large range of f

Figure 5.3 shows the circuits required for the determination of the frequency response curve for an op-amp in *closed-loop mode* (i.e. with negative feedback applied). As noted in **Section 3**, the overall gain of the amplifier has been reduced by the application of negative feedback.

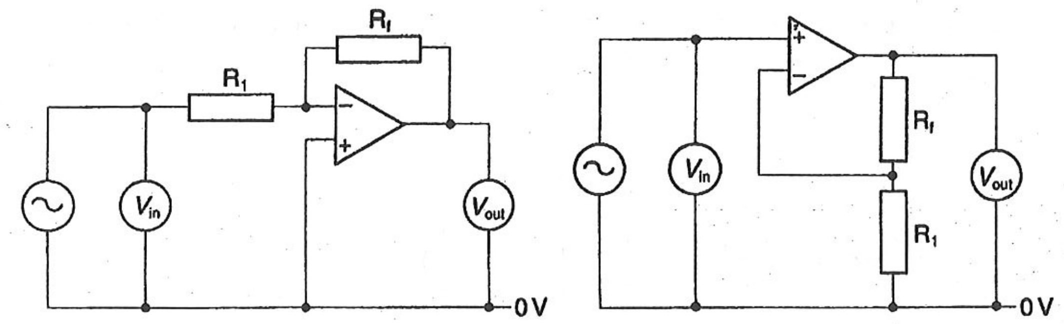


Fig 5.3

It should also be noted that, in both circuits of Fig 5.3, it is a simple matter to set the overall gain of the amplifier by suitable adjustment of the resistance ratio R_f/R_1 (see **Section 4**).

Figure 5.4 shows frequency response curves for the amplifier circuits of Fig 5.3 for three different settings of the voltage gain (both amplifiers produce the same frequency response).

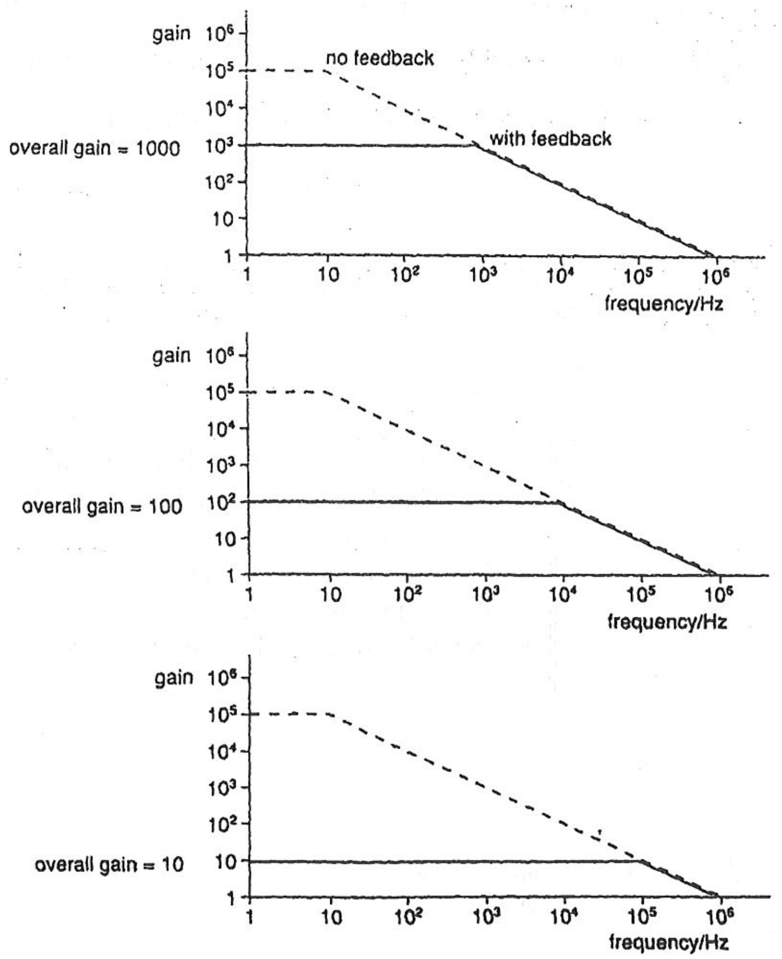


Fig 5.4

Gain-Bandwidth Product
For a particular op-amp, the product of its "gain" and "bandwidth" is constant.
Eg.
The op-amp used in Fig 5.4 has a gain-bandwidth product of 10^6. As the gain decrease, the bandwidth increases. However, the product remains the same!

Example 4 (N93/II/5)

An ideal operational amplifier is used in the circuit shown in Fig 4.4 with a constant input of 0.50 V and power supplies of +6.0 V and -6.0 V.

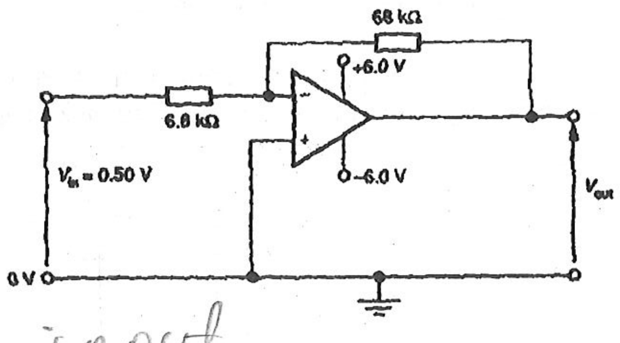


Fig 4.4

(a) State, with reason, the type of feedback used in the amplifier circuit.

Negative. Output is channeled back to the inverting input.

(b) Calculate the gain of this amplifier circuit.

$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1} = -\frac{68}{6.8} = -10$

(c) What is the output voltage V_{out}?

$V_{out} = -10 V_{in} = -5.0 V$

(c) The constant input is then changed from 0.50 V to a sinusoidal alternating voltage of RMS value 0.50 V.

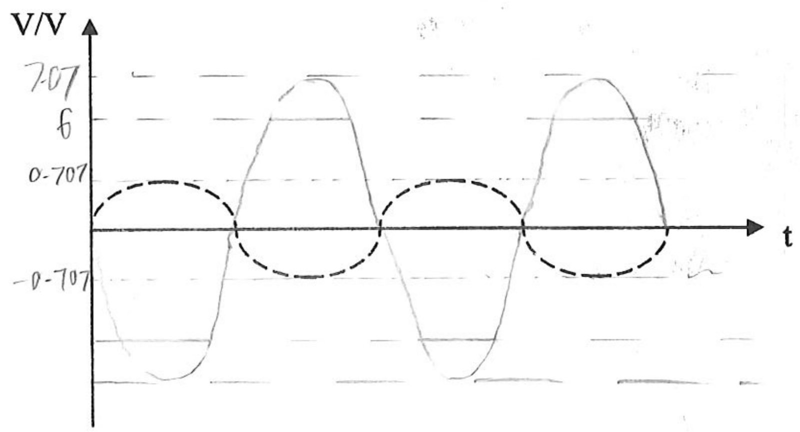
(i) Calculate the peak value of the input voltage.

$V_{peak} = \sqrt{2} \times 0.5 = 0.707 V$

(ii) With the power supply as indicated, what are the maximum and minimum values of the output voltage? Anything above +6V or -6V is violation of conservation of energy.

Max = +6V Min = -6V

(iii) Sketch a graph of output p.d. against time to show the shape of the output for this alternating input.



Now, referring back to Fig 4.1,

Know how to derive

current in R_1 = current in R_f
(the input resistance of the op-amp is *infinite*, ie. no current flow at the inputs of op-amp.)

By Ohm's law,

$$\frac{\text{p.d. across } R_1}{R_1} = \frac{\text{p.d. across } R_f}{R_f}$$

$$\frac{V_{in} - V_P}{R_1} = \frac{V_P - V_{out}}{R_f}$$

$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_f}$$ (potential at P = 0, *virtual earth*)

Thus, the overall voltage gain is given by

$$\boxed{\text{voltage gain} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}}$$

Checkpoint 2 – Inverting Amplifier

1. What type of feedback is used in the inverting amplifier? Negative
2. Is the overall gain known as open-loop or closed-loop gain? Closed-loop gain
3. Can we approximate both inputs to be at the same potential if the output is saturated? No
4. Is there any current flow through the
   (a) input, No (ideal)
   (b) output, of the op-amp? Yes ASD

Example 4

Figure 4.3 shows the variation of the output voltage V_{OUT} with input voltage V_{IN} for an amplifier.

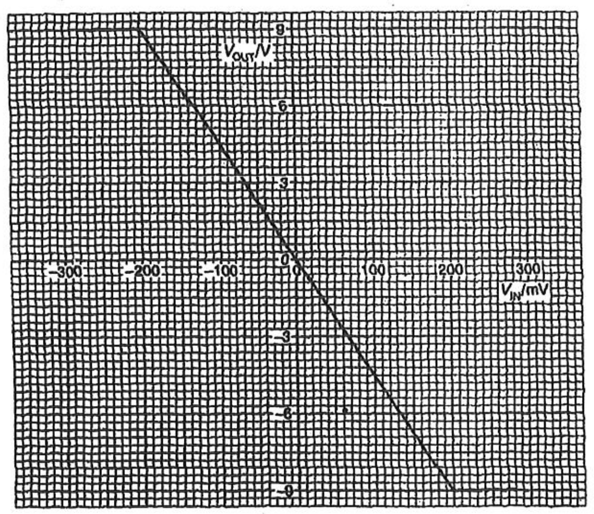


Fig 4.3

(i) Discuss whether the amplifier is an inverting or a non-inverting amplifier.
Inverting. Polarity of output voltage is opposite of input voltage.

(ii) Deduce the split power supply voltages.
± 9V

(ii) Use Fig 4.3 to calculate the magnitude of the voltage gain of the amplifier.

$$A = \left[\frac{9}{-200 \times 10^{-3}}\right] = 45$$

Inverting amplifier

The conclusion to be noted here is that as the level of negative feedback is increased the voltage gain of the amplifier is reduced. The reduction in gain is accompanied by an increase in the bandwidth of the amplifier circuit.

The gain remains constant over a *wider range of frequencies* and so the *frequency response is improved.*

Checkpoint 3 – Frequency Response

Using Fig 5.4, state the *maximum gain* that can be set *without distortion* when signals for the following frequency ranges are involved:

	Range	Max. Gain
(i)	DC signal only	10^5
(ii)	0 – 10 Hz	10^5
(iii)	0 – 100 Hz	10^4
(iv)	100 Hz – 100 kHz	10
(v)	Human audible range	50

References:

1. Nelkon & Parker, Advanced Level Physics 7th Edition, Chapter 32
2. Hutchings, Physics 2nd Edition, Chapter 21

Internet Resources:

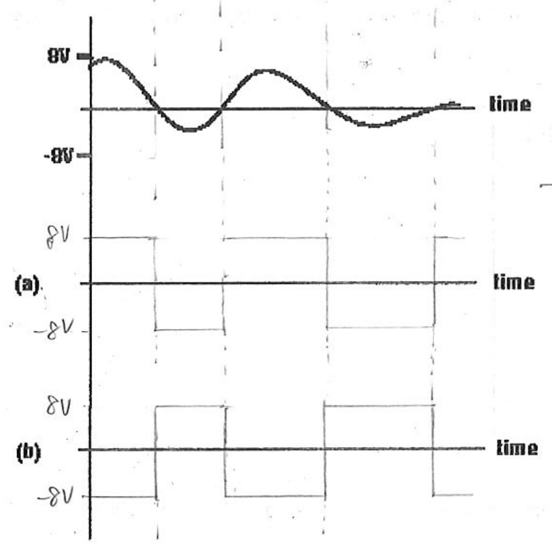
1. Op-amp (LM741) datasheet - http://www.fairchildsemi.com/ds/LM/LM741.pdf
2. Comparator Circuit with Thermistor (Animation) - http://www.bbc.co.uk/schools/gcsebitesize/design/electronics/operationalamplifiersrev3.shtml
3. Schmitt Trigger - http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/schmitt.html

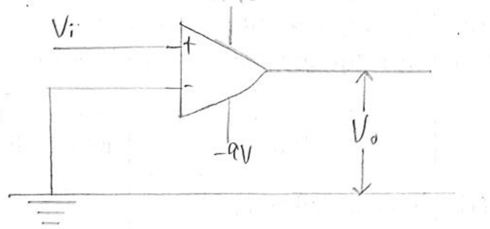
ANALOGUE ELECTRONICS TUTORIAL

Self-attempt

S1. State the main properties of an ideal operational amplifier. Describe how real operational amplifiers deviate from the ideal one.

S2. A signal shown below is applied to an open-loop amplifier whose power supplies are ±9V. Sketch the output of the amplifier if
(a) the signal is applied to the positive input with the negative input earthed;
(b) the signal is applied to the negative input with the positive input earthed.

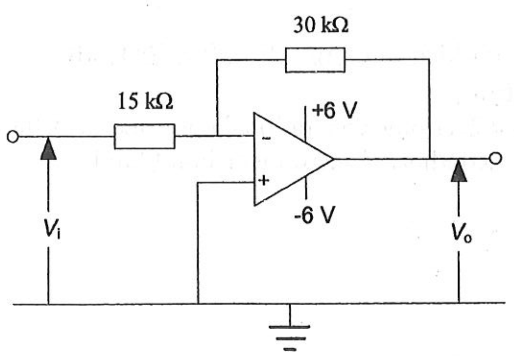


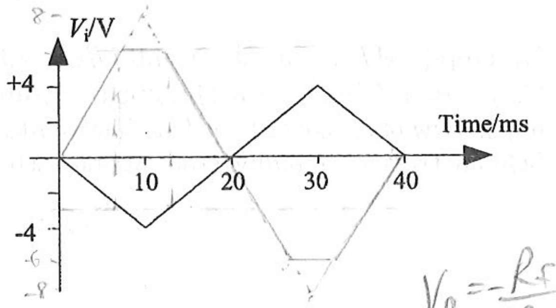


$V_o = A(V^+ - V^-)$
$= 10^5(0-8)$
$= -8 \times 10^5$ V

S3. Draw a circuit diagram for the each of the following configurations using one operational amplifier and a few 1 kΩ resistors:
(a) Amplifier with gain of –2.
(b) Amplifier with gain of 3.

S4. In the operational amplifier circuit below, V_i = + 2.0 V.





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

$= -\frac{30}{15}(-4)$

$= 8$ V

(a) Calculate the output potential V_o.
(b) The input signal V_i is then replaced by the signal shown in the graph. Sketch a graph to show the corresponding output potential V_o.

Discussion

D1. (a) What is meant by open-loop gain of an op-amp?
(b) Explain the terms "inverting" and "non-inverting" inputs with reference to an op-amp.
(c) As amplifiers, why are op-amps almost always used with negative feedback?

4.1 The Inverting Amplifier

The inverting amplifier is shown in Fig 4.1. An input signal V_{in} is applied to the resistor R_1. Negative feedback is applied via the resistor R_f.

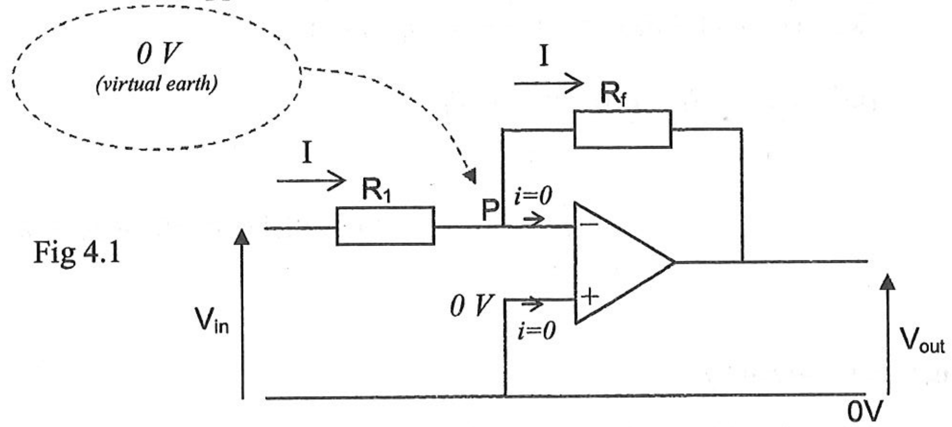


Fig 4.1

There are two things to note:

(i) If the output is not saturated then the two input voltages to the op-amp must be approximately the same (refer to *Example 1 in* **Section 2**). The non-inverting input (+) is connected directly to the zero-volt line (or earth) and so is at exactly 0 V. Thus, the inverting input (–) must be virtually at zero volts (or earth) and for this reason point P is known as a *virtual earth*. This can be seen from a simple calculation:

$$A_0 (V^+ - V^-) = V_{out}$$
$$(V^+ - V^-) = V_{out} / A_0$$

Since A_0 is large (10^5) while V_{out} is finite (≤ power supply voltage),

$$(V^+ - V^-) \approx 0$$
$$V^+ \approx V^-$$

(ii) As the input impedance of the op-amp itself is very large, *no current is drawn* into either the non-inverting or the inverting inputs. This means that the current from, or to, the signal source must go to, or come from, the output, as shown in Fig 4.2:

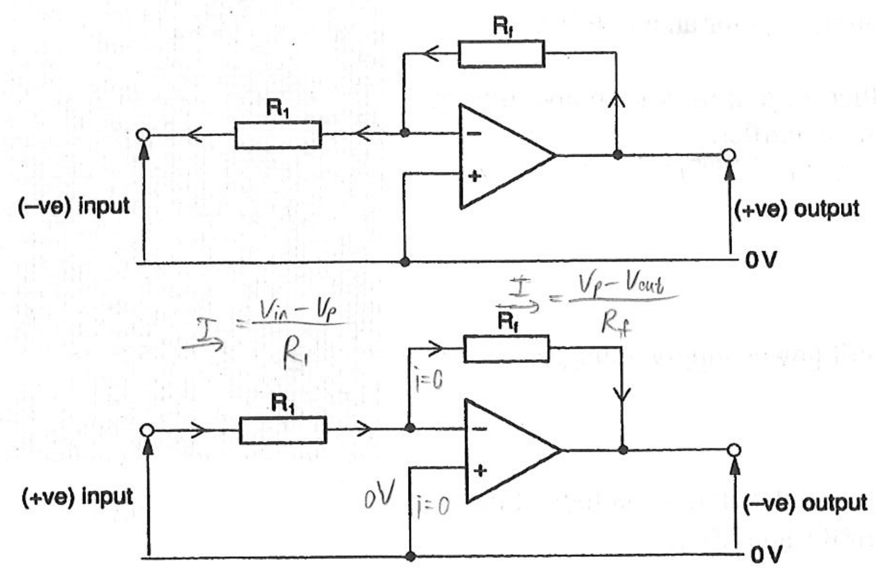


Fig 4.2

Note that when the input is positive, the output is negative and vice versa. Hence the name *inverting amplifier*, i.e. a positive input voltage causes a negative output voltage and vice versa.

3. Feedback

Definition: The process of taking some, or all, of the output of an amplifier and adding it to the input is known as *feedback.*

3.1 Positive Feedback

Positive feedback is created by arranging the output voltage to be fed back *in phase* with the input voltage. This is achieved by feeding back part of the output signal to the non-inverting input, as illustrated in Fig 3.1 (a).

Fig 3.1

3.2 Negative Feedback

Negative feedback occurs when part of the output signal is channeled back *out of phase* to the input signal. This is usually achieved by connecting the output to the inverting input of the op-amp via a resistor as illustrated in Fig 3.1 (b). This produces an amplifying system with an overall gain which is smaller than the open-loop gain A_0 of the amplifier itself.

There are reasons for using negative feedback in certain amplifiers which make the reduction in overall gain a small price to pay for its benefits.

The benefits are:
(i) an increase in bandwidth (see **Section 5**), wider range of f of operation
(ii) less distortion, high fidelity output
(iii) greater operating stability. signal doesn't change unexpectedly

With feedback, the gain is called the closed loop gain or $\mathbf{A_{CL}}$.

4. Operational Amplifier Circuits

Note that in both types of amplifiers described below, there is *negative* feedback applied by means of a potential divider circuit between the output and the input of the op-amp.

To simplify analysis of the circuits, the split power supplies to the op-amps have not been drawn. In order to calculate the overall voltage gains of the amplifiers below, it must be assumed that the op-amps are not saturated (otherwise it would be impossible to analyse the circuits).

D2. Figure D2.1 shows the variation with frequency f of the *open-loop gain* of a typical operational amplifier (op-amp). The op-amp is used in the amplifier circuit of Fig 6.2.

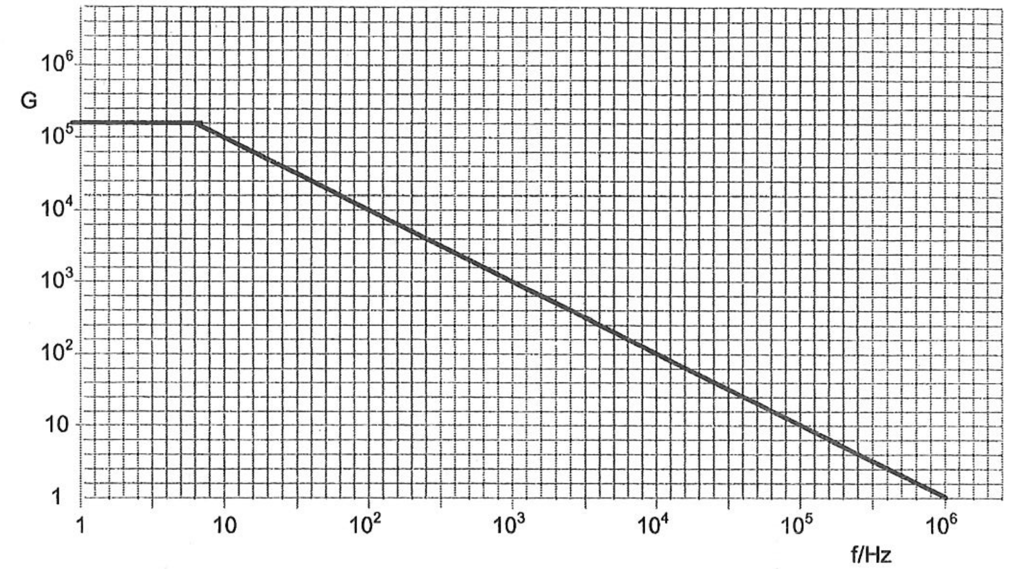


Fig D2.1

(a) Discuss
(i) the type of amplifier shown in Fig.D2.2,
(ii) what is meant by *negative feedback.*

(b) Calculate
(i) the gain of the amplifier,
(ii) the bandwidth of the amplifier,
(iii) the peak output voltage for an input signal of peak value 0.2 V and frequency 1.0×10^5 Hz.

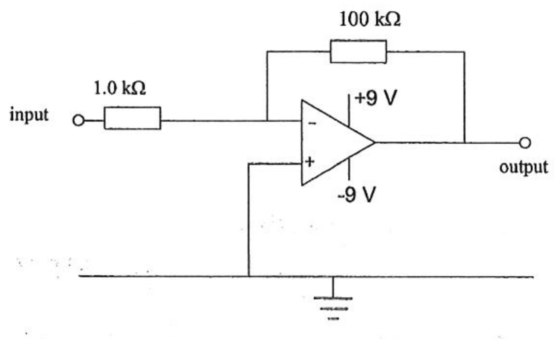
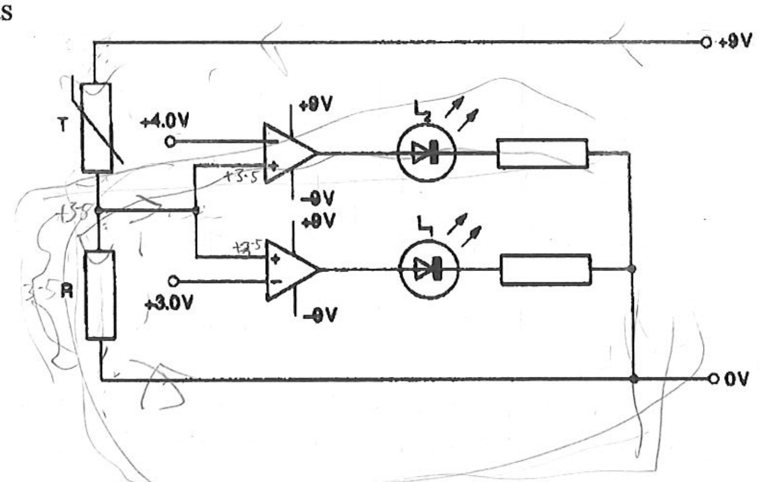


Fig D2.2

D3. A student set up the circuit as shown on the right.

The LED's L_1 and L_2 emit light when the output from the appropriate operational amplifier is positive and high. When the thermistor T, which has a negative temperature coefficient, is at 70 °C, the potential difference across the resistor R is 3.5 V.

T↑
R↓



(i) Explain why, when the thermistor is at 70 °C, L_1 emits light and L_2 does not.
(ii) The temperature of the thermistor is raised and there is a change of state of one or more of the LED's. State and explain what change is observed. L_2 lights up.
(iii) Suggest one use for the above circuit. Fire alarm
Oven to note temperature

Assignment

A1. The circuit shown below includes an ideal operational amplifier.

(a) Explain briefly why point P is known as the "virtual earth". [2]

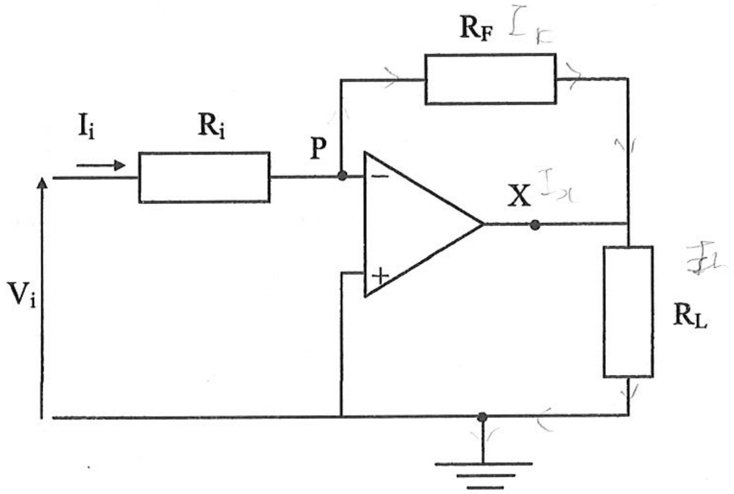
(b) For one particular input signal V_i, the current in the input resistor R_i, is I_i. Copy and indicate on your diagram the directions of

(i) I_F, the current in the feedback resistor R_F,

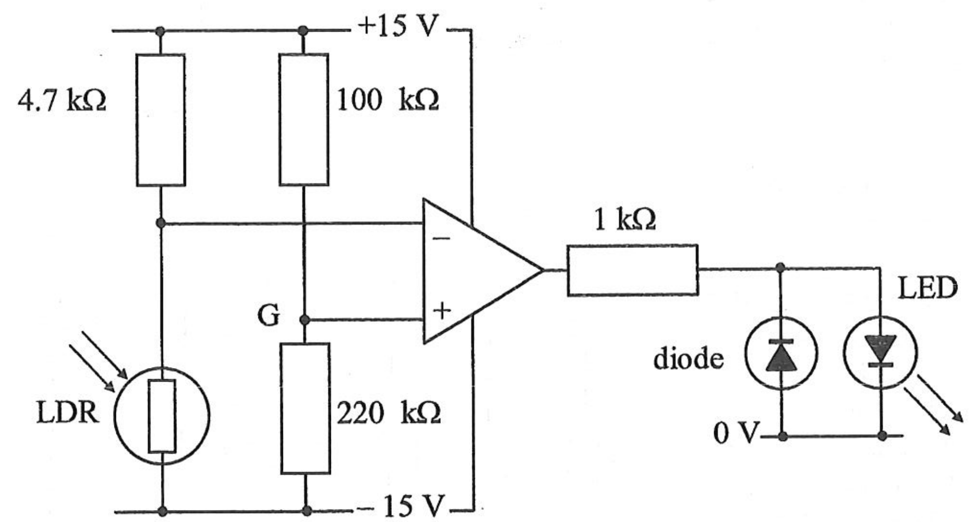
(ii) I_L, the current in the load resistor R_L,

(iii) I_X, the current at X [3]

(b) Write an equation relating I_F, I_L and I_X. [1]



A2. For the circuit shown:



(a) The resistance of the LDR used decreases with increasing light intensity. Describe what happens to the LED as the LDR is exposed to light of gradually increasing intensity. Explain your answer. [3]

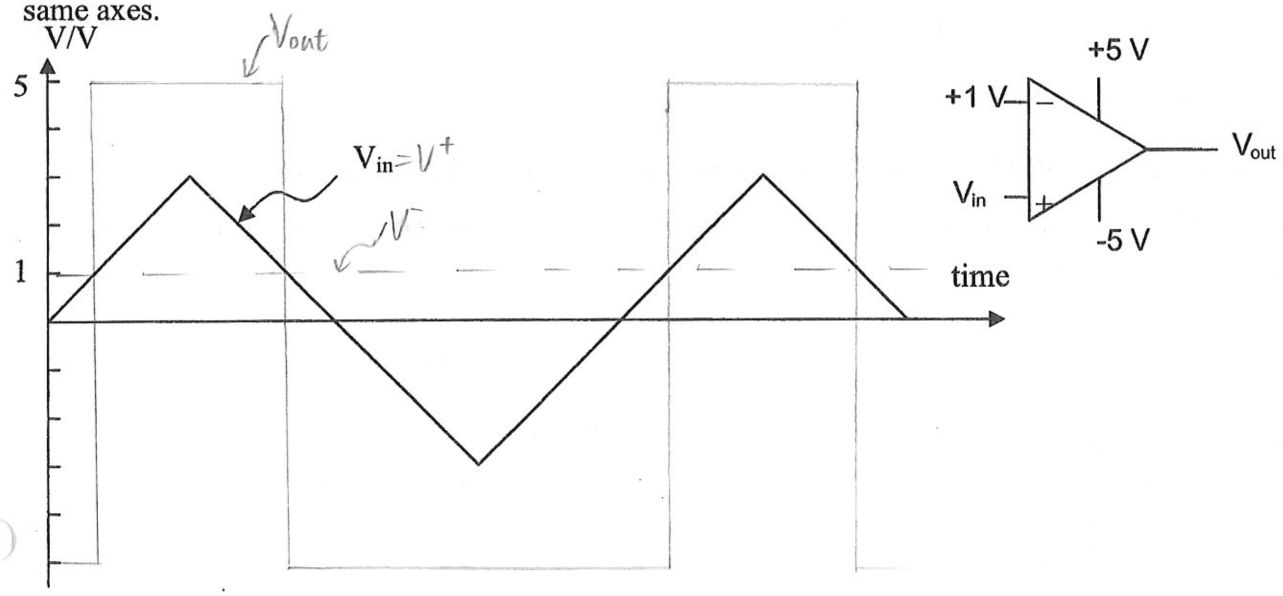
(b) What is the potential at point G in the circuit? [2]

(c) What will be the resistance of the LDR when the LED is about to go off? [2]

(d) Most LEDs are very limited in their tolerance of reverse bias voltages. Explain how the presence of the diode in the circuit protects the LED against destruction. [2]

Example 2

A signal shown below is applied to the non-inverting input of an open-loop amplifier whose power supplies are ± 5 V. The inverting input is held at +1 V. Sketch the output of the amplifier on the same axes.



Working: When $V^+ > V^-$ i.e $V_{in} > +1V$, op-amp saturates positively, so $V_{out} = +5V$
otherwise, $V_{out} = -5V$

When an op-amp is used as a comparator, it is usual to connect a potential divider to each of the two inputs. One of these potential dividers generates a fixed voltage while the other generates a voltage which depends upon some physical property.

Example 3

Suppose it is required to make an LED light up when it gets dark as a warning to a car driver to switch on the headlights. A circuit which can do this is shown in Fig 2.2, here the resistors have been chosen to produce a fixed voltage of 3.0 V at the inverting input.

Essentially, the op-amp compares the variable voltage at the non-inverting input with the fixed 3.0 V at the inverting input.

- In the dark, the LDR's resistance is greater than 10 kΩ and this causes the voltage input at the non-inverting input to be greater than 3.0 V. The output saturates positively and the LED lights.
- In daylight, the LDR's resistance is less than 10 kΩ and this causes the input to be lesser than 3.0 V, so the output saturates negatively and the LED does not light.

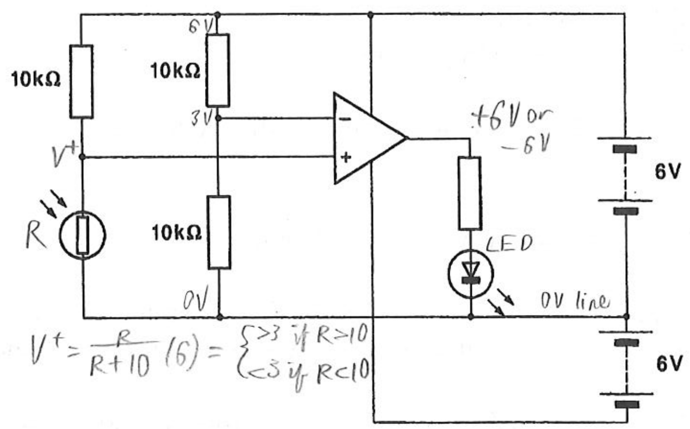


Fig 2.2

Note that the LDR could be replaced by a *thermistor* to produce an ice-warning LED circuit.

Now calculate the output voltage in the following examples:

Example 1

+ve supply line = +12V
-ve supply line = -12V

	Case 1	Case 2	Case 3	Case 4
V^+/V	$+5.1\times10^{-5}$	+1.3000	+1.3000	+3.652
V^-/V	$+4.3\times10^{-5}$	+1.3001	-1.3001	+3.654
V_{out}/V	+0.8	−10	+12	−12

Working:

Case 1: $V_{out} = 10^5(5.1-4.3)\times10^{-5}$
$= 10^5(0.8\times10^{-5})$
$= +0.8V$

Case 2: $V_{out} = 10^5(1.3000-1.3001)$
$= 10^5(-1\times10^{-4})$
$= -10V$

Case 3: $V_{out} = 10^5(1.3000-(-1.3001))$
$= 10^5(2.6001)$
$= +260\,010\ V$
$> +12\ V$

Case 4: $V_{out} = 10^5(3.652-3.654)$
$= 10^5(-0.002)$
$= -200V$
$< -12V$

In cases 1 and 2, the inputs are very, very close in magnitude (almost equal; difference to the order of 10^{-4} V). The output of the op-amp will be proportional to the difference of the inputs.

In cases 3 and 4, the calculated values of the output voltages are impossible as they exceed the amplifier's own power supply voltage. Hence, by energy considerations, the maximum output possible will be +12 V and -12 V respectively. The output is said to be saturated in these cases.

Thus, unless the two input voltages to an op-amp are almost the same value, the output of the op-amp will be saturated.

The op-amp circuit of Fig 2.1 is said to be a **comparator**. The circuit compares the voltages applied to the inverting and to the non-inverting inputs and provides an output which is dependent on whether $V^+ > V^-$ or $V^- > V^+$.

Checkpoint 1 – Op-amp Output Saturation

Unless $V^+ \approx V^-$, the op-amp will saturate. Conversely, if the op-amp is **not** saturated, the voltages at the inverting and non-inverting inputs must be almost equal.

When $V^+ > V^-$, the op-amp saturates positively, ie. V_{out} = +ve power supply

When $V^- > V^+$, the op-amp saturates negatively, ie. V_{out} = −ve power supply

SINGAPORE AMATEUR ATHLETIC ASSOCIATION

3rd ALLCOMERS/ JUNIOR PROGRESSIVE MEET
30 May 2004, Choa Chu Kang Stadium

TENTATIVE PROGRAMME

EVENT #	CATEGORY	EVENT	TIME	EVENT	CATEGORY	EVENT #
101	Women Open	400mH	2.00pm	Boys U17	Pole Vault	111
				Women Open	Shot Put	112
102	Men Open	400mH	2.20pm	Women Open	High Jump	113
103	Women Open	100m	2.40pm			
104	Men Open	100m	3.10pm			
105	Women Open	800m	3.40pm	Men Open	Shot Put	114
106	Men Open	800m	4.00pm	Men Open	High Jump	115
107	Women Open	1,500m	4.20pm	Women Open	Triple Jump	116
108	Men Open	1,500m	4.40pm			
109	Men Open	5,000m	5.10pm			
110	Women Open	5,000m	5.40pm			

Updated as at 13 May 2004

1.3 Ideal Amplifier memorise

The ***ideal*** operational amplifier has the following properties:

(i) an infinite input impedance* (i.e. no current flows into either of the two inputs),

(ii) infinite open-loop gain (i.e. if there is only the slightest difference between the two input voltages, the output will be saturated, see *Example 1 in* **Section 2.**),

(iii) zero output impedance (i.e. the amplifier can provide the correct current for any load, no matter how small its resistance),

(iv) infinite bandwidth (i.e. it amplifies all frequencies by the same amount),

(v) infinite slew rate (i.e. if the input suddenly changes, the output suddenly changes in step, without any time delay).

* Note that *impedance* in A.C. circuits is equivalent to *resistance* in D.C. circuits.

1.4 Real Amplifier

Note that ***real*** operational amplifiers deviate from this ideal in the following ways:

	ideal	real
(i) the input impedance is usually between 10^6 and 10^{12} Ω,	infinite	$10^6 - 10^{12}$ Ω
(ii) the open-loop gain is usually about 10^5 for d.c. signals,	infinite	10^5
(iii) the output impedance is usually about 100 Ω,	zero	100 Ω
(iv) there is a limited bandwidth (see **Section 5**),	infinite	limited
(v) there is a limited slew rate.	infinite	limited

2. Operational Amplifier as a Comparator

When an operational amplifier is to be used in a circuit, it is usually connected to *split, or dual, power supplies* to enable the output voltage to swing positively or negatively. Such supplies can be imagined to be composed of two sets of batteries arranged as shown in Fig 2.1 where their common link is termed the zero-volt line. This forms the reference line to which all input and output voltages are measured.

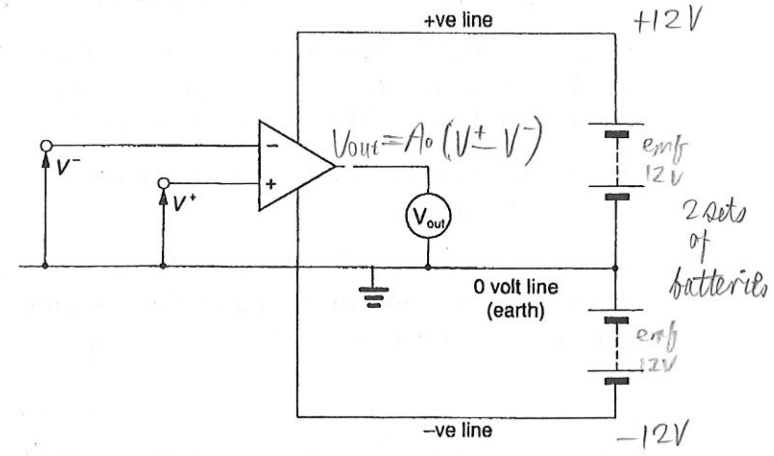


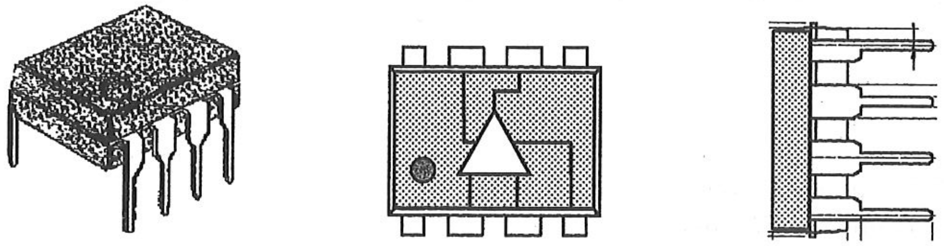
Fig 2.1

Figure 2.1 also shows two sources of voltage applied to the two inputs. This simple arrangement is termed ***open-loop*** mode because there is no feedback connection between the output of the op-amp and either of its inputs. The output voltage of the op-amp is given by

$$V_{out} = A_0(V^+ - V^-),$$

where A_0 is known as the open-loop gain (typically $\mathbf{10^5}$ for direct voltages).

1. The Ideal Operational Amplifier (Op-Amp)



Diagrams of Op-Amp IC Chip (LM741)

1.1 What is an Operational Amplifier?

The operational amplifier is an integrated circuit (IC) which consists of twenty transistors with a few resistors and capacitors. These components are formed on a tiny piece of silicon and sealed in a package from which various connections emerge (as shown above).

There are 5 main connections for an op-amp:
(i) +ve power supply
(ii) -ve power supply
(iii) inverting input, V^-
(iv) non-inverting input, V^+
(v) output, V_{out}

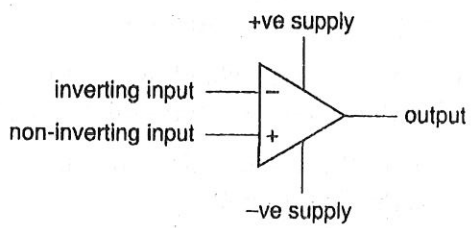


Fig 1.1

The complex circuitry of an operational amplifier can be represented by what is called its *equivalent circuit* shown in Fig 1.1.

1.2 Uses of Operational Amplifier

The device is termed "operational amplifier" because it is a "ready-to-be-used *amplifier*", ie. it can *easily* be made to perform many different operations. For example, it can be made to:

(i) *compare* two separate voltages and give an output which depends on the result of the comparison (see **Section 2**),
(ii) *amplify* direct and alternating voltages by a multiplying factor which is easy to control (see **Section 4**),
(iii) *buffer* a high impedance source of voltage which is to drive a low impedance load
(iv) *add* two or more voltages together
(v) operate as a Schmitt trigger, which "*cleans up*" noisy digital signal (see **Internet Resources 3** – optional).

When connected to appropriate power supplies, an op-amp produces an output voltage V_{out} which is proportional to the difference between the voltage V^+ at the non-inverting input and the voltage V^- at the inverting input. Thus,

$$\boxed{V_{out} = A_o (V^+ - V^-)}$$

where A_O is known as the ***open-loop gain**** of the op-amp.

* open-loop refers to a situation where there is no *feedback* (see **Section 3** "Feedback").

6 Electronics
7 Data Analysis
8 Paper 1
9-10 Paper 1
9 Prelim Design Prac

ANALOGUE ELECTRONICS

Content

1. The Ideal Operational Amplifier
2. Operational Amplifier Circuits

Learning Outcomes
At the end of the lesson, you should be able to:

(a) identify the properties of the ideal operational amplifier.

(b) deduce from the properties of the ideal operational amplifier, the use of an operational amplifier as a comparator.

(c) show an understanding of the effects of negative feedback on the gain and on the bandwidth of an operational amplifier.

(d) recall the circuit diagrams for both the inverting and the non-inverting amplifier for single signal input.

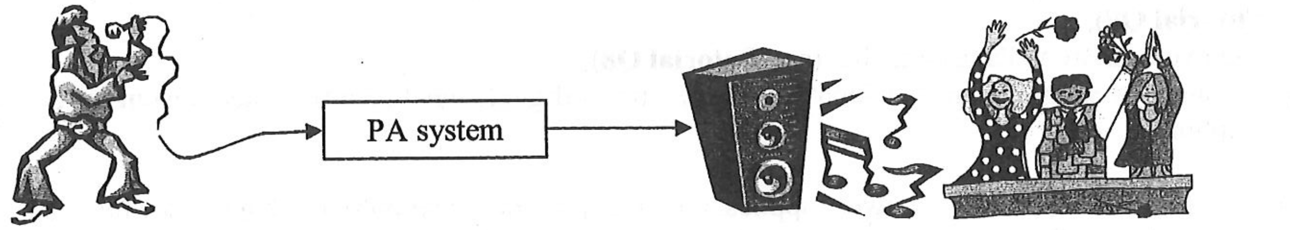
(e) show an understanding of the virtual earth approximation and derive an expression for the gain of inverting amplifiers.

(f) recall and solve problems using expressions for the voltage gain of inverting and non-inverting amplifiers.

Introduction

What is an amplifier?

Think of a public address (PA) system. When a person speaks into a microphone, his speech is amplified by the PA system and heard by the audience as shown below:



Ideally, the amplifier's outputs should be a louder version of the speaker's voice and distortion should be minimised. The amount of amplification is determined by the gain, **A**, which is the extent to which the amplifier boosts the strength of the signal input. Mathematically, this means

$$\boxed{V_{out} = A V_{in}}$$

Tan Zhi Yong 03564 Analogue Electronics

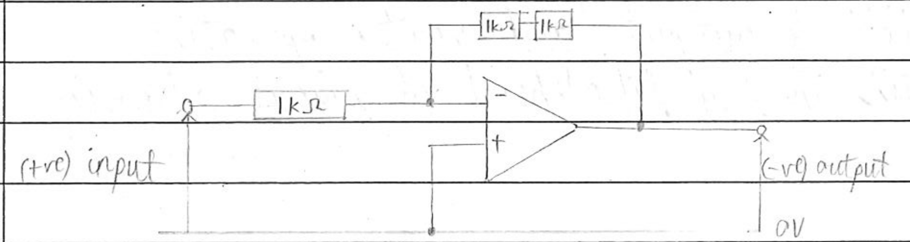
Subject: Self-Attempt

Date: 25/7/04

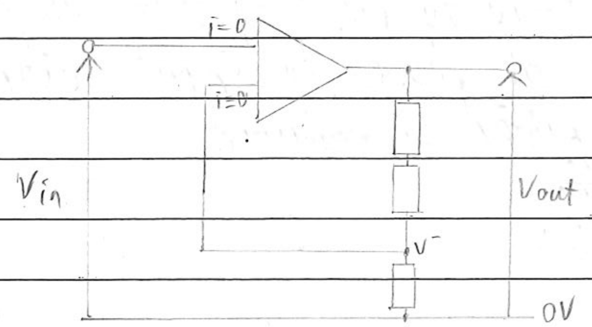
1) An ideal amplifier has an infinite input impedance, an infinite open-loop gain, zero output impedance, infinite bandwidth and infinite slew rate.

A real operational amplifier has limited input impedance of between $10^6 - 10^{12}\ \Omega$, limited open loop gain of about 10^5 for d.c. signals, an output impedance of around $100\ \Omega$, limited bandwidth and limited slew rate.

3a)
$$A = -\frac{R_f}{R_i}$$
$$= -\frac{2}{1}$$



3b)
$$A = 1 + \frac{R_f}{R_i}$$
$$= 1 + \frac{2}{1}$$



4a)
$$V_o = A V_{in}$$
$$= -4.0V$$

Subject: Date:

1a) Open-loop gain refers to the extent to which the amplifier boosts the strength of the signal input when there is no feedback.

1b) An inverting amplifier causes polarity of output voltage to be opposite to input voltage. A non-inverting produces an output voltage in phase with input voltage.

1c) Negative feedback causes a reduction in overall gain. However, it allows an increase in bandwidth and a higher range of frequencies of operation, less distortion and high fidelity ~~f~~ output, and greater operating stability resulting in less likelihood of signal changing unexpectedly.

2ai) Inverting amplifier. Input signal V_{in} is applied to $1.0\,k\Omega$ resistor and negative feedback via $100\,k\Omega$ resistor.

2aii) Negative feedback refers to part of the output signal channeled back 180° out of phase to input signal. As a result, overall gain of amplifier is reduced.

2bi)
$$A = -\frac{100}{1.0}$$
$$= -100$$

2bii) Bandwidth ~~= 8 Hz~~ 10^4 Hz

2biii)
$$V_o = -10(0.2)$$
$$= -2\ V$$