Answers to Exercises in Chapter 15

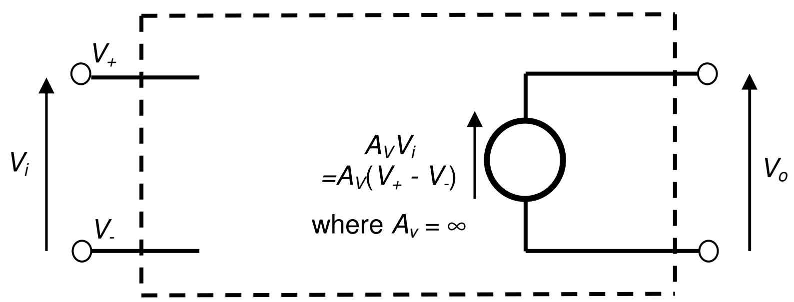
15.1 An 'integrated circuit' is a component constructed by integrating a large number of electronic devices into a single semiconductor component.

15.2 DIL stands for 'dual in line' while SMT stands for 'surface mounted technology'. The former is common where circuits are to be produced in relatively small numbers. The latter have the advantage of a much smaller physical size, but are consequently difficult to assemble manually. Such components are often used in high-volume products where automatic assembly techniques are used.

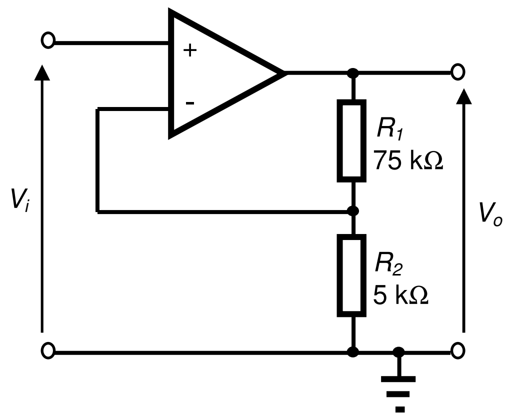
15.3 Typical values for these quantities might be +15 V and –15 V, but these values vary tremendously.

15.4 An 'ideal' op-amp would have an infinite voltage gain, an infinite input resistance and a zero output resistance.

15.5 An equivalent circuit of an ideal operational amplifier might be as follows:

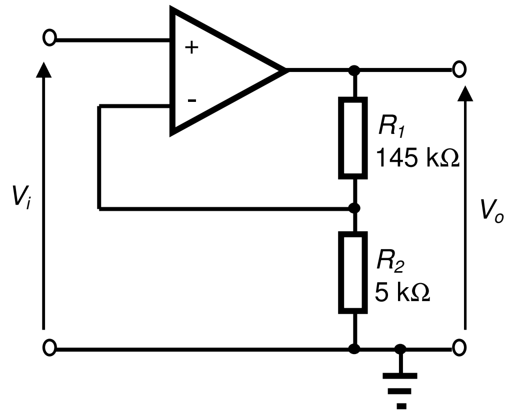


15.6



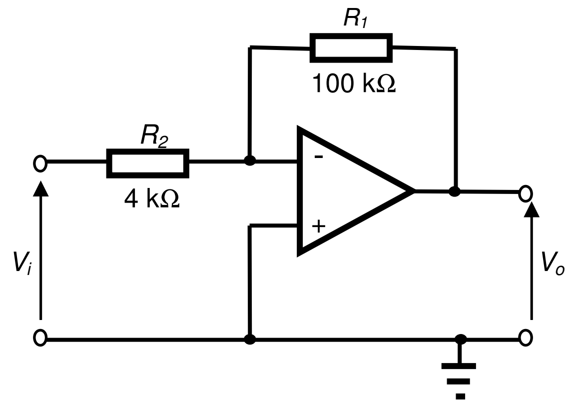
From the discussion in Section 15.3.1 the gain of the circuit is $(R_1 + R_2)/R_2 = 16$.

15.7 A suitable circuit would be:



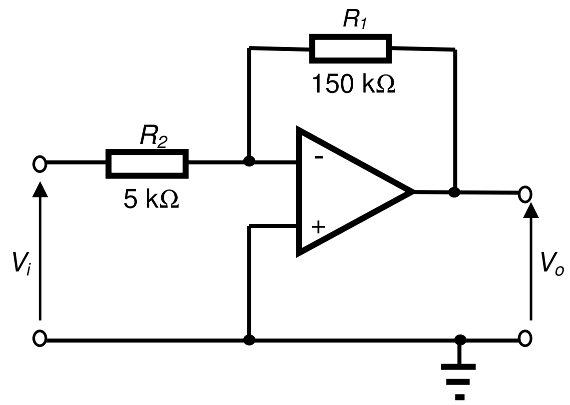
15.8 The circuit of Exercise 15.7 can easily be produced by modifying the circuit of the demonstration file for Computer Simulation Exercise 15.1.

15.9



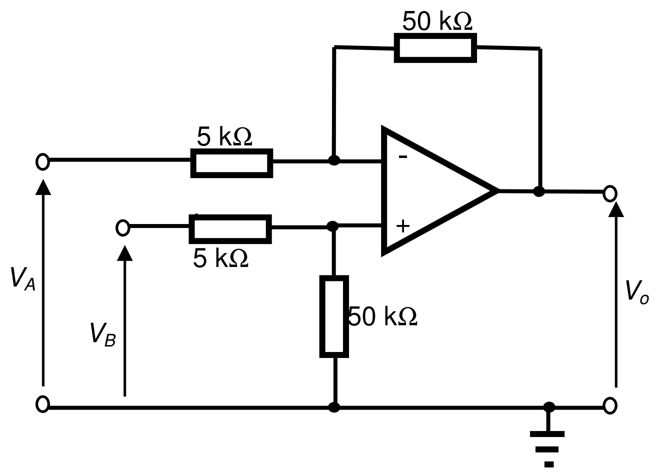
From the discussion in Section 15.3.2 the gain of the circuit is $-R_1/R_2 = -25$.

15.10 A suitable circuit would be:

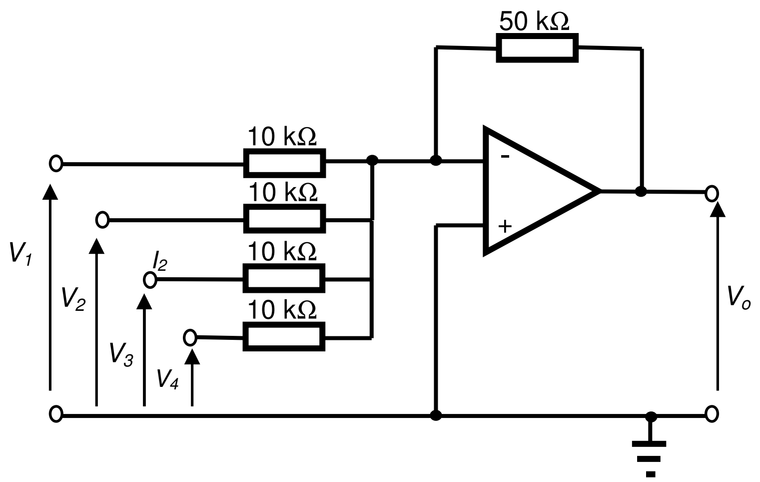


15.11 The circuit of Exercise 15.10 can easily be produced by modifying the circuit of the demonstration file for Computer Simulation Exercise 15.2.

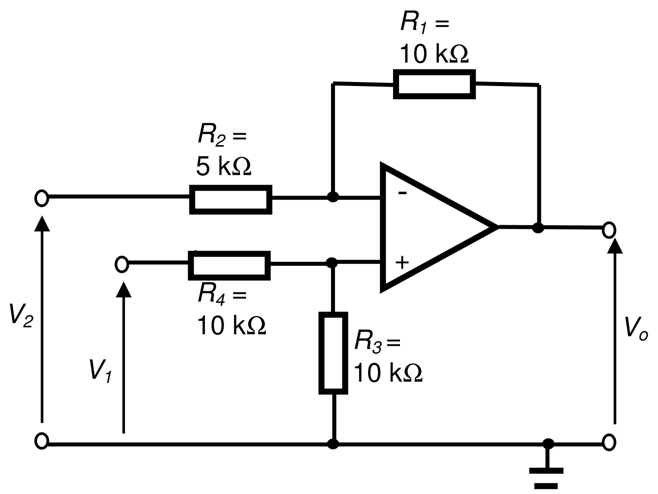
15.12 A suitable circuit would be:



15.13 A suitable circuit would be:



15.14



Performing an analysis similar to that in Section 5.4.3 (and using similar notation) we have:

$$V_+ = V_1 \frac{R_3}{R_3 + R_4} = V_1 \frac{10\,\text{k}\Omega}{10\,\text{k}\Omega + 10\,\text{k}\Omega} = \frac{V_1}{2}$$

$$V_- = V_2 + (V_o - V_2)\frac{R_2}{R_1 + R_2} = V_2 + (V_o - V_2)\frac{10\,\text{k}\Omega}{10\,\text{k}\Omega + 5\,\text{k}\Omega} = \frac{V_o}{3} + \frac{2V_2}{3}$$

Therefore, since $V_+ = V_-$

$$\frac{V_1}{2} = \frac{V_o}{3} + \frac{2V_2}{3}$$

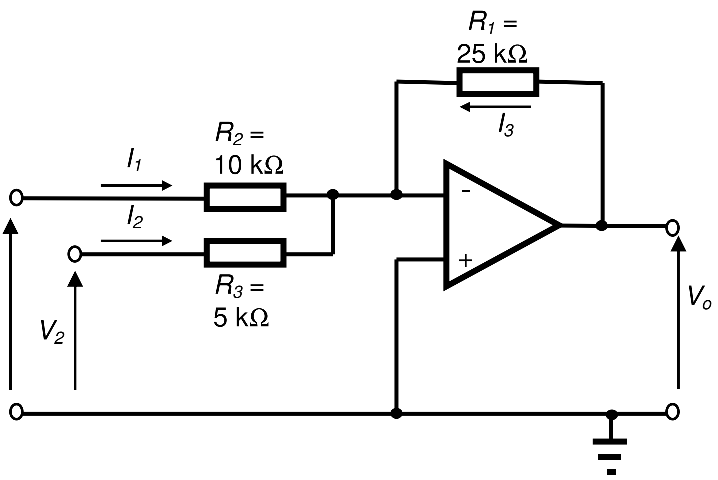
and rearranging gives

$$V_o = \frac{3}{2}V_1 - 2V_2$$

If $V_1 = 1$ V and $V_2 = 0.5$ V,

$$V_o = \frac{3}{2} \times 1 - 2 \times 0.5 = 0.5\ \text{V}$$

15.15



Performing an analysis similar to that in Section 15.4.4 (and using similar notation) we have:

$$I_1 = \frac{V_1}{R_2}$$

$$I_2 = \frac{V_2}{R_3}$$

$$I_3 = \frac{V_o}{R_1}$$

Since no current flows into the op-amp, the external currents flowing into the virtual earth must sum to zero. Therefore

$$I_1 + I_2 + I_3 = 0$$

or rearranging

$$I_3 = -(I_1 + I_2)$$

Substituting for the various currents then gives

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

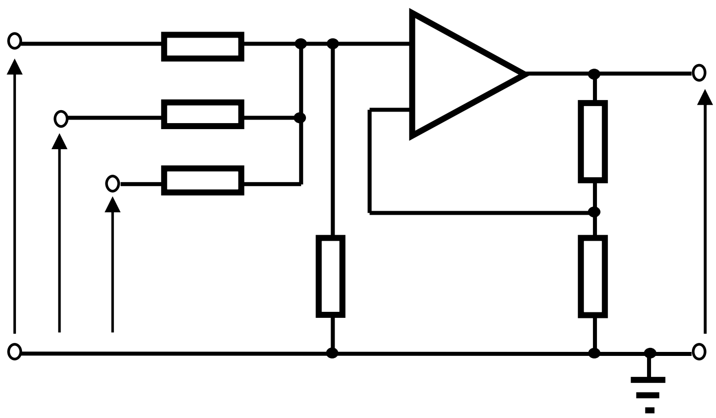
Substituting for the resistor values gives

$$V_o = -\left(V_1 \frac{25k\Omega}{10k\Omega} + V_2 \frac{25k\Omega}{5k\Omega} \right) = -(2.5V_1 + 5V_2)$$

If $V_1 = 1$ V and $V_2 = 0.5$ V,

$$V_o = -(2.5 \times 1 + 5 \times 0.5) = -5 \text{ V}$$

15.16



First we note that, as in earlier circuits, the negative feedback forces V_- to equal V_+, and therefore

$$V_- = V_+$$

Since no current flows into the inputs of the op-amp, V_- and V_+ are determined by the potential dividers formed by the resistors.

V_- is easy to calculate and is given by

$$V_- = V_O \frac{10\,\mathrm{k\Omega}}{10\,\mathrm{k\Omega} + 30\,\mathrm{k\Omega}} = \frac{V_O}{4}$$

V_+ is slightly more complicated to compute since it is determined by the three input voltages. However, applying the principle of superposition, we know that the voltage on V_+ will be equal to the sum of the voltages that would be generated if each input voltage were applied separately.

If V_1 is applied while V_2 and V_3 are set to zero, then the resistor connected to V_2 and V_3 effectively go to ground and are in parallel with the existing 10 kΩ resistor that goes from V_+ to ground. Therefore,

$$V_+ = V_1 \frac{10\,\mathrm{k\Omega}//10\,\mathrm{k\Omega}//10\,\mathrm{k\Omega}}{10\,\mathrm{k\Omega}//10\,\mathrm{k\Omega}//10\,\mathrm{k\Omega} + 10\,\mathrm{k\Omega}} = V_1 \frac{3.33\,\mathrm{k\Omega}}{3.33\,\mathrm{k\Omega} + 10\,\mathrm{k\Omega}} = \frac{V_1}{4}$$

Due to the symmetry of the circuit, a similar analysis can be applied when V_2 and V_4 are applied *alone*, which lead to the conditions that

$$V_+ = \frac{V_2}{4} \quad \text{and} \quad V_+ = \frac{V_2}{4}$$

Therefore if all three inputs are applied simultaneously we have

$$V_+ = \frac{V_1}{4} + \frac{V_2}{4} + \frac{V_3}{4}$$

Now since

$$V_- = V_+$$

we have

$$\frac{V_O}{4} = \frac{V_1}{4} + \frac{V_2}{4} + \frac{V_3}{4}$$

and

$$V_o = V_1 + V_2 + V_3$$

15.17 The circuit for this simulation can be easily produced by modifying the demonstration file for Computer Simulation Exercise 15.5.

15.18 Most operational amplifiers have a gain of between 100 and 140 dB (a voltage gain of between 10^5 and 10^7). Bipolar op-amps would typically have an input resistance in a range from a few hundred kilohms to perhaps a hundred megohms. FET op-amps might have an input resistance of about 10^{12} ohms. Output resistance will normally be in the range from a few tens of ohms to a few kilohms.

15.19 A typical arrangement for an operational amplifier is to use supply voltages of +15 V and –15 V, but some devices allow higher voltages to be used, perhaps up to ±30 V, while others are designed for low voltage operation, perhaps down to ±1.5 V. Many amplifiers allow operation from a single voltage supply. Typical voltage ranges for a single supply might be 4 to 30 V, though devices are available which will operate down to 1 V or less.

15.20 This is the ratio of the response produced by a differential-mode signal to the response produced by a common-mode signal of the same size. Typical values for CMRR for general-purpose operational amplifiers are between 80 and 120 dB. High performance devices may have ratios of up to 160 dB or more.

15.21 For an operational amplifier to work correctly, a small input current is required into each input terminal. This current is the input bias current.

15.22 The input offset voltage is defined as the small voltage required at the input to make the output zero. The input offset voltage of most op-amps is generally in the range of a few hundred microvolts up to a few millivolts. Many op-amps provide connections to allow an external potentiometer to 'trim' the offset to zero.

15.23 A typical frequency response for a 741 op-amp is given in Figure 15.14 of the text. Its upper cut-off frequency is a few Hertz. It does not have a lower cut-off frequency.

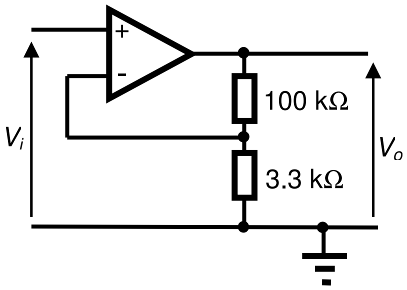
15.24 The gain-bandwidth product of a 741 is about 10^6 and is equal to the unity-gain bandwidth.

15.25 Since for a 741 Gain × Bandwidth ≈ 10^6, if the gain is 25, the bandwidth will be about $10^6/25 \approx 40$ kHz.

15.26 This is the maximum rate at which the output voltage can change and is typically a few volts per microsecond.

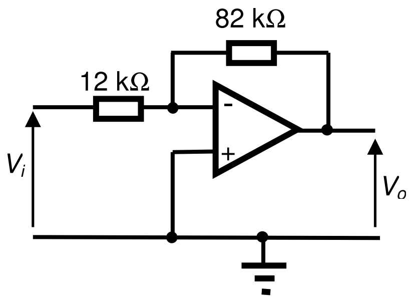
15.27 For circuits using bipolar operational amplifiers, resistors in the 1 kΩ to 100 kΩ range would normally be used.

15.28



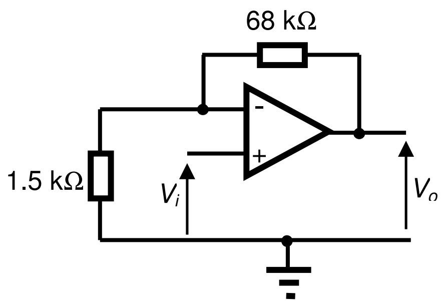
(a)

Gain = (100 kΩ + 3.3 kΩ)/3.3 kΩ = 31.3
B = 1/Gain = 1/31.3 = 0.0319
$A = 10^6$
Therefore
$(1 + AB) = (1 + 10^6 \times 0.0319) \approx 32\,000$
This circuit increases input resistance
Therefore $R_i \approx 10^6 \times 32\,000 = 32 \times 10^9 \Omega$
This circuit decreases output resistance
Therefore $R_o \approx 100 \div 32\,000 = 3.1$ mΩ.



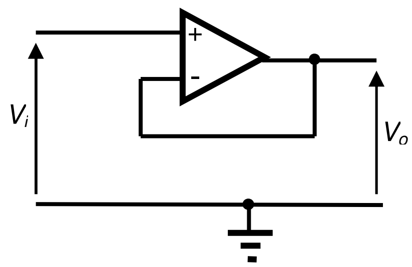
(b)

Gain = -(82 kΩ/12 kΩ) = -6.83
B = 1/Gain = 1/6.83 = 0.146
$A = 10^6$
Therefore
$(1 + AB) = (1 + 10^6 \times 0.146) \approx 146\,000$
This circuit decreases input resistance
R_i is equal to the input resistance =12 kΩ
This circuit decreases output resistance
Therefore $R_o \approx 100 \div 146\,000 = 680$ μΩ.



(c)

Gain = (68 kΩ + 1.5 kΩ)/1.5 kΩ = 46.3
B = 1/Gain = 1/46.3 = 0.0216
$A = 10^6$
Therefore
$(1 + AB) = (1 + 10^6 \times 0.0216) \approx 21\,600$
This circuit increases input resistance
Therefore $R_i \approx 10^6 \times 21\,600 \approx 22 \times 10^9 \Omega$
This circuit decreases output resistance
Therefore $R_o \approx 100 \div 21\,600 = 4.6$ mΩ.



(d)

Gain = 1
B = 1/Gain = 1/1 = 1
$A = 10^6$
Therefore
$(1 + AB) = (1 + 10^6 \times 1) \approx 10^6$
This circuit increases input resistance
Therefore $R_i \approx 10^6 \times 10^6 \approx 10^{12} \Omega$
This circuit decreases output resistance
Therefore $R_o \approx 100 \div 10^6 = 100$ μΩ.