Electronics 16-1a

Semiconductors

- They "collect" a positive electric charge on a small minority of the atoms.
- If a voltage is applied, the electron goes to the positive terminal.

Electronics 16-1b

Semiconductors

- If the semiconductor is doped with atoms that have three valence electrons, each dope atom forms three covalent bonds with its neighboring Si or Ge atoms, resulting in one neighbor atom in the lattice with no atom to bond with.
- If a semiconductor is doped with atoms that have five valence electrons, each dope atom forms four covalent bonds with its neighbors, resulting in one unshared electron in the dope atom, causing the dope atom to donate a free electron.

Semiconductors

- p-n Junction – when p-type and n-type doping occur next to each other in the same crystal
  - Diffusion Current – free electrons from the n-type material combine with the holes in the p-type material near the junction
  - Depletion Region – area near the junction
- Drift current – the potential difference creates an electric field that pushes electrons back toward the n-type material from the p-type material

Semiconductors

Example 1 (FEIM):

Which of the following is NOT true for intrinsic semiconductors?

(A) There are holes in intrinsic semiconductors.

(B) There are free electrons in intrinsic semiconductors.

(C) They make good insulators.

(D) Increasing thermal energy increases their conductivity.

Intrinsic semiconductors will carry current, so answer (C) is not true.

Therefore, (C) is the answer.

Electronics

Semiconductors

Example 2 (FEIM):

In the depletion region of a semiconductor p-n junction, there

(A) is an electric field.
(B) are more holes than outside the depletion region.
(C) are more free electrons than outside the depletion region.
(D) is current perpendicular to the current outside the depletion region.

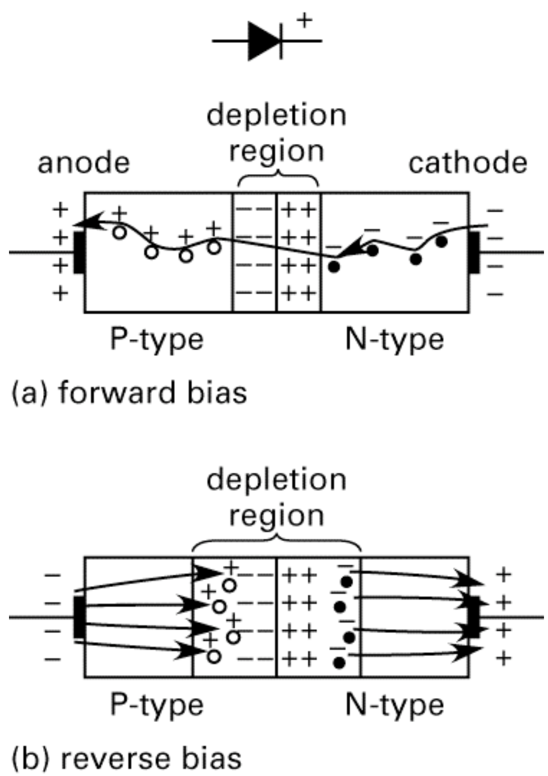
Answers (B) and (C) are wrong because the depletion region has fewer holes and free electrons than outside the depletion region. Answer (D) is nonsense. However, there is an electric field.

Therefore, (A) is correct.

Semiconductors

Diode Symbol

- P-type – anode
- N-type – cathode



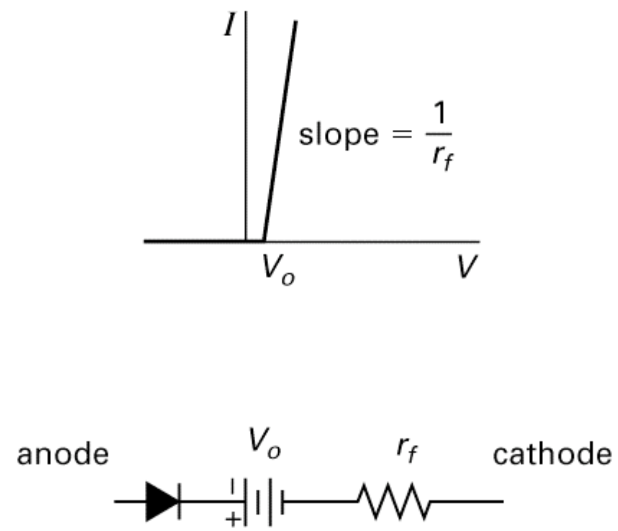
P-N Junction Biasing

- Forward biased
- Reverse biased

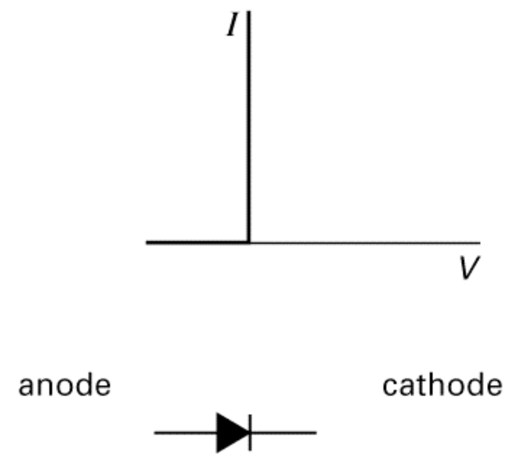
Diode Characteristics

- Static forward resistance
- Breakdown voltage

For an ideal diode in series with a voltage:



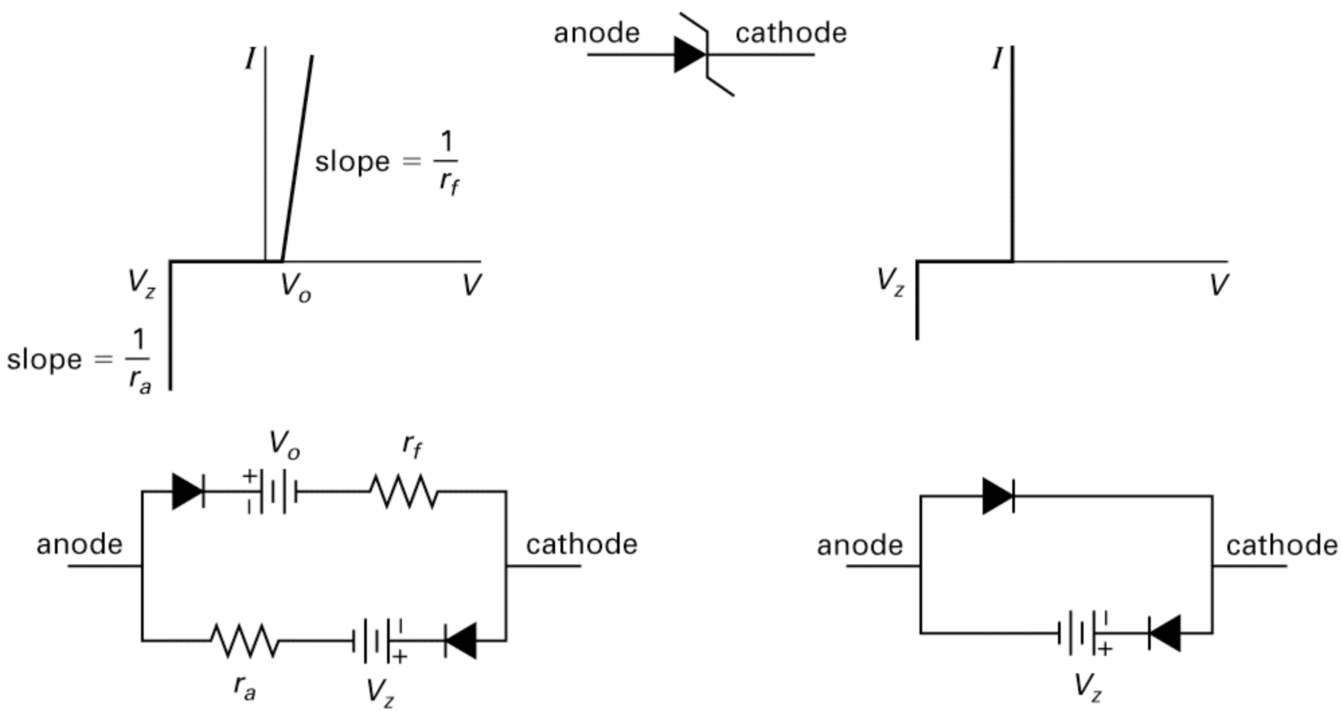
For an ideal diode with zero resistance in the forward bias direction and infinite resistance in the reverse bias direction:



Special Diodes

Zener Diodes

- They have a high doping concentration.
- Avalanche – the effect of the e^- in the depletion region accelerating and colliding.
- For an ideal Zener diode, $V_o = 0$, $r_f = 0$, and $r_a = 0$.



(a) simple model (b) ideal

Special Diodes

Example (FEIM):

When a Zener diode suffers breakdown, it

(A) is immediately destroyed.
(B) behaves as a reversed biased ideal diode.
(C) becomes an open circuit.
(D) behaves as a voltage source.

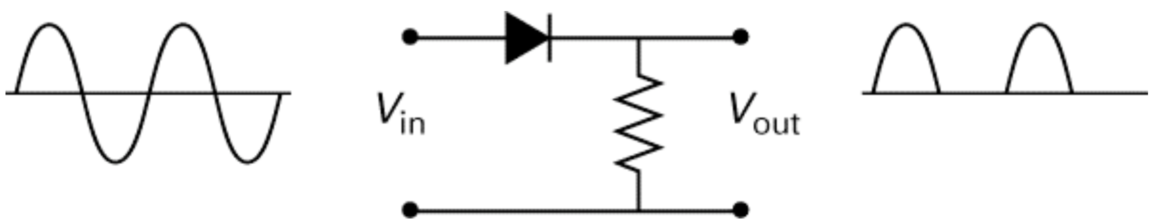
Since the Zener diode is at the Zener voltage in the reverse bias direction when it suffers breakdown, (D) is correct. Note that answers (B) and (C) are the same (just worded differently), so they both must be wrong.

Therefore, the answer is (D).

Diode Applications

Half-Wave Rectifiers

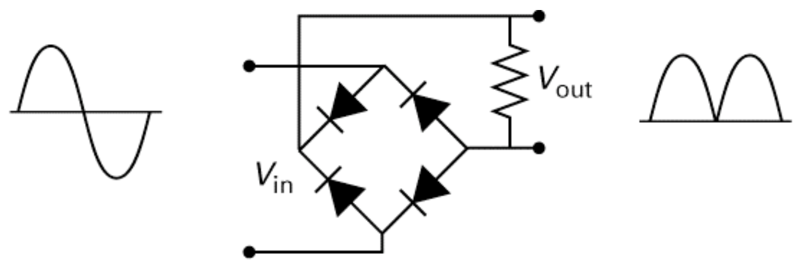
- Half of a symmetric AC signal gets through
- Used in AC-to-DC converters

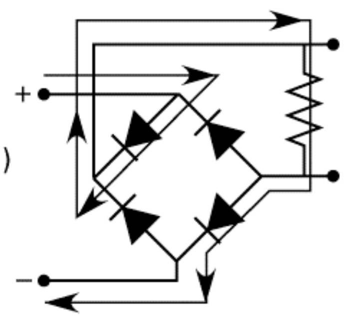


Diode Applications

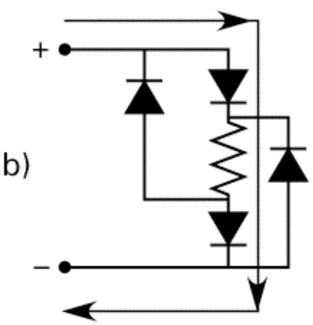
Full-Wave (Bridge) Rectifiers

- Current is always going in the same direction
- Used in AC-to-DC converters, and are more efficient than half-wave rectifiers

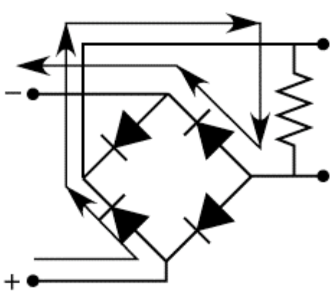




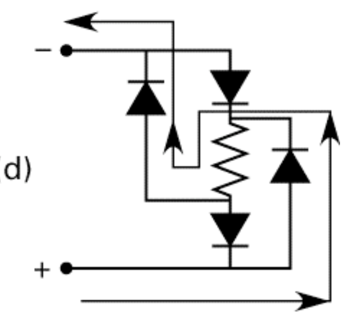
(a)



(b)



(c)



(d)

Diode Applications

Clamping Circuits

Output Voltage:

$V_{out} = V_{in} + V_p - V_m$

where

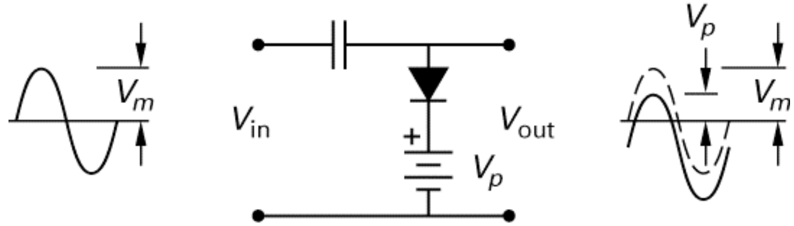
V_{in} = the input voltage

V_p = the clamping voltage

V_m = the maximum voltage of the input

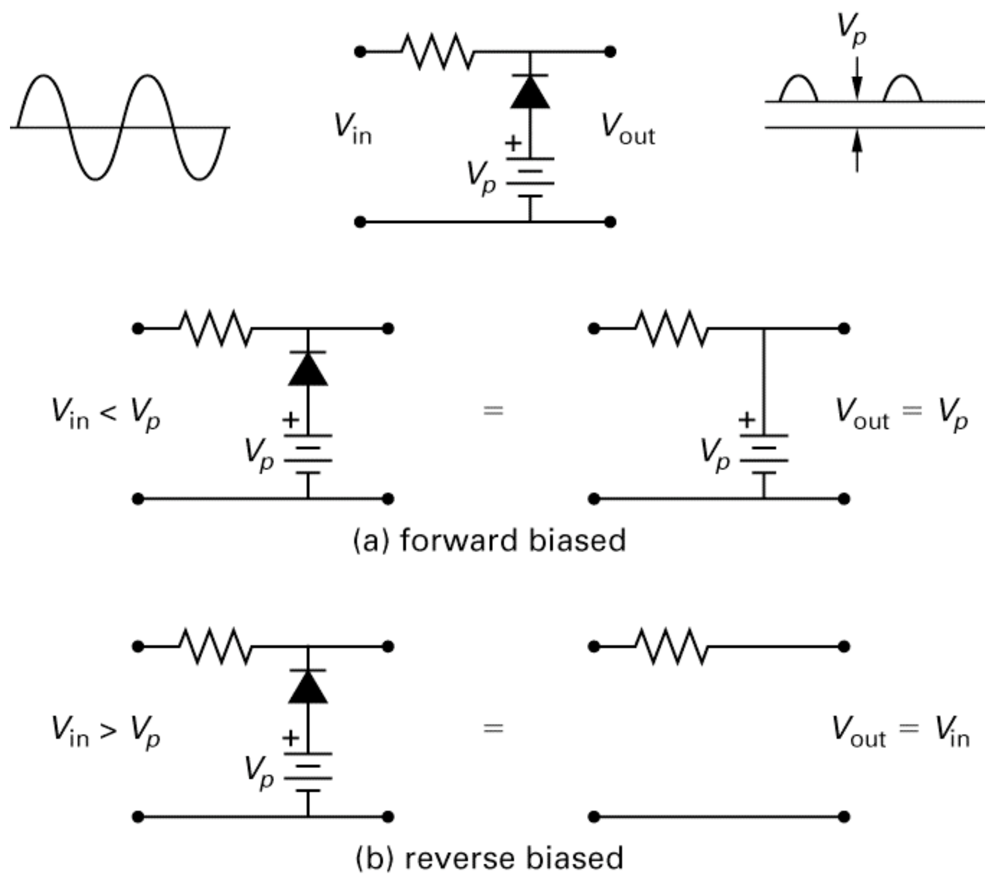
For a clamping circuit output with a *sinusoidal* input:

- Average Voltage: $V_{ave} = V_p - V_m$
- RMS Voltage: $V_{rms} = \frac{1}{\sqrt{2}} V_m + V_p - V_m$



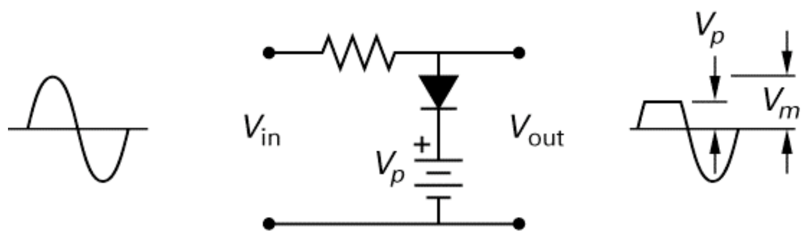
Diode Applications

Base Clipper

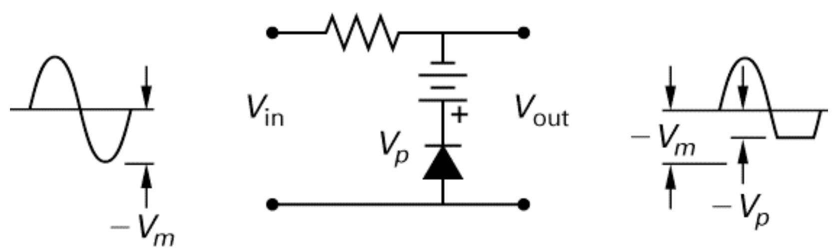


Diode Applications

Peak Clipper



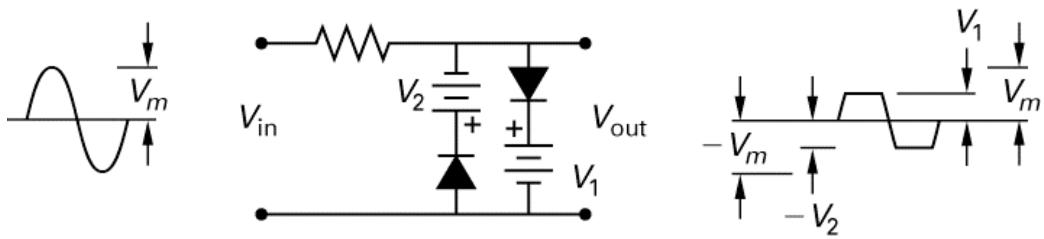
Valley Clipper



Diode Applications

Combined Clipper

1. Valley clipper + peak clipper

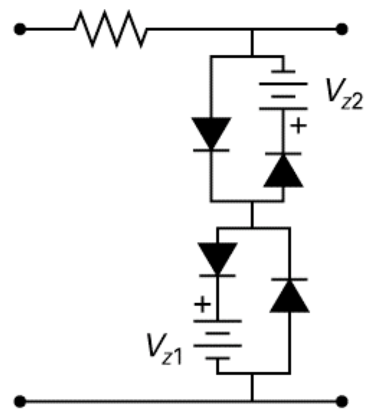


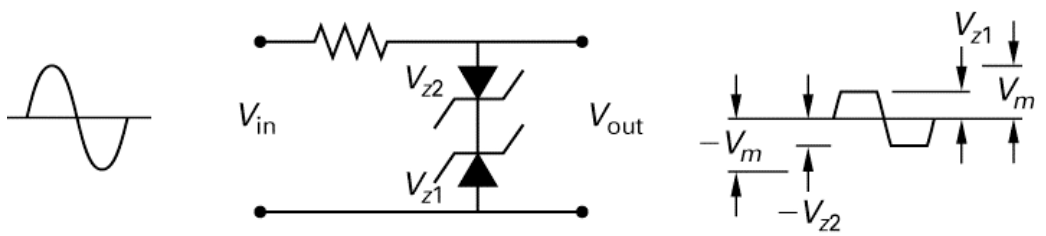
Diode Applications

Combined Clipper (cont.)

2. Two Zener diodes in series in the opposite direction

The ideal model for the Zener diode:





Diode Applications

Example (FEIM):

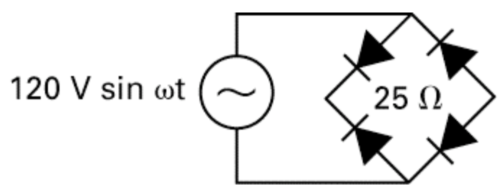
What is the average current through the resistor in the rectifier shown? Assume ideal diodes.

(A) 0 A

(B) 0.76 A

(C) 3.06 A

(D) 4.80 A



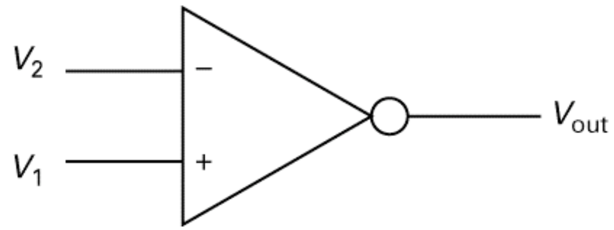
This is a full-wave rectifier, so

$$V_{ave} = \frac{2V_{peak}}{\pi} = \frac{(2)(120\text{ V})}{\pi}$$

$$I_{ave} = \frac{V_{ave}}{R} = \left(\frac{240\text{ V}}{\pi}\right)\left(\frac{1}{25\ \Omega}\right) = 3.06\text{ A}$$

Therefore, (C) is correct.

Operational Amplifiers

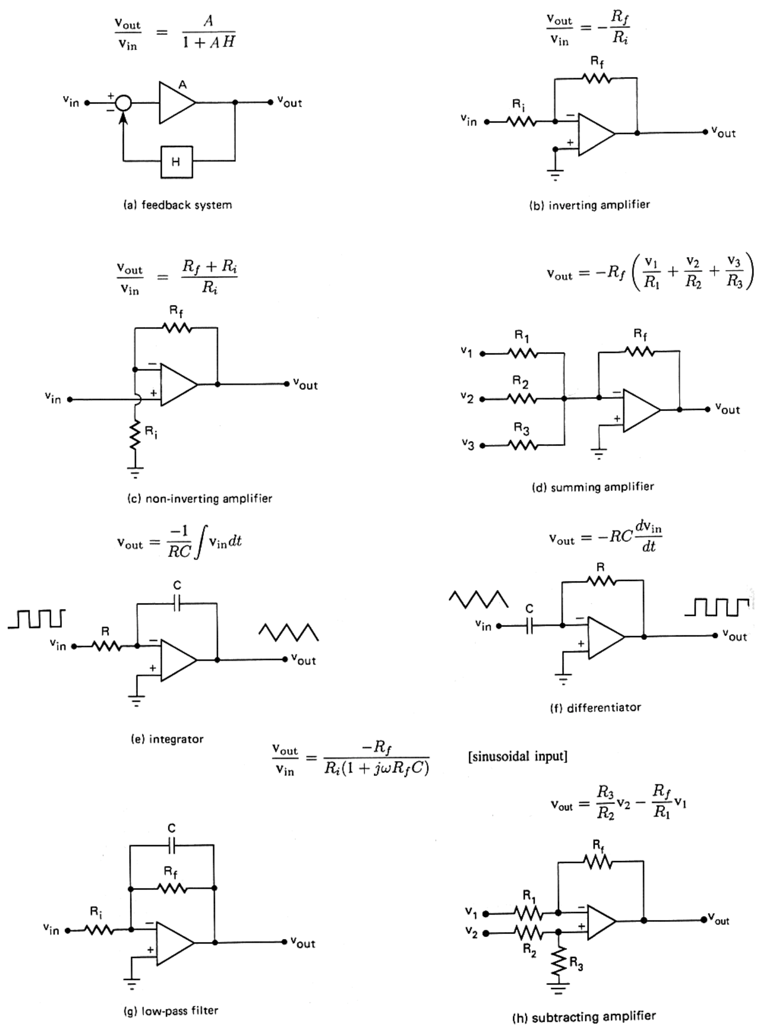


- An electronic device used to perform mathematical operations on analog signals.
  - Two inputs, one output, small current, and large gain

Operational Amplifiers

EIT8 Table 51.1

Table 51.1
Operational Amplifier Circuits

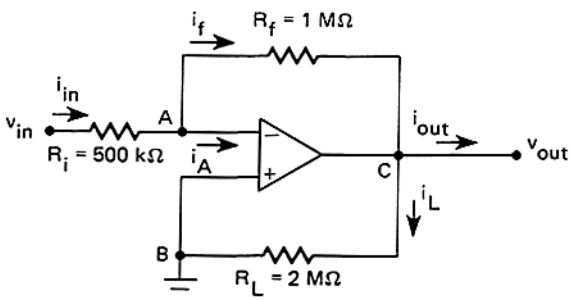


Operational Amplifiers

Example (EIT8):

Example 51.4

The circuit shown uses an ideal op amp and receives a 1 μV signal. Find the (a) current through the feedback resistor, (b) voltage gain, and (c) current through the load resistor.



(solution)

(a) Since the op amp is ideal, $i_A = 0$ and $v_A = v_B = 0$. The current through the input resistor is calculated from the voltage drop across it.

$$v_{in} - v_A = v_{in} - 0 = i_{in} R_i$$

$$i_{in} = \frac{v_{in}}{R_i} = \frac{1 \times 10^{-6}\ \text{V}}{500 \times 10^3\ \Omega} = 2 \times 10^{-12}\ \text{A}$$

However, $i_A = 0$, so $i_f = i_{in} = i = 2 \times 10^{-12}$ A.

(b) Similarly,

$$v_{out} = v_C = -i_f R_f$$

$$A_V = \frac{v_{out}}{v_{in}} = \frac{-iR_f}{iR_i} = \frac{-R_f}{R_i}$$

$$= \frac{-1 \times 10^6\ \Omega}{500 \times 10^3\ \Omega} = -2$$

(c) Since v_A and v_B are both zero, v_C can be calculated in two ways.

$$v_C = i_f R_f = i_L R_L$$

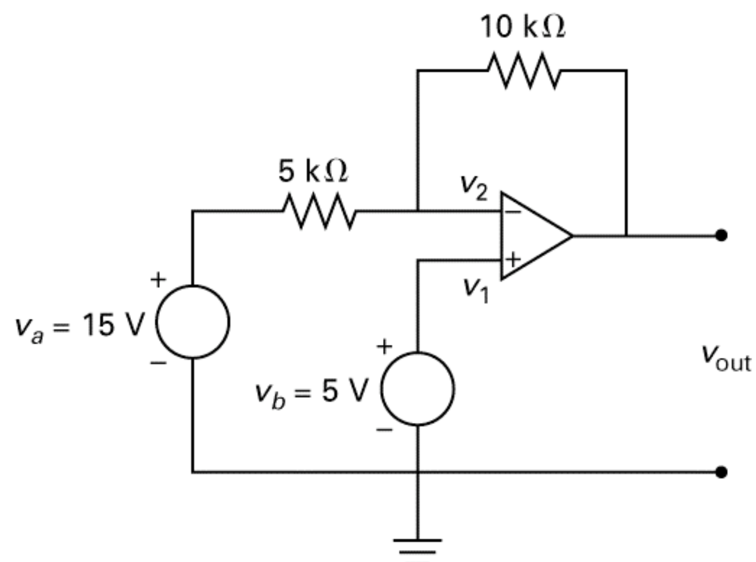
$$i_L = i_f \left(\frac{R_f}{R_L}\right) = (2 \times 10^{-12}\ \text{A}) \left(\frac{1\ \text{M}\Omega}{2\ \text{M}\Omega}\right)$$

$$= 1 \times 10^{-12}\ \text{A}$$

Input Impedance

Example 1 (FEIM):

What is the input impedance as seen by the source v_a of the following circuit?



(A) 5 kΩ
(B) 7.5 kΩ
(C) 10 kΩ
(D) 12.5 kΩ

Electronics

Input Impedance

The input voltage is 15 V. The input current is

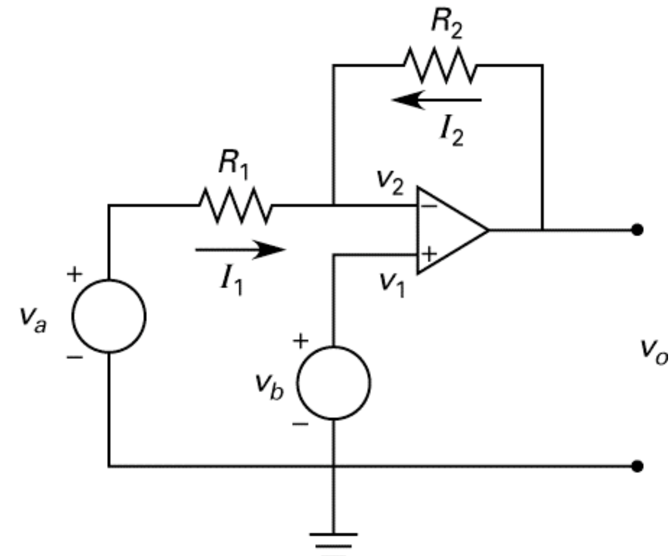
$$i_{\text{in}} = \frac{15\ \text{V} - 5\ \text{V}}{5\ \text{k}\Omega} = 2\ \text{mA}$$

The input impedance is the absolute value of the input voltage over the input current. So the input impedance is

$$Z_{\text{in}} = \frac{V_{\text{in}}}{i_{\text{in}}} = \frac{15\ \text{V}}{2\ \text{mA}} = 7.5\ \text{k}\Omega$$

Therefore, (B) is correct.

Amplifiers



$$I_1 = \frac{V_a - V_b}{R_1} \qquad I_2 = \frac{V_o - V_b}{R_2}$$

Therefore,

$$\frac{V_a - V_b}{R_1} = \frac{V_o - V_b}{R_2}$$

$$V_o = \frac{R_2}{R_1} V_a + \left(1 + \frac{R_2}{R_1}\right) V_b$$

Amplifiers

Noninverting Amplifiers

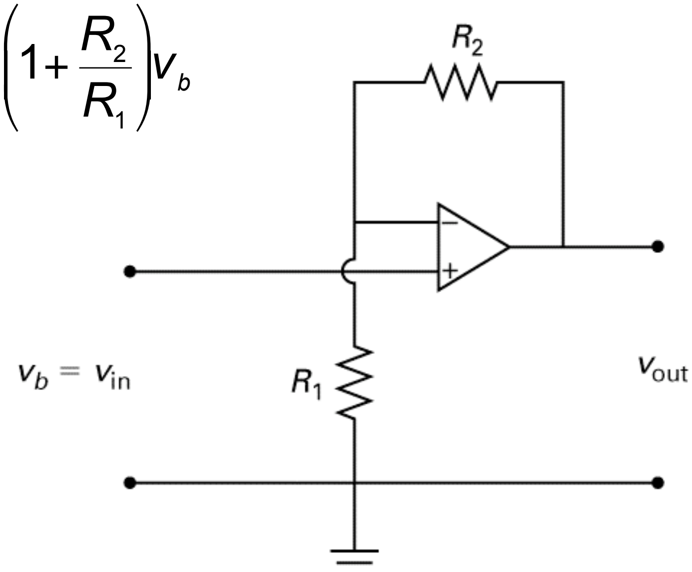
- $v_a = 0$
- $v_1 = v_2$

Since v_2 is a voltage divider circuit of the operational amplifier output,

$$v_2 = \left(\frac{R_1}{R_2 + R_1}\right) v_{\text{out}}$$

Since $v_b = v_1 = v_2$, we can substitute and solve for v_{out}:

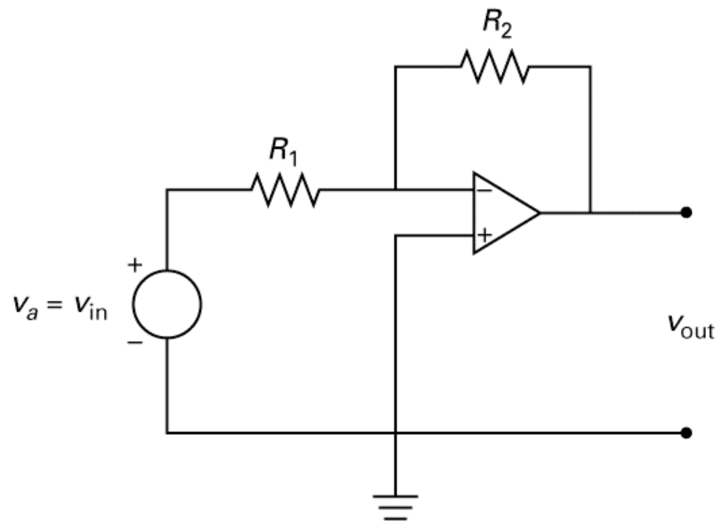
$$v_{\text{out}} = \left(1 + \frac{R_2}{R_1}\right) v_b$$



Amplifiers

Inverting Amplifiers

- $v_b = 0$
- $v_1 = v_2 = 0$



Since $v_1 = v_2 = 0$,

input current: $i_{in} = \frac{v_a}{R_1}$

current through the feedback resistor: $i_f = \frac{v_{out}}{R_2}$

Since $i_{in} = -i_f$,

$$\frac{v_a}{R_1} = -\frac{v_{out}}{R_2} \quad v_{out} = \frac{-R_2}{R_1} v_a$$

Amplifiers

Summing Amplifiers

- Superposition theorem – currents can be treated as independent forces trying to push electrons into (or out of) node A.

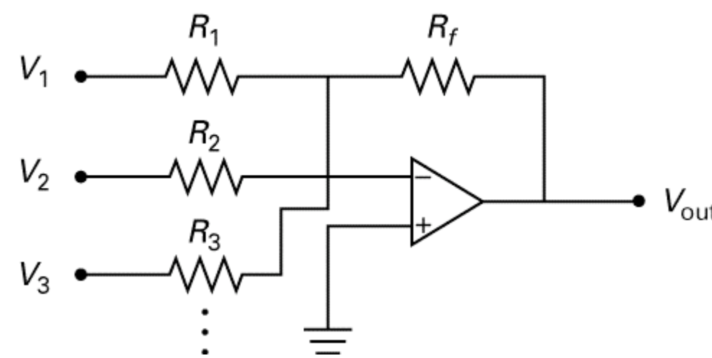
$$-i_f = i_1 + i_2 + i_3 + \cdots$$

$$-\frac{v_{out}}{R_f} = \frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} + \cdots$$

$$v_{out} = -R_f\left(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} + \cdots\right)$$

For the noninverting amplifier:

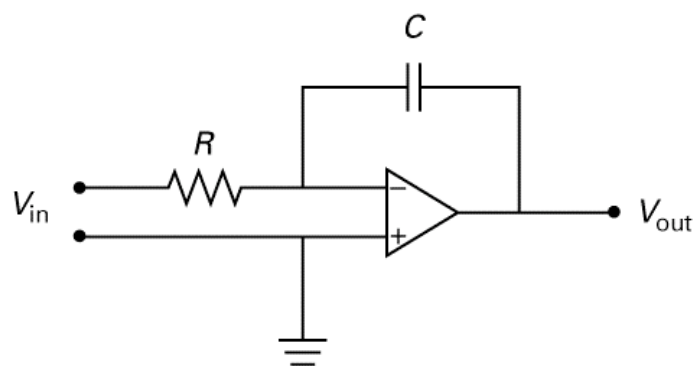
$$v_{out} = \left(1 + \frac{R_2}{R_1}\right)v_1$$



Amplifiers

Integrating Amplifiers

- Similar to inverting amplifier, feedback current has to be equal and opposite to the input current.
- The output voltage is the voltage across the capacitor.



Assume the initial voltage on the capacitor = 0; the voltage on the capacitor is:

$$v_{out} = \frac{1}{C}\int i\,dt$$

Applying Ohm's law:

$$v_{out} = \frac{1}{RC}\int v_{in}\,dt$$

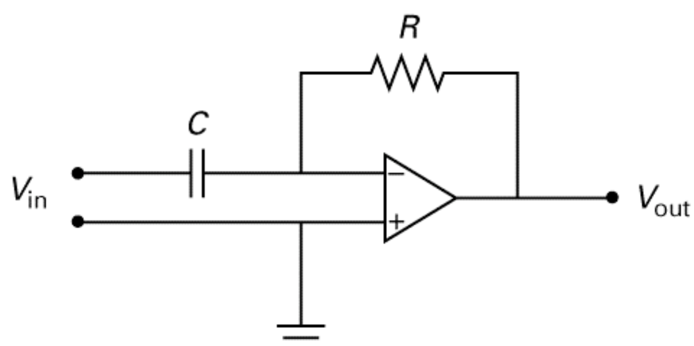
Amplifiers

Differentiating Amplifiers

- Feedback current has to be equal and opposite to the input current.
- The output voltage is the voltage across the resistor.

Since $v_1 = v_2 = 0$: $i = C\dfrac{dv_{in}}{dt}$

Substituting into $v_{out} = -iR$ gives: $v_{out} = -RC\dfrac{dv_{in}}{dt}$



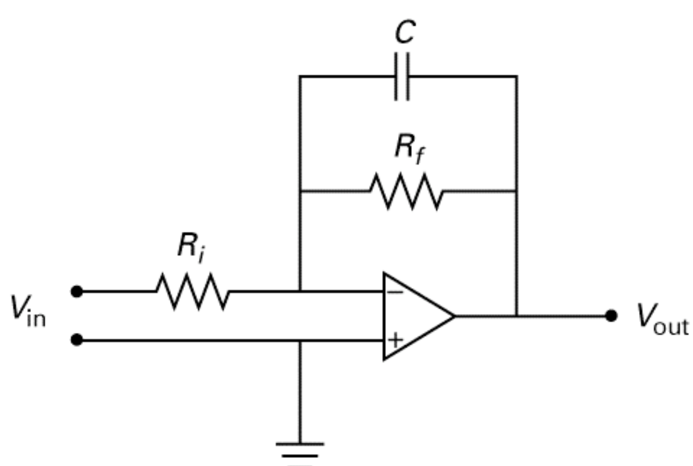
Amplifiers

Low-Pass Filters

The output voltage divided by the feedback impedance is equal and opposite to the input voltage divided by the input impedance.

$$\frac{v_{\text{out}}}{v_{\text{in}}} = -\frac{Z_f}{Z_{\text{in}}} = -\frac{1}{Z_{\text{in}} Y_f} = -\frac{1}{R_i\left(\dfrac{1}{R_f} + j\omega C\right)}$$

$$\frac{v_{\text{out}}}{v_i} = \frac{-R_f}{R_i\left(1 + j\omega R_f C\right)}$$



Amplifiers

Example 1 (FEIM):

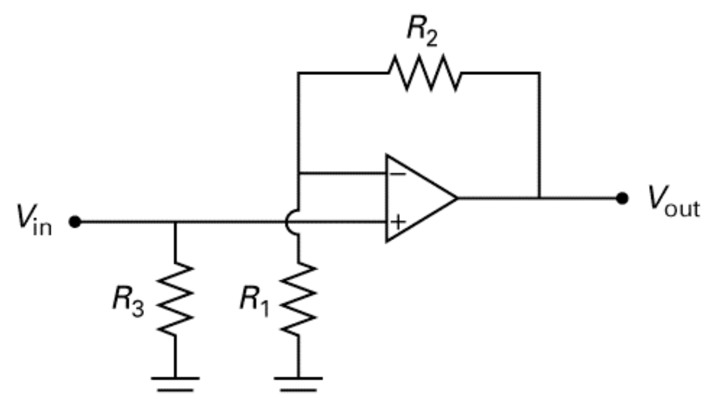
What is the input impedance of the following ideal amplifier?

(A) R_1

(B) R_3

(C) $\frac{R_2}{R_1} + R_3$

(D) $\frac{R_1 R_3}{R_1 + R_2}$



$$i_{in} = i_a + i_3$$

$i_a = 0$, because this is an ideal op amp.

$$R_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{in}}{i_3} = R_3$$

Therefore, (B) is correct.

Amplifiers

Example 2 (FEIM):

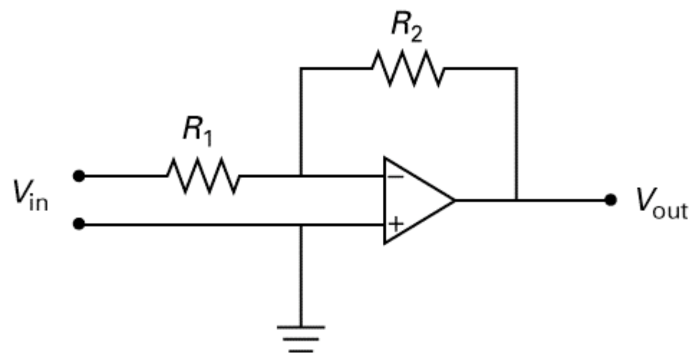
What is the input impedance of the ideal amplifier shown?

(A) R_1

(B) R_2

(C) $\frac{R_2}{R_1}$

(D) $\frac{R_1}{R_1 + R_2}$



$$R_{in} = \frac{V_{in}}{i_{in}} \qquad i_{in} = \frac{V_{in} - V_a}{R_1}$$

$V_a = 0$ because this is an ideal op amp.

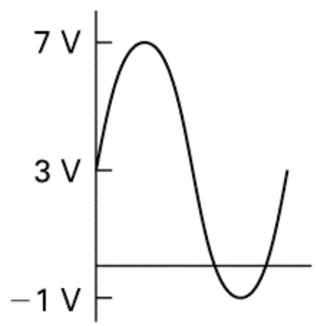
Substituting yields:

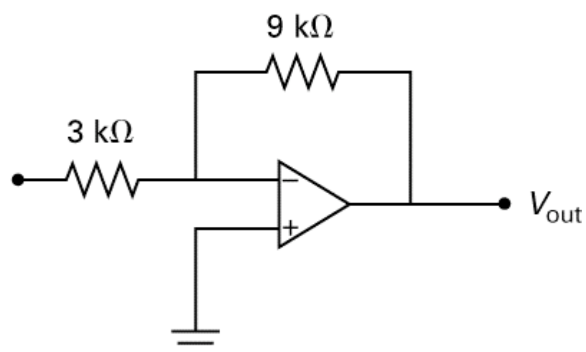
$$R_{in} = V_{in}\left(\frac{R_1}{V_{in}}\right) = R_1$$

Therefore, (A) is correct.

Amplifiers

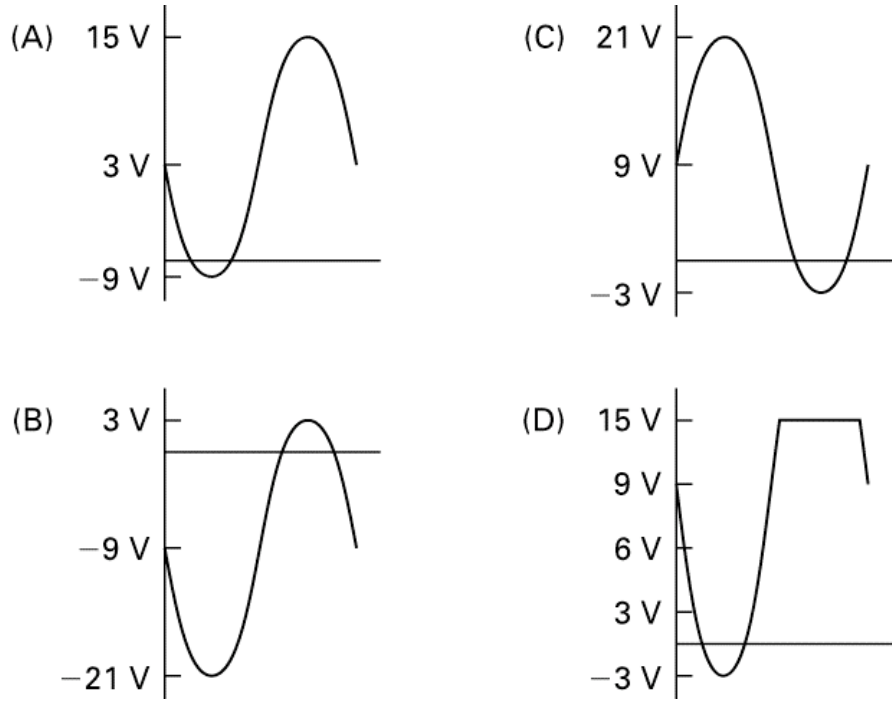
Example 3 (FEIM):
The 700 Hz signal shown is applied to the ideal amplifier circuit shown. What will the output signal be?





Electronics 16-8j2

Amplifiers



The input current and feedback currents must be equal and opposite, so:

$$i_{in} = \frac{V_{in}}{3\,\text{k}\Omega} = -i_{feedback} = \frac{-V_{out}}{9\,\text{k}\Omega} \qquad \frac{V_{out}}{V_{in}} = \frac{-9\,\text{k}\Omega}{3\,\text{k}\Omega} = -3$$

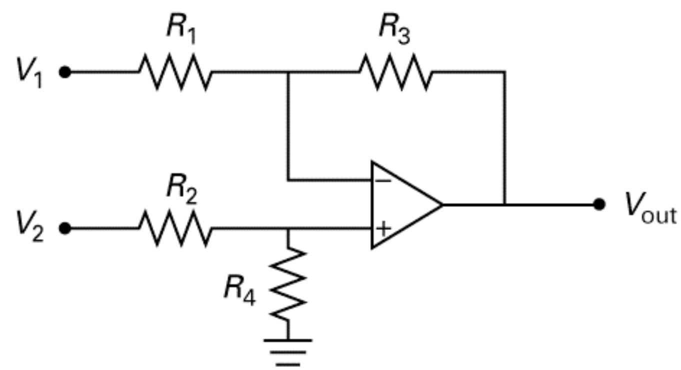
Both the DC and AC part are multiplied by –3.
Therefore, (B) is correct.

Amplifiers

Example 4 (FEIM):

Two AC signals V_1 and V_2 are to be combined such that $V_{out} = \frac{3}{2}V_2 - \frac{5}{2}V_1$.

The following subtracting amplifier circuit is used. What must be the values of R_1, R_2, R_3, and R_4?



(A) $R_1 = 2\ \text{k}\Omega,\ R_2 = 2\ \text{k}\Omega,\ R_3 = 5\ \text{k}\Omega,\ R_4 = 3\ \text{k}\Omega$

(B) $R_1 = 2\ \text{k}\Omega,\ R_2 = 4\ \text{k}\Omega,\ R_3 = 5\ \text{k}\Omega,\ R_4 = 3\ \text{k}\Omega$

(C) $R_1 = 4\ \text{k}\Omega,\ R_2 = 8\ \text{k}\Omega,\ R_3 = 10\ \text{k}\Omega,\ R_4 = 2\ \text{k}\Omega$

(D) $R_1 = 5\ \text{k}\Omega,\ R_2 = 3\ \text{k}\Omega,\ R_3 = 4\ \text{k}\Omega,\ R_4 = 2\ \text{k}\Omega$

Amplifiers

$$V_a = V_2\left(\frac{R_4}{R_2 + R_4}\right)$$

$$i_1 = \frac{V_1 - V_a}{R_1} = -i_{\text{out}} = -\left(\frac{V_{\text{out}} - V_a}{R_3}\right)$$

Solving for V_{out} yields:

$$V_{\text{out}} = \left(\frac{R_1 + R_3}{R_1}\right)\left(\frac{R_4}{R_2 + R_4}\right)V_2 - \frac{R_3}{R_1}V_1 = \frac{3}{2}V_2 - \frac{5}{2}V_1$$

$$\frac{R_3}{R_1} = \frac{5}{2}$$

So the possibilities narrow to (A), (B), and (C).
Trying R_1 = 2 kΩ in the other relationship yields

$$\left(\frac{R_1 + R_3}{R_1}\right)\left(\frac{R_4}{R_2 + R_4}\right) = \left(\frac{2+5}{2}\right)\left(\frac{R_4}{R_2 + R_4}\right) = \frac{3}{2}$$

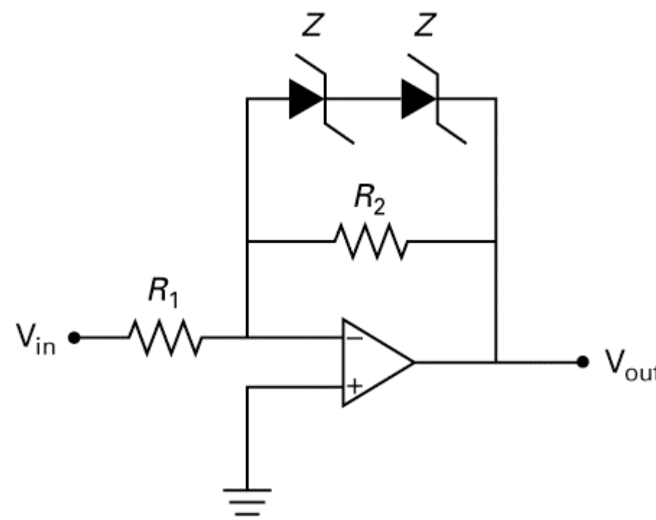
$4R_4 = 3R_2$
Answer (B) fits because R_4 = 3 kΩ, and R_2 = 4 kΩ.
Plugging in to confirm,

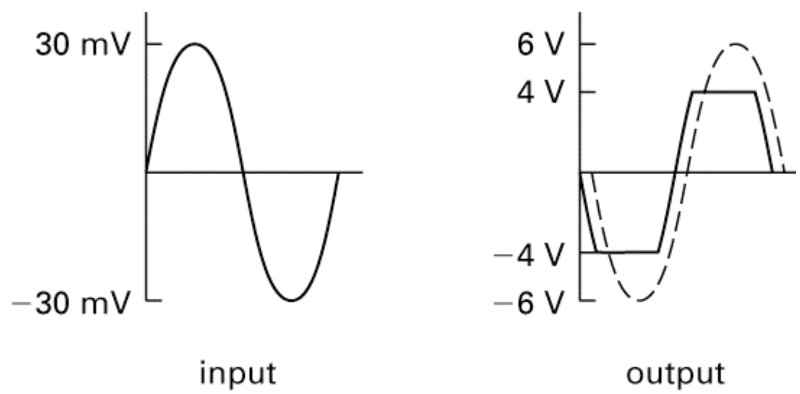
$$V_{\text{out}} = \left(\frac{2+5}{2}\right)\left(\frac{2}{4+3}\right)V_2 - \frac{5}{2}V_1 = \frac{3}{2}V_2 - \frac{5}{2}V_1$$

Therefore, (B) is correct.

Amplifiers

Example 5 (FEIM):
A 30 mV sinusoidal signal must be inverted, amplified to 6 V (peak), and chopped at 4 V. If the following circuit is used, what are the values of R_1 and R_2, and the avalanche voltage of the Zener diodes Z? Assume –0.7 V forward bias voltage drop and negligible diode resistance.





(A) R_1 = 1 kΩ, R_2 = 20 kΩ, Z = 4 V
(B) R_1 = 1 kΩ, R_2 = 200 kΩ, Z = 4 V
(C) R_1 = 2 kΩ, R_2 = 400 kΩ, Z = 3.3 V
(D) R_1 = 2 kΩ, R_2 = 800 kΩ, Z = 3.3 V

Amplifiers

The amplification without clipping is

$$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} = \frac{-6\ \text{V}}{30\times10^{-3}\ \text{V}}$$

$$R_2 = 200\,R_1$$

This narrows the choices to (B) and (C).

When $|V_{in}| > 2$ mV, the diodes will be forward biased and reversed biased respectively, so the voltage across the two diodes in series will be the Zener voltage plus the forward bias voltage. Thus, the Zener voltage is 3.3 V.

Therefore, (C) is correct.