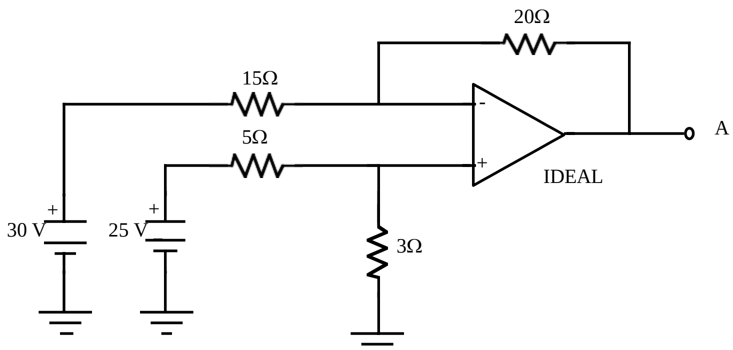
Solving problem

SAMPLE PROBLEMS

4. For the difference amplifier circuit shown, determine the output voltage at terminal A.



(A) - 18.13 V
(B) -6.07 V
(C) 6.07 V
(D) 15.45 V

Solution:

By voltage division,

$$v_{in+} = 25V\left(\frac{3\Omega}{5\Omega + \quad \Omega}\right) = 9.375V$$

By the virtual short circuit between the input terminals, v_{in-} = 9.375 V
Using **Ohm's** law, the current through the 15 **Ω** resistor is

$$I_{15} = \left(\frac{30V - 9.375V}{15\Omega}\right) = 1.375V$$

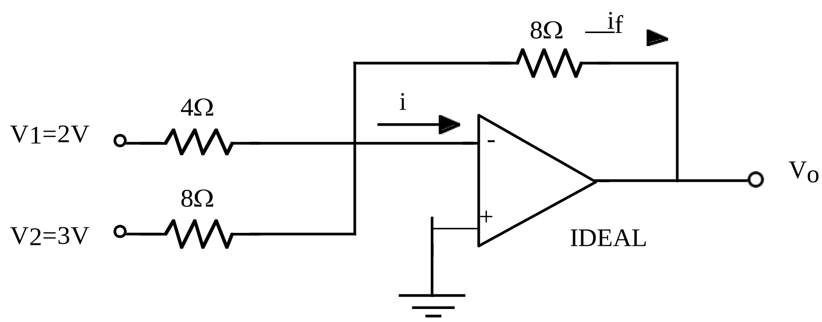
The input impedance is infinite; therefore, $I_{in-}=0$ and $I_{15}=I_{20}$.

Use Kirchoff's voltage law to find the output voltage at A.

$v_A=v_{in-} - 20I_{20}$ = 9.375 V - (20Ω)(1.375 A) = -18.125 V

Answer is A.

Problems 2 and 3 refer to the following figure.



2. What is the current, i?

(A) -0.88 A
(B) -0.25 A
(C) 0 A
(D) 0.25 A

Solution 2:

The input current in an op amp is so small that it is assumed to be zero.

Answer is C.

3. What is the output voltage, v_o?

(A) -7 V
(B) -6 V
(C) -1 V
(D) 6 V

Solution 3:

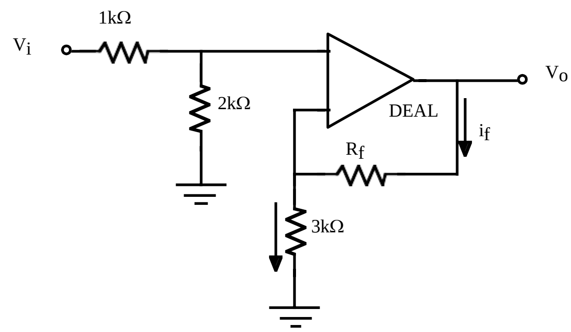
This op amp circuit is a summing amplifier. Since i=0,

$$i_f = \frac{v_1}{R_1} + \frac{v_2}{R_2} = \frac{3\text{ V}}{8\ \Omega} + \frac{2\text{ V}}{4\ \Omega} = 0.875\text{ A}$$

$v_o = -i_f R_f = -(0.875\text{ A})(8\ \Omega) = -7\text{ V}$

Answer is A.

4. For the ideal op amp shown, what should be the value of resistor R_f to obtain a gain of 5?



(A) 12.0 kΩ
(B) 19.5 kΩ
(C) 22.5 kΩ
(D) 27.0 kΩ

Solution:
By voltage division, $v_{in+} = v_i\left(\frac{2k\Omega}{3k\Omega}\right) = \frac{2}{3}v_i$

By the virtual short circuit, $v_{in-} = v_{in+} = \frac{2}{3}v_i$

$$i = \frac{v_{in-}}{3k\Omega} = \frac{\frac{2}{3}v_i}{3k\Omega}$$

Since the op amp draws no current, i_f=i

$$\frac{v_o - v_{in-}}{R_f} = \frac{\frac{2}{3}v_i}{3k\Omega}$$

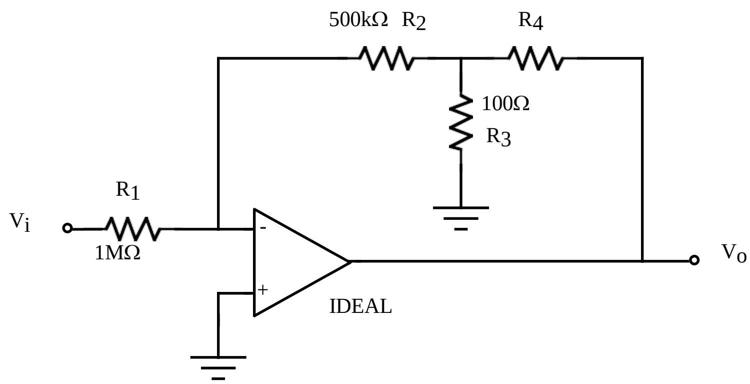
But, $v_o = 5v_i$.

$$\frac{5v_i - \frac{2}{3}v_i}{R_f} = \frac{\frac{2}{3}v_i}{3k\Omega}$$

$$\frac{\frac{13}{3}}{R_f} = \frac{\frac{2}{3}}{3k\Omega}$$

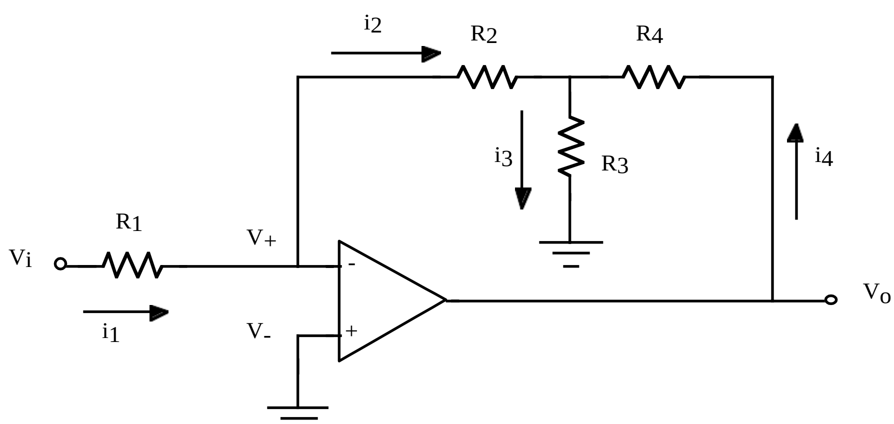
R_f=19.5 kΩ, Answer is B.

5. Evaluate the following amplifier circuit to determine the value of resistor R_4 in order to obtain a voltage gain (v_o/v_i) of -120.



(A) 25 Ω
(B) 23 kΩ
(C) 24 kΩ
(D) 25 kΩ

Solution:



v_{in+} is grounded, so v_{in-} is also a virtual ground.

$v_{in-} = 0$

Since $v_{in-} = 0$, $v_i = i_1 R_l$ and $i_l = v_i/R_1$.

Since $v_{in-} = 0$, $v_x = -i_2 R_2$ and $i_2 = -v_x/R_2$.

Similarly,
$v_x = -i_3 R_3$
$v_x - v_o = -i_4 R_4$

From Kirchhoff's current law,

$i_4 = i_2 + i_3$

$$\frac{v_x - v_o}{R_4} = \frac{-v_x}{R_2} + \frac{-v_x}{R_3}$$

Now, $v_o=-120v_i$.

Also, $i_l=i_2$, so

$$\frac{v_i}{R_1} = \frac{-v_x}{R_2}$$

$$v_x = -\left(\frac{R_2}{R_1}\right)v_i$$

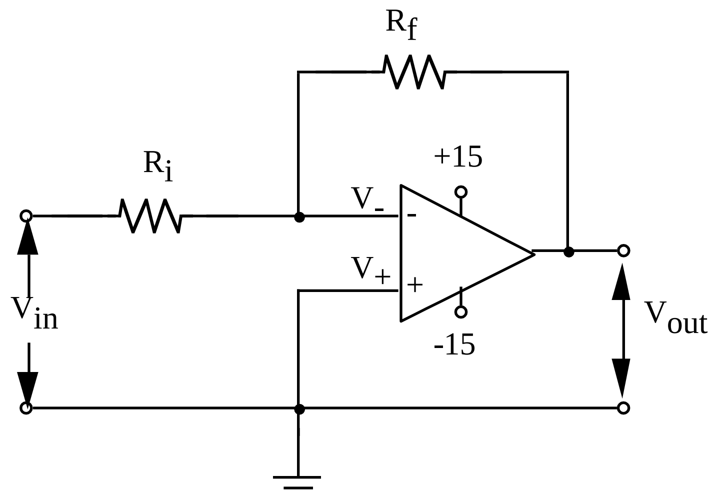
$$\frac{-\left(\frac{R_2}{R_1}\right)v_i - (-120v_i)}{R_4} = \frac{\left(\frac{R_2}{R_1}\right)v_i}{R_2} + \frac{\left(\frac{R_2}{R_1}\right)v_i}{R_3}$$

$$\frac{120\left(\frac{R_1}{R_2}\right) - 1}{R_4} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{R_2 + R_3}{R_2 R_3}$$

$$R_4 = \frac{120\left(\frac{R_1}{R_2}\right) - 1}{\frac{R_2 + R_3}{R_2 R_3}} = \frac{120\left(\frac{1x10^6\,\Omega}{5x10^5\,\Omega}\right) - 1}{\frac{5x10^5\,\Omega + 100\Omega}{(5x10^5\,\Omega)(100\Omega)}} = 2.39x10^4\,\Omega\ (24\ \text{k}\Omega)$$

Answer is C.

13. For the circuit shown below:

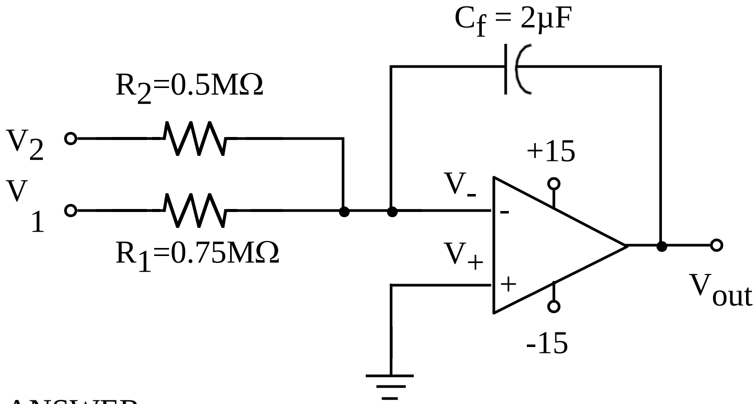


(a) If R_f = 1MΩ and R_i=50Ω, what is the voltage gain?
There are two ways to solve any problem involving an op amp. The first way is to use the formulas given in the Reference Handbook. Explicitly, $v_o = -\frac{R_2}{R_1}v_a + \left(1 + \frac{R_2}{R_1}\right)v_b$ where v_a is the input to the inverting terminal and v_b is the input to the non-inverting terminal. In this case, there is no input to the non-inverting input and v_b=0. The formula reduces to the simple result $v_o = -\frac{R_2}{R_1}v_a$. Using the given circuit values, we get $v_o = -\frac{R_2}{R_1}v_a = -\frac{R_f}{R_i}v_{in} = -\frac{1M\Omega}{50\Omega}v_{in} = -20{,}000v_{in}$. The voltage gain is then -20,000. Note that any value over 100 is impractical for any real amplifier.

A more general way of solving any op amp circuit is to note that an ideal (and most real) op amps must satisify the virtual short assumption, i.e. that $V_+ = V_-$. Using this assumption and KCL at an input node is adequate to solve most any op amp problem. In this case, KCl at the inverting input gives $+\frac{V_{in}}{R_i} - \frac{0 - V_{out}}{R_f} = 0$. Rearranging, $\frac{V_{in}}{R_i} + \frac{V_{out}}{R_f} = 0$ and, solving for the voltage gain,
$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i} = -\frac{10^6}{50} = -20{,}000$ just as before

(b) If V_{in}=0.1 volts, what is V_{out}?
This is a continuation of (a). Using our voltage gain from (a) we get
$v_o = -20{,}000v_{in} = -20{,}000(0.1\ volts) = -2000\ volts$
As mentioned previously, this is a ridiculous value for an output.

14. For the circuit shown below, $V_1 = 10\sin(200t)$ and $V_2 = 15\sin(200t.)$ What is V_{out}? The op amp is ideal with infinite gain.



ANSWER:
Any problem with a capacitor (or inductor) in it and sinusoidal voltages immediately indicates that phasors are required. This means that V_1 and V_2 should be represented as phasors, and C_f should be replaced by an impedance. This problem is not solved very well with the formulas in the Reference Handbook. This circuit is most easily solved using the virtual short assumption ($V_+=V_-$), and using KCL at the inverting input. Note that the grounding of V_+ then requires that $V_-=0$. This is also called the virtual short assumption.

$$+\frac{V_2 - 0}{R_2} + \frac{V_1 - 0}{R_i} - \frac{0 - V_{out}}{1/j\omega C} = 0\ .$$

Rationalizing this expression gives $+\frac{V_2}{R_2} + \frac{V_1}{R_i} + j\omega C V_{out} = 0$.

Solving for V_{out} gives $V_{out} = -\frac{V_2}{j\omega C R_2} - \frac{V_1}{j\omega C R_i}$

It is important to recognize that all sine functions should always be converted to cosines for proper phase in the phasor expressions, i.e. $\sin(200t) = \cos(200t - 90°)\ \xi\ 1\angle -90° = -j$

Using the circuit parameters given,

$$V_{out} = -\frac{-j15}{j(200)(2 \infty 10^{-6})(0.5 \infty 10^{6})} - \frac{-j10}{j(200)(2 \infty 10^{-6})(0.75 \infty 10^{6})}$$

$$= \frac{15}{200} + \frac{10}{300} = \frac{3}{40} + \frac{1}{30}$$

The answer is then $V_{out}(t) = \left(\frac{3}{40} + \frac{1}{30}\right)\cos(200t)$

Diodes

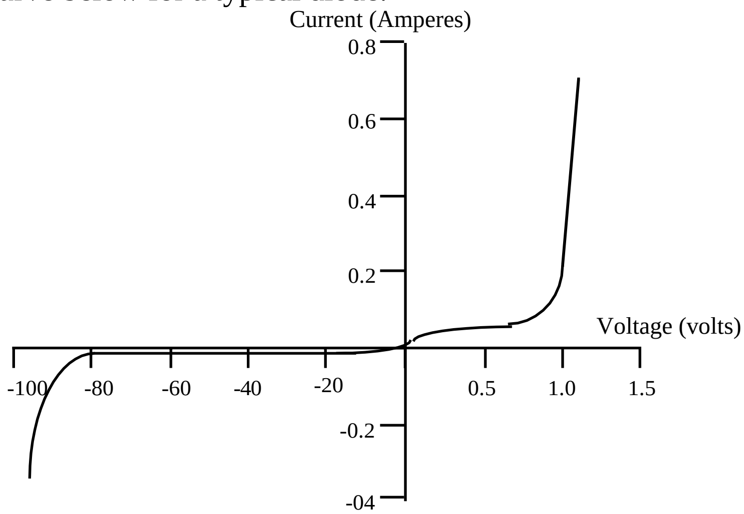
1. A germanium diode is operated at 20° C. A reverse bias of -1.5 volts results in a current of 70μA. Assuming that the temperature remains constant:

(a) What is the saturation current?

The general formula for the diode is $I = I_s\left(e^{\frac{qV}{\eta kT}} - 1\right)$. Solving for I_s gives $I_s = \dfrac{I}{e^{\frac{qV}{\eta kT}} - 1}$. Using the given parameters and recognizing that $\eta \approx 1$ for a germanium diode, we get

$$I_s = \frac{-70\ \mu A}{e^{\frac{(1.6\times10^{-19}C)(-1.5\ V)}{(1)(1.38\times10^{-23}J/)(20+273\ °K)}} - 1} \approx \frac{-70\ \mu A}{-1} = +70\ \mu A$$

As a point of information this current is essentially constant throughout the reverse bias region of the diode. See the curve below for a typical diode.



(b) What is the current that flows for a forward bias of +0.2 volts?

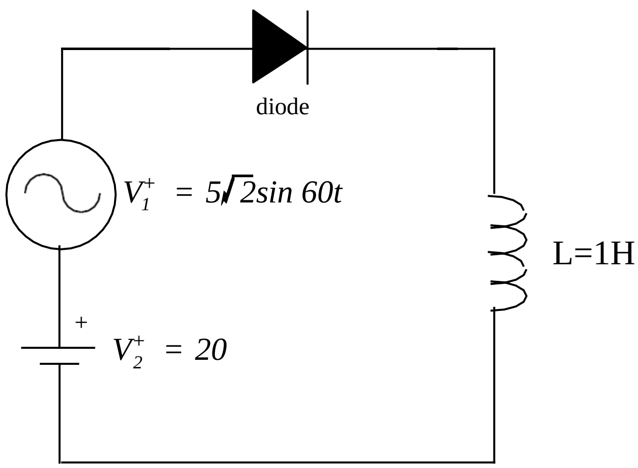
We use a commonly known result here to simplify the math, i.e. that, at room temperature, $\frac{q}{kT} \approx 40/_{volts}$. For this problem, using the I_S from (a),

$$I = I_s\left(e^{\frac{qV}{\eta kT}} - 1\right) \approx I_s\left(e^{\frac{V(40/volts)}{\eta}} \quad 1\right)$$

$$= (70\mu A)\left(e^{\frac{+0.2\ volts\ (40/volts)}{(1)}} - 1\right) = (70\mu A)\left(e^{+8} - 1\right) \approx 0.209\ amperes$$

(c) What is the current that flows for a forward bias of +0.2 volts at 40° C?

2. A voltage $V = 20 + 5\sqrt{2}\sin 60t$ (volts) is applied to the circuit shown below. The diode characteristics are static forward resistance r_f=120Ω and dynamic resistance r_p=100Ω. What is the voltage across the inductance?



This is a trick question since the V_2^+ voltage (+20 volts) > V_1^+ ($\pm 5\sqrt{2}$ volts max.) the diode is always forward biased and always conducting. Therefore, the diode serves no useful purpose. The model for the diode then becomes an ideal diode (which can be ignored) and a 100Ω dynamic resistance.

The circuit becomes that of a voltage divider. We can use superposition to determine the voltage across the inductor. Since the inductor appears as a short to the DC source the contribution from that source is zero. For the AC source we have a reactive voltage divider.

$$V_L = \frac{j\left(60\,{}^{rad}/_{sec}\right)(1)}{j\left(60\,{}^{rad}/_{sec}\right)(1) + 100\Omega}\left(-j5\sqrt{2}\ volts\right)$$

$$= \frac{j60}{j60 + 100}\left(-j5\sqrt{2}\ volts\right) = \left(0.26 + j0.44\right)\left(-j5\sqrt{2}\ volts\right)$$

$$= \left(+3.12 - j1.87\right)volts = 3.64\angle -31°$$

The total voltage across the inductor is then the sum of the ac and dc voltages or 3.64∠-31° volts.

3. At 25° C a germanium diode shows a saturation current of 100µA.

(a) What current would you expect at 100° C when the diode becomes "useless"?

This is simply formula evaluation. The saturation current doubles every 10° C. Therefore,

$$\frac{I_{s2}}{I_{s1}} = 2^{\frac{\Delta T}{10°C}} = 2^{\frac{100°C - 25°C}{10°C}} = 2^{7.5} = 181$$

This gives $I_{s2} = 181 I_{s1} = 181\left(100\mu A\right) = 18.1\ mA$

(b) What current would you expect at 0° C ?

Using the same approach we have

$$I_{s2} = 2^{\left(\frac{\Delta T}{10°C}\right)} I_{s1} = 2^{\left(\frac{0°C - 25°C}{10°C}\right)} I_{s1} = 2^{-2.5} I_{s1} = 0.177\left(100\mu A\right) = 17.7\ \mu A$$

(c) At 25° C, what current is predicted for a voltage of -0.5 volts?

This is purely formula evaluation.

$$I = I_s\left(e^{\frac{qV}{\eta kT}} - 1\right) \approx I_s\left(e^{\frac{V(40/volt)}{\eta}} - 1\right)$$

$$= \left(100\mu A\right)\left(e^{\frac{-0.5\ volts(40)}{1}} - 1\right) \approx -100\ \mu A$$

4. The forward resistance of the diodes is R_f=5kΩ.

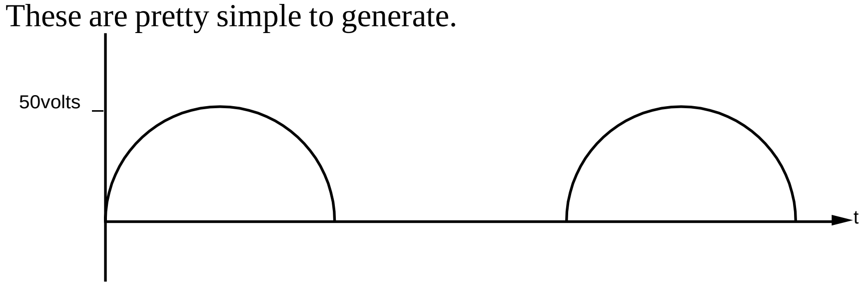
(a) What current is expected in the load resistor R_L=5kΩ if $V = 100 sin\left(\omega t\right)$volts?

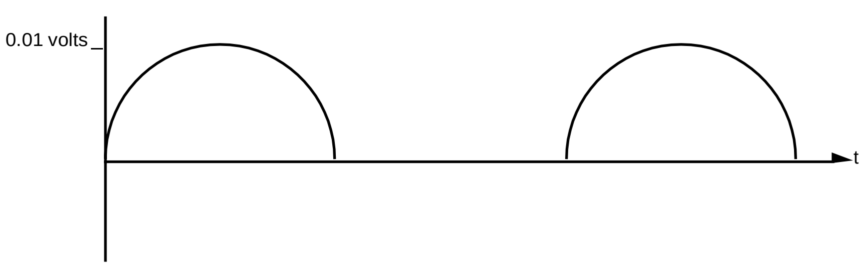
This is nothing but Ohm's Law evaluation. The diode is conducting in the positive half cycle and we use the forward resistance of the diode.

$$I = \frac{100 sin\left(\omega t\right)}{5000\Omega + 5000\Omega} = 0.01 sin\left(\omega t\right)\ volts$$

(b) Plot current and voltage versus ωt for 0 < ωt <2π.

These are pretty simple to generate.





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