13 AC ELECTRICITY

AC ELECTRICITY–1

An alternating current with a frequency of 60 Hz is passed through a moving coil galvanometer that measures DC current. What will the galvanometer reading be equal to?

(A) the peak value of the AC current
(B) the average value of the AC current
(C) the rms value
(D) a negligible amount

If the galvanometer is designed to measure DC current, it will not be able to respond quickly enough to measure an alternating current of 60 Hz. The reading will be negligible.

$\boxed{\text{The answer is (D).}}$

AC ELECTRICITY–2

Which of the following effects are generally less for an alternating current than for a direct current?

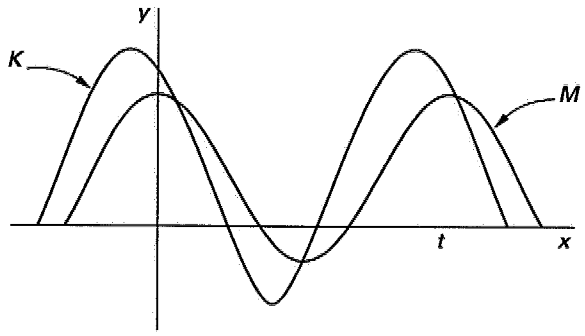
(A) heating effects (B) chemical effects (C) magnetic effects (D) impedance

Chemical effects are generally less for an AC current than for a DC current. Heating and magnetic effects are generally greater for an AC current than for a DC current. Impedance for an AC current is either larger than or the same as a DC current.

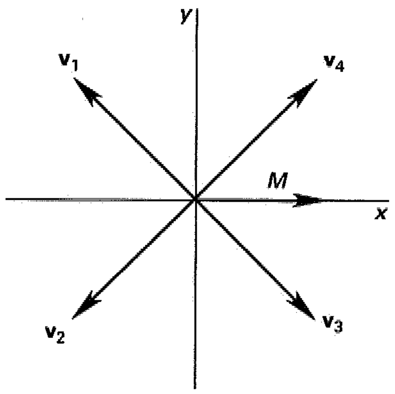
$\boxed{\text{The answer is (B).}}$

AC ELECTRICITY-3

The following two sine waves, K and M, are plotted as phasors. Determine which of the numbered vectors—$\mathbf{v}_1$, $\mathbf{v}_2$, $\mathbf{v}_3$, or $\mathbf{v}_4$—corresponds to K.



$K = K_0 \cos(\omega t + \theta)$
$M = M_0 \cos(\omega t)$



(A) $K = \mathbf{v}_1$ (B) $K = \mathbf{v}_2$ (C) $K = \mathbf{v}_3$ (D) $K = \mathbf{v}_4$

The magnitude of the vector corresponds to the amplitude of the wave. Thus, the vector, K, is longer than M. All angles are measured from the positive x-axis, with a leading angle measured counterclockwise by convention. Therefore, since the peak of K leads that of M by less than 90°, the K vector lies in the first quadrant. The only choice satisfying these conditions is option (D).

The answer is (D).

AC ELECTRICITY–4

A wire carries an AC current of $3\cos 100\pi t$ A. What is the average current over 6 s?

(A) 0 A (B) $\pi/6$ A (C) 1.5 A (D) $6/\pi$ A

If T is the total period of time and $I(t)$ is the current as a function of time, the average current is

$$I_{\text{ave}} = \frac{1}{T}\int_0^T I(t)\,dt$$

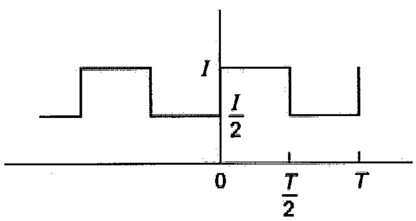
Therefore, for the particular AC current,

$$\begin{aligned} I_{\text{ave}} &= \frac{1}{6}\int_0^6 3\cos 100\pi t\,dt \\ &= \frac{1}{2}\int_0^6 \cos 100\pi t\,dt \\ &= \frac{1}{200\pi}\sin 100\pi t\Big|_0^6 \\ &= 0\text{ A} \end{aligned}$$

The answer is (A).

AC ELECTRICITY–5

What is the I_{rms} value for the waveform shown?



(A) $\frac{\sqrt{2}}{4}I$ (B) $\frac{\sqrt{3}}{4}I$ (C) $\frac{\sqrt{10}}{4}I$ (D) $\frac{\sqrt{3}}{2}I$

If T is the period and I is the current, the rms (effective) value is

$$I_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^T I^2(t)dt}$$

For the square wave shown,

$$I(t) = I \qquad 0 \le t \le \frac{T}{2}$$
$$I(t) = \frac{I}{2} \qquad \frac{T}{2} \le t \le T$$

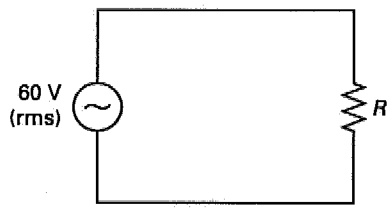
Therefore,

$$\begin{aligned}
I_{\text{rms}} &= \sqrt{\frac{1}{T}\int_0^{T/2} I^2 dt + \frac{1}{T}\int_{T/2}^{T} \left(\frac{I}{2}\right)^2 dt} \\
&= \sqrt{\left(\frac{1}{T}\right)\left(\frac{I^2T}{2}\right) + \left(\frac{1}{T}\right)\left(\frac{I^2T}{8}\right)} \\
&= \sqrt{\frac{5}{8}I^2} \\
&= \frac{\sqrt{10}}{4}I
\end{aligned}$$

The answer is (C).

AC ELECTRICITY–6

A sinusoidal AC voltage with an rms value of 60 V is applied to a purely resistive circuit as shown. What steady voltage most nearly generates the same power as the alternating voltage?



(A) 38 V (B) 42 V (C) 60 V (D) 85 V

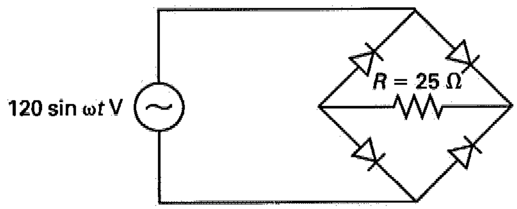
By definition of average power,

$$P_{\text{ave}} = \frac{E_{\text{rms}}^2}{R} = \frac{E^2}{R}$$
$$E = E_{\text{rms}}$$
$$= 60 \text{ V}$$

The answer is (C).

AC ELECTRICITY–7

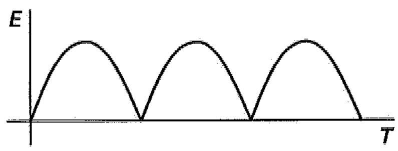
What is most nearly the average current through the resistor, R, in the rectifier shown? Assume ideal diodes.



(A) 0.0 A (B) 0.76 A (C) 3.1 A (D) 4.8 A

The type of rectifier shown is a "full wave" rectifier, with an average current of

$$I_{\text{ave}} = \frac{E_{\text{ave}}}{R}$$



E_{ave} for a full-wave rectifier is

$$E_{\text{ave}} = \frac{1}{T}\int_0^T (120 \text{ V}) \sin \omega t \, dt$$

In the preceding equation, $T = 2\pi/\omega$.

$$\begin{aligned} E_{\text{ave}} &= \frac{2}{T}\int_0^{T/2} (120\ \text{V}) \sin\omega t \, dt \\ &= \left(\frac{240\ \text{V}}{T}\right)\left(-\frac{\cos\omega t}{\omega}\right)\Bigg|_0^{T/2} \\ &= \left(\frac{240\ \text{V}}{T}\right)\left(\frac{2}{\omega}\right) \\ &= \frac{240\ \text{V}}{\pi} \end{aligned}$$

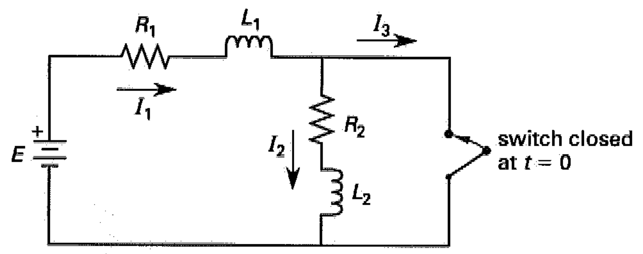
Therefore,

$$\begin{aligned} I_{\text{ave}} &= \left(\frac{240\ \text{V}}{\pi}\right)\left(\frac{1}{25\ \Omega}\right) \\ &= 3.06\ \text{A} \quad (3.1\ \text{A}) \end{aligned}$$

The answer is (C).

AC ELECTRICITY–8

For the circuit shown, $I_1 = I_2$ before the switch is closed. If the switch is closed at time $t = 0$, what is the behavior of I_1 at $t = 0$?

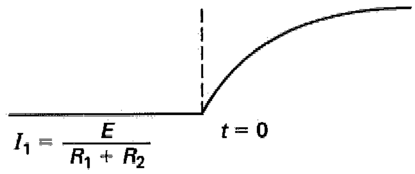


(A) I_1 is discontinuous and decreasing.
(B) I_1 is discontinuous and increasing.
(C) I_1 is continuous and decreasing.
(D) I_1 is continuous and increasing.

For $t < 0$, the current travels through L_1 and L_2. After the switch is closed, $I_1 = I_2 + I_3$, with I_2 slowly decaying through the short. As t goes to infinity, the current will travel around the outer loop with

$I_1 = I_3 = E/R_1$ and $I_2 = 0$. At $t < 0$, $I_1 = I_2 = E/(R_1 + R_2)$, but for $t \geq 0$,

$$\begin{aligned} I_1(t) &= I_1(0)e^{-R_1t/L_1} + \left(\frac{E}{R_1}\right)\left(1 - e^{-R_1t/L_1}\right) \\ &= \left(\frac{E}{R_1 + R_2}\right)e^{-R_1t/L_1} + \left(\frac{E}{R_1}\right)\left(1 - e^{-R_1t/L_1}\right) \\ &= \frac{E}{R_1} - \left(\frac{R_2E}{R_1(R_1 + R_2)}\right)e^{-R_1t/L_1} \end{aligned}$$

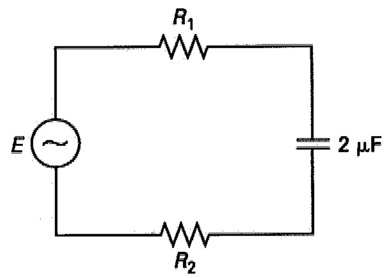


Therefore, I_1 is continuous and increasing at $t = 0$.

$\boxed{\text{The answer is (D).}}$

AC ELECTRICITY–9

A 2 μF capacitor in the circuit shown has a reactance of $X_C = 1500\ \Omega$. What is most nearly the frequency of the AC source?



(A) 3.0 Hz (B) 53 Hz (C) 60 Hz (D) 120 Hz

The reactance is

$$X_C = \frac{1}{\omega C}$$

Therefore,

$$\omega = \frac{1}{CX_C}$$

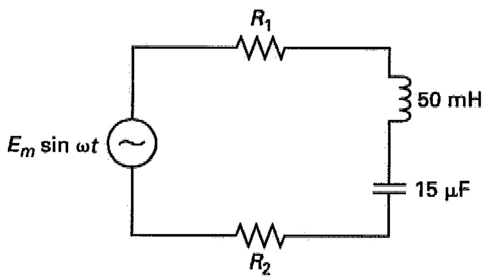
The frequency is

$$\begin{aligned} f &= \frac{\omega}{2\pi} = \frac{1}{2\pi CX_C} \\ &= \frac{1}{2\pi(2 \times 10^{-6}\ \text{F})(1500\ \Omega)} \\ &= 53\ \text{Hz} \end{aligned}$$

The answer is (B).

AC ELECTRICITY–10

If the capacitor and the inductor in the circuit shown have the same reactance, what is most nearly the frequency of the AC source?



(A) 27 Hz (B) 180 Hz (C) 210 Hz (D) 1200 Hz

If the inductor and capacitor have the same reactance, then

$$\begin{aligned} \frac{1}{\omega C} &= \omega L \\ \omega^2 &= \frac{1}{CL} \\ \omega &= \frac{1}{\sqrt{CL}} \end{aligned}$$

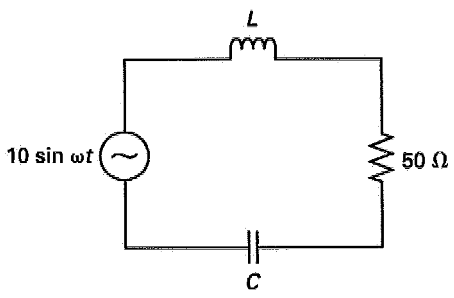
The frequency, f, is

$$\begin{aligned} f &= \frac{\omega}{2\pi} = \frac{1}{2\pi\sqrt{CL}} \\ &= \frac{1}{2\pi\sqrt{(15 \times 10^{-6}\ \text{F})(50 \times 10^{-3}\ \text{H})}} \\ &= 184\ \text{Hz} \quad (180\ \text{Hz}) \end{aligned}$$

The answer is (B).

AC ELECTRICITY–11

An alternating voltage of $E = 10 \sin \omega t$ V is applied to the RCL circuit shown. What is the effective current, I_{rms}, if the circuit is in resonance with the driving voltage?



(A) 0.141 A (B) 0.200 A (C) 7.07 A (D) 7.14 A

At resonance, the impedance of the circuit is equal to the impedance of the resistor. Therefore,

$$\omega L = \frac{1}{\omega C}$$

Additionally,

$$I = \frac{E}{\sqrt{R^2 + 0}} = \frac{E}{R}$$

$$I_{\text{rms}} = \frac{E_{\text{rms}}}{R} = \frac{\frac{E_{\text{max}}}{\sqrt{2}}}{R}$$

$$= \frac{\frac{10 \text{ V}}{\sqrt{2}}}{50 \ \Omega}$$

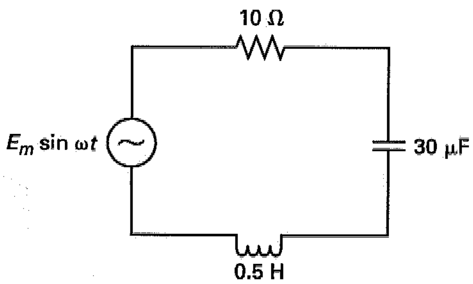
$$= 0.141 \text{ A}$$

The answer is (A).

AC ELECTRICITY-12

In the RCL circuit shown, $R = 10 \ \Omega$, $C = 30 \ \mu\text{F}$, and $L = 0.5$ H. At approximately what frequency will the rms current be one-third of the maximum possible rms current? The magnitude of the current is

$$I = E\left(R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right)^{-1/2}$$



(A) 37 Hz (B) 41 Hz (C) 46 Hz (D) 160 Hz

The maximum rms current occurs at resonance. That is,

$$I_{\text{rms,max}} = \frac{E_{\text{rms}}}{R}$$

For the rms current to be one-third of the maximum,

$$\frac{1}{3}\left(\frac{E_{\text{rms}}}{R}\right) = \frac{E_{\text{rms}}}{\left(R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right)^{1/2}}$$

$$\frac{1}{3R} = \frac{1}{\left(R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right)^{1/2}}$$

$$R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2 = 9R^2$$

$$\left(\omega L - \frac{1}{\omega C}\right)^2 = 8R^2$$

$$\omega L - \frac{1}{\omega C} = 2\sqrt{2}R$$

$$\omega^2 - \frac{2\sqrt{2}R\omega}{L} - \frac{1}{LC} = 0$$

Solving for the positive ω value,

$$\begin{aligned}\omega &= \frac{\sqrt{2}R}{L} + \sqrt{\frac{2R^2}{L^2} + \frac{1}{LC}} \\ &= \frac{(\sqrt{2})(10\ \Omega)}{0.5\ \text{H}} + \sqrt{\frac{(2)(10\ \Omega)^2}{(0.5\ \text{H})^2} + \frac{1}{(0.5\ \text{H})(30\times 10^{-6}\ \text{F})}} \\ &= 288\ \text{s}^{-1}\end{aligned}$$

$$\begin{aligned}f &= \frac{\omega}{2\pi} \\ &= \frac{\frac{288}{\text{s}}}{2\pi} \\ &= 45.8\ \text{Hz}\quad (46\ \text{Hz})\end{aligned}$$

The answer is (C).

AC ELECTRICITY–13

Which of the following statements regarding transformers is FALSE?

(A) The copper losses (I^2R) in the primary and secondary coils are equal.

(B) Transformer power losses are generally low, approximately 1–3%.

(C) Power losses in transformers are converted to heat, which is then dissipated.

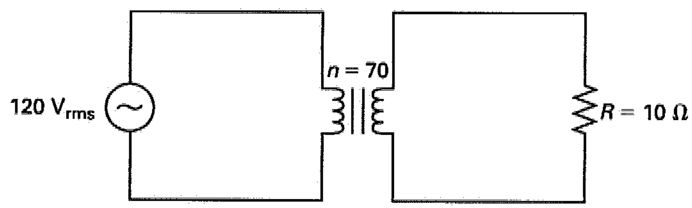
(D) One three-phase transformer weighs more than three equivalent single-phase transformers.

Power conversion using a three-phase transformer is more efficient than conversion using three separate single-phase units. Reduced weight and space requirements are obtained for the three-phase transformer.

$\boxed{\text{The answer is (D).}}$

AC ELECTRICITY–14

An ideal step-up transformer with a power factor of 1.0 is used in the circuit shown. The turns ratio is 70, and the primary rms voltage is 120 V. What is most nearly the average power dissipated due to the resistance, R?



(A) 17 W (B) 29 W (C) 8.4×10^4 W (D) 7.1×10^6 W

For an ideal transformer, the turns ratio is

$$\frac{V_{\text{rms},2}}{V_{\text{rms},1}} = \frac{N_2}{N_1} = 70$$

$$\begin{aligned} V_{\text{rms},2} &= 70V_{\text{rms},1} \\ &= (70)(120\ \text{V}) \\ &= 8400\ \text{V} \end{aligned}$$

Since power is given by $P = I^2R = V^2/R$,

$$P_{\text{ave},2} = \frac{V^2_{\text{rms},2}}{R} = \frac{(8400\ \text{V})^2}{10\ \Omega} = 7.06 \times 10^6\ \text{W} \quad (7.1 \times 10^6\ \text{W})$$

There is no power loss in the primary circuit.

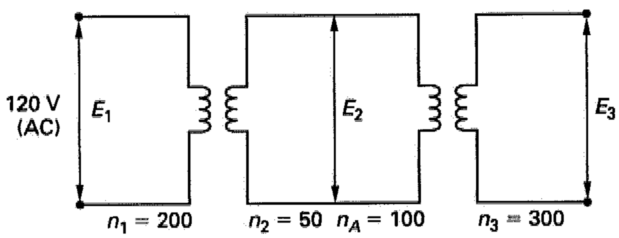
The answer is (D).

AC ELECTRICITY–15

In a transformer, the total voltage induced in each winding is proportional to the number of turns in that winding.

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

Disregarding all losses, determine E_3.



(A) 45 V (B) 65 V (C) 75 V (D) 90 V

From the ratio given,

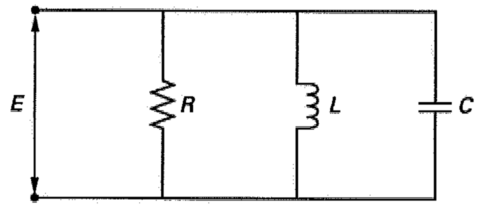
$$E_2 = \frac{n_2}{n_1}E_1$$

$$E_3 = \frac{n_3}{n_A}E_2 = \left(\frac{n_3}{n_A}\right)\left(\frac{n_2}{n_1}\right)E_1 = \left(\frac{300}{100}\right)\left(\frac{50}{200}\right)(120\ \text{V}) = 90\ \text{V}$$

The answer is (D).

AC ELECTRICITY–16

Determine the resonant frequency, ω, of the circuit shown.



(A) $\frac{1}{\sqrt{LC}}$ (B) $\frac{2}{\sqrt{LC}}$ (C) $\sqrt{\frac{LC}{3}}$ (D) $\sqrt{\frac{LC}{2}}$

Resonance occurs when $X_C = X_L$. Since $X_C = 1/j\omega C$ and $X_L = j\omega L$,

$$\frac{1}{j\omega C} = j\omega L$$

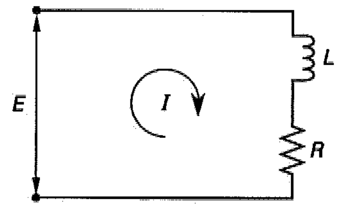
$$\omega^2 = \frac{1}{LC}$$

$$\omega = \frac{1}{\sqrt{LC}}$$

The answer is (A).

AC ELECTRICITY–17

Determine most nearly the power angle, ϕ, in the AC circuit if $R = 25\ \Omega$, $L = 0.2$ H, $V = 200$ V, and $f = 30$ Hz.



(A) 36° (B) 46° (C) 52° (D) 57°

The power angle is the impedance angle. The impedance for the circuit is

$$\begin{aligned} Z &= R + jX_L \\ &= 25\ \Omega + j2\pi(30\ \text{Hz})(0.2\ \text{H}) \\ &= 25\ \Omega + j37.7\ \Omega \end{aligned}$$

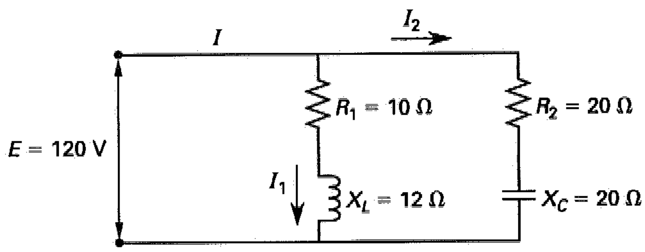
$$\tan\phi = \frac{X_L}{R}$$

$$\begin{aligned} \phi &= \tan^{-1}\left(\frac{37.7\ \Omega}{25\ \Omega}\right) \\ &= 56.5^\circ \quad (57^\circ) \end{aligned}$$

The answer is (D).

AC ELECTRICITY–18

Approximate the impedance of the circuit. The line current is **I**, and the line voltage lies along the real axis (i.e., has a zero phase angle).



(A) 12 Ω (B) 13 Ω (C) 14 Ω (D) 15 Ω

$$\begin{aligned} \mathbf{I}_1 &= \frac{\mathbf{E}}{\mathbf{Z}_1} = \frac{\mathbf{E}}{R_1 + jX_L} = \left(\frac{\mathbf{E}}{R_1 + jX_L}\right)\left(\frac{R_1 - jX_L}{R_1 - jX_L}\right) \\ &= \mathbf{E}\left(\frac{R_1 - jX_L}{R_1^2 + X_L^2}\right) \\ &= (120\ \text{V})\left(\frac{10\ \Omega - j12\ \Omega}{(10\ \Omega)^2 + (12\ \Omega)^2}\right) \\ &= 4.92 - j5.9\ \text{A} \end{aligned}$$

$$\begin{aligned}
\mathbf{I}_2 &= \frac{\mathbf{E}}{R_2 - jX_C} = \left(\frac{\mathbf{E}}{R_2 - jX_C}\right)\left(\frac{R_2 + jX_C}{R_2 + jX_C}\right) \\
&= \mathbf{E}\left(\frac{R_2 + jX_C}{R_2^2 + X_C^2}\right) \\
&= (120\ \text{V})\left(\frac{20\ \Omega + j20\ \Omega}{(20\ \Omega)^2 + (20\ \Omega)^2}\right) \\
&= 3 + j3.0\ \text{A}
\end{aligned}$$

The total current is

$$\begin{aligned}
\mathbf{I} &= \mathbf{I}_1 + \mathbf{I}_2 \\
&= (4.92 - j5.90\ \text{A}) + (3 + j3.0\ \text{A}) \\
&= 7.92 - j2.90\ \text{A}
\end{aligned}$$

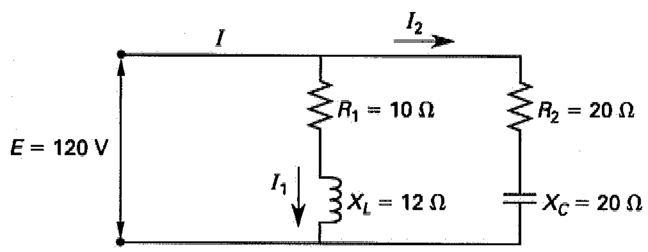
The impedance is

$$\begin{aligned}
\mathbf{Z} &= \frac{\mathbf{E}}{\mathbf{I}} = \frac{120 + j0\ \text{V}}{7.92 - j2.9\ \text{A}} \\
&= 13.4 + j4.90\ \Omega \\
Z &= |\mathbf{Z}| \\
&= \sqrt{x^2 + y^2} \\
&= \sqrt{(13.4\ \Omega)^2 + (4.90\ \Omega)^2} \\
&= 14.3\ \Omega \quad (14\ \Omega)
\end{aligned}$$

The answer is (C).

AC ELECTRICITY–19

What is most nearly the power factor for the following circuit? The total impedance of the circuit is $\mathbf{Z} = 13.4 + j4.9\ \Omega$.



(A) 74% (B) 79% (C) 84% (D) 94%

The power factor is

$$\cos\phi = \frac{P_{\text{real}}}{P_{\text{apparent}}} = \frac{R}{Z}$$

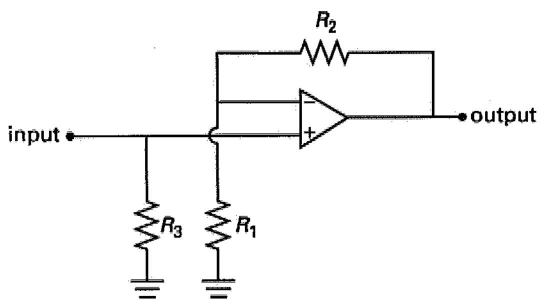
Since $R = 13.4\ \Omega$ and $Z = 14.3\ \Omega$,

$$\cos\phi = \frac{13.4\ \Omega}{14.3\ \Omega} \times 100\% = 93.7\% \quad (94\%)$$

$\boxed{\text{The answer is (D).}}$

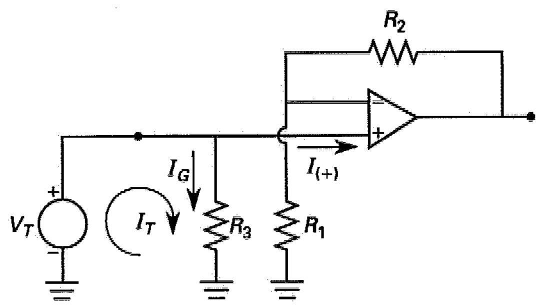
AC ELECTRICITY-20

What is the input impedance of the ideal op amp shown?



(A) R_1 (B) R_3 (C) $\dfrac{R_2}{R_1} + R_3$ (D) $\dfrac{R_1R_3}{R_1 + R_3}$

To find the input impedace, a test voltage, V_T, is applied to the input. The resistance seen by the test voltage will be equal to the impedance: $R_{\text{in}} = V_T/I_T$. The circuit can be replaced with its equivalent.



By Kirchoff's law, $I_T = I_G + I_{(+)}$. In an ideal op amp, there is no current drawn by the positive and negative terminals. Therefore, $I_{(+)} = 0$ and $I_T = I_G$. Around that loop,

$$I_T = \frac{V_T}{R_3}$$

$$\frac{V_T}{I_T} = R_3$$

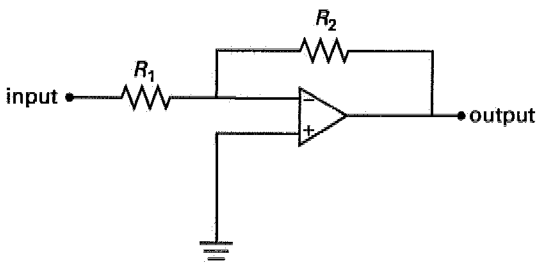
$$R_{\text{in}} = \frac{V_T}{I_T}$$

$$= R_3$$

The answer is (B).

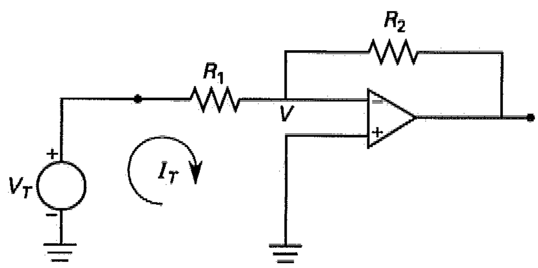
AC ELECTRICITY–21

What is the input impedance of the following ideal op amp?



(A) R_1 (B) R_2 (C) $\frac{R_2}{R_1}$ (D) $\frac{R_1}{R_1 + R_2}$

To find the input impedance or resistance, the circuit is examined using a test voltage, V_T, and a test current, I_T. The circuit diagram becomes



The input resistance will be

$$R_{\text{in}} = \frac{V_T}{I_T}$$

For an ideal op amp, the voltage at the (+) terminal equals the voltage of the (−) terminal. Therefore, $V = 0$ and

$$I_T = \frac{V_T - V}{R_1} = \frac{V_T}{R_1}$$

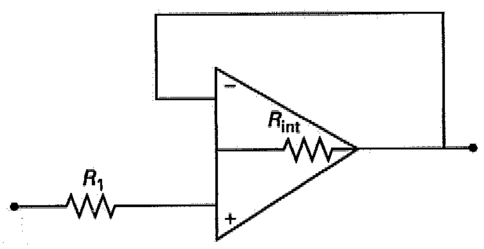
$$R_{\text{in}} = V_T \frac{R_1}{V_T}$$

$$= R_1$$

The answer is (A).

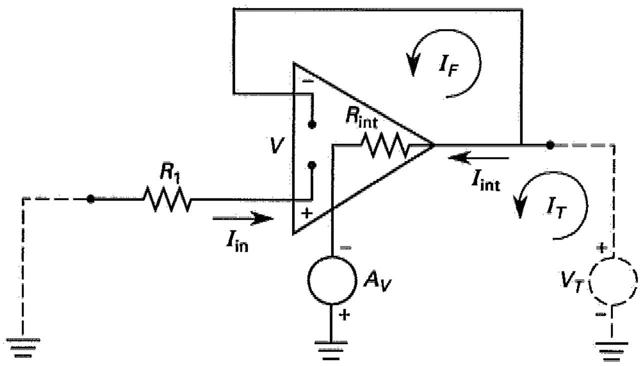
AC ELECTRICITY–22

What is most nearly the output impedance, R_{out}, of the circuit shown? Assume no current is drawn at the (+) and (−) inputs, and that the op amp has a small internal resistance, R_{int}, at the output.



(A) R_{int} (B) R_1 (C) $\dfrac{R_1 R_{\text{int}}}{R_1 + R_{\text{int}}}$ (D) 0

In terms of its operation, the op amp diagram is like the solid part in the following illustration.



A_V is very large. To find the output resistance, a test voltage, V_T, is attached to the output and the input is grounded. Then,

$$R_{out} = \frac{V_T}{I_T}$$

The test current, I_T, is equal to the internal current, I_{int}, plus the forced current, I_f. Since the inputs draw no current, $I_f = 0$. Therefore,

$$\begin{aligned} I_T = I_{int} &= \frac{V_{int}}{R_{int}} \\ &= \frac{V_T - (-A_V V)}{R_{int}} \end{aligned}$$

Since no current is drawn at the inputs, the (+) input is at 0 V, and the (−) input is at V_T, so that $V = V_T$. Thus,

$$\begin{aligned} I_{int} &= \frac{V_T(1+A)}{R_{int}} \\ \frac{V_T}{I_{int}} &= \frac{R_{int}}{1+A} \\ R_{out} &= \frac{V_T}{I_{int}} = \frac{R_{int}}{1+A} \end{aligned}$$

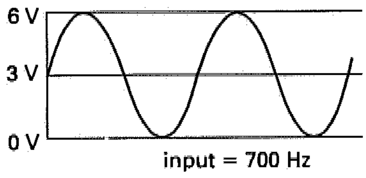
Since A_V is very large and R_{int} is very small,

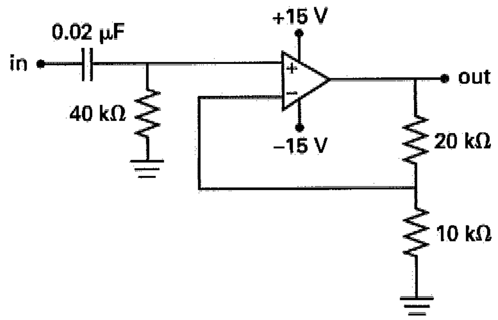
$$R_{out} \approx 0$$

The answer is (D).

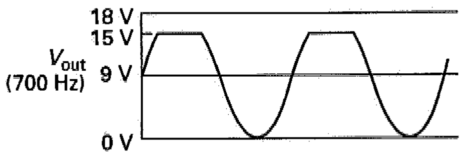
AC ELECTRICITY–23

The 700 Hz signal shown is injected into the circuit shown. What will be the output signal?

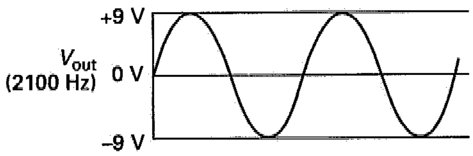




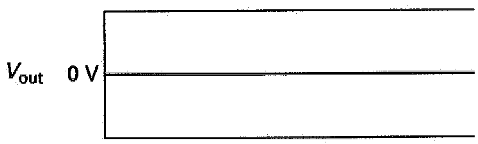
(A)



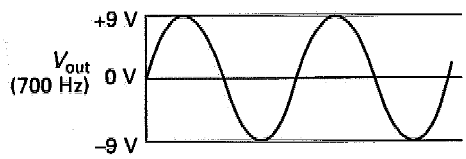
(B)



(C)



(D)



The op amp part of the circuit is a simple noninverting amplifier with a gain of

$$\frac{V_{out}}{V_{in}} = \frac{10\ \text{V} + 20\ \text{V}}{10\ \text{V}} = 3\ \text{V}$$

The input into the amplifier is a high-pass filter with a cutoff frequency of

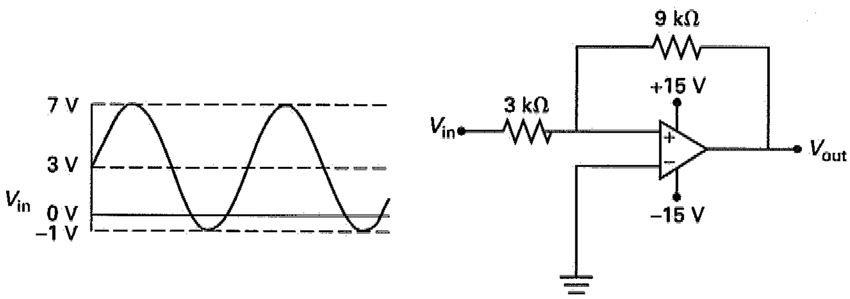
$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(40 \times 10^3\ \Omega)(0.02 \times 10^{-6}\ \text{F})}$$
$$= 200\ \text{Hz}$$

Thus, the AC component of the signal will pass through and be amplified three times, while the DC component will be cut out, resulting in a 9 V amplitude sinusoid centered about 0 V. This is known as an active high-pass filter. Thus, the correct output is shown in option (D).

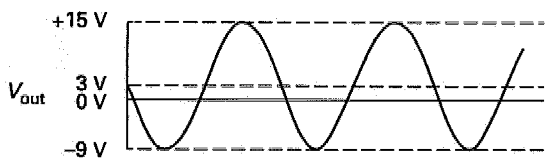
$\boxed{\text{The answer is (D).}}$

AC ELECTRICITY–24

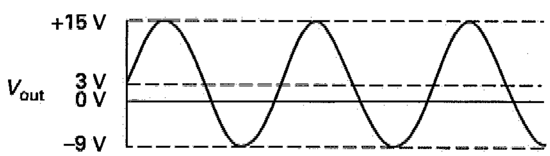
The signal shown is the input to the ideal op amp. Which of the choices is the output signal?



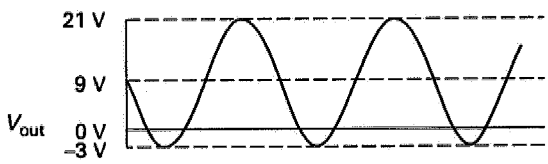
(A)



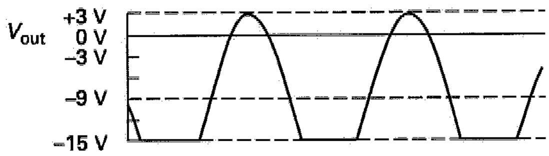
(B)



(C)



(D)



Since the amplifier is an inverting amplifier,

$$V_{\text{out}} = -\left(\frac{9\ \text{k}\Omega}{3\ \text{k}\Omega}\right) V_{\text{in}} = -3V_{\text{in}}$$

Both the DC and the AC components will be amplified. The DC component is $(-3)(3\ \text{V}) = -9\ \text{V}$, so the new waveform is centered at $V = -9\ \text{V}$. The AC component is $(3)(8\ \text{V}) = 24\ \text{V}$ peak-to-peak. Since the amplifier has only a 15 V source, though, the voltage will be clipped at $\pm15\ \text{V}$. Since it never goes to $+15\ \text{V}$, the upper half of the output signal will be intact, and the lower half will be clipped at $-15\ \text{V}$.

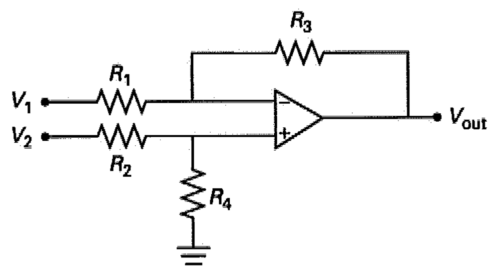
The answer is (D).

AC ELECTRICITY–25

Two AC signals, V_1 and V_2, are to be combined such that

$$V_{\text{out}} = \tfrac{3}{2}V_2 - \tfrac{5}{2}V_1$$

The subtracting amplifier circuit shown 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) $R_1 = 5\ \text{k}\Omega,\ R_2 = 3\ \text{k}\Omega,\ R_3 = 4\ \text{k}\Omega,\ R_4 = 2\ \text{k}\Omega$

The output for this op amp configuration is

$$\begin{aligned} V_{\text{out}} &= V_{(-)} - \left(\frac{V_1 - V_{(-)}}{R_1}\right) R_3 \\ &= \left(1 + \frac{R_3}{R_1}\right) V_{(-)} - \frac{R_3}{R_1} V_1 \end{aligned}$$

Additionally,

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

Therefore,

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

The ratio R_3:R_1 must be 5:2. Therefore, the initial values $R_1 = 2\ \text{k}\Omega$ and $R_3 = 5\ \text{k}\Omega$ are chosen. Thus, the coefficient of V_2 is

$$\begin{aligned} \left(\frac{R_1 + R_3}{R_1}\right)\left(\frac{R_4}{R_2 + R_4}\right) = \left(\frac{2\ \text{k}\Omega + 5\ \text{k}\Omega}{2\ \text{k}\Omega}\right)\left(\frac{R_4}{R_2 + R_4}\right) &= 3/2 \\ \left(\frac{7}{2}\right)\left(\frac{R_4}{R_2 + R_4}\right) &= 3/2 \\ \frac{R_4}{R_2 + R_4} &= 3/7 \\ 7R_4 &= 3R_2 + 3R_4 \\ 4R_4 &= 3R_2 \\ R_4 &= \tfrac{3}{4} R_2 \end{aligned}$$

Try the values of R_2 and R_4 in the four answer choices to see if they satisfy the relation.

$R_2 = 4\ \text{k}\Omega$ and $R_4 = 3\ \text{k}\Omega$ are chosen. Checking the results,

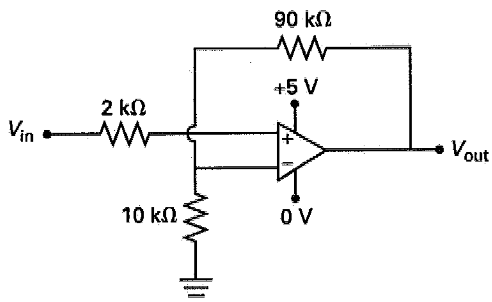
$$\begin{aligned} V_{\text{out}} &= \left(\frac{2\ \text{k}\Omega + 5\ \text{k}\Omega}{2\ \text{k}\Omega}\right)\left(\frac{3\ \text{k}\Omega}{4\ \text{k}\Omega + 3\ \text{k}\Omega}\right)V_2 - \tfrac{5}{2}V_1 \\ &= \tfrac{3}{2}V_2 - \tfrac{5}{2}V_1 \end{aligned}$$

The answer is (B).

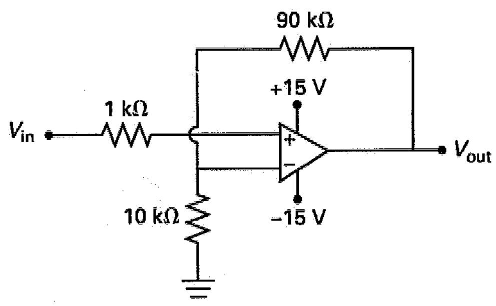
AC ELECTRICITY–26

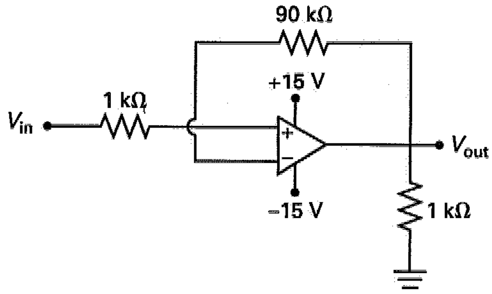
A sinusoidal signal with maximum voltage, $V_0 = 30$ mV, is to be amplified without inversion to at least 0.3 V. Which of the following operational amplifier configurations will best achieve this? Assume ideal op amps.

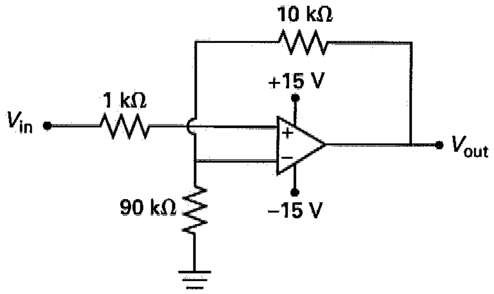
(A)



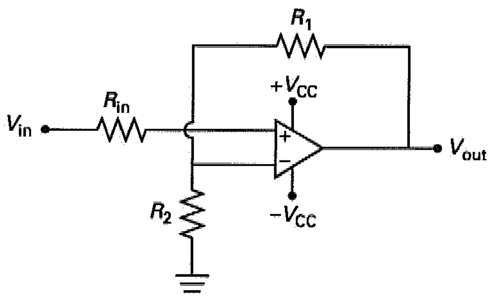
(B)



(C) 

(D) 

A noninverting topology is required. The resistances and voltages are labeled in the following illustration.



For this topology,

$$V_{out} = \left(\frac{R_1 + R_2}{R_2}\right) V_{in}$$

The voltage has to be amplified by a factor of 10 in order to get 30 mV up to 0.3 V.

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

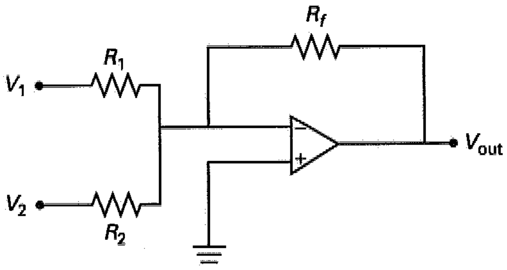
$$R_1 = 9R_2$$

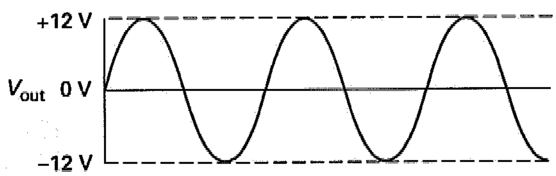
R_{in} is not important, since very little current is drawn through it. Of the answer choices, options (A), (B), and (D) are the correct topologies, and options (A) and (B) have the correct R_1 to R_2 ratio. The next criterion is that the supply voltage, $\pm V_{CC}$, must be greater in magnitude than the output voltage, or clipping will occur. Since option (A) has a negative input supply of 0 V, it will clip the output. Only option (B) will satisfy all requirements.

$\boxed{\text{The answer is (B).}}$

AC ELECTRICITY-27

In the ideal op-amp configuration shown, $V_{out} = 12$ V sinusoidal as shown in the waveform, $R_f = 60$ kΩ, $R_1 = 30$ kΩ, and $R_2 = 10$ kΩ. Nothing is known about the inputs except that $V_1 = 5V_2$, and that they are 180° out of phase with the output. From this information, what are the maximum voltages of the inputs?





(A) $V_1 = 0.75$ V, $V_2 = 3.75$ V
(B) $V_1 = 5.00$ V, $V_2 = 1.00$ V
(C) $V_1 = 12.5$ V, $V_2 = 2.50$ V
(D) $V_1 = 3.75$ V, $V_2 = 0.75$ V

This is an adding amplifier with an output of

$$V_{\text{out}} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2\right)$$

It is known that $V_1 = 5V_2$. Substituting this into the equation for V_{out} and evaluating with the given R values and V_{out},

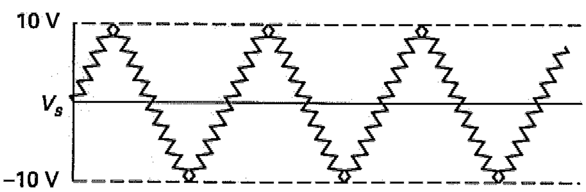
$$\begin{aligned} 12 &= -\left(\left(\frac{60\ \text{k}\Omega}{30\ \text{k}\Omega}\right)5V_2 + \left(\frac{60\ \text{k}\Omega}{10\ \text{k}\Omega}\right)V_2\right) \\ V_2 &= -0.75\ \text{V} \\ V_1 &= (5)(-0.75\ \text{V}) \\ &= -3.75\ \text{V} \end{aligned}$$

Since the output is a sinusoid, the inputs must also be sinusoids. It is known that they are 180° out of phase, which is confirmed by the negative sign of the voltage. Thus, the maximum voltages are $V_1 = 3.75$ V and $V_2 = 0.75$ V.

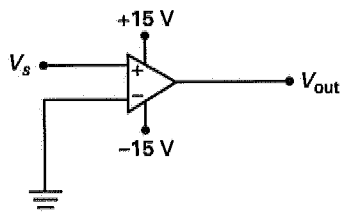
The answer is (D).

AC ELECTRICITY–28

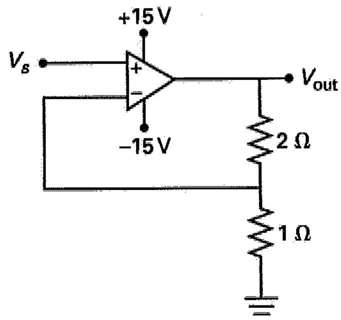
A zero-crossing detector is needed for the noisy circuit shown. The phase of the detector output is not important. (That is, the detector can show a time lag.) Which of the following op amp configurations would be best?



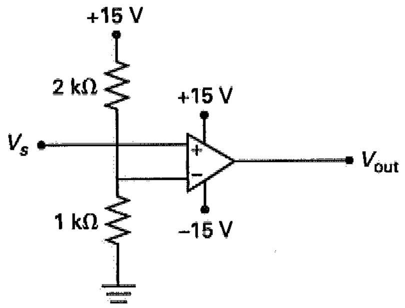
(A)



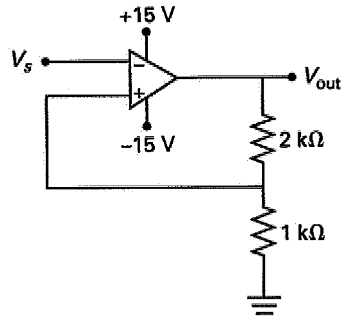
(B)



(C)

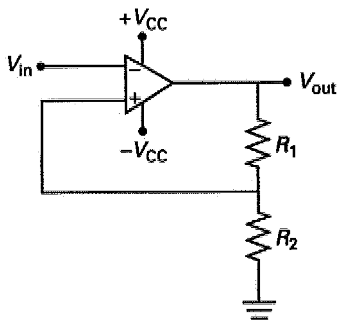


(D)



Because of the noise, a simple comparator such as in option (A) will not work. There will be false zero crossings where the noise crosses zero at the signal crossing.

The configuration shown in option (C) will not work for the same reason as the comparator. The device shown in option (B) is a noninverting amplifier, which will amplify the entire signal. A device with hysteresis, such as a Schmitt trigger, is needed. Such a device will not change until a threshold is reached, and will not change again until the negative threshold is reached. The configuration is



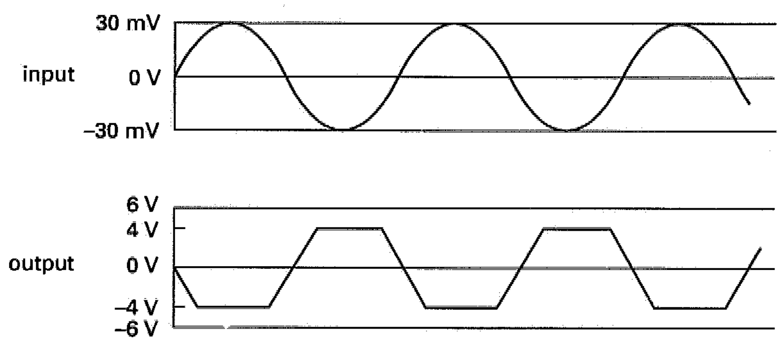
$$V_{\text{threshold}} = \left(\frac{\pm R_2}{R_1 + R_2} \right) V_{CC}$$

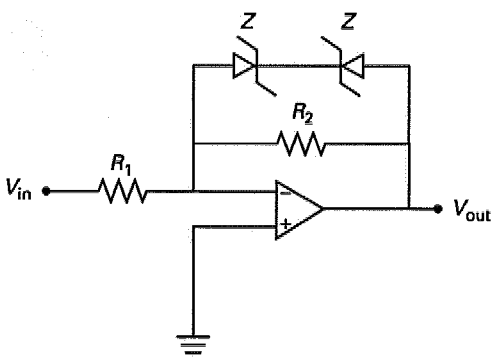
The only Schmitt trigger circuit is given in option (D). With the R_1 and R_2 resistances shown, it will trigger at $V = (1\ \text{k}\Omega/2\ \text{k}\Omega + 1\ \text{k}\Omega)$ $(15\ \text{V}) = 5\ \text{V}$, which will work. There will be some delay, and the signal will be inverted.

The answer is (D).

AC ELECTRICITY–29

A 30 mV sinusoidal signal must be inverted, amplified to 6 V, and chopped at 4 V. If the following circuit is used, what are the values of R_1, R_2, and the avalanche voltage of the zener diodes, Z? There is a forward voltage drop of −0.7 V for the diodes.





(A) $R_1 = 1\ \text{k}\Omega,\ R_2 = 20\ \text{k}\Omega,\ Z = 4.0\ \text{V}$
(B) $R_1 = 1\ \text{k}\Omega,\ R_2 = 200\ \text{k}\Omega,\ Z = 4.0\ \text{V}$
(C) $R_1 = 2\ \text{k}\Omega,\ R_2 = 400\ \text{k}\Omega,\ Z = 3.3\ \text{V}$
(D) $R_1 = 2\ \text{k}\Omega,\ R_2 = 800\ \text{k}\Omega,\ Z = 3.3\ \text{V}$

The amplification is similar to that found in the normal inverting amplifier.

$$V_{\text{out}} = -\frac{R_2}{R_1}V_{\text{in}}$$
$$\frac{R_2}{R_1} = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{6\ \text{V}}{30 \times 10^{-3}\ \text{V}} = 200$$

This leaves options (B) and (C) to be the possible choices.

When $\pm V_{\text{out}} < Z$, one of the diodes will be reverse biased, but not avalanched. There is essentially an open circuit across the diodes, and the amplifier is a simple inverting amplifier. When $\pm V_{\text{out}} \geq Z$, one of the diodes is forward biased with a voltage drop of 0.7 V, while the other diode is avalanched at the zener voltage. This keeps V_{out} constant. Thus, $V_{\text{out}} = 4$ V is equal to the zener voltage plus the 0.7 V voltage drop of the other diode.

$$V_{\text{out}} = Z + 0.7\ \text{V}$$
$$Z = 4\ \text{V} - 0.7\ \text{V} = 3.3\ \text{V}$$

So, $R_2 = 200R_1$ and $Z = 3.3$ V.

The answer is (C).

AC ELECTRICITY–30

An AC alternator operated as a motor is called a synchronous motor. Which of the following statements regarding synchronous motors is FALSE?

(A) The average speed, regardless of load, does not decrease, since the motor must operate at a constant speed.
(B) When a load is increased, the increased torque is a result of the shift in the relative positions of the fields on the rotor and stator.
(C) The relationship between speed, frequency, and number of poles is the same for the rotating field of the induction motor and for the alternator.
(D) The poles of a synchronous motor must be salient.

Salient poles have laminated pole pieces. Although salient poles are generally used, either salient or nonsalient poles can be used in a synchronous motor.

The answer is (D).

AC ELECTRICITY–31

Which of the following statements about induction motors is FALSE?

(A) They are used to increase the line power factor.
(B) They have no slip rings, no brushes, and no excited field current.
(C) They have no commutators and no windings on the armature.
(D) Squirrel-cage induction motors operate at essentially constant speeds.

Induction motors degrade the power factor. All the other answer choices are true.

The answer is (A).

AC ELECTRICITY–32

A single-phase induction motor is not self-starting. Instead, auxiliary methods must be used, such as varying inductance, resistance, and capacitance. Which of the following is FALSE regarding this situation?

(A) A capacitor motor uses capacitance to split the phase, resulting in two phases almost 90° apart.

(B) Capacitor motors have lower starting torque than comparably sized single-phase induction motors.

(C) To obtain a higher reactance, a capacitor can be used when starting and then be switched out of the circuit by mechanical means.

(D) If the capacitor remains in the circuit, the power factor will have a value close to unity.

Due to the favorable phase relationship, the torque is higher for a capacitor motor than for other types of single-phase motors. For example, a capacitive phase split motor gives better torque than a resistively split motor. Therefore, option (B) is false.

The answer is (B).

AC ELECTRICITY–33

A squirrel-cage motor has such low resistance that it draws excessive currents when starting. Which of the following actions will NOT reduce this problem?

(A) connecting the windings as in a three-phase, wye, transformer, taking 58% of the normal line voltage; then, at sufficient motor speed, switching to a delta connection
(B) using an in-line rheostat
(C) using an autotransformer to reduce line voltage
(D) using a class A motor

A class A motor draws a heavy starting current, usually 200–300% of the normal load. The other alternatives reduce the effective voltage across the windings, thus reducing the problem of excessive currents.

The answer is (D).

AC ELECTRICITY–34

Which of the following statements about AC generators is FALSE?

(A) The poles of an AC generator are located on the rotor.
(B) The three main types of AC generator are direct-connect engine driven, water driven, and turbine driven.
(C) An AC generator uses commutators.
(D) Large turbine driven generators usually have two pole rotors to accommodate the high speed of the turbine.

Commutators are not used in AC machines. It is the relative motion between the rotor and the stationary armature located on the stator that generates the power.

The answer is (C).

AC ELECTRICITY–35

Which of the following is FALSE regarding rotating machinery?

(A) The avoidance of harmonics in the production of a sine wave can be achieved by using a coil having multiple loops passing through adjacent slots rather than using only one pair of slots.

(B) Uniformity in the production of flux on a pole can be obtained by using distributed field windings over a portion of the rotor surface.

(C) AC generator ratings are usually given in units of kVA (kilovolt amps).

(D) At zero power factor, the generator delivers real power to a load.

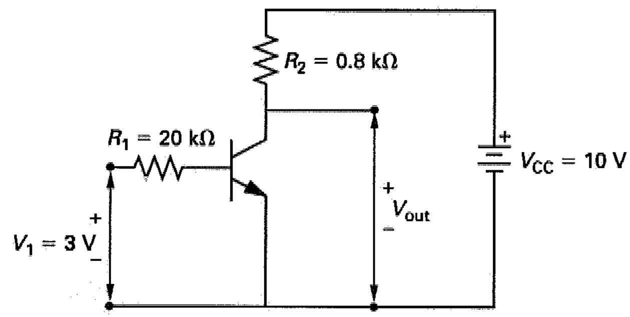
A power factor of 1 delivers only real power and no reactive power to a resistive load. A zero power factor is associated with a nonresistive load or with no-load conditions.

The answer is (D).

AC ELECTRICITY–36

In the following transistor circuit, β is 100, and the DC base-to-emitter voltage is 0.6 V. What is the output voltage, V_{out}?

(A) 0.3 V (B) 2 V (C) 3 V (D) 10 V



$$I_B = \frac{V_1 - V_{be}}{R_1} = \frac{3\ \text{V} - 0.6\ \text{V}}{20 \times 10^3\ \Omega} = 0.000\,12\ \text{A} \quad (0.12\ \text{mA})$$

$$I_C = (1+\beta)I_B = (1+100)(0.12\ \text{mA}) = 12.1\ \text{mA}$$

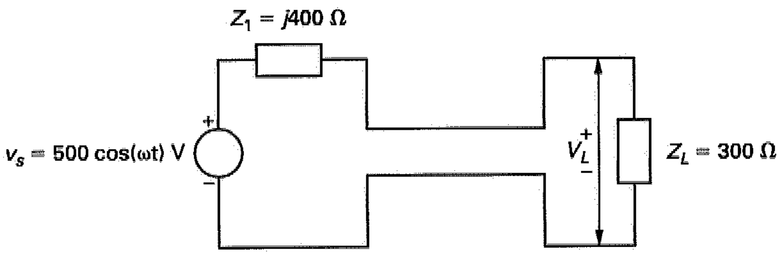
$$V_{out} = V_{CC} - I_c R_2 = 10\ \text{V} - (12.1\ \text{mA})\left(\frac{1\ \text{A}}{1000\ \text{mA}}\right)(0.8\ \text{k}\Omega)\left(\frac{1000\ \Omega}{1\ \text{k}\Omega}\right)$$

$$= 0.3\ \text{V}$$

The answer is (A).

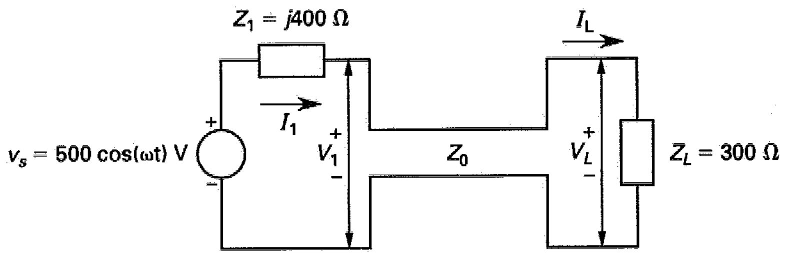
AC ELECTRICITY–37

The circuit shown represents a matched lossless transmission line. What is the maximum load voltage, V_L?



(A) 200 V (B) 300 V (C) 400 V (D) 500 V

For a matched lossless transmission line, the characteristic impedance, Z_0, equals the load impedance, Z_L, with $V_1 = V_L$ and $I_1 = I_L$ as shown in the following illustration .



$$I_1 = \frac{v_s}{Z_1 + Z_0}$$

$$V_L = I_1 Z_L = \left(\frac{v_s}{Z_1 + Z_0}\right) Z_L$$

$$V_{L,\text{max}} = v_{s,\text{max}} \left|\frac{Z_L}{Z_1 + Z_0}\right| = (500\text{ V})\left(\left|\frac{300\ \Omega}{300\ \Omega + j400\ \Omega}\right|\right) = 300\text{ V}$$

The answer is (B).

AC ELECTRICITY–38

A 10-pole synchronous motor operates on a 60 cycle voltage. What is the speed of the motor?

(A) 520 rpm (B) 620 rpm (C) 660 rpm (D) 720 rpm

The synchronous speed for AC motors is

$$\begin{aligned} n_s &= \frac{120f}{p} = \frac{(120)(60\ \text{Hz})}{10} \\ &= 720\ \text{rpm} \end{aligned}$$

The answer is (D).

AC ELECTRICITY–39

The core of a 400 Hz aircraft transformer has a net cross-sectional area of 13 cm^2. The maximum flux density is 0.9 T, and there are 70 turns in the secondary coil. What is most nearly the rms voltage induced in the secondary coil?

(A) 130 V (B) 150 V (C) 170 V (D) 1500 V

The induced voltage is

$$V = -N\frac{d\phi}{dt} = -N\frac{d}{dt}\int_s B ds$$

In the preceding equation, N is the number of turns, and B is the flux density in Teslas. $B = 0.9\sin\omega t$, where $\omega = 2\pi f = 2\pi(400\ \text{rad/s})$.

Therefore,

$$V = -N\frac{d}{dt}BA$$

In the preceding formula, A is the cross-sectional area of the core.

Therefore,

$$\begin{aligned} V_{\text{rms}} &= \frac{N\omega BA}{\sqrt{2}} = \frac{(70)(2\pi)(400\ \text{Hz})(0.9\ \text{T})(13\times 10^{-4}\ \text{m}^2)}{\sqrt{2}} \\ &= 146\ \text{V} \quad (150\ \text{V}) \end{aligned}$$

The answer is (B).

AC ELECTRICITY–40

A 150 kVA, 1000 V single-phase alternator has an open circuit emf of 750 V. When the alternator is short circuited, the armature current is 460 A. What is most nearly the synchronous impedance?

(A) 1.6 Ω (B) 2.2 Ω (C) 2.6 Ω (D) 3.2 Ω

Synchronous impedance, Z, is

$$Z = \frac{V_{\text{oc}}}{I_a}$$

V_{oc} is the open-circuit voltage, and I_a is the armature current when the alternator is short circuited. Therefore,

$$Z = \frac{750 \text{ V}}{460 \text{ A}} = 1.63 \ \Omega \quad (1.6 \ \Omega)$$

The answer is (A).

AC ELECTRICITY–41

In a balanced three-phase system with a power factor of unity, the line voltage, E_l, and the line current, I_l, deliver normal AC power. What is the expression for the power, P?

(A) $P = E_l I_l$ (B) $P = \frac{1}{2} E_l I_l$

(C) $P = \frac{1}{\sqrt{2}} E_l I_l$ (D) $P = \sqrt{3} E_l I_l$

The power developed by a three-phase generator is three times the coil voltage, E_c, multiplied by the coil current, I_c.

$$P = 3 E_c I_c$$

The line voltage has the following relationship with the coil voltage.

$$E_l = \sqrt{3} E_c$$

Therefore, since $I_c = I_l$ for a power factor of 1,

$$P = \frac{3}{\sqrt{3}} E_l I_l$$
$$= \sqrt{3} E_l I_l$$

The answer is (D).

AC ELECTRICITY–42

A three-phase alternator has three armature coils, each rated at 1200 V and 120 A. What is most nearly the kVA rating of this unit?

(A) 430 kVA (B) 440 kVA (C) 520 kVA (D) 540 kVA

The kVA rating is equal to the power output.

$$\begin{aligned} \text{kVA} &= 3E_c I_c \\ &= (3)(1200\ \text{V})(120\ \text{A}) \\ &= 432\,000\ \text{VA} \quad (430\ \text{kVA}) \end{aligned}$$

The answer is (A).

AC ELECTRICITY–43

What is the relationship between the line current, I_l, and the coil current, I_c, in a balanced delta system?

(A) $I_l = \frac{I_c}{\sqrt{3}}$ (B) $I_l = \frac{I_c}{\sqrt{2}}$ (C) $I_l = I_c$ (D) $I_l = \sqrt{3} I_c$

The three-phase line-phase relations for a balanced three-phase delta system are

$$I_l = \sqrt{3} I_p = \sqrt{3} I_c$$

The answer is (D).