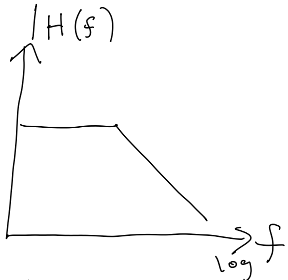
Homework #7 Solutions

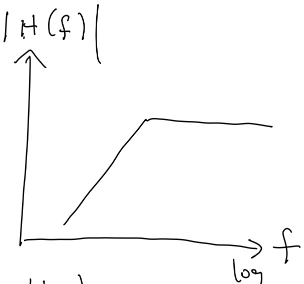
Tuesday, May 11, 2021 8:59 AM

Problem 1 (10 points)

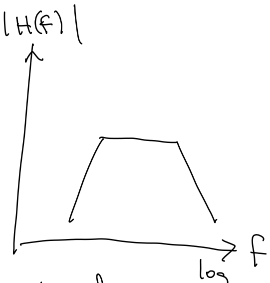
(a) Draw the expected frequency response of each of the following: *(i) low-pass, (ii) high-pass, (iii) band-pass, and (iv) band-stop filters.*



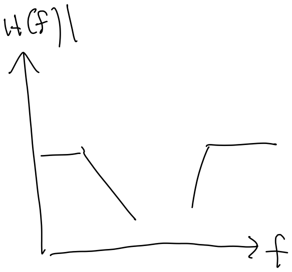
Low-pass



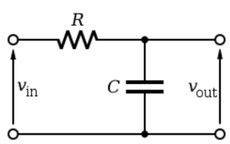
High-pass



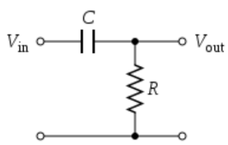
band-pass



band-stop



(b)



(c)

(b) $Z_C = \frac{1}{j\omega C}$

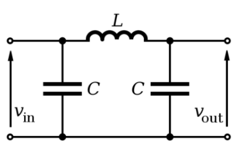
as $\omega \to \infty$, $Z_C \to 0 \to V_{out} \approx 0$

$\boxed{\text{Low-pass filter}}$

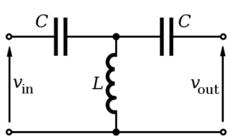
(c) as $\omega \to \infty$, $Z_C \to 0$

$\to V_{out} \approx V_{in}$

$\boxed{\text{high-pass filter}}$



(d)



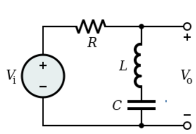
(e)

(d) $\omega \to \infty$, $Z_C \to 0 \to V_{out} \approx 0$

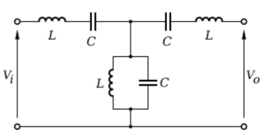
$\boxed{\text{Low-pass}}$

(e) $\omega \to \infty$, $\left.\begin{matrix} Z_C \to 0 \\ Z_L \to \infty \end{matrix}\right\} V_{out} \approx V_{in}$

$\boxed{\text{high-pass}}$



(f)



(g)

(f) $\omega \to 0$, $Z_C \to \infty \to V_{out} \approx V_{in}$

$\omega \to \infty$, $Z_L \to \infty \to V_{out} \approx V_{in}$

$\boxed{\text{band-reject / band-stop}}$

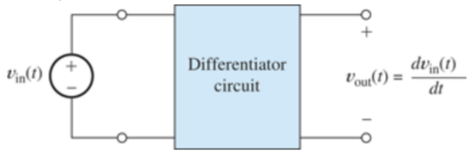
(g) $\omega \to 0$, $Z_C \to \infty \to V_{out} \approx 0$

$\omega \to \infty$, $Z_L \to \infty \to V_{out} \approx 0$

$\boxed{\text{band-pass}}$

Problem 2 (10 points)

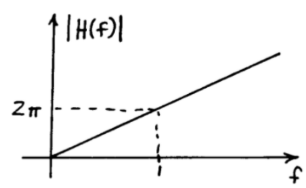
P6.20. Suppose we have a circuit for which the output voltage is the time derivative of the input voltage, as illustrated in Figure P6.20. For an input voltage given by $v_{in}(t) = V_{max}\cos(2\pi f t)$, find an expression for the output voltage as a function of time. Then, find an expression for the transfer function of the differentiator. Plot the magnitude and phase of the transfer function versus frequency.

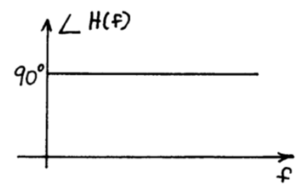


$$V_{in}(t) = V_{max}\cos(2\pi f t) \longrightarrow V_{in} = V_{max}\angle 0^\circ$$

$$V_{out}(t) = -2\pi f\, V_{max}\sin(2\pi f t)$$
$$= -2\pi f\, V_{max}\cos(2\pi f t - 90^\circ)$$
$$= 2\pi f\, V_{max}\cos(2\pi f t + 90^\circ) \longrightarrow V_{out} = 2\pi f\, V_{max}\angle 90^\circ$$

$$H(f) = \frac{V_{out}(f)}{V_{in}(f)} = \frac{2\pi f\, V_{max}\angle 90^\circ}{V_{max}\angle 0^\circ} = 2\pi f\angle 90^\circ = j2\pi f$$



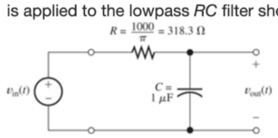


Problem 3 (10 points)

*__P6.25.__ An input signal given by

$$v_{in}(t) = 5\cos(500\pi t) + 5\cos(1000\pi t) + 5\cos(2000\pi t)$$

is applied to the lowpass *RC* filter shown in Figure P6.25. Find an expression for the output signal.



voltage divider $\left\{ V_{out}(f) = \frac{\frac{1}{j2\pi fC}}{R + \frac{1}{j2\pi fC}} V_{in}(f) = \frac{1}{1 + j2\pi fRC} V_{in}(f) \right.$

can be written as:

$$H(f) = \frac{V_{out}(f)}{V_{in}(f)} = \frac{1}{1 + j\frac{f}{f_B}} \quad \text{where } f_B = \frac{1}{2\pi RC} = 500\text{ Hz}$$

$$V_{in}(t) = 5\cos(\underbrace{500\pi}_{}t) + 5\cos(\underbrace{1000\pi}_{}t) + 5\cos(\underbrace{2000\pi}_{}t)$$

$f_1 = 250$ Hz $f_2 = 500$ Hz $f_3 = 1000$ Hz

(1) $H(f_1 = 250\,\text{Hz}) = \dfrac{1}{1 + j\frac{250}{500}} = 0.8944 \angle -26.57^\circ$

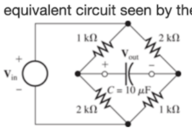
(2) $H(f_2 = 500\,\text{Hz}) = \dfrac{1}{1 + j(500/500)} = 0.701 \angle -45^\circ$

(3) $H(f_3 = 1000\,\text{Hz}) = \dfrac{1}{1 + j(1000/500)} = 0.4472 \angle -63.43^\circ$

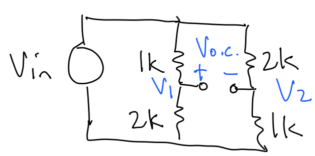
$$\boxed{\begin{aligned} V_{out}(t) = {} & 5 \times 0.8944 \cos(500\pi t - 26.57^\circ) + \\ & 5 \times 0.701 \cos(1000\pi t - 45^\circ) + \\ & 5 \times 0.4472 \cos(2000\pi t - 63.43^\circ) \end{aligned}}$$

Problem 4 (optional)

*P6.30. Sketch the magnitude of the transfer function $H(f) = \mathbf{V}_{out}/\mathbf{V}_{in}$ to scale versus frequency for the circuit shown in Figure P6.30. What is the value of the half-power frequency? [*Hint:* Start by finding the Thévenin equivalent circuit seen by the capacitance.]



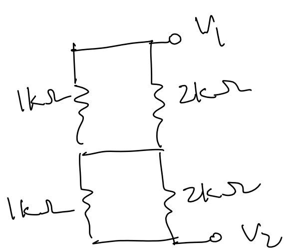
Thevenin Equivalent:



(1) $V_{o.c.} = V_1 - V_2$

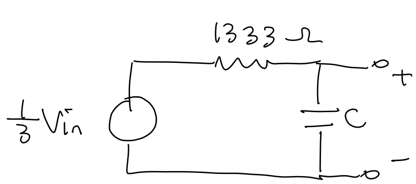
$$= \frac{2k\Omega}{1k\Omega + 2k\Omega} V_{in} - \frac{1k\Omega}{1k\Omega + 2k\Omega} V_{in} = \underline{\frac{1}{3} V_{in}}$$

(2) R_{th} (set $V_{in} = 0$, aka "short")



$$R_{th} = (1k\Omega \| 2k\Omega) + (1k\Omega \| 2k\Omega)$$
$$= 2\left(\frac{1k\Omega \times 2k\Omega}{1k\Omega + 2k\Omega}\right) \cong \boxed{1333\,\Omega}$$

Equivalent:



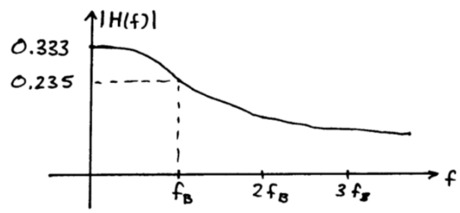
$$\frac{V_{out}}{\frac{1}{3}V_{in}} = \frac{1}{1 + j\left(\frac{f}{f_B}\right)} \qquad f_B = \frac{1}{2\pi RC}$$

$\Rightarrow$ $\dfrac{V_{out}}{\ } = \dfrac{1}{\ } \dfrac{1}{\ }$ where $f_B = \dfrac{1}{\ }$

$$V_{in} \qquad s \qquad 1 + j\frac{f}{f_B}$$

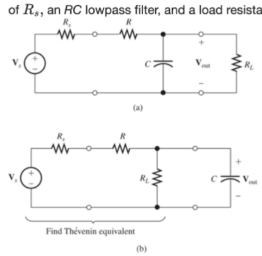
$$2\pi(1333\,\Omega)(10\,\mu F)$$

$$\approx \boxed{11.94\,Hz}$$



Problem 5 (20 points)

P6.32. Consider the circuit shown in **Figure P6.32(a)**. This circuit consists of a source having an internal resistance of R_s, an *RC* lowpass filter, and a load resistance R_L.



a. Show that the transfer function of this circuit is given by

$$H(f) = \frac{\mathbf{V}_{out}}{\mathbf{V}_s} = \frac{R_L}{R_s + R + R_L} \times \frac{1}{1 + j(f/f_B)}$$

in which the half-power frequency f_B is given by

$$f_B = \frac{1}{2\pi R_t C} \quad \text{where} \quad R_t = \frac{R_L\,(R_s + R)}{R_L + R_s + R}$$

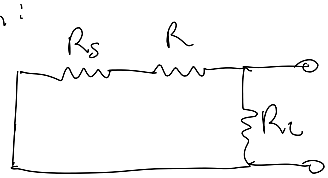
Notice that R_t is the parallel combination of R_L and $(R_s + R)$. [*Hint:* One way to make this problem easier is to rearrange the circuit as shown in **Figure P6.32(b)** and then to find the Thévenin equivalent for the source and resistances.]

b. Given that $C = 0.2\ \mu\text{F}$, $R_s = 2\ \text{k}\Omega$, $R = 47\ \text{k}\Omega$, and $R_L = 1\ \text{k}\Omega$, sketch (or use MATLAB to plot) the magnitude of *H(f)* to scale versus f/f_B from 0 to 3.

(a) find thevenin:

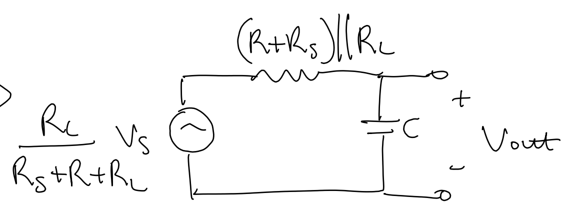
(1) $V_{o.c.} = \dfrac{R_L}{R_s + R + R_L} V_s$

(2) R_{th}:



$\leftarrow R_{th} = (R + R_s)\,||\,R_L$

$\Rightarrow$



$$V_{out} = \frac{\frac{1}{j2\pi fC}}{(R+R_s)||R_L + \frac{1}{j2\pi fC}} \times \frac{R_L}{R_s + R + R_L} V_s$$

$$\boxed{V_{out} = \left(\frac{R_L}{R_S+R+R_L}\right)\left(\frac{1}{1 + j(2\pi f C)\left(\frac{(R+R_S)R_L}{R+R_L+R_S}\right)}\right)V_S}$$

(b)

$$f_B = 2\pi\left(\frac{(R+R_S)R_L}{R_S+R+R_L}\right)C = \underline{\underline{812\ Hz}}$$

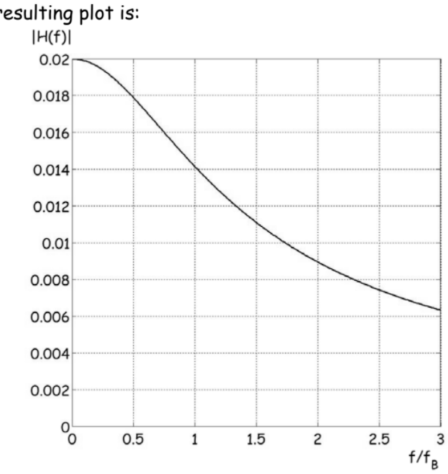
$$\frac{R_L}{R_S+R+R_L} = \frac{1k\Omega}{2k\Omega + 47k\Omega + 1k\Omega} = 0.02$$

$$\boxed{H(f) = \frac{0.02}{1 + j\frac{f}{f_B}}}$$

A MATLAB program to plot the transfer-function magnitude is:

```
foverfb=0:0.01:3;
Hmag=abs(0.02./(1 + i*foverfb));
plot(foverfb,Hmag)
axis([0 3 0 0.02])
```

The resulting plot is:



Problem 6 (optional)

*P6.46. Two first-order lowpass filters are in cascade as shown in Figure P6.46. The transfer functions are

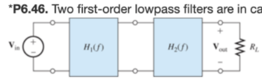


Figure P6.46

$$H_1(f) = H_2(f) = \frac{1}{1 + j(f/f_B)}$$

a. Write an expression for the overall transfer function.
b. Find an expression for the half-power frequency for the overall transfer function in terms of f_B.

[Comment: This filter cannot be implemented by cascading two simple *RC* lowpass filters like the one shown in Figure 6.7 on page 296 because the transfer function of the first circuit is changed when the second is connected. Instead, a buffer amplifier, such as the voltage follower discussed in Section 14.3, must be inserted between the *RC* filters.]

(a) $H(f) = H_1(f) \times H_2(f) = \dfrac{1}{1+j\left(\frac{f}{f_B}\right)} \times \dfrac{1}{1+j\left(\frac{f}{f_B}\right)}$

$$\rightarrow \boxed{H(f) = \frac{1}{\left(1+j\frac{f}{f_B}\right)^2}} = \frac{1}{1+j^2\left(\frac{f}{f_B}\right)^2 + j2\frac{f}{f_B}} = \frac{1}{1-\left(\frac{f}{f_B}\right)^2 + j2\frac{f}{f_B}}$$

(b)

$$|H(f)| = \frac{1}{\sqrt{\left(1-\left(\frac{f}{f_B}\right)^2\right)^2 + \left(2\frac{f}{f_B}\right)^2}}$$

$$= \frac{1}{\sqrt{1-2\left(\frac{f}{f_B}\right)^2 + \left(\frac{f}{f_B}\right)^4 + 4\left(\frac{f}{f_B}\right)^2}}$$

$$= \frac{1}{\sqrt{1+2\left(\frac{f}{f_B}\right)^2 + \left(\frac{f}{f_B}\right)^4}} = \frac{1}{\sqrt{\left(1+\left(\frac{f}{f_B}\right)^2\right)^2}}$$

$$\rightarrow \boxed{|H(f)| = \frac{1}{1+\left(\frac{f}{f_B}\right)^2}}$$

half-power $\rightarrow$ -3dB point:

$$|H(f_{3dB})| = \frac{1}{\sqrt{2}} = \frac{1}{1+\left(\frac{f_{3dB}}{f_B}\right)^2}$$

$$\boxed{f_{3dB} = \sqrt{\left(\sqrt{2}-1\right)}\, f_B = 0.6436\, f_B}$$

Problem 7 (optional)

P6.67. Suppose we need a first-order highpass filter (such as Figure 6.19 on page 309) to attenuate a 60-Hz input component by 60 dB. What value is required for the break frequency of the filter? By how many dB is the 600-Hz component attenuated by this filter? If $R = 5\ \mathrm{k\Omega}$, what is the value of C?

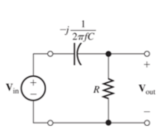


Figure 6.19
First-order highpass filter.

$$\boxed{H(f) = \frac{\mathbf{V}_{out}}{\mathbf{V}_{in}} = \frac{j(f/f_B)}{1+j(f/f_B)}}$$

in which

$f_B = \frac{1}{2\pi RC}$

(1) to attenuate a 60-Hz signal by 60dB, f_B must be 3 decades higher (1000x)

$\Rightarrow \boxed{f_B = 60\,kHz}$

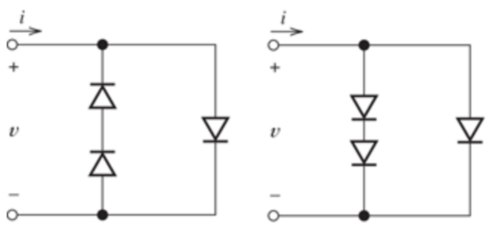
(2) 600 Hz component would be attenuated by $\boxed{40dB}$ (100x)

(3) $f_B = \frac{1}{2\pi RC} = 60\,kHz$

$R = 5k\Omega \rightarrow \boxed{C = 530.5pf}$

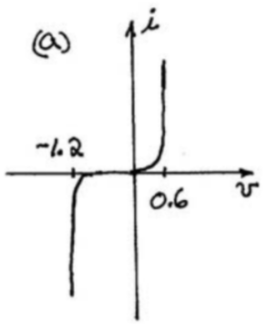
Problem 8 (optional)

Sketch i vs v for the following circuits. Assume voltages of 0.6V for all diodes when current flows in the forward direction.

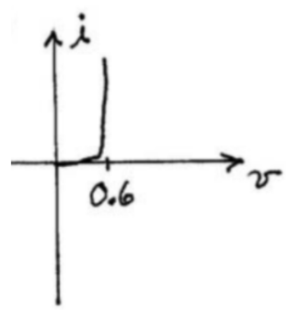


(a) (b)

(a)

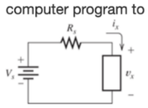


(b)



Problem 9 (optional)

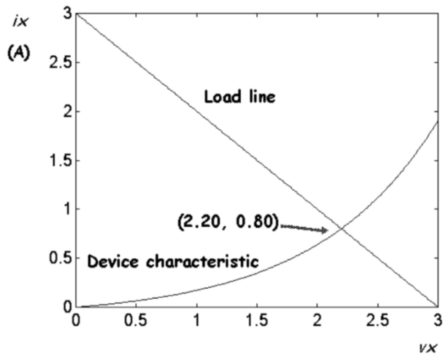
*P9.16. The nonlinear circuit element shown in Figure P9.16 has $i_x = [\exp(v_x) - 1]/10$. Also, we have $V_s = 3$ V and $R_s = 1\ \Omega$. Use graphical load-line techniques to solve for i_x and v_x. (You may prefer to use a computer program to plot the characteristic and the load line.)



load-line equation: $V_s = i_x R_s + V_x$

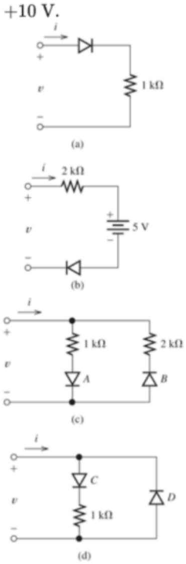
$\rightarrow \quad 3V = i_x(1\Omega) + V_x \qquad (1)$

$\rightarrow \quad i_x = \dfrac{\left[e^{v_x} - 1\right]}{10} \qquad (2)$

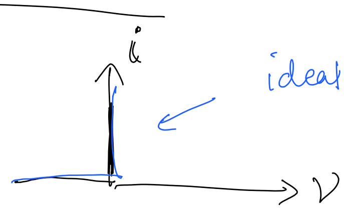


Problem 10 (10 points)

P9.39. Sketch *i* versus *v* to scale for each of the circuits shown in **Figure P9.39**. Assume that the diodes are ideal and allow *v* to range from -10 V to $+10$ V.

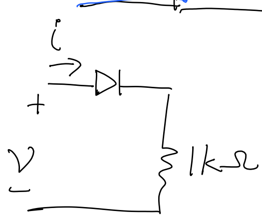


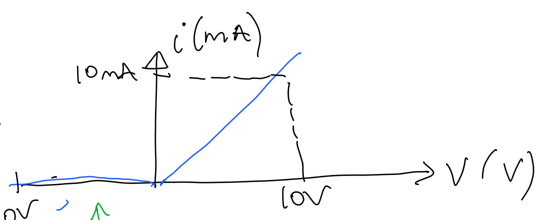
ideal diode:



ideal diode turns on @ $v = 0$

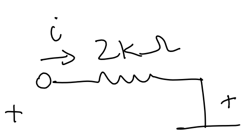
(a)



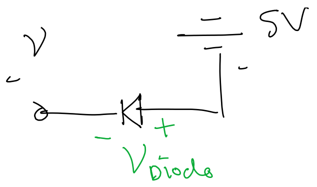


$i = 0$ for $v < 0$ (diode off)

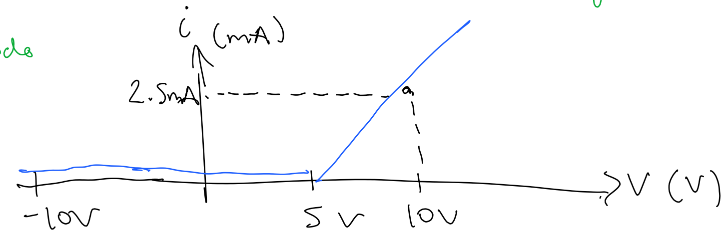
(b)



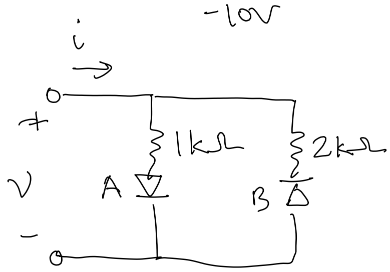
$v = i(2k\Omega) + 5V$



*diode is on as long as $V \geq 5V$

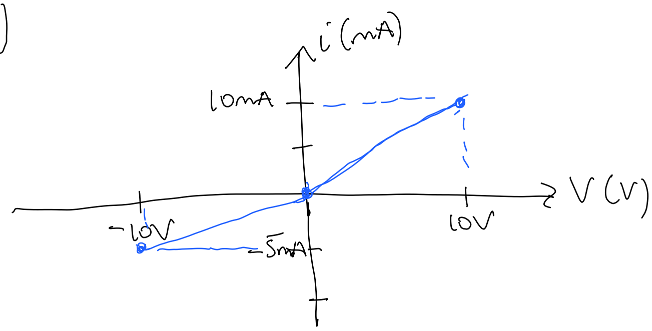


(c)

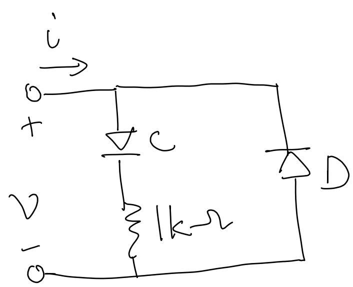


$v > 0$: A on

$v < 0$: B on

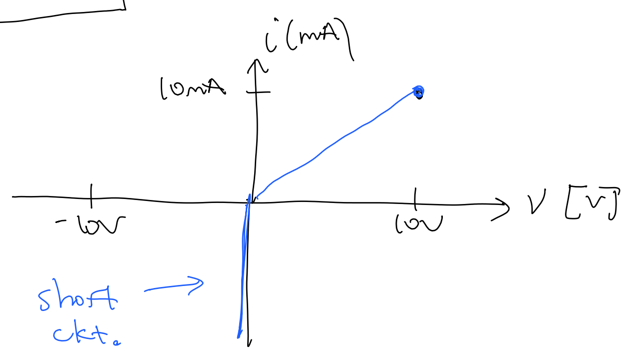


(d)



$v > 0$: C is on

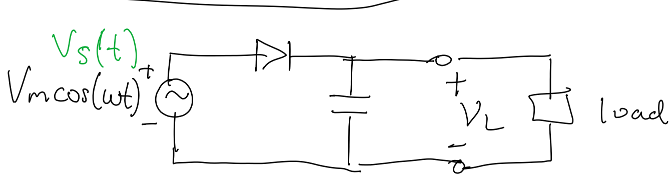
$v < 0$: D is on

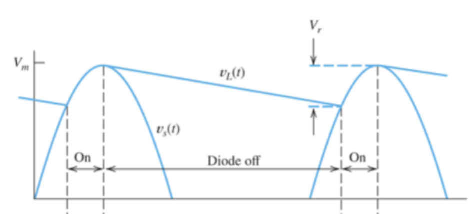


Problem 11 (optional)

P9.49. Draw the circuit diagram of a half-wave rectifier for producing a nearly steady dc voltage from an ac source. Draw two different full-wave circuits.

(a) half-wave rectifier

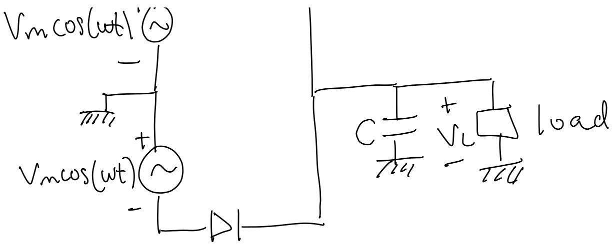


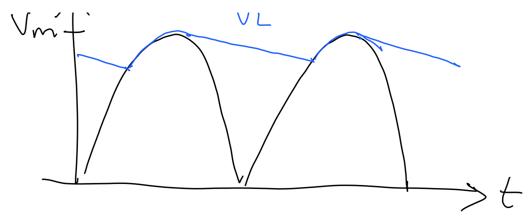


(b) Voltage waveforms

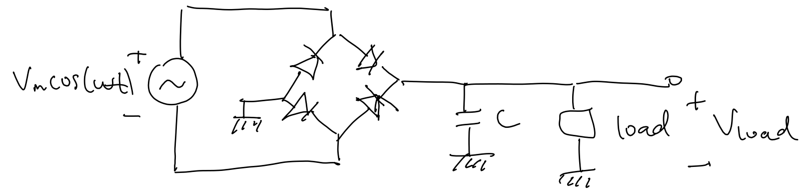
(b) full-wave rectifier

①





2



Problem 12 (optional)

P9.52. Consider the half-wave rectifier shown in Figure 9.26 on page 477. The ac source has an rms value of 20 V and a frequency of 60 Hz. The diodes are ideal, and the capacitance is very large, so the ripple voltage V_r is very small. The load is a 100-Ω resistance. Determine the PIV across the diode and the charge that passes through the diode per cycle.

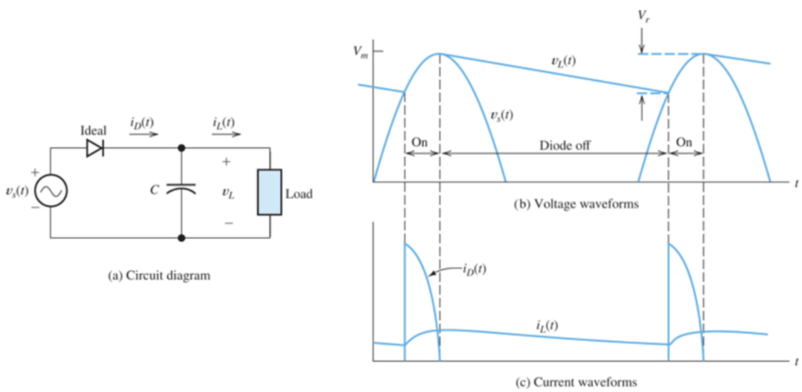


Figure 9.26

Half-wave rectifier with smoothing capacitor.

- $V_m = 20V$ (rms)

  ↳ ac peak magnitude

- DC output voltage:

  $V_L = 20\sqrt{2}\ V$ (converting from rms value)

- Load current, i_L:

  $$i_L = \frac{20\sqrt{2}\ V}{100\Omega} = \boxed{282.8mA}$$

- The charge that passes thru the load must also pass thru the diode

  $Q = i_L T$ $\qquad T = \frac{1}{60Hz}$

$$Q = (282.8\,mA)\left(\frac{1}{60\,Hz}\right) = \boxed{4.714\,mC} \quad \text{(per cycle)}$$

• Peak inverse voltage:

$$\sim 2V_m = 2(20\sqrt{2}) = 40\sqrt{2} = \boxed{56.57\,V}$$

↳ discussed on page 478 of textbook

Problem 13 (10 points)

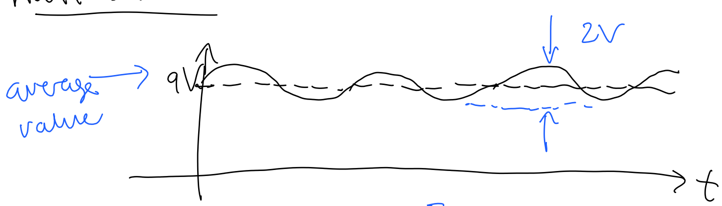
***P9.54.** Design a half-wave rectifier power supply to deliver an average voltage of 9 V with a peak-to-peak ripple of 2 V to a load. The average load current is 100 mA. Assume that ideal diodes and 60-Hz ac voltage sources of any amplitudes needed are available. Draw the circuit diagram for your design. Specify the values of all components used.

P9.55. Repeat Problem P9.54 with a full-wave bridge rectifier.

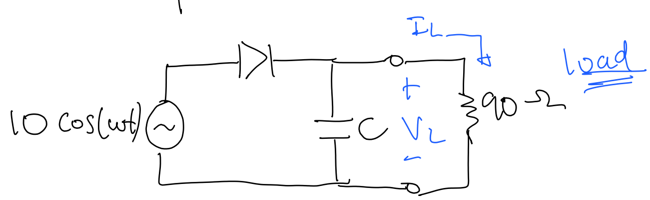
P9.56. Repeat Problem P9.54 with two diodes and out-of-phase voltage sources to form a full-wave rectifier.

P9.57. Repeat Problem P9.54, assuming that the diodes have forward drops of 0.8 V.

(a) half-wave:



$I_L(\text{average}) = 100\,mA$



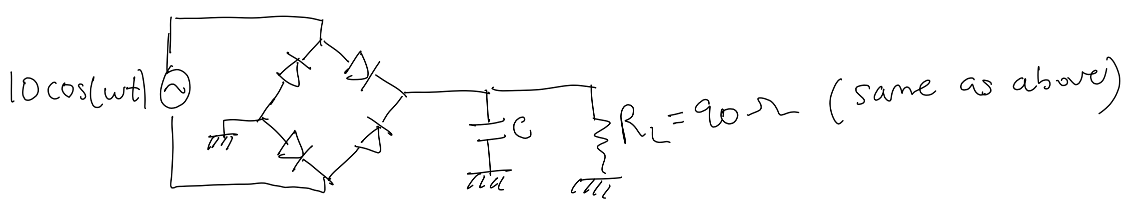
$$R_L = \frac{V_L(\text{average})}{I_L(\text{average})} = \frac{9V}{100\,mA}$$

$$R_L = 90\,\Omega$$

$$C = \frac{I_L T}{V_r} = \frac{(100\,mA)\left(\frac{1}{60\,Hz}\right)}{2V} = \boxed{833\,\mu F}$$

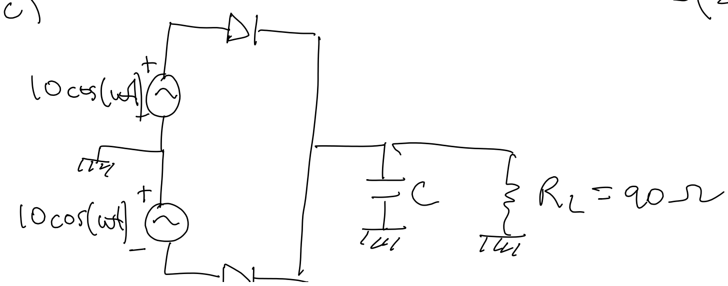
ripple → V_r

(b) full-wave:



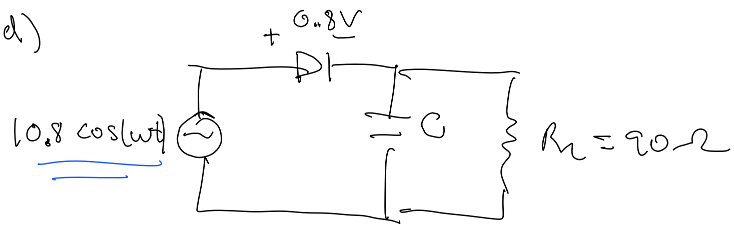
$$C = \frac{I_L T}{2V_r} = \frac{(100\,mA)\left(\frac{1}{60\,Hz}\right)}{2(2V)} = \boxed{417\,\mu F}$$

(c)



$$C = \frac{I_L T}{2V_r} = \boxed{417\,\mu F}$$

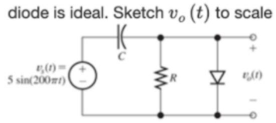
(d)

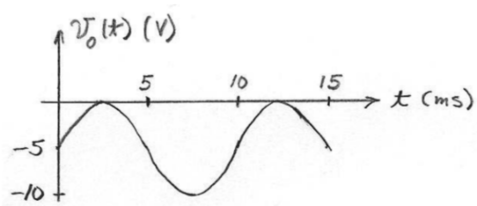


$\boxed{C = 833\,\mu F}$

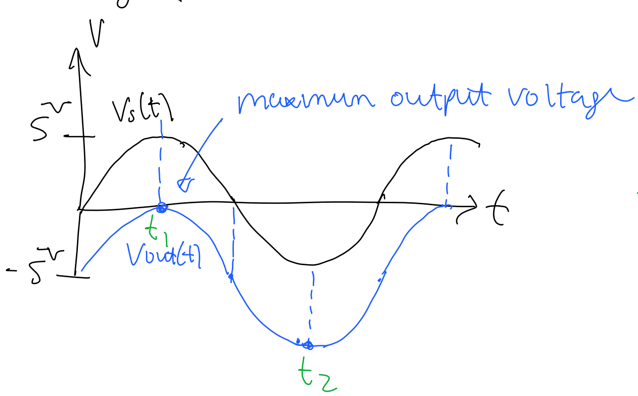
Problem 14 (10 points)

P9.69. Consider the circuit shown in **Figure P9.69**, in which the *RC* time constant is very long compared with the period of the input and in which the diode is ideal. Sketch $v_o(t)$ to scale versus time.





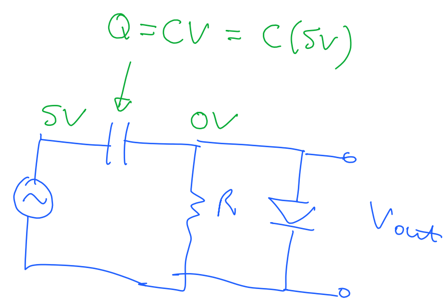
Why?



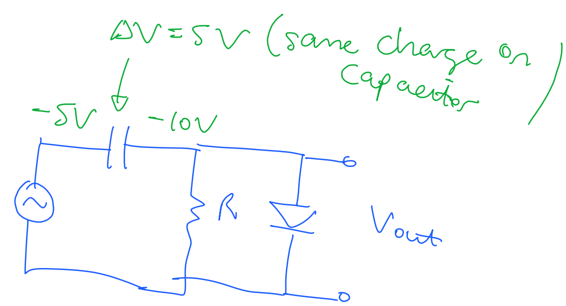
Why?:

- Vo(t) ≤ 0 b/c at Vout = 0, diode turns and short R
  ↳ defines max output voltage Vout = 0

t₁:

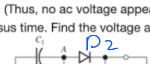


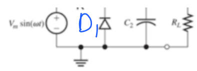
t₂:

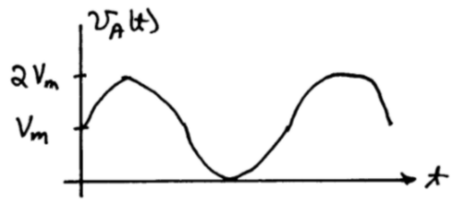


Problem 15 (optional)

P9.71. Voltage-doubler circuit. Consider the circuit of **Figure P9.71**. The capacitors are very large, so they discharge only a very small amount per cycle. (Thus, no ac voltage appears across the capacitors, and the ac input plus the dc voltage of C_1 must appear at point *A*.) Sketch the voltage at point *A* versus time. Find the voltage across the load. Why is this called a voltage doubler? What is the PIV across each diode?

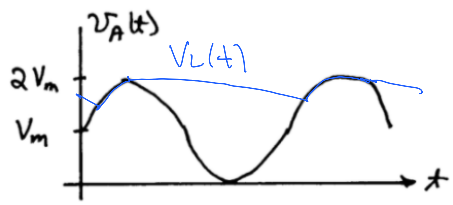






- Diode (D1) and C_1 form clamping circuit that clamps negative peak of $V_A(t)$ to zero

- D_2 and C_2 act as half-wave peak rectifier



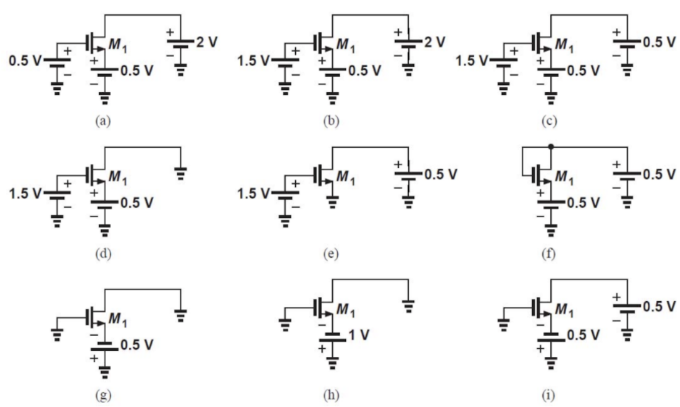
$\boxed{V_L(t) \cong 2V_m}$

Peak Inverse Voltage (PIV):

$\boxed{2V_m}$ for both D_1 and D_2

Problem 16 (10 points)

MOSFET as a Resistor: If the threshold is equal to 0.7 V, for each circuit determine whether the device is off or acts as a resistor or neither:



(a) $V_{gs} = 0.5V - 0.5V = 0V$ $\quad V_{gs} < V_{TH} \rightarrow$ off

$V_{ds} = 2V - 0.5V = 1.5V$

(b) $V_{gs} = 1V$ $\quad V_{gs} > V_{TH} \rightarrow$ $\boxed{\text{on; does not act as resistor}}$

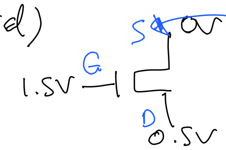
$V_{ds} = 1.5V$

↳ in saturation

(c) $V_{gs} = 1V$ $\quad V_{gs} > V_{TH} \rightarrow$ $\boxed{\text{on; resistor}}$ w/ ~~zero~~ current

$V_{ds} = 0V$

(d)



→ note: source terminal

$V_{GS} = 1.5V - 0V = 1.5V \rightarrow$ $\boxed{\text{on; resistor}}$

$V_{DS} = 0.5V - 0V = 0.5V$ → linear/triode mode

↳ $V_{DS} < V_{GS} - V_{TH}$

$0.5V < 1.5 - 0.7 = 0.8V$

(e) $V_{gs} = 1.5V$, $V_{ds} = 0.5V$ } $\boxed{\text{on; resistor}}$ $\quad V_{ds} < V_{gs} - V_{TH}$

(f) $V_{gs} = 0$, $V_{ds} = 0$ } $\boxed{\text{off}}$

(g) $V_{gs} = 0 - (-0.5V) = 0.5V$

$V_{ds} = 0 - (-0.5V) = 0.5V$ } $\boxed{\text{off}}$

(h) $V_{gs} = 1V$ $\quad V_{gs} > V_{TH}$

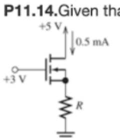
$V_{ds} = 1V$ $\quad V_{DS} > V_{GS} - V_{TH} \rightarrow$ saturation

$\boxed{\text{on; does not act like a resistor}}$

(i) $V_{gs} = 0.5V$, $V_{ds} = 1V$ $\quad \boxed{\text{off}}$

Problem 17 (optional)

P11.14. Given that the enhancement transistor shown in **Figure P11.14** has $V_{to} = 1\ \mathrm{V}$ and $K = 0.5\ \mathrm{mA/V^2}$, find the value of the resistance *R*.



(1) $V_{DS} > V_{GS} - V_{TH}$: saturation

$V_D - V_S > (V_G - V_S) - V_{TH} \rightarrow V_D > V_G - V_{TH}$

$5V > 3V - 1V = 2V$ ✓ <u>in saturation</u>

$\rightarrow i_D = K(V_{GS} - V_{TH})^2 = 0.5mA$

$K = \frac{0.5mA}{V^2} \rightarrow (V_{GS} - V_{TH})^2 = 1$

$\rightarrow V_{GS} = 1V + V_{TH}$ $\quad V_{TH} = 1V$

$V_{GS} = 2V$

$\rightarrow V_S = 1V$ $\quad (V_G - V_S = 3V - 1V = 2V)$

$R = \frac{1V}{0.5mA} = \boxed{2k\Omega}$

Problem 18 (optional)

*P11.19. Consider the circuit shown in Figure 11.10 on page 567. The transistor characteristics are shown in Figure 11.11. Suppose that V_{GG} is changed to 0 V. Determine the values of V_{DSQ}, $V_{DS\min}$, and $V_{DS\max}$. Find the gain of the amplifier.

For $V_{GG} = 0$, the FET remains in cutoff so $V_{DSmax} = V_{DSQ} = V_{DSmin} = 20$ V. Thus, the output signal is zero, and the gain is zero. For amplification to take place, the FET must be biased in the saturation or triode regions.

Problem 19 (10 points)

P11.20. Consider the amplifier shown in Figure P11.20.

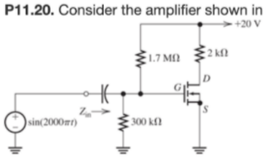
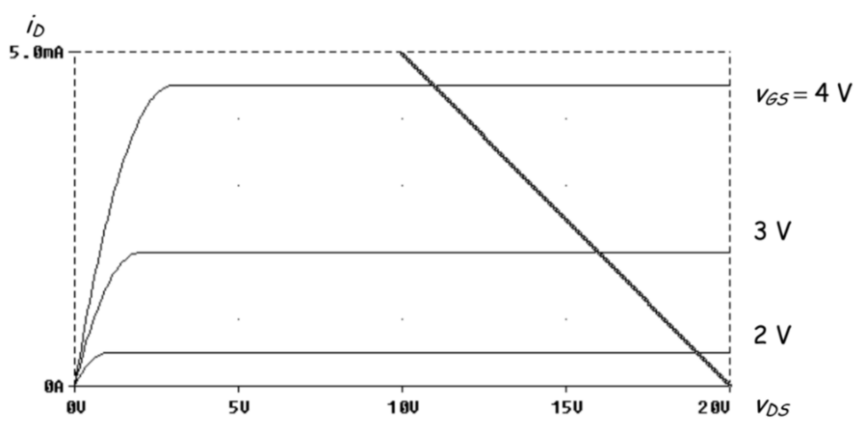


Figure P11.20

a. Find $v_{GS}(t)$, assuming that the coupling capacitor is a short circuit for the ac signal and an open circuit for dc. [*Hint:* Apply the superposition principle for the ac and dc sources.]
b. If the FET has $V_{to} = 1$ V and $K =$ sketch its drain characteristics to scale for $v_{GS} = 1, 2, 3,$ and 4 V.
c. Draw the load line for the amplifier on the characteristics.
d. Find the values of V_{DSQ}, $V_{DS\min}$, and $V_{DS\max}$.

(a) The 1.7 MΩ and 300 kΩ resistors act as a voltage divider that establishes a dc voltage $V_{GSQ} = 3$ V. Then if the capacitor is treated as a short for the ac signal, we have $v_{GS}(t) = 3 + \sin(2000\pi t)$

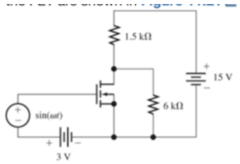
(b), (c), and (d)



From the load line we find $V_{DSQ} = 16$ V, $V_{DSmax} = 19$ V, and $V_{DSmin} = 11$ V.

Problem 20 (optional)

P11.22. Use a load-line analysis of the circuit shown in Figure P11.22 to determine the values of V_{DSQ}, $V_{DS\min}$, and $V_{DS\max}$. The characteristics of the FET are shown in Figure 11.21 on page 576. [Hint: First, replace the 15-V source and the resistances by their Thévenin equivalent circuit.]



The Thévenin equivalent for the drain circuit contains a 12-V source in series with a 1.2-kΩ resistance. Then, we can construct the load line and determine the required voltages as shown: