บทที่ 7

Integrating Factor Method Method for obtaining the solution of a differential equation by multiplying the equation by an exponential factor that makes one side of the equation a perfect derivative and then integrating both sides of the equation.

Pulse Signal Function of time that is zero for $t < t_0$, has magnitude M for $t_0 < t < t_1$, and is equal to zero for $t > t_1$.

Natural Response The general solution of the differential equation that represents the circuit.

Operator A symbol that represents a mathematical operation. Differential operator s such that $s^n x = d^n x/dt^n$.

Sequential Switching Action of two or more switches activated at different instants of time in a circuit.

Signal Real-valued function of time; waveform that conveys information.

Sinusoidal Signal A waveform that varies in accordance with a sine or cosine function of time.

Stability A property of well-behaved circuits. A first-order circuit is stable if, and only if, its time constant is not negative, that is, $\tau \geq 0$.

Steady-State Response When the input to the circuit is either a constant or a sinusoid, the forced response is also called the steady-state response.

Step Response Response of a circuit when the input is equal to a unit step function and all the initial conditions of the circuit are equal to zero.

Time Constant The parameter τ in the first-order differential equation $\frac{d}{dt}x(t) + \frac{x(t)}{\tau} = K$. The time constant τ is the time for the response of a first-order circuit to complete 63 percent of the transition from initial value to final value.

Transient Response A term sometimes referring to the "transient part of the complete response" and at other times to a complete response which includes a transient part. In particular, PSpice uses the term *transient response* to refer to the complete response. Since this can be confusing, the term must be used carefully.

Unit Step Function Denoted as $u(t-t_0)$ and a function of time that is zero for $t < t_0$ and unity for $t > t_0$. At $t = t_0$ the magnitude changes from zero to one. The unit step is dimensionless.

Problems

Section 8.3 The Response of a First-Order Circuit to a Constant Input

P 8.3-1 A circuit containing a single inductor is at steady state until time $t = 0$. Before $t = 0$, the inductor current is $i_L(t) = 3$ mA. The circuit is disturbed at time $t = 0$. Figure P 8.3-1 shows the circuit after $t = 0$. Find the inductor current after time $t = 0$.

Answer: $i_L(t) = 5 - 2e^{-\frac{t}{3.75}}$ mA after $t = 0$, where t is in ms

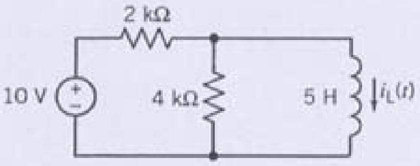


Figure P 8.3-1

P 8.3-2 A circuit containing a single capacitor is at steady state until time $t = 0$. Before $t = 0$, the capacitor voltage is $v_c(t) = 8$ V. The circuit is disturbed at time $t = 0$. Figure P 8.3-2 shows the circuit after $t = 0$. Find the capacitor voltage after time $t = 0$.

Answer: $v_c(t) = 4 + 4e^{-\frac{t}{0.67}}$ V after $t = 0$, where t is in ms.

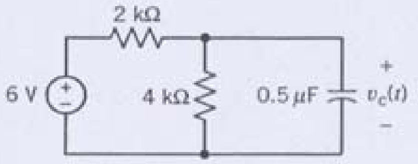


Figure P 8.3-2

P 8.3-3 A capacitor is connected to a voltage source at position 1 as shown in Figure P 8.3-3. The switch is moved instantaneously to position 2 at $t = 0$. Determine the voltage, $v(t)$, appearing across the capacitor, for $t > 0$.

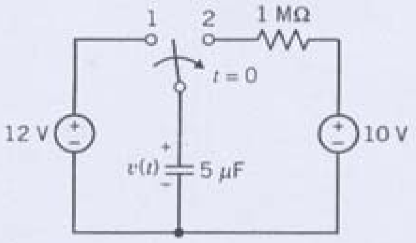


Figure P 8.3-3

P 8.3-4 For the circuit of Figure P 8.3-4, find $v_L(t)$.

Answer: $v_L(t) = 10e^{-20{,}000t}$ V, $t > 0$

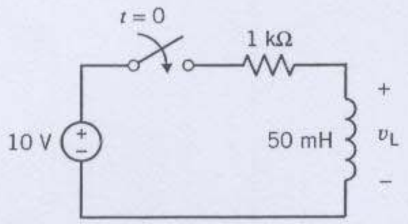


Figure P 8.3-4

P 8.3-5 Determine the inductor current $i_L(t)$ for the circuit of Figure P 8.3-5.

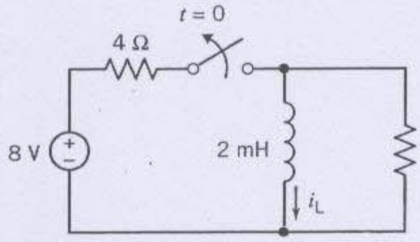


Figure P 8.3-5

P 8.3-6 Determine the capacitor voltage $v_c(t)$ for the circuit of Figure P 8.3-6.

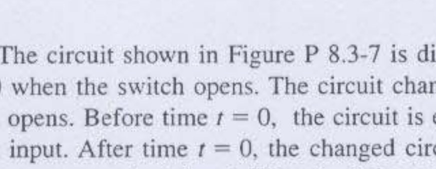


Figure P 8.3-6

P 8.3-7 The circuit shown in Figure P 8.3-7 is disturbed at time $t = 0$ when the switch opens. The circuit changes when the switch opens. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the changed circuit is excited by the same constant input. This circuit has two steady-state responses, $v_C(t)$, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $v_C(t) = 2$ V before $t = 0$ and $v_c(t) = 4$ V after $t = 0$

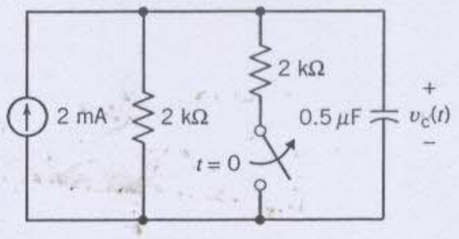


Figure P 8.3-7

P 8.3-8 The circuit shown in Figure P 8.3-8 is disturbed at time $t = 0$ when the switch closes. The circuit changes when the switch closes. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the changed circuit is excited by the same constant input. This circuit has two steady-state responses, $i_L(t)$, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $i_L(t) = 2$ mA before $t = 0$ and $i_L(t) = 4$ mA after $t = 0$

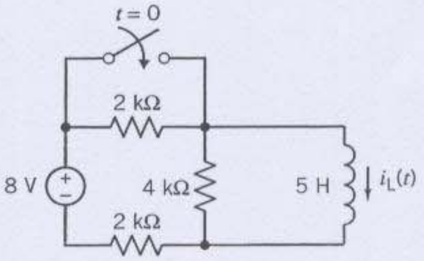


Figure P 8.3-8

P 8.3-9 The circuit shown in Figure P 8.3-9 is disturbed at time $t = 0$ when the switch closes. The circuit changes when the switch closes. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the changed circuit is excited by the same constant input. This circuit has two steady-state responses, $i_L(t)$, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $i_L(t) = 2$ mA before $t = 0$ and $i_L(t) = 2$ mA after $t = 0$

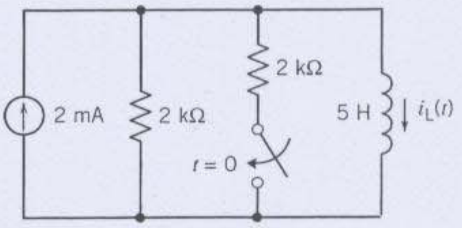


Figure P 8.3-9

P 8.3-10 The circuit shown in Figure P 8.3-10 is disturbed at time $t = 0$ when the switch opens. The circuit changes when the switch opens. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the changed circuit is excited by the same constant input. This circuit has two steady-state responses, $v_C(t)$,one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.
Answer: $v_C(t) = 5.33$ V before $t = 0$ and $v_C(t) = 4$ V after $t = 0$

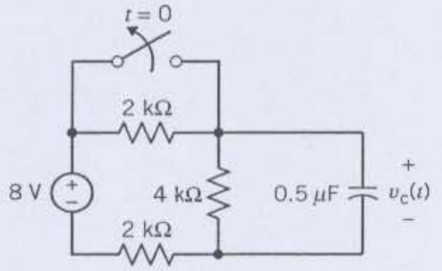
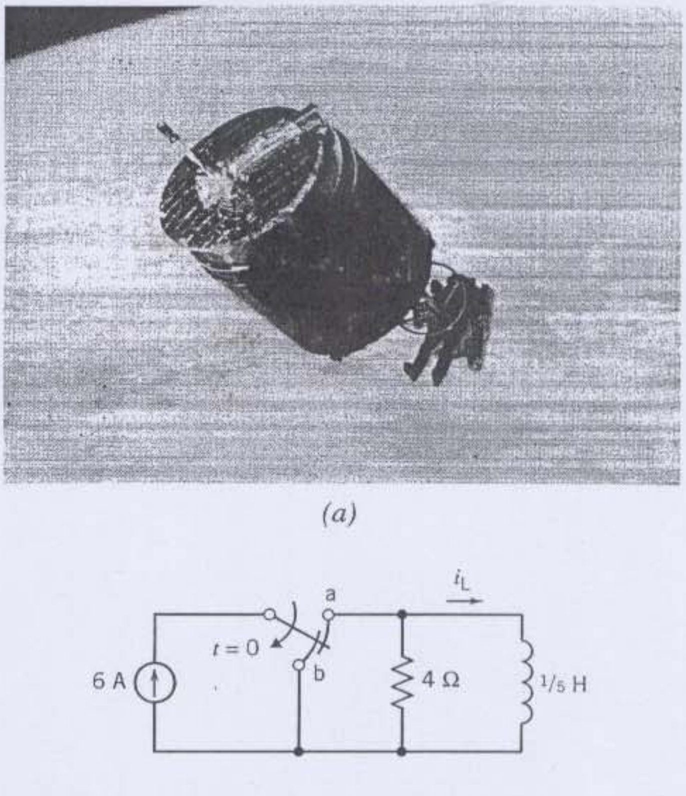


Figure P 8.3-10

P 8.3-11 Figure P 8.3-11*a* shows astronaut Dale Gardner using the manned maneuvering unit to dock with the spinning Westar VI satellite on November 14, 1984. Gardner used a large tool called the apogee capture device (ACD) to stabilize the satellite and capture it for recovery, as shown in Figure P 8.3-11*a*. The ACD can be modeled by the circuit of Figure P 8.3-11*b*. Find the inductor current i_L for $t > 0$.
Answer: $i_L(t) = 6e^{-20t}$ A



(*a*)

(*b*)

Figure P 8.3-11 (*a*) Astronaut Dale Gardner using the manned maneuvering unit to dock with the Westar VI satellite. Courtesy of NASA. (*b*) Model of the apogee capture device. Assume that the switch has been in position for a long time at $t = 0^-$.

P 8.3-12 An electronic flash of a camera uses a small battery to charge a capacitor. Then, when the flash is activated, the capacitor is switched across the flashbulb. Assume that the battery is a 6-V battery that should not be operated with a current above 100 μA. The capacitor is to be selected. (a) Draw a circuit model that will represent the charging and discharging action. (b) It is desired to charge the capacitor within 5 s and to discharge it within 1/2 s. Select the appropriate values for the elements in the circuit. Assume that the value of the bulb resistance is 10 kΩ. Assume that the capacitor is charged or discharged in five time constants.

P 8.3-13 A security alarm for an office building door is modeled by the circuit of Figure P 8.3-13. The switch represents the door interlock, and v is the alarm indicator voltage. Find $v(t)$ for $t > 0$ for the circuit of Figure P 8.3-13. The switch has been closed for a long time at $t = 0^-$.

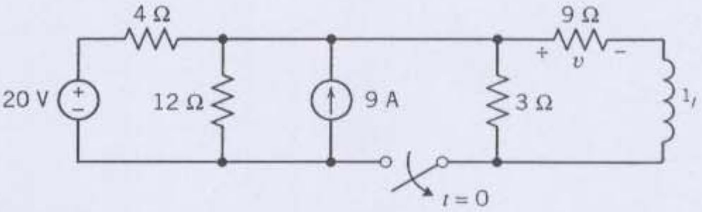


Figure P 8.3-13 A security alarm circuit.

P 8.3-14 Find $i(t)$ for $t > 0$ for the circuit of Figure P 8.3-14. The circuit is in steady state at $t = 0^-$.
Answer: $i(t) = -14.3e^{-3.25t}$ A

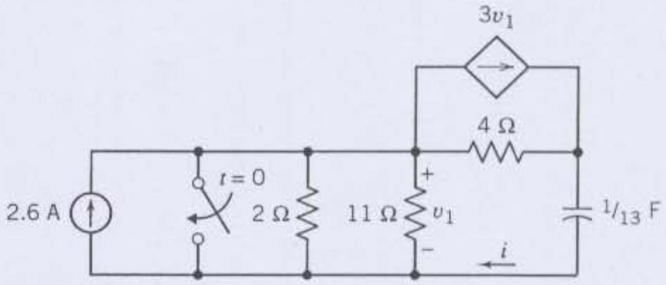


Figure P 8.3-14

P 8.3-15 Find $i(t)$ for $t > 0$ if $v_c(0) = 12$ V for the circuit of Figure P 8.3-15.

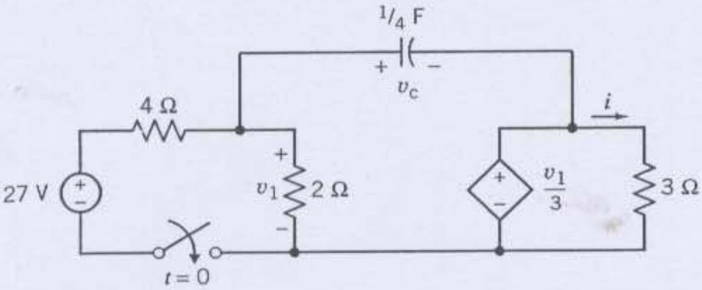


Figure P 8.3-15

P 8.3-16 Consider the circuit shown in Figure P 8.3-16. The switch is moved from A to B at $t = 0$ after being at A for a long time. Let $v_2(0^-) = 0$ V. Find $v_1(0^-)$, $v_1(0)$, $v_2(0)$, $v_R(0)$, $v_R(t)$, $i(t)$, $v_1(t)$, and $v_2(t)$ for $t > 0$.
Answer: $v_1(0^-) = 40$ V, $v_1(0) = 40$ V,
$v_2(0) = 0$ V, $v_R(0) = 40$ V,
$v_R(t) = 40e^{-18t}$ V, $i(t) = 8e^{-18t}$ A,
$v_1(t) = \frac{80}{3} + \frac{40}{3}e^{-18t}$ V, $v_2(t) = \frac{80}{3} - \frac{80}{3}e^{-18t}$ V

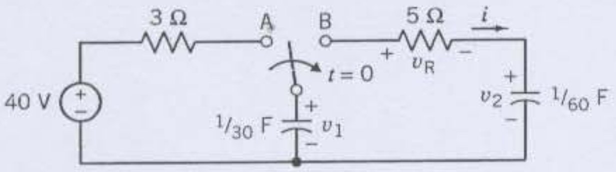


Figure P 8.3-16

P 8.3-17 A complex electronic circuit for a communication satellite is represented by Figure P 8.3-17. Find $i(t)$ for $t > 0$ for the circuit shown in Figure P 8.3-17. The circuit is in steady state at $t = 0^-$.
Answer: $i = (1/6)e^{-3000t}$ mA

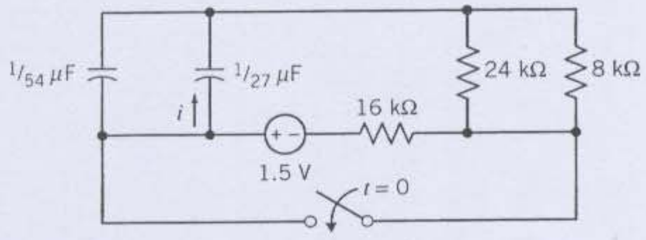


Figure P 8.3-17 A circuit for a communication satellite.

P 8.3-18 Determine $v(t)$ for $t > 0$ for the circuit of Figure P 8.3-18.

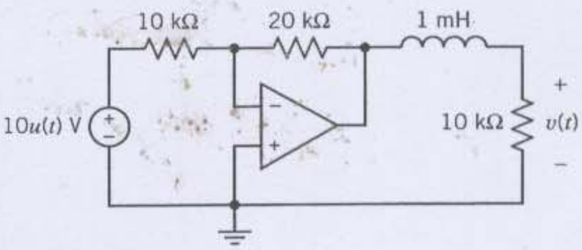


Figure P 8.3-18

Section 8.4 Sequential Switching

P 8.4-1 Switch 1 has been open, and switch 2 has been closed for a long time at $t = 0^-$ in the circuit of Figure P 8.4-1. At $t = 0$, switch 1 is closed, and then switch 2 is opened at $t = 3$ s. Determine $i(t)$ and plot $i(t)$ for $0 \le t \le 8$ s.

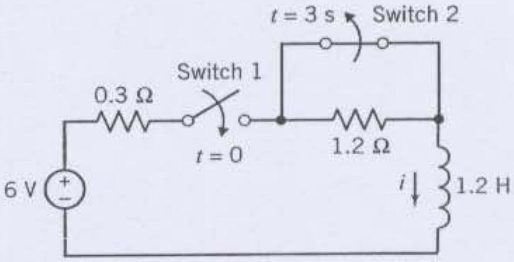


Figure P 8.4-1

P 8.4-2 The uncharged capacitor of the circuit shown in Figure P 8.4-2 is switched from position a to position b at $t = 0$ and remains there for 200 ms before being switched to position c, where it remains indefinitely. Find v and plot v for $0 < t < 500$ ms.

Answer: $v = \begin{cases} 200(1 - e^{-10t}), & 0 < t < 200 \text{ ms} \\ 173e^{-20(t-0.2)}, & t > 200 \text{ ms} \end{cases}$

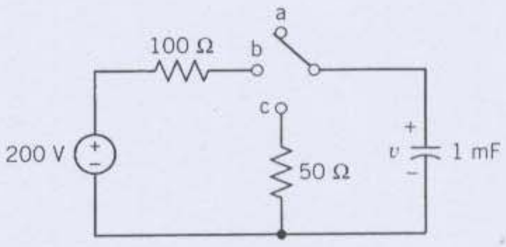


Figure P 8.4-2

P 8.4-3 Find $i(t)$ for $t > 0$ for the circuit shown in Figure P 8.4-3. The circuit is in steady state at $t = 0^-$.

Answer: $i(t) = 2/3e^{-6t}$ A for $0 \le t \le 51$ ms
$i(t) = 1.47e^{-14(t-0.051)}$ A for $t > 51$ ms

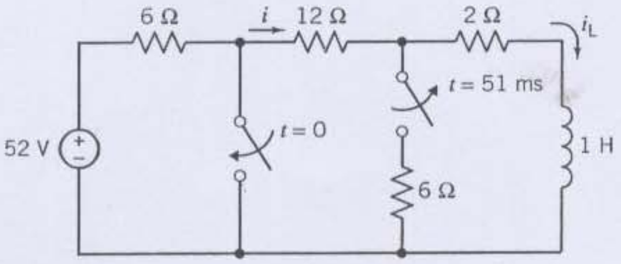


Figure P 8.4-3

P 8.4-4 Cardiac pacemakers are used by people to maintain regular heart rhythm when they have a damaged heart. The circuit of a pacemaker can be represented as shown in Figure P 8.4-4. The resistance of the wires, R, can be neglected since $R < 1$ mΩ. The heart's load resistance, R_L, is 1 kΩ. The first switch is activated at $t = t_0$ and the second switch is activated at $t_1 = t_0 + 10$ ms. This cycle is repeated every second. Find $v(t)$ for $t_0 \le t \le 1$. Note that it is easiest to consider $t_0 = 0$ for this calculation. The cycle repeats by switch 1 returning to position a and switch 2 returning to its open position.

Hint: Use $q = Cv$ to determine $v(0^-)$ for the 100-μF capacitor.

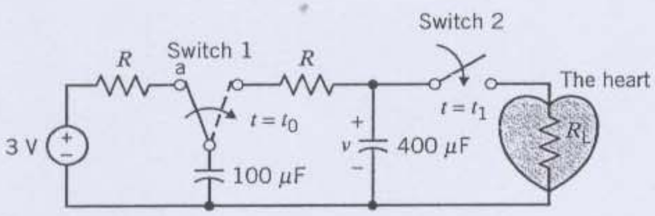


Figure P 8.4-4

P 8.4-5 Determine and sketch $i(t)$ for the circuit shown in Figure P 8.4-5. Calculate the time required for $i(t)$ to reach 99 percent of its final value.

In practice, a solenoid is not directly shorted to turn it off but is shorted through a device called a diode with a voltage drop of 0.7 V, as this is easier to implement. Why would you not simply open-circuit the coil to achieve zero current?

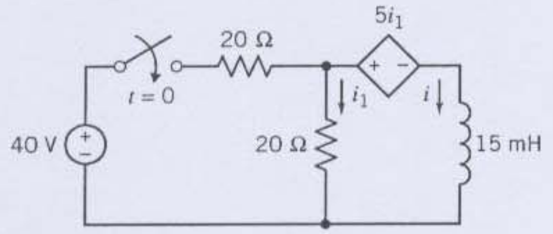


Figure P 8.4-5

P 8.4-6 An electronic flash on a camera uses the circuit shown in Figure P 8.4-6. Harold E. Edgerton invented the electronic flash in 1930. A capacitor builds a steady-state voltage and then discharges it as the shutter switch is pressed. The discharge produces a very brief light discharge. Determine the elapsed time t_1 to reduce the capacitor voltage to one-half of its initial voltage. Find the current at $t = t_1$.

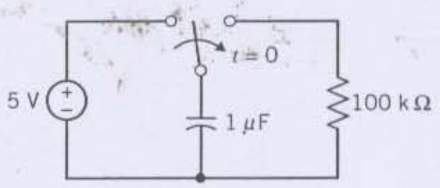


Figure P 8.4-6 Electronic flash circuit.

P 8.4-7 Sequential switching is used repetitively to generate communication signals. For the circuit shown in Figure P 8.4-7, switch a has been in position 1 and switch b has been open for a long time. At $t = 0$, switch a moves to position 2. Then, 100 ms after switch a moves, switch b closes. Find the capacitor voltage v for $t \ge 0$.

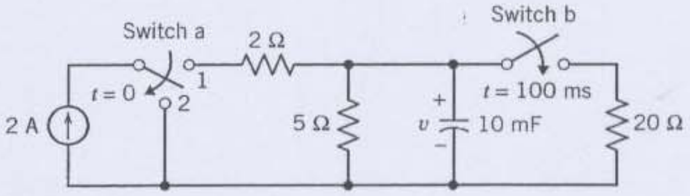


Figure P 8.4-7

P 8.4-8 For the circuit of Figure P 8.4-8, determine $v_c(t)$ and $v_x(t)$ for $t > 0$ when $C = 0.2$ F. Assume that the circuit is in steady state when $t = 0^-$.

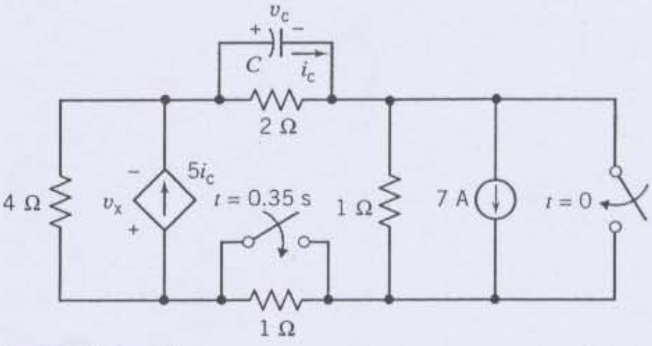


Figure P 8.4-8

Section 8.5 Stabiltiy of First-Order Circuits

P 8.5-1 The circuit in Figure P 8.5-1 contains a current-controlled voltage source. What restriction must be placed on the gain, R, of this dependent source in order to guarantee stability?

Answer: $R < 400\Omega$

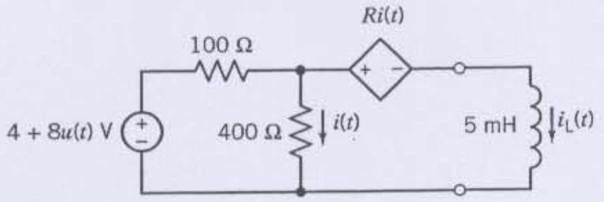


Figure P 8.5-1

P 8.5-2 The circuit in Figure P 8.5-2 contains a voltage-controlled voltage source. What restriction must be placed on the gain, A, of this dependent source in order to guarantee stability?

Answer: $A < 5$

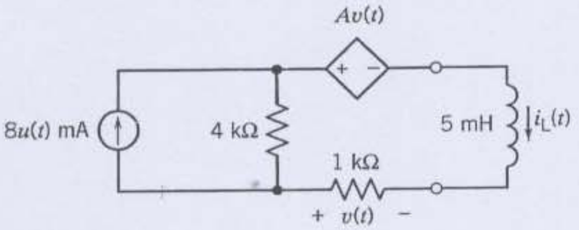


Figure P 8.5-2

P 8.5-3 The circuit in Figure P 8.5-3 contains a current-controlled current source. What restriction must be placed on the gain, B, of this dependent source in order to guarantee stability?

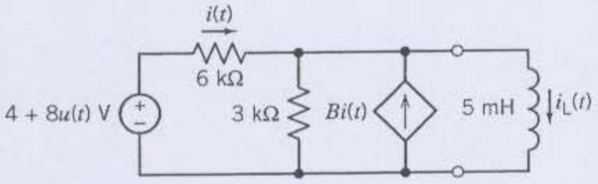


Figure P 8.5-3

P 8.5-4 The circuit in Figure P 8.5-4 contains a voltage-controlled voltage source. What restriction must be placed on the gain, A, of this dependent source in order to guarantee stability?

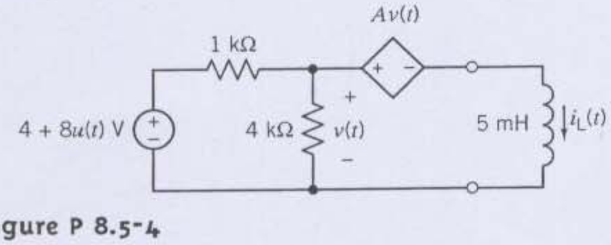


Figure P 8.5-4

Section 8.6 The Unit Step Response

P 8.6-1 The input to circuit shown in Figure P 8.6-1 changes at time $t = 0$. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the circuit is excited by a different constant input. The response of this circuit is the inductor current, $i_L(t)$. This circuit has two steady-state responses, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $i_L(t) = -2$ mA before $t = 0$ and $i_L(t) = 3$ mA after $t = 0$

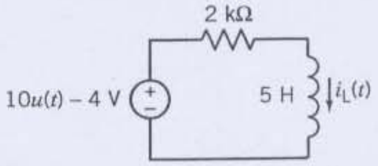


Figure P 8.6-1

P 8.6-2 The input to circuit shown in Figure P 8.6-2 changes at time $t = 0$. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the circuit is excited by a different constant input. The response of this circuit is the inductor current, $i_L(t)$. This circuit has two steady-state responses, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $i_L(t) = 3$ mA before $t = 0$ and $i_L(t) = 2$ mA after $t = 0$

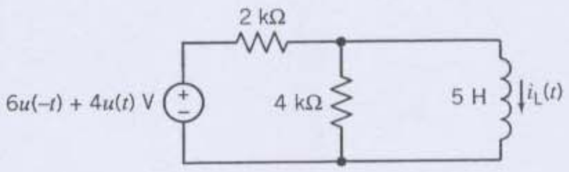


Figure P 8.6-2

P 8.6-3 The input to circuit shown in Figure P 8.6-3 changes at time $t = 0$. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the circuit is excited by a different constant input. The response of this circuit is the capacitor voltage, $v_C(t)$. This circuit has two steady-state responses, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $v_C(t) = 8$ V before $t = 0$ and $v_C(t) = 12$ V after $t = 0$

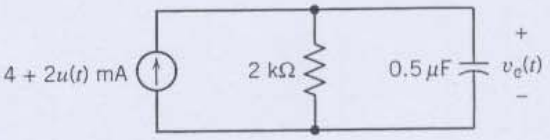


Figure P 8.6-3

P 8.6-4 The input to circuit shown in Figure P 8.6-4 changes at time $t = 0$. Before time $t = 0$, the circuit is excited by a constant input. After time $t = 0$, the circuit is excited by a different constant input. The response of this circuit is the capacitor voltage $v_C(t)$. This circuit has two steady-state responses, one before $t = 0$ and one after $t = 0$. Find both of these steady-state responses.

Answer: $v_C(t) = 8$ V before $t = 0$ and $v_C(t) = 4$ V after $t = 0$

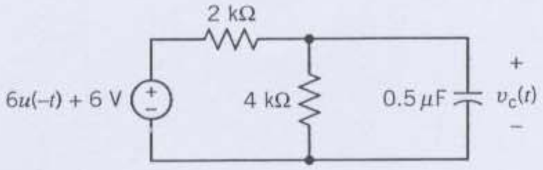


Figure P 8.6-4

P 8.6-5 Find $i(t)$ for $t > 0$ for the circuit of Figure P 8.6-5. Assume the circuit is in steady state at $t = 0^-$.

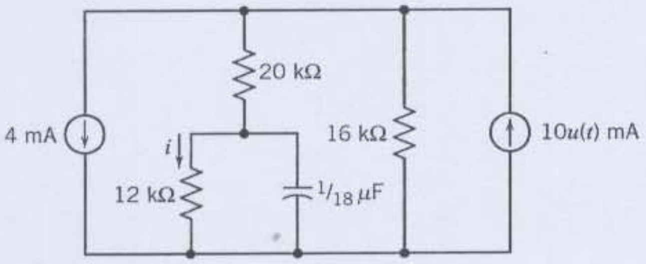


Figure P 8.6-5

P 8.6-6 Find the step response $v_c(t)$ of the circuit shown in Figure P 8.6-6 when $v_s = 20u(t)$ V. The initial voltage $v_c(0)$ is zero.

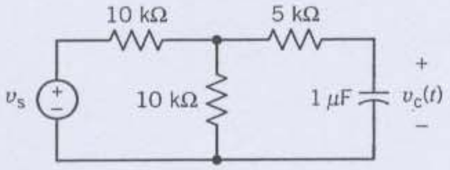


Figure P 8.6-6

P 8.6-7 Find $v(t)$ for $t > 0$ for the circuit shown in Figure P 8.6-7 when $v_s = 15e^{-t}[u(t) - u(t-1)]$ V. The circuit has reached steady state before $t = 0$.

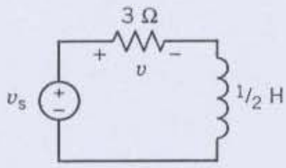


Figure P 8.6-7

P 8.6-8 Use step functions to represent the signal of Figure P 8.6-8.

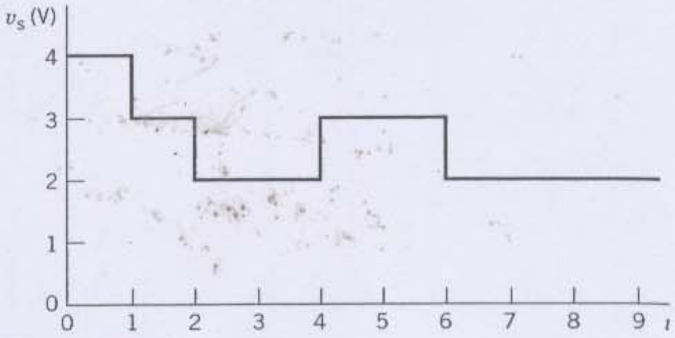


Figure P 8.6-8

P 8.6-9 The initial voltage of the capacitor of the circuit shown in Figure P 8.6-9 is zero. Determine the voltage $v(t)$ when the source is a pulse, described by

$$v_s = \begin{cases} 0 & t < 1 \text{ s} \\ 4 \text{ V} & 1 < t < 2 \text{ s} \\ 0 & t > 2 \text{ s} \end{cases}$$

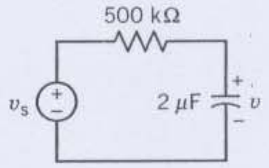


Figure P 8.6-9

P 8.6-10 Studies of an artificial insect are being used to understand the nervous system of animals (Beer 1991). A model neuron in the nervous system of the artificial insect is shown in Figure P 8.6-10. A series of pulses, called synapses, is the input signal, v_s. The switch generates a pulse by opening at $t = 0$ and closing at $t = 0.5$ s. Assume that the circuit is in steady state and that $v(0^-) = 10$ V. Determine the voltage $v(t)$ for $0 < t < 2$ s.

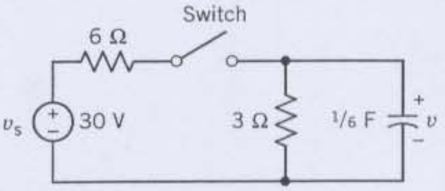


Figure P 8.6-10 Neuron circuit model.

P 8.6-11 An electronic circuit can be used to replace the springs and levers normally used to detonate a shell in a handgun (Jurgen 1989). The electric trigger would eliminate the clicking sensation, which may cause a person to misaim. The proposed trigger uses a magnet and a solenoid with a trigger switch. The circuit of Figure P 8.6-11 represents the trigger circuit with $i_s(t) = 40[u(t) - u(t - t_0)]$ A where $t_0 = 1$ ms. Determine and plot $v(t)$ for $0 < t < 0.3$ s.

Answer: $v = \begin{cases} 480(1 - e^{-1000t}) & 0 < t < 1 \text{ ms} \\ 480(1 - e^{-1})e^{-1000(t-t_0)} & t > 1 \text{ ms}, t_0 = 1 \text{ ms} \end{cases}$

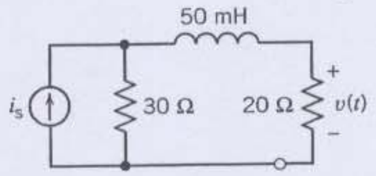


Figure P 8.6-11 Electric trigger circuit for handgun.

P 8.6-12 Determine $v_C(t)$ for $t > 0$ for the circuit of Figure P 8.6-12.

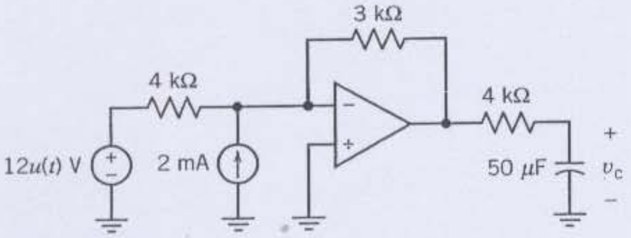


Figure P 8.6-12

Section 8.7 The Response of an *RL* or *RC* Circuit to a Nonconstant Source

P 8.7-1 Find $v_C(t)$ for $t > 0$ for the circuit shown in Figure P 8.7-1 when $v_1 = 8e^{-5t}u(t)$ V. Assume the circuit is in steady state at $t = 0^-$.

Answer: $v_C(t) = 4e^{-9t} + 18e^{-5t}$ V

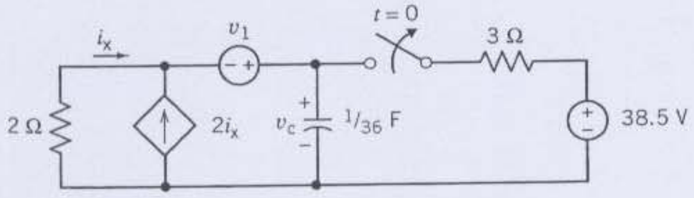


Figure P 8.7-1

P 8.7-2 Find $v(t)$ for $t > 0$ for the circuit shown in Figure P 8.7-2. Assume steady state at $t = 0^-$.

Answer: $v(t) = 20e^{-10t/3} - 12e^{-2t}$ V

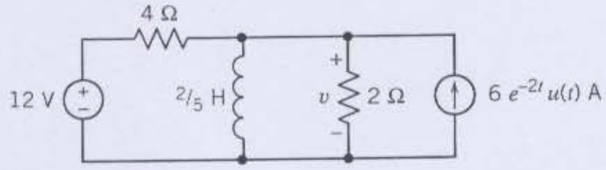


Figure P 8.7-2

P 8.7-3 Find $v(t)$ for $t > 0$ for the circuit shown in Figure P 8.7-3 when $v_1 = (25 \sin 4000t)u(t)$ V. Assume steady state at $t = 0^-$.

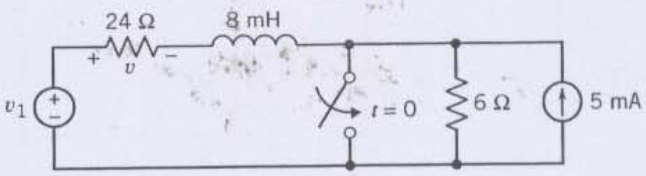


Figure P 8.7-3

P 8.7.4 Find $v_C(t)$ for $t > 0$ for the circuit shown in Figure P 8.7-4 when $i_s = [2 \cos 2t]u(t)$ mA.

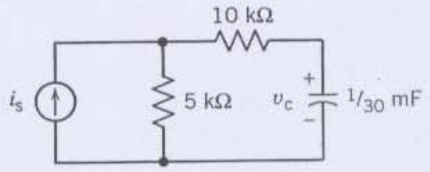


Figure P 8.7-4

P 8.7-5 Many have witnessed the use of an electrical megaphone for amplification of speech to a crowd. A model of a microphone and speaker is shown in Figure P 8.7-5*a*, and the circuit model is shown in Figure P 8.7-5*b*. Find $v(t)$ for $v_s = 10(\sin 100t)u(t)$, which could represent a person whistling or singing a pure tone.

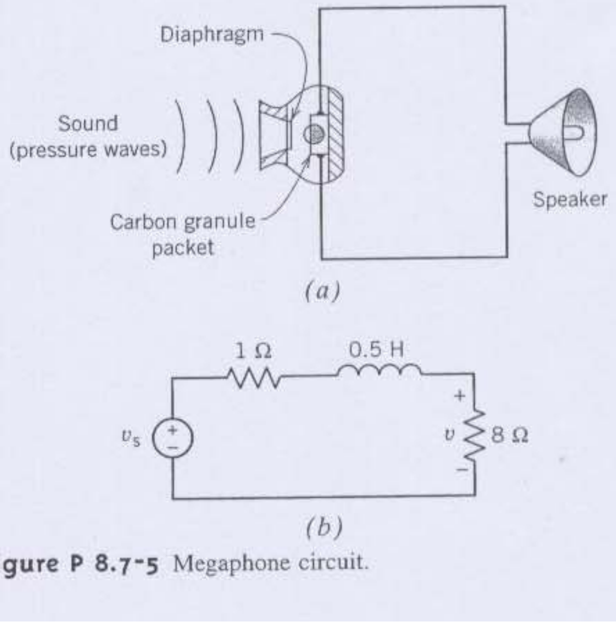


Figure P 8.7-5 Megaphone circuit.

P 8.7-6 A lossy integrator is shown in Figure P 8.7-6. It can be seen that the lossless capacitor of the ideal integrator circuit has been replaced with a model for the lossy capacitor, namely, a lossless capacitor in parallel with a 1 kΩ resistor. If $v_s = 15e^{-2t}u(t)$ V and $v_o(0) = 10$ V, find $v_o(t)$ for $t > 0$. Assume an ideal op amp.

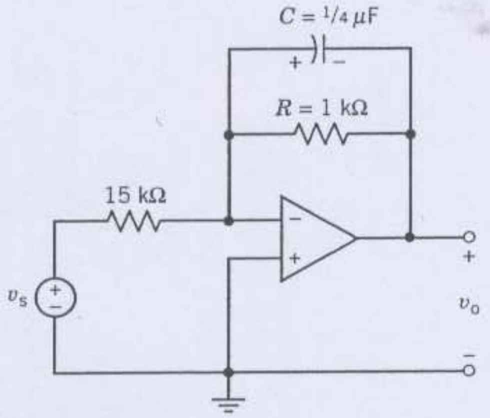
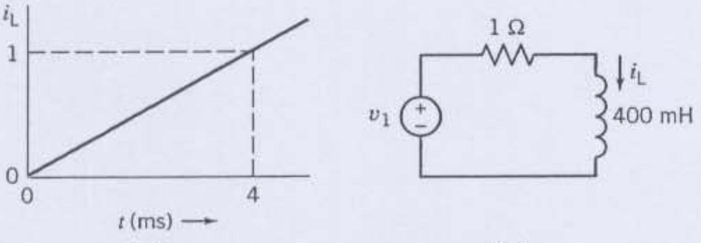


Figure P 8.7-6 Integrator circuit.

P 8.7-7 Most television sets use magnetic deflection in the cathode ray tube. To move the electron beam across the screen, it is necessary to have a ramp of current as shown in Figure P 8.7-7*a*, to flow through the deflection coil. The deflection coil circuit is shown in Figure P 8.7-7*b*. Find the waveform v_1 that will generate the current ramp, i_L.



(*a*) (*b*)

Figure P 8.7-7 Television deflection circuit.

P 8.7-8 Determine $v(t)$ for the circuit shown in Figure P 8.7-8.

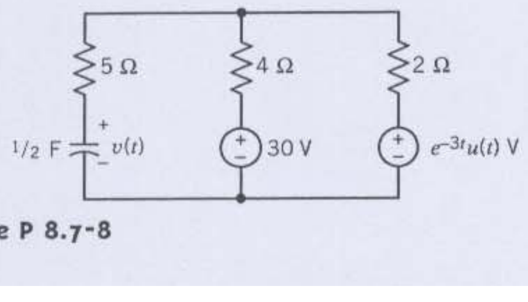


Figure P 8.7-8

P 8.7-9 (a) In the circuit of Figure P 8.7-9, given $v_{c1}(0) = 10$ V, $v_{c2}(0) = 20$ V, find $v_o(t)$ in terms of $v_1(t)$ and $v_2(t)$ for $t > 0$. (b) If $v_1(t) = 10e^{-2000t}$ V and $v_2(t) = 20e^{-1000t}$ V, find $v_o(t)$ for $t > 0$.

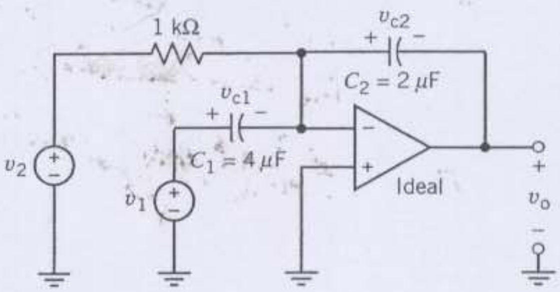


Figure P 8.7-9

P 8.7-10 For the circuit shown in Figure P 8.7-10, find $v_C(t)$, $t \geq 0$, when $v_C(0^-) = 3$ V.
Answer: $v_C(t) = 4 - e^{-250t}$ V, $t \geq 0$

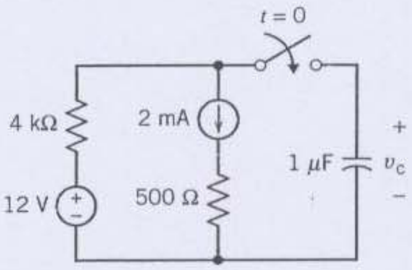
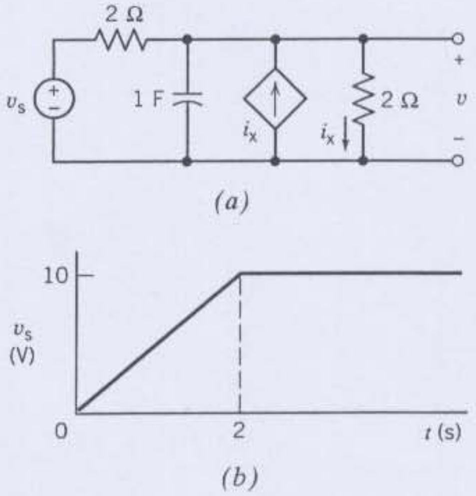


Figure P 8.7-10

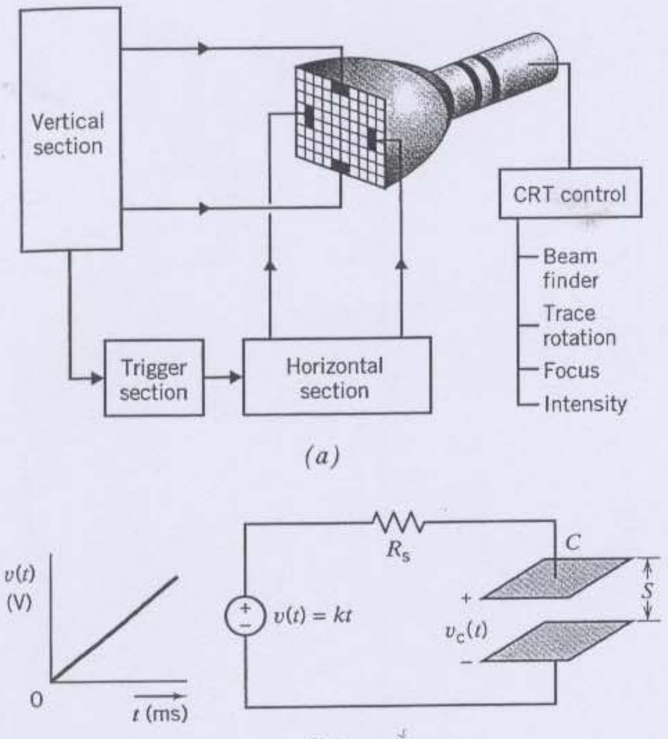
P 8.7-11 Determine $v(t)$ for the circuit shown in Figure P 8.7-11*a* when v_s varies as shown in Figure P 8.7-11*b*. The initial capacitor voltage is $v_C(0) = 0$.



(*a*)

(*b*)

Figure P 8.7-11



(a)

(b)

Figure P 8.7-12 Cathode-ray tube beam circuit.

P 8.7-12 The electron beam, which is used to "draw" signals on an oscilloscope, is moved across the face of a cathode-ray tube (CRT) by a force exerted on electrons in the beam. The basic system is shown in Figure P 8.7-12*a*. The force is created from a time-varying, ramp-type voltage applied across the vertical or the horizontal plates. As an example, consider the simple circuit of Figure P 8.7-12*b* for horizontal deflection where the capacitance between the plates is C.

(a) Derive an expression for the voltage across the capacitance. If $v(t) = kt$ and $R_s = 625$ kΩ, $k = 1000$, and $C = 2000$ pF, compute v_c as a function of time. Sketch $v(t)$ and $v_c(t)$ on the same graph for time less than 10 ms. Does the voltage across the plates track the input voltage?

(b) Describe the deflection of the electron beam if the force is $F = qE$, where q is the charge and E is the electric field; E is the ratio of the voltage across the plates to the spacing of the plates ($E = v/S$). Assume a zero initial condition for the capacitor.

PSpice Problems

SP 8.1 Determine and plot $i(t)$ for the circuit of Figure SP 8.1.

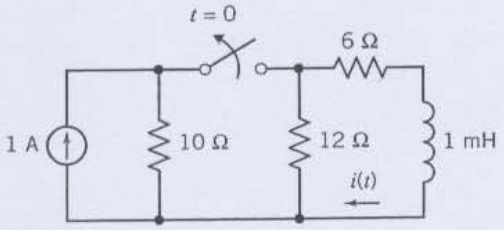


Figure SP 8.1

SP 8.2 An *RC* circuit is shown in Figure SP 8.2 with $R = 1$ kΩ and $C = 20$ μF. Determine the time, t_1, when $v(t_1) = 4.00$ V, given $v(0^-) = 12$ V.

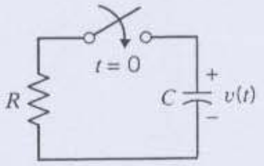


Figure SP 8.2

SP 8.3 For the circuit shown in Figure SP 8.3 find $v_c(t)$, $t \geq 0$, when $v_c(0^-) = 5$ V. Plot $v_c(t)$ for five time constants.

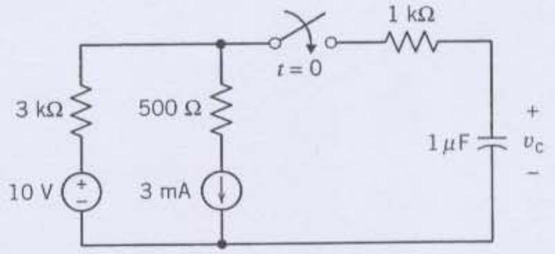


Figure SP 8.3

SP 8.4 An *RC* circuit as shown in Figure SP 8.4 has $v(0) = 0$. It is desired to plot the response of the circuit for four time constants: 2, 4, 8, and 16 ms. Select the appropriate value of R and use a PSpice program to plot the step response for the four time constants on one graphical plot.

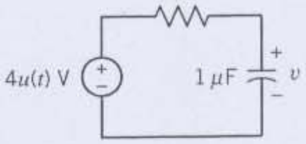


Figure SP 8.4

Verification Problems

VP 8.1 Figure VP 8.1 shows the transient response of a first-order circuit. This transient response was obtained using the computer program PSpice. A point on this transient response has been labeled. The label indicates a time and the capacitor voltage at that time. Placing the circuit diagram on the plot suggests that the plot corresponds to the circuit. Verify that the plot does indeed represent the voltage of the capacitor in this circuit.

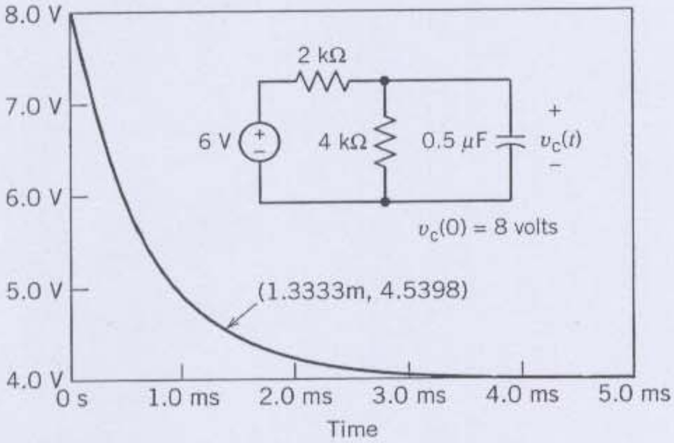


Figure VP 8.1

VP 8.2 Figure VP 8.2 shows the transient response of a first-order circuit. This transient response was obtained using the computer program PSpice. A point on this transient response has been labeled. The label indicates a time and the inductor current at that time. Placing the circuit diagram on the plot suggests that the plot corresponds to the circuit. Verify that the plot does indeed represent the current of the inductor in this circuit.

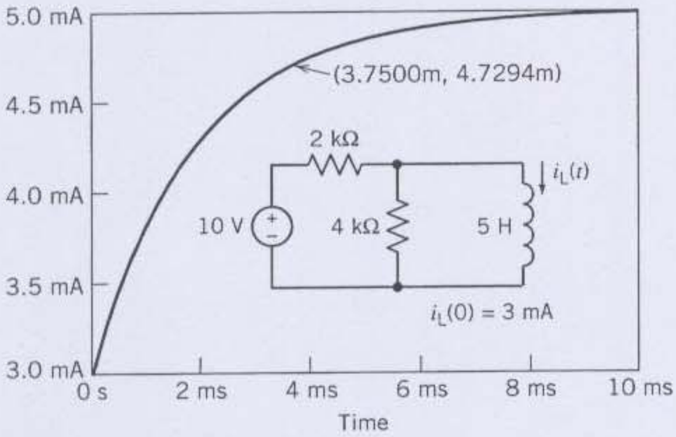


Figure VP 8.2

VP 8.3 Figure VP 8.3 shows the transient response of a first-order circuit. This transient response was obtained using the computer program PSpice. A point on this transient response has been labeled. The label indicates a time and the inductor current at that time. Placing the circuit diagram on the plot suggests that the plot corresponds to the circuit. Specify that value of the inductance, *L*, required to cause the current of the inductor in this circuit to be accurately represented by this plot.

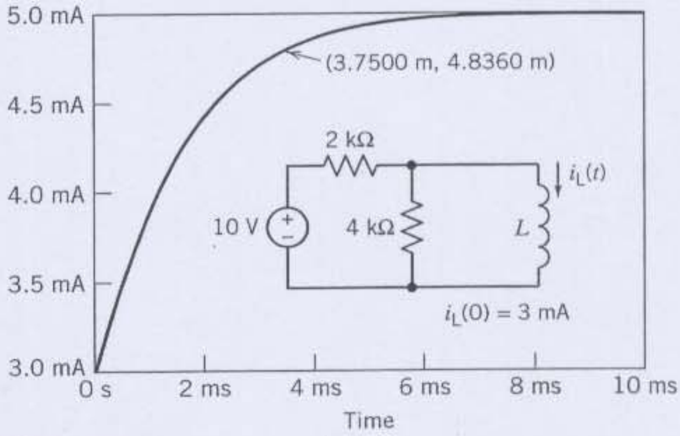


Figure VP 8.3

VP 8.4 Figure VP 8.4 shows the transient response of a first-order circuit. This transient response was obtained using the computer program PSpice. A point on this transient response has been labeled. The label indicates a time and the capacitor voltage at that time. Assume that this circuit has reached steady state before time $t = 0$. Placing the circuit diagram on the plot suggests that the plot corresponds to the circuit. Specify values of A, B, R1, R2, and C that cause the voltage across the capacitor in this circuit to be accurately represented by this plot.

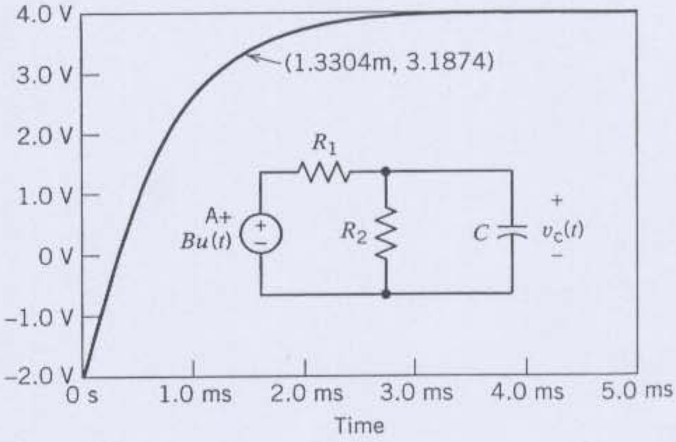


Figure VP 8.4

Design Problems

DP 8.1 For the circuit shown in Figure DP 8.1, it is desired that $i(t) = 2.5$ A at $t = 47$ ms. Determine the resistance R that meets this specification when $v_s = 300$ V. The initial voltage on the capacitor is $v_c(0) = 100$ V.

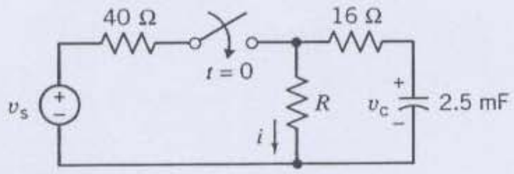


Figure DP 8.1

DP 8.2 For the circuit shown in Figure DP 8.2, specify the inductance L so that the current in the inductor reaches its steady-state value (five time constants) in 3.1 μs after the switch is closed at $t = 0$. Determine the energy stored in the inductor after $t > 3.1$ μs. Assume that the circuit was unexcited prior to $t = 0$.

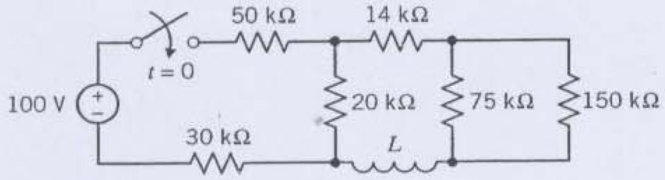


Figure DP 8.2

DP 8.3 For the circuit shown in Figure DP 8.3, select the inductance L so that the inductor current $i(t) = 3$ A at $t = 14$ ms. What is $i(t)$ when $t = 1$ s?

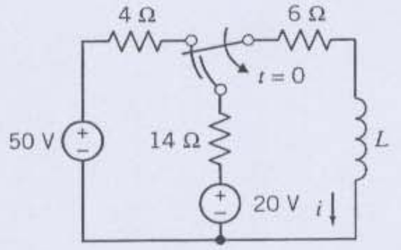


Figure DP 8.3

DP 8.4 Solenoids are electromechanical components that convert electrical energy into mechanical work and move a plunger. Current passing through a helical coil winding of closely spaced turns of copper magnet wire produces a magnetic field that surrounds the coil. All solenoids develop magnetizing force, which has a relationship to the current and number of turns in the coil. Solenoid size determines the amount of work a solenoid can perform. A large unit will develop more force at a given stroke than a small solenoid (with the same coil current) because its greater physical volume will accommodate more turns of wire on the coil. It is important that a solenoid selected for a particular application have a rated force as close to the load requirements as possible. Too much force reduces solenoid life because the unit must absorb the excess energy. If the force is too low, the result will be unsatisfactory performance because the plunger will not pull in or seat properly.

The circuit model of a simple solenoid is shown in Figure DP 8.4. The source is a 12-V dc battery with a resistance $R_s = 1$ Ω. Select the required R and L of the solenoid and $v_s = V_0u(t)$ so that the solenoid will close in 100 ms while restricting the force to less than 0.5 N. The force-developed relationship is measured as $f = i(t)$ N.

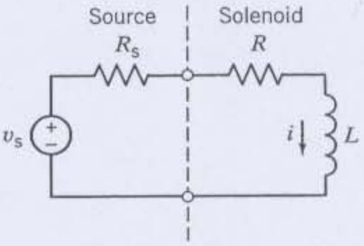


Figure DP 8.4 Model of solenoid circuit.

DP 8.5 The switch in the circuit shown in Figure DP 8.5 is at position 1 for a long time and is switched to position 2 at $t = 0$. The output voltage, $v(t)$, is to be changed from the initial voltage $v(0)$ to within 1 percent of its final value within 0.2 s. Determine the required C and sketch $v(t)$ for $t \geq 0$.

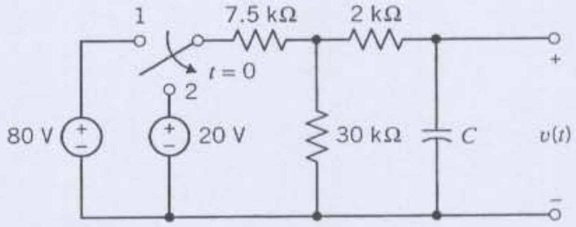


Figure DP 8.5

DP 8.6 A laser trigger circuit is shown in Figure DP 8.6. In order to trigger the laser, we require 60 mA $< |i| <$ 180 mA for $0 < t < 200$ μs. Determine a suitable value for R_1 and R_2.

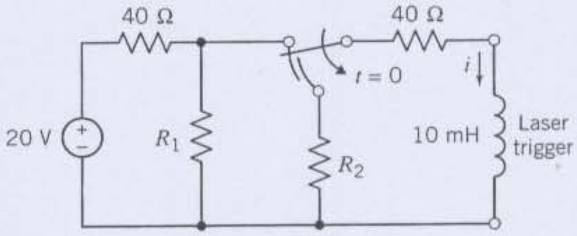


Figure DP 8.6 Laser trigger circuit.

DP 8.7 The initial voltage of the capacitor in the circuit of Figure DP 8.7 is −10 V. Select C so that $v(t) = 0$ at $t = 4.0$ s when $v_s = 20$ V. Sketch $v(t)$ for $0 < t < 5$ s.

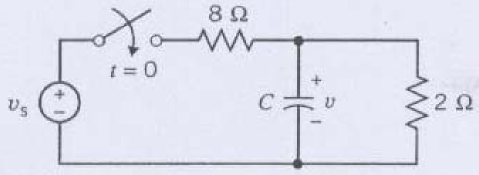


Figure DP 8.7

DP 8.8 Fuses are used to open a circuit when excessive current flows (Wright 1990). One fuse is designed to open when the power absorbed by R exceeds 10 W for 0.5 s. The source represents the turn-on condition for the load where $v_s = A[u(t) - u(t - 0.75)]$ V. Assume that $i_L(0^-) = 0$. The goal is to achieve the maximum current while not opening the fuse. Determine an appropriate value of A and sketch the current waveform. The circuit is shown in Figure DP 8.8.

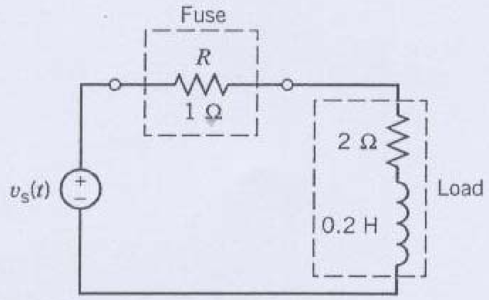


Figure DP 8.8 Fuse circuit.

DP 8.9 An *RL* circuit as shown in Figure DP 8.9 is used to provide an actuating pulse for a power laser. The circuit is at steady state at $t = 0^-$ and $i(0^-) = 0$. The voltage source $v_s = V_0e^{-bt}$ V is connected at $t = 0$. Select V_0 and b so that the peak magnitude of the current pulse is greater than 0.6 A. Determine $i(t)$ and plot the current pulse.

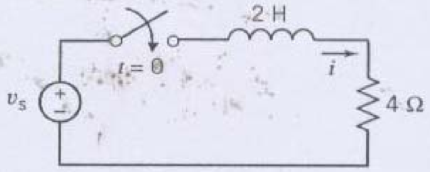


Figure DP 8.9 Laser pulse circuit.

DP 8.10 The adjustable valve in an oil refinery is actuated by a control voltage v_s that consists of a pulse signal. The model of the actuator circuit is shown in Figure DP 8.10 where v is the voltage across the valve actuator and the actuator load is $R = 2\Omega$. Determine the circuit L and select the required pulse when it is desired that

$$v = \begin{cases} 10(1 - e^{-4t})\text{ V} & 0 < t < \dfrac{1}{2}\text{ s} \\ 8.65e^{-4t}\text{ V} & t > \dfrac{1}{2}\text{ s} \end{cases}$$

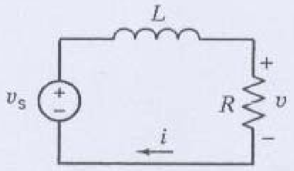


Figure DP 8.10 The circuit for actuating an oil refinery valve.