$$i(t) = \frac{1}{L}\int_{t_0}^{t} v(t)\,dt + i(t_0)$$

e energy stored in an inductance is given by

$$w(t) = \frac{1}{2}Li^2(t)$$

12. Inductances in series or parallel are combined in the same manner as resistances.

13. Real inductors have several parasitic effects.

14. Mutual inductance accounts for mutual coupling of magnetic fields between coils.

lems

3.1: Capacitance

What is a dielectric material? Give two examples.

Briefly discuss how current can flow "through" a capacitor even though a nonconducting layer separates the metallic parts.

What current flows through an ideal capacitor if the voltage across the capacitor is constant with time? To what circuit element is an ideal capacitor equivalent in circuits for which the currents and voltages are constant with time?

Describe the internal construction of capacitors.

A voltage of 50 V appears across a 10-μF capacitor. Determine the magnitude of the net charge stored on each plate and the total net charge on both plates.

A 2000-μF capacitor, initially charged to 100 V, is discharged by a steady current of 100 μA. How long does it take to discharge the capacitor to 0 V?

A 5-μF capacitor is charged to 1000 V. Determine the initial stored charge and energy. If this capacitor is discharged to 0 V in a time interval of 1 μs, find the average power delivered by the capacitor during the discharge interval.

The voltage across a 10-μF capacitor is given by $v(t) = 100\sin(1000t)$. Find expressions for the current, power, and stored energy. Sketch the waveforms to scale versus time.

P3.9. The voltage across a 1-μF capacitor is given by $v(t) = 100e^{-100t}$. Find expressions for the current, power, and stored energy. Sketch the waveforms to scale versus time.

P3.10. Prior to $t = 0$, a 100-μF capacitance is uncharged. Starting at $t = 0$, the voltage across the capacitor is increased linearly with time to 100 V in 2 s. Then, the voltage remains constant at 100 V. Sketch the voltage, current, power, and stored energy to scale versus time.

P3.11. The current through a 0.5-μF capacitor is shown in Figure P3.11. At $t = 0$, the voltage is zero. Sketch the voltage, power, and stored energy to scale versus time.

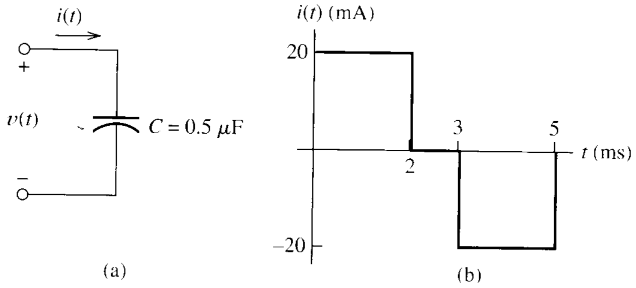

Figure P3.11

P3.12. Determine the capacitor voltage, power, and stored energy at $t = 20$ ms in the circuit of Figure P3.12.

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enotes that answers can be found on the OrCAD CD and on the website www.myengineeringlab.com

Section 3.6: Practical Inductors

P3.68. A 10-mH inductor has a parasitic series resistance of $R_s = 1\ \Omega$, as shown in Figure P3.68. **a.** The current is given by $i(t) = 0.1\cos(10^5 t)$. Find $v_R(t)$, $v_L(t)$, and $v(t)$. In this case, for 1-percent accuracy in computing $v(t)$, could the resistance be neglected? **b.** Repeat if $i(t) = 0.1\cos(10t)$.

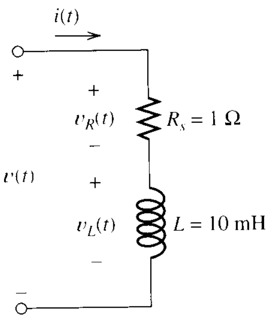

Figure P3.68

P3.69. Draw the equivalent circuit for a real inductor, including three parasitic effects.

P3.70. Suppose that the equivalent circuit shown in Figure 3.22 accurately represents a real inductor. A constant current of 100 mA flows through the inductor, and the voltage across its external terminals is 500 mV. Which of the circuit parameters can be deduced from this information and what is its value?

P3.71. Consider the circuit shown in Figure P3.71, in which $v_C(t) = 10\sin(1000t)$ V, with the argument of the sine function in radians. Find $i(t)$, $v_L(t)$, $v(t)$, the energy stored in the capacitance, the energy stored in the inductance, and the to tal stored energy. Show that the total store energy is constant with time. Comment on th results.

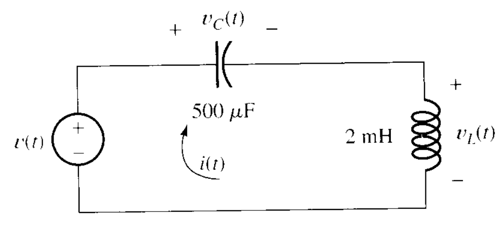

Figure P3.71

P3.72. The circuit shown in Figure P3.72 has $i_L(t)$ = $0.1\cos(5000t)$ A in which the argument of th cos function is in radians. Find $v(t)$, $i_C(t)$, $i(t)$ the energy stored in the capacitance, the energ stored in the inductance, and the total store energy. Show that the total stored energy constant with time. Comment on the results.

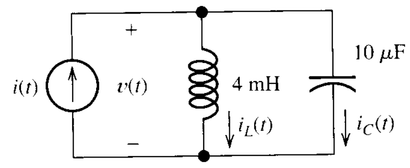

Figure P3.72

Section 3.7: Mutual Inductance

P3.73. Describe briefly the physical basis for mutu inductance.

P3.74. The mutually coupled inductances in Figu P3.74 have $L_1 = 1$ H, $L_2 = 2$ H, a $M = 1$ H. Furthermore, $i_1(t) = \sin(10t)$ a $i_2(t) = 0.5\sin(10t)$. Find expressions for v_1(and $v_2(t)$. The arguments of the sine functio are in radians.

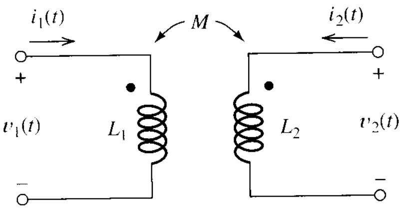

Figure P3.74

*__P3.75.__ Repeat Problem P3.74 with the dot placed the bottom of L_2.

*__P3.76.__ **a.** Derive an expression for the equivalent ductance for the circuit shown in Figure P3. **b.** Repeat if the dot for L_2 is moved to bottom end.

sistance. At what time t_2 has 50 percent of e initial energy stored in the capacitance been issipated in the resistance?

t $t = 0$, a charged 10-μF capacitance is conected to a voltmeter, as shown in Figure P4.11. he meter can be modeled as a resistance. At $= 0$, the meter reads 50 V. At $t = 30$ s, he reading is 25 V. Find the resistance of the voltmeter.

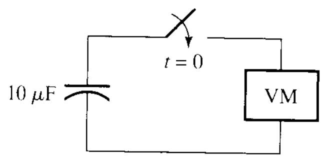

Figure P4.11

At $t = 0$, an initially uncharged 10-μF capacitance is connected to a charging circuit consisting of a 1000-V voltage source in series with a 1-MΩ resistance. At $t = 25$ s, the capacitor is disconnected from the charging circuit and connected in parallel with a 2-MΩ resistor. Determine the voltage across the capacitor at $t = 25$ s and at $t = 50$ s. (*Hint:* You may find it convenient to redefine the time variable to be $t' = t - 25$ for the discharge interval so that the discharge starts at $t' = 0$.)

A person shuffling across a dry carpet can be approximately modeled as a charged 100-pF capacitance with one end grounded. If the person touches a grounded metallic object such as a water faucet, the capacitance is discharged and the person experiences a brief shock. Typically, the capacitance may be charged to 20,000 V and the resistance (mainly of one's finger) is 100 Ω. Determine the peak current during discharge and the time constant of the shock.

A capacitance C is charged to an initial voltage V_i. At $t = 0$, a resistance R is connected across the capacitance. Write an expression for the current. Then, integrate the current from $t = 0$ to $t = \infty$, and show that the result is equal to the initial charge stored on the capacitance.

***P4.15.** At time t_1, a capacitance C is charged to a voltage of V_1. Then, the capacitance discharges through a resistance R. Write an expression for the voltage across the capacitance as a function of time for $t > t_1$ in terms of R, C, V_1, and t_1.

P4.16. In the circuit of Figure P4.16, the switch instantaneously moves back and forth between contacts A and B, spending 1 s in each position. Thus, the capacitor repeatedly charges for 1 s and then discharges for 1 s. Assume that $v_C(0) = 0$ and that the switch moves to position A at $t = 0$. Determine $v_C(1)$, $v_C(2)$, $v_C(3)$, and $v_C(4)$.

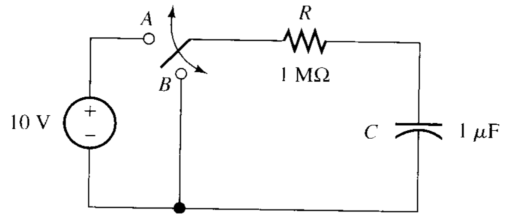

Figure P4.16

P4.17. Consider the circuit shown in Figure P4.17. Prior to $t = 0$, $v_1 = 100$ V and $v_2 = 0$. **a.** Immediately after the switch is closed, what is the value of the current [i.e., what is the value of $i(0+)$]? **b.** Write the KVL equation for the circuit in terms of the current and initial voltages. Take the derivative to obtain a differential equation. **c.** What is the value of the time constant in this circuit? **d.** Find an expression for the current as a function of time. **e.** Find the value that v_2 approaches as t becomes very large.

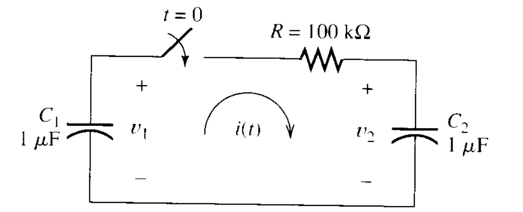

Figure P4.17

. Consider the circuit of Figure P4.26 in which the switch has been open for a long time prior to $t = 0$. Determine the values of $v_C(t)$ before $t = 0$ and a long time after $t = 0$. Also, determine the time constant after the switch closes and expressions for $v_C(t)$. Sketch $v_C(t)$ to scale versus time for $-2 \le t \le 5$ s.

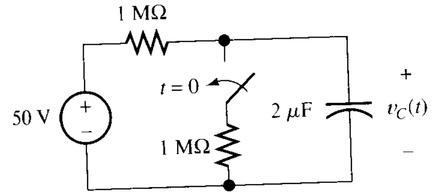

Figure P4.26

7. The circuit of Figure P4.27 has been connected for a very long time. Determine the values of v_C and i_R.

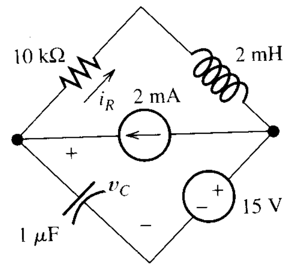

Figure P4.27

28. In the circuit of Figure P4.28, the switch is in position A for a long time prior to $t = 0$. Find expressions for $v_R(t)$ and sketch it to scale for $-2 \le t \le 10$ s.

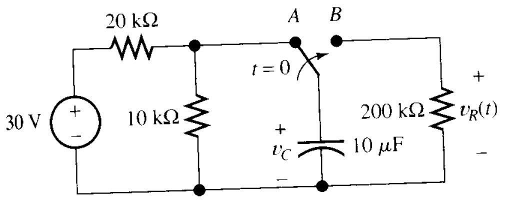

Figure P4.28

29. For the circuit shown in Figure P4.29, the switch is closed for a long time prior to $t = 0$. Find expressions for $v_C(t)$ and sketch it to scale for $-60 \le t \le 300$ ms.

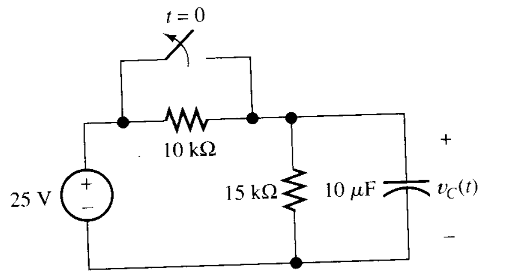

Figure P4.29

Section 4.3: *RL* Circuits

P4.30. Give the expression for the time constant of a circuit consisting of an inductance with an initial current in series with a resistance R. To attain a long time constant, do we need large or small values for R? For L?

P4.31. A circuit consists of switches that open or close at $t = 0$, resistances, dc sources, and a single energy storage element, either an inductance or a capacitance. We wish to solve for a current or a voltage $x(t)$ as a function of time for $t \ge 0$. Write the general form for the solution. How is each unknown in the solution determined?

***P4.32.** The circuit shown in Figure P4.32 is operating in steady state with the switch closed prior to $t = 0$. Find $i(t)$ for $t < 0$ and for $t \ge 0$.

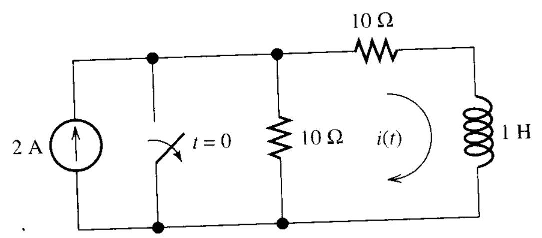

Figure P4.32

P4.33. Consider the circuit shown in Figure P4.33. The initial current in the inductor is $i_L(0-) = 0$. Find expressions for $i_L(t)$ and $v(t)$ for $t \ge 0$ and sketch to scale versus time.

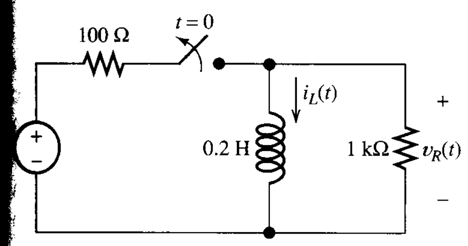

Figure P4.40

nsider the circuit shown in Figure P4.41. A ltmeter VM is connected across the induc- nce. The switch has been closed for a long ne. When the switch is opened, an arc ap- ars across the switch contacts. Explain why. ssuming an ideal switch and inductor, what ltage appears across the inductor when the itch is opened? What could happen to the ltmeter when the switch opens?

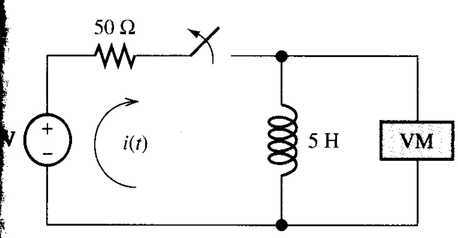

Figure P4.41

eal inductors have series resistance associated ith the wire used to wind the coil. Suppose at we want to store energy in a 10-H inductor. etermine the limit on the series resistance so e energy remaining after one hour is at least 5 percent of the initial energy.

4: *RC* and *RL* Circuits with General Sources

hat are the steps in solving a circuit having resistance, a source, and an inductance (or apacitance)?

rite the differential equation for $i(t)$ and d the complete solution for the circuit of igure P4.44. [*Hint:* Try a particular solution of e form $i_p(t) = Ae^{-t}$.]

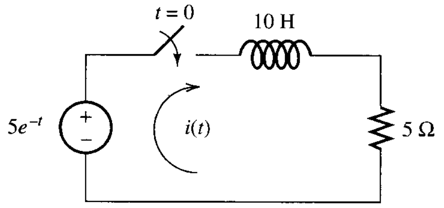

Figure P4.44

P4.45. Consider the circuit shown in Figure P4.45. The voltage source is known as a **ramp function**, which is defined by

$$v(t) = \begin{cases} 0 & \text{for } t < 0 \\ t & \text{for } t \geq 0 \end{cases}$$

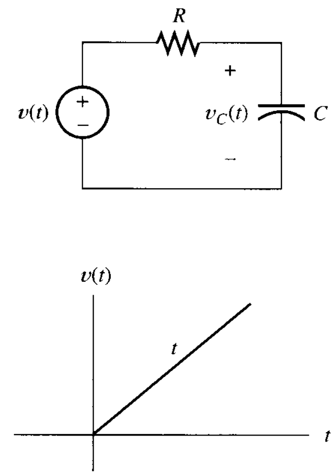

Figure P4.45

Assume that $v_C(0) = 0$. Derive an expression for $v_C(t)$ for $t \geq 0$. Sketch $v_C(t)$ to scale versus time. [*Hint:* Write the differential equation for $v_C(t)$ and assume a particular solution of the form $v_{Cp}(t) = A + Bt$.]

***P4.46.** Solve for $v_C(t)$ for $t > 0$ in the circuit of Figure P4.46. [*Hint:* Try a particular solution of the form $v_{Cp}(t) = Ae^{-3t}$.]

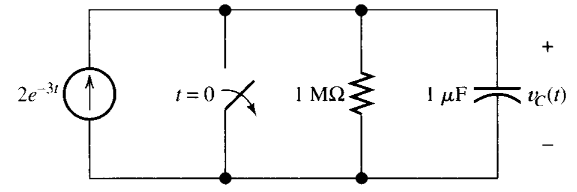

Figure P4.46

***P4.47.** Solve for $v(t)$ for $t > 0$ in the circuit of Figure P4.47, given that the inductor current is zero prior to $t = 0$. [*Hint:* Try a particular solution of the form $v_p = A\cos(10t) + B\sin(10t)$.]

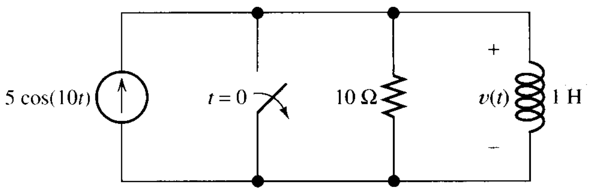

Figure P4.47

P4.48. Consider the circuit shown in Figure P4.48. The initial current in the inductor is $i(0+) = 0$. Write the differential equation for $i(t)$ and solve. [*Hint:* Try a particular solution of the form $i_p(t) = A\cos(300t) + B\sin(300t)$.]

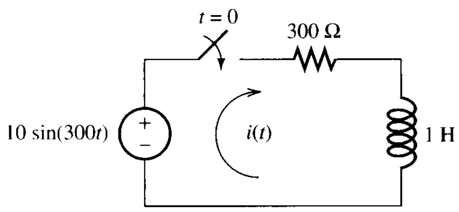

Figure P4.48

P4.49. The voltage source shown in Figure P4.49 is called a ramp function. Assume that $i(0) = 0$. Write the differential equation for $i(t)$, and find the complete solution. [*Hint:* Try a particular solution of the form $i_p(t) = A + Bt$.]

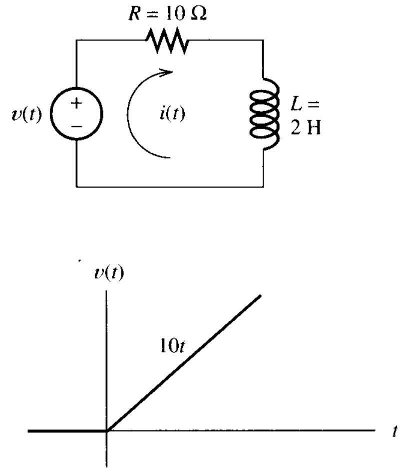

Figure P4.49

P4.50. Solve for $i_L(t)$ for $t > 0$ in the circuit of F ure P4.50. You will need to make an educat guess as to the form of the particular solutio [*Hint:* The particular solution includes ter with the same functional forms as the ter found in the forcing function and its deri tives.]

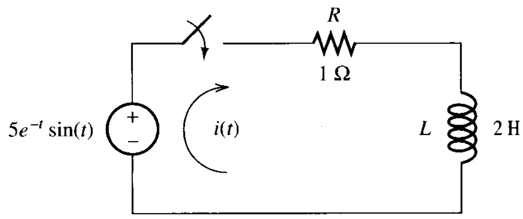

Figure P4.50

P4.51. Determine what form you would try for particular solution for the differential equat

$$2\frac{dv(t)}{dt} + v(t) = 5t\sin(t)$$

Find the particular solution. [*Hint:* The p ticular solution includes terms with the sa functional forms as the terms found in the fo ing function and its derivatives.]

P4.52. Consider the circuit shown in Figure P4

a. Write the differential equation for i

b. Find the time constant and the f

of the complementary solution. **c.** Usually, for an exponential forcing function like this, we would try a particular solution of the form $i_p(t) = K\exp(-2t)$. Why doesn't that work in this case? **d.** Find the particular solution. [*Hint:* Try a particular solution of the form $i_p(t) = Kt\exp(-2t)$.] **e.** Find the complete solution for $i(t)$.

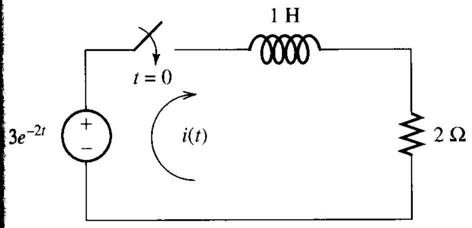

Figure P4.52

4.5: Second-Order Circuits

How can an underdamped second-order system be identified? What form does its complementary solution take? Repeat for a critically damped system and for an overdamped system.

Discuss two methods that can be used to determine the particular solution of a circuit with constant dc sources.

How can first- or second-order circuits be identified by inspecting the circuit diagrams?

What is a unit step function?

Sketch a step response for a second-order system that displays considerable overshoot and ringing. In what types of circuits do we find pronounced overshoot and ringing?

A dc source is connected to a series RLC circuit by a switch that closes at $t = 0$, as shown in Figure P4.58. The initial conditions are $i(0+) = 0$ and $v_C(0+) = 0$. Write the differential equation for $v_C(t)$. Solve for $v_C(t)$ if $R = 80\ \Omega$.

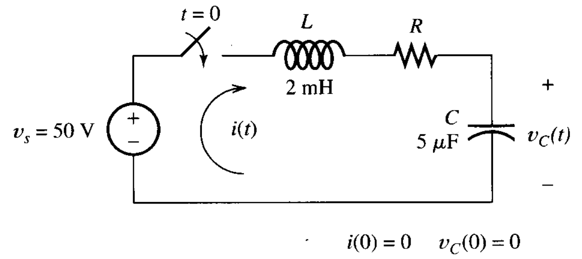

Figure P4.58

***P4.59.** Repeat Problem P4.58 for $R = 40\ \Omega$.

***P4.60.** Repeat Problem P4.58 for $R = 20\ \Omega$.

P4.61. Consider the circuit shown in Figure P4.61, with $R = 25\ \Omega$. **a.** Compute the undamped resonant frequency, the damping coefficient, and the damping ratio. **b.** The initial conditions are $v(0+) = 0$ and $i_L(0+) = 0$. Show that this requires that $v'(0+) = 10^9$ V/s. **c.** Find the particular solution for $v(t)$. **d.** Find the general solution for $v(t)$, including the numerical values of all parameters.

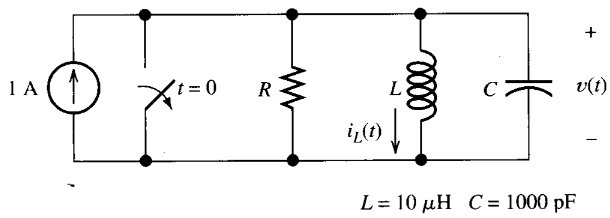

Figure P4.61

P4.62. Repeat Problem P4.61 for $R = 50\ \Omega$.

P4.63. Repeat Problem P4.61 for $R = 500\ \Omega$.

P4.64. Solve for $i(t)$ for $t > 0$ in the circuit of Figure P4.64, with $R = 50\ \Omega$, given that the inductor current and capacitor voltage are both zero prior to $t = 0$. [*Hint:* Try a particular solution of the form $i_p(t) = A\cos(100t) + B\sin(100t)$.]

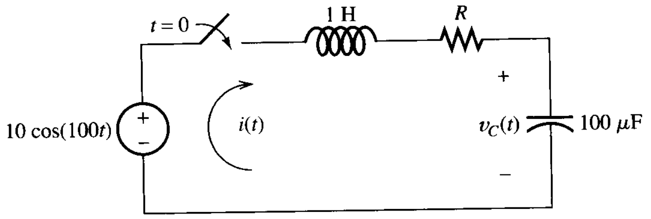

Figure P4.64

P4.65. Repeat Problem P4.64 with $R = 200\ \Omega$.

P4.66. Repeat Problem P4.64 with $R = 400\ \Omega$.

P4.67. Consider the circuit shown in Figure P4.67. **a.** Write the differential equation for $v(t)$. **b.** Find the damping coefficient, the natural frequency, and the form of the complementary solution. **c.** Usually, for a sinusoidal forcing function, we try a particular solution of the form $v_p(t) = A\cos(10^4) + B\sin(10^4)$. Wh doesn't that work in this case? **d.** Find the par ticular solution. [*Hint:* Try a particular solutio of the form $v_p(t) = At\cos(10^4) + Bt\sin(10^4)$ **e.** Find the complete solution for $v(t)$.

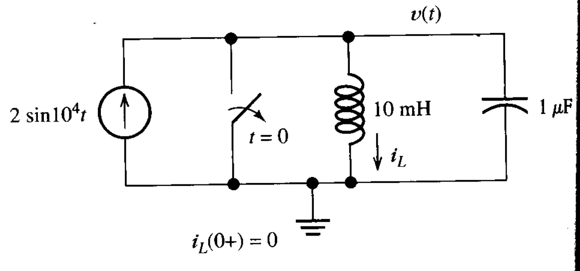

Figure P4.67

P10.66. Sketch the transfer characteristic (v_o versus v_{in}) to scale for the circuit shown in Figure P10.66. Allow v_{in} to range from −5 V to +5 V and assume that the diodes are ideal.

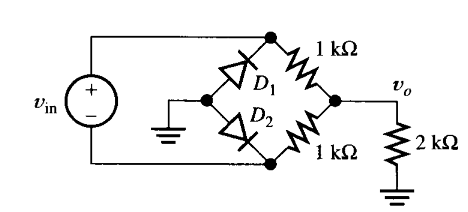

Figure P10.66

P10.67. Sketch the transfer characteristic (v_o versus v_{in}) for the circuit shown in Figure P10.67, carefully labeling the breakpoint and slopes. Allow v_{in} to range from −5 V to +5 V and assume that the diodes are ideal.

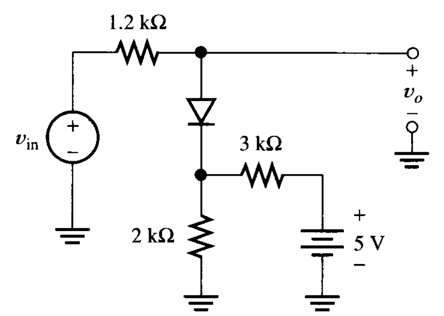

Figure P10.67

P10.68. What is a clamp circuit? Draw an example circuit diagram, including component values, an input waveform, and the corresponding output waveform.

P10.69. Consider the circuit shown in Figure P10.69, in which the RC time constant is very long compared with the period of the input a which the diode is ideal. Sketch $v_o(t)$ to versus time.

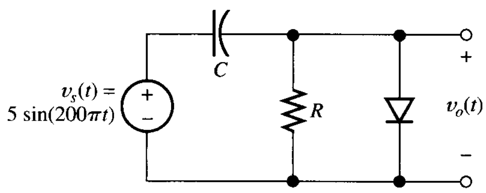

Figure P10.69

***P10.70.** Sketch to scale the steady-state output form for the circuit shown in Figure P Assume that RC is much larger than th riod of the input voltage and that the d are ideal.

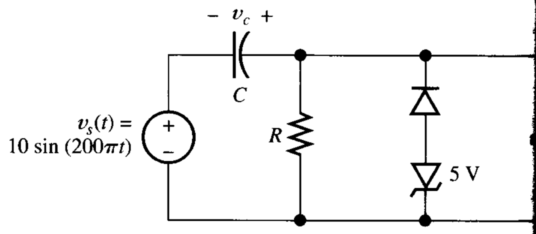

Figure P10.70

P10.71. Voltage-doubler circuit. Consider the c of Figure P10.71. The capacitors are very so they discharge only a very small an per cycle. (Thus, no ac voltage appears the capacitors, and the ac input plus t voltage of C_1 must appear at point A.) S the voltage at point A versus time. Fin voltage across the load. Why is this a voltage doubler? What is the peak in voltage across each diode?

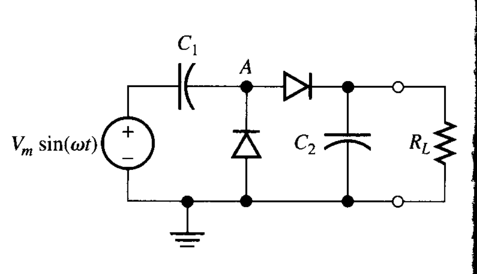

Figure P10.71

***P10.72.** Design a clipper circuit to clip off the po of an input voltage that fall above 3 below −5 V. Assume that diodes hav constant forward drop of 0.7 V are ava Ideal Zener diodes of any breakdown v amplifiers may be ac coupled, in which case the gain falls off at low frequencies, reaching zero gain at dc. Gain magnitude falls to zero at sufficiently high frequencies for all amplifiers.

10. Linear distortion can be either amplitude distortion or phase distortion. Amplitude distortion occurs if the gain magnitude is different for various components of the input signal. Phase distortion occurs if amplifier phase shift is not proportional to frequency.
11. Amplifier pulse response is characterized by rise time, overshoot, ringing, and tilt.
12. Nonlinear distortion occurs if the transfer characteristic of an amplifier is not straight. Assuming a sinusoidal input signal, nonlinear distortion causes harmonics to appear in the output. The total harmonic distortion rating of an amplifier i the degree of nonlinear distortion.
13. A differential amplifier ideally responds the difference between its two input sig the differential input signal).
14. The common-mode input is the average o inputs to a differential amplifier. Comm rejection ratio (CMRR) is the ratio of the tial gain to the common-mode gain. CM important specification for many instrum applications.
15. Dc offset is the addition of a dc term to t being amplified. It is the result of bias offset current, and offset voltage, and i canceled by use of a properly designed circuit.

Problems

Section 11.1: Basic Amplifier Concepts

P11.1. Explain how an inverting amplifier differs from a noninverting amplifier.

P11.2. Draw the voltage-amplifier model and label its elements.

P11.3. What are two causes of "loading effects" in an amplifier circuit?

***P11.4.** A signal source with an open-circuit voltage of $V_s = 2$ mV rms and an internal resistance of 50 kΩ is connected to the input terminals of an amplifier having an open-circuit voltage gain of 100, an input resistance of 100 kΩ, and an output resistance of 4 Ω. A 4-Ω load is connected to the output terminals. Find the voltage gains $A_{vs} = V_o/V_s$ and $A_v = V_o/V_i$. Also, find the power gain and current gain.

***P11.5.** A certain amplifier operating with a 100-Ω load has a voltage gain of 50 and a power gain of 5000. Determine the current gain and input resistance of the amplifier.

P11.6. The current gain of an amplifier is 500, the load resistance is 100 Ω, and the input resistance of the amplifier is 1 MΩ. Determine th gain and power gain under these co

P11.7. An amplifier having $R_i = 1$ MΩ, R_o and $A_{voc} = -10^4$ is operated wit load. A source having a Thévenin r of 2 MΩ and an open-circuit vo $3\cos(200\pi t)$ mV is connected to t terminals. Determine the output vo function of time and the power gain.

P11.8. A certain amplifier has an open-cir age gain of unity, an input resistance and an output resistance of 100 Ω. nal source has an internal voltage o and an internal resistance of 100 kΩ. resistance is 50 Ω. If the signal sour nected to the amplifier input termina load is connected to the output term the voltage across the load and the p livered to the load. Next, consider c the load directly across the signal so out the amplifier, and again find the l age and power. Compare the results.

* Denotes that answers can be found on the OrCAD CD and on the website www.myengineeringlab.com

mall-signal drain resistance of a FET is defined as

$$\frac{1}{r_d} = \left.\frac{\partial i_D}{\partial v_{DS}}\right|_{Q \text{ point}}$$

small-signal midband analysis of FET amplifiers, e coupling capacitors, bypass capacitors, and dc ltage sources are replaced by short circuits. The ET is replaced with its small-signal equivalent cuit. Then, we write circuit equations and derive eful expressions for gains, input impedance, and tput impedance.

find the output resistance of an amplifier, we sconnect the load, replace the signal source by its internal resistance, and then find the resistance looking into the output terminals.

14. The common-source amplifier is inverting and can have voltage-gain magnitude larger than unity.
15. Unbypassed impedance between the FET source terminal and ground strongly reduces the gain of a common-source amplifier.
16. The source follower has voltage gain slightly less than unity, high current gain, and relatively low output impedance. It is noninverting.
17. Complex digital systems can be constructed by interconnecting millions of NMOS and PMOS transistors, all of which are fabricated on a single chip by a relatively small number of processing steps.

lems

12.1: NMOS and PMOS Transistors

Sketch the physical structure of an n-channel enhancement MOSFET. Label the channel length L, the width W, the terminals, and the channel region. Draw the corresponding circuit symbol.

Give the equations for the drain current and the ranges of v_{GS}, v_{DS}, and v_{GD} in terms of the threshold voltage V_{to} for each region (cutoff, saturation, and triode) of an n-channel MOSFET.

A certain NMOS transistor has $V_{to} = 1$ V, $KP = 50\,\mu$A/V^2, $L = 5\,\mu$m, and $W = 50\,\mu$m. For each set of voltages, state the region of operation and compute the drain current. **a.** $v_{GS} = 4$ V and $v_{DS} = 10$ V; **b.** $v_{GS} = 4$ V and $v_{DS} = 2$ V; **c.** $v_{GS} = 0$ V and $v_{DS} = 10$ V.

Suppose that we have an NMOS transistor with $KP = 50\,\mu$A/V^2, $V_{to} = 1$ V, $L = 10\,\mu$m, and $W = 200\,\mu$m. Sketch the drain characteristics for v_{DS} ranging from 0 to 10 V and $v_{GS} = 0, 1, 2, 3,$ and 4 V.

P12.5. We have an n-channel enhancement MOSFET with $V_{to} = 1$ V and $K = 0.1$ mA/V^2. Given that $v_{GS} = 4$ V, for what range of v_{DS} is the device in the saturation region? In the triode region? Plot i_D versus v_{GS} for operation in the saturation region.

P12.6. Suppose we have an NMOS transistor that has $V_{to} = 1$ V. What is the region of operation (linear, saturation, or cutoff) if **a.** $v_{GS} = 5$ V and $v_{DS} = 10$ V; **b.** $v_{GS} = 3$ V and $v_{DS} = 1$ V; **c.** $v_{GS} = 3$ V and $v_{DS} = 6$ V; **d.** $v_{GS} = 0$ V and $v_{DS} = 5$ V?

P12.7. What is the region of operation of an enhancement NMOS device if the gate is connected to the drain and a positive voltage greater than the threshold is applied to the drain with respect to the source? If the applied voltage is less than the threshold?

P12.8. Determine the region of operation for each of the enhancement transistors and the currents shown in Figure P12.8. The transistors have $|V_{to}| = 1$ V and $K = 0.1$ mA/V^2.

otes that answers can be found on the OrCAD CD and on the website www.myengineeringlab.com