the same shape as the input. Clipping is generally undesirable, though there are situations in which it is exploited on purpose to achieve specific effects.

PROBLEMS

1.1 Amplifier fundamentals

1.1 In the voltage amplifier circuit of Fig. 1.1, let $v_S = 100$ mV, $R_s = 100$ kΩ, $v_I = 75$ mV, $R_L = 10$ Ω, and $v_O = 2$ V. If connecting a 30-Ω resistance in parallel with R_L drops v_O to 1.8 V, find R_i, A_{oc}, and R_o.

1.2 Sketch the transconductance and transresistance amplifiers; derive expressions for their source-to-load gains.

1.3 (*a*) A transresistance amplifier with $R_i = 20$ kΩ, $A_{oc} = 1$ V/ma, and $R_o = 300$ Ω is driven by a source i_S with parallel resistance $R_s = 100$ kΩ and drives a load $R_L = 600$ Ω. Find the transresistance gain v_L/i_S as well as the power gain p_L/p_S, where p_S is the power delivered by the source i_S and p_L that absorbed by the load R_L. (*b*) To what value must A_r be changed to achieve $v_L/i_S = 1$ V/mA exactly? What is the corresponding power gain?

1.4 A transconductance amplifier is driven by a source with $v_S = 30$ mV and $R_s = 100$ kΩ and drives a load R_L. Digital multimeter (DMM) readings at the input and output ports yield $v_I = 25$ mV, $i_L = 0.9$ A for $R_L = 20$ Ω, and $i_L = 0.8$ A for $R_L = 30$ Ω. Predict the DMM readings if the same amplifier is driven by a source with $v_S = 33$ mV and $R_s = 50$ kΩ and drives a load $R_L = 40$ Ω.

1.2 The operational amplifier

1.5 Given an op amp with $r_d \cong \infty$, $a = 10^4$ V/V, and $r_o \cong 0$, find (*a*) v_O if $v_P = 750.25$ mV and $v_N = 751.50$ mV, (*b*) v_N if $v_O = -5$ V and $v_P = 0$, (*c*) v_P if $v_N = v_O = 5$ V, and (*d*) v_N if $v_P = -v_O = 1$ V.

1.6 A 741 op amp drives a 1-kΩ load. Find the voltages across and the currents through r_d and r_o if $v_P = 1$ V and $v_O = 5$ V.

1.3 Basic op amp configurations

1.7 In the noninverting amplifier of Fig. 1.6*a*, let $R_1 = 100$ kΩ, $R_2 = 200$ kΩ, and $a = \infty$. (*a*) What is its closed-loop gain? How does its gain change if a third resistance $R_3 = 100$ kΩ is connected in series with R_1? In parallel with R_1? In series with R_2? In parallel with R_2? (*b*) Repeat (*a*) for the inverting amplifier of Fig. 1.10*a*.

1.8 (*a*) Design a noninverting amplifier whose gain is variable over the range 1 V/V $\le A \le$ 5 V/V by means of a 100-kΩ pot. (*b*) Repeat (*a*) for 0.5 V/V $\le A \le$ 2 V/V. *Hint:* To achieve $A \le 1$ V/V, you need an input voltage divider.

1.9 (*a*) A noninverting amplifier is implemented with two 10-kΩ resistances having 5% tolerance. What is the range of possible values for the gain A? How would you modify the circuit for the exact calibration of A? (*b*) Repeat, but for the inverting amplifier.

1.10 In the inverting amplifier of Fig. 1.10*a*, let $v_I = 0.1$ V, $R_1 = 10$ kΩ, and $R_2 = 100$ kΩ. Find v_O and v_N if (*a*) $a = 10^2$ V/V, (*b*) $a = 10^4$ V/V, (*c*) $a = 10^6$ V/V. Comment on your findings.

1.11 (*a*) Design an inverting amplifier whose gain is variable over the range -10 V/V $\le A \le 0$ by means of a 100-kΩ pot. (*b*) Repeat, but for -10 V/V $\le A \le -1$ V/V. *Hint:* To prevent A from reaching zero, you must use a suitable resistor in series with the pot.

1.12 (*a*) A source $v_S = 2$ V with $R_s = 10$ kΩ is to drive a gain-of-five inverting amplifier implemented with $R_1 = 20$ kΩ and $R_2 = 100$ kΩ. Find the amplifier output voltage and verify that because of loading its magnitude is *less* than $2 \times 5 = 10$ V. (*b*) Find the value to which R_2 must be changed if we want to compensate for loading and obtain a full output magnitude of 10 V.

1.13 (*a*) A source $v_S = 10$ V is fed to a voltage divider implemented with $R_A = 120$ kΩ and $R_B = 30$ kΩ, and the voltage across R_B is fed, in turn, to a gain-of-five noninverting amplifier having $R_1 = 30$ kΩ and $R_2 = 120$ kΩ. Sketch the circuit, and predict the amplifier output voltage v_O. (*b*) Repeat (*a*) for a gain-of-five inverting amplifier having $R_1 = 30$ kΩ and $R_2 = 150$ kΩ. Compare and comment on the differences.

1.14 An inverting amplifier is implemented with $R_1 = 10$ kΩ, $R_2 = 20$ kΩ and an op amp with $r_d \cong \infty$, $a = 1$ V/mV, and $r_o \cong 0$. Sketch and label v_I, v_O, and v_N versus time if v_I is a 1-kHz sine wave with ±5-V peak values.

1.4 Ideal op amp circuit analysis

1.15 Find v_N, v_P, and v_O in the circuit of Fig. P1.15, as well as the power released by the 4-V source; devise a method to check your results.

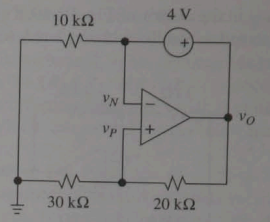

FIGURE P1.15

1.16 (*a*) Find v_N, v_P, and v_O in the circuit of Fig. P1.16. (*b*) Repeat (*a*) with a 5-kΩ resistance connected between A and B.

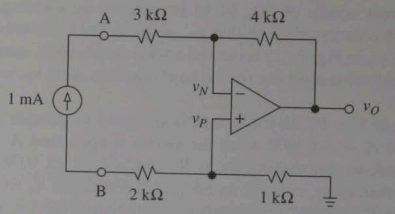

FIGURE P1.16

1.17 (*a*) Find v_N, v_P, and v_O in the circuit of Fig. P1.17 if $v_S = 9$ V. (*b*) Find the resistance R that, if connected between the inverting-input pin of the op amp and ground, causes v_O to double. Verify with PSpice.

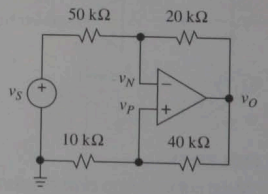

FIGURE P1.17

1.18 (*a*) Find v_N, v_P, and v_O in the circuit of Fig. P1.18. (*b*) Repeat (*a*) with a 40-kΩ resistance in parallel with the 0.3-mA source.

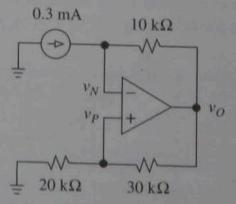

FIGURE P1.18

1.19 (*a*) Find v_N, v_P, and v_O in the circuit of Fig. P1.19 if $i_S = 1$ mA. (*b*) Find a resistance R that when connected in parallel with the 1-mA source will cause v_O to drop to half the value found in (*a*).

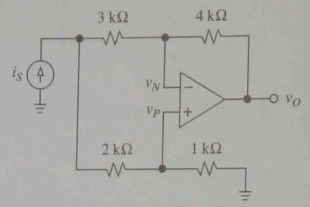

FIGURE P1.19

1.20 (*a*) If the current source of Fig. P1.16 is replaced by a voltage source v_S, find the magnitude and polarity of v_S so that $v_O = 10$ V. (*b*) If the wire connecting the 4-V source to node v_O in Fig. P1.15 is cut and a 5-kΩ resistance is inserted in series between the two, to what value must the source be changed to yield $v_O = 10$ V?

1.21 In the circuit of Fig. P1.21 the switch is designed to provide gain-polarity control. (*a*) Verify that $A = +1$ V/V when the switch is open, and $A = -R_2/R_1$ when the switch is closed, so that making $R_1 = R_2$ yields $A = \pm 1$ V/V. (*b*) To accommodate gains greater than unity, connect an additional resistance R_4 from the inverting-input pin of the op amp to ground. Derive separate expressions for A in terms of R_1 through R_4 with the switch open and with the switch closed. (*c*) Specify resistance values suitable for achieving $A = \pm 2$ V/V.

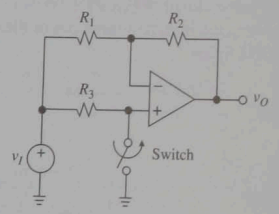

FIGURE P1.21

1.22 In the circuit of Fig. P1.22 the pot is used to control gain magnitude as well as polarity. (*a*) Letting k denote the fraction of R_3 between the wiper and ground, show that varying the wiper from bottom to top varies the gain over the range $-R_2/R_1 \le A \le 1$ V/V, so that making $R_1 = R_2$ yields -1 V/V $\le A \le +1$ V/V. (*b*) To accommodate gains greater than unity, connect an additional resistance R_4 from the op amp's inverting-input pin to ground. Derive an expression for A in terms of R_1, R_2, R_4, and k. (*c*) Specify resistance values suitable for achieving -5 V/V $\le A \le +5$ V/V.

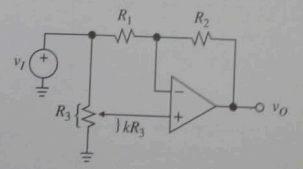

FIGURE P1.22

1.23 Consider the following statements about the input resistance R_i of the noninverting amplifier of Fig. 1.14*a*: (*a*) Since we are looking straight into the noninverting-input pin, which is an open circuit, we have $R_i = \infty$; (*b*) since the input pins are virtually shorted together, we have $R_i = 0 + (R_1 \parallel R_2) = R_1 \parallel R_2$; (*c*) since the noninverting-input pin is virtually shorted to the inverting-input pin, which is in turn a virtual-ground node, we have $R_i = 0 + 0 = 0$. Which statement is correct? How would you refute the other two?

1.24 (*a*) Show that the circuit of Fig. P1.24 has $R_i = \infty$ and $A = -(1 + R_3/R_4)R_1/R_2$. (*b*) Specify suitable components to make A variable over the range -100 V/V $\le A \le 0$ by means of a 100-kΩ pot. Try minimizing the number of resistors you use.

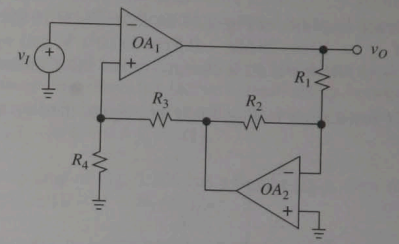

FIGURE P1.24

1.25 The audio panpot circuit of Fig. P1.25 is used to continuously vary the position of signal v_I between the left and the right stereo channels. (*a*) Discuss circuit operation. (*b*) Specify R_1 and R_2 so that $v_L/v_I = -1$ V/V when the wiper is fully down, $v_R/v_I = -1$ V/V when the wiper is fully up, and $v_L/v_I = v_R/v_I = -1/\sqrt{2}$ when the wiper is halfway.

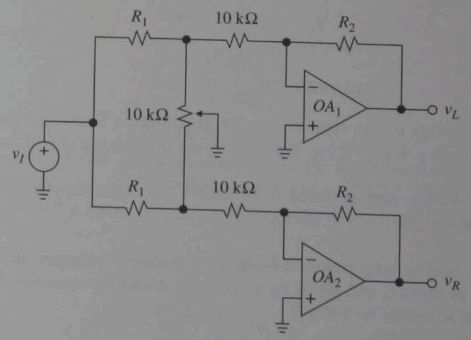

FIGURE P1.25

1.26 (*a*) Using standard 5% resistances in the kilohm range, design a circuit to yield $v_O = -100(4v_1 + 3v_2 + 2v_3 + v_4)$. (*b*) If $v_1 = 20$ mV, $v_2 = -50$ mV, and $v_4 = 100$ mV, find v_3 for $v_O = 0$ V.

1.27 (*a*) Using standard 5% resistances, design a circuit to give (*a*) $v_O = -10(v_I + 1\text{ V})$; (*b*) $v_O = -v_I + V_O$, where V_O is variable over the range -5 V $\le V_O \le +5$ V by means of a 100-kΩ pot. *Hint:* Connect the pot between the ±15-V supplies and use the wiper voltage as one of the inputs to your circuit.

1.28 In the circuit of Fig. 1.17 let $R_1 = R_3 = R_4 = 10\,\text{k}\Omega$ and $R_2 = 30\,\text{k}\Omega$. (*a*) If $v_1 = 3$ V, find v_2 for $v_O = 10$ V. (*b*) If $v_2 = 6$ V, find v_1 for $v_O = 0$ V. (*c*) If $v_1 = 1$ V, find the range of values for v_2 for which $-10\text{ V} \le v_O \le +10$ V.

1.29 You can readily verify that if we put the output in the form $v_O = A_2 v_2 - A_1 v_1$ in the circuit of Fig. 1.17, then $A_2 \le A_1 + 1$. Applications requiring $A_2 \ge A_1 + 1$ can be accommodated by connecting an additional resistance R_5 from the node common to R_1 and R_2 to ground. (*a*) Sketch the modified circuit and derive a relationship between its output and inputs. (*b*) Specify standard resistances to achieve $v_O = 5(2v_2 - v_1)$. Try minimizing the number of resistors you use.

1.30 (*a*) In the difference amplifier of Fig. 1.17 let $R_1 = R_3 = 10\,\text{k}\Omega$ and $R_2 = R_4 = 100\,\text{k}\Omega$. Find v_O if $v_1 = 10\cos 2\pi 60t - 0.5\cos 2\pi 10^3 t$ V, and $v_2 = 10\cos 2\pi 60t + 0.5\cos 2\pi 10^3 t$ V. (*b*) Repeat if R_4 is changed to 101 kΩ. Comment on your findings.

1.31 Show that if all resistances in Fig. P1.31 are equal, then $v_O = v_2 + v_4 + v_6 - v_1 - v_3 - v_5$.

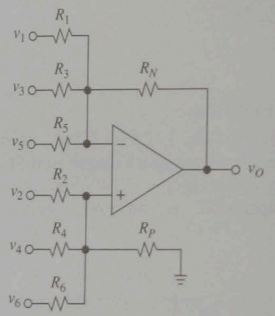

FIGURE P1.31

1.32 Using a topology of the type of Fig. P1.31, design a four-input amplifier such that $v_O = 4v_A - 3v_B + 2v_C - v_D$. Try minimizing the number of resistors you use.

1.33 Using just one op amp powered from ±12-V regulated supplies, design a circuit to yield: (*a*) $v_O = 10v_I + 5$ V; (*b*) $v_O = 10(v_2 - v_1) - 5$ V.

1.34 Using just one op amp powered from ±15-V supply voltages, design a circuit that accepts an ac input v_i and yields $v_O = v_i + 5$ V, under the constraint that the resistance seen by the ac source be 100 kΩ.

1.35 Design a two-input, two-output circuit that yields the sum and the difference of its inputs: $v_S = v_{I1} + v_{I2}$, and $v_D = v_{I1} - v_{I2}$. Try minimizing the component count.

1.36 Obtain a relationship between v_O and v_I if the differentiator of Fig. 1.18 includes also a resistance R_s in series with C. Discuss the extreme cases of v_I changing very slowly and very rapidly.

1.37 Obtain a relationship between v_O and v_I if the integrator of Fig. 1.19 includes also a resistance R_p in parallel with C. Discuss the extreme cases of v_I changing very rapidly and very slowly.

1.38 In the differentiator of Fig. 1.18 let $C = 10$ nF and $R = 100\,\text{k}\Omega$, and let v_I be a periodic signal alternating between 0 V and 2 V with a frequency of 100 Hz. Sketch and label v_I and v_O versus time if v_I is (*a*) a sine wave; (*b*) a triangular wave.

1.39 In the integrator of Fig. 1.19 let $R = 100\,\text{k}\Omega$ and $C = 10$ nF. Sketch and label $v_I(t)$ and $v_O(t)$ if (*a*) $v_I = 5\sin 2\pi 100t$ V and $v_O(0) = 0$; (*b*) $v_I = 5[u(t) - u(t - 2\text{ ms})]$ V and $v_O(0) = 5$ V, where $u(t - t_0)$ is the unit step function defined as $u = 0$ for $t < t_0$, and $u = 1$ for $t > t_0$.

1.40 (*a*) In the integrator of Fig. 1.19 let $R = 10\,\text{k}\Omega$ and $C = 0.1\,\mu$F. Assuming that C is initially discharged, sketch and label $v_O(t)$ for $0 \le t \le 10$ ms if v_I is a 1-V step. (*b*) Repeat (*a*) with a 100-kΩ resistance connected in parallel with C.

1.41 If R_F in the summing amplifier of Fig. 1.15 is replaced by a capacitance C, the circuit becomes a *summing integrator*. (*a*) Derive a relationship between its output and its inputs. (*b*) Using a 10-nF capacitance, specify suitable resistances for $v_O(t) = v_O(0) - 10^3(\int_0^t v_1\,d\xi + 2\int_0^t v_2\,d\xi + 0.5\int_0^t v_3\,d\xi)$.

1.42 Show that if the op amp of Fig. 1.20*b* has a finite gain a, then $R_{\text{eq}} = (-R_1 R/R_2) \times [1 + (1 + R_2/R_1)/a]/[1 - (1 + R_1/R_2)/a]$.

1.43 Find an expression for R_i in Fig. P1.43; discuss its behavior as R is varied over the range $0 \le R \le 2R_1$.

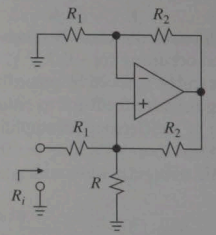

FIGURE P1.43

1.44 The circuit of Fig. P1.44 can be used to control the input resistance of the inverting amplifier based on OA_1. (*a*) Show that $R_i = R_1/(1 - R_1/R_3)$. (*b*) Specify resistances suitable for achieving $A = -10$ V/V with $R_i = \infty$.

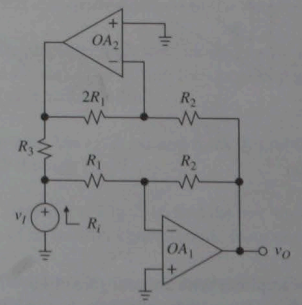

FIGURE P1.44

1.5 Negative feedback

1.45 A voltage amplifier has $a = 10^5$ V/V and $v_i = 10$ mV. Find v_d, v_f, v_o, A, T, and the percentage deviation of A from A_{ideal} for $\beta = 10^{-3}$ V/V, 10^{-2} V/V, 10^{-1} V/V, and 1 V/V. Compare the various cases and comment.

1.46 (*a*) Find the desensitivity factor of a negative-feedback system with $a = 10^3$ and $A = 10^2$. (*b*) Find A exactly via Eq. (1.40), and approximately via Eq. (1.49) if a drops by 10%. (*c*) Repeat (*b*) for a 50% drop in a; compare with (*b*) and comment.

1.47 You are asked to design an amplifier with a gain A of 10^2 V/V that is accurate to within $\pm 0.1\%$, or $A = 10^2$ V/V $\pm$ 0.1%. All you have available are amplifier stages with $a = 10^4$ V/V $\pm$ 25% each. Your amplifier can be implemented using a cascade of basic stages, each employing a suitable amount of negative feedback. What is the minimum number of stages required? What is the β of each stage?

1.48 The open-loop VTC of a certain amplifier can be approximated piecewise by five segments with symmetric breakpoints at $(v_D, v_O) = \pm(80\ \mu\text{V}, 8\ \text{V})$, $\pm(280\ \mu\text{V}, 12\ \text{V})$, and $\pm(530\ \mu\text{V}, 13\ \text{V})$. (*a*) Sketch the above VTC; calculate and sketch the closed-loop VTC when the amplifier is placed in a feedback loop with $\beta = 0.5$ V/V. (*b*) Sketch v_I, v_O, and v_D versus time if v_I is a triangular wave with $\pm$5-V peak values; comment on the waveform of v_D. *Hint:* $v_D(t)$ can be derived point by point from $v_O(t)$ using the open-loop VTC of (*a*).

1.49 A crude BJT power amplifier of the class B (push-pull) type exhibits the VTC of Fig. P1.49*b*. The dead band occurring for $-0.7\ \text{V} \le v_I \le +0.7$ V causes a crossover distortion at the output that can be reduced by preceding the power stage with a preamplifier stage and then using negative feedback to reduce the dead band. This is shown in Fig. P1.49*a* for the case of a difference preamplifier with gain a_1 and $\beta = 1$ V/V. (*a*) Sketch and label the closed-loop VTC if $a_1 = 10^2$ V/V. (*b*) Sketch v_I, v_1, and v_O versus time if v_I is a 100-Hz triangular wave with peak values of $\pm$1 V.

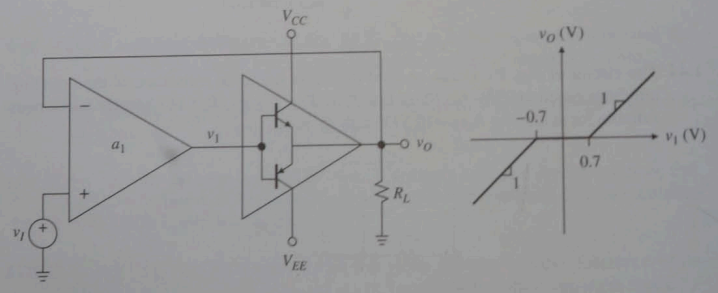

FIGURE P1.49

1.50 A certain audio power amplifier with a signal gain of 10 V/V is found to produce a 2-V peak-to-peak 120-Hz hum. We wish to reduce the output hum to less than 1 mV without changing the signal gain. To this end, we precede the power stage with a preamplifier stage with gain a_1 and then apply negative feedback around the composite amplifier. What are the required values of a_1 and β?

1.6 Feedback in op amp circuits

1.51 A voltage follower is implemented with an op amp having $r_d = 1$ MΩ, $a = 1$ V/mV, and $r_o = 1$ kΩ. (*a*) Find v_O if the follower is driven by a source $v_S = 10.000$ V with $R_s = 2$ MΩ. (*b*) Repeat (*a*) with a 1-kΩ output load.

1.52 An inverting amplifier is implemented with two precision resistors $R_1 = 100$ kΩ and $R_2 = 200$ kΩ and drives a 2-kΩ load. Assuming an op amp with $r_d = 1$ MΩ and $r_o = 100$ Ω, find the minimum gain a needed to contain the deviation of A from the ideal within (*a*) 1%, (*b*) 0.001%.

1.53 Let a voltage follower be implemented with an op amp having $r_d = 1$ kΩ, $r_o = 20$ kΩ, and $a = 10^6$ V/V (poor resistances, but excellent gain). Find A, R_i, and R_o, and comment on your findings.

1.7 The loop gain

1.54 (*a*) Find A_{ideal} in the circuit of Fig. P1.54 if all resistances are equal. (*b*) Assuming $r_d \cong \infty$ and $r_o \cong 0$, find $a_{\min}$ such that the deviation of A from A_{ideal} is less than 0.1%.

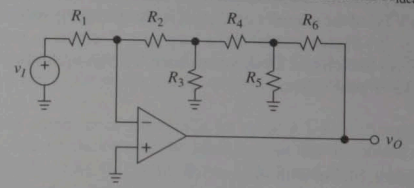

FIGURE P1.54

1.55 (*a*) Assuming that R_3 in Fig. 1.32*a* is a potentiometer connected as a variable resistance over the range $0 \le R_3 \le 1$ MΩ, specify suitable components for an input resistance of 500 kΩ and a continuously variable gain over the range -10^3 V/V $\le A_{\text{ideal}} \le -0.5$ V/V. (*b*) If $r_d = 1$ MΩ, $a = 10^5$ V/V, $r_o = 100$ Ω, and $R_L = 2$ kΩ, estimate the gain departure from the ideal at the two extremes of the range.

1.56 (*a*) Design a difference amplifier such that, ideally, $v_O = 100(v_2 - v_1)$. (*b*) Assuming an op amp with $r_d \cong \infty$ and $r_o \cong 0$, find the open-loop gain needed to approximate the ideal closed-loop gain within 0.1%.

1.57 Assuming that the op amp has $r_d \cong \infty$ and $r_o \cong 0$, find the feedback factor β in the circuits of Figs. P1.15 through P1.19.

1.58 For the dc-offsetting amplifier of Fig. 1.16 find the minimum open-loop gain needed to contain the deviation of its transfer characteristic from the ideal within 1%.

1.59 Using a single op amp, along with the ideas expressed in Problem 1.29, design a circuit that accepts two inputs v_1 and v_2 and yields $v_O = 100(3v_2 - 2v_1)$. Hence, assuming

$r_d = \infty$ and $r_o = 0$, find the minimum open-loop gain a needed to contain the transfer characteristic's deviation from ideality within 0.1%.

1.60 Assuming the op amp of Fig. P1.60 has $a = 3000$ V/V, $r_d = \infty$, and $r_o = 0$, find the loop gain T.

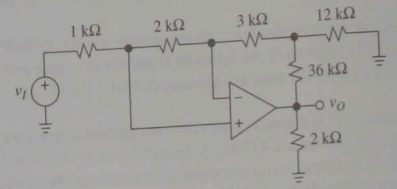

FIGURE P1.60

1.61 (*a*) Assuming the op amp of Fig. P1.16 has $r_d = \infty$ and $r_o = 0$, find β_N, β_P, and β. (*b*) Repeat, but with the current source replaced by a voltage source.

1.62 Repeat Problem 1.61, but for the circuit of Fig. P1.19.

1.63 In the circuit of Fig. P1.49*a* let $a_1 = 3000$ V/V and $R_L = 2$ kΩ, and suppose an additional 10-kΩ resistor is connected from node v_1 to node v_O. (*a*) Sketch and label the open-loop VTC of the overall circuit, that is, the plot of v_O versus the input difference $v_D = v_P - v_N$. (*b*) Sketch and label the loop gain T versus v_I over the range -0.3 V $\leq v_I \leq 0.3$ V. (*c*) Sketch and label, versus time, v_I, v_O, v_1, and v_D if v_I is a triangular wave with ±0.3-V peak values.

1.8 Op amp powering

1.64 Repeat Example 1.14, but with $v_I = -5$ V.

1.65 Assuming that $I_Q = 1.5$ mA in the circuit of Fig. P1.65, calculate all currents and voltages, as well as the power dissipated inside the op amp, if (*a*) $v_I = +2$ V; (*b*) $v_I = -2$ V.

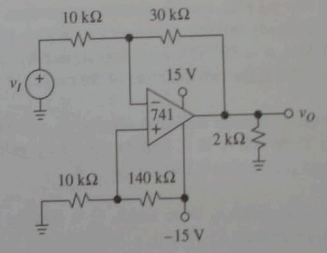

FIGURE P1.65

1.66 Using a 741 op amp powered from ±12-V supplies, design a noninverting amplifier with a gain of 6 V/V. Sketch and label v_I, v_O, and v_N versus time if v_I is a sine wave with ±3-V peak values.

1.67 (*a*) Assuming ±15-V power supplies, design a variable voltage source over the range $0 \text{ V} \leq v_S \leq 10$ V. (*b*) Assuming a 1-kΩ grounded load and $I_Q = 1.5$ mA, find the maximum internal power dissipation of your op amp.

1.68 Assuming a 741 op amp in the dc-offsetting amplifier of Fig. 1.16, find: (*a*) v_I and v_N if $v_O = 5$ V; (*b*) find v_N and v_O if $v_I = 3$ V.

1.69 The noninverting amplifier of Fig. 1.14*a* is implemented with $R_1 = 10$ kΩ and $R_2 = 15$ kΩ, and a 741 op amp powered from ±12-V supplies. If the circuit includes also a third 30-kΩ resistor connected between the inverting input and the 12-V supply, find v_O and v_N if (*a*) $v_I = 4$ V, and (*b*) $v_I = -2$ V.

1.70 (*a*) Assuming $I_Q = 50$ μA and a grounded load of 100 kΩ at the output of the dc-offsetting amplifier of Fig. 1.16, find the values of v_I for which the op amp dissipates the maximum power. Show all corresponding voltages and currents. (*b*) Assuming $\pm V_{\text{sat}} = \pm 12$ V, find the range of values of v_I for which the op amp still operates within the linear region.

1.71 In the amplifier of Fig. 1.17 let $R_1 = 30$ kΩ, $R_2 = 120$ kΩ, $R_3 = 20$ kΩ, and $R_4 = 30$ kΩ, and let the op amp be a 741-type powered from ±15 V. (*a*) If $v_2 = 2 \sin \omega t$ V, find the range of values of v_1 for which the amplifier still operates in the linear region. (*b*) If $v_1 = V_m \sin \omega t$ and $v_2 = -1$ V, find the maximum value of V_m for which the op amp still operates in the linear region. (*c*) Repeat (*a*) and (*b*) for the case in which the power supplies are lowered to ±12 V.

1.72 Assuming that the op amps of Figs. P1.17 and P1.19 saturate at ±10 V, find the range of values of v_S and i_S for which the op amps still operate in the linear region.

1.73 In the inverting amplifier of Fig. 1.32*a* let v_I be a 1-kHz triangular wave with peak values $\pm V_{im}$, and let the op amp be ideal, except that its output saturates at ±10 V. Assuming that $R_1 = R_2 = 1$ MΩ, $R_3 = 18$ kΩ, and $R_4 = R_L = 2$ kΩ, sketch and label v_I, v_N, v_1, and v_O versus time if (*a*) $V_{im} = 0.5$ V; (*b*) $V_{im} = 2$ V.

1.74 The circuit of Fig. P1.74, called a *bridge amplifier,* allows one to double the linear output range as compared with a single op amp. (*a*) Show that if the resistances are in the ratios shown, then $v_O/v_I = 2A$. (*b*) If the individual op amps saturate at ±13 V, what is the maximum peak-to-peak output voltage that the circuit can provide without distortion?

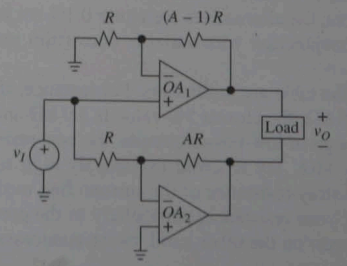

FIGURE P1.74

1.75 For the circuit of Fig. P1.65 sketch and label v_I, v_N, and v_O versus time if v_I is a triangular wave with ±5-V peak values.

1.76 In the integrator of Fig. 1.19 let $R = 100$ kΩ and $C = 10$ nF, and let the op amp be ideal, except that its output saturates at ±13 V. Assuming that $v_O(0) = 0$ V, sketch and label v_O and v_N versus time if (*a*) $v_I = 1$ V; (*b*) $v_I = 1$ mV; (*c*) $v_I = -1$ mV.

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APPENDIX 1A
STANDARD RESISTOR VALUES

As a good work habit, always specify standard resistance values for the circuits you design (see Table 1A.1). In many applications 5% resistors are adequate; however, when higher precision is required, 1% resistors should be used. When even this tolerance is insufficient, the alternatives are either 0.1% (or better) resistors, or less precise resistors in conjunction with variable ones (trim pots) to allow for exact adjustments.

The numbers in the table are multipliers. For instance, if the calculations yield a resistance of 3.1415 kΩ, the closest 5% value is 3.0 kΩ and the closest 1% value is 3.16 kΩ. In the design of low-power circuits, the best resistance range is usually between 1 kΩ and 1 MΩ. Try to avoid excessively high resistances (e.g., above 10 MΩ), because the stray resistance of the surrounding medium tends to decrease the effective value of your resistance, particularly in the presence of moisture and salinity. Low resistances, on the other hand, cause unnecessarily high-power dissipation.

TABLE 1A.1
Standard resistance values

5% resistor values	1% resistor values			
10	100	178	316	562
11	102	182	324	576
12	105	187	332	590
13	107	191	340	604
15	110	196	348	619
16	113	200	357	634
18	115	205	365	649
20	118	210	374	665
22	121	215	383	681
24	124	221	392	698
27	127	226	402	715
30	130	232	412	732
33	133	237	422	750
36	137	243	432	768
39	140	249	442	787
43	143	255	453	806
47	147	261	464	825
51	150	267	475	845
56	154	274	487	866
62	158	280	499	887
68	162	287	511	909
75	165	294	523	931
82	169	301	536	953
91	174	309	549	976