Norton circuit transformation
Norton equivalent circuit
Operational amplifier (op amp)
Phasor
Problem-solving approach
Quantization error
Random numbers
Resolution of the converter
Small-scale integration (SSI)
Superposition principle
Temperature coefficient
Temperature coefficient of resistance (TCR)
Thévenin circuit transformation
Thévenin equivalent circuit
Thévenin equivalent resistance
Tolerance
Transistor
Triode
Ultra-large-scale integration (ULSI)
Uniform random number generator
Vacuum diode
Vacuum tube
Very-large-scale integration (VLSI)
Virtual ground
Voltage-controlled current source (VCCS)
Voltage-controlled voltage source (VCVS)
Voltage division
Voltage gain
Worst-case analysis

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ADDITIONAL READING

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Digest of Technical Papers of the IEEE Custom Integrated International Circuits Conference, September of each year.

Digest of Technical Papers of the IEEE International Electronic Devices Meeting, December of each year.

Digest of Technical Papers of the IEEE International Solid-State Circuits Conference, February of each year.

Digest of Technical Papers of the IEEE International Symposia on VLSI Technology and Circuits, June of each year.

Electronics, Special Commemorative Issue, April 17, 1980.

Garratt, G. R. M. *The Early History of Radio from Faraday to Marconi.* London: Institution of Electrical Engineers (IEE), 1994.

"200 Years of Progress." *Electronic Design* 24, no. 4, February 16, 1976.

PROBLEMS

1.1 A Brief History of Electronics: From Vacuum Tubes to Ultra-Large-Scale Integration

1.1. Make a list of 20 items in your environment that contain electronics. A PC and its peripherals are considered one item. (Do not confuse electromechanical timers, common in clothes dryers or the switch in a simple thermostat, with electronic circuits.)

1.2. The straight line in Fig. 1.4 is described by $N = 1610 \times 10^{0.1548(\text{Year}-1970)}$. Based on a straight-line projection of this figure, what will be the number of transistors in a microprocessor in the year 2020?

1.3. The change in memory density with time can be described by $B = 19.97 \times 10^{0.1977(\text{Year}-1960)}$. If a straight-line projection is made using this equation, what will be the number of memory bits/chip in the year 2020?

1.4. (a) How many years does it take for memory chip density to increase by a factor of 2, based on the equation in Prob. 1.3? (b) By a factor of 10?

1.5. (a) How many years does it take for microprocessor circuit density to increase by a factor of 2, based on the equation in Prob. 1.2? (b) By a factor of 10?

1.6. If you make a straight-line projection from Fig. 1.5, what will be the minimum feature size in integrated circuits in the year 2025? The curve can be described by $F = 8.00 \times 10^{-0.05806(\text{Year}-1970)}$ μm. Do you think this is possible? Why or why not?

1.7. Based on Fig. 1.4, how many processors will we be able to place on one chip in the year 2020?

1.8. The filament of a small vacuum tube uses a power of approximately 1.5 W. Suppose that 268 million of these tubes are used to build the equivalent of a 256 Mb memory. How much power is required for this memory? If this power is supplied from a 220 V ac source, what is the current required by this memory?

1.2 Classification of Electronic Signals

1.9. Classify each of the following as an analog or digital quantity: (a) status of a light switch, (b) status of a thermostat, (c) water pressure, (d) gas tank level, (e) bank overdraft status, (f) light bulb intensity, (g) stereo volume, (h) full or empty cup, (i) room temperature, (j) TV channel selection, and (k) tire pressure.

1.10. A 12-bit D/A converter has a full scale voltage of 10.00 V. What is the voltage corresponding to the LSB? To the MSB? What is the output voltage if the binary input code is equal to (100100100101)?

1.11. A 10-bit D/A converter has a full scale voltage of 2.5 V. What is the voltage corresponding to the LSB? What is the output voltage if the binary input code is equal to (0101100100)?

1.12. An 8-bit A/D converter has $V_{FS} = 5$ V. What is the value of the voltage corresponding to the LSB? If the input voltage is 2.97 V, what is the binary output code of the converter?

1.13. A 15-bit A/D converter has $V_{FS} = 10$ V. What is the value of the LSB? If the input voltage is 6.85 V, what is the binary output code of the converter?

1.14. (a) A digital multimeter is being designed to have a readout with four decimal digits. How many bits will be required in its A/D converter? (b) Repeat for six decimal digits.

1.15. A 12-bit ADC has $V_{FS} = 5.12$ V and the output code is (101110111010). What is the size of the LSB for the converter? What range of input voltages corresponds to the ADC output code?

1.3 Notational Conventions

1.16. If $i_B = 0.003(1 + \cos 1000t)$ A, what are I_B and i_b?

1.17. If $v_{GS} = (2.5 + 0.5u(t-1) + 0.1 \cos 2000\pi t)$ V, what are V_{GS} and v_{gs}? [$u(t)$ is the unit step function.]

1.18. If $V_{CE} = 4$ V and $v_{ce} = (2 \cos 5000t)$ V, write the expression for v_{CE}.

1.19. If $V_{DS} = 5$ V and $v_{ds} = (2 \sin 2500t + 4 \sin 1000t)$ V, write the expression for v_{DS}.

1.5 Important Concepts from Circuit Theory

1.20. Use voltage and current division to find V_1, V_2, I_2, and I_3 in the circuit in Fig. P1.21 if $V = 1$ V, $R_1 = 24$ kΩ, $R_2 = 30$ kΩ, and $R_3 = 11$ kΩ.

1.21. Use voltage and current division to find V_1, V_2, I_2, and I_3 in the circuit in Fig. P1.21 if $V = 8$ V, $R_1 = 24$ kΩ, $R_2 = 30$ kΩ, and $R_3 = 11$ kΩ.

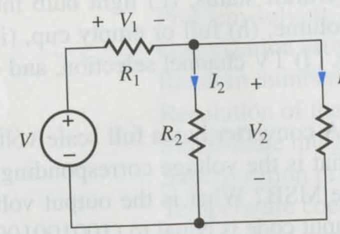

Figure P1.21

1.22. Use current and voltage division to find I_1, I_2, and V_3 in the circuit in Fig. P1.23 if $I = 300$ μA, $R_1 = 150$ kΩ, $R_2 = 68$ kΩ, and $R_3 = 82$ kΩ.

1.23. Use current and voltage division to find I_1, I_2, and V_3 in the circuit in Fig. P1.23 if $I = 5$ mA, $R_1 = 2.4$ kΩ, $R_2 = 5.6$ kΩ, and $R_3 = 3.9$ kΩ.

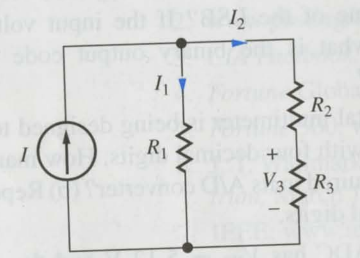

Figure P1.23

1.24. Find the Norton equivalent representation of the circuit in Fig. P1.25 if $g_m = 0.025$ S and $R_1 = 10$ kΩ.

1.25. Find the Thévenin equivalent representation of the circuit in Fig. P1.25 if $g_m = 0.002$ S and $R_1 = 75$ kΩ.

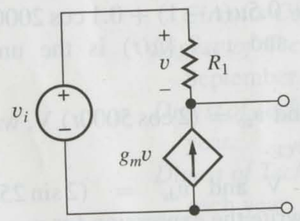

Figure P1.25

1.26. Find the Thévenin equivalent representation of the circuit in Fig. P1.26(a) if $\beta = 150$, $R_1 = 100$ kΩ, and $R_2 = 39$ kΩ. (b) Repeat for the circuit in Fig. P1.26(b).

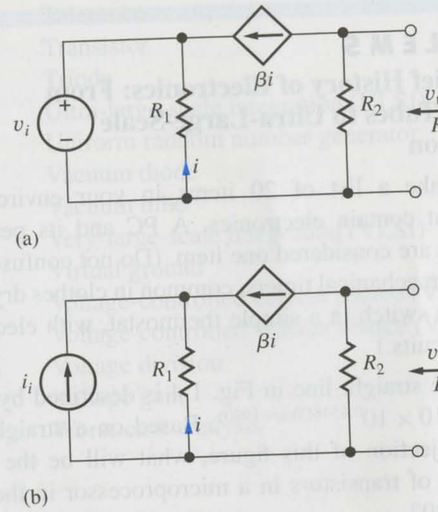

Figure P1.26

1.27. Find the Norton equivalent representation of the circuit in Fig. P1.26(a) if $\beta = 120$, $R_1 = 75$ kΩ, and $R_2 = 56$ kΩ.

1.28. What is the resistance presented to source v_s by the circuit in Fig. P1.26(a) if $\beta = 75$, $R_1 = 100$ kΩ, and $R_2 = 39$ kΩ?

1.29. Find the Thévenin equivalent representation of the circuit in Fig. P1.29 if $g_m = .0025$ S, $R_1 = 200$ kΩ, and $R_2 = 1.5$ MΩ.

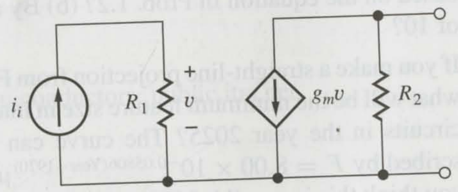

Figure P1.29

1.30. (a) What is the equivalent resistance between terminals A and B in Fig. P1.30? (b) What is the equivalent resistance between terminals C and D? (c) What is the equivalent resistance between terminals E and F?

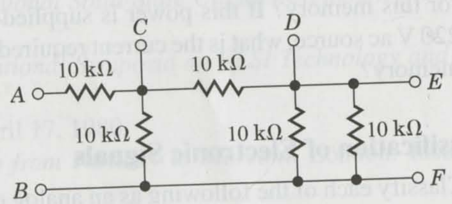

Figure P1.30

1.31. (a) Find the Thévenin equivalent circuit for the network in Fig. P1.31. (b) What is the Norten equivalent circuit?

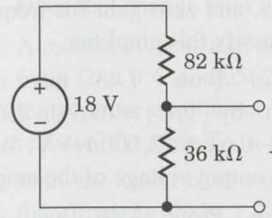

Figure P1.31

1.32. (a) Find the Thévenin equivalent circuit for the network in Fig. P1.32. (b) What is the Norten equivalent circuit?

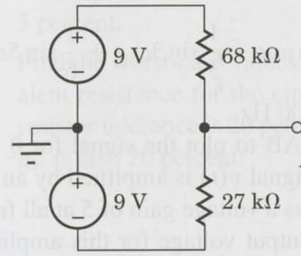

Figure P1.32

1.6 Frequency Spectrum of Electronic Signals

1.33. A signal voltage is expressed as $v(t) = (5 \sin 4000\pi t + 3 \cos 2000\pi t)$ V. Draw a graph of the amplitude spectrum for $v(t)$ similar to the one in Fig. 1.17(b).

*1.34. Voltage $v_1 = 2 \sin 20{,}000\pi t$ is multiplied by voltage $v_2 = 2 \sin 2000\pi t$. Draw a graph of the amplitude spectrum for $v = v_1 \times v_2$ similar to the one in Fig. 1.17(b). (Note that multiplication is a nonlinear mathematical operation. In electronics it is often called *mixing* because it produces a signal that contains output frequencies that are not in the input signal but depend directly on the input frequencies.)

1.7 Amplifiers

1.35. The input and output voltages of an amplifier are expressed as $v_s = 10^{-4} \sin(2 \times 10^7 \pi t)$ V and $v_o = 4 \sin(2 \times 10^7 \pi t + 56°)$ V. What are the magnitude and phase of the voltage gain of the amplifier?

*1.36. The input and output voltages of an amplifier are expressed as

$$v_s = [10^{-3} \sin(3000\pi t) + 2 \times 10^{-3} \sin(5000\pi t)] \text{ V}$$

and

$$v_o = [10^{-2} \sin(3000\pi t - 45°) + 10^{-1} \sin(5000\pi t - 12°)] \text{ V}$$

(a) What are the magnitude and phase of the voltage gain of the amplifier at a frequency of 2500 Hz? (b) At 1500 Hz?

1.37. What is the voltage gain of the amplifier in Fig. 1.20 if (a) $R_1 = 14$ kΩ and $R_2 = 560$ kΩ? (b) For $R_1 = 18$ kΩ and $R_2 = 360$ kΩ? (c) For $R_1 = 1.8$ kΩ and $R_2 = 62$ kΩ?

1.38. Write an expression for the output voltage $v_o(t)$ of the circuit in Fig. 1.20 if $R_1 = 910$ Ω, $R_2 = 7.5$ kΩ, and $v_s(t) = (0.01 \sin 750\pi t)$ V. Write an expression for the current $i_s(t)$.

1.39. Find an expression for the voltage gain $A_v = v_o/v_i$ for the amplifier in Fig. P1.39.

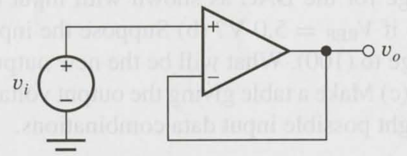

Figure P1.39

1.40. Find an expression for the voltage gain $A_v = v_o/v_i$ for the amplifier in Fig. P1.40.

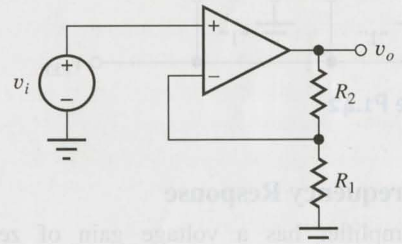

Figure P1.40

1.41. Write an expression for the output voltage $v_o(t)$ of the circuit in Fig. P1.41 if $R_1 = 2$ kΩ, $R_2 = 10$ kΩ, $R_3 = 51$ kΩ, $v_1(t) = (0.01 \sin 3770t)$ V, and $v_2(t) = (0.05 \sin 10{,}000t)$ V. Write an expression for the voltage appearing at the inverting input (v_-).

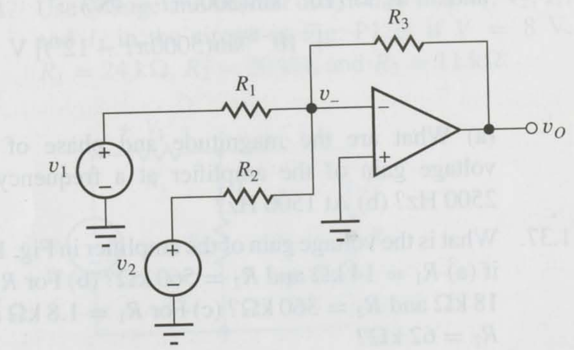

Figure P1.41

1.42. The circuit in Fig. P1.42 can be used as a simple 3-bit digital-to-analog converter (DAC). The individual bits of the binary input word (b_1 b_2 b_3) are used to control the position of the switches, with the resistor connected to 0 V if $b_i = 0$ and connected to V_{REF} if $b_i = 1$. (a) What is the output voltage for the DAC as shown with input data of (011) if $V_{REF} = 5.0$ V? (b) Suppose the input data change to (100). What will be the new output voltage? (c) Make a table giving the output voltages for all eight possible input data combinations.

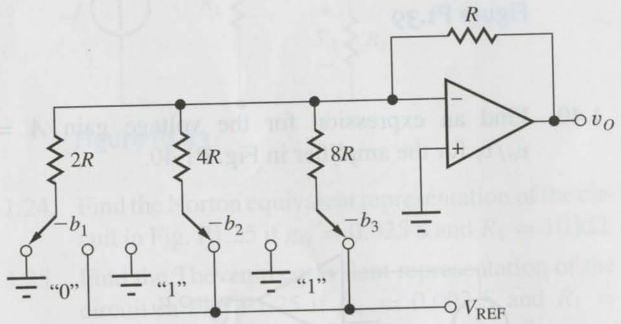

Figure P1.42

Amplifier Frequency Response

1.43. An amplifier has a voltage gain of zero for frequencies below 1000 Hz, and zero gain for frequencies above 5000 Hz. In between these two frequencies the amplifier has a gain of 20. Classify this amplifier.

1.44. An amplifier has a voltage gain of 10 for frequencies below 6000 Hz, and zero gain for frequencies above 6000 Hz. Classify this amplifier.

1.45. The amplifier in Prob. 1.44 has an input signal given by $v_s(t) = (5 \sin 2000\pi t + 3 \cos 8000\pi t + 2 \cos 15000\pi t)$ V. Write an expression for the output voltage of the amplifier.

1.46. An amplifier has a voltage gain of 16 for frequencies above 10 kHz, and zero gain for frequencies below 10 kHz. Classify this amplifier.

1.47. The amplifier in Prob. 1.43 has an input signal given by $v_s(t) = (0.5 \sin 2500\pi t + 0.75 \cos 8000\pi t + 0.6 \cos 12{,}000\pi t)$ V. Write an expression for the output voltage of the amplifier.

1.48. The amplifier in Prob. 1.46 has an input signal given by $v_s(t) = (0.5 \sin 2500\pi t + 0.75 \cos 8000\pi t + 0.8 \cos 12{,}000\pi t)$ V. Write an expression for the output voltage of the amplifier.

1.49. An amplifier has an input signal that can be represented as

$$v(t) = \frac{4}{\pi}\left(\sin \omega_o t + \frac{1}{3}\sin 3\omega_o t + \frac{1}{5}\sin 5\omega_o t\right) \text{V}$$

where $f_o = 1000$ Hz

(a) Use MATLAB to plot the signal for $0 \leq t \leq 5$ ms. (b) The signal $v(t)$ is amplified by an amplifier that provides a voltage gain of 5 at all frequencies. Plot the output voltage for this amplifier for $0 \leq t \leq 5$ ms. (c) A second amplifier has a voltage gain of 5 for frequencies below 2000 Hz but zero gain for frequencies above 2000 Hz. Plot the output voltage for this amplifier for $0 \leq t \leq 5$ ms. (d) A third amplifier has a gain of 5 at 1000 Hz, a gain of 3 at 3000 Hz, and a gain of 1 at 5000 Hz. Plot the output voltage for this amplifier for $0 \leq t \leq 5$ ms.

1.8 Element Variations in Circuit Design

1.50. (a) A 4.7-kΩ resistor is purchased with a tolerance of 1 percent. What is the possible range of values for this resistor? (b) Repeat for a 5 percent tolerance. (c) Repeat for a 10 percent tolerance.

1.51. A 10,000 μF capacitor has an asymmetric tolerance specification of +20%/−50%. What is the possible range of values for this capacitor?

1.52. The power supply voltage for a circuit must vary by no more than 50 mV from its nominal value of 1.8 V. What is its tolerance specification?

1.53. An 8200-Ω resistor is purchased with a tolerance of 10 percent. It is measured with an ohmmeter and found to have a value of 7905 Ω. Is this resistor within its specification limits? Explain your answer.

1.54. (a) The output voltage of a 5-V power supply is measured to be 5.30 V. The power supply has a 5 percent tolerance specification. Is the supply operating within its specification limits? Explain your answer. (b) The voltmeter that was used to make the measurement has a 1.5 percent tolerance. Does that change your answer? Explain.

1.55. A resistor is measured and found to have a value of 6066 Ω at 0°C and 6562 Ω at 100°C. What are the temperature coefficient and nominal value for the resistor? Assume $T_{NOM} = 27$°C.

1.56. Find the worst-case values of I_1, I_2, and V_3 for the circuit in Prob. 1.22 if the resistor tolerances are 5 percent and the current source tolerance is 2 percent.

1.57. Find the worst-case values of V_1, I_2, and I_3 for the circuit in Prob. 1.20 if the resistor tolerances are 10 percent and the voltage source tolerance is 5 percent.

1.58. Find the worst-case values for the Thévenin equivalent resistance for the circuit in Prob. 1.25 if the resistor tolerance is 20 percent and the tolerance on g_m is also 20 percent.

1.59. Perform a 200-case Monte Carlo analysis for the circuit in Prob. 1.56 and compare the results to the worst-case calculations.

1.60. Perform a 200-case Monte Carlo analysis for the circuit in Prob. 1.57 and compare the results to the worst-case calculations.

1.9 Numeric Precision

1.61. (a) Express the following numbers to three significant digits of precision: 3.2947, 0.995171, −6.1551. (b) To four significant digits. (c) Check these answers using your calculator.

1.62. (a) What is the voltage developed by a current of 1.763 mA in a resistor of 20.70 kΩ? Express the answer with three significant digits. (b) Express the answer with two significant digits. (c) Repeat for $I = 102.1$ μA and $R = 97.80$ kΩ.