SOLUTIONS

Effects of Feedback on Noise and Nonlinearities | 2

Note: All references to Figures and Equations whose numbers are *not* preceded by an "S" refer to the textbook.

There are two regions of operation for this circuit. When $|v_o|$ is less than 1, the feedback element has an incremental gain of 1. Thus:
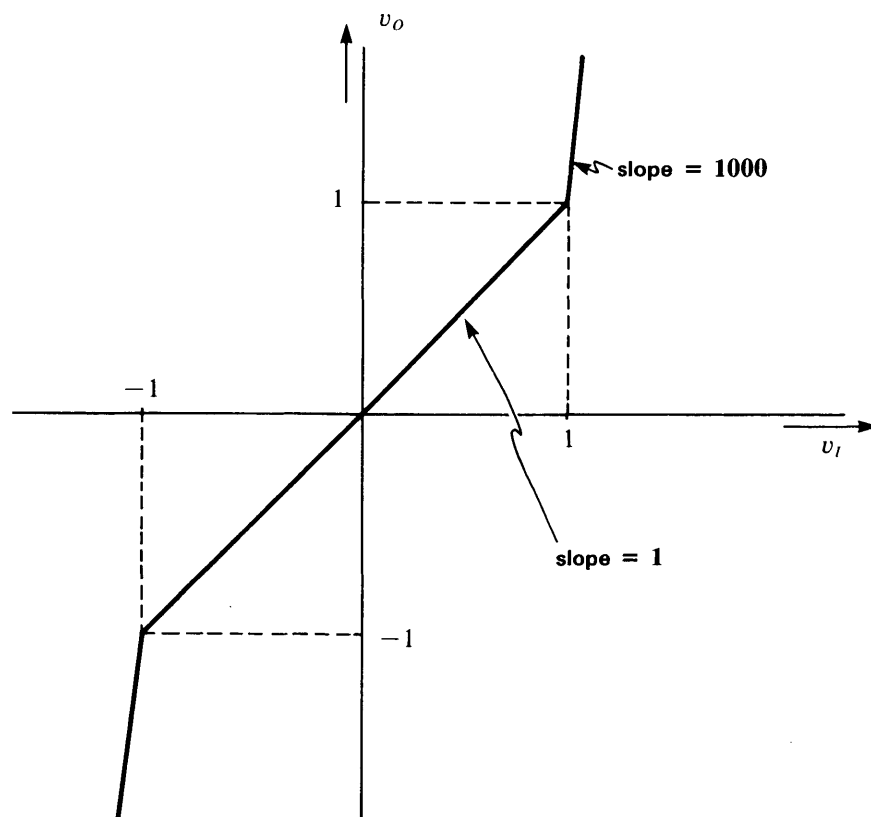
Solution 2.1 (P2.3)

$$\frac{v_o}{v_i} = \frac{1000}{1 + 1000} \simeq 1, \ |v_o| \leq 1 \qquad (S2.1)$$

When $|v_o|$ is greater than 1, the feedback element has an incremental gain of zero. Thus:

$$\frac{v_o}{v_i} = \frac{1000}{1 + 0} = 1000, \ |v_o| > 1 \qquad (S2.2)$$

These two equations describe the complete range of operation. The closed-loop transfer characteristics are plotted in Figure S2.1:

**Figure S2.1** Closed-loop transfer characteristics for Problem 2.1 (P2.3).

Solution 2.2 (P2.4)

(a) The complementary emitter–follower has the transfer characteristic shown in Figure S2.2. Note the ±0.6 volt deadzone.

(b) For a closed-loop gain of +5, we use the noninverting connection with a value for the feedback signal of ⅕ of the output voltage, as shown in Figure S2.3:

(c) Here we must consider two nonlinear effects:

- the ±0.6 volt deadzone
- saturation due to the finite value of V_C

Because the open-loop gain of the operational amplifier is high (10^5), we expect the effect of the deadzone to be greatly reduced, as was shown in Section 2.3.2 of the textbook.

The transistor stage has two regions of operation that we analyze separately. For $|v_I| \leq 0.6$ volts, the output is zero. For $|v_I| \leq 0.6$, we must have $v_A - v_F \leq \dfrac{0.6}{10^5}$. However, in this range, $v_F = 0$. Therefore $v_O = 0$ when v_A is less than 6×10^{-6} volts. For $v_A > 6 \times 10^{-6}$ volts, the complementary emitter–follower will be driven in its linear range, with $v_I > 0.6$ volts. Here, it has an incremental gain of 1. Thus,

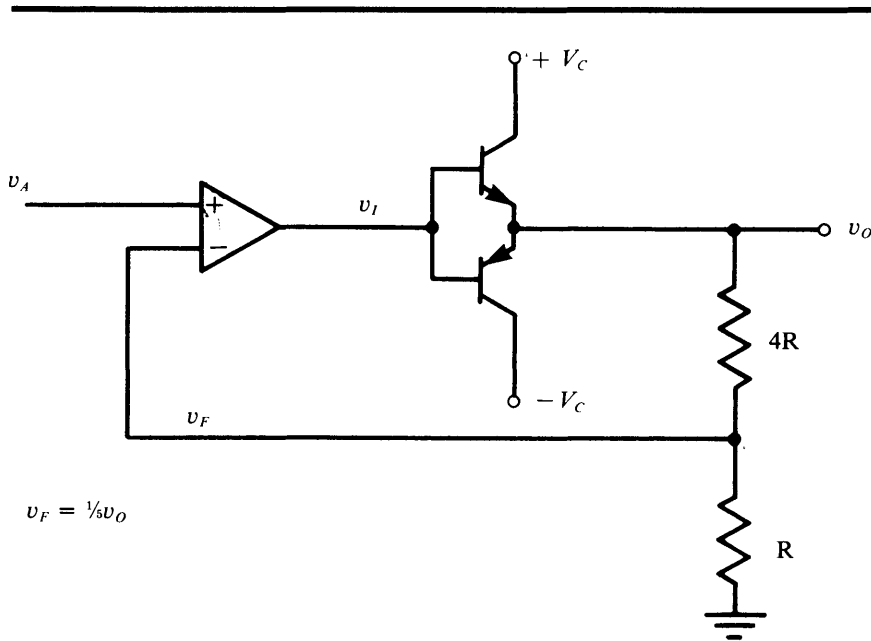**Figure S2.2** Complementary emitter–follower transfer characteristics.
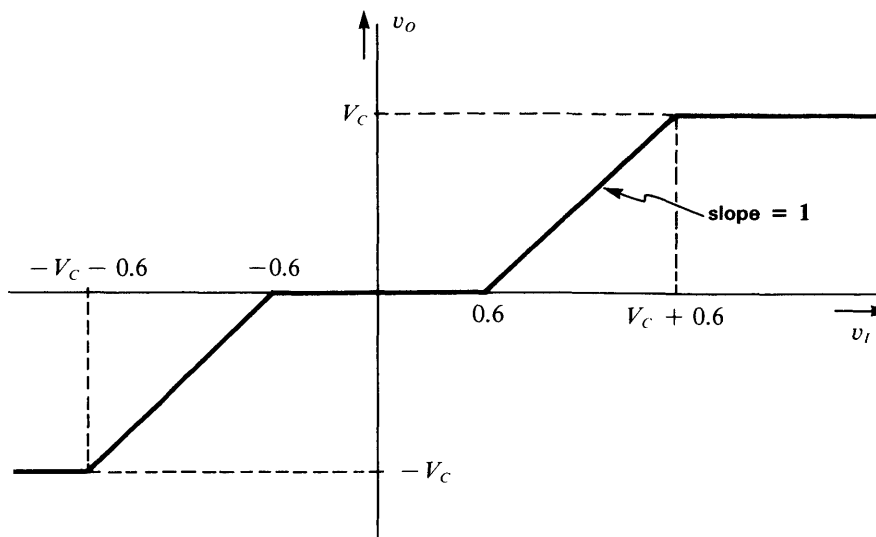
Figure S2.3 Circuit with closed-loop gain of 5.

$$\frac{v_o}{v_a} = \frac{10^5}{1 + \frac{1}{5}10^5} \simeq 5 \qquad |v_A| > 6 \times 10^{-6} \qquad \textbf{(S2.3)}$$

Finally, we account for the finite value of V_C. When v_O reaches $\pm V_C$ the output will saturate. This will occur for $v_A \simeq \dfrac{V_c}{5}$. The complete closed-loop characteristic is plotted in Figure S2.4. As predicted, the deadzone has been greatly reduced (by a factor of 10^5).
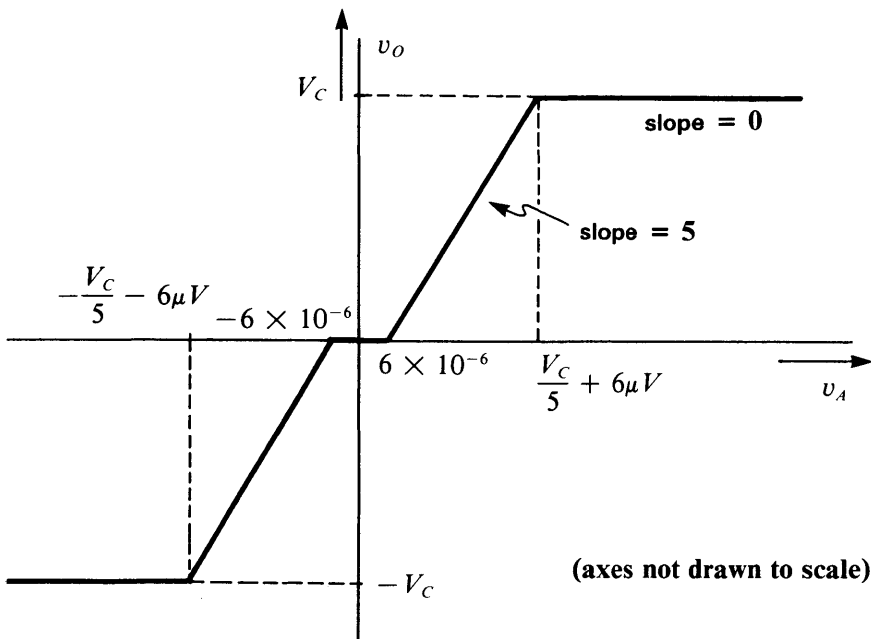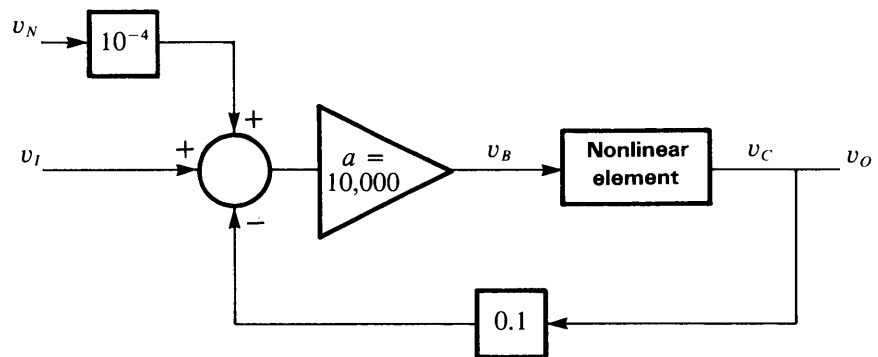

Figure S2.4 Transfer characteristics for circuit of Figure S2.3.

Solution 2.3 (P2.5)

We start this problem by redrawing the block diagram of Figure 2.24. We move the summation point for v_N to the input, as shown in Figure S2.5:

Figure S2.5 Manipulated block diagram for Problem 2.3 (P2.5)

Note that due to the large gain of $a = 10,000$, the sinusoidal v_N is attenuated by a factor of 10,000 relative to v_I. As stated in the problem assignment, in parts (a) and (b) we assume that $v_N = 0$.

(a) Now, for $V_I = 0.5$, V_O will be approximately 5, and the nonlinear element has an incremental gain of 1. Thus, the incremental gain is:

$$\frac{v_o}{v_i} = \frac{10^4}{1 + 10^4 \times 0.1} = \frac{10,000}{1001} = 9.99 \qquad \textbf{(S2.4)}$$

For $V_I = 1.25$, V_O will be approximately 12.5, and the nonlinear element has an incremental gain of ½. Thus, the overall incremental gain is:

$$\frac{v_o}{v_i} = \frac{5 \times 10^3}{1 + 5 \times 10^3 \times 0.1} = \frac{5000}{501} = 9.98 \qquad \textbf{(S2.5)}$$

(b) The signal v_A is interesting to examine, because we will see that it is acting in such a way as to reduce the effect the nonlinearity has on the output signal v_O.

In the absence of the sinusoid, v_N, for $|v_I| = 1.001$, $|v_o| = 10$. For $|v_o| < 10$, the nonlinear element has an incremental gain of 1. Thus,

$$\frac{v_a}{v_i} = \frac{10^4}{1 + 10^4 \times 0.1} = 9.99 \qquad 0 \leq |v_I| \leq 1.001 \quad \text{(S2.6)}$$

For $|v_I| = 1.502$, $|v_O| = 15$. For $10 < |v_O| < 15$, the nonlinear element has an incremental gain of $\frac{1}{2}$. Thus,

$$\frac{v_a}{v_i} = \frac{10^4}{1 + 10^4 \times \frac{1}{2} \times 0.1} = 19.96 \qquad 1.001 < |v_I| \leq 1.502$$

$$\text{(S2.7)}$$

For $|v_I| > 1.502$, the nonlinear element saturates, and $|v_O| = 15$. Here, the nonlinear element has an incremental gain of zero. Thus,

$$\frac{v_a}{v_i} = 10^4 \qquad |v_I| > 1.502$$

$$\text{(S2.8)}$$

$$|v_A| < 30$$

Finally, when $|v_A| = 30$ volts, the amplifier saturates.

Then, with $v_I(t) = t$, $t \geq 0$, we can use the above expressions to solve for $v_A(t)$.

$$v_A(t) = 9.99t \qquad 0 \leq t \leq 1.001 \tag{S2.9}$$

$$v_A(t) = 10 + 19.96(t - 1.001) \qquad 1.001 < t \leq 1.502 \tag{S2.10}$$

$$v_A(t) = 20 + 10^4(t - 1.502) \qquad 1.502 < t < 1.503 \tag{S2.11}$$
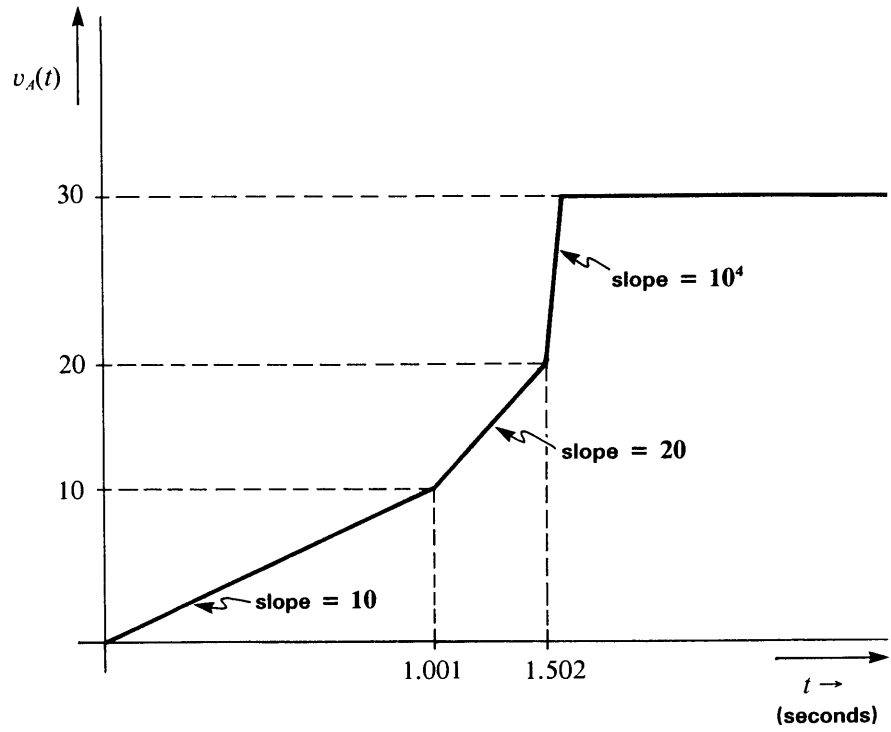
$$v_A(t) = 30 \qquad t \geq 1.503 \tag{S2.12}$$

The resulting $v_A(t)$ is plotted in Figure S2.6.

(c) For $v_I = 0$, the incremental gain $\dfrac{v_o}{v_i} = 9.99$, as calculated earlier. As mentioned earlier, the gain for v_N is a factor of 10^4 less, or

$$\frac{v_o}{v_N} = 9.999 \times 10^{-4} \tag{S2.13}$$

So the sinusoidal component of v_O has an amplitude of about 10^{-3} volts.

Figure S2.6 Plot of $v_A(t)$ for $v_I(t)$ = t, $t \geq 0$.

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