LEARNING ASSESSMENTS

E2.24 Determine the total resistance R_T in the circuit in Fig. E2.24.

ANSWER: $R_T = 34\ \text{k}\Omega$.

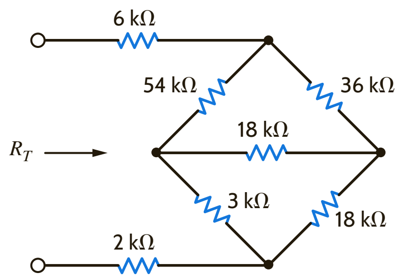


Figure E2.24

E2.25 Find V_o in the network in Fig. E2.25.

ANSWER: $V_o = 24$ V.

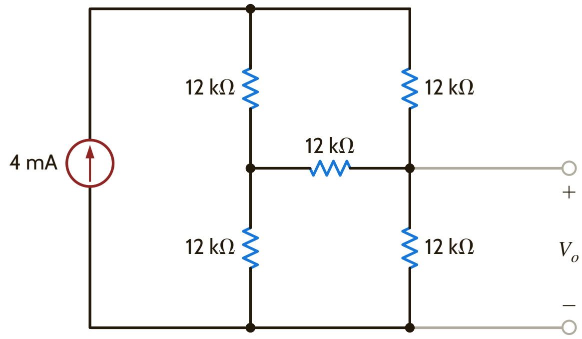


Figure E2.25

E2.26 Find I_1 in Fig. E2.26.

ANSWER: $I_1 = -1.2$ A.

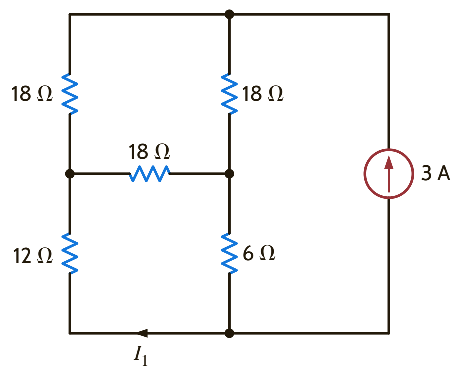


Figure E2.26

2.7 Circuits with Dependent Sources

In Chapter 1 we outlined the different kinds of dependent sources. These controlled sources are extremely important because they are used to model physical devices such as *npn* and *pnp* bipolar junction transistors (BJTs) and field-effect transistors (FETs) that are either metal-oxide-semiconductor field-effect transistors (MOSFETs) or insulated-gate field-effect transistors (IGFETs). These basic structures are, in turn, used to make analog and digital devices. A typical analog device is an operational amplifier (op-amp). This device is presented in Chapter 4. Typical digital devices are random access memories (RAMs), read-only memories (ROMs), and microprocessors. We will now show how to solve simple one-loop and one-node circuits that contain these dependent sources. Although the following examples are fairly simple, they will serve to illustrate the basic concepts.

PROBLEM-SOLVING STRATEGY

CIRCUITS WITH DEPENDENT SOURCES

STEP 1. When writing the KVL and/or KCL equations for the network, treat the dependent source as though it were an independent source.

STEP 2. Write the equation that specifies the relationship of the dependent source to the controlling parameter.

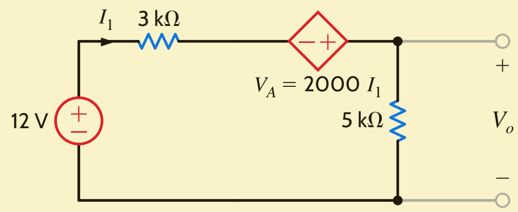
STEP 3. Solve the equations for the unknowns. Be sure that the number of linearly independent equations matches the number of unknowns.

The following four examples will each illustrate one of the four types of dependent sources: current-controlled voltage source, current-controlled current source, voltage-controlled voltage source, and voltage-controlled current source.

EXAMPLE 2.27

Let us determine the voltage V_o in the circuit in Fig. 2.38.

Figure 2.38 Circuit used in Example 2.27.



SOLUTION

Applying KVL, we obtain

$$-12 + 3kI_1 - V_A + 5kI_1 = 0$$

where

$$V_A = 2000I_1$$

and the units of the multiplier, 2000, are ohms. Solving these equations yields

$$I_1 = 2 \text{ mA}$$

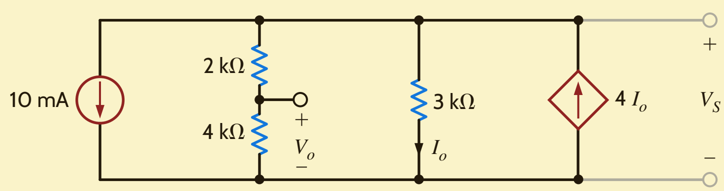
Then

$$\begin{aligned} V_o &= (5\text{ k})I_1 \\ &= 10 \text{ V} \end{aligned}$$

EXAMPLE 2.28

Given the circuit in Fig. 2.39 containing a current-controlled current source, let us find the voltage V_o.

Figure 2.39 Circuit used in Example 2.28.



SOLUTION

Applying KCL at the top node, we obtain

$$10 \times 10^{-3} + \frac{V_S}{2\text{k} + 4\text{k}} + \frac{V_S}{3\text{k}} - 4\text{m}I_o = 0$$

where

$$I_o = \frac{V_S}{3\text{k}}$$

Substituting this expression for the controlled source into the KCL equation yields

$$10^{-2} + \frac{V_S}{6\text{k}} + \frac{V_S}{3\text{k}} - \frac{4V_S}{3\text{k}} = 0$$

Solving this equation for V_S, we obtain

$$V_S = 12 \text{ V}$$

The voltage V_o can now be obtained using a simple voltage divider; that is,

$$V_o = \left[\frac{4\text{k}}{2\text{k} + 4\text{k}}\right] V_S$$
$$= 8 \text{ V}$$

EXAMPLE 2.29

The network in Fig. 2.40 contains a voltage-controlled voltage source. We wish to find V_o in this circuit.

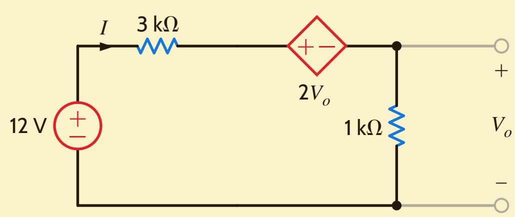


Figure 2.40
Circuit used in Example 2.29.

SOLUTION

Applying KVL to this network yields

$$-12 + 3\text{k}I + 2V_o + 1\text{k}I = 0$$

where

$$V_o = 1\text{k}I$$

Hence, the KVL equation can be written as

$$-12 + 3\text{k}I + 2\text{k}I + 1\text{k}I = 0$$

or

$$I = 2 \text{ mA}$$

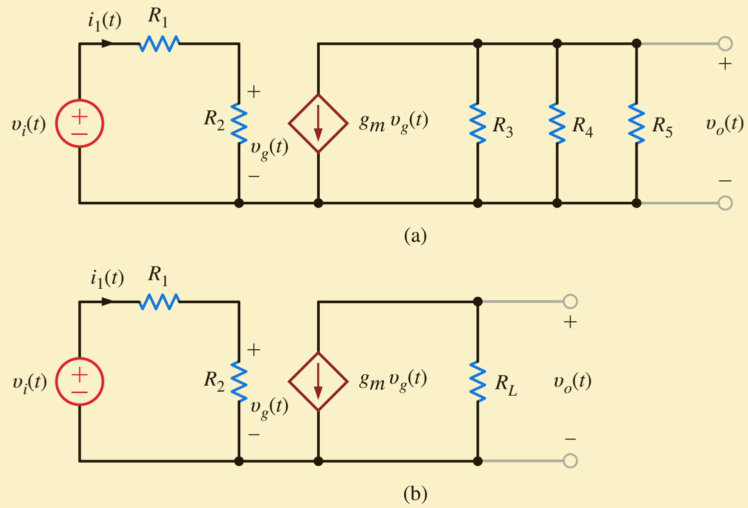
Therefore,

$$V_o = 1\text{k}I$$
$$= 2 \text{ V}$$

EXAMPLE 2.30

An equivalent circuit for a FET common-source amplifier or BJT common-emitter amplifier can be modeled by the circuit shown in **Fig. 2.41a**. We wish to determine an expression for the gain of the amplifier, which is the ratio of the output voltage to the input voltage.

Figure 2.41
Example circuit containing a voltage-controlled current source.



SOLUTION

Note that although this circuit, which contains a voltage-controlled current source, appears to be somewhat complicated, we are actually in a position now to solve it with techniques we have studied up to this point. The loop on the left, or input to the amplifier, is essentially detached from the output portion of the amplifier on the right. The voltage across R_2 is $v_g(t)$, which controls the dependent current source.

To simplify the analysis, let us replace the resistors R_3, R_4, and R_5 with R_L such that

$$\frac{1}{R_L} = \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

Then the circuit reduces to that shown in **Fig. 2.41b**. Applying Kirchhoff's voltage law to the input portion of the amplifier yields

$$v_i(t) = i_1(t)(R_1 + R_2)$$

and

$$v_g(t) = i_1(t)R_2$$

Solving these equations for $v_g(t)$ yields

$$v_g(t) = \frac{R_2}{R_1 + R_2} v_i(t)$$

From the output circuit, note that the voltage $v_o(t)$ is given by the expression

$$v_o(t) = -g_m v_g(t) R_L$$

Combining this equation with the preceding one yields

$$v_o(t) = \frac{-g_m R_L R_2}{R_1 + R_2} v_i(t)$$

Therefore, the amplifier gain, which is the ratio of the output voltage to the input voltage, is given by

$$\frac{v_o(t)}{v_i(t)} = -\frac{g_m R_L R_2}{R_1 + R_2}$$

Reasonable values for the circuit parameters in Fig. 2.41a are $R_1 = 100\ \Omega$, $R_2 = 1\ \text{k}\Omega$, $g_m = 0.04$ S, $R_3 = 50\ \text{k}\Omega$, and $R_4 = R_5 = 10\ \text{k}\Omega$. Hence, the gain of the amplifier under these conditions is

$$\frac{v_o(t)}{v_i(t)} = \frac{-(0.04)(4.545)(10^3)(1)(10^3)}{(1.1)(10^3)}$$
$$= -165.29$$

Thus, the magnitude of the gain is 165.29.

At this point it is perhaps helpful to point out again that when analyzing circuits with dependent sources, we first treat the dependent source as though it were an independent source when we write a Kirchhoff's current or voltage law equation. Once the equation is written, we then write the controlling equation that specifies the relationship of the dependent source to the unknown variable. For instance, the first equation in Example 2.28 treats the dependent source like an independent source. The second equation in the example specifies the relationship of the dependent source to the voltage, which is the unknown in the first equation.

LEARNING ASSESSMENTS

E2.27 Find V_o in the circuit in Fig. E2.27.

ANSWER: $V_o = 12$ V.

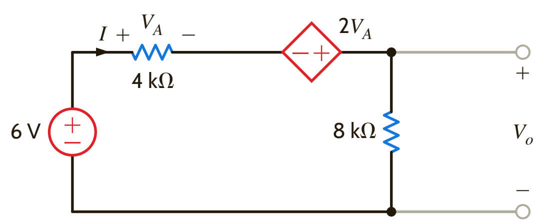


Figure E2.27

E2.28 Find V_o in the network in Fig. E2.28.

ANSWER: $V_o = 8$ V.

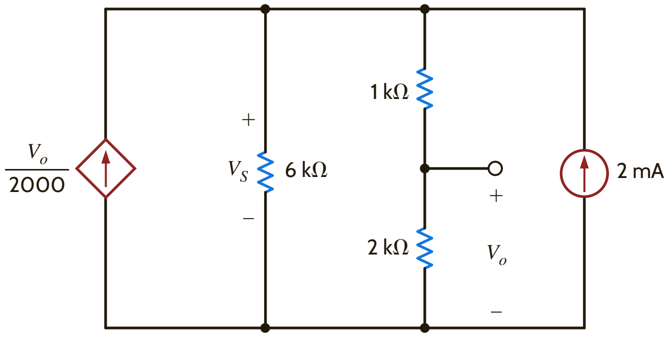


Figure E2.28

E2.29 Find V_A in Fig. E2.29.

ANSWER: $V_A = -12$ V.

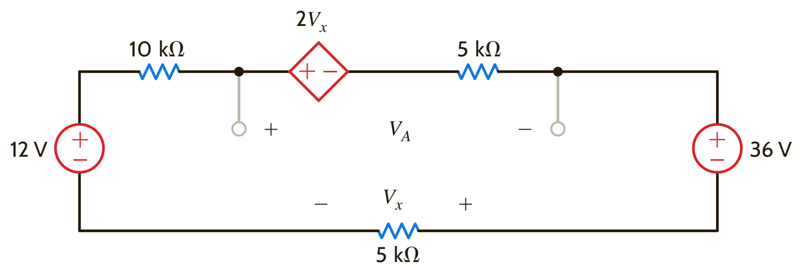


Figure E2.29