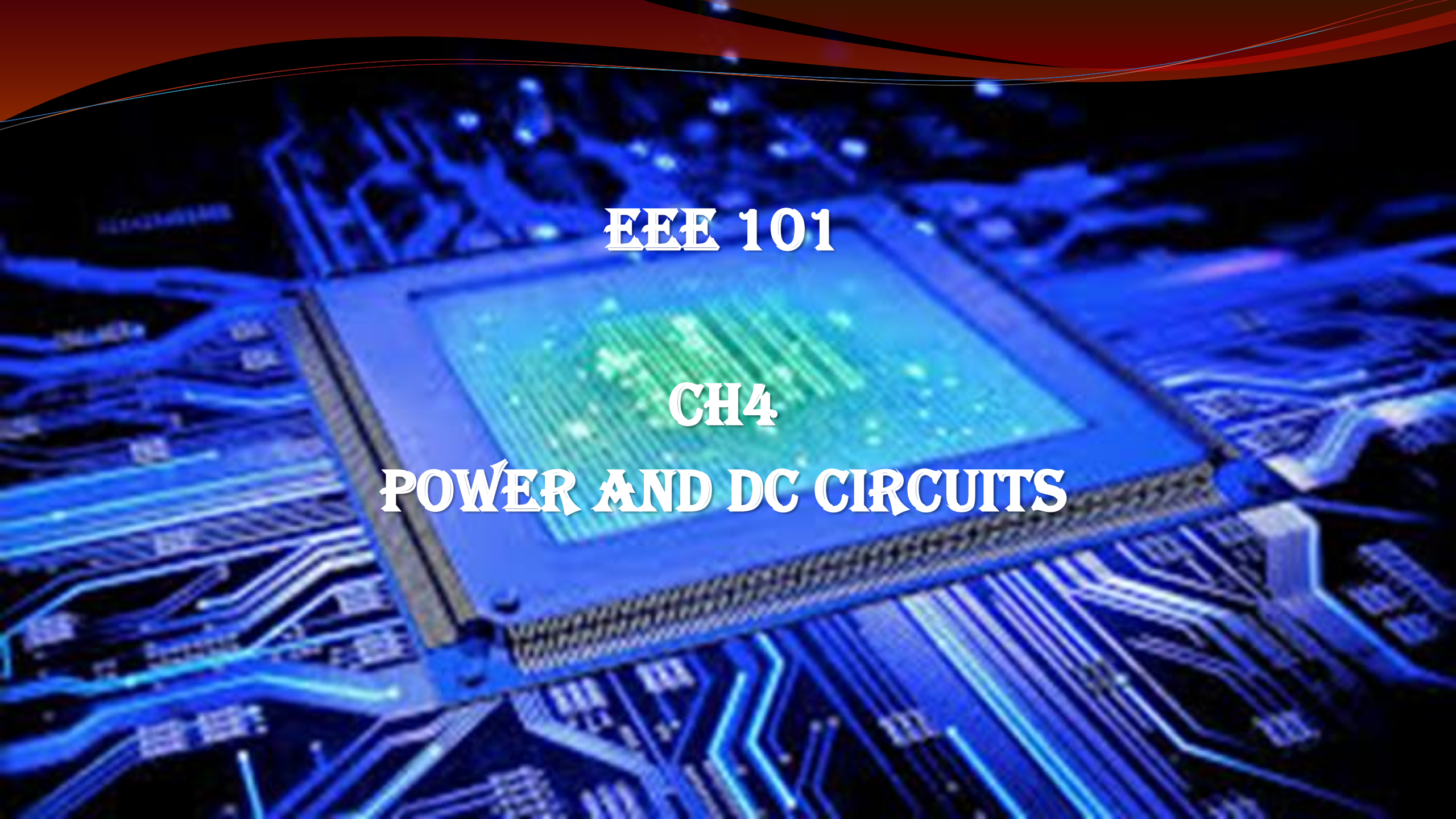

EEE 101
CH4
POWER AND DC CIRCUITS

CH4 – Power and DC Circuits

OBJECTIVES

After completing this chapter, the student will be able to:

- Define power as it relates to electric circuits.
- State the relationship of current and voltage.
- Solve for power consumption in an electrical circuit.
- Determine the total power consumption in aseries, parallel, or series-parallel circuit.
- Solve for all unknown values (current, voltage, resistance, and power) in a series, parallel, or series-parallel circuit.
- Understand the importance of voltage dividers.
- Design and solve for all unknown values in a voltage divider circuit.

Power and DC Circuits

- In addition to current, voltage, and resistance, a fourth quantity is important in circuit analysis. This quantity is called power.
- Power is the rate at which work is done. Every time a circuit is energized, power is expended.
- Power is directly proportional to both current and voltage.

Power

- Electrical or mechanical power relates to the rate at which work is being done.
- **Work** is done whenever a force causes motion. If a mechanical force is used to lift or move a weight, work is being done.
- Voltage is an electrical force that creates current to flow into a closed circuit. When voltage exists between two points and current cannot flow, no work is done.
- The **instantaneous rate** at which work is done is called the **electric power rate** and is measured in **watts**.
- **Power** can be defined at the rate which energy is dissipated in a circuit. The symbol for power is **P**.

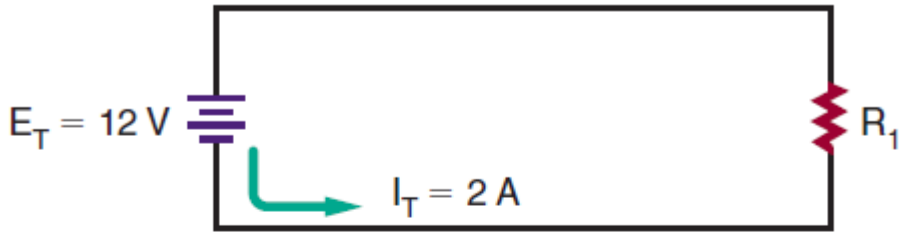
Power

- A watt is equal to the voltage across a circuit multiplied by the current through the circuit.
- It represents the rate at any given instant in which work is being done, moving electrons through the circuit.
- The relationship of power, current, and voltage may be expressed as follows:

$$P = I \times E, \text{ or } P = IE$$

- I represents the current through the circuit and E represents the voltage applied to the circuit being measured.

Power



EXAMPLE: Calculate the power consumed in the circuit shown in Figure 16-1.

Given	**Solution**
P = ?	P = IE
I = 2 A	P = (2)(12)
E = 12 V	P = 24 W

Power

EXAMPLE: What voltage is required to deliver 2 amperes of current at 200 watts?

Given	Solution
$P = 200\,W$	$P = IE$
$I = 2\,A$	$200 = 2(E)$
$E = ?$	$100\,V = E$

EXAMPLE: How much current does a 100-watt, 120-volt light bulb use?

Given	Solution
$P = 100\,W$	$P = IE$
$I = ?$	$100 = (I)(120)$
$E = 120\,V$	$0.83\,A = I$

Power Application (Circuit Analysis)

- Resistive components in a circuit consume power. To determine the **power dissipated** by a component, multiply the voltage drop across the component by the current flowing through the component.

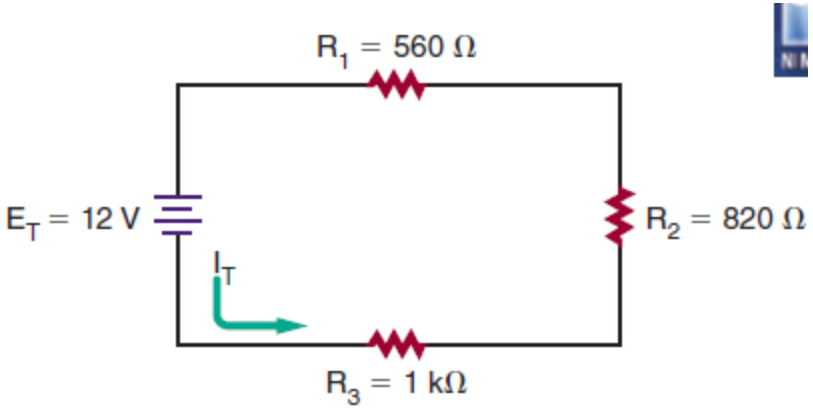
$$P = IE$$

- The total power dissipated in a series or parallel circuit is equal to the sum of the power dissipated by the individual components. This can be expressed as:

$$P_T = P_{R_1} + P_{R_2} + P_{R_3} \ldots + P_{R_n}$$

Power Application (Circuit Analysis)

- **Example:** How much power is consumed in the circuit shown in Figure



First determine the total resistance for the circuit.

Given	Solution
$R_T = ?$	$R_T = R_1 + R_2 + R_3$
$R_1 = 560\ \Omega$	$R_T = 560 + 820 + 1000$
$R_2 = 820\ \Omega$	$R_T = 2380\ \Omega$
$R_3 = 1000\ \Omega$	

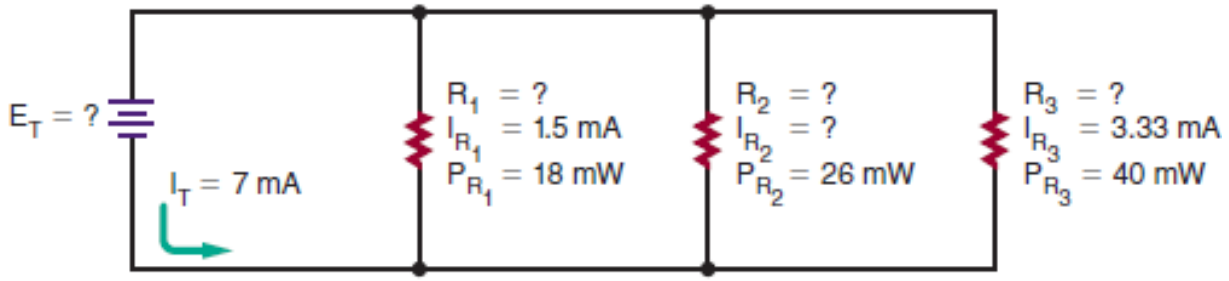
Now determine the total current flowing in the circuit, using Ohm's law.

Given	Solution
$I_T = ?$	$I_T = \frac{E_T}{R_T}$
$E_T = 12\ V$	$I_T = \frac{12}{2380}$
$R_T = 2380\ \Omega$	$I_T = 0.005\ A$

The total power consumption can now be determined using the power formula.

Given	Solution
$P_T = ?$	$P_T = I_T E_T$
$I_T = 0.005\ A$	$P_T = (0.005)(12)$
$E_T = 12\ V$	$P_T = 0.06\ W$, or $60\ mW$

Power Application (Circuit Analysis)



EXAMPLE: What is the value of resistor R_2 in the circuit shown in Figure 16-3?

First determine the voltage drop across resistor R_1.

Given	Solution
$P_{R_1} = 0.018\,W$	$P_{R_1} = I_{R_1}E_{R_1}$
$I_{R_1} = 0.0015\,A$	$0.018 = (0.0015)(E_{R_1})$
$E_{R_1} = ?$	$E_{R_1} = 12\,V$

Now the current through resistor R_2 can be determined. Remember, in a parallel circuit, the voltage is the same in all branches and $E_T = E_{R_1} = E_{R_2} = E_{R_3}$.

Given	Solution
$P_{R_2} = 0.026\,W$	$P_{R_2} = I_{R_2}E_{R_2}$
$I_{R_2} = ?$	$0.026 = (I_{R_2})(12)$
$E_{R_2} = 12\,V$	$I_{R_2} = 0.00217\,A$

The resistance value of R_2 can now be determined using Ohm's law.

Given	Solution
$I_{R_2} = 0.00217\,A$	$I_{R_2} = \frac{E_{R_2}}{R_2}$
$E_{R_2} = 12\,V$	$0.00217 = \frac{12}{R_2}$
$R_2 = ?$	$R_2 = 5530\,\Omega$

DC Circuits

- In the study of electronics, certain circuits appear again and again. The most commonly used circuits are the series circuit, the parallel circuit, and the series-parallel circuit.
- This section applies information from the last few section to the solving of all unknowns in these three basic types of circuits.
- **Voltage dividers** can make available several voltages from a single voltage source. Voltage dividers are essentially series circuits with parallel loads.
- This section helps the student understand how significant voltage dividers are as an application of series circuits and how to design one for a specific application.

Series Circuits

- A series circuit (Figure) provides only one path for current flow. The factors governing the operation of a series circuit are as follows:
- The same current flows through each component in a series circuit.

$$I_T = I_{R_1} = I_{R_2} = I_{R_3} \ldots = I_{R_n}$$

- The total resistance in a series circuit is equal to the sum of the individual resistances.

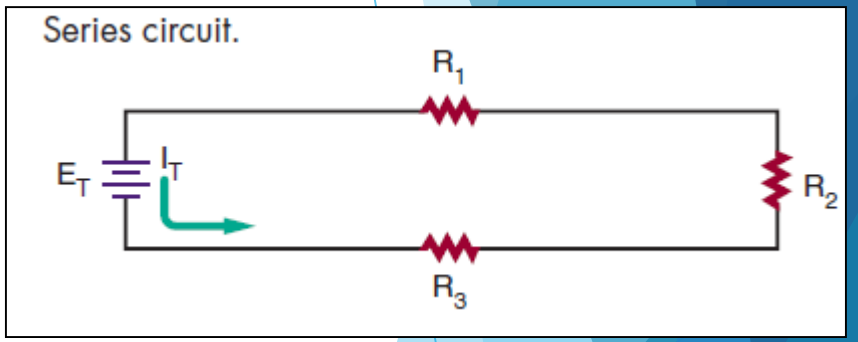
$$R_T = R_1 + R_2 + R_3 \ldots + R_n$$

- The total voltage across a series circuit is equal to the sum of the individual voltage drops.

$$E_T = E_{R_1} + E_{R_2} + E_{R_3} \ldots + E_{R_n}$$

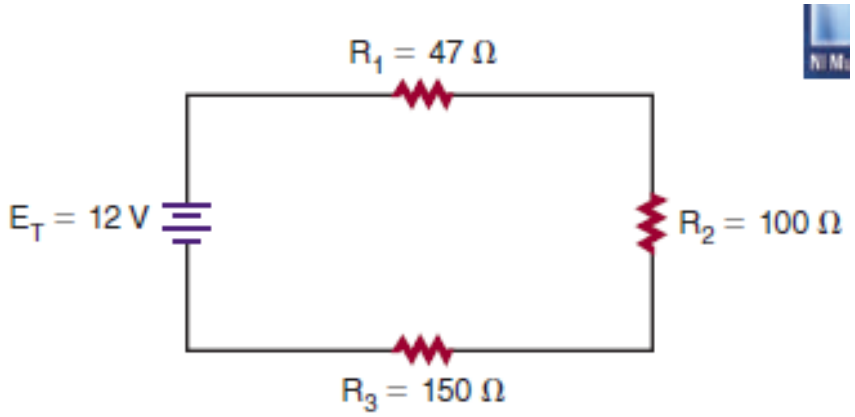
- The voltage drop across a resistor in a series circuit is proportional to the size of the resistor. $(I = E/R)$
- The total power dissipated in a series circuit is equal to the sum of the individual power dissipations.

$$P_T = P_{R_1} + P_{R_2} + P_{R_3} \ldots + P_{R_n}$$



Series Circuits

- **Example:** Three resistors, 47 ohms, 100 ohms, and 150 ohms, are connected in series with a battery rated at 12 volts. Solve for all values in the circuit.



Given

$I_T = ?$	$R_1 = 47\,\Omega$	$E_{R1} = ?$
$E_T = 12\,V$	$R_2 = 100\,\Omega$	$E_{R_2} = ?$
$R_T = ?$	$R_3 = 150\,\Omega$	$E_{R_3} = ?$
$P_T = ?$		$P_{R_1} = ?$
		$P_{R_2} = ?$
		$P_{R3} = ?$

In solving for all values in a circuit, the total resistance must be found first. Then the total circuit current can be determined.

Once the current is known, the voltage drops and power dissipation can be determined.

Given	**Solution**
$R_T = ?$	$R_T = R_1 + R_2 + R_3$
$R_1 = 47\,\Omega$	$R_T = 47 + 100 + 150$
$R_2 = 100\,\Omega$	$R_T = 297\,\Omega$
$R_3 = 150\,\Omega$	

Using Ohm's law, the current is as shown here:

Given	**Solution**
$I_T = ?$	$I_T = \frac{E_T}{R_T}$
$E_T = 12\,V$	$I_T = \frac{12}{297}$
$R_T = 297\,\Omega$	$I_T = 0.040\,\Omega$

Series Circuits

Because $I_T = I_{R_1} = I_{R_2} = I_{R_3} \ldots = I_{R_n}$, the voltage drop ($E_{R_1}$) across resistor R_1 is as follows:

Given	Solution
$I_{R_1} = 0.040\ A$	$I_{R_1} = \frac{E_{R_1}}{R_1}$
$E_{R_1} = ?$	$0.040 = \frac{E_{R_1}}{47}$
$R_1 = 47\ \Omega$	$E_{R_1} = 1.88\ V$

The voltage drop (E_{R_2}) across resistor R_2 is as shown here:

Given	Solution
$I_{R_2} = 0.040\ A$	$I_{R_2} = \frac{E_{R_2}}{R_2}$
$E_{R_2} = ?$	$0.040 = \frac{E_{R_2}}{100}$
$R_2 = 100\ \Omega$	$E_{R_2} = 4\ V$

The voltage drop (E_{R_3}) across resistor R_2 is as follows:

Given	Solution
$I_{R_3} = 0.040\ A$	$I_{R_3} = \frac{E_{R_3}}{R_3}$
$E_{R_3} = ?$	$0.040 = \frac{E_{R_3}}{150}$
$R_3 = 150\ \Omega$	$E_{R_3} = 6\ V$

Verify that the sum of the individual voltages is equal to the total voltage.

Given	Solution
$E_T = 12\ V$	$E_T = E_{R_1} + E_{R_2} + E_{R_3}$
$E_{R_1} = 1.88\ V$	$E_T = 1.88 + 4 + 6$
$E_{R_2} = 4\ V$	$E_T = 11.88\ V$
$E_{R_3} = 6\ V$	

There is a difference between the calculated and the total given voltage due to the rounding of the total current to three decimal places.

The power dissipated across resistor R_1:

Given	Solution
$P_{R_1} = ?$	$P_{R_1} = I_{R_1}E_{R_1}$
$I_{R_1} = 0.040\ A$	$P_{R_1} = (0.040)(1.88)$
$E_{R_1} = 1.88\ V$	$P_{R_1} = 0.075\ W$

The power dissipated across resistor R_2:

Given	Solution
$P_{R_2} = ?$	$P_{R_2} = I_{R_2}E_{R_2}$
$I_{R_2} = 0.040\ A$	$P_{R_2} = (0.040)(4)$
$E_{R_2} = 4\ V$	$P_{R_2} = 0.16\ W$

The power dissipated across resistor R_3:

Given	Solution
$P_{R_3} = ?$	$P_{R_3} = I_{R_3}E_{R_3}$
$I_{R_3} = 0.040\ A$	$P_{R_3} = (0.040)(6)$
$E_{R_3} = 6\ V$	$P_{R_3} = 0.24\ W$

The total power dissipated:

Given	Solution
$P_T = ?$	$P_T = P_{R_1} + P_{R_2} + P_{R_3}$
$P_{R_1} = 0.075\ W$	$P_T = 0.075 + 0.16 + 0.24$
$P_{R_2} = 0.16\ W$	$P_T = 0.475\ W$, or $475\ mW$
$P_{R_3} = 0.24\ W$	

Parallel Circuits

- A parallel circuit (Figure) is defined as a circuit having more than one current path. The factors governing the operations of a parallel circuit are listed here:
- The same voltage exists across each branch of the parallel circuit and is equal to that of the voltage source.

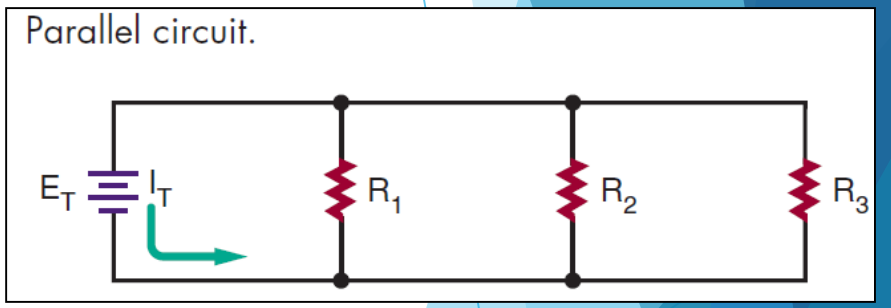
$$E_T = E_{R_1} = E_{R_2} = E_{R_3} \ldots = E_{R_n}$$

- The current through each branch of a parallel circuit is inversely proportional to the amount of resistance of the branch (I=E/R).
- The total current in a parallel circuit is the sum of the individual branch currents. $I_T = I_{R_1} + I_{R_2} + I_{R_3} \ldots + I_{R_n}$
- The reciprocal of the total resistance in a parallel circuit is equal to the sum of the reciprocals of the individual resistances.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots + \frac{1}{R_n}$$

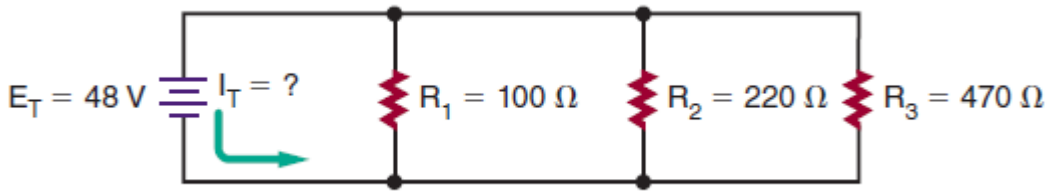
- The total power consumed in a parallel circuit is equal to the sum of the power consumed by the individual resistors.

$$P_T = P_{R_1} + P_{R_2} + P_{R_3} \ldots + P_{R_n}$$



Parallel Circuits

- **Example:** Three resistors, 100 ohms, 220 ohms, and 470 ohms, are connected in parallel with a battery rated at 48 volts. Solve for all values of the circuit.



Given

$I_T = ?$	$R_1 = 100\ \Omega$	$I_{R_1} = ?$
$E_T = 48\ V$	$R_2 = 220\ \Omega$	$I_{R_2} = ?$
$R_T = ?$	$R_3 = 470\ \Omega$	$I_{R_3} = ?$
$P_T = ?$		$P_{R_1} = ?$
		$P_{R_2} = ?$
		$P_{R_3} = ?$

In solving the circuit for all values, the total resistance must be found first. Then the individual currents flowing through each branch of the circuit can be found.

Once the current is known, the power dissipation across each resistor can be determined.

Given	Solution
$R_T = ?$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
$R_1 = 100\ \Omega$	$\frac{1}{R_T} = \frac{1}{100} + \frac{1}{220} + \frac{1}{470}$
$R_2 = 220\ \Omega$	$R_T = 59.98\ \Omega$
$R_3 = 470\ \Omega$	

The current (I_{R_1}) through resistor R_1:

Given	Solution
$I_{R_1} = ?$	$I_{R_1} = \frac{E_{R_1}}{R_1}$
$E_{R_1} = 48\ V?$	$I_{R_1} = \frac{48}{100}$
$R_1 = 100\ \Omega$	$I_{R_1} = 0.48\ A$

The current (I_{R_2}) through resistor R_2:

Given	Solution
$I_{R_2} = ?$	$I_{R_2} = \frac{E_{R_2}}{R_2}$
$E_{R_2} = 48\ V$	$I_{R_2} = \frac{48}{220}$
$R_2 = 220\ \Omega$	$I_{R_2} = 0.218\ A$

The current (I_{R_3}) through resistor R_3:

Given	Solution
$I_{R_3} = ?$	$I_{R_3} = \frac{E_{R_3}}{R_3}$
$E_{R_3} = 48\ V$	$I_{R_3} = \frac{48}{470}$
$R_3 = 470\ \Omega$	$I_{R_3} = 0.102\ A$

The total current:

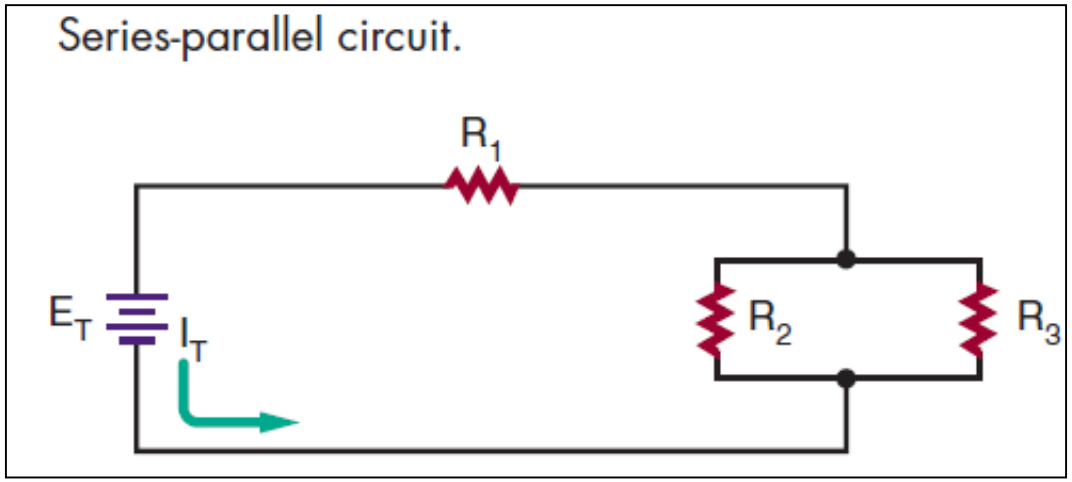
Given	Solution
$I_T = ?$	$I_T = I_{R_1} + I_{R_2} + I_{R_3}$
$I_{R_1} = 0.48\ A$	$I_T = 0.48 + 0.218 + 0.102$
$I_{R_2} = 0.218\ A$	$I_T = 0.800\ A$
$I_{R_3} = 0.102\ A$	

The total current can also be found using Ohm's law:

Given	Solution
$I_T = ?$	$I_T = \frac{E_T}{R_T}$
$E_T = 48\ V$	$I_T = \frac{48}{59.98}$
$R_T = 59.98\ \Omega$	$I_T = 0.800\ A$

Series- Parallel Circuits

- Most circuits consist of both series and parallel circuits. Circuits of this type are referred to as series-parallel circuits (Figure).
- The solution of most series-parallel circuits is simply a matter of applying the laws and rules discussed earlier.
- Series formulas are applied to the series part of the circuit, and parallel formulas are applied to the parallel parts of the circuit.



Voltage Divider Circuits

- One of the more common uses of resistors is voltage division, which is used extensively in electronics.
- Voltage dividers are often used to set a bias or operating point of various active electronic components such as transistors or integrated circuits.
- A voltage divider is also used to convert a higher voltage to a lower one so that an instrument can read or measure a voltage above its normal range. This often referred to as **scaling**.
- Ohm's law states that the current through a circuit is directly proportional to the voltage across the circuit and inversely proportional to the resistance.

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

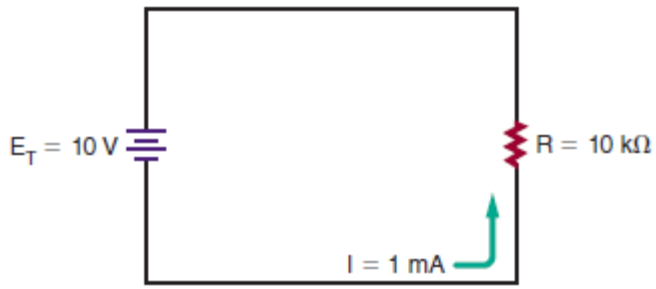
$$I = \frac{E}{R}$$

Voltage Divider Circuits

- Figure 1 depicts the simplest of circuits. It has a single voltage source of 10 volts, which is connected to a single 10 kΩ resistor. By Ohm's law, 1 milliampere of current is flowing in this circuit.

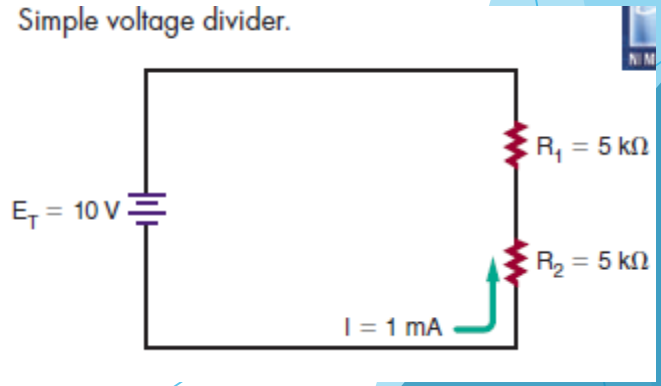
$$I = \frac{E}{R}$$
$$I = 10/10000$$
$$I = 0.001 \text{ A or } 1 \text{ mA}$$

Simple circuit.



- In Figure 2, the original 10 kΩ resistor in Figure 1 is shown divided into two equal resistors, R1 and R2.
- This circuit still has the same total resistance as Figure 1 and therefore has the same amount of current flowing through it (i.e., 1 mA).
- Ohm's law can be used to determine the voltage across each of the resistors.

Simple voltage divider.

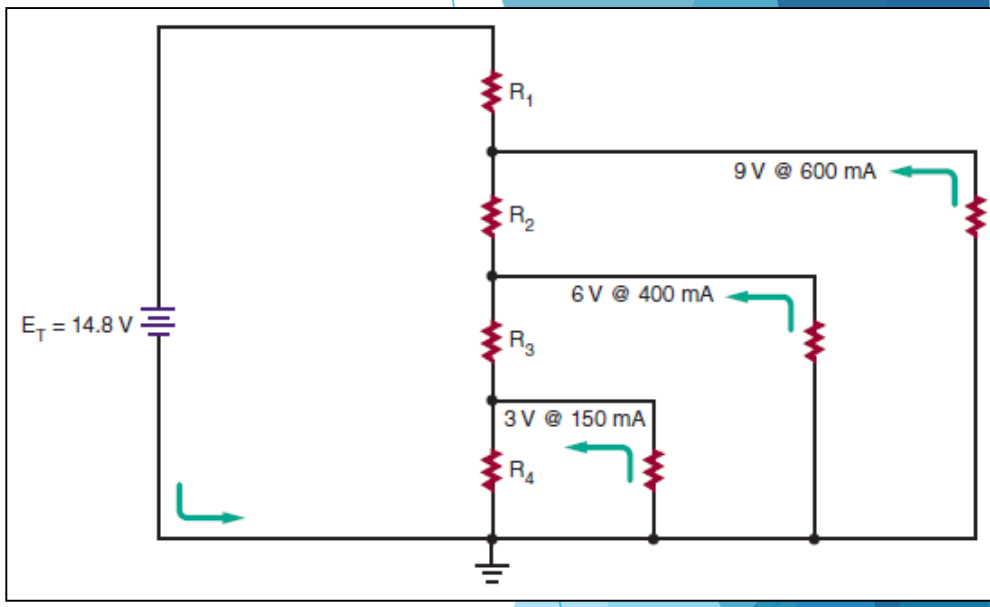


Voltage Divider Circuits

- A generalization can be stated for voltage dividers of this nature. The voltage drop is equal to the percentage of the dropping resistor to the sum of the dropping network.

$$E_{Drop} = \frac{E_{source} \times R_{Drop}}{R_{Total}}$$

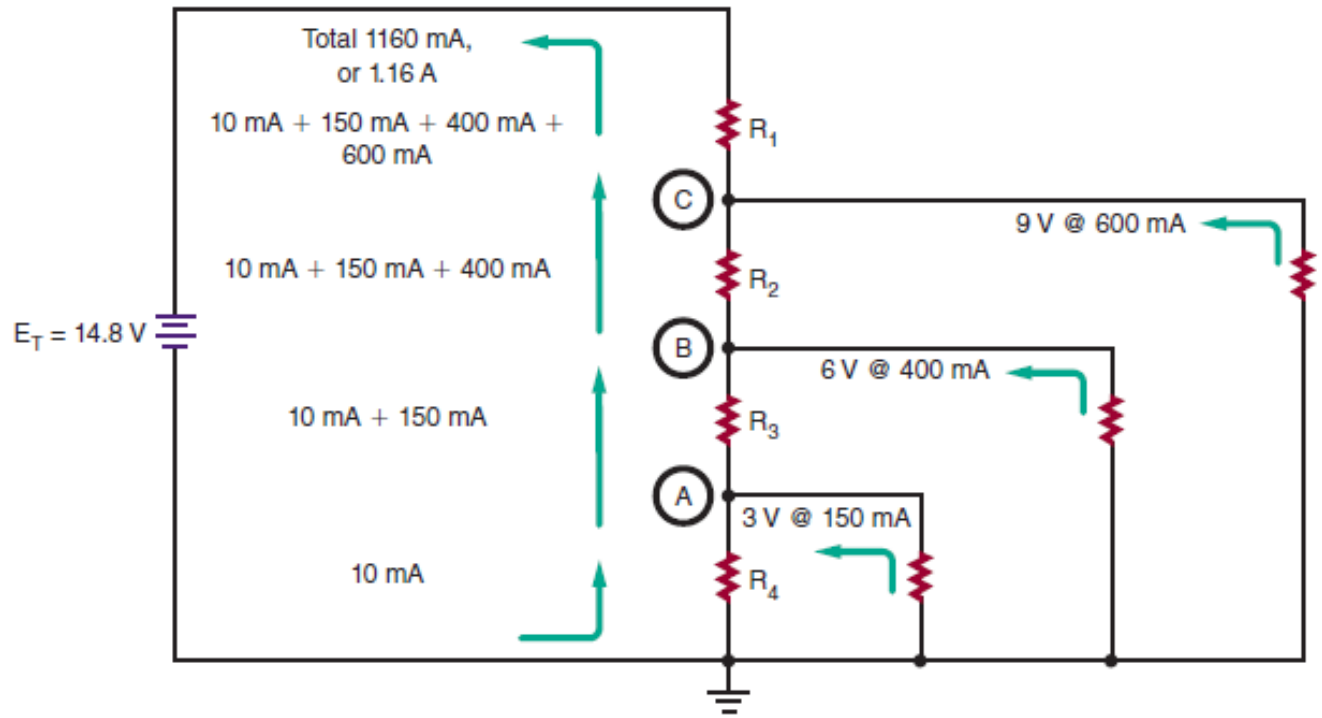
- The voltage source is the standard automotive accessory power source of 14.8 volts. What is desired is a voltage divider network that will divide this 14.8 volt source into a lower-voltage source specified by the manufacturer of a tape or CD player.
- The first voltage desired is 3 volts, and the load for this voltage will draw 150 mA.
- The second voltage required is 6 volts, and this voltage's load will draw 400 mA. The final voltage required is 9 volts, and its load draws 600 mA.
- Reviewing Figure indicates that both series and parallel networks are involved. It is necessary to know the load currents for each voltage in advance.



Voltage Divider Circuits

- Analyzing the circuit…

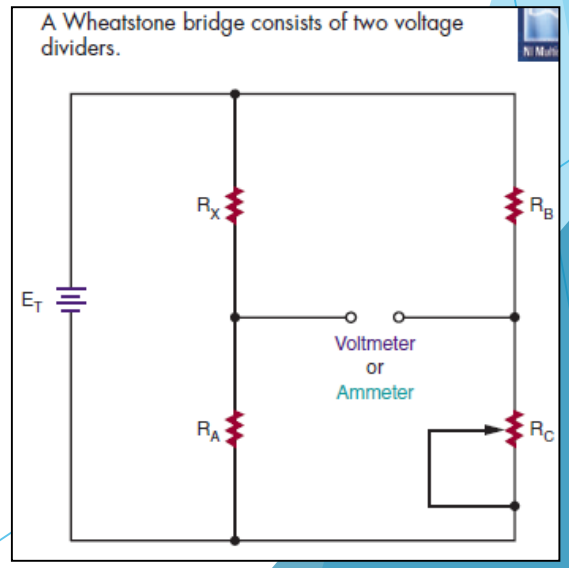
Analyzing the circuit.



Wheatstone Bridge

- A **Wheatstone bridge** is a measuring instrument that was invented by Samuel Hunter Christie in 1833.
- In 1843, a talented and versatile scientist named Sir Charles Wheatstone improved on the original design
- of the Wheatstone bridge.
- He did not claim to have invented the circuit named after him, but he was the first to use the circuit effectively for making resistance measurements.
- The Wheatstone bridge consists essentially of two voltage dividers (Figure 1). It is used to measure an unknown electrical resistance by balancing one leg that includes the unknown component against another leg of known components, with one being variable.

- In the circuit, RX is the unknown resistor value. RC is a potentiometer and is adjusted until the voltage from the second voltage divider is equal to voltage from the voltage divider containing RX.
- When the voltage values are equal, the bridge balanced. The balance point can be detected by connecting either a voltmeter or an ammeter across the output terminals.
- Both meters will give a zero reading when a balance is achieved.



Wheatstone Bridge

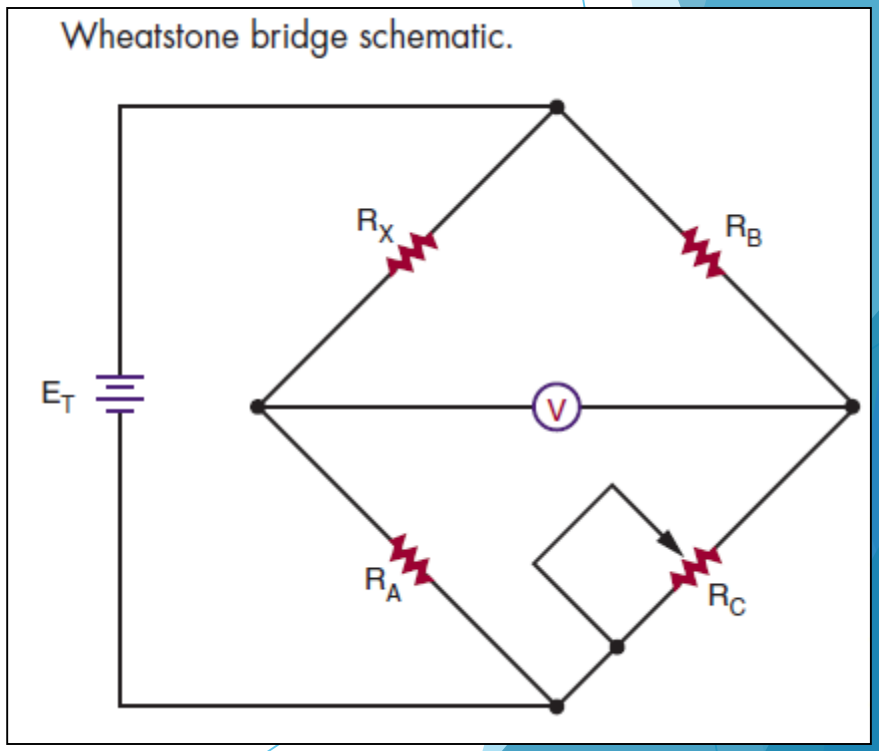
- In a balanced circuit, the ratio RX/RA is equal to the ratio RB/RC.

$$\frac{R_X}{R_A} = \frac{R_B}{R_C}$$

$$R_X = \frac{R_A \times R_B}{R_C}$$

- In other words, if the values of RA, RB, and RC are known, it is easy to calculate RX. RC would have to be measured with a meter to determine its value after adjusting for a zero reading.

- The circuit for a Wheatstone bridge as designed by Wheatstone is shown in Figure
- This is how the circuit is drawn for applications using it.



Wheatstone Bridge

- Wheatstone bridge circuits are rarely used today to measure resistance values. They are now used for designing sensing circuits such as **strain gauges** for transforming a strain applied to a proportional change of resistance, widely used in industry; **variometers** to detect changes in air pressure for alerting glider pilots to updrafts or thermals so height can be gained allowing for longer flights; and **explosimeters** for sampling the amount of combustible gases in a space.