Chapter 6

Series-Parallel Circuits

Objectives

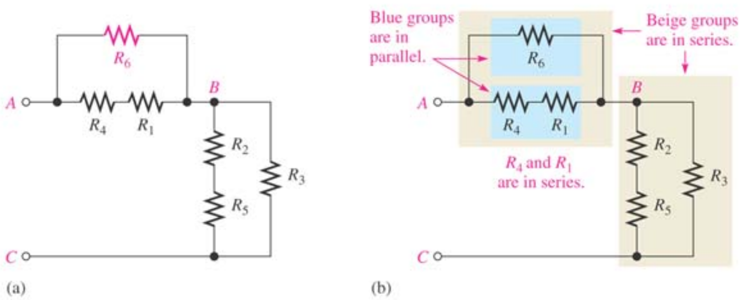
- Identify series-parallel relationships
- Analyze series-parallel circuits
- Analyze loaded voltage dividers
- Determine the loading effect of a voltmeter on a circuit
- Analyze a Wheatstone bridge circuit

Objectives

- Apply Thevenin's theorem to simplify a circuit for analysis
- Apply the maximum power transfer theorem
- Apply the superposition theorem to circuit analysis

Identifying Series-Parallel Relationships

- A series-parallel circuit consists of combinations of both series and parallel current paths



Analysis of Series-Parallel Circuits

- Determine total resistance
- Determine all currents
- Determine all voltage drops

Total Resistance

- Identify the parallel resistances, and calculate the equivalent resistance(s)
- Identify the series resistance, and calculate the total resistance for the circuit

Total Current

- Using the total resistance and the source voltage, find the total current by applying Ohm's law

$$\mathbf{I_T = V_S/R_T}$$

Branch Currents

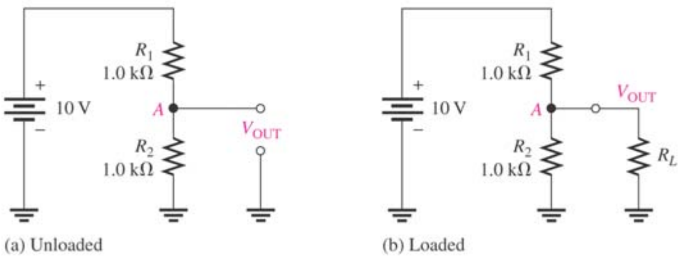
- Using the current-divider formula, Kirchhoff's current law (KCL), Ohm's law, or combinations of these, you can find the current in any branch of a series-parallel circuit

Unloaded Voltage Dividers

- A voltage divider produces an output which depends upon the values of the dividing resistors
- This voltage is the **unloaded output voltage**

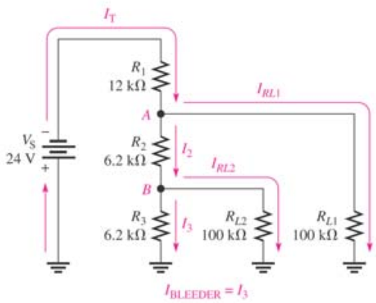
Loaded Voltage Dividers

- When a load resistor R_L is connected from the output to ground, the output voltage is reduced by an amount that depends on the value of R_L



Load Current and Bleeder Current

- Bleeder current is the current left (I_3) after the total load current is subtracted from the total current into the circuit



Loading Effect of a Voltmeter

- When measuring across a resistor, a voltmeter is connected in parallel with the resistor
- Being in parallel, the internal resistance of the voltmeter will have a loading effect on the circuit that is being measured
- Modern digital voltmeters (DMM) have an internal resistance of 10MΩ

Loading Effect of a Voltmeter

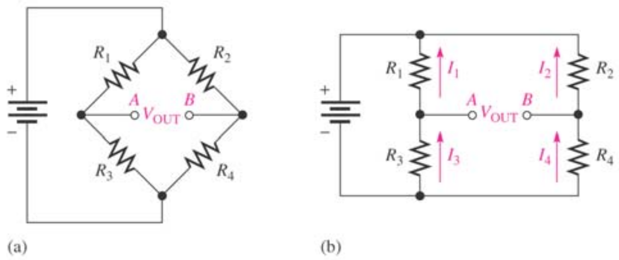
- If the meter resistance is at least ten times greater than the resistance across which it is connected, the loading effect can be neglected
  - measurement error is less than 10%

Wheatstone Bridge

- A Wheatstone bridge is used to precisely measure resistance
- A Wheatstone bridge is also applied with transducer measurements, to measure physical quantities such as temperature, strain, and pressure, where small transducer resistance changes may need to be precisely measured
  - Tiny changes in transducer resistance will unbalance the bridge, thereby providing a measurement reading

Balanced Wheatstone Bridge

- The Wheatstone bridge is in the balanced bridge condition when the output voltage between terminals A and B is equal to zero



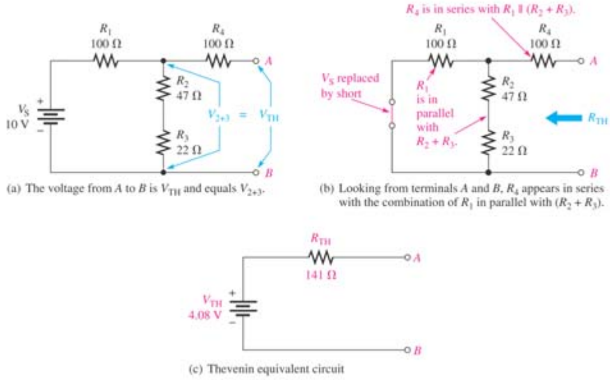
Unbalanced Wheatstone Bridge

- The unbalanced bridge, when V_{OUT} is not equal to zero, is used to measure some transducer quantities, such as strain, temperature, or pressure
- The bridge is balanced at a known point, then the amount of deviation, as indicated by the output voltage, indicates the amount of change in the parameter being measured

Thevenin's Theorem

- Thevenin's theorem provides a method for simplifying a circuit to a standard equivalent form
- The Thevenin equivalent voltage (V_{TH}) is the open circuit (no-load) voltage between two terminals in a circuit
- The Thevenin equivalent resistance (R_{TH}) is the total resistance appearing between two terminals in a given circuit with all sources replaced by their internal resistances

Thevenin Equivalent of a Circuit



(a) The voltage from A to B is V_{TH} and equals V_{2+3}.

(b) Looking from terminals A and B, R_4 appears in series with the combination of R_1 in parallel with $(R_2 + R_3)$.

(c) Thevenin equivalent circuit

Summary of Thevenin’s Theorem

1 Open the two terminals (remove any load) between which you want to find the Thevenin equivalent circuit

2 Determine the voltage (V_{TH}) across the two open terminals

3 Determine the resistance (R_{TH}) between the two open terminals with all sources replaced with their internal resistances (short voltage sources and open current sources)

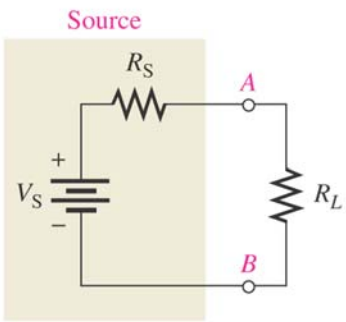
Summary of Thevenin’s Theorem

4 Connect V_{TH} and R_{TH} in series to produce the complete Thevenin equivalent for the original circuit

5 Place the load resistor removed in Step 1 across the terminals of the Thevenin equivalent circuit. The load current and load voltage can now be calculated using only Ohm’s law. They have the same value as the load current and load voltage in the original circuit

Maximum Power Transfer

- Maximum power is transferred from a source to a load when the load resistance is equal to the internal source resistance



Maximum Power Transfer

- The source resistance, R_S, of a circuit is the equivalent resistance as viewed from the output terminals using Thevenin's theorem
- A typical application of the maximum power transfer theorem is in audio systems, where the speaker resistance must be matched to the audio power amplifier in order to obtain maximum output

Superposition Theorem

- Some circuits require more than one voltage or current source
- The superposition theorem is a way to determine currents and voltages in a circuit that has multiple sources by considering one source at a time

General statement of Superposition Theorem

- The current in any given branch of a multiple-source circuit can be found by determining the currents in that particular branch produced by each source acting alone, with all other sources replaced by their internal resistances. The total current in the branch is the algebraic sum of the individual source currents in that branch

Applying Superposition Theorem

1 Take one voltage (or current) source at a time and replace the remaining voltage sources with shorts (and remaining current sources with opens)

2 Determine the particular current or voltage that you want, just as if there were only one source in the circuit

Applying Superposition Theorem

3 Take the next source in the circuit and repeat Steps 1 and 2 for each source

4 To find the actual current in a given branch, algebraically sum the currents due to each individual source. Once the current is found, voltage can be determined by Ohm’s law

Summary

- A series-parallel circuit is a combination of both series paths and parallel paths
- To determine total resistance in a series-parallel circuit, identify the series and parallel relationships, and then apply the formulas for series resistance and parallel resistance
- To find the total current, apply Ohm’s law and divide the total voltage by the total resistance

Summary

- To determine branch currents, apply the current-divider formula, KCL, or Ohm’s law
- To determine voltage drops across any portion of a series-parallel circuit, use the voltage-divider formula, KVL, or Ohm’s law
- When a load resistor is connected across a voltage-divider output, the output voltage decreases

Summary

- A load resistor should be large compared to the resistance across which it is connected, in order that the loading effect may be minimized
- A balanced Wheatstone bridge can be used to measure an unknown resistance
- A bridge is balanced when the output voltage is zero. The balanced condition produces zero current through a load connected across the output terminals of the bridge

Summary

- An unbalanced Wheatstone bridge can be used to measure physical quantities using transducers
- Any two-terminal resistive circuit, no matter how complex, can be replaced by its Thevenin equivalent, made up of an equivalent resistance (R_{TH}) in series with an equivalent voltage source (V_{TH})
- The maximum power transfer theorem states that the maximum power is transferred from a source to a load when Load Resistance equals Source Resistance