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Introduction

This Student Workbook provides a unit-by-unit outline of the Fault Assisted Circuits for Electronics Training (F.A.C.E.T.) curriculum.

The following information is included together with space to take notes as you move through the curriculum.

♦ The unit objective
♦ Unit fundamentals
♦ A list of new terms and words for the unit
♦ Equipment required for the unit
♦ The exercise objectives
♦ Exercise discussion
♦ Exercise notes

The Appendix includes safety information.
UNIT 1 – DC NETWORK THEOREMS

UNIT OBJECTIVE
At the completion of this unit, you will be able to locate and identify the major components on the DC NETWORK THEOREMS circuit board.

UNIT FUNDAMENTALS
The DC NETWORK THEOREMS circuit board consists of 9 training circuit blocks and a CONSTANT CURRENT SOURCE generator block.

The board is designed to enhance your knowledge of voltage and current distribution in dc circuits.

Theorems are used to determine voltage and/or currents in circuits where Ohm's law cannot easily be applied.

For example, Ohm's law cannot easily be applied in a circuit having two voltage sources applied in different branches. The voltage drop across R3 cannot easily be determined.

One circuit block on the board is a constant current source. A constant current source circuit provides fixed current values that are independent of load changes.
Load changes do not affect the output current of the constant current source.

**NEW TERMS AND WORDS**

*constant current source* - a circuit designed to provide a fixed current that does not vary with changes in load.

*theorems* - statements or methods that propose verifiable solutions of voltage and/or current within a network.

*networks* - groups of components that form interrelated circuits.

**EQUIPMENT REQUIRED**

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter
Exercise 1 – Component Location/Identification

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to locate the major circuit blocks of the DC NETWORK THEOREMS circuit board. You will verify your results by correctly identifying circuits and components.

DISCUSSION
• The DC NETWORK THEOREMS circuit board provides examples of networks that can be solved with various theorems.
• The circuit board is organized into the following 9 circuit blocks:
  - KIRCHHOFF’S CURRENT LAW
  - KIRCHHOFF’S VOLTAGE LAW
  - KIRCHHOFF’S LAWS COMBINED
  - SUPERPOSITION
  - THEVENIN CIRCUITS
  - THEVENIZING A BRIDGE CIRCUIT
  - THEVENIN / NORTON CONVERSION
  - \( \Delta \) TO Y OR Y TO \( \Delta \)
• A tenth block is configured as a CONSTANT CURRENT SOURCE.
• Three types of resistors are used on the DC NETWORK THEOREMS circuit board. The resistors are carbon composition, carbon film, and metal film types.
• Fixed and variable power sources are used on the board.
Exercise 2 – Circuit Board Operation

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to connect the various circuit blocks on the circuit board by using the KIRCHHOFF’S CURRENT LAW circuit block as an example. You will verify your results with a multimeter.

DISCUSSION
• Use the KIRCHHOFF’S CURRENT LAW circuit block: to determine current in a two-branch circuit.
• Apply Ohm’s law to verify Kirchhoff’s current law solutions.

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UNIT 2 – KIRCHHOFF’S CURRENT LAW

UNIT OBJECTIVE
At the completion of this unit, you will be able to analyze dc circuits by using Kirchhoff’s current law.

UNIT FUNDAMENTALS

Kirchhoff’s current law can be used to determine current into or out of circuit junction

Kirchhoff’s current law provides a solution for determining current in parallel branch circuits. Each parallel branch, R1 and R2, allows current to flow from the power source.

Each branch circuit provides a current path. Resistor R1 in this circuit is one branch. Resistor R2 in this circuit is another branch.
Kirchhoff's current law deals with currents at circuit points called nodes. A node is a junction, or a circuit point, where components are joined. Current enters and exits each node.

Kirchhoff's current law deals with the relationship of circuit currents and circuit nodes.

Circuit current flows into and out of each node of a two-branch circuit. $I_T$ flows into NODE 1. Two currents ($I_1$ and $I_2$) leave NODE 1. Therefore, $I_T = I_1 + I_2$. $I_1$ and $I_2$ combine at NODE 2. The combination of $I_1$ and $I_2$ results in $I_T$ at NODE 2. Therefore, $I_T$ from the power source is the same as $I_T$ to the power source.
The connection on each side of the power source is represented by a node (NODE 1 and NODE 2).

Kirchhoff’s current law can be stated in two ways:

1. The sum of the currents leaving a node in a circuit equals the sum of the currents entering the node.

2. The algebraic sum of the currents at any node in a circuit must equal zero.

If your calculations show a net gain or loss of node current, you have made an error.

When applying an algebraic equation to node current, you must give a + or - sign to the current. In dealing with current flow, consider currents flowing into a node as negative (-), such as $I_1$ and $I_2$ into NODE 2. Consider currents leaving a node as positive (+), such as $I_T$ out of NODE 2.
NEW TERMS AND WORDS

Kirchhoff's current law - the algebraic sum of the currents at any node must equal zero.

junction - a circuit point where components are joined.

parallel branch - a circuit loop through which a part of the total circuit current flows.

nodes - circuit points where Kirchhoff's current law can be applied; also called junctions.

algebraic sum - a combination of positive and negative values based on the rules of algebra.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter

NOTES
Exercise 1 – Current in a Branch Circuit

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to calculate total and individual branch currents in a two-element parallel circuit by using Kirchhoff’s current law. You will verify your results by measuring the circuit currents.

DISCUSSION
- The sum of the branch currents in a parallel circuit is equal to the total current flowing through the circuit.
- In a two-element parallel circuit, Kirchhoff’s current law can be used to solve for an unknown current when two of the three currents are known.
- Kirchhoff’s current law applies to all parallel circuits.
- Ohm’s law is used to determine the resistance of each circuit branch (R = E/I).

NOTES
Exercise 2 – Node Currents in a Branch Circuit

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to determine the magnitude and direction (sign) of node currents by using a two-element branch circuit. You will verify your results by measuring the circuit currents.

DISCUSSION
- Current flow is defined as the movement of electrons (electron flow).
- Current flowing into a node is labeled negative; while current flowing out of a node is labeled positive.
- Kirchhoff’s Current Law states that the algebraic sum of all current into or out of a node must equal zero.
- Ohm’s law is used in combination with Kirchhoff’s Current Law to determine the total circuit current when the source voltage and branch resistances are known. \[ I_T = I_{R1} + I_{R2} = \frac{V_{R1}}{R1} + \frac{V_{R2}}{R2} \]

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UNIT 3 – KIRCHHOFF'S VOLTAGE LAW

UNIT OBJECTIVE
At the completion of this unit, you will be able to analyze dc circuits by using Kirchhoff's voltage law.

UNIT FUNDAMENTALS

Kirchhoff's voltage law provides the solution of voltage drops and voltage sources around a closed loop.

A solution for determining voltage is applied to series circuits, such as the circuit shown here.

The same current flows throughout the series circuit. As the current passes through each resistor, it generates a voltage drop. The sum of all voltage drops equals the value of the circuit voltage source.

This drawing illustrates the polarities of voltages generated around a closed series circuit. Consider voltage drops negative (-) and voltage sources positive (+). Kirchhoff's voltage law deals with the relationship of the circuit voltage drops to the source voltage and to one another.
Kirchhoff's voltage law may be stated in two ways.

1. The sum of all the voltage drops in a series circuit equals the circuit applied (source) voltage.

For example, in this circuit, the sum of all voltage drops is 20V (10 + 7 + 3). The source voltage is also 20V. Because the sum of the voltage drops equals the source voltage, the first requirement of Kirchhoff's law is met.

Kirchhoff's voltage law may be stated a second way.

2. The algebraic sum of the voltage source(s) and voltage drops in a series circuit equals zero.

For example, in this circuit, voltage drops are assigned a negative (-) polarity, and the voltage source is assigned a positive (+) polarity. Combining all voltages algebraically results in 0 (+20 - 10 - 7 - 3 = 0). Because the algebraic sum of all voltages in the loop is zero, the second requirement of Kirchhoff's law is met.
Due to the relationship of the circuit voltages, you can determine any one voltage drop or voltage source if you know all other voltages. The missing voltage (V) in this circuit must be the difference between the sum of the known voltage drops and the circuit source voltage.

Determine V (the missing voltage) by using Kirchhoff's voltage law and the following equation, where the source voltage equals 20V and the known voltage drops equal 3V and 7V.

\[ 20 = 3 + 7 + V \]
\[ 20 = 10 + V \]
\[ 20 - 10 = V \]
\[ 10 = V \]

**NEW TERMS AND WORDS**

*Kirchhoff's voltage law* - The algebraic sum of the voltages around a closed loop must equal zero. The sum of the voltage drops around a closed loop must equal the source voltage.

*closed loop* - A complete path or circuit for current flow.

**EQUIPMENT REQUIRED**

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter
Exercise 1 – 3-Element Series Voltages

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to calculate total voltage and individual voltage drops by using a 3-element series circuit. You will verify your results with a multimeter.

DISCUSSION
- Individual voltage drops can be summed to determine the voltage source of a series circuit.
- Ohm’s law can be used to determine the resistance of any element when the voltage across the element and the current through the element is known. $R = \frac{E}{I}$
- Kirchhoff’s voltage law can be used on a series circuit to determine an unknown voltage when all other voltages are known.
- Kirchhoff’s voltage law and Ohm’s law can be used to analyze a series circuit.

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Exercise 2 – Algebraic Sum of Series Voltages

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to calculate the algebraic sum of voltage drops by using a 3-element series circuit. You will verify your results with a multimeter.

DISCUSSION
• Kirchhoff’s voltage law states that the algebraic sum of the voltages in a closed loop equals zero.
• Negative and positive polarities must be assigned to the voltages when applying Kirchhoff’s voltage law.
• This method designates a negative sign to all voltage drops and a positive sign to all voltage sources.

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UNIT 4 – KIRCHHOFF’S LOOP EQUATIONS

UNIT OBJECTIVE
At the completion of this unit, you will be able to use loop equations by applying Kirchhoff’s laws to a series/parallel circuit.

UNIT FUNDAMENTALS

A loop is a closed circuit path. Shown is one example of a loop, where a single path is the only possible loop for the series circuit.

Kirchhoff’s voltage law states that the algebraic sum of voltages in a closed loop equals zero.

A series/parallel circuit, such as this one, consists of more than one loop. To generate loop equations, use the voltages around each loop. One loop is from the - side of $V_S$, through $R_1$ and $R_S$, and back to $V_S$. The loop equation, therefore, is $V_{R_1} + V_{R_S} = V_S$. 
Another loop is from the - side of $V_S$, through $R_2$ and $R_S$, and back to $V_S$. The relationship of the current, loops, and nodes of a series/parallel circuit is shown. The sum of the currents into NODE A equals the total circuit current ($I_T$). The sum of the currents out of NODE B also equals the total circuit current ($I_T$). $I_T$ equals the sum of the $I_1$ and $I_2$ currents. Total circuit current ($I_T$) flows through $R_S$. Kirchhoff's laws and the loop equations can be combined to define a series/parallel circuit.

**NEW TERMS AND WORDS**

None

**EQUIPMENT REQUIRED**

- F.A.C.E.T. base unit
- DC NETWORK THEOREMS circuit board
- Multimeter
Exercise 1 – Loop Equations

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to use loop equations for a series/parallel circuit. You will verify your results by measuring voltage drops and calculating equations.

DISCUSSION
• To write a loop equation, begin at a starting point, go around the loop and record the voltages. Designate the polarity of the voltages based on which terminal is encountered first.
• Loop equations satisfy Kirchhoff’s voltage law.
• There can be more than one loop in a circuit.

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Exercise 2 – Node Equations

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to generate node equations for a series/parallel circuit. You will verify your results by measuring voltage drops and ensuring that the loop equations equal zero.

DISCUSSION
• Currents flowing into or out of nodes can be used to determine current distribution.
• Node equations apply Kirchhoff’s current law.

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UNIT 5 – KIRCHHOFF'S SOLUTION WITH 2 SOURCES

UNIT OBJECTIVE
At the completion of this unit, you will be able to find voltage and current in circuits with two voltage sources by using Kirchhoff's laws. You will verify your results by comparing measured and calculated values.

UNIT FUNDAMENTALS

This circuit has two voltage sources. For each voltage source, current is assumed to flow in the direction shown.

The application of Kirchhoff's laws to the circuit gives you the current through R3. The direction of the current is determined by the sign (+ or -) of the current. A negative (-) sign for current through R3 indicates an incorrect assumption about the initial current direction. The problem is to find the voltage drops and the current flow through each resistor. You can apply Kirchhoff's laws to determine these circuit solutions.

This is a two-source circuit (VS1 and VS2). There are 3 loops in this circuit, but only two are required for Kirchhoff's voltage law application.
Based on Kirchhoff's current law, the current into NODE 1 \((I_1 + I_2)\) must equal the current out of NODE 1 \((I_3)\). Therefore, \(I_3 = I_1 + I_2\).

\[ I_1 + I_2 = I_3 \]
\[ \frac{V_{R1}}{R_1} + \frac{V_{R2}}{R_2} = \frac{V_{R3}}{R_3} \]

Another method of applying Kirchhoff's laws is to implement a solution by using mesh currents. A mesh is the simplest possible closed path within a circuit.

The following mesh equations are based on this circuit.

FOR MESH 1
\[ (I_1 \times R_1) + (I_1 \times R_3) - (I_2 \times R_3) = V_{S1} \]

FOR MESH 2
\[ (I_2 \times R_2) + (I_1 \times R_3) - (I_2 \times R_3) = -V_{S2} \]
NEW TERMS AND WORDS

nodes - common connections for two or more components.

mesh - a single closed path without any branches.

mesh equations - equations that define the current within a mesh

loop equations - equations that define the voltage drops around a closed loop.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter

NOTES
Exercise 1 – Kirchhoff's Voltage Law/2 Sources

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to apply Kirchhoff's voltage law to a circuit having two voltage sources. You will verify your results by using measured data.

DISCUSSION
- Circuits containing two voltage sources can be analyzed using Kirchhoff’s voltage law.
- Loop equations are written by applying Kirchhoff’s voltage law to each circuit loop.

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Exercise 2 – Kirchhoff’s Current Law/2 Sources

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to apply Kirchhoff’s current law to a circuit having two voltage sources. You will verify your results by using measured data.

DISCUSSION
- Circuits containing two voltage sources can be analyzed using Kirchhoff’s current law.
- Assume a current direction for circuit elements that have no explicit indication of current direction.
- Node equations are written by applying Kirchhoff’s current law to each circuit node.
- Each current can be rewritten as a voltage / resistance relationship.
- Any negative current solution indicates that the assumed current direction was incorrect.

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Exercise 3 – Mesh Solution With 2 Sources

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to apply a mesh solution to a circuit having two voltage sources. You will verify your results by using measured data.

DISCUSSION
• Mesh currents can be designated clockwise (CW) or counter clockwise (CCW). Once designated the same convention must be used for every mesh in the circuit.
• A voltage drop is considered positive when it is generated by its own mesh current.
• Circuit elements common to more than one mesh, have mesh currents from each mesh flowing through them.
• Mesh analysis determines the currents flowing through each circuit element.
• Apply Ohm’s law to determine voltage drops.

NOTES
UNIT 6 – SUPERPOSITION AND MILLMAN'S THEOREMS

UNIT OBJECTIVE
At the completion of this unit, you will be able to determine voltages and currents by using the superposition theorem and Millman's theorem.

UNIT FUNDAMENTALS

The superposition theorem allows for a solution of $V_{R3}$ when $V_{S1}$, $V_{S2}$, $R_1$, $R_2$, and $R_3$ are known. In this circuit, $R_3$ is common to each voltage source ($V_{S1}$ and $V_{S2}$). When finding $V_{R3}$, you can determine all circuit voltages and currents by applying Ohm's law.

Each voltage source causes a current ($I_1$ and $I_2$) through $R_3$. Based on Ohm's law, each current generates a voltage drop across $R_3$. The two voltage drops are algebraically combined to determine the actual voltage across $R_3$: $V_{R3} = (I_1 \times R_3) + (I_2 \times R_3)$.

Millman's theorem provides another method of determining the voltage drop across the common circuit element ($R_3$). The circuit perspective is changed to make the junction of $R_3$, $R_2$, and $R_1$ one side of the circuit, and the junction of $R_3$, $V_{S1}$, and $V_{S2}$ the other side of the circuit.
NEW TERMS AND WORDS

**superposition theorem** - an analysis technique where the effects of multiple voltage sources are considered individually and then added algebraically to determine the combined result.

**Millman's theorem** - a method for finding the voltage at the common point in a circuit with multiple branches. To find the common point voltage, add the branch currents algebraically, and then divide by the sum of the branch conductances.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter

NOTES
Exercise 1 – Superposition Theorem

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to apply the superposition method of circuit analysis. You will verify your results with a multimeter.

DISCUSSION
• Each voltage source’s effect on R3 must be determined.
• With one voltage source removed, determine the effect the remaining voltage source has on R3.
• Find the effect on R3 caused by the second voltage source by reversing the procedure.
• Algebraically combine the two results to determine the actual voltage across R3.

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Exercise 2 – Millman's Theorem

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to solve a circuit by applying Millman's theorem. You will verify your results by comparing calculated and measured data.

DISCUSSION
• Millman’s theorem is used to determine voltages across branches by summing branch currents and conductances.
• Identify the individual branches in the circuit.
• Calculate the current through each branch.
• Calculate the conductance of each branch.
• Determine the voltage drop across R3 by dividing the sum of the branch currents by the sum of the branch conductances.

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UNIT 7 – THEVENIN CIRCUITS

UNIT OBJECTIVE
At the completion of this unit, you will be able to simplify one- and two-source circuits by using Thevenin's theorem.

UNIT FUNDAMENTALS
Thevenin's theorem named after the French engineer M.L. Thevenin, allows for the reduction of a network into an equivalent voltage and resistance. The equivalent voltage is called $V_{TH}$. The equivalent resistance is called $R_{TH}$.

Thevenizing a circuit allows you to see the effects of changing load conditions without the need for repeating many Ohm's law equations for each load change. On the equivalent circuit, a simple voltage divider replaces the more complex network circuit.

Thevenin's theorem reduces the circuit network into $V_{TH}$ and $R_{TH}$. The reduction occurs with respect to A and B, the network output terminals. The circuit network is composed of a voltage source and 4 resistors. $R_L$ represents the circuit load.

To calculate $V_{TH}$, remove $R_L$ and apply Ohm's law to determine the output voltage of the network: $V_{TH}$ between A and B. The polarity of $V_{TH}$ is identical to the polarity of the network source voltage: A positive with respect to B.
To determine $R_{TH}$, replace the source voltage with a short circuit, and calculate the total resistance between terminals A and B of the network.

$V_{TH}$ and $R_{TH}$ make up the equivalent circuit. The original load is connected across terminals A and B. $V_{TH}$ and $R_{TH}$ develop the same load voltage and load current as that of the original network.

Two-source networks are thevenized in the same way. However, the superposition theorem can be used to determine $V_{TH}$.

**NEW TERMS AND WORDS**

*Thevenin's theorem* - a network can be represented by an equivalent $V_{TH}$ and a series $R_{TH}$ circuit with respect to a selected pair of output terminals.

$V_{TH}$ - the Thevenin equivalent voltage of a network without a load.

$R_{TH}$ - the Thevenin equivalent resistance of a network without its source voltage.

*Thevenizing* - applying Thevenin's theorem to a network.

**EQUIPMENT REQUIRED**

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter
Exercise 1 – Thevenizing a Single Source Network

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to simplify a single-source network by applying Thevenin's theorem. You will verify your results by comparing calculated and measured values.

DISCUSSION
• The network consists of R1, R2 and VS.
• RL is the network load.
• With RL removed from the circuit, determine the open circuit voltage ($V_{TH}$) across points A and B (the load).
• With RL removed and short the voltage source, determine the equivalent resistance ($R_{TH}$) looking into the circuit from points A and B.
• $V_{TH}$, $R_{TH}$ and RL form a simple series circuit known as Thevenin’s equivalent circuit.

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EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to simplify a dual source network by applying Thevenin's theorem. You will verify your results by comparing calculated and measured values.

DISCUSSION
• With RL removed, use the superposition method to determine the Thevenin equivalent voltage across points A and B.
• With RL removed and both voltage sources shorted, determine the equivalent resistance \( R_{TH} \) looking into the circuit from points A and B.
• \( V_{TH} \), \( R_{TH} \) and RL form a simple series circuit known as Thevenin’s equivalent circuit.

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UNIT 8 – THEVENIZING A BRIDGE CIRCUIT

UNIT OBJECTIVE
At the completion of this unit, you will be able to thevenize a resistive bridge circuit by using the resistor divider equation.

UNIT FUNDAMENTALS

A resistive bridge circuit has 4 terminals, here labeled A through D. The source voltage (VS) is applied across 2 opposing terminals (A and C). The output voltage is taken across the load resistor (RL) connected between terminals D and B.

In this circuit, the bridge components are rearranged. Terminals D and B are the bridge output. You can use the voltage divider equation or Ohm's law to determine the bridge output voltage between D and B. This voltage is the Thevenin voltage of the bridge circuit.

To find the Thevenin resistance, replace the voltage source with a short circuit, and calculate R_TH between terminals D and B.

With the Thevenin voltage and the Thevenin resistance, the bridge circuit is simplified into a Thevenin equivalent circuit. You can now use Ohm's law to determine the load voltage (VRL) and the load current (IRL) for any value of RL.
NEW TERMS AND WORDS

*bridge circuit* - A circuit configuration of 4 elements and having 4 terminals. The source voltage is applied across 2 opposing terminals, and the output is taken across the remaining 2 terminals.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter

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Exercise 1 – Bridge Circuit Resistance

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to calculate the Thevenin resistance (R_{TH}) of a bridge circuit. You will verify your results by comparing calculated and measured data.

DISCUSSION
• An unloaded bridge circuit is equivalent to 2 parallel voltage dividers.
• The Thevenin voltage is the difference between the voltages of the 2 parallel voltage dividers.
• The Thevenin resistance of the bridge is the resistance across the output terminals when the input is shorted.

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Exercise 2 – Thevenizing Bridge Circuit Voltage

EXERCISE OBJECTIVE
When you have completed this exercise you will be able to calculate the Thevenin equivalent voltage ($V_{TH}$) of a bridge circuit. You will verify your results by comparing calculated and measured data.

DISCUSSION

• To determine the Thevenin voltage, remove the load resistor.
• Use Ohm's law or the voltage divider equation to calculate the voltage drop across the output terminals of the bridge circuit.
• The Thevenin equivalent circuit generates the same voltage and current across the load resistor as the bridge network.
• In the Thevenin’s equivalent circuit, use the voltage divider equation to determine the voltage across the load.

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UNIT 9 – THEVENIN/NORTON CONVERSION

UNIT OBJECTIVE
At the completion of this unit, you will be able to convert networks into equivalent voltage and current sources by using Thevenin's and Norton's theorems.

UNIT FUNDAMENTALS

You can use Thevenin's theorem to reduce a network into an equivalent circuit called a voltage source. $V_{TH}$ is the voltage source. $R_{TH}$ is the internal source resistance. Terminals A and B are the output terminals of the source.

In a practical circuit, the no-load output voltage equals $V_{TH}$. When a load ($R_L$) is connected across terminals A and B, the output voltage equals $V_{TH} - V_{RTH}$ because $R_{TH}$ and $R_L$ form a voltage divider.

You can use Norton's theorem to reduce a network into an equivalent circuit called a current source. $I_N$ is the current source and is represented by an arrow in a circle. $R_N$ is the internal source resistance. Terminals A and B are the output terminals of the source.
In an ideal situation, $R_N$ is infinite [conductance (G) = 0]. Therefore, output current is constant, and terminal voltage varies with load resistance or load conductance.

You can use the formulas shown to convert between a Thevenin voltage source and a Norton current source. Each source generates the same load voltage and current as the network represented.

**NEW TERMS AND WORDS**

*Voltage source* - a circuit that provides a constant voltage at its output terminals.

*Norton's theorem* - a network can be represented by an equivalent current source and parallel resistor with respect to a pair of output terminals.

*Current source* - a circuit that provides a constant current at its output terminals.

**EQUIPMENT REQUIRED**

F.A.C.E.T. base unit
DC NETWORK THEOREMS circuit board
Multimeter
Exercise 1 – Thevenin to Norton Conversion

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to convert a voltage source to a current source. You will verify your results by comparing calculated and measured data.

DISCUSSION
• When Thevenin’s theorem is applied to a network it is reduced to an equivalent constant voltage source ($V_{TH}$).
• The Thevenin equivalent resistance becomes the internal resistance of the constant voltage source.
• Convert this voltage source to a current source by applying Ohm’s law.
• The constant current ($I_N$) provided by the source is $V_{TH} / R_{TH}$ and its parallel internal resistance ($R_N$) is equal to $R_{TH}$.
• This is a Norton constant current source.

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Exercise 2 – Norton to Thevenin Conversion

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to convert a current source to a voltage source. You will verify your results by comparing calculated and measured data.

DISCUSSION
- Norton current sources can be converted to Thevenin voltage sources.
- The Norton equivalent resistance becomes the internal resistance of the constant current source.
- Convert this current source to a voltage source by applying Ohm’s law.
- The constant voltage ($V_{TH}$) provided by the source is $I_N \times R_N$ and its series internal resistance ($R_{TH}$) is equal to $R_N$.

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UNIT 10 – DELTA AND WYE NETWORKS

UNIT OBJECTIVE
At the completion of this unit, you will be able to simplify a resistive bridge network by using delta and wye transformations.

UNIT FUNDAMENTALS

This configuration in the shape of a Y is a **wye** network.

This configuration in the shape of a T is a **tee** network.

This configuration in the shape of the Greek letter Δ is a **delta** network.

This configuration in the shape of the Greek letter π is a **pi** network.
Conversion from delta to wye generates a wye circuit that is electrically identical to the delta network. To determine each wye resistor, divide the product of the two adjacent delta resistors by the sum of all the delta resistors.

\[
\text{PRODUCT OF 2 ADJACENT Rs IN DELTA} \\
\text{RY} = \frac{\text{PRODUCT OF 2 ADJACENT Rs IN DELTA}}{\text{SUM OF Rs IN DELTA}}
\]

Conversion from wye to delta generates a delta circuit that is electrically identical to the wye network. To determine each delta resistor, divide the sum of all cross products in the wye network by the opposite resistor in the wye network.

\[
\text{SUM OF ALL CROSS PRODUCTS IN Y} \\
\text{RD} = \frac{\text{SUM OF ALL CROSS PRODUCTS IN Y}}{\text{OPPOSITE R IN Y}}
\]

Delta to wye transformation simplifies bridge circuit calculations. To easily determine total circuit current \((I_T)\), convert one bridge delta section to a wye. This conversion results in a series/parallel circuit in which total current equals the supply voltage divided by the total circuit resistance \((I_T = V_S/R_T)\).
NEW TERMS AND WORDS

**wye** - a resistor configuration in the shape of a Y. Tee and wye are different names for the same network.

**tee** - a resistor configuration in the shape of a T. Tee and wye are different names for the same network.

**delta** - Greek letter that refers to a resistor configuration in the shape of a triangle. Pi and delta are different names for the same network.

**pi** - Greek letter that refers to a resistor configuration in the shape of the symbol for pi. Pi and delta are different names for the same network.

**cross products** - multiplication of each pair of resistors in a Y network.

EQUIPMENT REQUIRED

- F.A.C.E.T. base unit
- DC NETWORK THEOREMS circuit board
- Multimeter

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Exercise 1 – Tee/Wye and Pi/Delta Networks

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to identify and compare tee, wye, delta, and pi networks. You will verify your results by using measured data.

DISCUSSION
• Tee networks are electrically identical to wye networks.
• Pi networks are electrically identical to delta networks.

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Exercise 2 – Delta and Wye Transformations

EXERCISE OBJECTIVE
When you have completed this exercise, you will be able to convert between delta and wye circuits. You will verify your results by comparing calculated and measured values.

DISCUSSION
• Converting between each network configuration requires that an equivalent resistor value be calculated.
• Most basic electronics books provide formulas to determine the resistor equivalents of delta to wye and wye to delta configurations.

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APPENDIX A – SAFETY

Safety is everyone’s responsibility. All must cooperate to create the safest possible working environment. Students must be reminded of the potential for harm, given common sense safety rules, and instructed to follow the electrical safety rules.

Any environment can be hazardous when it is unfamiliar. The F.A.C.E.T. computer-based laboratory may be a new environment to some students. Instruct students in the proper use of the F.A.C.E.T. equipment and explain what behavior is expected of them in this laboratory. It is up to the instructor to provide the necessary introduction to the learning environment and the equipment. This task will prevent injury to both student and equipment.

The voltage and current used in the F.A.C.E.T. Computer-Based Laboratory are, in themselves, harmless to the normal, healthy person. However, an electrical shock coming as a surprise will be uncomfortable and may cause a reaction that could create injury. The students should be made aware of the following electrical safety rules.

1. Turn off the power before working on a circuit.
2. Always confirm that the circuit is wired correctly before turning on the power. If required, have your instructor check your circuit wiring.
3. Perform the experiments as you are instructed: do not deviate from the documentation.
4. Never touch “live” wires with your bare hands or with tools.
5. Always hold test leads by their insulated areas.
6. Be aware that some components can become very hot during operation. (However, this is not a normal condition for your F.A.C.E.T. course equipment.) Always allow time for the components to cool before proceeding to touch or remove them from the circuit.
7. Do not work without supervision. Be sure someone is nearby to shut off the power and provide first aid in case of an accident.
8. Remove power cords by the plug, not by pulling on the cord. Check for cracked or broken insulation on the cord.