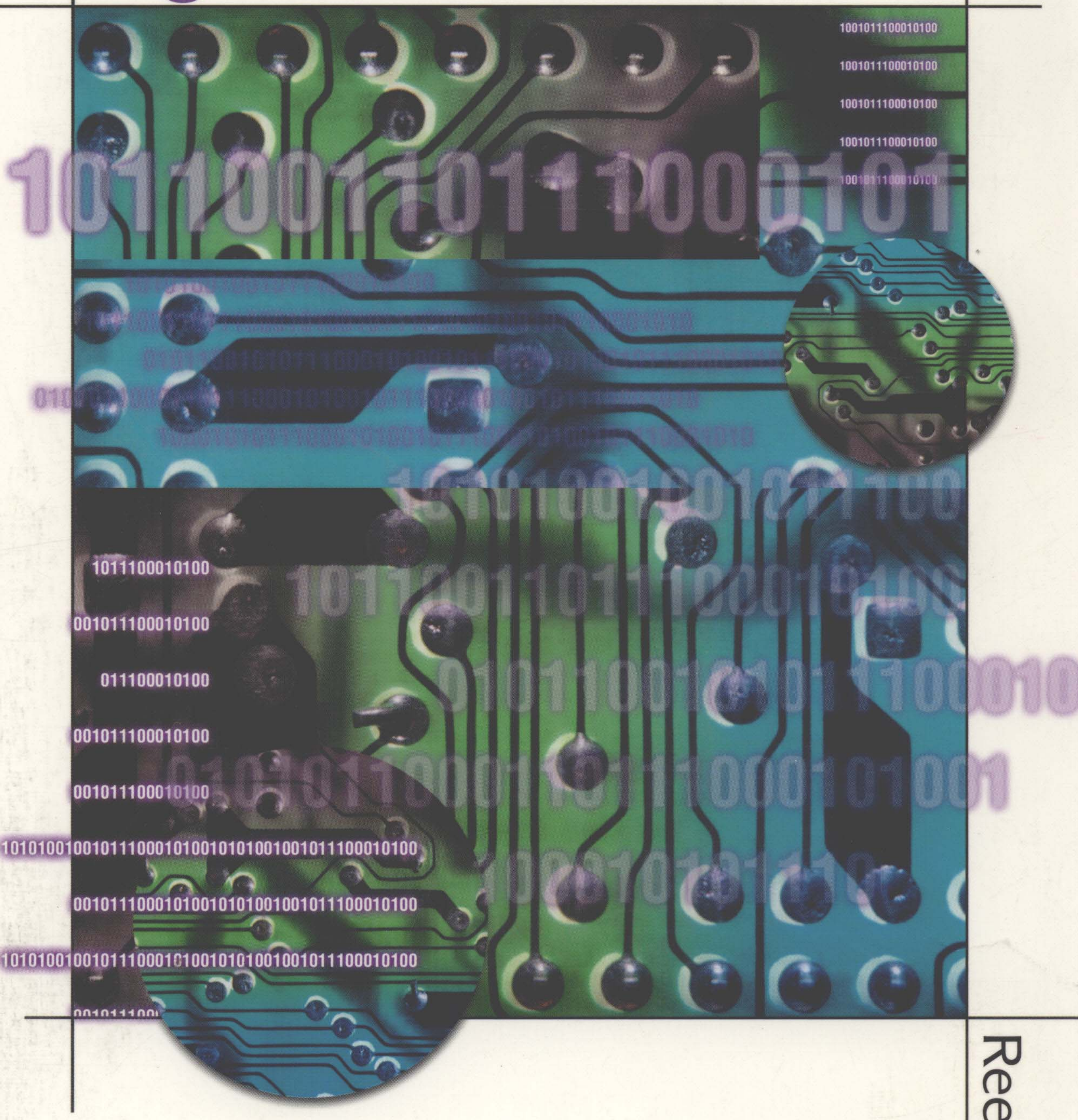
DELMAR
THOMSON LEARNING

CD-ROM Includes MultiSIM™ Circuits

Using MultiSIM™ Digital Electronics



Reeder

Using *MultiSIM*: Digital Electronics

John Reeder
Merced College
Merced, CA

DELMAR
THOMSON LEARNING™

Australia Canada Mexico Singapore Spain United Kingdom United States

DELMAR
THOMSON LEARNING™

Using *MultiSIM*: Digital Electronics
John Reeder

Business Unit Director:
Alar Elken

Executive Editor:
Sandy Clark

Senior Acquisitions Editor:
Gregory L. Clayton

Developmental Editor:
Michelle Ruelos Cannistraci

Executive Marketing Manager:
Maura Theriault

Marketing Coordinator:
Karen Smith

Executive Production Manager:
Mary Ellen Black

Production Manager:
Larry Main

Senior Project Editor:
Christopher Chien

Art/Design Coordinator:
David Arsenault

Editorial Assistant:
Jennifer M. Luck

Printed in Canada

1 2 3 4 5 XX 05 04 03 02 01

For more information contact Delmar,
3 Columbia Circle, PO Box 15015,
Albany, NY 12212-5015.

Or find us on the World Wide Web at
http://www.delmar.com

ISBN: 07668-12693

NOTICE TO THE READER

Publisher does not warrant or guarantee any of the products described herein or perform any independent analysis in connection with any of the product information contained herein. Publisher does not assume, and expressly disclaims, any obligation to obtain and include information other than that provided to it by the manufacturer.

The reader is expressly warned to consider and adopt all safety precautions that might be indicated by the activities herein and to avoid all potential hazards. By following the instructions contained herein, the reader willingly assumes all risks in connection with such instructions.

The publisher makes no representation or warranties of any kind, including but not limited to, the warranties of fitness for particular purpose or merchantability, nor are any such representations implied with respect to the material set forth herein, and the publisher takes no responsibility with respect to such material. The publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or part, from the readers' use of, or reliance upon, this material.

Using *MultiSIM*: Digital Electronics

Contents

Preface

Approach

This workbook is designed to teach the student how to virtually measure, operate, and troubleshoot digital electronic circuits created within the *MultiSIM 2001*® software environment and to reinforce digital theory learned in the classroom. The computer and the computer monitor become the electronics workbench. Students using this manual must have *MultiSIM 2001* installed on their computers to be able to operate the provided software projects. These software projects, along with the textbook edition of *Using MultiSIM,* are stored on the CD that accompanies this text.

One advantage to the virtual laboratory approach to electronics is the low cost of the software package in comparison to the expenses required to establish an electronics laboratory with all of the necessary test equipment and the related facility costs. Virtual electronic circuits can be easily modified on the monitor screen, and circuit analysis is also easily obtained as circuits are modified. Simultaneously, this software can be used as an additional tool to help the electronics student learn more about digital theory.

Circuit troubleshooting is an integral component of the software package. It is relatively easy for the instructor or textbook author to install faults, such as shorts, leakage, and opens, into the circuit for the digital electronics student to locate. The troubleshooting exercises will provide the student with the confidence and skills necessary to troubleshoot circuits constructed on the electronics laboratory workbench.

One additional technique used in this book to reinforce learning is a construction project at the end of many of the activities. These projects will help the student work through the connection requirements of complex integrated circuits.

System Requirements

Pentium 166 or greater PC
Windows 95/98/NT
32MB RAM (64MB RAM recommended)
100-250 MB hard disk space (min.)
CD-ROM drive
800 × 600 minimum screen resolution

Organization

Each chapter in this workbook attempts to sequentially follow the material found in most textbooks teaching digital theory. **Activity** sections, located in each chapter, divide the overall subject of the chapter into smaller blocks. The individual software projects are related to subtopics within the larger topic.

Within each activity, **circuit files** progressively provide individual projects related to the subject material of the chapter. Many related subjects are touched upon as progress is made through the projects. Each activity has one or more circuit files containing component and connection faults, which are **troubleshooting** problem/s. Finally, most of the activities contain a construction circuit requiring the student to construct and test a circuit related to the subject of the activity.

Circuit Files

The CD that accompanies the text contains all of the circuit files in this book. They are pre-built and ready to be used with *MultiSIM 2001*.

Circuit files follow the DOS system of nomenclature. There is a maximum of eight digits in each circuit name, but unlike previous versions of *Electronics Workbench*®, the circuit file name is not followed by a DOS extension. The first two numbers of the circuit file name represent the chapter in the book and are followed by a hyphen. After the hyphen, the next two numbers represent the activity within the chapter. The final letter, in most cases, represents the sequence of events within an activity. The DOS extension for *MultiSIM* files is .msm.

Concerning Instrumentation

Test instruments are accessed through the **Instruments** button on the Design Bar above the circuit workspace. A left-click on this button will cause the instruments toolbar to appear at the right side of the screen. You will use the DMM, the oscilloscope, and the function generator with this workbook. The DMM, the oscilloscope, and the function generator are common instruments found on the electronics test bench. One new feature of *MultiSIM 2001* is the ability to place more than one piece of the same type of test instrument, such as two oscilloscopes, on the workspace simultaneously.

Additional Resources

Additional support for electronics instructors is provided on the publisher's web site at **www.electronictech.com**. Answers to questions and problems in the text will be provided in a password-protected location accessible only to instructors.

MultiSIM can be purchased through your college bookstore or through **www.electronictech.com**. Interactive Image Technologies, the producers of *Electronics Workbench®*, *MultiSIM 2001*, can be contacted at (416) 977-5550 for sales or technical support. Their web page is:

www.electronicsworkbench.com.

About the Author

John Reeder, A.A., B.A., M.S., is an electronics instructor at Merced College and also taught high school electronics for nine years. Prior to becoming a teacher, he worked for 28 years in the electronics and electrical industries as a technician, electrician, and engineer. He has been using *Electronics Workbench®* and *MultiSIM* for many years as a supplement to help students gain a better understanding of their electronics material. At Merced College, he has developed a course curriculum using *EWB* and *MultiSIM* as the software core of the overall electronics program. These electronics software classes at Merced College are corequisite requirements for all foundational classes in the electronics program.

Acknowledgments

I would like to express my grateful appreciation to the publishing team at Delmar Thomson Learning for patiently working with me and helping me over the hurdles of a second book. The members of this team are Greg Clayton, Michelle Ruelos Cannistraci, Larry Main, Chris Chien, David Arsenault, Jennifer Luck, and Jennifer Thompson.

I would also like to express my grateful appreciation to the software team at Electronics Workbench, Scott Duncan, Luis Alves, Roman Bysh, and Kevin Braham, who helped me through the difficult moments when the software wasn't responding to my efforts. All worked out well and the result is this finished product.

I want to thank my partners in electronics instruction at Merced College, Eugen Constantinescu and Bill Walls, who reviewed the initial draft of the book and software projects. Their review of the initial draft and software is greatly appreciated.

I also want to thank my student, Sharol Stang, who reviewed the book from the student vantage point and also my electronics students, who provided the original impetus to get me started in writing and developing these files for their use. Their enthusiasm over the book and the *MultiSIM* projects is wonderful.

Last, but not least, I want to acknowledge the most important member of my team here in Merced, my wife Barbara, who put up with the long hours spent on the computer over a summer break, winter break, weekends, and every other spare moment. She always provided the right touch (coffee and chocolate) at the right moments and kept me going at critical points in the writing process.

While writing the book, I referred to many digital texts published by various authors and publishers. Among my primary sources of reference was the excellent text authored by Robert Dueck, *Digital Design with CPLD Applications and VHDL* and the text authored by James Bignell and Robert Donovan, *Digital Electronics,* both of which are published by Delmar Thomson Learning. I with to especially give my thanks to Robert Dueck for his kind permission to use his definitions regarding the difference between latch and flip-flop circuits.

1. Introduction to Digital Concepts

References
MultiSIM 2001
MultiSIM 2001 User's Guide

Objectives After completing this chapter, you should be able to:

- Understand and use the Binary number system.
- Use timing diagrams of digital circuits.
- Understand and use the term BIT (binary digit).
- Differentiate between analog and digital.
- Calculate period and frequency of digital waveforms on an oscilloscope.
- Interpret a digital waveform in terms of highs and lows (1s and 0s).
- Understand the basic concepts of Boolean Algebra.

Introduction

Number Systems

Digital logic circuits operate in the binary mode where the inputs have two possible states, a binary 1 represented normally by a "HIGH" voltage and a binary 0 represented normally by a "LOW" voltage. Digital logic can be developed with the use of logic symbols and the Boolean algebra equations that define the logic. Logic gates are redundant electronic circuits that combine digital logic signals in specific patterns according to the dictates of the related Boolean algebra equation.

Other number systems used in digital electronics include the **Octal** and **Hexadecimal** systems. The octal system is a number system with a base of 8, and the hexadecimal system is a number system with a base of 16. Both of these systems work well with the binary system with its base of 2, being powers of that base (i.e., $8 = 2^3$ and $16 = 2^4$).

Boolean Algebra

In 1854, George Boole published a work entitled *An Investigation of the Laws of Thought, on Which are Founded the Mathematical Theories of Logic and Probabilities.* In this work, Boole developed a system of logical algebra known in the modern scientific world as **Boolean algebra**. After he completed his work, George Boole's concepts gathered dust until Claude Shannon used Boole's work to develop his master's thesis at Massachusetts Institute of Technology. His thesis was entitled "A Symbolic Analysis of Relay and Switching Circuits."

The reintroduction of Boole's logic, by Shannon, into modern technical thought and usage assumed the title of Boolean algebra. This method of logic greatly simplified the design, development, and application of complex telephone logic circuits and ultimately, the logic circuit requirements of the newly developing field of digital computers.

All functions, no matter how complex, that may be required in digital logic, can be created from three basic logic functions, AND, OR, and NOT. The basic logic gates that you will study in this text can be used to solve Boolean algebra equations. The algebraic logical variables are the inputs to the logic gates, and the logical functions and/or formulas are the outputs of these gates or combination of gates. The more complex gates such as the NAND and NOR can be thought of as combinations of ANDs, ORs, and NOTs.

Activity 1.1: The Concept of a Digital Circuit

1. In the electronics world, there are basically two types of circuits, the analog circuit and the digital circuit. We are more familiar with analog circuits because most of the natural phenomena that we deal with in the physical world are analog in nature. They are always changing and have an infinite number of variables between any two points of measurement. In the realm of voltages, analog voltages can and do vary continuously at the inputs and outputs of these types of circuits. That is their nature.

2. On the other hand, digital circuits are generally referred to as circuits that deal only in highs and lows with discrete binary values. When discussing digital circuits, we use the terms **HIGH** and **LOW**. We are referring to voltages with only two distinct possibilities, a high voltage or a low voltage.

3. Open circuits file **d01-01**. Turn on the circuit and watch the lamps.

   Which bulb is steady state and which bulb is changing? X_____ is steady state, and X _____ is changing.

4. As you can see, X1 is in a digital type of circuit (direct current and a fixed voltage) in the HIGH condition and X2 is in an analog circuit (alternating current and an alternating voltage).

5. Many electronic systems use a combination of analog and digital circuits. The CD player is an example. The data that originates on the compact disk itself is digital in nature, but that data is usually analog in origin. The digital data is typically a binary representation of music that is analog,

the CD is the medium for storage only, and the purpose of the CD player is to restore the digital information to its original analog form for the listener. The music was recorded using an analog-to-digital converter (ADC) and the music is restored using a digital-to-analog converter (DAC).

Activity 1.2: Binary Digits and Logic Levels

1. Specific HIGHs and LOWs in a binary system are referred to as **bits**, an acronym coming from the term **binary digits**. The two digits in the binary number system are **1** (one) and **0** (zero). In a digital circuit, a binary 1 is usually referred to as a HIGH voltage and the 0 is usually represented as a LOW voltage. A common voltage representing a binary 1 is +5 VDC and 0 V usually represents a binary 0. Some electronic systems, for various reasons, use negative logic where HIGHs and LOWs have opposite meanings and some families of integrated circuits (ICs) use voltage levels other than 0 and +5 volts.

2. The other factor regarding binary digits is in the realm of time. Many times HIGHs and LOWs are referred to in relationship to a period of time. Figure 1-1 displays a typical digital waveform on the screen of an oscilloscope. This display of a digital waveform has to be interpreted in relationship to time. The duration of one cycle of the waveform can be measured in time; each square on the scope face represents a calibrated period of time. In this case, each square is equal to 1 millisecond (.001 seconds) and one complete cycle of an individual waveform takes one square or 1 millisecond (the period of one square is referred to as the Timebase). Using the formula: Frequency = 1/Time (or Period), you can calculate the frequency of the digital waveform. The frequency of this

   waveform is equal to _____ Hertz (Hz).

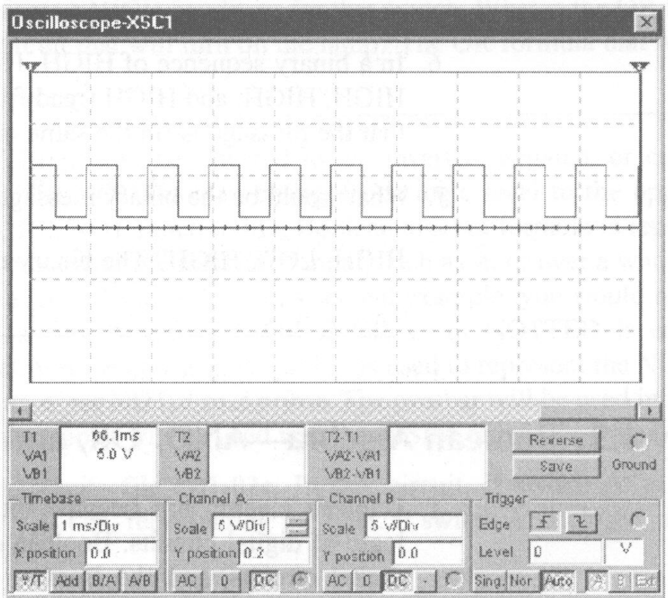


Figure 1-1 Oscilloscope Display of Digital Waveform

3. If we specify that the duration of one bit of binary data (in the case of this specific waveform) is one half of a square or 0.5 milliseconds in duration, then we can also state that each square contains one HIGH and one LOW. Also, we can state that the waveform is HIGH for 0.5 milliseconds (or 500 microseconds) and LOW for 500 microseconds (500 µseconds). This period of time is called **bit time**.

4. Figure 1-2 displays a digital pulse waveform with a 20% duty cycle (HIGH 20% of the time). If the timebase is 50 µseconds, what is the duration of one cycle of the waveform? One cycle of the waveform is _____ µseconds in duration. What is the frequency of the waveform? The frequency of the waveform is _____ kHz or _____ Hz (1 kHz = 1000 Hz).

5. The amount of time that one bit of digital data in a binary sequence occupies is defined as bit time. If the bit time for the waveform of Figure 1-2 is 10 µseconds and the time between bits is 90 µseconds, then we can state that this waveform is HIGH for _____ bit(s) and LOW for _____ bits.

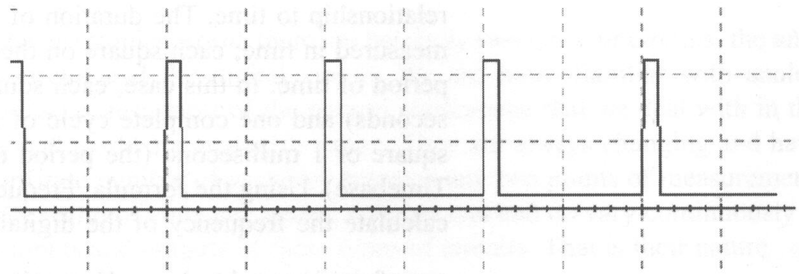


Figure 1-2 Digital Pulse Waveform

6. In a binary sequence of HIGH, HIGH, LOW, LOW, LOW, HIGH, LOW, HIGH, HIGH, and HIGH (read from left to right), we can state in binary that the message is (in the same order) 1100010111.

7. What would be the binary message for HIGH, LOW, LOW, LOW, HIGH, HIGH, LOW, HIGH? The binary message would be ____________________.

Activity 1.3: Boolean Algebra—AND, OR, and NOT Functions

1. Boolean algebra has become the preferred method of specifying the logic of digital circuits. Boolean can be thought of as the shorthand of digital circuits, and the Boolean expression as the defining factor in circuit design. Boolean is a universal digital language understood by

programmers, engineers, technicians, and anyone else involved in digital circuitry.

2. All logic functions, no matter how complex, that are required in digital logic can be created from three basic logic functions, AND, OR, and NOT. The basic logic gates to be studied in the following chapters are examples of solutions to Boolean algebra equations. The Boolean algebra variables are the logic inputs to our logic gates and the logical function or formula is the output of the gate or of even more complex logic circuits. The more complex gates, such as the NAND and NOR, can be thought of as at the bottom level as various combinations of AND, OR, and NOT gates.

3. **AND Logic** can be referred to as 'all-or-nothing' logic. Using the terms A and B as inputs and the term Y as an output, we can state, using AND logic, that inputs A AND B have to be HIGH for output Y to be HIGH. This can be stated in terms of Boolean algebra as $A \cdot B = Y$ (the $\cdot$ represents the AND function).

4. Open circuits file **d01-03a**. In this circuit, switches A, B, and C are connected in an AND (series) configuration. Closing each switch with the related computer keyboard key represents a HIGH condition. What is the AND formula that will turn on the lamp? The AND formula that will turn on the lamp is ______________________________.

5. **OR Logic** can be referred to as 'any-or-all' logic. Again, using the terms A and B as inputs and the term Y as an output, we can state, using OR logic, that if input A OR B is HIGH (or both A and B), then output Y will be HIGH. This can be stated in terms of Boolean algebra as $A + B = Y$ (the + represents the OR function).

6. Open circuits file **d01-03b**. In this circuit, switches A, B, and C are connected in a parallel OR configuration. Closing one of the switches represents a HIGH condition for that switch. What is the OR formula for this circuit that will turn on the lamp? The OR formula that will turn the lamp ON is ______________________________.

7. **NOT Logic** can be referred to as 'inverted, negated, or complement' logic. The NOT function changes one logic level to the opposite logic level. The NOT function in a Boolean algebra formula is represented by an overbar over the individual input, such as $\overline{A}$, or over a whole function, such as $\overline{A + B + C} = Y$. In this second example, you would read the formula as the "quantity A OR B OR C all NOTTED is equal to Y". Sometimes the apostrophe symbol is used to represent the NOT function such as A' for NOT A or A prime. The overbar will be used in the text and the apostrophe will be used with MultiSIM circuit diagrams.

8. Open circuits file **d01-03c**. In this circuit, if switch A' is open, then lamp Y is ON, representing a HIGH. If switch A' is closed, then lamp Y

is OFF, representing a LOW. What is the Boolean equation for this circuit? The Boolean equation for this circuit is ________________

____.

Activity 1.4: Troubleshooting Problems

1. Troubleshooting problems will be found in this text after every activity. There will be two basic types of troubleshooting problems.
   - One type of problem will be a connection problem where the circuit will be connected incorrectly. Many times there will be a statement regarding how to connect a certain type of integrated circuit and that clue will be the key to finding the connection problem.
   - The other type will be a component fault introduced by the instructor. This type of problem will consist of opens and shorts. If, for example, all of the inputs to a circuit are correct, then the problem might be an open output. Many times there will be shorted inputs or outputs. Switches and power sources can be open or shorted.
2. Open circuits file **d01-04a**. This circuit has a connection problem. Actuate the circuit and the switches. Did the lamp turn on, Yes _____ or No _____? It should not have turned on because of the connection problem. The wire from the bottom of the lamp is connected to junction B rather than junction A. Move the wire from junction B to junction A. Activate the circuit and close the switches. Did the lamp turn on, Yes _____ or No _____?
3. Open circuits file **d01-04b**. This circuit has a component problem. Actuate the circuit and the switch. Did the lamp turn on, Yes _____ or No _____? It should not have turned on because of the circuit problem. Use the Digital Multimeter (DMM) to troubleshoot the circuit. Measure the voltage output of the power source. What was the value of the output voltage? The output voltage was _____ V. Obviously, the problem is the lack of voltage from the power source. Replace V 1 with V 2. Does the circuit work now, Yes _____ or No _____?
4. Open circuits file **d01-04c**. This circuit has a component problem. Actuate the circuit and the switch. Did the lamp turn on, Yes _____ or No _____? It should not have turned on because of the circuit problem. Use the Digital Multimeter to troubleshoot the circuit. Measure the