Lab Manual: A Design Approach to accompany

DIGITAL SYSTEMS

PRINCIPLES AND APPLICATIONS

9TH EDITION

Ronald J. Tocci, Neal S. Widmer, and Gregory L. Moss

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Ninth Edition

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PREFACE

This laboratory manual is written for students in an introductory digital electronics course that emphasizes logic circuit analysis, applications, and design. This newest edition lab manual to accompany the ninth edition of *Digital Systems: Principles and Applications* by Ronald J. Tocci, Neal S. Widmer, and Gregory L. Moss continues the design approach for new students that has been presented in previous editions. A few introductory projects provide student practice in circuit construction, testing, and operational analysis using standard logic devices as well as detailed software procedures for the development of digital circuits using complex logic devices. Most laboratory projects presented here challenge the student to perform at a much higher level than is found in most other lab manuals that merely ask them to "build this circuit and fill-in-the-blanks in the manual."

This latest edition of the lab manual has been extensively revised to cover not only standard digital logic devices and functions, but also digital system implementation using Altera Corporation's MAX+PLUS II software and complex programmable logic devices (CPLDs). The MAX+PLUS II software is a flexible and easy-to-learn integrated digital system development package for Altera's CPLDs that runs on personal computers. With MAX+PLUS II, hierarchical digital designs can be entered using schematics (graphical entry), timing diagrams, and/or hardware description languages (HDLs). The development software also provides design verification through circuit simulation and timing analysis. A compiled digital design can be downloaded at a student's lab station directly to a target CPLD device via the PC's parallel port. Many examples and step-by-step procedures for using principal features of this software are given in this lab manual. A nearly full-featured, student version of the industry-standard software is available on a CD-ROM in the back of the textbook or via the web at http://www.altera.com/education/univ/unv-index.html.

The lab manual is divided into 23 major topical units, with each unit containing an introductory discussion of the digital topic addressed, one or more examples of procedures and applications, and a variety of laboratory projects. Introductory units on combinational logic circuits and sequential logic circuits target using standard logic devices for pedagogical reasons and because such devices are still found widely in industry. The MAX+PLUS II software is introduced using the graphical (schematic) entry technique and is followed by units that discuss writing HDL code for combinational and sequential circuits. Two different HDL languages that can be compiled by MAX+PLUS II are presented in the lab manual. A proprietary language, Altera hardware description language (AHDL), and an industry-standard language, VHDL, are both discussed. Both languages are very similar (and also quite different). AHDL is much easier for beginners to learn, but VHDL has the advantage that it can be used with other development system software. Introduction to the two HDLs is given in separate lab manual units for combinational circuits and also for sequential circuits. Later lab units that deal with common digital functions, such as decoders, encoders, multiplexers, counters, and shift registers, each have a variety of lab projects that use standard digital devices as well as many lab projects using CPLDs. CPLD examples and lab projects utilize a mix of graphical and HDL techniques. Both HDL language solutions to examples are given and clearly labeled with AHDL or VHDL.

The manual provides an extensive selection of projects for a two-semester introductory digital course sequence. The sequencing of topics primarily follows the textbook by Tocci, Widmer, and Moss. However, the lab manual is designed for flexibility by including many different lab projects. Several of the lab manual units have been written to optionally provide extensive student practice and mastery of many of the topics. These lab units may be assigned over more than one laboratory period. I do not expect that any course would have sufficient time for students to perform all of the laboratory projects in all of the units. Rather, instructors can select and rearrange the topics and projects to fit their particular course objectives. There is no expectation by this author that an introductory digital course would teach both HDLs. Both HDLs are presented so that a school can decide which language approach can best suit its program goals.

The applications-oriented lab projects are designed to provide beginning students with extensive experience in the analysis and design of digital logic circuits. The lab assignments consist of circuit projects that range from investigating basic logic concepts to synthesizing circuits for new applications. The projects are intended to challenge all students and to provide them with some directed laboratory experience that develops insight into digital principles, applications, and techniques of logic circuit analysis and design.

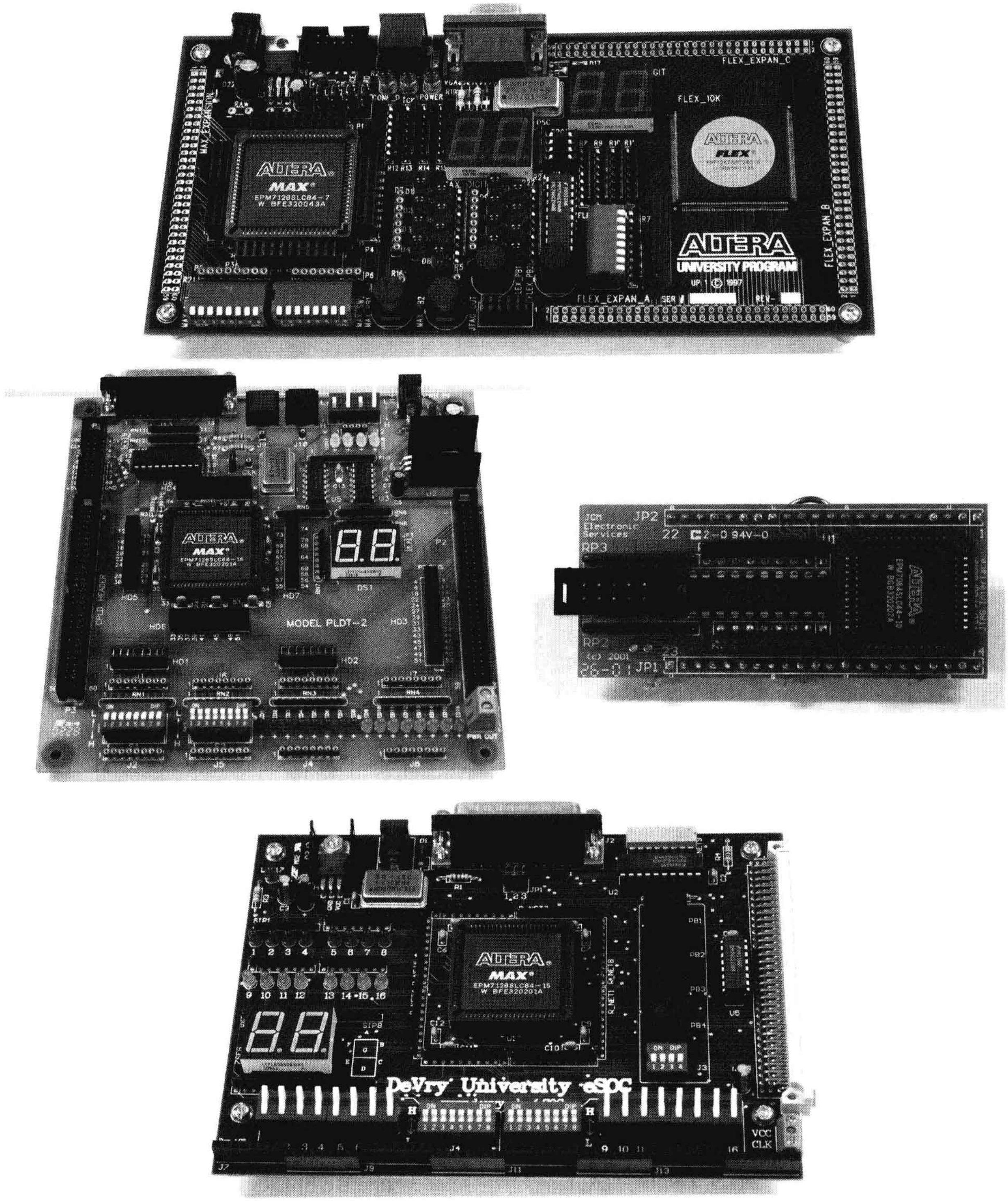
Personal computers and electronic design automation software have changed how digital systems are designed and developed in industry today. Programmable logic devices and logic circuit development software are popular and extremely important digital technologies. These technologies need to be included in the educational experience of future electronics personnel. Accordingly, the custom implementation of logic circuits using CPLDs is emphasized in this manual.

There are several relatively low cost prototyping boards for Altera CPLDs that can be utilized in the digital laboratory. Photographs of example training boards are shown on page ix. The Altera, RSR, and DeVry boards each contain an EPM7128SLC84 chip. The HVW board has a smaller EPM7064SLC44 chip. The Altera board also has a large Flex 10K family chip. Each of these boards can be programmed via the parallel port of a standard PC using a JTAG interfacing option on the MAX 7000S family of CPLDs.

A list of laboratory equipment, integrated circuits, and other necessary components is found in the Equipment List on pages x-xi. Only standard digital integrated circuit part numbers (74XX) are listed. Either TTL or CMOS families can be used for the standard logic device projects (but note that mixing CMOS and TTL devices in a single project may not work properly). Logic design today primarily uses CMOS technology, but TTL components may be used since they are readily available. Data sheets for most logic devices can be found on the *Texas Instruments Data Sheets* CD-ROM in the back of the textbook or on the web at http://www.ti.com. Data sheets for the Altera CPLD devices can be found on the web at http://www.altera.com.

I am very grateful to the Altera Corporation, whose support has helped to make this laboratory manual possible.

Gregory L. Moss



Example CPLD prototyping boards (clockwise from top): Altera Corporation UP2, HVW Technologies Intro-FPGA, DeVry University eSOC, RSR Electronics PLDT-2 (photographs by G. L. Moss)

EQUIPMENT LIST

Laboratory Equipment and Software

Digital breadboarding system
Power supply (5 V, 500 mA)
Logic probe
Digital voltmeter
Oscilloscope (4-trace, dual-trace minimum)
Frequency counter
Signal generator
Personal computer
Altera MAX+PLUS II Development Software
CPLD training board with Altera EPM7128SLC84 (or other MAX 7000S family devices)

Digital Integrated Circuits

Quantity	*Part #*	*Logic families*	*Description*
1	7400	ALS, LS, HC, HCT	Quad 2-input NAND
1	7402	ALS, LS, HC, HCT	Quad 2-input NOR
1	7404	ALS, LS, HC, HCT	Hex INVERTERs
1	7408	ALS, LS, HC, HCT	Quad 2-input AND
1	7410	ALS, LS, HC	Triple 3-input NAND
1	7414	LS, HC, HCT	Hex Schmitt-trigger INVERTERs
1	7420	ALS, LS, HC	Dual 4-input NAND
1	7427	ALS, LS, HC	Triple 3-input NOR
1	7432	ALS, LS, HC, HCT	Quad 2-input OR
2	7447	LS	BCD-to-7-segment DECODER/DRIVER
1	7485	LS	4-bit MAGNITUDE COMPARATOR
1	7486	ALS, LS	Quad 2-input EXCLUSIVE-OR
2	74112	ALS, LS, HC	Dual JK, neg.-edge triggered FLIP-FLOPs
1	74138	ALS, LS, HC, HCT	3-line-to-8-line DECODER/DEMUX
1	74148	LS, HC	8-line-to-3-line priority ENCODER
1	74151	ALS, LS, HC	1-of-8 MULTIPLEXER
1	74157	LS, HC	Quad 2-line-to-1-line MULTIPLEXER
1	74160	ALS, LS, HC	Synchronous decade COUNTER
1	74161	ALS, LS, HC	Synchronous binary COUNTER
1	74166	ALS, LS, HC	8-bit SHIFT REGISTER (PISO)
1	74190	ALS, LS, HC, HCT	Synchronous up/down decade COUNTER
1	74221	LS	Dual MONOSTABLE MULTIVIBRATOR
1	74244	ALS, LS, HC, HCT	Octal 3-state BUFFER

Quantity	*Part #*	*Logic families*	*Description*
1	74375	LS	4-bit bistable LATCH
1	74390	LS, HC, HCT	Dual Decade COUNTER
1	74393	LS, HC, HCT	Dual 4-bit binary COUNTER
2	2114		Static RAM (1K × 4) [9114]

Linear Integrated Circuits

1	NE555	Timer
1	AD557	8-bit digital-to-analog converter
1	ADC0804	8-bit analog-to-digital converter

Miscellaneous Components

MAN72 (or equivalent) common-anode, 7-segment LED display (×2)

Resistors (1/4 watt):

330 Ω (×14)	1 kΩ (×10)	1.1 kΩ
2.2 kΩ (×2)	3.3 kΩ	10 kΩ (×2)
27 kΩ	33 kΩ	47 kΩ
62 kΩ	68 kΩ	72 kΩ
82 kΩ		

Capacitors:

10 μf	0.1μf	0.01 μf (×8)
0.001 μf	0.0047 μf	150 pf

Potentiometers (10-turn):

10 kΩ

Rectifier diode: 1N4001

Grayhill 84BB1-003 (or equivalent) Keypad (4 x 4 matrix) – optional

To my family,
Marita, David, and Ryan

CONTENTS

UNIT 1

INTRODUCTION TO DIGITAL TEST EQUIPMENT

Objective

- To describe the function and operation of a typical digital breadboarding and testing system.

Suggested Parts		
	7408	7432

Digital Test Equipment

Typical breadboarding and testing equipment used with digital circuits are shown in Fig. 1-1. Included are a power supply, lamp monitors, logic switches, pulsers, clock, breadboarding sockets, and a logic probe.

Power supply

The power supply typically provides a regulated +5 V DC voltage to be used to power TTL or CMOS integrated circuits. Note that some units may also contain additional fixed voltages or a variable DC power source for other types of circuits.

Lamp monitors

The lamp monitors indicate the voltage level at various points in the digital circuit being tested. The lamp monitors will light when a digital "high" voltage is applied to them.

Logic switches

The logic switches input either of the two logic levels (voltages) to the circuit being tested. A switch in the "down" position will provide a logic "low" voltage, while a switch in the "up" position will provide a logic "high" voltage.

Pushbuttons or pulsers

A pushbutton provides a momentary "bounce free" logic input to the test circuit. Pulsers that are provided on some testing systems produce a short duration (narrow) pulse or change in the logic level of the pulser's output.

Clock

The clock provides a variable frequency pulse waveform that can be used for the timing control of some digital circuits.

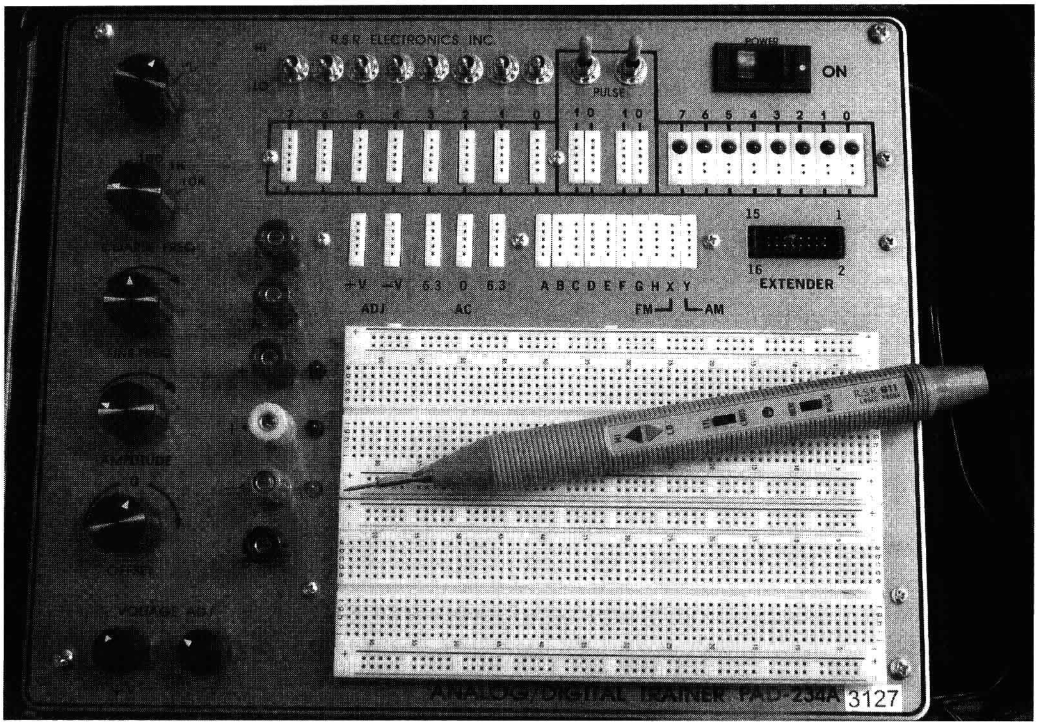


Fig. 1-1 Digital breadboarding and testing equipment (photograph by G. L. Moss)

Breadboarding sockets

Breadboarding sockets are very convenient devices on which circuits may be constructed for testing purposes. The socket contains a matrix of contacts that are used to interconnect the various components and wires needed to construct the digital circuit. The socket holes are small and only #30 to #22 solid "jumper" wires should be inserted into them. A typical breadboarding socket is illustrated in Fig. 1-2. This style of socket is designed to breadboard DIP (dual-in-line package) type integrated circuits (ICs or chips). The socket shown has several separate electrical buses across the top and bottom of the board. Not all breadboarding sockets will have these buses or may have fewer of them. The buses will often be used to connect power and ground to **each** of the chips in the circuit. The chips will be inserted into the socket so that their pins will be parallel to and on either side of the center groove in the socket. Electrical connections are made to any pin by inserting wires into the holes that line up with that pin. See the photograph of a breadboarded digital circuit in Fig. 1-3.

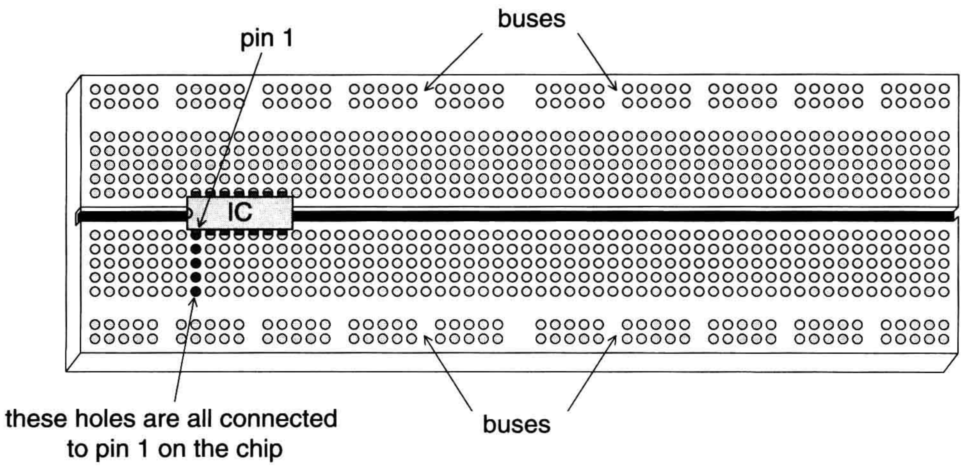


Fig. 1-2 Typical IC breadboarding socket

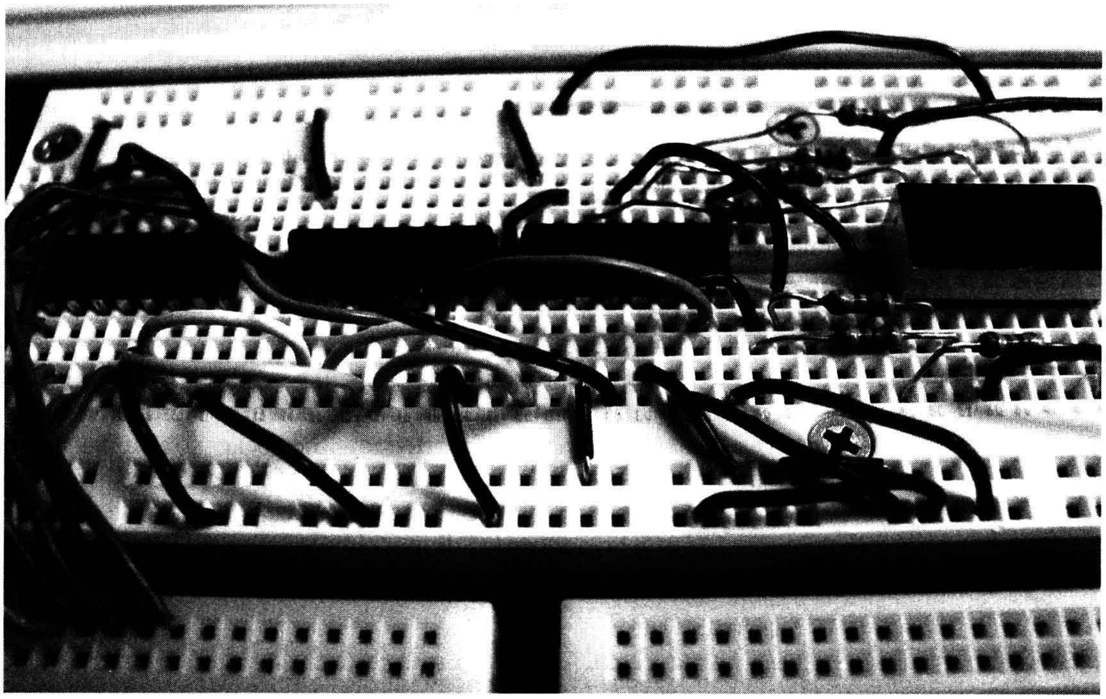


Fig. 1-3 A digital circuit wired on a breadboarding socket (photograph by G. L. Moss)

Test Equipment Operation

Measuring Voltage with a Digital Voltmeter (DVM)

The potential difference or voltage between the positive and negative terminals of a battery or power supply connected to a circuit will cause current to flow through the circuit. The basic unit to measure potential difference is the volt (V). A potential difference or voltage drop occurs across the various devices in a circuit when current flows through them. The magnitude (and polarity with respect to a reference point in the circuit) of a potential difference is measured with an instrument called a voltmeter. You must be extremely careful when making voltage measurements since the measurement is made on a "live" (powered) circuit. The voltmeter test leads (probes) are placed across (in parallel with) the device or power source whose voltage is to be measured. The procedure to measure DC voltages using a typical digital voltmeter is:

(1) *Connect the test leads to the DVM*
(2) *Set the function switch to measure DC voltages*
(3) *Set the range switch for the maximum voltage anticipated*
(4) *Connect (or touch) the black test lead to the reference point of the circuit (or component)*
(5) *Connect (or touch) the red test lead to the point in the circuit where you wish to measure the voltage*
(6) *Read the voltage on the digital display*
(7) *Readjust the range setting if necessary for a proper reading*

Ask your lab instructor if you have any questions concerning the use of the DVM.

Measuring Logic Levels with a Logic Probe

The logic probe is an extremely handy and easy to use piece of digital test equipment. It is used to detect and display the logic levels at various test points within a circuit. To use a logic probe to test TTL circuits:

(1) *Connect the alligator clip leads to the power supply for the circuit being tested (red to +5 V and black to ground)*
(2) *Set the logic family switch to TTL*
(3) *Carefully touch the probe tip to the circuit node (normally a chip pin) to be tested (do not short any nodes together in the process)*
(4) *Note the logic level present at the test point by which LED (HIGH or LOW) is illuminated*
(5) *If neither HIGH nor LOW is indicated, the proper logic voltage is not present at the test point*

Some logic probes also have a pulse detector (indicated on a separate LED) feature to indicate that the logic level at the test point is changing. Ask your lab instructor if you have any questions concerning the use of the logic probe.

Laboratory Projects

Investigate the features of the digital breadboarding and test system available in the laboratory by performing the following tasks with the unit. Carefully plug it into the AC outlet and turn on the power. Consult your lab instructor if you have any problems or questions concerning the laboratory procedures or equipment operation.

1.1 Measure and record the TTL **power supply** output voltage (with respect to ground) using a DVM. Remember that one of the most important safety precautions to observe in electronics is to avoid personal contact with any voltage source or component in a "live" circuit. You may need a short piece of jumper wire if the DVM's probes do not easily make electrical contact to the power supply connectors. Make sure that you are reading the TTL supply voltage if the unit has more than the single output supply. The TTL supply voltage should be between +4.75 V and +5.25 V DC. If you are unfamiliar with the use of the DVM, refer to the "Measuring Voltage with a Digital Voltmeter (DVM)" section of this lab assignment.

1.2 Locate the **logic switches** on the digital tester and determine the number of individual input switches available. Measure and record the voltage (with respect to ground) from a logic switch when it is placed in each of its two positions (up and down). In TTL logic, a "low" voltage will be approximately 0 V and a "high" will be approximately +5 V (actually anywhere from +2 V to +5 V).

1.3 Record your observations when a **logic probe** is used to test the output from the logic switch in each of its two positions. What does it mean if both logic probe lights are off at the same time? You may need a short piece of jumper wire. See the "Measuring Logic Levels with a Logic Probe" section of this lab.

1.4 Locate the **lamp monitors** on the digital tester and determine the number of individual lights available. Record your observations of the operation of the lamp monitors by connecting a jumper wire from one of the logic switches to a lamp monitor and then moving the switch between the two logic levels (high and low voltage). In positive logic, a high voltage is referred to as a "1" and a low voltage is referred to as a "0." How does the result from the lamp monitor compare to the logic probe's result?

1.5 Locate the **pushbuttons** or pulsers on the digital tester and determine the number of individual momentary inputs available. Note the operation of a pushbutton or pulser by connecting it to an unused lamp monitor and then pressing and releasing the button. If your unit has pushbuttons with two complementary outputs available, connect each of the outputs to a separate, unused lamp monitor and then press and release the button.

1.6 Note the operation of the **clock** output by connecting it to an unused lamp monitor with the clock set at its lowest frequency. If your unit has a clock with two complementary outputs available, connect each of the clock outputs to a separate, unused lamp monitor. Describe the lamp action when the clock frequency is increased.

1.7 Investigate the internal connections of the **breadboarding socket** shown in the following diagram. Wire the connections to the power supply, to the clock, and to a logic switch as shown in the diagram. Use the logic probe to test the socket holes around the connections that you have made to the socket. Sketch the breadboarding socket and explain its internal electrical conductor pattern. Note: If your breadboarding socket does not have bus strips available as illustrated, connect the power supply instead to other sections of the socket to make your tests.