EXPERIMENTS MANUAL FOR

Digital Electronics

Principles and Applications

SIXTH EDITION

Tokheim

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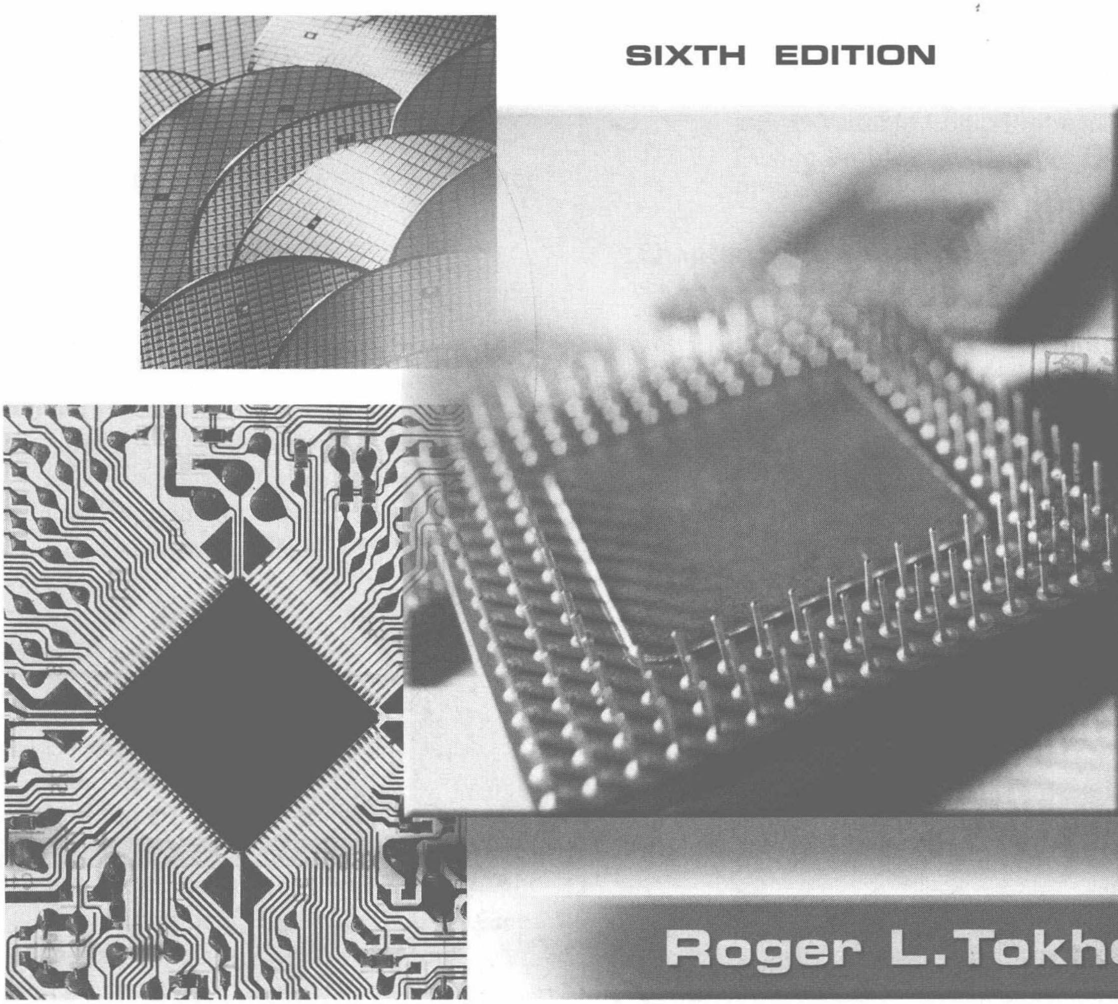

Roger L. Tokheim

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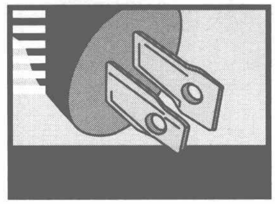

Editors' Foreword

The Glencoe *Basic Skills in Electricity and Electronics* series has been designed to provide entry-level competencies in a wide range of occupations in the electrical and electronic fields. The series consists of coordinated instructional materials designed especially for the career-oriented student. A textbook, an experiments manual, and an instructor productivity center support each major subject area covered in the series. All of these focus on the theory, practices, applications, and experiences necessary for those preparing to enter technical careers.

There are two fundamental considerations in the preparation of a series like this: the needs of the learner and needs of the employer. This series meets these needs in an expert fashion. The authors and editors have drawn upon their broad teaching and technical experiences to accurately interpret and meet the needs of the student. The needs of business and industry have been identified through personal interviews, industry publications, government occupational trend reports, and reports by industry associations.

The processes used to produce and refine the series have been ongoing. Technological change is rapid and the content has been revised to focus on current trends. Refinements in pedagogy have been defined and implemented based on classroom testing and feedback from students and instructors using the series. Every effort has been made to offer the best possible learning materials. These include animated PowerPoint presentations, circuit files for simulations, a test generator with correlated test banks, dedicated websites for both students and instructors, and basic instrumentation labs. All of these are well coordinated and have been prepared by the authors.

The widespread acceptance of the *Basic Skills in Electricity and Electronics* series and the positive responses from users confirm the basic soundness in content and design of all the components as well as their effectiveness as teaching and learning tools. Instructors will find the texts and experiments manuals in each of the subject areas logically structured, well-paced, and developed around a framework of modern objectives. Students will find the materials to be readable, lucidly illustrated, and interesting. They will also find a generous amount of self-study and review materials and examples to help them determine their own progress.

Both the initial and ongoing success of this series are due in large part to the wisdom and vision of Gordon Rockmaker, who was a magical combination of editor, writer, teacher, electrical engineer, and friend. Gordon has retired but he is still our friend. The publisher and editors welcome comments and suggestions from instructors and students using the materials in this series.

Charles A. Schuler, Project Editor
Brian P. Mackin, Editorial Director

Basic Skills in Electricity and Electronics

Charles A. Schuler, Project Editor

New Editions in This Series

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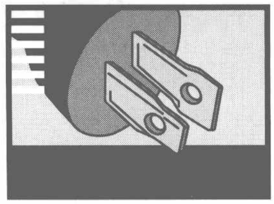


Preface

The field of digital electronics continues its rapid growth. This growth, a result of advances in microelectronic design and manufacturing, computer technology, and information systems, has caused a rapid increase in the use of digital circuits. This trend is expected to continue and perhaps accelerate in the future. Digital circuits are found in almost every type of electronic equipment. All well-trained technicians and servicers should have a knowledge of the fundamental theory of digital electronics. It is also very important to have practical experience in working with the components, circuits, tools, and test equipment used in the field. This *Experiments Manual for Digital Electronics: Principles and Applications* is designed to provide this practical, hands-on experience.

The sixth edition of the *Experiments Manual for Digital Electronics: Principles and Applications* is closely correlated, chapter by chapter, with its companion textbook, *Digital Electronics: Principles and Applications,* Sixth Edition. Trainers used for the lab experiments in the highly successful first five editions can also be used with the new sixth edition. Most components and equipment used in the fifth edition are also used in the sixth edition lab experiments. A digital trainer, display board, and components are available from Dynalogic Concepts, 1-800-246-4907.

The sixth edition includes several new features. In response to instructor suggestions, selected labs can now be performed using either hardware or using circuit simulation software such as Electronics Workbench® or Multisim. A CD-ROM containing a student version of Multisim 2001 plus circuit simulations from the Experiments Manual is included with the lab manual. Circuit simulations from the companion textbook, *Digital Electronics: Principles and Applications,* Sixth Edition, are also contained on the CD-ROM. Guided lab experiments are retained for the beginners with more open-ended design problems provided for advanced students.

The components used in the *Experiments Manual* are the same as those that may be encountered by technicians and servicers. The breadboarding, circuit simulations, and troubleshooting techniques are those used by engineers, designers, and technicians. Students will work with a variety of digital ICs, using both TTL and CMOS technology. Other components, including diodes, transistors, linear ICs, resistors, switches, relays, dc, servo, and stepper motors, buzzers, optoisolators, opto-coupled interrupter modules, Hall-effect switches, thermistors, NV trimmer potentiometers, and displays are used in the lab experiments, design problems, and troubleshooting problems. Students will practice wiring using more than 40 different ICs and displays in about 75 different circuits. The more challenging digital systems circuits use ICs, either LED, LCD or VF displays, and components already studied in earlier chapters.

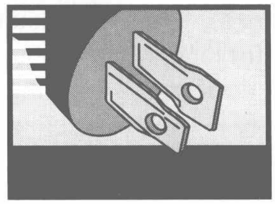
Each of the more than 70 experiments/design problems is self-contained. Most of the activities are guided lab experiments. Some of the activities can be wired in hardware or simulated on a computer. Each experiment uses the following time-proven format:

Objectives
Materials
System Diagrams
Procedure
Questions

The *Experiments Manual for Digital Electronics: Principles and Applications,* Sixth Edition, is thought to be the most comprehensive lab manual in the industry serving this level. All experiments, troubleshooting and design problems have been tested. The circuit simulations were tested using Electronics Workbench® and Multisim electronic circuit simulation software.

Special thanks to family members Marshall, Rachael, Carrie, Dan, and Natalie for their help and encouragement. Suggestions and comments about the experiences and results of the reader are welcome.

Roger L. Tokheim



Safety

Electric and electronic circuits can be dangerous. Safe practices are necessary to prevent electrical shock, fires, explosions, mechanical damage, and injuries resulting from the improper use of tools.

Perhaps the greatest hazard is electrical shock. A current through the human body in excess of 10 milliamperes can paralyze the victim and make it impossible to let go of a "live" conductor or component. Ten milliamperes is a rather small amount of current flow: It is only *ten one-thousandths* of an ampere. An ordinary flashlight can provide more than 100 times that amount of current!

Flashlight cells and batteries are safe to handle because the resistance of human skin is normally high enough to keep the current flow very small. For example, touching an ordinary 1.5-V cell produces a current flow in the microampere range (a microampere is one-millionth of an ampere). This amount of current is too small to be noticed.

High voltage, on the other hand, can force enough current through the skin to produce a shock. If the current approaches 100 milliamperes or more, the shock can be fatal. Thus, the danger of shock increases with voltage. Those who work with high voltage must be properly trained and equipped.

When human skin is moist or cut, its resistance to the flow of electricity can drop drastically. When this happens, even moderate voltages may cause a serious shock. Experienced technicians know this, and they also know that so-called low-voltage equipment may have a high-voltage section or two. In other words, they do not practice two methods of working with circuits: one for high voltage and one for low voltage. They follow safe procedures at all times. They do not assume protective devices are working. They do not assume a circuit is off even though the switch is in the OFF position. They know the switch could be defective.

Even a low-voltage, high-current-capacity system like an automotive electrical system can be quite dangerous. Short-circuiting such a system with a ring or metal watchband can cause very severe burns—especially when the ring or band welds to the points being shorted.

As your knowledge and experience grow, you will learn many specific safe procedures for dealing with electricity and electronics. In the meantime:

1. Always follow procedures.
2. Use service manuals as often as possible. They often contain specific safety information. Read, and comply with, all appropriate material safety data sheets.
3. Investigate before you act.
4. When in doubt, *do not act*. Ask your instructor or supervisor.

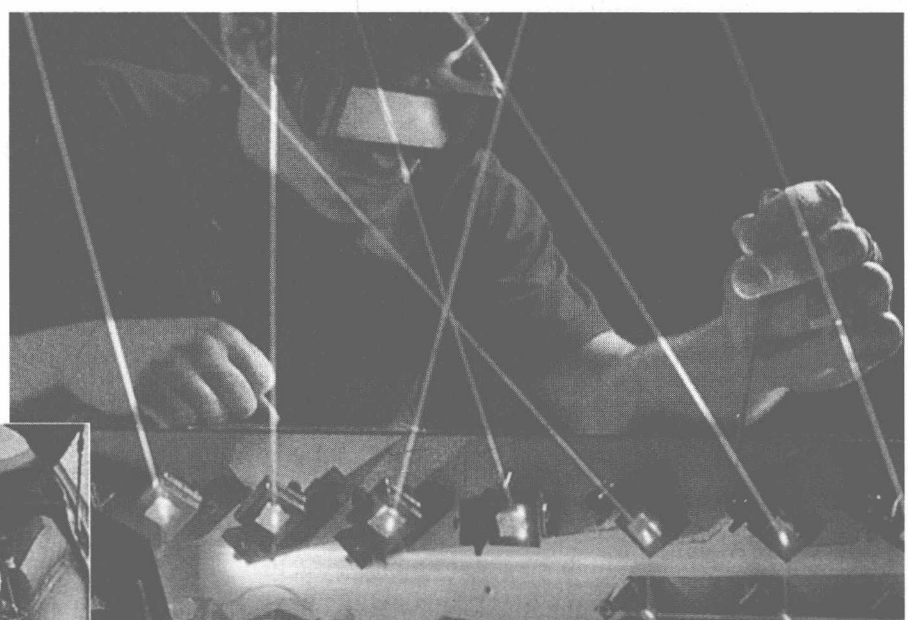
General Safety Rules for Electricity and Electronics

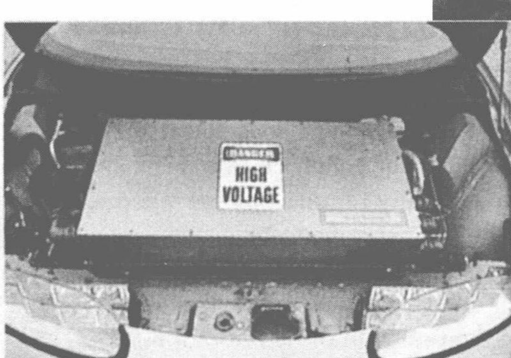
Safe practices will protect you and your fellow workers. Study the following rules. Discuss them with others, and ask your instructor about any you do not understand.

1. Do not work when you are tired or taking medicine that makes you drowsy.
2. Do not work in poor light.
3. Do not work in damp areas or with wet shoes or clothing.
4. Use approved tools, equipment, and protective devices.
5. Avoid wearing rings, bracelets, and similar metal items when working around exposed electric circuits.
6. Never assume that a circuit is off. Double-check it with an instrument that you are sure is operational.
7. Some situations require a "buddy system" to guarantee that power will not be turned on while a technician is still working on a circuit.
8. Never tamper with or try to override safety devices such as an interlock (a type of switch that automatically removes power when a door is opened or a panel removed).
9. Keep tools and test equipment clean and in good working condition. Replace insulated probes and leads at the first sign of deterioration.

10. Some devices, such as capacitors, can store a *lethal* charge. They may store this charge for long periods of time. You must be certain these devices are discharged before working around them.
11. Do not remove grounds and do not use adaptors that defeat the equipment ground.
12. Use only an approved fire extinguisher for electrical and electronic equipment. Water can conduct electricity and may severely damage equipment. Carbon dioxide (CO_2) or halogenated-type extinguishers are usually preferred. Foam-type extinguishers may also be desired in *some* cases. Commercial fire extinguishers are rated for the type of fires for which they are effective. Use only those rated for the proper working conditions.
13. Follow directions when using solvents and other chemicals. They may be toxic, flammable, or may damage certain materials such as plastics. Always read and follow the appropriate material safety data sheets.
14. A few materials used in electronic equipment are toxic. Examples include tantalum capacitors and beryllium oxide transistor cases. These devices should not be crushed or abraded, and you should wash your hands thoroughly after handling them. Other materials (such as heat shrink tubing) may produce irritating fumes if overheated. Always read and follow the appropriate material safety data sheets.
15. Certain circuit components affect the safe performance of equipment and systems. Use only exact or approved replacement parts.
16. Use protective clothing and safety glasses when handling high-vacuum devices such as picture tubes and cathode-ray tubes.
17. Don't work on equipment before you know proper procedures and are aware of any potential safety hazards.
18. Many accidents have been caused by people rushing and cutting corners. Take the time required to protect yourself and others. Running, horseplay, and practical jokes are strictly forbidden in shops and laboratories.

Circuits and equipment must be treated with respect. Learn how they work and the proper way of working on them. Always practice safety: your health and life depend on it.





Electronics workers use specialized safety knowledge.

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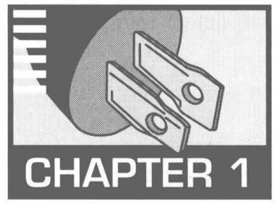

Digital Electronics

TEST: DIGITAL ELECTRONICS

Answer the questions in the space provided.

1. A waveform that has just two distinct voltages, such as 0 V and 3.5 V, is called a(n) ______________ signal. — **1.** ______________
- **a.** Analog
- **b.** Digital

2. The +5-V level of a TTL digital signal is also called a logical — **2.** ______________
- **a.** 0 or LOW
- **b.** 0 or HIGH
- **c.** 1 or LOW
- **d.** 1 or HIGH

3. Microcomputers are designed around complex integrated circuits called — **3.** ______________
- **a.** Binary counters
- **b.** Microprocessors
- **c.** Modems
- **d.** Multiplexers

4. A mechanical slide switch can be used to generate a digital signal if the output is debounced using a(n) — **4.** ______________
- **a.** Astable multivibrator
- **b.** Counter
- **c.** Latch
- **d.** Shift register

5. A mechanical normally open pushbutton switch can be used to generate a single digital pulse if the output is conditioned using a(n) ______________ multivibrator. — **5.** ______________
- **a.** Astable
- **b.** Bistable
- **c.** Free-running
- **d.** Monostable

6. A continuous series of TTL-level pulses can be generated using several discrete components and a 555 ______________ IC. — **6.** ______________
- **a.** Bistable multivibrator
- **b.** Counter
- **c.** Multiplexer
- **d.** Timer

7. A free-running clock that produces a series of TTL-level pulses can also be called a(n) — 7. ______
   a. Astable multivibrator
   b. Bistable multivibrator
8. The simple-to-use instrument often employed to detect logic levels is the — 8. ______
   a. Logic analyzer
   b. Logic comparator
   c. Logic probe
   d. Logic pulser
9. Most logic probes are designed to detect HIGH and LOW logic levels in both ______ IC logic families. — 9. ______
   a. CMOS and TTL
   b. HTL and RTL
10. Assume a 5-V power supply. In a TTL logic circuit, a voltage of 2.5 V would be interpreted as a(n) ______ logic level. — 10. ______
    a. HIGH
    b. LOW
    c. Undefined
11. Assume a 5-V power supply. In a CMOS logic circuit, a voltage of 2.5 V would be interpreted as a(n) ______ logic level. — 11. ______
    a. HIGH
    b. LOW
    c. Undefined
12. Most inexpensive logic probes use components called ______ to indicate HIGH and LOW logic levels. — 12. ______
    a. Fluorescent lamps
    b. Light-emitting diodes
13. Historically, ______ circuits have been more popular. — 13. ______
    a. Analog
    b. Digital
14. Most real world information (time, weight, light intensity, etc.) is ______ in nature. — 14. ______
    a. Analog
    b. Digital
15. When complicated calculations must be done in the processing stage, the electronic system will probably be ______ in nature. — 15. ______
    a. Analog
    b. Digital
16. The primary reason digital circuits are becoming more popular is — 16. ______
    a. Availability of low-cost digital ICs
    b. Total compatibility with natural world measurements
17. Unwanted electrical interference in an electronic circuit is commonly called ______. — 17. ______
    a. Noise
    b. Saturation signals
18. To switch to an alternative state such as a switch or flip-flop generating a digital output of HIGH, LOW, HIGH, LOW is referred to as ______. — 18. ______
    a. Polarization
    b. Toggling

NAME ____________________ DATE ____________

1-1 LAB EXPERIMENT: CLOCK CIRCUIT

OBJECTIVE

To wire and test a free-running clock circuit.

MATERIALS

Qty.		Qty.	
1	555 timer IC	1	470-kΩ, ¼-W resistor
1	LED indicator-light assembly	1	5-V dc regulated power supply
1	1-kΩ, ¼-W resistor	1	1-μF electrolytic capacitor
1	100-kΩ, ¼-W resistor	1	10-μF electrolytic capacitor

SYSTEM DIAGRAM

You will wire and operate a free-running clock circuit. This circuit will generate a TTL-level digital signal. The 555 timer IC is used to generate the continuous string of square-wave pulses. The frequency is low (1 to 2 pulses per second), and therefore the pulses may be directly observed on a simple LED output indicator. A schematic diagram for the astable multivibrator (free-running clock) circuit is shown in Fig. 1-1.

A very simple LED output indicator light assembly is shown connected to the free-running clock circuit in Fig. 1-1. A HIGH logic level is indicated when the LED lights. A LOW logic level is indicated when the LED does not light. Although very simple, the LED output indicator in Fig. 1-1 does have the disadvantage of loading the output of the IC more than recommended.

A more complicated LED output indicator-light assembly that may be used on your digital lab trainer is sketched in Fig. 1-2. This circuit contains a general-purpose NPN driver transistor. When the input voltage is HIGH, the transistor turns on (conducts), causing the LED to light. When the input voltage is LOW (near ground), the transistor is turned off, causing the LED to be off. This commonly used circuit does not exceed the drive capabilities of the ICs energizing the output indicators.

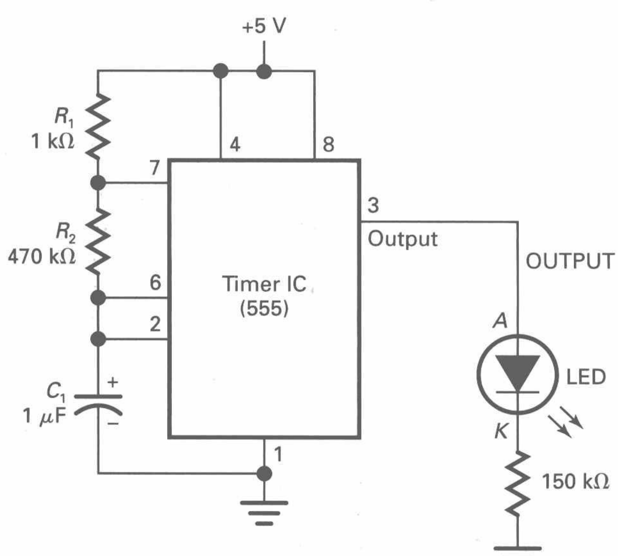

Fig. 1-1 Schematic diagram of a free-running clock circuit.

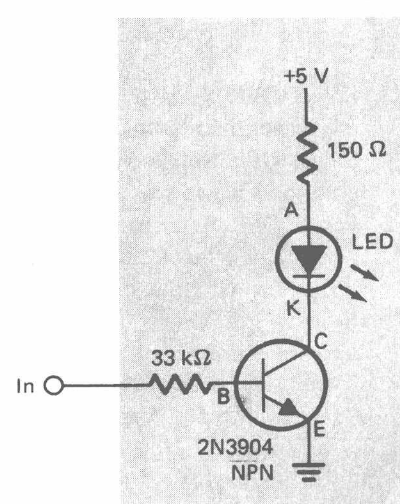

Fig. 1-2 Alternative circuit for LED indicator-light assembly.

Many digital lab trainers have the LED indicator-light assemblies prewired. If not, your instructor will tell you which LED indicator-light assembly to use in your experiments.

PROCEDURE

1. Insert the 555 IC into a mounting board. Use care because the eight pins may not match the holes in the mounting board.
2. Refer to Fig. 1-3. This is a simplified view of solderless breadboards similar to those on a digital trainer manufactured by Dynalogic Concepts.
   a. *Power block.* The four holes on the left side of the power block supply GND (like the negative of a battery). The eight holes on the right side of the power block supply +5 V. The main power switch on the trainer is used to energize the power block.
   b. *Power distribution strip.* All the holes in the top row of the power distribution strip are connected and distribute +5 V in this example. Likewise, all the holes in the bottom row are connected and distribute GND voltage in this example.
   c. *IC mounting board.* On the main IC mounting board, only the four holes in each vertical group are connected.

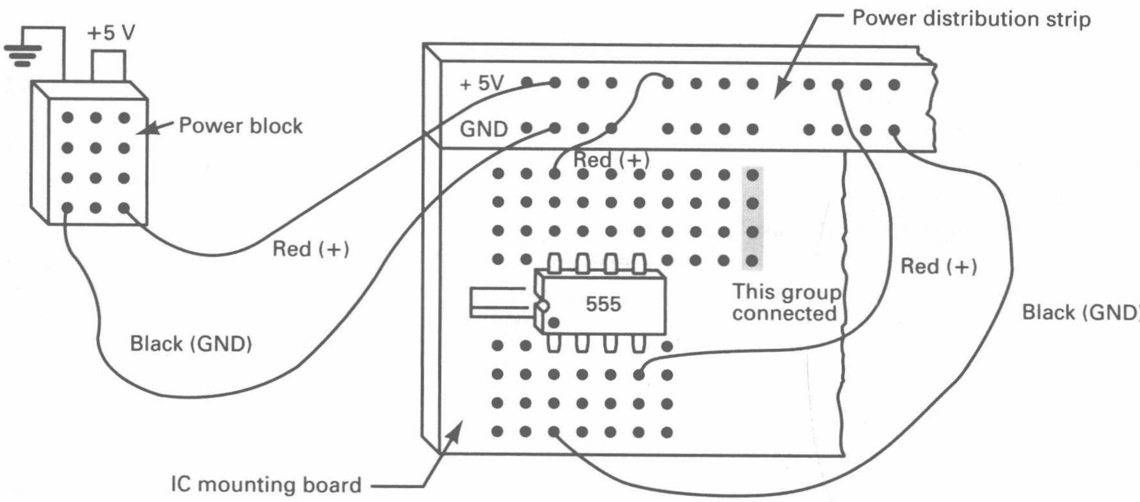

Fig. 1-3 Mounting and powering the 555 IC on a typical trainer.

3. Power OFF. Refer to Fig. 1-3. Connect power from the power block to the power distribution strip. Color code wires as shown.
4. Power OFF. Refer to Fig. 1-3. Connect power to the 555 timer IC. Use color-coded wires as shown.
5. Power OFF. Refer to the schematic diagram in Fig. 1-1. Wire the entire free-running clock circuit. For inexperienced students, a typical wiring layout for the clock circuit is detailed in Fig. 1-4.
6. Refer to Fig. 1-4.
   a. *Output connector.* A solderless breadboard has been added at the upper right in Fig. 1-4 as a convenient method of connecting to prewired LED indicator-light assemblies. Each vertical group of four holes is connected. In this example, output LED indicator-light assembly L_1 is being used.
   b. *Output LED indicator-light assembly.* A schematic of a typical output LED indicator-light assembly using a driver transistor is shown near the top in Fig. 1-4.

NAME ______________________ DATE ____________

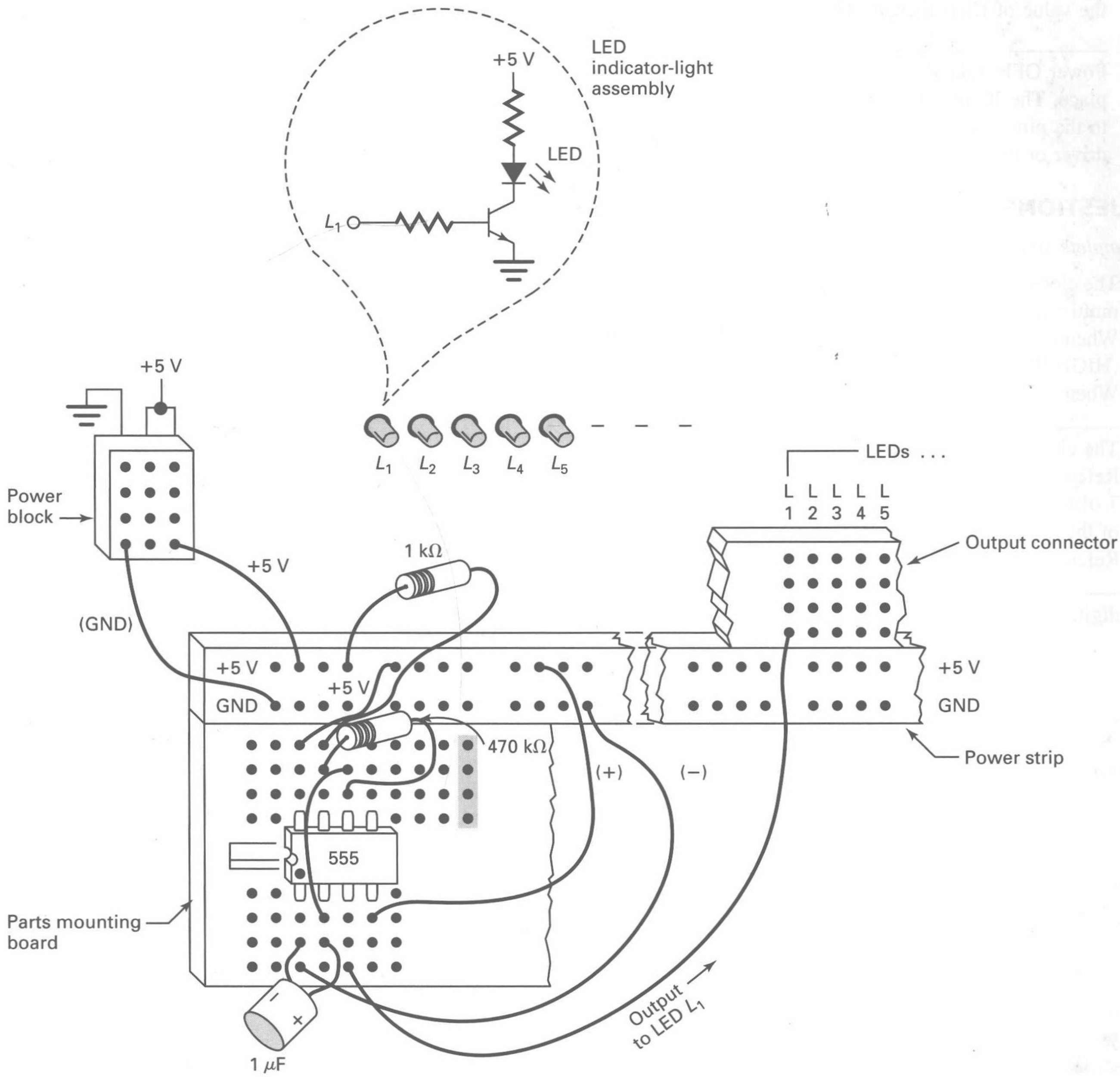

Fig. 1-4 Wiring clock circuit on digital trainer. (Trainer is DT-1000 by Dynalogic Concepts)

7. Power ON. The output LED should flash on and off at a low frequency. A light means a HIGH or logical 1. No light means a LOW or logical 0 digital signal.

8. Have your instructor check the proper operation of your free-running clock.

9. Power OFF. Take out the 470-kΩ resistor (R_2) and replace it with the 100-kΩ resistor.

10. Power ON. What happened to the frequency of the digital signal when the value of R_2 is decreased?

____

11. Power OFF. Remove the 1-μF (C_1) capacitor and replace it with a 10-μF electrolytic capacitor.
12. Power ON. What happened to the frequency of the digital signal when the value of C_1 is increased?

    ____

13. Power OFF. Take down the circuit and return all equipment to its proper place. The IC removes easily from the mounting board without damage to the pins if you *carefully* pry it up from both ends with a small screwdriver or use an IC removal tool.

QUESTIONS

Complete statements 1 to 6.

1. The clock in Fig. 1-1 on page 3 is sometimes called a(n) ______________ multivibrator. **1.** ______________
2. When the LED indicator lights, the output of the clock is ______________ (HIGH, LOW). **2.** ______________
3. When the LED indicator is not lit, the output of the clock is ______________ (HIGH, LOW). **3.** ______________
4. The clock wired in this experiment is based on the ______________ IC. **4.** ______________
5. Refer to Fig. 1-1. Decreasing the value of the resistor between pins 6 and 7 of the IC ______________ (decreases, increases) the output frequency of the digital clock. **5.** ______________
6. Refer to Fig. 1-1. Increasing the value of capacitor C_1 will ______________ (decrease, increase) the output frequency of the digital clock. **6.** ______________

NAME ______________________ DATE ______________

1-2 LAB EXPERIMENT: ONE-SHOT MULTIVIBRATOR AND DEBOUNCED SWITCH

OBJECTIVES

1. To wire and test a one-shot multivibrator circuit.
2. To add a debounced input switch to the one-shot multivibrator.
3. *OPTIONAL:* To measure the time duration of the output pulse from the one-shot multivibrator with an oscilloscope.

MATERIALS

Qty.		Qty.	
1	74121 one-shot multivibrator IC	1	0.033-μF capacitor
1	555 timer IC	1	0.1-μF capacitor
1	LED indicator-light assembly	1	10-μF electrolytic capacitor
1	330-Ω, ¼-W resistor	1	N.O. pushbutton switch (not debounced)
1	1-kΩ, ¼-W resistor	1	debounced switch assembly
1	33-kΩ, ¼-W resistor	*OPTIONAL:*	oscilloscope
2	100-kΩ, ¼-W resistor		
1	5-V dc regulated power suppy		

SYSTEM DIAGRAM

You will wire a monostable multivibrator circuit based on the 74121 IC. The circuit in Fig. 1-5 shows the wiring of the 74121 one-shot MV. The external components R_3 and C_1 determine the pulse width (time duration) of the positive pulse. This circuit was designed to emit a positive pulse of about 2 to 3 msec. A positive pulse of 2 to 3 msec is long enough to produce a visible flash on the attached LED indicator-light assembly. The one-shot is triggered by a positive voltage appearing at *B* of the 74121 IC caused by the closing of SW_1. The normal *Q* output of the 74121 emits a short positive pulse. Remember that the pulse width is determined by the design of the multivibrator circuit and not on how long the input switch (SW_1) was pressed. To increase the pulse width of the one-shot in Fig. 1-5, the values of R_3 and/or C_1 would be increased.

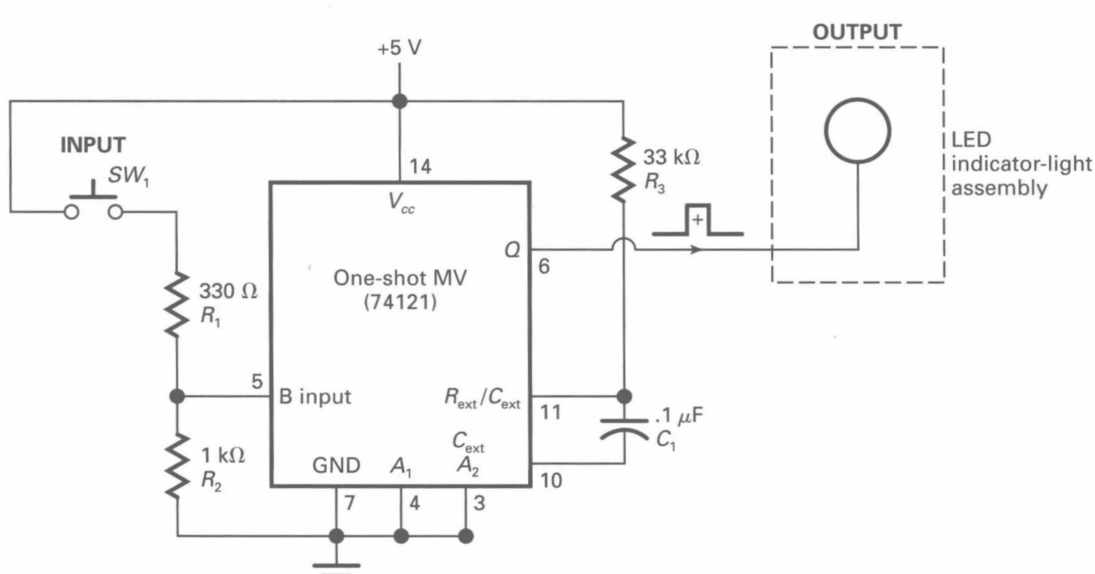

Fig. 1-5 A one-shot multivibrator circuit.