BASIC ELECTRONIC TROUBLESHOOTING FOR BIOMEDICAL TECHNICIANS

2nd Edition

Nicholas Cram

Selby Holder

Basic Electronic Troubleshooting for Biomedical Technicians

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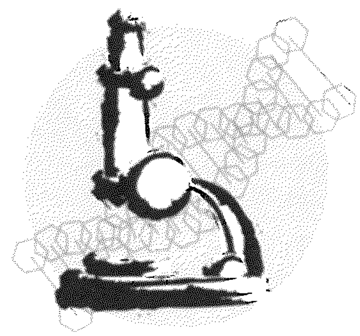

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Introduction

Working with biomedical electronics in the healthcare environment is an exciting and rewarding career. Our goal is to bring that career challenge to the student with mechanical and critical thinking abilities in addition to a compassion for those suffering from medical maladies. And, given that healthcare is evolving into a technological monolith, the available technology is changing the ways doctors and nurses treat their patients.

Maintaining and repairing medical devices is distinctly correlated to the healthcare profession itself. The biomedical troubleshooting process requires clinical knowledge of the device and its application. An error in judgment during the repair of a medical device could result in misdiagnosis, patient injury, or death. Due to this significance in the troubleshooting and repair process of medical devices, the authors feel a separate text is required apart from that of basic bench electronics troubleshooting and repair.

Unfortunately, there just aren't current or applicable technical books available with relevant content. They're all out of print or a rewrite of the same old book with a new cover. Professors and instructors are required to mold their courses around the available texts and bring 300 pounds of handouts to class. In many ways, it was this frustration that led us to produce this book.

Our primary objective in writing this book was to impart knowledge with a minimum of theoretical perplexity. We each have several decades of field experience and attempt to share our experiences when appropriate in order to better understand concepts in a hands-on approach rather than a mathematical approach. There are a multitude of diagrams and pictures throughout the book that illustrate concepts in a manner superior to any mathematical equation. (You'll rarely hear that claim from a graduate-level educated engineer.)

In addition, this text has been designed to be the most student friendly of all biomedical electronics troubleshooting books published. The chapters flow from elemental to more complex concepts. Each chapter outlines its objectives and ends with review questions over chapter material.

The authors would like to thank Glen Ridings, TSTC Waco Electronics Core, for his invaluable expertise by reviewing chapter content throughout the book. Mr. Ridings is a long-time electronics and semiconductor instructor and is a living testimony to the knowledge you can retain if you have a passion for a subject matter combined with high personal standards.

We would also like to thank Mark Long, our publishing manager, editor, sounding board, and overall source of inspiration. Mr. Long is our standard bearer and this book is a testament to his perseverance.

Nicholas Cram
Selby Holder

Chapter 1: Electric Shock & Industrial Safety Systems

After completing this chapter you will have an understanding of:

- *Electrical shock hazards associated with the repair of electronic components*
- *Electrical monitoring and protection devices used to create a safe environment wherever electronic devices may be used*
- *The one-hand rule for personal protection from shock hazards, when repairing electronic components*
- *The skin effect of electrical current*
- *Voltage potentials*
- *National Fire Protection Association Section 99 electrical safety requirements for medical devices*
- *The purpose of grounding*

Safety Practices

Voltage Potentials

Voltage potentials are created when the voltage at one point is higher than a voltage at another point with respect to the reference point or ground. Potential differences in voltage due to variable grounding sources create a unique hazard with electronic devices. The common reference point for a voltage potential may be the facility electrical conduit, the facility plumbing fixtures, the device associated with patient or consumer use, or other persons in contact with any combination of the above reference points.

Voltage potentials can be created during the renovation or new construction associated with the same electrical path. Old wiring that has become corroded or worn wiring insulation can also be sources of voltage potentials. Any of these combinations cause a difference in the resistance of the current path.

Because of the potential harm related to electric shock, special equipment and facility design consideration and monitoring instrumentation are required for both electronic devices and the facilities where they are located. The best electrical safety system in a facility is a well-trained staff.

Safety: The One-Hand Rule

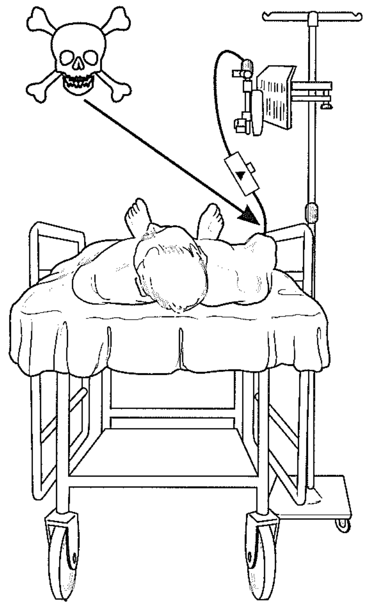
Due to the many hazards related to repair and maintenance of medical and consumer electronic devices, special safety rules such as the one-hand rule have been developed.

The premise of the one-hand rule states that when inserting tools or touching any component of a device, one hand should be held purposefully away from the device and only the tool-holding hand has a possibility of contact with electric current. This prevents the creation of a completed circuit across the chest and heart and returning through the chassis (conductive case) of the device.

Figure 1.01

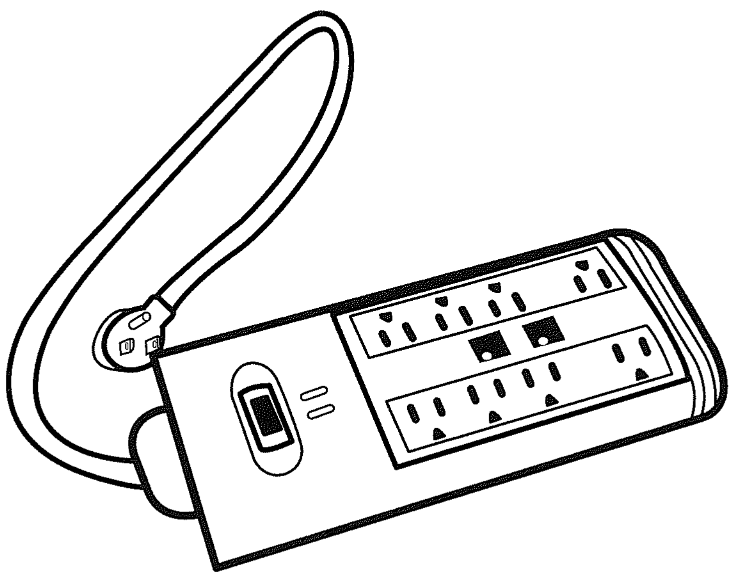
Patients are most susceptible to voltage potentials and current leakage when there is a nonstandard method of common grounding. All medical devices, electric beds, and other electronic devices (e.g. televisions) in a common room should have a common grounding reference. This is especially important if housekeeping enters a patient room with a high-voltage device such as a buffer, or in circumstances where portable high-voltage medical devices such as ultrasound or X-ray units are used at the patient's bedside. If a voltage potential develops and the metal portion of a bed becomes part of the circuit, microshock (a shock across the heart) could occur.

Figure 1.02



A 10μV voltage potential could cause cardioversion.

Figure 1.03 **Common power bus**



Multiple connections to power buses can create potential safety hazards from power cords crossing in the same area and also as a fire hazard due to high currents flowing into one circuit.

Intravenous (IV) lines represent one of the most serious hazards of leakage current and grounding potentials in the health care environment. An IV line provides a direct path to the heart. A current of 1OμA can cause cardioversion (interruption of the heart beat) if leakage current enters the intravenous catheter site.

The electrical panel should accommodate the required current and the grounding of all receptacles should have a common reference. A visitor, physician, or nurse can provide a source of electrical continuity between any bedside device and the bed railing or patient if the grounding is not unified.

Macroshock and Microshock

Electric Shock

Electric shock is an unwelcome and avoidable physiological response to current. Electrical stimulation may cause a cellular depolarization due to a change in membrane potential by approximately 20%. The result can range from muscle contraction, injury, or death from cardiac failure or respiratory failure.

Macroshock is a physiological response to a current applied to the surface of the body (e.g. hand) that produces an electrical shock resulting in an unwelcome and avoidable physiological response to current and unwanted and unnecessary stimulation, muscle contractions, or tissue damage.

Microshock is a physiological response to current applied to the surface of the heart that results in electrical shock as an unwelcome or avoidable physiological response to current and unwanted or unnecessary stimulation, muscle contractions, or tissue damage. In contrast to macroshock, microshock occurs with currents as low as 10μA.

The Skin Effect

The effect of electricity on a body structure is related to the magnitude and the frequency of the electrical current. As frequency increases in a conductor, the current tends to flow near the surface. This is known as the skin effect if electrical current contacts a person. High frequency currents have a lower penetration through the skin. Low frequency currents have a higher penetration through the skin.

Electrical safety tests are scheduled on a regular basis for medical equipment in order to protect patients, staff, and visitors in the hospital from becoming shocked. The scheduled maintenance including electrical safety tests and operational tests are known as preventive maintenance (PM). The accepted values for an electrical safety test are listed in Table 1.01.

Devices deemed non-medical equipment by the manufacturer may exceed the recommended 500 μA limit if reasonable grounding precautions are in place or isolation transformers can be implemented. This situation may occur with personal devices that patients, visitors, physicians, or staff members bring into the hospital.

ALL devices must be tested by the clinical engineering department for mechanical and electrical safety when entering a medical facility. Video cameras, radios, electric razors, electric hair dryers, laptop computers, and electronic video games commonly fall into this category.

Health-care facilities have become "hospitality-friendly" in all aspects of accommodation.

Devices that are battery operated pose little or no threat to patient safety due to power isolation. Therefore, battery operated power should be encouraged if personal electronic items are approved for use in the hospital. In addition to the electrical hazard, there is also a bio-contamination hazard when personal items penetrate the skin or an open wound. Bacteria or viruses from the personal item may be transferred to the body of the patient, staff, and/or visitors.

Table 1.01 **NFPA Section 99 (1993 ed.) maximum allowable values for ground impedance and leakage current of medical devices**

Maximum safe testing values for electronic connections of medical devices

Ground integrity	(new) .15 Ω	(used) 0.5 Ω
Wet Areas (hydrotherapy)		100 μA
General portable equipment		300 μA
Non-patient care areas		500 μA
	closed	open
Lead to Ground	10 μA	50 μA
Lead to Lead	10 μA	50 μA
ISO		50 μA

Table 1.02 **Electric current values and associated physiological effects on the body**

Body Response	Current in mA	Category of Current
Tingling or prickly feeling	1-5	Threshold
Physical pain	5-8	Pain Intensity
Muscles contract involuntarily [considered very dangerous since you can't let go of the object]	8-20	Let go
Muscles in the lungs become paralyzed – pain	>20	Paralysis
Uncontrollable contractions of the ventricles (large muscles) of the heart	80-1000	Fibrillation
Heart ventricles remain contracted, external burns, shock, death	1000-10,000	Defibrillation

Monitoring & Testing Devices

Ground Fault Current Interrupters

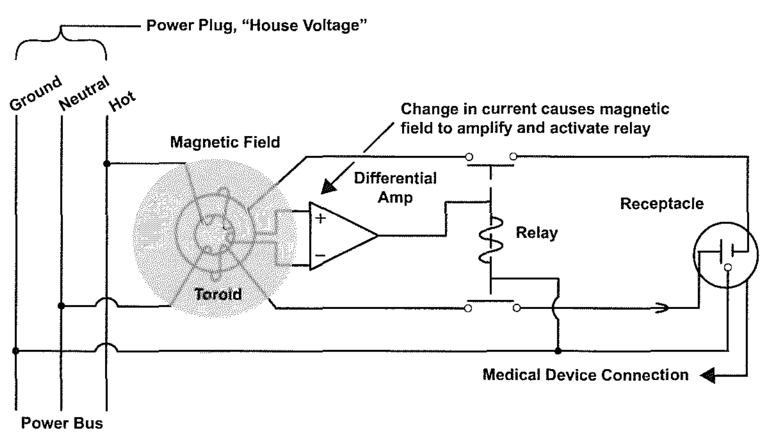
A ground fault current interrupter (GFCI) is the most common safety device found in hospitals. The National Electric Code (NEC) also requires GFCIs in residential (home) hazardous areas. All wet areas of the hospital require GFCI receptacles.

A typical wet area in a hospital would be a hydrotherapy room or patient shower. A GFCI prevents the possibility of electric shock if both the ground and hot leads come in contact with the body simultaneously. Refer to the Figure 1.04 of a ground fault current interrupter.

If there is a difference of approximately 6 mA for at least 0.2 seconds between the hot lead and the neutral lead, the sensing amplifier (differential amplifier) will cause both the hot and neutral contacts to open, shunting all electric current to the ground circuit. The sensing circuit utilizes an equal number of wire turns of the hot and neutral wires in opposite directions around a magnetic core (torroid). In the normal state, the inputs to the differential amplifier are equal and therefore the ideal output is zero (current in = current out). The creation of another circuit path in either the hot wire (input) or neutral wire (output) causes a current imbalance at the differential amplifier (Kirchhoff's Current Law), which results in an output of electric voltage from the differential amplifier to the solenoid relay, opening the contacts.

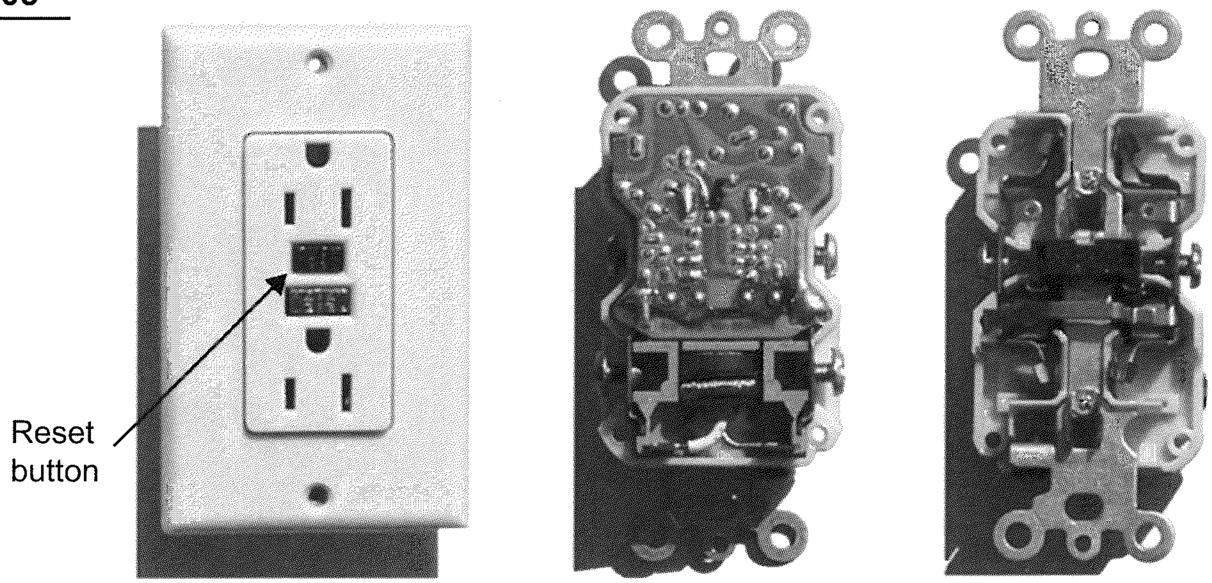
Figure 1.04 **Diagram of a ground fault current interrupter (GFCI)**

The two coils around the torroid are wrapped in opposite directions from the hot and neutral wires. Without loading, the corresponding output is zero volts. If either side of the coil has an increase or decrease in current due to loading, then the relay will be magnetically energized, shunting the output current to ground.



GFCIs are never used in an operating room setting. If current flow is interrupted to a surgical device during a procedure, there may be serious consequences or even death. If there is a problem with the circuit breaker or a medical device in a wet area of the surgical suite, it will be attended to immediately following the completed surgical procedure.

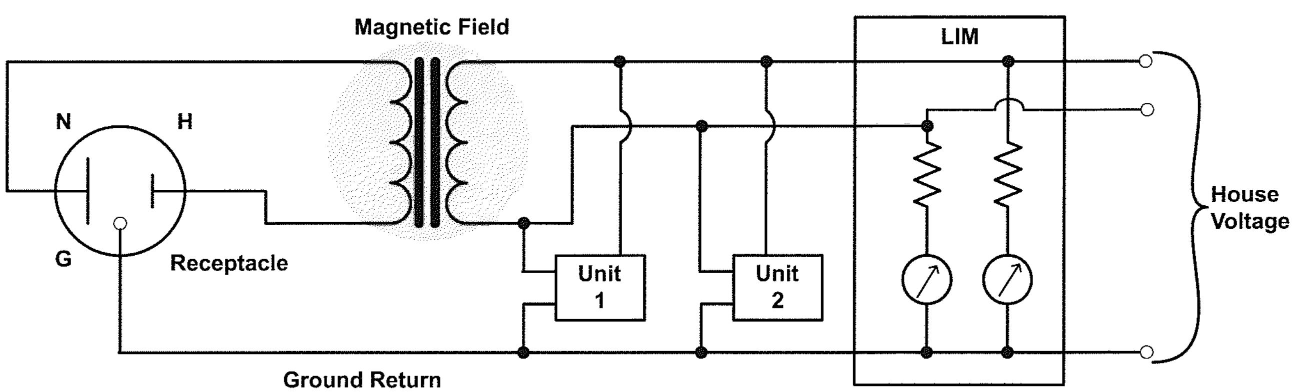
Figure 1.05 **GFCI wall outlet and inner circuit**



Line Isolation Monitors

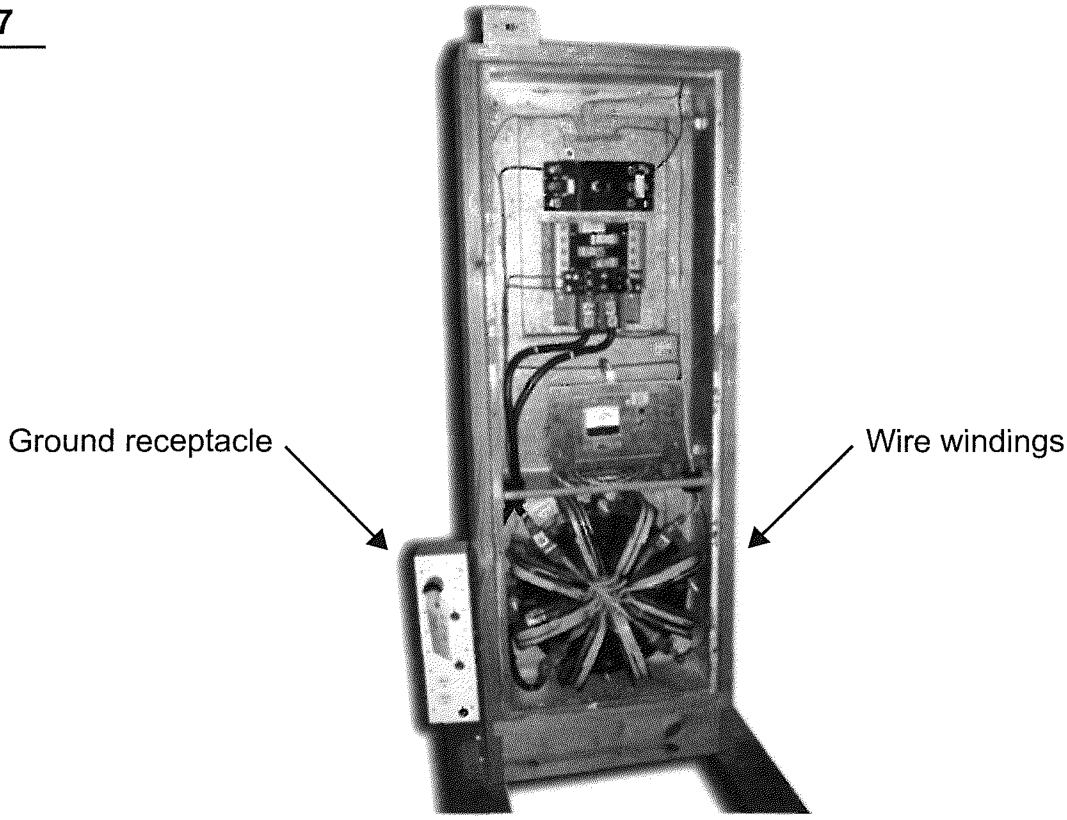
Line isolation monitors (LIMs) are normally found in critical areas such as the operating room of most hospitals. The purpose of the LIM is to monitor differences between the impedance in the hot and neutral leads of a particular device or room circuit. This is accomplished by measuring the difference in impedance between the hot lead through an ammeter to ground and current flowing from the neutral lead through an ammeter to ground. If this difference exceeds a certain limit, normally 2-5 mA of current, an alarm is sounded. A LIM will not shunt current away from the circuit as in the case of a GFCI. An alarm does not necessarily mean that the system must be shut down. In critical cases, power can remain on to allow surgical procedures to be completed.

Figure 1.06 **Diagram of a line isolation monitor**



Line isolation monitor connected to medical devices (Unit 1 & Unit 2) commonly found in operating room settings for surgery and obstetrical operating suites.

Figure 1.07 **Line isolation monitor with visible coil**



Isolation of power sources to prevent the hazard of electrical shock is an important consideration in the design of medical devices. Medical device and facility design methods to provide patient isolation from leakage current will be presented in detail in the following sections covering power supplies. Note that the wire windings on the equipment side of the isolation transformer are grounded to the ground receptacle of the power plug.

Electrical Safety Analyzer

Electrical safety analyzers are used as part of an on-going preventive maintenance (PM) program and also to test devices entering a healthcare facility. The basic safety tests performed are 1) ground integrity (impedance from ground pin to chassis) and 2) leakage current (the unintentional flow of current from the chassis to the ground pin). This current may be due to mechanical disruptions or capacitive inductance. (Refer to NFPA 99 standards in Table 1.01.)

The device to be tested is plugged into the safety analyzer receptacle. All current entering the device being tested must first pass through the safety analyzer.

Leakage current is obtained with an open ground and either open hot or open neutral (forward and reverse current flow occurs in either position). Ground integrity is obtained by placing one lead test probe on the chassis or ground pin, with both neutral and hot leads open. In the calibration (Cal) position a normal reading should be 1 mA.

Figure 1.08 **Block diagram of medical device in position to perform electrical safety test**

Note: Safety analyzer is positioned between wall outlet and the device to be tested.

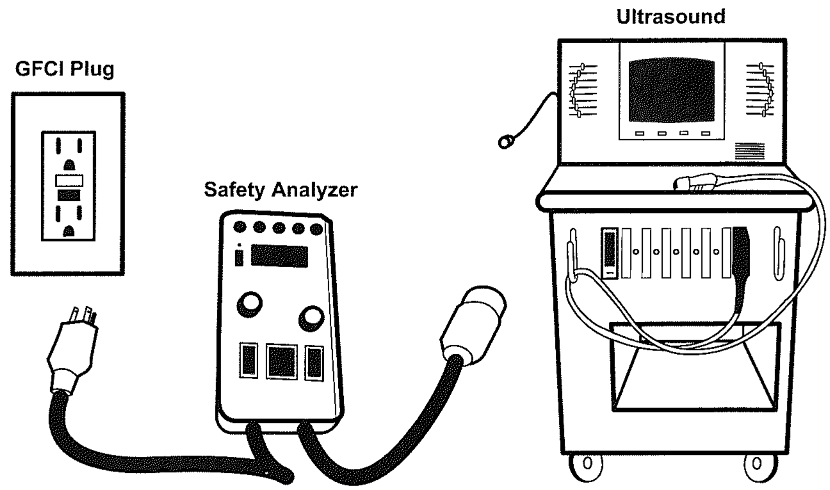
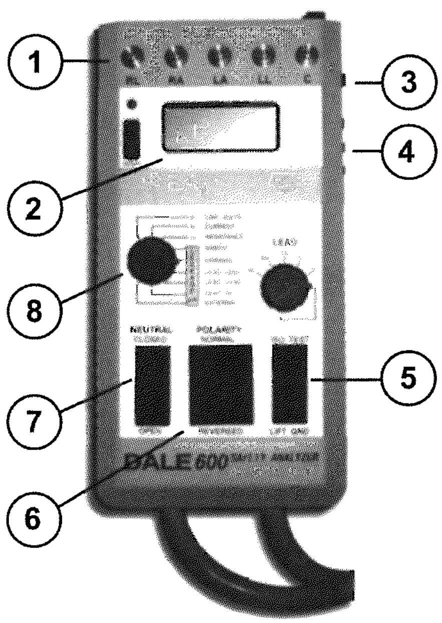


Figure 1.09 **Safety analyzer**



1. **ECG CONNECTORS:** Snap-on connectors to ECG leads.
2. **DISPLAY:** Shows result of the selected test measurement.
3. **LOAD SELECTOR SWITCH:** Selects the AAMI or the IEC 601-1 test load.
4. **TEST JACKS:** Calibrated outputs for resistance (1 Ohm) and leakage current (200 µA).
5. **GROUND SWITCH:** Temporarily opens the ground connection from device to analyzer.
6. **POLARITY SWITCH:** Selects Normal and Reverse polarity of the test receptacle and turns power off.
7. **NEUTRAL SWITCH:** Temporarily opens the neutral line from device to analyzer.
8. **SELECTOR SWITCH:** Selects desired test mode.

The Concept of Grounding

Normally, medical devices will be plugged into house voltage and therefore a brief review of electrical wiring and outlets is in order. All plugs used for medical devices must be heavy-duty, designed for extreme conditions and labeled (or equivalent to) hospital grade.

Hospital grade specifications are referenced in the National Electric Code (NEC), American National Standards Institute (ANSI) section C73, and the National Fire Protection Agency (NFPA) 70, section 410. The notation for hospital-grade power plugs is a green dot near the outside center of the hub. All hospital-grade power plugs must be the three-pronged variety. Most commercial electronic devices are equipped with two-prong plugs. This can present some safety concerns if these devices are brought into hospitals.

Three-Prong Plugs

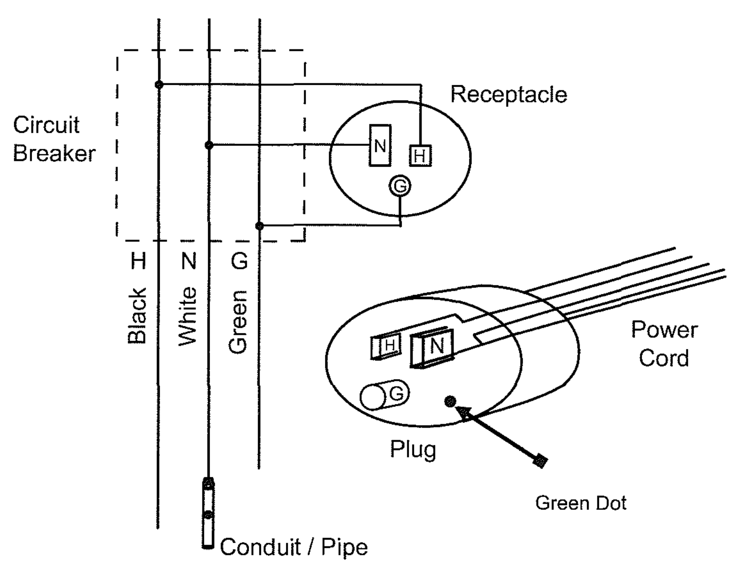
Refer to the diagram of the three-pronged plug in Figure 1.10. The three wires connected to the three metal prongs are known as hot(H), neutral(N), and ground(G).

The hot wire is colored black for North American manufactured devices and brown for European and Japanese manufactured devices. It is called hot to describe it visually as delivering current flow into the device (conventional or Franklin current flow reference).

The neutral wire is colored white for North American manufactured devices and blue for devices manufactured in Europe and Japan. This wire is called neutral to describe visually an acceptance of current flow from the device (conventional or Franklin current flow reference). The hot and neutral wires are connected to the flat-spade prongs. The third wire (ground) is connected to the oval mid-line prong. North American made devices have solid green colored ground wires. European and Japanese manufactured devices have green with a yellow spiral stripe(s) to denote the ground wire. At the outlet, the hot wire will run through the conduit from the main power source for the facility. The neutral and ground wires run as parallel circuits, with the neutral wire acting as the return circuit for the power source and the ground wire attaches to conduit which has an eventual connection to a metal stake in the earth, hence the term "ground wire." If the neutral wire becomes broken, current will flow to the ground wire. Lowered resistance increases the current through the hot wire, which is always connected to a fuse. When the current limit of the fuse is exceeded the fuse element will open causing the device to shut down. If the ground wire isn't available on the device, anyone touching the outer shell (chassis) or any conductive area would act as the ground wire in the absence of a neutral wire path, and the current would flow through the body. Ground wires also carry current away from the chasis if the hot wire breaks and touches the chassis.

Figure 1.10 **Hospital grade power plug and corresponding wall outlet**

Hospital-grade plugs are certified by Underwriters Laboratories and require stringent physical specifications and testing.



A green dot on the outer ring of the plug indicates that the plug is of hospital-grade quality. Hospital-grade quality electrical materials require more rigorous testing than those of consumer devices and are rated as Underwriters Lab (UL) quality.

Glossary of Important Terms

Electric shock: An electrical shock is an unwanted or unnecessary physiological response to current.

Ground fault current interrupters: GFCIs are the most common safety device found in hospitals and prevent the possibility of electric shock if both the ground and hot leads come in contact with the body simultaneously. All wet areas of the hospital require GFCI receptacles. (A typical wet area in a hospital would be a hydrotherapy room or patient shower.)

Ground wire: Neutral and ground wires run as parallel circuits, with the neutral wire acting as the return circuit for the power source and the ground wire attaches to the chassis.

Hot wire: Called hot to describe it visually as delivering current flow into the device (conventional or Franklin current flow reference).

Line isolation monitors: LIMs are normally found in critical areas such as the operating room of most hospitals. The purpose of the LIM is to monitor differences between the currents in the hot and neutral leads of a particular device or room circuit.

Macroshock: A physiological response to a current applied to the surface of the body that produces unwanted or unnecessary stimulation, muscle contractions, or tissue damage.

Microshock: A physiological response to current applied to the surface of the heart that results in unwanted or unnecessary stimulation, muscle contractions, or tissue damage. In contrast to macroshock, microshock occurs with currents as low as 10 mA.

Neutral wire: Called neutral to describe visually an acceptance of current flow from the device (conventional or Franklin current flow reference). The neutral and ground wires run as parallel circuits, with the neutral wire acting as the return circuit for the power source, and the ground wire attaches to conduit which has an eventual connection to a metal stake in the earth, hence the term ground wire.

One-hand rule: When inserting tools or touching any tool make sure only the holding hand has a possibility of contact with electric current. This prevents the creation of a completed circuit across the chest and heart and returning through the chassis (conductive case) of the device.

Safety analyzers: A test device used as part of an on-going preventive maintenance (PM) program and also to test devices entering a healthcare facility. The basic safety tests performed are 1) ground integrity (impedance from ground pin to chassis) and 2) leakage current (the unintentional flow of current from the chassis to the ground pin).

Voltage potentials: Created when the voltage at one point is higher than a voltage at another point with respect to the reference point or ground.

Additional Suggested References

Aston, Richard. *Principles of Biomedical Instrumentation and Measurement.* New York: Macmillan, 1990.

National Fire Protection Association. *National Electrical Code 2005 Handbook.* Thomson Delmar Learning, 2005.

National Fire Protection Association. *NFPA 99: Standard for Health Care Facilities.* 2002.

CHAPTER ONE REVIEW QUESTIONS

Name:____________________________

Date: ____________________________

1. Explain the difference between microshock and macroshock.

2. How does the one-hand rule provide protection from macro and microshock?

3. Explain the principle of operation of a ground fault current interrupter (GCFI).

4. Where would you expect to find GFCIs in the hospital setting?

5. Explain the principle of operation of a line isolation monitor (LIM).

6. Where would you expect to find LIMs in the hospital setting?

7. What is the purpose of a safety analyzer?

8. Draw a power cord used for a medical device and identify the hot, neutral, and ground wires and corresponding plug pins.

9. What does the term "ground" or "grounding" mean?

LABORATORY SAFETY RULES

1. Safety is everyone's responsibility.
2. No food, drinks, or tobacco allowed in labs.
3. No horseplay.
4. Safety glasses are required. If you do not bring your safety glasses you will not be permitted to work.
5. Remove watches and jewelry.
6. Do not perform inspections or work on equipment when you are wet or sweaty.
7. Practice the one-hand technique when performing testing on energized equipment as it may be defective and pose a serious shock hazard.
8. Familiarize yourself with the equipment you are testing and the test equipment BEFORE testing.
9. Do not leave your workstation without first removing power from the equipment you're working on.
10. Clean your lab work area before leaving.
11. Wash your hands.
12. Stay sharp. Be aware of what is going on in your surroundings.
13. Any other policies and rule established by the lab instructor must be followed.

I have read and understand the policy and rules stated above:

Print Name: ______________________ Date: ____________

Signature: ________________________

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CHAPTER 1 LABORATORY EXERCISE 1.1

Name:______________________________

Date:_______________________________

Objectives

After performing this lab, you will be able to:

1. Draw a simple electrical circuit with necessary safety devices for a wet care area of a hospital.
2. Draw a simple GFCI receptacle circuit in the normal position and in the fault position.
3. Explain the steps you would take to correct an open GFCI receptacle/circuit.
4. Measure the resistance using your digital multimeter (DMM).

Reading

Electroic Shock and Industrial Safety Systems

Lab materials

Stranded 16 AWG wire
Student's index finger

Procedures

1. Draw a simple electrical circuit for a hydrotherapy room in a hospital. Use a minimum of five receptacles for the step. Draw the circuit in the space provided below.

2. Using the knowledge from Electroic Shock and Industrial Safety Systems, draw a ground fault circuit interrupter (GFCI) in the normal position. Next, draw the GFCI as it would appear if water were to enter the wall outlet containing the GFCI. Draw both circuits in the space provided below.

3. Using your DMM, test the resistance of your index finger. Place the negative lead at the base of your finger and measure to the tip of your finger. Write this value in the area below.

4. Next measure about a half-inch from the end of your finger towards your knuckle. Write this value in the area below. Compare your values to those of your other classmates.

5. Why are the values from step 3 and 4 different from you other classmates?

Measurement from the base of your finger to the tip of your finger.	
Measurement from the middle of your finger to the base of your hand.	

6. Measure the resistance of a two-foot insulated stranded wire with your DMM. Write this value in the area below.

7. Cut the wire in half and twist the two ends together. Remeasure the wire with your DMM. Write this value in the area below.

8. Explain the difference in the resistance.

Measurement of a two-foot insulated strand of wire.	
Measurement of a two-foot insulated wire cut and tied together.	

Lab Review Questions

1. What is the purpose of a GFCI receptacle in a hospital?

2. What happens to the resistance of a stranded wire when the length is increased?

3. Does a GFCI measure resistance or current?

4. Does the GFCI measure between ground and the hot and neutral or between the hot a neutral?

5. The neutral and __________run parallel and are tied together in the breaker panel.

CHAPTER ONE LABORATORY EXERCISE 1.2

Name:____________________________

Date: _____________________________

Objectives

After performing this lab, you will be able to:

1. Identify and explain the usages of an electrical safety analyzer.
2. Inspect and test two electrical receptacles using a safety analyzer.
3. Inspect and test one piece of designated general equipment using the safety analyzer.

Reading

Electroic Shock and Industrial Safety Systems

Lab Materials

Designated safety analyzer
Technical literature for the analyzer
Designated piece of medical equipment

Procedures

1. Observe the demonstration of the safety analyzer by the instructor.
2. Read the technical literature (handout) for the analyzer you will use.
3. Become familiar with the controls on the analyzer.
4. Make a simple receptacle polarity and line voltage check on an electrical outlet at or near your station and indicate the results below.

Plug #: ____________

Polarity: ___________ OK: _________________

Reversed: ____________

Open Ground: ________

Line Voltage: _______

5. Measure the ground resistance and chassis leakage current on the designated piece of equipment. Record the results below. 22

Type of equipment:______________________________

Grounding Resistance:___________________________ ohms

Chassis Leakage to ground (UUT on): _____________ Ungrounded _________

Chassis Leakage to ground (UUT off): ___________ Ungrounded _________

Chapter 2: Reading Electronic Schematics

After completing this chapter you will have an understanding of:

- *The application of resistor values*
- *Common electronic symbols as they appear on an electronic schematic*
- *Necessary electronic symbols to complete the circuits of an electronic schematic*
- *The application of troubleshooting from Basic Troubleshooting Methods, based on an understanding of complete circuits of an electronic schematic*

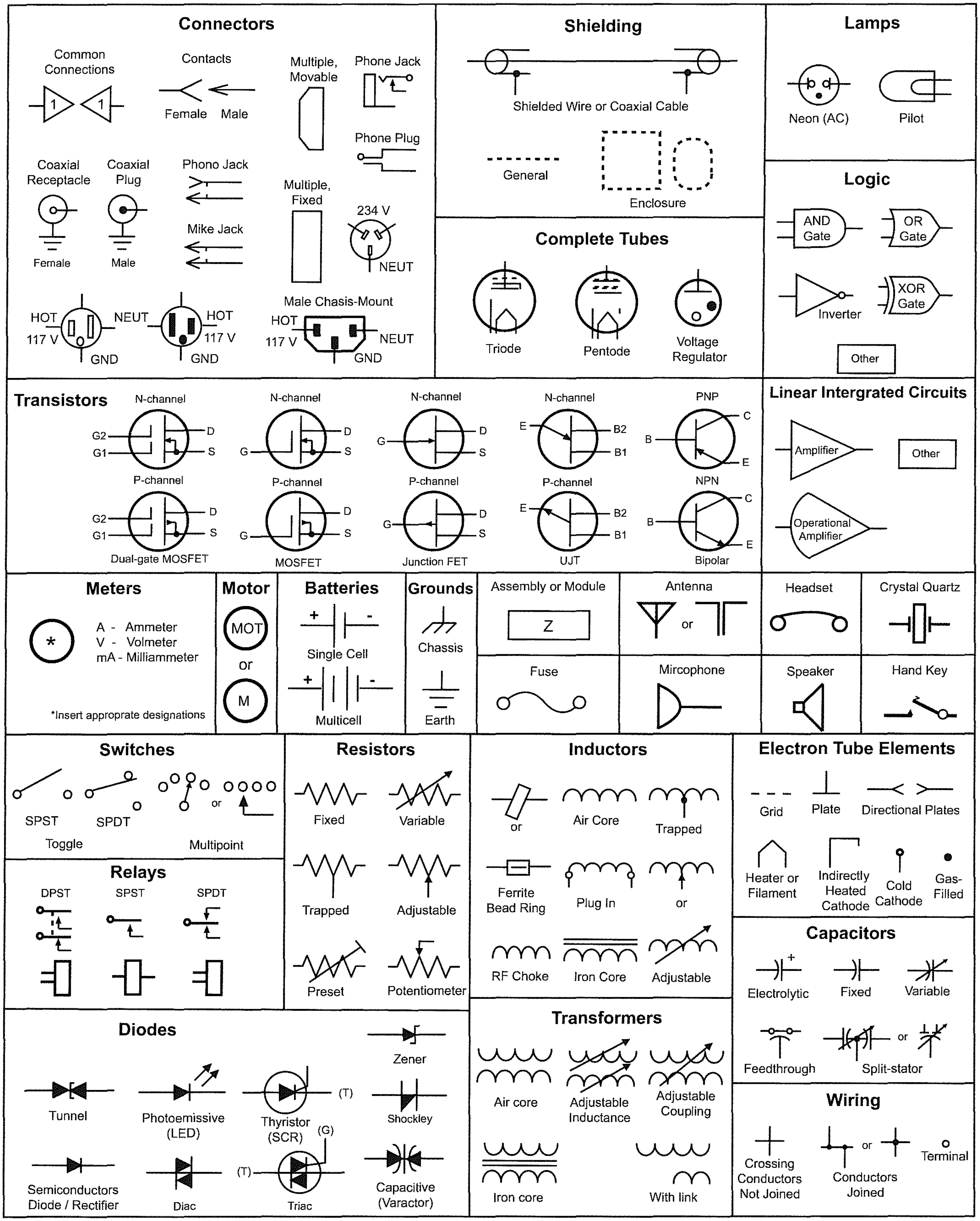
How to Read Electronic Schematics

Electronic troubleshooting requires expertise and understanding of electronic schematics. The electronic schematic is a representation of the actual circuit in a written, symbolic form. Schematics provide technicians with a tool to isolate and repair electronic devices. The symbols on the schematic are similar to words in a book. Therefore, the process of understanding how each electronic symbol relates to the entire circuit or a portion of the circuit is known as "reading" the schematic. The first step in reading an electronic schematic is a thorough understanding of electronic symbols. If you don't understand electronic symbols, it's much like reading a book and not understanding some of the words in the book. You must understand the electronic symbols in order to understand the function of the electronic circuit. If the circuit functions improperly, there must be a problem in one of the components in the circuit. It's also possible that an adjoining electronic circuit is damaged and is causing problems which create abnormal voltages or signals in other circuits.

Each component on the electronic schematic will be labeled. The alpha-numeric (letter-number) system used on the schematic is also found on the parts list. Reading the parts list allows a technician to replace the exact component by manufacturer and specification. The parts list also provides a corresponding value to each component found on the schematic.

Reading electronic schematics is an art form. To become competent in understanding electronic schematics and how they relate to abnormal outputs, you must practice the reading process. Over time, you will become proficient at this process and your troubleshooting skills will improve.

Common Electronic Symbols

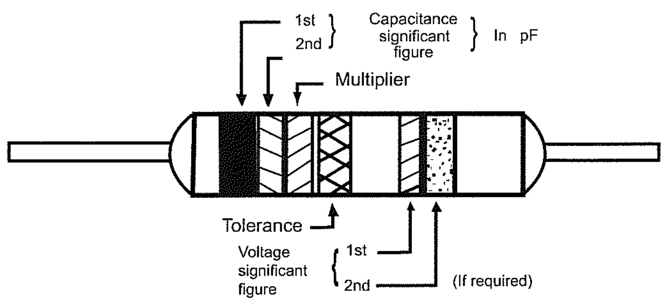


Understanding Resistor Values

Resistors are components in an electronic circuit that resist the flow of electric current. The power supply will lose some of its potential energy (voltage) as the electric current flows through a resistor. This is commonly known as a "voltage drop." Fixed value resistors have color bands that indicate the resistance value in ohms and the tolerance as a percent of indicated value.

Resistors also range in size to indicate the power in watts for various circuit load requirements. The most common resistor used in electronic circuits is made of molded carbon. High quality resistors are available for precision circuits with extremely low tolerances in the tenths of a percent up to one or two percent of indicated value. Most of these resistors are constructed of coiled wire (usually platinum) with a polymer or ceramic coating.

Figure 2.01



Band Color Code	Significant Figure	Decimal Multiplier	Tolerance ±%
Black	0	1	20
Brown	1	10	–
Red	2	100	–
Orange	3	1,000	30
Yellow	4	10,000	40
Green	5	10^5	5
Blue	6	10^6	–
Violet	7	–	–
Gray	8	–	–
White	9	–	10

The illustration in Figure 2.02 shows a resistor with six color bands that determine the magnitude in ohms and the fourth band, which determines the tolerance.

Figure 2.02

Resistor

Resistor Value Codes

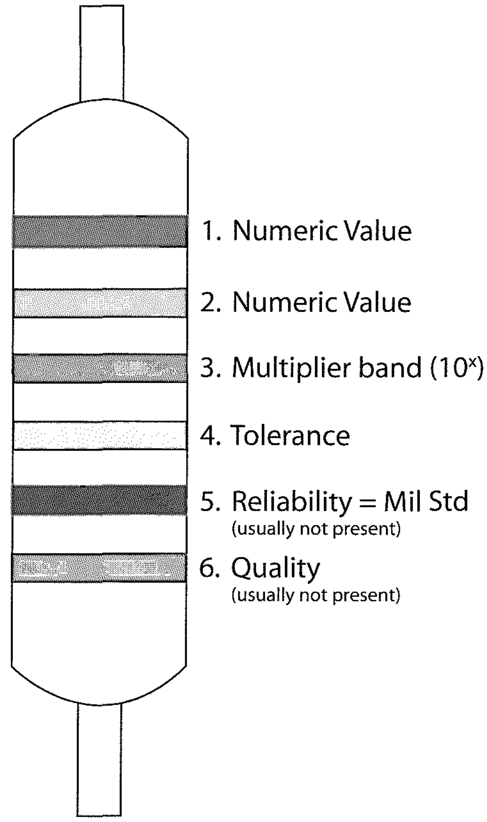
Black = 0
Brown = 1
Red = 2
Orange = 3
Yellow = 4
Green = 5
Blue = 6
Violet = 7
Gray = 8
White = 9
Gold = 10^{-2} } Used in band 3 only
Silver = 10^{-1} } Used in band 3 only

Tolerance Codes (Band 4)

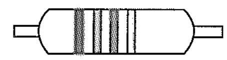
(Plain) Brown = ± 20%
Silver = ± 10%
Gold = ± 5%

*Quality resistors ± 1% stamped on resistor

(Example 1, 2, 3, . . . etc.)



Example 1



Band 1 = Blue = 6
Band 2 = Brown = 1
Band 3 = Red = 1×10^2
Resistor value = 61×10^2 = 6100
Band 4 = Gold = ± 5% tolerance

Therefore, resistor value is 5795Ω - 6405Ω

Example 2

Band 1 = Yellow = 4
Band 2 = Violet = 7
Band 3 = Green = 1×10^5
Resistor value = 47×10^5 = 4.7 megaohms
Band 4 = Silver = ± 10% tolerance

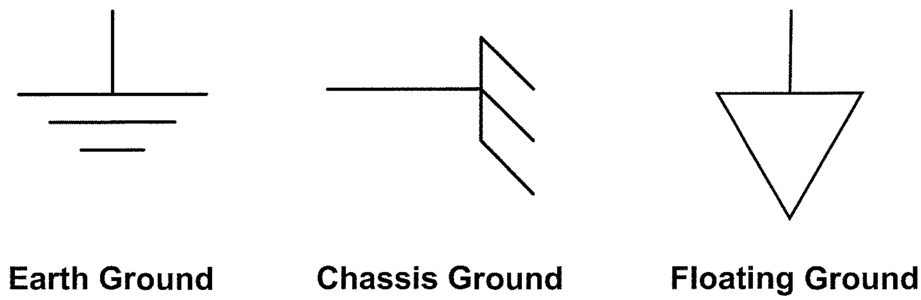
Therefore, resistor value is 4.23 megaohms or 5.17 megaohms.

Reference "Ground"

The term "ground" is probably the most misused and misunderstood term in electronics nomenclature. True "ground" is an earth ground (refer to Electric Shock and Industrial Safety Systems, Figure 1.10). This refers to a circuit path connected to the device that will carry current to an actual metal stake in the ground. All electrical circuits in a home or commercial facility have a true ground as part of the circuit breaker system. The round pin on a power plug connects to a wire that is attached to the chassis of a device. The current that flows out of the chassis to the ground pin of the power cord is known as "leakage current." When the power plug is inserted into the wall socket, the ground pin connects to a circuit, usually through a strap connected to metal pipe or conduit that eventually travels to the true ground metal stake in the ground.

Chassis ground refers to internal wires of a device that connect to the chassis or case of a device and the green or green with yellow stripe wire on the power cord. A third type of ground that is commonly seen represented on electronic schematics is the isolated or floating ground. These three grounds (earth, chassis, and floating) represent reference points for potential voltage in the circuits of the device. You should never use the earth ground as a test point reference for a circuit that displays a floating ground on the schematic. Your meter may create a current path that causes a large current surge and damages the circuit board. The symbols below illustrate the three ground symbols.

Figure 2.03



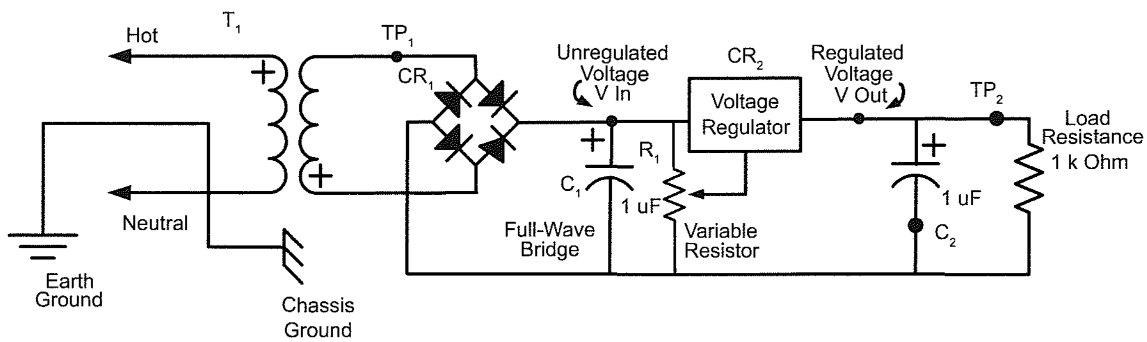
Troubleshooting Techniques With Electronic Schematics

Reading the schematic allows a technician to visualize the actual electronic circuit in an organized manner. Schematics from the manufacturer usually provide test points (TP) in the circuit. Test points (TP) will be clearly marked on the electronic schematic. The test point on the schematic corresponds to a physical point on the electronic device that a measurement can be taken. Most test points are listed as voltage. The test point voltage indicates the value that should appear at that physical location on the circuit with respect to reference ground (eg. chassis or isolated). Using the half-step method, if you measure a test point with your DMM you have started the troubleshooting isolation process.

After looking at the environment where the electronic device is operating, you can determine if there is an electronic problem. Match the electronic problem to the area corresponding to the electronic schematic. Match the symptoms of the problem with common failures of the components in that region of the circuit.

You should always use the half-step method described in Basic Troubleshooting Methods to isolate the problem. Take measurements of the components to determine the actual cause of the failure.

Figure 2.04 **Linear power supply schematic**



Glossary of Important Terms

Electronic schematic: The symbolic written form of an electronic circuit.

"Reading" the schematic: The process of understanding how each electronic symbol relates to the entire circuit or a portion of the circuit.

Resistors: Components in an electronic circuit that "resist" the flow of electric current.

Test point: A physical point on the electronic device that corresponds to the schematic where measurement can be taken of expected values.

CHAPTER TWO REVIEW QUESTIONS

Name:______________________________

Date:______________________________

1. What is the resistor value and tolerance of resistors with the following color bands?

   a. red-red-green-silver ____________ ohms _________%

   b. brown-black-black ____________ ohms _________%

   c. white-brown-silver-silver ____________ ohms _________%

   d. violet-yellow-gold____________ ohms _________%

   e. gray-white-green-gold ____________ ohms _________%

   f. orange-blue-gold-silver ____________ ohms _________%

   g. red-red-red ____________ ohms _________%

   h. brown-white-white-gold ____________ ohms _________%

   i. orange-orange-gold-gold ____________ ohms _________%

   j. black-brown-black ____________ ohms _________%

2. List the resistor color codes for the following resistor values.

   a. 1000 ohms @ 10% ____________________

   b. 12 ohms @ 20% ____________________

   c. 1 Megaohm @ 5% ____________________

   d. 0.5 ohm @ 5% ____________________

   e. 2300 ohm @ 20% ____________________

3. Draw the appropriate electronic symbol for the following electronic components.

   a. diode

   b. NPN transistor

   c. Resistor

d. Capacitor

e. N-channel JFET

f. P-channel CMOS transistor

g. Inductor

h. Potentiometer

i. Variable resistor

j. Light emitting diode

k. Photo transistor (NPN)

l. SCR

m. Transformer

n. Zener diode

o. Fuse

p. DPDT switch

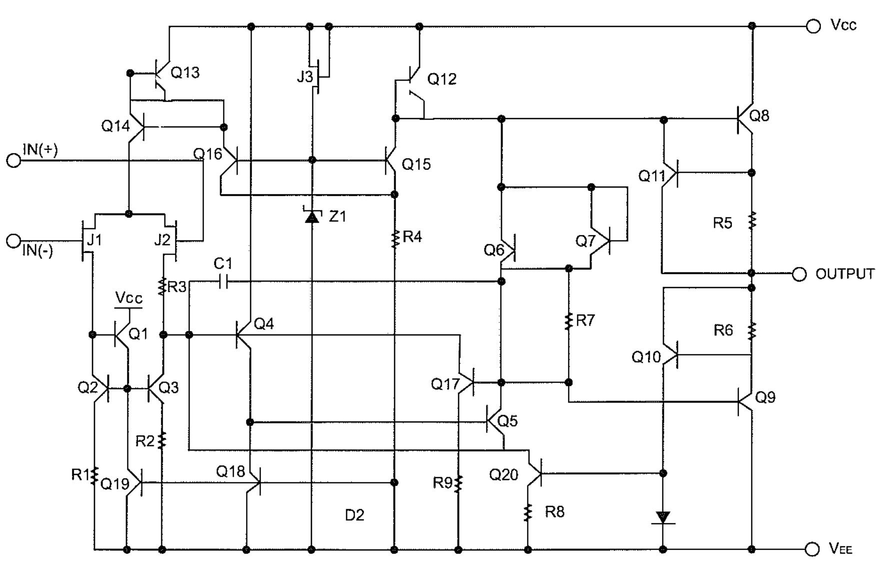
q. STDP switch

r. Earth ground

s. Chassis ground

t. Isolated ground

4. In the schematic below circle Q1, C1, Vcc, Z1, and R5.



Chapter 3: Alternating & Direct Current Theory

After completing this chapter you will have an understanding of:

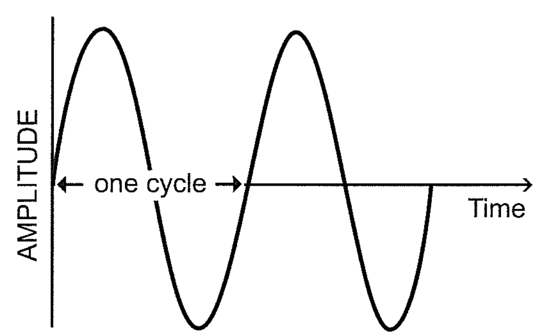
- *The difference between alternating current (AC) and direct current (DC)*
- *The relationship between frequency and AC voltage*
- *The relationship between frequency and DC voltage*
- *The components in a circuit that are related to AC voltage*
- *The components in a circuit that are related to DC voltage*
- *The use of Ohm's Law and Kirchhof's Law for electronic troubleshooting*

House Voltage

Alternating Current and Voltage vs. Direct Current and Voltage

The electrical current supplied from the local power company to the wall outlet of your house (house voltage) is known as alternating current (AC). AC current and voltage occurs as a sine wave (the letter "s" tilted sideways) as shown below at a frequency of 60 cycles per second (CPS). A cycle (one full wave form) per second is measured in a unit known as Hertz (Hz). The graph below illustrates how one waveform of house voltage would appear on an oscilloscope.

Figure 3.01

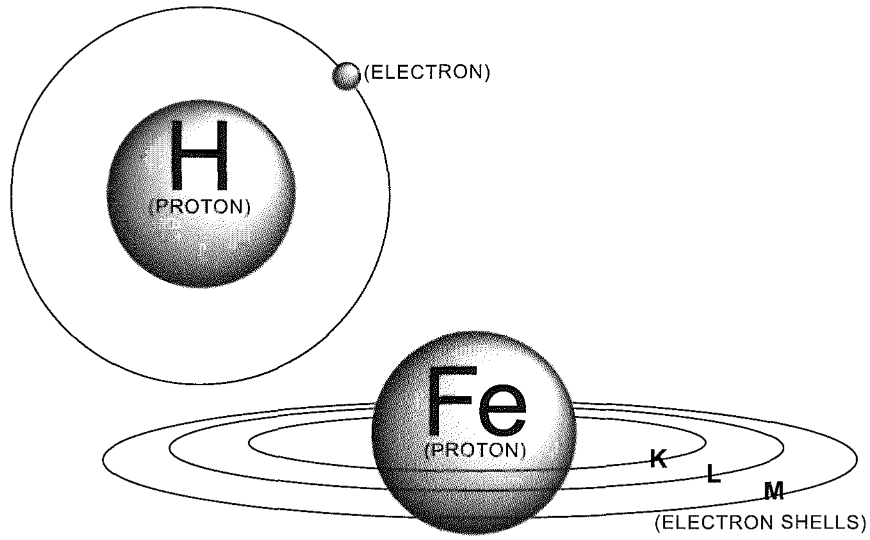


Sine wave cycles of alternating current (AC)

This would appear 60 times (cycles) in one second if you recorded the waveform of house voltage or 60 Hertz (Hz).

Electricity is an invisible force caused by attraction or repulsion of electrons and protons in an atom. Electrons have a negative charge and protons have a positive charge.

Figure 3.02

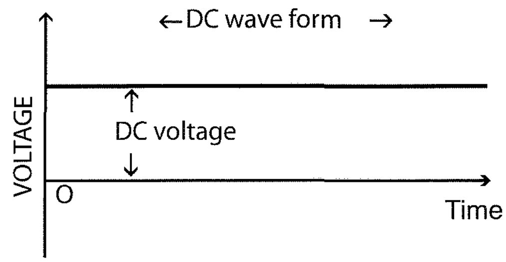


The difference in the number of electrons and protons in a certain amount of space creates a voltage potential. A fixed voltage potential has a positive terminal, which has more protons than electrons, and a negative terminal, which has more electrons than protons. The electrons from the negative terminal are attracted to the protons from the positive terminal. This movement of electrons is known as current flow. Negative charges repel other negative charges and are attracted to other positive charges. Therefore, an electron flow is created between the negative and positive terminals. This unidirectional flow (flow in one direction) is known as direct current (DC) flow.

Frequency and AC Voltage vs. Frequency and DC Voltage

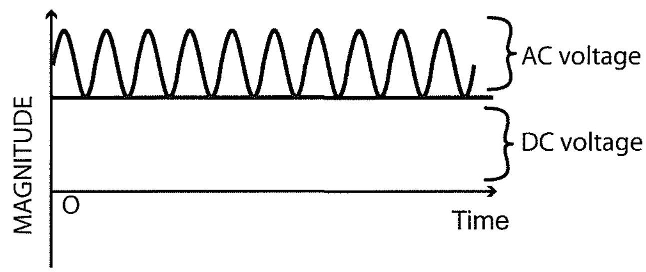
AC current and voltage has a voltage size or magnitude and a frequency (waveform in cycles per second). DC current and voltage have a current and voltage size or magnitude but the frequency is considered to be zero. This means that DC current and voltage does not fluctuate. The voltage and current from a battery is DC. DC current and voltage appear on the oscilloscope as a straight line as shown in Figure 3.03.

Figure 3.03



If there is a mixture of AC and DC voltage, it would appear on an oscilloscope similar to Figure 3.04 below.

Figure 3.04



AC/DC Voltage and Current: Ohm's Law (V = IR)

AC current and voltage have both a positive and negative component as the waveform moves up and down. AC current and voltage are delivered to a facility from the electric power company and each individual machine converts the AC voltage to the required DC voltage using a power supply. (Power supplies will be discussed in detail in Introduction to Power Supply Components and Introduction to Power Supplies.)

Voltage is a potential energy that becomes a force when a conductor (material that allows the flow of electrons) is present between a negative and positive pole or point on the circuit. The flow of electrons, which becomes a force, is called current. It is important to remember when troubleshooting that a potential voltage (AC or DC voltage) can exist without current if there is no pathway between the two points (poles), but if current is present voltage must be present. Theoretically, it is possible to show by an equation known as Ohm's Law that current exists without voltage. This requires that no resistance is present in the pathway of current flow. This is a major difference in concept between applying troubleshooting methods and the theory of electronics. One equation that you must be familiar with in troubleshooting electronic devices is Ohm's Law (V = IR). In other words, this equation means that the voltage present is equal to the amount of current flow multiplied by the resistance to the current flow. Theoretically, if there is voltage present, there must be current and resistance. When measuring with a multimeter across a fuse, the meter will read zero if the fuse is good and read a potential voltage value if the fuse is bad. These concepts will be further illustrated in your laboratory exercises.

AC current and voltage are generally associated with electric motors and compressors. Most of the appliances in your home utilize AC current and voltage. Most medical devices utilize DC current and voltage. Electric motors will be discussed in detail in Troubleshooting Electronic Motors.

Kirchoff's Laws

Voltage Law

The sum of the voltage drops in a closed circuit is zero. There is a very important concept in physics introduced by Albert Einstein that states "Energy can neither be created nor destroyed." This concept is important to understand in electronics.

Current Law

According to Kirchoff's Current Law, the total amount of current entering a conductor must be equal to the total amount of current coming out of a conductor. As an example, if you have a water hose connected to several sprinkler heads, the force of the water running through the hose will be the same as the amount of force of water running through all the sprinklers added together. If you have a set amount of current flowing into an electronic circuit, you can't increase or create more current coming out of the circuit.

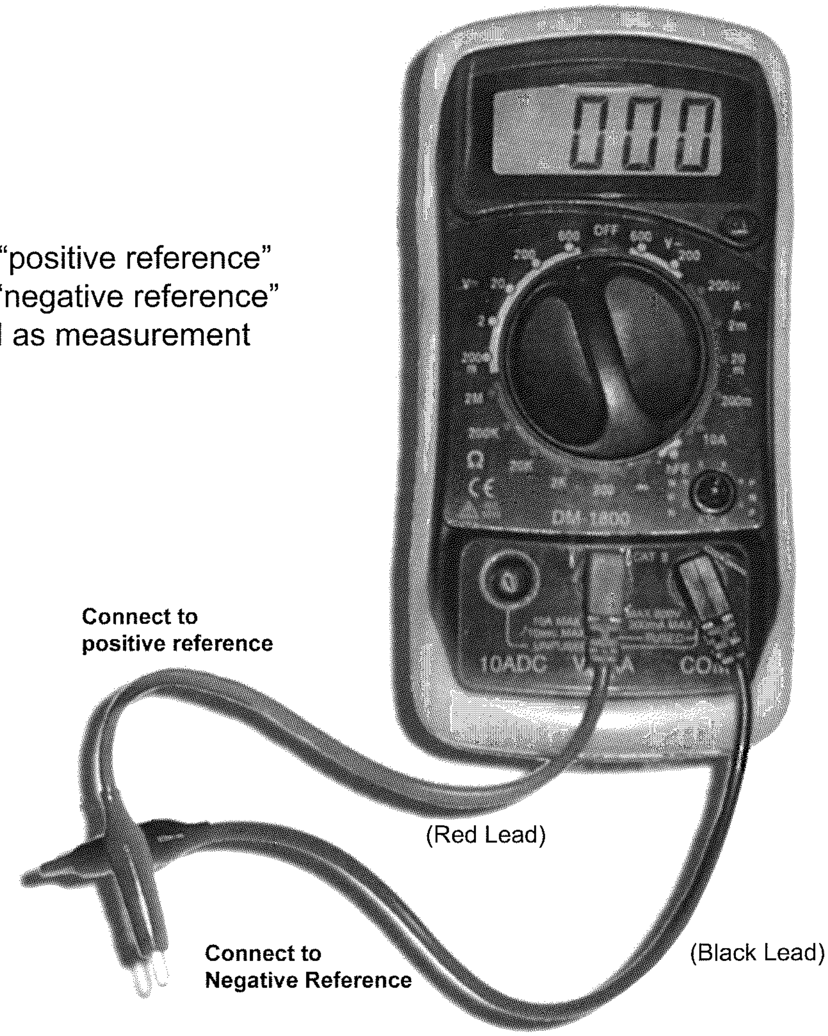
Using the Digital Multimeter

The digital multimeter (DMM) or digital volt meter (DVM) is the most important electronic troubleshooting tool in your tool inventory for purposes of troubleshooting electronic failures.

The DMM is a versatile hand-held measurement instrument that allows a technician to determine AC and DC voltage and current, resistance and, on some meters, capacitance, transistor tests, diode tests, and current and voltage frequency. You must understand the concepts of electricity in order to utilize the DMM to its maximum potential. A picture of a DMM is shown in Figure 3.05A, with references to the desired measurement.

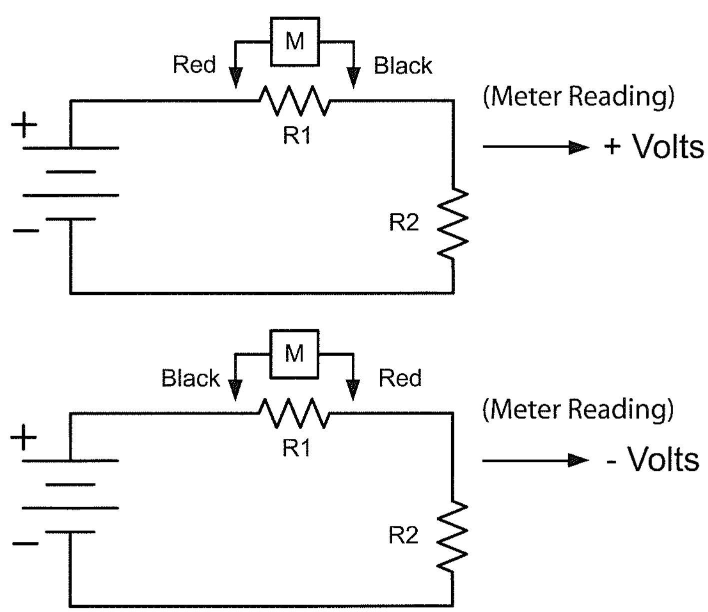
Figure 3.05A **Hand-held digital multimeter**

Note: The red "positive reference" and the black "negative reference" leads are used as measurement "references."



Example: If your DMM displays a negative voltage, it is negative only in respect to the position of each lead.

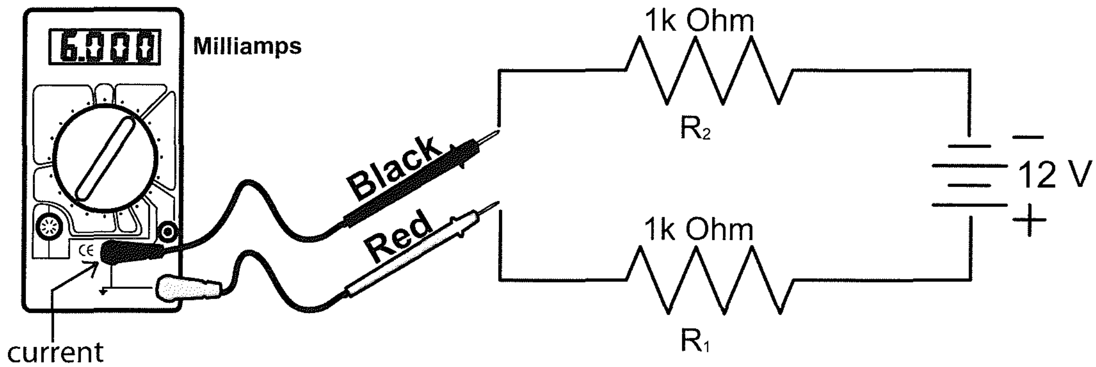
Figure 3.05B



There are a few safety rules to remember when using the DMM. Take measurements with the device powered off if possible. This will allow you to take resistance measurements. Some electronics schematics will have test points (TP) that require the device to be powered on. Always use the one-hand rule and remove all jewelry or objects that can conduct an electrical current.

Current must be measured with the meter in series position with the circuit as shown below.

Figure 3.06

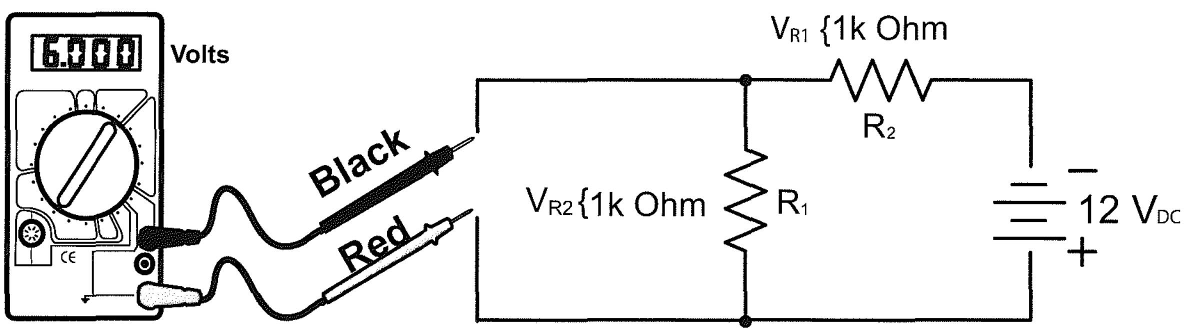


$$\text{Ohm's Law} = \frac{12\ \text{V}}{2000\Omega} = 6\ \text{mA}$$

This is usually not practical when repairing a device, since the circuit would need to be intentionally "broken" in order to connect the DMM.

Voltage is measured with the meter in parallel with the circuit or component to be measured.

Figure 3.07



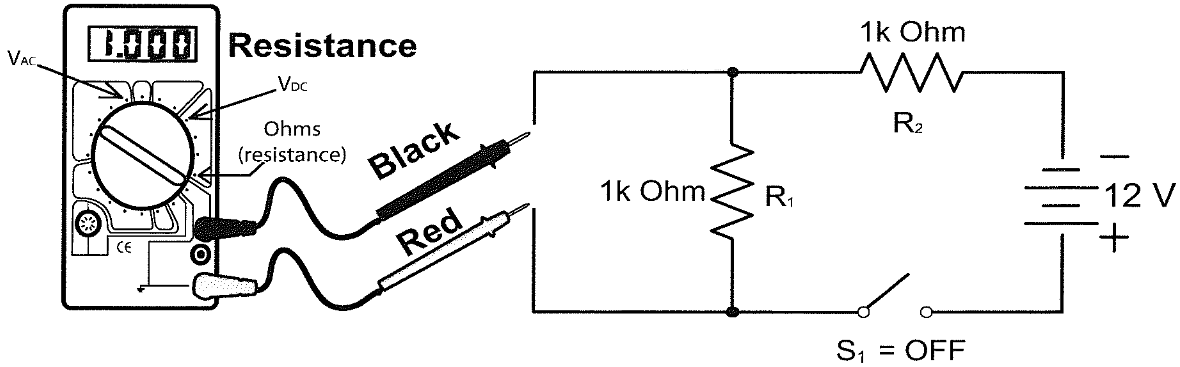
Ohm's Law says $V = IR$, but since $R_1 = R_2$, $V_{R1} = \frac{1}{2}\,V\ \text{Total} = 6V$

$$V_{R1} + V_{R2} = 12\ V_{DC}$$

Due to the extremely high internal resistance of the DMM (several hundred megaohms) the meter will not alter the current or voltage of the circuit and allows for a very precise measurement. Inexpensive DMMs will not have as many features or the larger internal resistance of more expensive meters. The added features aren't always necessary, but the internal resistance known as "impedance" is very important.

Resistance is also measured with the meter in parallel with the circuit, but the circuit is powered off.

Figure 3.08



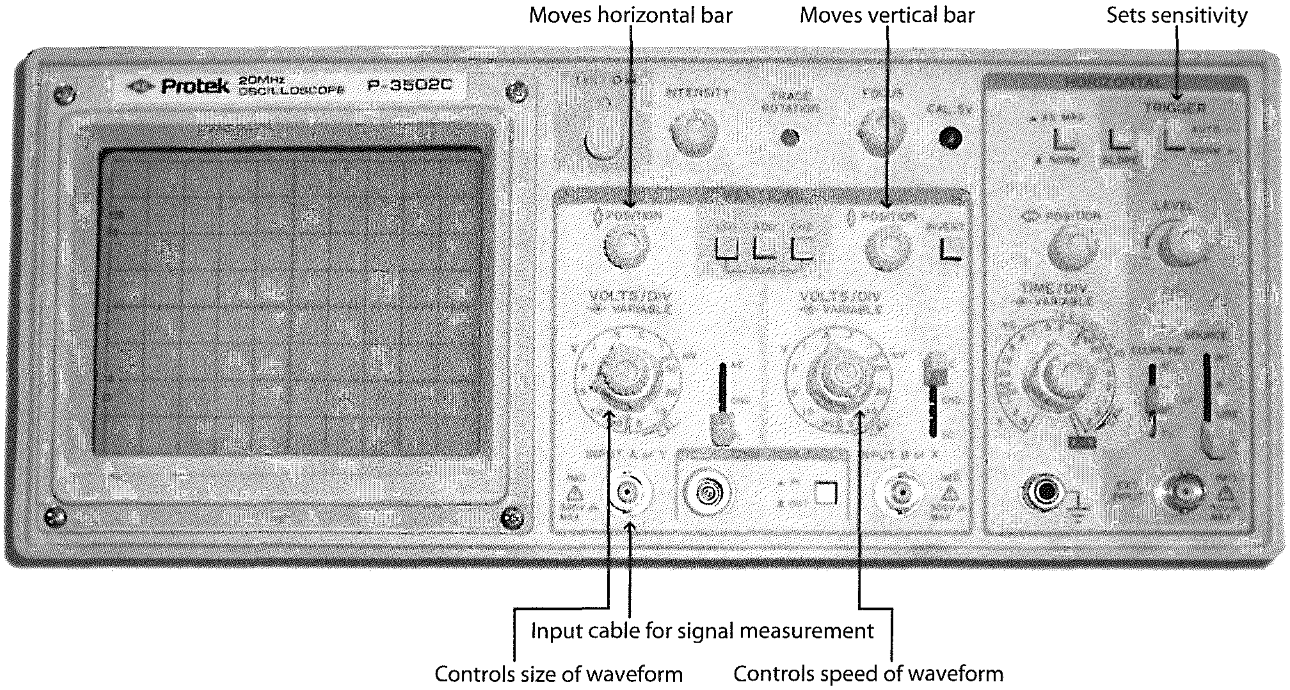
Always measure resistance with power off. Resistance measured = 1k Ohm.

The most common mistake made by persons unfamiliar with the DMM is in ensuring that the meter selection is in the proper position for the desired measurement. Placing the DMM on DC voltage when measuring AC voltage will normally produce a reading of zero volts. And likewise when measuring DC voltage with the meter in the AC voltage position produces a very small voltage measurement in a DC circuit.

Using the Oscilloscope

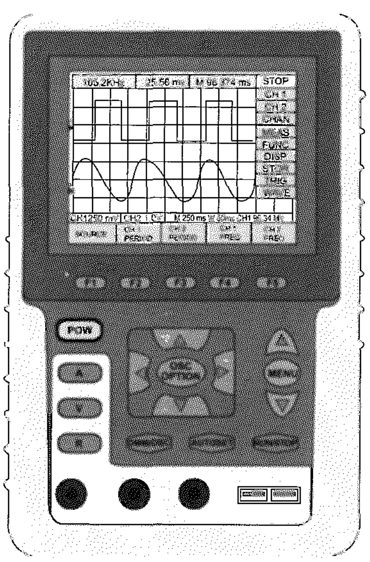
The oscilloscope is an important "bench" electronic troubleshooting tool. The oscilloscope provides an actual picture of the waveform you are testing. There are some hand-held oscilloscopes on the market, but most electronics and biomedical repair shops have the larger bench-type. Oscilloscopes are useful for electronic troubleshooting of devices that produce oscillating (up-and-down) waveforms that may vary with time. Oscilloscopes also allow the technician to view both the DC and AC voltage at the same time. This is important when you learn about DC offset and AC "ripple," which will be covered in Introduction to Power Supply Components and Introduction to Power Supplies when discussing power supplies, operational amplifiers, and transistors. The best means of learning how to use both the DMM and the oscilloscope is through laboratory hands-on exercises.

Figure 3.09 **Bench oscilloscope**



Oscilloscopes are essential for troubleshooting signal processing and AC voltage.

Figure 3.10 **Hand-held oscilloscope**



Glossary of Important Terms

AC (alternating current) and voltage: Voltage and current size or magnitude with a frequency (waveform in cycles per second) that moves in a wave-like fashion, creating a constant change in polarity from positive to negative.

Kirchoff's Current Law: The total amount of current entering a conductor must be equal to the total amount of current coming out of a conductor.

Digital multimeter (DMM) or digital volt meter (DVM): The most important electronic troubleshooting tool in your tool inventory for purposes of troubleshooting electronic failures. The DMM is a versatile hand-held measurement instrument that allows a technician to determine AC and DC voltage and current, resistance and, on some meters, capacitance, transistor tests, diode tests and current and voltage frequency.

Frequency: The number of times one complete waveform appears in one second (cycles per second).

Hertz: A cycle (one full wave form) per second.

Current flow: The movement of electrons or charge through a conductor (measured in amps as a force).

Oscilloscope: A full-screen analog measurement device that provides an actual picture of the waveform under test. There are some hand-held oscilloscopes on the market, but most electronics and biomedical repair shops have the larger bench-type. Oscilloscopes are useful for electronic troubleshooting of devices that produce oscillating (up-and-down) waveforms that may vary with time. Oscilloscopes also allow the technician to view both the DC and AC voltage at the same time.

Resistance: The opposition to the flow of electrons.

Voltage: A potential energy, which has a capacity to do "work."

Additional Suggested References

Boylestad, Robert, *Introductory Circuit Analysis*. Columbus, OH: Merril, 2002.

Floyd, Thomas, *Principles of Electric Circuits.* NJ: Prentice Hall, 1997.

Fowler, Richard, *Electricity Principles and Applications.* NY: Glencoe, 1999.

CHAPTER THREE REVIEW QUESTIONS

Name:____________________________

Date: _____________________________

1. What is the frequency of a DC waveform?

2. House voltage in the U.S. has a frequency of __________ hertz.

3. A normal "sine" wave has a DC voltage of ___________ volts.

4. Explain the difference between current and voltage.

5. Explain why resistance is a factor in determining current and voltage.

6. Why must current be measured in "series" with a device?

7. Why is voltage measured in parallel with a component?

8. If you have a DMM with a low internal resistance, what effect will that have on your measurements?

9. If you wish to measure an AC waveform, explain the advantages of using the oscilloscope.

10. Draw the waveform seen on an oscilloscope for a 120 Vac, 20 hertz signal for 3 seconds.

LABORATORY SAFETY RULES

1. Safety is everyone's responsibility
2. No food, drinks, or tobacco allowed in labs.
3. No horseplay.
4. SAFETY GLASSES are required. If you do not bring your safety glasses you will not be permitted to work.
5. Remove watches and jewelry.
6. Do not perform inspections or work on equipment when you are wet or sweaty.
7. Practice the "one-hand" technique when performing testing on energized equipment as it may be defective and pose a serious shock hazard.
8. Familiarize yourself with the equipment you are testing and the test equipment BEFORE testing.
9. Do not leave your workstation without first removing power from the equipment you're working on.
10. Clean your lab work area before leaving.
11. Wash your hands.
12. Stay sharp. Be aware of what is going on in your surroundings.
13. Any other policies and rule established by the lab instructor must be followed.

I have read and understand the policy and rules stated above:

Print Name:_______________________ Date: ____________

Signature: ________________________

CHAPTER THREE LABORATORY EXERCISE

Name:____________________________

Date: ____________________________

Instructor Materials

Oscilloscope lab
Resistor kit

Student Materials

Digital multimeter
Protoboard

Procedures

1. Demonstrate your knowledge of the oscilloscope by measuring signals from a signal generator.

2. Draw the waveforms seen on the oscilloscope.

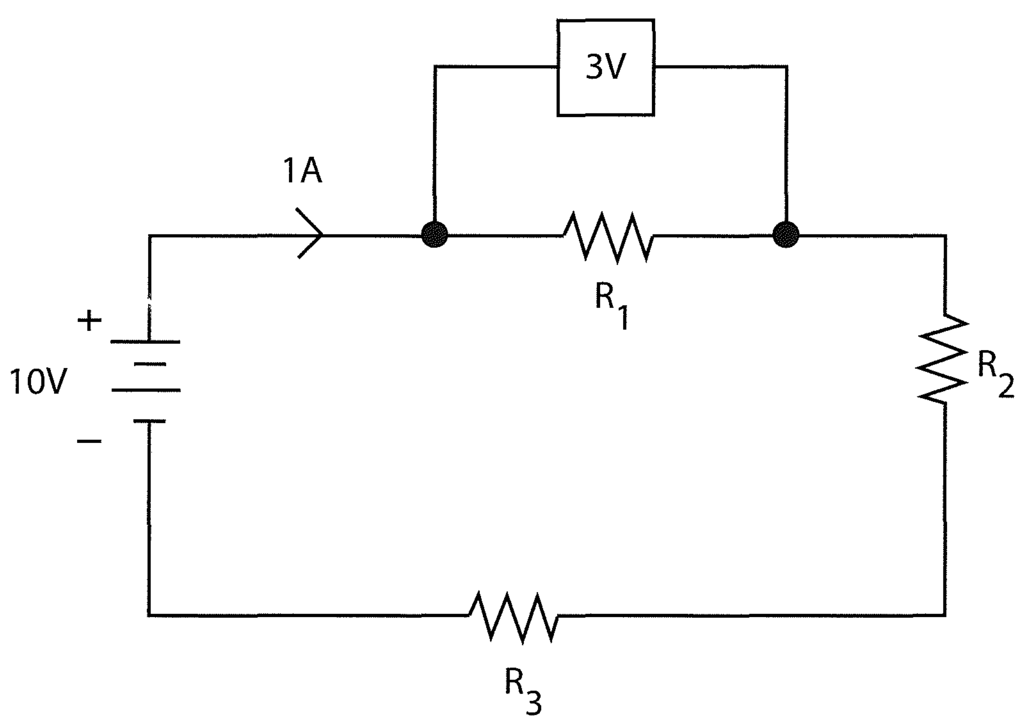
3. Review the simple DC resistor circuit in figure 3L-1 and determine the expected value for R1. What is the voltage drop for $V_{R_2} + V_{R_3}$?

4. Build the circuit shown below in figure 3L-1.

5. Demonstrate your knowledge of the DMM by measuring the voltage drops across the simple DC circuit you have just built on a protoboard from figure 3L-1.

6. Are your answers in question #3 the same as your answers in question #5? Explain.

Figure 3L-1



Chapter 4: Basic Troubleshooting Methods

After completing this chapter you will have an understanding of:

- *Problem-solving techniques for efficient repair of medical devices*
- *Common causes of device failure*
- *Failure modes*
- *Applying the "half-step" troubleshooting method*
- *Recognizing circuit loading and correcting the problem*

Survey the Environment

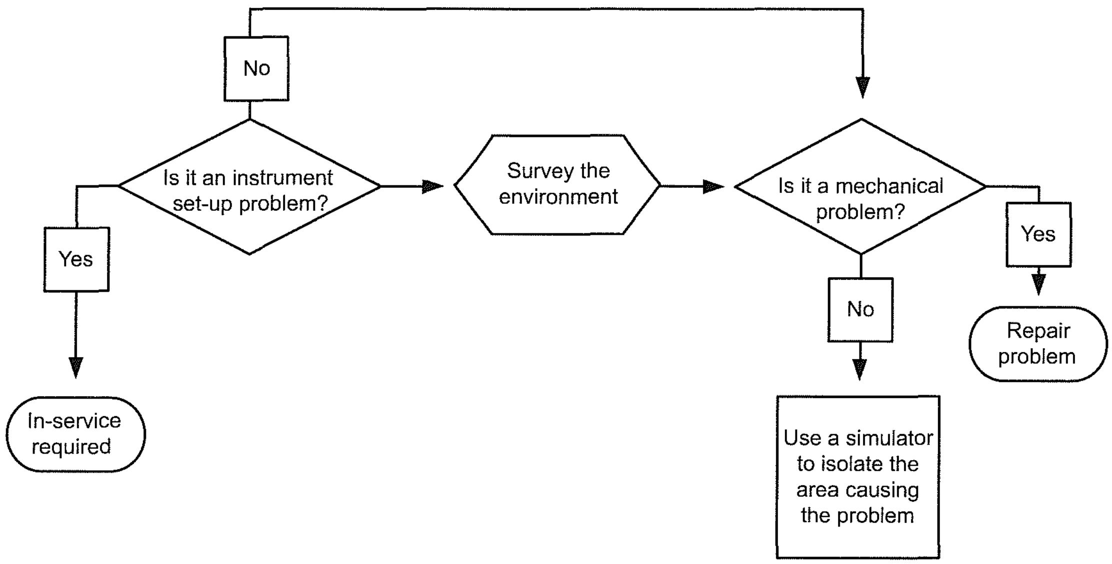
Troubleshooting medical devices requires an extensive knowledge of what the device is suppose to accomplish and how it performs that particular task or tasks. Most medical device problems are a result of the device user's misunderstanding of how or what the device is capable of doing or a minor mechanical problem. Broken wires, switches in the wrong position, power plugs which have become detached from the wall outlet, and/or drained batteries make up the bulk of medical device repair problems. A good biomedical technician should always survey the environment where the equipment is located as a first step in troubleshooting. Contacting the user who initiated the complaint is also very important. The person who requests service is usually the one who witnessed the failure. This makes equipment operators one of the best troubleshooting aids a technician can have. Many problems may be resolved or prevented by providing user information. In the healthcare setting this is known as an "in-service."

If you receive a call for failed equipment, ask the attending nurse or other health care personnel directly involved with the use of this equipment as many questions as possible about the conditions involved prior to the failure (e.g. did it make funny noises, smoke came out, smelled something, what were you attempting to do with the machine when it failed?). Look at the environment that the equipment was exposed to and assess possible failure modes (e.g. dust build up, water on floor).

Check for physical damage. If nothing looks unusual upon physical inspection, look at the maintenance history of the device. Many times this can save hours of frustrating troubleshooting. If a failure occurred once, it is likely to occur again.

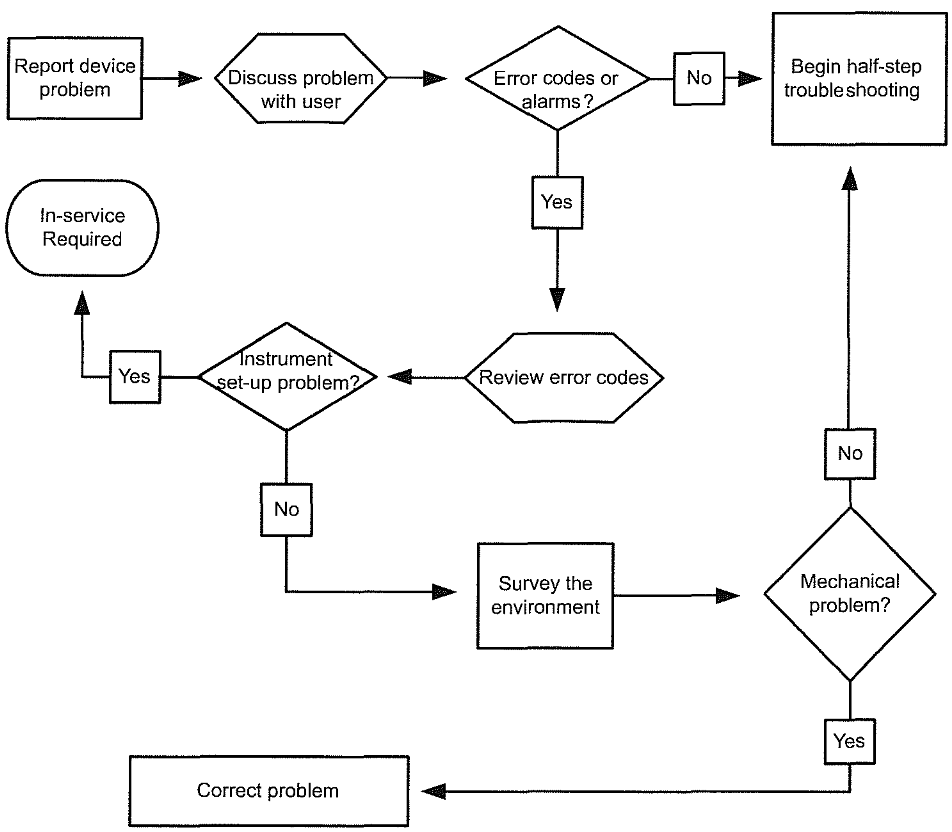
Call the original equipment manufacturer (OEM) and ask for technical support. Many times if you describe the symptoms of the failure they can quickly have you directed towards the problem. Remember, the technician at the other end of the phone can make suggestions but you have knowledge of electronics also. Don't sell yourself short. If technical support says something that you know to be incorrect, don't be afraid to challenge the reasoning. Always be polite. You'll get better and quicker service by acting professional in all conversations dealing with technical support personnel.

Figure 4.01



Once the problem has been identified as an electronic failure, your knowledge of electronic components and systems (board-level) troubleshooting can be utilized.

Figure 4.02



Remember: The user is a troubleshooting tool, not "The Enemy."

Understanding Failure Modes

Medical Equipment Repair & Troubleshooting

The order of most likely failure to least likely failure is:

1. Clinical failure (Use error)

2. Mechanical failure

3. Electromechanical failure

4. Electronic failure

Clinical Failure—Use Error

This category is the highest probable cause of medical equipment failure. Clinical failure includes:

1. Patient abuse

2. Set-up error

3. Displayed outputs do not agree with expected clinical results

4. Machine is asked to perform a function it is incapable of

Mechanical Failure

A mechanical failure is a physical breakage at some area of the device. Also it could be a disconnected harness connection in any circuits of the device. Mechanical failures and clinical failures cause the majority of all equipment complaints. Always look for obvious physical damage externally. Cords which can be run over and power cord connections are always good candidates for mechanical damage. Equipment with long hoses or cords attached to the patient may become entangled and cause the equipment to be pulled from shelves or cause tipping of caster-mounted devices.

Electromechanical Failure

Most medical devices contain electromechanical components in the form of electric motors and relays. There are many devices which utilize relays. Centrifuges in the clinical lab contain many relays, and lid latch components. Relay and relay switching devices are the main source of electromechanical failure. Basic knowledge of electric motors, generators, and motor controls is essential for repair of these types of problems. Proper lubrication and cleaning prevent most of these failures. A good preventative maintenance (PM) program is highly cost effective and provides a means of inventory control.

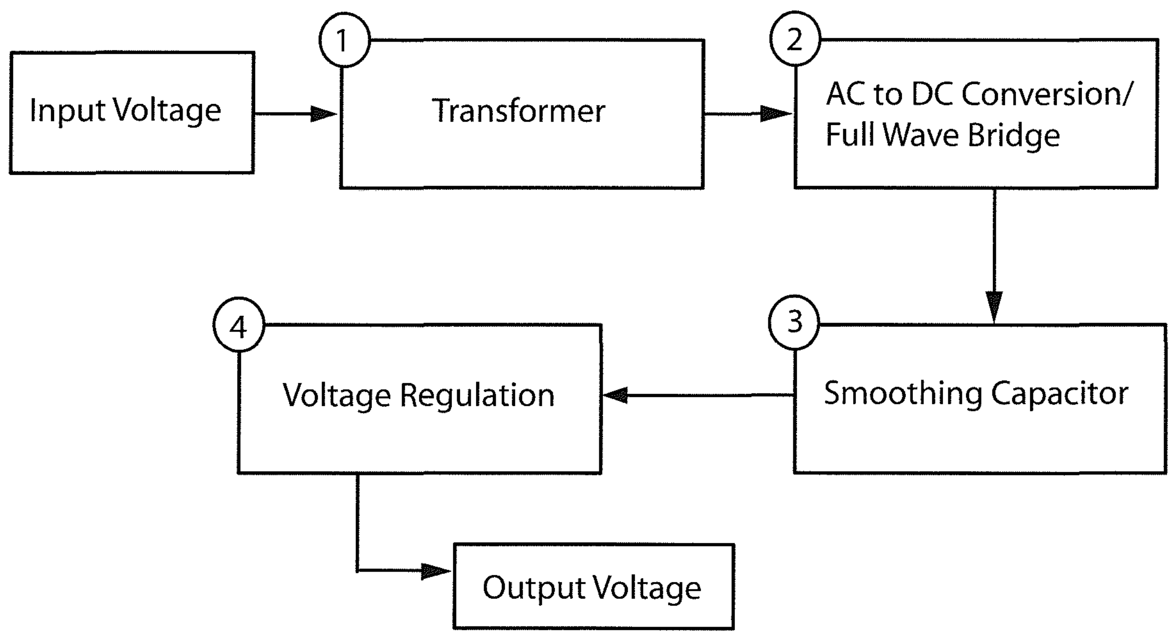
Electronic Failure

Although this is the most sophisticated form of repair, and involves the most training, due to the high level of development and technology transfer in electronics electronic failure rarely occurs. When electronic failures do occur it is usually a result of a failed cooling apparatus (e.g. a cooling fan) or due to dust build-up causing overheating of the electronic system. Board exchange is commonly used instead of board level component replacement. Knowledge of electronic troubleshooting can be tremendously cost effective.

The Half-Step Method

An efficient means of isolating electronic problems is a technique known as "half-stepping." Mentally divide the problem area of the failed device into halves. Using the digital multimeter (DMM) and the one-hand rule test for voltage readings. Once a correct voltage reading is either found or lost, mentally divide the problem area into halves again. Continue applying the half-step method until you have isolated a small area of the electronic portion of the device.

Figure 4.03



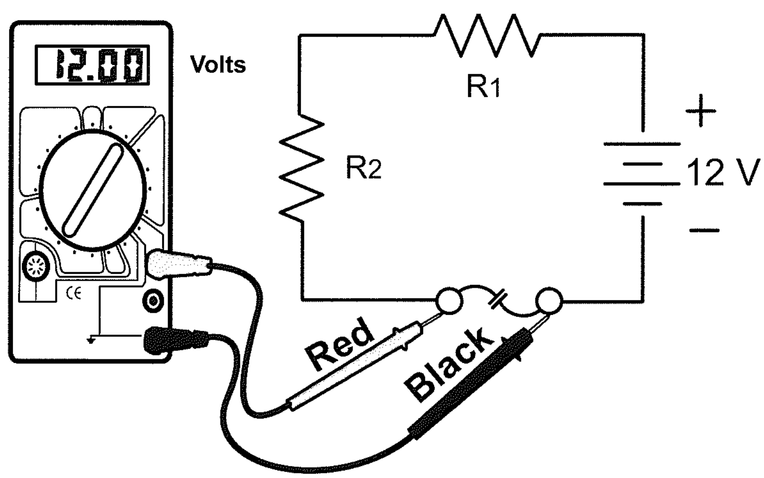
Block Diagram of Power Supply

Open Circuits

After applying the half-step method, the abnormal voltage readings obtained will be a result of open circuits or shorted circuits. An open circuit refers to an electronic problem caused by an incomplete circuit path, which prevents electron flow from the negative side of the circuit to the positive side of the circuit. As the name "open circuit" implies, there is an opening due to a failed component or physical damage to the circuit path.

A common example of an open circuit would be a fuse that has been exposed to a high current that exceeds the current rating of the fuse. The fuse physically burns a hole across the circuit opening within the fuse itself. Measuring an open fuse with a digital multimeter (DMM) would provide a voltage reading of the potential voltage on the positive side of the circuit, with respect to the negative side of the input voltage. This is an example of measuring potential voltage without current flow. The absence of current flow results in the electronic failure observed. Open circuits cause higher resistance in the system, since there is no current path through some or all of the components in the circuit.

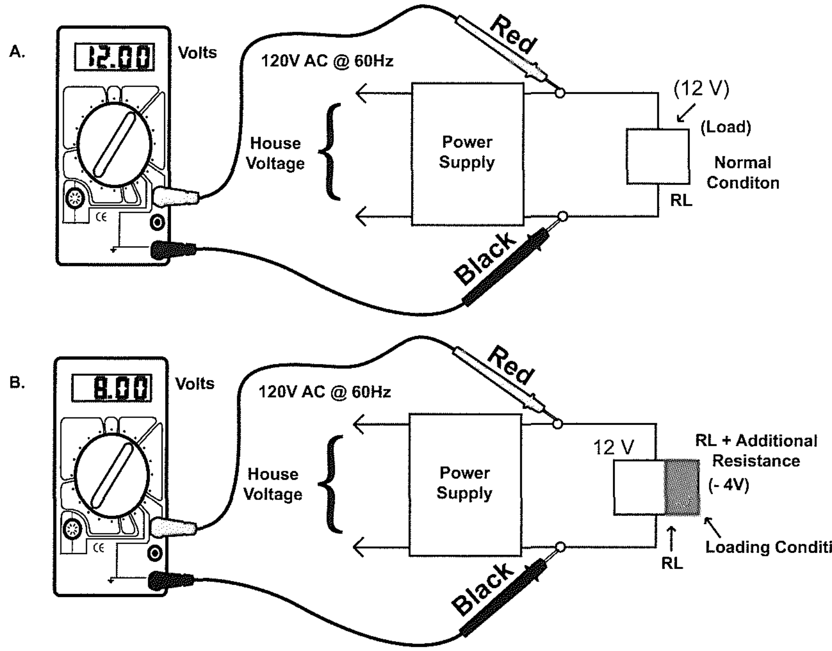
Figure 4.04



Circuit Loading

A common problem often associated with open circuits is circuit loading. This problem is a result of higher than normal resistance in the circuit. Circuit loading can be caused by loose board connectors or corrosion of the circuit path.

Figure 4.05

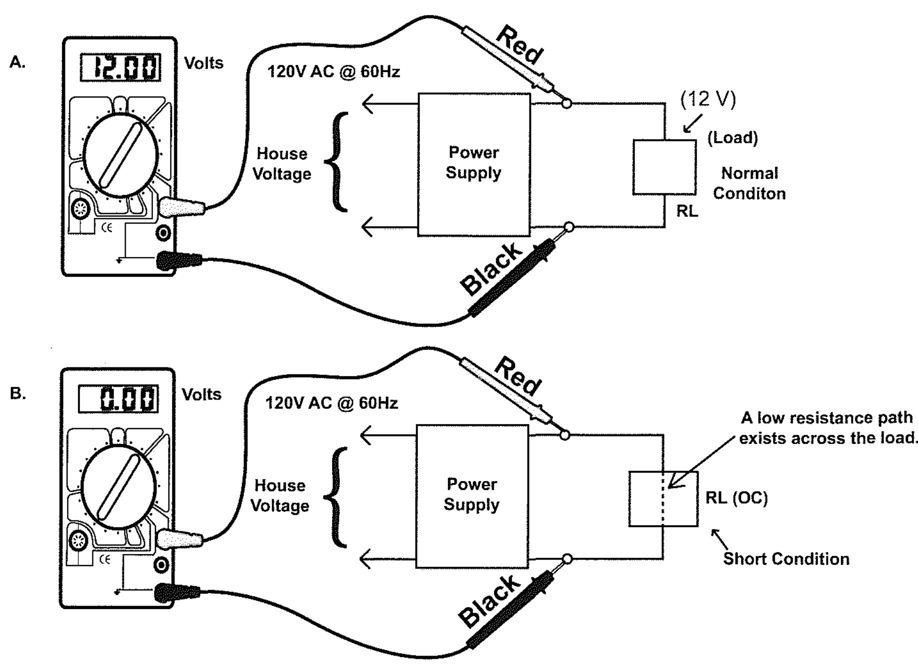


In example B the circuit is draining more power than normal (example A).

Shorted Circuits

A shorted circuit is circuit that has a lower resistance due to a direct current path avoiding or bypassing normal resistance. A shorted circuit can be caused by internal circuit wires or leads breaking their normal connections and touching the circuit in a different location. A wire or other conductive surface that becomes disconnected and presses against the equipment's conductive case is an example of a shorted circuit. A shorted circuit can also be created by solder that extends beyond the area intended to be soldered. Occasionally, a circuit path can be created by dust and grit build-up in a circuit if the dust contains conductive material such as metal flakes or room aerosol sprays. This happens rarely because typically a fuse or circuit breaker opens.

Figure 4.06



In example B there is no resistance from the load.
The meter reads zero volts.

Glossary of Important Terms

Clinical failure: Device failure due to patient abuse, displayed outputs do not agree with expected clinical results, or the machine is asked to perform a function it is incapable of.

Electronic failure: A malfunction in one of the components or integrated circuits (ICs) systems related to a resistor, capacitor, inductor, or semiconductor part on a board.

Electromechanical failure: A malfunction in an electric motor or relay.

Half-step method: A method of electronic troubleshooting that mentally divides the problem area of the failed device into halves. Using the digital multimeter and the one-hand rule, test for voltage readings. Once a correct voltage reading is either found or lost, mentally divide the problem area into halves again. Continue applying the half-step method until you have isolated a small area of the electronic portion of the device.

Open circuit: Refers to an electronic problem caused by an incomplete circuit path which prevents electron flow from the negative side of the circuit to the positive side of the circuit. As the name "open circuit" implies, there is an opening due to a failed component or physical damage to the circuit path.

Shorted circuit: In an electrical circuit, a short allows the current to travel along a different path that bypasses the intended load and significantly increases current draw. This is usually a catastrophic event resulting in extreme equipment damage.

CHAPTER FOUR REVIEW QUESTIONS

Name:____________________________

Date: ____________________________

1. A nurse from the pediatric unit calls the biomed shop about an equipment problem. In relation to surveying the environment, what questions might you ask to assist you in the troubleshooting process?

2. Referring to question #1 above, if the nurse replied that the device with the problem was making a funny noise, which of the four categories in the failure hierarchy is indicated?

3. The nurse for floor 3 B-West Wing calls in a work order for an infusion pump. The work order states "Improper infusion rate." When you arrive on the floor you notice two empty 1000ml bags hanging from the IV pole with tubing running into the infusion pump. The IV pump is set at a rate of 150 ml/hr. After inspecting the pump, in casual but professional conversation you learn that the IV bags were to be started at 0600 and run for 12 hours. It is now 12:00 (noon). Given rate = $\frac{\text{amount}}{\text{time}}$

   a. What is an obvious problem?

   b. What is the correct IV rate?________________________

   c. How do you correct this problem? ________________

   d. You should also check the IV pumping mechanism to ensure that the channel is clean. If the channel has "grunge" in it, what solution presents itself?

   ____

   ____

   ____

LABORATORY SAFETY RULES

1. Safety is everyone's responsibility
2. No food, drinks, or tobacco allowed in labs.
3. No horseplay.
4. SAFETY GLASSES are required. If you do not bring your safety glasses you will not be permitted to work.
5. Remove watches and jewelry.
6. Do not perform inspections or work on equipment when you are wet or sweaty.
7. Practice the "one hand" technique when performing testing on energized equipment as it may be defective and pose a serious shock hazard.
8. Familiarize yourself with the equipment you are testing and the test equipment BEFORE testing.
9. Do not leave your workstation without first removing power from the equipment you're working on.
10. Clean your lab work area before leaving.
11. Wash your hands.
12. Stay sharp. Be aware of what is going on in your surroundings.
13. Any other policies and rule established by the lab instructor must be followed.

I have read and understand the policy and rules stated above:

Print Name:________________________ Date: ____________

Signature: ________________________

CHAPTER FOUR LABORATORY EXERCISE 4.1:
Mechanical Troubleshooting

Name:____________________________

Date: _____________________________

Reminders

Take your time with this lab. Correct disassembly and assembly is what is wanted. Speed will come later. Remember to label all components or connectors to prevent cross connecting or misalignment of boards. Take into consideration the length of screws, type of screws and any protective plastic or shielding components that may be involved. These are all necessary for correct and continuous operation of the machine. Remember that there are certain ways to remove and install boards, connectors and components. If you do not know how they come out, look in the service manual or ask.

Do not destroy or damage the unit. This will reflect in your grade for this lab.
This lab will be graded on correct disassembly, assembly, and the use of the service manual and correct operation of the unit upon completion.

Please fill out the attached form and document all steps taken in this lab.

Objectives

After performing this lab, you will be able to:

1. Disassemble a piece of medical equipment to a designated level.
2. Replace the necessary parts that are needed to repair the device.
3. Reassemble the device to complete working condition.
4. Test the device for correct operation.

Reading

Basic Troubleshooting Methods

Instructor Materials

Oscilloscope lab
Resistor kit
Semiconductor kit

Lab Materials

Designated piece of medical equipment
Service manual for the piece of equipment
Student tool kit
Safety glasses

Procedures

1. Test the designated device for proper operation.
2. Using the service manual provided, look through the manual and find the area of the manual that shows the pictorial disassembles of the machine.
3. Using the above information, disassemble the machine to the designated point as instructed by the instructor.
4. Install a component or device as per the instructor.
5. Reassemble the device.
6. Test the device for proper operation.

CHAPTER FOUR LABORATORY EXERCISE 4.2:
Electromechanical Troubleshooting

Name:______________________________

Date: ______________________________

Reminders

Take your time with this lab. Correct disassembly and assembly is what is wanted. Speed will come later. Remember to label all components or connectors to prevent cross connecting or misalignment of boards. Take into consideration the length of screws, type of screws and any protective plastic or shielding components that may be involved. These are all necessary for correct and continuous operation of the machine. Remember that there are certain ways to remove and install boards, connectors, and components. If you do not know how they come out or apart, look in the service manual or ask.

Do not destroy or damage the unit. This will reflect your grade for this lab.
This lab will be graded on correct disassembly, assembly, and the use of the service manual and correct operation of the unit upon completion.

Please fill out the attached form and document all steps taken in this lab.

Instructor Notes

Use a centrifuge for this lab. You can remove a single brush, disconnect the lid latch circuitry, disconnect the speed control (tachometer) circuitry, or braking system.

Objectives

After performing this lab, you will be able to:

1. Test a designated piece of equipment for proper operation.
2. Replace the necessary parts that are needed to repair the device.
3. Reassemble the device to complete working condition.
4. Test the device for correct operation.

Reading

Basic Troubleshooting Methods

Lab Materials

Designated piece of medical equipment
Service manual for the piece of equipment
Student tool kit
Safety glasses

Procedures

1. Test the designated device for proper operation.
2. Using the service manual provided, look through the manual and find the area of the manual that shows the pictorial disassembles of the machine.
3. Using the service manual, locate the troubleshooting section.
4. Follow the steps or chart to find the cause of the problem.
5. Install or repair the unit with the instructor's supervision.
6. Reassemble the device.
7. Test the device for proper operation.

CHAPTER FOUR LABORATORY EXERCISE 4.3:
Electronic Failure, Half-Step Method, Open/Shorted Circuits

Name:____________________________

Date:____________________________

Reminders

Take your time with this lab. Correct disassembly and assembly is what is wanted. Speed will come later. Remember to label all components or connectors to prevent cross connecting or misalignment of boards. Take into consideration the length of screws, type of screws, and any protective plastic or shielding components that may be involved. These are all necessary for correct and continuous operation of the machine. Remember that there are certain ways to remove and install boards, connectors, and components. If you do not know how they come out or apart, look in the service manual or ask.

Do not destroy or damage the unit. This will reflect your grade for this lab.
This lab will be graded on correct disassembly, assembly, and the use of the service manual and correct operation of the unit upon completion.

Please fill out the attached form and document all steps taken in this lab.

Instructor Notes

Use a NIBP for this lab. You can adjust the power supply voltages to simulate failure or remove boards, or disconnect wires or connectors to simulate failures in components or boards.

Objectives

After performing this lab, you will be able to:

1. Determine the problem with a piece of equipment by using the troubleshooting section of a service manual.
2. Use the half-step method of troubleshooting and isolate the problem to an area or board within the piece of equipment.
3. Replace the necessary parts that are needed to repair the device.
4. Reassemble the device to complete working condition.
5. Test the device for correct operation.

Reading

Basic Troubleshooting Methods

Lab Materials

Designated piece of medical equipment
Service manual for the piece of equipment
Student tool kit
Safety glasses

Procedures

1. Test the designated device for proper operation.
2. Using the service manual provided, look through the manual and find the area of the manual that shows the pictorial disassembles of the machine.
3. Using the service manual, locate the troubleshooting section.
4. Follow the steps or chart to find the cause of the problem.
5. Install or repair the unit with the instructor's supervision.
6. Reassemble the device.
7. Test the device for proper operation.

Chapter 5: Troubleshooting Relays & Other Electromechanical Components

After completing this chapter you will have an understanding of:

- *The visual recognition of common electromechanical devices*
- *The principles of operation of common electromechanical devices*
- *The application of electromechanical device operation in the repair and troubleshooting processes*

Device Identification and Pictorial Diagrams of Electromechanical Devices

Electromechanical devices are often over looked as a failure component of devices due to the emphasis of electronics and semiconductors in most formal education processes for device repair. Electromechanical devices are used as a latch to open or close a switch. Some very common electromechanical components are pictured below in Figures 5.01A and B.

Figure 5.01A **Solenoids**

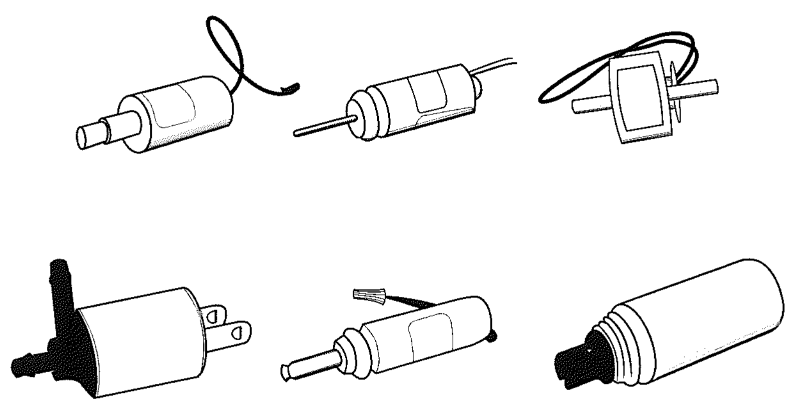
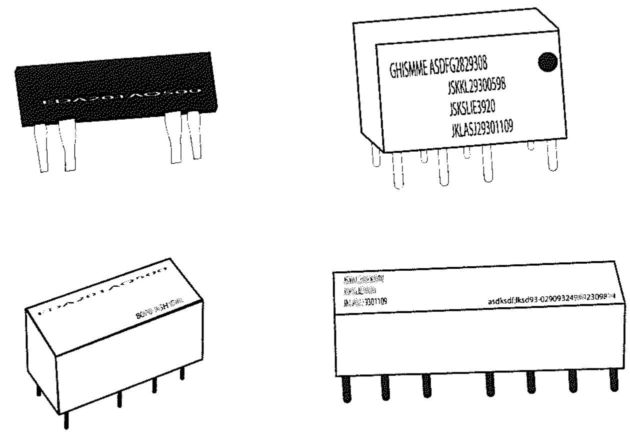


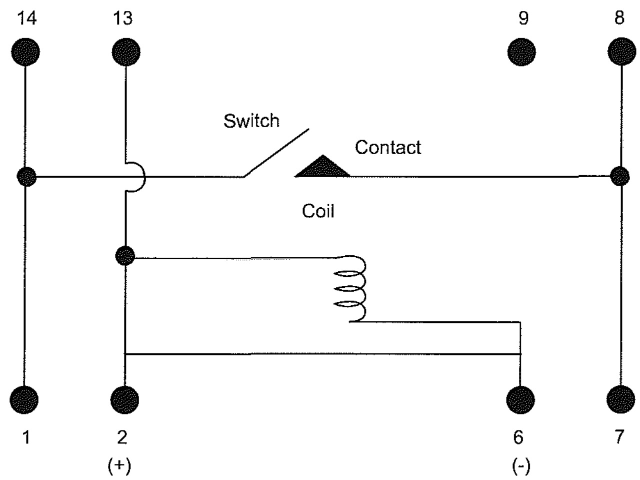
Figure 5.01B **Relays**



Relays

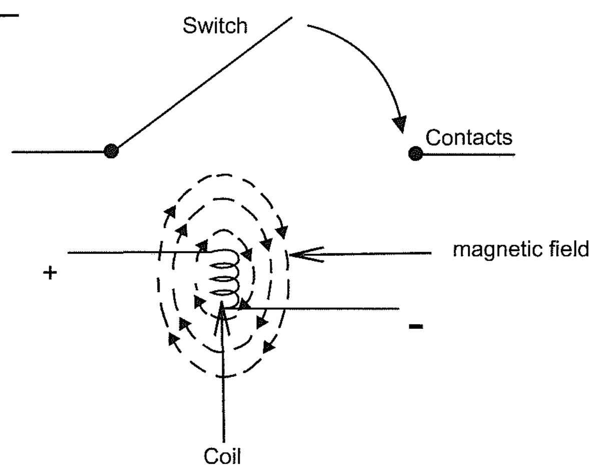
A relay is a switch controlled by electromagnetic contacts. A relay consists of an electromagnet, armature, spring and a set of electrical contacts. Figure 5.02 illustrates a typical electromechanical relay and its corresponding parts.

Figure 5.02 **Electronic diagram of a relay**



The number refers to the pin numbers on the relay. (Notice on the previous page how the pins extend down.) The relay (switch) may be open in an unmagnetized state or it may be closed in an unmagnetized state. This is known respectively as a normally open (NO) and a normally closed (NC) relay. Figure 5.03A illustrates a normally open relay and figure 5.03B illustrates a normally closed relay.

Figure 5.03A **Normally open relay**

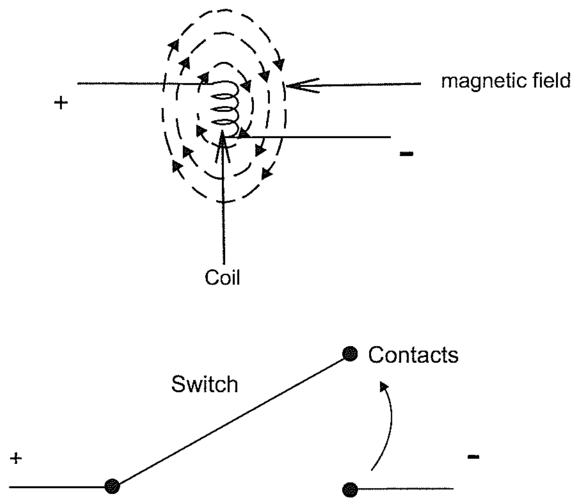


Current through the coil creates a magnetic field that closes the contact.

Testing a Bad Relay

In today's devices, most relays are electronic or encased. Therefore, repair of the relay is either impractical or impossible. To test a relay, check if there is voltage coming into the input of the coil. If there is no voltage to the coil, half-step back to find the voltage, see Figures 4.01 & 4.02. If there is voltage to the coil and the output of the relay is not what is expected, then the relay is bad.

Figure 5.03B **Normally closed relay**

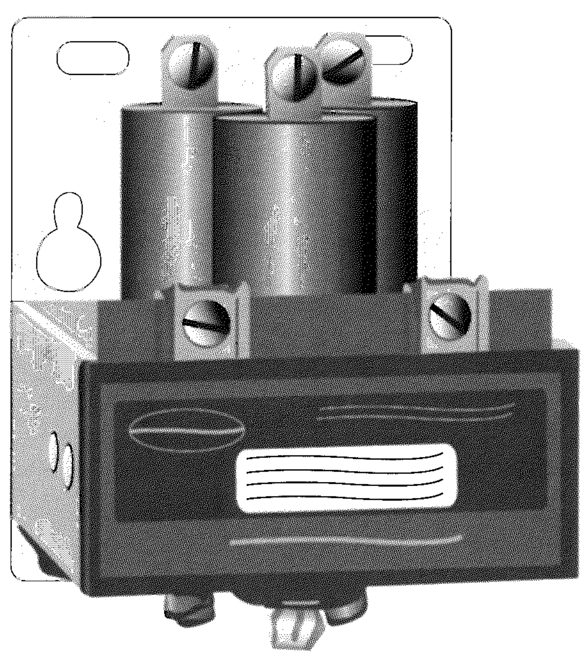


Current through the coil creates a magnetic field that opens the relay

There is also a special group of relays that are different in construction from the typical electromechanical relay. Two such relays are the mercury switch relay and the reed relay.

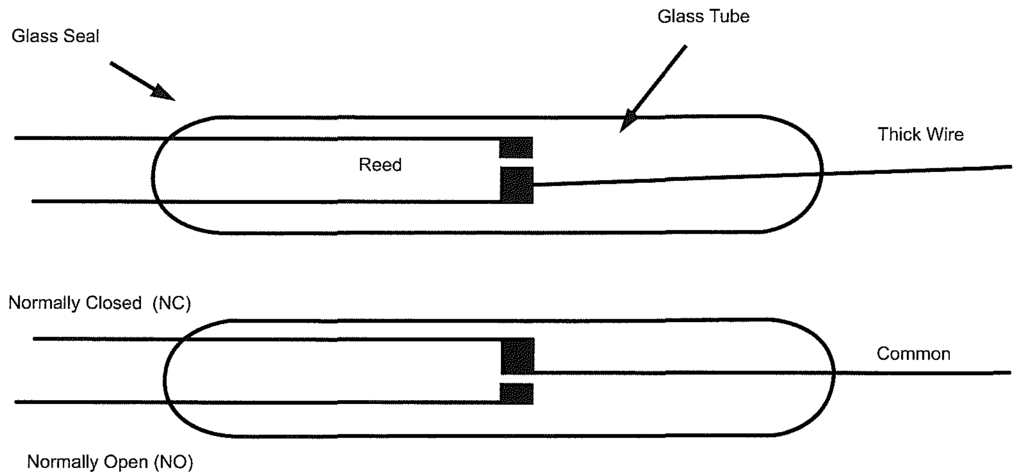
The mercury switch relay utilizes the conductive property of the element mercury to act as the contact points for the relay. Mercury switch relays are used for high current and voltage applications and for switches in areas where the sparking action of a typical electromechanical relay could be hazardous such as flammable products or near oxygen. Mercury switch relays are more expensive than a common relay due to their construction, which typically encases mercury in a glass compartment. Figure 5.04 illustrates a common mercury switch relay.

Figure 5.04 **Mercury switch relay**



The reed switch relay has an elongated configuration due to its long thin contact area (reed). Reed switches are utilized where space may be limited. Figure 5.05 illustrates a common reed switch.

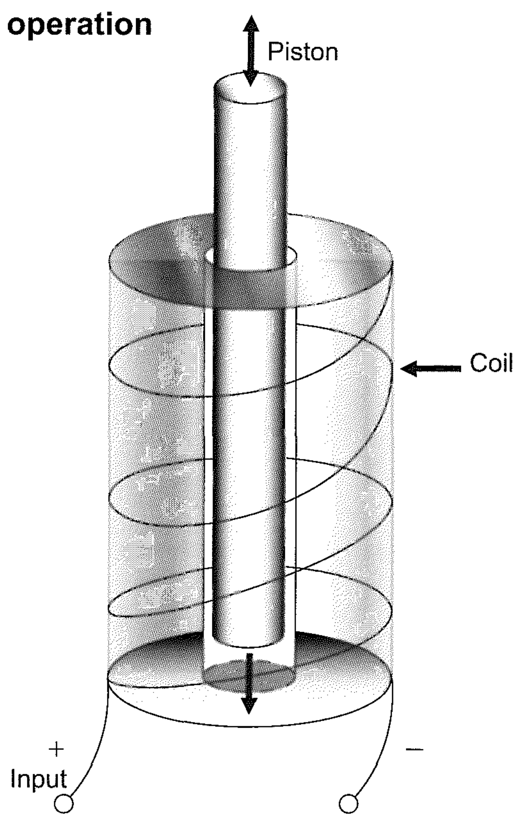
Figure 5.05 Reed Switch



Solenoids

A solenoid is commonly used as a lid-latch device or remote control actuator. A solenoid consists of a piston, wire windings, and a spring. The principle of operation of a solenoid is similar to that of a relay, except the piston is acted upon by magnetic force instead of the contacts. The piston moves either in or out of the magnetized coil, depending on the direction of the magnetic field. Figure 5.06 illustrates the operation of a solenoid with identification and purpose of each part.

Figure 5.06 Typical solenoid operation



Failure Modes and Repair of Electromechanical Components

Electromechanical devices generally fail due to dirty contacts. Remove the relay portion of the electromechanical component and gently file away the carbon or other debris that has collected on the contact. You may use a special small metal file specifically manufactured for this purpose or you may use a fine-grain fingernail file. Make certain that all of the dust and debris are removed from the electrical contact and the relay coil. In some instances, oil may have collected on the contact, which prohibits electrical conduction across the contact. Use a solvent such as isopropyl alcohol placed sparingly on a soft cloth to remove the oil. Make certain that the contact is completely dry before reassembling the coil and outer casing.

After long periods of use, electrical contacts may become worn. It is generally more cost effective to replace the entire relay than attempt to replace the contact. If the contact is easily accessible and removable, it is feasible to replace the contact. This can be done within a matter of minutes. If a device no longer has an available parts supplier, you may decide to be innovative and use conductive adhesive to repair the contact. REMEMBER, THE ADHESIVE MUST BE ELECTRICALLY CONDUCTIVE AS WELL AS THE MATERIAL USED AS A REPLACEMENT CONTACT. Whenever replacement parts are available, the authors recommend replacement of the contact.

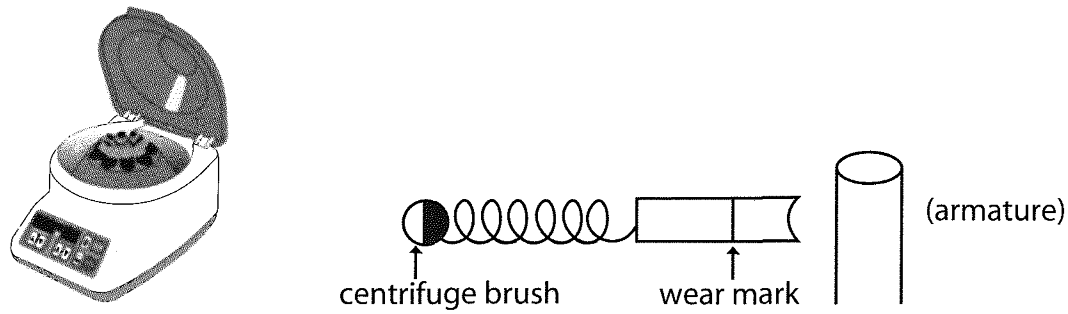
Solenoids are commonly subject to physical damage. The solenoid pin has a purpose of latching an opening or engaging (contacting) a remote electronic or mechanical switch. Never attempt to bend the solenoid pin back into position. Eventually, the damaged pin will create another failure. The entire solenoid should be replaced in circumstances of physical damage.

The troubleshooting process for relays and solenoids is very similar to that of transformers. Check to ensure that there is voltage to the coil. Examine the insulation of the wires that produce the magnetic force. Never attempt to rewind the coil. Test the continuity of the solder joints at all terminals. If it is possible to remove the solenoid or relay, you may wish to test it with a battery to determine is operability. If battery power engages the magnetic coils, the failure is due to the connecting circuit or the power supply.

Review the troubleshooting flow chart in Troubleshooting Power Supply Problems. Using the half-step method, trace the failure from the power supply back to the magnetic coil. Always ensure that plug-in relays are properly seated into the socket. Mobile devices may cause circuit boards and relay sockets to become loose. Always clean the area around the relay or solenoid to eliminate future problems created by debris preventing full contact.

Replacing Brushes on a Centrifuge

Figure 5.07



1) Find the slotted plastic cap on each side of the lower part of the centrifuge.
2) Remove cap with small screwdriver. CAUTION: It is spring loaded! Gradually release pressure on the cap.
3) If the brush is worn down close to the wear mark, replace the brush.
4) IMPORTANT: Notice the curve on the end of the new brush. Insert the rectangular brush so that the curve on the end matches the curve of the armature.
5) Shine a pen light in the brush hole. If there is a large amount of graphite buildup remove it from the machine and clean the armature with an alcohol swab.

Glossary of Important Terms

Centrifuge: Device that spins lab samples at high rates of speed. It is measured in rotations per minute (RPM).

Contact: The conductive portion of a relay that closes or opens a switch when drawn by a magnetized coil.

Mercury switch relay: A specialized switch, which utilizes the conductive property of the element mercury to act as the contact points for the relay. Mercury switch relays are used for high current and voltage applications and for switches in areas where the sparking action of a typical electromechanical relay could be hazardous such as flammable products or near oxygen.

Normally closed (NC) relay: A switch, which is normally closed in an unmagnetized state.

Normally open (NO) relay: A (switch), which is normally open in an unmagnetized state.

Reed switch: A relay with an elongated configuration due to its long thin contact area (reed). Reed switches are utilized where space may be limited.

Relay: A switch controlled by electromagnetic contacts.

Solenoid: An electromechanical device similar to that of a relay, except the piston is acted upon by magnetic force instead of the contacts. The piston moves either in or out of the magnetized coil, depending on the direction of the magnetic field. A solenoid consists of a piston, wire windings, and a spring.

CHAPTER FIVE REVIEW QUESTIONS

Name:______________________________

Date: ______________________________

1. Explain the difference between a normally open (NO) relay and a normally closed (NC) relay.

2. Draw a simple schematic that illustrates how a solenoid could be used to provide a safety latch on a door to a hazardous materials room after the lights to the room had been turned off.

3. You have a work order for a centrifuge in the clinical lab. The work order is shown below.

   Work Order #12345 Device ID #12345 (Centrifuge) Location: Clinical Lab

   Problem: The power light comes on but the motor will not rotate.

   a. What questions should you ask the lab technician to begin your troubleshooting process?
   b. What tools and test equipment should you bring with you?
   c. List three probable device failures that produce this symptom.

4. You have a work order for a heart-lung machine in the operating room.

   Work Order #12345 Device ID #12345 (heart-lung machine)
   Location: Operating Room #6

   Problem: The power light comes on but the motor will not rotate.

a. What questions should you ask the nurses or perfusionist to begin your troubleshooting process?

b. What tools and test equipment should you bring with you?

c. List three probable device failures that produce this symptom.

5. You have a work order from the emergency room.

Work Order #12345 Device ID #12345 (defibrillator)
Location: ER Trauma Room #6

Problem: The machine powers up but the paddles won't discharge

a. What questions should you ask the nurses or perfusionist to begin your troubleshooting process?

b. What tools and test equipment should you bring with you?

c. List three probable device failures that produce this symptom.

CHAPTER FIVE LABORATORY EXERCISE:
Troubleshooting Relays and other Electromechanical Components

Name:______________________________

Date: ______________________________

Objectives

1. To have a better understanding of the correct operation of a relay in relation to medical devices.
2. Understand the tolerance/limits of circuits and how they are obtained.

Reading

Troubleshooting Relays and Other Electromechanical Components

Materials

DPDT 6Vdc or 12Vdc relay
1Kohm potentiometer
330 ohm resistors (2 ea.)
Red LED
Green LED
Dual DC power supply
VOM or DMM

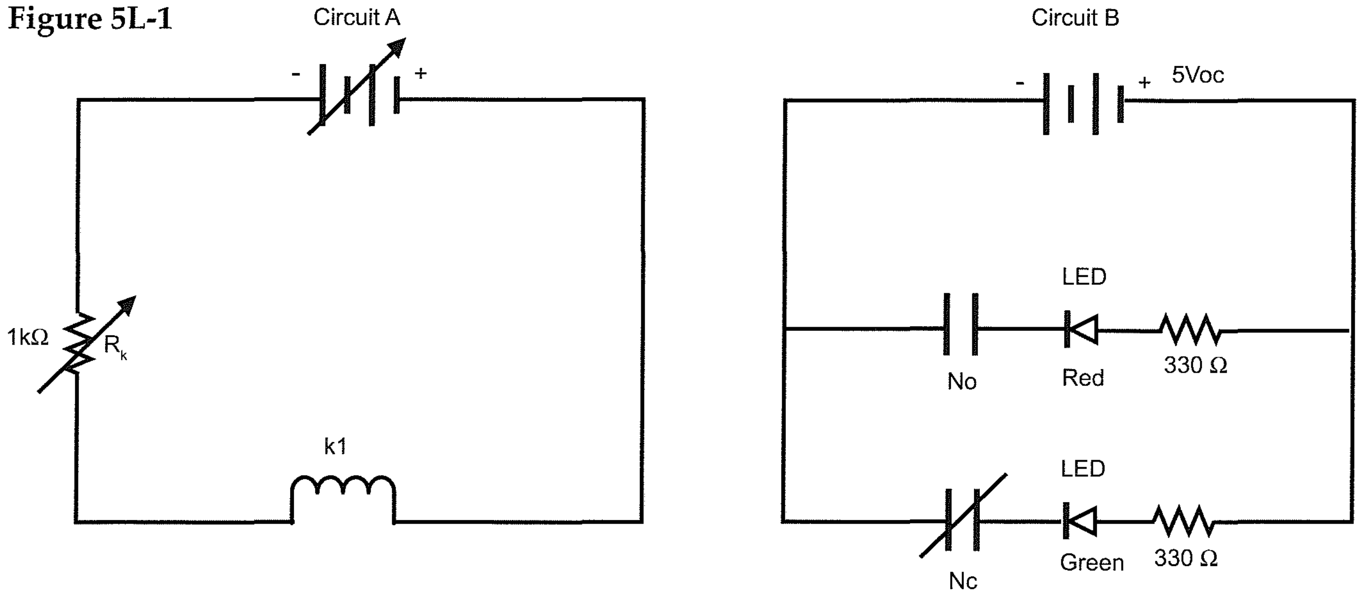
Procedure

The circuit you are about to build is the basis for most sensor/temperature circuits found on medical devices.

Basically you have a monitoring/display side that is displaying a certain pressure or temperature (Circuit B), and you have a circuit that is actually monitoring the pressure or temperature(Circuit A).

You may have a sensor that is designed to change due to pressure, temperature, or current. No matter which style you have, this basic circuit will give you a general idea of how the unit operates. Some systems will use electromagnetic style relays and some will use solid state relays, but the basis is still the same.

Figure 5L-1



1. Assemble the two circuits from Figure 5L-1, making sure to correctly wire the relay into the two circuits. (Make sure to use the wiring diagram on the relay case or literature that came with the relay.)

2. Using one side of the dual power supply, apply 5Vdc to circuit B. If the green led light is not on, turn the potentiometer fully clockwise or counter clockwise to obtain a lit green led.

3. Next using the other side of the dual power supply, apply voltage to circuit A till the relay activates and the green light goes off and the red led is on.

4. Measure the voltage across the coil of the relay.
   a. Vcoil___________Vcr
   b. This is the voltage that is required to activate the coil and cause an alarm or change in the display.

5. Next turn the potentiometer till the red light goes off and the green light is lit.
   a. Vcoil __________Vcg
   b. This is the voltage that is required across the coil to reset the circuit into a ready or non-alarming state.

6. Using the two voltages from questions 4 and 5 list the voltage tolerance or difference that is needed between a alarming/active state and a ready/non-alarming state.
   a. Vcr-Vcg/Vcr= _______%
   b. As with many devices, you will have tolerances on the temperature or pressure readings. This is basically the standard of how this is determined.

7. What would happen to your circuit if the normally closed (NC) contact was dirty and the contact was open?

8. What is the operating voltage range of the coil in this circuit?

Chapter 6: Troubleshooting Electric Motors

After completing this chapter you will have an understanding of:

- *The principles of electric motor operation*
- *The concepts of a block diagram of an electric motor*
- *The differences between AC and DC motors and be able to apply this knowledge to electric motor troubleshooting*
- *The use of the oscilloscope and digital multimeter in the repair and troubleshooting of electric motors*
- *The basic components of electric motors and be able to apply this knowledge to repair and parts ordering*

Introduction to Electromagnetic Principles

Electric motors utilize inductive magnetic principles similar to those used in transformers. Recall from Introduction to Power Supply Components, transformers step-up or step-down common wall voltage by the property of induced voltage (electromagnetic force) from the wire windings around the transformer coils of the primary side to the secondary side. Electric motors also create an electromagnetic force around the wire windings of the core or stator of the motor. An electric motor can be defined as a device that creates an electromagnetic force and converts it into a mechanical force. Electric motors may have a DC or AC power source. AC motors may use single-phase, two-phase, or three-phase power.

Figure 6.01A **Stator**

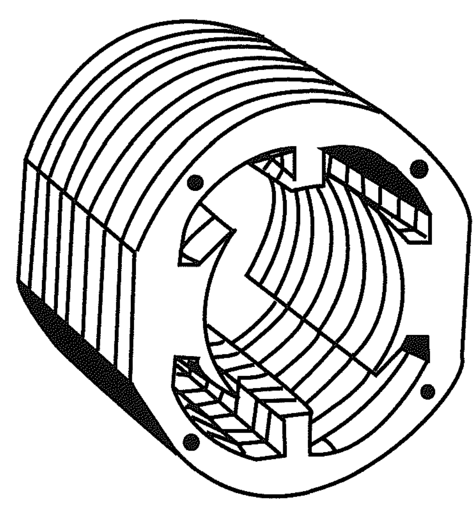
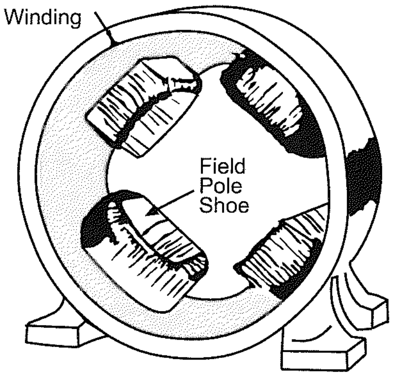


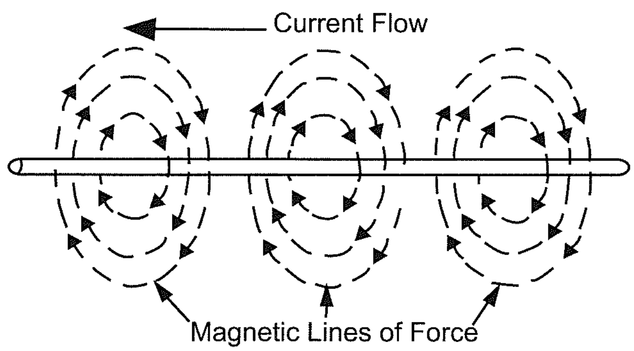
Figure 6.01B



Stator with field pole windings

A significant background in Faraday's Law of Electromagnetic Induction is required to explain all of the basic physics of magnetism involved in the concept of induced voltage. For the purposes of troubleshooting electric motors, this theory is not required but readers are encouraged to review this basic concept from other texts. Essentially, when a conductor (wire windings) passes through a magnetic field a voltage is induced in the conductor (wire windings). The windings of the stator (the non-rotating portion of the motor, Figure 6.01A) create an electromagnet around the core (stator). The wire coils around the core (stator) create a current flow, which in turn creates magnetic poles in the stator. Current flow is determined by the "left-hand rule." The left-hand rule is a visual means of determining which direction current will flow through a conductive coil. Current flows from the north pole designation of the conductor towards the south pole designation. If you could imagine grasping the core of windings with your left hand, current would flow in the direction of your left thumb. Figure 6.03A illustrates the left-hand rule for current flow.

Figure 6.02A



Current flow through a conductor in a magnetic field

Figure 6.02B **DC motor**

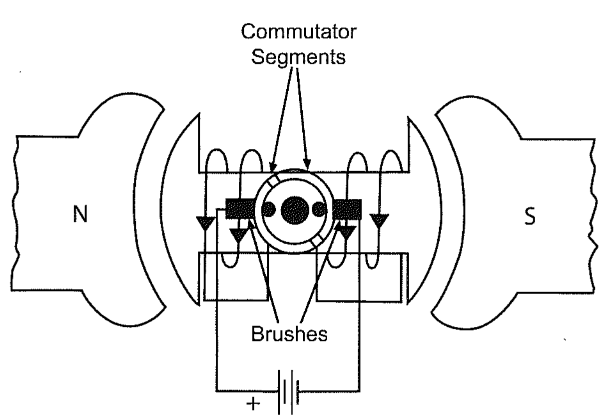


Figure 6.03A

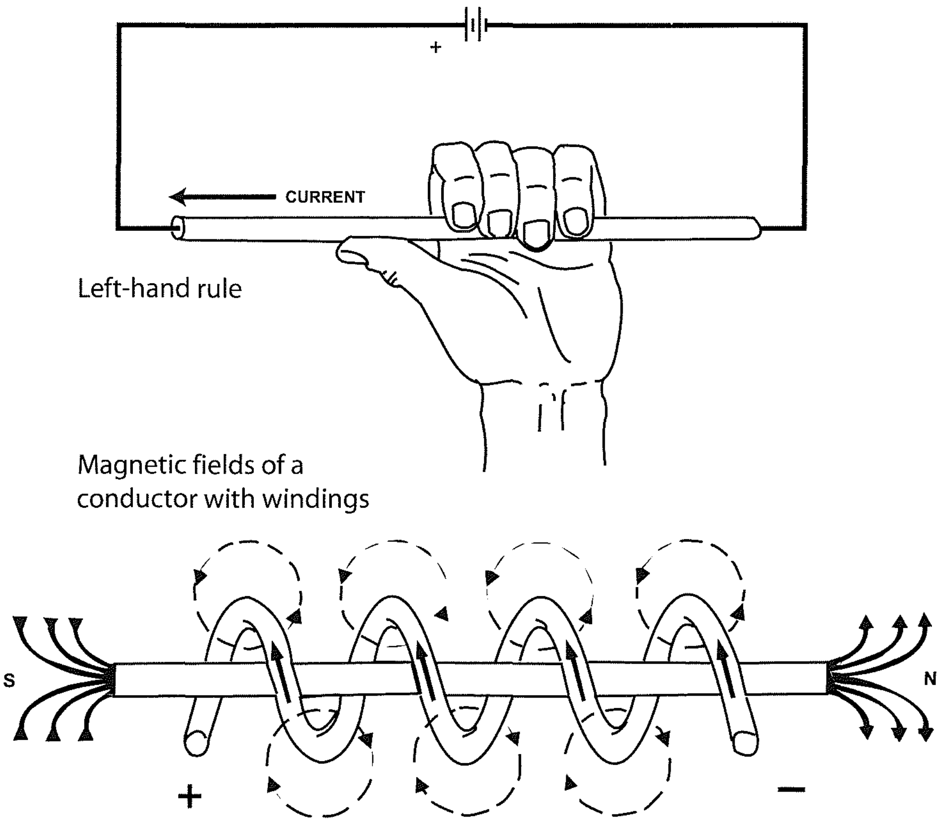
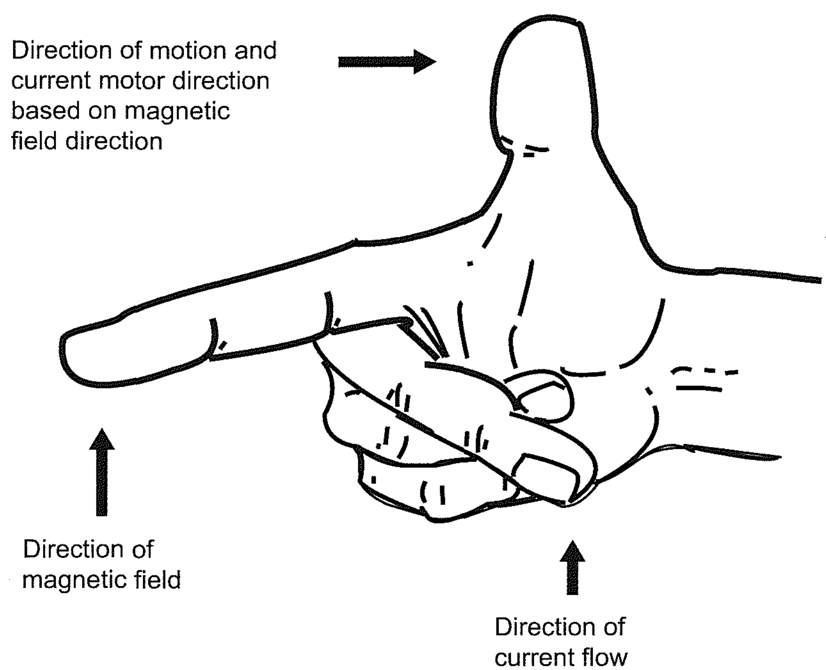
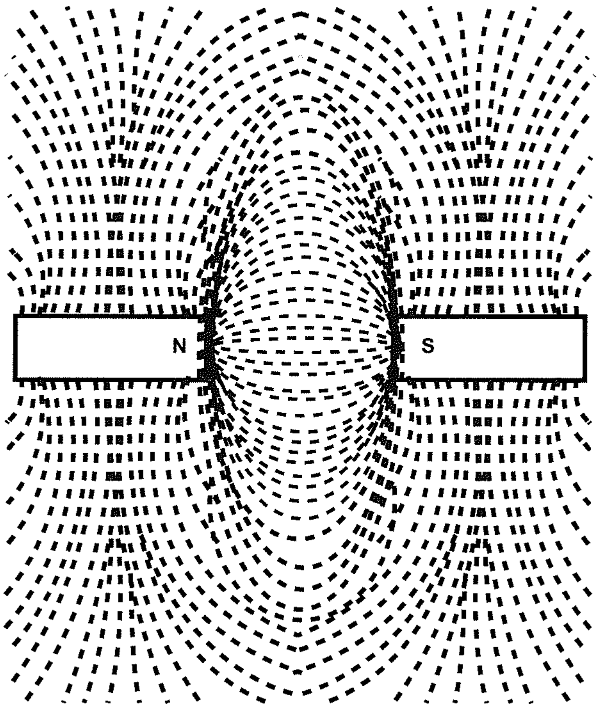


Figure 6.03B



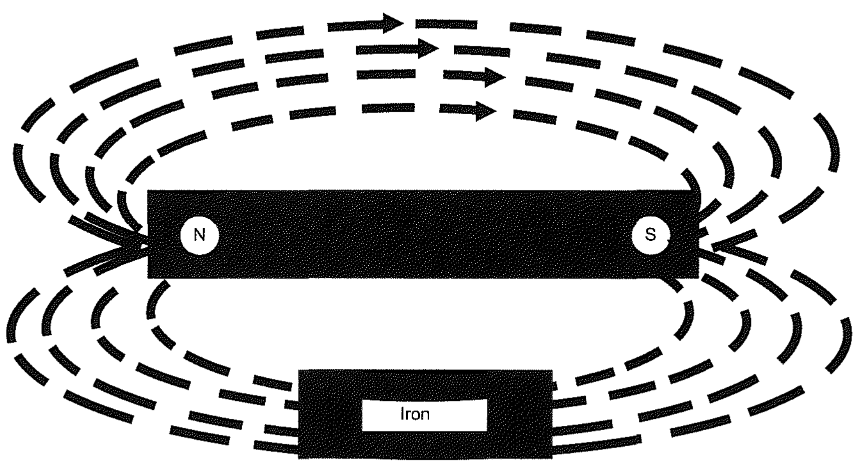
A basic principle of magnetism states that a movement is produced when two like fields (positive-positive or south-south) repel each other and two opposite fields (positive-negative or south-north) attract each other. This repulsion and attraction is the basis of motor movement. Electric motors create several fields within the stator and a continuous movement of the rotor occurs around the stator. (Figures 6.04A and B illustrate a magnetic field.)

Figure 6.04A **Magnetic field around the poles of a conductor**



The field is three dimensional and has a polarity.

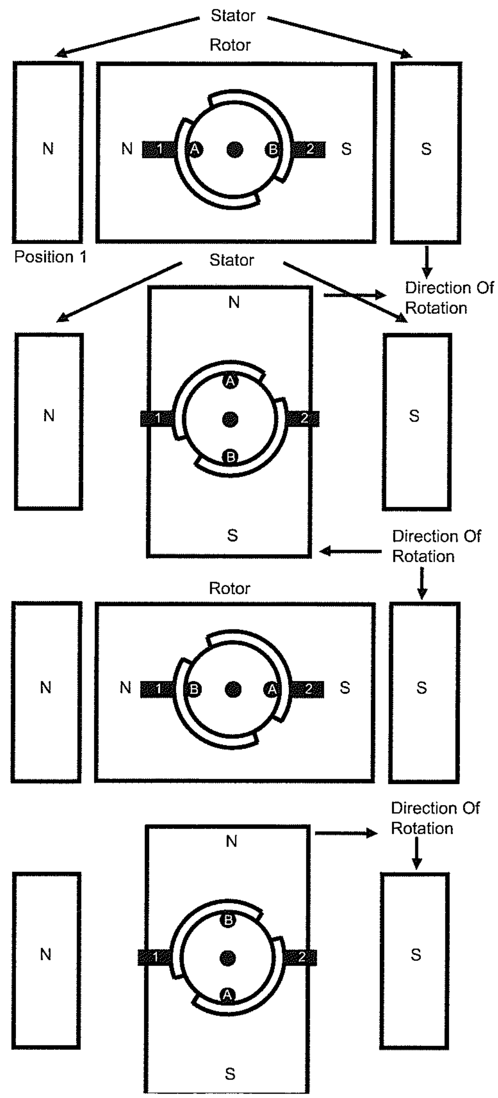
Figure 6.04B



Ferromagnetic Material

Induced flow through a conductor (iron) in a magnetic field.

Figure 6.05



Rotating action of a DC motor

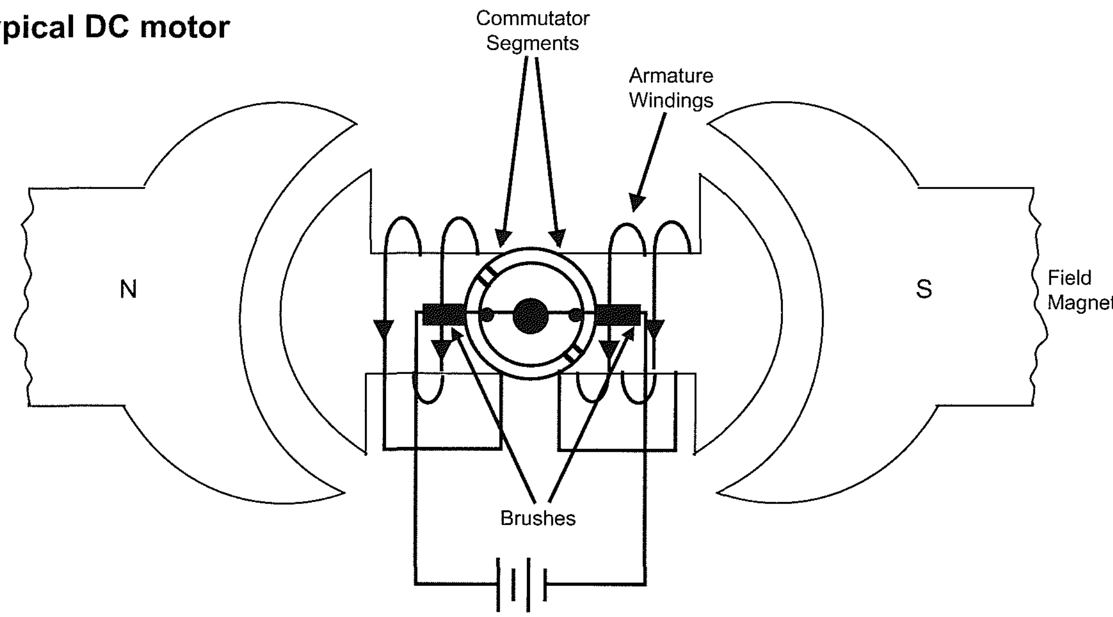
Introduction to DC Motors

DC motors use either a battery or a DC power supply to provide current flow through the coils of the stator. Since DC current is continuous, another magnetic field is required to create "cross-fields" or "cutting fields" to create poles within the motor. Either a permanent magnet or an electromagnet can be used for this purpose. A conductive material made of a carbon base with iron filings is used to provide contact and current flow from the stator (stationary portion) to the rotor or armature (moving portion).

This contact component, known as a brush, is usually rectangular and has a spring on the end away from the rotor. The purpose of the spring is to place a force against the rotor for continuous contact. Two brushes are required to complete the electrical circuit from the power supply. (Not all motors require brushes.) The rotor turns based on its attraction or repulsion of a strong or weak magnetic field. Each turn of the rotor changes the position of the strength of the magnetic field. Therefore, the rotor is constantly being pushed from one pole and pulled towards another pole.

This creates the movement of a DC electric motor. All DC motors have windings on the rotor. The rotor will also have a component known as a commutator on one end of the shaft. The commutator is a slotted metal cylinder that creates magnetic fields in between the "slots" of the cylinder. The brushes of the motor make contact with the commutator. Figure 6.06 illustrates a basic DC motor with the essential parts labeled.

Figure 6.06 **Typical DC motor**



Introduction to AC Motors

AC motors are constructed very similar to DC motors and utilize the same principles of operation. AC motors have a 60 hertz current flow through the windings of the stator. In order to create polarity within an AC motor, polyphase (two- or three-phase) power is required. A single phase AC motor requires changes in its design for the creation of a rotating magnetic field. (Single-phase AC motors will be discussed in the next section.) With either two-phase or three-phase power, there will always be a phase rotation of current and therefore there will be a phase rotation of the magnetic field. AC motors may have either a wound rotor, like a DC motor, or a squirrel cage rotor. A squirrel cage rotor uses conductive bars to create different magnetic fields in place of the wound wires. Figure 6.07 illustrates a squirrel cage rotor. Figure 6.08 illustrates a basic three-phase AC motor with the parts labeled.

Figure 6.07

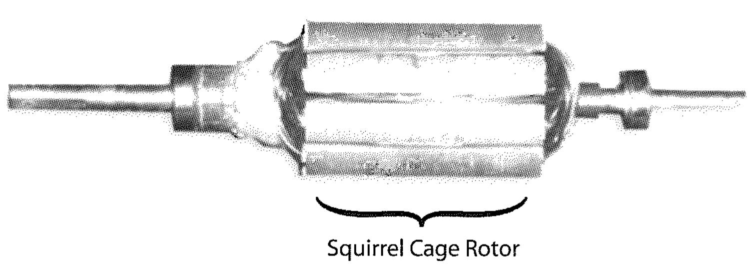
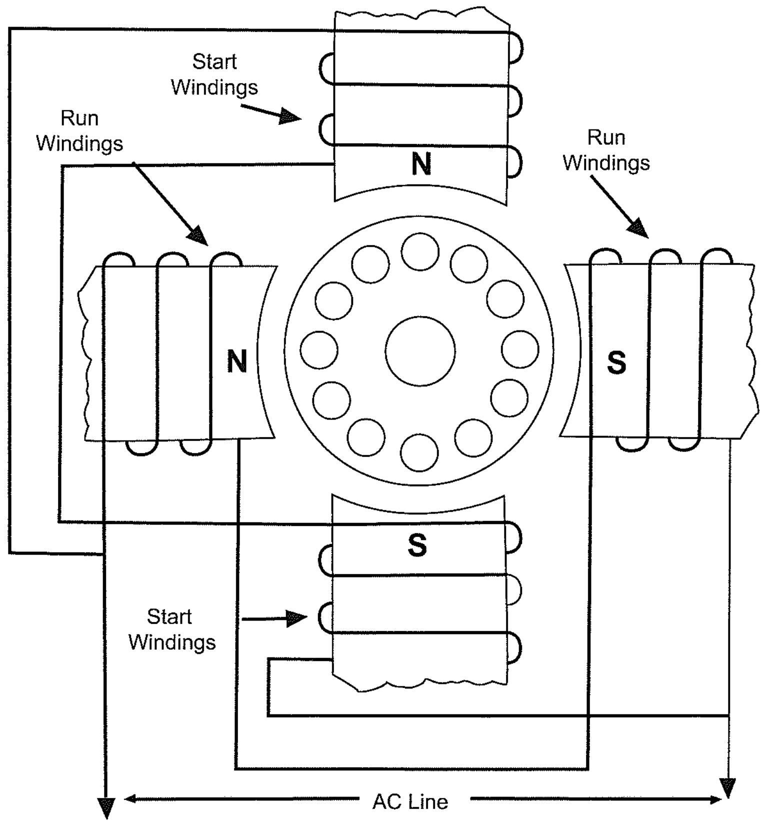


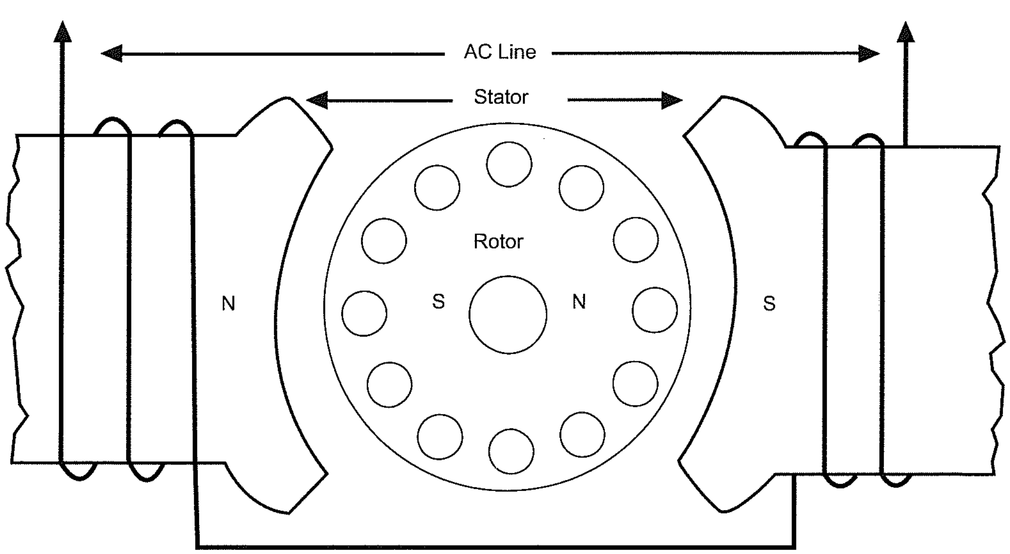
Figure 6.08 **Typical AC motor with start and run windings**



Single-Phase AC motors

With both the two- and three-phase AC motors there are at least two fields generated by the windings to create the push-pull of magnetic repulsion and attraction. Single-phase motors must use opposite winding directions of the wire core to create two magnetic fields. Figure 6.09 illustrates the opposite winding concept of a single-phase AC motor.

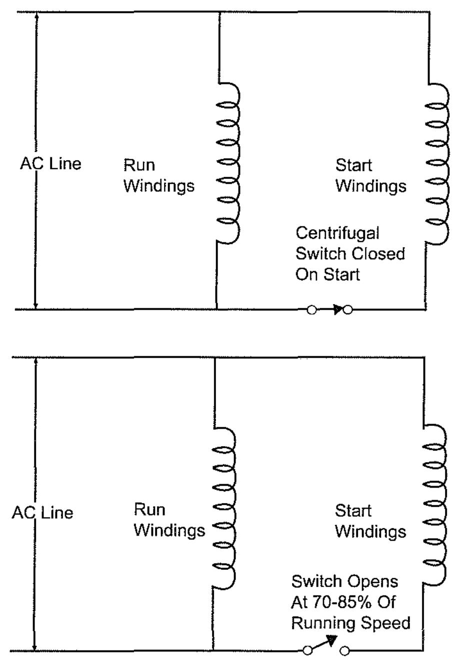
Figure 6.09 **Single-phase AC motor**



There are two other basic concepts of electric motors, which you will need to understand in order to successfully repair and troubleshoot motors. Motors may have start windings and run windings. These windings are energized based on a centrifugal start switch. After the rotor reaches a specified speed (rotations per minute) the centrifugal switch opens due to centrifugal force. At this point only the run windings are energized. Figure 6.10 illustrates an AC motor with start and run windings energized by a centrifugal start switch.

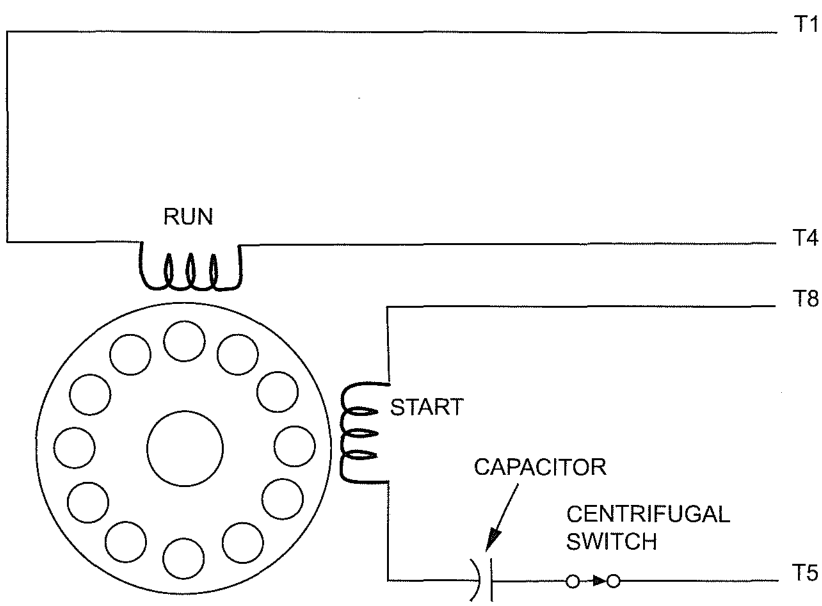
Some motors use a capacitor as a means to start the rotation cycle. Capacitors cause the current to lead the voltage phase by 90°. This phase shift provides a rotating magnetic field in the motor and thus a means for attraction and repulsion of the rotor or armature.

Figure 6.10A



Centrifugal start AC motor

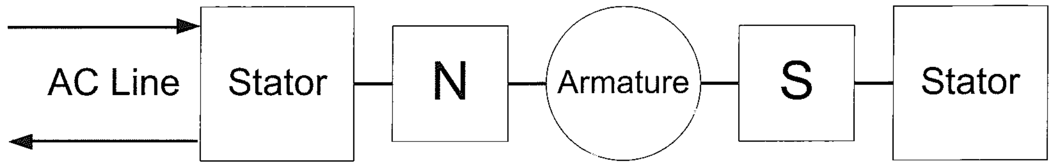
Figure 6.10B



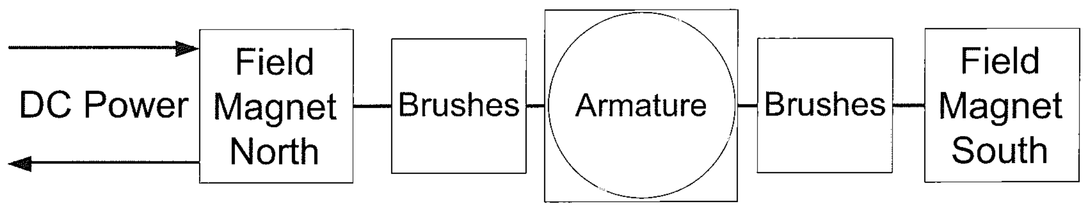
Centrifugal start AC motor with capacitor holding charge

Figure 6.11

AC Motor Block Diagram



DC Motor Block Diagram



Failure Modes and Repair of Electric Motors

Electric motors and transformers will have many failure modes in common. Transformer winding failures and troubleshooting were discussed in Troubleshooting Power Supply Problems. One comment regarding the windings of electric motors: never attempt to rewind or place a solder bridge across and open winding. If the windings are shorted, replace the motor, with the exception of any instrumentation attached.

The following list contains common symptoms of motor failure and the corresponding troubleshooting and repair guide.

1. Motor has no power. Power indicator light does not come on.

- Check the power cord for continuity.
- Check the wall outlet for available power.
- Check the on/off switch.

Troubleshooting technique:

a. Check the power cord for continuity.

- Switch your voltmeter to resistance or to the continuity test setting.
- Place one lead of the DMM on the plug tip and the other lead of the DMM on the corresponding color wire coming into the motor.
- If there is large or infinite resistance, the power cord is bad.

- Replace the power cord.

b. Check the wall outlet for available power.

(This may seem remedial but it will eliminate wasted time. This procedure is often overlooked, even by experienced biomedical technicians.)

- Switch your voltmeter to the AC voltage setting.
- Place one lead into one socket (not the ground) and the other lead into the socket next to it. You may place the red or black into either socket. The measured AC voltage will be the same regardless of the lead placement, as long as you leave the ground untouched.
- Your meter should have a reading of 110-120 Vac.
- If no voltage is present, report the outage to physical plant and move the apparatus near a functioning outlet.

c. Check the on/off switch.

- With the switch on the on position and the device unplugged, measure the resistance across the switch. Your meter should be in the resistance measurement position.

2. Motor has no power. Power indicator light is on.

- Check the brushes if DC.
- Check hot and neutral wires to the stator if AC.
- Check for debris or bearing wear preventing proper motor rotation.

Troubleshooting technique:

For DC motors:

a. Check the brushes.

- On most brushes there will be a "wear line" indicating the required length of the brushes to provide proper contact. If the brushes wear past this point, they will not properly contact the armature and the motor will not provide the required magnetic field. There will normally be a slotted head cover covering the brushes. Remove the cover and inspect the armature. If the brushes have caused wear on the armature, it must be replaced.

  The rotor will have compressed bearings on each end. Most biomedical repair shops will not have the proper tools required for rotor bearing replacement. Take the motor to an electrical repair shop that specializes in motors.

- If there is no noticeable wear on the armature, replace the brushes. Some brushes have an curved tip that contacts the rotor. Ensure that this tip is in the correct position to match the curve of the armature. Run the motor for five minutes to provide proper seating of the brushes.

For AC motors:

b. Check hot and neutral wires to the stator.

- The hot and neutral wires enter the motor housing from the power cord. Using your multimeter select AC voltage. Remember the one-hand rule and place the red lead on either the hot or neutral wire and connect the black lead to a chassis ground or the ground from the power cord. Your multimeter should read house voltage. If your meter reads no voltage, the wire from the motor housing to the contact terminal is open and must be replaced.

c. Check for debris preventing proper magnetic field strength

- Motors are frequently lubricated and the lubricant will trap dust particles. Over time, this build-up of lubricant and dust (grime) will prevent proper conduction. Overheating of the motor is also a result of grime build-up. Clean the motor with a clean, lint-free cloth. Apply lubricant where indicated. Do not use solvents such as alcohol to clean the motor. This may remove the lacquer coating from the windings.

- The device utilizing the motor may be a centrifuge or a compressor. Ensure there is proper ventilation around the device. This will lessen the occurrence of grime build-up and over-heating.

Glossary of Important Terms

Brushes: A contact component that are usually rectangular and have a spring on the end away from the rotor.

Capacitor start motor: A means to start the rotation cycle of an electric motor. Capacitors cause the current to lead the voltage phase by 90°. This phase shift provides a rotating magnetic field in the motor and thus a means for attraction and repulsion of the rotor or armature.

Centrifugal switch: A switch that opens due to centrifugal force once the rotor reaches a specified speed (rotations per minute).

Commutator: A slotted metal cylinder that creates magnetic fields in between the "slots" of the cylinder.

Electric motor: A device that creates an electromagnetic force and converts it into a mechanical force.

Faraday's Law of Electromagnetic Induction: A theory required to explain all of the basic physics of magnetism involved in the concept of induced voltage.

Left-hand rule: A visual means of determining which direction current will flow through a conductive coil. Current flows from the North Pole designation of the conductor towards the South Pole designation. If you could imagine grasping the core of windings with your left hand, current would flow in the direction of your left thumb.

Rotor or armature: Moving portion of a motor.

Stator: Stationary portion of a motor.

Squirrel cage rotor: AC motor with conductive bars to create different magnetic fields in place of the windings.

Additional Suggested References

Gottlieb, Irvin M. *Electric Motors and Control Techniques*. New York: McGraw Hill, 1994.

CHAPTER SIX REVIEW QUESTIONS

Name:____________________________

Date: _____________________________

1. Name the major components of an electric motor and explain the purpose of each component.

2. Describe the left-hand rule for current flow through a conductor.

3. You have a work order for a centrifuge in the clinical lab. The motor on the centrifuge has an irregular rotation (e.g. it turns properly for a time period and then it slows down). Explain some possible causes for this symptom and list a troubleshooting technique. Explain the repair process.

4. You receive a work order for a ventilator that will not pump the air-oxygen mixture. The tech operating the ventilator states that it smells like oil fumes are coming from the motor. Explain some possible causes for this symptom and list a troubleshooting technique. Explain the repair process.

Chapter 7: Introduction to Common Electronic Components

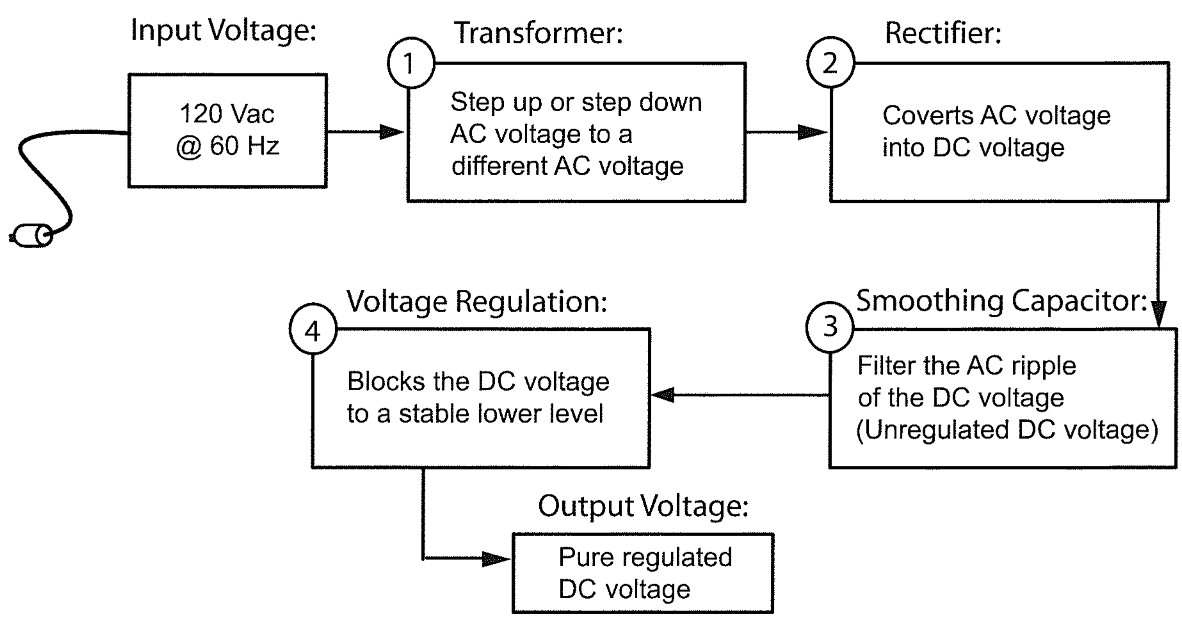
After completing this chapter you will have an understanding of:

- *The common electronic components used in power supplies*
- *How to order the correct components for a power supply*
- *The function of the common electronic components used in power supplies*
- *The knowledge of electronic schematics gained from Basic Troubleshooting Methods to understand the flow of electrons to each of the components of the electronic circuits*
- *The function of each portion of the power supply block diagram*

Power Supply Block Diagram

Block diagrams are figures used to simplify the concepts of how a device operates. In the case of the power supply, there are four major processes that illustrate its operation and function. Figure 7.01 illustrates a power supply as a block diagram. It is important that you understand each of the four processes represented in the power supply block diagram. You should also note which components are located in each of the blocks. The individual components will be discussed in detail in this chapter.

Figure 7.01



Transformers

A transformer consists of two sets of wire windings around a ferrite (iron) core or metal plates. There will be an air gap in between the two windings (see Figure 7.03). When a wire loops around a ferrite core, it creates a magnetic field. The magnetic field is transferred from one group of wire windings to the second group of wire windings. This is known as an "induced voltage" because the transfer process involves magnetic induction.

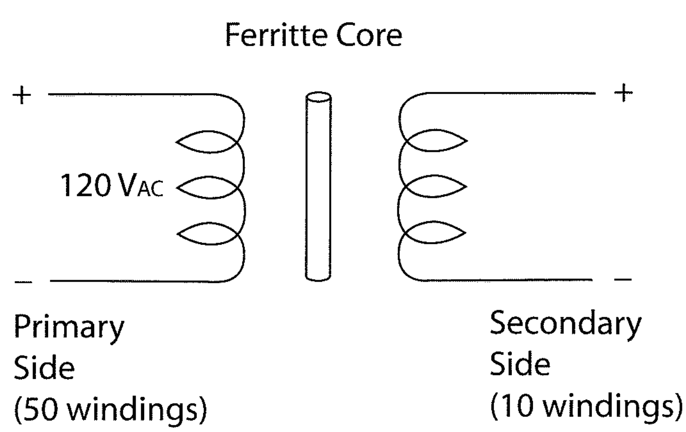
There are several factors that determine the size or magnitude of the magnetic field. A transformer has the same materials for both sets of windings; therefore, these variables are accounted for and provide a constant induction between the two sets of wire windings. The difference in induced voltage is produced by the number of windings on one side of the iron core being greater or less than the opposite side windings (see Figure 7.03). This allows the transformer to either increase or decrease the input voltage (house voltage for our purposes – 120 Vac @ 60 Hz). The wire windings connected to input voltage are known as "primary windings." This is called the "primary" side of the transformer. The wire windings connected to the circuit are known as "secondary windings." This is called the "secondary" side of the transformer.

Calculating the voltage on the secondary side of the transformer is a matter of knowing the ratio of the number of primary wire windings compared to the secondary wire windings. A "step-up" transformer has a greater number of windings on the secondary side of the transformer. As an example, if the ratio of primary windings to secondary windings is 1:10, the output voltage on the secondary side will be 120 Vac @ 60 Hz X 10 = 1200 Vac @ 60 Hz. A "step-down" transformer has fewer windings on the secondary side.

For example, if the ratio of primary windings to secondary windings is 10:1, the output voltage on the secondary side will be 120 Vac @ 60 Hz/ 10 = 12 Vac @ 60 Hz. If we convert this process to a mathematical formula we have:

Ns/Np x input voltage = secondary side voltage
Where: Ns = secondary winding ratio and Np = primary winding ratio

Figure 7.01A



$\frac{50}{10}$ (primary windings) (secondary windings)

5:1 step-down transformer

$\frac{120}{5}$ = 24 volts

Figure 7.02 **Power Supply Illustrated as the Power Supply Board**

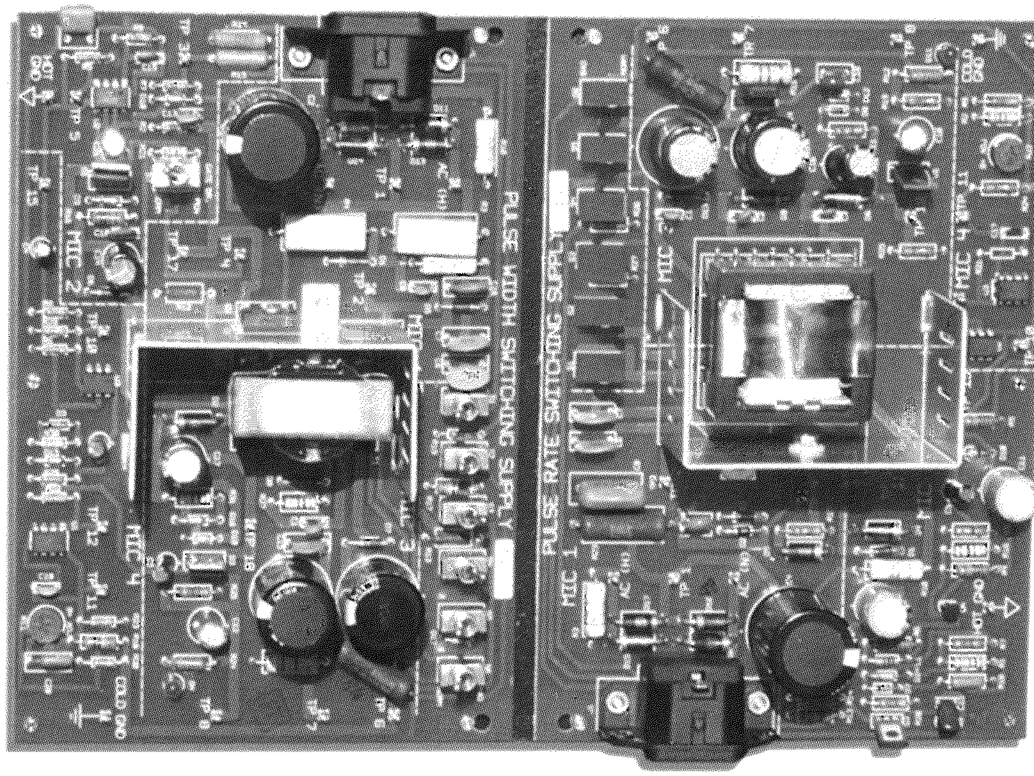
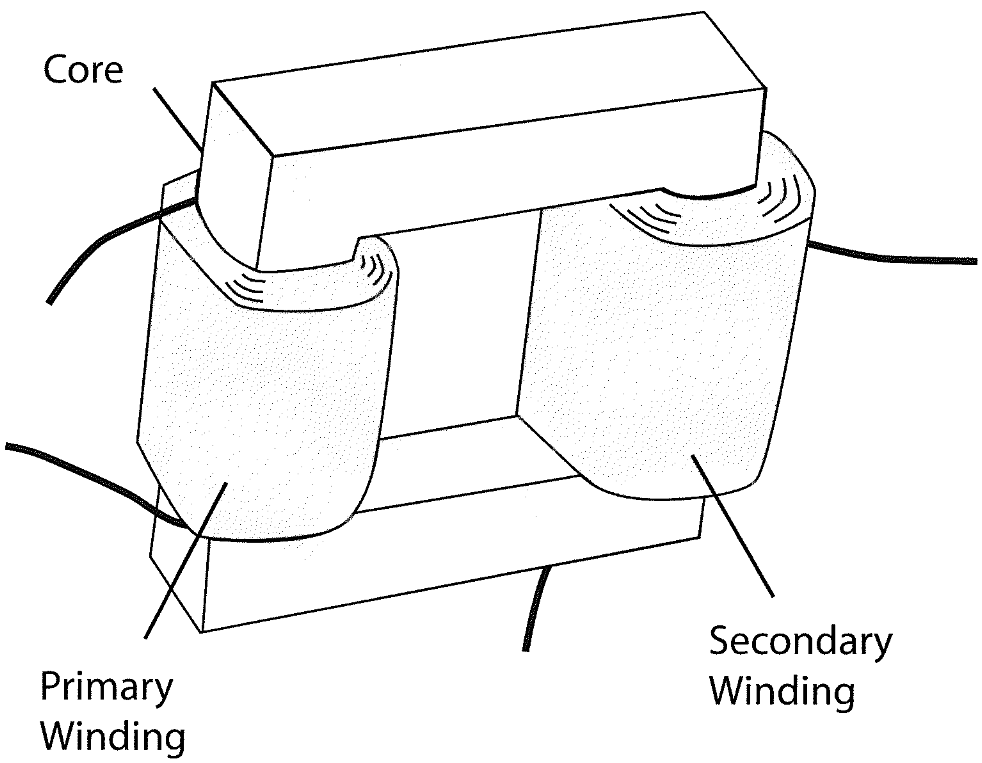
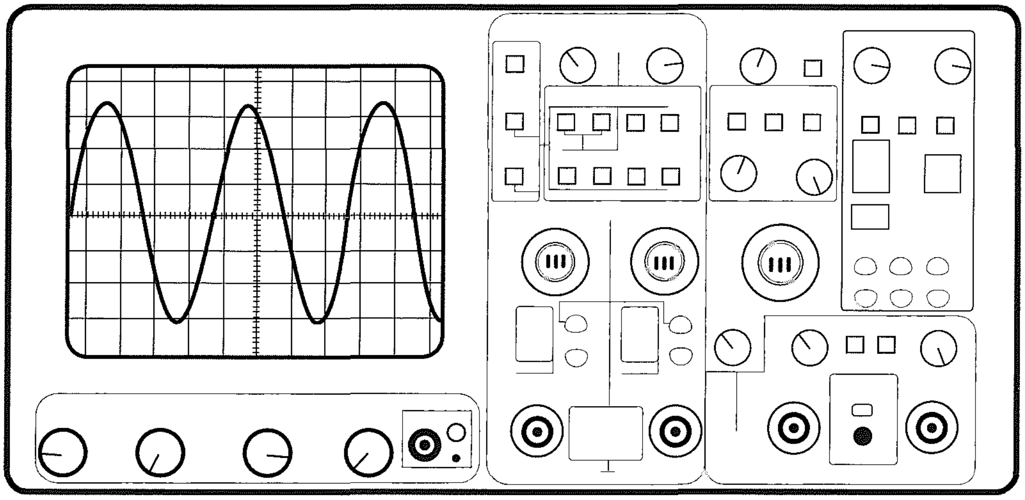


Figure 7.03



Alternating current (AC) voltage will appear on the oscilloscope as a sine wave. The transformer "induces" an AC voltage at the desired magnitude for the device requiring a power source (see Figure 7.01 block #1). Figure 7.04 illustrates the voltage output from a transformer as seen on an oscilloscope.

Figure 7.04



The secondary of the transformer may have multiple outputs. The most common multiple output transformer is known as a "center tap" transformer. The secondary AC voltage is one-half the full secondary voltage value from the "center tap" to either end of the secondary (see Figure 7.05).

Figure 7.05

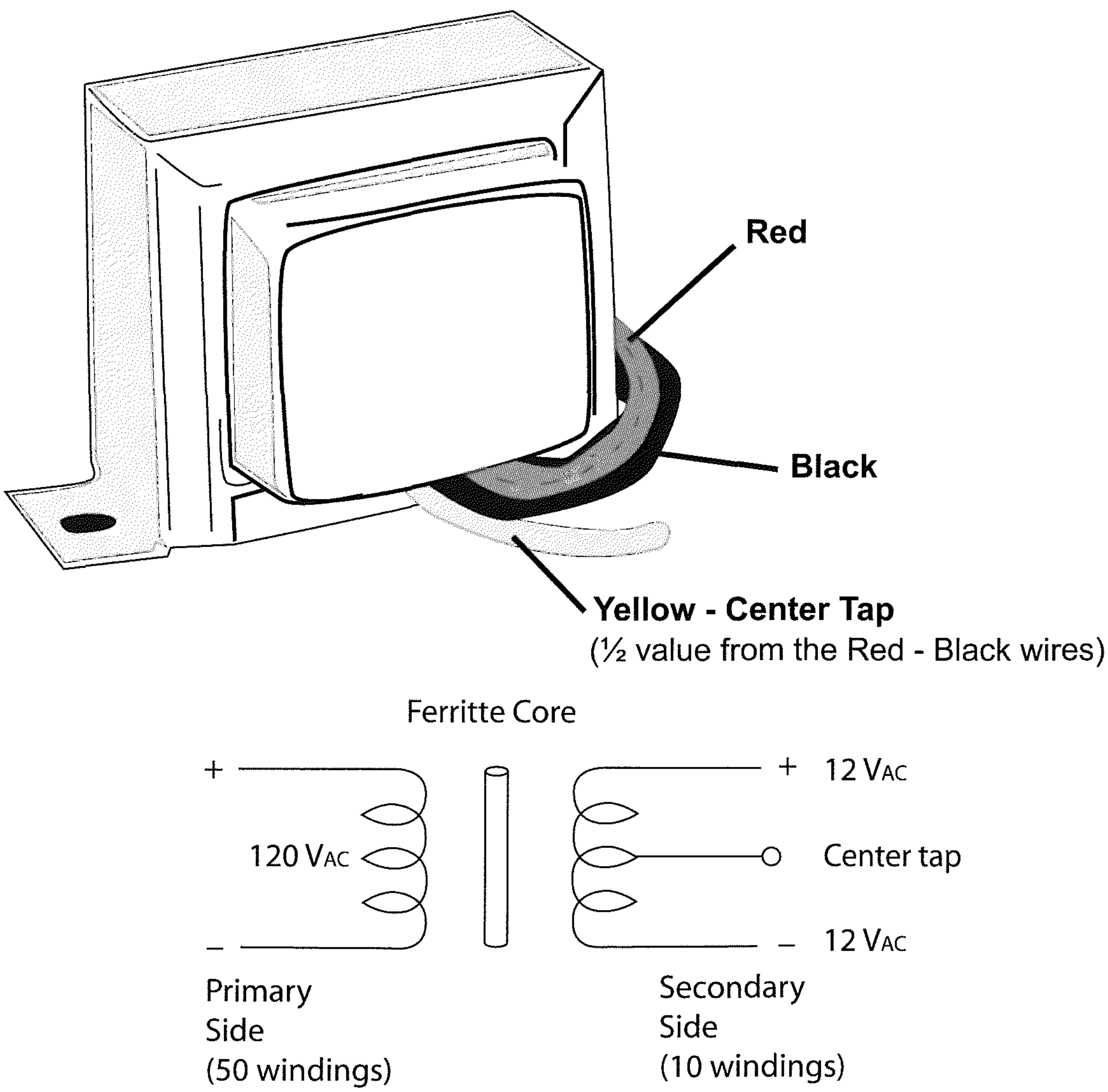
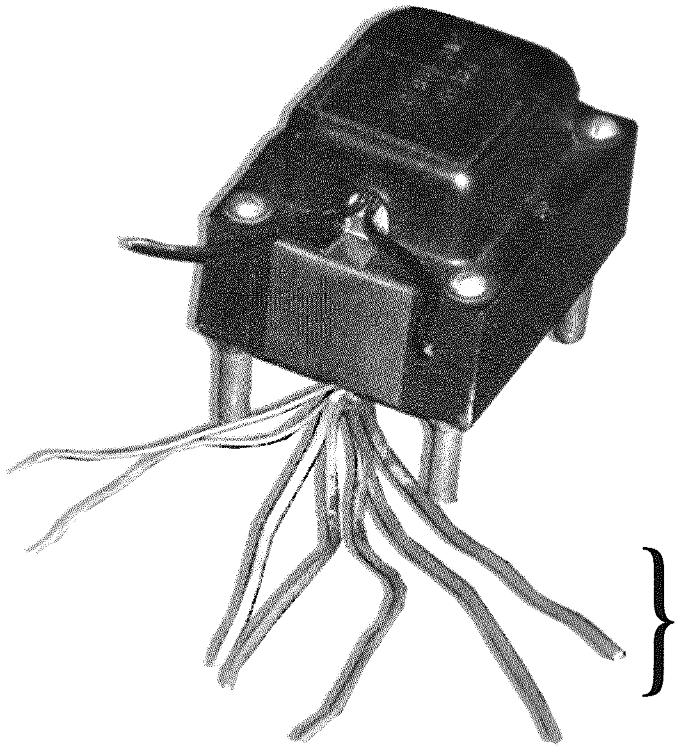


Figure 7.06



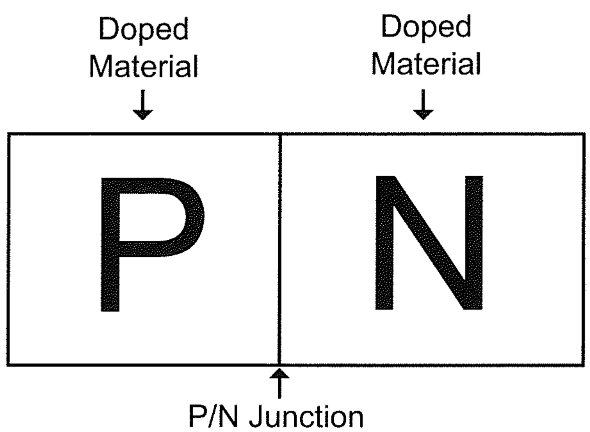
How to order transformers

When replacing and placing a parts order for transformers, you must specify the required secondary output and the amperage required. If a multiple output voltage transformer is required, each output must be specified in AC volts. The best method of replacing any part is to order the part by the specific part number. You will find the vendor or manufacturer's part number in their catalog. This eliminates the potential of receiving the wrong part.

Rectifiers and Semiconductors

A semiconductor component will allow electric current to pass through it under certain conditions but it lacks the atomic and structural properties of a true conductor. Therefore, semiconductors possess some resistivity. True conductors allow flow of electric current (electrons) in any state. Semiconductors are constructed of a silicon or germanium base. They are made more "conductive" by adding impurities into the base. This process is known as "doping." You can visualize this as a perfectly flat white field with holes in it. Some of the holes have a positive charge and some of the holes have a negative charge. Energy (the power supply) is required to create a pathway between the holes in order to reach the other side to "remove" the electric charges from the pathway. A semiconductor may contain either "N" doped or "P" doped impurities added to the silicon or germanium base. The boundary where the "P" doped and "N" doped materials meet is known as the PN junction. A semiconductor allows electrons to flow across the PN junction when the "P" doped side is positive (has a positive power supply terminal) with respect to the "N" doped side. This "state" or condition of the semiconductor is known as "forward bias." When the "P" doped side of the semiconductor is negative (negative with respect to the power (-) supply terminal) and positive with respect to the "N" doped side, it will not conduct current (prevents the flow of electrons). This state or "condition" of the semiconductor is known as "reverse bias." Figure 7.09 illustrates a semiconductor with "P" and "N" doped areas and the PN junction.

Figure 7.07 **Diode Construction**

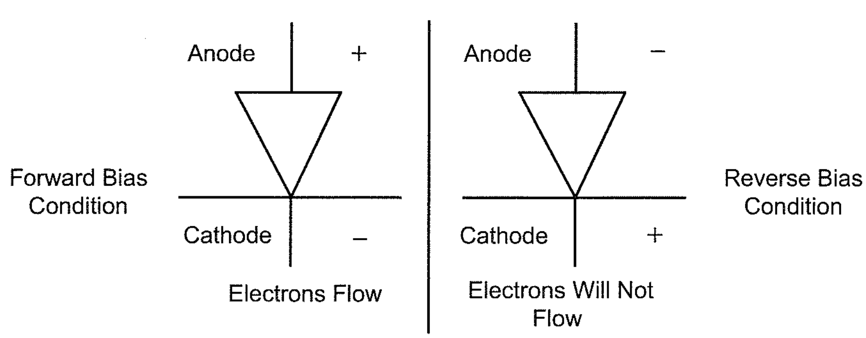


All semiconductor devices have one or more PN junctions (the area where the "P" doped material borders the "N" doped material). Semiconductor components include diodes, transistors, diacs, triacs, silicon controlled rectifiers, and operational amplifiers as well as several application specific semiconductors. It is essential that you have a working knowledge of each semiconductor component when troubleshooting electronic failures.

Diodes - Electrical "One-Way Valves"

A diode is the simplest of all semiconductor devices. It consists of a single PN junction. Figure 7.10 illustrates the forward and reverse bias conditions of a diode. When a diode is in the forward bias condition electrons are allowed to flow across the PN junction. The energy requirement to cross the PN junction of a forward bias diode is 0.7 Vdc for silicon based diodes and 0.6 Vdc for germanium based diodes.

Figure 7.08



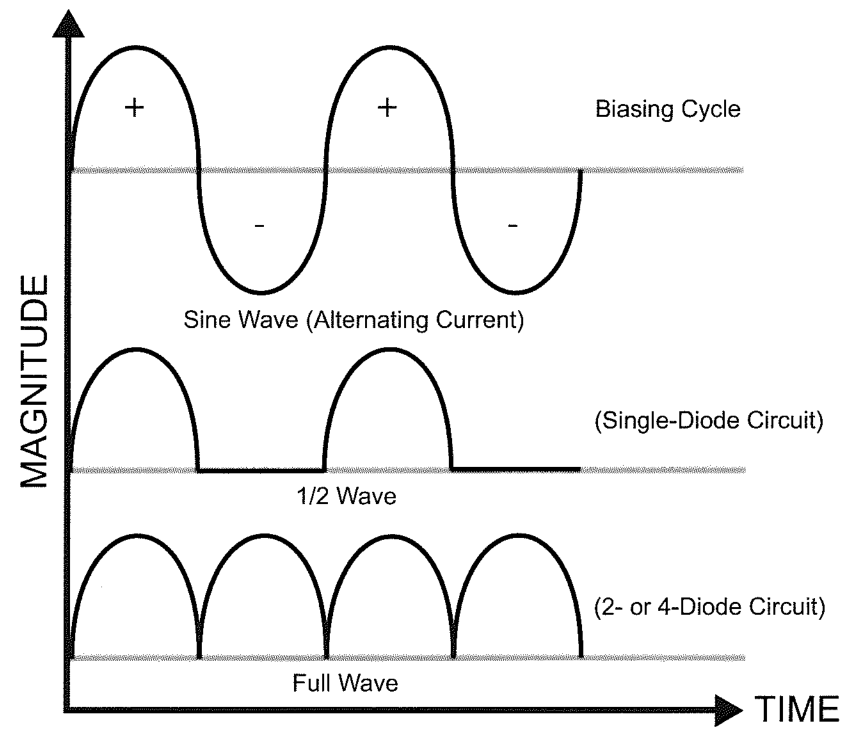
AC to DC Rectification Using Diodes

Due to this "biasing" condition, diodes will only conduct in one direction. When a diode is placed in a circuit with AC voltage, it only allows conduction during the "forward bias" condition of the diode. This property of diodes allows them to be used in power supplies for conversion of the AC sine wave signal into unregulated DC voltage. Diodes are sometimes referred to as "rectifiers," since they "rectify" or correct the problem of converting an AC voltage into a DC voltage. Figure 7.11B and Figure 7.11C illustrate the use of diodes to convert an AC voltage into a DC voltage.

Figure 7.09A

Figure 7.09B

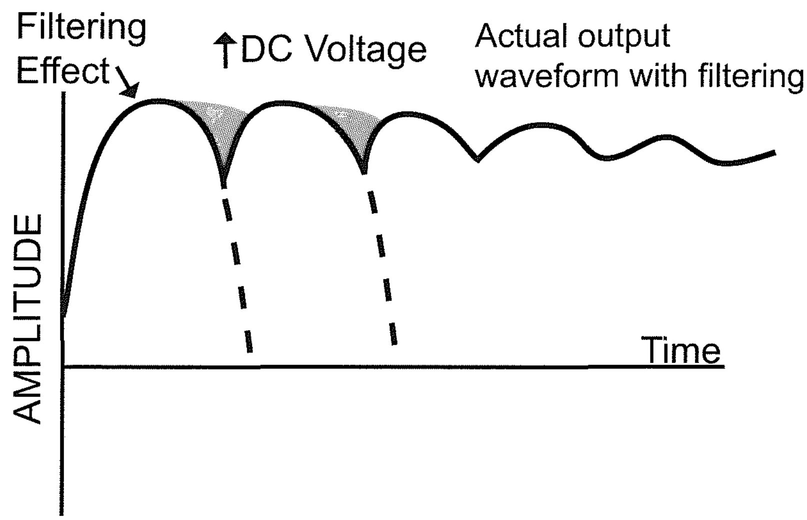
Figure 7.09C



Filtering

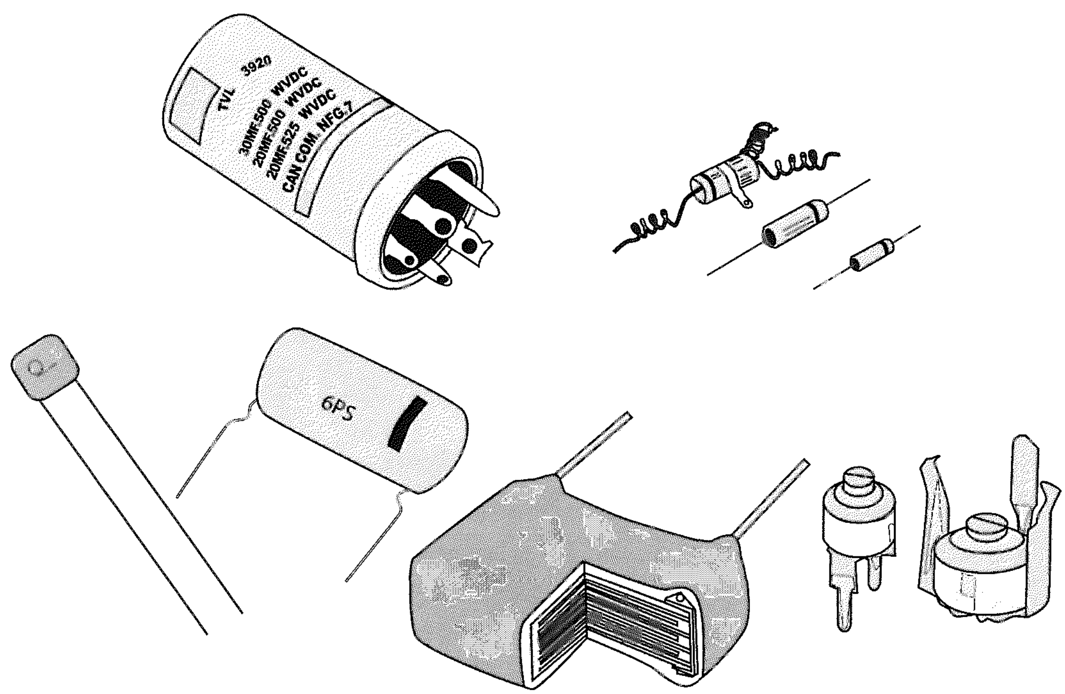
Filtering is a term used to describe the manipulation of an electromagnetic wave form. The sine was produced by a transformer is an electromagnetic wave form (see Figure 7.04). A component known as a capacitor filters the AC portion of the power supply's unregulated voltage (see Figure 7.01 block #3). Capacitors store charge on film plates wrapped inside the case. Some capacitors have positive and negative leads. If the leads are connected incorrectly (e.g. the positive end is connected to the negative side of the circuit) the capacitor may explode. You must be extremely careful when replacing capacitors. The charging and discharging cycle of a capacitor is determined by the size in farads of the capacitor and the series resistance of the capacitor-resistor circuit. This is referred to as the RC time constant and is measured in milli or micro seconds. The larger the resistor or capacitor, the longer the RC time constant. The following figure illustrates the effect of the RC time constant by extending the discharge time and increasing the DC voltage component of the power supply.

Figure 7.10



Capacitors are made from several materials including, polyester film, ceramic and tantalum. The figure below provides illustrations of various types of capacitors.

Figure 7.11

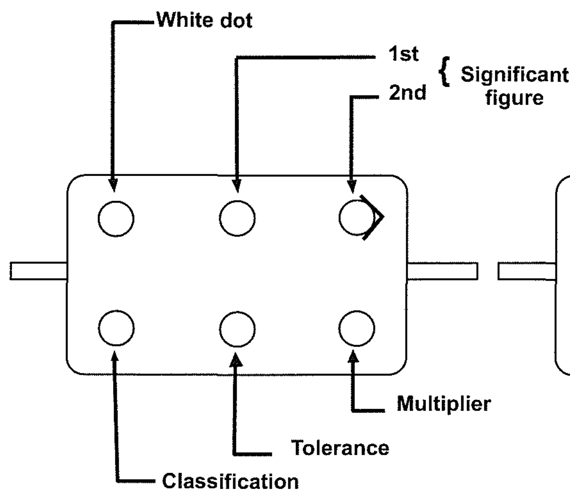


When ordering a capacitor, you must specify the ability to store electrons in farads and the maximum voltage potential as well as the type (material) desired. As an example, you might require a 100 microfarad, 30 volt, electrolytic capacitor for your circuit. Table 5.01 provides an example of the specifications required to order the exact replacement capacitor.

Table 7.01

Color	Sig-nificant Figure	Decimal Multiplier	Tolerance ±%	Class	Temp. Coeff. PPM/ C Not More than	Cap.Drift Not more than
Black	0	1	20	A	+1000	+(5% + 1pF)
Brown	1	10	–	B	+500	+(3% + 1pF)
Red	2	100	2	C	+200	+(0.5% + 0.5 pF)
Orange	3	1000	3	D	+100	+(0.3% + 0.1 pF)
Yellow	4	10,000	–	E	+100-20	+(0.1% + 0.1 pF)
Green	5	–	5	–	–	–
Blue	6	–	–	–	–	–
Voilet	7	–	–	–	–	–
Gray	8	–	–	I	+150 - 50	+(0.03% + 0.2 pF)
White	9	–	–	J	+100 - 50	+(0.2% + 0.2 pF)
Gold	–	0.1	–	–	–	–
Silver	–	0.01	10	–	–	–

Present RETMA 6-DOT Color Code



Present MIL Color Code

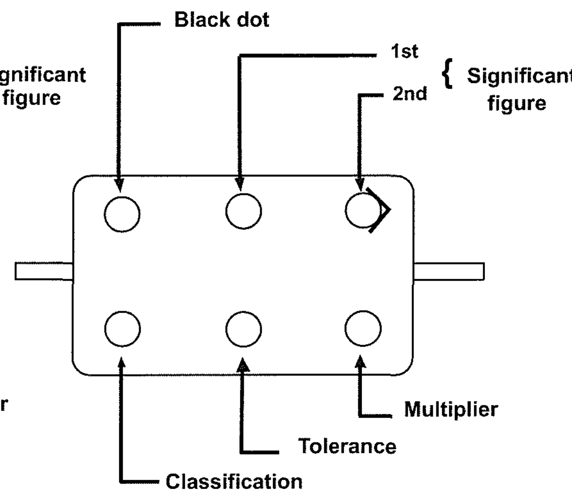
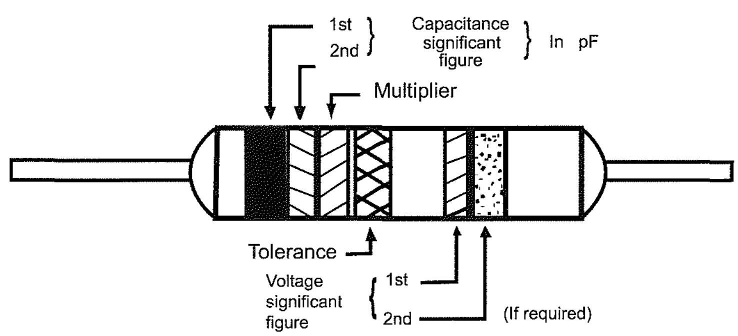


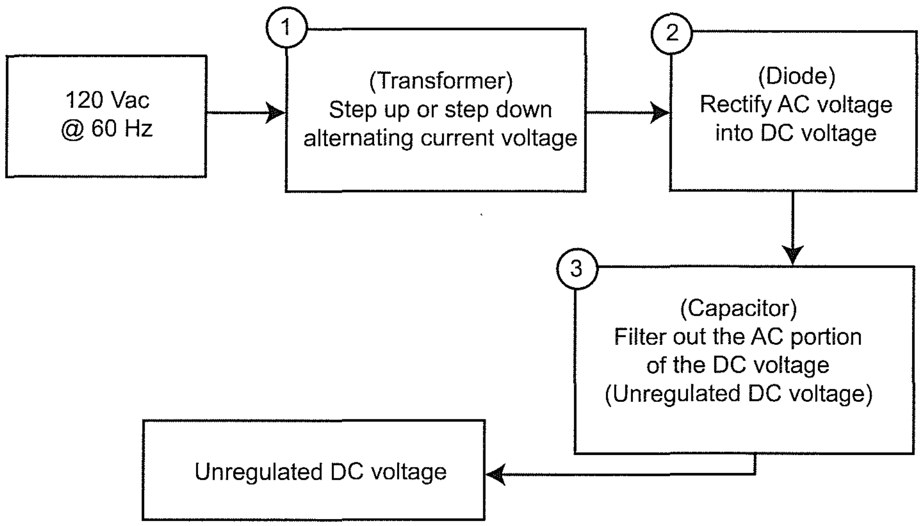
Table 7.02



Band Color Code	Significant Figure	Decimal Multiplier	Tolerance ±%
Black	0	1	20
Brown	1	10	–
Red	2	100	–
Orange	3	1,000	30
Yellow	4	10,000	40
Green	5	10^5	5
Blue	6	10^6	–
Violet	7	–	–
Gray	8	–	–
White	9	–	10

Referring to the original block diagram of a power supply, the "blocks" will be filled in with the components that have been presented this far in the chapter.

Figure 7.12



Bipolar and Field Effect Transistors - Voltage Regulators

The final stage of the power supply involves transistors and integrated circuits (ICs) known as voltage regulators. The remainder of the chapter will be devoted to transistors. A full understanding of transistors is necessary for general electronic troubleshooting as well as understanding the principles of voltage regulation. Voltage regulation will be covered in detail in Introduction to Power Supplies.

Transistors are classified as either bipolar junction or junction field effect depending on the construction of the "doping" layers. Bipolar junction transistors (BJTs) have two PN junctions. The amount of current to the "base" leg of the BJT determines the flow of electrons from the "emitter" leg to the "collector" leg. If there is no current flowing into the "base" leg of a BJT, the transistor will not allow electrons to cross the two PN junctions. Figure 7.14A illustrates the conduction of a NPN BJT and Figure 7.14B illustrates the PNP BJT conduction features.

Figure 7.13

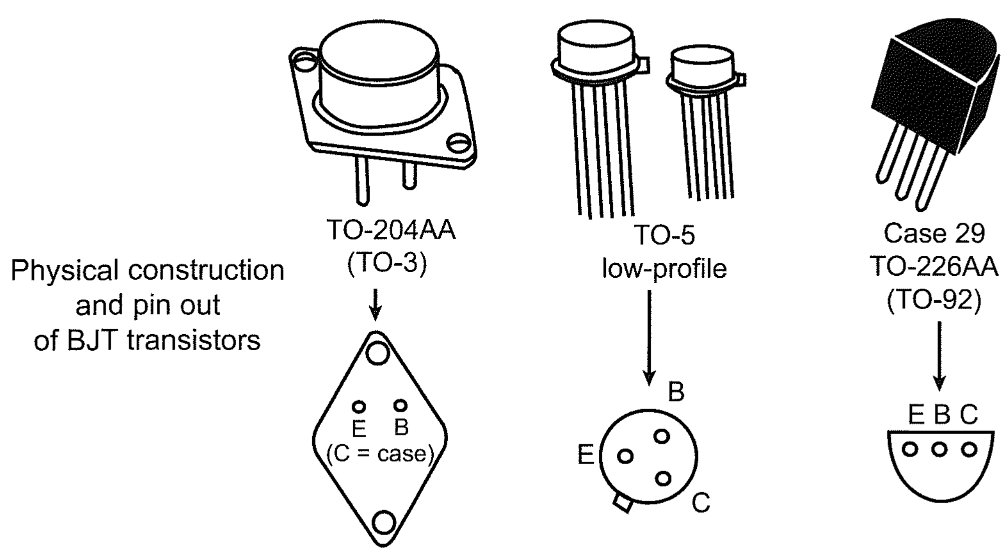


Figure 7.14A

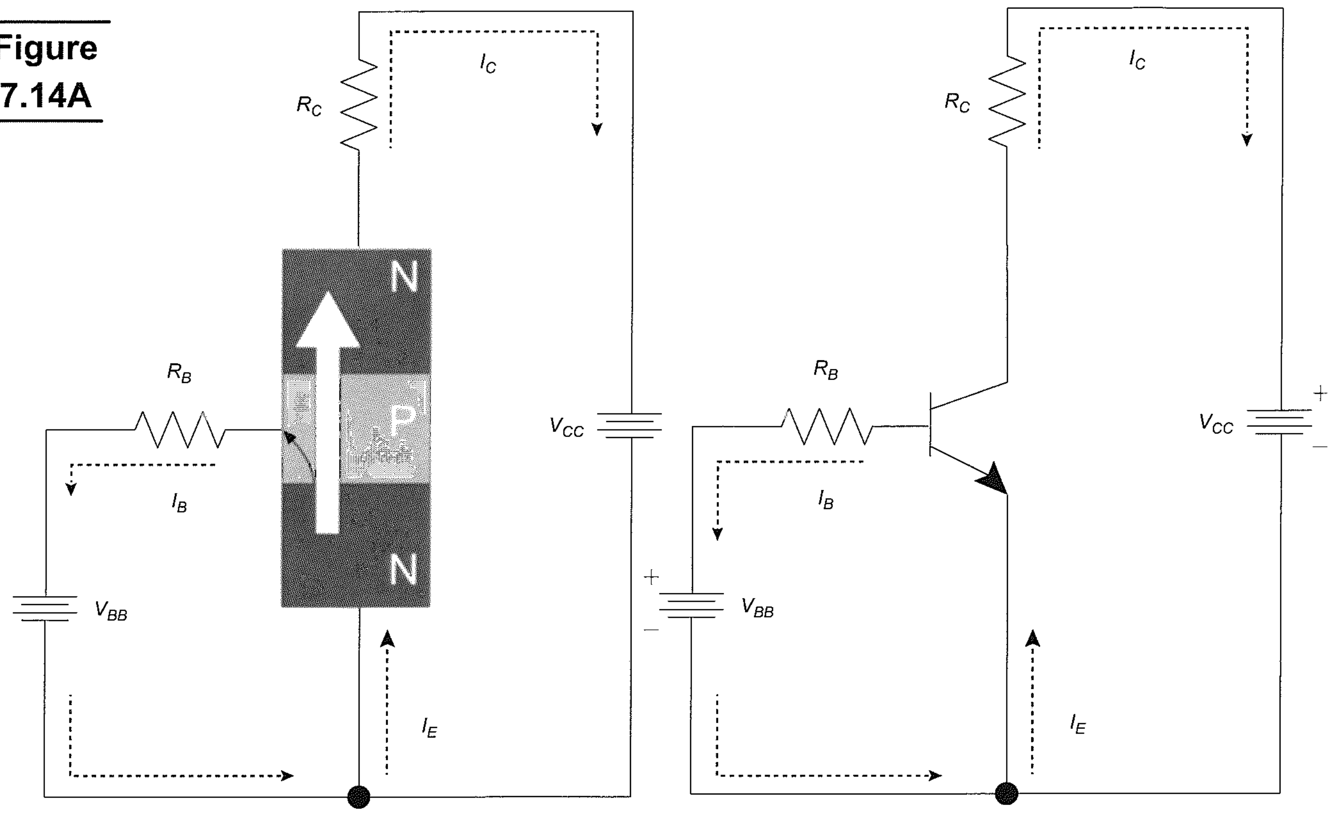
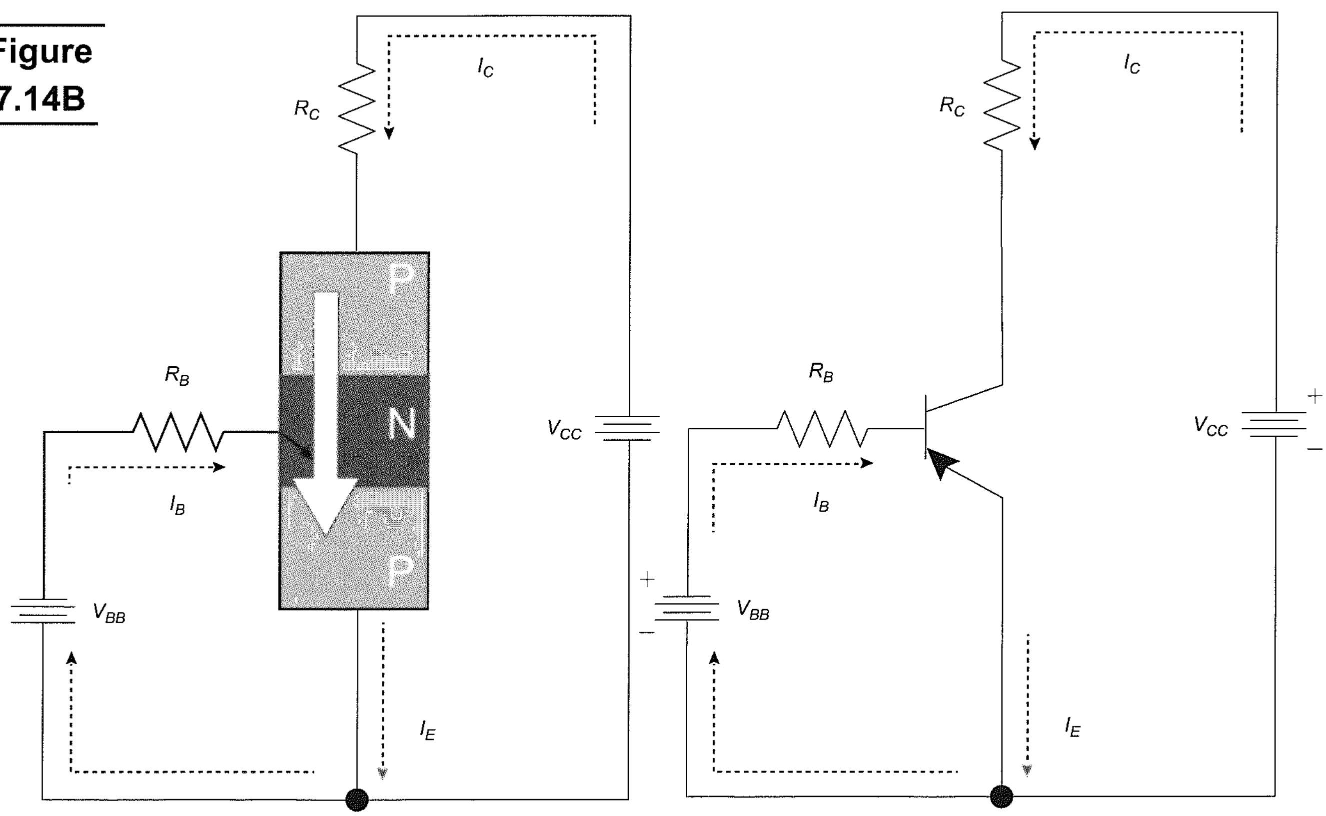


Figure 7.14B

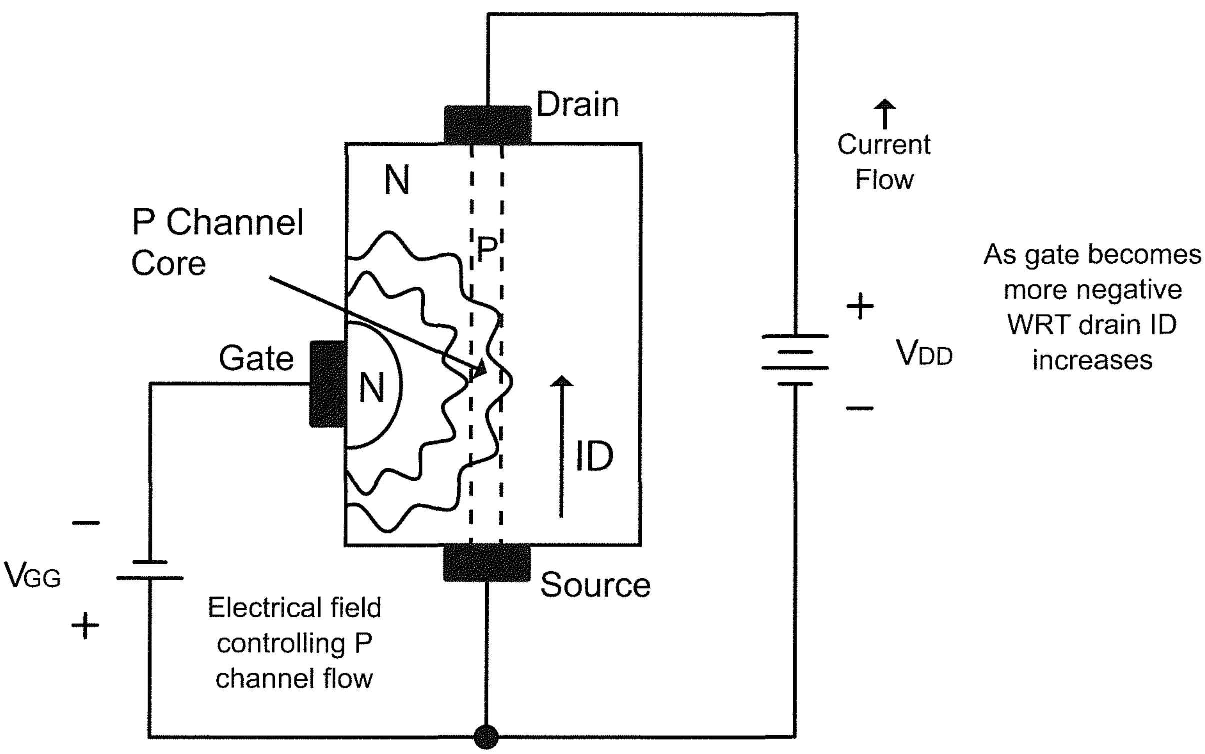


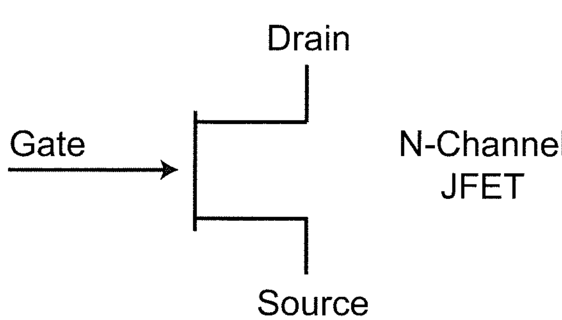
Bipolar junction transistors are generally used in circuits with power applications. The BJT may act as an amplifier, switch, or feedback variable resistor.

Junction field effect transistors (JFETs) are constructed with a variable doped "channel" and a doped gate. The "channel" variability or "width" is controlled by the "gate" voltage.

JFETs have a very large input impedance. This refers to the passive and active resistance encountered by a signal as it enters the input of a JFET. This is very desirable for signal amplification, since only the higher power "true" physiological signal passes through the JFET. Stray electromagnetic signals that may be generated from fluorescent lighting, elevator motors, and other equipment operating in a nearby environment will not have the energy to pass through the JFET input. Therefore, weak stray electromagnetic signals will not be amplified and coupled with "true" physiological signals. JFETs are used extensively in signal processing, due to their property of high input impedence and low output impedence. Figure 7.15 illustrates the effect of gate voltage on the channel width of a JFET. JFETs also find applications as power amplifiers. In general, JFETS have more precise control over the "channel width," which controls output amplification and current than BJTs. The drain and gate voltages of the JFET are less complex to modify than BJT circuits. BJTs may also create more heat loss energy and be subject to lower life expectancy. BJTs still remain the best choice component where high voltages are required.

Figure 7.15





Metal Oxide Semiconductor Field Effect Transistors

A specialized form of a field effect transistor (FET) is the metal oxide semiconductor (MOS) FET. The gate of the MOSFET is isolated and allows it to be operated with or without a gate source. It has no PN junction. Figures 7.16A and 7.16B illustrate the N-channel D-MOSFET and P-Channel D-MOSFET.

Figure 7.16A

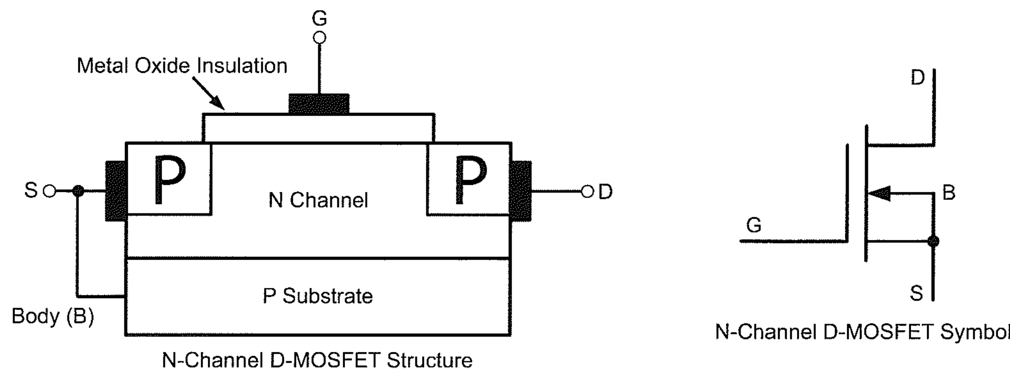
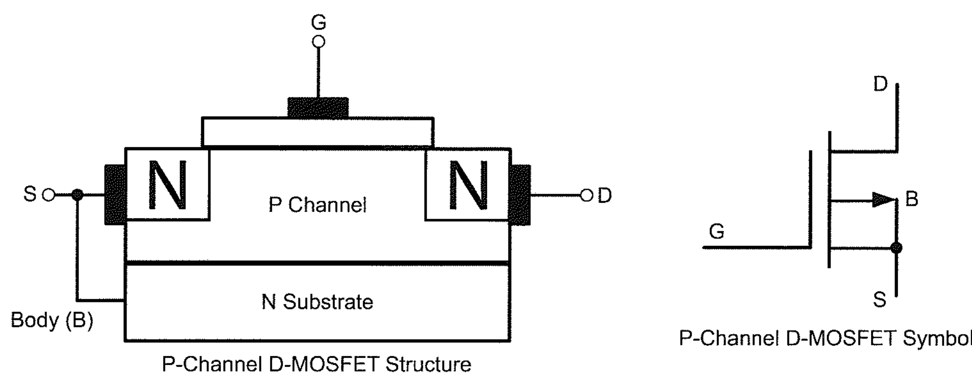
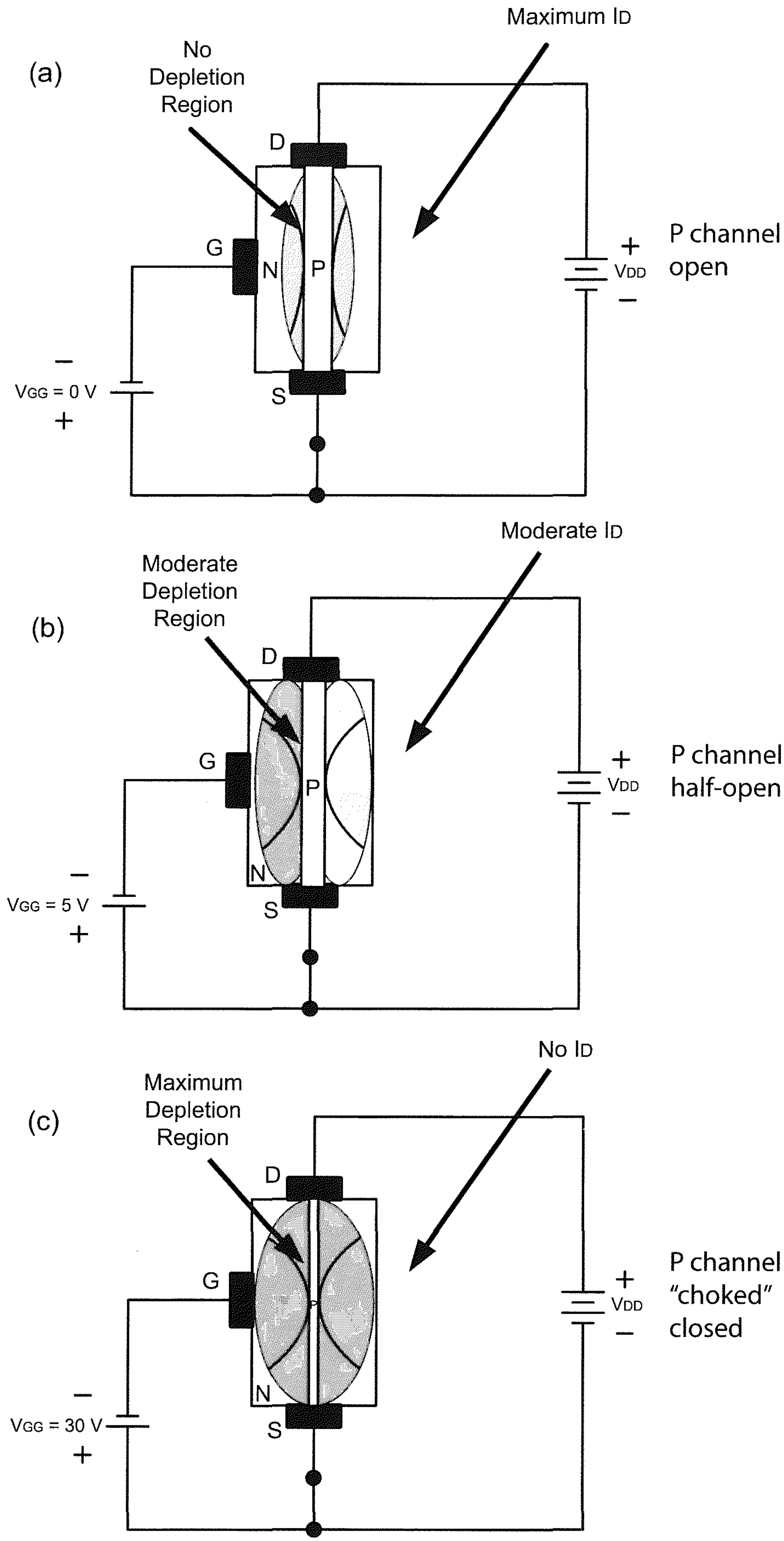


Figure 7.16B



It is essential that an anti-static strap is used when handling MOSFETs. Very small static currents will damage or destroy a MOSFET. This static precaution is necessary due to the very high input impedence of the MOSFET. The primary advantage of a MOSFET is a greater conductivity through the channel. Current control is more sensitive with MOSFETs compared to JFETS.

Figure 7.17 **Electron Channel Control of the JFET**



CHAPTER SEVEN REVIEW QUESTIONS

Name:____________________________

Date: _____________________________

1. Draw the electronic symbol for the following components:

   Transformer

   Electrolytic capacitor

   N-channel JFET

   NPN Bipolar junction transistor

   Diode

2. Which of the following combinations will require the longest time to discharge:

   a. 500 Ω resistor and 100 M micro-farad capacitor

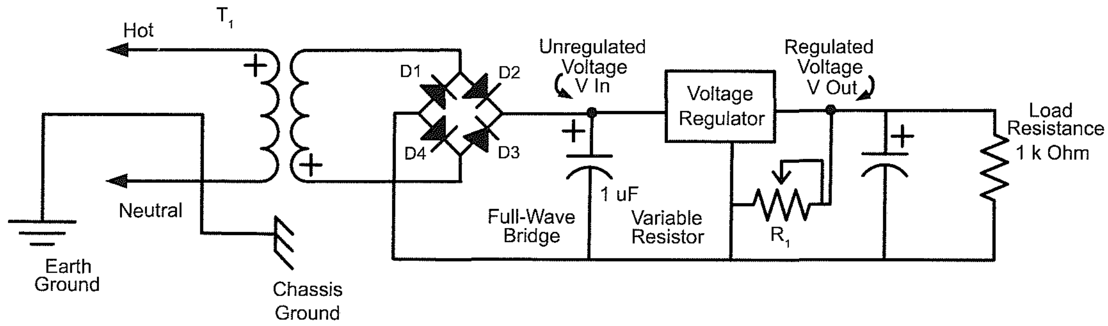
   b. 1000 Ω resistor and 100 M micro-farad capacitor

   c. 100 Ω resistor and 100 M micro-farad capacitor

   d. 200 Ω resistor and 100 M micro-farad capacitor

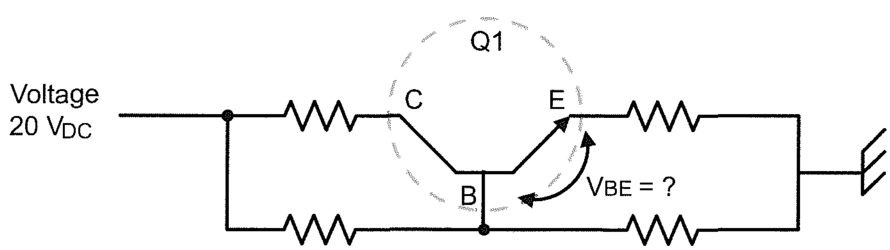
   Explain your answer.

3. In the schematic below, which diodes are forward biased?



4. Draw a block diagram that explains the four sub-systems of a power supply.

5. In the circuit below, if there is current to the base of Q1, what is the voltage from the base to the emitter?



6. What are the advantages and disadvantages of using JFETs in a circuit as compared to BJTs?

7. Explain the concept of the "push-pull" Class B amplifier configuration. How is this configuration useful?

Chapter 8: Common Power Supplies

After completing this chapter you will have an understanding of:

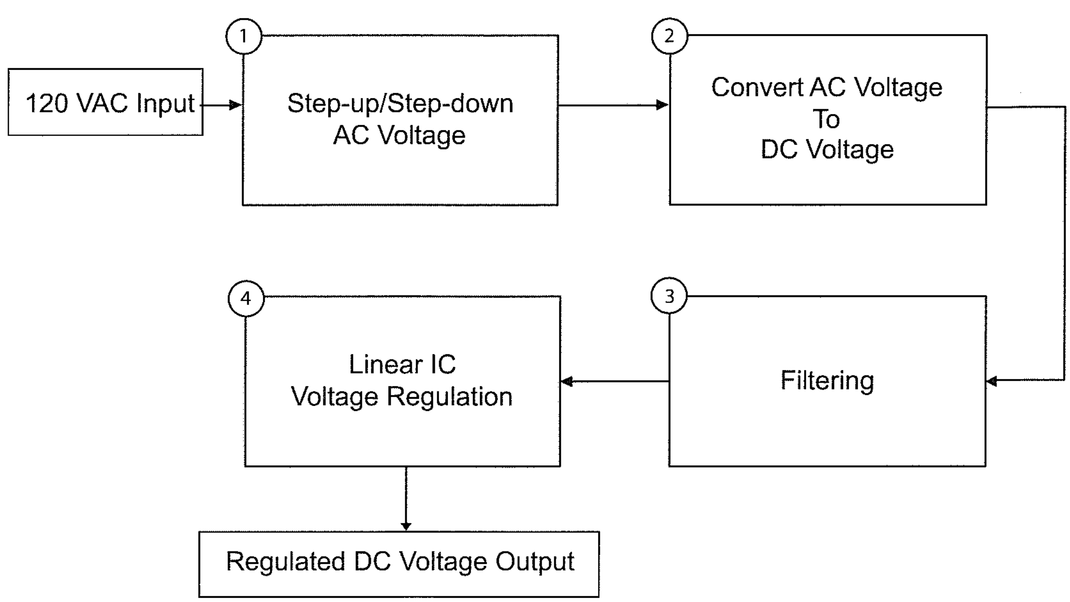
- *The purpose of a power supply*
- *The functions of each component of the block diagram of a power supply*
- *The components required to construct and troubleshoot a power supply*
- *The components required to troubleshoot a power supply in a medical electronics circuit*

Introduction to DC Voltage Regulation

Power Supplies: Input Source

Refer to the block diagram of a basic power supply Figure 8.01. Most medical devices require 110/120 VAC @ 60Hz, known among electricians as house voltage, because this is the normal voltage found in North American homes. In Europe, power is distributed at 50Hz and the voltage at the outlet will vary. Some medical devices for diagnostic imaging will operate from three-phase power and require input sources from step-up transformers in the 1000 volt or kV range. For the purposes of our discussion on basic power supplies, we will assume 110/120 VAC sources @ 60Hz.

Figure 8.01



Alternating and Direct Current Theory introduced the concept of alternating current (AC). The house voltage measured on an oscilloscope would appear as a sine wave shown in figure 8.02A In Introduction to power Supply Components the forward biasing condition of a diode was introduced. You may want to review that chapter to refresh your memory of these concepts. Figure 8.02B illustrates house voltage measured on an oscilloscope as it would appear after passing through a forward biased diode. The waveform illustrates "half-wave" rectification. Figure 8.03 illustrates a two-diode full wave rectifier. The bias conditions of D_1 and D_2 are indicated during the complete sine wave in both the negative and positive wave cycles. Note that D_1 conducts during the first half of the wave cycle and D_2 conducts during the second half of the wave cycle.

Figure 8.02A

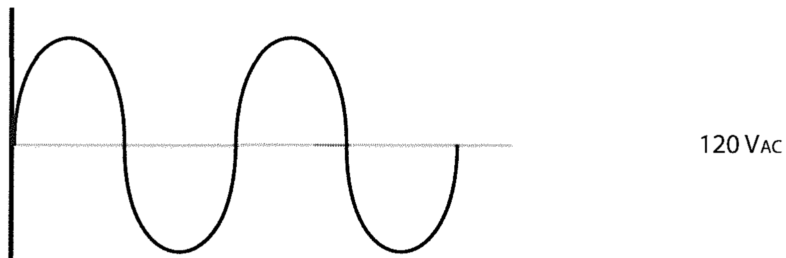


Figure 8.02B

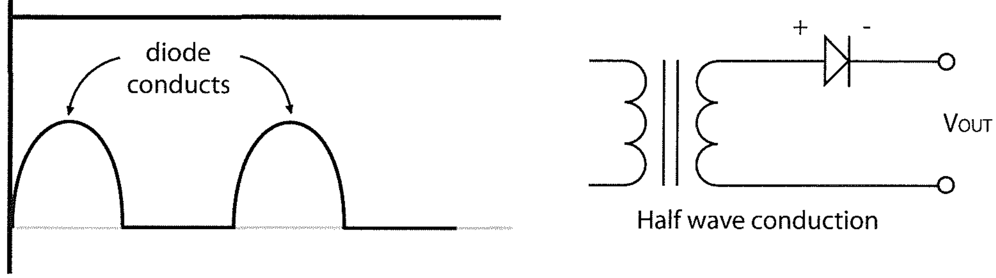
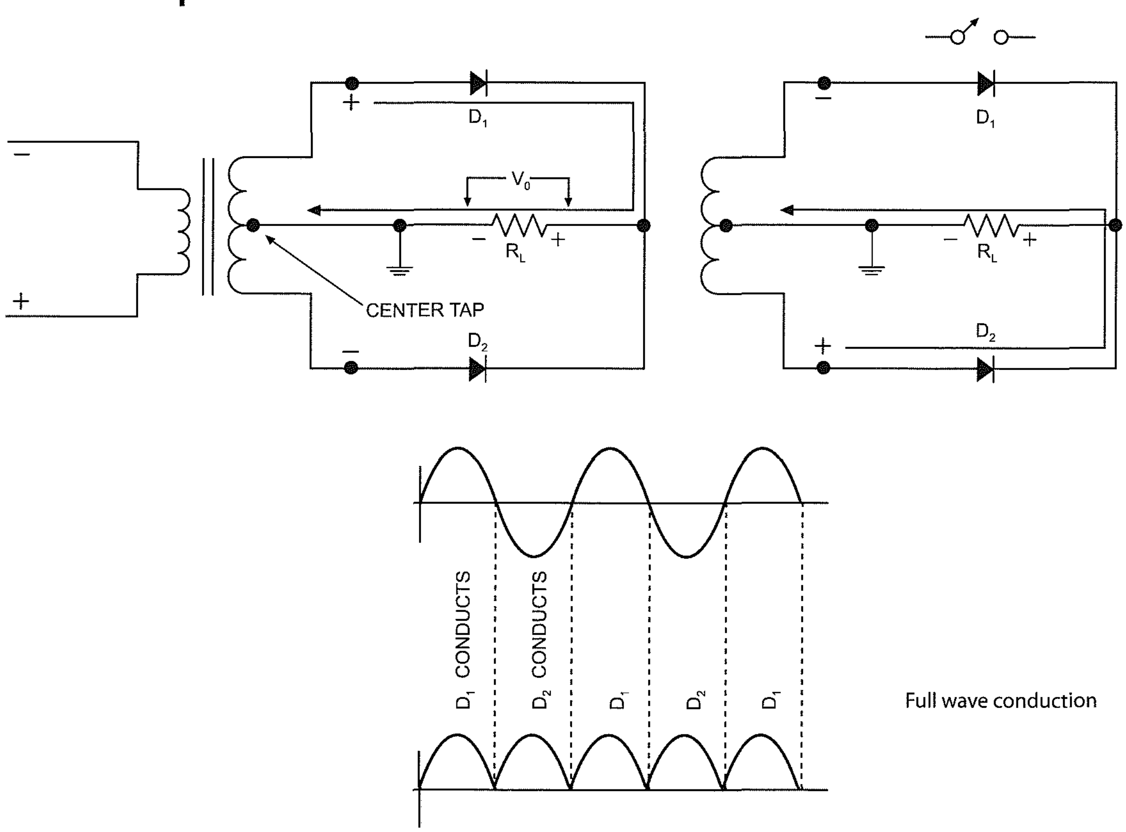


Figure 8.03



With full-wave rectification, the waveform is considered to be DC. As you can see by the illustrations in Figure 8.03, there is a tremendous amount of AC voltage or ripple still remaining. Remember from previous chapters, the purpose of a power supply is to provide DC voltage at a magnitude and polarity required by a particular device. The purpose of the voltage regulator or voltage regulation system is to complete the voltage regulation process to provide pure regulated DC voltage at the output of the power supply. The next process in conversion of AC voltage to pure regulated DC voltage is filtering. Filtering is accomplished by using a capacitor or a capacitor-inductor combination. Figure 8.04 illustrates a circuit with filtering of the full-wave bridge rectification. Figure 8.05 illustrates how the waveform would appear on an oscilloscope.

Figure 8.04

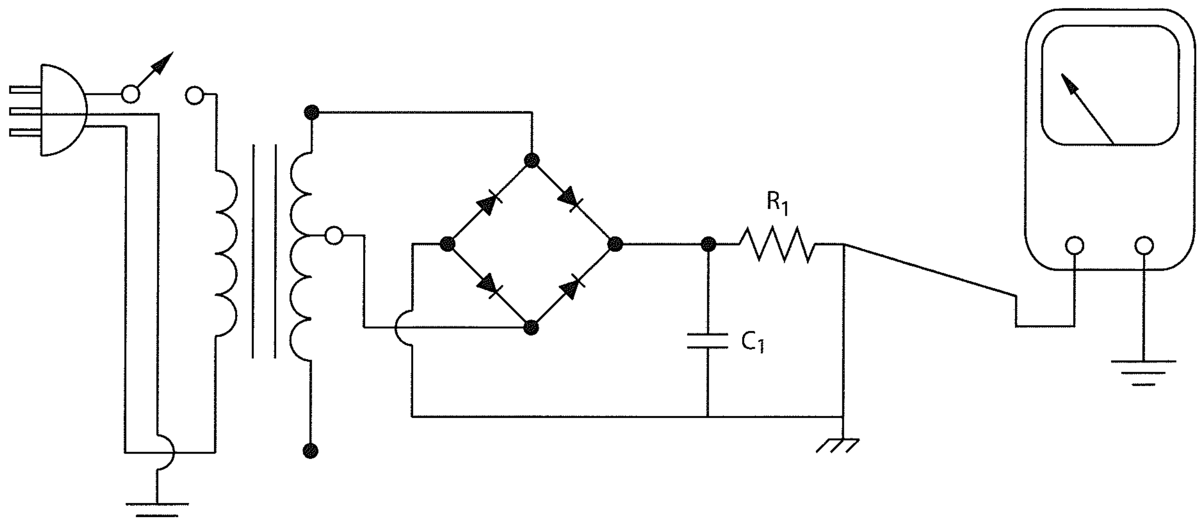
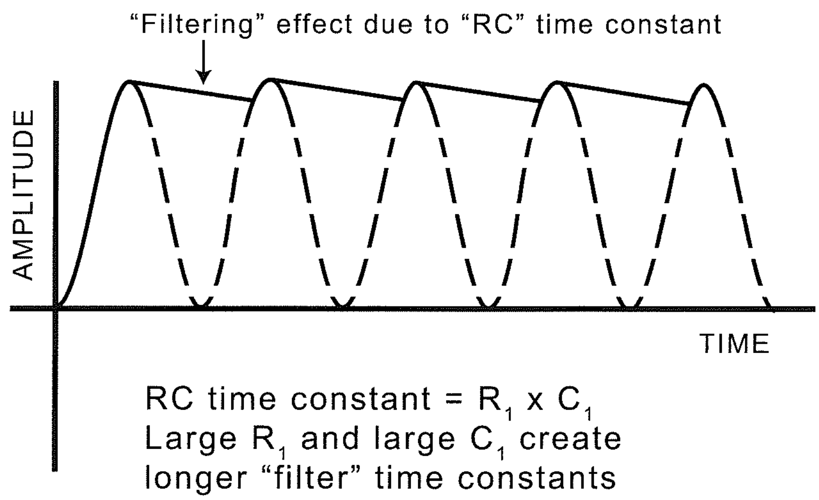


Figure 8.05



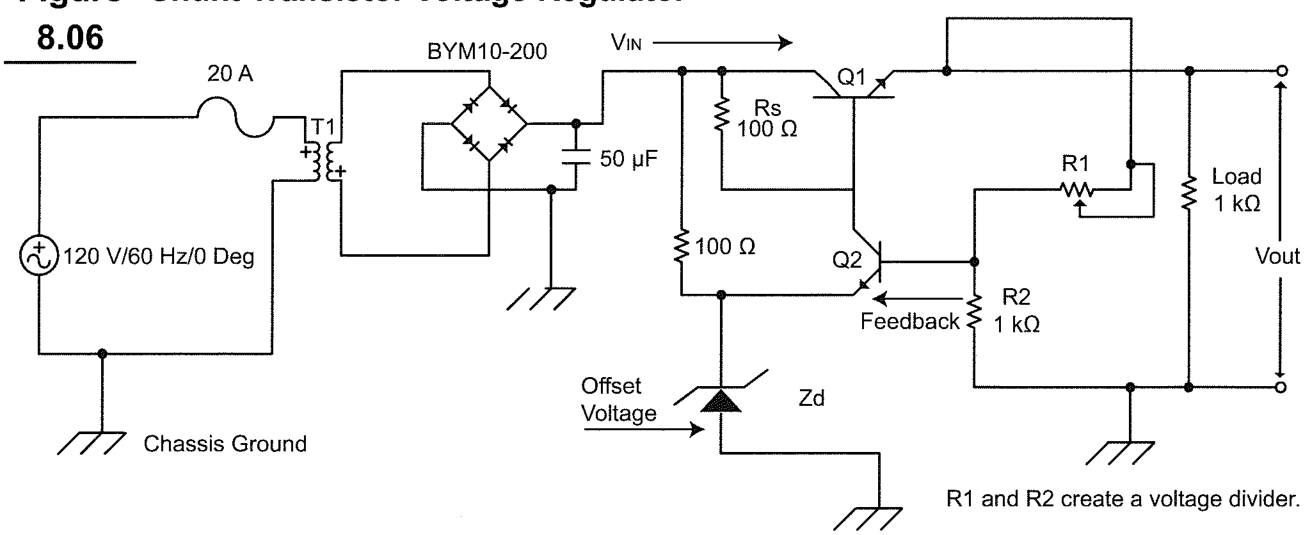
The Transistor Shunt Voltage Regulator

Refer to Figure 8.01. Notice that the last sequence in converting AC voltage to DC voltage is "voltage regulation." The remainder of this chapter will introduce the "voltage regulation" concept and the components that provide pure regulated DC voltage.

Power supplies are classified as either linear or switching, based on their method of voltage regulation. Voltage regulators can be purchased as integrated circuits (ICs). These ICs contain hundreds of transistors, operational amplifier circuits and resistor, capacitor, inductor components. In order to better understand the voltage regulation process, voltage regulator circuits of discrete components will be introduced. The transistor shunt voltage regulator contains only two transistors and is a simplified version of a linear power supply. Switching power supplies will be discussed in the Switching Power Supplies section.

In Figure 8.06 a complete transistor shunt voltage regulator circuit is illustrated in detail. Notice that the Q1 transistor is the shunt transistor and transistor Q2 is the feedback transistor. This basic concept of an input voltage (Q1) and a feedback mechanism (Q2) is common to all voltage regulators.

Figure 8.06 **Shunt Transistor Voltage Regulator**



Notice that the collector of Q2 (the feedback transistor) is connected directly to the base of Q1 (the voltage shunt transistor). Recall from Introduction to Power Supply Components, the current to the base of Q2 determines the magnitude of the voltage across the collector to the emitter of Q2. The purpose of the voltage regulator is to remove any remaining AC voltage from the DC voltage. (Add the feedback from Q2.) In Figure 8.06, as the voltage from Q1 increases, the current to the base of Q2 increases. As a feedback system, this increases the voltage at the emitter of Q2. Increasing the voltage at Q2 removes some of the available current at the base of Q1. With a lower base current at Q1, the emitter of Q1 produces a lower output voltage and corrects the high output. The opposite will occur if the voltage at Q1 decreases. With a decrease in voltage at the emitter of Q1, there is a complimentary decrease in the current to the base of Q2. This decrease in base current causes a lower Q2 emitter voltage. The lower Q2 emitter voltage allows more available current to flow into the base of Q1. This then causes Q1 to increase the emitter voltage and correct the lowered output voltage.

Linear Integrated Circuit Voltage Regulators

The linear integrated circuit (IC) voltage regulator appears in several packages. It is normally a three-pin component, as shown in Figure 8.07. Figure 8.07 illustrates the dual output linear IC voltage regulator circuit.

Figure 8.07

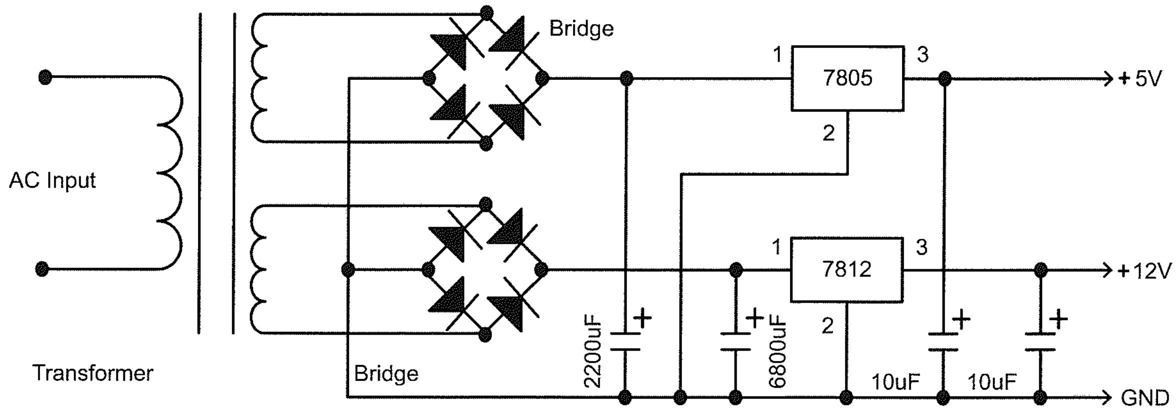
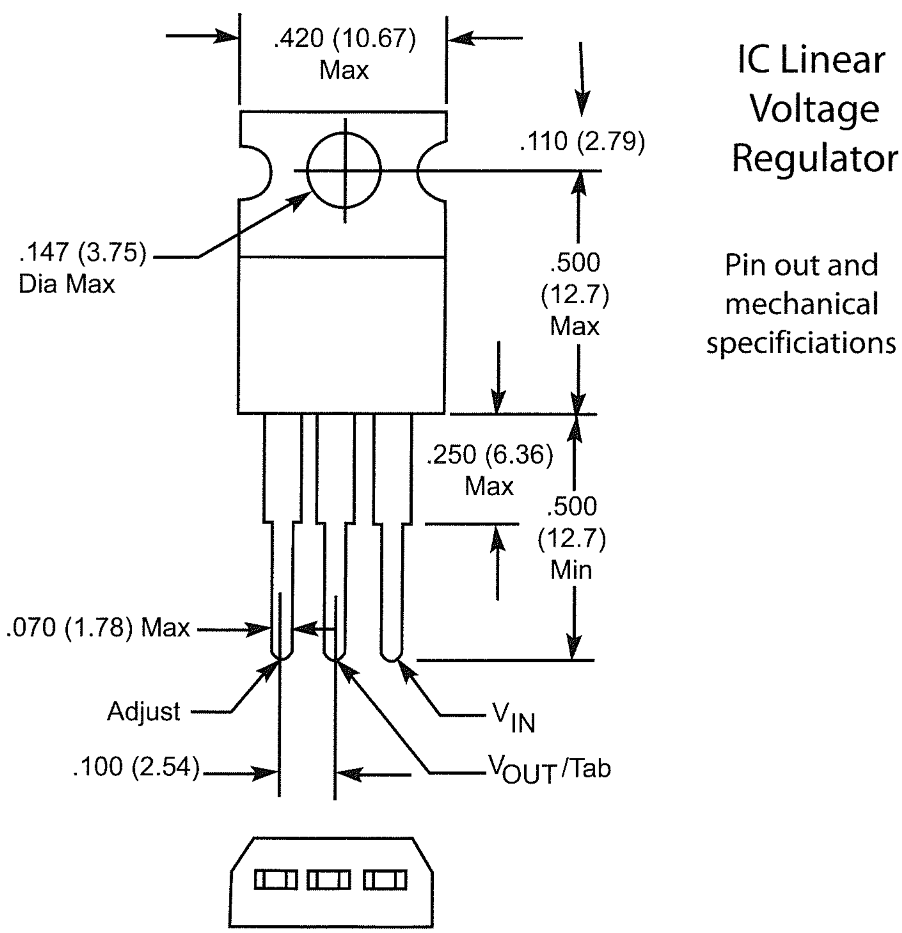


Figure 8.08



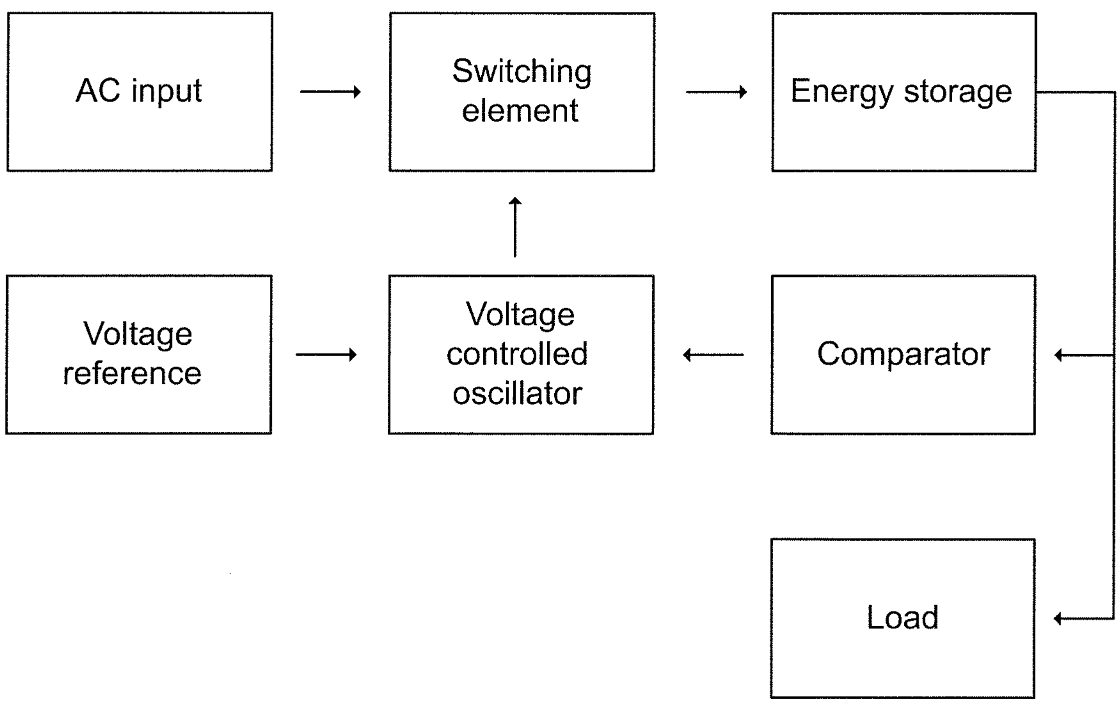
The linear IC voltage regulator may have a fixed or adjustable voltage output, a positive or negative voltage output, and three or more terminals. Figure 8.08 illustrates a common three-pin voltage regulator. A variable positive and negative power supply using a linear IC voltage regulator is shown in Figure 8.07. This power supply allows an output of both positive and negative voltages. Most power supplies in medical devices will have one or more fixed DC voltages. The voltages may be both positive and negative. Appendix D provides several Web sites for additional information.

Linear voltage regulators are constantly in the "on" state, which is a primary disadvantage of this design of power supplies. Linear voltage regulators are almost always mounted on heat sinks to shunt heat away from the regulator.

Switching Power Supplies

Switching power supplies have the same purpose as linear power supplies. Both provide DC voltage at a magnitude(S) and polarity required by the device they power. The common source for DC voltage is AC house voltage available from the wall outlets. Switching power supplies do not remain constantly in the "on" state. They switch on and off, thus the name switching power supplies. This on-off process is a major advantage of switching power supplies. It allows them to operate over long periods of time with less heat energy being released. Figure 8.09 provides a block diagram of a switching voltage power supply.

Figure 8.09



The switching power supply utilizes a shunt transistor similar to the linear power supply but the shunt transistor of the switching power supply is in a an on-off state. There are two basic methods of creating the switching process for switching power supplies. The input current to the shunt transistor is regulated by changing the length of the duty cycle or the frequency of the duty cycle. Figures 8.10A and B illustrate both switching methods.

Figure 8.10A

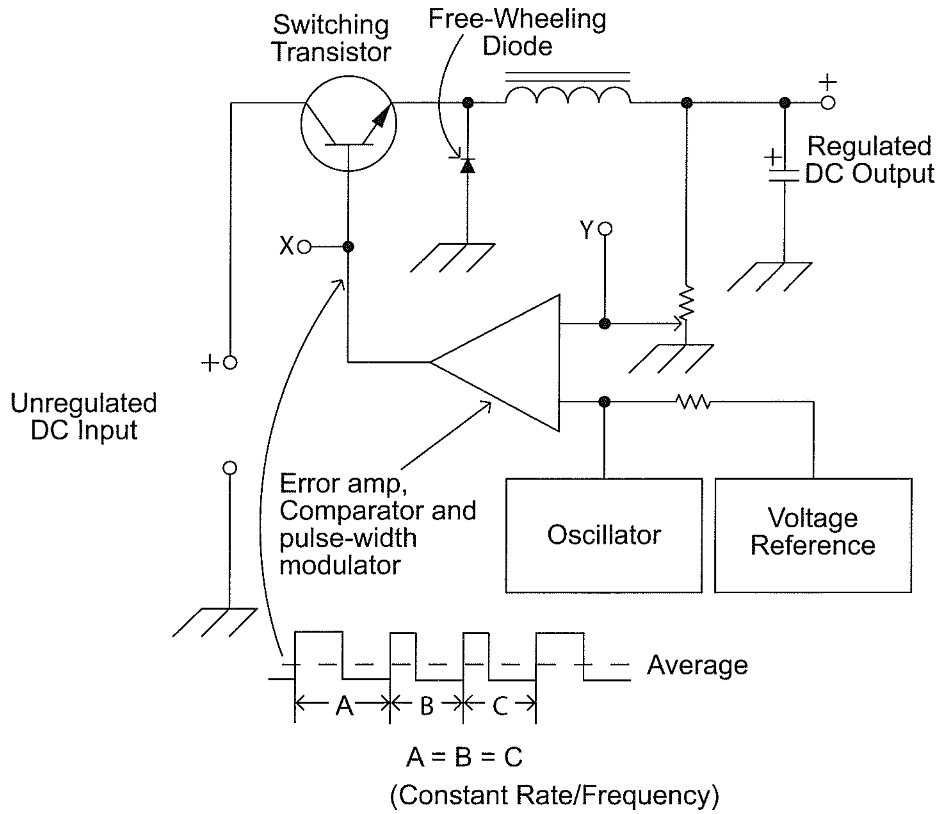


Figure 8.10B

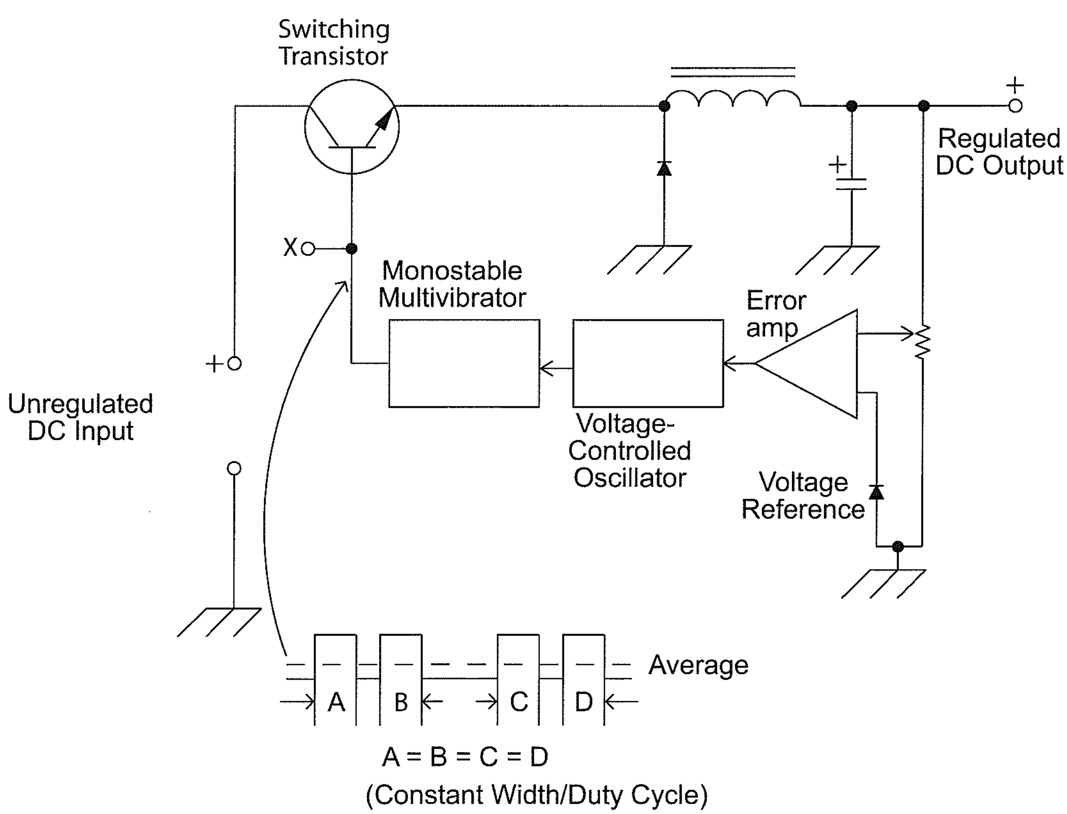
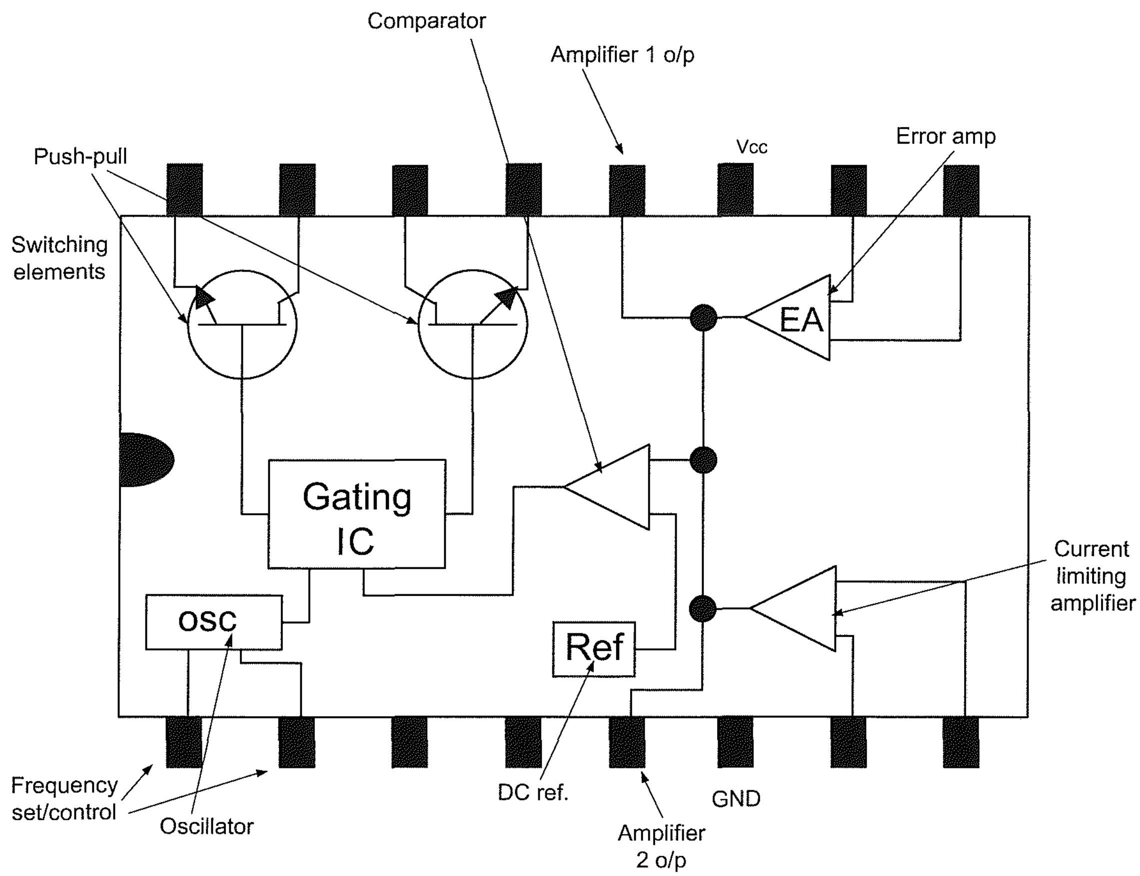


Figure 8.10C **Integrated Circuit Switching Regulator**



Having a working knowledge of both the linear power supply and the switching power supply is critical in troubleshooting medical device electronic problems. Troubleshooting Power Supply Problems will provide examples of applications in troubleshooting using various types of power supplies. At this point of the text, you have mastered all of the knowledge necessary to become proficient in basic electronic troubleshooting. There are still, however, a few techniques that will be presented to provide you with the skills to apply your knowledge.

Glossary of Important Terms

Feedback system: The portion of the output that is relayed to the input in order to maintain tight control of the process. In a power supply, this occurs at the point of voltage regulation. The output voltage is constantly monitored in order to produce pure regulated DC voltage.

Full-wave rectification: A two- or four-diode (full wave bridge) system that converts both the positive and negative portions of an alternating current sine wave into available direct current voltage.

"Half-wave" rectification: A single diode system that converts only the positive reference side of an alternating current sine wave. This results in half of the sine wave being converted into available direct current voltage.

Linear integrated circuit (IC) voltage regulator: A single package, usually three-pin component, that contains hundreds of transistors and other components to provide pure regulated DC voltage.

Pure regulated DC voltage: The end process voltage of a complete DC power supply.

Shunt transistor: A voltage regulation system that utilizes a transistor feedback to control or shunt current to obtain pure regulated DC voltage.

Switching Voltage Regulator: An electronic system that contains several discrete components with an oscillator that provides output control by changing the duty cycle. The switching voltage regulator contains an isolation transformer and is constantly switching from the on and off states for output regulation.

Voltage regulation: The process of providing reduced ripple or AC voltage in a DC power supply.

CHAPTER EIGHT REVIEW QUESTIONS

Name:______________________________

Date: ______________________________

1. What is the secondary transformer voltage of a transformer with a 10:1 turns ratio utilizing house voltage?

2. What is the secondary transformer voltage of a transformer with a 1:10 turns ratio utilizing house voltage?

3. What is the purpose of a filter capacitor in a power supply?

4. What does the term ripple refer to in output voltage? What are three causes of high output voltage ripple?

5. Describe the advantages and disadvantages of switching and linear power supplies.

6. Why would an oscilloscope be more advantageous than a DMM in troubleshooting problems with switching power supplies as compared to linear power supplies?

7. Refer to the schematic below to answer questions a through d. All measurements are made with black lead of DMM to ground reference.

   a. What is the expected voltage at TP1? ________________

   b. What is the expected voltage at TP2? ________________

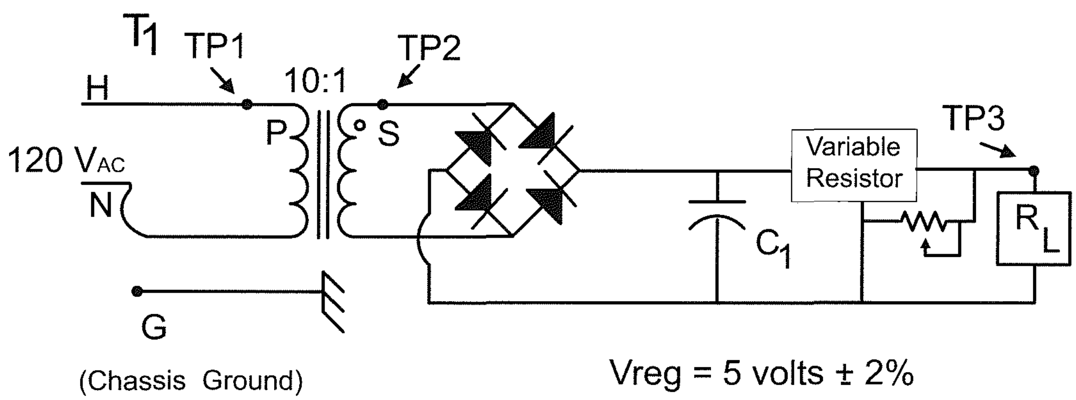
   c. What is the expected voltage at TP3? ________________

   d. If the voltage at TP2 is lower than expected, list three possible failures.

____

____

____



CHAPTER EIGHT LABORATORY EXERCISE

Name:______________________________

Date: ______________________________

Objective

1. Troubleshoot and analyze the operation of a linear power supply

Materials

Linear power supply circuit
Signal generator
Oscilloscope
Multimeter
Power supply (bench)
1ea. 100K, 10 ohm resistors

Procedures

1. Build the linear power supply circuit shown in Figure 8L-1. Refer to book or notes if needed.

2. Measure the voltages at test points (TP) 1, 2, 3, 4 and 5 indicated on the schematic of figure #1. Record your results in Data Table #1. Note: some of the voltages are AC and some are DC. Set your multimeter accordingly.

3. Measure the DC and AC output voltage with a 1000 ohm load resistor using your multimeter. Record your results in Data Table #1.

3. Calculate the percent ripple in your power supply. Record your results in Data Table #1. (Percent Ripple = AC voltage/ DC voltage X 100%)

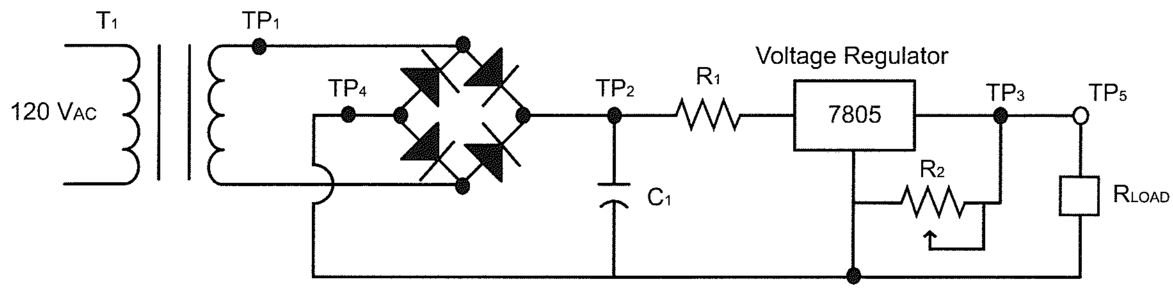
4. Use a clip lead to bypass the linear IC voltage regulator on your linear power supply. YOUR CIRCUIT SHOULD HAVE NO POWER WHEN PERFORMING THIS STEP!!!!

5. Measure the voltage across the 1000 ohm load resistor with the oscilloscope. Use the peak AC voltage as your measured reading. Record your results in Data Table #1.

6. Measure the DC and AC voltage across the 1000 ohm load resistor with the multimeter. Record your results in Data Table #1. Explain the difference in your measured voltage readings using the oscilloscope and your multimeter on a separate sheet of paper. Attach this page to your finished lab.

Figure 8L-1

Linear Power Supply



Data Table 1

	Test Point 1	**Test Point 2**	**Test Point 3**	**Test Point 4**	**Test Point 5**
Voltage measured					
Load Voltage	**Volts AC**	**Volts DC**			
Percent Ripple	________%				
Q#5 Oscilloscope reading	________Vp				
Q#6 DMM reading	________Vac	________Vdc			

Troubleshooting

	Symptom	**Fault**
Linear Voltage Supply		Bypass Regulator

Chapter 9: Troubleshooting Power Supply Problems

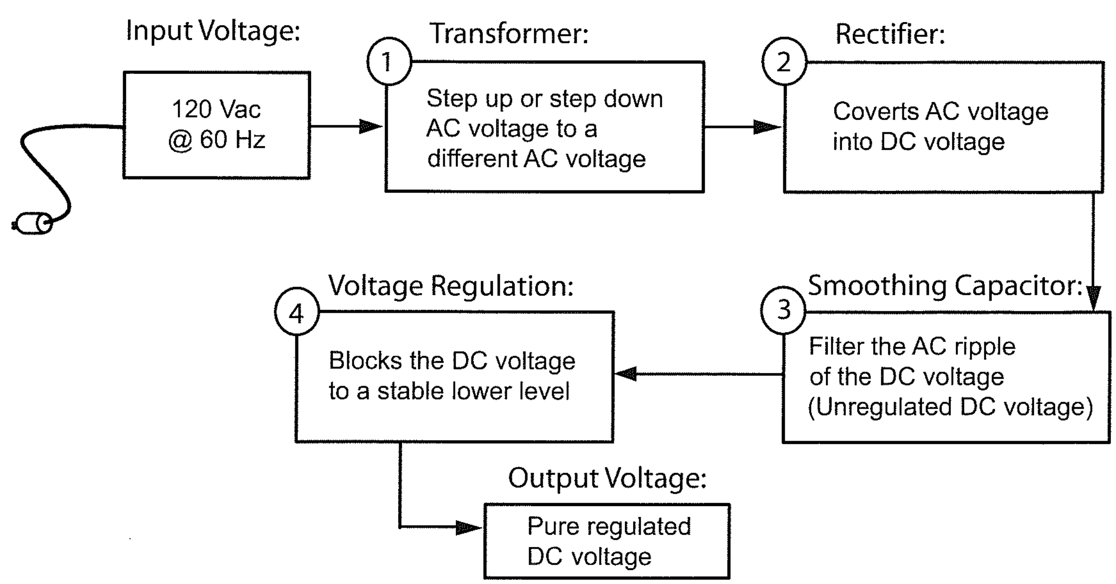
After completing this chapter you will have an understanding of:

- *Where to start in the electronic troubleshooting process*
- *How to utilize the half-step method to troubleshoot electronic problems more efficiently*
- *Associating DMM and oscilloscope readings with component or board-level failures*
- *Critical thinking processes involved in troubleshooting by understanding the power supply troubleshooting flow chart*

Power Supply Block Diagram Review

You will recall from chapters 5 and 7, the block diagram of a typical power supply as shown in Figure 9.01. You should also recall the purpose of a power supply is to provide a regulated DC voltage at the desired magnitude(s).

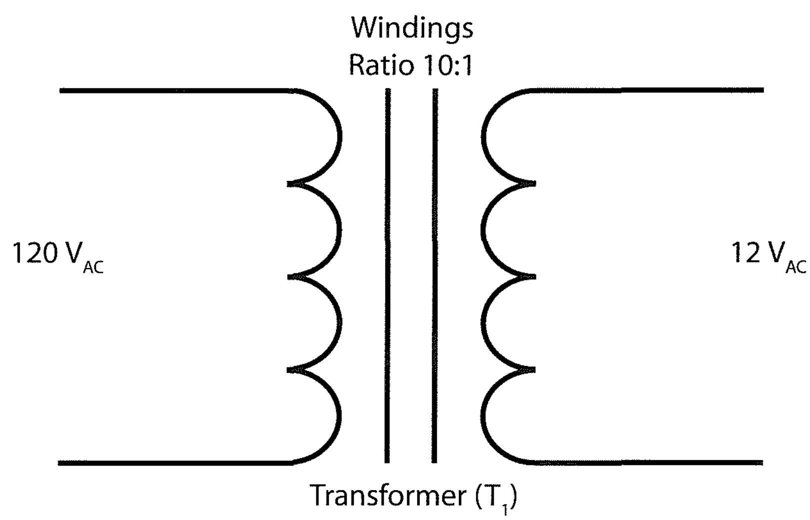
Figure 9.01



Examining each segment of the power supply block diagram allows you to concentrate on a specific set of components. Each segment also has a known desired output. This provides an uncomplicated means to isolate problems within the power supply.

In segment 1 of the block diagram the component required to step-up or step-down the AC voltage is the transformer. Recall that the transformer is essentially a wire-wound ferro-magnetic core. The wires may either touch one another causing a shorted winding or the wires may break causing an open winding. An open winding on the primary side of the transformer creates an open circuit and therefore no electro-magnetic force can be created. The output of the power supply will be zero. If the windings of the primary side of the transformer become bare due to scraping, heat, or age a shorted circuit will result. If a large current passes through the relatively small wire windings, it may cause the wires to overheat and break apart creating an open circuit. If the bare windings of the transformer primary make contact, the entire primary side of the transformer may become hot. In this situation, there will not be sufficient current in all of the primary windings and little or no electro-magnetic force will be produced. Similar failures may occur on the secondary side of the transformer with comparable results.

Figure 9.02



Ratio of Primary:Secondary windings.
For example, 10:1 = Ten-to-one Step-down Transformer

Segment 2 of the power supply block diagram consists of diodes, normally in the full-wave bridge configuration. Diodes conduct only in one direction, during the forward bias condition.

A diode may exhibit both open and shorted failure modes. If the bridge has a completed circuit with one or more diodes open, the resulting half-wave bridge allows some of the AC voltage from the secondary side of the transformer to pass through to the voltage regulator. The common symptom is a low output from the voltage regulator, possibly larger than acceptable AC ripple and perhaps overheating of the voltage regulator. A shorted diode (or diodes) will cause similar symptoms with the exception of a possibility of higher current flowing into the voltage regulator.

If the entire bridge rectifier is shorted or open, no voltage will appear at the power supply output.

Figure 9.03A

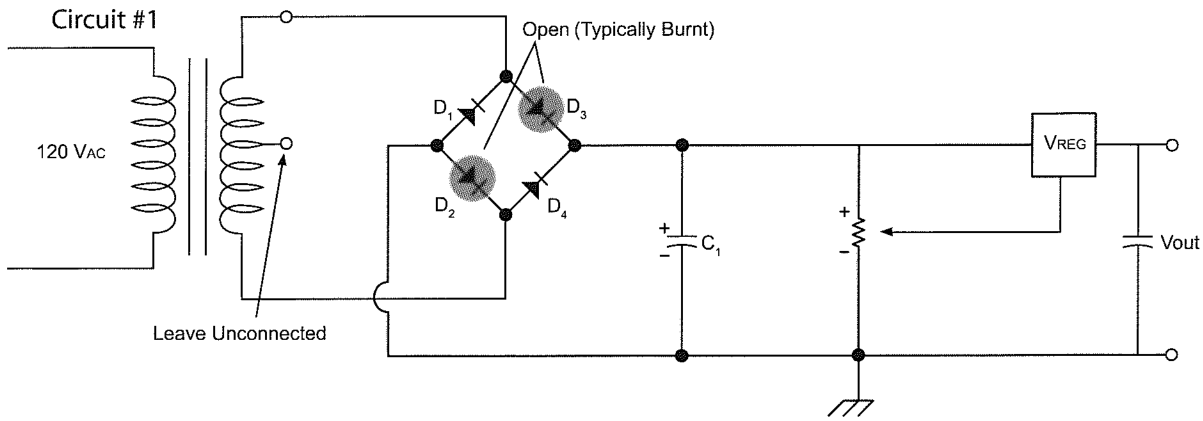


Figure 9.03B

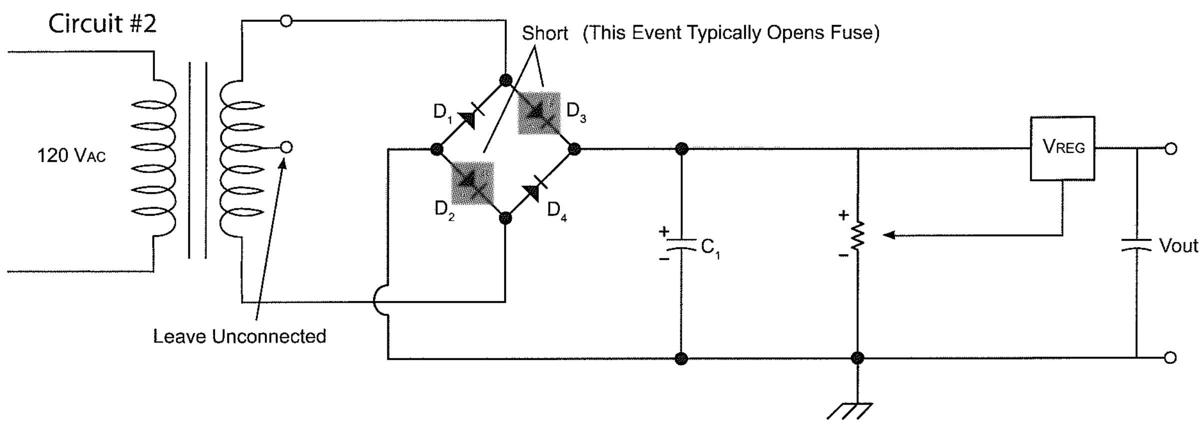
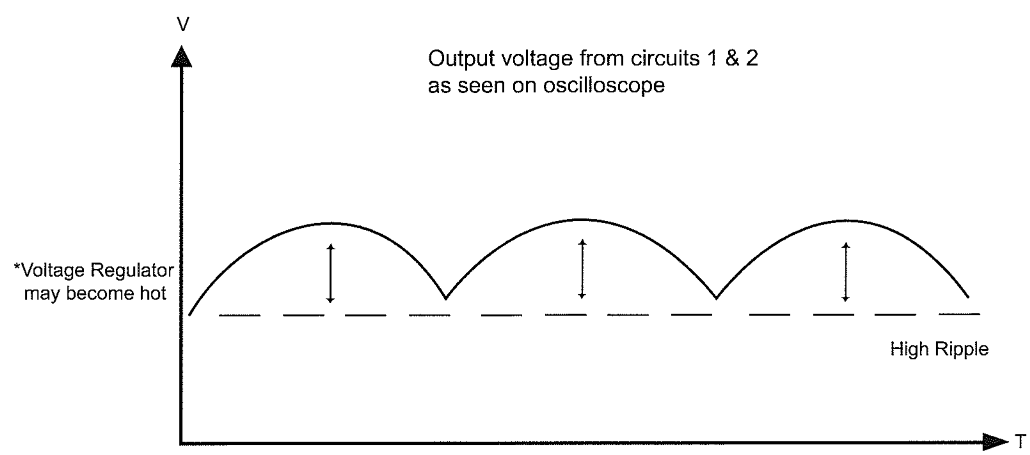


Figure 9.03C



With D2 & D3 open or shorted, the resulting wave form is the same despite being the product of two different failure modes.

Figure 9.04A

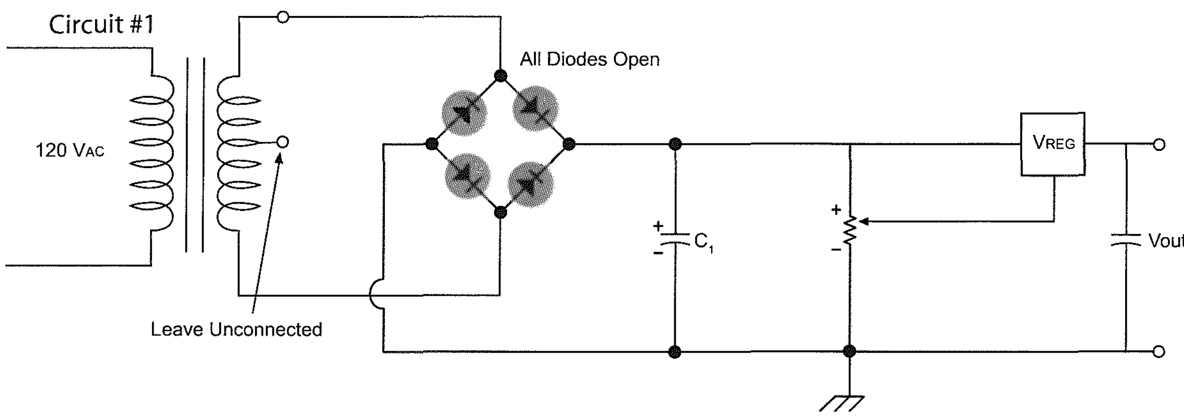


Figure 9.04B

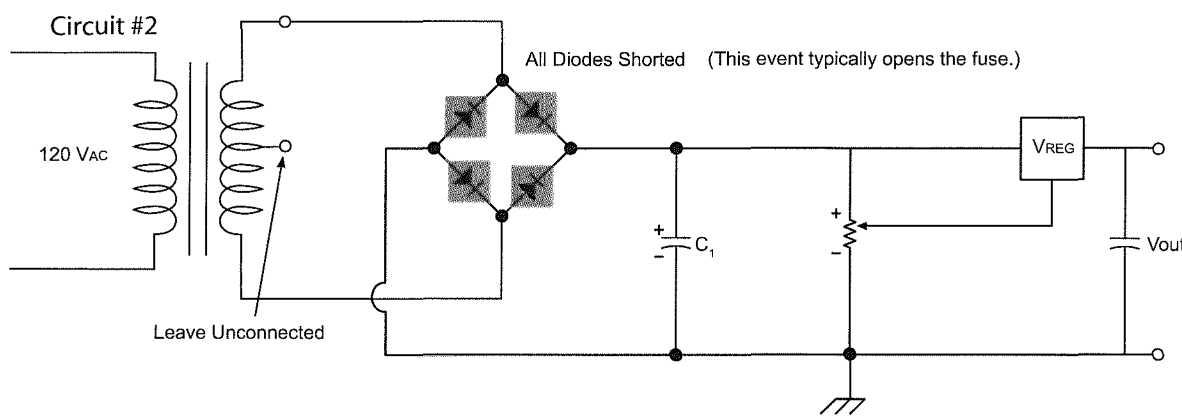
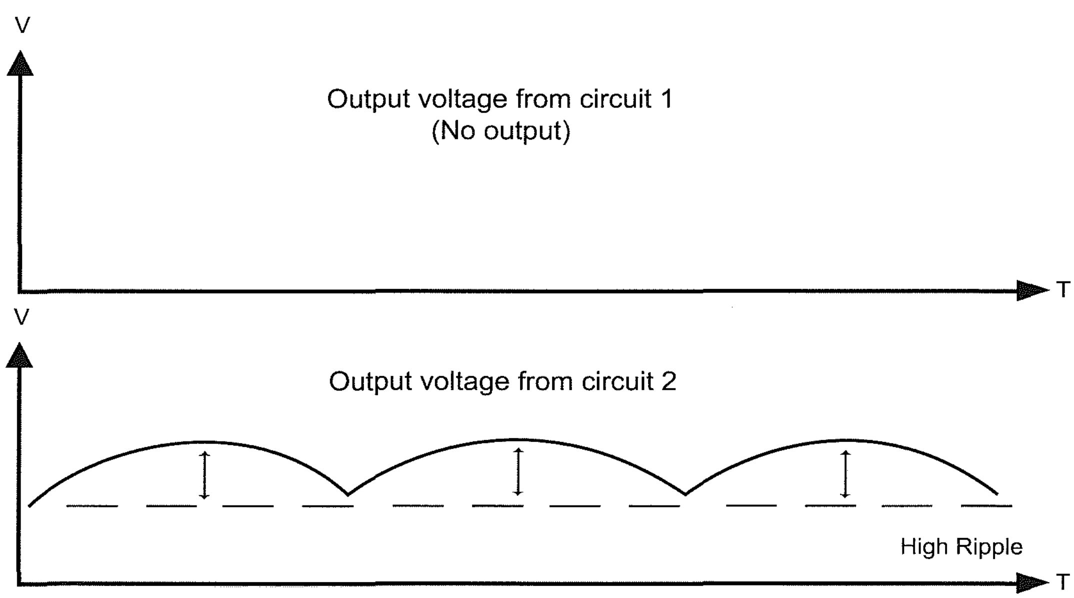


Figure 9.04C



The third segment of the power supply bock diagram provides *filtering*. *Filtering* in this context refers to removal of additional AC voltage waveforms. The size of the resistor-capacitor combination determines the extent of the AC voltage waveform which is removed.

This resistor-capacitor combination is known as the "R (resistor) C (capacitor) time constant," since these components determine the time required for the capacitor to begin its discharge phase. Resistors will change values with age. Some resistors may have open solder joints or internal fractures causing an open resistor. An open resistor results in a resistor circuit with "infinite resistance" (approaching a value too large to calculate). The RC time constant is calculated by multiplying the resistance by the capacitance. Since the resistance is infinite, the RC time constant is infinite. Ideally, the capacitor would not be allowed to discharge. Some resistance from the power supply circuit is available to the capacitor. Therefore, a very small amount of DC voltage is returned to the circuit from the capacitor and a very large amount of AC voltage will be retained in the circuit. The result will be a large amount of AC ripple. This could cause the voltage regulator to overheat and result in low or no regulated DC voltage output.

Shorted resistors are usually a result of the creation of a conductive circuit path around the resistor. This can result from grime and build-up on the circuit board. Cleaning the circuit board with a nonconductive solvent spray will eliminate this problem. The symptoms of a shorted resistor are similar to that of the open resistor. The capacitor filtering circuit is completely bypassed. Little or no DC voltage is captured. A large amount of AC ripple will result and the voltage regulator will become hot due to low DC "headroom" (the voltage required for the voltage regulator to operate) or excessive feedback voltage due to a large amount of AC ripple in the output.

The final segment of the power supply block diagram contains the voltage regulator. Recall from Introduction to Power Supplies that there are two classes of voltage regulators: linear and switching. Power supplies are classified based on the type of voltage regulator in the power supply circuit.

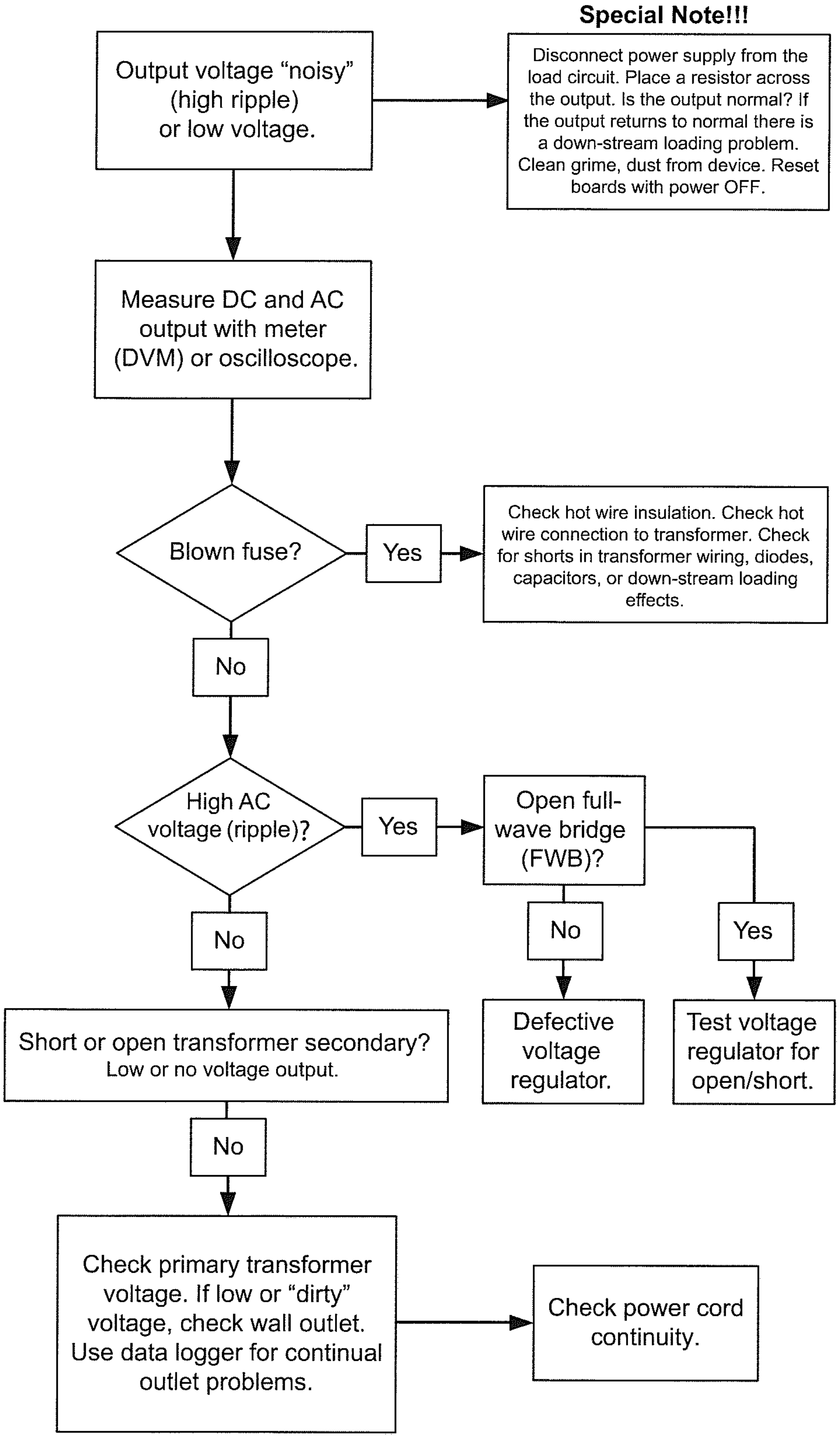
Linear voltage regulators are three terminal devices and relatively easy to troubleshoot. A voltage measurement of the input terminal indicates that the first three segments of the power supply block diagram are operating properly. If a voltage measurement of the V_{IN} is normal but the output terminal of the linear voltage regular is higher, lower, or contains excess AC ripple, it can be determined that the linear integrated circuit (linear voltage regulator) is defective and must be replaced.

Switching voltage regulator power supplies are more complicated than the linear version. Generally, a switching voltage regulator will have a more complex feedback system. You should refer to Introduction to Power Supplies to review the components of a switching regulator. The same principle applies for basic troubleshooting for both linear and switching voltage regulators. If the measured input voltage (unregulated DC voltage) is within tolerance and the output voltage (regulated DC voltage) is higher, lower, or contains excessive ripple, the switching voltage regulator circuit must be replaced.

The flowchart on the next page provides a visual means of troubleshooting power supply problems. All of the malfunctions and symptoms discussed thus far in this chapter are illustrated by means of this flowchart.

Figure 9.05

Power Supply Symptom



Glossary of Important Terms

DC power supply: An electronic device that provides a regulated DC voltage at the desired magnitude(s).

Diode: The simplest of all semiconductor devices consisting of a single PN junction. Diodes conduct only in one direction, during the forward bias condition.

Filtering: In this context of power supplies, refers to removal of additional AC voltage waveforms traveling above the desired DC voltage waveform.

Flow chart: A diagram that provides a visual means of examining a system or device using general categories of yes/no scenarios.

Full-wave bridge configuration: The use of four diodes in a staggered triangular arrangement that allows two diodes to always conduct in a forward bias position with an AC input, usually connected to an isolation transformer. (See Figure 9.03.)

Headroom: The voltage required for the voltage regulator to operate or excessive feedback voltage due to a large amount of AC ripple in the output.

RC time constant (tau): The size of the resistor-capacitor combination, which determines the charge-discharge time of a capacitor in an AC circuit.

CHAPTER NINE REVIEW QUESTIONS

Name:______________________________

Date: ______________________________

1. If you have a switching power supply, explain what measurements you should take with the oscilloscope and what measurements you should take with the DMM.

2. List three most probable causes of a low voltage output from a power supply and explain the troubleshooting steps in each case.

3. What output problems can result from not having enough headroom for the voltage regulator?

4. How would you test a capacitor to determine if it is a cause of increased ripple?

5. If the fuse is open on a power supply, why should you investigate the cause of the blown fuse and not simply replace the fuse?

6. After repairing a device failure, a fuse replacement is required. The original manufacturer's recommendation is a 150V, 2 A fuse. The only fuses available in the parts room are; 150V, 1A fuse, 150V 3A fuse and 150V 0.5A fuse. Which fuse would you use temporarily to make the device operational? Explain your answer.

CHAPTER NINE LABORATORY EXERCISE:

Troubleshooting Power Supply Problems

Name:______________________________

Date: ______________________________

Objectives

1. To demonstrate the operation of a full-wave rectifier.
2. To demonstrate some of the common fault symptoms that occur in a full-wave bridge rectifier circuit.

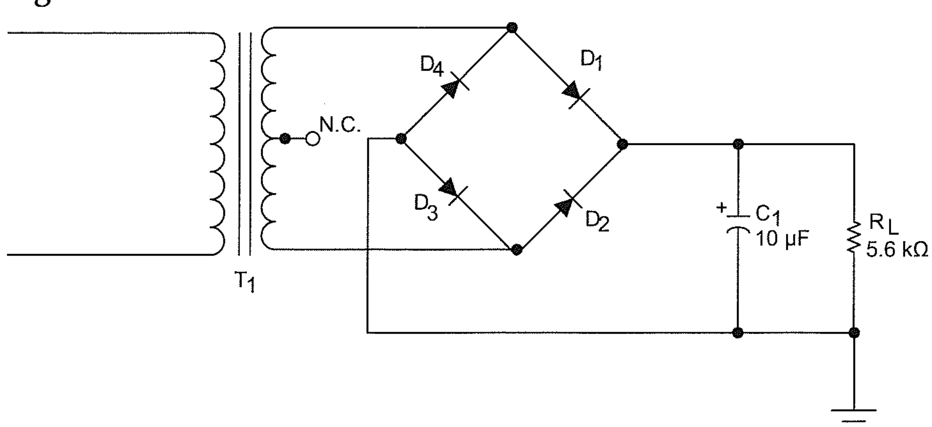
Reading:

Troubleshooting Power Supply problems

Materials

VOM or DMM
Dual channel oscilloscope
Transformer rated between 12-24 Vac
IN4001 rectifier diodes (4 ea.)
5.6K ohm resistor
1k ohm resistor
100uF capacitor
10uF capacitor
.01uF capacitor
5-volt regulator (7812 or 78L12)

Figure 9L-1



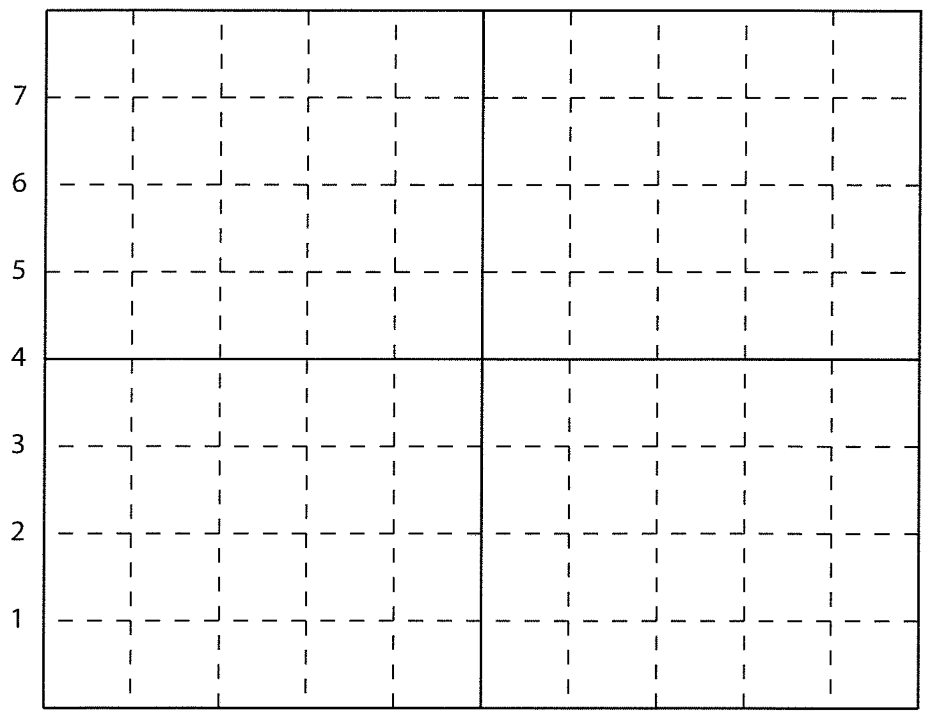
Procedure

1. Construct the circuit shown in Figure 9L-1

2. Apply power to the circuit and measure the rms secondary voltage of the transformer using the VOM or DMM.

   a. V2=___________Vac

3. Set your oscilloscope for DC coupling and observe the output waveform for the rectifier. Draw this waveform as neatly as possible in the space provided below.



Time/Div:_______________ V/Div:_______________

4. From the oscilloscope display, determine the peak output voltage from the rectifier.

   a. Vout(peak)=___________V

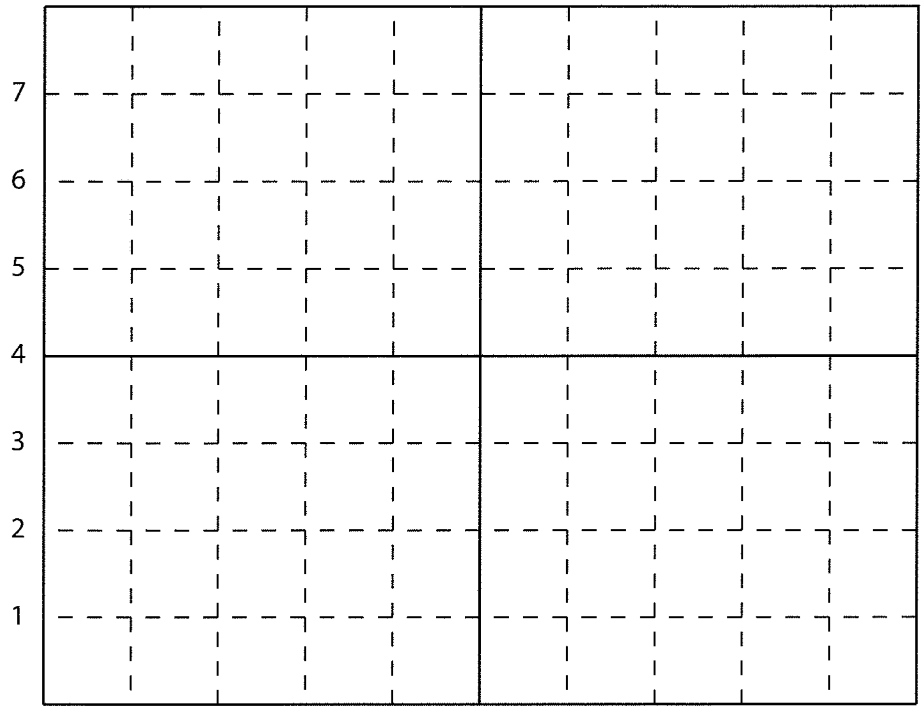
5. Using your VOM or DMM set on DC volts, measure the average output voltage from the rectifier.

   a. Vavg=______________Vdc (Tp1)

6. Remove the load resistor from the circuit and observe the waveform at Tp1.

   a. Vtp1____________V

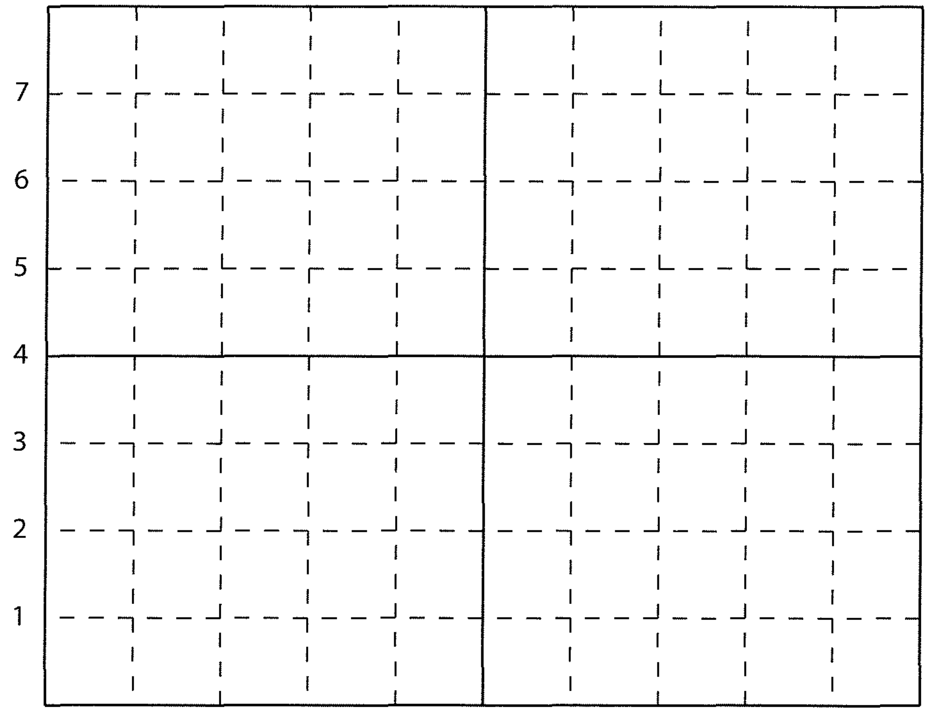
7. Draw the output waveform for the rectifier in the space provided below.



Time/Div:______________ V/Div:______________

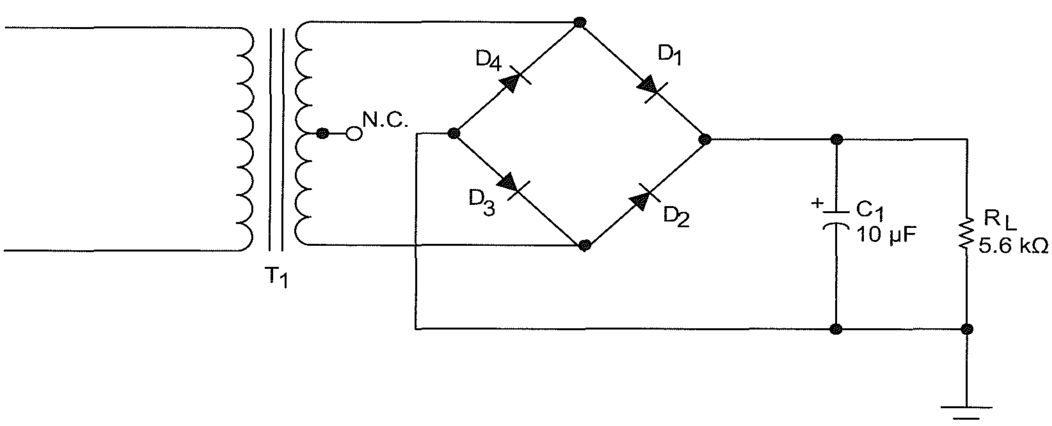
8. Disconnect the power from the circuit and return Rl to its original position in the circuit and remove D1 from the circuit. Reapply power to the circuit.

9. Observe the output from the rectifier. Draw the output waveform in the space provided.



Time/Div:______________ V/Div:______________

Figure 9L-2

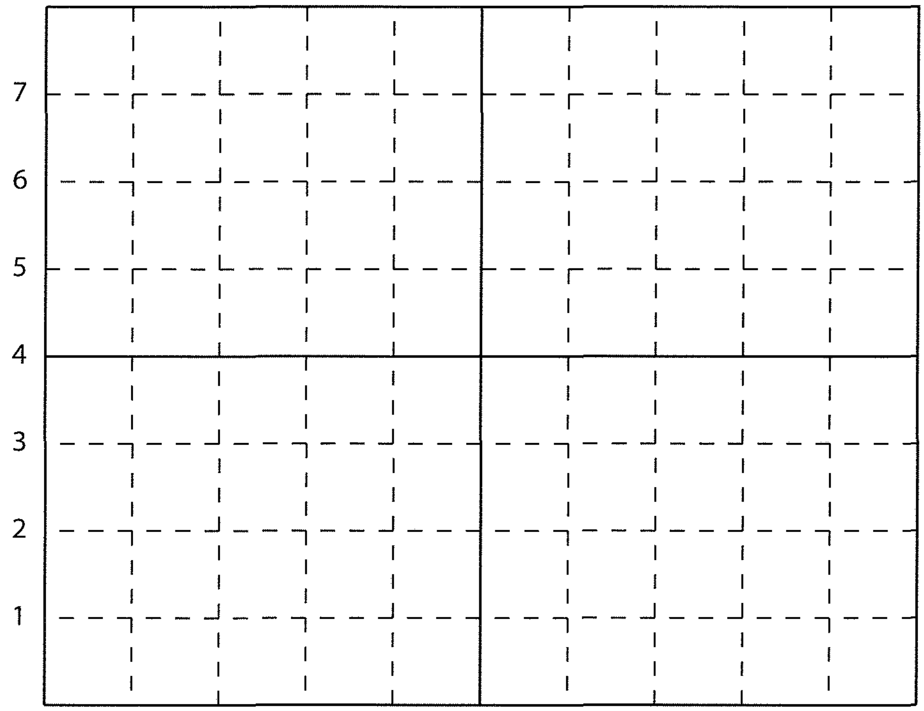


10. Construct the circuit shown in figure 9L-2.

11. Apply power to the circuit and measure the rms secondary voltage of the transformer using the VOM or DMM.

a. V2=____________Vac

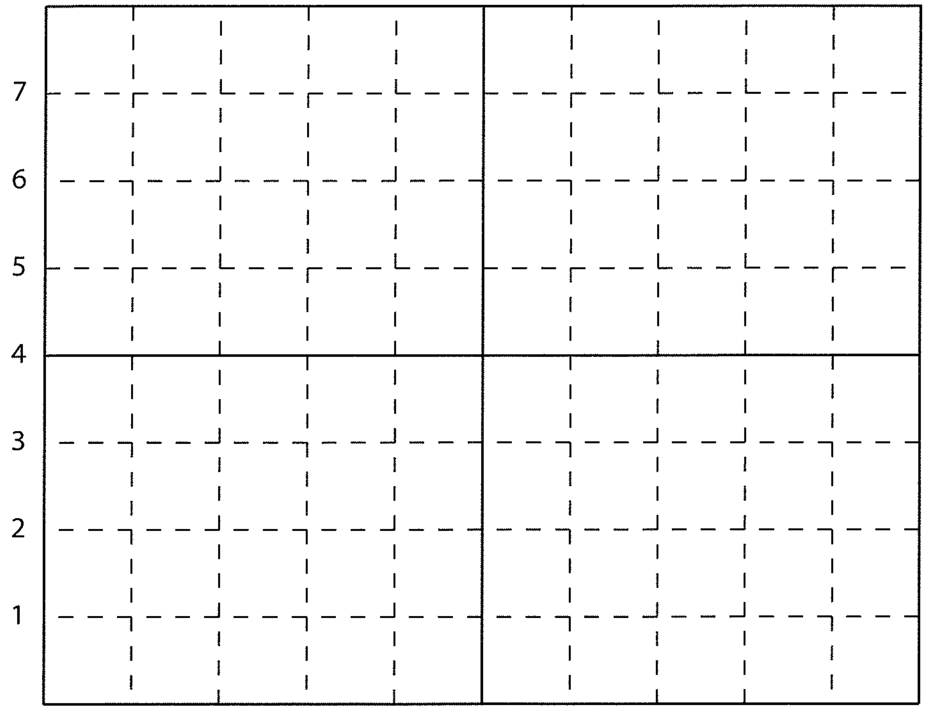
12. Set your oscilloscope for DC coupling and observe the output waveform for the rectifier. Draw this waveform as neatly as possible in the space provided below.



Time/Div:________________ V/Div:____________________

13. Remove power from the circuit and change the 10uf capacitor to a .01uf capacitor.

14. Set your oscilloscope for DC coupling and observe the output waveform for the rectifier. Draw this waveform as neatly as possible in the space provided below.



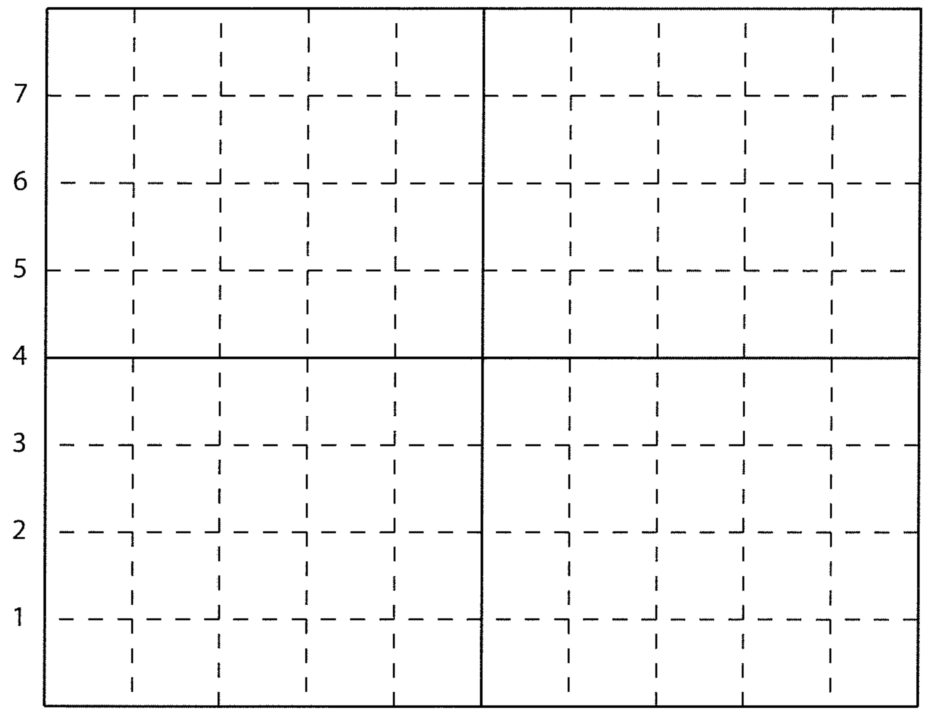
Time/Div:________________ V/Div:__________________

15. Remove the 5.6k ohm resistor from the circuit and install the 1k ohm resistor.

16. Apply power to the circuit and measure the rms secondary voltage of the transformer using the VOM or DMM.

   a. V2=___________Vac

17. Set your oscilloscope for DC coupling and observe the output waveform for the rectifier. Draw this waveform as neatly as possible in the space provided below.

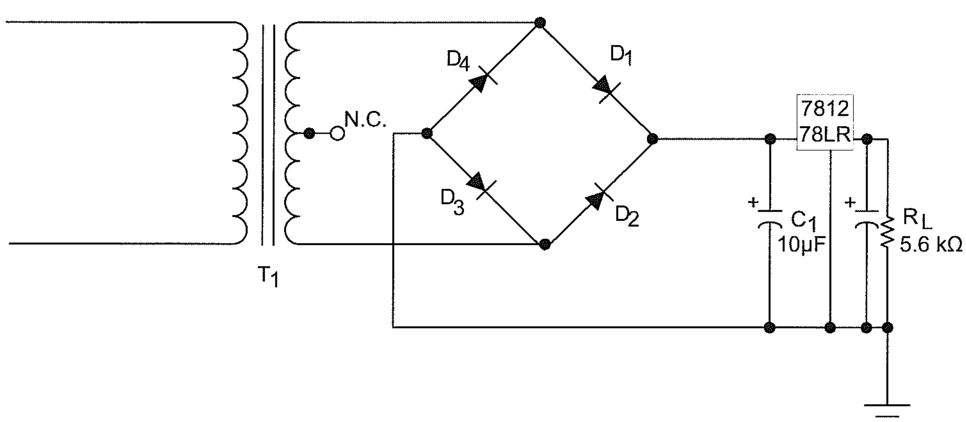


Time/Div:________________ V/Div:________________

18. Measure the output voltage across Rl.

a. Vtp1_________Vdc

Figure 9L-3

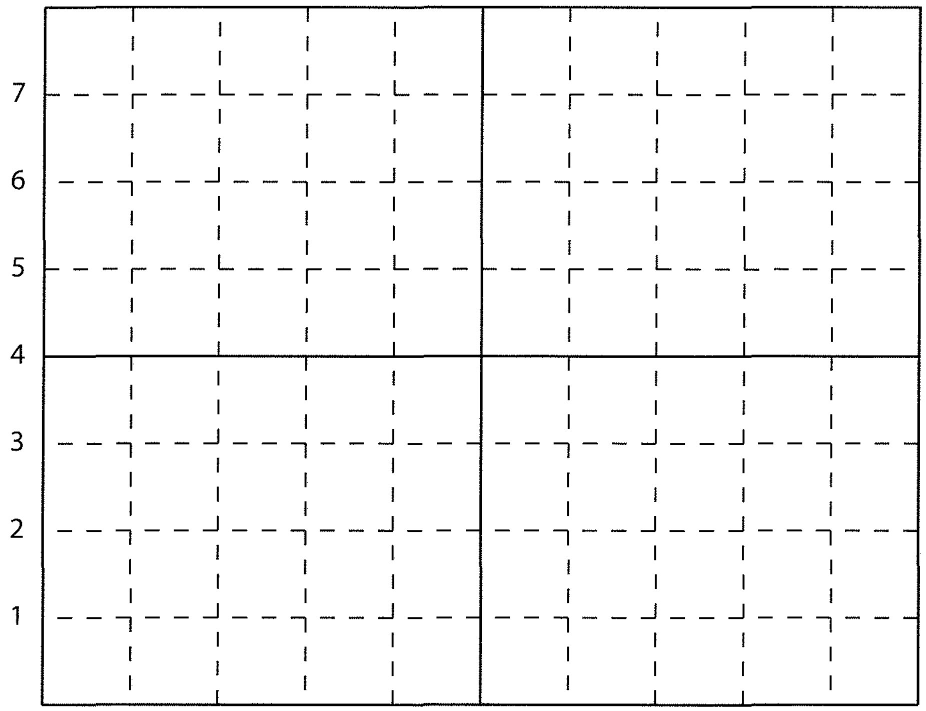


19. Remove power from the circuit and attach a 5 volt regulator in parallel with Rl as seen in Figure 9L-3.

20. Attach power to the circuit and measure the voltage across TP1.

    a. Vtp1__________Vdc

21. Set your oscilloscope for DC coupling and observe the output waveform for the rectifier. Draw this waveform as neatly as possible in the space provided below.



Time/Div:________________ V/Div:__________________

LAB REVIEW QUESTIONS

1. Explain why an open load resistor caused the waveform you saw in Step 6 of the procedure.

2. Explain why an open diode in the bridge caused the waveform you saw in Step 8 of the procedure.

3. What effect if any did the addition of the capacitor have on the V_{DC} or output voltage?

4. What effect if any did the addition of the capacitor do to the output waveform?

5. What effect does the changing of the capacitor size do to the output wavefrom?

6. What effect does the changing of the resistor have on the output voltage?

7. What effect does the addition of the regulator have on the output of the power supply.

8. What effect does the regulator have on the output waveform?

Chapter 10: Amplifiers

After completing this chapter you will have an understanding of:

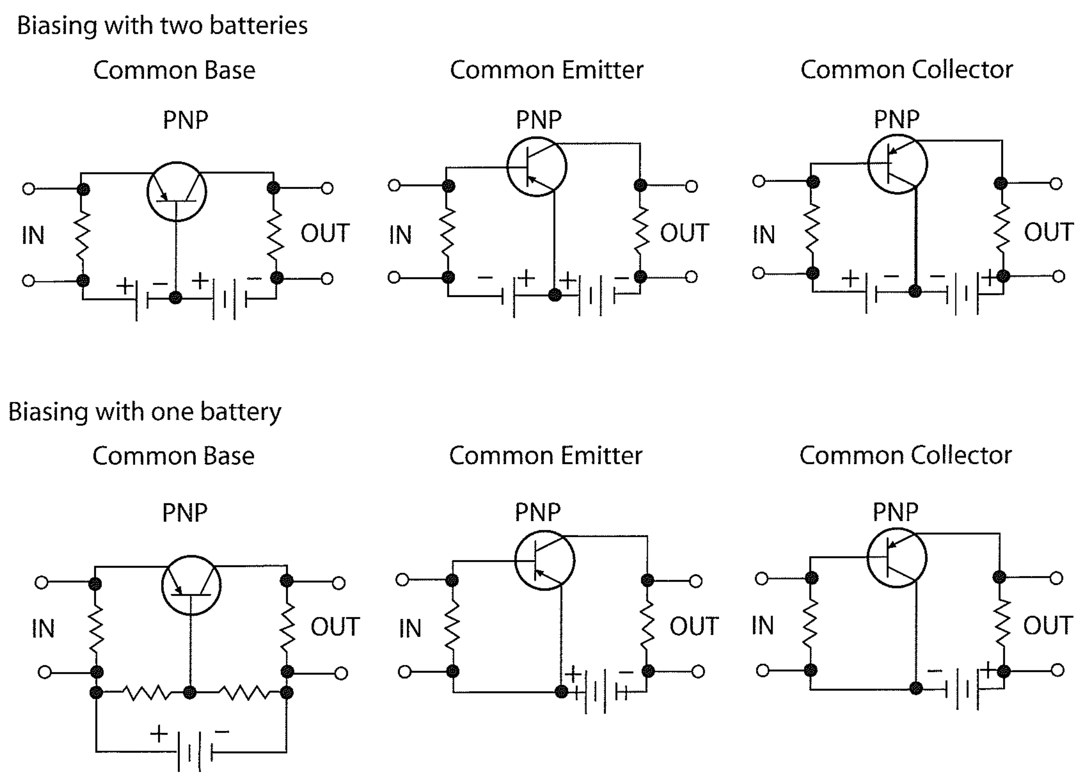
- *Classic transistor logic amplifier design: class A, B, and C*
- *Class A amplifiers, especially common emitter, base and collector configurations*
- *Class B amplifiers such as push-pull amplifiers*
- *Class C amplifiers such as the common digital inverter*
- *Common problems and applications of transistor based amplifiers*

Amplifier Classification and Push-Pull Transistor Arrangments

Both BJTs and JFETs have an output classification based on how the output signal is amplified. The three output classifications are class A, class B, and class C amplifiers. Class A amplifiers have identical input and output signal configurations. The signal magnitude will change according to the gain characteristics of the transistor. Figure 10.01 illustrates a class A amplifier.

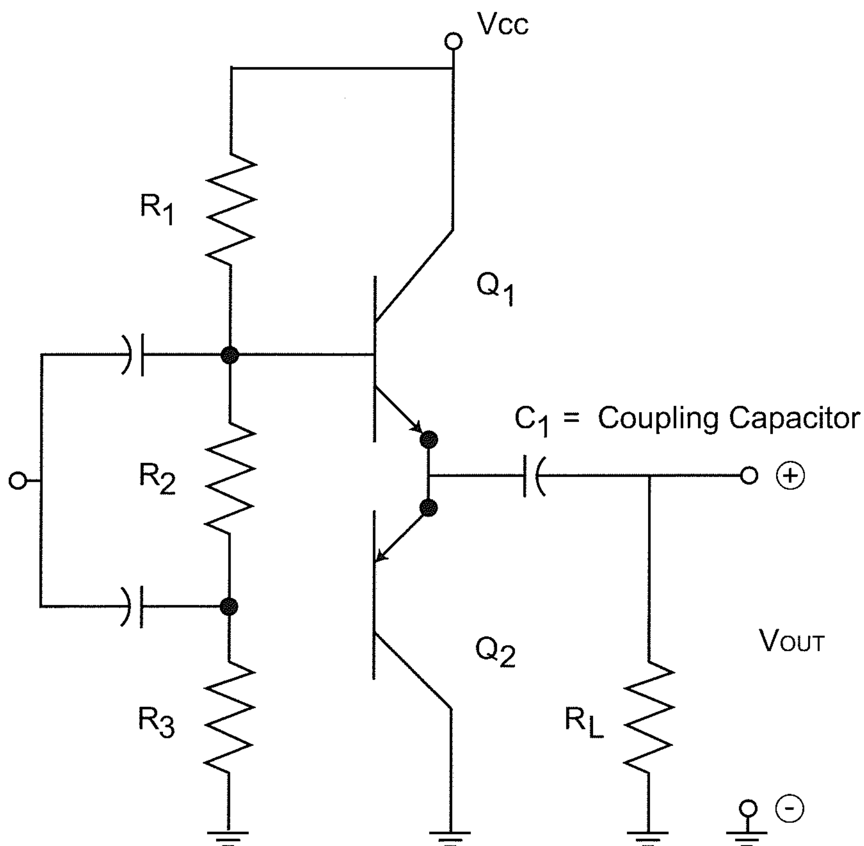
Figure 10.01

Class A Amplifier Circuits



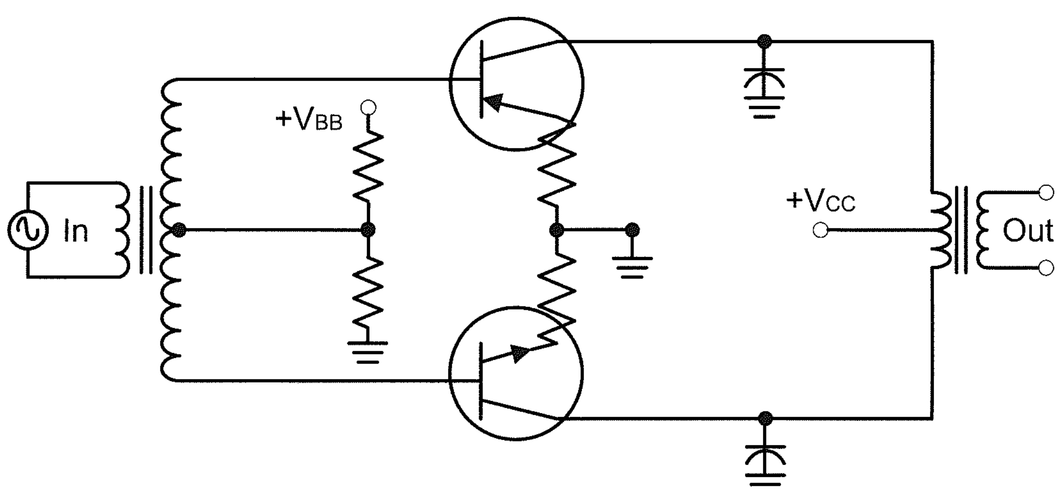
A class B amplifier is the most useful of the three signal configurations since it can be used in what is known as a "push-pull" mode. This mode is more efficient than a class A amplifier. A class B signal amplifier has a "cut-off" region where the amplifier will not conduct. For a sine wave input signal it will have an output in the positive region of the signal and a cut-off in the negative region of the signal. Figure 10.02 illustrates a class B amplifier operation.

Figure 10.02



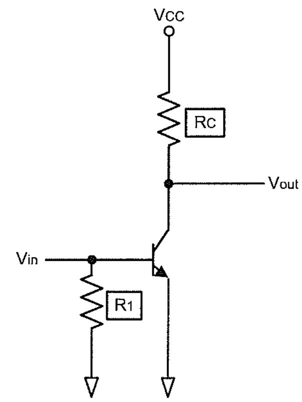
The push-pull operation of a class B amplifier utilizes one NPN transistor and one PNP transistor connected emitter to emitter. The push-pull class B amplifier configuration is shown in Figure 10.03.

Figure 10.03

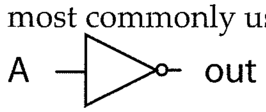


Class C signal amplifiers have a signal output in a 180 degree difference from the class B signal amplifier. If a sine wave is the input signal of a class C amplifier the positive portion of the waveform is in the cut-off region. The negative portion of the sine wave is amplified at the output. Class C amplifiers have a highly distorted output and therefore have limited applications for biomedical equipment. Figure 10.04a illustrates the class C amplifier operation.

Figure 10.04A

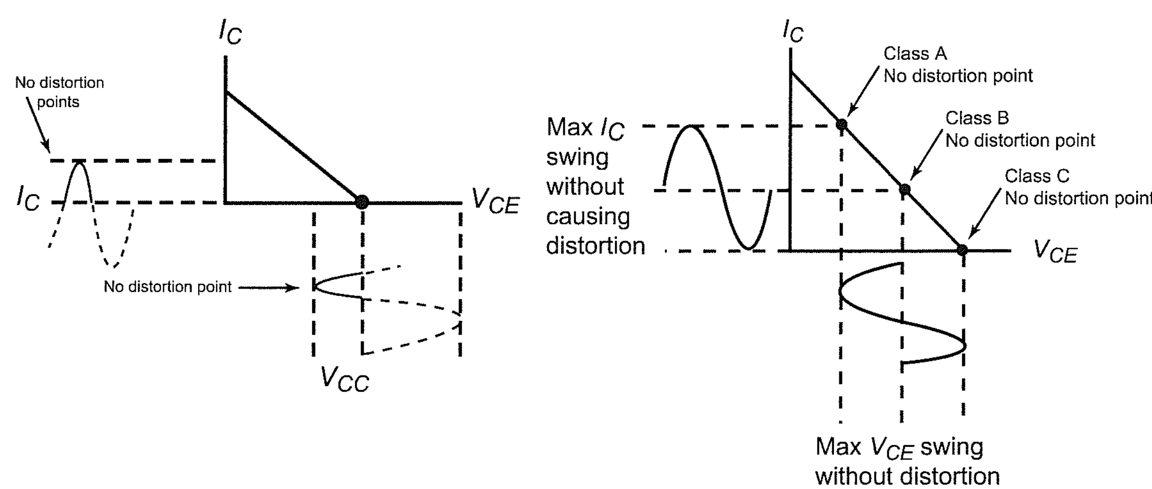


As seen above, this device will amplify a basic AC signal riding on the .7v range to a simple, clipper "yes or no" square wave. For this reason, the above circuit is usually not used in analog signal processing, but rather in digital systems where a VCD signal is turned into a 0VCD and vice versa. For this reason, the C Class amplifier is most commonly used as a digital systems inverter and has the schematic symbol:



The images below show a series of amplifier points and further describe distortion or "clipping." This occurs when the waveform causes the amplifier to reach its maximum range for a signal. The resulting wave is lost or clipped at the power limit of the amplifier. Excessive clipping will cause an AC sign wave to become a clipped square wave. This has applications in guitar music where distortion is preferred. Since this causes lost data, it is not used in the medical equipment field.

Figure 10.04B



Glossary of Important Terms

AC voltage: A voltage that oscillates in the form of a sine wave.

Bipolar junction transistors (BJTs): A semiconductor device that has two PN junctions. The amount of current to the "base" leg of the BJT determines the flow of electrons from the "emitter" leg to the "collector" leg. If there is no current flowing into the base leg of a BJT, the transistor will not allow electrons to cross the two PN junctions.

Bipolar junction transistor structure – NPN: A semiconductor device with a positive source at the collector.

Bipolar junction transistor structure – PNP: A semiconductor device with a negative source at the collector.

Center tap transformer: A transformer that has an exit winding in the center of the transformer and a winding exit at the top and bottom of the transformer. A total of three wires will exit the secondary side of the transformer.

Class A amplifiers: One of the three output classifications of transistor amplifiers. Class A amplifiers have identical input and output signal configurations. The signal magnitude will change according to the gain characteristics of the transistor.

Class B amplifier: One of the most useful of the three signal configurations because it can be used in what is known as a "push-pull" mode. This mode is more efficient than a class A amplifier. A class B signal amplifier has a cut-off region where the amplifier will not conduct. For a sine wave input signal it will have an output in the positive region of the signal and a cut-off in the negative region of the signal.

Diode: The simplest of all semiconductor devices. It consists of a single PN junction.

DC voltage: An average voltage with a frequency of zero hertz.

Doping: A process of making semiconductors more conductive by adding impurities into the base. You can visualize this as a perfectly flat white field with holes in it. Some of the holes have a positive charge and some of the holes have a negative charge. Energy (the power supply) is required to create a pathway between the holes in order to reach the other side to remove the electric charges from the pathway. A semiconductor may contain either "N" doped or "P" doped impurities added to the silicon or germanium base. A semiconductor allows electrons to flow across the PN junction when the P doped side is positive (has a positive power supply terminal) with respect to the N doped side.

Filtering: A term used to describe the manipulation of an electromagnetic wave form, usually consisting of one or more capacitors and in some cases an inductor paired with the capacitor(s).

"Forward bias" condition: Diodes will only conduct in one direction. When a diode is placed in a circuit with AC voltage, it only allows conduction when the anode is positive with respect to the cathode it is considered to be "forward biased." This property of diodes allows them to be used in power supplies for conversion of the AC sine wave signal into unregulated DC voltage.

Input impedence: Refers to the passive and active resistance encountered by a signal as it enters the input of an electronic device.

Junction field effect transistors (JFETs): Semiconductor devices constructed with a variable doped channel and a doped gate. The channel variability or width is controlled by the gate voltage.

Junction field effect transistor structure – N Channel : A semiconductor device with an N doped channel. The channel variability or width is controlled by the gate voltage.

Junction field effect transistor structure – P Channel : Semiconductor device with a P doped channel. The channel variability or width is controlled by the gate voltage.

Metal oxide semiconductor (MOS) FET: A specialized form of a field effect transistor (FET). The gate of the MOSFET is isolated and allows it to be operated with or without a gate source. It has no PN junction.

P and N-Channel D-MOSFET: A depletion MOSFET with an "N or P doped channel" that contains a physical channel between the drain and source.

Multiple output transformer: A transformer that has more than one regulated DC output voltage. More than two wires will exit the secondary side of the transformer.

PN junction: The boundary where the "P" doped and "N" doped materials meet.

Primary windings: The wire windings connected to input voltage.

Primary to secondary winding ratio: The number of wire windings on the primary voltage side of a transformer compared to the number of windings on the circuit side of a transformer. This determines whether a transformer is a voltage "step-up" or "step-down" transformer.

RC time constant: The charging and discharging cycle of a capacitor determines the size in farads of the capacitor and the series resistance of the capacitor-resistor circuit. RC time constants are measured in milli or micro seconds. The larger the resistor or capacitor, the longer the RC time constant.

"Reverse bias" condition: Diodes will only conduct in one direction. When a diode is placed in a circuit with AC voltage, it only allows conduction; when the anode is negative with respect to the cathode it is considered to be in the "reverse bias condition."

Secondary windings: Windings with "induced magnetic voltage" on the circuit side of a device.

Semiconductor component: A device that allows electric current to pass through it under certain conditions but it lacks the atomic and structural properties of a true conductor. Therefore, semiconductors possess some resistivity.

Transformer: A component that consists of two sets of insulated wire windings around a ferrite (iron) core or metal plates. There will be an air gap in between the two windings. The primary voltage windings induce a magnetic voltage to the "secondary" or circuit side of a device.

True conductors: A material that allows the flow of electric current (electrons) in any state. Ideally, true conductors have no resistance.

CHAPTER TEN LABORATORY EXERCISE:
Common Emitter Circuit

Name:______________________________

Date: ______________________________

Objective

After performtingthis lab, you will be able to:

1. Breadboard and analyze the AC function of a Common Emitter Circuit.

Lab materials

Power supply
Multimeter
Capacitors (1ea.)
Breadboard
Misc. wires 22uF, 4.7uF
Transistor (2N3053)
Resistor (1ea.) 75K, 12K, 4.7K, 1K, 220K
Signal generator
Oscilloscope

Procedures

1. Using the same circuit from Lab #2, do a DC and AC analysis of the circuit in the schematic and calculate all of the values of Table #1. Make all of the corresponding measurements on the circuit and record them in the table. Compare your calculated values to your measured values and calculate the error percentage. If the error percentage is greater than +/-15%, you must redo that step and verify the readings and calculations. Explain any errors as part of your report.

2. Breadboard the circuit shown in the schematic by adding the additional components to your existing circuit.

3. Apply a 2KHz ,50mV sine wave signal to the input (measure at Vin with respect to ground) and obtain an undistorted output. Measure Vin and Vout and calculate

the gain. Compare against your calculated value. Demonstrate your circuit to the instructor.

4. Adjust the frequency of the incoming signal by lowering it until your output is .707 of the original amplitude measured in the previous step (Step #3). Record this new frequency in your table. Reset the frequency to 2KHz. Adjust the frequency of the incoming signal by increasing it until your output is .707 of the original amplitude measured in step #3. Record this new frequency in your table. Reset the frequency to 2KHz.

5. Remove the emitter bypass capacitor and measure your Vin and Vout. Calculate your gain at this step. In your report you must be able to explain what happened to the circuit when you did this.

6. Once you have completed the above steps, let the instructor know and he will then put a bug in your circuit. You must find the malfunction and correct it. IT IS NOT A MATTER OF VISUALLY FINDING THE FAULT BUT TO ANALYZE THE READINGS THAT YOU MAKE AND USE THAT INFORMATION TO LOCATE THE FAULT. As you go through the process of finding the problem, make notes of what you do and find. This information will be part of your report.

Table 1

Value	Calculated	Measured
VB		
VE		
IE		
IC		
VC		
VCE		
VRC		
re		
rin		
rin total		
AV		
Vout		
Freq. Low		
Freq. High		

Troubleshooting

Symptoms	Fault	Solution
Problem		
Problem		
Problem		

CHAPTER TEN LABORATORY EXERCISE:
TWO-STAGE AMPLIFIER

Name:______________________________

Date: ______________________________

Objective

Troubleshoot and analyze the operation of a two-stage amplifier

Lab Materials

Two stage circuit
Signal generator
Oscilloscope
Multimeter
Power supply
1ea. 100K, 10 ohm resistors

Procedures

1. Build the circuit in schematic #1. Complete a DC and AC analysis. Record all of the calculated values in Table #1. Refer to book or notes if needed.

2. Obtain a circuit from the instructor (which is similar to schematic #1) and record the number that is on the back of the circuit on your data table. Remember that all of these circuits have built in malfunctions. Your task is to find the fault. You must complete at least one circuit.

3. Connect the circuit to a DC power supply and connect a signal generator to the attenuator circuit and set Vs to 10Vpp at a frequency of 3KHz. The resulting signal (Vin) should be about **1mVpp.** Measure all of the required voltages and verify if the circuit is working properly. If both stages are working properly, proceed to the next step. If it is not working properly, trouble shoot the circuit and find the fault. Once you find the fault, determine whether or not you can correct the fault (ask for assistance from the instructor

if needed). If you are able to correct the fault, proceed to the next step. If you are not able to correct the fault, obtain another circuit from the instructor and repeat Step 3. Make sure that you include this in your report.

4. Measure the AC signal at each collector and record these values in Table #1. The output of stage number one (vo1) should be larger than Vin and the output of stage number two (vo2) should be larger than vo1. Calculate the gain of each stage (Av1, Av2) and the overall gain (Avtot). Record these values in the table.

Av1= vo1/Vin   Av2= vo2/vo1   Avtot= vo2/vo1

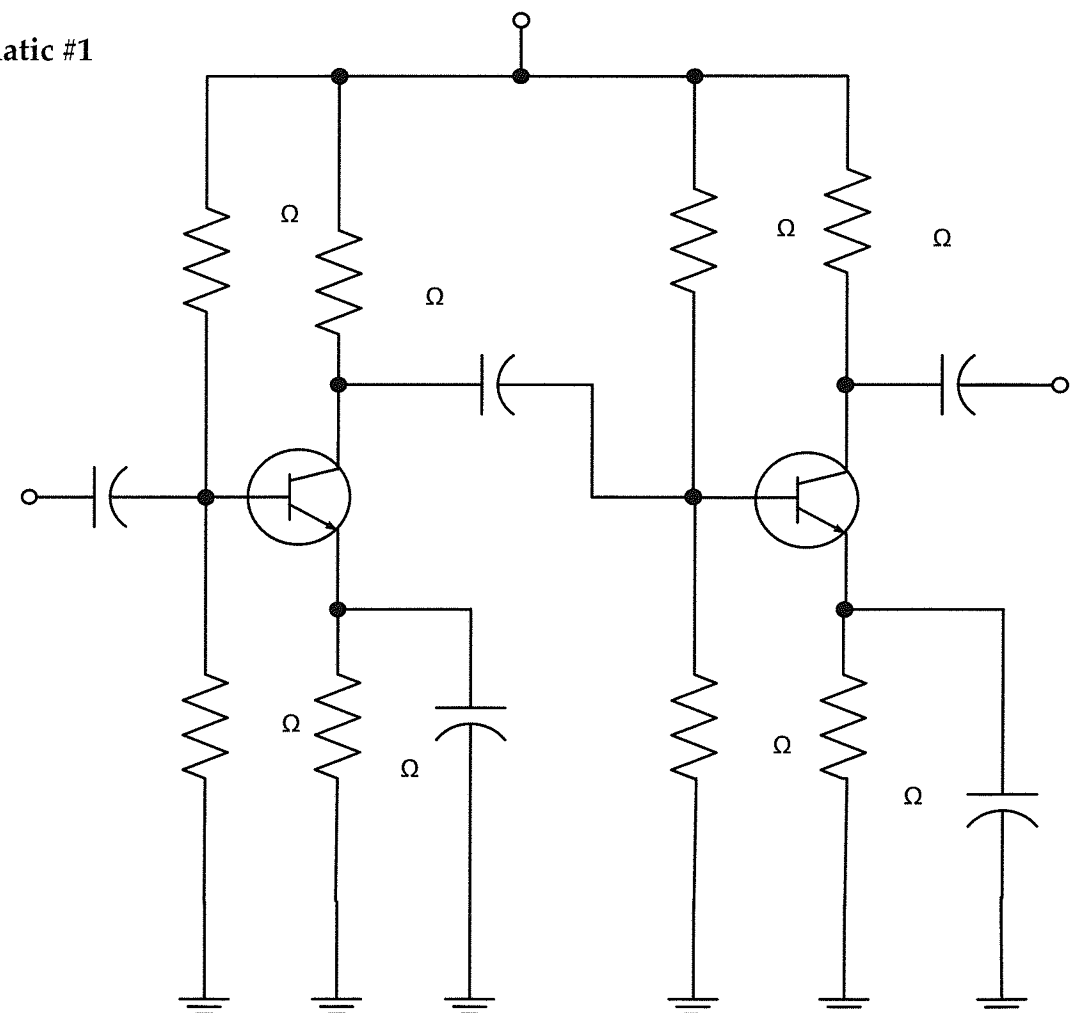
Table 1

	Calculated		Measured	
CKT#_______	Q1	Q2	Q1	Q2
VB				
VE				
VC				
VCE				
VRC				
IE				
IC				
Rin				
Rin total				
rl				
Vout	vo1=	vo2=	vo1=	vo2=
Av	Av1=	Av2=	Av1=	Av2=
Avtot				

Troubleshooting

CKT#	Symptom	Fault

Schematic #1



Two-Stage Amplifier

Chapter 11: Operational Amplifiers (Op-Amps)

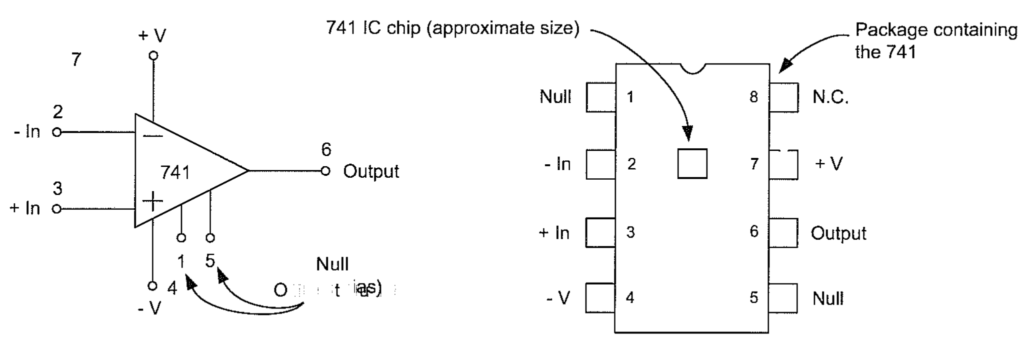
After completing this chapter you will have an understanding of:

- *The available packages and specifications of op-amps*
- *The electronic symbol for an op-amp*
- *The terminals of op-amp packages*
- *Operational amplifier applications through laboratory exercises*
- *Operational amplifier troubleshooting through laboratory exercises*

Op-Amps and Packaging Diagrams

Operational amplifiers (op-amps) are extremely useful electronic components and are found in several medical device applications. An op-amp is an integrated circuit (IC) containing several (10 or more) transistors and the necessary components to allow for very efficient signal amplification. The connection of the transistors to the signal input and output create a very large (several megaohms) input impedance. The output on the other hand, has very low impedance (ideally zero). A general purpose op-amp will have two power supply terminals (one positive and one negative), two input terminals, and an output terminal. Figures 11.01B and C illustrate six different terminal configurations for a typical op-amp.

Figure 11.01A



Circuit symbol for a 741 with pin-outs numbered

The 741 chip is shown packaged in an 8-pin dual-in-line package (top view)

Figure 11.01B

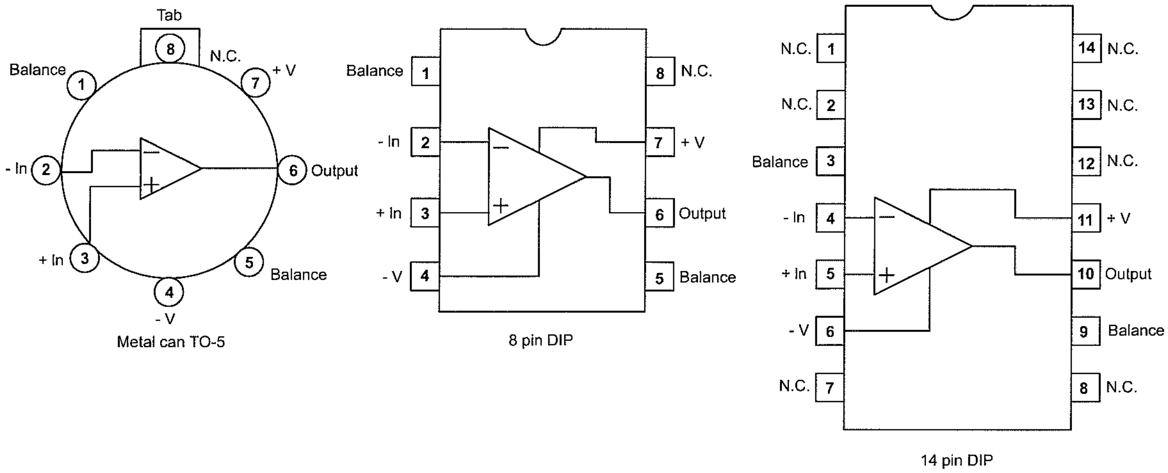


Figure 11.01C

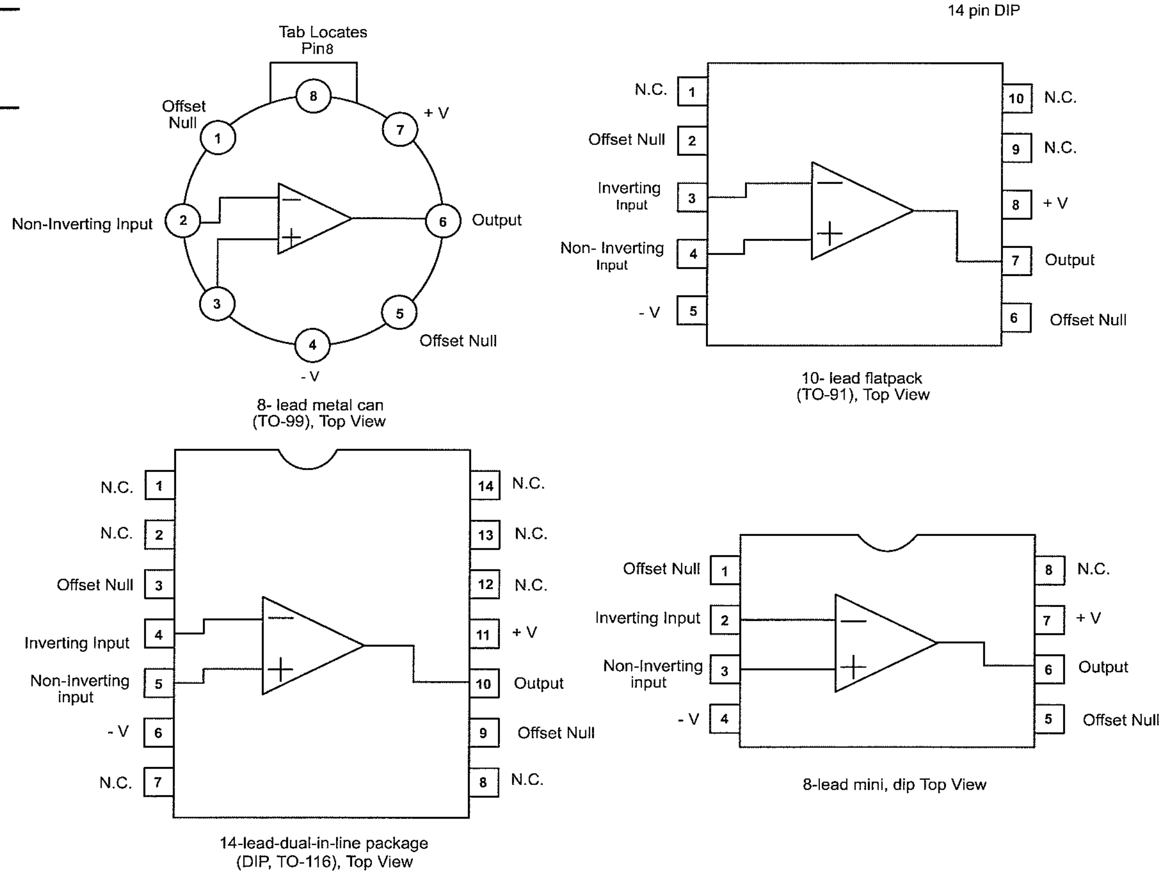
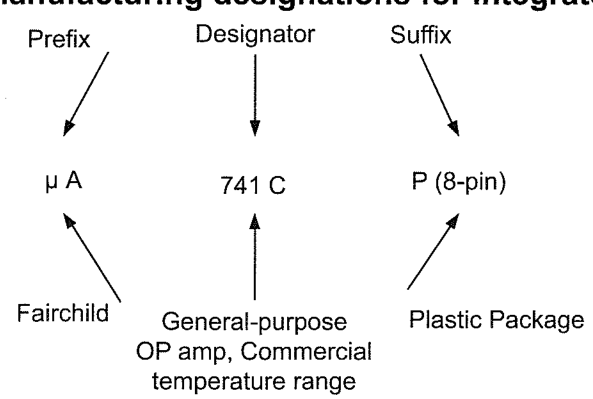


Figure 11.01D **Understanding manufacturing designations for integrated circuits**



For IC with label μA 741C P

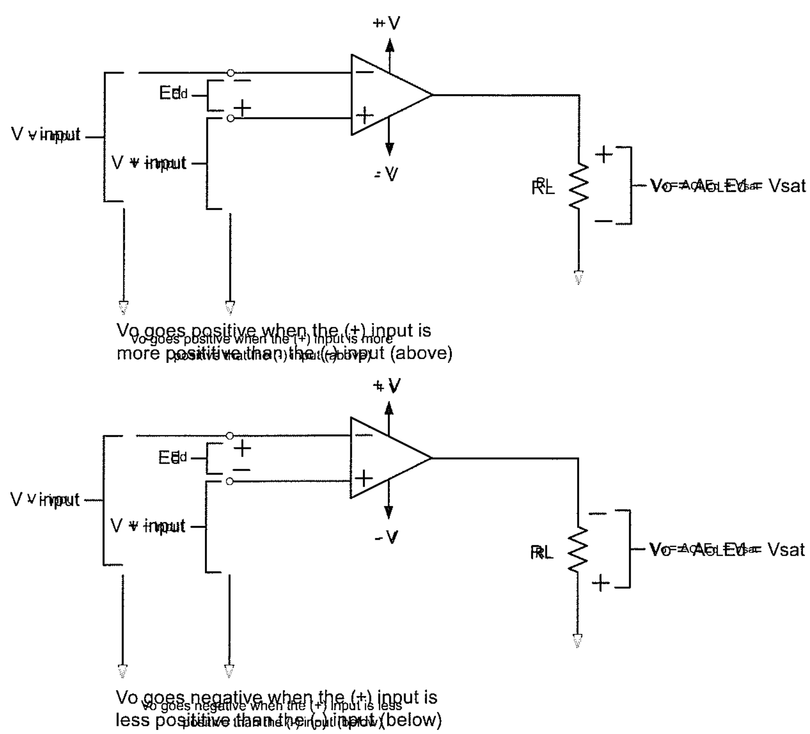
Table 11.01

Letter Prefix	Manufacturer
AD	Analog Devices
CA	RCA
LM	National Semiconductor Corp.
µC	Motorola
NE/SE	Signetics
OP	Precision Mechanics
RC/RM	Raytheon
SG	Silicon General
TL	Texas Instruments
UA	Fairchild

Theory of Operation

An op-amp is powered using one positive power supply (V+) and one negative power supply (V-). The two input terminals are referred to as differential input terminals because the op-amp output (Vout) terminal is determined by the difference in voltage between the positive (non-inverting) terminal and the negative (inverted) terminal. This difference voltage is notated by the letters Ed. If there is no feedback connection from the output terminal, the op-amp is in a state of open loop gain (Aol). A typical open loop gain for an op-amp ranges from 150,000-250,000. Therefore, voltage inputs in the Aol configuration for difference voltage are in the micro-volt range. If the voltage inputs are higher in Aol, the op-amp will have a "saturation" gain. Figure 11.02 illustrates open loop gain.

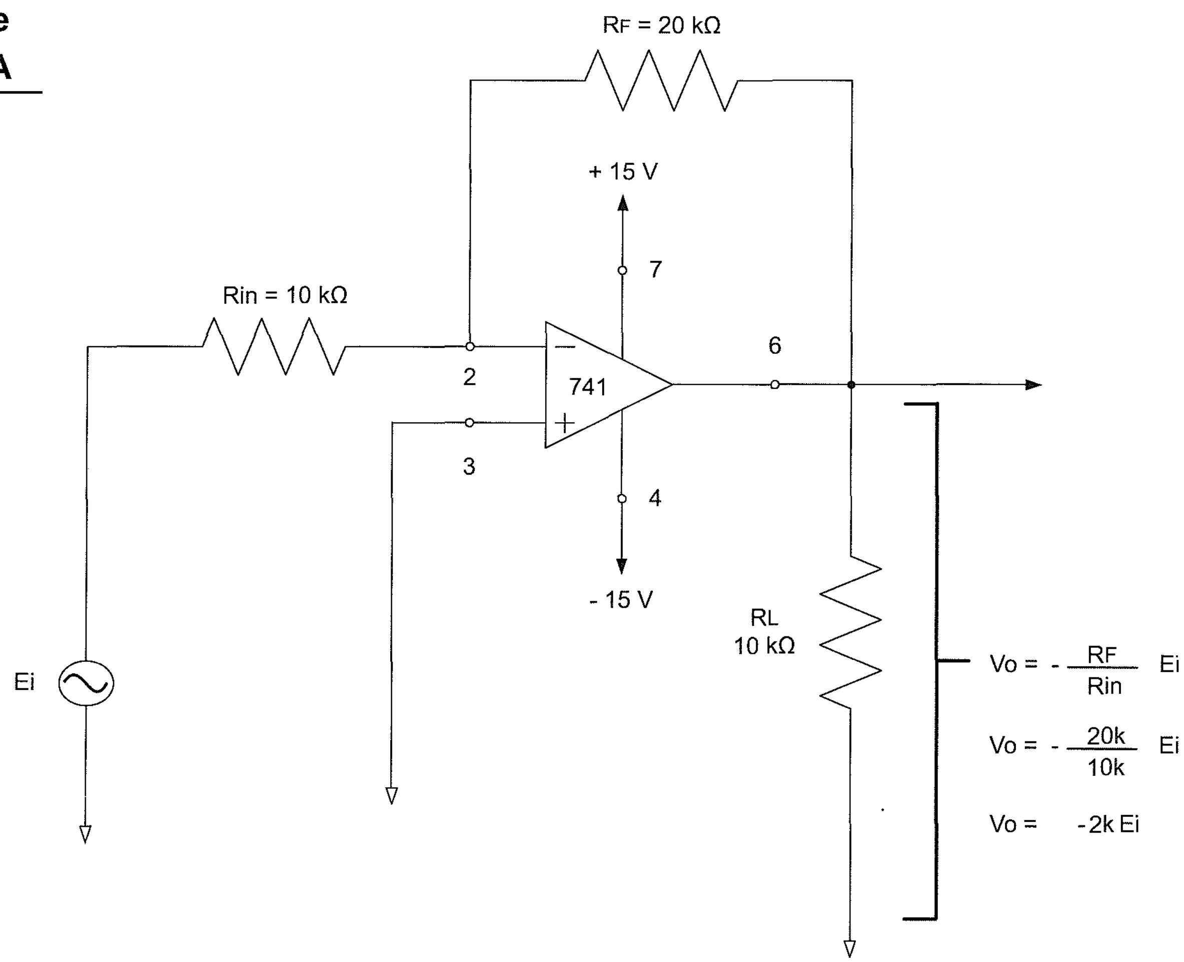
Figure 11.02



Inverting and Noninverting Applications

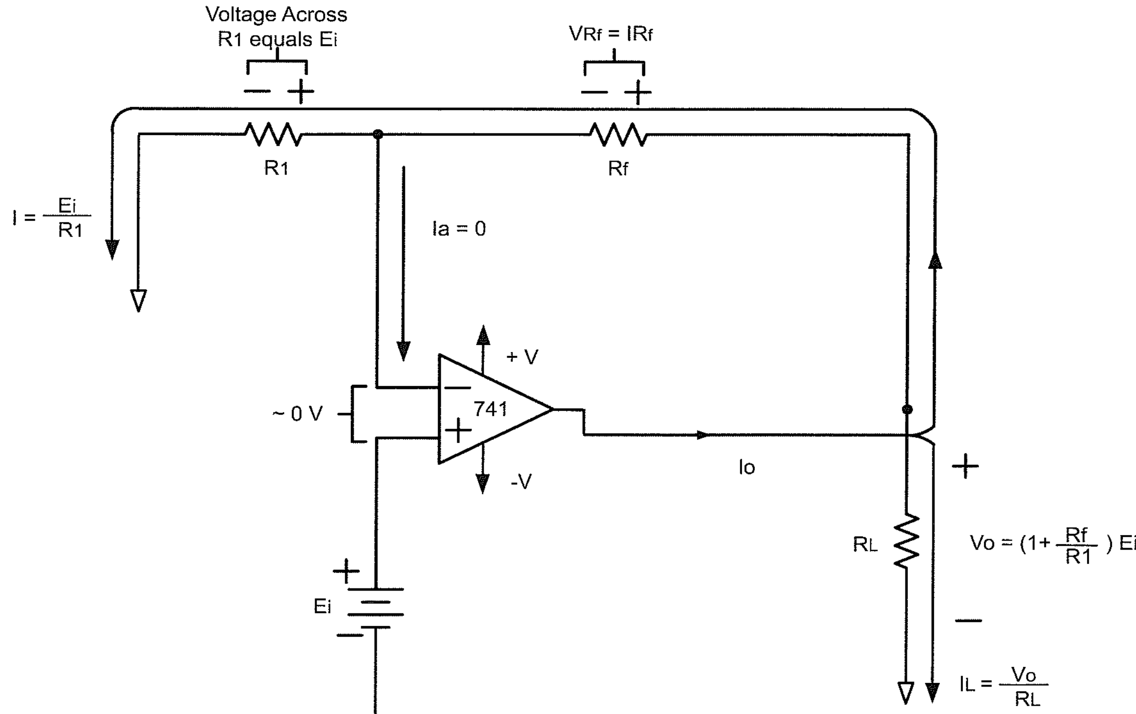
When an op-amp is used for signal amplification, resistors are connected to the input and output terminals. The output signal may be either positive (non-inverted) or negative (inverted) depending on which terminal is attached to isolated ground. Figures 11.03A and B illustrate the non-inverted and inverted signal amplification of an op-amp and the corresponding gain for each signal. The amplification or voltage gain (Av) is calculated by dividing the Rf resistor by the Rin resistor. If the circuit is connected in a similar manner without resistors, a unity gain op-amp will result. As the term unity gain implies, the gain of this op amp will be "one" or no gain. Unity gain op-amp circuits are also known as "voltage followers" since the output voltage follows the input voltage without gain. Figure 11.04 illustrates a unity gain op-amp. Unity gain op-amps are used as buffers in electronic circuits. A buffer is a component or circuit that has high input impedance and a low output impedance. This provides signal clarity and reduces noise.

Figure 11.03A

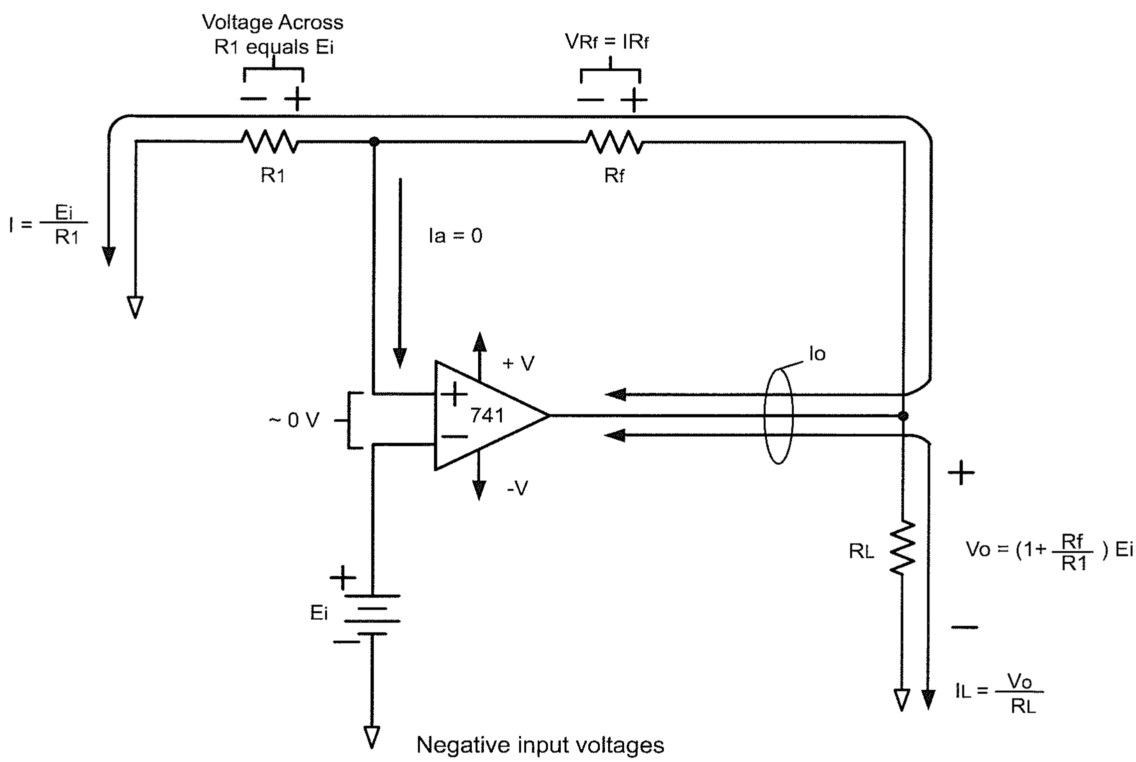


Ac input voltage Ei is amplified by -2

Figure 11.03B

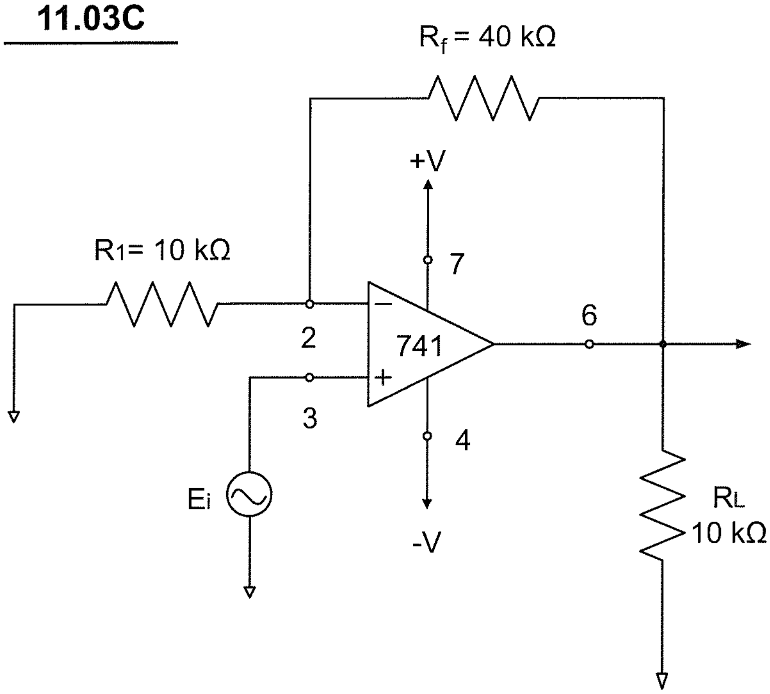


Positive input voltages



Negative input voltages

Figure 11.03C Calculating signal gain of a non-inverting amplifier



(a) Calculated Gain

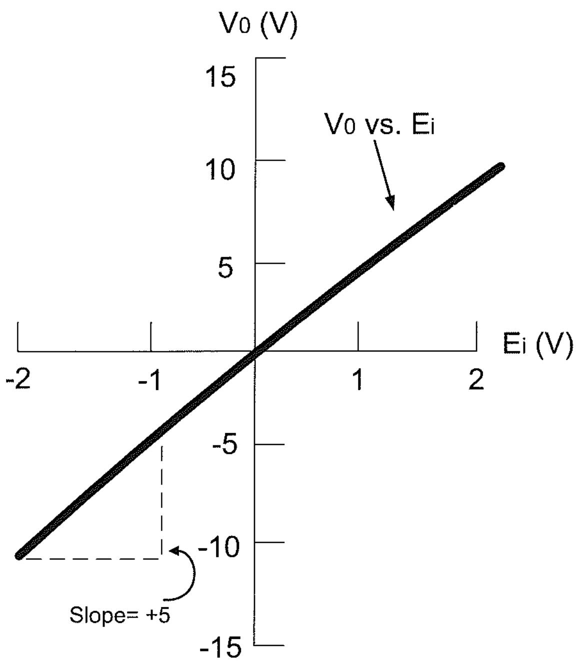
$$Av = \frac{R_f}{Rin} = \frac{40k\Omega}{10k\Omega} = 4$$

(b) Actual Gain

$$Av = \frac{R_f + R_i}{R_1} = \frac{40k\Omega + R_i}{R_1}$$

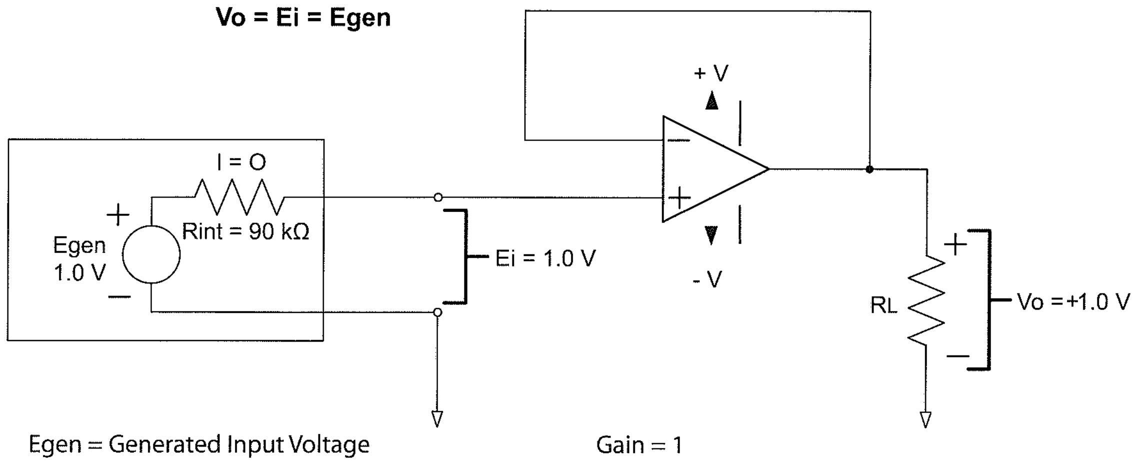
Ri = Internal resistance = 10kΩ

$$Av = \frac{40k\Omega + 10k\Omega}{10k\Omega} = \frac{50k\Omega}{10k\Omega} = \boxed{5} \text{(actual)}$$



(c) Input-output characteristics of a non-inverting amplifier

Figure 11.04



Buffers provide high input impedance for signal clarity.

Input Mode Applications

Operational amplifiers are found in a variety of electronic circuits due to their reliability, low cost and intuitive input and output connections. One of the most common op-amp circuits is the differential amplifier (diff-amp). A diff-amp combines the two inputs of the op-amp and produces an output voltage and waveform that is equal to the difference between the inverting and non-inverting inputs. Figure 11.05 illustrates an example of a differential amplifier application and the corresponding output. Earlier in the chapter, the gain process was demonstrated as a result of external resistors (Rf and Rin). There is also a gain component due to the internal components of the op-amp. Laboratory exercises will demonstrate this effect. The calculated values will not equal the measured values of the differential amplifier circuit you build in the lab. This difference in output voltage when the op-amp swings (changes) from a positive saturation voltage to a negative saturation voltage is known as "hysteresis." Hysteresis is common to all semiconductor integrated circuits. Figure 11.06 illustrates a saturation hysteresis voltage. To offset or correct this problem there are input pins on the op-amp package labeled DC offset.

Figure 11.05 **Differential Amplifier**

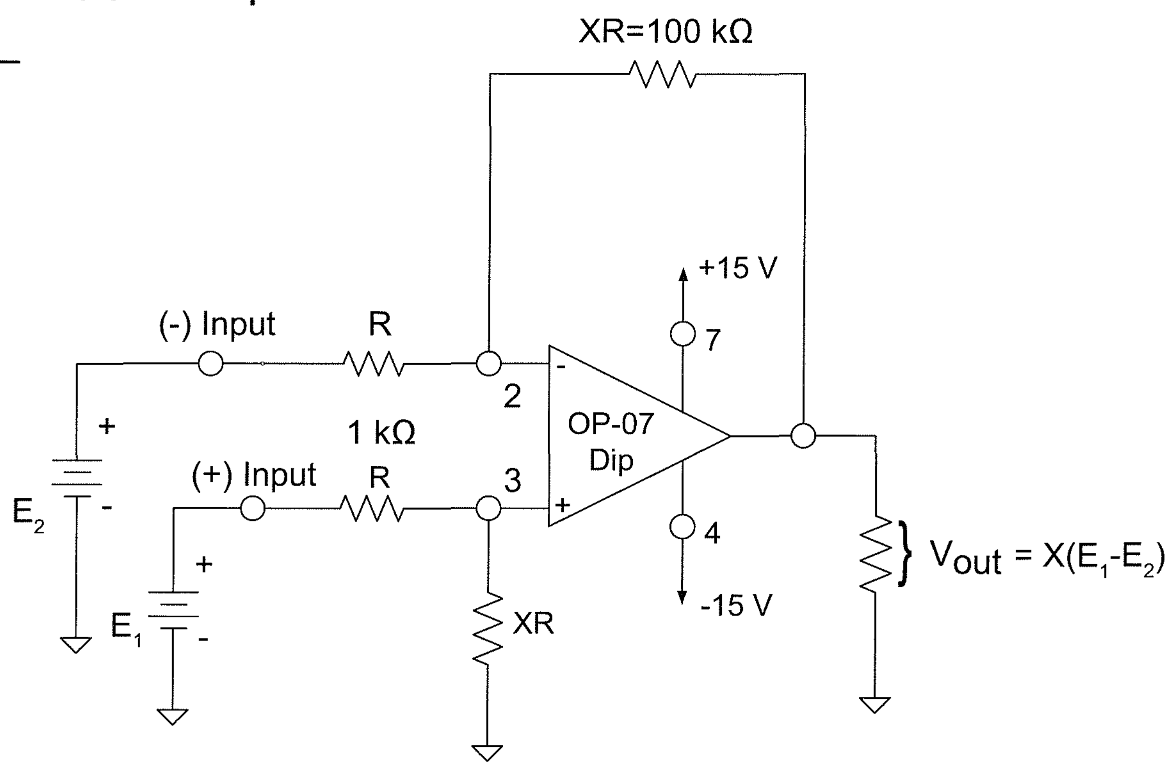
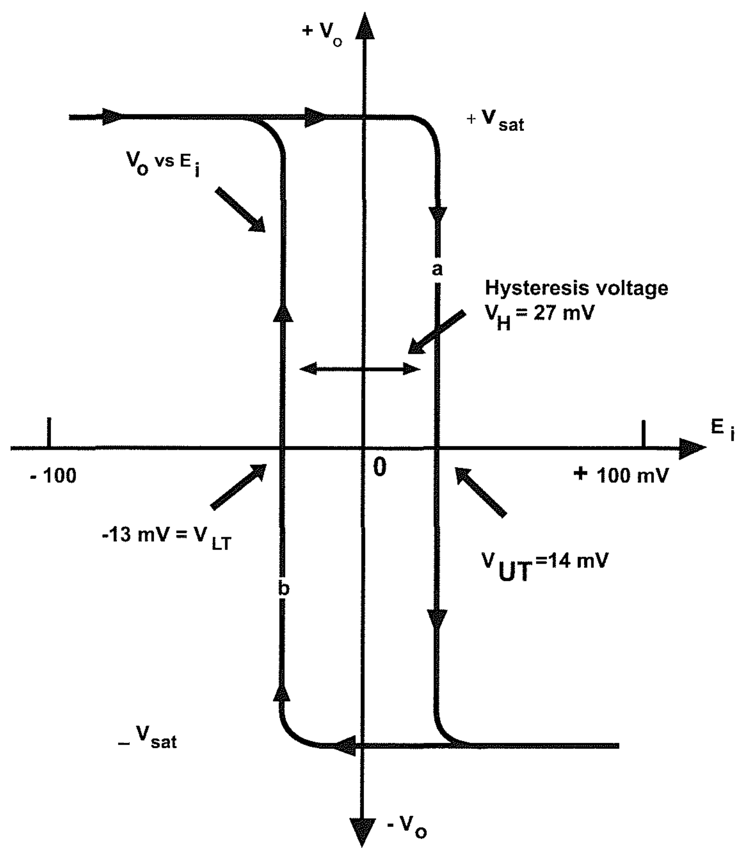
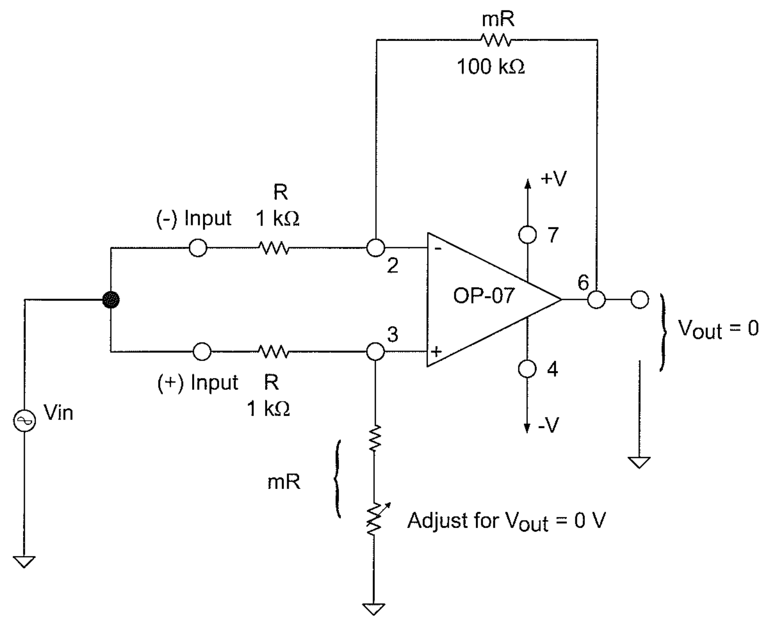


Figure 11.06 **Hysteresis Voltage**



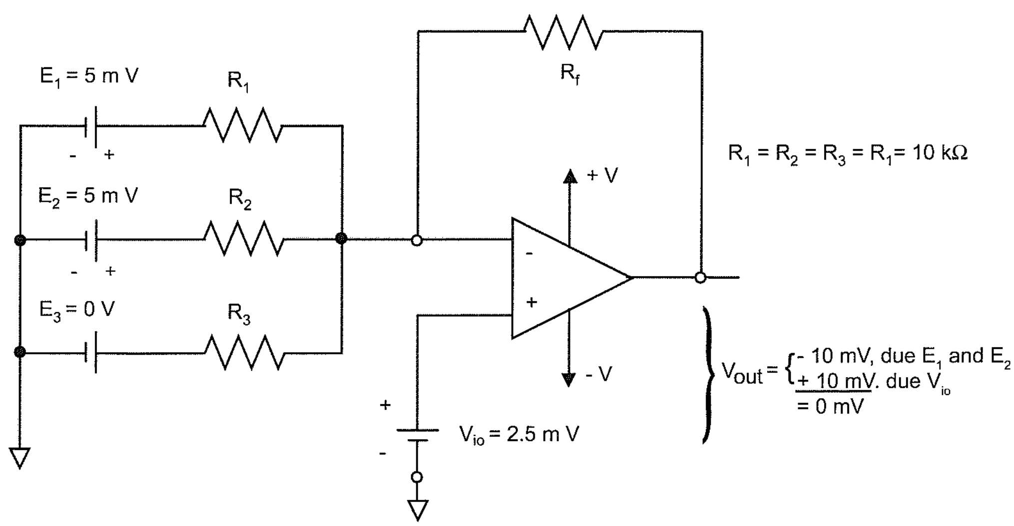
Differential op-amps illustrate a property known as "common mode rejection" (CMR). Common mode rejection is used extensively in medical electronics to eliminate unwanted signals coupled with the output signal. In an electrocardiogram (ECG) circuit, a feedback circuit from the right leg acts as a common mode rejection circuit to eliminate the body's normal electrical impulses from the muscles. This provides a true output ECG signal from the conductive tissues of the heart, while removing other signals from the output. Figure 11.07 illustrates a common mode rejection circuit and a common mode rejection circuit application.

Figure 11.07



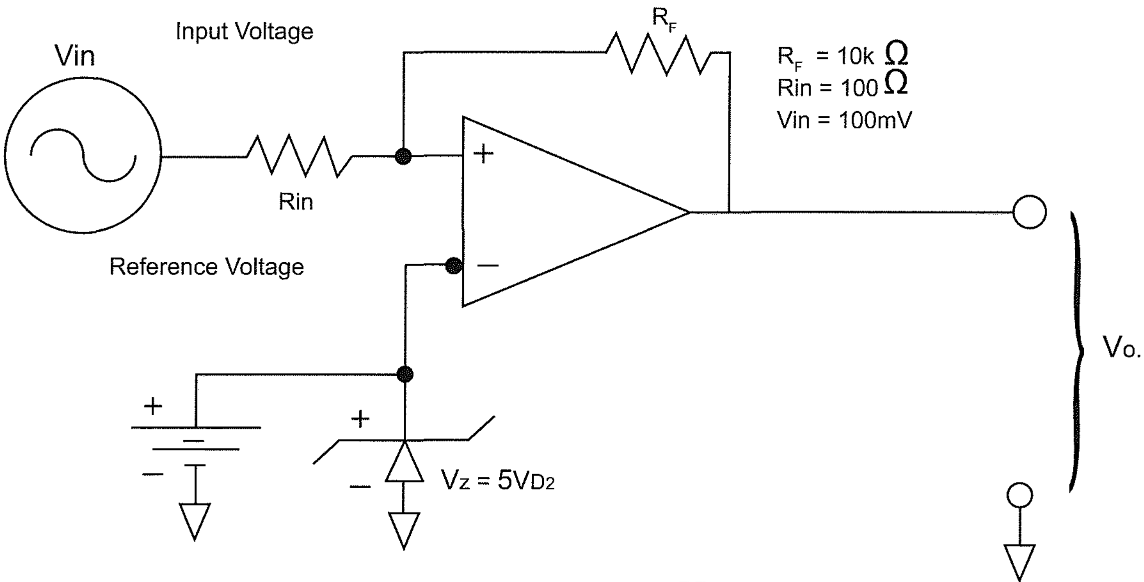
Op-amps are also used as summing circuits. Figure 11.08 illustrates the summing circuit diagram and an application of an op-amp summing circuit.

Figure 11.08



Comparator op-amp circuits are extremely useful electronic circuits for the purposes of relating voltage level differences in physiological sensors and also for troubleshooting purposes. A simple addition or subtraction of the input signals at the inverted (-) input and the non-inverted (+) input should result in the expected output. If the output does not measure the expected input, there could be input impedance problems, improper resistor gain connections, or a malfunctioning op-amp. Figure 11.09 illustrates the expected output of a comparator and the corresponding troubleshooting techniques.

Figure 11.09



$$\text{Expected Vo} = \text{Vin}\left(\frac{RF}{Rin}\right) - \text{Vref}$$

$$\text{Example Vo} = 0.100\text{ V}\left(\frac{10{,}000}{100}\right) - 5\text{V} = +5\text{V}_{DC}$$

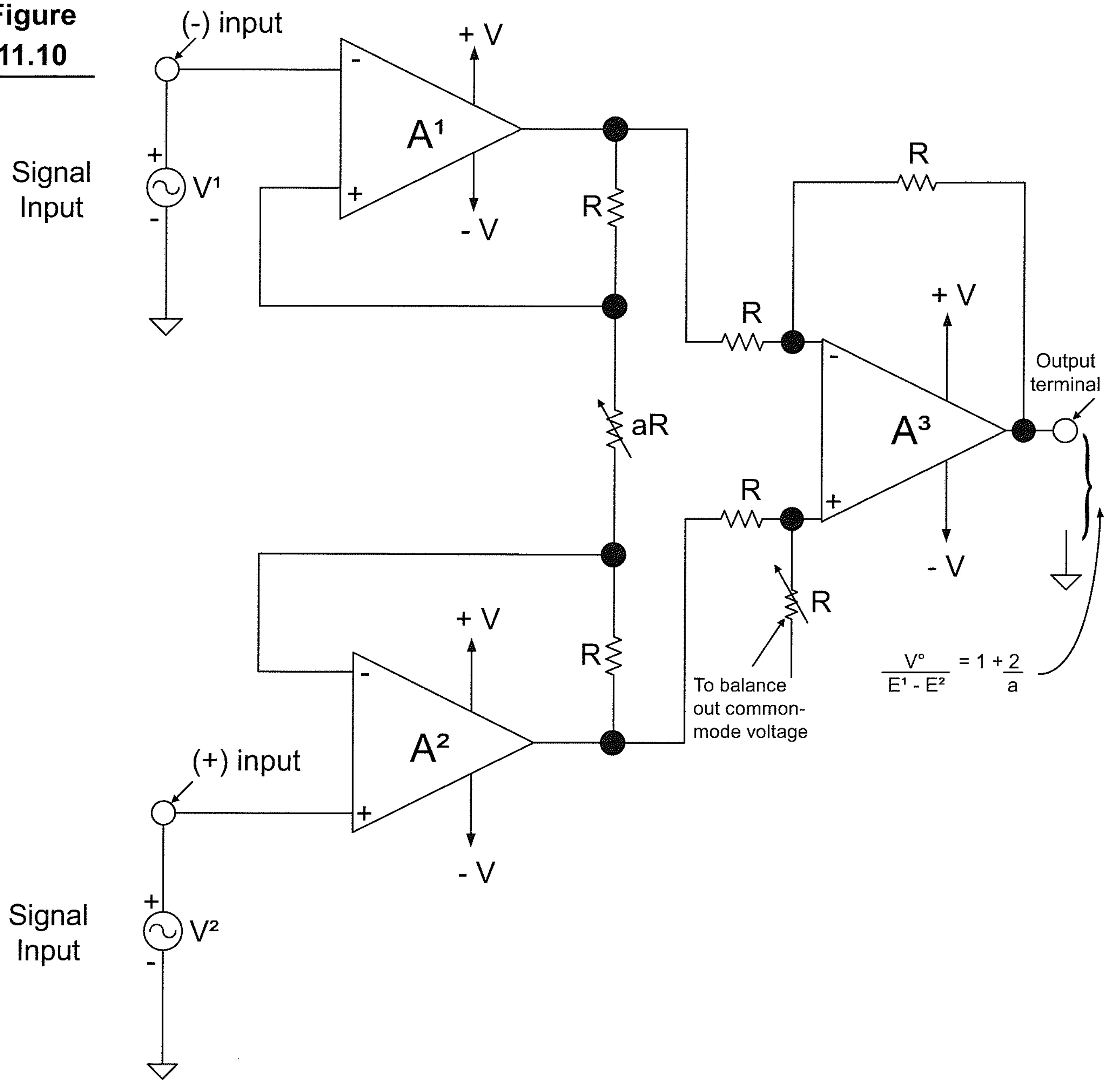
* Troubleshooting Techniques:

1. Measure Vin or use known signal generator voltage.
2. Measure V out.
3. Calculate $Av = \frac{RF}{Rin}$
4. Does output equal accepted value?
5. If Vo = Ov, there is an open in the circuit.
6. If Vo is above zero volts but lower than expected, check Zener diode voltage.

Voltage level detector op-amp circuits are used to determine the magnitude levels of signals. A common use for a voltage detector circuit in medical electronics is in the sensing of the "R" wave in the QRS complex of the heart's ECG.

Some medical circuits require precision outputs with a large gain. This requires a very high input impedance op-amp circuit. The instrumentation amplifier, also known as a "bio-instrumentation amplifier," uses three op-amps to provide high input impedance (normally 300 MΩ) and internal common mode rejection. The instrumentation amplifier configuration is illustrated in Figure 11.10.

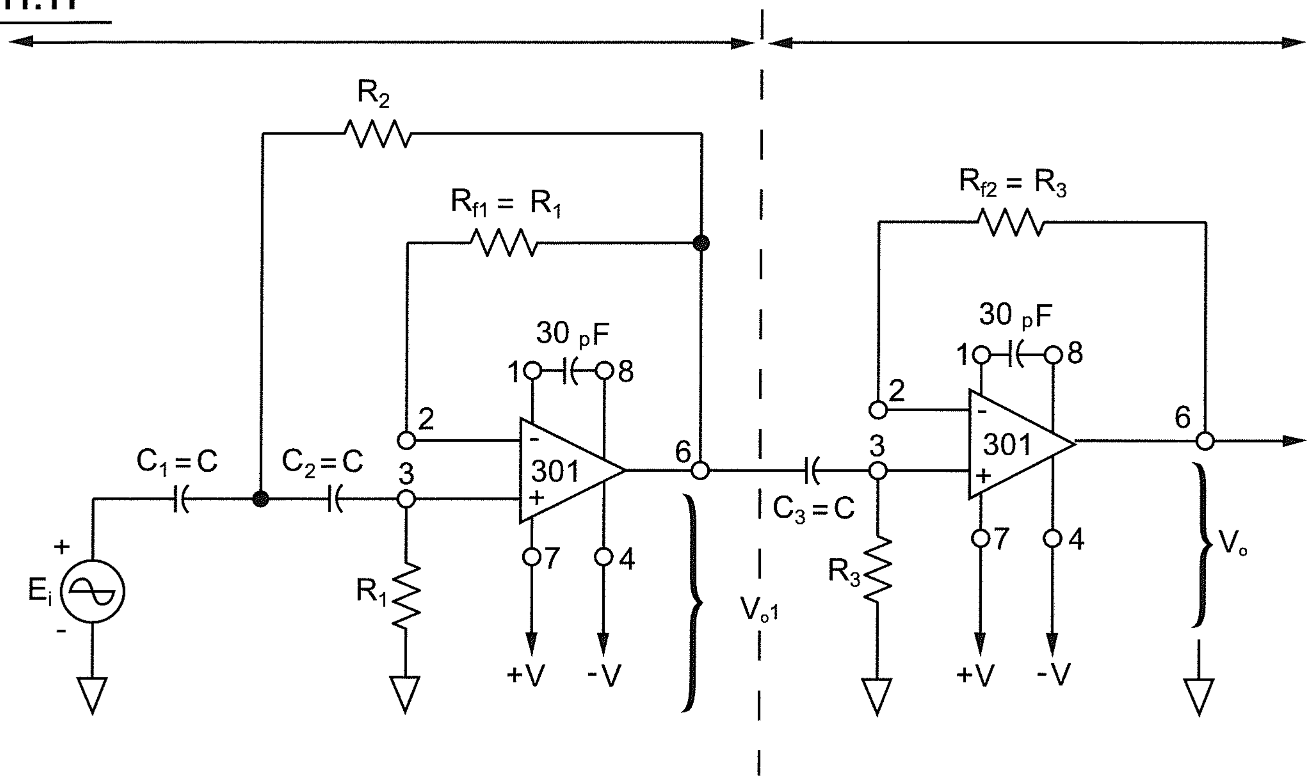
Figure 11.10



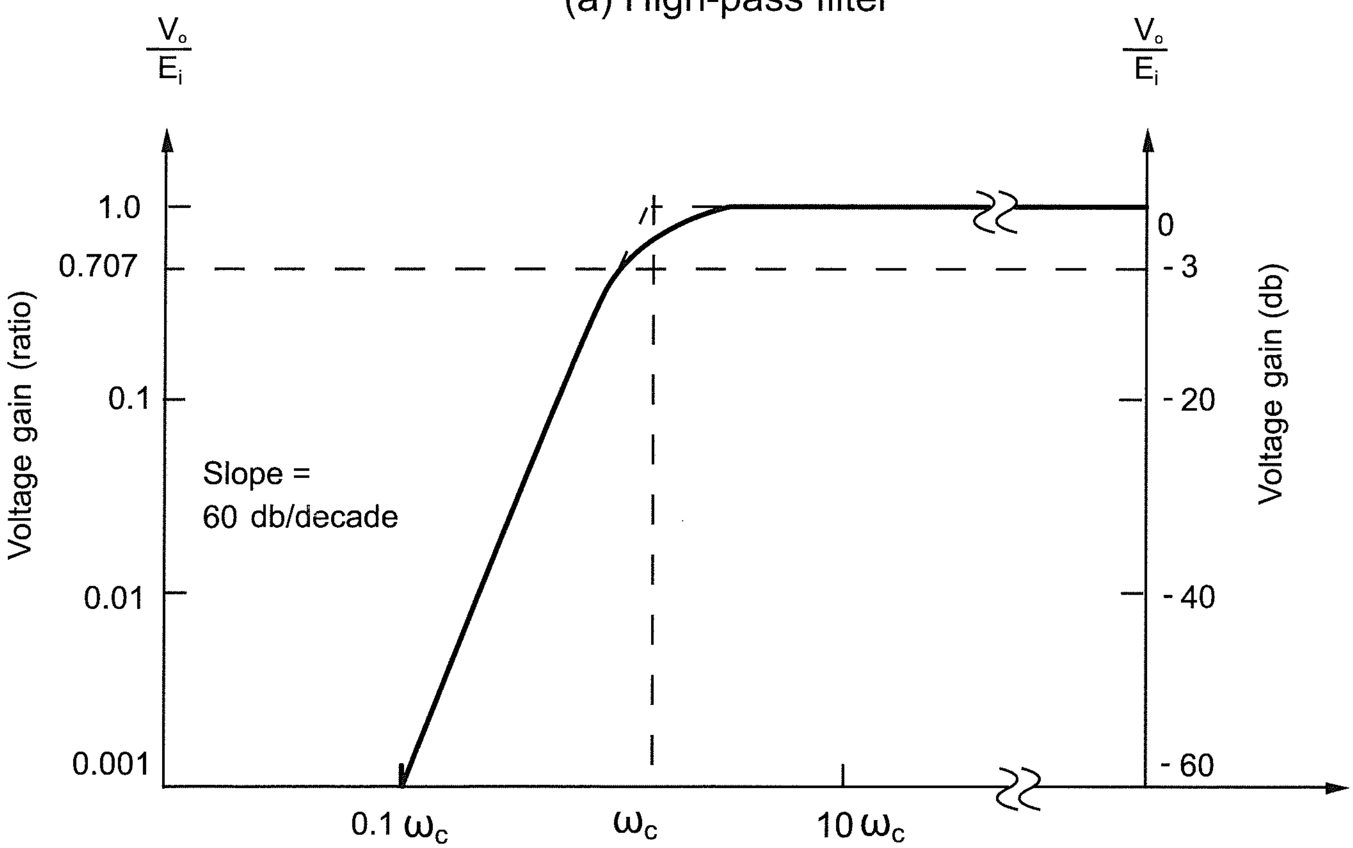
Differentiator and integrator op-amp circuits are special purpose circuits that can also act as signal filters. Do not confuse the differentiator circuit with the differential op-amp. They sound similar but have completely different functions. A differential mathematical process provides an answer for change over time. A differentiator op-amp also provides a voltage output that represents the rate of signal change in a certain time period. Figure 11.11 illustrates the differentiator circuit and application.

Figure 11.11

2 Stage High-Pass Filter

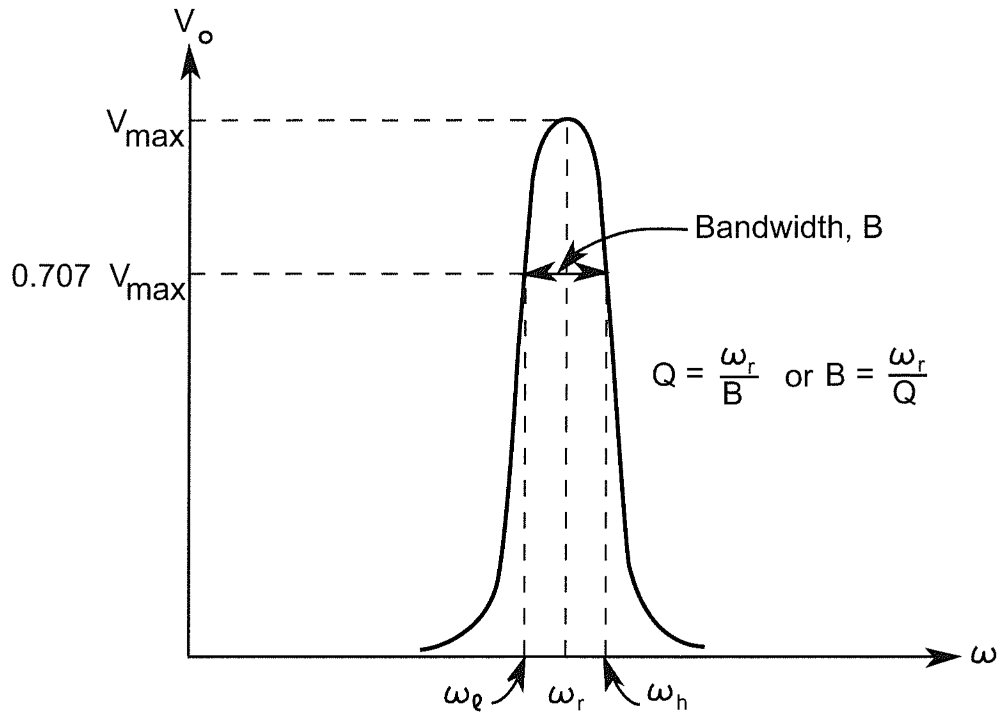


(a) High-pass filter

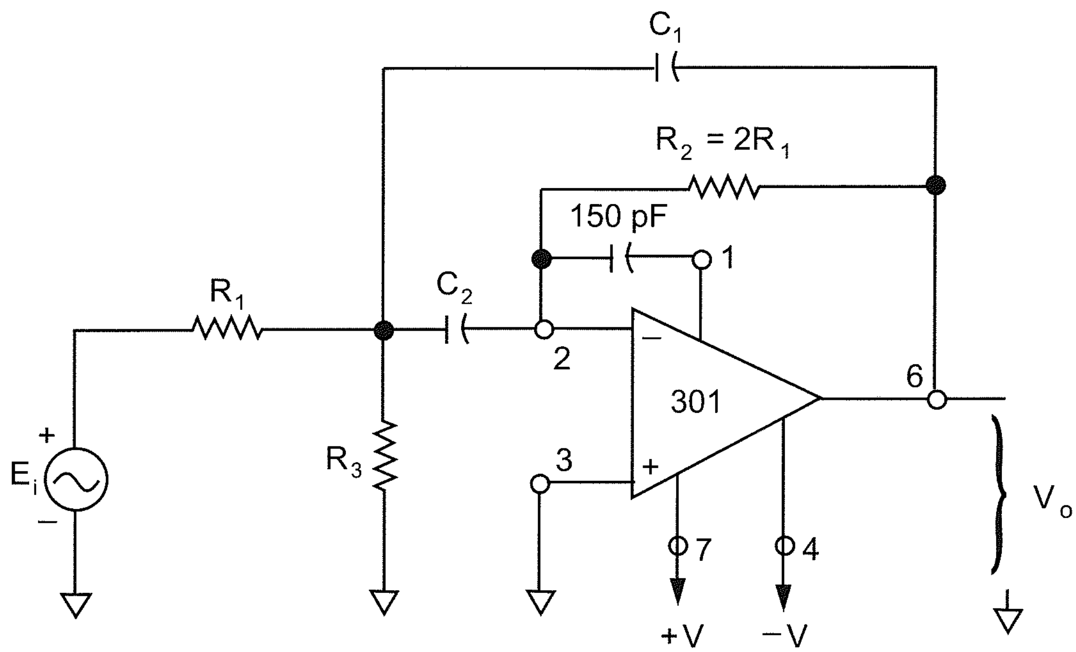


Frequency-response plot for circuit of part (a)

Figure 11.12A

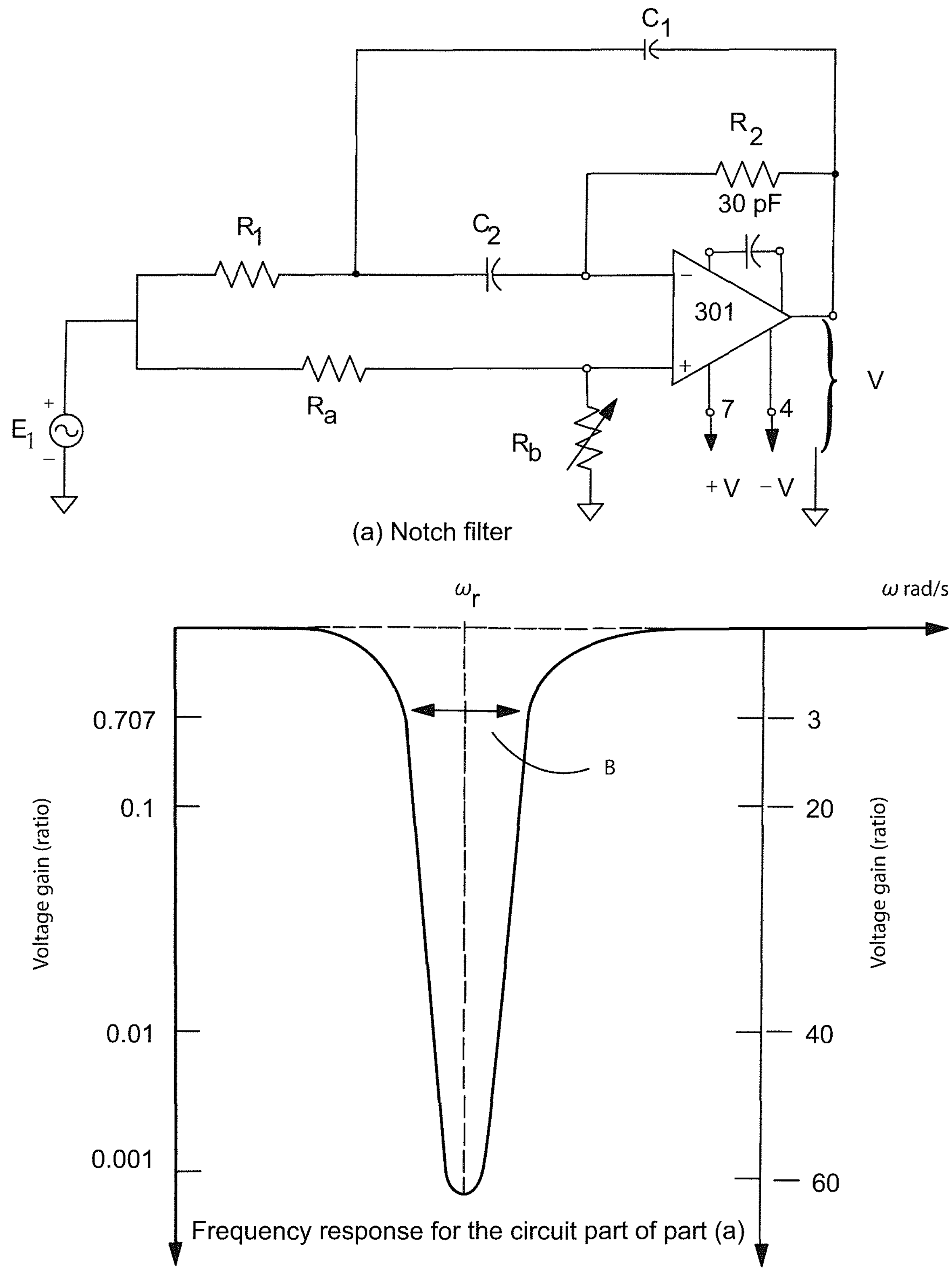


Frequency response of a bandpass filter



Bandpass filter

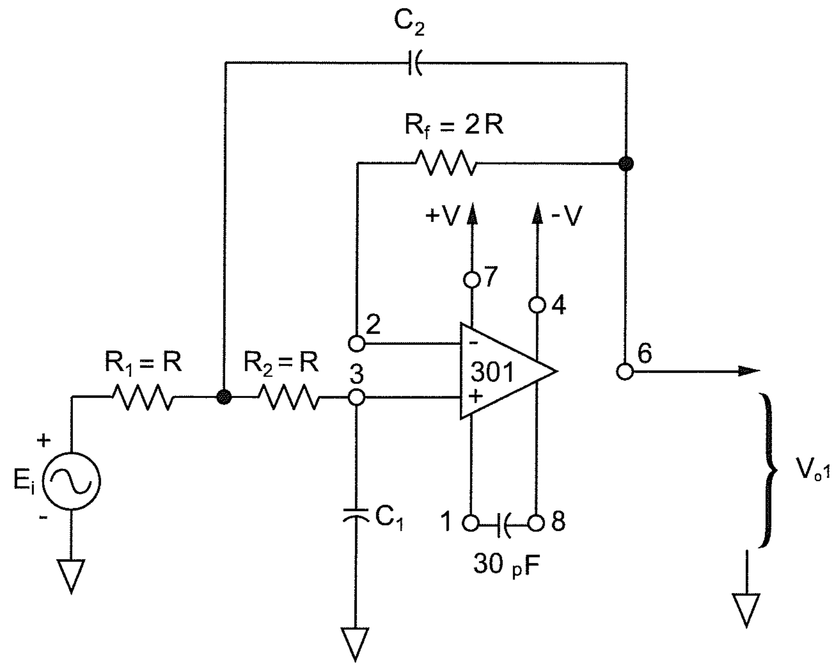
Figure 11.12B



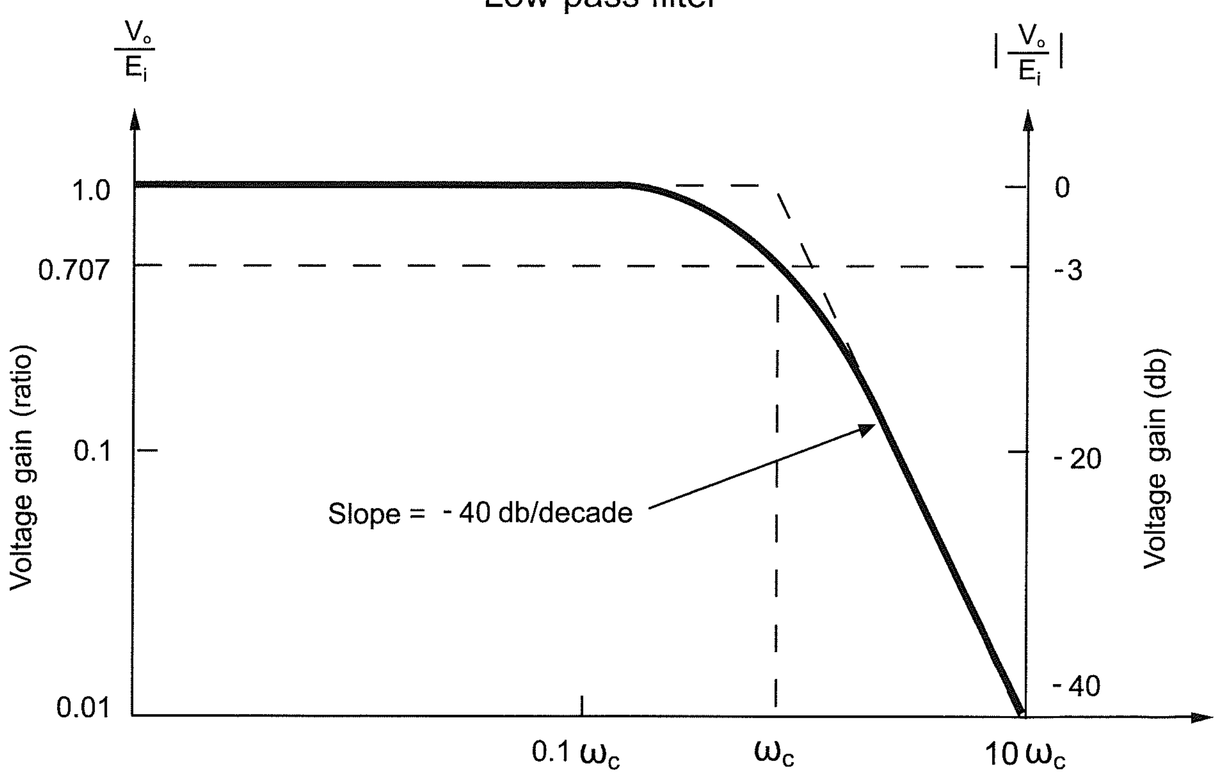
Integration is a mathematical process that provides the total sum of a function, which is expressed in calculus as the area under the curve. The medical electronic equivalent of an integrator op-amp provides the total voltage of a circuit over a certain time period. The output of an op-amp integrator is a triangular waveform. This is the same circuit used in signal generators to produce a triangular waveform. Figure 11.13 illustrates the circuit for an integrator op-amp.

Figure 11.13

-40 DB/Decade Low-Pass Butterworth Filter



Low-pass filter



Oscillators

Oscillators are electronic circuits that are used to produce signal sources such as square, triangular, and sine waves. An oscillator essentially has two components: 1) the amplifier and 2) feedback system. Figure 11.14A illustrates a block diagram of an oscillator circuit. As you can see from the block diagram, the feedback system takes away gain from the amplifier circuit. This combined gain of the feedback system and the amplifier is known as open loop gain. In order to produce an oscillating waveform the open loop gain (Av1 x Av2) must be greater than or equal to "1." Two basic "tuned" oscillators that are often found in medical circuits are the Colpitts oscillator (Figure 11.14B) and the Hartley oscillator (Figure 11.14C). Tuned oscillators allow the oscillation frequency to be varied. This is accomplished in the Colpitts oscillator by changing the size of the inductor. In the Hartley oscillator, the tuning is accomplished by changing the size of the capacitor.

Another common oscillator is the crystal oscillator. Quartz crystals emit a specific frequency when stimulated by electric current. This is known as the piezoelectric effect. Quartz oscillators are common in most watches. Several medical devices also utilize crystal oscillators in timing circuits and as the clock in digital circuits.

Figure 11.14A

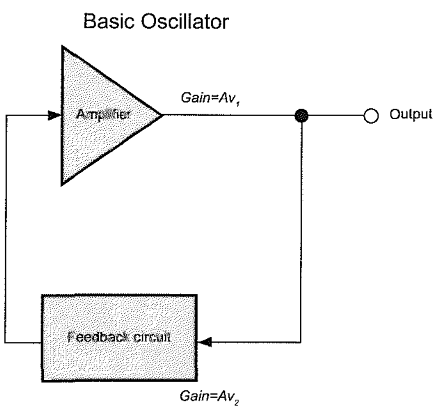


Figure 11.14B

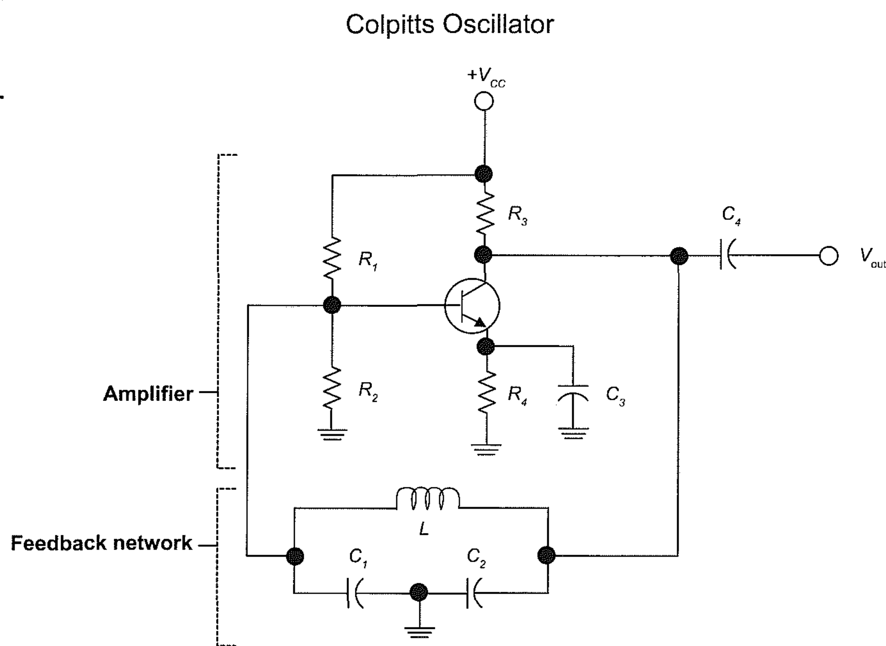


Figure 11.14C

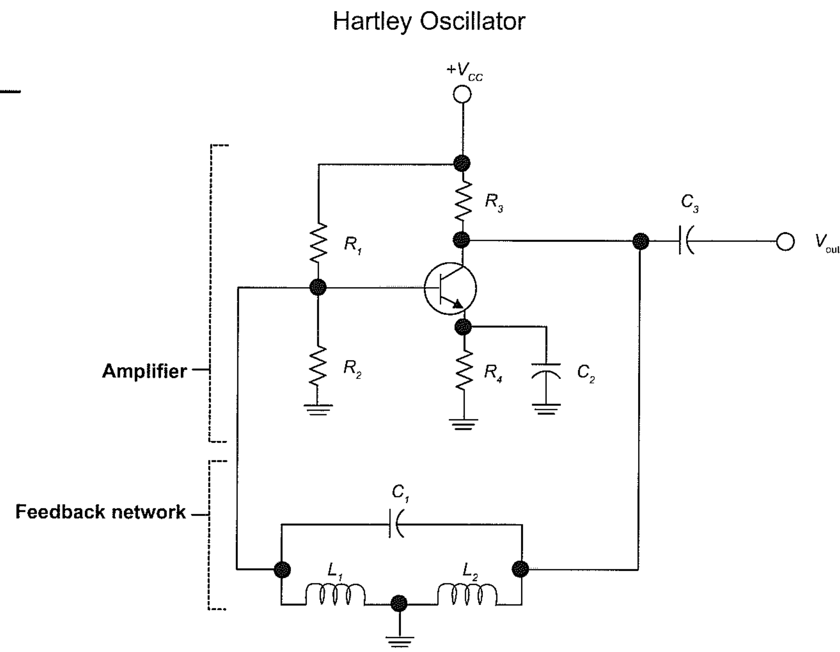
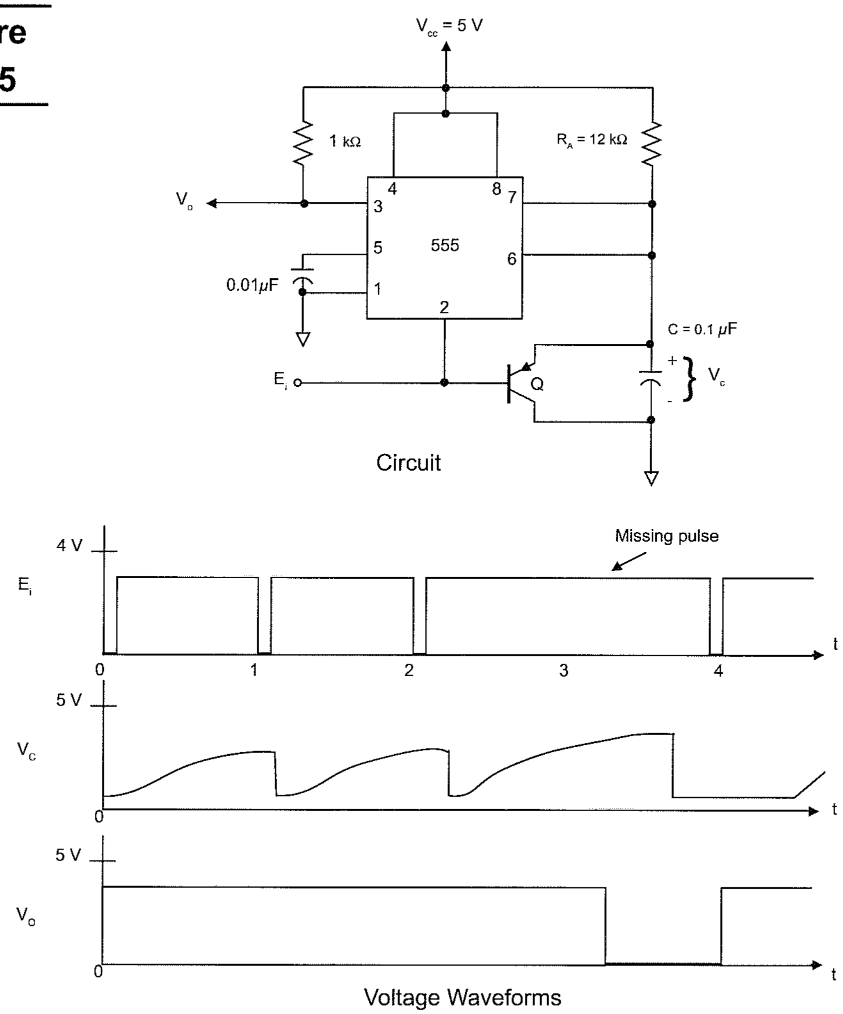


Figure 11.15

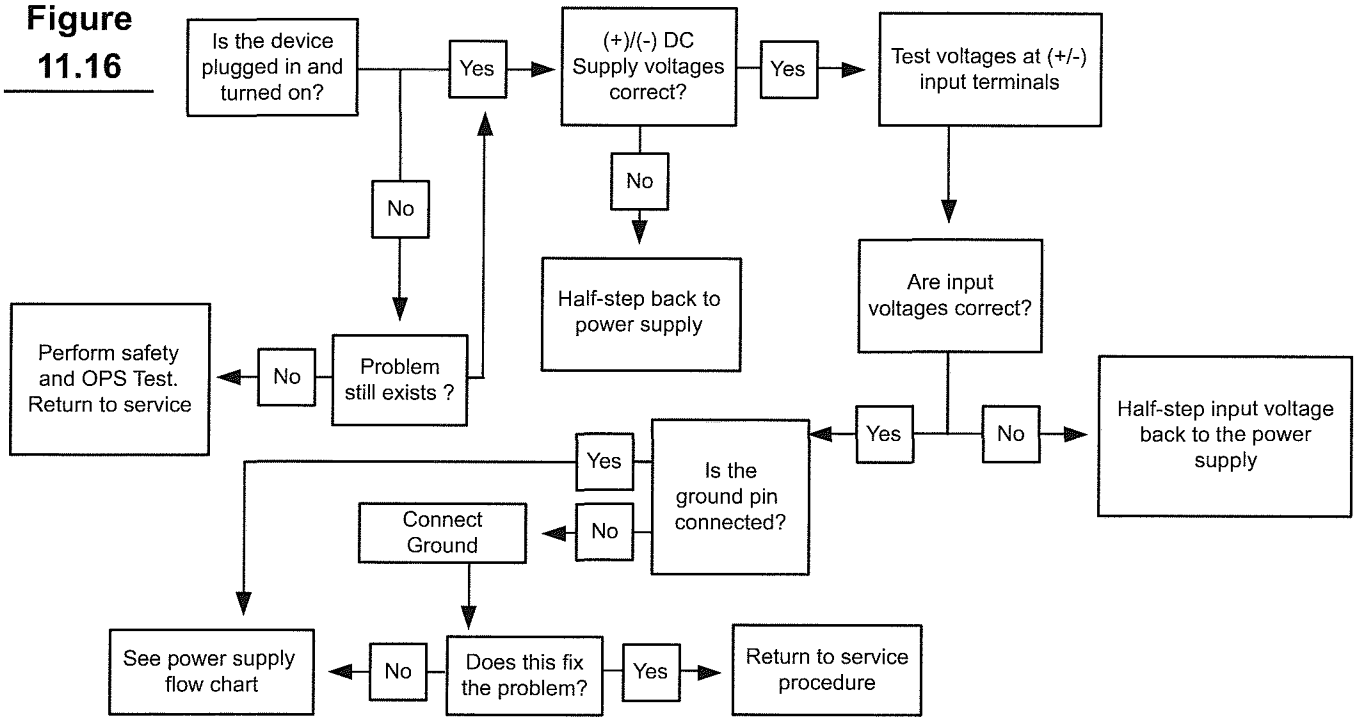


Oscillator Circuits, Colpitts, (variable inductor) Hartley (variable capacitor), Crystal (set quartz frequency due to natural harmonics of the quartz stone structure)

Op-Amp Troubleshooting Flow Chart

Operational amplifier circuits are found in almost every area of a medical electronic circuit. Knowledge of their operation and corresponding troubleshooting methods are essential in order to become proficient as a biomedical equipment technician. The flow chart below provides a logical and critical thinking process to quickllocate problems with op-amp circuits.

Figure 11.16



Glossary of Important Terms

Op-amp: An integrated circuit (IC) containing several (10 or more) transistors and the necessary components to allow for very efficient signal amplification, with high input impedence.

Unity gain circuits: Op-amp circuits with a gain of "one." The output voltage follows the input voltage without gain. Also known as "voltage followers."

Buffer: A component or circuit that has high input impedance and a low output impedance. This provides signal clarity and reduces noise.

Hysteresis: The difference in output voltage when the op-amp swings (changes) from a positive saturation voltage to a negative saturation voltage.

Diff-amp: Combines the two inputs of the op-amp and produces an output voltage and waveform equal to the difference between the inverting and non-inverting inputs.

Common mode rejection: Used extensively in medical electronics to eliminate unwanted signals coupled with the output signal. Signals of opposite polarity (inverting and non-inverting input) cancel each other out.

Instrumentation amplifier: Uses three op-amps to provide high input impedance (normally 300 MΩ) and internal common mode rejection for medical circuits that require precision outputs with a large gain. Also know as a "bio-instrumentation amplifer."

Oscillator: A device that changes the shape, magnitude, and frequency of a wave form in a designated manner using a DC input. Examples of oscillator wave forms include sine, triangular, and square waves.

Differentiator and integrator op-amp circuits: Special purpose circuits that can also act as signal filters.

Integration: A mathematical process that provides the total sum of a function, which is expressed in calculus as the area under the curve. The medical electronic equivalent of an integrator op-amp provides the total voltage of a circuit over a certain time period. The output of an op-amp integrator is a triangular waveform.

CHAPTER ELEVEN REVIEW QUESTIONS

Name:_______________________________

Date: ________________________________

1. What is the gain (Av) of a unity (voltage follower) op-amp?

2. Explain the difference between a differential op-amp (diff amp) and a differentiator op-amp.

3. What is the gain (Av) of an op-amp with Rin equal to 100 ohms and Rf equal to 1k ohms?

4. Troubleshooting scenario: You have an op-amp circuit with no output. Explain the troubleshooting process to determine the cause.

5. List three uses for an oscillator and describe each use.

CHAPTER ELEVEN LABORATORY EXERCISE 11.1:
Operational Amplifiers

Name:______________________________

Date: ______________________________

Objectives

1. Understand the signal amplification process of an operational amplifier.
2. Build a unity gain amplifier.
3. Build a multiple gain amplifier.

Materials

741 op amp
Resistor pack (various ¼ W resistors)
Power supply +/- 15 volt
Signal generator
Oscilloscope (bench)

Procedure

1. Build the op-amp circuit shown in Figure L11-1. (Refer to book or notes if needed.)
2. Calculate the expected gain (Av) from the op-amp circuit (Refer to book or notes if needed.)
3. Measure a 10mV sine wave signal from the signal generator, with the oscilloscope.
4. Apply a 10mV signal to the inverting input.
5. Measure the output signal on the oscilloscope.
6. Record your results in Table 1.

7. Build the op-amp circuit shown in Figure L11-2. (Refer to book or notes if needed.) 180

8. Calculate the expected gain (Av) from the op-amp circuit (Refer to book or notes if needed.)

9. Measure a 10mV sine wave signal from the signal generator, with the oscilloscope.

10. Apply a 10mV signal to the inverting input.

11. Measure the output signal on the oscilloscope.

12. Record your results in Table 2.

Explain the results from Tables 1 & 2 on a separate sheet of paper. Do the measured results correspond to the calculated results? Explain the percent error in calculated vs. measured gain.

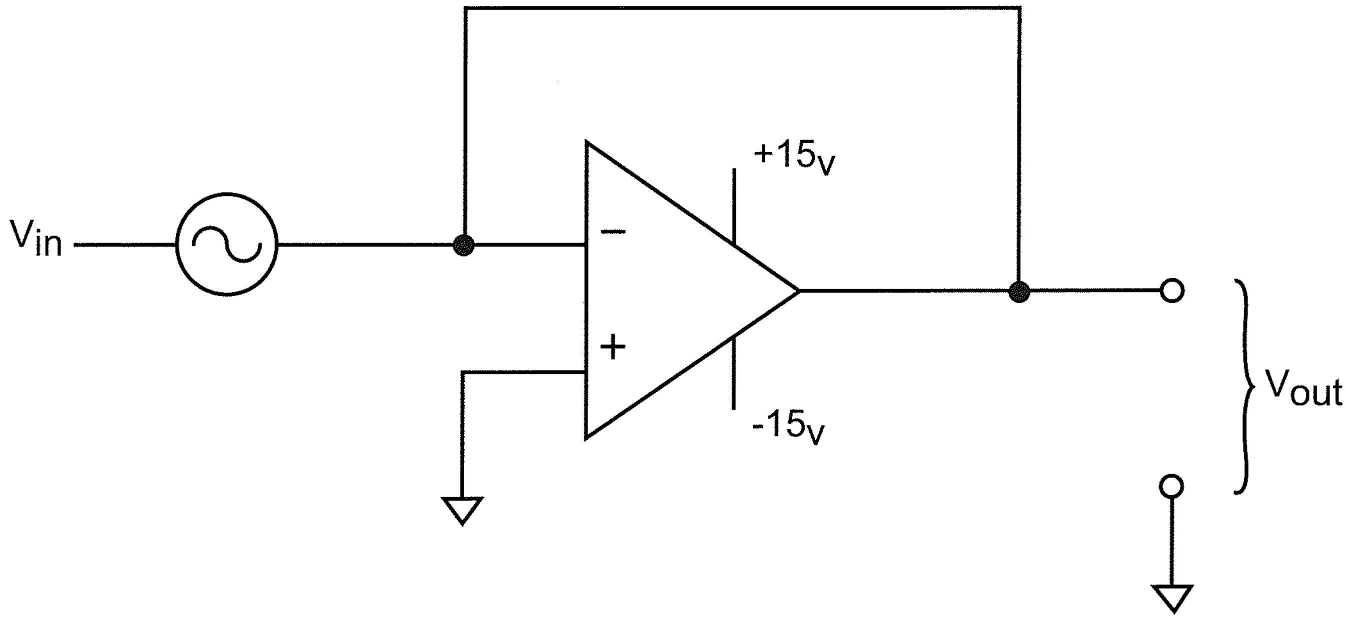
TABLE 1 Unity Gain Amplifier

Calculated Gain (Av)	
Measured Gain (Av)	
Percent Error	

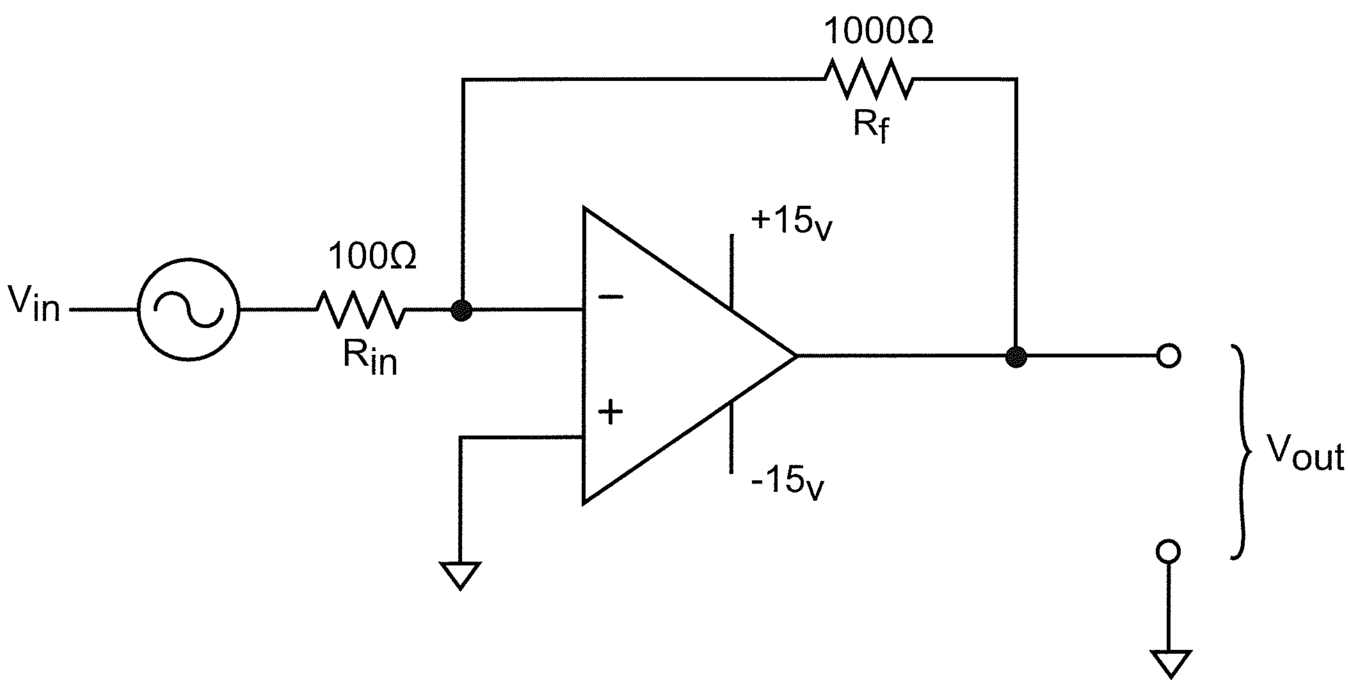
TABLE 2 Multiple Gain Amplifier

Calculated Gain (Av)	
Measured Gain (Av)	
Percent Error	

Circuit L11-1



Circuit L11-2



CHAPTER ELEVEN LABORATORY EXERCISE 11.2:

Operational Amplifiers

Name:______________________________

Date: _______________________________

Objectives

1. Apply the knowledge of operational amplifiers to build a working device.
2. Build a DC voltmeter.
3. Build an AC/DC voltmeter.

Materials

741 op amp
Resistor pack (various ¼ W resistors)
1000 ohm potentiometer
Analog Panel Milliammeter with a 10mA swing
Power supply +/- 15 volt
Signal generator
Digital multimeter

Theory and Set Up

Using a panel ammeter to measure current in the op-amp feedback loop, it is possible to build and calibrate a high-resistance DC voltmeter. Place the milliammeter in the normal position for the Rf resistor. Add a 1000 ohm potentiometer in series with the panel meter as shown in circuit L10-3. Apply a measured voltage to the non-inverting input. Check the deflection of the ammeter corresponding to the input voltage. Start with a 0.5 Vdc measured input voltage and increase in increments of 0.5 volts. The ammeter deflection should be linear (have the same movement) for each 0.5 Vdc increment increase. You may want to use the potentiometer to adjust the deflection to an exact decimal reading on the ammeter. Using this "known meter deflection" it is possible to input an unknown voltage at the non-inverting input and read a corresponding DC voltage.

Procedure

1. Build the op-amp circuit shown in Figure L11-3. (Refer to book or notes if needed.)

2. Have the instructor inspect your circuit before moving to Step 3.

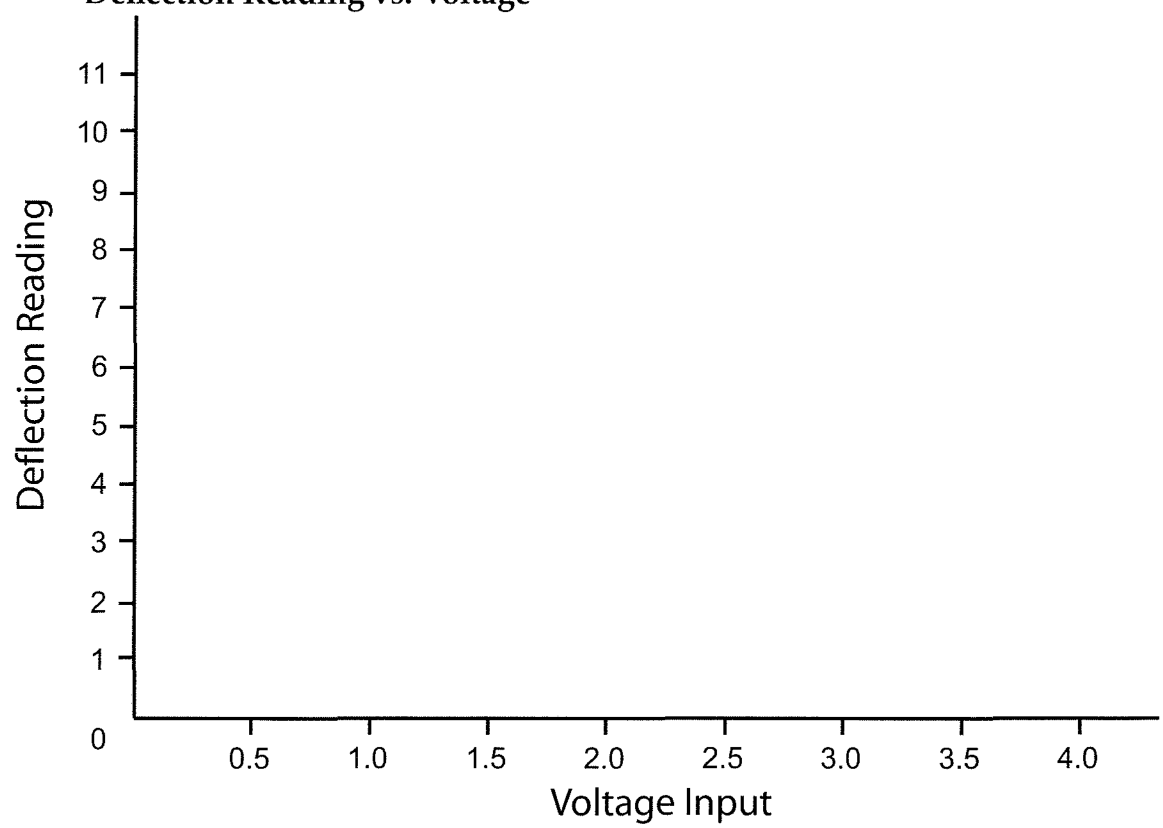
3. Measure 0.5 Vdc from your power supply with your digital multimeter.
4. Apply 0.5 Vdc from the power supply to the non-inverting input of the op-amp.
5. Notice and record the deflection on the ammeter in Table 1. You may use the potentiometer to move the deflection to a common reference point on the ammeter.
6. Repeat Step 3 but increase the voltage to 1.0 Vdc.
7. Repeat Step 5
8. Repeat Step 3 with additional increments of 0.5 Vdc until you reach 4.0 Vdc.
9. Repeat Step 5 with each 0.5 Vdc increment.
10. Make a graph of deflection setting vs. voltage.
11. Have the instructor select an "unknown" voltage from the DC power supply between 0.5-4.0 Vdc.
12. Apply the unknown DC voltage to the non-inverting input of the op-amp.
13. Record the deflection in Table 1.
14. Estimate the value of the unknown voltage based on your graph of deflection setting vs. voltage.
15. Measure the actual "unknown" voltage with your DMM.
16. Record the results in Table 1.

17. On a separate sheet of paper, discuss the actual DMM measurement of the unknown Vdc and the value of the unknown Vdc based on your graph of deflection setting vs. voltage. What was the percent error in the two values? Explain how this error might have occurred.

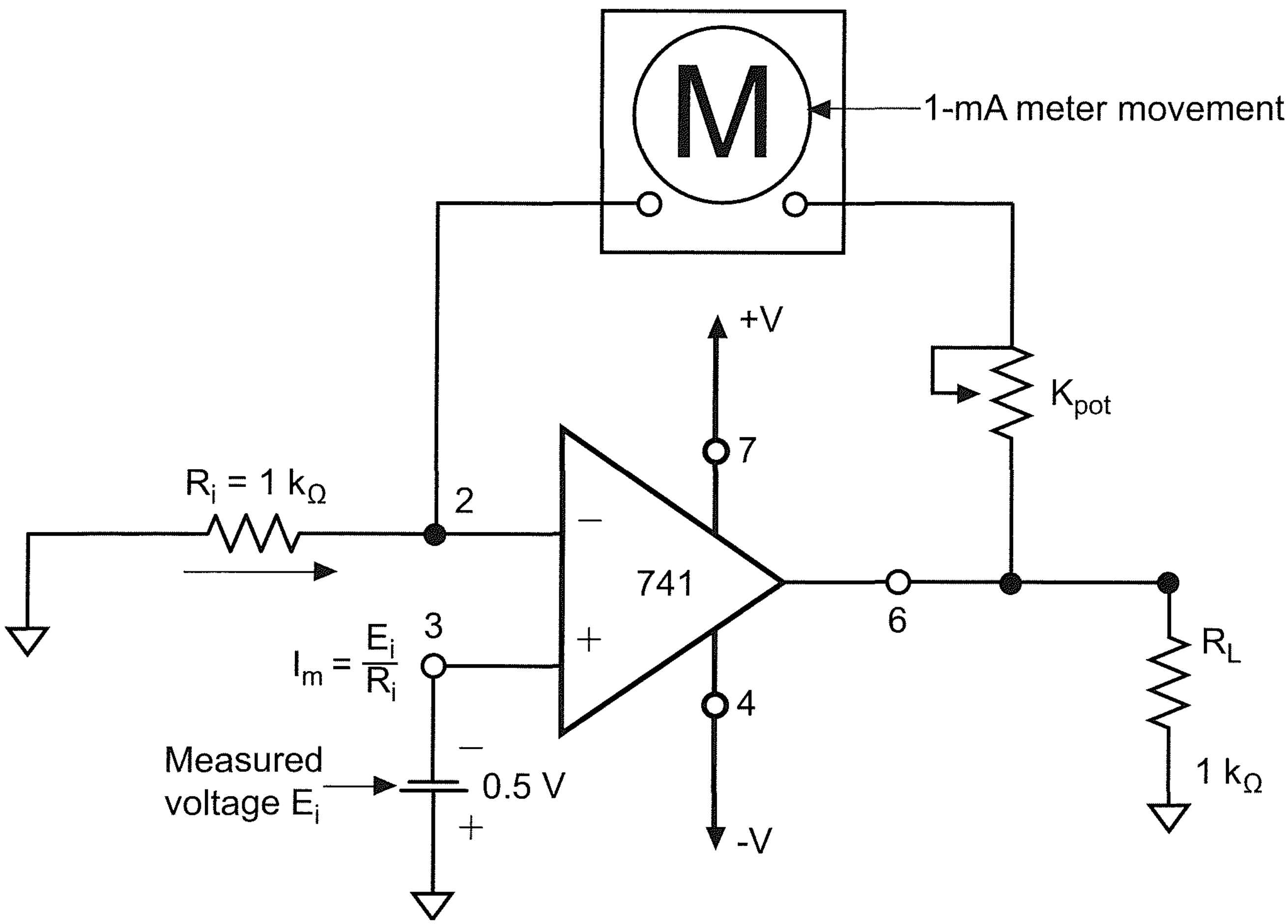
TABLE 1 OP-AMP CIRCUIT/DC VOLTMETER

0.5 Vdc	Deflection Reading	
1.0 Vdc	Deflection Reading	
1.5 Vdc	Deflection Reading	
2.0 Vdc	Deflection Reading	
2.5 Vdc	Deflection Reading	
3.0 Vdc	Deflection Reading	
3.5 Vdc	Deflection Reading	
4.0 Vdc	Deflection Reading	
Unknown voltage	Deflection Reading	
Unknown voltage	DMM Measurement	

Graph Deflection Reading vs. Voltage



Circuit L11-3



Chapter 12: Board-Level Troubleshooting

After completing this chapter you will have an understanding of:

- *Device repair priorities*
- *Applying a block diagram of a medical device in the troubleshooting and repair processes*
- *Isolating repair problems*
- *Recognizing and applying knowledge of device inputs and device outputs in the troubleshooting and repair processes*

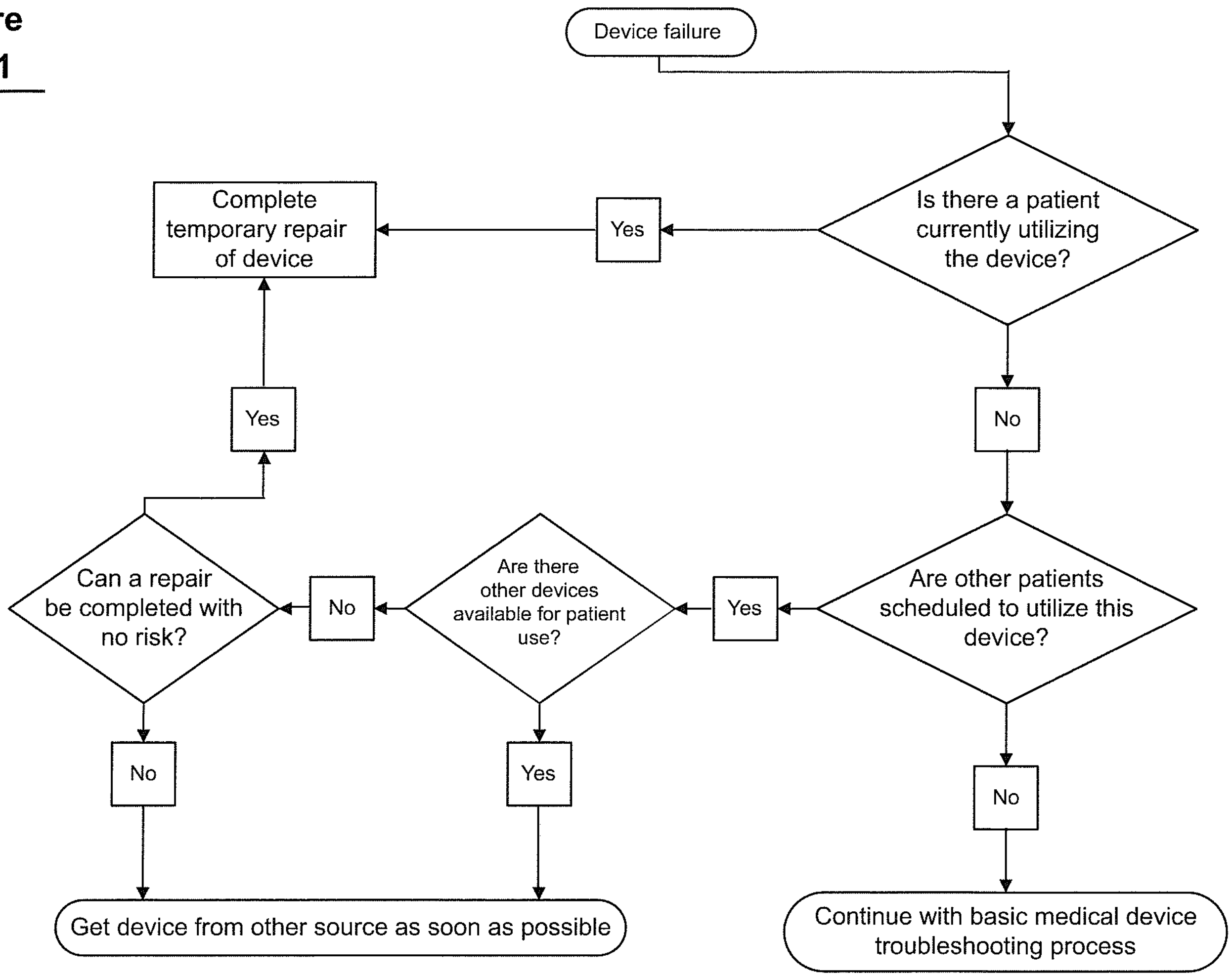
Historical Device Repair Perspective

Recent (post 1999) changes in healthcare modalities, clinical processes, and financial reimbursement have required a new perspective in the repair and maintenance of medical devices. Biomedical equipment technicians (BMETs) must apply critical thinking and knowledge of clinical process in prioritizing maintenance and repair of facility medical equipment. The lowered cost and increased reliability of electronic components and the rise of healthcare fees create repair decisions that were nonexistent twenty years ago. In the introduction of this book, the authors stated that the concentration of troubleshooting processes presented would be confined primarily to power supplies and printed circuit boards. This is a new paradigm in medical device repair. Most seasoned biomedical equipment technicians (BMETs) were taught to repair devices at the component failure. In the past, much time and effort was spent in the BMET education process teaching this component-level repair process. This historical practice of the repair of medical devices is not always cost effective in today's healthcare settings.

The big picture of healthcare economics is as important in determining the repair process as knowledge of the repair process itself. If an ultrasound machine is reported as malfunctioning, the time to bring the machine back on line and the number of patients scheduled for procedures with that particular ultrasound machine during this downtime must be considered in the troubleshooting process. This decision making prioritizing is known as "critical thinking" in the troubleshooting process.

A typical flow chart for critical thinking in troubleshooting is illustrated in Figure 12.01.

Figure 12.01



The Concept of Board-Level Troubleshooting

Troubleshooting is not a skill that you are necessarily born with but certain personal character traits seem to improve troubleshooting proficiency. Some of these traits are: a natural curiosity about what makes things work, an understanding of the physical principles of nature, a sense of satisfaction in completing a repair, and the intellectual stimulation involved in problem solving.

Board-level troubleshooting is a process of using systems level problem solving to correct a device malfunction. Board-level troubleshooting should start with a review of power supply outputs, unless an obvious situation presents itself. "Dirty power" is a common cause of device microprocessor and sensor problems. Dirty power refers to a DC voltage with a large amount of AC voltage (ripple) or a large fluctuation in DC voltage.

If it has been determined that the test point voltages of the power supply are within tolerance, then the next step in the process is to confirm that the voltage required at the board level is within tolerance. If the voltage at the test point of the board is correct and the output of the board is incorrect, it can be assumed that the problem is board related.

Isolating Device Repair Problems

Turn off the power to the device and remove the suspect board. Clean the board contacts with a non-corrosive spray that is recommended for "board washing." Inspect the contact slots to ensure that they are free from debris. The board contacts should be clean and absent of any dull metallic color. A pencil eraser can be used to mechanically clean the oxidized metal contacts. Reseat (re-insert) the suspect board into the contact slot and turn on the power to the device. Use a simulator to determine if the output from the board returns to the expected state. If the problem remains, a board exchange is indicated.

Most parts manufacturers will provide a rebate (reduced price) on the purchase of a replacement board. If you attempt to resolder components, you will probably lose any rebate provision. Board-level troubleshooting is cost effective if the steps indicated above are followed. Simply inserting boards until the correct output is achieved is NOT board-level troubleshooting and in most instances will not be cost effective but very time consuming. Additionally, if the board-level troubleshooting process is not followed, the actual problem causing the malfunction will cause further damage to the device, additional downtime and added expense.

Check all fuses from the power supply to the suspect board. Loading effects (see Basic Troubleshooting Methods) may cause blown fuses. Check all cooling apparatus such as fans and heat sinks to ensure that they are providing proper heat transduction away from the sensitive components. Clean or replace them if necessary. The device should also have breathing room (proper distance away from enclosures and other equipment to provide air circulation around the device). Always clean the exterior of the device as a final step in your maintenance procedure. These simple maintenance procedures will prolong the life of the equipment and reduce unnecessary work orders and equipment replacement costs.

Properly performing equipment not only accomplishes cost effective work flow processes, it also makes a positive impression on your customers (clinical practitioners and patients). By ensuring that your biomedical equipment is always in proper working order, you are contributing to positive outcomes of the patients visiting your facility by guarantying the optimal diagnostic and therapeutic procedures of your technology.

The Decision-Making Process: When to Repair the Board

In some instances it may be necessary to repair the board. If the clinical procedure is critical or the procedure must be completed in order that no harm comes to the patient, the BMET must use critical thinking and ingenuity. In his book *Critical Careers: A Guide to Opportunities in Medical Equipment Service* (Upstream Press, 2001), Roger Bowles coined the term "BMETs, the special forces of healthcare" to define these particular circumstances. The goal of the BMET in these scenarios is to do whatever it takes to make the device operational to finish the procedure, without inducing risk to the patient.

Another scenario, which may require repair of the board, is in cases where the device is no longer supported by parts (refurbished boards) from any vendor. After the repair process is complete, the BMET may want to address upgrading this particular piece of equipment, since it could result in patient harm and litigation.

Glossary of Important Terms

Board-level repair: The concentration of troubleshooting processes that are confined primarily to power supplies and printed circuit boards. The entire board is replaced rather than a single component. Board-level troubleshooting is a process of using systems level problem solving to correct a device malfunction.

Breathing room: A proper distance away from enclosures and other equipment to provide air circulation around the device.

Dirty power: A DC voltage with a large amount of AC voltage (ripple) or a large fluctuation in DC voltage.

Rebate: Reduced price on the purchase of a replacement board when the failed board is returned.

Reseat: Firmly removing and reinserting a board into the contact slot to remove oxidation on the contacts.

CHAPTER TWELVE REVIEW QUESTIONS

Name:__________________________

Date:___________________________

1. You are paged to the cardiac catheriazation lab. There is a clinical procedure in progress. All of the physiologic signal display channels show only a constant line. Which of the following critical thinking processes should you follow:
   a. Determine if the leads and cables to all of the signal channels are properly connected.
   b. If the answer to "a" is yes, can you get to the power supply and boards without disrupting the clinical process or causing risk to the patient?
   c. Can you test the voltage to the signal board without risk to the patient?
   d. Can or should you attempt to repair the board?
   e. Can the patient be moved into an available room?

2. The ultrasound machine in room #4 has a head display distortion problem. Six patients are scheduled for this room today. Explain what actions you can take to solve this problem. What members of the clinical staff will you communicate with? Who should you discuss your proposed solution with first?

3. You are working on some preventive maintenance (PM) procedures for the emergency room over the weekend. One of the devices you are testing has a defect. There is a serious multiple auto crash resulting in three serious trauma injuries being transported into your hospital's emergency room. The emergency nurse informs you that all three of the devices

you have been inspecting are required "STAT" in trauma rooms #1, #2, and #3. You know there is another exact device in the biomed shop with a bad power supply. What are your options? What critical thinking processes should you follow? List all clinical personnel that you should be involved in your proposed medical device solution.

4. You work for an original equipment manufacturer (OEM). The self-diagnostics on the bedside monitor indicate that board #3 is malfunctioning. Your options are:
   1. Call in a board from another biomed working for your company that is 100 miles from your location.
   2. Test the power supply of the bedside monitor, and the power to the suspect board.
   3. Remove the suspect board and examine it for improper seating or non-conductive debris in the contact slot.
   4. Take a suspect board from the bedside monitor next to the one you're working on.

   Also, What communication should you provide the clinical staff and the in-house biomeds?

Chapter 13: Repair of Wireless Devices

After completing this chapter you will be able to:

- *Describe a typical hospital telephony system.*
- *Describe a typical "Local Area Network" (LAN).*
- *Describe a wireless enterprise system.*
- *Describe the block diagram of a typical wireless medical device.*
- *Describe common medical device frequencies and bandwidth.*
- *Describe methods used to transmit and receive wireless information.*
- *Describe the block diagram of an ECG telemetry system.*
- *Describe common wireless medical device failures.*
- *Describe the causes of electromagnetic interference.*
- *Demonstrate wireless medical device troubleshooting techniques.*
- *Demonstrate restoration techniques of wireless medical device failures.*

Introduction

Wireless technology has entered the healthcare realm, and it is here to stay. There will be a continuum of applications for wireless capabilities of individual medical devices as well as entire medical device systems, hospital-to-hospital wireless systems and medical device-to-vendor/service technician virtual diagnostics. Understanding wireless technology is an essential skill set for biomedical technicians. There has been much discussion and turf battles between Information Technology (IT) Departments and Clinical Engineering (CE) Departments within the hospital concerning the responsibility for maintaining wireless systems. Life science courses in anatomy, physiology and systems biology are a core component of all biomedical equipment technology and biomedical engineering programs. Biomedical equipment technicians understand the clinical or patient care aspect of health care, which is an application of medical technology and life sciences. Internship programs reinforce this intrinsic relationship of life sciences and medical device applications with hands-on experience. There is an innate task urgency and risk to the patient during a medical device failure. This characteristic of the CE environment cannot be duplicated or rationalized in the IT environment. It is the opinion of the authors that wireless communications of healthcare devices are a natural extension of the responsibilities of biomedical equipment technicians. Untrained and untested IT professionals create unnecessary added risk to patients and healthcare staff in the clinical setting.

The wireless gadget world began with pocket pagers and was extended exponentially with the application of cell phones. Internal wireless medical devices consist of two major network designs: 1) real-time physiologic information transmission to handheld device (point-of-care devices) – downloaded information from handheld device using infrared or physical connection to database and 2) physiologic information transmission from patient connected device to internal antennae hard-wired to monitors and database (telemetry). A hybrid medical device wireless network utilizes one or both of the two main network designs inside the hospital with an interface to the hospital telephony network or to another data transmission system outside of the hospital. These multi-building systems are known as enterprise network systems.

Each of these three wireless networks are illustrated by the block diagrams; figure 13.1 point-of-care wireless system, figure 13.2 telemetry system, and figure 13.3 hybrid wireless system.

Figure 13.01 **Point-of-Care (POC) System Block Diagram**

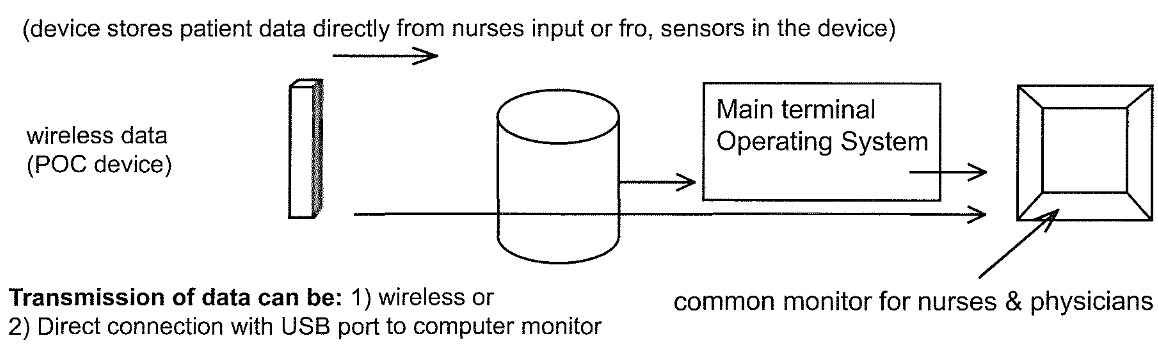


Figure 13.02 **Telemetry System**

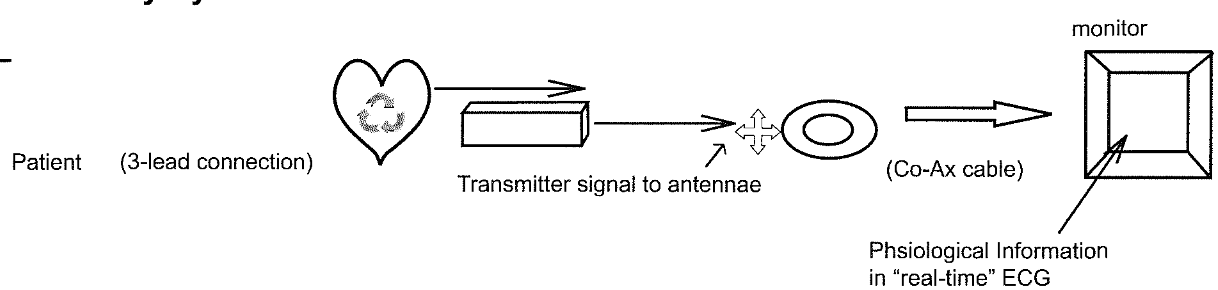
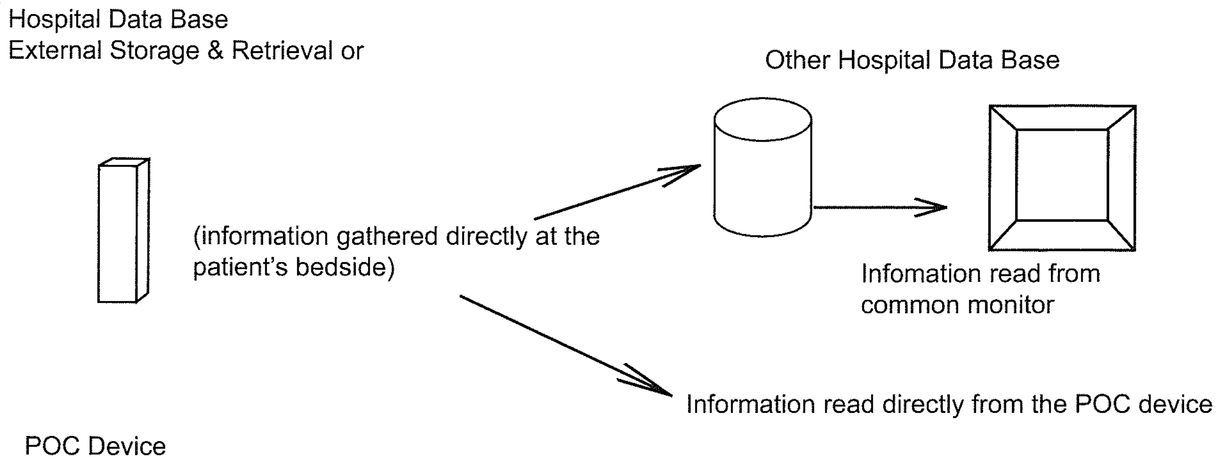


Figure 13.03 **Internal Wireless System with External Interface**



(typical bandwidth is in the giga-hertz (GHz) range for signal transmission)
*Note: cell phones also use a bandwidth in the giga-hertz range. Cell phones may cause interference with POC signals!

The common monitor in Figure 13.3 may be at the same hospital where the POC device resides or it may be at a sister hospital. Information is transmitted by a wireless mode and received by a common frequency antennae, which feeds information from the receiver to the monitor.

The main purpose of a POC device is to bring the technology to the patient; instead of bringing the patient to the technology!

Troubleshooting techniques with POC devices are similar to traditional devices BUT physical connections must be tested and problems with signal transmission and signal reception must be tested.

Public Domain (Operating) Telephone System (POTS)

Within the hospital, there is a hard-wired telephone system that connects to the public domain telephone system. This system is known as the "Public Operating Telephone System" or POTS. Professionals in the telephone business commonly refer to POTS as the "Plain Old Telephone System" (Figure 13.4). Figure 13.5 illustrates a typical hospital or clinic telephone system.

Figure 13.04 Public Domain Operating Telephone System (POTS)

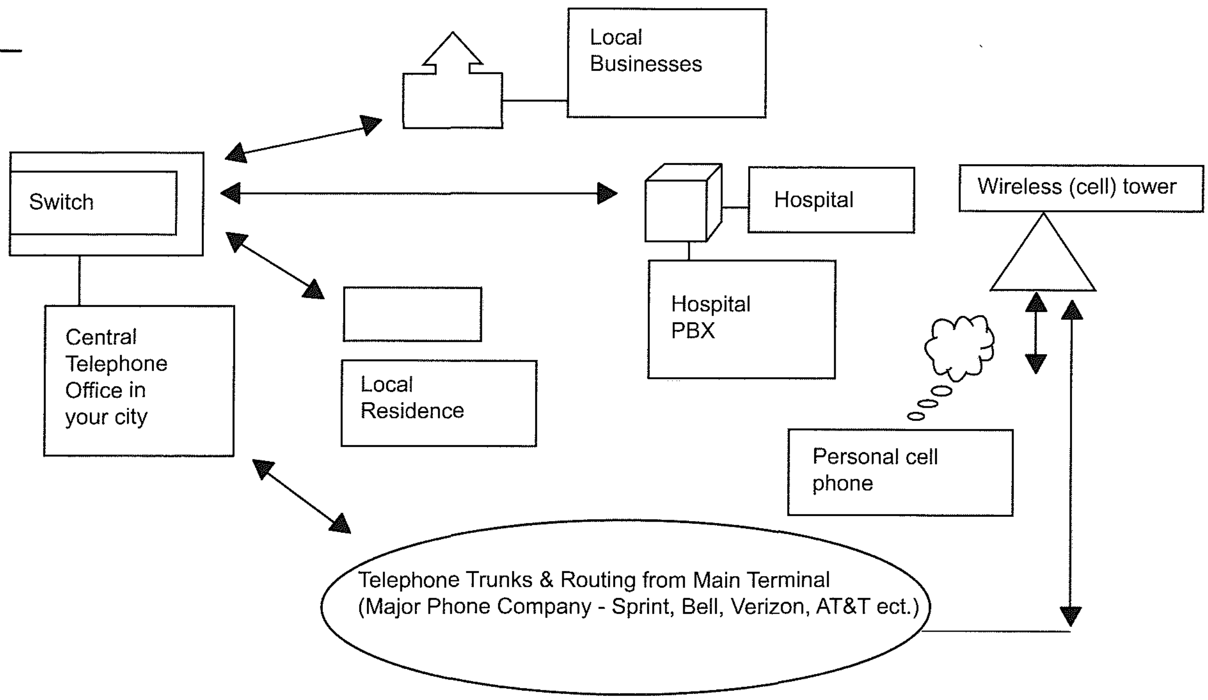


Figure 13.05 Block Diagram of Hospital-to-Public Telephone Operating System

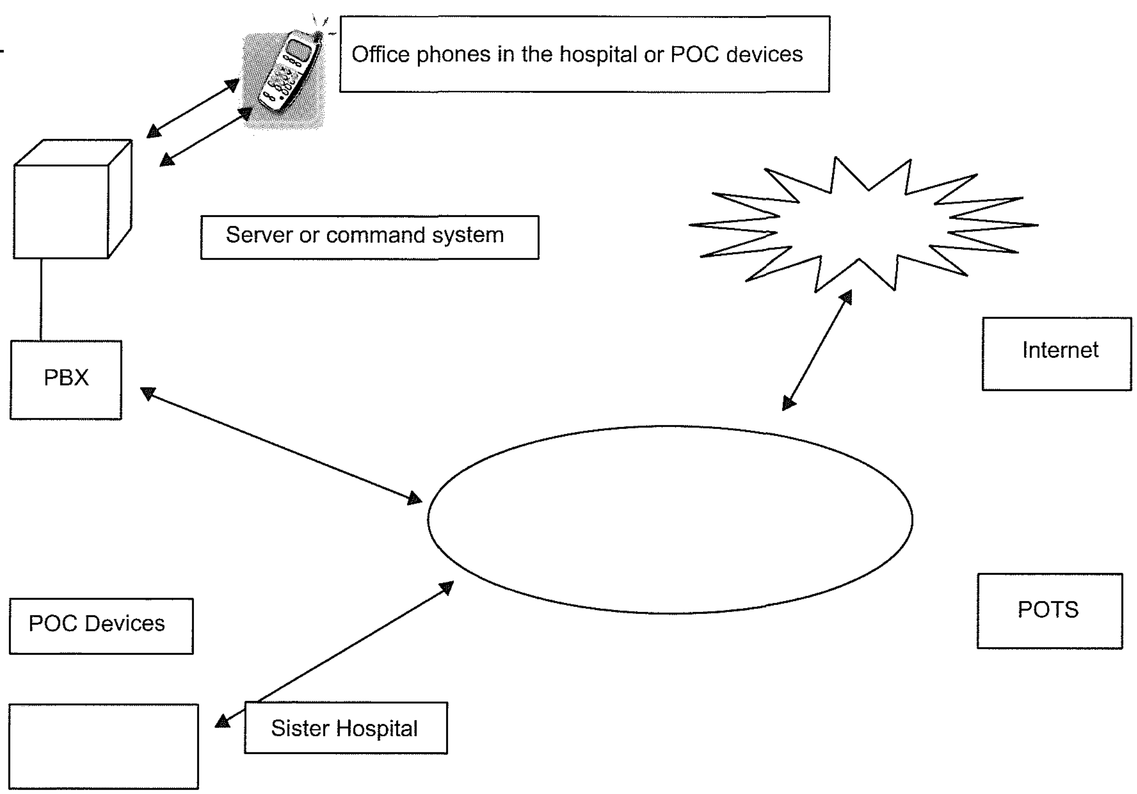
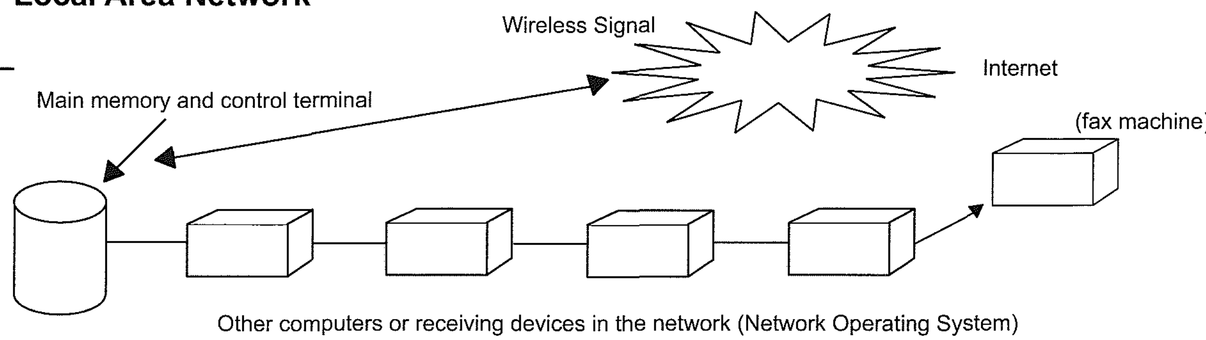


Figure 12.5 Block Diagram of Hospital-to-Public Telephone Operating System
[Private Branch Exchange (PBX)]

Figure 13.06 **Local Area Network**



Local area networks (LANs) connect several individual electronic communications devices into a shared group. The individual devices are connected as "members" of a common operating system known as the "network operating system" (NOS).

Normally, one person or group (Information Technology) will be responsible for the maintenance and control of the NOS. The advantages of a LAN with NOS administration include: network security, the ability to share common files and printers, file protection and direct access to files and directories through virtual drives.

A wireless medical device may be passive (sends or receives data only) or it may contain algorithms (short computer programs that provide data collection and transmission commands or signal processing actions). Some of the newer wireless medical devices contain "fuzzy logic" algorithms. Fuzzy logic allows the program to "learn" commands as it applies algorithms that provide "best fit for scenario." Figure 13.6 demonstrates the ability of a LAN system to access the Internet with a wireless connection. The system could also connect to another hospital's LAN with a wireless connection.

Troubleshooting Wireless Medical Device Failures

Finding the cause of the problem in any medical device begins with an inspection of the area where the device is located and using your eyes, ears and nose. You may want to review Chapter Four "Basic Troubleshooting Methods." You will use the same techniques to begin your troubleshooting process with wireless devices that are used for standard medical devices. If possible, ask the nurse or technician what problems they noticed when the device failed. This will save several steps in the troubleshooting process. This technique also provides the nurse or technician with an assurance that you are helping to resolve "their" problem. Remember, nothing is more important in your role of biomedical engineer or biomedical technician than excellence in customer service. You are now in a position to begin a planned troubleshooting process. You should always write down what you observe and what comments the nurse or technician has provided. Use an iPod, note pad, laptop or whatever technology your department provides to record all of this information. You have just completed step 1 in the troubleshooting process. This is the most important step in the troubleshooting process. Everything that happens after this is based on your initial observations and also the fact that you have made a personal introduction to the clinical staff. You have just built a great platform for troubleshooting of a medical device and also excellence in customer service. Now let's step through the troubleshooting process:

1) Was there any obvious physical damage to the device?

   A. This is an obvious place to start your troubleshooting process. Review your notes. Is there anything in your notes that corresponds to what you observe from the damaged device? Are there any loose wires or broken connections? Can the unit be powered up if the wires or connections are reconnected? Is the monitor damaged?

2) Is there power to the unit?

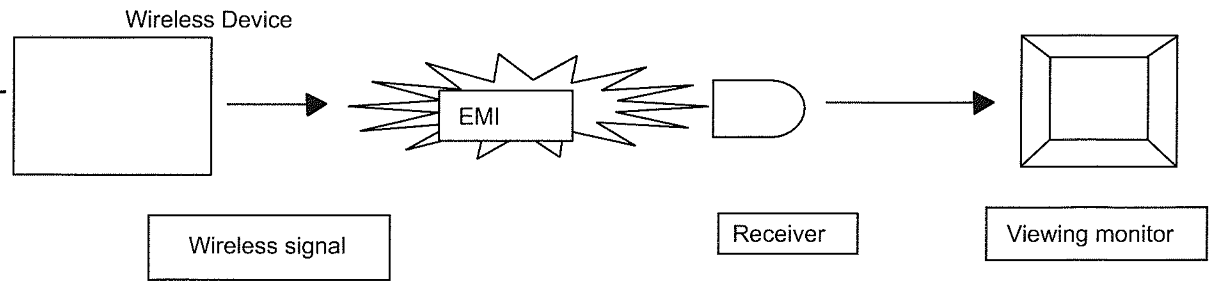
   A. This will be indicated if the display panel or monitor is blank. A blank screen or unlit display panel may also be caused by loose connections internally, a loss of sensor reception or a damaged monitor. Remember, a point-of-care or mobile device is battery powered. A larger central device will have a power supply; trace the power cord back to the area where the power supply is located.

   B. No power to the unit does not necessarily mean that the power supply or battery supply system are not functional. Check the voltage at the power supply output. Again, reviewChapter Four for the procedure of testing for power output. There may be harness connections to the monitor or display system that have come loose. If you have voltage from the power supply, the problem is somewhere between the power supply and the portion of the unit that is not functioning. Half-step through the device until you find an area that does not show a voltage reading on your DMM or has a low voltage reading. Correct the problem at this point in the system.

3) If the nurse or technician states that they see "snow" or loose visual display on the monitor in an intermittent manner, you should be think about a possible cause of electro-magnetic interference (EMI).

   A. Electromagnetic interference (EMI) is a signal or group of signals that are more powerful (in Watts) crossing the path of the signal you wish to view. Some causes of EMI include digital TV stations, citizen band (CB) radio in close proximity to your signal, university physics projects with large magnetic waves and unshielded X-ray or MRI signals.

Figure 13.07



B. EMI problems are difficult to troubleshoot. Many times the EMI signal will be intermittent. Move the POC device to different locations in the hospital. Is there a location that is problematic? Elevator and air handler units may create low frequency or mid-frequency high energy signals. Meet with the Safety Committee and discuss the facts you have documented. Recommendations include signage in problematic areas, mesh wiring in ceilings and walls in problematic areas (this will not be a popular recommendation but it is very effective) and covering the POC transmitter in aluminum foil. Grounding your device is the primary means to remove radio frequency interference (RFI) and EMI. A grounding strap from the chassis to a grounded electrical outlet is the best means to remove EMI. A grounded environment with some type of wire mesh ceilings and walls is also an excellent means to remove unwanted external electrical charge interference. This is usually not a feasible solution in most medical facilities except in areas with a sleep lab.

4) Use a simulator with the same frequency to test the signal acuity at the receptor. Turn on the signal simulator. If the signal receptor displays the signal on the monitor, your problem is now limited to the transmitter or the device itself.

5) If you turn on the simulator and no signal appears on the monitor, check the antennae feed for telemetry type systems. An open coupling is a common antennae problem.

Glossary of Terms

***Bandwidth*:** The frequencies centered around the main frequency of a data or voice transmission. As an example, if the main frequency is 10kHz there will be a frequency above (12kHz) and below (8kHz) the main frequency. This "band" from 8kHz to 12kHz is the "bandwidth" of the transmission.

***Electromagnetic Interference (EMI)*:** An invisible energy wave, packet, or electrical transmission signal that has more power in Watts/meter than a lower power signal of interest. The effect of EMI will be displayed on a monitor as "snow" or a complete "white out" of the signal intended to be displayed on the monitor. EMI has dangerous potential in medical devices that are hard-wired (antennae) or wireless that are intended to monitor electro cardio grams (ECGs) and vital signs of blood pressure, temperature and respiratory functions.

Local area network: A system of connected devices in a designated area, usually an office configuration, single building or two or more buildings in close proximity, that share a common communications link and a central server.

Network: A communications or data system that is designed to accommodate several users for several functions.

Point of Care (POC) Device: A device in the medical field that is portable and designed with the function of obtaining patient information and/or sensors to obtain physiological data, ultrasound images and skeletal muscle scans at the bedside or site where the patient is located. This is a new paradigm in health care organization where the medical device required for testing is taken to the patient instead of the patient being required to go to the medical device. POC devices may store patient information in the device for "downloading" after initial input or the information may be transmitted by wireless means in real-time to the nurses station, admitting station, central server or all of the mentioned locations.

Private Branch Exchange (PBX): An internal phone system located within the premises of the facility that has all the essential functions of a local telephone company. A PBX has voice mail, call forwarding, message call greetings and call center functions.

Public Domain Operating System (POTS): This is a term used to describe the telephony system that may be accessed by all users (the public) within a telephone company's geographical area. A voice or data transmission may leave one telephone company's geographical domain and enter another through a series of "central office" telephone connections. POTS are also called "land line" connections, since the final connection to the user involves use of wire cables or fiber optic cables that physically connect the transmission "over land" and not with a wireless connection such as a cell phone. Land line systems have an advantage over wireless systems due to their immunity to EMI. In a natural disaster or bioterrorist scenario, a land line is more secure and reliable than a wireless cell transmission. All hospitals should have a dedicated land line for disaster scenarios. If the internal PBX system is compromised a VHF transmission system should be available as a back up. Internal communications should include an internal network of "radio phones."

CHAPTER THIRTEEN REVIEW QUESTIONS

Name: ______________________________

Date: ______________________________

1. If a 3-lead connection to a patient is not connected with the green or red lead to the patient's lower abdominal side, what problems will this cause with monitor signals?

2. If the leads of a 3-lead telemetry system have not been changed in 3 or more days, hair or sweat may cause a disconnected reception signal to the monitor. How do you resolve this problem? How do you recognize this problem?

3. Explain how you would distinguish between a low battery problem on a POC device and a disconnection of the power supply (battery) to the POC main board.

4. Explain the purpose of a POC and how it differs from a standard medical device.

5. Explain the troubleshooting process in determining that you have a problem with EMI.

6. If you have determined that you have an EMI problem, what steps should you take to remedy the problem?

7. **T F** You have determined that you have an EMI problem. Never communicate this problem with the nurse or technician since it may cause anxiety in patient care.

8. Explain the troubleshooting process to determine if you have a transmitter or receiver problem with signal to the monitor. Use a simulator.

9. What is the purpose of a simulator in troubleshooting a signal problem?

10. You are called to the ER concerning a problem with a POC device. Explain the steps you would take in the troubleshooting problem. Do not forget the customer service aspect in your role as a BMET or biomedical engineer.

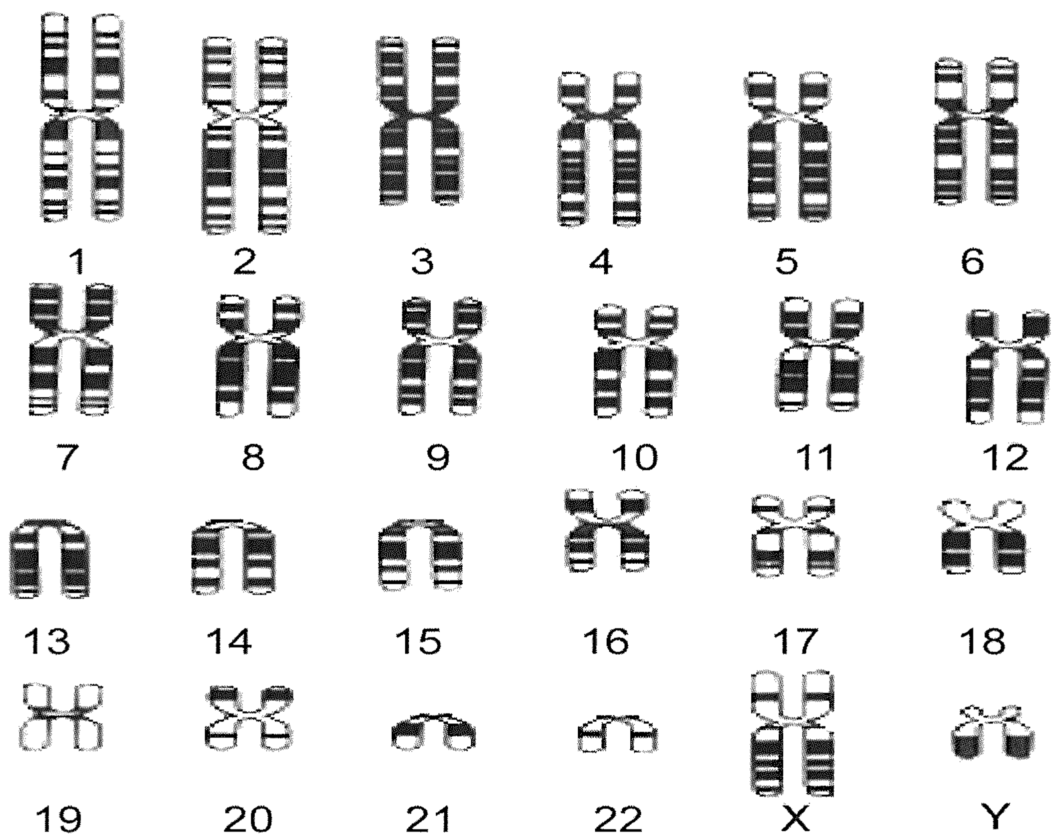
11. Describe problems that could occur in a LAN system that are unique to the LAN configuration. Think about the device-to-device connections.

Epilogue: The Future of Medical Devices

Nanotechnology and biotechnology will define the 21st century. Without knowledge of these technologies, you will be without the tools needed to be proficient in your career field. Nanotechnology is an interdisciplinary science based on chemistry and physics. Essentially, nanotechnology is the science that studies the effects and/or manipulates objects 100 nanometers or less in size. A nanometer is 1 x 10^-9 meters, or a billionth of a meter. Particles in the nanometer range do not obey the traditional rules of physics. Quantum physics defines the actions of nanotechnology. This phenomenon of quantum physics creates some interesting possibilities for assembly of "nano devices." Imagine creating a device that has the ability to enter a cell and move proteins in and out of the cell or repair damage to a cell wall. This will be the medical device of the future.

Biotechnology is the interdisciplinary science of cellular biology, anatomy and physiology, biochemistry, computer science and biomedical engineering that is used to modify or study genetic makeup, DNA or genetic sequences and cellular responses to such transactions. Wow! What an impressive combination of sciences. At first glance, it may also seem a bit overwhelming. The rules of biotechnology are actually quite simple to learn. An introductory course in biotechnology is recommended in order to understand the terminology of the science.

Biotechnology begins with the human genome. Congress commissioned the Institute of Health in 1990 to "map" the human genome. This was known collectively as the "Human Genome Project." The purpose of the project was to identify every gene in the human body. A genome is the complete identification of all genes within a living organism. After five years of research on the Human Genome Project, about 80% of the human genes had been identified. The project accumulated a mountain of information. This information was extremely important and several genes related to serious diseases had been identified. The project was stopped at this point in order to sift through all of the data that had been collected. It is estimated that it will take an additional ten years to sort, examine, and test the information collected. Humans have about 25,000 genes contained in the deoxyribose nucleic acid (DNA) and proteins of 23 human chromosomes. A chromosome is a tightly packed coiled unit of DNA and protein. Chromosomes are numbered from one to twenty three based on their length. Chromosome number one is the longest and number 22 is the shortest. Chromosome 23 is identified by the XX or XY pair.



Chromosome 23 is the gender chromosome. If you have the XY 23rd chromosome you are male if you have the XX chromosome you are a female.

So what does all this nanotechnology, microscopic cell tool and chromosome stuff have to do with your career in biomedical technology? In short, everything! Medical devices will consist of small tongue depressor sized diagnostic tools that can be used in the doctor's office. On the "tongue depressor" will be micro-channels that connect several "wells" of different proteins. The nurse will swab your mouth and extract some DNA. The DNA will be cleaned of tissue and debris, and a micro-pipette will place a small amount of your DNA into the "well" of the device. As your DNA runs through the micro-fluidic channels across the wells filled with special DNA pieces or proteins a reaction will take place indicating specific health problems. The "plastic stick" with the samples will be run through a spectrometer. The spectrometer will print out a spectrograph. The lines one the spectrograph indicate the presence of certain protein combinations.

These protein combinations detect cells such as breast and colon cancer, or problems with other organs in the body. This "lab-on-a-chip" is being used for limited tests currently. As "recombinant DNA" and "gene markers" are better understood, the "lab-on-a-chip" medical device will become more widely used. This will allow many tests now done in the hospital lab to be done in the doctor's office.

The device technology that must be understood by biomedical engineers and biomedical technicians will be in the area of spectrometry. Take classes in mass spectrometry. Go to seminars that involve the used of biotechnology devices. This technology is moving at a rapid pace. There will still be infusion pumps, centrifuges, and bed scales to repair and calibrate in the hospital. Many medical devices will become smaller, smarter, and more technical in their capability. Following these trends will make you a technician or engineer that is in demand, and your pay increases will follow that demand.

Appendix A: Common Resistor Values

Standard values of commercially available resistors.

Ohms (Ω)					Kilohms (kΩ)		Megohms (MΩ)	
0.10	**1.0**	**10**	**100**	**1000**	**10**	**100**	**1.0**	**10.0**
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	**1.2**	**12**	**120**	**1200**	**12**	**120**	**1.2**	**12.0**
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	**1.5**	**15**	**150**	**1500**	**15**	**150**	**1.5**	**15.0**
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	**1.8**	**18**	**180**	**1800**	**18**	**180**	**1.8**	**18.0**
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	**2.2**	**22**	**220**	**2200**	**22**	**220**	**2.2**	**22.0**
0.24	2.4	24	240	2400	24	240	2.4	
0.27	**2.7**	**27**	**270**	**2700**	**27**	**270**	**2.7**	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	**3.3**	**33**	**330**	**3300**	**33**	**330**	**3.3**	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	**3.9**	**39**	**390**	**3900**	**39**	**390**	**3.9**	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	**4.7**	**47**	**470**	**4700**	**47**	**470**	**4.7**	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	**5.6**	**56**	**560**	**5600**	**56**	**560**	**5.6**	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	**6.8**	**68**	**680**	**6800**	**68**	**680**	**6.8**	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	**8.2**	**82**	**820**	**8200**	**82**	**820**	**8.2**	
0.91	9.1	91	910	9100	91	910	9.1	

NOTE: **Boldface** figures are 10% values.

Appendix B: Technical Math

Conversion Tables - Powers of 10

Example of powers of 10:

100,000	=	$1\text{-}0^{1}\text{-}0^{2},0^{3}\text{-}0^{4}\text{-}0^{5}$	=	$1\text{x}10^{5}$
1,000,000	=	$1,0^{1}\text{-}0^{2}\text{-}0^{3},0^{4}\text{-}0^{5}\text{-}0^{6}$	=	$1\text{x}10^{6}$
0.0001	=	$0^{-1}.0^{-2}\text{-}0^{-3}0^{-4}\text{-}1$	=	$1\text{x}10^{-4}$
0.01	=	$0^{-1}.0^{-2}\text{-}1$	=	$1\text{x}10^{-2}$

Positive power of 10 $\longleftarrow$0.0$\longrightarrow$ Negative power of 10

Multiplying and dividing with powers of 10

$$\frac{1000}{0.01} = 10^{3} \div 10^{-2} = 10^{3} \cdot 10^{2} = 1 \times 10^{(3+2)} = 1 \times 10^{5}$$

$$1000 \times 0.01 = 10^{3} \cdot 10^{-2} = 1 \times 10^{(3-2)} = 1 \times 10^{1}$$

$$(1{,}000)(10{,}000) = 10^{3} \cdot 10^{4} = 1 \times 10^{(3+4)} = 1 \times 10^{7}$$

$$(100)(0.0001) = 10^{2} \cdot 10^{-4} = 1\times 10^{(2-4)} = 1\times 10^{-2}$$

Power of 10	Prefix	Abbreviation
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{-3}	Milli	m
10^{-6}	Micro	μ
10^{-9}	Nano	n
10^{-12}	Pico	p

Delta-Wye Transformation

$$R_1 = \frac{R_a R_c}{R_a + R_b + R_c}$$

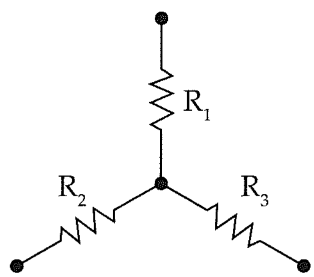
$$R_2 = \frac{R_a R_b}{R_a + R_b + R_c}$$

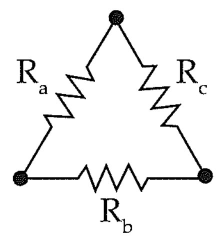
$$R_3 = \frac{R_b R_c}{R_a + R_b + R_c}$$

$$R_a = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_3}$$

$$R_b = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_1}$$

$$R_c = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_2}$$





Energy

Energy is the amount of power used over a period of time. It may be defined by:

W = Pt where W = energy (W-s, J)
P = power (W)
t = time (s)

For most practical prposes, W-s is too small a quantity, so energy may be defined also in terms of watt-hour (W-h) or kilowatt-hour (kW-h).

Kirchoff's Current Law

Kirchoff's Current Law states that the algebraic sum of the currents entering and leaving a junction (node) is zero. In other words, the sum of the currents entering a node equals the sum of the currents leaving the node.

Kirchoff's Voltage Law

Kirchoff's Voltage Law (KVL) states that the algebraic sum of the potential rises and drops around a closed loop (or path) is zero. In other words, the sum of the potential rises will equal the sum of the potential drops around a closed path.

Maximum Power Transfer

A load will receive maximum power from a linear bilateral DC network when its total resistive value is exactly equal to the equivalent (Thevenin or source) resistance of the network as seen by the load.

Ohm's Law

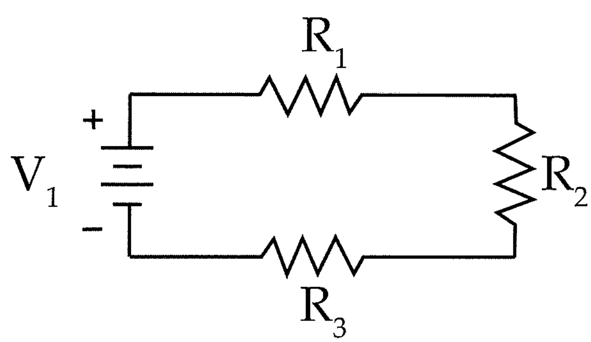
Ohm's Law states that for a fixed resistance, the amount of current flowing though the device is directly proportional to the amount of voltage (pressure) imposed across the device, and is defined by the equation:

V = IR where	V	=	voltage (V)
	I	=	current (A)
	R	=	resistance (Ω)

Applications

Ohm's Law—Common Algebra Conversions and Related Equations

V = I•R (Voltage is equal to the current in amperes multiplied by the resistance in ohms)



Example I: Find the voltage of the DC circuit in the figure above if the current is 100 milliamperes.

Step one: Find the total resistance Rt. RT = R1 + R2 + R3 = 100Ω + 150Ω + 200Ω = 450Ω

Step two: Plug in the known values for Ohm's Law. Voltage = Current 0.001 A (convert milliamperes [1x10-3 amperes] into amperes) X resistance 450 ohms = 0.001A x 450 = 0.450 Volts.

Example II: Find the DC current in the figure above if the voltage source is 10V.

Step one: Find the total resistance Rt. RT=R1+R2+R3=100(Ω)+150(Ω)+200(Ω)=450(Ω)

Step two: Plug in the known values for Ohm's Law. Voltage (10V) = current (the unknown value) X total resistance (450(Ω))

Step three: Create an equation to solve for "I" (DC current).

DC Current (I) - Voltage/Resistance = 10V/450(Ω)= 0.222V/(Ω) = 0.222A

Example III: Find the total resistance of the circuit if the voltage is 5V and the current is 0.01A.

In order to find total resistance, both the voltage and current of the circuit must be calculated. In this problem both values for voltage and current are given in a "live circuit" the voltage must be measured, in order to calculate total resistance (Rt) of a circuit.

Create an equation to solve for "Rt" (total resistance).

Total Resistance (Rt) = Voltage/Current = 5V/0.01A = 500 (Ω)

Appendix C: Useful Web Sites

www.aha.org

American Hospital Association
840 N. Lake Shore Drive
Chicago, IL 60611
(312) 280-6374

www.ashe.org

American Society for Healthcare Engineering
One North Franklin 28th Floor
Chicago, IL 60606
(312) 422-3800

Contains information on testing of electrical and electronic components. Good resource for conferences. Useful job site information

www.aami.org

Association for the Advancement of Medical Instrumentation
1110 North Glebe Road, Suite 220
Arlington, VA 22201-4795
(703) 525-4890

www.fda.gov/cdrh

Safe Medical Devices Act/Center for Devices and Radiological Health

www.cdc.gov

Centers for Disease Control and Prevention
1600 Clifton Road
Atlanta, GA 30333
(404) 639-3534

www.howstuffworks.com

HowStuffWorks.com
C/O Convex Group, Inc.
One Capital City Plaza
3350 Peachtree Road, Suite 1500
Atlanta, GA 30326

www.ieee.org

IEEE Operations Center
445 Hoes Lane,
Piscataway, NJ 08854-1331
(732) 981-0060

Institute of Electrical and Electronics Engineers, one of the more established professional organizations. Some of their articles are a bit esoteric. Useful job site information.

www.jcaho.org

Joint Commission on Accreditation of Healthcare Organizations
One Renaissance Boulevard
Oakbrook Terrace, IL 60181
(630) 792-5000

www.nfpa.org

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02169-7471
(617) 770-3000

www.newegg.com

Newegg.com
132 South 6th Avenue
La Puente, CA 91746-3026
(909) 395-9046

Electronic supplies including power supplies.

www.rsna.org

Radiological Society of North America
820 Jorie Boulevard
Oak Brook, IL 60532-2251
(630) 571-2670

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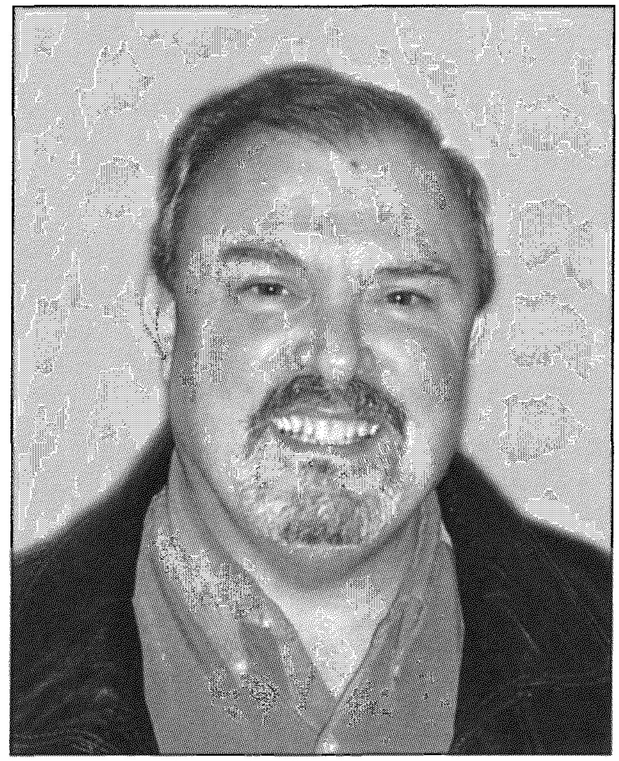
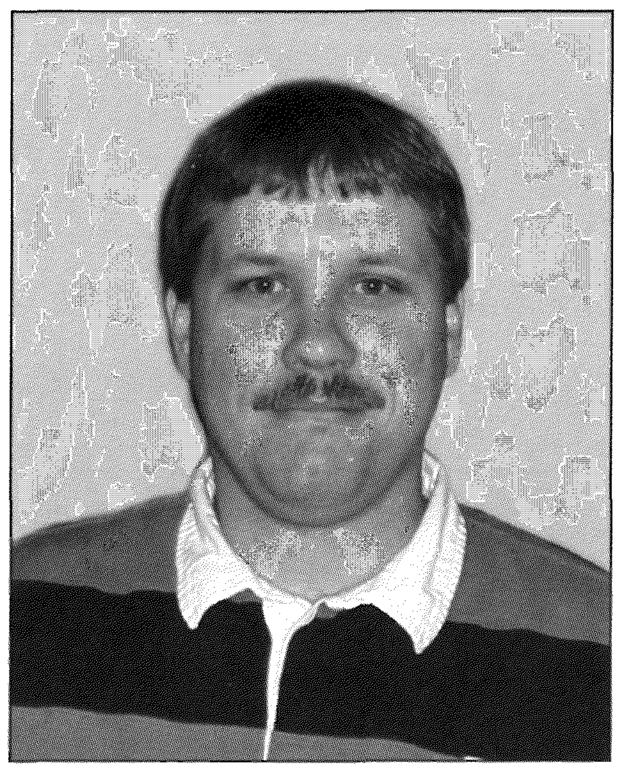
Nicholas Cram



Cram received a Biomedical Equipment Technology degree from Texas State Technical Institute (now Texas State Technical College Waco) and worked as a biomedical technician while completing his Bachelor and Master of Science degrees in Biomedical Engineering from Texas A&M University. He has published extensively on topics relating to the biomedical and biotechnology fields in addition to being an editor of *The Journal of Clinical Engineering* for the past eight years. Cram currently serves as CEO of Dominion Biomedical in College Station, TX.

Selby Holder



Holder graduated from Connally High School in Waco, Texas, with honors in 1989 and only a year later graduated from Texas State Technical Institute (now Texas State Technical College Waco) with a Biomedical Equipment Technology degree. He was subsequently employed by Healthcare Biomedical Services of Waco for eleven years and worked on a variety of medical devices including defibrillators, monitors, diagnostic ultrasounds, sterilizers, infusion devices, and more. Since 1999 he has been a certified biomedical technician. After the birth of his son—and therefore wanting to spend more time at home than on the road—Holder became an instructor at TSTC Waco in 2002. He currently serves as Physical Plant Director at TSTC Waco.

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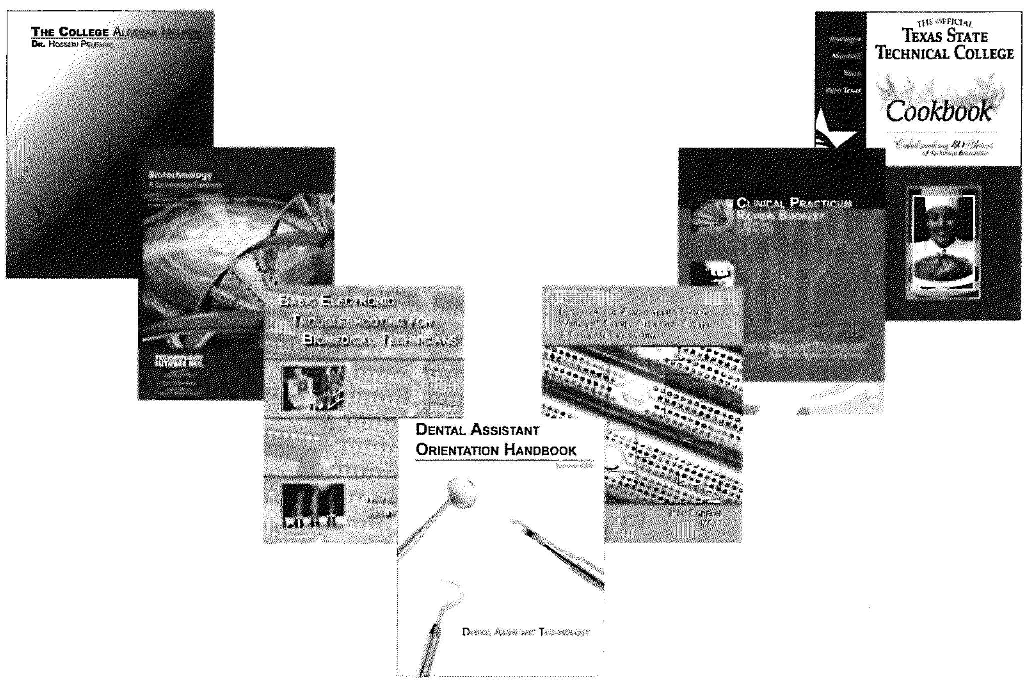

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- Chapters on industrial safety systems, AC/DC theory, reading electronic schematics, semiconductor devices, power supplies, and more
- Lab assignments and worksheets at the end of each chapter
- Appendices with resistor color codes, common electronic symbols, technical math, and useful Web sites

Nicholas Cram has taught and written extensively about the biomedical field at Texas A&M University and Texas State Technical College Waco. *Selby Holder* is assistant BET department chair at TSTC Waco.

More information about this book as well as other books published by Texas State Technical College Waco can be found at:
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