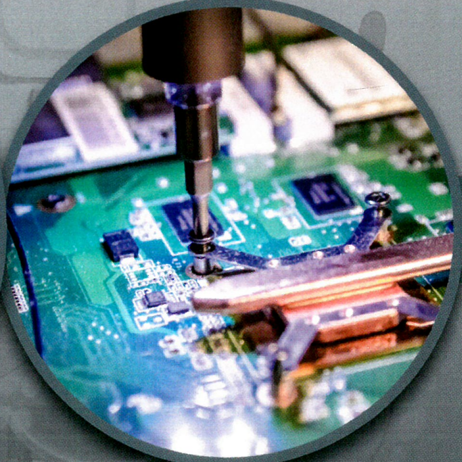
AIRCRAFT TECHNICAL BOOK COMPANY

B1

AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

ELECTRONIC FUNDAMENTALS

4



COMPLIANT WITH EASA European Aviation Safety Agency EASA PART 66/147

EASA 2023-989 COMPLIANT

AIRCRAFT TECHNICAL BOOK COMPANY

B1/B2

AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

ELECTRONIC FUNDAMENTALS

4

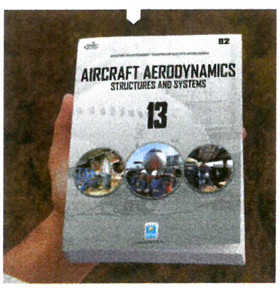
COMPLIANT WITH EASA European Aviation Safety Agency EASA PART 66/147

The publishers of this Aviation Maintenance Technician Certification Series welcome you to the world of aviation maintenance. For additional educational tools created to prepare candidates for licensure, contact Aircraft Technical Book Company. We wish you good luck and success in your studies and in your aviation career!

EASA TEXTBOOKS ARE AVAILABLE IN PRINT, EBOOK DOWNLOAD, OR ONLINE READER

1 — PRINT
EASY ON THE EYES
SUPERIOR ILLUSTRATIONS
GREAT FOR NOTE TAKING

3 — ONLINE
NO DOWNLOADS, JUST LOG IN
ACCESSABLE ANYTIME
5 YEAR LICENSE TO MATERIAL



2 — EBOOK
PORTABILITY
A LIBRARY IN YOUR HAND
LESS STORAGE SPACE

Special thanks to our instructors, contributors, and authors
Contributor - Jim Wasson
Contributor - Nerijus Baublys

Layout and Design by Michael Amrine

VERSION	EFFECTIVE DATE
004	2024.01

To order books or for customer service, please call +1 (970) 726-5111, or visit us online at www.actechbooks.com

ISBN-13: 978-1951275877
9 781951 275877

Aircraft Technical Book Company EASA Modules are in a constant state of review for quality, regulatory updates, and new technologies. This book's version is given in the revision log below and on the previous page.
Update notices for this book will be available online at www.actechbooks.com/revisions.html
If you would like to be notified when changes occur, please join our mailing list at www.actechbooks.com

VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2016.01	Module creation and release.
002	2016.05	Minor corrections and layout adjustments.
003	2018.07	Adjusted content for alignment to Part 66, Appendix 1. Added *Static Electricity Protection* to Submodule 2; Removed *Logic Circuits* from Submodule 1, page 1.2; other minor corrections.
003.1	2022.06	Clarified number of electrons in *Orbital Shells*. Submodule 1, page 1.2
003.2	2023.04	Inclusion of Measurement Standards for clarification, page iv. Minor appearance and format updates.
004	2024.01	Regulatory update for EASA 2023-989 Compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria. Enhancements included in this version:

4.1.1 *Diodes* - added Impurities on P and N materials.
4.1.2 *Transistors* - added Classification and identification of Transistors.
4.1.2 *Transistors* - added Logic Circuits.
4.3 Servomechanisms - added Servomechanism, Null, Overshoot, Hunting, Deadband, and Proximity Switches.
Additional minor non-regulatory adjustments throughout text and figures.

MEASUREMENT STANDARDS

SI Units

The measurements used in this book are presented with the International System of Units (SI) standards in all cases except when otherwise specified by ICAO (for example, altitude expressed in feet or performance numbers as specified by a manufacturer). The chart below can be used should your studies call for conversions into imperial numbers.

Number Groups

This book uses the International Civil Aviation Organization (ICAO) standard of writing numbers. This method separates groups of 3 digits with a space, versus the European method by periods and the American method by commas.

For example, the number one million is expressed as:

ICAO Standard	1 000 000
European Standard	1.000.000
American Standard	1,000,000

Prefixes

The prefixes used in the table below form names of the decimal equivalents in SI units.

PREFIX AND SYMBOLS CHART

MULTIPLICATION FACTORS	PREFIX	SYMBOL
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	µ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

COMMON CONVERSIONS CHART

IMPERIAL	TO	SI (METRIC)
Distance		
1 Inch	is equal to	2.54 Centimeters
1 Foot	is equal to	0.304 Meters
1 (Statute) Mile	is equal to	1.609 Kilometers
Weight		
1 Pound	is equal to	0.454 Kilograms
Volume		
1 Quart	is equal to	0.946 Liters
1 Gallon	is equal to	3.785 Liters
Temperature		
°0 Fahrenheit	is equal to	(-)17.778 Celsius (°C)
°0 Fahrenheit	is equal to	255.37 Kelvin (K)
Area		
1 Square Inch	is equal to	6.451 Square Centimeters
1 Square Foot	is equal to	0.093 Square Meters
1 Square Mile	is equal to	2.59 Square Kilometers
Velocity		
1 Foot Per Second	is equal to	0.304 Meters Per Second
1 Mile Per Hour	is equal to	1.609 Kilometers Per Hour
1 Knot	is equal to	1.852 Kilometers Per Hour

SI (METRIC)	TO	IMPERIAL
Distance		
1 Centimeter	is equal to	0.394 Inches
1 Meter	is equal to	3.28 Feet
1 Kilometer	is equal to	0.621 Miles
Weight		
1 Kilogram	is equal to	2.204 Pounds
Volume		
1 Liter	is equal to	1.057 Quarts
1 Liter	is equal to	0.264 Gallons
Temperature		
°0 Celsius (°C)	is equal to	33.8° Fahrenheit
°0 Kelvin (K)	is equal to	(-)437.87 Fahrenheit
Area		
1 Square Centimeter	is equal to	0.155 Square Inches
1 Square Meter	is equal to	10.764 Square Feet
1 Square Kilometer	is equal to	0.386 Square Miles
Velocity		
1 Meter Per Second	is equal to	3.281 Feet Per Second
1 Kilometer Per Hour	is equal to	0.621 Miles Per Hour
1 Kilometer Per Hour	is equal to	0.540 Knots

Pressure		
pounds per square inch (psi)	kiloPascals (kPa)	6.897
pounds per square inch (psi)	Pascals (Pa)	6.894

Qualification on basic subjects for each aircraft maintenance license category or subcategory is accomplished in accordance with the following matrix. Where applicable, subjects are indicated by an "X" in the column below the license heading.

EASA LICENSE CATEGORY CHART MODULE NUMBER AND TITLE		A1 Airplane Turbine	B1.1 Airplane Turbine	B1.2 Airplane Piston	B1.3 Helicopter Turbine	B1.4 Helicopter Piston	B2 Avionics
1	Mathematics	X	X	X	X	X	X
2	Physics	X	X	X	X	X	X
3	Electrical Fundamentals	X	X	X	X	X	X
4	Electronic Fundamentals		X	X	X	X	X
5	Digital Techniques, Electronic Instrument Systems	X	X	X	X	X	X
6	Materials and Hardware	X	X	X	X	X	X
7	Maintenance Practices	X	X	X	X	X	X
8	Basic Aerodynamics	X	X	X	X	X	X
9	Human Factors	X	X	X	X	X	X
10	Aviation Legislation	X	X	X	X	X	X
11	Aeroplane Aerodynamics, Structures and Systems	X	X				
12	Rotorcraft Aerodynamics, Structures and Systems				X	X	
13	Aircraft Aerodynamics, Structures and Systems						X
14	Propulsion						X
15	Gas Turbine Engine	X	X		X		
16	Piston Engine			X		X	
17	Propeller	X	X	X			

Basic knowledge requirments as outlined in Part-66, Appendix I

The knowledge level indicators are defined on 3 levels as follows:

Level 1

A familiarization with the principal elements of the subject.

Objectives:

a. The applicant should be familiar with the basic elements of the subject.
b. The applicant should be able to give a simple description of the whole subject, using common words and examples.
c. The applicant should be able to use typical terms.

Level 2

A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:

a. The applicant should be able to understand the theoretical fundamentals of the subject.
b. The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
c. The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
d. The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
e. The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

Level 3

A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

a. The applicant should know the theory of the subject and interrelationships with other subjects.
b. The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
c. The applicant should understand and be able to use mathematical formula related to the subject.
d. The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
e. The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
f. The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

KNOWLEDGE LEVEL DESCRIPTIONS

Competency consists of knowledge, skills and attitude. The applicant for an aircraft maintenance licence, or for the addition of an aircraft category or subcategory in the aircraft maintenance licence, shall demonstrate by examination and practical assessment that they meet the competency requirements.

	SUBMODULE KNOWLEDGE DESCRIPTIONS	LEVEL B1
4.1	**Semiconductors**	
4.1.1	**Diodes**	
	(a) Description and characteristics; Diode symbols; Diode characteristics and properties; Diodes in series and in parallel; Materials, electron configuration, electrical properties; P and N type materials: effects of impurities on conduction, majority and minority characters; P–N junction in a semiconductor, development of a potential across a P–N junction in unbiased, forward-biased and reverse-biased conditions; Diode parameters: peak inverse voltage, maximum forward current, temperature, frequency, leakage current, power dissipation; Main characteristics and use of silicon-controlled rectifiers (thyristors), light-emitting diodes (LEDs), photo-conductive diodes, rectifier diodes.	2
	(b) Operation and function Operation and function of diodes in the following circuits: clippers, clampers, full- and half-wave rectifiers, bridge rectifiers, voltage doublers and triplers; Detailed operation and characteristics of the following devices: silicon-controlled rectifier (thyristor), light-emitting diode (LED), Schottky diode, photo-conductive diode, varactor diode, varistor, rectifier diodes, Zener diode. Functional testing of diodes.	-
4.1.2	**Transistors**	
	(a) Description and characteristics Transistor symbols; Component description and orientation;	1
	Transistor characteristics and properties.	-
	(b) Construction and operation Construction and operation of PNP and NPN transistors; Base, collector and emitter configurations; Testing of transistors; Basic appreciation of other transistor types, including types of FET and their uses; Application of transistors: amplifier classes (A, B, C); Simple circuits including bias, decoupling, feedback and stabilisation; Multistage circuit principles: cascades, push–pull, oscillators, multivibrators, flip-flop circuits; Operation and amplifier stages connecting methods: resistive, capacitive, direct, inverting, non-inverting and adding.	
4.1.3	**Integrated Circuits**	
	(a) Description and operation of logic circuits and linear circuits/operational amplifiers;	1
	(b) Introduction to the operation and function of an operational amplifier used as: an integrator, a differentiator, a voltage follower, a comparator; Advantages and disadvantages of positive and negative feedback.	-
4.2	**Printed Circuit Boards** Description and use of printed circuit boards.	1
4.3	**Servomechanisms**	
	(a) Principles Understanding of the following principles: open- and closed-loop systems, servomechanism, feedback, follow-up, null, overshoot, damping, deadband, hunting, proximity switches, analogue transducers, synchro systems and components, digital tachometers and encoders, inductance, and capacitance transmitters;	1
	(b) Construction operation and use of the following synchro-system components: resolvers, differential, control and torque, E and I transformers, inductance transmitters, capacitance transmitters, synchronous transmitters; Construction, operation and use of servomechanism and PID controller; Fault-finding of servo defects, reversal of synchro leads, hunting.	-

ELECTRONIC FUNDAMENTALS

Revision Log iii
Measurement Standards iv
Basic Knowledge Requirements v
Knowledge Level Descriptions vi
Table of Contents vii

4.1 - SEMICONDUCTORS 1.1
Solid-State Devices 1.1
Semiconductors 1.1
Doping 1.2
Majority and Minority Carriers 1.3
PN Junctions and the Basic Diode 1.4
Unbiased PN Junction 1.4
Forward Bias PN Junction 1.4
Reverse Biased PN Junction 1.5
Diode Symbols 1.5
Diode Identification 1.6
Diode Characteristics and Properties 1.6
Diode Behavior 1.7
Diodes in Series and Parallel 1.7
Characteristics and use of Diodes 1.8
Light Emitting Diodes 1.8
Liquid Crystal Displays (LCD) 1.10
Photodiodes 1.10
Power Rectifier Diodes 1.11
Silicon Controlled Rectifiers 1.11
Zener Diode 1.11
Signal Diodes 1.11
Schottky Diodes 1.11
Varistors 1.12
Varactor Diodes (Varicap) 1.12
Functional Testing of Diodes 1.14
Introduction to Transistors 1.15
Classification and Symbols 1.15
Identification of Transistors 1.15
Component Description and Orientation 1.16
Shockley Diode 1.17
Silicon Controlled Rectifiers (Thyristors) 1.17
Triacs 1.17
Transistors, Characteristics and Properties 1.19
Unijunction Transistors (UJT) 1.19
Field Effect Transistors (FET) 1.20
Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and Complementary Metal Oxide Semiconductors (CMOS) 1.20
Dual In-line Package (DIP) 1.21
Linear Circuits 1.21
Linear Circuits and Operational Amplifiers 1.21
Submodule 1 Practice Questions 1.23
Submodule 1 Practice Questions 1.24

4.2 PRINTED CIRCUIT BOARDS 2.1
Description and Use of Printed Circuit Boards 2.1
Static Electricity 2.2
Risks And Possible Damage 2.2
Anti-Static Protection 2.2
Controlled Environment 2.2
Static-Safe Workstation 2.3
Anti-Static Wrist Straps 2.3
Grounding Test Stations 2.3
Ionizers 2.3
Special Handling 2.4
Submodule 2 Practice Questions 2.5
Submodule 2 Practice Questions 2.6

4.3 SERVOMECHANISMS 3.1
Servomechanism Principles 3.1
Open and Closed Systems 3.1
Feedback and Follow-up 3.1
Null 3.1
Overshoot 3.2
Damping 3.2
Hunting 3.2
Deadband 3.2
Proximity Switches 3.2
Analog Transducer 3.2
Synchro Systems 3.3
AC Synchro Systems 3.3
DC Selsyn Systems 3.4
Digital Tachometers and Encoders 3.5
Inductance Transmitters 3.5
Capacitance Transmitters 3.5
Submodule 3 Practice Questions 3.7
Submodule 3 Practice Questions 3.8

Acronym Definitions A.1

This page was intentionally left blank.

Semiconductors

SUBMODULE 1 KNOWLEDGE DESCRIPTIONS

		LEVEL
		B1
4.1	**Semiconductors**	
4.1.1	**Diodes** (a) Description and characteristics; Diode symbols; Diode characteristics and properties; Diodes in series and in parallel; Materials, electron configuration, electrical properties; P and N type materials: effects of impurities on conduction, majority and minority characters; P–N junction in a semiconductor, development of a potential across a P–N junction in unbiased, forward-biased and reverse-biased conditions; Diode parameters: peak inverse voltage, maximum forward current, temperature, frequency, leakage current, power dissipation; Main characteristics and use of silicon-controlled rectifiers (thyristors), light-emitting diodes (LEDs), photo-conductive diodes, rectifier diodes. (b) Operation and function Operation and function of diodes in the following circuits: clippers, clampers, full- and half-wave rectifiers, bridge rectifiers, voltage doublers and triplers; Detailed operation and characteristics of the following devices: silicon-controlled rectifier (thyristor), light-emitting diode (LED), Schottky diode, photo-conductive diode, varactor diode, varistor, rectifier diodes, Zener diode. Functional testing of diodes.	2 -
4.1.2	**Transistors** (a) Description and characteristics Transistor symbols; Component description and orientation; Transistor characteristics and properties. (b) Construction and operation Construction and operation of PNP and NPN transistors; Base, collector and emitter configurations; Testing of transistors; Basic appreciation of other transistor types, including types of FET and their uses; Application of transistors: amplifier classes (A, B, C); Simple circuits including bias, decoupling, feedback and stabilisation; Multistage circuit principles: cascades, push–pull, oscillators, multivibrators, flip-flop circuits; Operation and amplifier stages connecting methods: resistive, capacitive, direct, inverting, non-inverting and adding.	1 -
4.1.3	**Integrated Circuits** (a) Description and operation of logic circuits and linear circuits/operational amplifiers; (b) Introduction to the operation and function of an operational amplifier used as: an integrator, a differentiator, a voltage follower, a comparator; Advantages and disadvantages of positive and negative feedback.	1 -

4.1 - SEMICONDUCTORS

SOLID-STATE DEVICES

Solid-state devices began replacing vacuum tube electron control valves in the late 1950s. Their long life, reliability, and resilience in harsh environments make them ideal for use in avionics.

SEMICONDUCTORS

The key to solid-state electronic devices is the electrical behavior of semiconductors. To understand semiconductors, a review of what makes a material an insulator or a conductor follows. Then, an explanation for how materials of limited conductivity are constructed and some of their many uses are given. Semiconductor devices are the building blocks of modern electronics and avionics.

An atom of any material has a characteristic number of electrons orbiting the nucleus of the atom. The arrangement of the electrons occurs in somewhat orderly orbits called rings or shells. In most cases, the closest shell to the nucleus can only contain two electrons. If the atom has more than two electrons, those are found in the next orbital shell away from the nucleus. The second shell can only hold eight electrons. If the atom has more than 10 electrons (2 + 8), they orbit a third shell further out from the nucleus which can hold a maximum of 18 electrons. If the atom has more than 28 electrons (2 + 8 + 18) a fourth shell forms which can hold up to 32 electrons, etc. [**Figure 1-1**]

Shell or Orbit Number	1	2	3	4	5
Maximum Number of Electrons	2	8	18	32	50

Figure 1-1. Maximum number of electrons in each orbital shell of an atom.

The outer most orbital shell of any atom's electrons is called the valence shell. The number of electrons in the valence shell determines the chemical properties of the material. When the valence shell has the maximum number of electrons, it is complete and the electrons tend to be bound strongly to the nucleus. Materials with this characteristic are chemically stable. It takes a large amount of force to move the electrons in this situation from one atom valence shell to that of another. Since the movement of electrons is called electric current, substances with complete valence shells are known as good insulators because they resist the flow of electrons (electricity). [**Figure 1-2**]

In atoms with an incomplete valence shell, that is, those without the maximum number of electrons in their valence shell, the electrons are bound less strongly to the nucleus. The material is chemically disposed to combine with other materials or other identical atoms to fill in the unstable valence configuration and bring the number of electrons in the valence shell to maximum. Two or more substances may share the electrons in their valence shells and form covalent bond. A covalent bond is the method by which atoms complete their valence shells by sharing valence electrons with other atoms.

Electrons in incomplete valence shells may also move freely from valence shell to valence shell of different atoms or compounds. In this case, these are known as free electrons. As stated, the movement of electrons is known as electric current or current flow. When electrons move freely from atom to atom or compound to compound, the substance is known as a conductor. [**Figure 1-3**]

Not all materials are pure elements, that is, substances made up of one kind of atom. Compounds occur when two or more different types of atoms combine. They create a new substance with different characteristics than any of the component elements. When compounds form, valence shells and their maximum number of electrons remain the rule of physics. The new compound molecule may either share electrons to fill the valence shell or free electrons may exist to make it a good conductor.

Silicon is an atomic element that contains four electrons in its valence shell. It tends to combine readily with itself and form a lattice of silicon atoms in which adjacent atoms share electrons to fill out the valance shell of each to the maximum of eight electrons. [**Figure 1-4**] This unique symmetric alignment of silicon atoms results in a crystalline structure.

Once bound together, the valence shells of each silicon atom are complete. In this state, movement of electrons does not occur easily. There are no free electrons to move to another atom and no space in the valence shells to accept a free electron. Therefore, silicon in this form is a good insulator. Silicon is a primary material used in the manufacture of semiconductors. Germanium and a few other materials are also used.

DOPING

Since silicon is an insulator, it must be modified to become a semiconductor. The process often used is called doping. Starting with ultra-pure silicon crystal, arsenic, phosphorus, or some other element with five valence electrons in each atom is mixed into the silicon. The result is a silicon lattice with flaws. [**Figure 1-5**] The elements bond, but numerous free electrons are present in the material from the 5th electron that is part of the valence shell of the doping element atoms. These free electrons can now flow under certain conditions. Thus, the silicon becomes semiconductive. The conditions required for electron flow in a semiconductor are discussed in the following paragraphs.

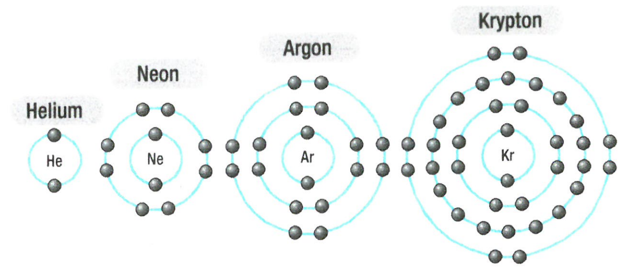


Figure 1-2. Elements with full valence shells are good insulators. Most insulators used in aviation are compounds of two or more elements that share electrons to fill their valence shells.

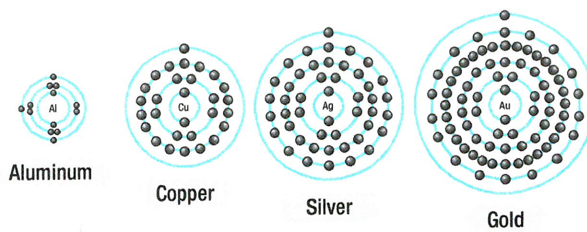


Figure 1-3. The valence shells of elements that are common conductors have one (or three) electrons.

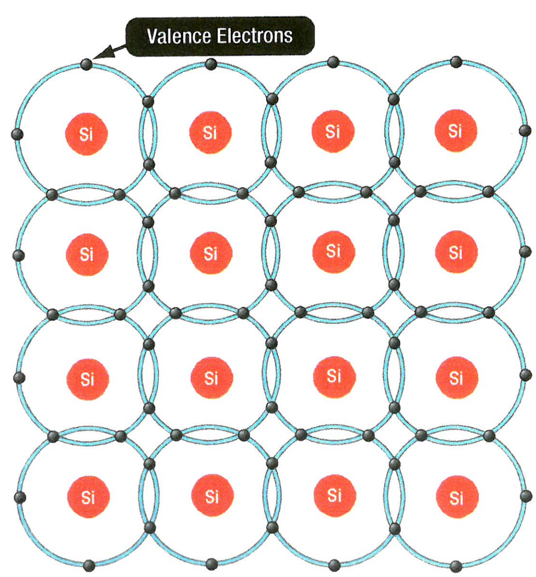


Figure 1-4. The silicon atoms with just the valence shell electrons share these valence electrons with each other. By sharing with four other silicon atoms, the number of electrons in each silicon atom valence shell becomes eight, which is the maximum number. This makes the substance stable and it resists any flow of electrons.

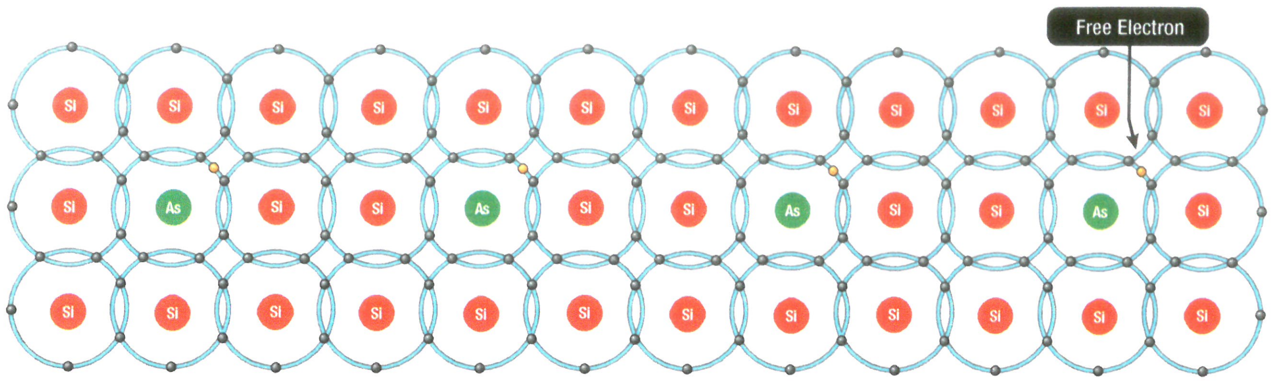


Figure 1-5. Silicon atoms doped with arsenic form a lattice work of covalent bonds. Free electrons exist in the material from the arsenic atom's 5th valence electron. These are the electrons that flow when the semiconductor material, known as N-type or donor material, is conducting.

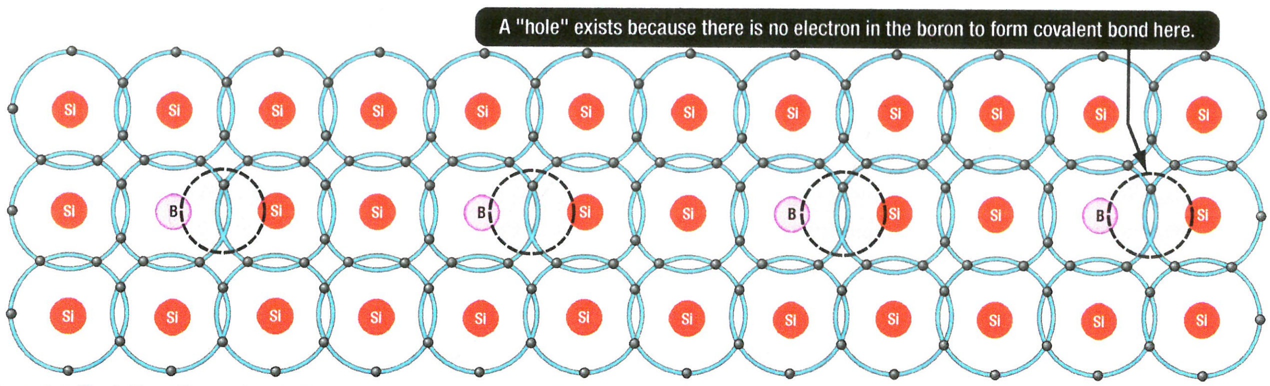


Figure 1-6. The lattice of boron doped silicon contains holes where the three boron valence shell electrons fail to fill in the combined valence shells to the maximum of eight electrons. This is known as P-type semiconductor material or acceptor material.

When silicon is doped with an element or compound containing five electrons in its valence shell, the result is a negatively charged material due to the excess free electrons, and the fact that electrons are negatively charged. This is known as an N-type semiconductor material. It is also known as a donor material because, when it is used in electronics, it donates the extra electrons to current flow.

Doping silicon can also be performed with an element that has only three valence electrons, such as boron, gallium, or indium. Valence electron sharing still occurs, and the silicon atoms with interspersed doping element atoms form a lattice molecular structure. However, in this case, there are many valence shells where there are only seven electrons and not eight. This greatly changes the properties of the material. The absence of the electrons, called holes, encourages electron flow due to the preference to have eight electrons in all valence shells. Therefore, this type of doped silicon is also semi-conductive. It is known as P-type material or as an acceptor since it accepts electrons in the holes under certain conditions. [**Figure 1-6**]

MAJORITY AND MINORITY CARRIERS

Both N-type and P-type semiconductors are able to conduct electricity. In the N-type material, current flows primarily like it does in any conductor. The valence electrons move from one valence shell to another as they progress through the material. Due to the surplus of electrons, the electrons are considered the majority current carriers in N-type semiconductors. Any movement of current in N-type material by the filling of holes is considered the minority current carrier.

In P-type material, current primarily flows by valence electrons filling holes that exist in the doped lattice. This makes holes the majority carrier in P-type material. Any current flow in P-type material that occurs without holes (valence electrons exchanging with other valence electrons) is known as the minority carrier.

Figure 1-7 shows the progression of a hole moving through a number of atoms. Notice that the hole illustrated at the far left of the top depiction of **Figure 1-7** attracts the next valance electron into the vacancy, which then produces another vacancy called a hole in the next position to the right. Once again this

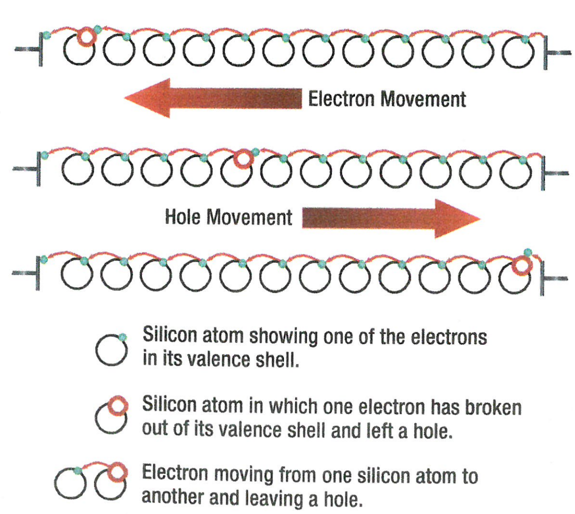


Figure 1-7. A hole moving through atoms.

vacancy attracts the next valance electron. This exchange of holes and electrons continues to progress, and can be viewed in one of two ways: electron movement or hole movement. For electron movement, illustrated by the top depiction of **Figure 1-7**, the electron is shown as moving from the right to the left through a series of holes. In the second depiction in **Figure 1-7**, the motion of the vacated hole can be seen as migration from the left to the right, called hole movement. The valence electron in the structure will progress along a path detailed by the arrows. Holes, however, move along a path opposite that of the electrons. Combining N-type and P-type semiconductor material in certain ways can produce very useful results.

4.1.1 DIODES

PN JUNCTIONS AND THE BASIC DIODE

A single type of semiconductor material by itself is not very useful. But, applications have been developed when P-type and N-type materials are joined that have revolutionized electrical and electronic devices. The boundary where the P-type material touches the N-type material is called the junction or PN junction. Interesting and useful phenomenon occur at this contact region. Furthermore, when joined, the entire two-element semiconductor device becomes a basic diode.

A diode is an electrical device that allows current to flow in one direction through the device but not the other. Because of this, the semiconductor diode is used in electronic circuits to convert alternating current into direct current. Thus, the PN semiconductor device can act as a rectifier. An explanation of what happens at the PN junction and how it affects the entire PN semiconductor device follows. A glass encased semiconductor diode is shown in **Figure 1-8**.

UNBIASED PN JUNCTION

Figure 1-9 illustrates the electrical characteristics of an unbiased diode, which means that no external voltage is applied. The P-side in the illustration is shown to have many holes, while the N-side shows many electrons. When the P and N material contact each other, the electrons on the N-side tend to diffuse out in all directions. Some of the electrons enter the P region. With so many holes in the P material, the electrons soon drop into a hole. When this occurs, the hole then disappears. A negatively charged ion is created since there is now one more electron than the number of protons in the nucleus of the boron (or gallium or indium) atom to which the hole belonged.

Figure 1-8. A silicon diode, the square silicon crystal can be seen between the two leads.

Meanwhile, in the N material near the junction, the valence electrons that departed for the P-type material leave behind a band of positive ions since there are now more positively charged protons in the nucleus of the arsenic (or phosphorous, etc) atoms than there are electrons in their shells. Thus, each time an electron crosses the PN junction, it creates a pair of ions. In **Figure 1-9**, this is shown in the area outlined by the dash lines. The circled plus signs and the circled negative signs are the positive and negative ions, respectively. These ions are fixed in the crystal and do not move around like electrons or holes in the conduction band. They constitute the depletion zone where neither excess electrons or excess holes exist. The ions create an electrostatic field across the junction between the oppositely charged ions.

Because holes and electrons must overcome this field to cross the junction, the electrostatic field is usually called a barrier or potential hill. As the diffusion of electrons and holes crosses the junction, the strength of the electrostatic field increases until it becomes strong enough to prevent more electrons or holes from crossing over. At this point, a state of equilibrium exists and there is no further movement across the junction. The PN junction and the entire PN device is said to be unbiased.

FORWARD BIAS PN JUNCTION

The two semiconductors joined at the PN junction form a diode that can be used in an electrical circuit. When a voltage source (battery) is attached to the diode with the negative terminal connected to the N-type semiconductor material and the positive terminal connected to the P-type material, it is said to have forward bias and electricity can flow in the circuit. [**Figure 1-10**]

The voltage opposes the electrostatic field at the junction and reduces the potential hill. The positive potential of the battery forces holes in the P-type material toward the junction. The

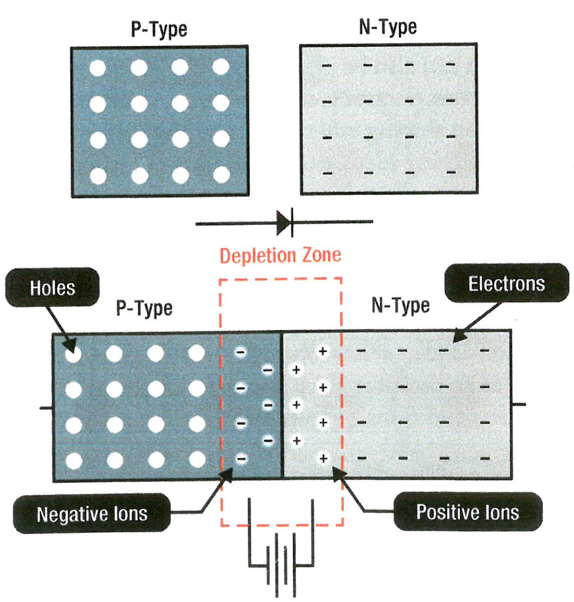


Figure 1-9. An unbiased PN junction - the depletion zone creates a barrier that electrons or holes must overcome for current to flow. The electrostatic field that forms the barrier is shown by a battery circuit involving the positive and negative ions in the depletion zone.

negative potential of the battery forces free electrons in the N-type material towards the opposite side of the junction. The depletion zone become very narrow and electrons in the N-type material flow across into the P-type material. There, they combine with holes. The electron and holes continuously come together resulting in current flow. These majority carriers in each semiconductor material increase in number as voltage is increased. This increases current flow. When disconnected from the battery, the depletion zone widens, the electrostatic field strength is restored and current flow ceases.

Note the potential hill or barrier is reduced when connected to the battery as explained, but it still exists. A voltage of approximately 0.7 volts is needed to begin the current flow over the potential hill in a silicon semiconductor diode and about 0.3 volts in a germanium semiconductor diode. Thereafter, current flow is linear with the voltage. Caution must be exercised because it is possible to overheat and "burn out" the semiconductor device at the junction with excessive current flow. Also note that temperature has a significant impact of current flow in semiconductors.

REVERSE BIASED PN JUNCTION

When the battery connections to the PN semiconductor are reversed as shown in **Figure 1-11**, the diode is said to have reverse bias and current will not flow. The most noticeable effect of reverse bias seen in this illustration is the widened depletion zone.

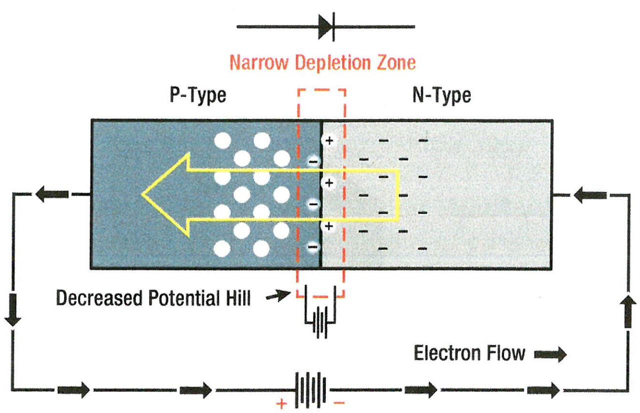


Figure 1-10. The flow of current and the PN junction of a forward biased semiconductor diode in a simple circuit with battery.

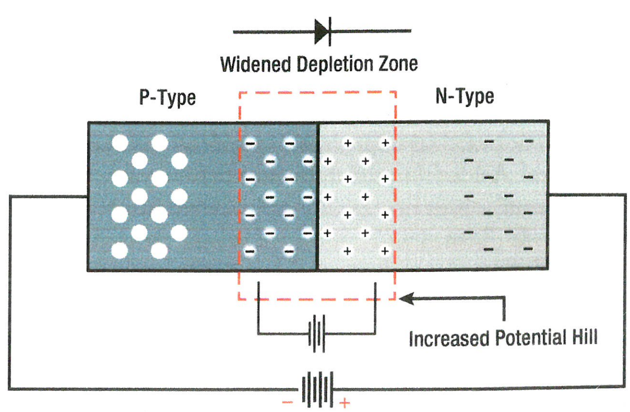


Figure 1-11. Reversed biased PN junction-no current flow.

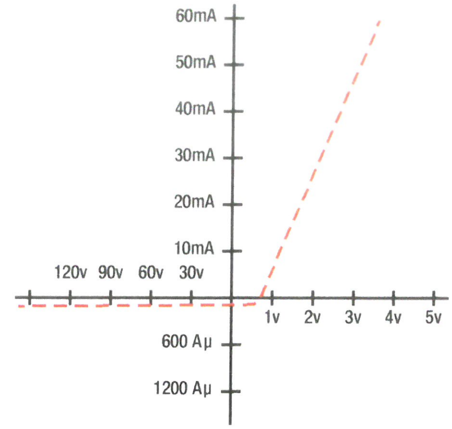


Figure 1-12. Silicon PN junction diode characteristics.

The negative terminal of the battery attracts the holes away from the junction and the positive terminal attracts the electrons away from the junction. The result is a wider depletion zone. The applied battery voltage is in the same direction as the depletion zone field which strengthen and widens with more ions. Majority current carriers no longer have the energy to cross the barrier at the junction. Minority carrier current flow does exist across the junction but it is negligible.

PN junction diodes offer very little resistance to current in forward biased diode and maximum resistance when the diode is reverse biased. **Figure 1-12** shows a graph of the current characteristics of a diode that is biased in both directions.

DIODE SYMBOLS

Diode symbols used in circuit diagrams are shown in **Figure 1-13**. Different types of diodes have slightly altered symbols for quick identification. These will be shown as they are discussed.

Note that electron flow is typically discussed in this text. The conventional current flow concept where electricity is thought to flow from the positive terminal of the battery through a circuit to the negative terminal is sometimes used in the field. To differentiate between the two in diagrams, the arrows in **Figure 1-14** may be used.

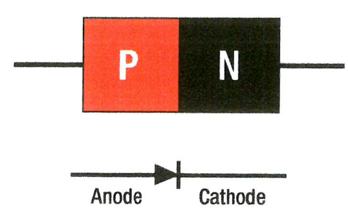


Figure 1-13. Diode symbols.

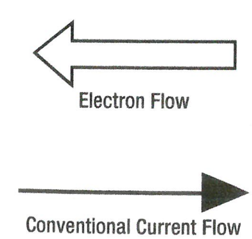


Figure 1-14. Current flow arrows used on diagrams.

DIODE IDENTIFICATION

There are many types of diodes varying in size from the size of a pinhead (used in subminiature circuitry) to large 250-ampere diodes (used in high-power circuits). Because there are so many different types of diodes, some system of identification is needed to distinguish one diode from another. This is accomplished with the semiconductor identification system shown in **Figure 1-15**. This system is not only used for diodes but transistors and many other special semiconductor devices as well.

As illustrated in this figure, the system uses numbers and letters to identify different types of semiconductor devices. The first number in the system indicates the number of junctions in the semiconductor device and is a number, one less than the number of active elements. Thus 1 designates a diode; 2 designates a transistor (which may be considered as made up of two diodes); and 3 designates a tetrode (a four-element transistor). The letter "N" following the first number indicates a semiconductor. The 2- or 3-digit number following the letter "N" is a serialized identification number. If needed, this number may contain a suffix letter after the last digit. For example, the suffix letter "M" may be used to describe matching pairs of separate semiconductor devices or the letter "R" may be used to indicate reverse polarity. Other letters are used to indicate modified versions of the device which can be substituted for the basic numbered unit. For example, a semiconductor diode designated as type 1N345A signifies a two-element diode (1) of semiconductor material (N) that is an improved version (A) of type 345.

When working with these different types of diodes, it is also necessary to distinguish one end of the diode from the other (anode from cathode). For this reason, manufacturers generally code the cathode end of the diode with a "k," "+," "cath," a color dot or band, or by an unusual shape (raised edge or taper) as shown in **Figure 1-16.** In some cases, standard color code bands are placed on the cathode end of the diode. This serves two purposes: (1) it identifies the cathode end of the diode, and (2) it also serves to identify the diode by number.

The standard diode color code system is shown in **Figure 1-17.** Take, for example, a diode with brown, orange, and white bands at one terminal and figure out its identification number. With brown being a "1," orange a "3," and white "9," the device would be identified as a type 139 semiconductor diode, or specifically 1N139.

XNYYY

XN — YYY

Component — Identification Number

X- Number of Semiconductor Junctions
N - A Semiconductor
YYY - Identification Number (Order or Registration Number) also includes suffix letter (if applicable) to indicate:

1. Matching Devices
2. Reverse Polarity
3. Modification

Example - 1N345A
(An improved version of the semiconductor diode type 345)

Figure 1-15. Semiconductor identification codes.

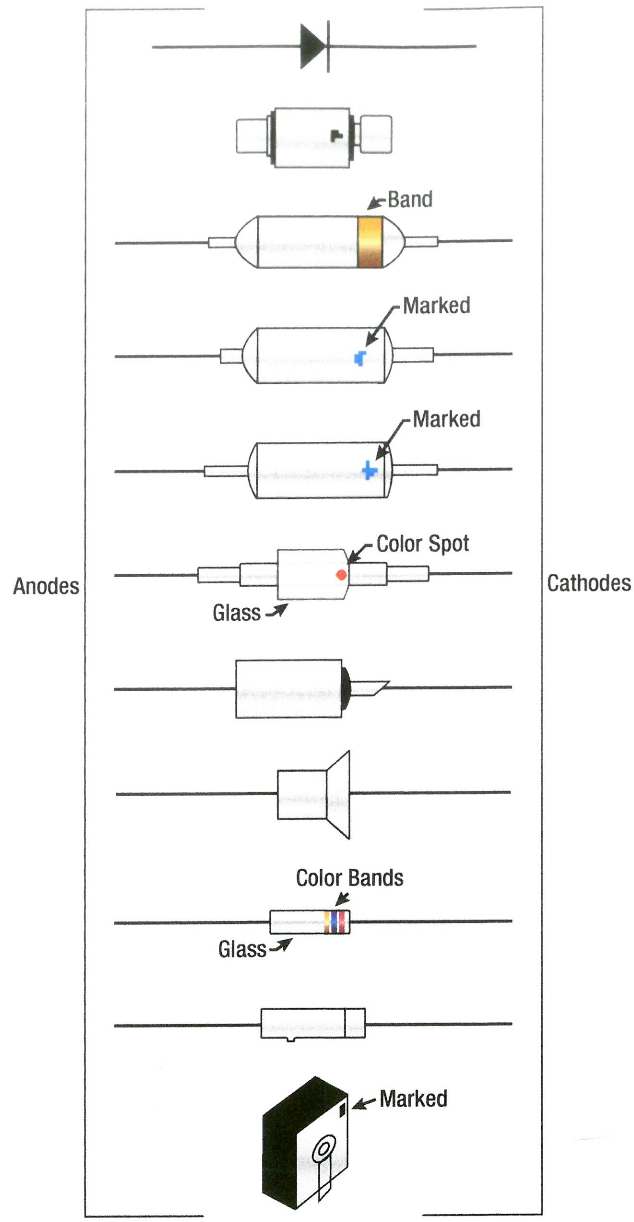
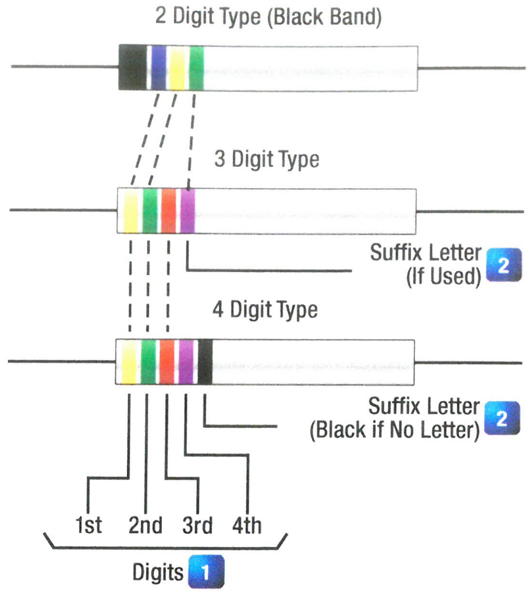


Figure 1-16. Semiconductor diode markings.

DIODE CHARACTERISTICS AND PROPERTIES

Semiconductor diodes have properties that enable them to perform many different electronic functions. To do their jobs, engineers and technicians must be supplied with data on these different types of diodes. The information presented for this purpose is called diode characteristics. These characteristics are supplied by manufacturers either in their manuals or on specification sheets (data sheets). Because of the scores of manufacturers and numerous diode types, it is not practical to present a specification sheet here and call it typical. Aside from the difference between manufacturers, a single manufacturer may even supply specification sheets that differ both in format and content. Despite these differences, certain performance and design information is normally required.

A brief description including the type of diode, the major area of application, and any special features is normally given. Particular interest is the specific application for which the diode is suited. The manufacturer also provides a drawing of the diode which gives



Color	1 Digit	2 Diode Suffix Letter
Black	0	-
Brown	1	A
Red	2	B
Orange	3	C
Yellow	4	D
Green	5	E
Blue	6	F
Violet	7	G
Gray	8	H
White	9	J
Silver	-	-
Gold	-	-
None	-	-

Figure 1-17. Semiconductor diode color code system.

dimension, weight, and, if appropriate, any identification marks. A static operating table giving spot values of parameters under fixed conditions is often given and sometimes a characteristic curve similar to the one in **Figure 1-12** is also supplied. (The graph shows how parameters vary over the full operating range.) Finally, the diode ratings are given since they are the limiting values of operating conditions outside of which the diode could be damaged. The PN junction diodes are generally rated for the following:

1. Maximum Average Forward Current - this refers to the maximum amount of average current that can be permitted to flow in the forward direction. If this exceeded, structure breakdown can occur. Maximum average forward current is usually given at a specific temperature, (typically 25°C).
2. Peak Recurrent Forward Current - the maximum peak current that can be permitted to flow in the forward direction in the form of recurring pulses.
3. Maximum Surge Current - the maximum current permitted to flow in the forward direction in the form of nonrecurring pulses. Current should not equal this value for more than a few milliseconds.
4. Peak Reverse Voltage (PRV) - indicates the maximum reverse-bias voltage that may be applied to a diode without causing junction breakdown.

All of the above ratings are subject to change with temperature variations. If, for example, the operating temperature is above that stated for the ratings, the ratings must be decreased. Some other diode characteristics are:

- Reverse Current (IR) - the small value of direct current that flows when a semiconductor diode has reverse bias.
- Maximum Forward Voltage Drop At Indicated Forward Current (VF@IF) - the maximum forward voltage drop across the diode at the indicated forward current.
- Reverse Recovery Time (TRR) - the maximum time taken for the forward-bias diode to recover its reverse bias.
- Semiconductor diodes are used often in electronic circuits. When AC current is applied to a semiconductor diode, current flows during one cycle of the AC but not during the other cycle. The diode, therefore, becomes a rectifier and changes AC current to pulsating DC current. When the semiconductor diode is forward biased, electrons flow; when the AC cycles, the diode becomes reverse biased and electrons do not flow.

DIODE BEHAVIOR

Semiconductor diodes have limitations as mentioned. They are rated for a range of current flow. Above a certain level, the diode overheats and burns up. The amount of current that passes through the diode when forward biased is directly proportional to the amount of voltage applied. But, as mentioned, it is affected by temperature. **Figure 1-18** indicates the actual behavior of a semiconductor diode. In practice, a small amount of current does flow through a semiconductor diode when reversed biased. This is known as leakage current and it is in the micro amperage range. However, at a certain voltage, the blockage of current flow in a reversed biased diode breaks down completely. This voltage is known as the avalanche voltage because the diode can no longer hold back the current and the diode fails.

DIODES IN SERIES AND PARALLEL

The simple battery circuit with the PN junction places the diode in series circuit. The diode offers resistance to current flow and, therefore, a voltage drop occurs as current flows through the diode. In the forward biased circuit, the voltage drop is approximately 0.7 volts for a silicon semiconductor diode and about 0.3 volts for a germanium semiconductor diode. The remainder of the initial

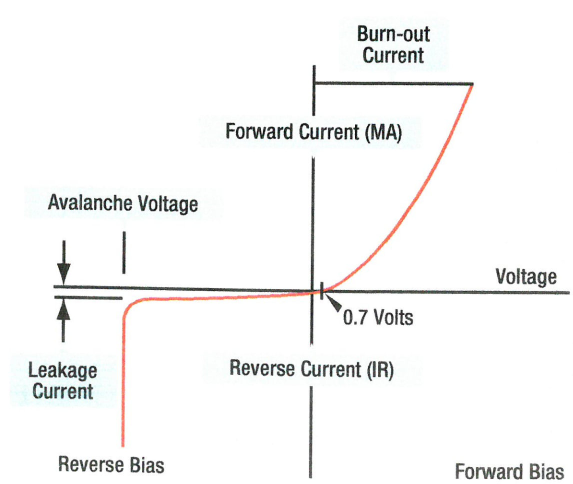


Figure 1-18. A semiconductor diode.

applied voltage is applied to any load in the circuit downstream of the diode. In a series circuit where the diode is reverse biased, no current flows. In this simple battery circuit with PN junction diode, the applied voltage is DC from the battery.

With the application of AC voltage to the diode series circuit, the diode allows current to flow in only one direction and blocks it in the opposed direct. This is the definition of a diode. The diode in series also rectifies the AC voltage, that is, AC voltage is converted to DC voltage. So, in addition to being a diode, it can also be said that the diode is a rectifier. However, only half of the AC voltage is used when the diode is in series. The other half is wasted since current cannot flow across the reverse biased diode. The widened depletion zone acts as an open circuit and the potential is not used. This is known as half wave rectification and is shown in the diagram in **Figure 1-19**.

AC voltage applied to diodes in a parallel circuit creates similar results but with greatly improved efficiency. **Figure 1-20** illustrates diodes in a parallel circuit that supplied a load (R_L). The AC that is induced into the circuit flows from negative to positive as always. The full wave of the AC voltage is converted to DC, unlike in the series circuit. As a result, the DC pulses are not separated from each other. The arrows in the diagram show the direction of current flow during the positive and negative cycles of the voltage. Notice that the transformer coil is grounded in the center. This is known as a center tapped rectifier circuit. The positive and negative cycles of the AC are used but the magnitude of the AC voltage is half of what is supplied because of the center tap.

A widely used variation of the full wave rectifier is the bridge rectifier. [**Figure 1-21**] The arrows in the diagram show that current flows in each direction as the AC cycles. The entire applied voltage is used with a non-interrupted DC pulse voltage resulting at the output.

CHARACTERISTICS AND USE OF DIODES

LIGHT EMITTING DIODES

Light emitting diodes (LEDs) have become so commonly used in electronics that their importance may tend to be overlooked. Numerous avionics displays and indicators use LEDs for indicator lights, digital readouts, and backlighting of liquid crystal display (LCD) screens.

LEDs are simple and reliable and are constructed of semiconductor material. In a forward biased diode, electrons cross the junction and fall into holes. As the electrons fall into the valence band, they radiate energy. This is true in all semiconductor materials. In most diodes, this energy is dissipated as heat. However, in the light-emitting diode (LED), the energy is dissipated as light. By using elements, such as gallium, arsenic, and phosphorous, an LED can be designed to radiate colors, such as red, green, yellow, blue and infrared light. LEDs that are designed for the visible light portion of the spectrum are useful for instruments, indicators, and even cabin lighting. The advantages of the LED over the incandescent lamps are longer life, lower voltage, faster on and off operations, and less heat.

Figure 1-22 is a table that illustrates common LED colors and the semiconductor material that is used in the construction of the diode.

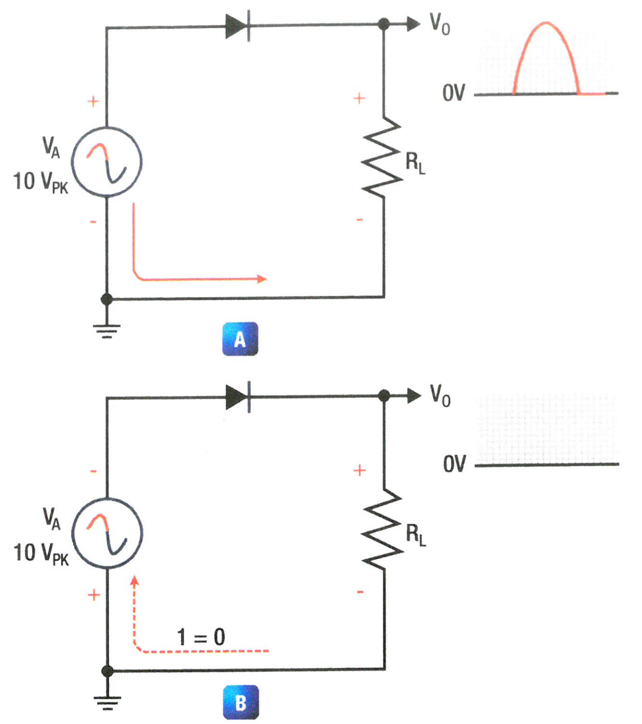


Figure 1-19. A diode and load in a series circuit with AC power applied rectifies the voltage. Only half of the AC voltage is used.

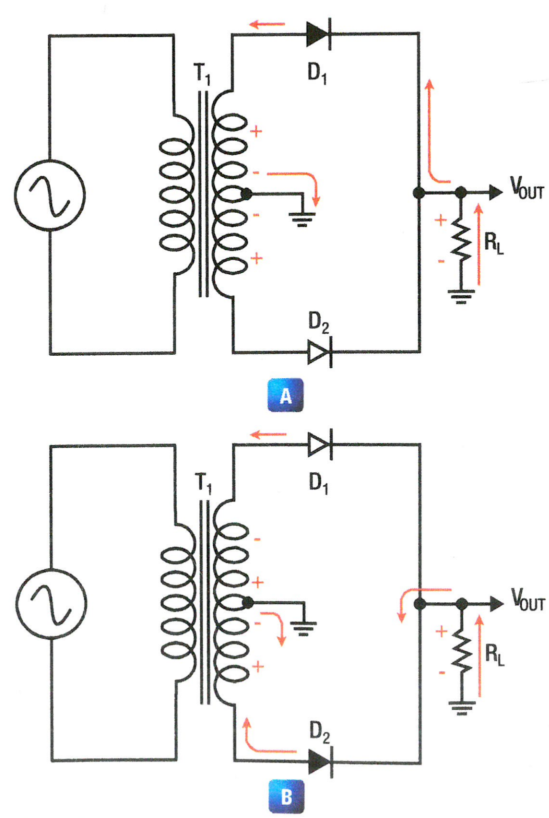


Figure 1-20. Diodes in a parallel circuit create a full wave rectifier.

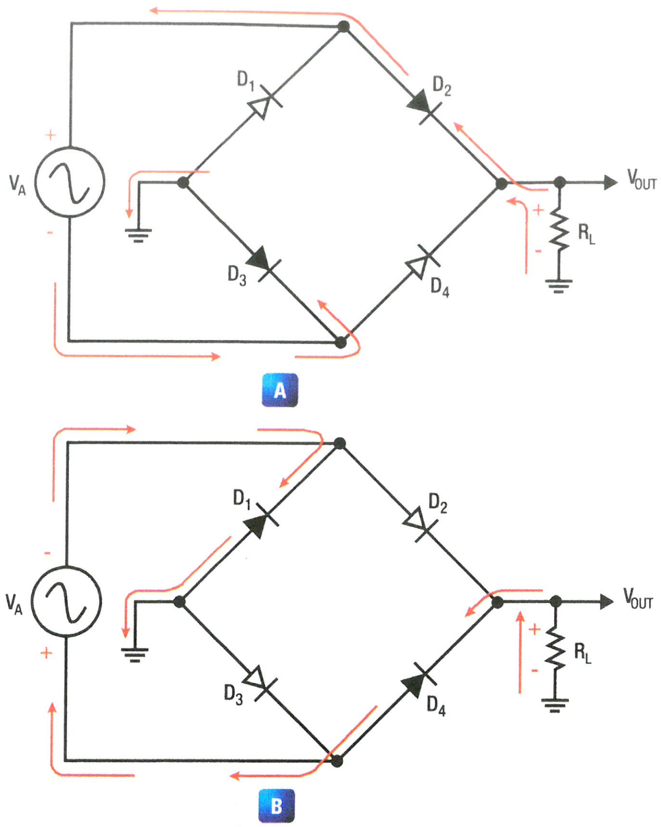


Figure 1-21. A bridge rectifier circuit converts the entire applied AC voltage to DC voltage.

Note that when the diode is reversed biased, no light is given off. When the diode is forward biased, the energy given off is visible in the color characteristic for the material being used. **Figure 1-23** illustrates the anatomy of a single LED, the symbol of an LED, and a graphic depiction of the LED process.

LEDs are used widely as "power on" indicators of current and as displays for pocket calculators, digital voltmeters, frequency counters, etc. For use in calculators and similar devices, LEDs are typically placed together in seven-segment displays, as shown in **Figure 1-24** (view A and B). This display uses seven LED segments, or bars (labeled A through G in the figure), which can be lit in different combinations to form any number from "0" through "9." The schematic, view A, shows a common-anode display. All anodes in a display are internally connected.

When a negative voltage is applied to the proper cathodes, a number is formed. For example, if negative voltage is applied to all cathodes except that of LED "E," the number "9" is produced, as shown in view A of **Figure 1-25**. If the negative voltage is changed and applied to all cathodes except LED "B," the number "9" changes to "6" as shown in view B.

Seven-segment displays are also available in common-cathode form, in which all cathodes are at the same potential. When replacing LED displays, you must ensure the replacement display is the same type as the faulty display. Since both types look alike,

Color	Wavelength (nm)	Voltage (V)	Semiconductor Material
Infrared	λ > 760	ΔV < 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
Red	610 < λ < 760	1.63 < ΔV < 2.03	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	590 < λ < 610	2.03 < ΔV < 2.10	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	570 < λ < 590	2.10 < ΔV < 2.18	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	500 < λ < 570	1.9[32] < ΔV < 4.0	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
Blue	450 < λ < 500	2.48 < ΔV < 3.7	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	400 < λ < 450	2.76 < ΔV < 4.0	Indium gallium nitride (InGaN)
Purple	Multiple Types	2.48 < ΔV < 3.7	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	λ < 400	3.1 < ΔV < 4.4	diamond (235 nm)[33] Boron nitride (215 nm)[34][35] Aluminium nitride (AlN) (210 nm)[36] Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN) — (down to 210 nm)[37]
White	Broad Spectrum	ΔV = 3.5	Blue/UV diode with yellow phosphor

Figure 1-22. LED colors and the materials used to construct them as well as their wavelength and voltages.

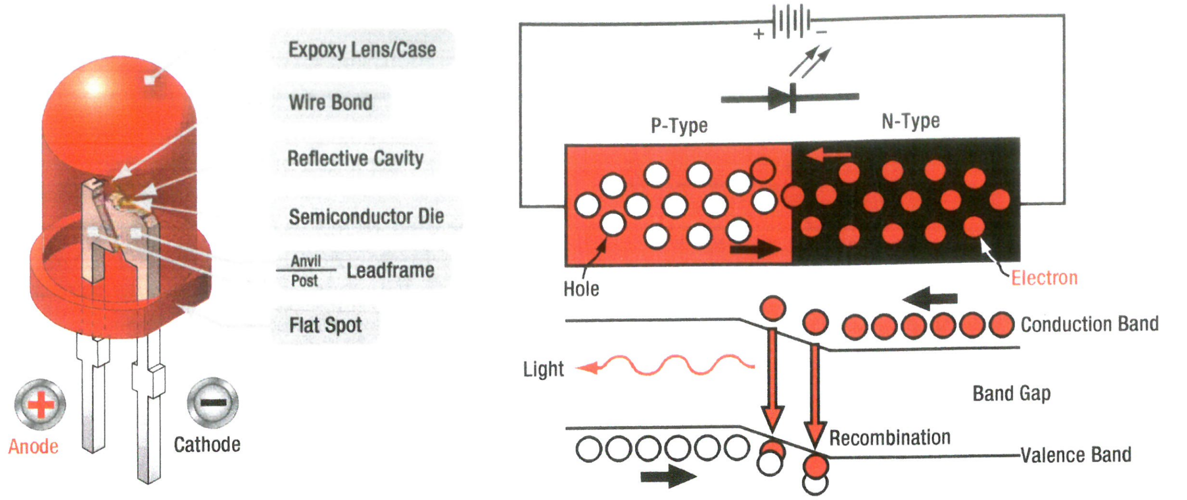


Figure 1-23. A close up of a single LED (left) and the process of a semi-conductor producing light by electrons dropping into holes and giving off energy (right). The symbol for a light emitting diode is the diode symbol with two arrows pointing away from the junction.

you should always check the manufacturer's number. LED seven-segment displays range from the very small, often not much larger than standard typewritten numbers, to about an inch. Several displays may be combined in a package to show a series of numbers, such as the one shown in **Figure 1-26**.

LIQUID CRYSTAL DISPLAYS (LCD)

The liquid crystal display (LCD) has an advantage over the LED in that it requires less power to operate. Where LEDs commonly operate in the milliwatt range, the LCD operates in the microwatt range. The liquid crystal is encapsulated between two glass plates. When voltage is not applied to the LCD, the display is clear. However, when voltage is applied, the result is a change in the orientation of the atoms of the crystals. The incident light is then reflected in a different direction. A frosted appearance results in the regions that have voltage applied and permits distinguishing of numeric values.

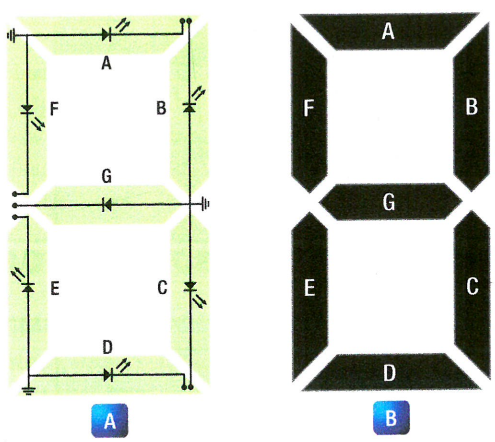


Figure 1-24. Seven segment LED display.

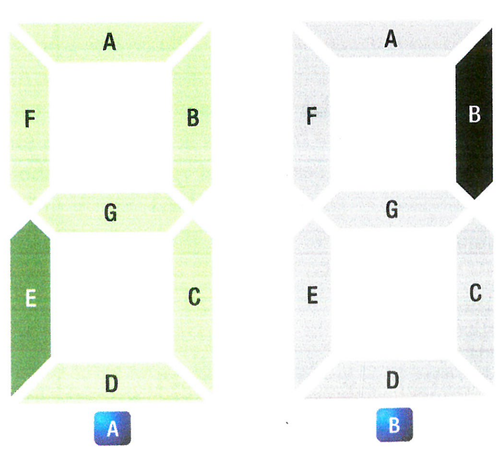


Figure 1-25. Seven segment LED display examples.

Figure 1-26. Stacked seven segment LED display.

PHOTODIODES

Light contains electromagnetic energy that is carried by photons. The amount of energy depends on the frequency of light of the photon. This energy can be very useful in the operation of electronic devices since all semiconductors are affected by light energy. When a photon strikes a semiconductor atom, it raises the energy level above what is needed to hold its electrons in orbit. The extra energy frees an electron enabling it to flow as current. The vacated position of the electron becomes a hole. In photodiodes, this occurs in the depletion area of the reversed biased PN junction turning on the device and allowing current to flow.

Figure 1-21 illustrates a photodiode in a coil circuit. In this case, the light striking the photodiode causes current to flow in the circuit whereas the diode would have otherwise blocked it. The result is the coil energizes and closes another circuit enabling its operation.

Thermal energy produces minority carriers in a diode. The higher the temperature, the greater the current in a reverse current diode. Light energy can also produce minority carriers. By using a small window to expose the PN junction, a photodiode can be built. When light fall upon the junction of a reverse-biased photodiode, electrons-hole pairs are created inside the depletion layer. The

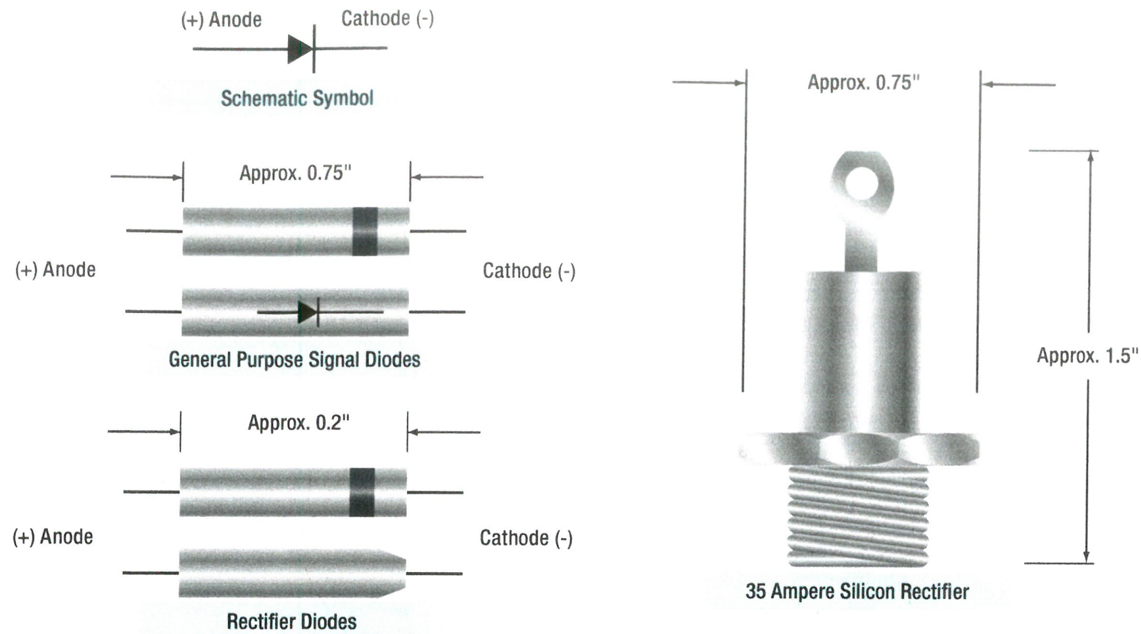


Figure 1-27. Examples of power rectifier diodes with the one on the right encased in metal to provide a heat shrink.

stronger the light, the greater the number of light-produced carriers, which in turn causes a greater magnitude of reverse current. Because of this characteristic, the photodiode can be used in light detecting circuits.

POWER RECTIFIER DIODES

The rectifier diode is usually used in applications that require high current, such as power supplies. The range in which the diode can handle current can vary anywhere from one ampere to hundreds of amperes. One common example of diodes is the series of diodes, part numbers 1N4001 to 1N4007. The "1N" indicates that there is only one PN junction, or that the device is a diode. The average current carrying range for these rectifier diodes is about one ampere and have a peak inverse voltage between 50 volts to 1 000 volts. Larger rectifier diodes can carry currents up to 300 amperes when forward biased and have a peak inverse voltage of 600 volts. A recognizable feature of the larger rectifier diodes is that they are encased in metal in order to provide a heat sink. **Figure 1-27** illustrates a few types of rectifier diodes.

SILICON CONTROLLED RECTIFIERS

Silicon controlled rectifiers are discussed in detail in the following section *4.1.2 Transistors.*

ZENER DIODE

Diodes can be designed with a zener voltage. This is similar to avalanche flow. When reversed biased, only leakage current flows through the diode. However, as the voltage is increased, the zener voltage is reached. The diode lets current flow freely through the diode in the direction in which it is normally blocked. The diode is constructed to be able to handle the zener voltage and the resulting current, whereas avalanche voltage burns out a diode. A zener diode can be used as means of dropping voltage or voltage regulation. It can be used to step down circuit voltage for a particular application but only when certain input conditions exist. Zener diodes are constructed to handle a wide range of voltages. [**Figure 1-28**]

SIGNAL DIODES

Signal diodes are common semiconductor diodes that are typically used in radio signal processing. They pass small current usually up to 100 milliamps. [**Figure 1-29**]

SCHOTTKY DIODES

A Schottky diode is designed to have a metal, such as gold, silver, or platinum, on one side of the junction and doped silicon, usually

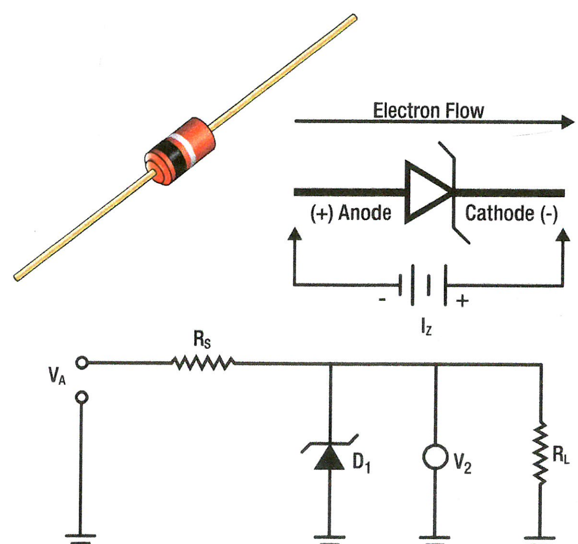


Figure 1-28. A Zener diode, when reversed biased, will break down and allow a prescribed voltage to flow in the direction normally blocked by the diode.

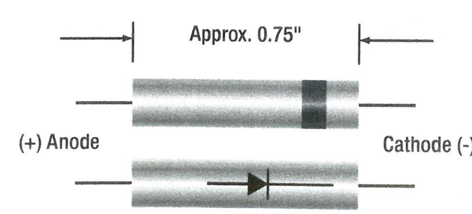


Figure 1-29. General purpose signal diodes.

an N-type, on the other side of the junction. In this respect, it is not a pure semiconductor diode. It is a metal semiconductor diode. A Schottky diode is considered a unipolar device because free electrons are the majority carrier on both sides of the junction. The Schottky diode has no depletion zone or charge storage, which means that the switching time can be as high as 300 MHz. The typical PN semiconductor switches much slower. When an opposite voltage to the voltage supply that forward biases a PN junction diode is applied, current in the diode continues to flow for a brief moment. This time is measurable and is known as reverse recovery time. Schottky diode reverse recovery time is much shorter which makes it suited for use in high frequency rectification. It also has a very low voltage drop (0.15 volts versus 0.7 volts for a silicon diode). **Figure 1-30** illustrates a Schottky diode and gives the schematic symbol.

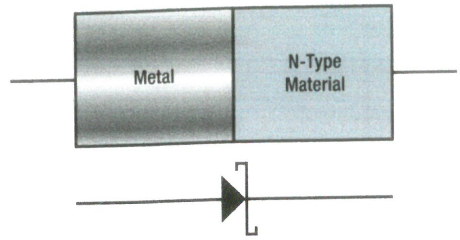


Figure 1-30. Schottky diode construction and schematic symbol.

VARISTORS

A varistor is not exactly a semiconductor diode. It is typically made of a ceramic mass of zinc oxide grains in a matrix of other metal oxides. This material is sandwiched between two metal plates which are the electrodes. [**Figure 1-31**] The numerous grains form diode relationships with other grains so that current flows in one direction only through the device. The current voltage relationship is nonlinear. A small or moderate amount of voltage applied to the varistor causes very little current flow. However, when a large voltage is applied, the effective junction breaks down and large current flow follows. Therefore the varistor has high resistance at low voltage and low resistance at high voltage. Varistors are often used to protect circuits against excessive transient voltages. They are incorporated so that, when triggered, they shunt the current created by the high voltage away from sensitive components. **Figure 1-32** illustrates the schematic symbol of a varistor. **Figure 1-33** shows the performance graph of a typical varistor.

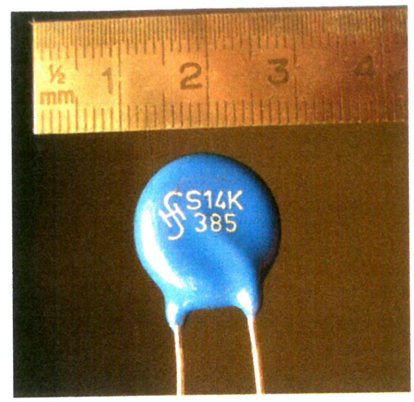


Figure 1-31. A Varistor.

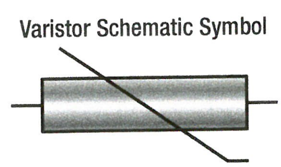


Figure 1-32. Schematic symbol of a varistor.

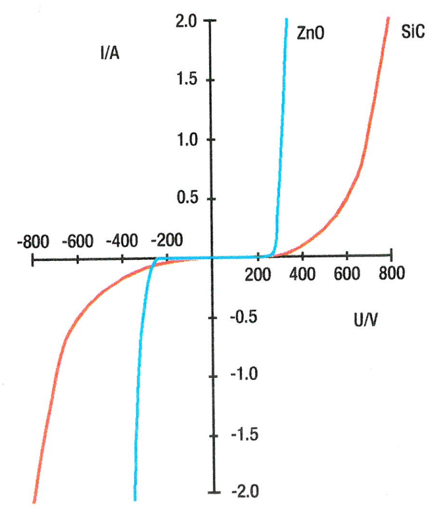


Figure 1-33. Varistor current-voltage characteristics for zinc oxide (ZnO) and silicon carbide (SiC) devices.

VARACTOR DIODES (VARICAP)

The varactor, or varicap, is a diode that behaves like a variable capacitor. Its capacitance is dependent on the applied voltage. The PN junction functions like the dielectric and the N and P materials like the plates of a common capacitor. Understanding how the varactor operates is an important prerequisite to understanding field-effect transistors (FETs), which are covered later in this *Submodule*. The schematic symbol and a varactor drawing is illustrated in **Figure 1-34**.

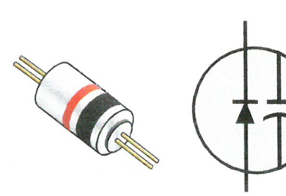


Figure 1-34. Varactor diode.

Figure 1-35 shows a PN junction. Surrounding the junction of the P and N materials is a narrow zone void of both positively and negatively charged current carriers. This area is called the depletion zone.

The size of the depletion zone in a varactor diode is directly related to the bias. Forward biasing makes the zone smaller by repelling the current carriers toward the PN junction. If the applied voltage is large enough (about 0.5 volt for silicon material), the negative particles will cross the junction and join with the positive particles, as shown in **Figure 1-36**. This forward biasing causes the depletion zone to decrease, producing a low resistance at the PN junction and a large current flow across it. This is the condition for a forward-biased diode.

On the other hand, if reverse-bias voltage is applied to the PN junction, the size of its depletion zone increases as the charged particles on both sides move away from the junction. This condition, shown in **Figure 1-37**, produces a high resistance between the terminals and allows little current flow (only in the microampere range). This is the operating condition for the varactor diode, which is nothing more than a special PN junction.

As the figure shows, the insulation gap formed by reverse biasing of the varactor is comparable to the layer of dielectric material between the plates of a common capacitor. Furthermore, the formula used to calculate capacitance (C) can be applied to both the varactor and the capacitor:

$$C = \frac{AK}{d}$$

Where:
- A = plate area
- K = a constant value
- d = distance between plates

In this case, the size of the insulation gap of the varactor, or depletion zone, is substituted for the distance between the plates of the capacitor. By varying the reverse-bias voltage applied to the varactor, the width of the "gap" may be varied. An increase in reverse bias increases the width of the gap (d) which reduces the capacitance (C) of the PN junction. Therefore, the capacitance of the varactor is inversely proportional to the applied reverse bias.

The ratio of varactor capacitance to reverse bias voltage change may be as high as 10 to 1. **Figure 1-38** shows one example of the voltage-to-capacitance ratio. View A shows that a reverse bias of 3 volts produces a capacitance of 20 picofarads in the varactor. If the reverse bias is increased to 6 volts, as shown in view B, the depletion zone widens and capacitance drops to 5 picofarads. Each 1-volt increase in reverse bias voltage causes a 5-picofarad decrease in the capacitance of the varactor; the ratio of change is therefore 5 to 1. Of course any decrease in applied reverse bias voltage would cause a proportionate increase in capacitance, as the depletion zone narrows. Notice that the value of the capacitance is small in the picofarad range.

Varactors are used to replace the old style variable capacitor tuning. They are used in tuning circuits of more sophisticated communication equipment and in other circuits where variable capacitance is required. One advantage of the varactor is that it allows a DC voltage to be used to tune a circuit for simple remote control or automatic tuning functions. One such application of the varactor is as a variable tuning capacitor in a receiver or transmitter tank circuit like that shown in **Figure 1-39**.

Figure 1-39 shows a dc voltage felt at the wiper of potentiometer R1 which can be adjusted between +V and –V. The DC voltage, passed through the low resistance of radio frequency choke L2, acts to reverse bias varactor diode C3. The capacitance of C3 is

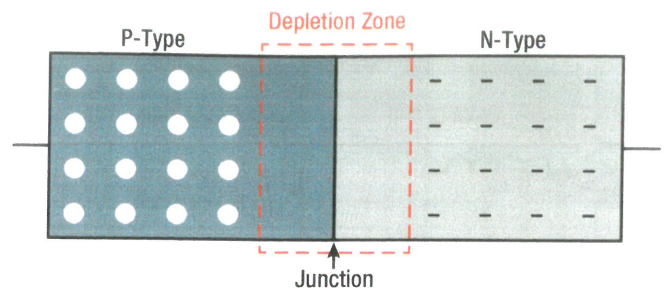


Figure 1-35. PN Junction.

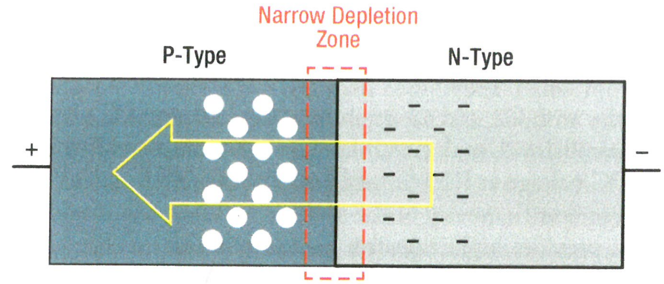


Figure 1-36. Forward biased PN Junction.

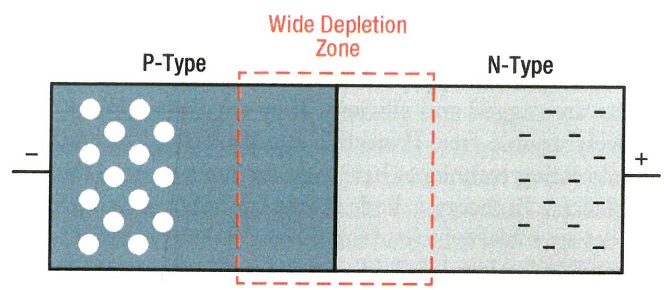


Figure 1-37. Reverse-bias PN Junction.

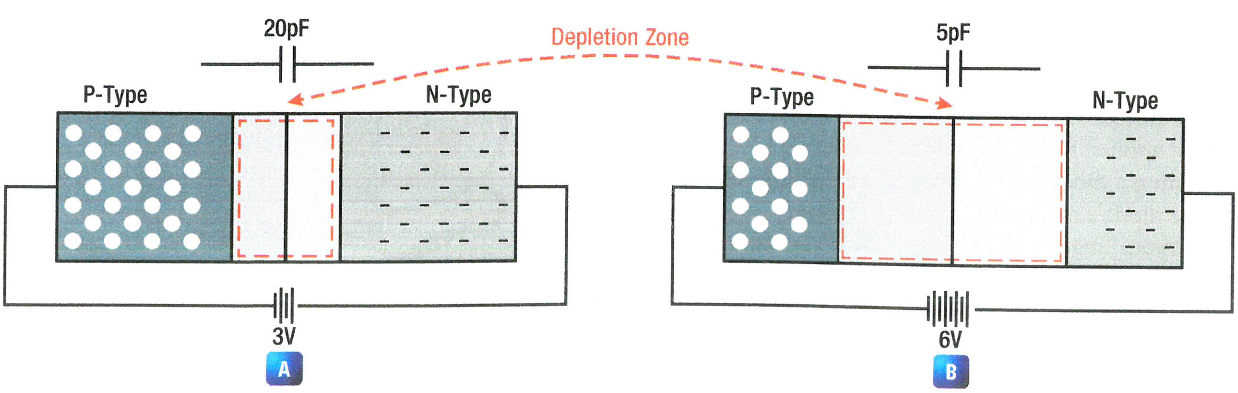


Figure 1-38. Varactor capacitance versus reverse-bias voltage.

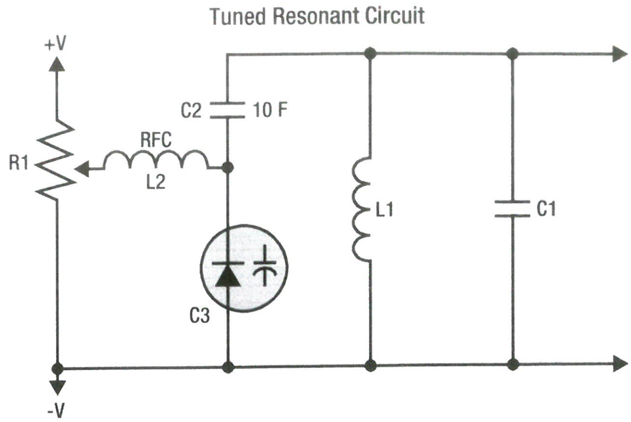


Figure 1-39. Varactor tuned resonant circuit.

in series with C2, and the equivalent capacitance of C2 and C3 is in parallel with tank circuit L1-C1. Therefore, any variation in the DC voltage at R1 will vary both the capacitance of C3 and the resonant frequency of the tank circuit. The radio frequency choke provides high inductive reactance at the tank frequency to prevent tank loading by R1. C2 acts to block DC from the tank as well as to fix the tuning range of C3. An ohmmeter can be used to check a varactor diode in a circuit. A high reverse-bias resistance and a low forward-bias resistance with a 10 to 1 ratio in reverse-bias to forward-bias resistance is considered normal.

FUNCTIONAL TESTING OF DIODES

Diodes are rugged and efficient. They are also expected to be relatively trouble free. Protective encapsulation processes and special coating techniques have even further increased their life expectancies. In theory, a diode should last indefinitely. However, if diodes are subjected to current overloads, their junctions will be damaged or destroyed. In addition, the application of excessively high operating voltages can damage or destroy junctions through arc-over, or excessive reverse currents.

One of the greatest dangers to the diode is heat. Heat causes more electron-hole pairs to be generated, which in turn increases current flow. This increase in current generates more heat and the cycle repeats itself until the diode draws excessive current. This action is referred to as thermal runaway and eventually causes diode destruction. Extreme caution should be used when working with equipment containing diodes to ensure that these problems do not occur and cause irreparable diode damage. The following is a list of some of the special safety precautions that should be observed when working with diodes:

- Never remove or insert a diode into a circuit with voltage applied.
- Never pry diodes to loosen them from their circuits.
- Always be careful when soldering to ensure that excessive heat is not applied to the diode.
- When testing a diode, ensure that the test voltage does not exceed the diode's maximum allowable voltage.
- Never put your fingers across a signal diode because the static charge from your body could short it out.
- Always replace a diode with a direct replacement, or with one of the same type.
- Ensure a replacement diode is put into a circuit in the correct direction.

If a diode has been subjected to excessive voltage or temperature and is suspected of being defective, it can be checked in various ways. The most convenient and quickest way of testing a diode is with an ohmmeter. [**Figure 1-40**] To make the check, simply disconnect one of the diode leads from the circuit wiring, and make resistance measurements across the leads of the diode. The resistance measurements obtained depend upon the test-lead polarity of the ohmmeter; therefore, two measurements must be taken. The first measurement is taken with the test leads connected to either end of the diode and the second measurement is taken with the test leads reversed on the diode.

The larger resistance value is assumed to be the reverse (back) resistance of the diode, and the smaller resistance (front) value is assumed to be the forward resistance. Measurement can be made for comparison purposes using another identical-type diode (known to be good) as a standard. Two high-value resistance measurements indicate that the diode is open or has a high forward resistance. Two low-value resistance measurements indicate that the diode is shorted or has a low reverse resistance. A normal set of measurements will show a high resistance in the reverse direction and a low resistance in the forward direction. The diode's efficiency is determined by how low the forward resistance is compared with the reverse resistance. That is, it is desirable to

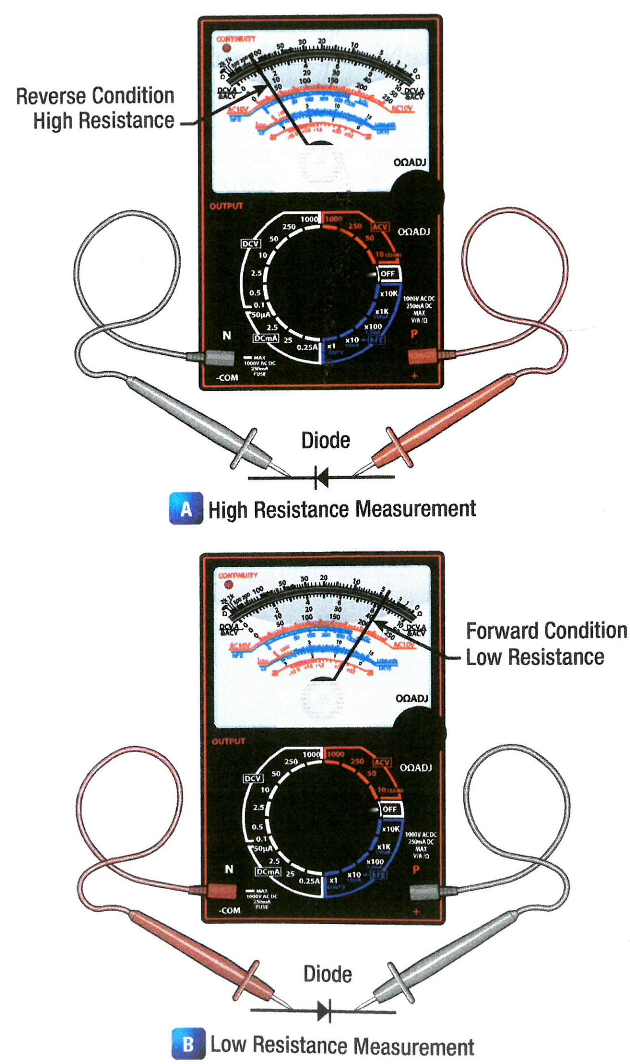


Figure 1-40. Checking a diode with an ohmmeter.

have as great a ratio (often known as the front-to-back ratio or the back-to-front ratio) as possible between the reverse and forward resistance measurements. However, as a rule of thumb, a small signal diode will have a ratio of several hundred to one, while a power rectifier can operate satisfactorily with a ratio of 10 to 1.

The ohmmeter check is not conclusive. It is still possible for a diode to check good under this test, but break down when placed back in the circuit. This occurs because the ohmmeter uses a lower voltage than that used by the diode when operating in the circuit. Another important point to remember is that a diode should not be condemned because two ohmmeters give different readings on the diode. This occurs because of the different internal resistances of the ohmmeters and the different states of charge on the ohmmeter batteries. Because each ohmmeter sends a different current through the diode, the two resistance values read on the meters will not be the same.

Another way of checking a diode is with the substitution method. In this method, a good diode is substituted for a questionable diode. This technique should be used only after you have made voltage and resistance measurements to make certain that there is no circuit defect that might damage the substitution diode. If more than one defective diode is present in the equipment section where trouble has been localized, this method becomes cumbersome, since several diodes may have to be replaced before the trouble is corrected. To determine which stages failed and which diodes are not defective, all of the removed diodes must be tested. This can be accomplished by observing whether the equipment operates correctly as each of the removed diodes is reinserted into the equipment.

Conclusion, the only valid check of a diode is a dynamic electrical test that determines the diode's forward current (resistance) and reverse current (resistance) parameters. This test can be accomplished using various crystal diode test sets that are readily available from many manufacturers.

4.1.2 TRANSISTORS

INTRODUCTION TO TRANSISTORS

The transistor is a three-terminal device primarily used to amplify signals and control current within a circuit. [**Figure 1-41**] The basic two-junction semiconductor must have one type of region sandwiched between two of the other type. The three regions in a transistor are the collector (C), which is moderately doped, the emitter (E), which is heavily doped, and the base (B), which is significantly less doped. The alternating layers of semiconductor material type provide the common commercial name for each type of transistor. The interface between the layers is called a junction. Selenium and germanium diodes previously discussed are examples of junction diodes. Note that the sandwiched layer or base is significantly thinner than the collector or the emitter. In general, this permits a "punching through" action for the carriers passing between the collector and emitter terminals.

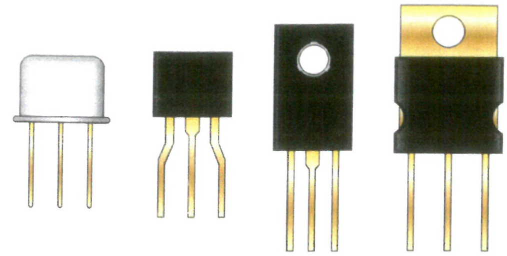


Figure 1-41. Typical transistors, diagrams of a PNP and NPN transistor.

CLASSIFICATION AND SYMBOLS

The transistors are classified as either NPN or PNP according to the arrangement of their N and P-materials. The NPN transistor is formed by introducing a thin region of P-material between two regions of N-type material. The opposite is true for the PNP configuration.

The two basic types of transistors along with their circuit symbols are shown in **Figure 1-42.** Note that the two symbols are different. The horizontal line represents the base, and two angular lines represent the emitter and collector. The angular line with the arrow on it is the emitter, while the line without is the collector. The direction of the arrow on the emitter determines whether or not the transistor is a PNP or an NPN type. If the arrow is pointing in, the transistor is a PNP. On the other hand, if the arrow is pointing out, then it is an NPN type.

IDENTIFICATION OF TRANSISTORS

Figure 1-43 illustrates some of the more common transistor lead identifications. The methods of identifying leads vary due to a lack of a standard and require verification using manufacturer information to properly identify. However, a short description of the common methods is discussed below.

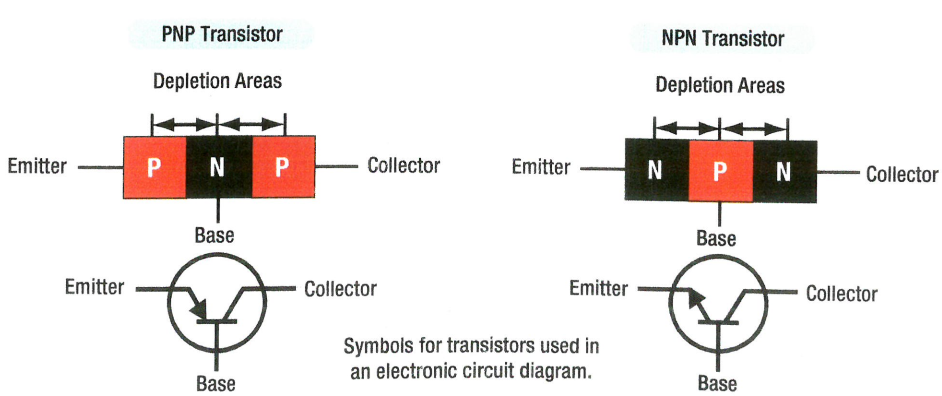


Figure 1-42. Typical transistors, diagrams of a PNP and NPN transistor, and the symbol for those transistors when depicted in an electronic circuit diagram.

Figure 1-43D shows an oval-shaped transistor. The collector lead in this case is identified by the wide space between it and the lead for the base. The final lead at the far left is the emitter. In many cases, colored dots indicate the collector lead, and short leads relative to the other leads indicate the emitter. In a conventional power diode, as seen in Figure 1-43E, the collector lead is usually a part of the mounting bases, while the emitter and base are leads or tines protruding from the mounting surface.

COMPONENT DESCRIPTION AND ORIENTATION

Like a vacuum tube triode, the transistor has three electrodes or terminals, one each for the three layers of semiconductor material. The emitter and the collector are on the outside of the sandwiched semiconductor material. The center material is known as the base. A change in a relatively small amount of voltage applied to the base of the transistor allows a relatively large amount of current to flow from the collector to the emitter. In this way, the transistor acts as a switch with a small input voltage controlling a large amount of current.

If a transistor is put into a simple battery circuit, such as the one shown in Figure 1-44, voltage from the battery (EB) forces free electrons and holes toward the junction between the base and the emitter just as it does in the junction of a semiconductor diode. The emitter-base depletion area becomes narrow as free electrons combine with the holes at the junction. Current (IB) (solid arrows) flows through the junction in the emitter-base battery circuit. At the same time, an emitter-collector circuit is constructed with a battery (EC) of much higher voltage in its circuit. Because of the narrow depletion area at the emitter base junction, current IC is able to cross the collector base junction, flow through emitter-base junction, and complete the collector-emitter battery circuit (hollow arrows).

To some extent, varying the voltage to the base material can increase or decrease the current flow through the transistor. The emitter-base depletion area changes width in response to the base voltage. If base voltage is removed, the emitter-base depletion area becomes too wide and all current flow through the transistor ceases. Current in the transistor circuit illustrated has a relationship as follows: $I_E = I_B + I_C$. It should be remembered

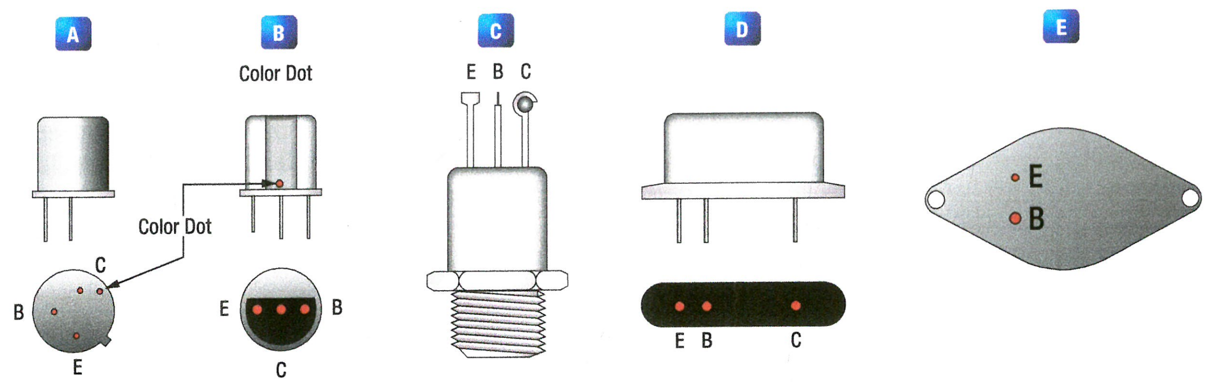


Figure 1-43. Common transistor lead identifications.

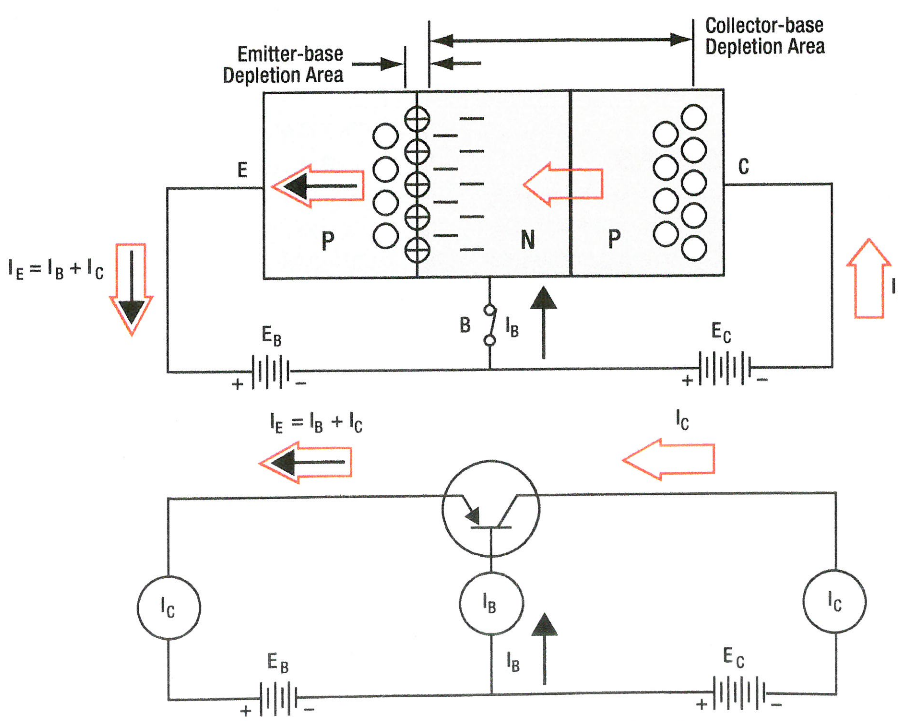


Figure 1-44. The effect of applying a small voltage to bias the emitter-base junction of a transistor (top). A circuit diagram for this same transistor (bottom).

that it is the voltage applied to the base that turns the collector-emitter transistor current ON or OFF.

Controlling a large amount of current flow with small independent input voltage is very useful when building electronic circuits. Transistors are the building blocks from which all electronic devices are made, including Boolean gates that are used to create micro processor chips. As production techniques have developed, the size of reliable transistors has shrunk. Now, hundreds of millions and even billions of transistors may be used to construct a single chip such as the one that powers your computer and various avionic devices.

SHOCKLEY DIODE

The combination of semiconductor materials is not limited to a PN junction diode or a two type, three layer sandwich transistor. Creating a four layer sandwich of alternating types of semiconductor material (i.e., PNPN or NPNP), a slightly different semiconductor diode is created. As is the case in a two layer diode, circuit current is either blocked or permitted to flow through the diode in a single direction.

Within a four layer diode, sometimes known as a Shockley diode, there are three junctions. The behavior of the junctions and the entire four layer diode can be understood by considering it to be two interconnected three layer transistors. [**Figure 1-45**]

Transistor behavior includes no current flow until the base material receives an applied voltage to narrow the depletion area at the base emitter junction. The base materials in the four layer diode transistor model receive charge from the other transistor's collector. With no other means of reducing any of the depletion areas at the junctions, it appears that current does not flow in either direction in this device. However, if a large voltage is applied to forward bias the anode or cathode, at some point the ability to block flow breaks down. Current flows through whichever transistor is charged. Collector current then charges the base of the other transistor and current flows through the entire device.

Some caveats are necessary with this explanation. The transistors that comprise this four layer diode must be constructed of material similar to that described in a zener diode. That is, it must be able to endure the current flow without burning out. In this case, the voltage that causes the diode to conduct is known as breakover voltage rather than breakdown voltage. Additionally, this diode has the unique characteristic of allowing current flow to continue until the applied voltage is reduced significantly, in most cases, until it is reduced to zero. In AC circuits, this would occur when the AC cycles.

SILICON CONTROLLED RECTIFIERS (THYRISTORS)

While the four-layer, Shockley diode is useful as a switching device, slight modification to its design creates a silicon controlled rectifier (SCR). To construct a SCR, an additional terminal known as a gate is added. It provides more control and utility. In the four-layer semiconductor construction, there are always two junctions forward biased and one junction reversed biased. The added terminal allows the momentary application of voltage to the reversed biased junction. All three junctions then become forward biased and current at the anode flows through the device. Once voltage is applied to the gate, the SCR become latched or locked on. Current continues to flow through it until the level drops off significantly, usually to zero. Then, another applied voltage through the gate is needed to reactivate the current flow. [**Figure 1-46 and 1-47**]

SCRs are often used in high voltage situations, such as power switching, phase controls, battery chargers, and inverter circuits. They can be used to produce variable DC voltages for motors and are found in welding power supplies. Often, lighting dimmer systems use SCRs to reduce the average voltage applied to the lights by only allowing current flow during part of the AC cycle. This is controlled by controlling the pulses to the SCR gate and eliminating the massive heat dissipation caused when using resistors to reduce voltage.

Figure 1-48 graphically depicts the timing of the gate pulse that limits full cycle voltage to the load. By controlling the phase during which time the SCR is latched, a reduced average voltage is applied.

TRIACS

SCRs are limited to allowing current flow in one direction only. In AC circuitry, this means only half of the voltage cycle can be used and controlled. To access the voltage in the reverse cycle from an AC power source, a triac can be used. A triac is also a four layer semiconductor device. It differs from an SCR in that

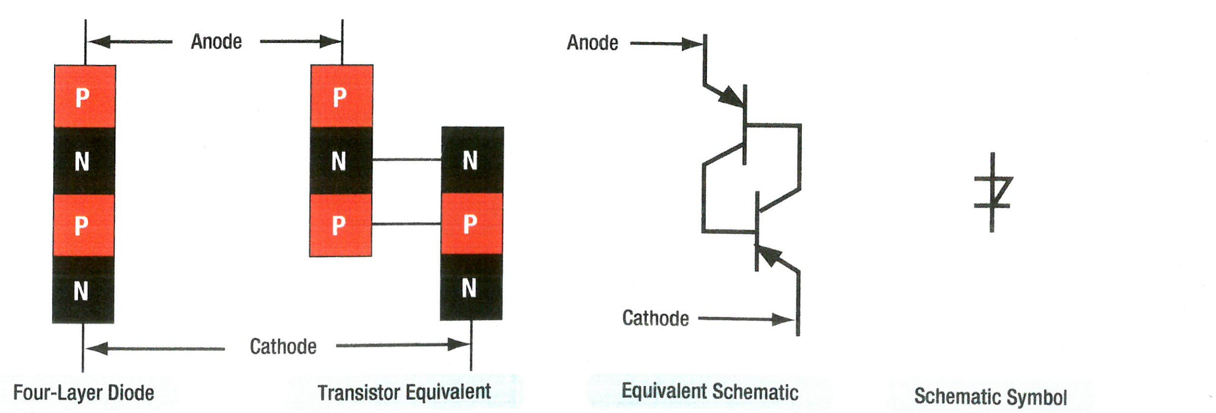


Figure 1-45. A four-layer semiconductor diode behaves like two transistors. When breakover voltage is reached, the device conducts current until the voltage is removed.

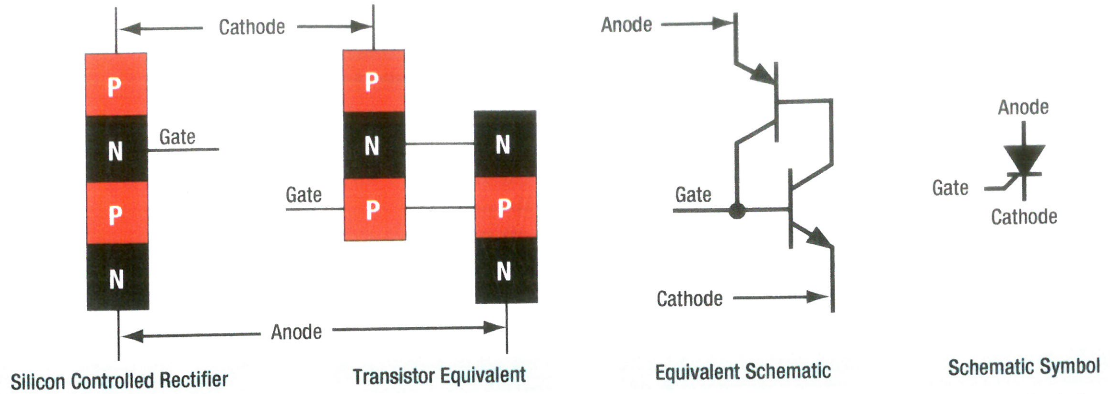


Figure 1-46. A silicon controlled rectifier (SCR) allows current to pass in one direction when the gate receives a positive pulse to latch the device in the on position. Current ceases to flow when it drops below holding current, such as when AC current reverses cycle.

it allows current flow in both directions. A triac has a gate that works the same way as in a SCR; however, a positive or negative pulse to the gate triggers current flow in a triac. The pulse polarity determines the direction of the current flow through the device.

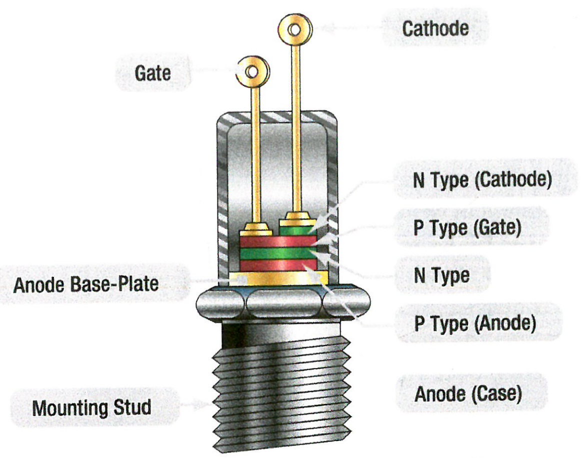


Figure 1-47. Cross-section of a medium power SCR.

Figure 1-49 illustrates a triac and shows a triac in a simple circuit. It can be triggered with a pulse of either polarity and remains latched until the voltage declines, such as when the AC cycles. Then, it needs to be triggered again. In many ways, the triac acts as though it is two SCRs connected side by side only in opposite directions. Like an SCR, the timing of gate pulses determines the amount of the total voltage that is allowed to pass. The output waveform is triggered at 90° cycles as shown in **Figure 1-49**. Because a triac allows current to flow in both directions, the reverse cycle of AC voltage can also be used and controlled.

When used in actual circuits, triacs do not always maintain the same phase firing point in reverse as they do when fired with a positive pulse. This problem can be regulated somewhat through the use of a capacitor and a diac in the gate circuit. However, as a result, where precise control is required, two SCRs in reverse of each other are often used instead of the triac. Triacs do perform well in lower voltage circuits.

Figure 1-50 illustrates the semiconductor layering in a triac.

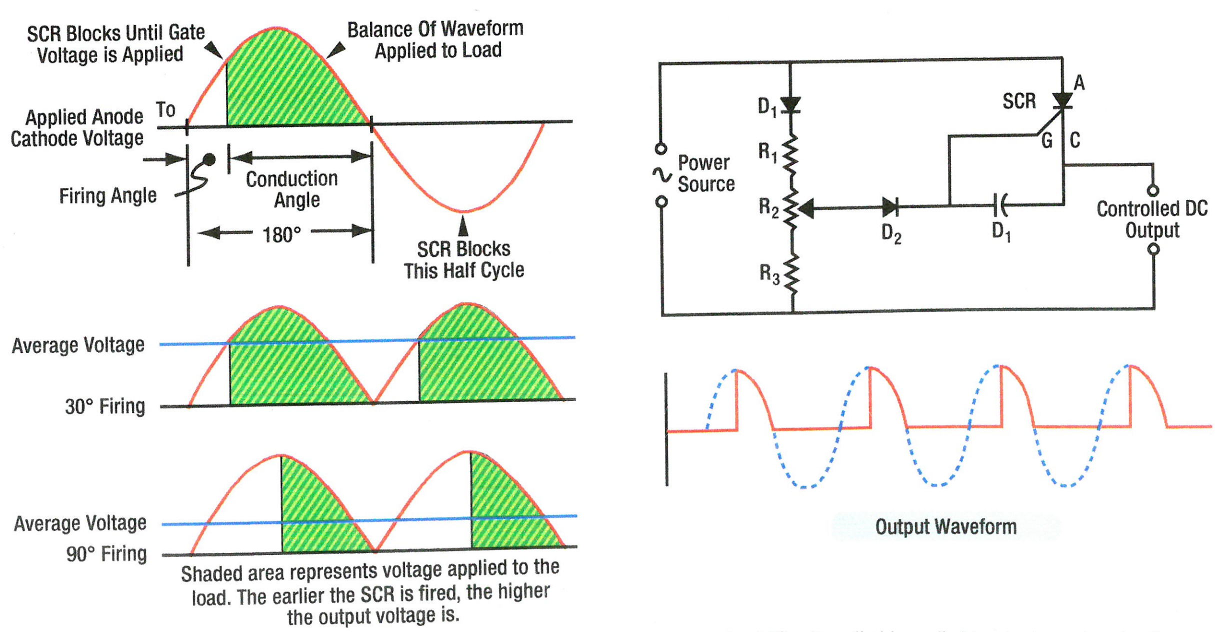


Figure 1-48. Phase control is a key application for SCR. By limiting the percentage of a full cycle of AC voltage that is applied to a load, a reduced voltage results. The firing angle or timing of a positive voltage pulse through the SCR's gate latches the device open allowing current flow until it drops below the holding current, which is usually at or near zero voltage as the AC cycle reverses.

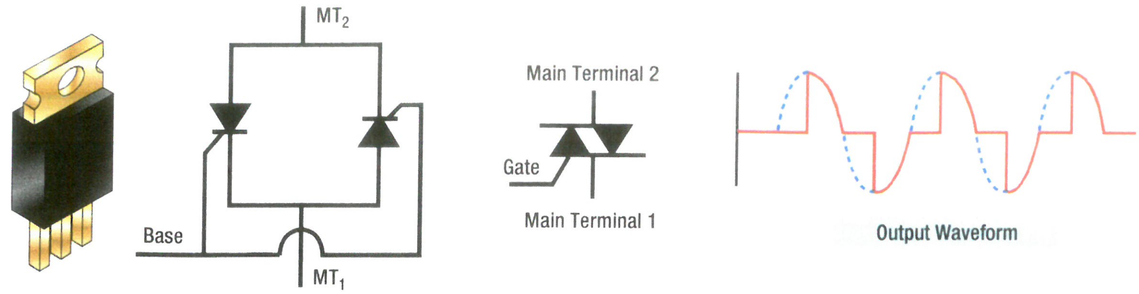


Figure 1-49. A triac is a controlled semiconductor device that allows current flow in both directions.

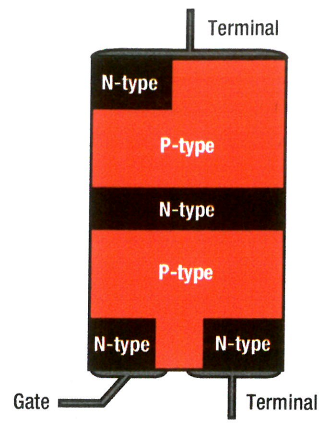


Figure 1-50. The semiconductor layering in a triac. A positive or negative gate pulse with respect to the upper terminal allows current to flow through the devise in either direction.

Note that the four layers of N-type and P-type materials are not uniform as they were in previously described semiconductor devices. None the less, gate pulses affect the depletion areas at the junctions of the materials in the same way allowing current to flow when the areas are narrowed.

TRANSISTORS, CHARACTERISTICS AND PROPERTIES

Tiny transistors are at the heart of all electronic devices. There are many different types of transistors. All have semiconductor junctions arranged in various fashions to product slightly different operating characteristics.

UNIJUNCTION TRANSISTORS (UJT)

The behavior of semiconductor materials is exploited through the construction of numerous transistor devices containing various configurations of N-type and P-type materials. The physical arrangement of the materials in relation to each other yields devices with unique behaviors and applications. The transistors described above having two junctions of P-type and N-type materials (PN) are known as bipolar junction transistors. Other more simple transistors can be fashioned with only one junction of the PN semiconductor materials.

These are known as Unijunction Transistors (UJT). **[Figure 1-51]** The UJT contains one base semiconductor material and a different type of emitter semiconductor material. There is no collector material. One electrode is attached to the emitter and two electrodes are attached to the base material at opposite ends. These are known as base 1 (B1) and base 2 (B2). The electrode configuration makes the UJT appear physically the same as a bipolar junction transistor. However, there is only one PN junction in the UJT and it behaves differently. The base material of a UJT behaves like a resistor between the electrodes. With B2 positive with respect to B1, voltage gradually drops as it flows through the base. **[Figure 1-52]**

By placing the emitter at a precise location along the base material gradient, the amount of voltage needed to be applied to the emitter electrode to forward bias the UJT base-emitter junction is determined. When the applied emitter voltage exceeds the voltage at the gradient point where the emitter is attached, the junction is forward biased and current flows freely from the B1

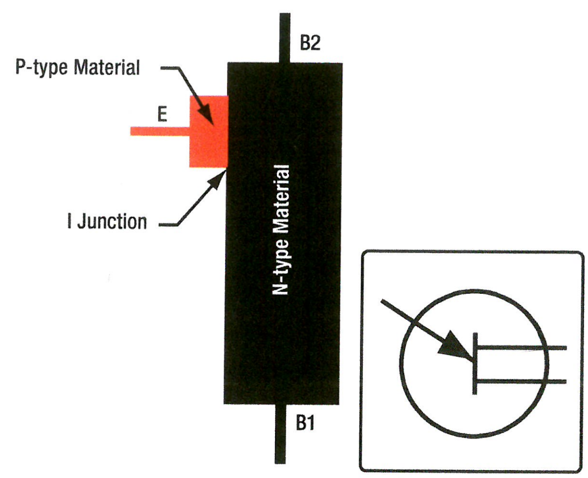


Figure 1-51. A unijunction transistor (UJT).

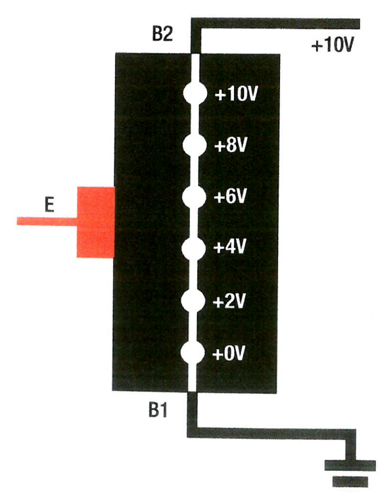


Figure 1-52. The voltage gradient in a UJT.

electrode to the E electrode. Otherwise, the junction is reversed biased and no significant current flows although there is some leakage. By selecting a UJT with the correct bias level for a particular circuit, the applied emitter voltage can control current flow through the device.

UJTs transistors of a wide variety of designs and characteristics exist. A description of all of them is beyond the scope of this discussion. In general, UJTs have some advantages over bipolar transistors. They are stable in a wide range of temperatures. In some circuits, use of UJTs can reduce the overall number of components used, which saves money and potentially increases reliability. They can be found in switching circuits, oscillators, and wave shaping circuits. However, four-layered semiconductor thyristors that function the same as the UJT just described are less expensive and most often used.

FIELD EFFECT TRANSISTORS (FET)

As shown in the triac and the UJT, creative arrangement of semiconductor material types can yield devices with a variety of characteristics. The field effect transistor (FET) is another such device which is commonly used in electronic circuits. Its N-type and P-type material configuration is shown in **Figure 1-53.** A FET contains only one junction of the two types of semiconductor material. It is located at the gate where it contacts the main current carrying portion of the device. Because of this, when an FET has a PN junction, it is known as a junction field effect transistor (JFET). All FETs operate by expanding and contracting the depletion area at the junction of the semiconductor materials.

One of the materials in a FET or JFET is called the channel. It is usually the substrate through which the current needing to be controlled flows from a source terminal to a drain terminal. The other type of material intrudes into the channel and acts as the gate. The polarity and amount of voltage applied to the gate can widen or narrow the channel due to expansion or shrinking of the depletion area at the junction of the semiconductors. This increases or decreases the amount of current that can flow through the channel. Enough reversed biased voltage can be applied to the gate to prevent the flow of current through the channel. This allows the FET to act as a switch. It can also be used as a voltage controlled resistance.

FETs are easier to manufacture than bipolar transistors and have the advantage of staying on once current flow begins without continuous gate voltage applied. They have higher impedance than bipolar transistors and operate cooler. This makes their use ideal for integrated circuits where millions of FETs may be in use on the same chip. FETs come in N-channel and P-channel varieties.

METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTORS (MOSFETS) AND COMPLEMENTARY METAL OXIDE SEMICONDUCTORS (CMOS)

The basic FET has been modified in numerous ways and continues to be at the center of faster and smaller electronic component development. A version of the FET widely used is the metal oxide semiconductor field effect transistor (MOSFET). The MOSFET uses a metal gate with a thin insulating material between the

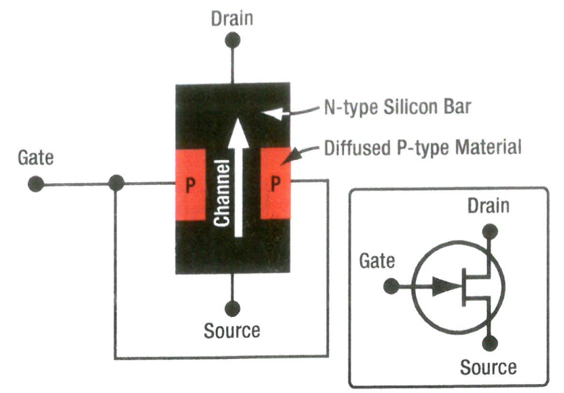


Figure 1-53. The basic structure of a field effect transistor and its electronic symbol.

gate and the semiconductor material. This essentially creates a capacitor at the gate and eliminates current leakage in this area.

As with FETs, MOSFETs come with N-channels or P-channels. They can also be constructed as depletion mode or enhancement mode devices. This is analogous to a switch being normally open or normally closed. Depletion mode MOSFETs have an open channel that is restricted or closed when voltage is applied to the gate (i.e., normally open). Enhancement mode MOSFETs allow no current to flow at zero bias but create a channel for current flow when voltage is applied to the gate (normally closed). No voltage is used when the MOSFETs are at zero bias. Millions of enhancement mode MOSFETs are used in the construction of integrated circuits. They are installed in complimentary pairs such that when one is open, the other is closed. This basic design is known as complementary MOSFET (CMOS), which is the basis for integrated circuit design in nearly all modern electronics. Through the use of these transistors, digital logic gates can be formed and digital circuitry is constructed. Other more specialized FETs exist. Some of their unique characteristics are owed to design alterations and others to material variations. The transistor devices discussed above use silicon-based semiconductors. But the use of other semiconductor materials can yield variations in performance. Metal semiconductor FETs (MESFETS) for example, are often used in microwave applications.

They have a combined metal and semiconductor material at the gate and are typically made from gallium arsenide or indium phosphide. MESFETs are used for their quickness when starting and stopping current flows especially in opposite directions. High electron mobility transistors (HEMT) and pseudomorphic high electron mobility transistors (PHEMT) are also constructed from gallium arsenide semiconductor material and are used for high frequency applications. Many have poly-crystalline silicon gates rather than metal, but the MOSFET name remains and the basic behavioral characteristic are the same. [**Figure 1-54**]

4.1.3 INTEGRATED CIRCUITS

Integrated Circuits (ICs) are many complete digital electronic circuits constructed in the same basic location. The location is known as a chip, processor, microchip or microprocessor. TTL or CMOS circuits are miniaturized and manufactured on tiny, thin silicon semiconductor wafers. Assemblies with billions of transistors can fit on a chip the size of a fingernail. [**Figure 1-55**]

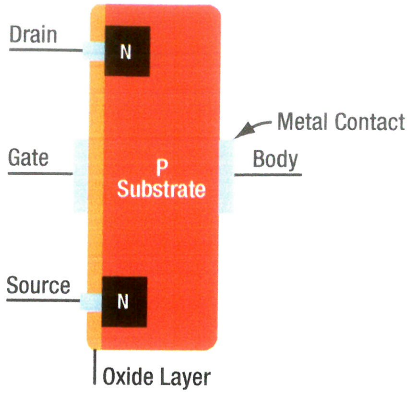


Figure 1-54. A MOSFET has a metal gate and an oxide layer between it and the semiconductor material to prevent current leakage.

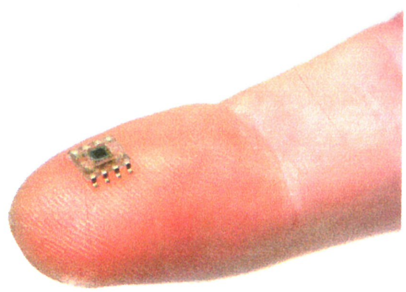


Figure 1-55. Integrated circuits.

With so many transistors and logic gates, a yes/no system of computing virtually any task is developed. Integrated circuits are used in nearly every modern computing and electronic device, including the many electronic devices found on aircraft. The microscopic circuits are constructed directly on the silicon chip during manufacture and cannot be removed or separated.

A microprocessor contains one (or more) integrated circuit microchips at the core of the processing unit. It responds to input in accordance with instructions contained in its own memory. The chips are programmable to accomplish different tasks with little change to the actual processor other than the instructions. At the physical limitations of placing integrated circuits on a single chip, electronic developers have created microprocessors that combine the use of more than one chip in the architecture. These enable 64 bit (and more) processing with extremely fast processing times due to the proximity of the integrated circuits to each on the tiny chip assemblies.

DUAL IN-LINE PACKAGE (DIP)

To facilitate the use of integrated circuits and other electronic components, standards have been developed. The dual in-line package standard (DIP) is one such standard that allows the installation of micro components onto printed circuit boards. It basically calls for two rows of connecting terminals, equally spaced along each edge of the IC housing as shown in **Figure 1-56**. The dimensions of the terminals are standardized as is their use (i.e. power, ground, output, etc). They come in a variety of sizes with various numbers of terminals. Inside a DIP element there can be transistor circuits, logic circuits and even complete integrated circuits and microprocessors as shown in the illustration.

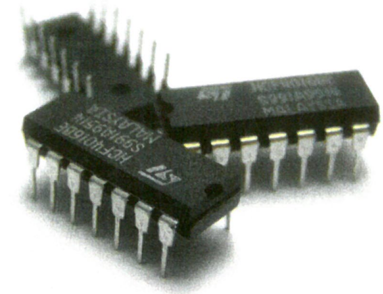


Figure 1-56. A DIP element containing a microprocessor and connection terminals for installation on a printed circuit board.

LINEAR CIRCUITS

A logic circuit is device that performs a logical operation with on one or more binary inputs that produces a single binary output. The primary way of building logic circuits (or gates) is with diodes or transistors which act as electronic switches. Most logic gates are made from MOSFETs but can also be constructed using vacuum tubes, electromagnetic relays or even mechanical devices. Logic circuits include such devices as multiplexers, registers, computer memory, all the way up through complete microprocessors, which may contain more than 100 million logic gates.

Basic logic gate types; (AND, NOT, NAND, OR, NOR, and exclusive OR) can be combined into more complex circuits so that a complex function can be achieved with only simple yes/no instructions. [**Figure 1-57**] The various types of logic gates/circuits are covered in more detail in module 5 of this series.

LINEAR CIRCUITS AND OPERATIONAL AMPLIFIERS

A linear circuit is one in which the output is directly proportional to the input. If graphed, the performance of the circuit would be drawn as a straight line. An electronic circuit made up of linear components that maintain their values regardless of the level of voltage or current in the circuit is linear. Circuits composed exclusively of ideal resistors, capacitors, inductors, transformers and other linear circuit elements are linear.

Linear circuits are easy to analyze mathematically. The sum of the inputs to a linear circuit is equal to the output. Linear circuits are used in small signal amplifiers, differentiators, and integrators. Diodes and transistors are nonlinear. However, nonlinear components are often used to assemble circuits that are approximately linear.

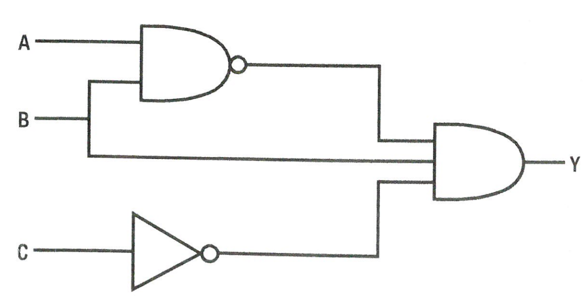


Figure 1-57. A simple logic circuit diagram in which 3 inputs equals 1 output.

An operational amplifier is an electronic high-gain differential voltage amplifier. The output can be hundreds of thousands times greater than the difference between the voltage of its inputs. The output is also linear with the difference between the input potential. Op-amps are integrated circuits usually constructed as a DIP for easy integration into a wide variety of electronic circuits. They are used in a wide variety of electronic circuits including signal processing circuits, control circuits and instrumentation. Operational amplifiers can also be used to drive small motors.

Question 1-1
What is done to an element to make it a semiconductor material?

Question 1-2
Which of the following are commonly used as rectifiers in electrical circuits?
1. Anodes
2. Reference to a parallel circuit
3. Diodes
   A. 1, 3
   B. 2, 3
   C. 3

Question 1-3
When a PN junction is forward biased, the depletion zone ___________.

Question 1-4
The voltage applied to a reversed biased diode that causes the diode to breakdown and allow current to flow is known as ___________.

Question 1-5
A typical application for zener diodes is as:
   A. full-wave rectifiers.
   B. half-wave rectifiers.
   C. voltage regulators.

Question 1-6
A rectifier diode is used in applications that require ___________ current.

Question 1-7
Name three dangers of diodes.

Question 1-8
A diode offers ___________ to current flow which causes a ___________ drop.

Question 1-9
A silicon controlled rectifier (SRC's) use a ___________ to control when current flows through the device.

Question 1-10
UJT's and FET's are types of ___________.

SUBMODULE 1 PRACTICE QUESTIONS

Answer 1-1
The lattice of pure element is doped with elements that contain 3 or 5 valence electrons.

Answer 1-2
C

Answer 1-3
narrows.

Answer 1-4
avalanche voltage.

Answer 1-5
C

Answer 1-6
high

Answer 1-7
Heat, over-voltage, over-current.

Answer 1-8
resistance
voltage

Answer 1-9
gate

Answer 1-10
transistors

Printed Circuit Boards

SUBMODULE KNOWLEDGE DESCRIPTIONS		LEVEL
		B1
4.2	**Printed Circuit Boards** Description and use of printed circuit boards.	1

4.2 PRINTED CIRCUIT BOARDS

DESCRIPTION AND USE OF PRINTED CIRCUIT BOARDS

An electric circuit is typically comprised of various components connected by wire. In many cases, the circuit performs a function that doesn't require the circuit or components to be large. The development of solid state devices and the use of transistors has enabled many required electric functions on an aircraft to be carried out with small electronic circuits saving both space and weight. These circuits are often created on printed circuit boards (PCBs). PCBs are building blocks of nearly all electronic devices from the simple mouse used with a personal computer to the computer itself. Very complex avionics radio and navigation equipment are also constructed with printed circuit board technology.

A printed circuit board is constructed from a thin sheet of non-conductive material often just 1⁄16-inch (1.5 mm) thick. It can be sized as needed to contain the required circuit(s) and components or to fit the housing designed to contain the board. Two common materials used to make PCBs are resin impregnated paper and epoxy resin impregnated fiber glass cloth. Typically, copper foil is bonded to the surface of the board in a heat press operation. Then, the copper is etched away leaving only the conductive pathways of the circuits. Early PCBs commonly had holes drilled at the connection points of the components. The conductive paths called traces were created with the copper foil on one side of the board and components were located on the opposite side. Component leads were passed through the holes to be soldered to the traces on the other side. [**Figure 2-1**] Modern PCBs surface mount the components on the same side as the copper traces.

Circuit boards can be single-sided as described but are often double-sided or multi-layered with copper circuit traces and components on both sides. Surface mounted components then allow more components and circuits on the same PCB since they are attached on both sides of the board. Multilayer PCBs also are used where several layers of boards are stacked. These can be joined electrically by what looks like a hollow rivet called a via. Vias resemble the early holes used to attached components but are actually conductive paths between layers of PCB.

The circuit(s) to be placed on the board are typically designed with computer software and transferred to the bonded copper surface by various techniques. The unnecessary copper material is etched away leaving only the circuit traces. Very complex circuits are possible with attachment of all types of electronic devices including resistors, transistors, integrated circuits and microprocessors. [**Figure 2-2**]

The soldering process required for attaching components to printed circuit boards requires special equipment with precise heat control and is not performed in the field. Removable PCBs, called cards, allow replacement of defective units or repair in an equipped shop by knowledgeable technicians. [**Figure 2-3**]

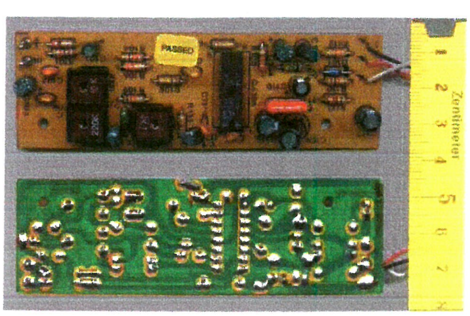


Figure 2-1. A single layer printed circuit board with traces and solder connections on one side and the soldered components on the other side.

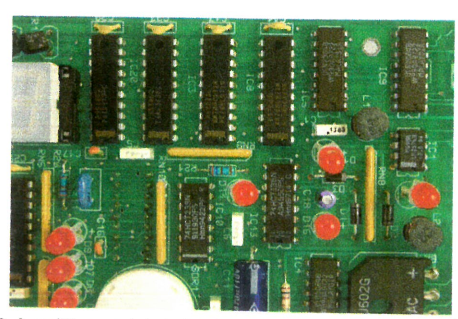


Figure 2-2. A multilayer printed circuit board with LED's, Microprocessors and various other components and traces mounted on both sides of the board.

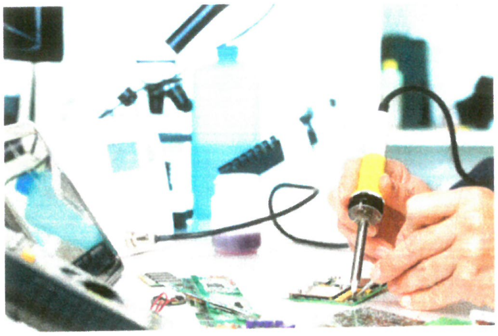


Figure 2-3. Repair of a printed circuit board or card.

Often, the boards with components attached are coated with a protective substance that must be removed before repairs can be made.

STATIC ELECTRICITY

RISKS AND POSSIBLE DAMAGE

Static electricity is a simple fact of nature. It is around us all the time and is caused by friction. Most work environments have non-conductive floors and no means of controlling the humidity. As the humidity drops below 20%, a static charge builds up on a person's body. The faster the person walks, the higher the charge. Simply walking across a carpet can generate 1 500 volts of static electricity at 65% relative humidity and up to 35 000 volts of static electricity at 20% relative humidity. Plastics used in most products will produce charges from 5 000 to 10 000 volts. Once the person sits down at the work station, the electrostatic field surrounding their body is enough to cause damage to sensitive electronic components without even touching them. However, when the person touches the component, an electrostatic discharge or spark occurs, and zap, the component is most certainly destroyed. [**Figure 2-4**]

Electro-Static Discharge (ESD) is defined in U.S. military handbook DOD-HKBK-263 as "transfer of electrostatic charges between bodies at different potentials caused by direct contact or induced by an electrostatic field". In other words, an electrostatic charge on one body can be imparted to another body through induction from an electromagnetic field, or through conduction via physical contact. If an electronic component that is charged is then suddenly grounded, the charge will dissipate to ground, but in the process, the component will be damaged due to excessive heat from breakdown of the dielectric material within the component.

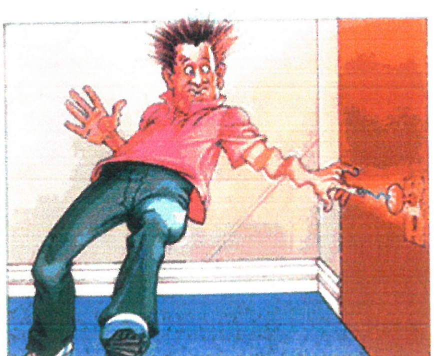


Figure 2-4. Electrostatic discharge.

Electrostatic induction occurs when a charged object induces the redistribution of charges in another object. A classic example of this is picking up pieces of paper using a comb that was rubbed against fur. In **Figure 2-5**, the comb is charged negative, meaning that there exists an excess of electrons built up on the comb. The side of the paper closest to the comb will end up being slightly positive due to the attraction of opposite charges, while the opposite side of the paper will be slightly negative due to the repulsion of similar charges.

MIL-STD-1686C is the US military standard for "ESD control programs for the protection of electrical and electronic parts, assemblies, and equipment". It recognizes two classes of ESD-sensitive items: Class I for 100 to 1 000 volts and Class II for 1 001 to 4 000 volts sensitivity. Most electronic components are in Class I. For example, bi-polar transistors are susceptible to ESD between 380 to 7 000 volts; CMOS devices are susceptible between 250 volts and 3 000 volts; and EPROMs, used in computer memories, are susceptible to as low as 100 volts.

The ESD issue is not going away. In fact, the problem is getting much worse. As component technology continues to advance to achieve higher speeds and greater functionality, their physical geometries are shrinking, which are causing components to become even more susceptible to lower discharge voltages. The following section will discuss special handling of ESD-sensitive components and anti-static protection devices which must be used to protect these sensitive electronic components from the dangers of electrostatic discharge.

ANTI-STATIC PROTECTION

CONTROLLED ENVIRONMENT

Static electricity can't be eliminated. It can only be controlled. Therefore, it is essential to only handle ESD sensitive devices in static-safe controlled environment. Signage must be placed outside any ESD controlled areas to warn people that special precautions must be taken before entering the controlled environment. [**Figure 2-6**] Any insulating materials, such as nylon, mylar, vinyl, rubber, mica, ceramics, fiberglass, wood, styrofoam, and plastic, will store static electricity, and therefore, should be kept out of the work area. Technicians should only enter the work area wearing anti-static (steel mesh) smocks and conductive (leather-soled) footwear. If wearing an anti-static heel strap in place ofconductive shoes, the grounding cord must run into the sock in order to make contact with the skin.

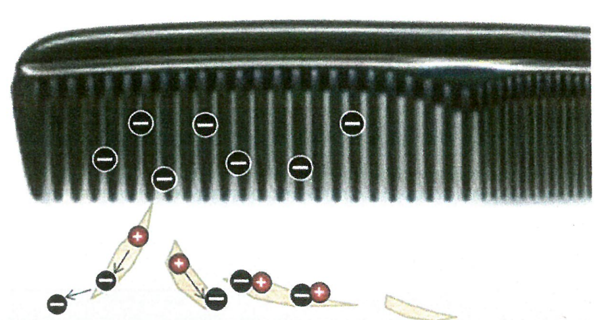


Figure 2-5. Electrostatic induction.

STATIC-SAFE WORKSTATION

Conductive materials, including personnel, must be grounded. The floor surface should be covered with conductive paints or coatings, anti-static floor finishes, or anti-static vinyl flooring. As shown in **Figure 2-7**, the work station should have a static dissipative floor mat and table-top mat that have a surface resistivity of 105 to 1 012 ohms per square inch. The conductive mat not only provides a surface that is free of static charge on which to work, but must also remove the static charge from conductive items placed on it. Both the floor and table-top mats should be connected through a 1 mega-ohm resistor connected to a common ground point. The resistor is required to protect personnel in the event the ground becomes electrically live.

ANTI-STATIC WRIST STRAPS

The same safety requirement holds true for the anti-static wrist strap [**Figure 2-8**] in that the coil cord must be plugged or clipped into a receptacle with a 1 mega-ohm resistor connected to a common ground point. The wrist strap must be secure around the wrist at all times while seated at the work station so that it makes good electrical connection with the skin to dissipate any electrical charge to ground before touching sensitive electronic components.

GROUNDING TEST STATIONS

All anti-static devices should be tested before entering the static-safe controlled environment. **Figure 2-9** is a picture of a typical grounding test station used to determine whether the anti-static devices are working properly. A green indicator light means that the wrist strap is worn properly and is working as intended. The test station can also be used to test footwear, heal straps, and coil cords as well.

IONIZERS

Since it is not practical to raise the relative humidity to high levels due to operator discomfort and the fact that it would cause metals to rust, the controlled environment should be equipped with ionizers to neutralize any charged insulators commonly found in the work environment. Because positively or negatively charged surfaces will attract ions of the opposite charge, an air stream containing both positive and negative ions is used to neutralize the charged surface. Once the surface is neutralized, it remains so as long as the ion stream is present.

Ionizers are available in high-pressure, low-volume air guns for periodic localized cleaning, and low-pressure, high-volume wall-mounted units designed to be suspended over the work station with the ionized air blowing down over the area to be protected against an ESD event. [**Figure 2-10**]

Designed to cover a work station area, the ionizer will neutralize even the highest electrostatic charge. Normally the system is mounted 30"-36" above the area to be controlled, producing a balanced ionization pattern of approximately 36" wide by 48" long. It is highly recommended to use an electrostatic field

Figure 2-6. Warning sign for an ESD controlled area.

Figure 2-8. Anti-static electricity grounding wristband.

Figure 2-7. Static-safe workstation.

Figure 2-9. Typical grounding test station.

meter to detect static charges in the work area to be assured that the ionizer is functioning properly before handling sensitive components. If the ionizer is not working properly, topical anti-static should be sprayed in the work area to control the generation and accumulation of electrostatic charges.

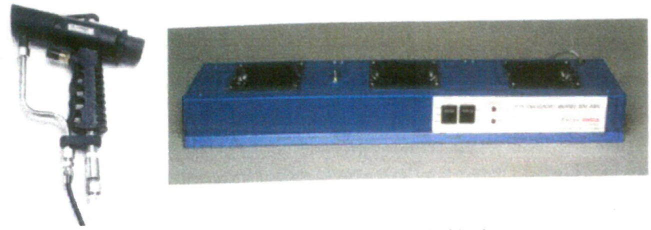


Figure 2-10. Hand-held and wall-mounted ionizers.

SPECIAL HANDLING

All ESD sensitive components should transported in a closed conductive container (e.g., LRU or a tote box). The container must be stored on a grounded rack, and when moved to the work station, it must make contact with the grounded table mat. Any accumulated charge on the human body should first be discharged, by wearing the grounded anti-static wrist strap, before opening the protective container containing the ESD sensitive component. Also, always use a grounded soldering iron to install ESD sensitive components.

All ESD components should be packaged in an electrostatic shielded conductive bag. These laminated bags are made from an outer layer of transparent metalized sheet or an aluminum foil material, a middle insulation layer, and an inner anti-static layer. Finally, the bag is sealed with a label warning that there is an ESD sensitive component inside. [**Figure 2-11**]

Figure 2-11. Laminated metalized bag for storing ESD sensitive components.

Question 2-1
The board of a printed circuit board is made of __________ material.

Question 2-2
A conductive path on a printed circuit board is called a __________.

Question 2-3
What is the purpose of hollow rivets connecting layers of a stacked circuit board?

Question 2-4
In what circumstance during line maintenance may a printed circuit board be repaired.

Question 2-5
How does one maintain a static-free workstation?

Question 2-6
What is the reason for using ionizers?

SUBMODULE 2 PRACTICE QUESTIONS

Answer 2-1
non-conductive.

Answer 2-2
trace

Answer 2-3
Provides and electrical path between the boards.

Answer 2-4
Never. Printed circuit boards may not be repaired in the field. They must be replaced.

Answer 2-5
The work station should have a static dissipative floor mat and table-top mat that are connected through a 1 mega-ohm resistor to a common ground point. The wrist strap must be secure around the wrist at all times while seated at the work station so that it makes good electrical connection with the skin to dissipate any electrical charge to ground before touching sensitive electronic components. The wrist strap cord must be plugged into a receptacle with a 1 mega-ohm resistor connected to the same common ground point.

Answer 2-6
A controlled environment should be equipped with ionizers to neutralize any charged insulators commonly found in the work environment. Because positively or negatively charged surfaces will attract ions of the opposite charge, an air stream containing both positive and negative ions is used to neutralize the charged surface. Once the surface is neutralized, it remains so as long as the ion stream is present.

Submodule

3

Servomechanisms

SUBMODULE KNOWLEDGE DESCRIPTIONS		LEVEL
		B1
4.3	**Servomechanisms** (a) Principles Understanding of the following principles: open- and closed-loop systems, servomechanism, feedback, follow-up, null, overshoot, damping, deadband, hunting, proximity switches, analogue transducers, synchro systems and components, digital tachometers and encoders, inductance, and capacitance transmitters;	1
	(b) Construction operation and use of the following synchro-system components: resolvers, differential, control and torque, E and I transformers, inductance transmitters, capacitance transmitters, synchronous transmitters; Construction, operation and use of servomechanism and PID controller; Fault-finding of servo defects, reversal of synchro leads, hunting.	-

4.3 SERVOMECHANISMS

SERVOMECHANISM PRINCIPLES

A servomechanism is a physical device that responds to an input control signal by forcing an output actuator to perform a desired function. Servomechanisms are often the connection between computers, electronics, and mechanical actions. If computers are the brains, servomechanisms are the muscles and the hands that do physical work. Servomechanisms use electronic, hydraulic, or mechanical devices to control power. Servomechanisms enable an operator to perform dangerous tasks at a distance and are often employed to control large objects using fingertip control.

The power steering assistance accessory on automobiles is a familiar example of a servomechanism. Automotive power steering uses hydraulic fluid under great pressure to power an actuator that redirects the wheels of a car as needed. The driver gently turns the steering wheel and the power-assist servomechanism provides the necessary energy to position the wheels.

The Boeing 777 is the first heavy jet plane engineered to fly with all major flight-control functions managed by servomechanisms. The design of this revolutionary plane is based on the so-called "fly-by-wire" system. In normal flight a digital signal communicates the pilot's instructions electrically to control servomechanisms that position the plane's control surfaces as needed.

A servomechanism is an electric control system for an automatic powered mechanism that produces motion or force using a low energy input signal. The amplified system typically drives an electric or hydraulic motor however the motion can be rotary or linear depending on the mechanical transmission of the force. Servomechanisms are integral in automatic flight control systems (autopilots). They are also used in auto throttle systems, radar scanner systems and more. The next discussion focuses on autopilot systems but the principles are the same for any servomechanism.

OPEN AND CLOSED SYSTEMS

An open loop system is one in which the controls are set to the desired setting. The signal produced in the controller is amplified to operate a motor which moves the controlled unit, in this case the flight controls, to the selected setting. If there is something that prevents the unit from actually reaching the desired setting, the control system does not know this. The system is said to be open because of this lack of feedback as to the results of the setting. Bearing friction, wind resistance and other factors may cause a flight control setting on the controller to not actually be achieved. Open systems are not used on advanced aircraft autopilot or automatic flight control systems.

FEEDBACK AND FOLLOW-UP

A closed servomechanism system is one in which there is feedback, or follow-up, from the controlled unit. This is done in the form of an electric or electronic signal. The actual position of the unit is fed back as an input to the controller so that adjustments can be made to achieve or maintain the original selected settings. The follow-up information on the position of a controlled device is often accomplished with an analog transducer.

NULL

As related to servomechanisms, the term "Null" refers to a neutral or zeroed condition. It is the standby point where the controlling actuator is in a neutral position and is neither engaging nor disengaging a controlled function.

In a closed loop system, if a disagreement exists between the input instructions and the output results, the system will automatically "null" the disagreement or cancel the command, leaving the actuator in a neutral or un-commanded position.

In radio electronics, "null" has a different meaning. "Null" is a direction in an antenna's radiation pattern where the antenna radiates almost no waves.

OVERSHOOT

There are three characteristics that indicate when a servo system is properly tuned: response time, settling time, and overshoot. Response time is the time it takes the system to reach a specified target. Settling time is how long it takes for the target value to be settled. Overshoot is when the system exceeds the target value. The goal of tuning a servomechanism is to minimize response time, settling time, and overshoot.

Figure 3-1 describes this process, along with that of Dampening. As shown, zero % value represents the Null state, and the light blue line represents the target. Overshoot is depicted by the red line where the target value is at first exceeded. The actuator movement then bounces back below the target value and then gradually settles at the desired target value. The extent of this settling and the time it takes to occur is known as dampening.

DAMPING

In **Figure 3-1** the damping of the system can reduce the oscillations and prevent hunting. A servo system in which oscillations exist, but cease after a few passes of the target point, is said to be underdamped. If the system approaches the target point without any oscillations in a minimum time, the system is said to be critically damped.

HUNTING

The goal of tuning a servomechanism is to minimize position error. One undesirable result of a poorly tuned system can be that it continuously overshoots and then undershoots, struggling to settle at the target position. This process is often referred to as hunting.

DEADBAND

The interval in the signal of the transducer where there is no output present is called the "deadband". For example, the deadband for a transducer would be the amount of motion on either side of Null before a signal appears in the transducer outputs. This interval determines the accuracy of the control system. A small interval is said to have a tight deadband and results in a higher degree of precision. However, if the deadband is too tight, it will cause oscillations to occur due to the inertia of the output. As a result, the transducer will successively hunt back and forth to converge on its null point and achieve control system stability.

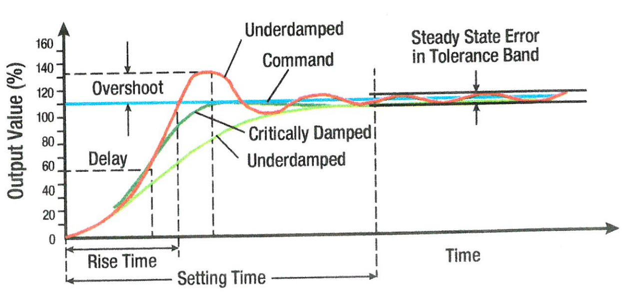


Figure 3-1. A depiction of a servomechanism actuator movement including an initial overshoot surge and the following dampening to the target value.

PROXIMITY SWITCHES

A proximity switch is used to determine how close an object is, or the proximity of an object. This is determined by using means such as magnetic, electric, or optical. Proximity switches can detect the approach of a metallic object with the help of a magnetic or electromagnetic field.

Most proximity switches use a permanent magnet to close a circuit if an object's ferrous part come close to it. Others operate by energizing a coil of wire with an electric current. The magnitude of the current is monitored and will trip if a metallic part gets close to the coil. Optical proximity sensors include a light source and a sensor that detects the light. These sensors detect objects directly in front of them by the detecting the sensor's own transmitted light reflected back from an object's surface. [**Figure 3-2**]

A typical use of a proximity sensor would be on an aircraft landing gear, thus providing feedback to the servomechanisms which control the raising or lowering the gear.

ANALOG TRANSDUCER

A transducer is an electric device which converts the differing position of the physical flight control surface in to a variable electric output signal that can be processed by the controller. It is basically a transformer with two secondary induction coils and a moving core that is attached to the controlled unit. As the unit moves, the core moves, which changes the value of the voltage induced in the two secondary coils. The differential of the output voltages of the coils is the feedback signal sent to the controller. [**Figure 3-3**]

Figure 3-2. A variety of proximity sensors used in aviation applications.

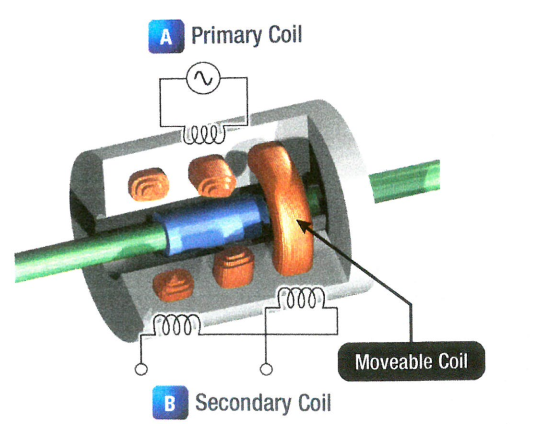


Figure 3-3. Cutaway view of a Linear Variable Differential Transducer (LVDT). Current is driven through the primary coil at A, causing an induction current to be generated through the secondary coils at B.

Both linear (LVDT) and rotary differential transducers (RVDTs) are used. Since there is only an inductive connection between the primary and secondary coils, the transducers are very stable linear devices that operate accurately and reliably for long periods of time. The core, which is mechanically linked to the flight control, or other unit whose movement is being controlled, is the only moving part.

SYNCHRO SYSTEMS

Another type of position monitoring system that incorporates feedback is known as a synchro system. A synchro system is an electric system used for transmitting information from one point to another. The word "synchro" is a shortened form of the word "synchronous" and refers to any one of a number of similarly operating two-unit electrical systems capable of measuring, transmitting, and indicating a certain parameter on the aircraft. Most analog position-indicating instruments are designed around a synchro system, such as a flap position indicator. Fluid pressure indicators may also use synchro systems. Synchro systems are used as remote position indicators for landing gear, autopilot systems, radar, and many other remote-indicating applications.

The common types of synchro systems include the autosyn, selsyn, and magnesyn synchro systems. These systems are similar in construction, and all operate by exploiting the consistent relationship between electricity and magnetism. The fact that electricity can be used to create magnetic fields that have definite direction, and that magnetic fields can interact with magnets and other electromagnetic fields, is the basis of their operation. A description of a DC synchro system provides the basic concept of how a synchro system works. AC systems are more refined and common on transport category aircraft.

AC SYNCHRO SYSTEMS

Aircraft with alternating current (AC) electrical power systems make use of autosyn or magnasysn synchro remote indicating systems. Both operate in a similar way to the DC selsyn system, except that AC power is used. Thus, they make use of electric induction, rather than resistance current flows defined by the rotor brushes.

Magnasyn systems use permanent magnet rotors such a those found in the DC selsyn system. Usually, the transmitter magnet is larger than the indicator magnet, but the electromagnetic response of the indicator rotor magnet and pointer remains the same. It aligns with the magnetic field set up by the coils, adopting the same angle of deflection as the transmitter rotor. [**Figure 3-4**] Again, the flight control surface or other unit whose position is being monitored is attached to the transmitter rotor.

Autosyn systems are further distinguished by the fact that the transmitter and indicator rotors used are electro-magnets rather than permanent magnets. Nonetheless, like a permanent magnet, an electro-magnet aligns with the direction of the magnetic field created by current flowing through the stator coils in the indicator. Thus, the indicator pointer position mirrors the transmitter rotor position. [**Figure 3-5**]

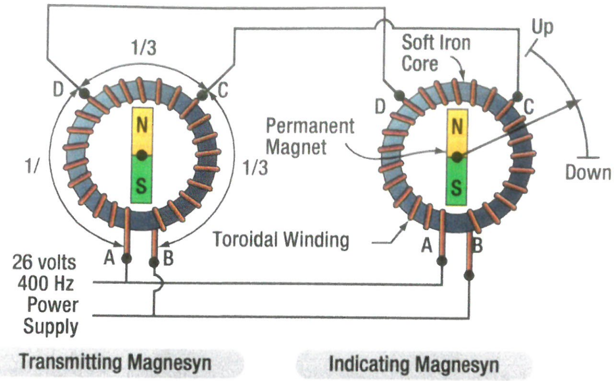


Figure 3-4. A magnasysn synchro remote-indicating system uses AC. It has permanent magnet rotors in the transmitter and indictor.

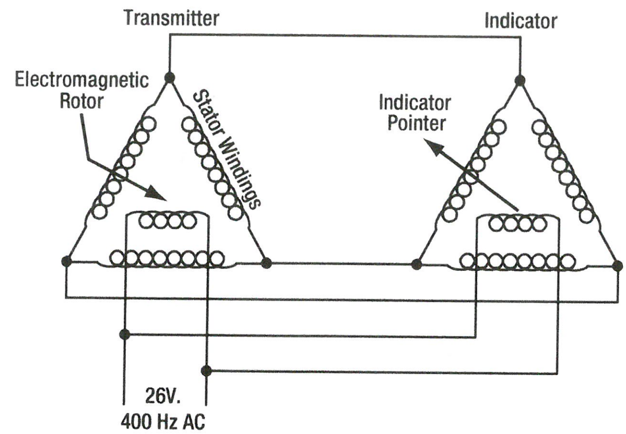


Figure 3-5. An autosyn remote-indicating system utilizes the interaction between magnetic fields set up by electric current flow to position the indicator pointer.

AC synchro systems are wired differently than DC systems. The varying current flows through the transmitter and indicator stator coils are induced as the AC cycles through zero and the rotor magnetic field flux is allowed to flow. The important characteristic of all synchro systems is maintained by both the autosyn and magnasyn systems. That is, the position of the transmitter rotor is mirrored by the rotor in the indicator. These systems are used in many of the same applications as the DC systems and more. Since they are usually part of instrumentation for high performance aircraft, adaptations of autosyn and magnasyn synchro systems are frequently used in directional indicators and in autopilot systems.

Modern AC synchro systems include variants of the AC synchros described. A torque synchro system was alluded to above. The transmitter synchro sets up the electromagnetic field in the receiver synchro and the electromagnetic rotor of the receiver, responding to the field, has enough torque to move the indicator pointer or some other small-torque device. In a control synchro, the receiver is known as the control transformer. It amplifies the signals from the transmitter which then turn a motor to position an indicator, or more typically, a larger device or heavier load. The signal produced in a control synchro is known as an error signal. This is because the voltage represents the amount and direction that the synchro rotors are out of correspondence. It is this error signal that is used to ultimately move the load once the signal has been amplified. **Figure 3-6** illustrates the basic setup of a control synchro system.

A differential synchro system includes the transmitter and receiver but also includes a differential synchro between the two. The basic concept is that the differential synchro accepts position input from two synchros and creates an output that is the differences between the two input synchros. This can be either the sum or difference between the inputs.

A resolver is a type of synchro system. Unlike those described, the stator windings on a resolver are at 90 degree angles to each other instead of 120 degrees. The 90 degree spacing provides Sine and Cosine stator outputs that represent the angular displacement of the rotor attached to the device being sensed. Signals from resolvers are typically input into analog to digital converters. **Figure 3-7** is a simplified diagram of a resolver.

DC SELSYN SYSTEMS

On aircraft with Direct Current (DC) electrical systems, the DC selsyn system is widely used. The DC selsyn system consists of a transmitter, an indicator, and connecting wires. The transmitter consists of a circular resistance winding and a rotatable contact arm. The rotatable contact arm turns on a shaft in the center of the resistance winding. The two ends of the arm are brushes and always touch the winding on opposite sides. [**Figure 3-8**]

On position indicating systems, the shaft to which the contact arm is fastened protrudes through the end of transmitter housing and is attached to the unit whose position is to be transmitted (e.g., flaps, landing gear). The transmitter is often connected to the moving unit through a mechanical linkage. As the unit moves, it causes the transmitter shaft to turn. The arm is turned so that voltage is applied through the brushes to any two points around the circumference of the resistance winding. The rotor shaft of DC selsyn systems, measuring other kinds of data, operates the same way, but may not protrude outside of the housing. The sensing device, which imparts rotary motion to the shaft, could be located inside the transmitter housing.

Referring to **Figure 3-8** note that the resistance winding of the transmitter is tapped off in three fixed places, usually 120°apart. These taps distribute current through the toroidal windings of the indicator motor. When current flows through these windings, a magnetic field is created. Like all magnetic fields, a definite north and south direction to the field exists. As the transmitter rotor shaft is turned, the voltage-supplying contact arm moves. Because it contacts the transmitter resistance winding in different positions, the resistance between the supply arm and the various tapoffs changes. This causes the voltage flowing through the tapoffs to change as the resistance of sections of the winding become longer or shorter. The result is that varied current is sent via the tapoffs to the three windings in the indicator motor.

The resultant magnetic field created by current flowing through the indicator coils changes as each receives varied current from the transmitter tapoffs. The direction of the magnetic field also changes. Thus, the direction of the magnetic field across the indicating element corresponds in position to the moving arm in the transmitter. A permanent magnet is attached to the centered rotor shaft in the indicator, as is the indicator pointer. The magnet aligns itself with the direction of the magnetic field and the pointer

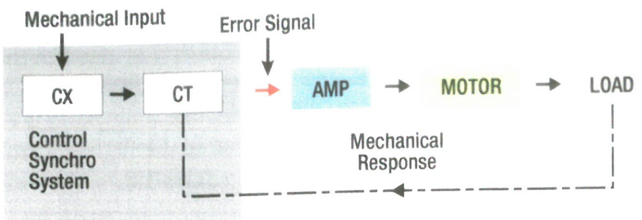


Figure 3-6. A positioning servo system using a control synchro system.

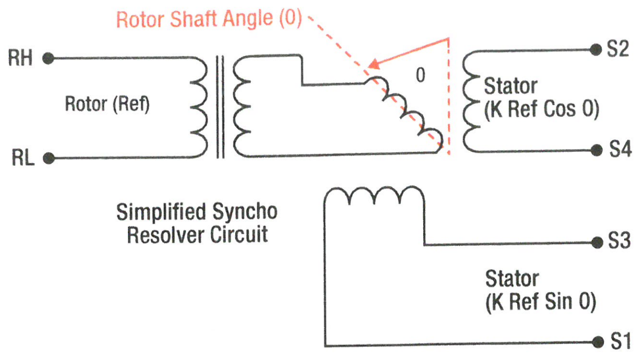


Figure 3-7. A simplified synchro resolver circuit.

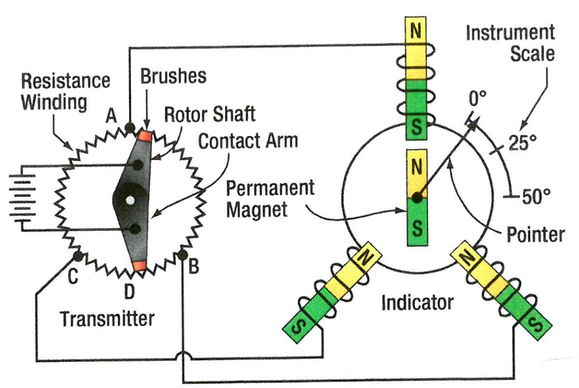


Figure 3-8. A schematic of a DC selsyn synchro remote indicating system.

does as well. Whenever the magnetic field changes direction, the permanent magnet and pointer realign with the new position of the field. Thus, the position of the aircraft device is indicated.

Landing gear contain mechanical devices that lock the gear up, called an up-lock, or down, called a down-lock. When the DC selsyn system is used to indicate the position of the landing gear, the indicator can also show that the up-lock or down-lock is engaged. This is done by again varying the current flowing through the indicator's coils. Switches located on the actual locking devices close when the locks engage. Current from the selsyn system described above flows through the switch and a small additional circuit. The circuit adds an additional resistor to one of the transmitter winding sections created by the rotor arm and a tapoff. This changes the total resistance of that section. The result is a change in the current flowing through one of the indicator's motor coils.

This, in turn, changes the magnetic field around that coil. Therefore, the combined magnetic field created by all three motor coils is also affected, causing a shift in the direction of the indicator's

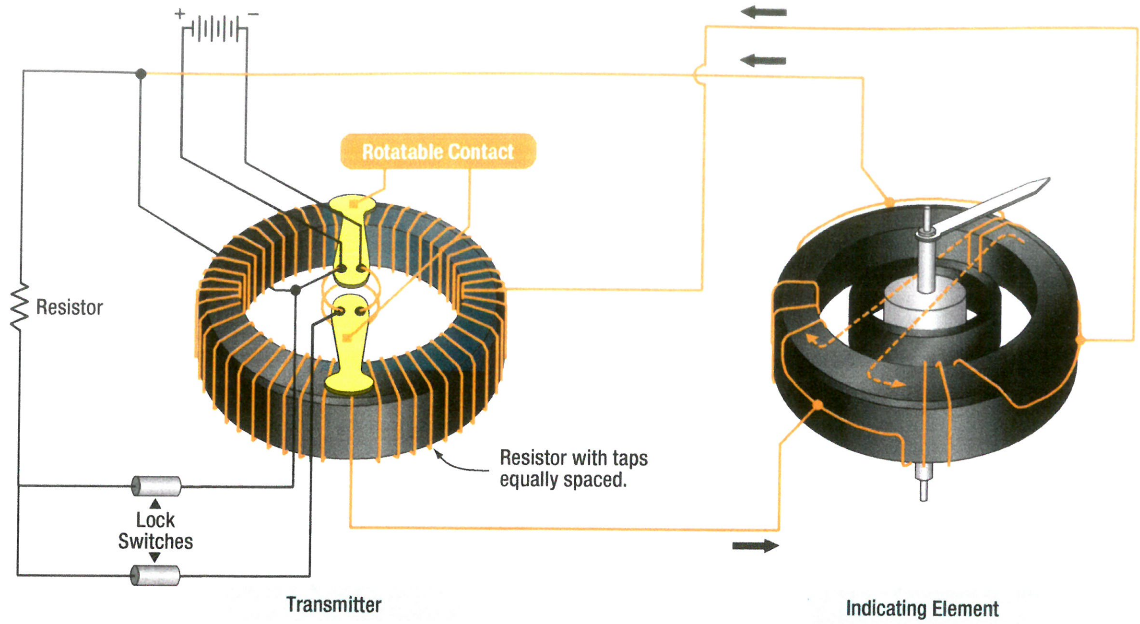


Figure 3-9. A lock switch circuit can be added to the basic DC selsyn synchro system when used to indicate landing gear position and up- and down-locked conditions on the same indicator.

magnetic field. The permanent magnet and pointer align with the new direction and shift to the locked position on the indicator dial. **Figure 3-9** shows a simplified diagram of a lock switch in a three-wire selsyn system and an indicator dial.

DIGITAL TACHOMETERS AND ENCODERS

An encoder is a sensor that notifies the servo driver of the speed and position of the motor. A servo motor encoder detects the rotation angle, speed, and travel distance of a moving part and sends positional feedback to the controller. The controller then sends electrical signals to the driver, which amplifies and translates the signals for the servo motor.

A servo tachometer, is similar but provides only rotational speed of the servo motor, without sensing the position, angle or distance of the motor or servo component.

INDUCTANCE TRANSMITTERS

There are other methods of transmitting condition information on aircraft. An inductance transmitter is used in older instruments, acceleration sensors and air data computers. It uses inductance windings similar to a synchro but the shape and spatial location of the laminated core is that of a capital letter "E". The center limb of the E is fed primary voltage and the upper and lower limbs contain secondary windings. An I-shaped bar of conductive material pivots in synch with the position of the element being sensed. It is located at the open end of the E. As the bar pivot, the space between the upper and lower limbs of the E changes. The voltage induced in the secondary coils on these limbs also changes due to the bar's influence on the electromagnetic field. The varied output of the secondary windings is interpreted as the sensor position.

Figure 3-10 shows the inductance transmitter set up with the pivoting sensor/bar in three different positions.

CAPACITANCE TRANSMITTERS

A capacitance transmitter is another type of device used on aircraft to transmit condition. It is found most often in transport category aircraft fuel quantity systems. Since a capacitor is a device that stores electricity, the amount it can store depends on three factors: the area of its plates, the distance between the plates, and the dielectric constant of the material separating the plates. A fuel tank unit contains two concentric plates that are a fixed distance apart. Therefore, the capacitance of a unit can change if the dielectric constant of the material separating the plates varies. The units are open at the top and bottom so they can assume the same level of fuel as is in the tanks. Therefore, the material between the plates is either fuel (if the tank is full), air (if the tank is empty), or some ratio of fuel and air depending on how much fuel remains in the tank. **Figure 3-11** shows a simplified illustration of this construction.

The voltage stored in a reference capacitor completely submerged in fuel is compared to the transmitter capacitor or group of capacitors wired in parallel. The basic bridge circuit for this is shown in **Figure 3-12**. The difference is a signal which is translated for display on the flight deck.

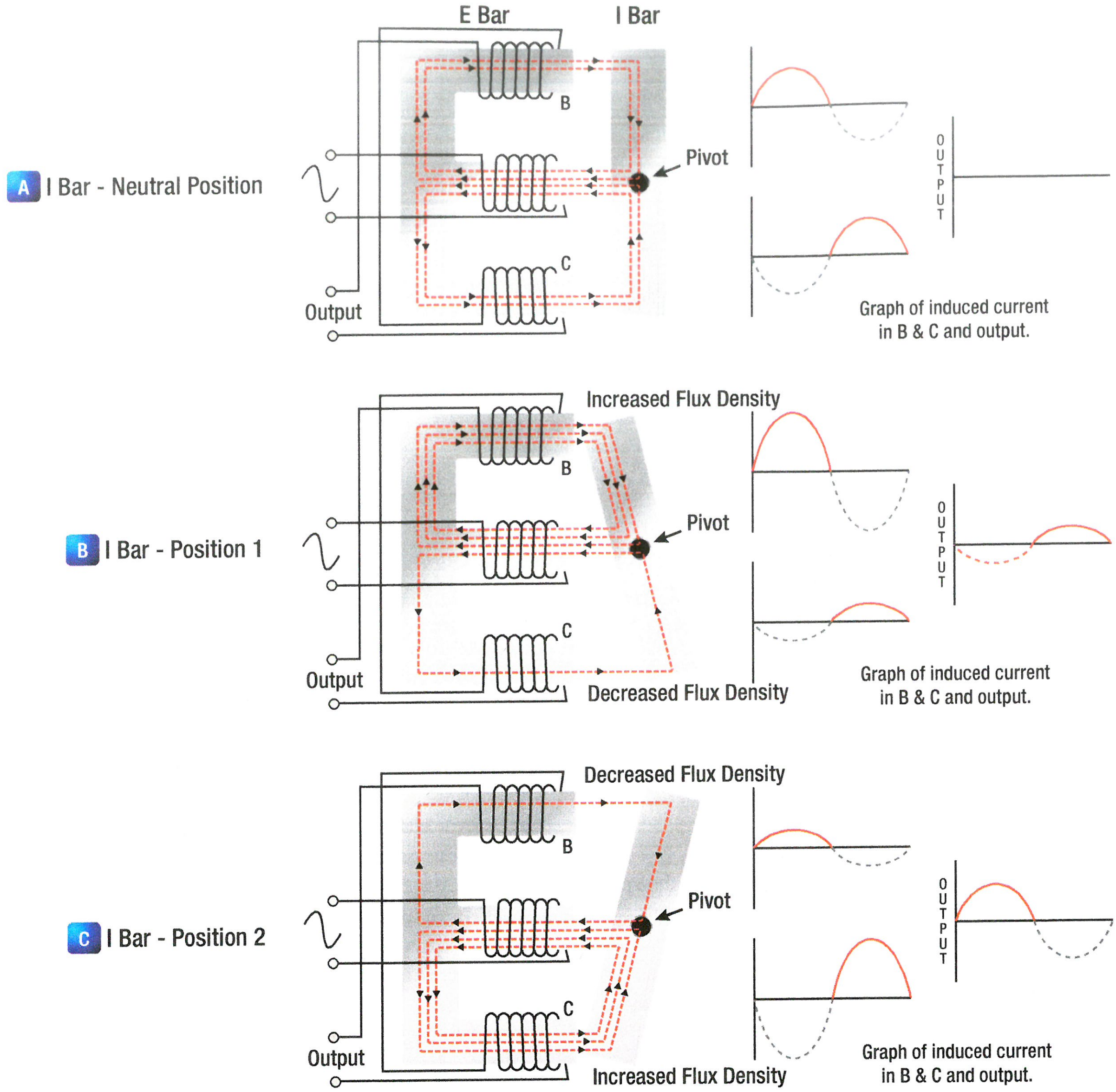


Figure 3-10. Configuration of an inductance transmitter.

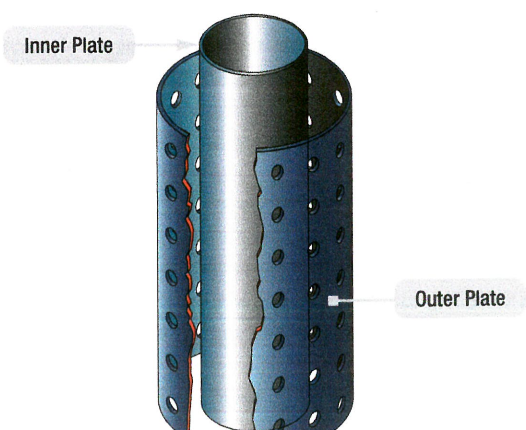


Figure 3-11. The capacitance of tank probes varies in a capacitance-type fuel tank indicator system as the space between the inner and outer plates is filled with varying quantities of fuel and air depending on the amount of fuel in the tank.

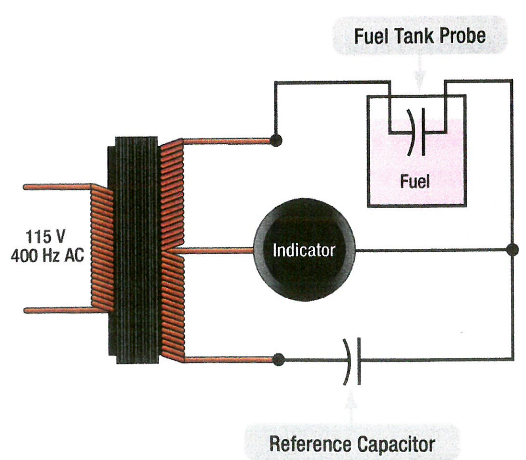


Figure 3-12. A simplified capacitance bridge for a fuel quantity system.

Question 3-1
True or False? An open loop system uses feedback to ensure that controlled mechanisms have been moved to the proper position.

Question 3-2
Which describes the basic operation of a synchro system for remote position indication?
A. A transmitter sends varying voltages to an indicator motor which moves a pointer.
B. Resistances are compared in the transmitter and the result is sent to the indicator motor to position a pointer.
C. A magnetic field in the transmitter is mirrored in the indicator where a magnetic rotor aligns with the magnetic field.

Question 3-3
What three factors affect the amount of electricity that a capacitor can store?

Question 3-4
The position of the pointer of a servo system is always based on what?

Question 3-5
What is the condition of a servomechanism device if a controlled application such as a flap is seen slightly but constantly moving up and down?

Question 3-6
Describe how a proximity sensor would be used with an aircraft's flaps actuator.

Answer 3-1
False. Closed loop systems have feedback, open loop systems do not.

Answer 3-2
C

Answer 3-3
Area of the plates.
Distance between the plates.
Dielectric constant of the material between the plates.

Answer 3-4
The north and south poles of a magnetic field.

Answer 3-5
The condition is known as "hunting" where output signal to the actuators is unable to settle into a certain position

Answer 3-6
The proximity sensor would detect when the flap is in the commanded position and direct the servomechanism computer to halt its operation at that point.

This is a list of the acronyms used throughout this book. This is not a complete list of acronyms used in aviation.

AC Alternating Current
ADF Automatic Direction Finder
ADS Automatic Dependent Surveillance
AM Amplitude Modulation
ATC Air Traffic Control
ATMS Air Traffic Management System
AWOS Automatic Weather Observation System
CMOS Complementary Metal Oxide Semiconductor
DC Direct Current
EHF Extremely High Frequency
ELT Emergency Locator Transmitter
EPIRB Maritime Vessel Emergency Locator Beacon
EPROM Erasable Programmable Read Only Memory
ESD Electrostatic Discharge
FCC Federal Communications Commission (USA)
FET Field Effect Transistor
FIS Flight Information Service
FM Frequency Modulation
GEOSAT Geostationary Satellites
GNSS Global Navigation Satellite System
GPS Global Positioning System
HEMT High Electron Mobility Transistor
HF High Frequency
IR Reverse Current
JFET Junction Field Effect Transistor
LCD Liquid Crystal Display
LED Light Emitting Diode
LEOSAT Low Earth Orbiting Satellite
LUT Local User Terminal
LRM Line Replaceable Modules
LVDT Linear Variable Differential Transducer
MCC Mission Control Centers
MESFETS Metal Semiconductor Field Effect Transistor
MF Medium Frequency
MHz Megahertz
MOSFET Metal Oxide Semiconductor Field Effect Transistor
NAS National Airspace System
NOTAM Notice To Airmen
PCB Printed Circuit Board
PHEMT Pseudomorphic High Electron Mobility Transistor
PLB Personal Locator Beacon
PRV Peak Reverse Voltage
RVDT Rotary Variable Differential Transducer
SCR Silicon Controlled Rectifier
SHF Super High Frequency
SSB Single Sideband
TRR Reverse Recovery Time
UAT Universal Access Transceiver
UHF Ultra High Frequency
UJT Unijunction Transistor
VHF Very High Frequency
VLF Very Low Frequency

NOTES

ELECTRONIC FUNDAMENTALS

Electronic Fundamentals strictly adheres to the requirements of Part 66 including its content, sequence, and the specified learning levels (1, 2, 3) required for a B1 mechanical and B2 avionics maintenance technician certification.

Topics are divided into the following submodules:

- Semiconductors
- Printed Circuit Boards
- Servomechanisms

Each topic is described in comprehensible language and with detailed illustrations and photographs allowing concepts to be understood and applied to each skill required in the aircraft technician and aviation maintenance environment. FAA A&P students benefit from all topics being covered to the more stringent EASA licensure requirements.

AIRCRAFT TECHNICAL BOOK COMPANY
1 (970) 726-5111
www.actechbooks.com
ISBN-13: 978-1951275877
9 781951 275877
VERSION 004
PRINTED IN CANADA