

Digital Technology Skills

Student Guide

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INTRODUCTION TO STUDENT

Welcome to Digital Technology Skills Training. This course is designed for novice and entry-level individuals who have little or no training in digital electronics fundamentals. From this course you will gain knowledge and skills in digital electronics concepts.

Course Duration and Schedule:

This course is offered as 8 sessions (24 hours total) with each session 3 hours in length.

Required Course Materials

Item	ISBN and/or Title	Vendor
DTS Instructor Guide	DTS IG 1.0 1.01.14	The Sage Group
DTS Student Guide	DTS SG 1.0 1.01.14	The Sage Group
NCCRS Packet	DTS NP 1.0 1-01.14	The Sage Group

Course Objectives

After completion of this course, including regular attendance at lecture sessions completion of Unit Review Quizzes, and completion of reading assignments, the student participant will be able to:

1. Explain the basic concepts of basic electricity that support and permit the functions of digital electronics
2. Describe and explain the use and application of Scientific and Engineering Notation in digital environments
3. Identify the primary number systems used by digital systems, and convert values between the different number system representations
4. Explain what "Digital" means and how it applies to Digital Systems
5. Describe TTL and its use, identify the symbols and the functions of the digital logic gates, and explain the use of truth tables

Student Intro and Overview

6. Describe the different digital signaling and digital transmission methods
7. Identify and describe the different digital modulation and multiplexing techniques
8. List the different common network topologies and architectures in use
9. Identify the different digital error detection and correction techniques in use
10. Identify and describe the different digital transport systems and the types of transmission media they use

Note: You will find several "intentionally left blank" pages, and also several cases where page numbers are not sequential. This is done to preserve format and mapping of Student Guide with Instructor Guide pages.

UNIT 1 - BASIC ELECTRICITY REVIEW

The Language of Electricity

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Unit 1 – Basic Electricity Review

INTRODUCTION

Even if you haven't had much experience with electricity or electronics, you know that it has a language of its own. As your technical career develops, you will need to master this language, including the symbols that are part of this language.

OVERVIEW

This unit reviews some of the basic concepts of electricity learned in basic electricity training. You will review the common electrical circuit elements and the units used to measure them, the general theory as to what makes electricity work for us, and in general, how these concepts support understanding of digital electronics.

UNIT 1 OBJECTIVES

Upon completion of this unit, you will be able to:

- Describe Common Electrical Terms from Basic Electricity
- Explain Basic Electrical Principles of Conduction and Conductance
- Define AWG; "Conductors" and "Insulators"; Identify conductor types and compare to Insulators
- Explain the concept of "Skin Effect"
- Describe direct current and alternating current
- List and explain the components of the sine wave
- Identify the basic symbols used in Digital Electronics
- Identify and describe the basic wiring symbols
- Describe the basic characteristics of a series circuit
- Explain the Concept of "Voltage Drop"
- Describe the characteristics of a parallel circuit
- Describe the different calculation methods for determining total resistance of a parallel circuit, and calculate total resistance
- Describe the methods for simplifying series-Parallel Combination Circuits

Unit 1 – Basic Electricity Review

- Explain the concept of Ground as a Reference Point
- Identify the Electrical Symbols for "Ground"
- Explain the concept of a "Short Circuit"
- Describe the "Polarity" Considerations of a Circuit
- Explain Ohm's Law and perform circuit calculations
- Identify and describe the elements of a circuit and their Ohm's Law Representations
- Describe the relationships of the circuit elements
- Describe the use of the Ohm's Law Memory Tools

Unit 1 – Basic Electricity Review

SECTION 1.1 – DEFINITIONS AND TERMINOLOGY

COMMON ELECTRICAL TERMS

Electricity is the result of negatively charged, moving particles. When there is an easy pathway available on which these particles can travel, these negatively charged particles will move along this path from a point that is more negatively charged, to a point that is less negatively charged. The negative charged particles are called electrons, and the path on which they travel is called a conductor path.

1. **ALTERNATING CURRENT (A.C.):** Electric current that results from applying an A.C. voltage source to a circuit; where current direction is always only in one direction on the conductor.
2. **CAPACITOR:** Two conductive plates separated by a dielectric material; where the device formed is capable of temporarily storing an electric charge measured in volts.
3. **CIRCUIT:** A configuration of individual electronic components, such as resistors, transistors, capacitors, inductors and diodes, connected by conductive wires or traces through which electric current can flow from a voltage source and return.
4. **CONDUCTORS:** Physical paths on, or through, which electrical current flows; typically a copper wire conductor or a coaxial cable. Not to be confused with a transmission "medium"; this includes optical fiber and free space (airways).
5. **CURRENT:** The movement of electrons through conductors. Current is measured in units of *Amperes*.

Unit 1 – Basic Electricity Review

6. **DIRECT CURRENT (D.C.):** Electric current that results from applying a D.C. voltage source to a circuit; where current direction is always only in one direction on the conductor.
7. **ELECTRIC LOADS:** Anything that use of electric current and power (either AC or DC).
8. **ELECTROMOTIVE FORCE (EMF):** A measurement of the energy that causes current to flow through a circuit. It can also be defined as the potential difference in charge between two points in a circuit. Electromotive force is also known as voltage, and it is measured in volts.
9. **INDUCTOR:** Wire conductor that is formed into a coiled loops, where current through the conductor results in a perpendicular propagation of an electro-magnetic field that resists a change in current.
10. **OHM'S LAW:** The relationships between voltage, current, resistance and power that allow us to mathematically calculate any unknown of these values, when two of the other values are known. These relationships include:
$$E = I \times R \qquad I = E/R \qquad R = E/I \qquad P = E \times I$$
11. **PARALLEL CIRCUIT ARRANGEMENT:** The arrangement of resistances and loads, where the circuit provides for multiple current paths.
12. **POWER:** The rate at which electric energy is transferred, or dissipated in another form, by an electric circuit; it is the rate of doing work. Power is measured in units of *Watts*.
13. **RESISTANCE:** The opposition, or limit, to the amount of current that can flow in an electric circuit. Resistance is measured in *Ohms*.
14. **SEMICONDUCTOR:** A material such as germanium and silicon which has electrical conductivity to a degree between that of a metal (such as copper) and that of an insulator (such as glass) used to make semiconductor devices for electronic circuits. Semiconductor devices are the foundation of modern electronics, including transistors, solar cells, diodes, light-emitting diodes (LEDs), quantum dots and digital and analog integrated circuits.

Unit 1 – Basic Electricity Review

- 15. SERIES CIRCUIT ARRANGEMENT:** The arrangement of resistances and loads, where the circuit provides for only a single current path.
- 16. VOLTAGE:** The electrical pressure that pushes the electric current through conductors. Voltage is measured in units of **Volts** (also called EMF for Electromotive Force).

Unit 1 – Basic Electricity Review

CONDUCTION AND CONDUCTANCE

Assuming presence of a complete electrical circuit (Figure 1.4):

- Electrical **conduction** is the actual movement of charged particles through an electrical conductor
- Electrical **conductance** is a measure of how easily electrons flow through a material

Consider now that in magnetism, **opposite charges attract**, and **like charges repel**, and the closer the charges the stronger the attraction or repulsion.

In the case of the copper atom, the 29th negatively charged electron is farthest away from the positively charged protons in the nucleus and, therefore, the attraction, since they are unlike charges, is weakest compared to the other electrons in the inner shells and the nucleus.

Therefore, in addition to considering the breaking away of billions of 'Free' electrons in a circuit conductor, we must also consider the polarities of the circuit. In considering this, we must include the laws of attraction and repulsion as represented in Figure 1.1.

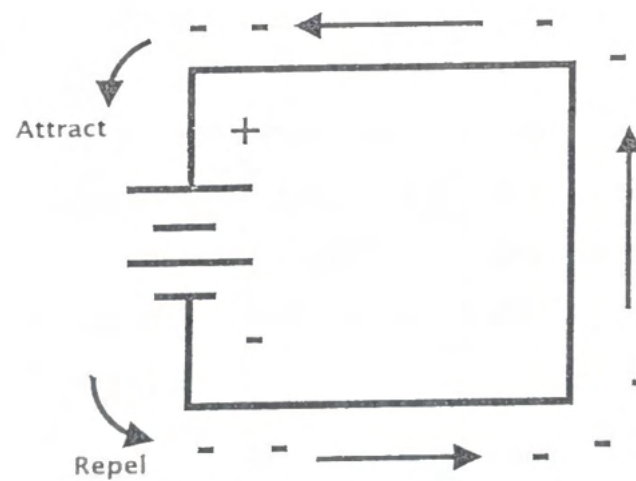


Figure 1.1

Using electron flow theory, electric charge moves from the negative (surplus of electrons) side of the battery to the positive (deficiency of electrons) side of the battery.

Having broken away from their energy shells, these free electrons are repelled away from the negative terminal of the battery, and attracted by the positive terminal of the battery. This is current flow.

Unit 1 – Basic Electricity Review

SECTION 1.2- AWG, CONDUCTORS AND INSULATORS

AMERICAN WIRE GAUGE (AWG)

The AWG is a standardized wire gauge system that describes the cross-sectional areas of round, solid, nonferrous, electrical conducting wire. The cross-sectional area of a wire is critically important as each gauge for every wire is an important factor in determining its current-carrying capacity. Basically, too high a current on too small a wire can burn the wire to cause an electrical fire.

- The term "gauge" in this standard refers to the diameter of the wire. Non-ferrous includes copper, aluminum and other materials, but this gauge mostly applies to copper wire since this is the type of wire we use as household electrical wiring and telephone wiring
- Typical household electrical wiring is AWG number #12 or #14; where, the National Electric Code (NEC), defines #14 solid wire as the minimum size and wire type that can be used to wire permanent structures
 - ✓ Telephone wire is usually 22, 24, or 26, but there are rare cases where AWG 19 is used.
 - ✓ Wire sizes larger than 4/0 are provided in the AWG in units of kcmils.
 - ✓ The cross-sectional area of each gauge of conductor wire is an important factor for determining its current-carrying capacity (called 'ampacity'). Ampacity determines the maximum amount of current that a conductor can carry without damaging the conductor.

Unit 1 – Basic Electricity Review

CONDUCTORS

There are three types of materials used in electronics where the material is one of the following:

- A good conductor
 - Semi-conductor
 - Insulator
-
- ✓ Examples of good conductors are gold, silver, aluminum, iron and copper
 - ✓ Examples of semi-conductors are silicon, germanium, carbon and nichrome
 - ✓ Examples of good insulators are rubber, glass, wood and ceramics

Copper–The Second Best Conductor

- Although we make extensive use of copper for electrical conductors, copper is actually considered only the second best conductor. However, it is, by far, the most common material used for wire in electric circuits because of its properties and because it is relatively inexpensive.
- Silver is the best conductor material in terms of its conductance properties, but it is far more expensive than copper.
- Thin gold plating is used on contacts because it doesn't tarnish, but gold is far more expensive than both silver and copper.

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The following table compares those materials that make the best conductors and insulators:

Terms	Definition	Examples
Conductor	Any material through which electricity can flow	• Silver • Copper • Gold • Aluminum • Salt water
Insulator	Material that prevents the flow of electricity	• Paper • Fiber • Plastic • Rubber & Teflon

CONDUCTORS AND SKIN EFFECT

Electric current travels in, or on, a conductor material if the conductor material provides lots of free electrons. "Skin Effect" is a tendency for alternating current (AC) to flow mostly near the outer surface of a solid electrical conductor, such as metal wire, at frequencies above the audio range. The effect becomes more and more apparent as the frequency increases; therefore, the higher the AC frequency, the more the current tends to travel along the surface as opposed to within the conductor.

Skin Effect does not relate as much to DC because Skin Effect is a function of the changing magnetic field of AC. Since the current direction alternates with AC, the magnetic field is constantly expanding and contracting. Thus, skin effect is produced.

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ELECTRICAL INSULATORS

An electrical insulator is a material whose internal electric charges do not flow freely (few free electrons) and which, therefore, does not conduct an electric current well. It is important to note that the availability of good insulators is as important as good conductors.

Insulators are used in electrical equipment to support and separate electrical conductors without allowing current through themselves.

- The term *insulator* is also used more specifically to refer to insulating supports used to attach electric power distribution or transmission lines to utility poles and transmission towers.
- The most important insulation material is Air
- The National Electric Code provides insulation information for the different types of wire sizes defined in the AWG

Electric Circuit

An electric circuit is a closed path, or loop, in which electrons from a voltage or current source flow. It is created by using AWG defined wire conductors to connect electrical components to each other.

- The point where those electrons enter an electrical circuit is called the "source" of electrons
- The point where the electrons leave an electrical circuit is called the "return" or "earth ground"

The exit point is called the "return" because electrons always end up at the source when they complete the path of an electrical circuit.

- The part of an electrical circuit that is between the electrons' starting point and the point where they return to the source is called an electrical circuit's "load"; as we defined earlier in this Unit.

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Below, we see the components that are basic to the circuit:



As you can see in the schematic diagram:

- A voltage source (such as a battery)
- A control element for turning the circuit on and off (such as a switch)
- A resistance load on the battery (such as a lamp)
- Wire conductors that provide the current path from the voltage source to the load, and then back to the source.

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Unit 1 – Basic Electricity Review

SECTION 1.3- AC & DC CHARACTERISTICS

CURRENT CHARACTERISTICS – DIRECT CURRENT

Electrical current is classified as being either Direct Current (DC) or Alternating Current (AC).

- Direct current is the one-direction flow of electric charge

Analogy

A car battery produces current flow (direct current) that is always in the same direction, just as the river water always travels in the same direction. See Figure 1.2.

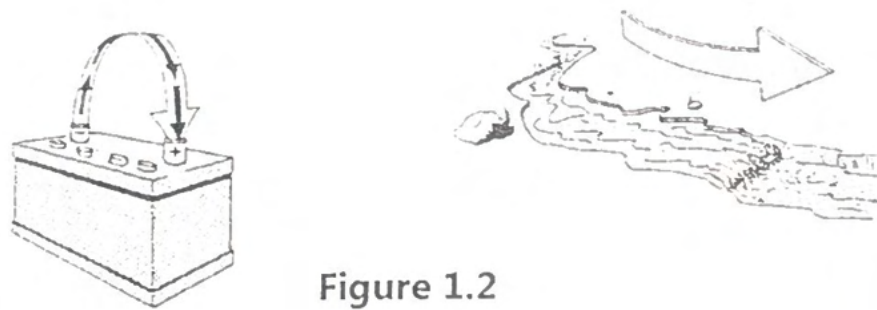


Figure 1.2

Electron flow vs. Conventional Flow theory

Do not confuse AC and DC vs. electron flow and conventional flow in a DC circuit.

- In technical theory, it is correct to say that current is the flow of electrons from a negative point to a less negative (or, from negative to positive) point of a circuit. In a DC environment, such as with a battery voltage source, the positive and negative terminals do not change.
- We now introduce Conventional flow theory that defines current flow from positive to negative direction. This doesn't mean the current alternates its direction of flow. It only assumes a different perspective as to the one way direction of DC current.

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The telephone industry typically assumes positive to negative flow when following current flow through a circuit diagram. Therefore, telephone circuits are assumed to flow positive to negative which is "hole" (positive) current flow.

A "hole" represents the "empty" place where an electron escaped the atom's energy shell to enter the conduction band. Without this electron, the atom becomes a positive ion, since there are now more protons (29) in the copper atom than there are electrons (28). These "holes" are called positive ions; therefore, "hole" flow is the flow of positive ions being repelled from the positive terminal of the battery, and also being attracted by the negative pole of the battery. This is in opposite direction to the negative electron flow.

Since the end terminals of the circuit, like the car battery, never change polarity, this means the positive-to-negative "hole" flow of current never changes direction through the circuit, and one direction of "hole" flow means Direct Current just as one direction of electrons means electron flow. Whichever perspective of current flow we choose to adopt, it is still only one direction of current flow and, therefore, it is still direct current.

A steady DC signal, figure 1.3, such as would be provided by a battery or a regulated power supply, is shown below. Note the DC line shows the amount of current or voltage always above the zero line. This area above the zero line represents one direction.

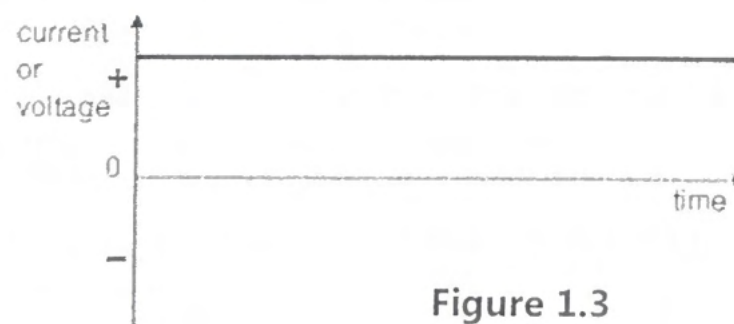


Figure 1.3

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CURRENT CHARACTERISTICS - ALTERNATING CURRENT

Conversely, AC current is alternating current in the sense that the direction of the current flow in an A.C. circuit is constantly, and literally, changing direction.

- This means that AC current flows in one direction, and then it reverses direction, and it continues this process in a constant pattern.
- The fundamental signal pattern for an A.C. signal is called a **sine wave** such as shown in figure 1.4.

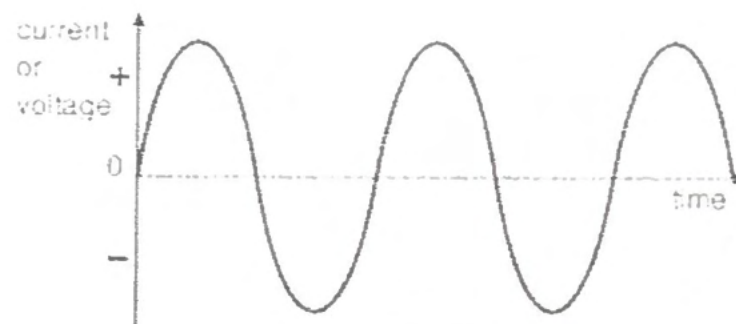


Figure 1.4

Note the varying nature of the signal with respect to the zero line. Unlike the straight line DC signal above the zero line, half of each wave of the AC signal is present below the zero line and half above the zero line. This appearance represents the changing directions of the current (due to reversing voltage polarity) since the signal energy above the zero line is flowing in one direction on the conductor, and the signal energy below the zero line is flowing in the opposite direction.

- Typical A.C. voltage sources that produce A.C. current are alternators and AC generators.
- A.C. voltage provided by power utility companies to houses and buildings comes from AC voltage sources.

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Although they do share common properties, an A.C. sine wave signal is much more complex than a straight DC signal. Figure 1.5 defines the different components of an A.C. sine wave. Note that both voltage and current can be represented by the sine wave, and that the horizontal axis of the sine wave graph represents the time domain.

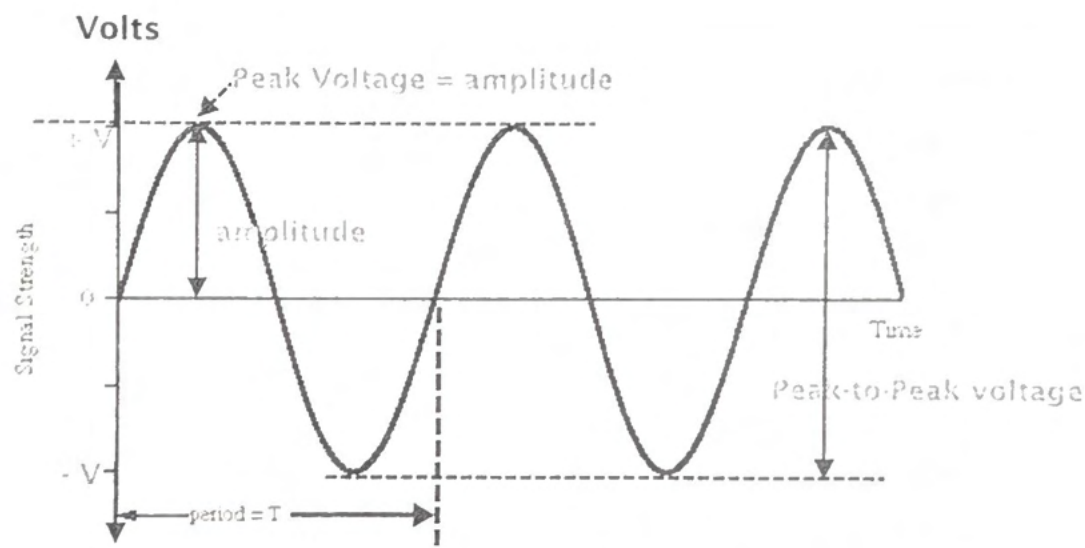


Figure 1.5

- Amplitude – the height of the signal from the zero line. This represents the signal strength; i.e. amount of volts or amps depending if voltage signal or current signal.
- Peak voltage/current – the maximum height point of the sine wave. Note that there is a positive peak and a negative peak for the two directions of current flow. Peak voltage = amplitude.
- Peak-to-Peak voltage – the voltage or current range between the maximum positive and maximum negative peak points.
- Period – The amount of time it takes to complete one cycle of a sine wave signal.
- Frequency – the number of cycles per second for a given sine wave signal. In the signal above, three cycles have completed in 1 second. Therefore, the frequency of this signal = 3 cycles/sec = 3Hertz (3Hz).

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The following table compares AC and DC current. Keep in mind that AC and DC refer to the currents. However, these currents are produced by AC and DC voltage sources such as AC generators/alternators and batteries respectively.

Look at the definitions and examples below.

Terms	Definition	Example
Direct current (DC)	Travels continuously through a circuit in the same direction	Batteries are used in flashlights, portable radios, cell phones, telephone central offices and for starting your automobile
Alternating current (AC)	Reverses direction continuously and at a constant rate	Power line coming into your home, alternator in your car

FREQUENCY (Hertz)

As described in the previous section, frequency of a sine wave is a measure of the number of cycles that complete for a given sine wave signal in a standard time of one second.

- A single cycle is one complete positive and one complete negative swing
- The cycle does not need to start and end at the zero line.

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This is demonstrated in figure 1.6 where one cycle is measured from time zero, or from 1 peak to the next peak.

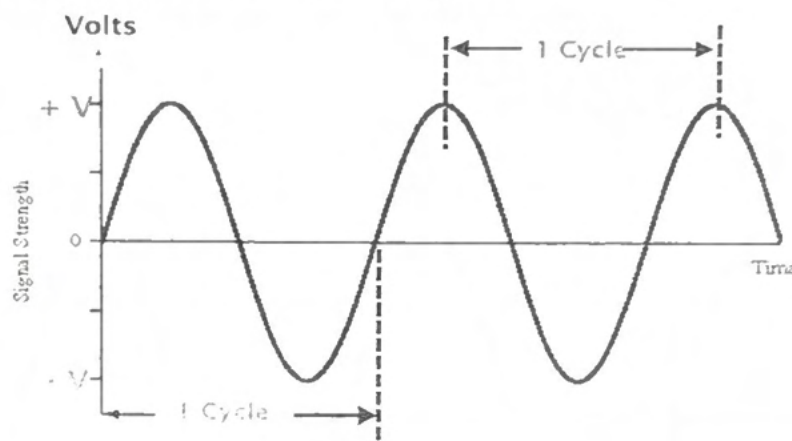


Figure 1.6

Frequency is an especially important component of a sine wave since, in the audio frequency range, frequency determines what the tone of a sound is.

For example:

- A high frequency audio signal is a high-pitched tone such as the charging sound of a camera flash or the high notes of a trumpet or a whistle.
- A low frequency signal would give a low-tone sound such as the sound of a base guitar tone or the sound of a very low hum.

Since frequency is always measured as the number of cycles that occur in a universal standard of one-second:

- Frequency is typically measured in units called 'hertz', where one hertz is equivalent to one cycle occurring in one second.

We identified the horizontal axis of the sine wave graph a representation of the time domain. Therefore:

- We can count the number of cycles that occur in any analog or (A.C.) signal in one second of time, and we measure this count as the frequency of the signal in units of "Hertz"

The standard frequency for alternating current used in homes and industry in the United States is 60 cycles per second, or as we now know, 60 Hertz.

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The frequency of a signal can be calculated using figure 1.7 as follows:

Given the signal below, what is its frequency?

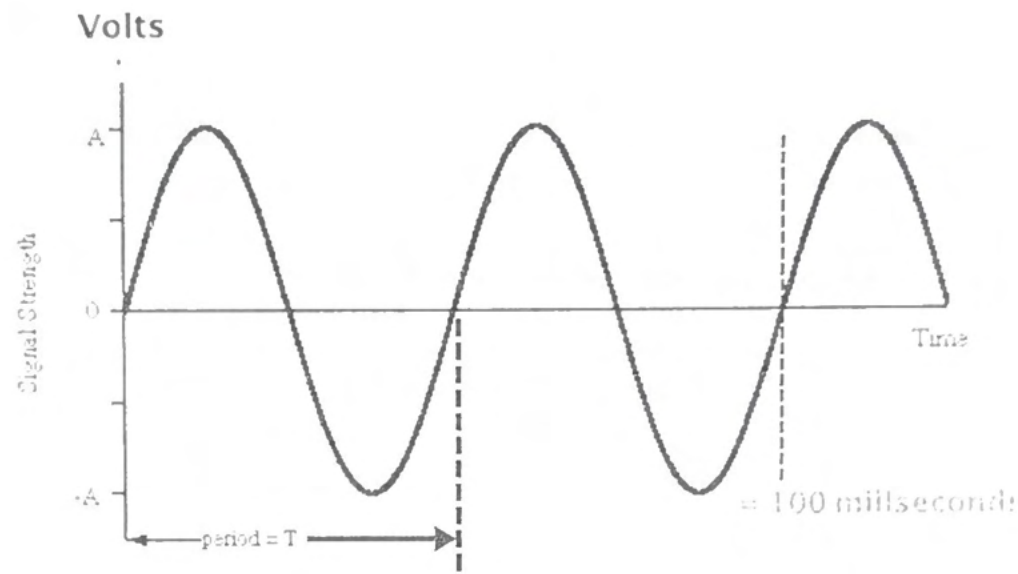


Figure 1.7

Solution:

Looking at the signal trace, we see that we have 2 complete cycles occur in 100 milliseconds of time; or, 2 cycles/100millisec.

Therefore:

$$Freq = \frac{2 \text{ cycles}}{100 \text{ msec}} \times \frac{1000 \text{ msec}}{1 \text{ sec}} = \frac{2000 \text{ cycles}}{100 \text{ sec}} = 20 \text{ cycles/sec} = 20 \text{ Hz}$$

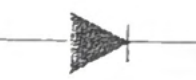
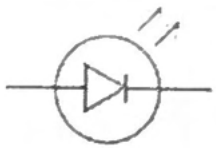
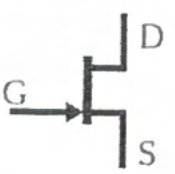
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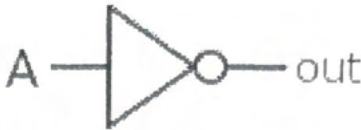
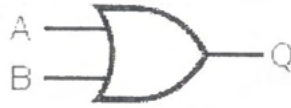
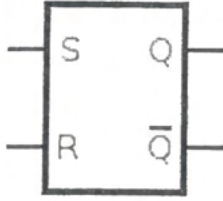
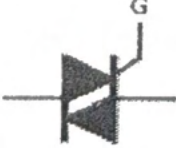
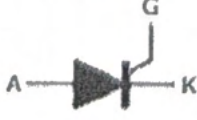
SECTION 1.4 – ELECTRICAL SYMBOLS

DIGITAL CIRCUIT SYMBOLS

The symbols of the most likely encountered digital electronics components are shown on the following pages. These are many symbols you should become familiar with.

Component Type	Symbol	
Semiconductors		Junction Diode, Rectifier
		
		Light emitting diode (LED)
		NPN Bipolar Junction Transistor
		PNP Bipolar Junction Transistor
		N-channel Field Effect transistor (FET)
		P-channel Field Effect Transistor (FET)

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Component Type	Symbol	
Logic Symbols		Not Gate (Inverter)
		AND Gate
		NAND (Not AND) Gate
		OR Gate
		NOR (Not OR) gate
		Exclusive OR (XOR) Gate
		Buffer
Flip Flops		Basic Set-Reset (SR) Latch
Miscellaneous		Triac
		Thyristor SCR (Silicon Controlled Rectifier)

Other Electrical Symbols are provided in Appendix B.

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WIRING SYMBOLS

In addition to component symbols, there are also wiring symbols to depict wire inter-connections and wire hops.

The symbols of figure 1.8 below show you whether or not wires that cross on a diagram make an electrical connection with one another at the crossing point.

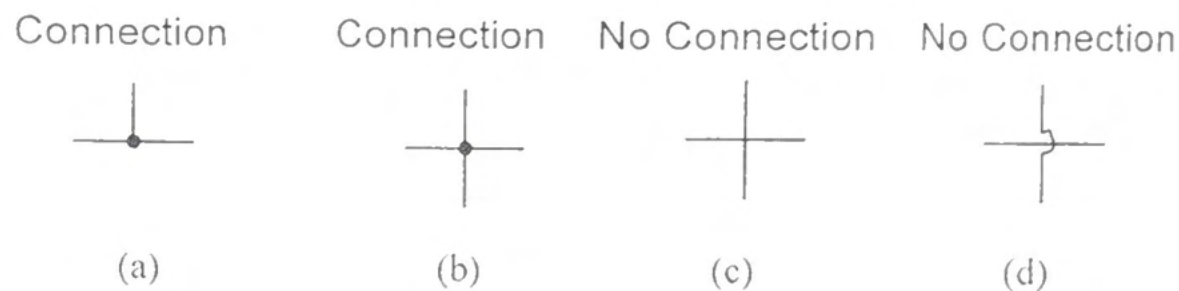


Figure 1.8

There are two rules to remember:

1. If wires meet, but do not cross, as in Figure 1.8 (a), an electrical connection is always indicated. There may or may not be a dot at the meeting point.
2. When wires cross each other as in Figure 1.8 (b), (c), and (d), there is no electrical connection unless there is a dot at the crossing point, as in (b).

If there is no connection, a hook or "hop" is shown, such as shown in Figure (d) above. This symbol makes it clear that the wires do not connect. This is called a "hop". However, in the interest of time, the hop is often omitted, such as the case with telephone schematics. The crossing point without a connection is shown in (c).

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SECTION 1.5 – ELECTRICAL CIRCUITS

CHARACTERISTICS OF A SERIES CIRCUIT

When a number of devices are connected in such a way that they form a single path for electrons to flow, these devices are connected in *series*. A series circuit pictorial of three resistors in series is shown below in figure 1.9.

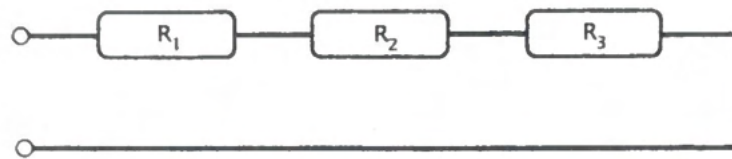


Figure 1.9

Keep in mind that it doesn't matter where in the circuit the three resistors are placed as long as they form a single path for current flow. Therefore, the same three resistors can alternatively be drawn pictorially as shown below in Fig. 1.10. These two circuits, and the circuit above, are all equivalent as the same series circuit; where the lines represent the wires that connect the resistors together. Any current that flows in this circuit must flow through each resistor in a series in order to get from one termination to the other; i.e., from point A to point B. The key to being connected in series is that there is only one path through which the electrons can travel.

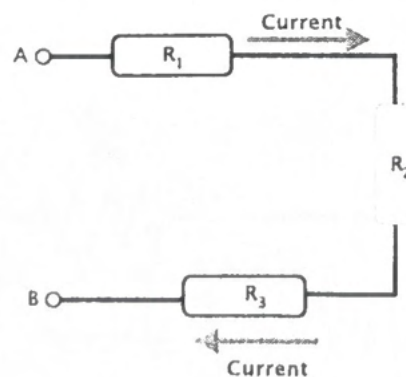
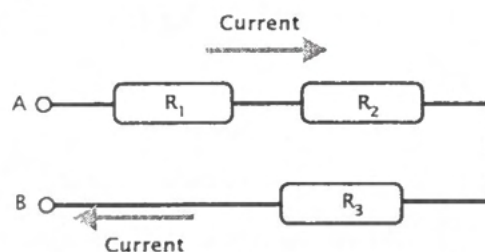


Figure 1.10

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Total Resistance of a series circuit

When resistors are connected together in series, the total resistance (R_T), (also called equivalent resistance or R_{eq}), is equal to the sum of the individual resistances. This is expressed mathematically as:

$$R_T = R_1 + R_2 + R_3 + \dots R_n$$

For example, in our circuit of figure 1.11, the total resistance is

$$5\Omega + 8\Omega + 7\Omega = 20\Omega$$

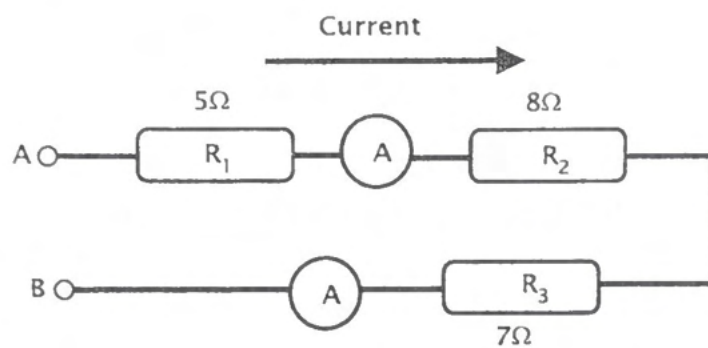


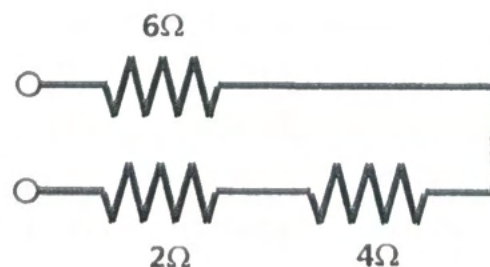
Figure 1.11

Therefore:

- For all the resistances contained in a series circuit; the total resistance of the circuit is equal to the sum of the individual resistances
This is called the circuit equivalent resistance.
- The combined resistance in a series circuit is ALWAYS greater than any of the individual resistances in the circuit

Example: Using the schematic symbol for a resistance:

What is the total (equivalent) resistance for the schematic circuit drawing below?



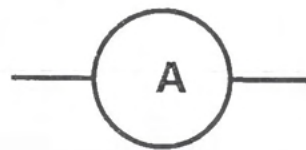
Solution: $R_{eq} = R_1 + R_2 + R_3 + \dots R_n$ Therefore: $6\Omega + 4\Omega + 2\Omega = 12\Omega$

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Current in a Series Circuit

- The amount of current at any point in a series circuit is the same as any other point, since all the circuit current flows in a single path
Therefore, the current measured at any point in a series circuit equals the total current of the circuit
- Any open in any part of a series circuit opens the entire circuit and zero current can flow

The symbol for a standard ampere meter (or just ammeter) is as follows:



(The upper-case letter I is used to represent current in Ohm's Law calculations)

The ammeter is used to measure the amount of current flowing in a circuit, and when connected to a circuit it must also be connected in series with the other components. This allows the meter to measure the current as it flows through the meter.

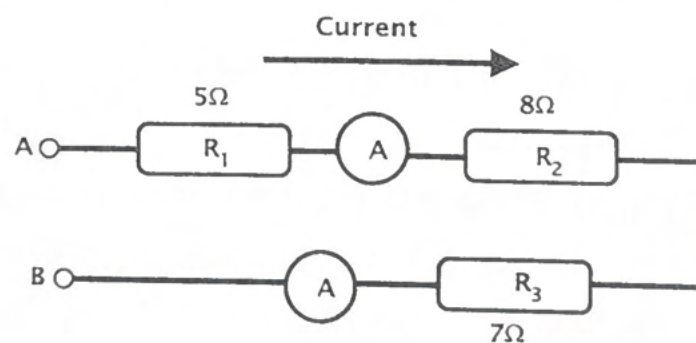


Figure 1.12

For our example circuit of figure 1.12, and for ANY series circuit, measured current flow is the same at any point in the circuit. In the circuit above, both of the ammeters will read the exact same current flowing through the circuit even though they are at different points in the circuit.

Therefore, for n number of resistances in a series circuit, the total current flowing can be expressed as:

$$I_T = I_{R1} = I_{R2} = I_{R3} = \dots = I_{Rn}$$

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Looking at this as a complete circuit, with a control mechanism (switch) and a voltage source (battery) as shown in figure 1.13, we have the following:

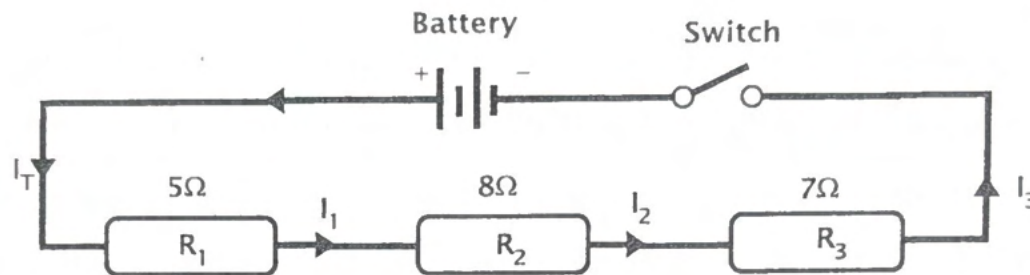


Figure 1.13 Current is the same everywhere in the circuit:
 $I_T = I_1 = I_2 = I_3$

As stated mathematically above, once the switch is closed, total current (I_T) will be equal to the current at point I_1 , which is equal to the current at point I_2 , which is equal to current at point I_3 , etc.

Now, let us suppose these resistors are lamps, we close the switch, and that the filament in the center lamp burns open as shown in Figure 1.14 when current starts to flow. You've probably seen this occur when you turned on a lamp switch and, "*flash!*"... a quick flash and the lamp goes out.

Now we have an open circuit in that the current path is open at the burned open filament; i.e., current cannot flow from the battery, through the lamps, and back to the battery as there is no complete path available. Therefore, none of the lamps will turn on as current = zero amps. This will be true if the circuit is opened at any point, just as if you opened the switch. This is, in fact, the function of the switch.

This is what occurs with a string of Christmas lights when one bulb is loose or burns open and the entire string goes out.

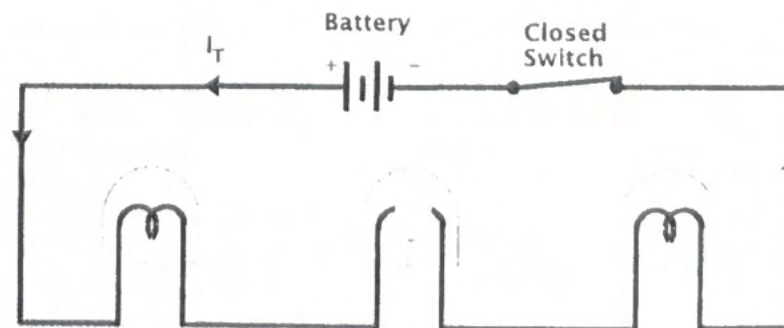


Figure 1.14

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The Voltage Drop

Another characteristic of the series circuit is the voltage drop. It takes a certain amount of voltage to push a given current through resistances in series.

The amount of voltage is called the "Voltage Drop". The voltage drop can be measured across a resistance with a voltmeter as shown in Fig 1.15.

Whatever the percentage is of an individual resistance to the total circuit resistance, the voltage drop across that resistance is the same percentage of the source voltage of the circuit.

For example, in Fig 1.15:

1. First find the total resistance of the circuit = the sum of the individual resistances.

$$R_T = R_1 + R_2 + R_3 = 55\Omega + 30\Omega + 15\Omega = 100\Omega$$

2. Next, find the percentage of a resistance to total resistance using the following:

$$\text{Percentage} = \frac{\text{individual resistance}}{\text{total resistance}}$$

Using R_2 below for our example:

$$\% = \frac{30}{100} = .30 = 30\%$$

3. Multiply this percentage times the voltage applied to the circuit

$$\text{Voltage drop across } R_2 = .30 \times 100 = 30V$$

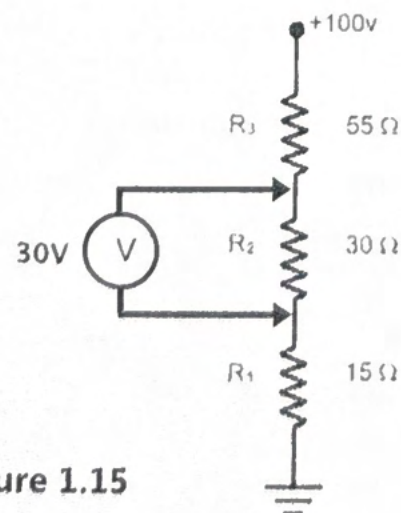


Figure 1.15

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As long as the resistance values stay the same in ratio to the total resistance, this percentage is still applied to the total voltage applied. For example:

Suppose the applied circuit voltage is doubles to 200 volts. This just means the 30% is applied to the higher voltage of 200V:

$$\% = \frac{30}{100} = .30 = 30\%$$

$$\text{Voltage drop across } R_2 = .30 \times 200 = 60V$$

Therefore, doubling the total applied voltage means each individual voltage drop is doubled as shown in figure 1.16.

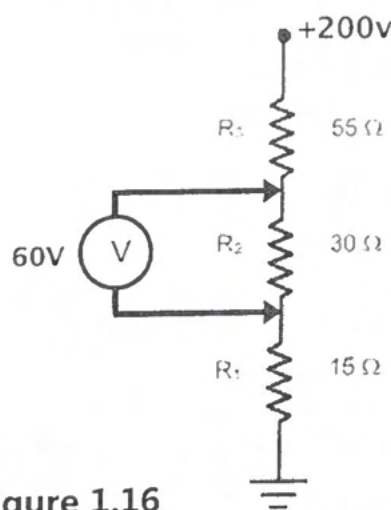


Figure 1.16

Another way to say what we described above is to say:

- The sum of n individual voltage drops of a series circuit = the Total applied voltage, or:

$$V_T = V_1 + V_2 + V_3 + \dots + V_n$$

One thing to note regarding the voltage drop reading is the proper way to connect the voltmeter. Unlike the ammeter, which is used to read current and connected in series (in-line) with the resistances, the voltmeter must be connected "across" or in "parallel" with the resistance as noted above.

ALWAYS connect an ammeter in series, and **ALWAYS connect a volt meter in parallel**.

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CHARACTERISTICS OF A PARALLEL CIRCUIT

When a number of devices are connected in such a way that they form two or more paths for electrons to flow, these devices are connected in *parallel*. A parallel circuit schematic of three resistors in parallel is shown below in figure 1.17.

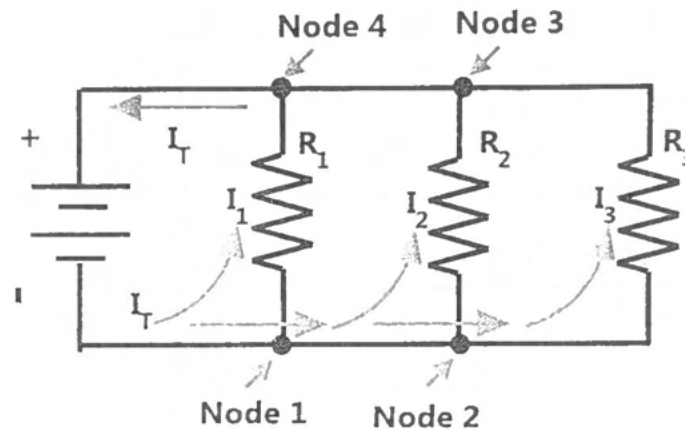


Figure 1.17

Note that the points of a circuit where current divides are called "**Nodes**".

You can see in figure 1.17 that the total current of the circuit leaves the battery and approached Node 1. At this point we have two possible paths; where some of the total current goes up through R_1 (we'll call this I_1 for current path #1), and the remaining current proceeds to Node 2. At Node 2, we again approach to possible current paths; where some of the current from Node 1 goes up through R_2 (we'll call this I_2 for current path #2), and the remaining current continues through the final current path we call I_3 .

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Not, also, that the current that divides among the three paths is the total current of the circuit. Therefore, when all three currents re-combine at Node 4, this current is, again, the total current that left the battery (I_T).

Therefore, total current in a parallel circuit = the sum of the individual current paths in the circuit; where for n current paths:

$$I_T = I_1 + I_2 + I_3 + \dots + I_n$$

Keep in mind that, just as with a series circuit schematic, it doesn't matter where or how the multiple resistances are drawn in the schematic as long as the resistors are connected to form two or more current paths for current flow.

Therefore, the same three resistors can be drawn in parallel as shown below in Figure. 1.17; where the orientation of the resistances are different in this schematic drawing vs. the schematic of figure 1.18, but where they are still parallel to each other forming three current paths.

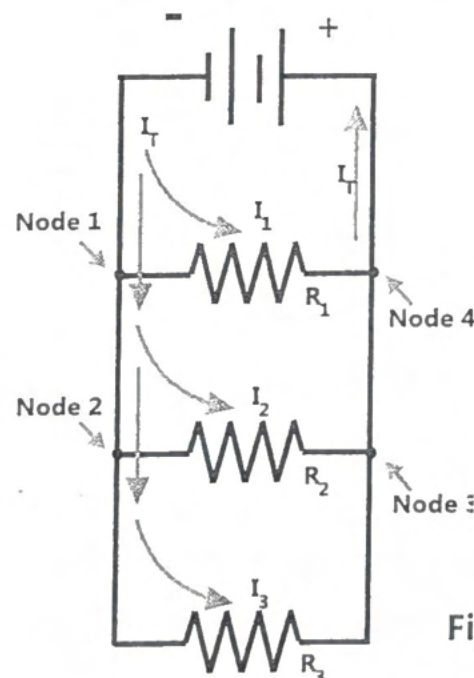


Figure 1.18

These two circuits in figures 1.17 and figure 1.18 are essentially the same in terms of three resistances in parallel to each other and in parallel with to a voltage source. The only difference is the orientation of the symbols as chosen by the author of the drawing.

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A key to remember for determining parallel components is that one side of each component is connected together to one side of the voltage source, such as the left sides of R_1 , R_2 , and R_3 all connected in common to the negative side of the battery, and the other side of each component also connected to each other and to the positive side of the battery.

Another way to say this is that Nodes 1 and 2 and the negative side of the battery are all the same point, and nodes 3 and 4 and the positive side of the battery are also all the same point.

Therefore, figure 1.19 can be drawn as shown below, where the conductor wires are removed and all components are connected to the same point on each side of the voltage source. So the difference is that in our original schematic of figure 5.z we include conductor wires between each component.

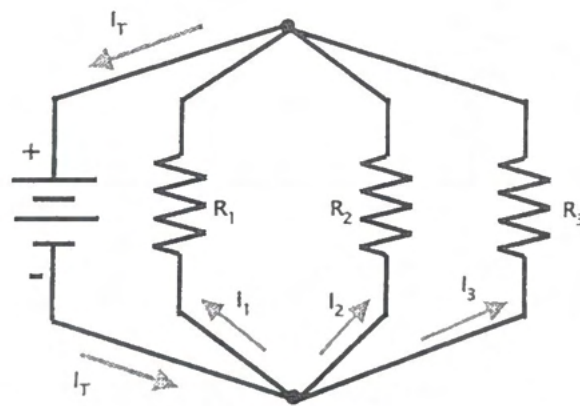


Figure 1.19

In either case, all components form multiple current paths, so this is a parallel circuit. All three of the preceding schematic drawings, electrically, are the same exact circuit.

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Total Resistance of a parallel circuit

Unlike a series circuit where the total resistance of a circuit is the sum of the individual resistances, when resistors are connected together in parallel, the total resistance (R_T), (also called equivalent resistance or R_{eq}), can be calculated using several methods.

Method 1: The Product over the Sum Formula

Used for two resistors at a time, where two resistance values are multiplied and their product is divided by the sum of the two resistances.

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

Example; given the following circuit of figure 1.20:

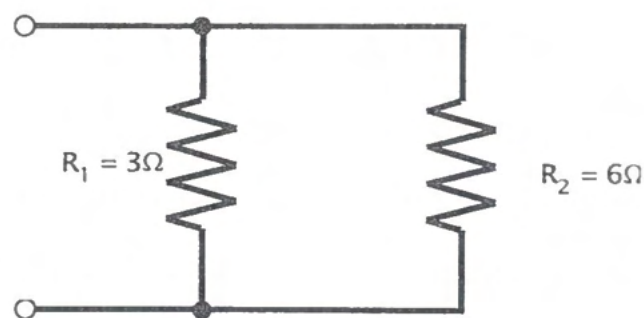


Figure 1.20

$$R_t = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2 \text{ ohms}$$

This method can be used for any number of resistances in parallel, as long as you calculate equivalent resistance for two at a time.

Example; given the following circuit of figure 1.21:

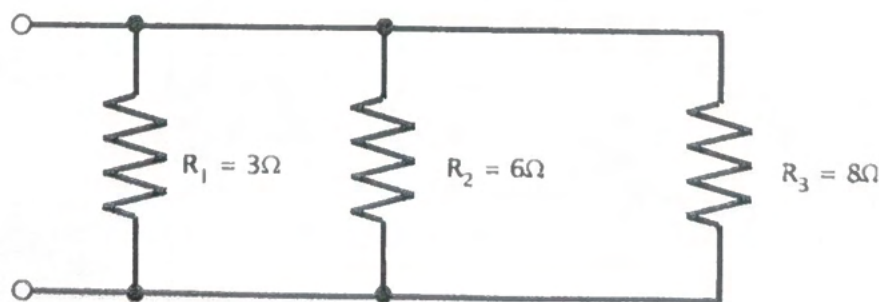


Figure 1.21

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To apply the Product over the Sum rule, we take two resistors at a time. For our purpose we already calculated the equivalent of the 3Ω and 6Ω resistances as 2 ohms. Therefore, we perform product over sum with these 2 ohms and the 8 ohm resistance.

$$R_t = \frac{2 \times 8}{2 + 8} = \frac{16}{10} = 1.6 \text{ ohms}$$

Therefore, the total (or equivalent) resistance of the three resistances above = 1.6Ω

Note that this value is less than the smallest resistance of the three individual resistors; i.e., less than 2Ω, less than 6Ω and less than 8Ω. This will ALWAYS be true:

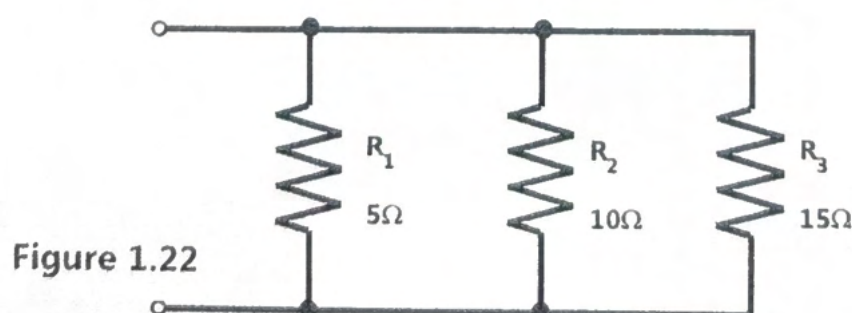
- ***For multiple resistors connected in parallel, the total equivalent resistance of the circuit is less than the smallest resistor in the circuit.***

Method 2: The Reciprocal formula (requires calculator)

With this method, we make use of the following 'Reciprocal Formula'; where we plug the numbers into the formula on a calculator using the 1/X key, (called the reciprocal key). For n number of resistors:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

Or, another way to express this: $R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + 1/R_n}$



The following steps apply to the circuit of figure 1.22.

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Step 1: Using your calculator, punch digit 5 and then 1/X. You will get .2

Step 2: Punch the + key, and then 10

Step 3: punch + key and then 15.

You should end up with a total of reciprocals of these values to = .3667

Step 4: Now punch the reciprocal (1/X) key once again to get 2.73Ω

The calculator series described above is as follows:

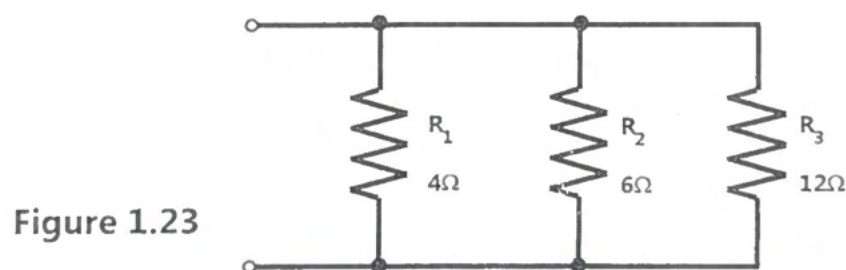
5 **1/X** **+** **1** **0** **1/X** **+** **1** **5** **1/X** **=** **1/X**

The resulting value after the last 1/X is the resistance value for the circuit (2.73Ω) for the circuit above.

Method 3: A Practical Method

The reciprocal method could, at times, be cumbersome. An alternative method is the following "Practical Method".

Example; given the following circuit of figure 1.23:



Step 1: Select the largest value resistor in the circuit (12Ω above)

Step 2: Divide this value by itself and by all the other resistances in parallel

$$12 \div 12 = 1$$

$$12 \div 4 = 3$$

$$12 \div 6 = 2$$

Step 3: Add the answers to the above dividing: $1 + 3 + 2 = 6$

Step 4: Now divide the largest resistance value by this sum:

$$12 \div 6 = 2$$

Therefore, the total resistance of this circuit = 2Ω

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Method 4: Special Condition: All Resistances are Equal Value

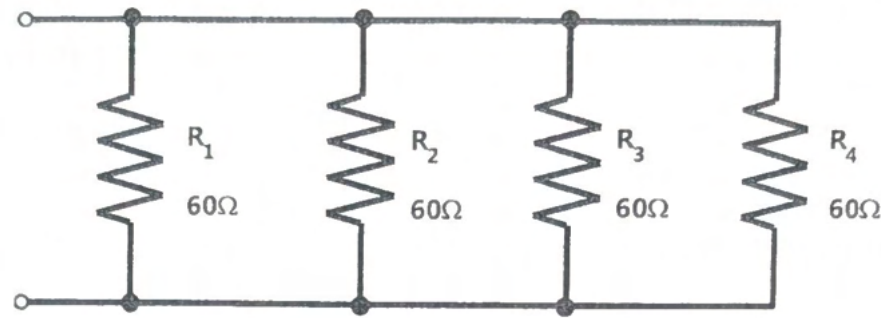


Figure 1.24

Occasionally, you might encounter a circuit where all load resistances are of equal value such as shown in figure 1.24.

To determine the total equivalent resistance for n number of equal value resistors is a simple process where:

$$R_t = \frac{R_1}{n}$$

Step 1: Divide the value of R_1 by the number of resistors in the circuit.

$$R_t = \frac{60}{4} = 15 \text{ ohms}$$

Step 2: That's it! You're done!

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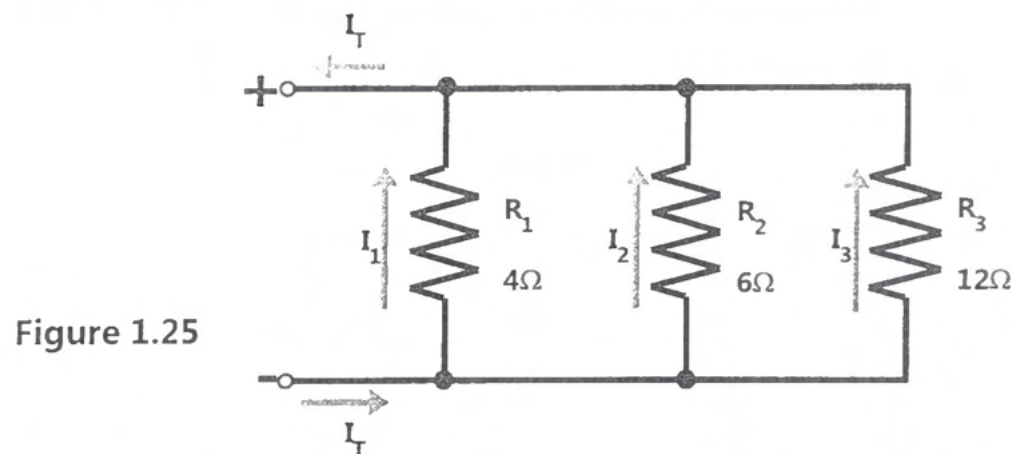
Current in a Parallel Circuit:

- We have stated that the total current flowing in a parallel circuit is equal to the sum of the individual branch currents, or...

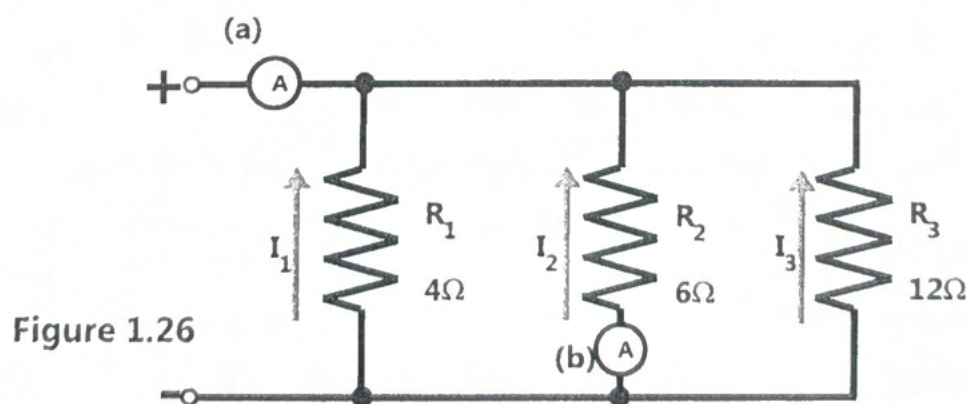
$$I_T = I_1 + I_2 + I_3 + \dots + I_n$$

- Each path of current flow in a parallel circuit is called a parallel branch

Therefore, I_1 , I_2 , and I_3 in the circuit of figure 1.25 are individual branch currents of the parallel circuit. These branch currents sum to the total current of the circuit (I_T).



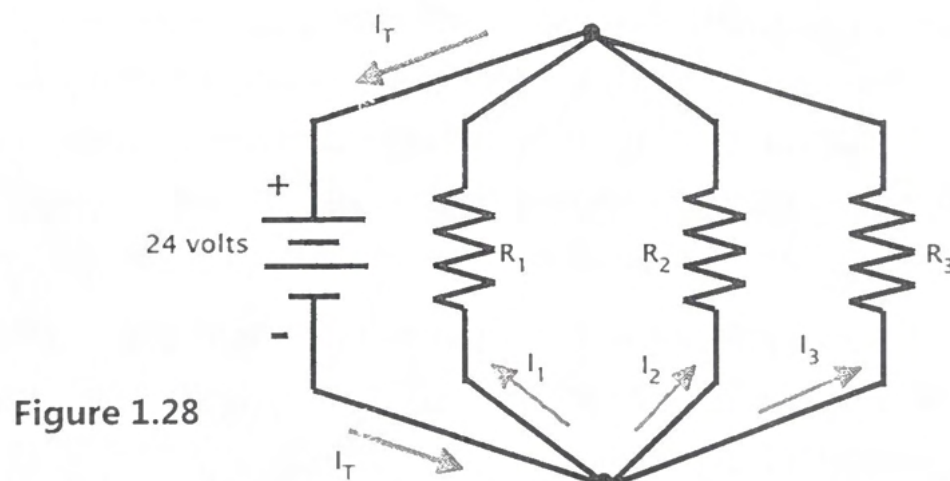
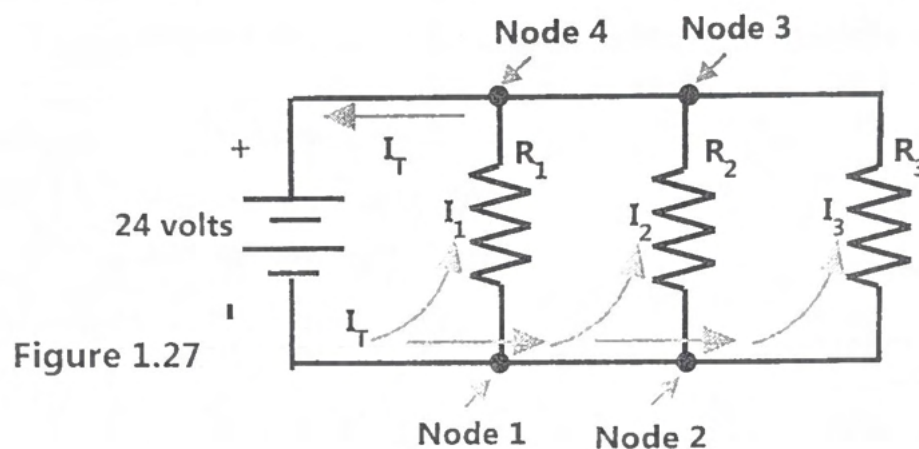
By placing an ammeter at point (a) in figure 1.26, you will be measuring the total current returning to the voltage source. By placing an ammeter at point (b) in figure 1.26, you will be measuring only the current through branch I_2 .



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Voltage in a Parallel Circuit

Going back to our original circuit at the start of this unit, note that the battery terminals in figure 1.27 are connected to all three of the resistors, just as if all the resistors and the battery were connected to a single point as in figure 1.28.



Therefore, if one single current path goes open, the remaining path currents will continue to flow. The change will be the amount of current through the remaining paths due to the change in resistance with the loss of one load.

Assume, for example, that the three resistances in the schematics above are all lamps (light bulbs). This means when one bulb burns out, or if it is removed, the remaining lamps will stay lit. This is what occurs in the Christmas light string where a single bulb does not affect the remaining bulbs.

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This also means that the voltage drop across each resistance is equal to the source voltage since the source voltage is connected across each resistance load independently.

It is important to remember:

➤ ***In a parallel circuit, current divides but voltage does not***

Therefore, 24 volts is measured across each of the resistances in the circuits of figures 5.12 and 5.13. This is exactly opposite of a series circuit where current does not divide (a single path), but the source voltage divides amongst the individual resistances.

SIMPLIFYING SERIES-PARALLEL

There is no single, one-size-fits-all formula that can be applied to an entire circuit in order to obtain the circuit information you are looking for. It really comes down to remembering how to simplify parallel branches into series equivalents, so that in the end, all you need to do is add the values as if the entire circuit is a simple series resistance circuit.

Recall we stated that Total resistance of a parallel circuit is also referred to as the "equivalent" resistance. This means that all we need to do is identify the parts of a circuit that are parallel branches and convert them into series equivalents. For example:

Given the combination circuit below and what we learned from previous lessons, we see that the Ohmmeter battery provides current to Node A. This is total circuit current which, at Node A, divides as I_2 and I_3 that meet again to form total current at Node B that flows back to the Ohmmeter, as shown in figure 1.29.

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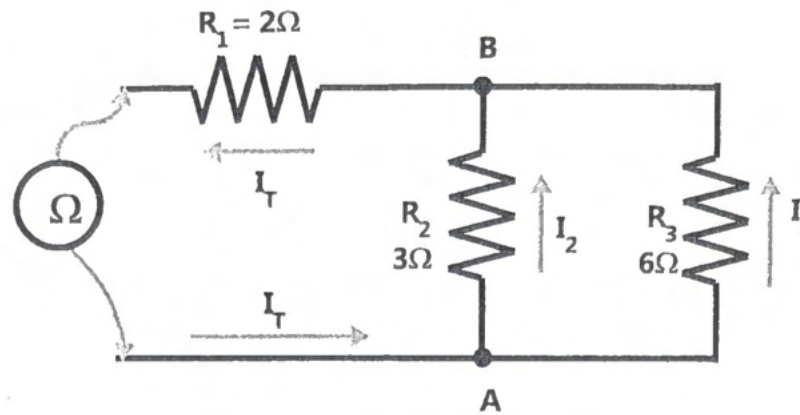


Figure 1.29

From this we can gather that Point A is an entry into a parallel branch, and that the 'out' point of this branch is Node B. Therefore, whatever the resistance equivalent of this parallel branch; which consists of a 3Ω (R2) resistance in parallel with a 6Ω (R3) resistance, then this equivalent is in series with the other 2Ω (R1) resistance.

We also know that:

- For two resistors in parallel we can use the Product-over-Sum Method to determine the equivalent resistance, and we also know that for resistances in series we simply add the resistances. Therefore, for the parallel branch total:

$$R_t = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\Omega$$

and:

We add the 2Ω equivalent of the parallel branch to the 2Ω series resistance to obtain a total of 4 ohms for the circuit.

Does it matter where the series resistance is placed in the circuit relative to the parallel branch? The answer is No. Consider the circuit of figure 1.30. It is, essentially the same circuit as figure 6.1 with the difference that the 2Ω series resistance is placed before the parallel branch instead of after the parallel branch. But for calculation purposes, we still simplify the parallel branch into its 2Ω equivalent and then add this to the 2Ω series resistance to obtain a total of 4 Ohms.

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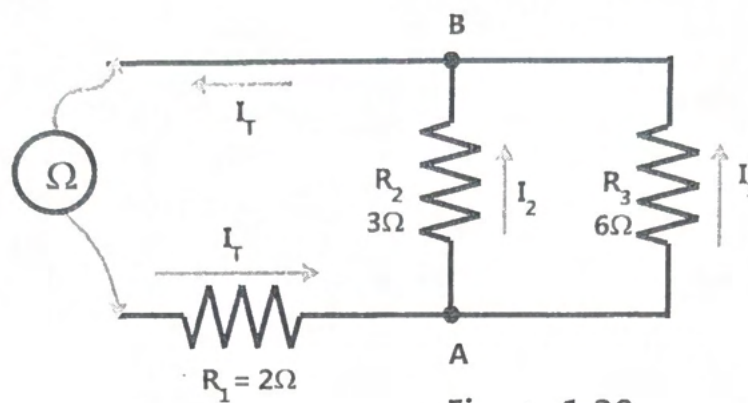


Figure 1.30

The trick to circuit analysis, therefore, is to determine where the parallel branches are, and then being able to convert these to series equivalents that can be added together.

Let's try another one...we'll look at this one in stages. Consider figure 6.3. Before we do, it is important to note:

➤ **The symbol for designating parallel resistances is:**

$R_2 || R_3$ - This states: Resistance R_2 is in parallel with resistance R_3

In this case stage (A) is the complete circuit which contains the parallel branch of R_2 and R_3 , and the parallel branch of R_4 and R_5 .

We can use any of the parallel resistance methods to obtain the series equivalent totals of the two parallel branches as shown in stage (B) of figure 1.31.

Once we determined the series equivalents, we just add up the resistances to obtain the total circuit resistance from the sum of all resistances in series.

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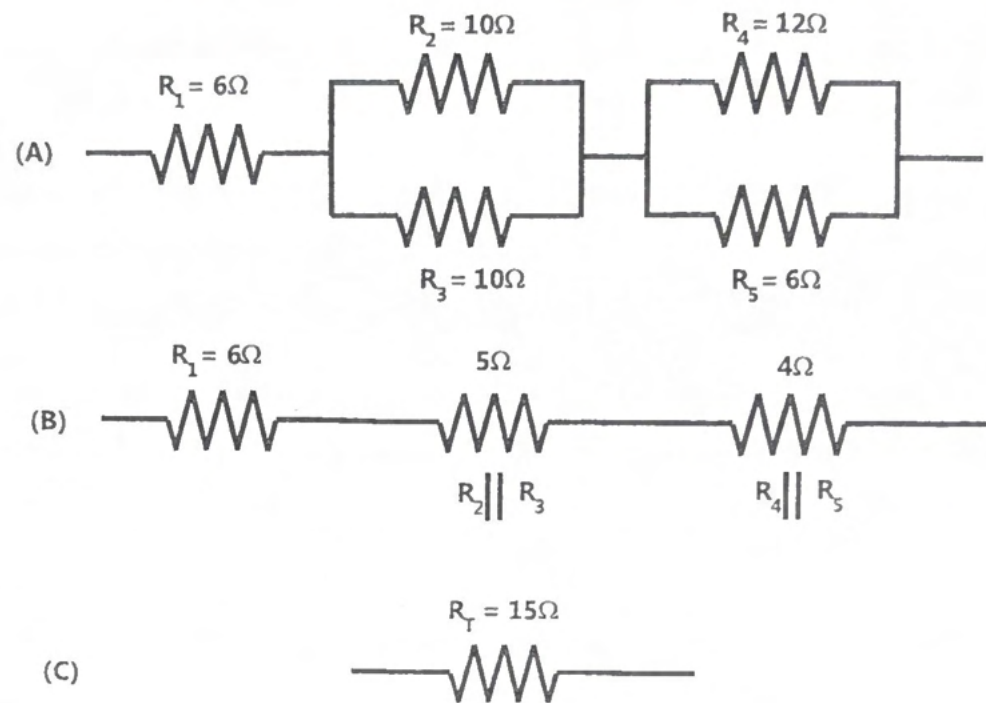
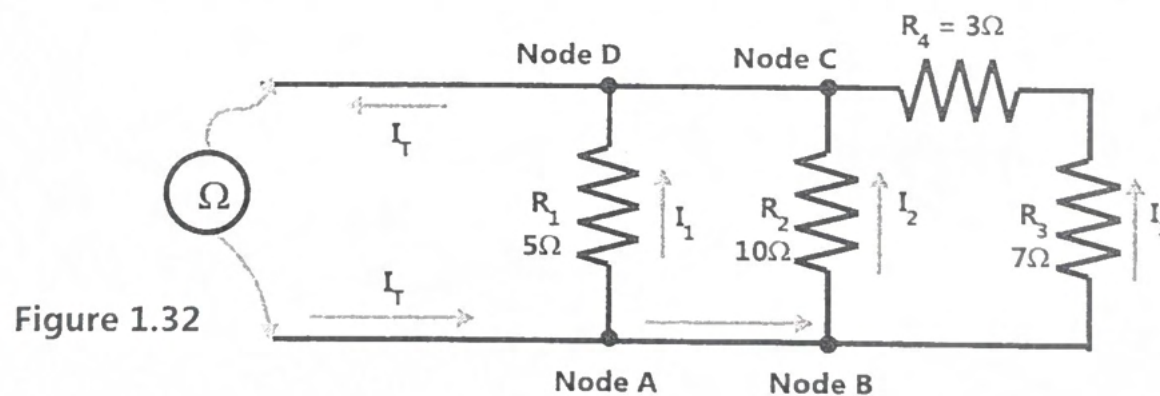


Figure 1.31

Typically, the tricky part is in determining just what is in parallel and what is in series. For example, consider figure 1.32. In this circuit, R_4 by itself is not in parallel with R_2 . Instead, R_2 is in parallel with the series total of R_3 and R_4 .



So what we really have is $R_2 || (R_3 + R_4)$, or $10\Omega || 10\Omega$.

From Unit 5, recall that for resistances of equal value we can simplify to equivalent series resistance by dividing one of the resistance values by the number of resistors in the circuit.

Therefore $10/2 = 5\Omega$

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The series equivalent of R_2 and $R_3 + R_4 = 5$ ohms. Therefore, 5Ω is in parallel with R_1 which is also 5 ohms and the series equivalent of this is 2.5 ohms.

- **Note: another way to look at equal resistances in parallel when there are only two resistors is to say that the series equivalent = $\frac{1}{2}$ of one resistor.**

For our circuit, $\frac{1}{2}$ of one resistance = $\frac{1}{2}$ of 5Ω ; which is 2.5 ohms.

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SECTION 1.6 – GROUNDS AND SHORTS

GROUND as a REFERENCE POINT

The concept of a reference point is important polarities, but it is also important in describing voltage levels. In electrical, the reference points we typically use are called ground points.

Point to remember:

- ***An electrical ground is called ground regardless of whether it is actually connected to the earth.***

For example, your car battery is by no means connected to the earth. If anything, it is completely isolated from the earth by the rubber tires, (Recall that rubber is an insulating material).

Therefore, "Ground" on your car's electrical system simply means that the chassis of the car is connected to the negative terminal of the battery; i.e., it is the common reference point.

Keep in mind, however, that ground can literally be the earth, such as when a ground rod is driven into the ground below your Main Service Panel and all your house grounds and neutrals are connected to that ground rod.

The two symbols for "ground" are provided in Unit 2 and repeated in figure 1.33 as follows:

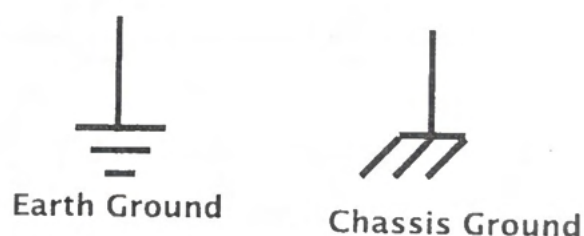


Figure 1.33

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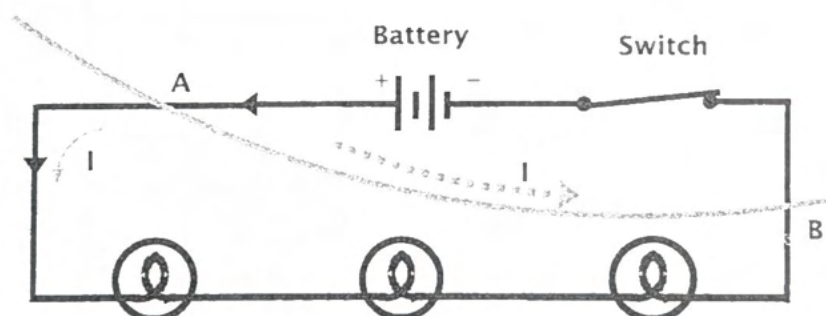
The Short Circuit

Suppose we have a three lamp circuit, where a wire clipping, (as represented by the curved line), falls across the circuit as shown in Fig 1.34 making contact with the circuit conductors at points A and B. As represented by the dashed lines in gray, the thicker dashed line represents the fact that due to very little resistance in the wire, a "short-cut" path is now available for the current to take as a return path back to the battery. Since this is a very low resistance compared to the resistance of the lamps, much more current will flow through the "short" than through the lamps, probably not enough to even turn the lamps on.

In fact, enough current can build up in the short circuit to exceed the rating of any protection device such as a fuse or a circuit breaker, where the fuse will burn open or the circuit breaker will "pop" open to protect the wiring.

This situation, where a low resistance "short-cut" path is available for current to return back to the voltage source is called a "short circuit".

Figure 1.34



Short circuits can occur at junction boxes, at switch and receptacle terminals, and at points where wires are cut or frayed. The high heat from the excessive current flow in the short circuit can cause wire insulation to catch flames where fires can start inside of walls. This is the reason we make use of fuses and circuit breakers as safety devices that open the circuit to remove current flow.

Don't get confused by the phrase "*electricity takes the path of least resistance*". In other words, in our circuit above, it doesn't mean zero current is flowing through the lamps. It just means less current is flowing through the lamps than would be without the short. There still may be enough current flow through the lamps to cause injury or death if a person comes in contact with this current. Current flow resulting from a 'short-circuit' is called **Fault Current**.

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Polarity Considerations

When we discuss voltage distribution we must consider not only the magnitude and division of the voltage, but also the polarities of the voltages.

To determine the polarity of a voltage drop, you must consider the direction of the current. Since electrons move from negative to positive, the current in the circuit of figure 1.35 is moving from point A to point B. This means that point A is more negative with respect to point B (or we can say point B is positive with respect to point A).

Do not be confused by the fact that at points B, C and D we have both a positive (+) and a negative (-). This just means each point is either positive or negative with respect to another. For example, point C is positive with respect to point B, but it is negative with respect to point D.

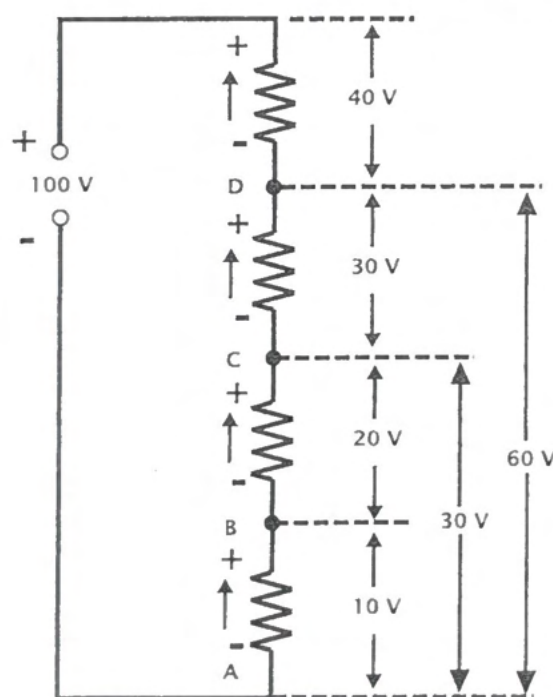


Figure 1.35

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SECTION 1.7 – OHM'S LAW

OHM'S LAW DEFINED

The elements of an electric circuit are defined as follows:

(I) - Current

Current is flow of electrical energy (electrons) on a wire conductor. Current flows from negative to positive on the surface of a conductor. Current is measured in (A) amperes or amps.

(E) - Voltage

Voltage is the difference in electrical potential between any two points of a circuit. Voltage is the push or pressure from the voltage source, such as a D.C. battery, that causes current flow through a circuit. current is measured in (V) volts.

(R) - Resistance

Resistance is the limiting factor of current; i.e, it determines how much current will flow through a circuit. Depending on the amount of voltage applied, high resistance allows a small amount of current to flow and low resistance allows a large amount of current to flow. Resistance is measured in ohms (Ω).

(P) - Power

Power is the amount of energy that is dissipated by a circuit in the form of heat, light or work being performed in a conversion process; such as electrical energy converted to mechanical energy by a motor to drive a load. Power is measured in units of watts.

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Ohm's Law is the set of mathematical formulas that represent the relationships that exist between voltage, current, resistance, and power in any circuit. Note that in Ohm's Law formulas these circuit elements are represented by the letters E or V for voltage, I for current, R for resistance, and P for power.

Ohm's Law relationships are expressed as follows:

- ✓ Current increases when voltage increases
 - ✓ Current decreases when voltage decreases
 - ✓ Current increases when resistance decreases
 - ✓ Current decreases when resistance increases
 - ✓ Power increases when current increases
 - ✓ Power increases when voltage increases
- } With Constant Resistance
- } With Constant Voltage
- } With Constant Voltage
- } With Constant Current

These relationships are expressed mathematically as:

- $V = I \times R$
- $I = E/R$
- $R = E/I$
- $P = E \times I$

Unit 1 – Basic Electricity Review

Figure 1.36 shows two versions of the Ohm's Law wheel; one (at left) for the relationships between voltage, current and resistance, and the other (at right) for the relationships between power, voltage and current.

The wheels serve as a memory tool for the formulas above. By holding your finger over the unknown value you are trying to determine, the relationship is visible with the other values. For example, holding the finger over E on the wheel leaves $I \times R$. Therefore, $E = I \times R$.

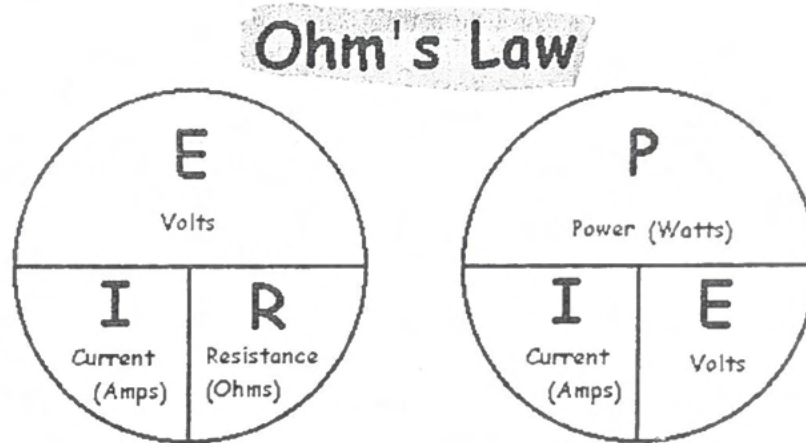


Figure 1.36

Unit 1 – Basic Electricity Review

Let's look at some examples of using Ohm's Law formulas.

Example 7-1:

Given: a resistance (R) of 6 Ohms connected to a 12 volt battery (E).

Find: The current (I).

Solution:

Covering the letter I in the memory circle we see that $I = E/R$.

$$I = \frac{E}{R} = \frac{12}{6} = 2 \text{ amps}$$

Example 7-2:

Given: a source of 6 volts forcing a current of 2 amps through a resistor.

Find: The value of the unknown resistor.

Solution:

Covering the letter R in the memory circle we see that $R = E/I$.

$$R = \frac{E}{I} = \frac{6}{2} = 3 \text{ ohms}$$

Example 7-3:

Given: a current of 8 amps flowing through a 3 ohm resistance.

Find: The voltage needed to push 8 amps of current through 3 ohms of resistance.

Solution:

Covering the letter E in the memory circle we see that $E = I \times R$.

$$E = I \times R; \quad E = 8 \times 3; \quad E = 24 \text{ volts}$$

The following example shows how to apply Ohm's Law formulas.

Unit 1 – Basic Electricity Review

Example 7- 4:

Given: A current of 2 milliamps (2mA) is flowing through a 5K Ω resistance.

Find: The voltage of this circuit

Solution #1:

$$E = I \times R$$

$$E = .002A \times 5,000\Omega$$

$$E = .002 \times 5,000 = \underline{10V}$$

Solution #2:

$$E = I \times R$$

$$E = (2 \times 10^{-3}) \times (5 \times 10^3)$$

$$E = (2 \times 5) \times (10^{-3} + 10^{+3})$$

$$E = 10 \times 10^0; \text{ (or } 10 \times 1, \text{ since any number to the zero power always} = 1.)$$

$$E = 10V$$

For Solution #2 you will have had to remember that milli = -3, and kilo = +3.

You also would need to remember that when multiplying exponents, you add them together. In this case $(-3) + (+3) = 0$, so they cancel each other out and we only have left the $10 \times 1 = 10$.

But we also know that anything divided by itself equals 1. Therefore, $R/R = 1$.

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Unit 1 – Basic Electricity Review



Unit 1 Review Quiz

Circle the correct response for the questions listed below.

1. The measurement of electrical pressure is expressed in:
 - a. Impedance
 - b. Resistance
 - c. Volts
 - d. Amperes
2. Current flows in an electrical circuit.
 - a. True
 - b. False
3. Current in an electrical circuit is measured in:
 - a. Volts
 - b. Ohms
 - c. Farads
 - d. Amperes
4. Of the following, which is the best conductor?
 - a. Glass
 - b. Wood
 - c. Silver
 - d. Copper
5. Resistance in an electrical DC circuit is:
 - a. The amount of voltage present
 - b. The opposition to current flow
 - c. The circuit pressure
 - d. All of the above

Unit 1 – Basic Electricity Review

6. According to the electron theory, direct current means that the current:
- a. Travels in only one direction in the circuit at all times
 - b. Travels in two directions, but in only one direction at a time
 - c. Travels in only one direction during each alternation
 - d. None of the above
7. The electron possesses a:
- a. Neutral charge
 - b. Negative charge
 - c. Positive charge
 - d. A positive or negative charge depending upon the circuit
8. If electrons will flow easily through a material, that material is said to be a good:
- a. Capacitor
 - b. Resistor
 - c. Insulator
 - d. Conductor
9. Match the symbols at left with the correct names on right.



e Ammeter

c Voltmeter

a Battery

d Switch

f Crossing Point

b Lamp

Unit 1 – Basic Electricity Review

10. When a conductor is moved through a magnetic field, d is developed across the conductor?
- a. Inductance
 - b. Resistance
 - c. Capacitance
 - d. Voltage
11. Resistance is measured in:
- a. EMF
 - b. Ampere
 - c. Volt
 - d. Ohms
12. In which of the following are all four methods, and/or sources, known as different ways of producing an electrical potential?
- a. Generator, thermocouple, battery, insulator
 - b. Piezoelectric, crystal, wire, battery
 - c. Generator, thermocouple, resistor, battery
 - d. Battery, generator, thermocouple, piezoelectric
13. The electron current flow theory states:
- a. Current flows from the negative terminal to the positive terminal
 - b. Current flows from the positive terminal to the negative terminal
 - c. Current doesn't flow, only voltage does
 - d. none of the above
14. Ohm's Law correctly states:
- | | | |
|---------------------|------------------|------------------|
| a. $E = I/R$ | $R = I/E$ | $I = E/R$ |
| b. $E = I \times R$ | $I = E/R$ | $R = E/I$ |
| c. $R = E \times I$ | $E = E \times R$ | $E = R \times I$ |
| d. $E = I/R$ | $I = E/I$ | $R = R/E$ |

Unit 1 – Basic Electricity Review

15. To explain what effect the cross-sectional area of a conductor has upon the resistance of the conductor per unit length, it would be correct to say:

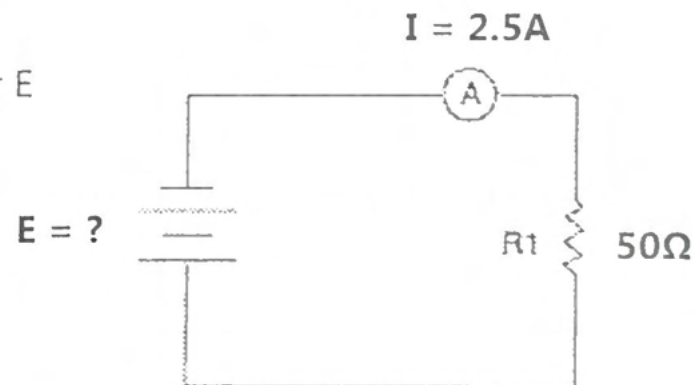
- a. Double the cross-sectional area and the resistance is halved
- b. Double the cross-sectional area and the resistance is doubled
- c. Halve the cross-sectional area and the resistance is halved
- d. The cross-sectional area has no effect on resistance

16. What effect will doubling the length of a conductor have on its resistance?

- a. It will be quartered
- b. It will remain the same
- c. It will be halved
- d. It will double

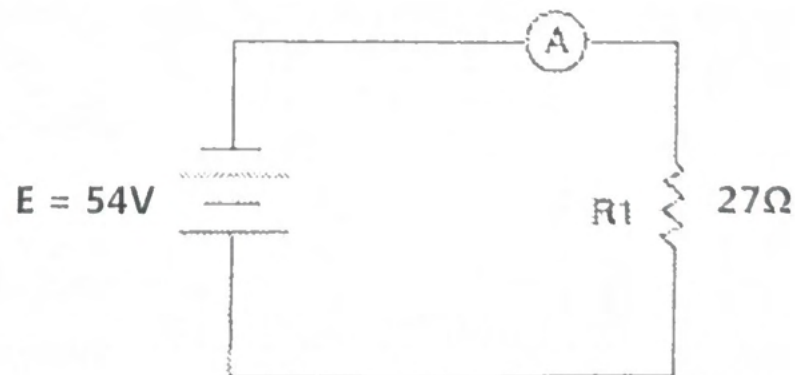
17. For circuit at right, solve for E

- a. 25 volts
- b. 100 volts
- c. 125 volts
- d. 150 volts



18. Solve for I.

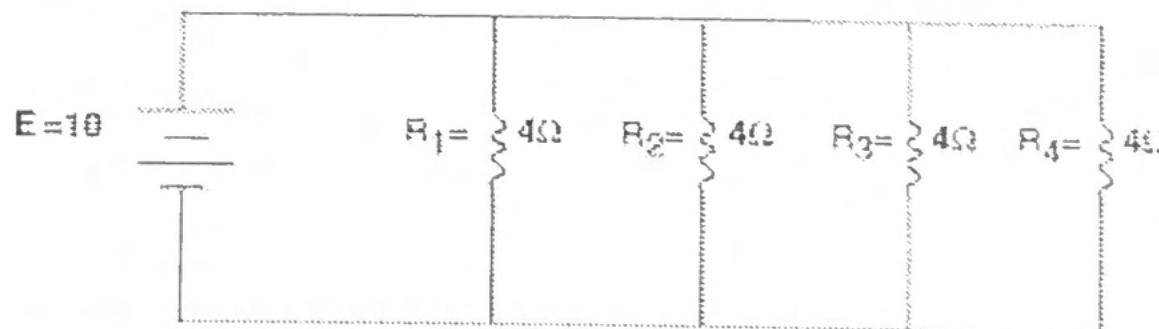
- a. 1458 amps
- b. 2 amps
- c. .5 amps
- d. 81 amps



Unit 1 – Basic Electricity Review

19. If, in an electrical DC series circuit, three resistors are connected; where one resistor is 50Ω , one is 100Ω , and one is 200Ω . What is their combined resistance?
- a. Less than 200Ω
 - b. 28.6Ω
 - c. 350Ω
 - d. Less than 50Ω
20. If a correctly wired DC series circuit were constructed, how many paths for current flow would there be?
- a. Two paths from the voltage source and one from the resistor
 - b. There must be at least two paths in a series circuit
 - c. There can only be one path in a series circuit
 - d. One in DC circuits and two in AC circuits

21. Find the total circuit current in the following circuit. $I_T =$ _____



22. In a correctly wired parallel circuit, there are how many paths for current to flow?
- a. Only one
 - b. Only two, in the same direction
 - c. Only two, in opposite directions
 - d. There can be two or more

Unit 1 – Basic Electricity Review

23. If the voltage across each of the components in a circuit is the same as the source voltage, the circuit is said to be connected in:

- a. Open
- b. Closed
- c. Parallel
- d. Series

24. If the current is found to be the same at all points in a circuit, the circuit is said to be:

- a. Shorted
- b. Open
- c. In Series
- d. In Parallel

25. Electrical power is measured in:

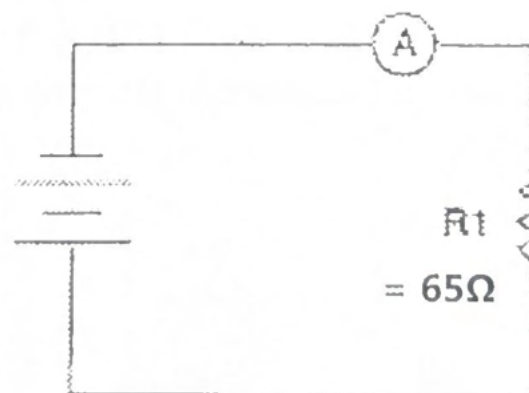
- a. Watts
- b. Ohms
- c. Amperes
- d. Volts

26. What is the power in the following circuit?

- a. 100 Watts
- b. 260 Watts
- c. 25 Watts
- d. 65 Watts

$E = 130V$

$I = 2A$



Unit 1 – Basic Electricity Review

27. Which of the following formulas should be used to determine power?

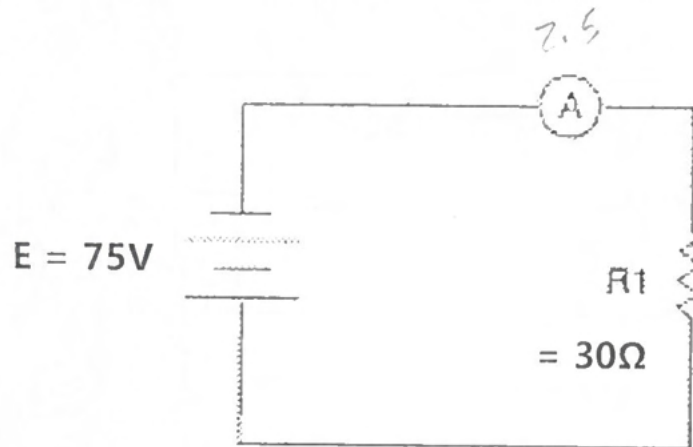
a. $P = E \times R$

b. $P = E \times I$

c. $P = E/R$

d. $P = I/R$

28. Solve for power in the circuit below. Power = _____.



29. Inductance is usually represented by the letter:

a. I

b. L

c. C

d. R

30. Capacitance in an electronic circuit is represented by the letter:

a. H

b. E

c. F

d. C

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UNIT 2 - ENGINEERING AND SCIENTIFIC NOTATION

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Unit 2 - Engineering & Scientific Notation

INTRODUCTION

To understand the language of technology, we must first introduce, study and understand engineering notation, scientific notation and metric prefixes. Why do we need to use these number notation systems or configurations? As you will soon see, in electronics there is a need to represent very large numbers and very small numbers with accuracy and with ease, usually within the same circuit or problem. This notation will allow us to communicate (in written form as well as verbally) circuit values and properties more accurately and will allow us to perform mathematical calculations with greater ease.

OVERVIEW

Scientific notation is just a fancy name for floating point arithmetic or notation also known commonly as Power-of-Ten Notation and can be applied to any number. In comparison, engineering notation only uses multiples of 3 for the power of ten notation exponent. This allows the use of the Greek prefixes to replace the power of ten notation values.

UNIT 2 OBJECTIVES

Upon completion of this unit, you will be able to:

- Describe Scientific and Engineering Notation formats
- Represent values using Scientific and Engineering formats
- Perform Math Operations using Scientific Notation

Unit 1 – Basic Electricity Review

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Unit 2 - Engineering & Scientific Notation

SECTION 2.1 – THE GREEK PREFIXES

In working with electricity and electronics, you will often find the following Greek prefixes used to express values for various units of measure. These units may be measures of volts, ohms, amperes, watts, Hertz, etc. For example, we could say 250 kilowatts or 85 milliamps.

Most of these are still used today in both electronics and data communications so you should become familiar with all of these. The bolded items, however, are particularly used often in electricity and electronics.

TABLE OF GREEK PREFIXES

Exponent	Name	Prefix	Symbol	Floating Decimal Number
10^{12}	Trillion	Tera-	T	1,000,000,000,000
10^9	Billion	Giga-	G	1,000,000,000
10^6	Million	Mega-	M	1,000,000
10^3	Thousand	Kilo-	K	1,000
10^2	Hundred	Hecto-	H	100
10^1	Ten	Deca-	D	10
10^{-1}	One Tenth	Deci-	d	.1
10^{-2}	One Hundredth	Centi-	c	.01
10^{-3}	One Thousandth	Milli-	m	.001
10^{-6}	One Millionth	Micro-	μ	.000001
10^{-9}	One Billionth	Nano-	n	.000000001
10^{-12}	One Trillionth	Pico-	p	.000000000001
10^{-15}	One Quadrillionth	Femto-	f	.000000000000001

Unit 2 - Engineering & Scientific Notation

SCIENTIFIC AND ENGINEERING NOTATION

Scientific notation, also called exponential notation, is a way to write values that are too large or too small to be conveniently written in standard decimal form. It is also a useful way to explain and use the "Powers of Ten" exponents.

When combined with the Greek Prefixes from the previous page, we can use "Powers of Ten" to represent electrical values. We call the application of these prefixes with Powers of Ten "Engineering Notation". Examples include Kilo Ohms ($K\Omega$), milliamps (mA), Megawatts (MW), and microwatts (μW).

Notation	Definition	Example
Scientific Notation	Value expressed as a number multiplied by a power of 10	1000 can be expressed in 1×10^3 format
Engineering Notation	A Scientific Notation value converted to a metric prefix (Greek letter)	Per Table of Greek Prefixes, 1×10^3 can be expressed as 1Kilo, or 1×10^6 can be expressed as 1Mega

The standard format for writing a value in scientific notation is as follows:

the significant **Number** x **BASE**^{Exponent}

where the 'Base' is multiplied by itself 'Exponent' times, then that result is multiplied by the 'Number', or ... **$n \times 10^m$** (which reads "**n times 10 to the mth**")

What this expression says is that we can take any decimal value and convert it to the above format where a number is multiplied to the base 10 with some exponent value.

Unit 2 - Engineering & Scientific Notation

For example, let's convert the decimal value 1,000 to scientific notation format. To do so, we must consider a couple of assumptions:

1. By convention, we always know that a decimal point is at the right end of a value or number, even though we don't write it unless we include a fractional part.
2. Any base number with an exponent of zero is always equal to one (e.g., $10^0 = 1$)

The value one thousand 1,000 is written as 1,000, but we know there is a decimal point at the right end of this value ($= 1,000.$) even though we typically only include the decimal point when we include a fractional part; such as when we write 1,000 and a half as 1,000.5.

Therefore, writing the value 1,000 is the same as writing $1000. \times 10^0$ because this is saying 1,000 times 1, which equals 1,000, and placing a decimal point at the right end of the value. The key here is that converting 1,000 to scientific notation format does not change the value...it is still 1,000.

Now, if we move the decimal point to the left three places we will have 1.000 instead of 1,000. This changes the value of the number by making it three places smaller in value. So, to compensate for this change, we can make the exponent larger in value by the same number of places we moved the decimal point, and we always make a value larger by *adding* to it.

Therefore, we can re-write the value of 1,000 as:

$$1.000 \times 10^{0+3}$$

And since $0 + 3 = 3$, we can now re-write 1,000 in Scientific Notation as: 1.000×10^3

Now, from the above, we know that $10^3 = 1,000$, but you also know that 10^3 is also called "Kilo" (refer to table of prefixes). Therefore, we can now also write 1,000 in Engineering Notation as 1.0K or just 1K.

If we were measuring resistance and we measured 1,000 ohms, we can say we measured "1Kilo ohm" or 1K ohm of resistance and write it as 1K Ω .

Unit 2 - Engineering & Scientific Notation

Let's try a small (fractional) number. Let's assume we measure .500 amps of current in a circuit with an ammeter and we want to express it using a Powers of Ten prefix. Looking at the value .500, we recognize that we can move the decimal point three places to the right this time to obtain a whole number of 500. However, 500 is a far cry from .500, which means we changed its value.

So to compensate, we use the exponent. What's the first step? We convert the value .500 to scientific notation format without changing its value, by multiplying .500 by 10^0 (multiply by 1).

$$.500 \times 10^0$$

Next, we move the decimal point to the right to make the value 500:

$$500. \times 10^0$$

This makes the original value larger in value from the original value, so we compensate by making the value of the exponent smaller. How do we make a value smaller? We subtract. How much do we subtract? The same number of places we moved the decimal point. Therefore we have:

$$500. \times 10^{0-3}$$

Since zero minus 3 = -3, we can re-write this as:

$$500. \times 10^{-3}$$

However, since we learned that 10^{-3} is called milli, (refer to Greek Prefixes), we can now say that we have measured 500 milliamps or 500mA of current in our circuit.

Hopefully, you can see now that we can change any value to a value we can represent with a Power of 10 prefix just by manipulating the number of places we move the decimal point.

Unit 2 - Engineering & Scientific Notation

Let's put a twist on what we've learned. Let's say we want to convert 7KHz to just plain hertz. The following steps are used to do this:

First, we write the value in scientific notation format with a decimal point to the right of the number. Since we know that Kilo = 10^3 , we can write 10KHz as:

$$7.0 \times 10^3$$

Now, we want to end up with a number times 10^0 so that we are multiplying the value times 1. How do we change 10^3 to 10^0 ? We subtract 3 from the exponent.

$$7.0 \times 10^{3-3} \text{ (which becomes } 7 \times 10^0)$$

But changing the exponent from 3 to zero changes the value of the number making it much smaller than it was. Therefore, we compensate for this by making the value itself larger. How much larger?

We move the decimal point to the right the number of places that we subtracted from the exponent. In order to move three places to the right we must add three zeros to the number and we get:

$$7000. \times 10^0$$

Since $10^0 = 1$, and since multiplying any number by 1 gives us the same number, we can ignore this 10^0 and we have 7,000 x 1 which is now 7,000 hertz.

Therefore 7KHz = 7,000 Hz.

Note: Scientific Notation used with Greek Prefixes is sometimes differentiated from what mathematicians call "Proper" Scientific Notation. "Proper" Scientific Notation is the process of always expressing a value with only a single digit to the left of the decimal point, and multiplying this times a base 10 exponent. This is what many calculators do when you use the "SCI" key. For example, in electrical work we can express 600 milliwatts as 600×10^{-3} since 10^{-3} represents "milli". This is Scientific Notation. However, with "Proper" Scientific Notation, this would be expressed as 6.0×10^{-1} . Therefore, the exponent value depends on the placement of the decimal point and the exponent does not need to match a Greek Prefix value.

Unit 2 - Engineering & Scientific Notation

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We move the decimal point to the right the number of places that we subtracted from the exponent. In order to move three places to the right we must add three zeros to the number and we get:

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Therefore 7KHz = 7,000 Hz.

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Unit 2 - Engineering & Scientific Notation



Unit 2 Review Quiz

Circle the letter of the correct answer. Choose only one answer.

1. 10 m is equivalent to _____.
 - A. 0.01 m
 - B. 0.00001
 - C. 1×10^{-3}
 - D. 10000 m

2. The notation kilo is equivalent to _____.
 - A. 1k
 - B. 10^3
 - C. $10 \times 10 \times 10$
 - D. all of these

3. 1000 k is equal to _____.
 - A. 1000×10^6
 - B. 1 Million
 - C. 1 one millionth
 - D. none of these

4. What is the engineering prefix for 10^6 ?
 - A. Kilo
 - B. Mega
 - C. milli
 - D. Giga

Unit 2 - Engineering & Scientific Notation

Convert one engineering prefix to another

5. 20,000 pico = _____ n
6. 0.56308 micro = _____ n
7. 9,454,003.67 = _____ k
8. 4,306.5050 nano = _____ μ
9. 0.45454545 = _____ m
10. 5,697 kilo = _____ M
11. 0.00330456 = _____ μ
12. 0.00049586 kilo = _____ m
13. 0.99950 milli = _____ μ
14. 843.79 = _____ k
15. 19,876 μ = _____ m
16. 0.97629 M = _____ k
17. 8395 p = _____ n
18. 35,754,046 k = _____ G

Unit 2 - Engineering & Scientific Notation

19. $0.667 \text{ m} = \text{_____} \mu$
20. $4976 \text{ m} = \text{_____}$ (in regular base 10 value)
21. $0.08976309 \text{ n} = \text{_____} \text{p}$
22. $0.00043210 = \text{_____} \mu$
23. $0.1999 = \text{_____} \mu$
24. $245 \mu = \text{_____}$ (in regular base 10 value)

Unit 2 - Engineering & Scientific Notation

Rewrite the following values in **engineering** notation.

25. $10 \times 10^{-3} = \underline{\hspace{1cm}}$ m

26. $1 \times 10^6 = \underline{\hspace{1cm}}$ M

27. $15 \times 10^{-6} = \underline{\hspace{1cm}}$ m

28. $180 \times 10^{-9} = \underline{\hspace{1cm}}$ n

29. $3 \times 10^6 = \underline{\hspace{1cm}}$ M

30. $10 \times 10^{-6} = \underline{\hspace{1cm}}$ m

31. $2 \times 10^{-12} = \underline{\hspace{1cm}}$ p

32. $3.3 \times 10^9 = \underline{\hspace{1cm}}$ G

33. $4.5 \times 10^{-3} = \underline{\hspace{1cm}}$ m

34. $7 \times 10^{-6} = \underline{\hspace{1cm}}$ m

Rewrite the following values in **scientific** notation.

35. $99 \text{ m} = 99 \times \underline{\hspace{1cm}}$

36. $6 \text{ G} = 6 \times \underline{\hspace{1cm}}$

37. $38 \text{ k} = 38 \times \underline{\hspace{1cm}}$

38. $63.3 \mu = 63.3 \times \underline{\hspace{1cm}}$

39. $81 \text{ p} = 81 \times \underline{\hspace{1cm}}$

40. $23 \text{ n} = 23 \times \underline{\hspace{1cm}}$

41. $45.45 \mu = 45.45 \times \underline{\hspace{1cm}}$

42. $6 \text{ m} = 6 \times \underline{\hspace{1cm}}$

43. $25 \text{ k} = 25 \times \underline{\hspace{1cm}}$

44. $75 \mu = 75 \times \underline{\hspace{1cm}}$

Unit 2 - Engineering & Scientific Notation

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UNIT 3 - NUMBER SYSTEMS AND CONVERSIONS

Unit 3 - Number Systems & Conversions

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Unit 3 - Number Systems & Conversions

INTRODUCTION

You probably already know what a number system is. Simply put, a number system is a way to represent values. Most of us are used to using the base-10 number system, which is also called the decimal number system. Other common number systems include base-16 (hexadecimal), base-8 (octal), and base-2 (binary).

OVERVIEW

Number systems refer to the number of symbols available for use in a given number system to represent values. In the decimal system, we use ten different symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Using these ten symbols, we can represent any quantity or value. The same holds true for binary, octal, and hexadecimal; where 2, 8, and 16 digits are available respectively, for each of these number systems. This unit reviews the binary, octal, and hexadecimal number systems; what they look like and the processes used to convert from one number system to another.

UNIT 3 OBJECTIVES

Upon completion of this unit, you will be able to:



- Identify and describe the common computer Number systems?
- Explain and Demonstrate the Number System Conversion Methods
- Explain procedures for performing Binary Addition
- Explain TTL
- Describe the "Digital Signal"
- Explain binary representation of Characters from the ASCII standard
- Describe and Review the application of Binary to IP Addressing
- Compare IPv4 and IPv6 formats and their use

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Unit 3 - Number Systems & Conversions

SECTION 3.1 – NUMBER SYSTEMS

CONVERTING THE DECIMAL (BASE₁₀) NUMBERING SYSTEM

The decimal system is what we use in everyday life; i.e., the counting system we learned in school. It is called a base₁₀ number system because there are 10 digits available in the system (0 through 9), and because as humans we have 10 fingers and it was convenient to choose this numbering system to count with our fingers. This is not to say there aren't other number systems which we will consider and review later in this section.

Every number system has a "highest" value digit in that system; where the total of digits available in any given system provides for the number system name. For example, the digit nine is the highest value in the base₁₀ number system and including the digit 0, there are ten digits available in the base₁₀ system (0 to 9). This highest value is, typically, one less than the value of the number system base.

In similar fashion, the binary number system (base₂) contains 2 available digits (0 and 1), the Octal (base₈) system has 8 available digits (0 to 7), and the hexadecimal system contains 16 available digits (0 to 15). In all cases, the highest value digit of any number system is called the "modulus" of that number system.

When using different number systems, we aren't changing the value or 'count' of anything. We are merely converting to a 'count' using the available digits of that system. For example, since base₈ contains neither digits 8 nor 9, instead of counting 10 ten items as "0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10", we count them as "0, 1, 2, 3, 4, 5, 6, 7, 10, 11". It doesn't change the fact there are 10 items as we count them in decimal digits. It just means that I can say the tenth item is counted as item number 11 because I skipped 8 and 9.

Since all counts of items can be represented in any number system value, we can convert any number system value to another value of a different number system. We will show this starting with a review of how we learned about base₁₀.

Unit 3 - Number Systems & Conversions

Using the decimal (base₁₀) value of two-hundred and thirty five (425), let's review the concept of base 10.

Each digit of this value 'hold' a place that we call the "one's" place", the "tens place", the hundreds place", etc.? We used these 'place holders' to determine the overall value of a number by assigning each place holder value, and then multiplying each digit of our value times each place value and adding these to a total. For the base₁₀ value of 425 we can show as follows:

We can map the 'place' of each of the digits of this number as follows:

100's	10's	1's
4	2	5

$$4 \times 100 = 400$$

$$2 \times 10 = 20$$

$$5 \times 1 = \underline{+ 5}$$
$$425$$

We just converted a base₁₀ value to a base₁₀ value using a process of multiply and add. In like manner, all different numbering system values can be converted to a base 10 value.

The Octal Number System – Converting Base₈ to Base₁₀

As we just described, per the base of the octal number system there are eight digits available (0 through 7). This means that no value can be represented with a digit 8 or a digit 9 included in the value. Counting from zero in base₈ we say "zero, one, two, three, four, five, six, seven, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, twenty", etc. There are simply no values containing an 8 or a 9.

Therefore, the place holders for base₈ digits are treated just like they are with decimal system values with the exception that the place holder values are now multiples of 8 instead of 10' i.e., one, eight, sixty-four, five-hundred and twelve, etc., and we call the place holder values "**weight**" values.

Unit 3 - Number Systems & Conversions

For example, going back to our 425 value as a base₈ value, we can express this with weight values 64, 8 and 1 as:

64	8	1	= weights
4	2	5	

And we can convert to decimal base₁₀ using the same process as we used with base 10; i.e., we multiply and add.

$$4 \times 64 = 256$$

$$2 \times 8 = 16$$

$$5 \times 1 = \underline{+ 5}$$
$$277$$

Therefore: 425 in Octal = 277 in decimal ($425_8 = 277_{10}$)

The Hexadecimal Number System – Converting Base₁₆ to Base₁₀

Just as with decimal and octal, we convert from hexadecimal to decimal using the same process, where the hexadecimal number system (also called "hex") has a modulus value of 16 and digits count from 0 to 16. A major exception, however, is the representation of values 10 through 16. These values are represented in "hex" using upper-case letters where we represent values from zero through nine as digits 0-9, but values 10 through 15 are represented using letters A through F. In this case A=10, B=11, C=12, D=13, E=14 and F=15.

Otherwise, just like decimal and octal, the hexadecimal number system contains "weight" values where these values are now multiples of 16; (i.e., 1, 16, 256, etc.).

Unit 3 - Number Systems & Conversions

For example, a hexadecimal number might look like this: 2AF

256	16	1	= weights
2	A	F	
	(10)	(15)	

We can convert to decimal base₁₀ using the same process as we used with base 10 and with base₈; i.e., we multiply and add.

$$2 \times 256 = 512$$

$$10 \times 16 = 160$$

$$15 \times 1 = \underline{+15}$$

687

Therefore: 2AF in Hexadecimal = 687 in decimal ($2AF_{16} = 687_{10}$)

The Binary Number System – Converting Base2 to Base10

In the binary number system there are only two digits: 0 and 1. Therefore, a binary value has the format of 01001110, depending on its value.

Note that I just used 8 binary bit positions to represent the binary format. In reality, any number of binary digits (called bits) can be used depending on the value, so we can write a binary number such as 0110, or 101, etc.

Typically, however, 8 bit positions are used in the computer world because a group of 8 bits equals what is called a "byte" of data. If you start counting the weight values for a group of 8 bits, from right to left, you'll see that the weight values are 1, 2, 4, 8, 16, 32, 64, and 128 (multiples of 2).

Lets convert binary 0110 to decimal base₁₀.

Unit 3 - Number Systems & Conversions

8	4	2	1
0	1	1	0

 = weights

Note that when multiplying a number by zero the answer is always zero, and when multiplying a number by one the answer is always the number multiplied; i.e., 1 times anything = anything. Therefore, in the binary conversion process, all we really need to do is add up all the weights that have a one binary value.

$$\begin{array}{r} 1 \times 2 = 2 \\ 1 \times 4 = +4 \\ \hline 6 \end{array}$$

Therefore binary 0110 = 6 in decimal ($0110_2 = 6_{10}$)

REVERSING THE PROCESS

We will now reverse the process and convert FROM the base₁₀ decimal value to any other numbering system value. This process includes reversing the math; i.e., instead of multiplying we divide using long division, and then reverse the order of the remainders.

Convert Decimal to Octal (The Process)

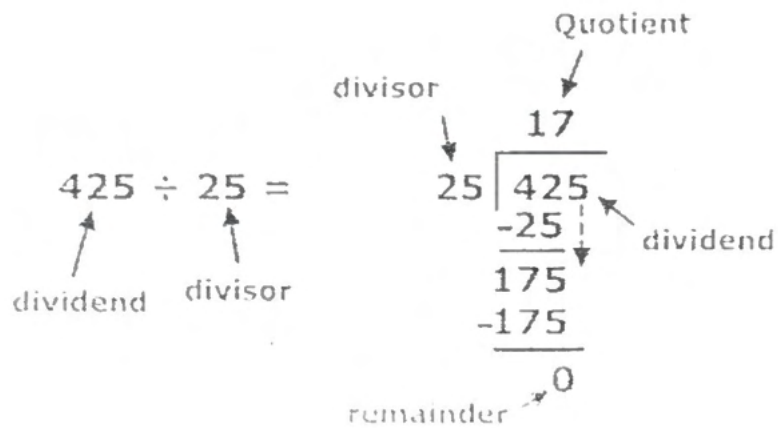
Starting with the base₁₀ value, we divide the value by the base of the number system we are converting to. For example, if we are converting from base₁₀ decimal to base₈, we divide the decimal value by 8. If we are converting from base₁₀ decimal to base₂, we divide the decimal value by 2, etc.

As shown below, each time we divide we get an answer we call the 'quotient'. We continuously divide each quotient by the base we are converting to until we obtain a quotient of zero. Our answer is then in the reversal of each remainder obtained with each division.

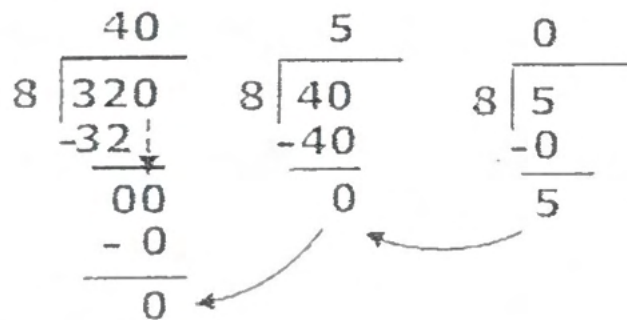
Note: It is important to remember, we must reverse the order of the remainders to obtain our conversion value.

Unit 3 - Number Systems & Conversions

The structure of long division, and the names of each component, is shown below.



Example: Let's convert base₁₀ decimal 320 to Octal base₈.



Reverse order of remainders = 500

Therefore: Base₁₀ 320 = base₈ 500 or **320₁₀ = 500₈**

This process is the same for converting ANY base 10 decimal value to a different number system value.

Unit 3 - Number Systems & Conversions

Convert Decimal to Hexadecimal

The example below converts decimal value 757 to Hex value. We provide this to show the conversion of the hex values 10 through 15 as represented by the uppercase alpha letters A through F. Recall earlier we converted the hex value 2AF to decimal. Here we reverse our process we divide 687 by 16.

$$\begin{array}{r} 47 \\ 16 \overline{) 757} \\ \underline{-64} \\ 117 \\ \underline{-112} \\ 5 \end{array} \quad \begin{array}{r} 2 \\ 16 \overline{) 47} \\ \underline{-32} \\ 15 \end{array} \quad \begin{array}{r} 0 \\ 16 \overline{) 2} \\ \underline{-0} \\ 2 \end{array}$$

Reverse order of remainders = 2 15 5

However, recall that in the hexadecimal number system the value 15 is represented with the uppercase letter F. Therefore, the decimal value 757_{10} is equivalent to hexadecimal value 2F5.

Convert Decimal to Binary

Finally, we will convert a base₁₀ value to a binary equivalent again using our previous example binary value 01001110_2 that we converted to decimal 78_{10} . Remember, we need to divide by base value 2.

$$\begin{array}{r} 39 \\ 2 \overline{) 78} \\ \underline{6} \\ 18 \\ \underline{18} \\ 0 \end{array} \quad \begin{array}{r} 19 \\ 2 \overline{) 39} \\ \underline{2} \\ 19 \\ \underline{18} \\ 1 \end{array} \quad \begin{array}{r} 9 \\ 2 \overline{) 19} \\ \underline{18} \\ 1 \end{array} \quad \begin{array}{r} 4 \\ 2 \overline{) 9} \\ \underline{8} \\ 1 \end{array} \quad \begin{array}{r} 2 \\ 2 \overline{) 4} \\ \underline{4} \\ 0 \end{array} \quad \begin{array}{r} 1 \\ 2 \overline{) 2} \\ \underline{2} \\ 0 \end{array} \quad \begin{array}{r} 0 \\ 2 \overline{) 1} \\ \underline{0} \\ 1 \end{array}$$

Unit 3 - Number Systems & Conversions

Now, we reverse the order of the remainders to get: Note that we represent this in 7 binary bits. Recall, however, that we define a byte as 8 bits; so we're missing a zero bit on the left. We can insert a zero into the left-most position and our answer with 8 bits = 01001110 as 1 byte of data. This becomes important in use of the 8-bit Extended ASCII code where 8 binary bits are used to represent any alpha-numeric character.

CONVERTING BETWEEN TWO NON-DECIMAL VALUES

Up to now we've shown you the two processes that involve conversion either from or to the decimal base₁₀ number system. Now we will shift gears and look at converting from one non-base₁₀ numbering system value to a different non-base₁₀ numbering system value.

Convert Octal to Binary

Consider the highest value of digit available in the octal number system. Recall that the octal number system uses 8 digits (0 through 7), so the highest octal value is 7.

Now, look at the binary weights, and starting from right to left, note the maximum number of binary bits, assuming they are all set to 1, that are needed to add up to the highest octal value possible (7). In other words, if you look at the first three weight positions for binary, which are 1, 2 and 4, these three weights add up to 7. Therefore, you will never need more than 3 binary bits to represent any octal digit value.

In terms of a process, we can take each digit of an octal value and represent each digit using three binary bits. Once we do this for all octal digits in our value, we simply group them together in a binary string. For example, note the convert the binary weights required to add up to each octal digit below.

Octal Value =	2	3	5
Binary weights for each digit =	4 2 1	4 2 1	4 2 1

Unit 3 - Number Systems & Conversions

In order to equal the value of each octal digit, we determine which weight positions need to be set to binary 1 in order to equal the digit value. In the case of the left-most octal digit 2, we need a binary 1 under the 2 weight. In the case of the middle digit 3, we need a binary 1 under the 2 and under the three, since $2+1 = 3$. In the case of the right-most octal number 5, we need a binary one under the weights 4 and 1 since $4+1 = 5$.

Note that if all three weight positions are set to 1, all three weights add up to 7, which is the highest octal value we need to represent for a single octal digit. So we'll never need more than three bits to represent any octal digit from 0 through 7.

Weight positions:	4 2 1	4 2 1	4 2 1
Octal Digits:	2	3	5
Binary Values:	0 1 0	0 1 1	1 0 1 (We add the left-most zero to fill the weight position)

Therefore, $235_8 = 010011101_2$

Convert Binary to Octal

Since we know that we will never need more than three binary digits to define an octal digit value from 0 to 7, we can now also convert from binary to octal. All we need to do is start from the right and group the binary digits into groups of three and add up the weights that contain a one bit. For example, using a binary string 10110111_2 value:

Binary digits: 1 0 1 1 0 1 1 1

Grouped into groups of three and adding weight positions:

Weight positions:	4 2 1	4 2 1	4 2 1
Binary Values:	0 1 0	1 1 0	1 1 1 (We add the left-most zero to fill the weight position)
Octal values:	2	6	7

Therefore, $10110111_2 = 267_8$

Unit 3 - Number Systems & Conversions

Convert Hexadecimal (Hex) to Binary

This conversion is exactly the same as octal to binary with one critical difference. Since a hex digit can be as high as a value of 15 ($F = 15$), then we need four binary digits to represent each hex digit because the weights of the first four binary positions add up to 15 (i.e., $8+4+2+1 = 15$). The conversion process is the same where the first four weight positions are used for each hex digit, and we again treat each hex digit independently using its weights.

Consider the first eight weight positions for the binary number system. Just as with the octal number system, we have a modulus, and we have a maximum number of weight positions needed to add up to the modulus value. In the case of "Hex", our highest possible Hex digit value = 15 (modulus = 15), and we need four weight positions to add up to 15 since $8+4+2+1 = 15$.

Exponent form	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Weight	128	64	32	16	8	4	2	1

Recall that in "Hex", the digit values 10 to 15 = A, B, C, D and E. So our digit C value = 12.

Example: Convert $7C5_{16}$ to binary:

Weight positions: 8 4 2 1 8 4 2 1 8 4 2 1

Hex digits: 7 C 5

Binary Values: 0 1 1 1 1 1 0 0 0 1 0 1

Therefore, $7C5_{16} = 011111000101_2$

Unit 3 - Number Systems & Conversions

Convert Binary to Hexadecimal (Hex)

We know that we will never need more, or less, than four binary weight positions to define a Hex digit value from 0 to 15. So, just as we did with binary to octal, we can now also convert from binary to Hex. All we need to do is start from the right again and group the binary digits into groups of four bits and then add up the weights that contain a one bit to determine the Hex value.

Let's convert our same binary 10110111_2 value we converted to octal, only now we will convert to Hex. Note that we now only have two groups of binary weights since there are only 8 bits and we group into groups of four.

Binary digits: 1 0 1 1 0 1 1 1

Grouped into groups of four and adding weight positions:

Weight positions: 8 4 2 1 8 4 2 1

Binary Values: 1 0 1 1 0 1 1 1

Hex values: 11 7

Since Hex 11 = B

Therefore, $10110111_2 = B7_{16}$

Unit 3 - Number Systems & Conversions

Convert Octal to Hexadecimal (Hex)

Let's now convert between Octal and Hex. One easy approach is to simply go through binary to perform the conversion; i.e., first convert the octal value to binary, then convert the Binary to Hex.

The key is to recall the maximum and minimum number of binary weights each number system requires. Octal requires 3 binary weight positions, and hex requires 4 binary weight positions.

First we convert 267_8 to binary as we did before.

Octal Weight positions:	4 2 1	4 2 1	4 2 1
Octal Digits:	2	6	7
Binary Values:	0 1 0	1 1 0	1 1 1 (We add the left-most zero to fill the weight position)

Therefore, ~~235~~²⁶⁷₈ = 010110111₂

Then we re-group our binary digits into groups of four bits and convert these groups to Hex digits.

Binary equivalent of 267 ₈ :	1 0 1 1	0 1 1 1 (convert to groups of 4 weight bits)
Hex Weight positions:	8 4 2 1	8 4 2 1
Hex digit Values:	11	7
Hex Value:	B	7

To convert in the opposite direction; i.e. from Hex to Octal, we simply convert hex to binary, then re-group the binary bits into groups of three weight bits and add up the weights that contain a 1 bit for each octal digit. In effect, it's this same process above in reverse.

SECTION 3.2 – BINARY ADDITION & APPLICATION

The Rules for binary addition are as follows:

$$1 + 0 = 1$$

Example:

$$\begin{array}{r}
 110000 \\
 00011010 \\
 +0000011000 \\
 \hline
 00100110
 \end{array}
 \begin{array}{l}
 \text{carries} \\
 = 26_{10} \\
 = 12_{10} \\
 = 38_{10}
 \end{array}$$

$$0 + 0 = 0$$

Unit 3 - Number Systems & Conversions

BINARY APPLICATION

As shown in our number conversions, we know that binary numbers are seen as strings of 0's and 1's. We also know that binary numbers are typically associated with the operation of computers, and it is natural to ask the question "why?" Why can't computers just use base 10 instead of converting to and from binary?

The answer lies in the fact that computers operate on the principle of two possible states. We can refer to these states as either "yes/no", "on/off", "high/low", voltage present/voltage not present", and "electrical current present/electrical current not present". The common characteristic of all these terms however, is that they represent only two possible states, and since the binary system contains only two possible digits, it makes sense to use the binary digits to represent these possible states.

This means that no matter what programming code, operating system, or application we use in any modern computer, every instruction in any programming language, every character, and every signal is eventually converted to the "machine level" of binary zeros and ones to represent the two possible states of voltage/no voltage, on/off, or high/low, etc.

In terms of electronics and the components of electronics, we know that these components operate on the basis of voltage or no voltage applied to turn things "on" and "off". Therefore, in digital, the pulses that represent digital states signify voltage and no voltage present at the component.

TTL (Transistor-Transistor Logic)

TTL is a name for the binary state levels; where the levels are defined in terms of the voltage values on the conductor wires that are the inputs and outputs of digital electronic components. Typically, most systems use "Positive" logic; where the "logic states" are expressed as binary "1" and binary "0", or "high" and "low" (voltage or no voltage) respectively.

Unit 3 - Number Systems & Conversions

Ideally, a TTL "high" signal would be 5.00 volts exactly, and a TTL "low" signal 0.00 volts exactly. However, real TTL gate circuits cannot output such perfect voltage levels, and are designed to accept "high" and "low" signals deviating substantially from these ideal values. "Acceptable" input signal voltages range from 0 volts to 0.8 volts for a "low" logic state, and 2 volts to 5 volts for a "high" logic state. "Acceptable" output signal voltages (voltage levels guaranteed by the gate manufacturer over a specified range of load conditions) range from 0 volts to 0.5 volts for a "low" logic state, and 2.7 volts to 5 volts for a "high" logic state as shown in figure 3.1.

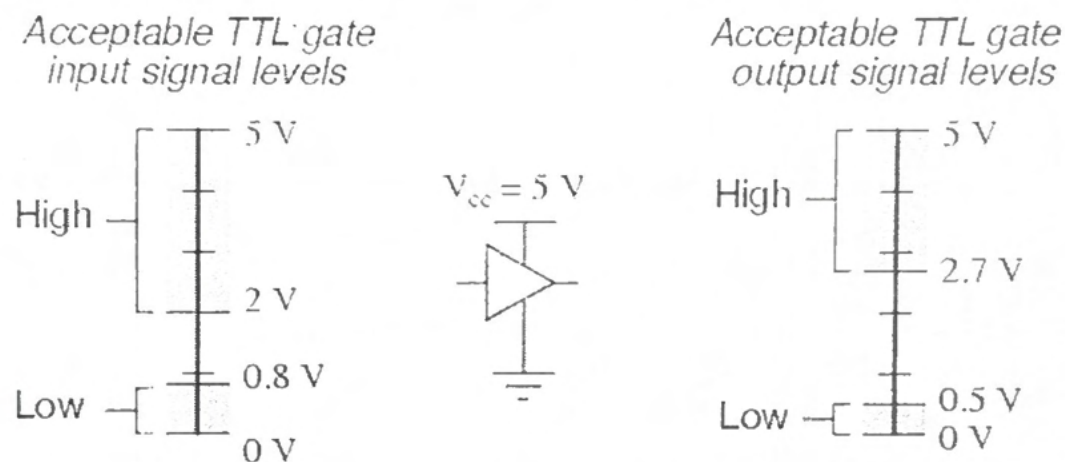


Figure 3.1

If a voltage signal ranging between 0.8 volts and 2 volts were to be sent into the input of a TTL gate, there would be no certain response from the gate. Such a signal would be considered *uncertain*, and no logic gate manufacturer would guarantee how their gate circuit would interpret such a signal.

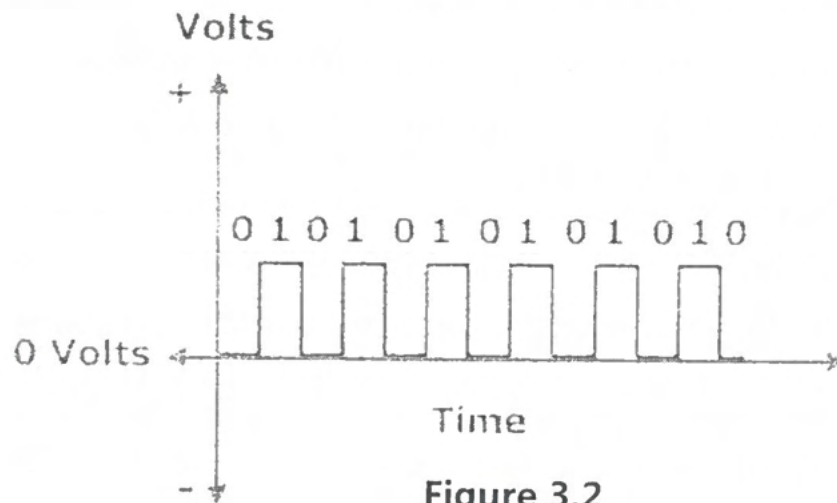
- Using Positive Logic TTL, a 0 state is generally between zero to .8 volts present on the conductor, and the 1 state is where voltage is between 2.4V and 5.5V on the conductor.

Unit 3 - Number Systems & Conversions

Digital Signals

An important thing to remember is that "binary" is a number system. Digital is an electrical signal format that is "binary" in nature.

Figure 3.2 is an example of a basic digital signal using TTL Positive logic.



- Note that the binary 1s represent those time slots where voltage is present, and the binary 0s represent where there is no voltage present. Voltage present is deemed a "high" state and no-voltage is deemed a "low" state. Therefore, with digital logic gates we speak of inputs and outputs as one's and zero's or as "hi" and "low".
- Note also that the amplitude (height) of each voltage pulse is reflective of the amount of voltage present as "peak" voltage, and that the width of each pulse typically, but not always, represents the width of each time slot, or the amount of time voltage is present.

Unit 3 - Number Systems & Conversions

Binary Representation of Characters

Another application of binary relates to what we call 8-bit Extended ASCII code' where 8 binary bits are used to represent any alpha-numeric character or other "keyboard" symbol or character.

The ASCII acronym stands for American Standard Code for Information Interexchange. The Standard ASCII is a 7-bit coding scheme that allowed for definition of 128 characters (2^7). Modern computers use Extended ASCII; an 8-bit code that allows for definition of 256 characters (2^8).

ASCII (or Extended ASCII) allows us to define alpha-numeric characters and symbols, such as those characters and symbols found on a keyboard, in binary format. For example, the extended ASCII code for the upper case letter A = 01000001.

Table 3.1 on the next page shows how an 8-bit byte of data is used to represent the digits 0 through 9, and the uppercase letters A through Z. note that the entire Extended ASCII table is available from many website sources that contain all 256 available characters defined in the entire table.

Looking at the table, note the 'symbol" that is being defined in different number system values. The left-most 4 bits (most significant bits) of each byte define the type of symbol; i.e., uppercase alpha, lower-case alpha, numeral, etc. The least-significant bits (rightmost 4 bits) represent the sequence position of each character. For example, the uppercase letter M is the 13th letter of the alphabet. Therefore, the rightmost four bit weights sum to 13. However, the leftmost 4 bits contain a 1 bit in weight position #64. Adding 64 to 13 = 77. Therefore, in ASCII, the letter M has a decimal value of 77.

Therefore, in a computer or in a data transmission, the binary byte of 01001101 equates to the uppercase letter M. Also note, as we showed in number conversions, that every value has an equivalent value representation in all other number system representations.

Unit 3 - Number Systems & Conversions

Partial Extended ASCII Table

DEC	OCTAL	HEX	BINARY	SYMBOL	DESCRIPTION
48	060	30	00110000	0	zero
49	061	31	00110001	1	one
50	062	32	00110010	2	two
51	063	33	00110011	3	three

55	067	37	00110111	7	seven
56	070	38	00111000	8	eight
57	071	39	00111001	9	nine
65	101	41	01000001	A	Uppercase A
66	102	42	01000010	B	Uppercase B
67	103	43	01000011	C	Uppercase C

77	115	4D	01001101	M	Uppercase M
78	116	4E	01001110	N	Uppercase N
79	117	4F	01001111	O	Uppercase O
80	120	50	01010000	P	Uppercase P
81	121	51	01010001	Q	Uppercase Q
82	122	52	01010010	R	Uppercase R
83	123	53	01010011	S	Uppercase S
84	124	54	01010100	T	Uppercase T
85	125	55	01010101	U	Uppercase U
86	126	56	01010110	V	Uppercase V
87	127	57	01010111	W	Uppercase W
88	130	58	01011000	X	Uppercase X
89	131	59	01011001	Y	Uppercase Y
90	132	5A	01011010	Z	Uppercase Z

Table 3.1

Unit 3 - Number Systems & Conversions

IP Addressing – IPv4

Internet Protocol version four, (IPv4), is a system of addresses used to identify devices on a network. Originally described in 1981 in RFC791, IPv4 is the most widely used Internet layer protocol, and is still used today by the vast majority of users to connect to the Internet.

IPv4 addresses, typically called "dotted decimal" because we normally write them in decimal numbers, where each decimal value is separated by a dot. For example, an IPv4 address may look like:

192.168.10.0 (dotted decimal)

But the values in each octet range from 0 to 255. This is because the IPv4 IP address is a 32 bit binary address that is divided into four eight bit parts each of which is called a "byte" or "octet". The singular eight bit octet is the building block of the IP address. Using the IP address above we demonstrate the values of each octet as shown in figure 3.3.

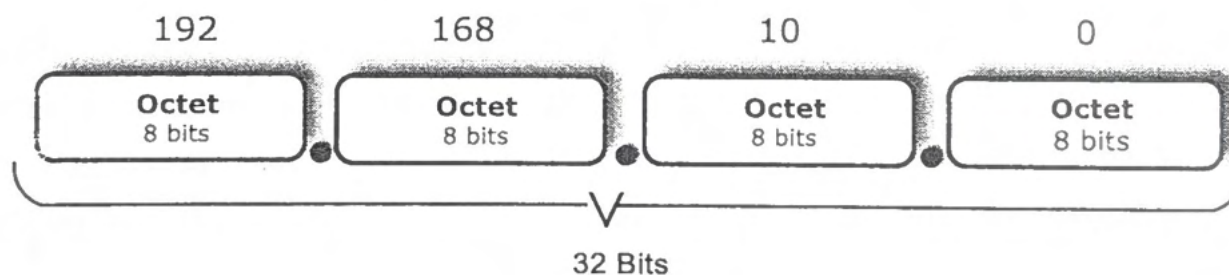


Figure 3.3

Looking again at the binary weight positions of an octet in Table 3.2 below, we can see that adding the weights of all 8 weight positions = 255. This means that with all 8 bits set to binary 1, an 8-bit byte can have a decimal value no larger than 255, and counting from zero, this means 256 values.

Exponent form	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Weight	128	64	32	16	8	4	2	1
Number	0	1	0	0	1	1	1	0

Table 3.2

Unit 3 - Number Systems & Conversions

Another way to look at the binary weights is as follows:

Octet 8 bits	
0	00000000
1	00000001
	⋮
128	10000000
	⋮
254	11111110
255	11111111

With 8 bit octets, the decimal value range = 0 to 255

Examining the preceding table we can see that the minimum value of all 8 bits is all zeros, and the maximum value all ones. Therefore, depending on which of the 8 bits are zeros and which bits are ones, the decimal value the binary digits can represent range from 0 to 255 and anything in between. This is why we never see a value in an IPv4 dotted decimal address field higher than 255. It's also why the subnet mask fields we populate in the TCP/IP configuration never have values higher than 255 in each field.

Using the logic just described, we can now convert in figure 3.4 our example IPv4 address of 192.168.10.0 to binary bits to see how the computer deals with dotted decimal addresses.

Octet	Octet	Octet	Octet
11000000	10101000	00001010	00000000
192	168	10	0

IP Address 192.168.10.0

Table 3.4

Unit 3 - Number Systems & Conversions

As we described earlier in our number conversions section, we can convert each set of hex digits to a binary number by assigning 4 bits to each Hex character. For example, for the 2nd Hex set of hex digits **A1B2** in our IPv6 address above; (where A = 10 and B = 11):

	A	1	B	2
Binary weights:	8 4 2 1	8 4 2 1	8 4 2 1	8 4 2 1
Binary digits:	1 0 1 0	0 0 0 1	1 0 1 1	0 0 1 0

Therefore: $A1B2_{16} = 1010000110110010_2$

Or

Hexadecimal value A1B2 = binary 1010000110110010

There are 8 groups of four hexadecimal characters and $8 \times 16 = 128$. So each IPv6 address is made up of 128 binary bits.

We will re-visit binary application in Unit 7 where we review digital signaling methods.

Unit 3 - Number Systems & Conversions



Unit 3 Review Quiz

Convert the following non-decimal values to their decimal equivalent values:

1. $1001\ 1110_2 = \underline{158}_{10}$

2. $778_{10} = \underline{63}_{10}$

3. $C5_{16} = \underline{197}_{10}$

Convert the decimal numbers below to their equivalent non-decimal values.

4. $46_{10} = \underline{101110}_2$

5. $89_{10} = \underline{131}_8$

6. $124_{10} = \underline{7C}_{16}$

Unit 3 - Number Systems & Conversions

Convert the non-decimal numbers below to their equivalent non-decimal values.

7. $1111\ 1010_2 = \underline{372}_8$

8. $238 = \underline{10011}_2$

9. $7368 = \underline{2DE}_{16}$

10. $1010\ 0010_2 = \underline{A2}_{16}$

11. $AF_{16} = \underline{1010\ 1111}_2$

12. $DEF_{16} = \underline{6757}_8$

Unit 3 - Number Systems & Conversions

Convert the binary numbers below to their decimal equivalents.

13. $1011\ 1010_2 = \underline{186}_{10}$

14. $1111\ 1110_2 = \underline{254}_{10}$

15. $1110\ 0010_2 = \underline{226}_{10}$

16. $1100\ 0110_2 = \underline{198}_{10}$

Convert the octal numbers below to their decimal equivalents.

17. $22_8 = \underline{18}_{10}$

18. $25_8 = \underline{21}_{10}$

19. $51_8 = \underline{41}_{10}$

20. $16_8 = \underline{14}_{10}$

Unit 3 - Number Systems & Conversions

Convert the hexadecimal numbers below to their decimal equivalents.

21. $5B_{16} = \underline{91}_{10}$

22. $1F_{16} = \underline{31}_{10}$

23. $A2_{16} = \underline{162}_{10}$

24. $C_{16} = \underline{12}_{10}$

Binary Addition

25. Add the following binary values:

$10011010 + 01001101 = \underline{01100111}$

UNIT 4 - DIGITAL SYSTEMS

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Unit 4 – Digital Systems

INTRODUCTION

Digital data, in information theory and in information systems, is composed of discrete, discontinuous representations (voltage pulses) of information, as contrasted with continuous representations, called analog signals, which behave in a continuous manner, or represent information using a continuous function (sine wave).

Digital systems make use of digital data in the design and use of digital computer hardware and software. Today, almost every electronic device made contains digital circuitry; typically in the form of microprocessors or application-dependent digital interfaces.

OVERVIEW

When we speak of digital systems, we are generally talking about digital networks and control systems. This means computers and how they interconnect, the need to convert from analog to digital and back so that computers can process information, the types of geographical network architectures that interface with the user devices, and how information is processed in a digital environment.

UNIT 4 OBJECTIVES

Upon completion of this unit, you will be able to:

- Define and describe "Digital Networks" and "Control Systems"
- Identify the major types of Computer Networks by geographical size
- List the primary elements of a computer system and their functions
- Explain A2D and D2A conversion
- Explain synchronous vs. asynchronous
- Compare "real-time" vs. non-real-time

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Unit 4 – Digital Systems

SECTION 4.1 – NETWORKS & CONTROL SYSTEMS

Digital Networks

A network consists of two or more computers that are linked in order to share resources (such as printers and CDs), exchange files, or allow electronic communications. The computers on a network may be linked through cables, telephone lines, radio waves, satellites, or infrared light beams. A Digital Network merely means that we are transporting voice, video, and data over digital telephone lines or normal telephone wires in the form of binary data bits; where this data is transmitted, received and processed by some sort of computer. Computers allow users to create and manipulate information, and the network provides both a place to store the information and mechanisms to share that information with other network users.

Two very common types of networks used by telecommunications and other businesses include:

- **Local Area Network (LAN)** - a network that is confined to a relatively small area. It is generally limited to a geographic area such as a writing lab, school, or building
- **Wide Area Network (WAN)** - connect smaller networks in larger geographic areas, such as locations in California to Florida, New York and other locations throughout the United States...or the world. Dedicated transoceanic cabling or satellite uplinks may be used to connect this type of global network.

You will also see references to a Metropolitan Area Networks (MAN); a Wireless LAN (WLAN) or Wireless WAN (WWAN); and even Personal Area Network (PANs).

These types of networks are all primarily defined on the basis of size of area they serve, and they interconnect via information formatted into binary data that is represented by discreet voltage pulses on a wire or by optical pulses of light on an optical fiber.

Figure 4.1 shows how LANs are connected to the Internet WAN.

Unit 4 – Digital Systems

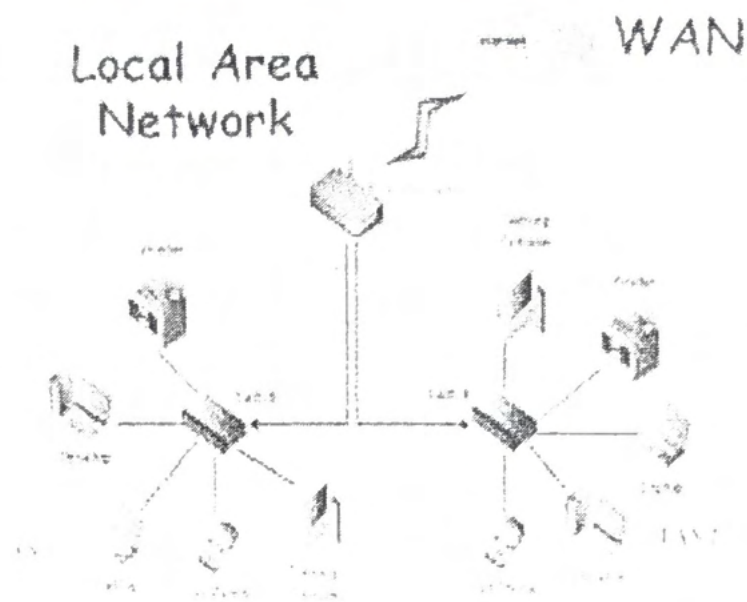


Figure 4.1

Digital Control System

Digital Control Systems consist of networked microprocessor-based controllers connected to analog and digital devices, which either sense information or control components. These systems can range from control of a building's heating, ventilating, and air-conditioning (HVAC) system, to robotic systems used in manufacturing. Control logic initiates and sequences operations programmed with software stored in the hardware. Analog-to-digital (A/D) converters transform analog electrical values into digital information for the microprocessor. The analog sensors may be thought of as transducers that convert a thermodynamic property to an electrical property.

Most digital systems include stand-alone or remote controllers with software loaded to eliminate the need for continuous human communication and interaction. A personal computer workstation typically provides for monitoring system status, to store back-up copies of the programs, to record alarms, and to analyze trending functions. Computer memory is used to archive historical information and to operate the Energy Management System (EMS). Relatively complex strategies and energy management functions are normally available at low levels in the system architecture, and pneumatic and hydraulic actuations can be designed into the system, controlled by software, and provided by electric-to-pneumatic and electric-to-hydraulic transducers.

Unit 4 – Digital Systems

SECTION 4.2 – COMPUTER SYSTEMS

Computer Central Processing Unit (CPU)

The core of any digital system is the computer, and within the computer is its brain called the Central Processing Unit (CPU). The CPU is the hardware within a computer that carries out the instructions of a computer program by performing the basic arithmetical, logical, and input/output operations of the system.

A computer can have more than one CPU; where multiple processes can occur simultaneously. This is called multiprocessing. All modern CPUs are microprocessors. This means they are contained on a single microchip (typically a silicon chip). Some integrated circuits (ICs) can contain multiple CPUs on a single chip; these ICs are called multi-core processors. An IC containing a CPU can also contain peripheral devices, and other components of a computer system; this is called a system on a chip (SoC).

The two primary components of a CPU are the arithmetic logic unit (ALU) and the control unit (CU). The ALU performs arithmetic and logical operations and the CU performs extractions of instructions from memory and decodes and executes the instructions. The CU will also call on the ALU when necessary.

The CPU plugs into the motherboard, which is a central connection point for all other devices within the computer. All commands or functions are calculated within the CPU. Since it calculates the processes, it is also one of the major components associated with the computer's speed.

Figure 4.2 shows the computer CPU and connecting elements.

Unit 4 – Digital Systems

Overview of Computer CPU
and Connecting Elements

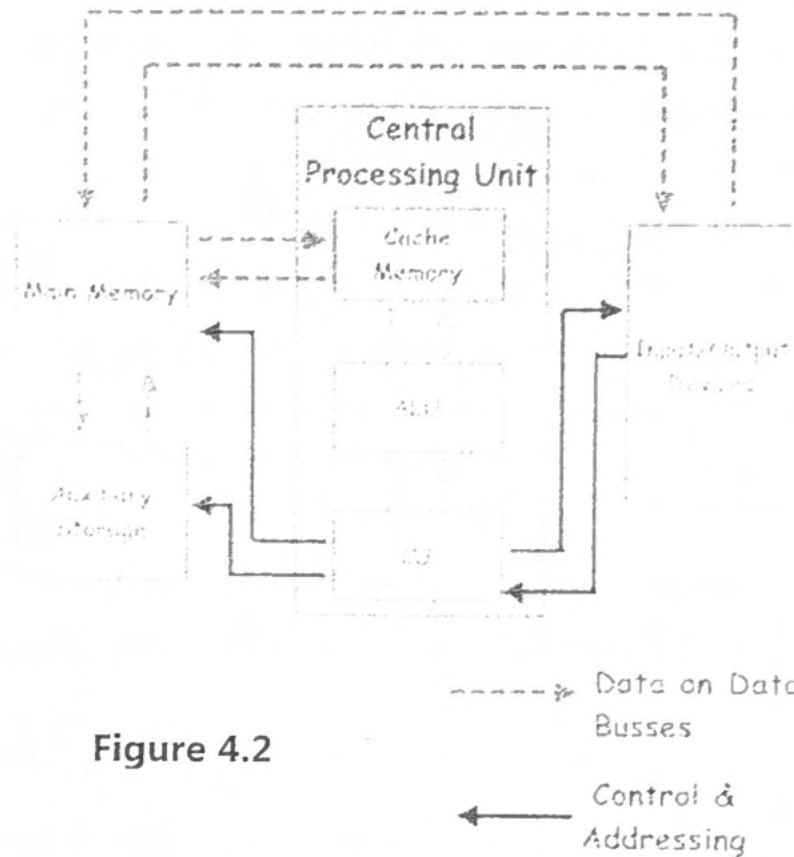


Figure 4.2

Computer Address and Data Busses

A computer *bus* is a communication system that transfers data between components inside a computer or between computers. There are typically two types of busses in a computer:

➤ Data Bus

The Data Bus carries data. Most processors have internal data buses that carry information inside the processor and external data buses that carry information back and forth between the processor and memory.

Unit 4 – Digital Systems

➤ Address Bus

The Address Bus carries address information. In most processors, memory is connected to the processor with separate address and data buses. The processor places the requested address in memory on the address bus for memory or the memory controller (if there is more than one chip or bank of memory, there will be a memory controller that controls the banks of memory for the processor). If the processor is writing data to memory, then it will assert a write signal and place the data on the data bus for transfer to memory. If the processor is reading data from memory, then it will assert a read signal and wait for data from memory to arrive on the data bus.

In some small processors the data bus and address bus will be combined into a single bus. This is a form of multiplexing.

Computer Memory

Computers also typically have memory capabilities. The most well-known type of memory is RAM (Random Access Memory). RAM is another major component that affects a computer's speed. RAM is volatile memory that is erased once the computer is turned off or loses power. RAM's function is to store temporary processes that the computer performs. When a user has many applications open but a low amount of RAM, the processes will slow down, as each one requires a specified amount of RAM.

Another major type of memory that people are familiar with is Hard Drive Memory. Much different from RAM, the hard drive serves as a permanent storage space that is readable and writable by the user. The hard drive, sometimes called the "hard disk" is not really "memory" as is the RAM memory. The hard-drive is actually the mechanism that holds the hard disk; it is a spindle of magnetic discs that can hold several gigabytes of data. Therefore, it provides "disk space"; where disk space refers to how much space you have available on your hard disk for storing files. When you save a document or install a new program, it gets stored on your hard disk.

Unit 4 – Digital Systems

Computer Mother Board

A *motherboard* (also known as the mainboard, system board, planar board or logic board, or colloquially, a "*mobo*") is the main printed circuit board (PCB) found in computers and other expandable systems. The motherboard contains many of the crucial electronic components of the system, such as the central processing unit (CPU) and memory, and provides connection interfaces for the hard drive and other peripherals.

Motherboard specifically refers to a PCB with expansion capability and as the name suggests, this board is the "mother" of all components attached to it. This typically includes network interface cards (NICs), video cards, sound cards, hard drives, or other forms of persistent storage; TV tuner cards, wireless adapters, and cards providing extra USB or FireWire slots and a variety of other custom components.

Input and Output Devices

The third basic function of a computer system is Input and output (I/O). I/O devices are the types that most people are familiar with since these are the devices that people interface with. Input devices include items such as the keyboard and mouse which allows you to control the functions of the computer. Input devices also provide a method to access files and folders and to alter data.

Output devices are those that display data. These include the monitor and the printer, (the most familiar of the output devices). These types of output devices provide a visual representation of the binary code within a computer's CPU.

I/O devices are part of the family of devices called peripherals. Other peripheral devices include scanners, external hard drives, game consoles and controllers, fax machines, digital cameras and other devices where information can be sent.

Unit 4 – Digital Systems

System Software and Application Software

There are two basic types of software installed in a computer:

1. System Software
2. Application Software

System Software is computer software designed to operate and control the computer hardware and to provide a platform for running application software.

The two general categories of System Software includes:

- **Operating System** (e.g., Microsoft Windows, Mac OS X and Linux, z/OS, etc.) allows the parts of a computer to work together by performing tasks like transferring data between memory and disks or rendering output onto a display device. Typically, this includes an "alphabet soup" of system application software that resides in the TCP/IP Application layer such as HTTP, FTP, SMTP, DHCP, etc.
- **Utility software** helps to analyze, configure, optimize and maintain the computer
- **Device drivers** such as computer BIOS and device firmware provide basic functionality to operate and control the hardware connected to or built into the computer
- **User Interface** allows users to operate a computer using a keyboard or a mouse that interacts with radial buttons, scroll bars, hot links and other point and click capabilities. Since the 1980s the graphical user interface (GUI) has been perhaps the most common user interface technology. The command-line interface is still an alternative, but rarely used today. Other versions of GUI include touch screen and voice recognition.

Unit 4 – Digital Systems

User Application software is all the computer software that causes a computer to perform useful tasks beyond the running of the computer itself. This is not the same as the system application software. A specific instance of such software is called a *software application, program, application* or "*app*".

Examples include:

- **Accounting Software** such as Peachtree and QuickBooks, etc.
- **Enterprise Software** such as Oracle, Adobe, SAP, etc.
- **Graphics Software** such as Smartdraw, Visio, Photoshop, Illustrator, Paint Shop Pro, MS Paint, etc.
- **Media Players** such as Windows Media Player, Flash Player, QuickTime, iTunes, etc.
- **Office Suites** such as MS Office WORD, PowerPoint, Excel; Word Perfect Office; iWork, etc.

A2D Converters

To say we live in an analog universe is to say all forms of energy that exist are analog in nature. Light, sound, you name it...all has to be converted to digital using a circuit called an Analog-to-Digital (A2D) converter before it can be processed by digital equipment.

Most of us have been involved with A2D conversion without even realizing it. When you scan a photo with a scanner you are performing A2D conversion. When you record your voice or use a VoIP phone you are performing A2D conversion. Even when you talk on a conventional telephone you are performing A2D conversion as your voice is converted to digital by equipment in the Central Office, and communication between telephone switches is done digitally. The graphic at right, Figure 4.3, shows the flow of analog information through the digital process.

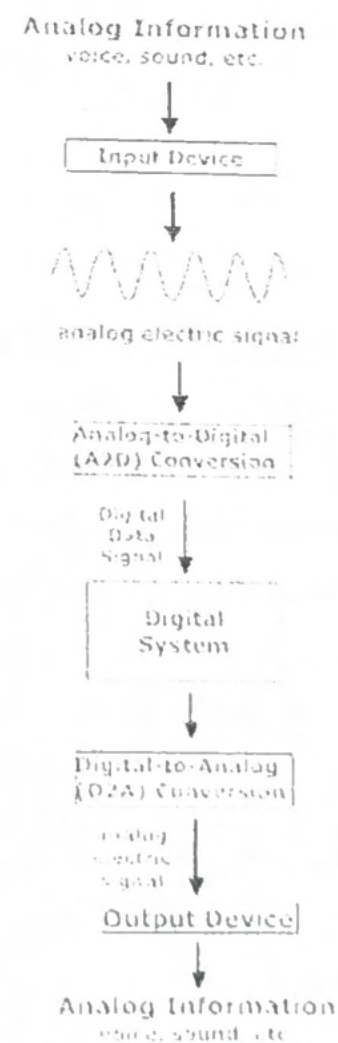


Figure 4.3

Unit 4 – Digital Systems

D2A Converters

A digital-to-analog converter (also called a *DAC*) is a circuit that converts digital binary data into an analog signal (current, voltage, or electric charge); i.e., the DAC performs the reverse function of the A2D Converter). It is needed, therefore, to convert the digital signal back to analog so that it can drive an earphone or loudspeaker amplifier to produce sound.

When data is in binary form, the 0's and 1's may be of several forms such as the TTL form where the logic zero may be a value from 0 up to 0.8 volts, and the logic 1 may be a voltage from 2 to 5 volts. The variance of the voltages can be "smoothed" to obtain "clean" digital data using logic gates that are designed to be on or off depending on the value of the incoming signal. Data in clean binary digital form can then be converted to an analog form by using a summing amplifier.

SYNCHRONOUS VS. ASYNCHRONOUS SYSTEMS

Synchronous Systems

In a synchronous system, operations are coordinated under the centralized control of a fixed-rate clock signal or several coordinated clock signals.

The word "*Synchronous*" means "agreed timing for the sending of ones and zeroes (bits)". This means the transmit and receive equipment on each end of the communications link have communicated with each other before any data has been transmitted. This communication is called a "hand-shake" between transmit and receive ends; where this "handshake" contains negotiation and agreement as to coordinating (synchronizing) their signals, as well as what line encoding they will use, and what timing mechanism will be involved in their transmissions. In some advanced systems the two ends will negotiate things like error detection/correction, data compression, and even security mechanisms.

Unit 4 – Digital Systems

Usually, there is a process defined in the system design used to decide which end should be in control. This can involve a lengthy negotiation cycle by each side of the link; where the two sides exchange communications parameters and status information. With a lengthy connection establishment process, a synchronous system using an unreliable physical connection will spend a great deal of time in negotiating, but not in actual data transfer. Once a connection is established, the transmitter sends out a signal, and the receiver sends back data regarding that transmission, and what it received. This connection negotiation process takes longer on low error-rate lines, but is highly efficient in systems where the transmission medium itself (an electric wire, radio signal or laser beam) is not particularly reliable.

Asynchronous Systems

An asynchronous digital system, in contrast, has no global clock. Instead, it operates under distributed control, with concurrent hardware components communicating and synchronizing via communications channels.

When the receiver of a signal that is carrying information has to figure out how that signal is organized without consulting the transmitting device, it is called asynchronous communication. In short, the two ends do not always negotiate or work out the connection parameters before communicating.

Asynchronous communication utilizes a transmitter, a receiver and a transmission medium just like synchronous systems do, but without coordination about the timing of individual bits. There is no "handshake" negotiation between the two end points regarding timing, error detection and correction, data compression, or security methods.

Sending data encoded into your signal requires that the sender and receiver are both using the same encoding/decoding method, and know where to look in the signal to find data. The receiver must determine the clocking of the signal on its own. This means the receiver must determine where to look in the signal stream to find the ones and zeroes that are the data, and decide for itself where each individual bit stops and starts, what compression, if any, is being used, or what error detection and correction is being used. This information is not in the data in the signal sent from transmitting unit.

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Asynchronous communication is more efficient when there is low loss and low error rates over the transmission medium because data is not retransmitted and no time is spent setting negotiating the connection parameters at the beginning of transmission. Asynchronous systems just transmit and let the far end station figure it out. Asynchronous is sometimes called "best effort" transmission because one side simply transmits, and the other does its best to receive and any lost data is recovered by a higher level protocol.

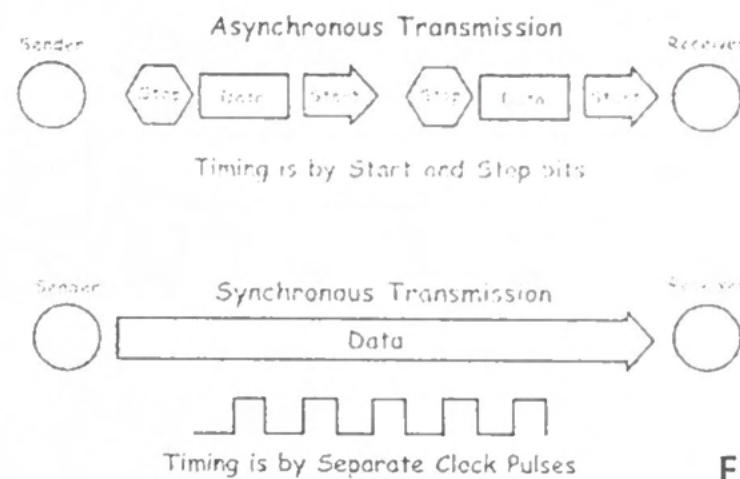


Figure 4.4

"REAL-TIME" VS. NON-"REALTIME"

The terms synchronous and asynchronous can also be applied to the concepts of data that can be delayed, and data that cannot be delayed. We call delay in a network "latency"; where it is ok to delay certain types of data, but not ok to delay other types of data. For example, communication occurs on a telephone call when two parties "talk" to each other in real-time. This is synchronous communication that cannot afford high delay (latency). Examples of synchronous communication include telephone calls and two-way radio communication where voice and video cannot be delayed in order to maintain a conversation or a video feed in real time.

In contrast, asynchronous communication is non-realtime communication. Examples are email, blog and message board postings, and especially text messaging. Delay of these types of data is not critical to the quality of the data or the message sent and received.

Due to the latency on digital networks, technically speaking, no communication is truly synchronous as there will always be some delay of at least a few milliseconds or more between parties in all network connections.

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Unit 4 – Digital Systems



Unit 4 Review Quiz

Circle the correct response for the questions listed below.

1. The two common telecommunications and business network types are:
 - a. LANs and CANs
 - b. LANs and WANs
 - c. FANs and CANs
 - d. WANs and CANs
2. The difference between types and names of networks is primarily relative to geographic size of area.
 - a. True
 - b. False
3. Systems with networked microprocessor-based controllers connected to analog and digital devices, which either sense information or control components, are called
 - a. Multiplexing Systems
 - b. Data Processing Systems
 - c. Digital Control Systems
 - d. none of the above
4. A computer's brain is the:
 - a. RAM
 - b. Busses
 - c. Hard Drive
 - d. CPU

Unit 4 – Digital Systems

5. The two primary components of a computer's brain are the:
 - a. RAM and Data Busses
 - b. ALU and CU
 - c. ROM and DVD
 - d. Data Busses and Address Busses

6. Which of the following memory types is considered volatile memory?
 - a. RAM
 - b. ROM
 - c. BIOS
 - d. Spam

7. The acronym "RAM" stands for:
 - a. Remote Access Memory
 - b. Random Access Memory
 - c. Remote Address Memory
 - d. Random Address Memory

8. A common nickname for a computer's motherboard is "*mobo*".
 - a. True
 - b. False

9. The motherboard is a type of PCB; which stands for:
 - a. Processor Control Board
 - b. Printed Circuit Board
 - c. Printed Control Board
 - d. Processor Circuit Board

Unit 4 – Digital Systems

10. A computer's I/O devices are part of a family of devices called:
- a. Peripheral Devices
 - b. Control Devices
 - c. Memory Devices
 - d. Processor Devices
11. The two communication bus systems in a computer are:
- a. System Bus and Application Bus
 - b. Primary Bus and Secondary Bus
 - c. Hardware Bus and Software Bus
 - d. Address Bus and Data Bus
12. The two basic types of application software installed in a computer are named:
- a. System Application Software and User Application Software
 - b. Operations Software and Diagnostic application Software
 - c. Printer application Software and Network application Software
 - d. Operating Software and Security Software
13. The Interface that allows users to operate a computer using a keyboard or a mouse that interacts with radial buttons, scroll bars, hot links and other point and click capabilities is called the:
- a. PCI
 - b. CPU
 - c. GUI
 - d. OSI

Unit 4 – Digital Systems

14. The process of converting light waves and sound waves to digital format is performed by device called a(n):
- a. D2A converter
 - b. A2D converter
 - c. MUX
 - d. CPU
15. When communications operations are coordinated under the centralized control of a fixed-rate clock signal or several coordinated clock signals, the system is called:
- a. Synchronous
 - b. Asynchronous
 - c. Latent
 - d. Quantized
16. Data that cannot be delayed by the process of error correction is called _____ data.
- a. Non Real Time
 - b. Asynchronous
 - c. Latent
 - d. Real-Time

UNIT 5 - DIGITAL LOGIC

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Unit 5 – Digital Logic

INTRODUCTION

Digital logic is fundamental in creating electronic devices; it is the basis for digital computing. Digital logic is fundamental to understanding how circuits and hardware communicate within a computer. Digital logic is the representation of signals and sequences of a digital circuit through numbers. Digital logic is typically embedded in most electronic devices including calculators, computers, video games and watches.

OVERVIEW

This unit reviews the different logic components and their functions, and also the Truth Table method for tracking logic component and circuit data outcomes for given inputs. We review the logic components and their symbols, their functions, and how they operate under given pulse train input combinations and in given circuit combinations.

UNIT 5 OBJECTIVES

Upon completion of this unit, you will be able to:

- Define what is meant by "Digital Logic"
- Explain the term TTL as used with Digital Logic
- Identify the Types and Functions of the various Logic Gates
- Explain the concept of the "Truth Table" or "Logic Table"
- Explain the Digital Pulse Train
- Explain and Demonstrate the flow of logic level signals through a logic circuit
- Describe the various Flip-flops and their use
- Explain "sequential logic" and identify its logic gates and flip-flop components
- Identify the Multivibrator; its types and applications

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SECTION 5.1 – LOGIC GATES & TRUTH TABLES

Digital logic is the basis for digital computing and fundamental to understanding of how computer circuits and hardware communicate with software human beings. It is the representation of signals and sequences of a digital circuit through representations of binary numbers; it is typically embedded in computers and in most digital electronic devices including calculators, video games and watches.

Digital logic starts with the understanding of two perspectives relative to binary number values. The logic that defines: (1) Positive logic and (2) Negative logic is called Transistor-Transistor Logic (TTL); where TTL can be Positive TTL or Negative TTL. These state as follows:

- ✓ With Positive logic, a binary 1 value = on or high state, and binary value 0 = off or low state.
- ✓ With Negative logic, a binary 0 value = on or high state, and binary value 1 = off or low state

These “states” are also called “Logic Levels” and refer to the presence or absence of voltage where, typically, most digital systems use ‘Positive Logic’ values.

A logic gate is an electronic circuit or device that makes logical decisions based on these logic levels. Logic gates, also called digital switches, are the building blocks of any digital circuit; where one or more inputs (binary zeros and/or binary ones) create conditions for only one output (a binary zero or a binary one). The output is active and dependent on certain input combinations of binary ones and binary zeros; where the one or zero output represents the condition of voltage present or no voltage present on the gate’s output.

In order to understand what digital is, it is important that you understand the function of the basic logic gates. The most common logic gates used in digital circuits are the OR, AND, NOT (inverter), NAND, and NOR gates, and logic devices called Flip-Flops and Multivibrators.

Unit 5 – Digital Logic

TRUTH TABLES

A digital truth table, also called a "logic table", shows how a logic circuit's output responds to various combinations of the inputs; i.e., the truth table describes the relationship between the input and output of a logic circuit.

Unlike most mathematics that deal with calculating numeric values, the math used by logic gates deals with logic. This math is called Boolean Algebra, and is based on the idea that logical propositions are either true or false; where "True" corresponds to the digital value of 1, and "false" corresponds to digital value 0.

The three basic Boolean operations used by standard logic gates are: (1) logical multiplication (AND gate), (2) logical addition (OR gate), and (3) logical inversion (NOT gate).

Therefore, the common logic gates listed above each have their own truth table that represents each of their functions using Boolean algebra; i.e., the truth table lists the output for each possible combination of input(s).

In addition, the number of possible input combinations for a logic device is determined by the number of physical inputs to the device; where the number of combinations = 2^n ; and where n = the number of physical inputs to the device. For example, a 2-input AND gate has 4 possible combinations: $(2^2) = 4$. These are 00, 01, 10 and 11. A three input AND gate has 8 possible input combinations: $2^3 = 8$, etc.

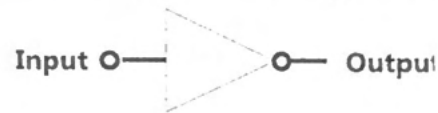
A truth, therefore, table describes the relationship between the input and output of a logic circuit.

Unit 5 – Digital Logic

The Common Logic Gates and their Truth Tables

NOT Gate (inverter)

Inverter (also called NOT Gate)



Truth Table

Input	Output
0	1
1	0

Figure 5.1

Note from the truth table, figure 5.1, there is one physical input, therefore, the number of possible input combinations = 2. These are an input of either zero, or an input of one.

Note also the function of an inverter; i.e., to invert the input to its opposite state on the output. Therefore, the characteristic of the NOT gate: the NOT gate produces a logic "0" at its output when the input is logic "1" and vice-versa.

AND Gate

Two input AND gate



Truth Table

Input A	Input B	Input C	Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Figure 5.2

From the truth table we see three physical inputs. Therefore, the number of input combinations = 8 as shown in figure 5.2.

Unit 5 – Digital Logic

Note the function of the AND gate.

The ONLY possible combination of inputs we see in figure 5.3 that provides for "truth"; i.e., a logical 1 output, is when ALL inputs = logical 1 state. Thus, the name AND gate where: one input must be a one, **AND** the other input(s) must be a 1 in order to obtain a 1 output.

Therefore, the characteristic of the AND gate: the AND gate produces a logic "1" at its output only if ALL inputs are a logic "1".

For a three-input AND gate there are 8 possible input combinations.

Three input AND gate



Truth Table

Input A	Input B	Input C	Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Figure 5.3

Note again, the only combination that provides a logic "1" output is when input A = 1, AND input B = 1, AND input C = 1.

Unit 5 – Digital Logic

OR Gate

The OR logic gate of figure 5.4 is a logic device that gives an output of logic "0" only when all of its inputs are logic "0". Conversely, the gate output is logic '1' when ANY or ALL of its inputs = logic "1". For example, for the 2-input OR gate below, if A, OR B = logic "1", then the output is logic "1", hence the name OR gate. However, the output is also a logic "1" if ALL of its inputs = logic "1". For the 3-input OR gate below, if either input A, OR B, OR C, OR A, B and C = logic "1", then the output is logic "1".

Two input OR gate



Truth Table

Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	1

Figure 5.4

Note also that like the AND gate, the number of input combinations = 2^n ; where n = the number of physical inputs.

The characteristic of the OR gate: The OR gate produces a logic "1" at its output if ANY or all inputs = logic "1".

Unit 5 – Digital Logic

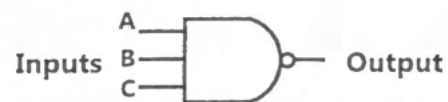
NOT AND (NAND)

The NOT AND, or NAND gate, is an AND gate with a NOT gate at its end. In digital logic convention, the NOT symbol is represented by the small circle at the output. (Note the NOT symbol on the output of the NOT gate). This symbol says, "whatever is the output of the normal respective gate function - invert it". Therefore, "NOT" means "invert".

For example, the output of a normal 2-input AND gate = logic "1" only if both inputs = logic "1". However, because of the 'NOT' symbol on the output of the AND gate, the gate becomes a NOT AND (NAND) gate, so this '1' output is inverted to logic "0". Thus, for the same combination of inputs, the output of a NAND gate will be opposite that of an AND gate.

The three-input NAND gate and its Truth Table are shown below, Figure 5.5.

Three input NAND gate



Truth Table

Input A	Input B	Input C	Output
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

Figure 5.5

The characteristic of a NAND gate: The NAND gate produces a logic "0" at its output only when all inputs = logic "1".

Note there are 8 input combinations because there are three inputs.

Unit 5 – Digital Logic

NOT OR (NOR) Gate

The NOR gate in figure 5.6 is an OR gate with a NOT symbol at its output. Thus, for the same combination of inputs, the output of a NOR gate will be opposite that of an OR gate, so it is an OR gate with the output inverted.

Two input OR gate



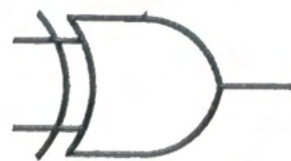
Truth Table

Input A	Input B	Output
0	0	1
0	1	0
1	0	0
1	1	0

Figure 5.6

The characteristic of a NOR gate: The NOR gate produces a logic "0" at its output if ANY or ALL inputs = logic "1".

There is a "special" gate you might encounter called an 'exclusive OR'. The difference between an exclusive OR gate and a standard OR gate is shown in the truth tables of figures 5.6 and 5.7. Note that this standard gate produces a high (1) output if ANY, but not ALL inputs are high. The 2-input exclusive OR gate symbol is shown below.



Exclusive OR

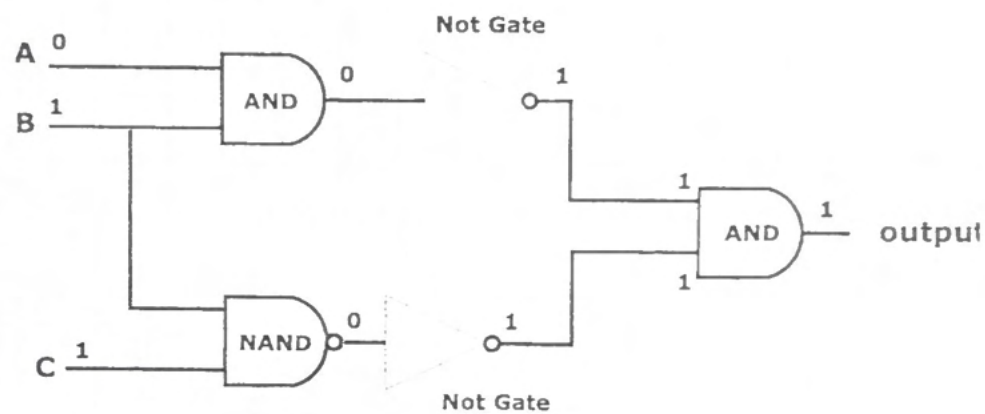
Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	0

Figure 5.7

Note the output = logic "0" for both inputs = logic "1". Compare with the standard OR gate where the output is logic "1".

Unit 5 – Digital Logic

Digital logic gates are typically combined in circuits that serve perform specific functions. Understanding digital logic includes the need to perform circuit analysis of these circuits in terms of combinations of inputs and their resulting output logic levels. For example, the circuit of Figure 5.8 shows the output state for the given set of inputs provided.



Inputs:

A = 0 (low)

B = 1 (high)

C = 1 (high)

Output = 1

Figure 5.8

Digital Pulse Trains

One aspect of digital signaling requires understanding of how a logic gates will perform under a given set of 0 and 1 gate inputs in the form of pulse trains. A pulse train is a series of regularly recurrent pulses having similar characteristics. A pulse train is also called pulse group.

The following graphic of figure 5.9 shows what an AND gate pulse train output would look like for given pulse train inputs. It is important to understand the reason for the output pulses relative to the type of logic gate, and relative to the inputs, and for any of the logic gate types.

Unit 5 – Digital Logic

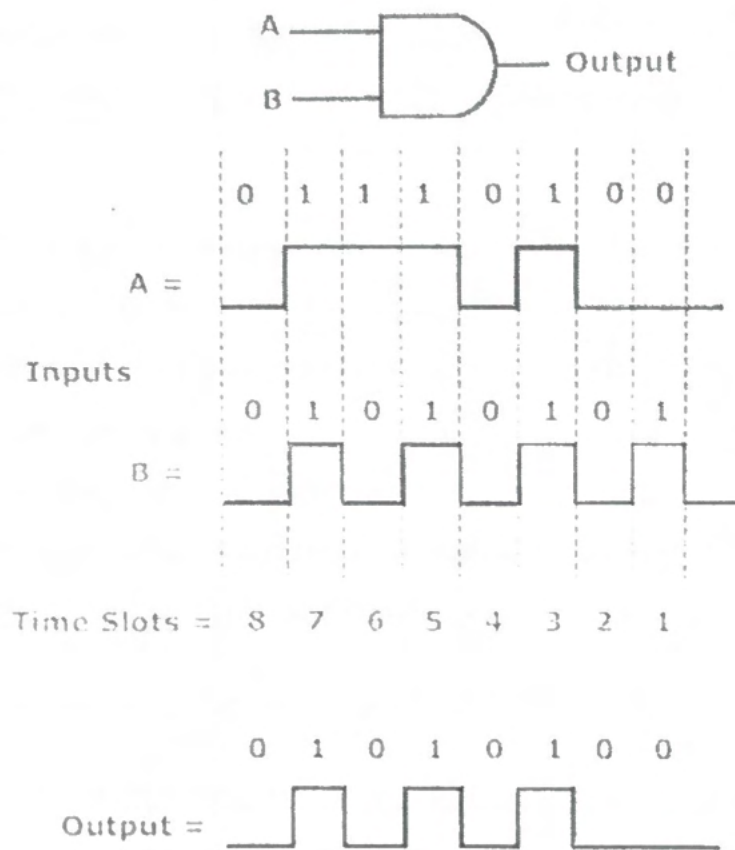


Figure 5.9

LATCHES AND FLIP FLOPS

A **flip-flop** is a **digital logic storage device** that has two stable states and, therefore, it is a device capable of storing one bit of binary data as memory. Since a flip-flop is capable of storing a binary value for an extended amount of time, it is also called a '*latch*'.

In the same way that logic gates are the building blocks of combinational circuits, *latches* and *flip-flops* are the building blocks of sequential circuits.

A *combinational logic circuit* is a circuit of which output is a function of only the present input; i.e., its output state depends only on the input states at a specific moment in time, and not on previous states.

Unit 5 – Digital Logic

In contrast, *sequential logic*, does have *state (memory)*; i.e., a sequential logic circuit is a combinational logic circuit of which its output states are related and defined by rules that depend, in part, on previous states (memory).

The word "Sequential" means that things happen in a "sequence", one after another and in *Sequential Logic* circuits, the actual clock signal determines when things will happen next. Simple sequential logic circuits can be constructed from standard *Bistable* circuits such as Flip-flops, Latches and Counters and which themselves can be made by simply connecting together universal *NAND Gates* and/or *NOR Gates* in a particular combinational way to produce the required sequential circuit.

In essence, flip flops and latches can be defined as follows:

- A flip-flop is Edge sensitive: Output only changes on rising (or falling) edge of a clock pulse.
- A latch is Level sensitive: Output changes whenever clock/Enable is high (or low)

In comparison:

- Gates are built directly from transistors
- Latches are built from gates
- Flip-flops are built from latches

These facts will make it somewhat easier to understand latches and flip-flops.

Both latches and flip-flops are circuit elements whose output depends not only on the current inputs, but also on previous inputs and outputs. The difference between a latch and a flip-flop is that a latch does not have a *clock signal*, whereas a flip-flop always does.

It is probably safe to say that pretty much all circuits in practical digital devices are a mixture of combinational and sequential logic.

Unit 5 – Digital Logic

Flip-flops can be divided into common types: the **SR** ("set-reset"), **D** ("data" or "delay"), **T** ("toggle"), and **JK** types are the common ones.

SR Flip Flop (also called RS flip-flop)

An example of how a flip flop works can be demonstrated using the SR flip flop. The SR flip-flop is considered as one of the most basic sequential logic circuits. This flip-flop is basically a one-bit memory bistable device that has two inputs, one which will "SET" the device (meaning the output = "1" and typically labeled "S"), and another which will "RESET" the device (meaning the output = "0" and typically labeled "R").

The SR description, therefore, stands for "Reset-Set". The reset input resets the flip-flop back to its original state with an output Q that will be either at a logic level "1" or logic "0" depending upon this set/reset condition. The SR flip flop as a symbol and as a combination of gates that is represented by the symbol is shown below in figure 5.10.

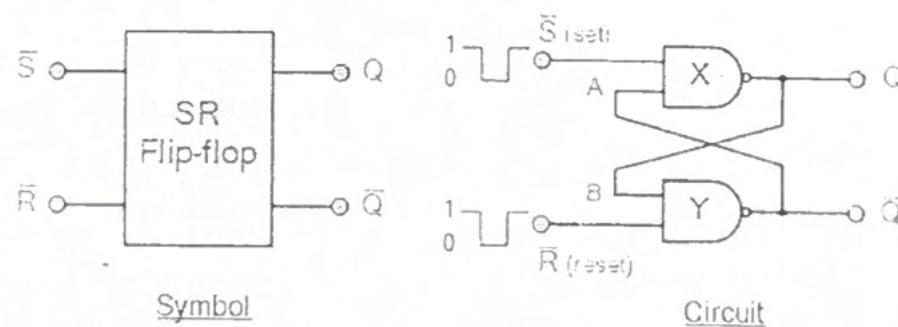


Figure 5.10

Set State

For the circuit above, if input R is at logic level "0" ($R = 0$) and input S is at logic level "1" ($S = 1$), NAND gate Y has at least one of its inputs at logic "0". Therefore, its output Q ($\bar{Q}$) must be at a logic level "1" (recall NAND Gate principles). Output Q is also fed back to input "A" and so both inputs to NAND gate X are at logic level "1", and therefore its output Q must be at logic level "0".

Unit 5 – Digital Logic

If the reset input R changes state, and goes HIGH to logic "1" with S remaining HIGH also at logic level "1", NAND gate Y inputs are now $R = "1"$ and $B = "0"$. Since one of its inputs is still at logic level "0" the output at Q still remains HIGH at logic level "1" and there is no change of state. Therefore, the flip-flop circuit is said to be "Latched" or "Set" with $\overline{Q} = "1"$ and $Q = "0"$.

Reset State

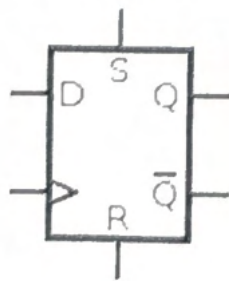
In a state change, if $\overline{Q}$ is at logic level "0", (not $Q = "0"$) its inverse output at Q is at logic level "1", ($Q = "1"$), and is given by $R = "1"$ and $S = "0"$. As gate X has one of its inputs at logic "0" its output Q must equal logic level "1" (again NAND gate principles). Output Q is fed back to input "B", so both inputs to NAND gate Y are at logic "1", therefore, $Q = "0"$.

If the set input, S now changes state to logic "1" with input R remaining at logic "1", output $\overline{Q}$ still remains LOW at logic level "0" and there is no change of state. Therefore, the flip-flop circuits "Reset" state has also been latched.

Other latches and Flip Flops

Flip-flops can be divided into common types: the SR ("set-reset"), D ("data" or "delay"), T ("toggle"), and JK types are the common ones. The D flip-flop symbol is shown below.

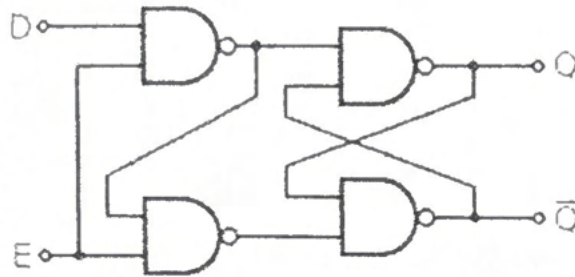
D Flip Flop



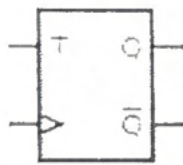
The Q output always takes on the state of the D input at the moment of a rising clock edge. (or falling edge if the clock input is active low). It is called the **D** flip-flop for this reason, since the output takes the value of the **D** input or *Data* input, and *Delays* it by one clock count.

Unit 5 – Digital Logic

A D flip flop circuit can be designed using NAND gates as shown in figure 5.11.



T Flip Flop



The **T** or "toggle" flip-flop changes its output on each clock edge, giving an output which is half the frequency of the signal to the T input.

It is useful for constructing binary counters, frequency dividers, and general binary addition devices. A T flip flop can be defined as follows:

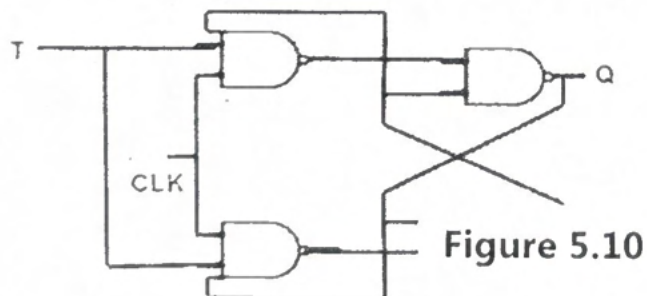
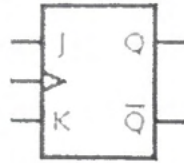


Figure 5.11

Unit 5 – Digital Logic

JK Flip Flop



The JK flip flop is a modified version of an S-R flip-flop; it is an S-R flip-flop with an added layer of feedback. This feedback selectively enables one of the two set/reset inputs so that they cannot both carry an active signal to the multivibrator circuit, thus eliminating the invalid condition that is possible with an SR flip flop. A JK flip flop symbol is shown above, and can be designed as follows in figure 5.12.

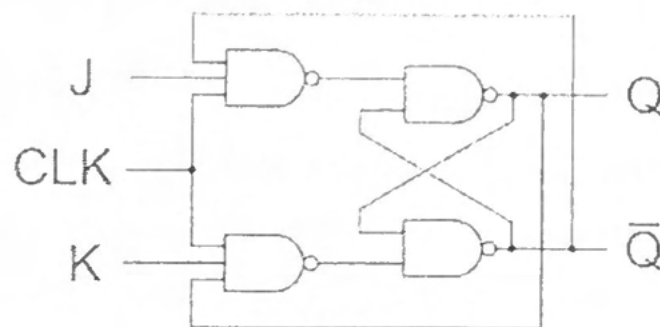


Figure 5.12

Note that each flip flop is a combination of 2 or more logic gates reviewed earlier in this section; where each type operates on different inputs and clock pulses.

Unit 5 – Digital Logic

MULTIVIBRATOR

Individual sequential logic circuits can be used to build more complex circuits such as Counters, Shift Registers, Latches and Memory, but for these types of circuits to operate in a "sequential" way, they require the addition of a clock pulse or timing signal to cause them to change their state. Clock pulses are generally continuous square or rectangular shaped waveform that is produced by a single pulse generator circuit such as a **Multivibrator**.

A *multivibrator* is a logic circuit comprised of logic gates configured as latches and flip flops. It is a circuit that oscillates between a "HIGH" state and a "LOW" state producing a continuous output that serves as a timing or "clock" circuit.

There are basically three types of clock pulse generation circuits:

1. Astable - A *free-running multivibrator* that has **NO** stable states; it switches continuously between two states. This action produces a train of square wave pulses at a fixed frequency.
2. Monostable - A *one-shot multivibrator* has only **ONE** stable state; it is triggered externally and after toggling to a 2nd state it returns back to its first stable state.
3. Bistable - A *flip-flop* that has **TWO** stable states that produces a single pulse that is either positive or negative in value.

Unit 5 – Digital Logic

Logic Practice Exercises

Fill in the truth table for each gate.



AND Gate

A	B	X
0	0	
0	1	
1	0	
1	1	



NAND Gate

A	B	X
0	0	
0	1	
1	0	
1	1	



NOT Gate

A	X
0	
1	

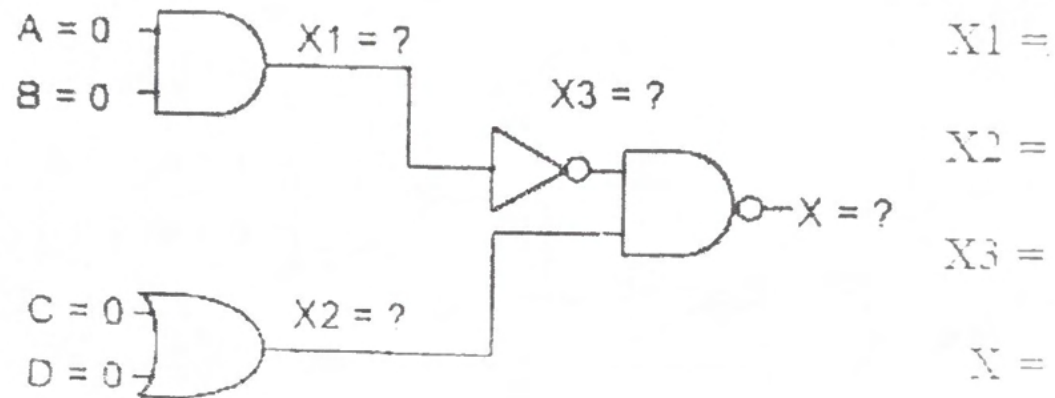


OR Gate

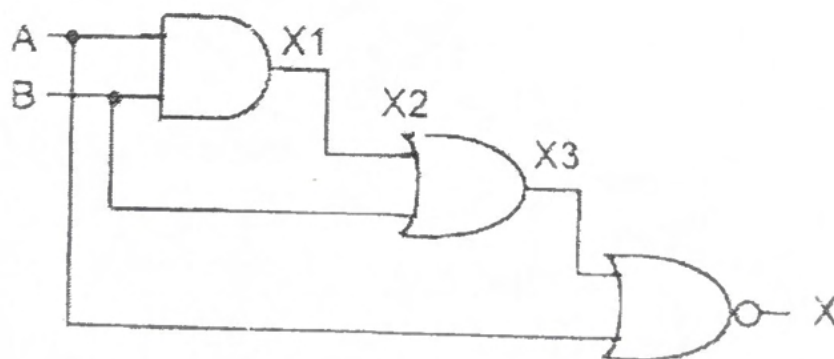
A	B	X
0	0	
0	1	
1	0	
1	1	

Unit 5 – Digital Logic

Given the inputs A, B, C and D, predict the values at right.



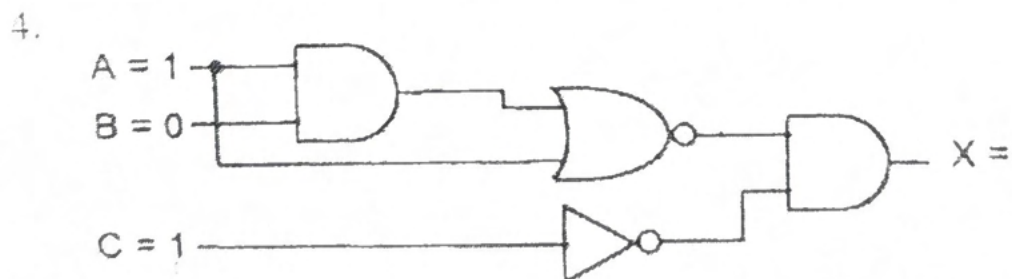
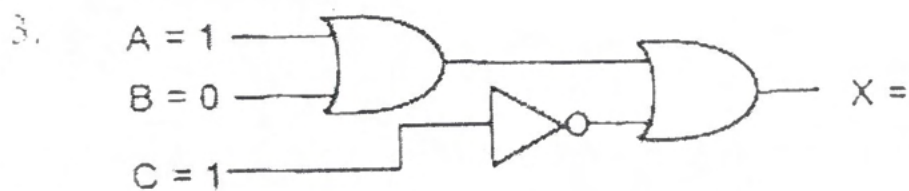
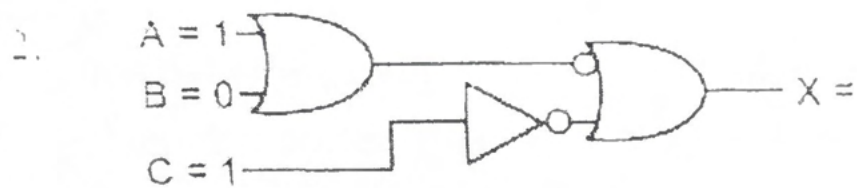
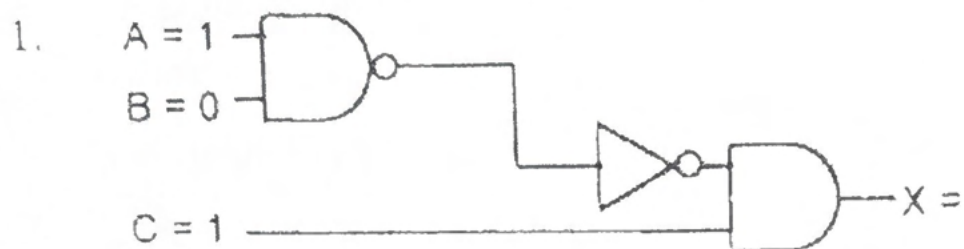
Fill in the truth table for the following logic diagram.



A	B	X
0	0	
0	1	
1	0	
1	1	

Unit 5 – Digital Logic

Which of the following combinations of logic gates will produce a logical high (1) output?



Unit 5 – Digital Logic



Unit 5 Review Quiz

Circle the correct response for the questions listed below.

1. Digital logic that defines a binary 1 logic level as being "on" or in "high" state, and a binary value 0 as being "off" or in "low" state, is called:
 - a. Positive TTL
 - b. Positive LTL
 - c. Negative TTL
 - d. Negative LTL
2. The representation of signals and sequences of a digital circuit through representations of binary numbers is called:
 - a. One's Logic
 - b. Data Logic
 - c. Digital logic
 - d. Transistor Logic
3. An electronic circuit or device that makes logical decisions based on logic input levels is called a:
 - a. Binary Gate
 - b. Logic Gate
 - c. Truth Gate
 - d. Data Gate
4. Which of the following is NOT a digital logic gate?
 - a. AND Gate
 - b. NOR Gate
 - c. OR Gate
 - d. IF Gate

Unit 5 – Digital Logic

5. A logic table that shows how a logic circuit's output responds to various combinations of the inputs is called a:

- a. Gate Table
- b. Binary Table
- c. Trace Table
- d. Truth Table

6. A logic gate with 3 inputs will have ____ possible binary input combinations.

- a. 2
- b. 4
- c. 6
- d. 8

7. The logic symbol below is a _____ gate.

- a. AND
- b. OR
- c. NOT
- d. NOR



8. The logic symbol below is a _____ gate.

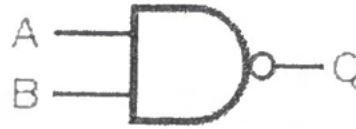
- a. AND
- b. OR
- c. NOT
- d. NOR



Unit 5 – Digital Logic

9. The logic symbol below is a _____ gate.

- a. AND
- b. OR
- c. NOT
- d. NAND



10. The logic symbol below is a _____ gate.

- a. NAND
- b. OR
- c. NOT
- d. NOR



11. The symbol below represents a:

- a. Flip Gate
- b. SR Flip-Flop
- c. NOT Flop
- d. Q Flip-Flop



12. Which of the following is NOT a common flip-flop?

- a. T
- b. D
- c. JK
- d. Q

Unit 5 – Digital Logic

13. Another name for a flip flop is:

- a. Latch
- b. Lock
- c. Hook
- d. trap

14. Clock pulses are generally continuous square or rectangular shaped waveforms that are produced by a single pulse generator circuit called a:

- a. synchrovibrator
- b. Multivibrator
- c. Timing Vibrator
- d. Pulse Vibrator

15. Relative to the device of question # 14 above, the term bistable means there are ____ possible stable states.

- a. 2
- b. 4
- c. 6
- d. 8

UNIT 6 - DIGITAL SIGNALING

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Unit 6 - Digital Signaling

INTRODUCTION

A digital signal is a representation of a sequence of a discrete value that takes the form of a bit stream. This includes the representation of a digitized analog signal.

OVERVIEW

The term digital signal can refer to either of the following:

- Any continuous-time waveform signal used in digital communication, representing a bit stream or other sequence of discrete values
- A pulse train signal that switches between a discrete number of voltage levels or levels of light intensity, also known as a line coded signal or baseband transmission. For example a signal found in digital electronics or in serial communications, or a pulse code modulation (PCM) representation of a digitized analog signal.

A signal that is generated by means of a digital modulation method (digital passband transmission), to be transferred between modems, is in the first case considered as a digital signal, and in the second case as converted to an analog signal.

UNIT 6 OBJECTIVES

Upon completion of this unit, you will be able to:

- Define the term "Digital Signaling" and "bit"
- Define and describe Extended ASCII
- Explain the representation of a digital bit pulse as a voltage pulse
- Define the term "synchronization"
- Explain "Line Encoding" and its common types used in telecommunications
- Explain the concepts "return to zero" and "non return-to-zero"
- Identify the use of the different line codes in different applications

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Unit 6 - Digital Signaling

SECTION 6.1 – DIGITAL SIGNALING METHODS

Digital signaling is the exchange of coded voltage pulses or currents that represent communications information between two digital equipment devices.

In essence, it is the presence or absence of electrical energy for short durations we call time slots.

Consider Morse Code and the old telegraph system. Every alpha-numeric character was assigned a unique series of dots and dashes to represent each character. For example, the letters S, O, S were represented as dot-dot-dot-dash-dash-dash-dot-dot-dot (or ' ' ' --- ' ' '). The duration of the telegraph clicks represented whether it was a dot or a dash.

The same is true when we see old war movies and the Navy ships communicate with flashes of light. Anywhere from one to three units of time, including the spacing between the dots and dashes, determined the letter and or words being transmitted.

Consider now the *Extended ASCII* code we use with networking systems and computers. The American Standard Code for Information Interchange is a coding scheme where, as with Morse Code, we assign a unique series of 8 **binary digits** (bits), of zeros and ones to represent each alpha-numeric character we use to make words and symbols. We then use digital electronics equipment to convert these bits into the presence or absence of voltage pulses on a wire, or light pulses on an optical fiber, and we put them together in a bit stream to represent transmitted information. On a copper wire, where there is a binary one in the data, we have a voltage pulse. Where there is a binary zero in the data, we have zero voltage present. For example, the letters C, A, T spell "Cat" in uppercase. In binary:

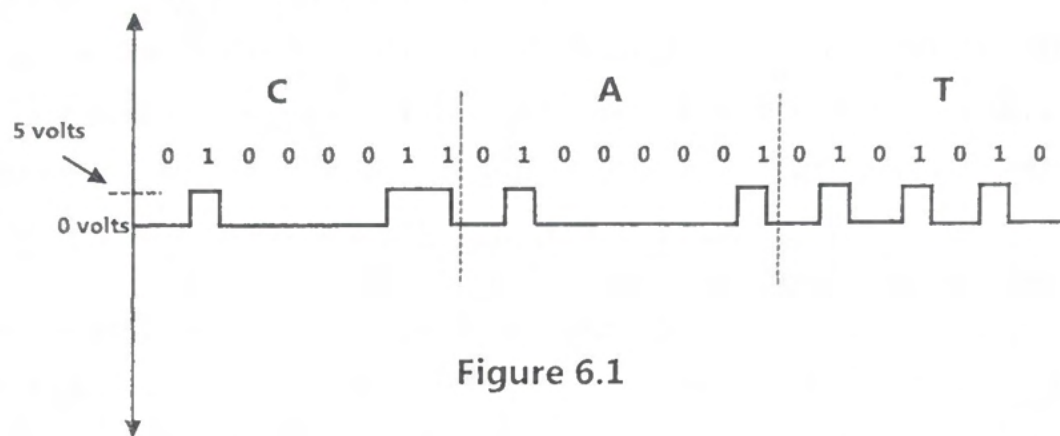
C = 01000011

A = 01000001

T = 01010100

Unit 6 - Digital Signaling

Therefore, where the binary ones are located we insert 5 volt pulses and string the characters together as shown below in figure 6.1:



Where we have binary zero data there is absence of voltage. Where we have binary one's of data, we insert 5-volt pulses, and combined, we can transmit the word on a wire as a series string of voltage and no-voltage that we call a pulse train.

Each binary digit (bit) position is a time slot so there is a timing mechanism at both ends of a link to determine where each bit starts and ends, and also where each character and each word starts and stops. This is called **synchronization**. Every character we display, store or transmit is a unique 8-bit (1 byte) string of binary digits.

In essence, it's like taking a flashlight circuit and opening and closing the switch at short time intervals where the lamp turns on when a D.C. voltage is applied at the binary one data. Consider the following lamp circuits. In the first circuit, a person could be manually pressing the switch to supply voltage to the lamp at the same points in time that the digital pulse stream provides voltage. Figure 6.2 shows the digital digits from equipment that replaces the person pressing the switch. Each voltage pulse turns on the lamp.

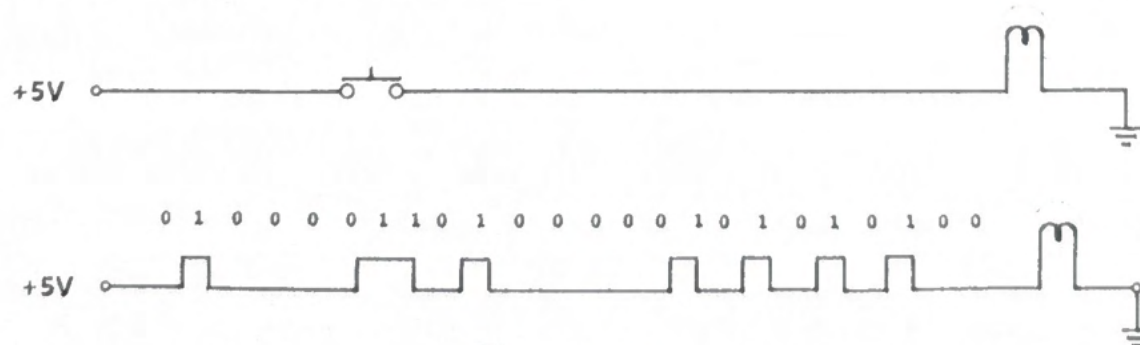


Figure 6.2

Unit 6 - Digital Signaling

LINE ENCODING

We know that digital signals are represented as binary digits 0 and 1. We will now look at the format of the pulses that are represented by the zeros and ones. These formats are called Line Codes, and the process of applying the waveform patterns of voltage or current that are used to represent the 1s and 0s on a given transmission link is called *line encoding*.

In telecommunications, therefore, a line code (also called *digital baseband modulation*) is a code format chosen for use within a communications system. It is often used for digital baseband data transport such as what we see in the T1 System or with SONET; where a T1 uses **Alternate Mark Inversion (AMI)** as its line code.

[Note: Baseband signaling is a type of data transmission in which digital or analog data is sent over a single un-multiplexed channel, such as an Ethernet LAN, only one signal at a time.]

In contrast to this is broadband signaling. Broadband is used to describe a type of data transmission in which a single medium (e.g., wire or coax cable) can carry multiple channels simultaneously. Cable TV, FiOS and U-Verse, for example, make use of broadband transmission.]

Line coding consists of representing the digital baseband signal to be transported by an amplitude- and time-discrete signal that is optimally tuned both for the specific properties of the physical medium that will carry it, and for the equipment that will receive the data. The waveform pattern of voltage or current used to represent the 1s and 0s of a digital data on a transmission link is called *line encoding*. The common types of line encoding are

- Unipolar
- Polar/Bipolar
- Manchester
- Alternate Mark Inversion (AMI)

Unit 6 - Digital Signaling

Return-to-Zero (RZ) and Non Return-to-Zero (NRZ)

Return-to-zero (RZ) describes a line code used in telecommunications signals in which the signal returns to zero volts level between each pulse. This takes place even if a number of consecutive 0s or 1s occur in the signal. The signal is self-clocking. This means that a separate clock does not need to be sent alongside the signal, but suffers from using twice the bandwidth to achieve the same data-rate as compared to non-return-to-zero format.

Non-Return-to-Zero (NRZ) is a binary line code in which binary 1s are represented by one significant condition (positive voltage with Positive TTL) and 0s are represented by some other significant condition (negative voltage with Positive TTL). With NRZ there is no neutral or "rest" condition after each pulse.

Unipolar Encoding

- Unipolar refers to the fact that only one (positive) voltage polarity is used in the signaling. It is classified as a non-return-to-zero (NRZ) code since the voltage does not return to zero for successive one bits. Unipolar signaling is most commonly found on the transmission bus within a computer or most other digital devices; i.e., it is used as a device internal signaling method. Figure 6.3 is an example of Unipolar encoding.

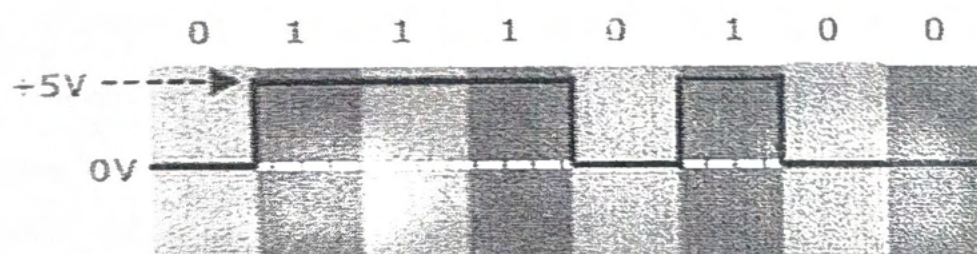


Figure 6.3

Unipolar NRZ Encoding

The Unipolar encoding scheme is not self-clocking. Therefore, a long string of either ones or zeroes in the data can result in the receiver losing track of the clock, which means the system can lose synchronization between the transmit and receive ends. This can be overcome using an adjacent and separate clocking (timing) circuit.

Unit 6 - Digital Signaling

Polar/Bipolar Encoding

Polar (also called Bipolar) encoding refers to the fact that both voltage polarities are used in the signaling; i.e., where two nonzero values are used, so that the three values are +, -, and zero. Bipolar signaling has been very popular for relatively short distance communication.

The Polar/Bipolar line code does not use the zero voltage state, so it is classified as a non-return-to-zero (NRZ) line code. With positive TTL, the positive voltage typically represents the binary 1 data bit, and the negative voltage represents the binary 0 data bit. Figure 6.4 shows an example of polar encoding.

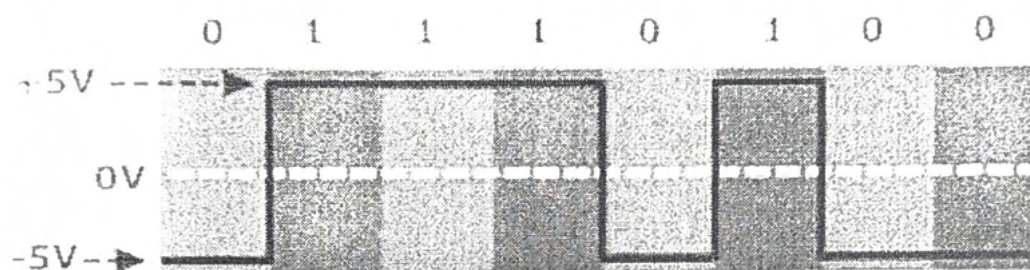


Figure 6.4

Polar/Bipolar NRZ Encoding

The Polar/Bipolar encoding scheme is also not self-clocking. Therefore, a long string of either ones or zeroes in the data can result in the receiver losing track of the clock, which means the system can lose synchronization between the transmit and receive ends. As with Unipolar, this can be overcome using an adjacent and separate clocking (timing) circuit.

Manchester Encoding

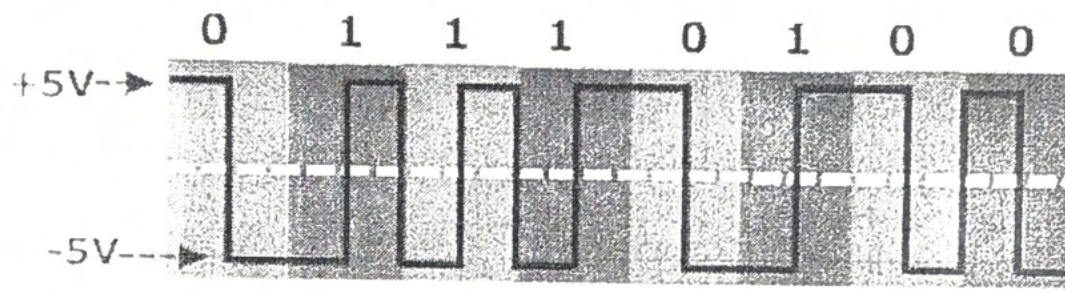
Manchester line code is a baseband line code in every bit contains a signal transition. Per figure 6.5, Manchester encoding represents a binary one bit by implementing a negative voltage polarity for the first half of the bit time slot, and then reversing to a positive voltage polarity for the second half of the bit time slot.

In contrast, a binary zero bit is represented by a positive voltage polarity for the first half of the bit time slot, and a negative voltage polarity for the second half of the bit time slot.

Since we can call ones "high" and zeros "low", we can say a binary 1 bit contains a low-to-high transition, and a binary 0 bit a high-to-low transition.

Unit 6 - Digital Signaling

Manchester is also considered NRZ, but because there is a transition in every bit time slot, whether 1 or 0, this signal is considered to be self-clocking. This means a separate timing circuit is not required and synchronization is accomplished within the bit transitions. However, since there is a need for two signal transitions to convey a single bit, this means the encoding scheme is only 50% efficient compared with the other schemes.



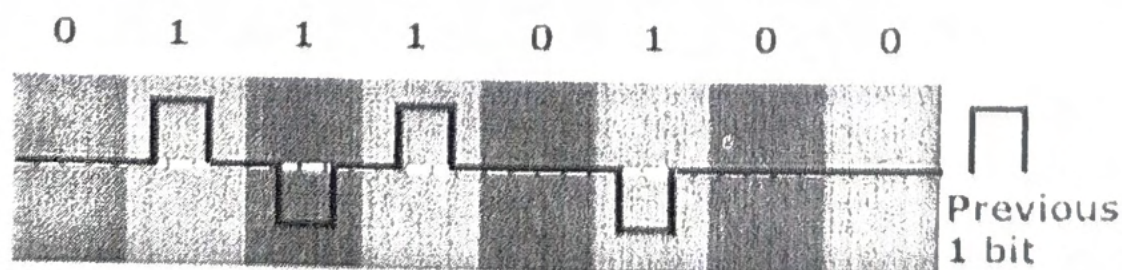
Manchester NRZ Encoding

Figure 6.5

Manchester encoding is commonly found in Ethernet LANs (especially the older Base10-T). This is encoding, for example, between two computers in a Ethernet LAN transferring a data file from one to the other.

Alternate Mark Inversion (AMI)

Alternate Mark Inversion is a baseband line code in which each binary one-bit is alternately signaled with an opposite polarity from the previous bit polarity, (i.e., if the first binary one bit is a positive polarity, the next binary one bit will be negative polarity. If the first one-bit has a negative polarity, the next will be positive polarity. A zero-bit is always signaled with no voltage. AMI is shown in figure 6.6.



AMI Encoding

Figure 6.6

Unit 6 - Digital Signaling

AMI is pseudo self-clocking. This means that as long as there are a sufficient number of one-bits in the digital data stream, the code is self clocking due to an ample number of signal transitions. A long string of zeroes, however, can result in the receiver losing track of the clock.

AMI can be implemented as a return-to-zero scheme, in which the signal returns to zero-voltage within the bit time. This is the variation that can be used on a T-1, as depicted in the previous graphic of figure 6.6.

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Unit 6 - Digital Signaling



Unit 6 Review Quiz

Circle the correct response for the questions listed below.

1. The exchange of coded and discrete voltage pulses or currents that represent communications information between two digital equipment devices is called:
 - a. Analog Signaling
 - b. Digital Signaling
 - c. Sine Wave
 - d. None of the above

2. The process of applying the waveform patterns of voltages or currents that are used to represent the 1s and 0s on a given transmission link is called:
 - a. Line Encoding
 - b. Multiplexing
 - c. A2D
 - d. D2A Conversion

3. Data transmission in which a single medium (e.g., wire or coax cable) can carry multiple channels simultaneously is called:
 - a. Baseband signaling
 - b. TDM
 - c. Broadband signaling
 - d. Line Encoding

4. The term "bit" is derived from:
 - a. binary digit
 - b. bi-directional Travel
 - c. bi-digit Timing
 - d. None of the above

Unit 6 - Digital Signaling

5. The coding scheme used by most computers; where we assign a unique series of 8 bits of zeros and ones to represent each alpha-numeric character and/or symbol, is the _____ standard.
- a. Nyquist Code
 - b. Extended ASCII
 - c. BITS
 - d. Morse Code
6. When there is a timing mechanism at both ends of a link to determine where each bit starts and ends, this is called:
- a. Synchronization
 - b. Asynchronization
 - c. Duplex Transmission
 - d. Non-controlled sequencing
7. Which of the following are the two classifications of line coding?
(Choose 2)
- a. Return-to-Zero
 - b. B8ZS
 - c. Non-Return-to-Zero
 - d. RF
8. Which of the following is NOT a digital encoding method?
- a. Westchester
 - b. Unipolar
 - c. AMI
 - d. Manchester

Unit 6 - Digital Signaling

9. Which digital signal encoding method is a line code in which each binary one-bit is alternately signaled with an opposite polarity from the previous bit polarity?

- a. Westchester
- b. Unipolar
- c. AMI
- d. Manchester

10. Unipolar encoding is a _____ code.

- a. RZ
- b. NRZ
- c. AMI
- d. UNI

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UNIT 7 - MODULATION AND MULTIPLEXING TECHNIQUES

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Unit 7 - Modulation & Multiplexing

INTRODUCTION

Often confused as to their functions, modulation and multiplexing are both integral parts of how transmission of information across physical media, such as wires, optical fibers, and radio waves, takes place.

OVERVIEW

Modulation is the way a source transmits information through a carrier. For example, consider human speech; a person, the source of information, transmits data by modulating the air with sound waves in a way that is understandable to other humans. In this case the air is the carrier.

In contrast, multiplexing is when many slower data lines (CAT5, POTS, etc.) are combined into a single faster line such as a data line (T1, Optical Fiber). An example is the communications backbone between two cities. A fast, high bandwidth optical line joins the cities together, but when it reaches either city's limits, it is split up into many individual phone or data circuits.

The bottom line is that modulation is how a source manipulates the carrier; whereas multiplexing is combining multiple circuits into a single, faster line and then separating them again.

UNIT 7 OBJECTIVES

Upon completion of this unit, you will be able to:

- Define and compare modulation vs. multiplexing
- Identify the devices used to perform modulation and multiplexing
- Review the characteristics of ASK, FSK and PSK Keying
- Explain the T-1 PCM processing steps for converting analog voice to digital
- Describe the North American Digital (T-1) Hierarchy
- Describe the PCM T-1 Frame and its structure
- List the common wireline and wireless Multiplexing methods in use and describe their characteristics

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SECTION 7.1 – MODULATION AND KEYING

The term *Modulation* represents a process that can be viewed in different perspectives.

- (1) In electronics and telecommunications, *modulation* is the process of varying one or more properties of a periodic waveform, called the *carrier signal* (High Frequency Signal), with a *modulating signal* which typically is the information or "content" that is transmitted. For example, FM and AM radio stations transmit analog information "piggybacked" over an analog carrier signal.
- (2) In telecommunications, modulation is also the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted in a different format. For example, we convert analog into electric voltage pulses, but we also convert electric voltage pulses into light pulses and transport these pulses over an optical fiber.

A device that performs modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator (also called a *detector* or *demod*). A device that can do both modulation and demodulation is called a modem (from "**m**odulator-**d**emodulator"); which is from where its name was derived.

In digital modulation, an analog carrier signal is modulated by a discrete signal. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion as we described earlier.

ASK, FSK and PSK

The most fundamental digital modulation techniques are based on something called "keying". "Keying" is the changing of one of 3 aspects of a carrier wave: (1) the amplitude, (2) the frequency, and (3) the phase angle. But instead of "modulation", we call these *keying* techniques because they are operating on a binary-number basis.

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Three basic, or fundamental, keying techniques in use for A2D and D2A are shown below in figure 7.1 .

- ASK (amplitude-shift keying): a finite number of amplitudes are used.
- FSK (frequency-shift keying): a finite number of frequencies are used.
- PSK (phase-shift keying): a finite number of phases are used.

The following shows each of these techniques applied to a digital baseband signal.

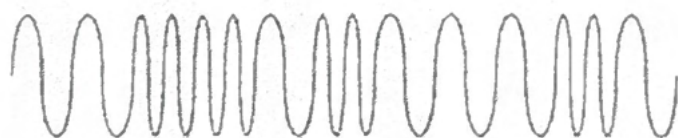


Digital Baseband Signal



Amplitude Shift Keying (ASK)

Note the 1s and 0s are represented by a different analog amplitude.



Frequency Shift Keying (FSK)

Note the 1s and 0s are represented by a different analog frequency.



Phase Shift Keying

Note the 1s and 0s are represented by a different phase; i.e. the phase shift occurs at the change in binary value.

Figure 7.1

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PULSE CODE MODULATION

Another very important and commonly used modulation process is called Pulse Code Modulation (PCM). PCM is used in the telecommunications T-1 system as well serving as the standard for many Coders/Decoders (CODECS) such as used in VoIP systems, digital audio sound cards in computers, Compact Discs, iPods, iPads and Smart Phones.

The simplest explanation of how PCM works is through the POTS phone call example over a T-1 System. PCM is a process that includes Sampling, Quantization and Encoding.

Sampling

Consider that the FCC dictates 4kHz of analog bandwidth to all telephone voice calls. Consider also a theorem, called Nyquist Theorem. According to Nyquist, when we convert an analog voice signal to a digital format for transmission over the telephone network, we must "sample" the height of the analog voice signal at a rate that is at least twice as fast as the bandwidth of the analog voice signal. This is necessary in order to have enough samples on the receiving end to be able to accurately reconstruct the analog waveform so that we can send the analog voice to the called party. By doing this the voice that is transmitted by the caller has the same audio characteristics at the receiving end; i.e., it sounds the same.

The PCM sampling process is a measurement of the height (amplitude) of the analog signal at regular intervals and at different points along the analog voice wave. Since the analog voice bandwidth is 4kHz, we double this per Nyquist to obtain a sampling rate of 8,000 samples per second. The graphic of Figure 7.2 shows how an analog signal's height is measured at intervals in the sampling process.

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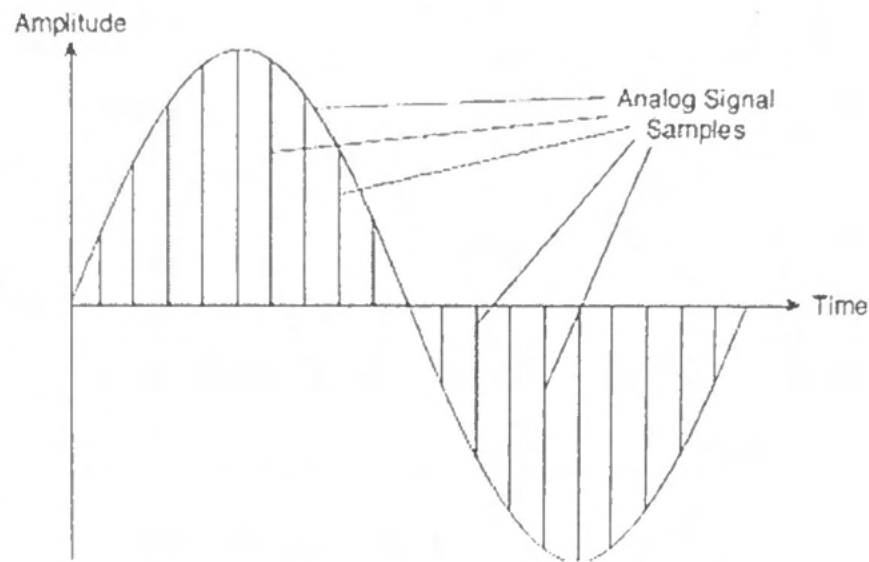
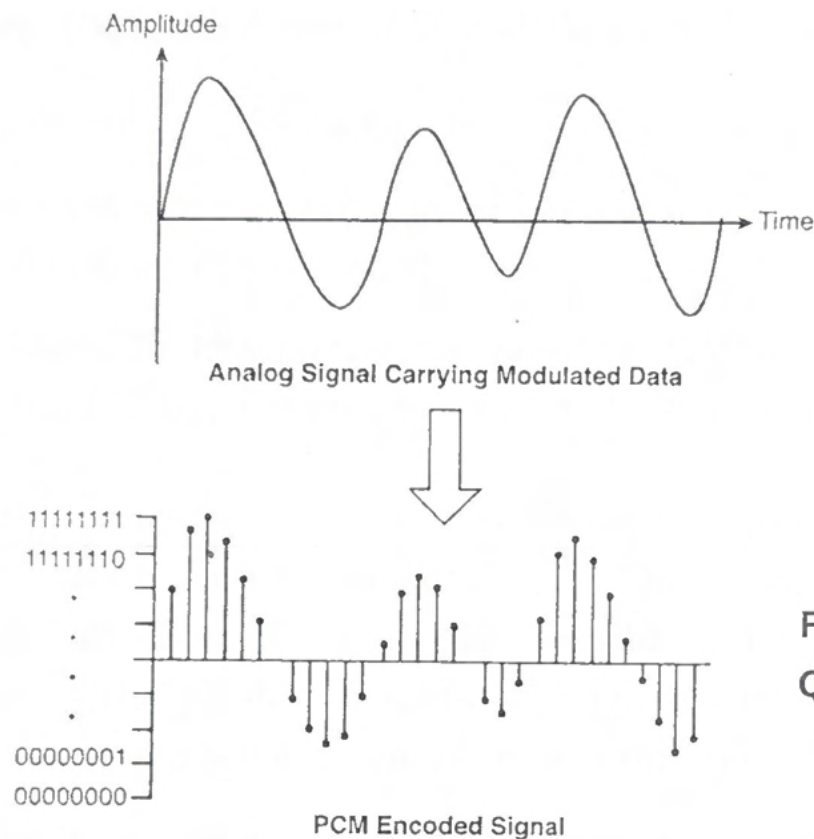


Figure 7.2 T-1 PCM Sampling

Quantization and Encoding

The instantaneous amplitude of the analog signal at each sampling point is rounded off to the nearest of several specific, predetermined levels. These levels are defined in the T-1 tables; where every T-1 contains the same mapping table and applies the same binary values to each sample. This mapping to a level and assignment to an 8-bit binary value is called *Quantization and Encoding*. The number of levels is always a power or multiple of 2. For example, the encoding can assign 4 bits, 8 bits, etc. The T-1 system uses an 8-bit encoding scheme as shown in figure 7.3, but many PCM devices use 4-bit and other schemes. Note how the height points at the ends of each sample map to an 8-bit digital representation of that height.

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**Figure 7.3 T-1 PCM
Quantizing & Encoding**

Designed as an 8-bit system, the T-1 representation of each sample is an 8-bit octet, or byte, of binary digits; where each byte represents one of 256 possible levels defined in the T-1 tables. There are 256 possible levels in the T-1 table because in a binary system $2^8 = 256$ possible combinations. Therefore there are 2^8 possible combinations of values; where $2^8 = 256$. Each 8-bit byte is then inserted into a T-1 Frame; where each byte represents 1 sample from one of 24 channels in the T-1.

Consider that since there are 8 bits per sample, and there are 8,000 samples per second, the single channel capacity of a T1 = $8,000 \times 8 = 64,000$ bits per second (64Kbps). In the North American Digital Hierarchy, as shown below, this is the data rate of a DS0 channel where 4KHz of analog bandwidth is equivalent to 64kbps of digital data rate.

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PCM, therefore, is the modulation process that converts analog voice to digital signaling. The North American Digital hierarchy (T-1) provides for:

- DS0 = 64 Kbps; the individual channel voice channel level
- DS1 = 1.544 Mbps; an entire individual T1 capacity of 24 DS0 channels (64,000 bits/sec x 24 channels)
- DS3 = 44.736 Mbps (typically called a 45Mbps system); also called T3, providing 672 DS0 channels or 28 multiplexed DS1 circuits

The digital output of the T-1 is segmented in groups of binary data called "Frames"; where each frame contains 192 bits each, (8 bits per sample X 1 sample out of each of 24 channels = 192 bits). Add + 1 Framing bits = 193 bits per frame. The graphic below shows a representation of the fundamental T1 frame. Note that each 8-bit sample is an 8-bit Time Slot.

Figure 7.4 shows the structure of a single T-1 Frame where 8 bits per sample are used. If this is the first frame of data (sample one of every channel), then the next frame out of the T-1 contains all the sample 2 heights of every channel, the 3rd frame contains all the sample 3's, etc. until all 8,000 samples are sent, and then the process continues for the next 8,000 samples and so on. Where there is no conversation on a channel, all zeros are inserted in a sample in the form of a unique sequence of binary ones and zeros. The receiving system recognizes this unique code as all zeros and not conversation, and ignores the data bits in the code assuming no conversation on that channel. This is done to provide binary one bits in each sample so as to not lose timing (sync) between the transmit and receive of the systems.

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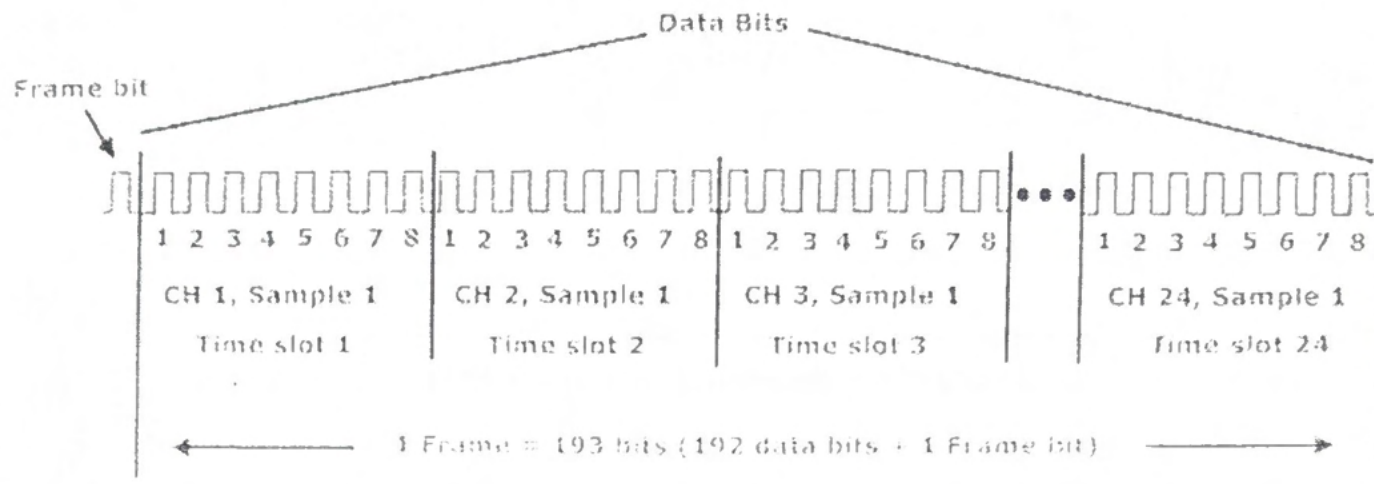


Figure 7.4 T-1 Frame containing all sample 1's of a voice signal in digital format

Figure 7.5 below is the sampling and encoding of a 4-bit CODEC such as used in audio music, VoIP telephony, and video devices. Some camcorders and other video systems use 12-bit and 16-bit PCM, and still other schemes are used by other devices.

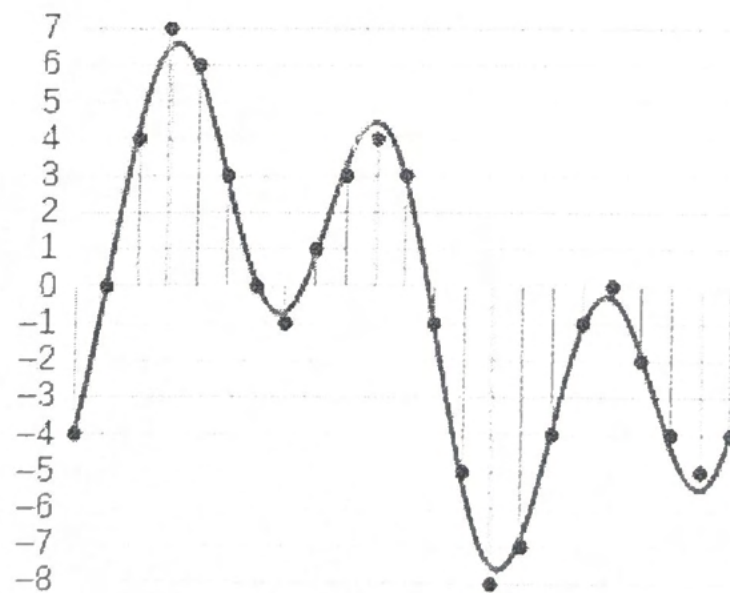


Figure 7.5 4-bit Codec PCM

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SECTION 7.2 – MULTIPLEXING TECHNIQUES

In computer Telecom and Data Comm. networks, multiplexing is a method by which two or more data signals are combined into one data signal and transmitted over a shared medium. The shared medium can be copper wire, optical fiber or the airways. The primary goal of multiplexing is to allow sharing of expensive transmission network facilities to transport data. This reduces costs of data transmission and improves efficiency of data transmission.

In telecommunications, for example, multiple telephone conversations can be carried over a single pair of wires (POTS), or over a limited number of wires such as performed in the multiplexing of 24 T1 voice channels over two pairs of wires (transmit and receive pairs). Multiplexing is extensively used in data and telecommunications services.

In the analog world, multiplexing is typically accomplished by channelizing the bandwidth capacity of the transmission medium and then transmitting radio frequencies as individual channels over the medium. This is possible because each channel operates on a different band of frequencies; where different frequencies do not interfere with each other over a shared transmission path. This is why multiple radio stations can broadcast without interfering with each other over the shared airways.

In the digital world, multiplexing can become a little more complicated. Digital multiplexing is accomplished by a device called a multiplexer (MUX) where a transmitting MUX combines signals onto a shared medium, and a receiving MUX separates each channel to send the content on each channel to its intended receive device. (This is called de-multiplexing).

Multiplexing technology processes in use today can be divided into several types; all of which have significant variations and each used in specific applications.

- Space-Division Multiplexing (SDM)
- Frequency-Division Multiplexing (FDM)
- Time-Division Multiplexing (TDM)
- Code Division Multiplexing (CDM)

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Space-Division Multiplexing (SDM)

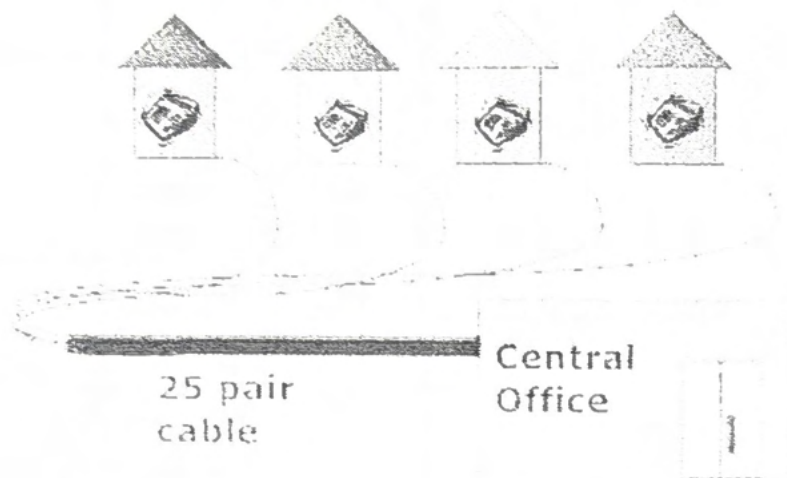


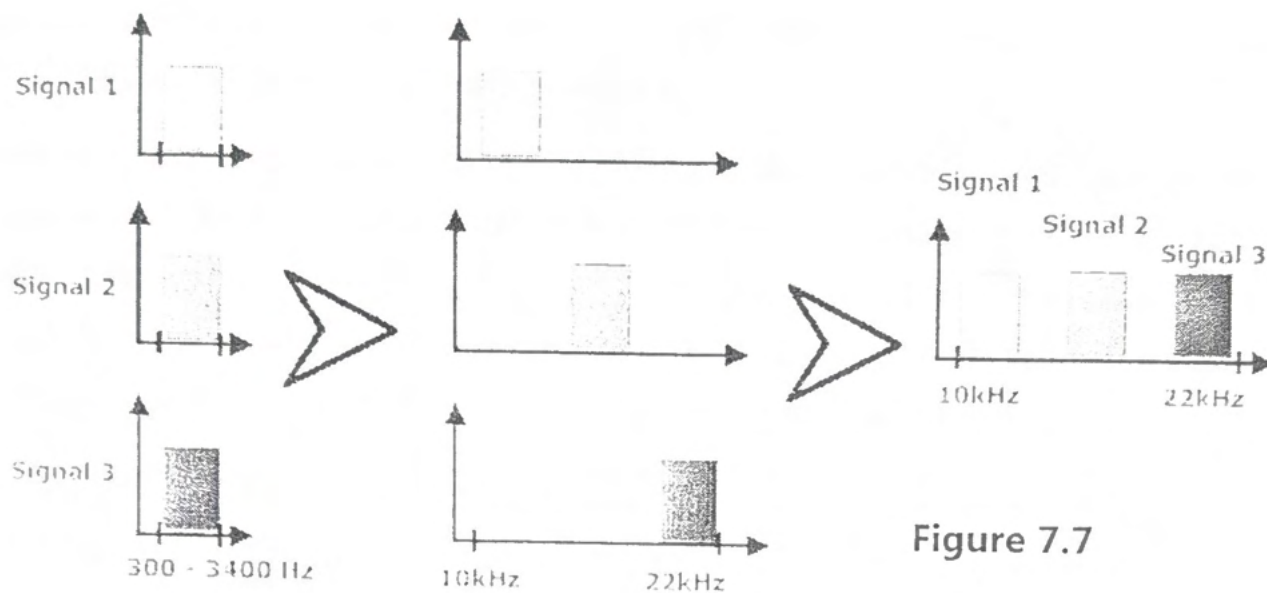
Figure 7.6

SDM is the separation of multiple fixed bandwidth channels by multiple physical paths such as pairs of wires in a telephone cable. The example above, figure 7.6, shows SDM via a 25-pair cable; where the 25 pairs of wires carry the conversations of 25 individual users from the customer's premises to the local telephone company's central office location.

SDM is not the most efficient or cost-effective multiplexing technique from the standpoint of available outside plant resources because these resources, and the cost of installing them as required by growth, can be expensive. However, since a given copper cable has a finite capacity for transporting information, additional installation of cable may be the only alternative when that capacity is exhausted.

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Frequency-Division Multiplexing (FDM)



FDM is a multiplexing scheme in which multiple voice signals of 3100Hz (or 3.1kHz) each are assigned different ranges, or bands, of frequency as sub-channels on a carrier band. These channels are combined onto the separate carrier frequency as sub-channels of 4kHz capacity, but assigned to a different part of the carrier bandwidth.

For example, in figure 7.7 above, you see three different bands of telephone voice bandwidth; where each voice channel contains voice frequencies that range from 300Hz to 3400Hz. Each voice, therefore, requires 300 to 3400 Hz (3.1kHz) in bandwidth.

If we place each of these voices onto a carrier signal that has a bandwidth of 10kHz to 22kHz, we can assign a sub-channel bandwidth of 4kHz to each of the 3.1kHz bandwidth voices so that we can accommodate each voice's required bandwidth. Voice signal 1 is assigned the sub-channel with frequency bandwidth of 10kHz to 14kHz. Voice signal 2 is assigned the sub-channel with frequency bandwidth of 14kHz to 18kHz, and voice signal 3 is assigned the sub-channel with frequency bandwidth of 18kHz to 22kHz. All three of our voice signal, therefore can be transported "piggyback" on a 12kHz carrier frequency; where each voice is kept separated from the others by the virtue of their individual 4kHz channel bandwidth.

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In fact, it is an FCC requirement that every telecommunications company provide 4KHz of bandwidth capacity to accommodate 3.1kHz of actual voice data in order to provide a little "cushion" between channels to avoid overlap and intrusion between conversations.

AM and FM radio uses FDM where each AM radio station, for example, is allocated 10kHz of bandwidth to transmit its content. So when you hear the AM radio announcer say: "This is AM 680 WPTF", this means that the radio station broadcasting at 680 kilohertz and its FCC-assigned call letters are WPTF. 680kHz is within a 10kHz bandwidth assigned to this station.

In the same way, when the announcer says, "You are listening to 91.5 FM WRKX The Rock!," what the announcer means is that you are listening to a radio station broadcasting an FM radio signal at a frequency of 91.5 megahertz, with FCC-assigned call letters of WRKX. Megahertz means "millions of cycles per second," so "91.5 megahertz" means that the transmitter at the radio station is oscillating at a carrier frequency of 91,500,000 cycles per second. Your FM (frequency modulated) radio can tune in to that specific frequency and give you clear reception of that station. All FM radio stations transmit in a band of frequencies between 88 megahertz and 108 megahertz. This is the range of numbers you see on a radio dial, and this band of the radio spectrum is used for no other purpose but FM radio broadcasts.

Time-Division Multiplexing (TDM)

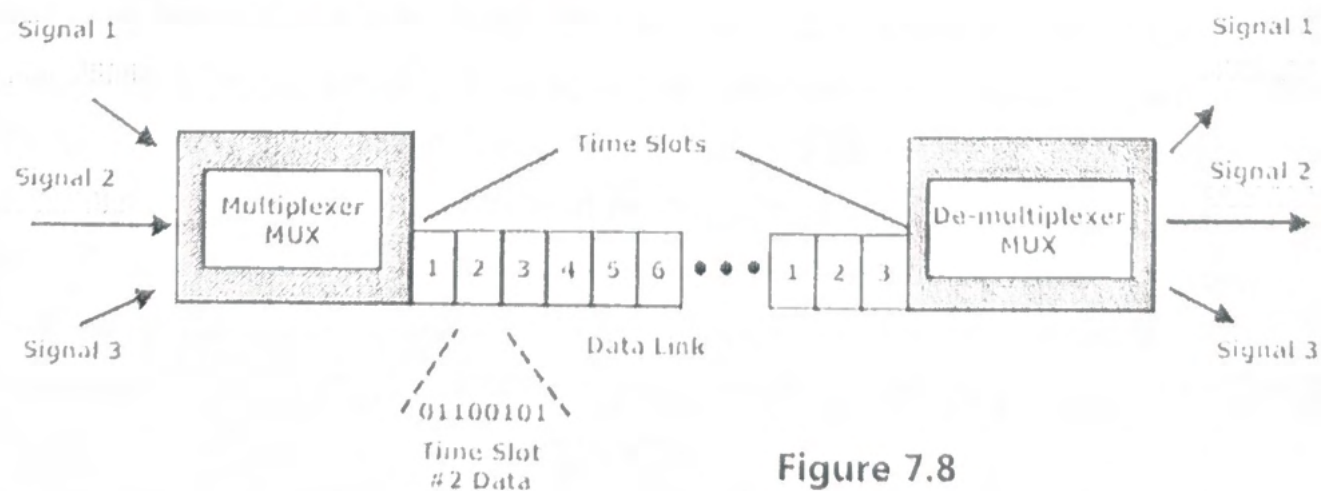


Figure 7.8

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TDM is a method of putting multiple data streams in a single signal by separating the data link between the multiplexers into segments called "Time Slots". Data from each data source input to the multiplexer is then parsed into each time slot in groups of bits (e.g., the time slots above contain 1 byte of data each) as shown in figure 7.8.

The multiplexer combines the input signals at the source (transmitting), segments the data, and places the data onto the data link for transport. The composite output signal from the multiplexer, thus, contains data from multiple end users. At the other end of the data link, the individual signals are separated into their individual channels by means of a receive MUX that performs a de-multiplexing function; i.e., it separates each data source to its intended end-user receive device. A two-way communications circuit requires a multiplexer at each end of the link using a high-bandwidth cable.

If multiple signals must be sent along a single data link, careful engineering is required to ensure that the system has enough bandwidth capacity to perform properly. TDM allows for a variation in the number of signals being sent along the link, and it constantly adjusts its time slot intervals to make optimum use of the available bandwidth.

Orthogonal FDM

Wireless signaling has its own form of frequency division multiplexing called Orthogonal FDM (OFDM). With OFDM, the main signal is divided into small independent sub-channels that together contain the entire message. With OFDM is then applied to each individual signal. These signals are then modulated with a carrier signal and re-multiplexed to create the OFDM signal. A common analogy for OFDM is a shipment of cargo using trucks. The two trucking options for shipping our cargo are (1) using one large truck to transport the cargo or (2) use several small trucks as shown in figure 7.9.

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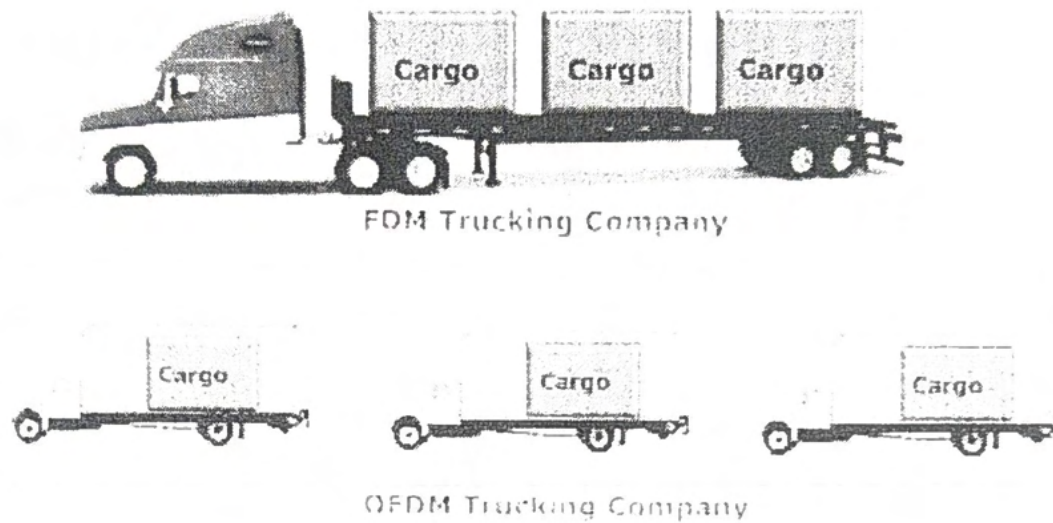


Figure 7.9

In either case, the same amount of cargo will be shipped and delivered, but in the case of the small trucks if one of the small trucks has an accident we lose only 1/3 of our load; whereas, if the large truck has an accident we lose the entire load. This is true with a data stream. With FDM, the data is transmitted as a large single stream, but with OFDM our signal comes out as a series of individual channels.

Another analogy is water out of a shower pipe. Using a faucet instead of a shower head we have a large volume of water out of the faucet. If we use a shower head the water is delivered as small individual streams. With OFDM, the MUX output signal is divided into individual channels such as the individual streams of water out of the showerhead. The same amount of water is delivered just as the same amount of cargo using small trucks.

If we look at our three small trucks and our individual water streams from a showerhead as data signals, each small truck and each stream of water would represent a sub-channel of an OFDM signal. Each of these independent sub-channels can be multiplexed by standard FDM and transmitted to a receiver simultaneously using different frequencies.

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The 'Google' definition of orthogonal is as follows:

adjective: **orthogonal**

1. of or involving right angles; at right angles.

Therefore, with orthogonal signaling, the sub-channels are at right angles to each other; i.e., each sine wave peak is the peak of a different sub-channel separated by and each peak is 90° from the sub-channels adjacent to it as shown below in figure 7.10.

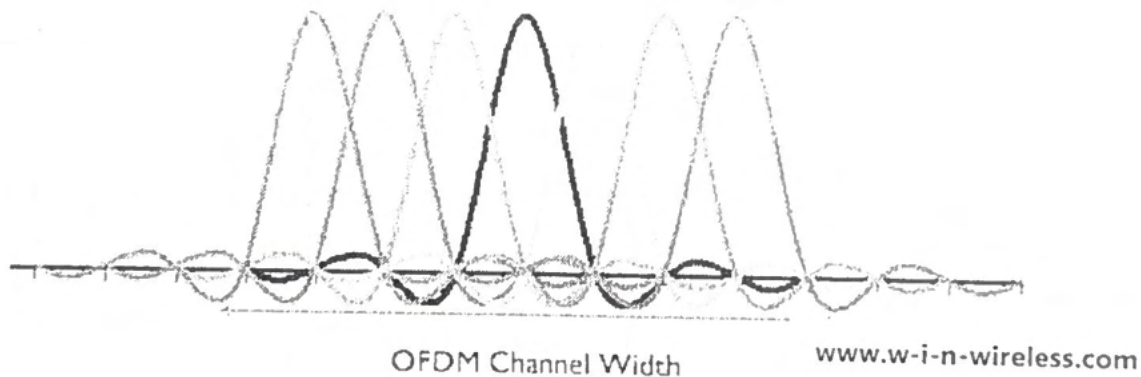


Figure 7.10

This means that with a wireless voice call we can eliminate cross-talk between the sub-channels. It also means inter-carrier guard band filters are not required; this greatly simplifies the design of the transmitter and the receiver and reduces costs.

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Unit 7 Review Quiz

Circle the correct response for the questions listed below.

1. The device that performs the modulation process is typically called a:
 - a. Modem
 - b. MUX
 - c. Detector
 - d. Both a and c are correct

2. Which of the following is NOT one of the fundamental digital modulation techniques?
 - a. Amplitude shift Keying
 - b. Frequency Shift Keying
 - c. Pulse Shift Keying
 - d. Phase Shift Keying

3. PCM stands for:
 - a. Phase Code Modulation
 - b. Pulse Code Modulation
 - c. Pulse Code Multiplexing
 - d. Phase Code Multiplexing

4. Which of the following is NOT one of the steps of the PCM process?
 - a. Mapping
 - b. Sampling
 - c. Quantization
 - d. Encoding

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5. There are ____ possible levels in the T-1 system encoding tables.
 - a. 64
 - b. 128
 - c. 256
 - d. 512

6. The T-1 DS0 Channel provides ____ of digital bandwidth capacity.
 - a. 64kbps
 - b. 128kbps
 - c. 1.544Mbps
 - d. 1Gbps

7. The T-1 DS1 provides ____ of digital bandwidth capacity.
 - a. 64kbps
 - b. 128kbps
 - c. 1.544Mbps
 - d. 1Gbps

8. The data unit output of a T-1 that consists of 192 data bits, plus a framing bit, is called a:
 - a. Packet
 - b. Protocol Data unit
 - c. Byte
 - d. Frame

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9. A DS-3 circuit is composed of ____ multiplexed T-1 circuits.
- a. 1
 - b. 12
 - c. 28
 - d. 50
10. CODEC is an acronym for a:
- a. Compander-Decompander
 - b. Coder-Decoder
 - c. Composer-Decomposer
 - d. Comuxer-Demuxer
11. The T-1 Codec is a ____ bit codec.
- a. 2
 - b. 4
 - c. 8
 - d. 12
12. The process by which two or more data signals are combined into one data signal and transmitted over a shared medium is called:
- a. Multiplexing
 - b. Modulation
 - c. Duplication
 - d. Dual Processing
13. Which of the following is NOT one of the media sharing processes in use today?
- a. Space-Division
 - b. Time Division
 - c. Code Division
 - d. Amplitude Division

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14. With TDM, the divisions on the link that contain the transmitted data are called:
- a. Space Slots
 - b. Time Slots
 - c. Code Slots
 - d. Travel Slots
15. Wireless Multiplexing makes use of a FDM process called:
- a. Optimal FDM
 - b. Originational FDM
 - c. Orthogonal FDM
 - d. Optical FDM

UNIT 8 - NETWORK TOPOLOGIES AND ARCHITECTURES

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Unit 8 - Topologies & Architectures

INTRODUCTION

Like modulation and multiplexing, network topology and network architecture are terms that are often confused. This unit compares the two concepts.

OVERVIEW

This unit reviews the types of networks classified according to the geographical areas they cover such as LANs, MANs and WANs. The network topologies that apply to each of these architectures are categorized according to the layout of equipments and computers; these include the star, ring, bus and mesh topologies.

This unit reviews the architectures and topologies of modern networks in the wireline and wireless environments.

UNIT 8 OBJECTIVES

Upon completion of this unit, you will be able to:

- Define and describe Network Architecture vs. Network Topology
- Identify the architectures in use and their characteristics
- Identify the different topologies in use and their characteristics
- Identify advantages and disadvantages of the different topologies
- Explain "physical" topology vs. "logical" topology
- Identify the wireline and wireless topologies used in the Ethernet environment

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Unit 8 - Topologies & Architectures

SECTION 8.1 – TOPOLOGY DEFINITIONS

Network *Topology* refers to the shape of a network in terms of the way internetwork devices are connected to each other and how they communicate with each other. Topologies are either *physical* or *logical*.

Network *Architecture* refers to the layout of the network in terms of the hardware, software, connectivity, communication protocols and mode of transmission used such as wired or wireless.

The four different topologies listed above can be arranged in different network architectures as:

- LANs (Local Area Network)
- MANs (Metropolitan Area Network)
- WANs (Wide Area Network) where the network extends over a local area (<1 km), metropolitan (<100 km) and long distance.
- PANs

THE PHYSICAL TOPOLOGIES

Physical topology is the physical layout of nodes on a network. The three fundamental shapes include:

- Bus
- Ring
- Star
- Mesh
- Hybrid topologies

Topology is integral to the type of network, its cabling infrastructure, and the transmission media used.

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Bus Topology

The characteristics of a Bus topology (Figure 8.1) are as follows:

- A single cable (the 'bus') connects all the network nodes without intervening connectivity devices (typically coax cable or 'Thick' Ethernet")
- The network devices share responsibility for getting data from one point to another
- Terminators are placed at the end of the bus to stop signals when they reach the end of the wire
- Bus arrangement prevents signal bounce
- They are inexpensive, but not very scalable
- They are difficult to troubleshoot, and they are not fault-tolerant. Single faults can easily bring down the entire network

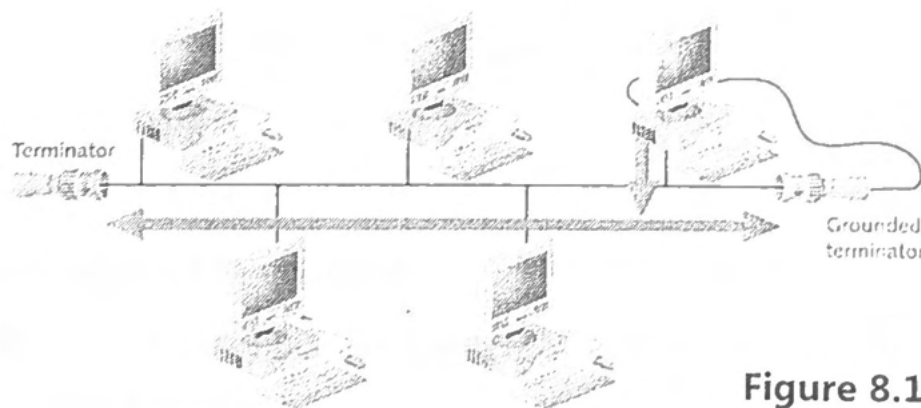


Figure 8.1

Advantages of Bus Topology:

- They work well for small networks
- They are relatively inexpensive to implement
- They are easy to add to for growth

Disadvantages:

- Management costs can be high
- They offer high potential for congestion with network traffic

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Ring Topology

The characteristics of a Ring topology (figure 8.2) are as follows:

- Each node on the ring is connected to the two nearest nodes so the entire network forms a circle
- It uses a method for passing data on the ring called '*token ring passing*'
- It is considered an "Active" topology where each workstation transmits data and the signal is regenerated (amplified) as it passes from one computer to another along the *network*

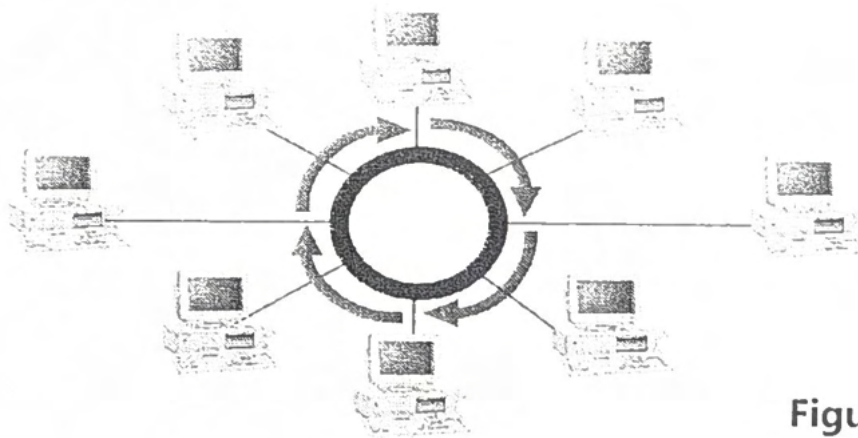


Figure 8.2

Advantages of Ring Topology:

- They are easier to manage, and easier for locating a defective node or cable problem
- They are well-suited for transmitting signals over long distances on a LAN
- They can handle a high-volume of network traffic without congestion
- They enable higher reliability of communication

Disadvantages:

- They are expensive
- They requires more cable and network equipment at initial implementation
- They offer fewer equipment options
- They offer fewer options for expansion to high-speed communication

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Star Topology

The characteristics of a Star topology (figure 8.3) are as follows:

- Every node on the network is connected through a central device
- Any single cable connects only two devices
- Supports max of 1024 addressable nodes on logical network
- It is the LAN topology most commonly used today

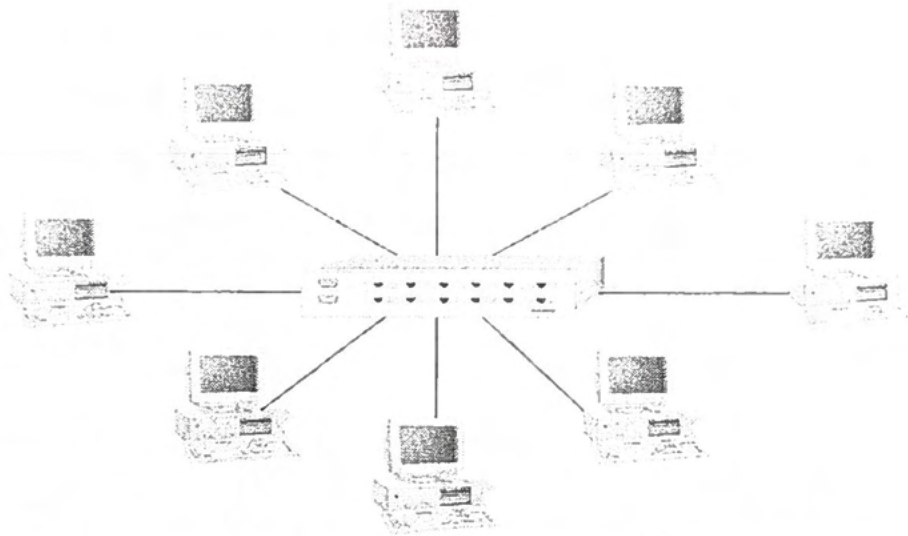


Figure 8.3

Advantages of Star Topology:

- More fault-tolerant than Bus and Ring
- Cabling problems affect two nodes at most
- They are easily moved, isolated, or interconnected with other networks
- They are highly Scalable
- They offer good option for modern networks
- They offer low startup costs
- They are easy to manage
- They offer opportunities for expansion
- A wide variety of equipment is available for Star LANs

Disadvantages:

- They can require more cabling than ring or bus networks
- The central hub is a single point of failure

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Mesh Topology

A mesh is a network topology in which devices are connected with many redundant interconnections between network nodes. In a true mesh topology every node has a connection to every other node in the network.

The characteristics of a Mesh topology (figure 8.4) are as follows:

- Two Types: full Mesh and Partial Mesh
- Full mesh is usually reserved for backbone networks.
- With partial mesh, some nodes are organized in a full mesh scheme but others are only connected to one or two in the network
- Partial mesh topology is commonly found in peripheral networks connected to a full meshed backbone

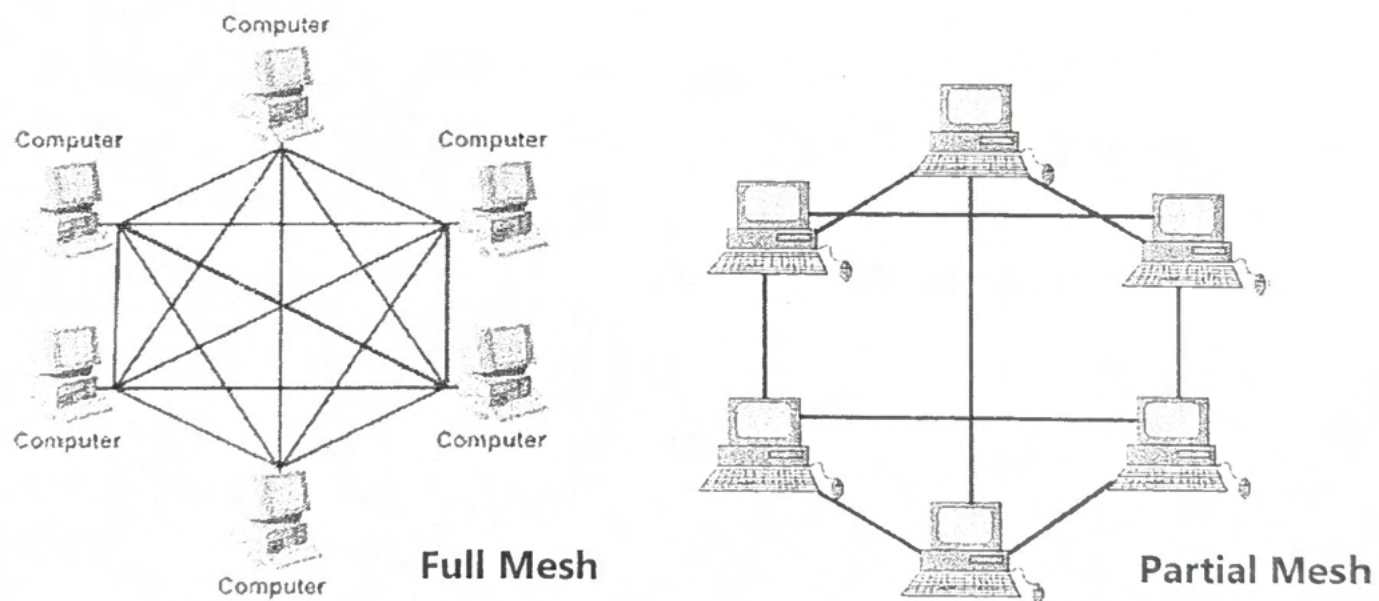


Figure 8.4

Advantages of Mesh Topology:

- In the event that one of those nodes fails, network traffic can be directed to any of the other nodes
- Partial mesh topology is less expensive to implement and yields less redundancy than full mesh topology
- Full mesh is very expensive to implement but yields the greatest amount of redundancy

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Disadvantages:

- Full mesh is very expensive to implement
- Requires large amount of cabling and hardware ports
- Because every device must be connected to every other device or most other devices, installation and reconnection are difficult

Hybrid Topology – Star Wired Bus

This is called Star-Wired-Bus because each computer (or other network device) connects to a central hub, with the cable forming the shape of a star. The star bus has become the most popular topology for local area networks.

The characteristics of a Star-Bus topology (figure 8.5) are as follows:

- Groups of nodes are connected to hubs which are then networked on a single bus
- They are typically used to cover longer distances
- They are also used to interconnect, or isolate, different network segments
- Modern Ethernet, and its faster cousins, are set up using this topology

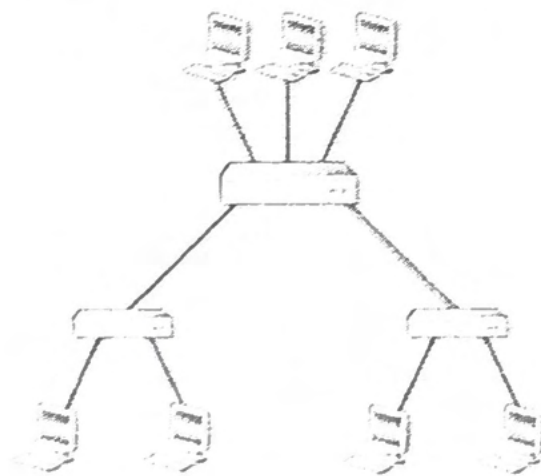


Figure 8.5

Advantages of star-Wired Bus Topology:

- They are fault tolerant
- They are inexpensive, flexible, and easy-to-use cable or media type
- They are easy to troubleshoot by removing computers from the hub or adding "smart" hubs to diagnose problem for you
- They are simple for adding more computers to the network

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Advantages of star-Wired Bus Topology: (cont.)

- They have fast processing Ethernet capability--up to 1000Mbps (1Gbps)
- They are an active topology set-up (with hub as a multi-station repeater) that amplifies the signal

Disadvantages

- They are expensive' they require more cable and more hubs

Hybrid Topology – Star Wired Ring

The star-wired ring topology uses the physical layout of a star in conjunction with the token-passing data transmission method. Data are sent around the star in a circular pattern.

The characteristics of a Star-Ring topology (figure 8.6) are as follows:

- Data is sent around the star in a circular fashion using physical layout of a star topology with ring topology data transmission method

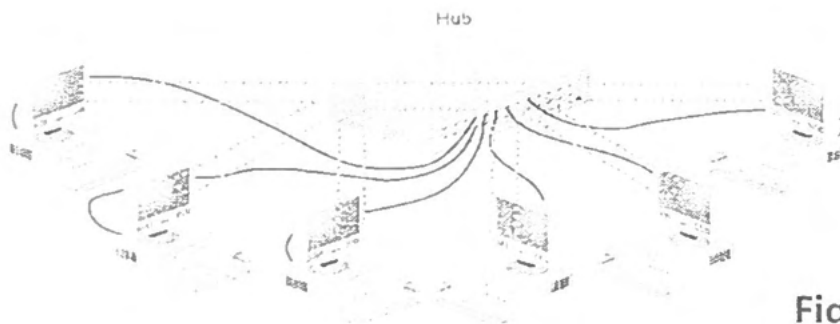


Figure 8.6

Advantages of Star-Wired Ring Topology:

- High fault tolerance of the star topology and the reliability of token passing
- They are capable of supporting a wider range of connecting cables than other topologies' support fiber optic cabling, shielded twisted pair (STP) cables and unshielded twisted pair (UTP)
- Troubleshooting, or fault isolation, is relatively easy
- Flexible and easy to expand

Disadvantages

- Due to extreme flexibility, configuration and cabling may be complicated

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Unit 8 - Topologies & Architectures

SECTION 8.2 – LOGICAL TOPOLOGIES

Logical topology refers to how data is transmitted between nodes of a network; i.e., the way that the signals act on the network media, or the way that the data passes through the network from one device to the next without regard to the physical interconnection of the devices.

The logical topologies are generally determined by network protocols as opposed to being determined by the physical layout of cables, wires, and network devices or by the flow of the electrical signals.

A network's logical topology is not necessarily the same as its physical topology. For example, the original twisted pair Ethernet using repeater hubs was a logical bus topology with a physical star topology layout. Token Ring is a logical ring topology, but is wired a physical star from the Media Access Unit. Therefore, a logical topology may not match the physical topology of a network. Even so, the terms physical and logical topology are often used interchangeably.

Logical topologies are often closely associated with Media Access Control methods and protocols. There are two classifications: (1) Shared Media and (2) Token Based.

Shared Media Logical Topology

In Shared Media, all the systems have the ability to access the physical layout whenever they need it.

- The main advantage in a shared media topology is that the systems have unrestricted access to the physical media.
- The main disadvantage to this topology is collisions. If two systems send information out at the same time, the packets collide and kill both packets.

Ethernet is an example of a shared media topology. To help avoid the collision problem, Ethernet uses a protocol called Carrier Sense Multiple Access/Collision Detection (CSMA/CD). In this protocol, each system monitors the wire, listening for traffic (Carrier Sense). If traffic is detected, the system waits until it hears no traffic before it sends packets out (Collision Detection).

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If a situation occurs where two systems send out packets at the same time and a collision occurs, each system waits for a period of time before it tries to send again. The waiting time period for retry is different for each system to ensure these systems do not collide again on the re-send.

The shared media topology works best on small networks where there is less data traffic to collide. However, as you begin to add more systems to the network, there is a greater opportunity for collisions. To help reduce the number of collisions, many networks are broken up into several smaller networks with the use of switches or hubs, and each network is then referred to as its own collision domain. Shared media networks are typically deployed in a bus, star, or hybrid physical topology.

Token Based logical Topology

The token-based topology works by using a token to provide access to the physical media. In a token-based network, there is a token packet that travels around the network. When a system needs to send out packets, it must take possession of the token off of the wire as it passes. It then attaches the token to the data packets that are sent by the device. When the device ends transmission it returns the token back out on the wire.

As the token travels around the network, each system examines the token. When the packets arrive at the destination (receive) systems, those systems copy the information off of the wire and the token continues its journey until it gets back to the sender. When the sender receives the token back, it pulls the token off of the wire and sends out a new empty token to be used by the next machine.

Token-based networks do not have the same collision problems that Ethernet-based networks do because of the need to have possession of the token to communicate. However, one problem that does occur with token-based networks is latency (delay). Because each machine has to wait until it can use the token, there is often a delay in when communications actually occur.

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Token-based networks are typically configured in a physical ring topology because the token needs to be delivered back to the originating machine for it to release. The ring topology best facilitates this requirement.

The most common logical topologies are:

- Carrier Sense Multiple Access with Collision Detection; (CSMA/CD used with Ethernet)
- Token Ring
- Fiber Distributed Data Interface (FDDI fiber LANs)
- Carrier Sense Multiple Access with collision Avoidance (CSMA/CA used with wireless technologies such as WiFi).

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Unit 8 Review Quiz

Circle the correct response for the questions listed below.

1. The data communications term that describes the physical shape or arrangement of a network in terms of how devices are interconnected is:
 - a. Network Geography
 - b. Network Topology
 - c. Network Alignment
 - d. None of the above

2. The layout of a network in terms of the hardware, software, connectivity, communications protocols, and mode of transmission used is called:
 - a. Network Architecture
 - b. Network Data Structure
 - c. Network Frame Structure
 - d. None of the above

3. Network topologies are categorized as either:
 - a. Physical or Logical
 - b. Natural or Un-natural
 - c. Secured or Non-Secured
 - d. Distributed or non-distributed

4. Which of the following is NOT one of the arrangements described in question #2 above?
 - a. Remote Area Network
 - b. Local Area Network
 - c. Wide Area Network
 - d. Personal Area Network

-
5. Which of the following is NOT one of the names of the physical arrangements of a digital network?
- a. Bus
 - b. Star
 - c. Ring
 - d. Train
6. The most commonly used arrangement of LANs today is the ____.
- a. Bus
 - b. Star
 - c. Ring
 - d. Train
7. The hybrid topology that uses the physical layout of a star, in conjunction with the token-passing data transmission method where data is sent around the star in a circular pattern, is called:
- a. Star Wired Bus
 - b. Logical Mesh
 - c. Star Ring Mesh
 - d. Star-Wired Ring
8. A network's logical topology is ALWAYS the same as its physical topology.
- a. True
 - b. False

9. The shared media topology used by Ethernet LANs is:

- a. Carrier Sense Multiple Access with Collision Avoidance
- b. Carrier Sense Multiple Access with Collision Detection
- c. Token Sharing Multiple Access
- d. Ethershare

10. The shared media topology used by Wireless WiFi is:

- a. Carrier Sense Multiple Access with Collision Avoidance
- b. Carrier Sense Multiple Access with Collision Detection
- c. Token Sharing Multiple Access
- d. Ethershare

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UNIT 9 – ERROR CONTROL METHODS

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Unit 9 – Error Control Methods

INTRODUCTION

A communications network is responsible for transmission of data from one network device to another network device. The end to end transfer of data from a transmitting application to a receiving application involves many steps; each subject to error.

OVERVIEW

Data can be corrupted during transmission. With error control we can be confident that the transmitted and received data are identical. For reliable communication, errors in the data must be detected and corrected.

Error control is the process of detecting and correcting both the bit level and packet level errors. We will look at the concepts of error detection and correction and what these provide in the success of different types of information transmission.

UNIT 9 OBJECTIVES

Upon completion of this unit, you will be able to:

- Define the terms "Error Control", Error Detection" and "Error Correction"
- List and describe the various typical causes of communications errors
- Describe the common error detection methods in use
- Explain the B8ZS Pattern in the T-1 System and how it is used
- Define Checksum CRC and its role in Ethernet
- Compare Connectionless vs. Connection Oriented Service relative to reliable and unreliable service guarantee and "real-time" data
- Define and explain the CRC and ARQ

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Unit 9 – Error Control Methods

SECTION 9.1 – ERROR CONTROL & DETECTION

The concept of Error Checking gets into the realm of Error Control Techniques. Error Control techniques enable reliable delivery of digital data over unreliable communication channels.

Many communication channels are subject to channel noise, and thus they create errors in the data during transmission from the source to the receiver. Error detection techniques allow detecting such errors, while error correction enables reconstruction of the original data.

The general definitions of the terms are as follows:

- *Error detection* is the detection of errors caused by noise or other impairments during transmission from the transmitter to the receiver
- *Error correction* is the detection of errors and reconstruction of the original, error-free data

CAUSES OF ERRORS

Errors in a digital communication are typically due to one or more of the following:

- **White Noise** - a type of noise that is produced by combining sounds of all different frequencies together. If you took all of the imaginable tones that a human can hear and combined them together, you would have white noise
- **Impulse Noise** - unwanted, almost instantaneous, and impulse-like sharp sounds (like clicks and pops). Noises of the kind are usually caused by electromagnetic interference
- **Crosstalk** - any phenomenon by which a signal transmitted on one circuit or channel of a transmission system creates an undesired effect in another circuit or channel. Crosstalk is usually caused by undesired capacitive, inductive, or conductive coupling from one circuit, part of a circuit, or channel, to another.

Unit 9 – Error Control Methods

- **Echo** - Echo in telephony voice system is caused by two main phenomena: (1) electrical echo due to imperfect impedance matching and, (2) acoustic echo due to microphone pickup of audio output. Both these sources produce similar effects and have to be treated similarly
- **Jitter** - the deviation in or displacement of some aspect of the pulses in a high-frequency digital signal; i.e.; "shaky pulses". Jitter is typically caused by electromagnetic interference (EMI) and crosstalk with other signals. Jitter can cause a display monitor to flicker; affect the ability of the processor in a personal computer to perform as intended; introduce clicks or other undesired effects in audio signals, and loss of transmitted data between network devices. The amount of allowable jitter depends greatly on the application.
- **Delay Distortion** - occurs when signal velocity and frequency vary. This means that all signals do not arrive at the same time, resulting in distortion of the signal. This type of distortion is common in fiber optics.
- **Attenuation** - occurs when signal velocity and frequency vary. This means that all signals do not arrive at the same time, resulting in distortion of the signal. This term is commonly used in fiber optics.

ERROR DETECTION

Parity Bit Checking

Probably the oldest and best known method for error detection is Parity Bit Checking. In digital data communications, parity checking refers to the use of *parity bits* to check that data has been transmitted accurately. The parity bit is an additional bit position taken from each byte of transmitted data, and then added back as a zero or a one to every data unit (typically seven or eight bits) that is transmitted. The parity bit for each unit is set so that all bytes have either an odd number or an even number of 1 bits.

Unit 9 – Error Control Methods

For example, let's assume that two devices negotiate to communicate using 8-bit even parity (the most common form of parity checking). As the transmitting device transmits the data, it counts the number of binary 1 bits in each byte of data bits. If the count of binary 1 bits is an even number, it sets the parity bit to a binary 0. If the count of binary 1 bits in the data byte is an odd number, it sets the parity bit to a binary 1 value. In this way, every byte of data transmitted contains an even number of 1 bits.

Having negotiated to communicate with even parity, the receiving end device checks each received byte of data and also counts the number of binary 1 bits. If it finds an odd count of 1 bits, the receiver will assume there was an error during transmission and a binary 1 bit (voltage pulse) got distorted or lost. This means the information represented by the data is corrupted.

Recall that in the ASCII coding scheme every byte of data represented a unique character, and which character was dependent on the position and number of the binary 0's and 1's. So loss of even a single binary 1 bit in a data byte means a character was changed. What was transmitted as an uppercase letter C may be received as the uppercase letter A due to loss of a voltage pulse on the wire.

The same process occurs with 'odd' parity, except the transmit and receive computers expect to find an odd number of 1's in every byte of data transmitted. In the case of an even number of binary 1's in the data, the parity bit is set to a binary 1 value to make it an odd count. The receive computer understands that one bit position of every byte is a parity bit position and does not count this bit as part of the information data that is transmitted.

During every connection process of two computers or systems, and prior to any exchange of data, a "handshake" process is performed. During this 'handshake' the computers determine if even parity, odd parity or some other error detection process will be implemented. If the two sides are not configured with the same *parity sense*, communication will not be possible.

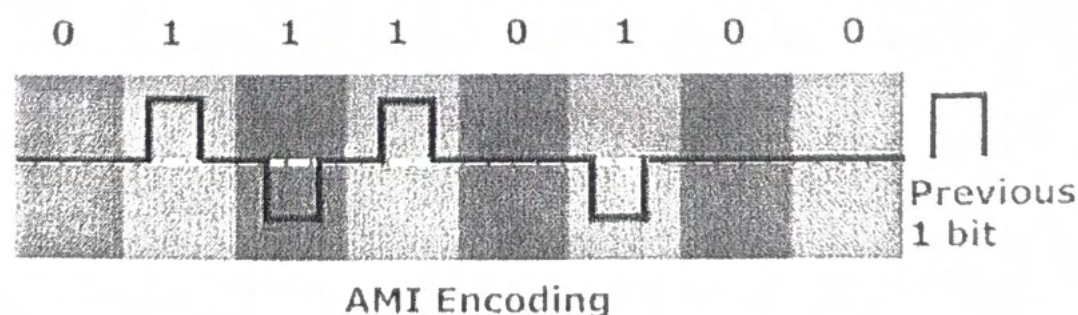
Unit 9 – Error Control Methods

Parity checking is the most basic form of error detection in communications, but it is not foolproof and not totally efficient. This is because it cannot detect situations in which an even number of bits in the same data unit are changed due to electrical noise. For example, if we use even parity and we lose two binary 1's of the data, the remaining count of binary 1's in the data will still be an error and parity checking cannot identify an error. Also, since we lose 1 bit position of every byte as a parity bit, we lose 1-out-of-8 bits of transmission bandwidth capacity. In a T-1 for example, this means that instead of 64kbps per channel, we would lose 1 bit from every sample to allow only 56kbps of bandwidth capacity. For this reason there are many other more sophisticated protocols available for ensuring transmission accuracy.

Parity checking is used not only in communications but also to test memory storage devices. Many PCs, for example, perform a parity check on memory every time a byte of data is read.

T-1 Binary 8, Zero Substitution (B8ZS)

In our review of the 8-bit T-1 Pulse Code Modulation (PCM) process, we stated that where there is no conversation on a T-1 channel, all zeros are inserted into the frame sample position in the form of a unique sequence of binary ones and zeros. The receiving system recognizes this unique code as all zeros and not conversation, and ignores the data bits in the code assuming no conversation on that channel. We also noted that the T-1 normally uses the AMI signaling format where every 1 bit of data produces a voltage pulse of opposite polarity from the previous binary 1 voltage pulse. AMI is represented in figure 9.1.



AMI Encoding

Figure 9.1

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With B8ZS, a sequence of eight consecutive zeroes, inserted into a sample byte position due to no conversation on a given channel, is replaced with the special bit pattern: 00011011. Note that this pattern contains two pairs of consecutive binary 1 bits. Each T-1 system recognizes this pattern as representing all zeros data, and it pulses the two pairs of binary 1 bits with the same polarity. To prevent this pattern from being confused with actual data, it is always the fourth and seventh bits are pulsed with same polarity and we call this a "bipolar violation". This is not an event that should normally occur on a T-1, and it renders the 8-bit pattern unique and recognizable by the repeaters and receiver in the T-1 span. The repeaters preserve the pattern, and the receiver replaces the pattern with the original eight zeroes.

The substitution of a B8ZS code can occur anywhere in the bit stream. It is performed by the transmitting hardware when data is sent out, and reversed by the receive system hardware as the data is received. Therefore, it is invisible to the equipment that examines the framing bit and handles the information data payload.

B8ZS, therefore, is a form of error detection technology for bipolar violations in an 8-bit PCM system, but it also serves as a timing mechanism since the 1 bits in the B8ZS pattern help keep timing in place when it substitutes for all zeros where there are no 1 bits for timing. Note, however, that it is only used for error detection; not for error correction.

The graphics in Figure 9.2, show the B8ZS Substitution pattern and how this pattern is substituted into a pattern of excessive zeros.

Unit 9 – Error Control Methods

Bipolar 8 - Zero Substitution

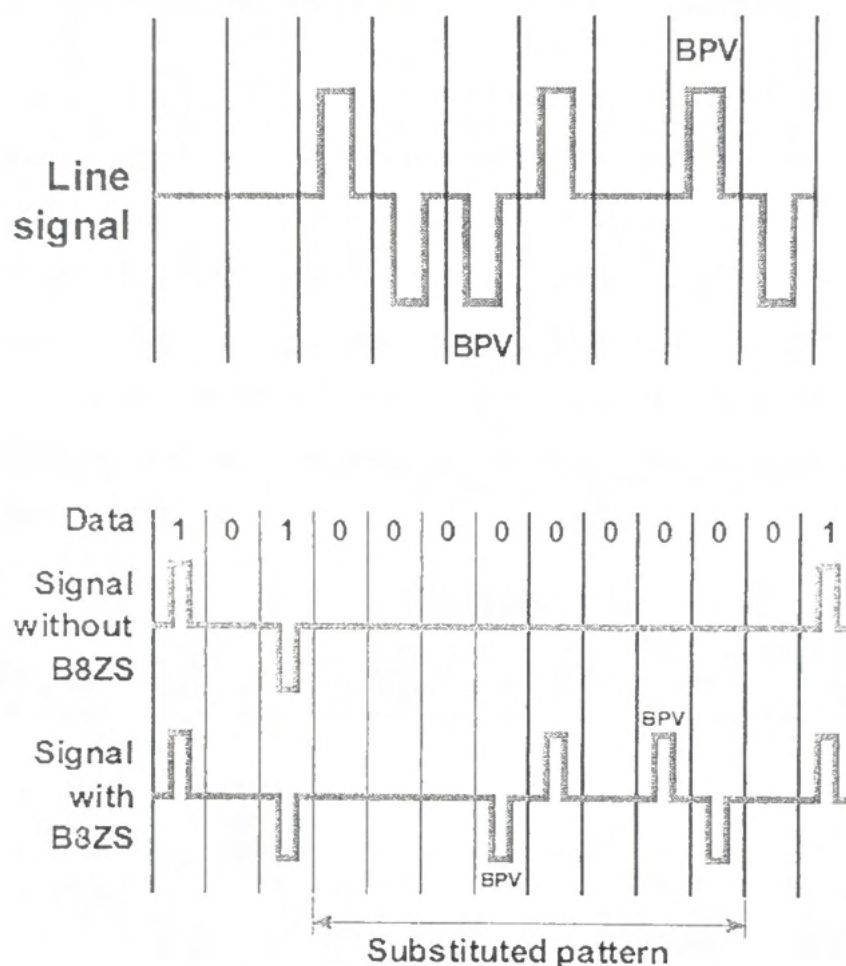


Figure 9.2

Checksums

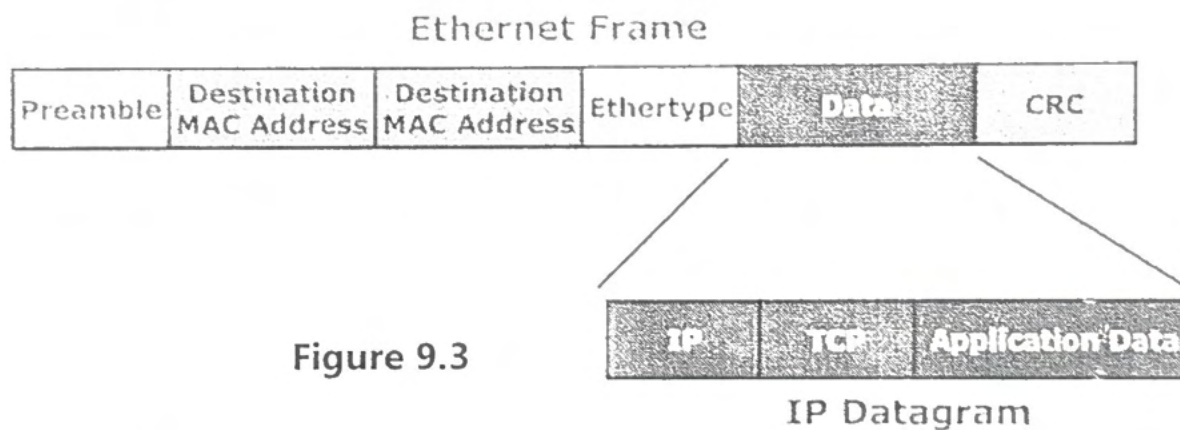
Another simple error-detection scheme that is based on the number of binary 1 bits in the message is called 'Checksum'. Checksum is a scheme in which each transmitted message is accompanied by a numerical value that is determined by an arithmetic algorithm (formula). This value is placed within the frame of a sent message, such as an Ethernet frame. The receiving station then applies the same formula to the received message and checks to make sure the numerical value it calculates is the same as the value calculated by the transmitting end found within the data frame. If the two values do not match, the receiver can assume that the received message has been corrupted.

The value calculated by the checksum process is called a *Cyclic Redundancy Check* (CRC) value. This is an error-detecting code commonly used in digital networks and storage devices to detect accidental changes to raw data.

Unit 9 – Error Control Methods

CRCs are popular because they are simple to implement in binary hardware, easy to analyze mathematically, and particularly good at detecting common errors caused by noise in transmission channels.

Below, figure 9.3, is a simplified view of an Ethernet Frame. In an Ethernet Frame, the CRC value is placed at the end of the frame. Note the Data portion of the Ethernet frame contains the actual data "Packet" that is comprised of the IP and TCP information for the network transport, attached to the actual user data that is being transported. This is the "Packet" that we refer to in Packet Switching systems; where other "headers" are attached and stripped off at each transmitting and receiving network node, and Checksum error detection is performed.



Repetition codes

A *repetition code* is a coding scheme that repeats the bits across a channel to achieve error-free communication. Given a stream of data to be transmitted, the data is divided into blocks of bits. Each block is transmitted some predetermined number of times. For example, to send the bit pattern "1011", the four-bit block can be repeated three times, thus producing "1011 1011 1011". However, if this twelve-bit pattern was received as "1010 1011 1011" – where the first block is unlike the other two – it can be determined that an error has occurred.

Repetition codes are very inefficient, and can be susceptible to problems if the error occurs in exactly the same place for each group (e.g., "1010 1010 1010" in the previous example would be detected as correct). The advantage of repetition codes is that they are extremely simple.

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Unit 9 – Error Control Methods

SECTION 9.2 – ERROR CORRECTION

A basic premise relating to error correction is that it cannot be performed on data that is called "Real-Time" data. The reason for this is that in data communications, real-time data such as voice and video must, inherently, have low latency (delay).

Recall, for example, our review of the T-1 system where every T-1 frame is comprised of a sample from each of 24 channels. This is done to allow immediate transport of voice conversation that is continuous and ongoing. If we delay a conversations transport, the callers continue to talk. This can create a huge problem. The same is true for live video feeds where the action continues and can't be delayed.

Therefore, real time systems must guarantee the delivery and response time; where non-real-time systems make no such guarantee. Non Real-time data such as text messages, email, and file transfers, conversely, guarantee the delivery will be intact and without errors. The concern with non-real time data is not delay, but accuracy. If it takes a few seconds longer to deliver an email, this is not a concern. The concern is ensuring every character and word of the email text is accurate.

Unit 9 – Error Control Methods

The question of real-time vs. non real-time plays a huge role in error correction processes because the process of correcting errors requires re-transmission of data frames and data packets. This takes time, and taking this time to correct errors involves delay of subsequent data.

Connectionless vs. Connection Oriented Service

The question of latency with real-time vs. non real-time data has led to the definition of two types of communications services: (1) Connectionless and (2) connection oriented.

Connectionless service provides best-effort delivery, which means that no guarantee exists that data will not be lost, corrupted, mis-ordered, or duplicated. This means lost or corrupted data is discarded and there is no mechanism for re-sending (re-transmitting) of lost or corrupted data. It is considered an "unreliable" service.

Connection-Oriented service does provide a mechanism for requesting a specific quality of service (QoS) that includes the resending of corrupted and discarded packets. Re-sending of corrupted data causes delay, but ensures accuracy. Therefore, Connection-Oriented service is considered "reliable" service.

During the transport of data, packet network elements rely on the TCP/IP Protocols to determine if data is real-time or non realtime, and from this assigns priority to the data as it transverses the networks. In the case of real-time data, the data is designated as UDP packets that are given higher priority and that do not generate Automatic Repeat Requests (ARQ). When a UDP packet is detected as containing an error, the network elements will discard the packet and proceed as normal with continuing packets. This might mean a very short audible "click" or "pop" in the audio of a voice conversation. In the case of digital video, missing packets may result in empty pixels seen on the video screen for a very short time, but generally do not affect the ongoing video. Depending on how often errors occur normally doesn't affect the quality of the conversation or the video presentation.

Unit 9 – Error Control Methods

In the case of non real-time data, the data packets are designated as TCP packets and given lower priority than UDP packets. TCP packets can afford delay, but cannot risk accuracy. Therefore, TCP packets that are detected to contain errors will generate an ARQ (automatic request to resend). The transmission will cease, the receiving network node will send back an ARQ to the transmitting node to re-send the corrupted packets, and the corrupted packets will be discarded. This incurs delay, but ensures accuracy.

Error Correcting Codes (ECC)

Some network systems make use of Error-Correcting Code (ECC) or Forward Error Correction (FEC) code. ECC/FEC is a system of adding redundant data, or *parity data*, to a message, such that it can be recovered by a receiver even when a number of errors (up to the capability of the code being used) are introduced, either during the process of transmission, or in the process of storing data.

With ECC/FEC, ARQs are not used, and since the receiver does not have to ask the sender for retransmission of the data, a back-channel is not required in forward error correction, and it is therefore suitable for simplex communication such as broadcasting. Error-correcting codes are often used in lower-layer communications, as well as for reliable storage in media such as CDs, DVDs, hard disks, and RAM.

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Unit 9 – Error Control Methods



Unit 9 Review Quiz

Circle the correct response for the questions listed below.

1. Error Control includes the two process: (**Choose 2**)
 - a. Error Reduction
 - b. Error Summation
 - c. Error Detection
 - d. Error Correction
2. The oldest of the error detection methods is probably:
 - a. ASCII
 - b. Parity bit checking
 - c. B8ZS
 - d. CRC Checksum
3. Parity Checking can involve either positive or negative parity.
 - a. True
 - b. False
4. T-1 signaling format is AMI; where T-1 the PCM process makes use of a unique 8-bit code to represent all zero data, and which contains 2 intentional bipolar violations. This process is called ____; where all other bipolar violations are considered errors in the data due to violation of AMI.
 - a. PCM
 - b. B8ZS
 - c. ASCII
 - d. None of the above

Unit 9 – Error Control Methods

5. Checksum is:

- a. An error detection scheme based on the number of binary zeros in the data.
- b. Another name for Parity bit checking
- c. Another name for B8ZS
- d. An error detection scheme based on the number of binary ones in the data.

6. The value calculated by the 'Checksum' process is called:

- a. Cyclic Redundancy Check Value
- b. Binary 8 count Value
- c. Data Interchange Value
- d. Error Sum value

7. A coding scheme that repeats the bits across a channel is called:

- a. ASCII Code
- b. Repetition Code
- c. Morse Code
- d. Duplicity code

8. The term '*Latency*' means:

- a. Delay
- b. Distortion
- c. Conversion
- d. Error Detection

9. Latency is more critical to real-time data vs. non real-time data.

- a. True
- b. False

Unit 9 – Error Control Methods

10. Typically, error correction is NOT performed on Real Time data transmissions.
 - a. True
 - b. False

11. Telecommunications service that is considered un-reliable best-effort; with no guarantee that data will not contain errors is:
 - a. Connectionless Service
 - b. Connection-Oriented Service
 - c. Text Data Service
 - d. None of the Above

12. In the TCP/IP Protocols, a request to re-send a data packet due to lost or corrupted packets is called:
 - a. Automatic Forward Correction
 - b. Error Code Request
 - c. Automatic Request to re-send
 - d. Request to discard and re-send

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UNIT 10 – DIGITAL TRANSPORT SYSTEMS & TRANSMISSION MEDIA

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Unit 10 – Transport Systems & Media

INTRODUCTION

Digital transport systems are systems that transport digital data. Typically, these are backbone or backhaul networks such as the T-1 North American Digital Hierarchy, the Synchronous Optical system (SONET) system, the Internet system of servers, and the Packet data Network that includes technologies such as Asynchronous Transfer Mode (ATM) and Frame Relay.

OVERVIEW

Unit 10 will review the categories and characteristics of Twisted Pair copper, the common types of coaxial cable, and the optical fiber used in digital transport systems to transmit and receive data. The unit also takes a look at the wireless technologies that rely on the airwaves as their transmission media, and includes technology platforms such as Bluetooth, WiFi and Satellite communications and briefly describes the wireless web.

UNIT 10 OBJECTIVES

Upon completion of this unit, you will be able to:

- Identify the transport systems in common use today
- Explain Wired Technologies vs. Wireless Technologies
- Define the term "transmission media"
- Identify and describe the characteristics of twisted pair Cat cables in use today
- Identify the industry standards that apply to the twisted pair Cat cables
- Describe the COAX cable and the applications for the Radio Grades in use today
- Define Radio Grades for COAX and identify the applications for 75 ohm coax
- Describe the major advantages of optical fiber over twisted pair copper
- Identify the industry standard that governs optical fiber
- Define "Wireless LAN"
- Identify the Industry Standards for WiFi wireless LANs

Unit 10 – Transport Systems & Media

UNIT 10 OBJECTIVES (CONT.)

- Describe the operating characteristics of Bluetooth
- Identify the two levels of Bluetooth
- List the types of Satellite Communications
- Explain the bandwidth limitations of satellite communications
- Describe the basic concept of wireless web

Unit 10 – Transport Systems & Media

SECTION 10.1 – WIRED TECHNOLOGY MEDIA

The term transmission medium refers to a physical technical device that employs the material substance that allows us to transmit or guide energy waves. Thus, an optical fiber or a copper cable is a transmission medium.

Transmission media are generally categorized as supporting two types of transport systems and their connectivity: (1) Wired Technologies and (2) Wireless Technologies.

- **Twisted Pair Copper** – Twisted pair copper is still the most widely used medium for telecommunications, but this is rapidly changing as more fiber is being installed. Twisted-pair are ordinary telephone wires that consist of two insulated copper wires twisted into pairs. These wire pairs are used for both voice and data transmission. The use of two wires, as twisted pairs, together helps to reduce crosstalk since twisted pair wire is susceptible to electromagnetic induction (noise). The transmission speed capacity of twisted pair wire ranges from 2 million bits per second to 100 million bits per second (2Mbps to 100Mbps). Twisted pair falls under TIA/EIA-568-C. 568C defines the structured cabling standards that will enable the design and implementation of structured cabling systems for commercial buildings, and between buildings in campus environments. Twisted pairs are classified in Categories from Cat 1 to Cat 7, but available today only in Cat 3 through Cat 6.

Unit 10 – Transport Systems & Media

TIA/EIA-568-B.1-2001 is the definition of wire color code and pin/pair assignments for eight-conductor 100-ohm balanced twisted-pair cabling, such as Category 5, Category 5E and Category 6 unshielded twisted-pair (UTP) cables. These standards for home telecommunications installations are named T568A and T568B and they define the pinout, or order of connections, for wires in 8P8C (typically referred to as RJ45) eight-pin modular connector plugs and sockets. Cat 5E and Cat 6 are the most used today in new network installations. Figure 10.1 shows the two color code standards; albeit in grey scale. Color versions of this color code are widely available via Internet search.

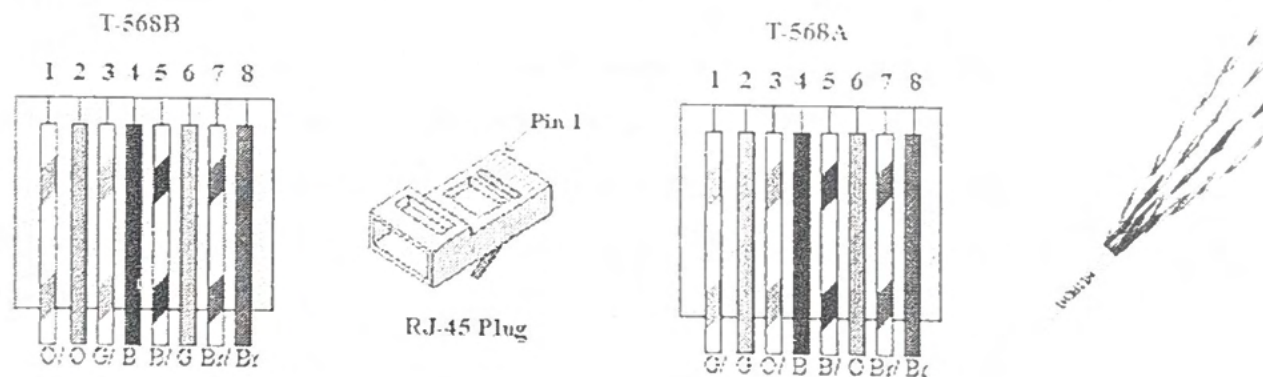


Figure 10.1 – 568A/B and Cat 5E Cable

Unit 10 – Transport Systems & Media

- **Coax Cable** – Coax cables were initially used for LAN connectivity using Bus Topology, then adopted for cable T.V. video systems. Today they find little application for Local Area Network applications, but still used in some CATV applications. Optical fiber is fast replacing coax in most applications.

The term *coaxial* comes from the inner conductor and the outer shield of a cable sharing a geometric axis. Coax cables consist of a copper or aluminum wire wrapped with an insulation layer and surrounded by a conductive layer of metal mesh. The layers of insulation help minimize interference and distortion from external electromagnetic signals. Transmission speed capacity of coax cable ranges from 200Mbps to 500Mbps.

Typically with impedances of 50 or 75 Ohms, coax cables have different outside diameters and maximum capacities for operating voltage. Cables are also rated for signal loss (attenuation in dBs per 100 feet). Coaxial cable types are designated with an RG (radio grade) prefix such as RG-6. Table 10.1 below shows the most common coaxial cables; there are many more types in use.

Cable Type	Impedance Range in Ohms	Core Diameter (mm)	Layers in the Sheath	Typical Application
RG-6	75-76	1.0	2	Cable T.V., Satellite
RG-6 Quad	75-76	1.0	4	Cable T.V., Satellite
RG-58	50-53.5	.9	1	T.V., thin Ethernet
RG-59	73-75	.81	1	TV, Cable, S/PDIF*
RG-59 Quad	73-75	.81	4	TV, Cable, S/PDIF*

* S/PDIF – a proprietary serial interface for transferring digital audio from CD and DVD players to amplifiers and TVs

Table 10.1

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Figure 10.2 below shows the design of a typical Coax Cable.

Coaxial Cable Construction

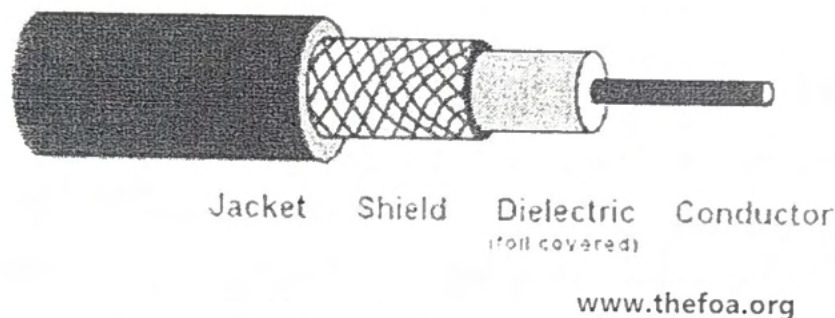


Figure 10.2 – Coax Cable Construction

- **Fiber Optics** - one or more thin filaments of optical glass fiber protected by a protective layer of acrylic coating and/or Teflon buffer. Optical fibers transmit information in the form of light pulses that represent the binary ones and zeros of digital data. These light pulses can travel over long distances and provide digital bandwidths in the Gbps and Tbps ranges; speeds that are hundreds of times faster than coaxial cable and thousands of times faster than twisted-pair copper wire.

Fiber-optic cables are not affected by electromagnetic radiation so they are not susceptible to electro-magnetic interferences, and they offer high security from interception.

Fiber Optics falls under a separate section of TIA/EIA-568-C: -568-C.3. An optical fiber aerial cable is shown below in figure 10.3.

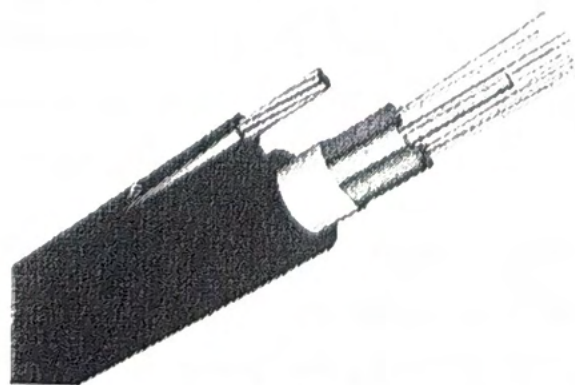


Figure 10.3 – Optical Fiber Outside Plant Aerial Cable

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SECTION 10.2 – WIRELESS TECHNOLOGIES

When we say Wireless Network, we are generally referring to the airways as the physical transmission media. Wireless means transmitting information signals over invisible radio frequency waves, microwaves and infra-red waves instead of wires or glass fibers. The wireless technologies include:

- **Wireless LANs** – A wireless LAN (or WLAN, for Wireless Local Area Network), is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection. The IEEE 802.11 group of standards specify the technologies for wireless LANs. The 802.11 standards use the Ethernet protocol for all LAN applications with the difference that WLAN doesn't rely on wired connections as compared to "Wired LAN". An example of open-standard wireless radio-wave technology are the widely used IEEE 802.11g, IEEE 802.11N, and 802.11ac standards.

Wireless local area networks use both high and low radio frequencies, with a Spread Spectrum technology, to enable communication between multiple devices in a limited area. Spread-spectrum is a "frequency-hopping" technology that is commonly used where the transmitter frequency changes abruptly many times each second.

A WLAN can be either an extension to a wired network or an alternative to a wired network. WLANs add flexibility to networking since a WLAN allows users to move around while keeping their computers connected.

WLANs have data transfer speeds ranging from 1 to 54Mbps, with some manufacturers offering proprietary 108Mbps solutions. For example, the 802.11n standard can reach 300 to 600Mbps. As for range, a WLAN access point provides access within a radius of about 65 to 300 feet; i.e., a small office to a large campus environment.

However, because the wireless signal is broadcast so everybody nearby can share it, security can be an issue with WLAN. In most cases security precautions are necessary with WLANs to ensure only authorized users can access your WLAN.

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- **Bluetooth** - A short range wireless and automatic technology. Bluetooth takes small-area networking to the next level by removing the need for user intervention and keeping transmission power extremely low to save battery power.

Bluetooth is essentially a networking standard that works at two levels:

- It provides agreement at the **physical** level -- Bluetooth is a radio-frequency standard.
- It provides agreement at the **protocol** level, where products have to agree on when bits are sent, how many will be sent at a time, and how the parties in a conversation can be sure that the message received is the same as the message sent.

Bluetooth Operates at approximately 1Mbps to a maximum distance of about 10 meters or 32 feet. Low power of about 1 milliwatt is the primary way Bluetooth devices avoid interfering with other systems. By comparison, the most powerful cell phones can transmit a signal of about 3 watts. This low power limits the range of a Bluetooth and, therefore, reduces the chance of interference between your computer system and your portable telephone or television.

Another advantage of this is that even with the low power, Bluetooth doesn't require line of sight between communicating devices. The walls in your house won't stop a Bluetooth signal, making the standard useful for controlling several devices in different rooms. It is an open wireless protocol intended for data exchange over short distances. A Bluetooth Personal Access Network (PAN) might look like the one in figure 10.4.

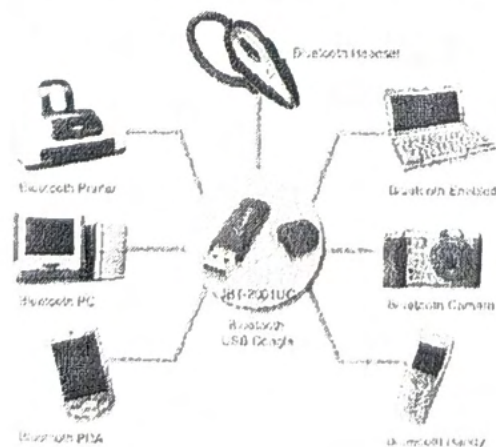


Figure 10.4

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- **Terrestrial Microwave** – use earth-based transmitters and receivers that look similar to satellite dishes. Terrestrial microwaves use low-gigahertz range frequencies which limit all communications to line-of-sight. You probably have seen terrestrial microwave transmitting and receiving antennas in the form of telephone relay towers, which are placed about 30 miles apart to relay telephone signals across the country. These antennas are usually placed on top of buildings, towers, hills, and mountain peaks.

Some LANs operate at microwave frequencies at low power and use non-directional transmitters and receivers. Network hubs can be placed strategically throughout an organization, and workstations can be mobile or fixed. This approach is one way to enable mobile workstations in an office setting.

In many cases, terrestrial microwave makes use of licensed frequencies. In these cases a license for use must be obtained from the FCC, and equipment must be installed and maintained by licensed technicians.

Microwave system data rate capacities can be very high, but most data communication microwave systems operate at data rates between 1 and 10 Mbps operating in the low-gigahertz range (4-6 GHz and 21-23 GHz). Under normal operating conditions properly designed systems are not overly affected by attenuation. Attenuation characteristics that are present are determined by transmitter power, frequency, and antenna size. Environmental conditions of rain and fog, however, can cause increased attenuation of higher frequencies and susceptibility to electromagnetic interference. Microwave signals are also more vulnerable to electronic eavesdropping. For this reason, signal encryption is frequently used in microwave transmissions. Terrestrial microwave might look as shown in figure 10.5.

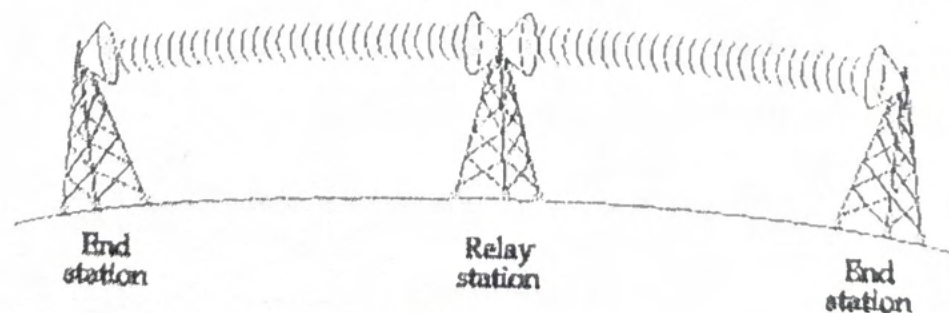


Figure 10.5

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- **Communication Satellites** - satellites use microwave radio as their telecommunications medium which are not deflected by the Earth's atmosphere. The first communications satellites were stationed in space in a geosynchronous (also called geostationary) orbit about 22,000 miles above the equator. Geostationary (or 'Geo') means that the satellite orbits the earth at the same speed that the earth turns, so the satellite is always over the same point on the earth. These Earth-orbiting systems are capable of receiving and relaying voice, data, and TV signals.

In today's world, modern communications satellites use a variety of orbits besides geostationary orbits including Medium Earth Orbit (or 'MEO') where navigational satellites (e.g., GPS) orbit between Low Earth Orbit and Geosynchronous Earth Orbit (1243 miles to 22,236 miles), other elliptical orbits and low (polar and non-polar) earth orbits, (or 'Leo') where satellites orbit between 100 and 1240 miles above the earth. This is usually where space shuttles and Space Stations orbit. There is also a 'Highly Elliptical' orbit called Molniya Orbit that the Russians have been using for their communications satellites since the 1960s.

Broadcasts from a satellite in geostationary orbit can cover only about one third of the Earth's surface. Therefore, in order to send signals anywhere in the world, three communications satellites in geostationary orbit are needed.

Two popular modern applications that use geostationary satellite orbit are Satellite Internet and Satellite TV. Satellite Internet has a high latency problem caused by the signal having to travel 35,000 km (22,000 miles) out into space to the satellite and back to Earth again. The signal delay can be as much as 500 milliseconds to 900 milliseconds, which makes this service unsuitable for applications requiring real-time user input such as voice and live video. TV satellites improve on this with use of high data compression, but they still rely on line-of-sight connections that all other satellites require.

Geo, MEO and LEO orbits are shown in figure 10.6.

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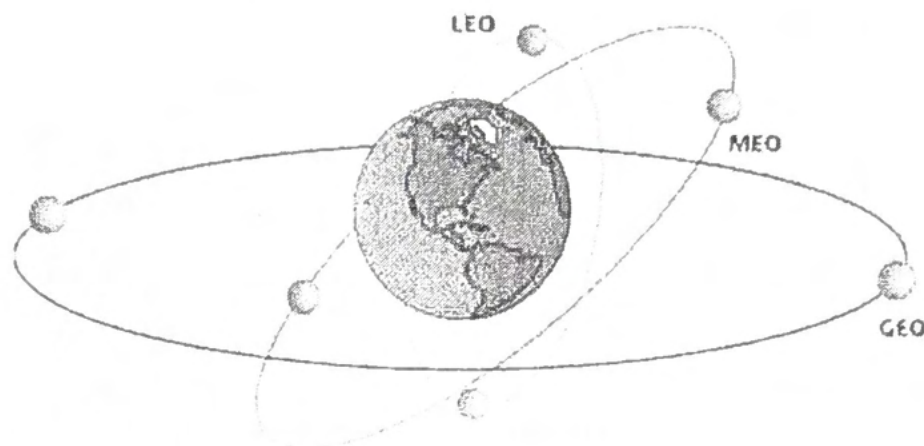


Figure 10.6

- **The Wireless Web** - refers to the use of the Internet's World Wide Web through mobile devices such as cellular phones, pagers, PDAs, and other portable communications devices.

Wireless Web connection provides anytime/anywhere connection to e-mail, mobile banking, instant messaging, weather and travel information, and other services. In general, sites aiming to accommodate wireless users must provide services in a format displayable on typically small wireless devices.

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Unit 10 Review Quiz

Circle the correct response for the questions listed below.

1. A physical technical device that employs the material substance that allows us to transmit or guide energy waves is called:
 - a. Packet
 - b. Transmission Medium
 - c. Vacuum Tube
 - d. A software application

2. Transmission media are always "wired" technologies; wireless does not make use of transmission media.
 - a. True
 - b. False

3. Twisted pair makes use of 2 wires in order to reduce:
 - a. Latency
 - b. Errors
 - c. Crosstalk
 - d. Loss

4. The most used category twisted pair in new installations today are:
 - a. Cat 5 and Cat 6
 - b. Cat 3 and Cat 5
 - c. Cat 5E and Cat 6
 - d. Cat 6 and Cat 7

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5. The telecommunications structured cabling standards are the 568 Standards of which the latest version is:
 - a. 568A
 - b. 568B
 - c. 568C
 - d. 568D

6. A specific type of twisted pair is UTP; where UTP stands for:
 - a. Unprotected Twisted Pair
 - b. Unshielded Twisted Pair
 - c. Unshielded Twin Pair
 - d. Universal Twisted Pair

7. The 75-ohm coax cable radio grade used by cable service providers for digital applications such as digital T.V., and Internet is:
 - a. RG-6
 - b. RG-58
 - c. RG-59
 - d. RG-75

8. Optical Fiber is more limited in its bandwidth capacity than coax cable due to the excessive amount of light lost in the fiber during transmission.
 - a. True
 - b. False

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9. Fiber Optic systems are considered digital systems since the pulses of light, and the dark spots absent of light, in a fiber represent binary ones and zeros of digital information.
- a. True
 - b. False
10. Which of the following is not a commonly used wireless platform?
- a. WLAN
 - b. Bluetooth
 - c. WiFi
 - d. fiberless fiber
11. A common Spread-Spectrum technology used by wireless digital devices is:
- a. Frequency hopping
 - b. ASK
 - c. PSK
 - d. CDMA/CD
12. Bluetooth operates at both a Physical level and at a Protocol level (software); where the protocol level deals with negotiation as to when and how many bits will be sent.
- a. True
 - b. False

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13. Bluetooth operates at a data rate of ____ and a maximum distance of about ____ ft.
- a. 64kbps, 10
 - b. 100Mbps, 12
 - c. 1Mbps, 32
 - d. 10Mbps, 200
14. Bluetooth technology avoids interference with other devices by limiting its range. This is accomplished through ____ power output from Bluetooth devices of about ____.
- a. high, 100W
 - b. high, 25W
 - c. low, 10mW
 - d. low, 1mW
15. Which of the following is NOT one of the common WiFi standards in use today?
- a. 802.11g
 - b. 802.11n
 - c. 802.11q
 - d. 802.11ac
16. The use of earth-based transmitters and receivers that look similar to satellite dishes, that operate in the low-gigahertz range frequencies and which limit all communications to line-of-sight, is called:
- a. Earth-based Satellite technology
 - b. Radio Frequency WAN technology
 - c. Terrestrial Microwave technology
 - d. Wi-Fi Technology

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17. Most data communication microwave systems operate at data rates between:
- a. 100Gbps – 150Gbps
 - b. 1Mbps- 100Mbps
 - c. 1Mbps – 10Mbps
 - d. 1Gbps – 10Gbps
18. Satellites that orbit the earth at a distance and location of 22,000 miles above the equator, so that the satellite is always positioned at the same speed that the earth turns and always over the same point on the earth over the equator, are called:
- a. Middle Earth Orbit Satellites
 - b. Geostationary Satellites
 - c. Low Earth-Orbiting Satellites
 - d. Equatorial Satellites
19. Satellites that orbit as described above in question #17, can cover only about one third of the Earth's surface. Therefore, in order to send signals anywhere in the world, a minimum of ____ communications satellites in this orbit are needed.
- a. 1
 - b. 3
 - c. 6
 - d. 8
20. One of the limitations of satellite communications is latency.
- a. True
 - b. False

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Appendices

APENDICES A, B, & C

Appendices

Appendix A

Powers of 10 – Greek Prefixes*

Exponent	Name	Greek Prefix	Symbol	Floating Decimal Number
10^{18}	Quintillion	Exa-	E	1,000,000,000,000,000,000
10^{15}	Quadrillion	Peta-	P	1,000,000,000,000,000
10^{12}	Trillion	Tera-	T	1,000,000,000,000
10^9	Billion	Giga-	G	1,000,000,000
10^6	Million	Mega-	M	1,000,000
10^3	Thousand	Kilo-	K	1,000
10^2	Hundred	Hecto-	H	100
10^1	Ten	Deca-	D	10
10^{-1}	One Tenth	Deci-	d	.1
10^{-2}	One Hundredth	Centi-	c	.01
10^{-3}	One Thousandth	Milli-	m	.001
10^{-6}	One Millionth	Micro-	μ	.000001
10^{-9}	One Billionth	Nano-	n	.000000001
10^{-12}	One Trillionth	Pico-	p	.000000000001
10^{-15}	One Quadrillionth	Femto-	f	.000000000000001
10^{-18}	One Quintillionth	Atto-	a	.000000000000000001

* **Note:** The above prefixes in bold text are those most commonly used in the electrical field.

Appendices

Appendix B – other Common Electrical Symbols

 Resistor

 Fuse

 Variable Resistor

 Circuit Breaker

 Battery

 Inductor Coil

 Capacitor

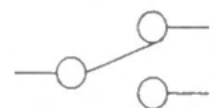
 Transformer

 Electrolytic Capacitor

 Transformer with core

 Switch

 Lamp

 Toggle Switch

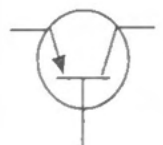
 Motor

 Junction Diode

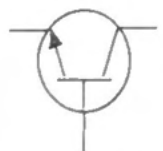
 Alternating Current Power Source

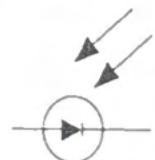
 Light Emitting Diode

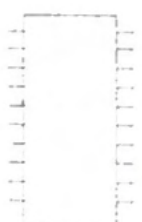
 A.C. Power Source or Signal Oscillator

 PNP Transistor

 Zener Diode

 NPN Transistor

 Photo-cell Diode

 Integrated Circuit (IC Chip)

 Ground

Appendices

APPENDIX C - GLOSSARY

A

A/D - Analog to Digital (converter). A device that converts an analog signal to a digital value. **ALTERNATOR** - An electromechanical device that converts mechanical energy to electrical energy in the form of alternating current.

AMERICAN WIRE GAUGE (AWG) - A common method of specifying wire size. The larger the AWG number, the smaller the wire diameter.

AMMETER - A meter designed to measure current.

AMPACITY - ampere capacity; the maximum amount of electrical current a conductor or device can carry before sustaining immediate or progressive deterioration. Also described as current rating or current-carrying capacity,

AMPERE, AMP - The basic unit for current. The ampere, also called an amp. The symbol for ampere is "A."

AMPERE-HOUR (AMP-HOUR) - The use of one amp of current for one hour

ANALOG - A continuously varying action or movement that takes time to change from one position to another. Standard audio and video signals are analog. An analog signal has an infinite number of levels between its highest and lowest value (unlike digital, in which changes are in steps).

ANODE - the positive charged side of a component; e.g., the anode of a battery

ASCII - American Standard Code for Information Interchange. The standard code consisting of 7-bit coded characters (8 bits including parity check) used to exchange information between data processing systems, data communication systems, and associated equipment. The ASCII set contains control characters and graphic characters.

Appendices

ASYNCHRONOUS - Intermittent, not synchronized or continuous. A conversational type of communication that allows the parties at each end to talk when they like instead of at a prescribed time. Used in videoconferencing.

ATTENUATE/ATTENUATION - To reduce the amplitude (strength) or current of a signal.

ATM - Asynchronous Transfer Mode. A standardized digital data transmission technology that is a cell-based switching technique which uses asynchronous time division multiplexing. This is the core protocol used over the SONET/SDH backbone of the ISDN (Integrated Services Digital Network).

B

BACKBONE - The primary transmission network for telecommunications that connects between key locations and branches off to buildings and other facilities.

BANDWIDTH - The data carrying capacity of a transmission path, measured in Hertz for analog signaling, and measured in bits or bytes per second (data rate) for digital signaling.

BASEBAND - A prime signal such as composite video, component video, and audio with its own path but is not modulated onto a carrier signal or combined with other signals on a path. An unmodulated signal or band of signals. The video signal seen on a waveform monitor is a baseband video signal.

BER - Bit Error Rate. The rate at which bit errors are experienced across a data connection.

BEST EFFORT - Describes a network service in which the network does not provide any guarantees that data is delivered or that a user is given a guaranteed quality of service level or a certain priority.

BINARY - A numbering system using base-2. Each digit is represented by a 1 or a 0 (on or off).

Appendices

BINARY CODE - A coding system using the digits 0 and 1 to represent a letter, numeral, or other character in a computer. For example: the character "A" in ASCII code becomes 0100 0001 in binary.

BIT - The shortened form of "binary digit" (0 or 1). A bit is the smallest unit of information in a computer.

BIT ERROR RATE – BER - The fraction of bits that were transmitted with errors, expressed at the ratio of incorrectly to correctly transmitted bits. BER is used to assess transmission accuracy in a fiber optic system.

BIT RATE - The number of bits that are conveyed or processed per unit of time. The bit rate is quantified using the bits per second (bit/s or bps) unit, often in conjunction with an SI prefix such as kilo- (kbit/s or kbps), mega- (Mbit/s or Mbps), giga- (Gbit/s or Gbps)

BUS - A path for transporting voltages, signals, or a ground between the different sections of an electronic device, such as a data bus between a CPU and memory or a peripheral device. Its width is determined by the number of lines (conductors) that make up the bus, and its speed (data transfer rate) is determined by the circuits that drive the lines.

C

CABLE JACKET - The outer protective covering of wire or fiber optic cable.

CAT 5e - Enhanced Category 5. The standard for the next higher grade of unshielded twisted pair (UTP) beyond Category 5. The CAT 5e specification was developed to provide more robust support for 1000Base-T. CAT 5e specifies tighter limits than CAT 5 for NEXT, ELFEXT, and return loss.

CATHODE – The negative side of a component; e.g., the cathode of a diode

CHARGE - An electrical property of particles, such as electrons and protons, which causes them to attract or repel each other.

Appendices

CIRCUIT (SCHEMATIC) DIAGRAMS - Circuit diagrams show how the elements in an electric circuit are connected. These diagrams are useful for troubleshooting or repairing electric circuits. They are also used to design new circuits.

CLOCK RATE - The rate at which analog audio is sampled and converted to a digital signal. Clock rate is important in digital audio recording and processing systems

CODEC - (1) Coder/decoder. A device that converts analog video and audio signals into a digital format for transmission over telecommunications facilities and also converts received digital signals back into analog format. It may also dial up the connection, like a modem for teleconferencing. (2) Compressor/decompressor. Codecs can be implemented in software, hardware, or a combination of both. Some popular codecs for computer video include MPEG, QuickTime, and Video for Windows.

CRC - Cyclic redundancy check, CRC or polynomial code checksum is a method used to detect changes or errors in raw data, and is commonly used in digital networks, data communications and storage devices.

CSMA/CD - Carrier Sense Multiple Access/Collision Detection. The Media Access Control method applied in Ethernet networks. When a device wants to gain access to the network, it checks to see if the network is quiet (senses the carrier). If it is not, it waits a random amount of time before retrying. If the network is quiet and two devices access the line at exactly the same time, their signals collide. When the collision is detected, they both back off and each waits a random amount of time before retrying.

CYCLE - In Alternating current, the change of the poles from negative to positive and back.

Appendices

D

D/A - Digital to analog.

DAC - Digital to analog converter.

DATA - (1) A representation of facts, concepts, or instructions in a format suitable for communication, interpretation, or processing by human or automated means. (2) Any representations, such as characters or analog quantities, that have meaning.

Data Compression - A mathematical algorithm for compressing or encoding data to fit within given bandwidth requirements for transmission or storage.

Data Link - A fiber optic system comprising the cable, transmitter, and receiver for transmission of data between two locations.

DIGITAL - A system of data or image values in the form of discrete, non-continuous codes, such as binary. When data is in a digital format, it can be processed, stored (recorded), and reproduced easily while maintaining its original integrity.

DIGITAL SIGNAL - An electrical signal which possesses two distinct states (on/off, positive/negative); typically represented by "0" or "1".

DIODE - A two-terminal semiconductor (rectifying) device that allows current flow in one direction, but blocks current flow in the opposite direction. The terminals of a diode are called the anode and cathode.

DSS - Digital Satellite System.

DUPLEX - Data transmission in both directions. Half duplex denotes transmission in one direction at a time, while full duplex refers to simultaneous transmission in both directions. In fiber optics, duplex also refers to a type of cable comprising two fibers for duplex transmission.

Appendices

E

ERROR CORRECTION - A method of detection errors and reconstructing the original information using extra, redundant information sent along with the original data.

ERROR DETECTION AND CORRECTION - The ability to detect errors caused by interference or other factors during the transmission of a signal, and then reconstruct the received signal so that it is a faithful reproduction of the original signal, without errors. A process known as Forward Error Correction is often used to allow the receiver to detect and correct some errors without having to "ask" the transmitter to send additional data.

ETHERNET - A Local Area Network (LAN) standard officially known as IEEE 802.3. Ethernet and other LAN technologies are used for interconnecting computers, printers, workstations, terminals, servers, etc. within the same building or campus. Ethernet operates over twisted pair and over coaxial cable at speeds starting at 10Mbps. For LAN interconnectivity, Ethernet is a physical link and data link protocol reflecting the two lowest layers of the OSI Reference Model.

ETHERNET MAC FRAMES - A digital data transmission unit or data packet that includes frame synchronization information and a data payload. The synchronization data makes it possible for the receiver to detect the beginning and end of the packet in the stream of symbols or bits.

F

FREQUENCY - In ac systems, the rate at which the current changes direction, expressed in hertz (cycles per second); A measure of the number of complete cycles of a wave-form per unit of time; e.g., cycles per second of a sine wave).

Appendices

Frequency Division Multiplexing – FDM - The combining of two or more signals into a single carrier signal for transmission through FM – frequency modulation. Each signal modulates the carrier signal at a different region of the frequency spectrum.

FULL DUPLEX - The ability of a device or line to transmit data simultaneously in both directions.

G

GENERATOR - A device that converts mechanical energy into electrical energy. A generator forces electric current to flow through an external circuit; i.e., it is a voltage source that provides current to an electric load.

GROUND (electrical) - The connecting of electrical equipment and wiring systems to the earth by a wire or other conductor. The primary purpose of grounding is to reduce the risk of serious electric shock from current leaking into un-insulated metal parts of an appliance, power tool, or other electrical device.

H

HANDSHAKE - In communications, the moment when the transmitting and receiving devices identify themselves to each other.

HERTZ - the unit of frequency in the International System of Units (SI). It is defined as the number of cycles per second of a sine wave.

HOP - In a packet-switching network, a hop is the trip a data packet takes from one router or intermediate point to another in the network

HUB - A shared transmission media to which devices on a network are interfaced. Ethernet hubs have mostly given way to Ethernet switches.

Appendices

I

IEEE 802.11 - The Institute for Electrical and Electronics Engineers standard for wireless Ethernet networks. IEEE 802.11 applies to wireless LANs and provides 1 or 2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS)

IEEE 802.11g - Applies to wireless LANs and provides 20+ Mbps in the 2.4 GHz band. This is the most recently approved 802.11 standard and offers wireless transmission over relatively short distances at up to 54 megabits per second (Mbps), compared with the 11 megabits per second of the 802.11b standard. Like 802.11b, 802.11g operates in the 2.4 GHz range.

IEEE 802.11n - Upcoming wireless standard that builds upon 802.11 standards by adding Multiple Input Multiple Output (MIMO) technology. MIMO uses multiple transmitter and receiver antennas to increase the data rate, promising between 100-200 Mbps. 802.11n is expected to be ratified in late 2006 or early 2007

IEEE 802.3 - The Institute for Electrical and Electronics Engineers standard for Ethernet networks.

INTERFACE - (noun) A device or module that operates as a link between dissimilar modules, usually because those modules cannot communicate directly with each other. An interface may act as a translator or interpreter and could be in the form of hardware and/or software. A computer video interface allows computer-video signals to be used by large screen video displays

I/O - Input/Output. Refers to the flow of information or signals (in or out) with respect to a particular device.

IP Address - A numerical label that is assigned to devices in a network, that uses the Internet Protocol. The IP address for the source and destination are included in an IP datagram.

Appendices

J

JOULE –

- The work required to move an electric charge of one coulomb through an electrical potential difference of one volt, or one "coulomb volt" (C·V). This relationship can be used to define the volt.
- The work required to produce one watt of power for one second, or one "watt second" (W·s) (compare kilowatt hour). This relationship can be used to define the watt.

K

KILOWATT (kW) - A unit of electrical power; the actual power expressed in kilowatts. The kilowatt is equal to 1000 watts. The symbol for kilowatt is kW.

L

LAN - Local Area Network. Supplies networking capability to a group of computers in close proximity to each other such as in an office building, a school, or a home. A LAN is useful for sharing resources like files, printers, games or other applications. A LAN in turn often connects to other LANs, and to the Internet or other WAN.

LATENCY - A measure of time delay experienced in a system, the precise definition of which depends on the system and the time being measured. In video processing or encoding products, it is a measure of the amount of time used to process an input signal. In a packet-switched network it is measured either one-way (the time from the source sending a packet to the destination receiving it), or round-trip (the one-way latency from source to destination plus the one-way latency from the destination back to the source).

M

MAC - Media Access Control. The Media Access Control data communication protocol sub-layer provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multi-point network, typically a local area network (LAN). Access to the media may be spread out over time, or as in Ethernet, a mechanism is developed which allows random access, but provides a method for reattempting use of the media if a collision is experienced.

MAC ADDRESS - Media Access Control. A unique hardware number given to devices that connect to the Internet. When your computer or networking device (router, hub, interface, etc.) is connected to the Internet, a table (see "ARP") relates the device's IP address to its corresponding physical (MAC) address on the LAN.

MODEM - Modulator/demodulator. A device that puts information on a carrier signal and transmits it over a (phone) network. The same device receives such signals and demodulates, or separates the information from the carrier. A modem connects computers with other communication devices through ordinary phone lines.

MUX - Short for multiplexer. A device that combine multiple signals for transmission over a single line. The signals are demultiplexed (DEMUX'd), or separated, at the receiving end.

N

NETWORKING - Two or more devices (or people) communicating with each other and sharing resources.

NODE (wiring) - Refers to any point on a circuit where two or more conductors meet and are connected together.

Appendices

P

PACKET - A block of data that is transmitted over a network in a packet-switched system. A packet is also referred to as a frame or datagram.

PCM – PULSE CODE MODULATION - The digital representation of an analog audio signal. PCM is the standard form of digital audio in computers and the compact disc (CD) "red book" format, as well as the standard used for the audio portion of digital video recording.

PEAK - The highest level of signal strength, as determined by the height of the signal's waveform.

PERIPHERAL DEVICE - Normally an external device that a CPU communicates with, such as a printer, mouse, disk drive, or interface.

PHASE - The relative timing of one signal to another, usually expressed in degrees of shift

Protocol - A set of agreed-upon standards that define the format, order, timing, handshaking, and error checking method for data transfer between two pieces of equipment.

PULSE CODE MODULATION - A method used to convert an analog signal into noise-free digital data that can be stored and manipulated by computer. PCM takes an 8-bit sample of a 4kHz bandwidth 8000 times a second, which gives 16K of data per second.

Pulse width - The time during which a source, such as a laser, is in an "on" state

R

REAL-TIME - A system is said to be real-time if the operation delivers a correct value in the time and frequency in which it is required. The video system applied in North America, NTSC requires a real-time system capable of delivering 30 frames per second.

Appendices

S

SAMPLE RATE - The rate at which an analog signal is sampled. It is frequently expressed as kilosamples/sec (kS/s) or Megasamples/sec (MS/s). For example, 44.1 kHz is the standard sample rate for compact disks; 48 kHz is often used with digital audio tape (DAT) recording. A higher sample rate allows a higher frequency response. In order to accurately reconstruct a sound, the sample rate must be at least twice the highest frequency in the sound.

SERIAL DATA - A way to transfer information by breaking the characters of a word into bits, which are then transmitted sequentially along a single line. Compare to parallel, which uses more than one line.

SINE WAVE - The graphic representation for the most familiar AC waveform is a sine wave. A sine wave is a graph with a curved shape representing movement that oscillates periodically.

SINE WAVE PEAK - The maximum instantaneous value of a varying current, voltage, or power during the time interval under consideration; e.g., the highest point of a sine wave curve.

SINE WAVE PERIOD - The time it takes to complete one cycle of a sine wave; Period (T) is inversely proportional to frequency (f); where $T = 1/f$

T

TELECOMMUNICATIONS - An electronic method of transmitting information from one location to another over a telephone network.

TERMINAL - A device typically having a keyboard and display that is capable of sending text to and receiving text from another device, a network, etc.

Appendices

TIME DIVISION MULTIPLEXING – TDM - A digital transmission scheme where the channel is divided into two or more time slots or subchannels, such that the subchannels are taking turns in the bit stream. Multiple digital signals are multiplexed into a serial digital stream. The serial digital stream is transmitted to the receiver where it is de-multiplexed into the individual digital signals

TP - Twisted Pair. Cable that uses small twisted pairs of wires in a common jacket/sheath to transmit and receive network or telephone signals; can be either shielded (STP) or unshielded (UTP). The Extron product family includes twisted pair transmitters, twisted pair receivers, and twisted pair cabling.

TRANSCEIVER - A device that can operate as a transmitter, receiver, or both.

TRANSISTOR - a semiconductor device used to amplify and switch electronic signals and electrical power. It is composed of semiconductor material with at least three terminals for connection to an external circuit.

TTL - 1) In electronics, Transistor-to-Transistor Logic. A digital signal, usually 4-5 volts peak-to-peak with a distance limitation is 6-10 feet (1.8-3.0 meters). Signal splitting is acceptable. TTL signals are either on or off, and are characteristic of low resolution computers (CGA/EGA). 2) In network video streaming, Time to live. Multicast streaming traffic is typically programmed with a TTL value indicating the number of router hops that are permissible for the packet.

V

VLAN - Virtual LAN. A group of devices on a network with a common set of requirements that communicate as if they were attached to the same broadcast domain, regardless of their physical location. A VLAN is a Layer 3 network function. A group of network devices can be grouped together into a functionally separate logical network. VLAN and their network traffic will be segmented from other devices that may be connected to the same physical system.

VOLT - The basic unit of voltage. The symbol for volt is V.

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VOLTAGE - Also called potential difference, electromotive force, or EMF. Voltage is a force that when applied to a conductor caused current to flow. Voltage is symbolized by the letters E or V and is measured in volts.

VPN - Virtual Private Network. A method of providing a private network connection via a secure communications tunnel over the Internet. VPNs maintain privacy applying tunneling protocol, encryption, and security procedures.

W

WAN - Wide Area Network. A computer network that covers a broad area such as a link across a metropolitan, regional, or national boundary

WATT -The basic unit of electrical power. The watt is equal to one volt times a current of one ampere. The symbol for watt is W.

WIDEBAND - A relative term indicating a high bandwidth

WLAN - Wireless Local Area Network. A form of local area network that uses radio waves to transmit data between nodes rather than through cable. Mobile devices, such as laptop computers and personal digital assistants, have helped spawn the "plugless" connection to WLANs. The IEEE 802.11 standard specifies the technologies for wireless LANs.