Objectives:

1. Define sound
2. Define waves and wave theory
3. Define electricity
4. Define a circuit

In telephony, the most commonly used source is the human voice. The path is a copper wire telephone cable and the destination is a human ear held to the receiver of the telephone set at the far end.

The purpose of this lesson is not to make you physicists or electrical engineers, but to introduce you to the language and terminology that are a daily part of the telecommunications industry. Mastering the language will go a long way in your introduction to telecom.

Sound

Sound has served as a fundamental means of communication since the dawn of time. We are going to examine the aspects of sound that play an essential role in telecommunications. Many of the principals associated with sound apply directly to the transmission of electrical signals that make telecommunications possible.

What is sound?

Sound is the banging of air molecules together at a rapid rate to create sound waves.

In the above definition we refer to sound as a sound wave.

What is a wave?

A wave is a disturbance that moves through a medium.

If you drop a stone into a still bucket of water you will notice a disturbance on the surface immediately after the stone breaks the surface of the water. This disturbance is a wave that moves outward from the point of impact toward the edge or boundary of the medium.

The sound waves created by the human vocal cords compress the air molecules at a rate of between 100 and 5000 times per second.

The three main characteristics of sound are:

- Frequency/Wavelength
- Amplitude
- Phase
The **frequency** of a sound wave can be represented in two ways:

- Period
- Vibrations per second

The **period** of a sound wave is the time required to produce one complete wave or one cycle. It is usually expressed in seconds or some portion of a second such as a millisecond \((10^{-3})\) or microsecond \((10^{-6})\).

Frequency is the inverse of the period; instead of stating how long it takes for a complete cycle to occur, **frequency** is a way of stating the number of cycles that occur per second, or cycles per second. Frequency is identify by the term Hertz with one **cycle per second** equal to one (1) **Hertz**.

The frequency of a sound wave also determines wavelength. **Wavelength** is used to describe the physical length of a waveform and is typically measured in meters or millimeters: the higher the frequency the shorter the wavelength.

The second property of sound that we need to consider is its volume, loudness, or **amplitude**. Little more is needed to understand amplitude except to define a unit of measurement.

The unit of measure used to describe amplitude of sound is the **decibel**, which was named in honor of Alexander Graham Bell. The average person can just perceive the difference in loudness of 1 decibel.

A decibel is a measurement of increase or decrease of signal power level expressed as a ratio of transmitted power to received power. A loss of signal strength is represented as a negative value.
**Our definition of decibel:**

The average person can just perceive the difference in loudness of 1 **decibel**.

The third characteristic of a sound wave is its phase. Phase specifies the time relationship between two sound waves. Two sound waves are in phase if they occur at the same time. If one sound wave is delayed we say that the two waves are out of phase.

The telephone translates sound waves into constantly varying electrical signals or electromagnetic waves that can be transported over great distances. The energy in the signal generated rises from zero amplitude to a peak level and falls back toward zero. To complete the cycle the amplitude decreases to a negative peak value then rises back toward zero. Sound waves and electrical signals are most commonly depicted as a sine wave or a combination of sine waves. A sine wave is shown below.

![Sine Wave](image)

The telephone networks were built to carry the electrical equivalent of speech. Early telephone research indicated that the majority of usable information in human speech fell within a narrow band of frequencies. Speech could be converted into electrical energy, transported over a telephone circuit, and converted back into intelligible speech in a frequency range of 3,000 cycles per second or 3kHz.

The range of frequencies that human beings can hear is from about 20 hertz to 20,000 hertz. These are the so-called **audio frequencies**. Stereo systems provide sound reproduction from 20 to 20,000 hertz, while telephone circuits are generally limited to a range of 300 to 3300 Hertz. This latter range is often referred to as the **Voice Band** of frequencies.
What is bandwidth?

Bandwidth is the range or band of frequencies required to accurately represent the information in the signal being transmitted. The bandwidth of the audio frequencies defined above is approximately 20KHz. The bandwidth for a voice band signal is 3KHz.

Complex waves can be created by combining multiple, fundamental sine waves. The frequency $2f$ is the first harmonic of the frequency $f$. Each harmonic is one of many of the octaves of the fundamental sine wave. This is a “good news – bad news” concept. Harmonics enhance musical tones and common every day sounds. Harmonics create havoc in many electrical circuits where precise frequencies are required. Combining a fundamental frequency with an infinite number of harmonics generates square waves or sawtooth waves.
Although human speech is a marvelous means of communication, there is severe limitation on the distance human generated sound can travel. The air around us transports sound waves. The loosely packed molecules of air rapidly disperse or attenuate the sound waves. Only very recently in human history have we been able, through electrical means, to conquer the distance limitation of sound.

**Our definition of attenuation:**

Attenuation is the reduction or loss experienced by sound, electrical or optical signals as they travel through their respective medium. Attenuation is measured in decibels.

## Sounds in Air

Air is the principle carrier or conductor of sound therefore the primary medium for sound is air. Sound vibrations must impart energy to the air for the sound to be heard. Our mouths are not ideal devices for projecting sounds. When we attempt to shout into the open air, our mouth is not well matched to the medium. Since sound from our mouth is not efficiently coupled to the air, it is rapidly dispersed or attenuated. This results from a mismatch with the medium.

### Mismatches Between a Sound Source and Medium Affect Sound Waves

A transformer can be used on the line to match the two transmission paths.
Echo is another phenomenon that occurs with sound. We have all shouted into a canyon or alley and heard our voice reflected back to us. Actually, echoes happen all the time. We do not notice the reflected sounds because they return to us so fast that we cannot detect them. Only a delayed reflection becomes noticeable or objectionable. Echoes are caused by discontinuities in the carrier or medium of sound.

**Reflection or Echo**

Sound is reflected from solid objects all the time. If the receipt of the reflected sound is sufficiently delayed and can be heard above the original sound, an echo will noticeable.

Phase is another phenomena related to delay. A sound that is delayed with respect to the original sound is said to be out of phase with the original. Sound travels in free air at about 1100 feet per second or 750 miles per hour. Phase is the time relationship of one signal to another.

**Phase Delay**

Stereophonic sound is a good example of the use of phase delay. Two microphones are used to pick up sound for recording. The left microphone is closer to the left sound source, so it receives sounds sooner and louder than the left source. However, it does receive sound from the right source, but with greater delay and a little less volume. The result at the right microphone is similar. When such recordings are played back through a stereo system’s left and right speakers, we detect the phase and amplitude differences and the sound takes on depth and direction.
Stereophonic Sound
A useful application of phase delay

The device used to convert sound energy into electrical energy is generically referred to as a microphone. The microphone translates motion created by sound waves into electrical energy by means of electromagnetism. A device that converts energy from one form to another is called a transducer.

All of the properties of sound apply directly to electrical or electronic telecommunications signals. We will now explore the nature of these signals.

Electricity

What is electricity?

Electricity is the flow of “free” electrons through a material or medium. Since this flow of electricity is a disturbance, electricity can be characterized by wave theory.

The three most basic characteristics of electricity are:

- Current
- Voltage
- Resistance

Current is a measure of the number of electrons that pass a point in a circuit in one second.

Voltage is a difference in potential energy between two points in a circuit which causes current to flow.

Resistance is the opposition to current flow.
From physics, we know that a typical circuit requires a source of current, a path to carry the signal, a load, and return path to complete the circuit. See the diagram below.

A Simple Circuit

A closed water system provides a simple analogy that is helpful in understanding the flow of electrical current in a circuit. From the picture below, we see a pump (the source) that supplies pressure (voltage) to the water in the pipes (the medium). The flow of water (current) created by the pump encounters resistance caused by the size and internal roughness of the pipe. The resistance of the pipe and the load placed on the system by the water wheel determines the flow of the water (current) in the system.

Water Analogy to Circuit

All materials offer some resistance to the flow of electric current through them. The degree to which they oppose current flow categorizes the materials as either conductors (copper, aluminum, or silver) or insulators (paper, glass, or air).

Conductors offer little resistance to the flow of electrical current. Insulators present an extremely high resistance to current flow.

Power is a measure of the rate of consumption of electrical energy.
There are two forms of electric current:

- Direct current (DC)
- Alternating current (AC)

Direct current (DC), such as produced by a dry cell battery, has constant amplitude and does not vary instantaneously with time.

Alternating current (AC), as produced by an electrical generator, has amplitude that varies constantly with time and can be represented by a sine wave.
Most electrical devices involved in telecommunications use alternating current. Alternating current is generated when a loop of wire is rotated in a magnetic field such as that surrounding a permanent magnet. As the wire rotates, its angle changes from 0° to 360°. The magnitude of the current created in the loop of wire increases from zero to a maximum value between 0° to 90° and decreases from the maximum value between 90° to 180°. If you plot this graphically the current follows a typical sine wave.

![Graph of Alternating Current](image)

**Resistance** is the only factor that opposes current in a DC circuit. The opposition to current flow in AC circuits is also a function of frequency. Resistance is replaced with impedance in an AC circuit. **Impedance** has a real or resistive component but also varies with frequency. The frequency related component of impedance is referred to as **reactance**.

**Reactance can be divided into two components:**

- Capacitive reactance
- Inductive reactance

Capacitance occurs as a result of the wires being close together. The closer they are, the greater the capacitance. **Capacitance** opposes current flow by storing electrical energy in an electrostatic field.

**Inductance** opposes changes in current flow resulting from the magnetic fields around wires. At voice frequencies inductance has minimal impact on circuits.

The following model is used to analyze telecommunications cables. This model indicates that a current flowing through a telephone circuit experiences series resistance, parallel capacitance, and series inductance.
Alternating Current Circuit Factors

Both capacitance and inductance vary with frequency and have effects on alternating current flow. In a typical ten-mile circuit composed of 19 gauge wire, the loss at DC is less than one decibel (dB), yet the same circuit carrying a thousand Hertz alternating current has a loss of ten decibels (dB).

The figure below demonstrates the losses due to capacitance in a telephone line. As the frequency of the source is increased, the more current is bypassed through the capacitance between the wires. The higher the frequency the higher the capacitance, the lower the capacitive reactance. Capacitors block direct current. The longer the local loop the more signal loss due to leakage through the capacitance between the wires.

Losses Due to Capacitance
Characteristic impedance is another term that describes an inherent characteristic of electrical transmission facilities. The important thing to know about characteristic impedance is that for maximum efficiency the characteristic impedance of the source and load must be properly matched to the facility. This concept is exactly the same as matching the speaking tubes discussed earlier. Transformers are used to properly match impedance in transmission lines.

The discovery of electromagnetic waves was one of the most significant discoveries. The electromagnetic spectrum was defined in the 1800’s.

When an electric charge vibrates in space, a magnetic field is induced and when the magnetic field changes, an electric field is induced. The changing magnetic and electric fields create waves projecting out from the source of the charge.

Electromagnetic Wave Theory

The discovery of electromagnetic waves was one of the important discoveries in telecommunications. Electromagnetic waves cannot be seen, touched, or heard directly. The electromagnetic spectrum was first defined in the 1800’s.

Many of the pioneers of modern electrical and electronics contributed to our knowledge of electromagnetic waves. When an electric charge moves or vibrates in space a magnetic field is created. An electric field is created when the magnetic field changes. The changing magnetic and electric fields create a wave projecting out from the source of the charge.

Energy is transferred in one of two ways:

- Through the motion of subatomic particles or large masses of material.
- Wave motion
Electricity is conducted along a wire by the motion of electrons. Heat is conducted from a bowl of hot soup up the handle of a spoon by the motion of the atoms and molecules in the metal. Winds and tides illustrate the transfer of energy by the motion of fluids.

Wave motion is a second means by which energy is transferred. The energy of the sun, radio waves, and sound waves transfer energy via wave motion.

Early last century the nature of light was supported by conflicting theories:

- Sir Isaac Newton believed light consisted of tiny particles of matter emitted by a source
- Christian Huygens correctly proposed that light consists of wave fronts perpendicular to the path of the light rays.

Waves have properties:

- The particles in a transverse wave vibrate at right angles to the path traveled (waves in water resulting from a dropped stone)
- Sound waves travel in a longitudinal wave where the particles vibrate to and fro along the path.
- All waves have a finite speed depending on the medium
- All waves have frequency which is the number of waves that pass a given point in a unit of time, typically a second
- Waves may be reflected at the boundary of the medium (edge of a bucket of water)
- The direction of a wave when traveling through a non-uniform medium is said to be refracted or bent (light waves by a lense)
- Waves bend around obstacles in their path are diffracted (water waves bend around the pylon of a pier