17.1.1: Microphones

The earliest sound recordings were made without the use of electronics at all. A large cone channeled sound to a diaphragm attached to a needle so that the needle would vibrate at the same rate as the sound vibrations entering the cone. To make a recording the needle was placed on a rotating cylinder coated in hot wax or plastic which was slowly moved past the needle as it vibrated. The vibrations of the needle were recorded as a single continuous fluctuating groove in the wax. The wax was hot initially so that it was soft enough to record the vibrations of the needle. Because the process was entirely mechanical it was not very efficient; singers had to practically shout into the cone to produce enough vibrations to form a recording.

Modern recording of music starts by turning sound into electrical impulses. This is an ***analog process***; the electrical current varies in strength and frequency in proportion to the loudness and frequency of the sound wave. In other words, when the sound varies more rapidly (high frequency) so does the electrical signal and when the sound is louder, the electrical signal has a higher amplitude in proportion to the sound. The conversion from sound to electrical signals is accomplished by a microphone and there are six major types based on three different physical processes.

The ***dynamic microphone*** is based on Faraday's law which we learned about in Chapter 17. The first figure below on the left is the ***moving-coil dynamic microphone***. A flexible diaphragm is attached to a coil so that vibrations in the diaphragm cause the coil to move. If the coil is close to a permanent magnet, movement of the coil in the magnetic field will cause a current to flow in the coil due to Faraday's law. Sound waves cause the diaphragm to vibrate so the sound vibrations are converted into a fluctuating current flow. In theory the same arrangement can be either a microphone (vibrations input, oscillating current output) or a speaker (fluctuating current input, vibrations output) as we will see.

The moving-coil microphone became popular in the late 1930s and is designed to pick up sound from one direction. This and the fact that it is a bit more durable than some of the other microphones makes it a favorite choice for live performances where there may be a lot of other stray sound present on stage. Because it can withstand loud sound without much distortion it is popular with blues and hip-hop singers.

The second arrangement is the ***magnetic microphone***. In this microphone a movable cone is attached to a small magnet or piece of iron which can move back and forth between the poles of a permanent magnet. A coil is wrapped around the permanent magnet. Sound causes the cone to vibrate which moves the small magnet. The moving magnet changes the magnetic field in the permanent magnet and therefore in the coil, creating a current that oscillates in proportion to the sound oscillation.

Faraday's law is also the physical principle behind the ***dynamic ribbon microphone*** shown in the third picture below. A thin piece of metallic foil vibrates when sound hits it. The principle is the same as the moving-coil microphone, the vibrating metal sheet is moving in the magnetic field of a permanent magnet and so a current that matches the variations in the vibrating ribbon is created. In the first two types the leads (not shown) are attached to the coil.

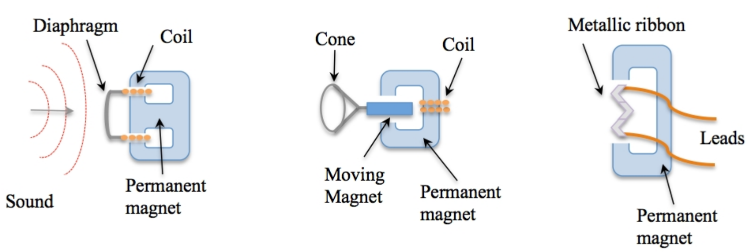

Figure 17.1.1.1

The ribbon microphone was invented in the early 1920s. The range of frequencies that it responds to is limited; it does not capture high frequencies well. However, it has a frequency range well suited for the human voice and was popular in studio recordings of the 1920s. Some microphones (such as the carbon microphone, below) produce crackling sounds (noise) when trying to record higher frequencies. The ribbon microphone produces a smooth response which attenuates at higher frequency so less noise is present. The ribbon microphone also exhibits a proximity effect, boosting lower frequencies a bit more as the source moves closer to the microphone, making the voice sound more intimate. The proximity effect made the crooner styles of singers like Nat King Cole, Bing Crosby, and Rosemary Clooney popular.

One problem of the above three types of microphones is that the phase of the electrical signal lags the phase of the original vibrations by a quarter of a wavelength. A close examination of Faraday's law shows that the voltage in the coil is a maximum when the coil is moving the fastest which occurs as the diaphragm passes its equilibrium point. When the diaphragm is pushed in to its furthest point it stops moving and the voltage produced by Faraday's law drops to zero. Suppose we have a sound wave from a tuning fork which we know is pretty close to a pure sine wave. An oscilloscope would show a sine wave like the red curve in the figure below. But if we could plot the voltage across the microphone we would see the blue curve which is ninety degrees ($\pi/2$ radians) out of phase with the sound.

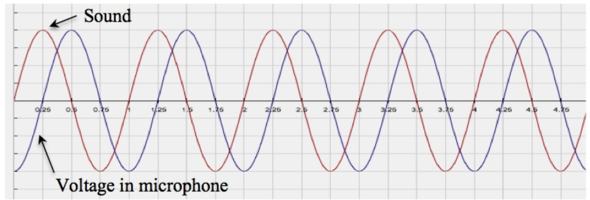

Figure 17.1.1.2

We know from Chapter 16 that one of the four ways the ear-brain system determines direction is the relative phase of the signal between one ear and the other. If the speaker or recording system does not correct for this quarter phase error in the microphone the reproduced sound may not sound right to our ears. A further complication is that other types of microphones (described below) do not have this quarter phase difference. So a recording session that uses multiple types of microphones may result in recorded sound that has a mixture of phase errors.

Three other techniques for making a microphone are described next. These microphones produce voltage changes based on physical mechanisms other than Faraday's law.

Physically squeezing certain types of crystals will cause a voltage to form across the crystal that is proportional to how much force is applied. A crystal that behaves this way is called a ***piezoelectric crystal*** and is the basis for a type of microphone called a ***piezoelectric microphone***. Because a crystal of a given size has a natural frequency of vibration that is very constant, piezoelectric crystals are also used in watches to keep time. The oscillations are driven by a circuit that is tuned to a certain frequency by the crystal oscillations acting as a voltage source for timing purposes. The first figure on the left is a schematic of a piezoelectric microphone.

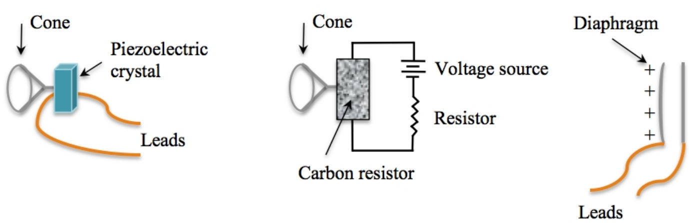

Figure 17.1.1.3

Another type of microphone, called a ***carbon microphone***, is based on the change in resistance of a container of carbon granules (a carbon resistor). As the microphone cone vibrates it squeezes the container so that the carbon granules are closer together, causing a change in the resistance of the container. Ohm's law, from the previous chapter, tells us that the current will be different for a circuit with a fixed voltage if the resistance changes. Fluctuations of the cone cause fluctuations in resistance, turning sound into a fluctuating current flow through the second resistor. The second diagram above is for a carbon microphone.

The carbon microphone was the first type of microphone used in recording music electronically and was invented in the early 1900s. It has a very narrow frequency response and some noise which gives it a distinctive sound, familiar from movies depicting old radio broadcasts or analog telephones. With the advent of the carbon microphone singers no longer had to shout as they did for mechanical recordings directly on wax and a style of music called whispering became popular.

The third figure above shows the ***electrostatic or condenser microphone***. In this microphone a flexible diagram is charged and placed close to a fixed plate with the opposite charge. The arrangement of two oppositely charged surfaces brought very close together but not touching is called a ***capacitor***. The voltage between the two surfaces depends on the amount of charge on one side and distance between them. As the diaphragm vibrates the voltage between the two surfaces oscillates. This oscillating voltage is the input signal to an amplifying circuit.

The condenser microphone was invented in 1917 but was not popularly used for recording until better versions were created in the late 1940s. The condenser microphone is better at higher frequencies than other microphones and has a slightly better response for the range of human vocalization than ribbon or carbon microphones. Frank Sinatra was one vocalist who helped popularize the sound of the condenser microphone.

Video/audio examples:

- A technical YouTube on how to check the phase of a set of microphones.
