How dynamic loudspeakers work

Sound Basics

To understand how speakers work, the first thing you need to do is understand how sound works. Inside your ear is a very thin piece of skin called the eardrum. When your eardrum vibrates, your brain interprets the vibrations as sound. Rapid changes in air pressure are the most common thing to vibrate your eardrum.

An object produces sound when it vibrates in air (sound can also travel through liquids and solids, but air is the transmission medium when we listen to speakers). When something vibrates, it moves the air particles around it. Those air particles in turn move the air particles around them, carrying the pulse of the vibration through the air as more and more particles are pushed farther from the source of the vibration.

To see how this works, let's look at a simple vibrating object -- a bell. When you ring a bell, the metal vibrates -- flexes in and out -- rapidly. When it flexes out on one side, it pushes out on the surrounding air particles on that side. These air particles then collide with the particles in front of them, which collide with the particles in front of them, and so on. When the bell flexes away, it pulls in on these surrounding air particles, creating a drop in pressure that pulls in on more surrounding air particles, which creates another drop in pressure that pulls in particles that are even farther out, and so on. This decreasing of pressure is called rarefaction.

In this way, a vibrating object sends a wave of pressure fluctuation through the atmosphere. When the fluctuation wave reaches your ear, it vibrates the eardrum back and forth. Our brain interprets this motion as sound. We hear different sounds from different vibrating objects because of variations in:

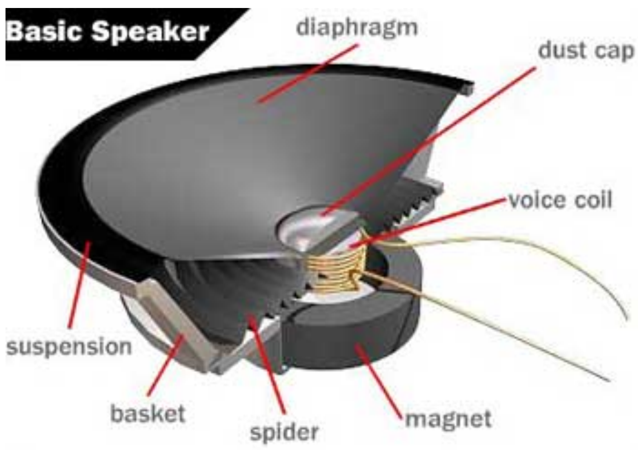
- sound wave frequency -- A higher wave frequency simply means that the air pressure fluctuates faster. We hear this as a higher pitch. When there are fewer fluctuations in a period of time, the pitch is lower.
- air pressure level -- the wave's amplitude -- determines how loud the sound is. Sound waves with greater amplitudes move our ear drums more, and we register this sensation as a higher volume.

A speaker is a device that is optimized to produce accurate fluctuations in air pressure. A microphone works something like our ears. It has a diaphragm that is vibrated by sound waves in an area. The signal from a microphone gets encoded on a tape or CD as an electrical signal. When you play this signal back on your stereo, the amplifier sends it to the speaker, which re-interprets it into physical vibrations. In the next section, we'll see how the speaker accomplishes this.

Making sound

In the last section we saw that sound travels in waves of air pressure fluctuation, and that we hear sounds differently depending on the frequency and amplitude of these waves. We also learned that microphones translate sound waves into electrical signals, which can be encoded onto CDs, tapes, LPs, etc. Players convert this stored information back into an electric current for use in the stereo system.

A speaker is essentially the final translation machine -- the reverse of the microphone. It takes the electrical signal and translates it back into physical vibrations to create sound waves. When everything is working as it should, the speaker produces nearly the same vibrations that the microphone originally recorded and encoded on a tape, CD, LP, etc.



Traditional speakers do this with one or more drivers. A driver produces sound waves by rapidly vibrating a flexible cone, or diaphragm.

- The cone, usually made of paper, plastic or metal, is attached on the wide end to the...
- suspension, or surround. This rim of flexible material allows the cone to move, and is attached to the...
- driver's metal frame, called the basket.
- The narrow end of the cone is connected to the voice coil.
- The coil is attached to the basket by the spider, a ring of flexible material. The spider holds the coil in position, but allows it to move freely back and forth.

Some drivers have a dome instead of a cone. A dome is just a diaphragm that extends out instead of tapering in.

A typical speaker driver, with a metal basket, heavy permanent magnet and paper diaphragm

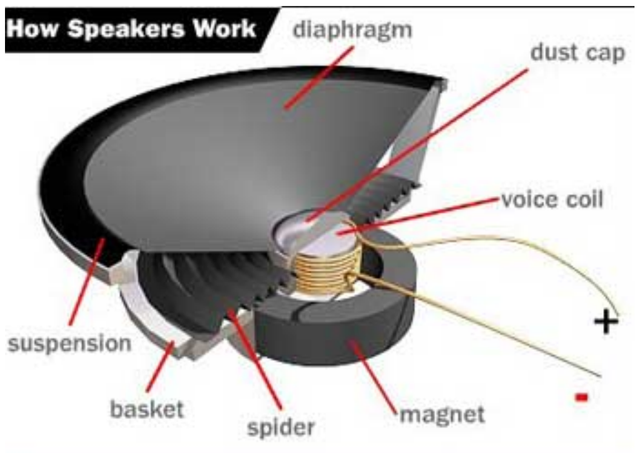
The voice coil is a basic electromagnet.Then you know that an electromagnet is a coil of wire, usually wrapped around a piece of magnetic metal, such as iron. Running electrical current through the wire creates a magnetic field around the coil, magnetizing the metal it is wrapped around. The field acts just like the magnetic field around a permanent magnet: It has a polar orientation -- a "north" end and and a "south" end -- and it is attracted to iron objects. But unlike a permanent magnet, in an electromagnet you can alter the orientation of the poles. If you reverse the flow of the current, the north and south ends of the electromagnet switch.

This is exactly what a stereo signal does -- it constantly reverses the flow of electricity. If you've ever hooked up a stereo system, then you know that there are two output wires for each speaker -- typically a black one and a red one.

The wire that runs through the speaker system connects to two hook-up jacks on the driver

Essentially, the amplifier is constantly switching the electrical signal, fluctuating between a positive charge and a negative charge on the red wire. Since electrons always flow in the same direction between positively charged particles and negatively charged particles, the current going through the speaker moves one way and then reverses and flows the other way. This alternating current causes the polar orientation of the electromagnet to reverse itself many times a second.

So how does this fluctuation make the speaker coil move back and forth? The electromagnet is positioned in a constant magnetic field created by a permanent magnet. These two magnets -- the electromagnet and the permanent magnet -- interact with each other as any two magnets do. The positive end of the electromagnet is attracted to the negative pole of the permanent magnetic field, and the negative pole of the electromagnet is repelled by the permanent magnet's negative pole. When the electromagnet's polar orientation switches, so does the direction of repulsion and attraction. In this way, the alternating current constantly reverses the magnet forces between the voice coil and the permanent magnet. This pushes the coil back and forth rapidly, like a piston.



When the electrical current flowing through the voice coil changes direction, the coil's polar orientation reverses. This changes the magnetic forces between the voice coil and the permanent magnet, moving the coil and attached diaphragm back and forth.

When the coil moves, it pushes and pulls on the speaker cone. This vibrates the air in front of the speaker, creating sound waves. The electrical audio signal can also be interpreted as a wave. The frequency and amplitude of this wave, which represents the original sound wave, dictates the rate and distance that the voice coil moves. This, in turn, determines the frequency and amplitude of the sound waves produced by the diaphragm.

Different driver sizes are better suited for certain frequency ranges. For this reason, loudspeaker units typically divide a wide frequency range among multiple drivers. In the next section, we'll find out how speakers divide up the frequency range, and we'll look at the main driver types used in loudspeakers.

Chunks of the Frequency Range

In the last section we saw that traditional speakers produce sound by pushing and pulling an electromagnet attached to a flexible cone. Although drivers all work on the same concept, there is actually a wide variety in driver size and power. The basic driver types are:

- Woofers

- Tweeters
- Midrange

Woofer

Tweeter

Midrange

Woofers are the biggest drivers, and are designed to produce low frequency sounds. Tweeters are much smaller units, designed to produce the highest frequencies. Midrange speakers produce a range of frequencies in the middle of the sound spectrum.

And if you think about it, this makes perfect sense. To create higher frequency waves -- waves in which the points of high pressure and low pressure are closer together -- the driver diaphragm must vibrate more quickly. This is harder to do with a large cone because of the mass of the cone. Conversely, it's harder to get a small driver to vibrate slowly enough to produce very low frequency sounds. It's more suited to rapid movement.

To produce quality sound over a wide frequency range more effectively, you can break the entire range into smaller chunks that are handled by specialized drivers. Quality loudspeakers will typically have a woofer, a tweeter and sometimes a midrange driver, all included in one enclosure.

Of course, to dedicate each driver to a particular frequency range, the speaker system first needs to break the audio signal into different pieces -- low frequency, high frequency and sometimes mid-range frequencies. This is the job of the speaker crossover.

The most common type of crossover is passive, meaning it doesn't need an external power source because it is activated by the audio signal passing through it. This sort of crossover uses

inductors, capacitors and sometimes other circuitry components. Capacitors and inductors only become good conductors under certain conditions. A crossover capacitor will conduct the current very well when the frequency exceeds a certain level, but will conduct poorly when the frequency is below that level. A crossover inductor acts in the reverse manner -- it is only a good conductor when the frequency is below a certain level.

The typical crossover unit from a loudspeaker. The frequency is divided up by inductors and capacitors and then sent on to the woofer, tweeter and mid-range driver.

When the electrical audio signal travels through the speaker wire to the speaker, it passes through the crossover units for each driver. To flow to the tweeter, the current will have to pass through a capacitor. So for the most part, the high frequency part of the signal will flow on to the tweeter voice coil. To flow to the woofer, the current passes through an inductor, so the driver will mainly respond to low frequencies. A crossover for the mid-range driver will conduct the current through a capacitor and an inductor, to set an upper and lower cutoff point.

There are also active crossovers. Active crossovers are electronic devices that pick out the different frequency ranges in an audio signal before it goes on to the amplifier (you use an amplifier circuit for each driver). They have several advantages over passive crossovers, the main one being that you can easily adjust the frequency ranges. Passive crossover ranges are determined by the individual circuitry components -- to change them, you need to install new capacitors and inductors. Active crossovers aren't as widely used as passive crossovers, however, because the equipment is much more expensive and you need multiple amplifier outputs for your speakers.

Crossovers and drivers can be installed as separate components in a sound system, but most people end up buying speaker units that house the crossover and multiple drivers in one box. In the next section, we'll find out what these speaker enclosures do and how they affect the speaker's sound quality.

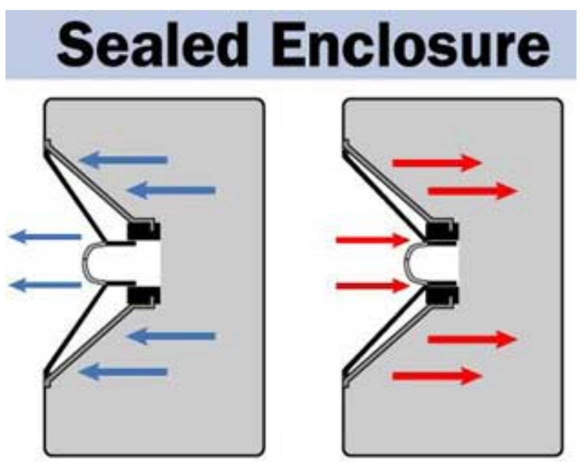
Boxes of Sound

In most loudspeaker systems, the drivers and the crossover are housed in some sort of speaker enclosure. These enclosures serve a number of functions. On their most basic level, they make it much easier to set up the speakers. Everything's in one unit and the drivers are kept in the right position, so they work together to produce the best sound. They are usually built with heavy wood or another solid material that will effectively absorb the driver's vibration. If you simply placed a driver on a table, the table would vibrate so much it would drown out a lot of the speaker's sound.

Additionally, the speaker enclosure affects how sound is produced. When we looked at speaker drivers, we focused on how the vibrating diaphragm emitted sound waves in front of the cone. But, since the diaphragm is moving back and forth, it's actually producing sound waves behind the cone as well. Different enclosure types have different ways of handling these "backward" waves.

A typical sealed speaker enclosure that holds a tweeter, a woofer and a midrange driver.

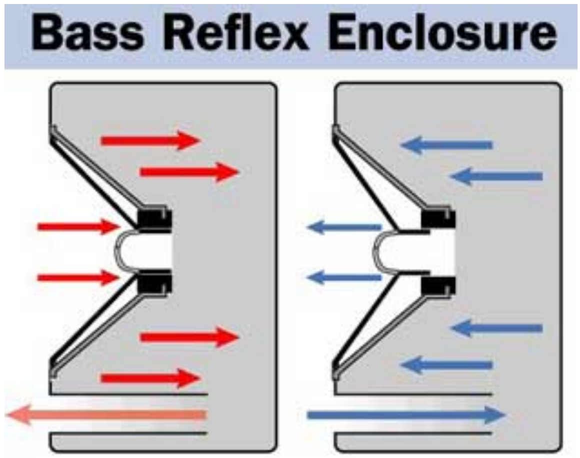
The most common type of enclosure is the sealed enclosure, also called acoustic suspension enclosure. These enclosures are completely sealed, so no air can escape. This means the forward wave travels outward into the room, while the backward wave travels only into the box. Of course, since no air can escape, the internal air pressure is constantly changing -- when the driver moves in, the pressure is increased, and when the driver moves out, it is decreased. Both movements create pressure differences between the air inside the box and the air outside the box. The air will always move to equalize pressure levels, so the driver is constantly being pushed toward its "resting" state -- the position at which internal and external air pressure are the same.



In a sealed speaker setup, the driver diaphragm compresses air in the enclosure when it moves in, and rarefies air when it moves out.

These enclosures are less efficient than other designs because the amplifier has to boost the electrical signal to overcome the force of air pressure. The force serves a valuable function, however -- it acts like a spring to keep the driver in the right position. This makes for tighter, more precise sound production.

The other thing you can do with the backward wave is to redirect it outward, using it to supplement the forward sound wave. The most common way to do this is to build a small port into the speaker. In these bass reflex speakers, the backward motion of the diaphragm pushes sound waves out of the port, boosting the overall sound level. The main advantage of bass reflex enclosures is efficiency. The power moving the driver is used to emit two sound waves rather than one. The disadvantage is that there is no air pressure difference to spring the driver back into place, so the sound production is not as precise.



A bass reflex speaker produces two sound waves by moving one driver. When the driver compresses air forward, it rarefies it backward, and vice versa. The second sound wave is emitted from a port at the base of the speaker enclosure.

Passive radiator enclosures are very similar to bass reflex units, but in passive radiator enclosures, the backward wave moves an additional, passive driver, instead of escaping out of the port. The passive driver is just like the main, active drivers except it doesn't have an electromagnet voice coil, and it isn't connected to the amplifier. It is moved only by the sound waves coming from the active drivers. This type of enclosure is more efficient than sealed designs and more precise than bass reflex models.