Planar Loudspeaker Technologies

John Doe Final Project 95.164 5/1/2020 Loudspeakers are devices designed specifically to produce a sonic waveform in response to an electrical signal. The goal of any loudspeaker is to reproduce this electrical signal as accurately as possible. This electrical signal often represents a musical event; in this case, there is a large amount of information that needs to be reproduced. The waveform to be reproduced is a function of frequency and time, and the amplitude of a given frequency is independent of all other frequencies. There are, however, limitations to every type of speaker; because of this, there is no one magic speaker that will reproduce a signal perfectly. Though a signal cannot be reproduced perfectly, that should not be used as an excuse for not trying to reproduce one more perfectly.

As stated above, a musical signal is a function of frequency and time. As such, an ideal loudspeaker must be able to reproduce every frequency of sound, and be able to respond to instantaneous changes in the electrical signal's waveform. For any real speaker, however, this is not possible. Loudspeakers create sound, ultimately, by moving air. This is often accomplished by moving a membrane or diaphragm through the air. Like all other matter, this membrane must have mass. For this reason alone, no material loudspeaker can ever be ideal. In reproducing a square wave, for example, a speaker must be able to instantly move from one position to another and this requires an instant acceleration. Knowing that F=MA, one can achieve instant acceleration either by having an infinite amount of force available to move the membrane, or by having a massless membrane. Because neither of these properties is present in a real loudspeaker, it can never reproduce a square wave perfectly. Furthermore, this reluctance to instantly change position creates issues whenever the nature of the sound is changed, for example,

when another instrument begins to play. Imagine now a concert; as a singer is singing softly, a trumpet begins to play loudly. To experience this in real life is to hear a clear sharp sound at the moment the trumpet begins to play. If this event were recorded and played back through a speaker, one would find the trumpet's entry to not be as sharp. The amplitude rises very fast, and the speaker is unable to match it perfectly. The speaker's ability to reproduce these types of sounds is called its *transient response*. Transient response, here, is the ability of a loudspeaker to respond to a change from equilibrium. Although the transient response of a loudspeaker cannot be perfect, it can be made to approximate an ideal speaker by having either a very low mass, or a very large force, or both. A good transient response is especially important in high frequency applications, where a sine wave can oscillate very quickly.

A loudspeaker, in addition to responding to changes in an electrical signal, must be able to reproduce a wide range of frequencies. This is known as the speaker's *frequency response*. The frequency response of a loudspeaker is dependent upon the type of loudspeaker utilized, the method of diaphragm propulsion, the geometry of the diaphragm, the materials used in construction of the driver, and the cabinet enclosing the driver, among many other variables. Determining the exact frequency response of a particular speaker is beyond the scope of this paper. Despite this, generalizations that are typically accurate will be made about types of speakers in order to compare the benefits of each type.

Humans are typically quoted as being able to hear from 20Hz to 20kHz. It is absolutely essential for any speaker to reproduce this range of sounds for obvious reasons. Moreover, it is important for the frequency response of a speaker to extend beyond these frequencies. In reproducing the upper registers of a piano, for example, a fundamental note may be 12kHz. Besides the fundamental frequency, a series of harmonics are created as well. The wavelength of these harmonic frequencies is 1/n for n = {1,2,3,4, etc.}, (other wavelengths, for n= { $\frac{1}{2}$, 1/3, $\frac{1}{4}$, etc.}, would be created, but physical constraints of the system often prevent this) and so the frequency of these harmonics is f, 2f, 3f, 4f, etc. The amplitude of the harmonics generally decreases as n increases, and to a good approximation, only the first few orders of harmonics need to be considered. If f=12khz, it is easy to see the 2nd harmonic has a frequency of 24kHz, and though this is beyond the range of human hearing, the inability to reproduce this frequency is audible and measurable as long as there is information to be reproduced at the fundamental frequency.

Besides frequency and transient response, there are many other factors that determine how realistic a speaker can sound. Most of these are beyond the scope of this paper and will not be discussed here in great length, and even then, only where appropriate.

Loudspeakers are most typically of the cone or dome type. That is, a dome or cone shaped diaphragm is attached to a solenoid called a voice coil. This coil is placed into a magnetic field usually created by a strong permanent magnet. The coil has a current passed through it, and in response, produces a magnetic field that varies in phase with the input signal. The varying magnetic field is repelled and attracted to the permanent magnet's magnetic field. As the voice coil responds to the current, it moves the diaphragm, which in turn moves the air. It is this principal by which the vast majority of speakers operate. There are some problems with this design, however. The largest problem is controlling resonances. Every speaker has a natural frequency at which it likes to resonate. Below this frequency, the frequency response tends to drop off. Likewise, if a speaker is given an input of its resonant frequency, it will oscillate in response. Unfortunately, after such a signal is stopped, the speaker will continue to oscillate until friction damps the motion away. This is true of all mechanical speakers. It is especially a problem for dynamic (conventional) speakers because the relatively large mass can force the resonant frequency to be in the audio band.

Another problem with dynamic speakers concerns how they are interconnected. Because of the way that most dynamic drivers are made, quality speakers are usually made into a 3-way arrangement. In a 3-way speaker, there are three types of speakers, tweeters, mid-ranges, and woofers. They each cover a specific portion of the audio band so that each driver may focus on what it does best. This is a problem because a complicated crossover network is required; a crossover network filters an audio signal so that each speaker is given a small range of frequencies to play. The design of the crossover is made more difficult by the fact that dynamic speakers are powered by what are essentially inductors and have an impedance that may change wildly with frequency. More to consider is that dynamic drivers often need sharp crossover curves so that one does not run out of 'room' beneath the driver's resonant frequency. To accomplish this, higher order crossovers are needed, which change the phase of the signal as compared to the original input. It is possible to have the drivers connected 90, 180, or 270 degrees out of phase, causing destructive or constructive interference, and changing the dispersion pattern of the speaker.

There are loudspeakers which do not suffer from many of these problems; they are planar loudspeakers. To be discussed here are the Heil Air Motion Transformer, Magneplanar speakers, Ribbon speakers, and Electrostatic speakers. Each of these types of drivers is a very low mass design. The moving mass of a proper ribbon tweeter, for example, may only be 1% or less of the moving mass of a conventional tweeter. If supplied with a similar force to a conventional speaker, this membrane would accelerate 100 times faster as a result. The transient response of such a speaker would be considered very good. All of these speaker designs have this advantage over conventional speakers.

Magneplanar speakers powered in a similar manner to dynamic speakers. For a magneplanar speaker, the voice coil has essentially been unwound and placed on a thin membrane. The conducting wire in magneplanar speakers often takes the form of a foil, rather than some thin wire. It is also possible to deposit a thin film of conductor on a membrane, creating a light speaker still. The entire membrane is then placed in the presence of a magnetic field. When a current is passed through the wire foil, the entire sheet moves in response to the electrical signal and sound is created. Whereas a dynamic speaker is powered by a voice coil at the center, which results in the edge of the cone and the center not being perfectly in phase due to the lack of rigidity, a magneplanar speaker has no such defect. The entire panel is driven at the same time across its whole surface. Because the panel is so light, it is easy to move in response to a wide range of electrical signals. Magneplanar speakers are often run without a crossover point from 1kHz upwards because of their ability to easily respond to changes in an electrical signal.

Like every loudspeaker technology, this one has some drawbacks. Its primary drawback is that in order to reproduce large volumes of bass, a magneplanar speaker must be fairly large. The best commercially produced magneplanar bass driver has an area of 0.52m², and is 144cm*36cm. An equivalent dynamic bass driver could have a moving area of only 0.05m². Some magneplanar speakers also tend to have a beam-like radiation pattern. That is, information is only beamed away in a straight line from the speaker. It is difficult to hear the sound if one is sitting off-axis. Because the sound is so focused, a strong sense of imaging and realism is created for a small 'sweet spot'. In many applications, however, it is more advantageous to fill an entire room with sound. This is a tradeoff that varies with individual preference.

Ribbon speakers are very similar to magneplanar speakers. The primary difference is that in a true ribbon speaker, a sheet of foil is suspended in air without the aid of a membrane. This prevents the ribbon from working in concert with other driving foils to move a large volume of air. This property typically limits ribbons to high frequency applications, though some have been created in recent times with good midrange response. Because of their typically small size, ribbon tweeters often exhibit very good dispersion throughout the room. That is because they begin to act as a point source rather than a radiating panel.

Electrostatic speakers, or electrostats, are apparently similar to magneplanar speakers. Though they look the same, other than moving air with a thin membrane, there are few similarities. Electrostatic loudspeakers move the diaphragm in a push/pull fashion. While one side is being pushed, the other side is being pulled. This membrane is made even lighter than magneplanar drivers because is needs no voice coil. Aluminized Mylar on the order of µm is typically used. Other less exotic solutions can be used as well, such as cellophane impregnated with graphite. The membrane, regardless of what is used, must be light and able to conduct electricity. This membrane is called a stator as well; this is because it is set up with a static DC voltage on the order of several kV. Set on both sides of this stator, are two conductive screens. A musical signal, also on the order of several hundred volts, is passed through each of these screens. One screen is set up180 degrees out of phase with the original input. In this way, the entire diaphragm is moved in response to an electrical signal, much in the same way that magneplanar speakers are. A recent development in electrostatic speaker technology has allowed this type of speaker to be made with a curved surface. This allows the manufacturer of such a speaker to create the dispersion pattern desired.

These speakers, while overcoming the downfalls of magneplanar speakers, have some of their own. The first big issue: people don't like 10kV electrical signals within reach of their children. The screens can be insulated very well, and the perforations made very small to minimize this risk. However, there must be holes in the screen to hear the sound produced, and sharp things can still be poked into the diaphragm. The second issue is that electrostats share the magneplanar disdain for producing bass. Nothing can be done about this except to produce fairly large electrostatic panels. The third issue with this type of speakers is the need for unconventional amplification. Normal audio amplifiers are not set up to provide the voltages needed for electrostatic speakers. Commercially produced electrostats usually have their own amplification system that can either be powered by a signal from an audio component, like a CD player, or powered from the output of a normal power amplifier. This extra amplification does add cost to the production of such speakers.

The third type of speaker to be discussed here is the Heil Air Motion Transform, or AMT. This type of speaker produces sound by compressing its diaphragm like a bellows. In this type of speaker, thin conducting wires or foil is applied to an accordionlike diaphragm. Each of these wires in oriented in the same way, and current flows in the same direction for each wire. As a current flows through the wire, the wires move towards each other in response to an applied magnetic field. As the current oscillates, so does the position of each wire and the part of the diaphragm it's bonded to. The movement of the pleats in the diaphragm is what forces the air forward. In this type of design, the wires can be made to move very quickly. In addition, a huge amount of moving surface can be forced into a very small area. As a result, the frequency response is exceptional for even a small driver. The largest AMT commercially produced was only 16cm*3.5cm (excluding the magnet structure). Despite this, there has never been a commercial design using this driver with a crossover point higher than 1kHz. If allowed to play without the use of a crossover, the driver's useful frequency response extends below 500Hz. Furthermore, this same driver's frequency response extends to not less than 25kHz. Because of the principal by which these types of drivers work, dispersion is exceptional. The only major caveat with this type of loudspeaker is, again, its lack of ultimate low frequency extension. As an aside, this type of speaker would be used more frequently except for issues concerning the ownership of this design and who may produce it. Despite this, some European companies have begun using this design in recent years to excellent sonic results.

Each of the planar speakers discussed here have a common problem: a lack of low frequency response. Conventional speakers, which have been shown to produce superb bass, lack frequency extension and transient response. In many cases, it is advantageous to combine a conventional bass driver to these planar speakers to produce the widest range of frequencies possible. Because these planar drivers typically have frequency responses that extend to the lower midrange, it is often possible to combine them to a woofer with a simple 1st order 2-way crossover that preserves the phase of the original input signal. This is done in commercial applications for ribbon, electrostatic, and AMT type drivers. Large magneplanar speakers are typically made to run full range, and are often used with an external subwoofer. All of these solutions produces sound of exceptional fidelity which is in many ways superior to that of conventional speakers.

In conclusion, planar type loudspeakers are very useful. They overcome many of the downfalls of conventional speakers. Like any physical transducer, they are not perfect, but when engineered properly, a speaker system can be created that approaches the sound of real life very closely.