Speaker Research

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1 How does a speaker work

1.1 The Basics

In the absolute basic sense, a speaker is an electromechanical system which converts electrical energy to mechanical energy (audio).

The speaker consists of three major components, those being the magnet, the voice coil and the diaphragm. When current is passed through the voice coil an electric field is produced. This causes the voice coil, and all the components attached, to move away from the magnet[1]. Figure 1 shows this system.

The diaphragm, also called the cone, aims to perfectly mimic the behaviour of the voice coil. It converts the mechanical motion of the voice coil into acoustic energy, thus the material of the diaphragm will affect the response of the speaker. The common material of choice is paper, plastic or metal[2].

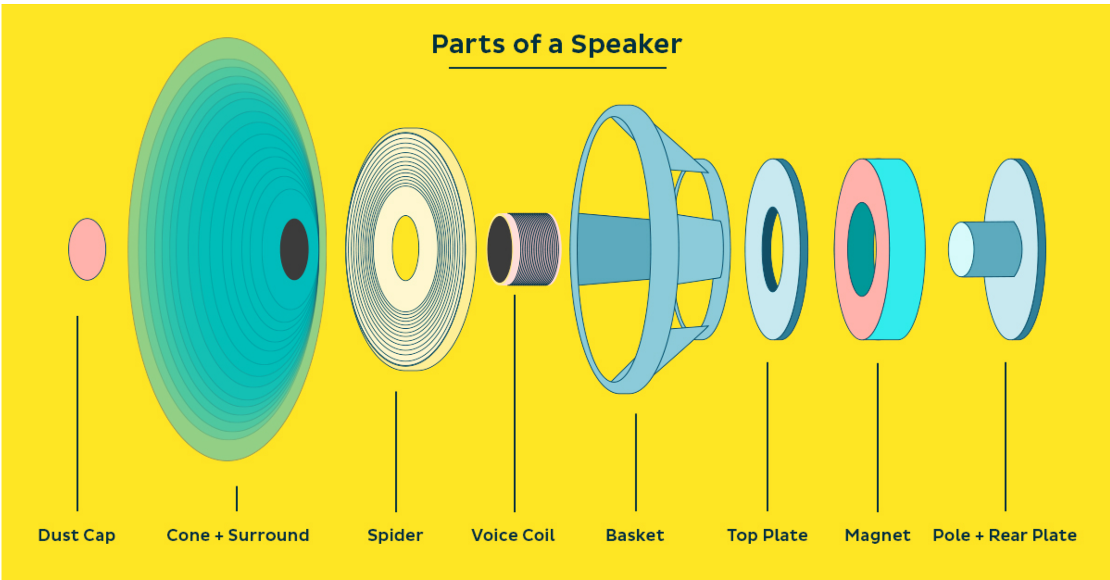

Figure 1: Parts of a speaker, source: [1]

Speakers have different frequency responses which tell how well the speaker will work at various frequencies. The goal is to get a flat frequency response, meaning the speaker will have the same response for all frequencies. Tweeters are speakers which are designed to produce high frequency audio (2kHz – 20kHz), they are often smaller than woofers. Woofers are designed to produce low frequency audio (50Hz – 1kHz) and are generally larger speakers [3].

2 Speaker Maximums

2.1 Frequency Response

- Increasing frequency response - Add more speakers like in [1] - Equaliser

2.2 Waveforms

- What waveforms will break the speaker over time.

3 Speaker Simulation

- How to model the speaker - Equivalent circuit - Treat speaker as a BPF?

4 Sound Parameters

4.1 Sound Power (SWL)

Sound power is the rate at which sound energy is emitted. The sound power of a speaker is generally given in decibels (dB). The formula for calculating the power in decibels is given in equation 1. [4][5]

$$L_W = 10log\left(\frac{P}{P_0}\right) \tag{1}$$

Where P is the sound power of the speaker, P_0 is the reference sound power and L_W is Sound Power Level (SWL). The reference sound power is set to 10^{-12} W, which is the lowest power sound a person could theoretically hear (i.e. someone with perfect hearing).

4.2 Sound Intensity (SIL)

Sound intensity is the measure of sound power per unit area. It is related to sound power by the formula in equation 2[6]

$$I(r) = \frac{P}{A(r)} \tag{2}$$

where P is the sound power at the source (W) and $A(r)$ is the area as a function of distance from the source.

For example, a spherical sound source will have a sound intensity which varies with distance at a rate shown in equation 3.

$$I = \frac{P}{4\pi r^2} \tag{3}$$

This is the inverse square law and it states that the sound intensity is proportional to the inverse of the distance from the source. i.e.

$$I \propto \frac{1}{r^2}$$

Speakers will produce a spherical sound wave in the direction of the source and therefore can be treated as a point source in a spherical field. Sound power is constant, therefore using the inverse square law the intensity at any distance can be calculated using the formula in equation 4. [4]

$$\begin{aligned} I_1 r_1^2 &= I_2 r_2^2 \\ \implies \frac{I_1}{r_2^2} &= \frac{I_2}{r_1^2} \end{aligned} \tag{4}$$

Sound intensity is often given in decibels, this is calculated using equation 5.

$$L_I = 10log\left(\frac{I}{I_0}\right) \tag{5}$$

Where L_I is the Sound Intensity Level (SIL) and I_0 is the intensity threshold of hearing, 10^{-12} W/m^2

4.3 Sound Pressure (SPL)

Sound pressure is the average variation in atmospheric pressure caused by sound. Sound pressure is often given in dB, calculated through equation 6. [7]

$$L_P = 20log\left(\frac{P}{P_0}\right) \tag{6}$$

Where L_P is the Sound Pressure Level (SPL), P is the rms sound pressure in Pa and P_0 is the reference sound pressure equal to $2x10^{-5}Pa$ which is the threshold of human hearing

Sound pressure is related to sound intensity through equation 7.

$$I = pv \tag{7}$$

where p is sound pressure and v is the particle velocity, both are functions of distance from the source

The sound pressure at two points can be related based on the equations in 7 and 4 results in equation 8.

$$p_2 = \frac{r_1}{r_2} p_1 \tag{8}$$

where p_n is the pressure at point n in Pa, r_n is the distance from the source in m

Sound pressure and sound power can be related through equation 9. [8]

$$L_W = L_P + 10log\left(\frac{A_s}{A_0}\right) \tag{9}$$

where A_s is an area of a surface which fully encompasses the source and $A_0 = 1m^2$

For certain areas drawn around the source, this can be simplified into equation 10 [5]

$$\begin{gathered}\textbf{Sphere:} L_W = L_P + 20log(r) + 11dB \\ \textbf{Hemishpere:} L_W = L_P + 20log(r) + 8dB\end{gathered} \tag{10}$$

5 Our Speaker

5.1 Specifications

We have an AS01508MS-SP11-WP-R speaker with the specifications shown in 1.

The frequency response shown in 2. The speaker has the best output between 600Hz and 20kHz. Between these frequencies the average sensitivity is 89dB SPL or 0.564Pa of sound pressure at 10cm away from the speaker.

Table 1: Specifications for AS01508MS-SP11-WP-R speaker, source: [9]

Parameters	**Values**	**Units**
Rated Input Power	0.7	Watts
Max Input Power	1	Watts
Impedance	8 ± 15%	Ohms
Sensitivity (SPL @ 2V/10cm) Average 0.8, 1.0, 1.5, 2.0 kHz	89 ± 3	dB
Resonant Frequency (free air)	600 ± 20%	Hz
Frequency Range	600 ~ 20,000	Hz
Frame Material	PBT	-
Magnet Material	NdFeB	-
Weight	1.5	Grams
Environmental Protection Rating	IP67	-
Buzz, Rattle, etc.	Should not be audible with 2.37V sine wave from 300 Hz to 3.4 kHz	-
Polarity	When positive voltage is applied to the positive terminal, the diaphragm will move outward	-
Storage Temperature	-40 ~ +80	°C
Operating Temperature	-20 ~ +70	°C

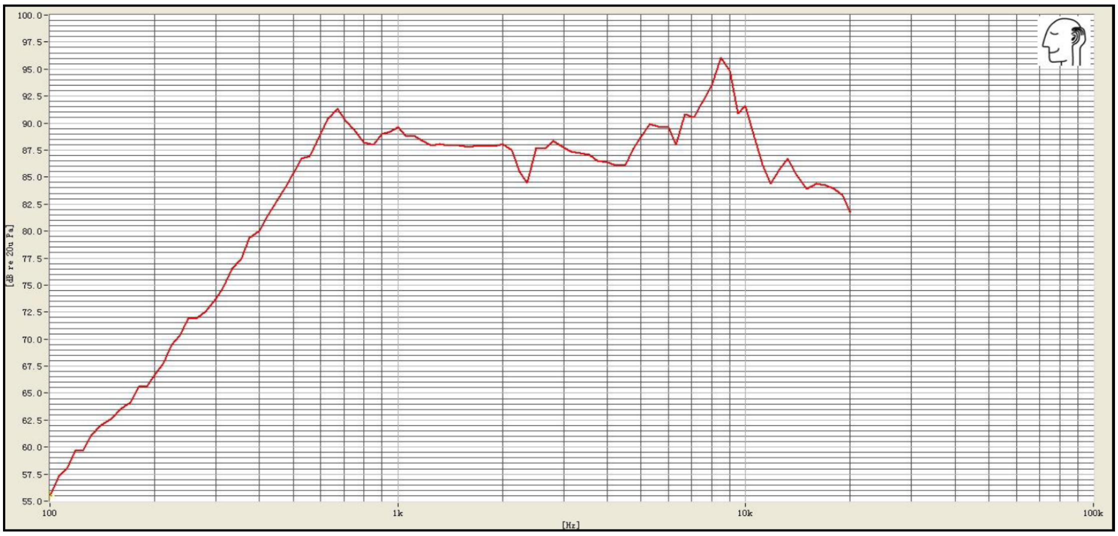

Figure 2: Frequency response for AS01508MS-SP11-WP-R speaker, source: [9]

5.2 Speaker Power and Efficiency

Following the calculation in [8] and equation 9. The sound pressure measurement was done with the speaker attached to a baffle board with the microphone at 10cm or 0.1m away. From figure 3, the radius between the centre of the speaker and the hemisphere must be 0.1 + (1/2)(0.0035)m = 0.102m. The area of the hemisphere is thus:

$$A = 2\pi r^2 = 2 \times \pi \times 0.102^2 = 0.065m^2$$

Using the average 89dB output, the sound power estimate is then calculated:

$$L_W = L_P + 10log\left(\frac{A}{A_0}\right) \therefore L_W = 89 \pm 3 + 10log\left(0.065\right) = 77.2dB \pm 3 \tag{11}$$

Alternatively, following equation 10 results in:

$$L_W = L_P + 20log(0.102) + 8dB = 77.2dB \pm 3$$

This result is useful as it can be used on the simulator `https://noisetools.net/noisecalculator2`.

The speaker efficiency can be calculated using the result from 11. From equation 1 the output sound power is P = 52.4μW. With an input of 0.5W, the efficiency is:

$$\eta = \frac{52.4\mu}{0.5} \times 100\% = 1.05\%$$

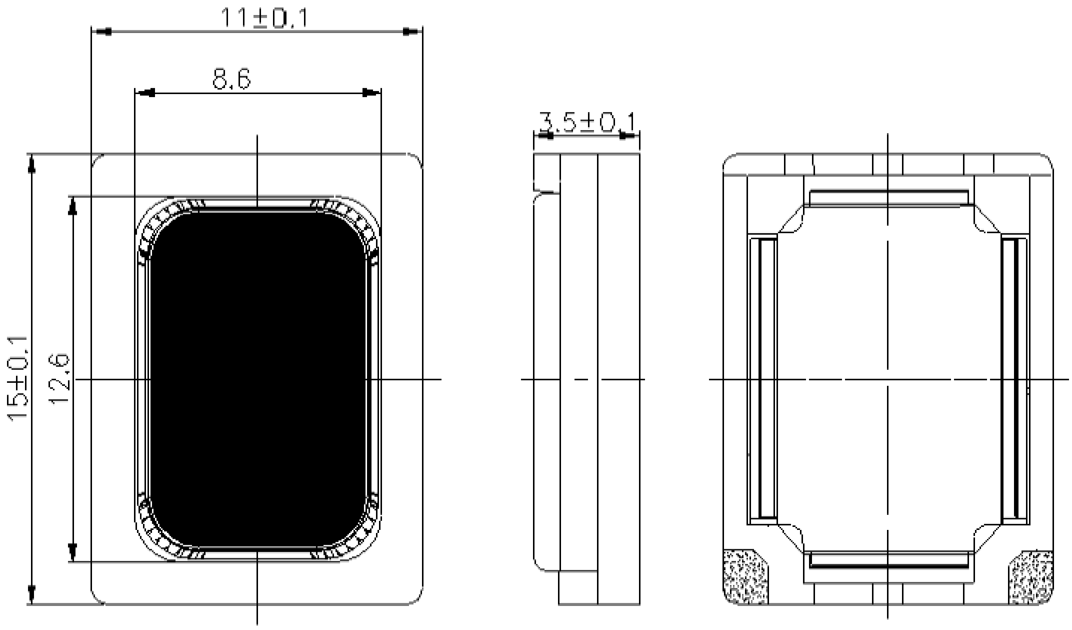

Figure 3: Dimensions of AS01508MS-SP11-WP-R speaker, source:[9]

5.3 Speaker Maximum

Our speaker has an output of 89dB SPL at 10cm with a 2V input at 1kHz. The speaker has 8Ω impedance thus the power input per output is:

$$P = \frac{V^2}{R} = \frac{2^2}{8} = 0.5W \tag{12}$$

Note: This is only true for some frequencies. The speaker has a maximum impedance of 11.4Ω at 600 Hz and 20kHz. From table 1, the speaker is rated for 0.7W and has a maximum input power of 1. This means we can double the power input. Based on the 3dB rule, this will only result in a 3dB increase in audio pressure[10]. Thus the average maximum output from the speaker will be:

92 ± 3dB at 1W input power

This is the maximum and running the speaker at above this input power for a period could result in damage done to the device.

6 Speaker Amplifiers

6.1 Introduction

Speakers typically require more power input than the output from a microcontroller pin can provide. Therefore we need a drive circuit to control the speaker. Our speaker is rated for 0.7W with a maximum of 1W input. Any less input will result in a lower than expected power output and any higher will burn out the voice coil and kill the speaker. There are various classes of amplifiers, the class is defined based on how much of the waveform does the active device conduct.

6.2 Class A Amplifier

In a class A amplifier, the output device conducts through the full waveform (360°). The most simple way to drive the speaker is to drive a BJT to control the input to the speaker this is shown in figure 4 (left). The circuit shown in figure 4 (right) shows a more complex class A amplifier which includes biasing and coupling and bypass capacitors to make a more reliable output. To operate for the full waveform, the transistor needs to be correctly biased such that it operates within its linear region.

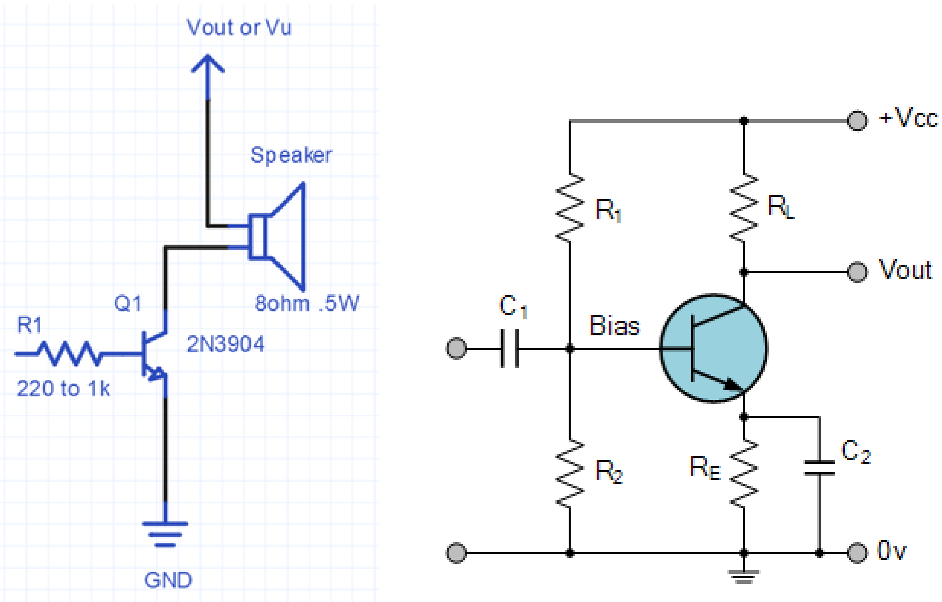

Figure 4: **Left:** simple speaker drive circuit. Source: [11] **Right:** Class A amplifier circuit. Source: [12]

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Advantages

- Simple, only has one active component therefore could easily be built without the need of a separate IC
- Low levels of distortion implies a high fidelity output

Disadvantages

- Inefficient, constant operation of the BJT in the active region causes power loss meaning the maximum theoretical efficiency is around 30%
- Need to correctly bias the transistor base DC voltage to allow for correct operation and low distortion
- Power supply must be sized correctly due to high idle current from the amplifier

6.3 Class B Amplifier "Push Pull"

Can improve on the efficiency of the class A amplifier by adding a complimentary pnp BJT. Class B amplifiers are defined based on each active component operating for half of the waveform (180°). An example of a class B amplifier is given in figure 5 which also shows decoupling capacitors and resistors for correctly biasing the transistors. The npn transistor conducts for the positive half of the cycle and the pnp transistor conducts for the negative half of the waveform. At the zero-crossing point of the waveform, neither of the transistors will conduct and thus will end up having a deadzone causing distortion in the output waveform.

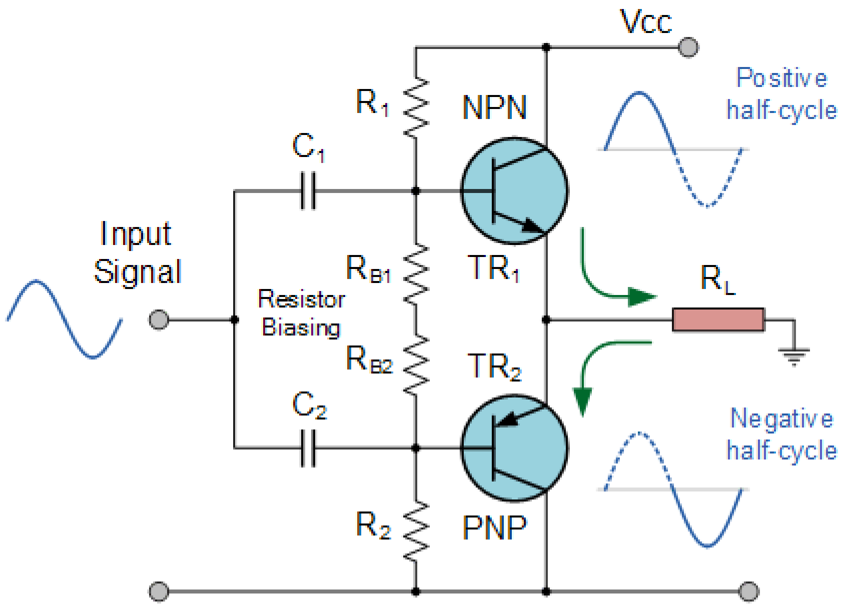

Figure 5: Class B amplifier circuit, source: [12]

Advantages

- More efficient than class A amplifier as each transistor operates 50% of the time. Theoretical maximum efficiency is 78.5%.
- Operating point of transistors is at around 0V

- Low standing bias (no input) current and thus low power consumption with no signal

Disadvantages

- The distortion at the crossover point makes the amplifier not useful for audio amplifier application
- More distortion than a class A amplifier

Since we care about the zero-crossing point of the waveform for distance measurements, this class of amplifier is unfit for our use.

6.4 Class AB Amplifier

Uses diodes, each transistor now conducts partially during the other transistors region. This reduces the distortion at the crossover point. Class AB each active component operates for between half the wave and the full wave (180°- 360°) depending on the biasing of the diodes. An example of a class AB amplifier is given in figure 6.

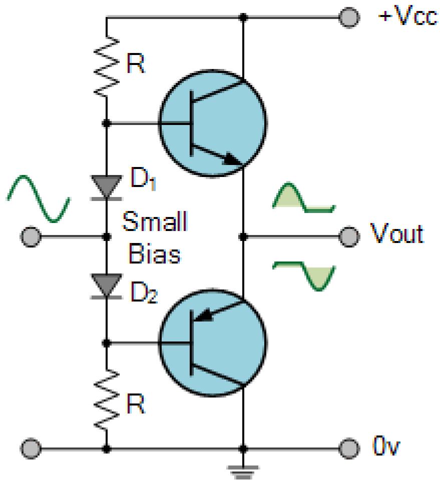

Figure 6: Class AB amplifier circuit, source: [12]

Advantages

- Can be more efficient than a class A amplifier if biased correctly
- Eliminates the distortion at the crossover point with class B therefore higher fidelity output signal

Disadvantages

- Less efficient than a class B amplifier, depends on biasing set by the diodes
- More complicated, have to correctly bias

6.5 Class D Amplifier

Class D amplifiers use PWM to control the amplifier. The block diagram for this class of amplifier is given in figure 7 and an example of the circuit is given in figure 8. Here the inductors and capacitors form a low-pass filter which takes the PWM input and forms the amplified sine wave which is fed to the speaker. Each output transistor is on and passes its full current when conducting, therefore there is very little voltage drop and thus power loss across the transistors. Class D amplifiers are a class of switching amplifiers, the active components act as switches as opposed to linear gain devices like in class A, B and AB above.

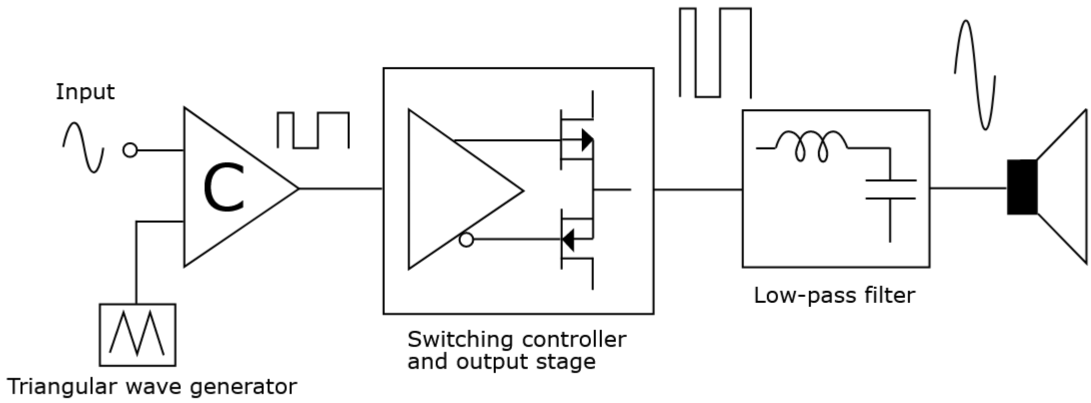

Figure 7: Class D amplifier block diagram, source: [13].

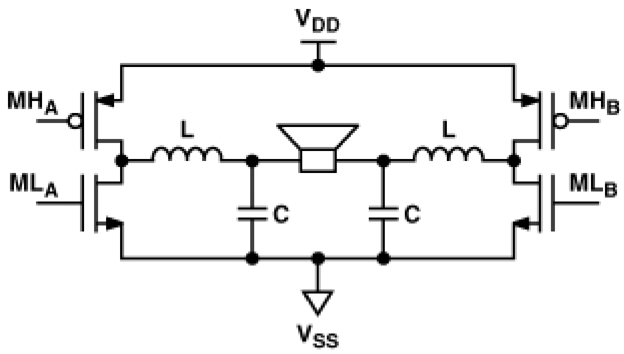

Figure 8: Class D amplifier circuit, source: [14]

Advantages

- Can reach up to 90% efficiency, on paper can reach 100%
- No need for biasing circuitry therefore less loss from biasing components

Disadvantages

- More active components than the other circuits

6.6 Chosen Amplifier

To start with, the chosen amplifier is the class AB LM386.

Notes

- Speaker moves both ways therefore want to have the resting position at 0V in order to be more efficient.
- Need to bias transistors such that the input voltage should exceed cut in voltage. BJT needs to be in the active region to operate as an amplifier. `https://www.tutorialspoint.com/amplifiers/transistor_biasing.htm` - Useful for calculating values for biasing: [15]

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