Calculating Gain for Audio Amplifiers

Audio Power Amplifiers

ABSTRACT

This application report explains the different types of audio power amplifier configurations, such as the single-ended (SE), the bridge-tied load (BTL) and the fully differential audio amplifier. Each configuration is illustrated with a block diagram, gain equations, and an example using realistic scenarios to illustrate to engineers how to calculate the gain of their audio amplifier.

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1 Introduction

The most common type of question that engineers ask when designing with audio power amplifiers is *what gain should I use?* or, in other words, *what resistor values should I choose?*

This application report is broken up into three sections with gain calculations for:

- The Single-Ended (SE) Audio Power Amplifier
- The Bridge-Tied Load (BTL) Audio Power Amplifier
- The Fully Differential Audio Power Amplifier

1.1 Power Into a Speaker

Before discussing the various audio power amplifier configurations, some basics about output voltage, speaker impedance and output power are presented.

1.2 Speaker Impedance

In the case of audio power amplifier design, most speaker impedances are in the range of 3 Ω and 32 Ω, determined by whether it is driving a notebook, flat panel, cell phone speaker, or a headphone. Output voltage (V_O) is always specified as RMS values, so for this application report, the following equation is used:

$$\text{Output Power } (P_O) = \frac{[V_{O(RMS)}]^2}{\text{Load Impedance } (R_L)}$$

where,

$$V_{O(RMS)} = \frac{V_{O(PP)}}{2\sqrt{2}}$$

It is important to understand the relationship between peak-to-peak output voltage, $V_{O(PP)}$, and the RMS output voltage $V_{O(RMS)}$, since this impacts the gain calculations of the audio power amplifier.

1.3 Gain Setting for the Audio Power Amplifier

It is also imperative to understand that the output signal from the CODEC or DAC driving the audio power amplifier should be as large as possible, to have a high SNR. Conversely, the gain of the audio power amplifier is set as low as possible. If the audio power amplifier's gain is set too high, then it amplifies the noise floor, along with the actual wanted signal of the CODEC or DAC. This decreases the dynamic range of the signal and reduces the quality of the sound.

2 The Single-Ended (SE) Audio Power Amplifier

2.1 Design

The SE amplifier is the simplest type of configuration and is used either when driving headphones, or when using a split voltage supply. Figure 1 illustrates the block diagram for such an amplifier.

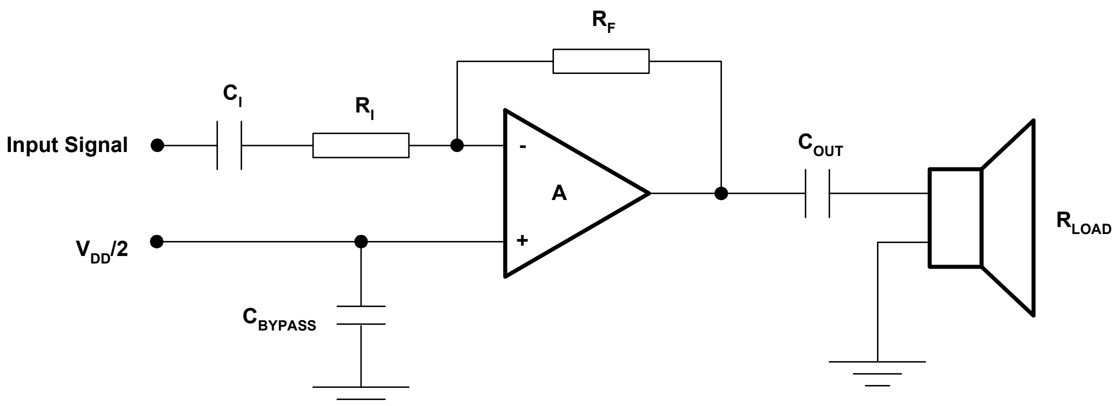

Figure 1. The SE Audio Power Amplifier

2.2 Equation

As illustrated in Figure 1, this type of amplifier has an inverting amplifier providing the gain. The input resistor, R_I, and the feedback resistor, R_F, provide the voltage gain of the amplifier in the following relationship:

$$|Gain| = \frac{R_F}{R_I}$$ *(Output signal is 180^O out of phase, versus the input signal)*

Therefore, for a voltage gain of 10 V/V or 20 dB, R_F is 10 times larger than R_I . Typical value for these resistors would be R_I = 10 kΩ and R_F = 100 kΩ. The following is an example for the gain calculation for a SE audio power amplifier.

2.3 SE Example

Questions:

An engineer's design requires 100 mW of RMS output power to be driven into his 16 Ω speaker. The audio amplifier runs off a 5 V supply and is driven by an audio CODEC that has a maximum (peak-to-peak) output voltage of 3.0 V. What must the gain of the amplifier be to ensure that the amplifier can delivery the required power into the load and what values of resistors should be used?

Answer:

Starting from the output power requirements, first, calculate the voltage across the load that allows 100 mW to drive the speaker. Using the following equation,

$$\text{Output Power }(P_O) = \frac{[\text{Output Voltage}(V_{O(RMS)})]^2}{\text{Load Impedance }(R_L)}$$

$100\text{ mW} = \frac{[V_{O(RMS)}]^2}{16\,\Omega}$ *, therefore,*

$V_{O(RMS)} = \sqrt{0.1 \text{ x } 16}$ *, which means that the RMS output voltage, $V_{O(RMS)}$, from the audio power amplifier is 1.26 V.*

Since the peak-to-peak output voltage of the CODEC is 3 V, convert this to RMS voltage,

$V_{O(RMS)} = \frac{V_{O(PP)}}{2\sqrt{2}}$ *, substituting in the number from this example*, $V_{O(RMS)} = \frac{3}{2\sqrt{2}}$ *= 1.06 V.*

Therefore, the RMS output voltage from the CODEC is 1.06 V and the RMS output voltage needed from the amplifier is 1.26 V. The gain of the amplifier is 1.18 V/V or 1.4 dB. Using Equation 3, as illustrated earlier,

$|\text{Gain}| = \frac{R_F}{R_I}$ *, substituting in the numbers from this example,* $R_F = 1.18 R_I$.

This means that R_I is 10 kΩ and R_F is 11.8 kΩ. This results in the following block diagram illustrated in Figure 2.

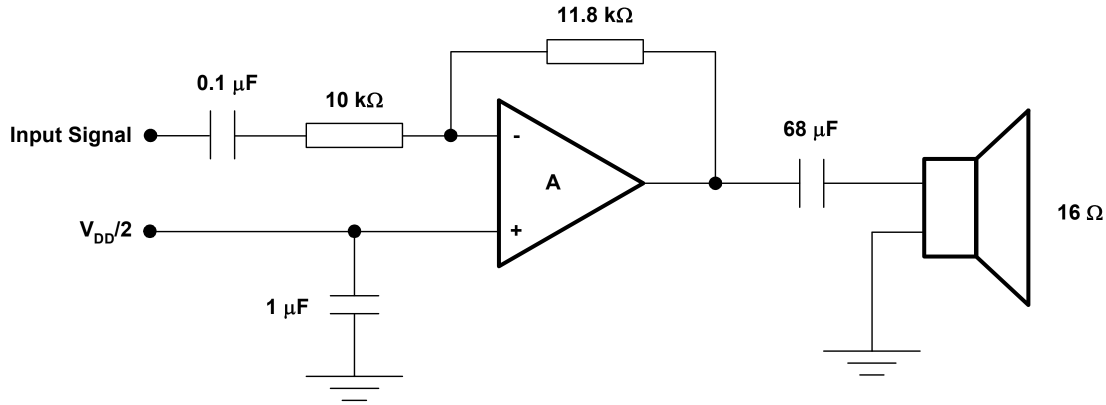

Figure 2. The SE Audio Power Amplifier Example

Note: The input coupling capacitor, C_I, and the input resistor, R_I, form a high-pass filter with a cutoff frequency, f_C, at:

$$f_C = \frac{1}{2 \times \pi \times C_I \times R_I}$$

The value of C_I and R_I should be carefully chosen to ensure that the high-pass filter does not attenuate the wanted audio frequencies.

In this example, setting the input capacitor to 0.1 µF results in a cutoff frequency of 169 Hz.

This also applies to the output dc blocking capacitor, since this, together with the speaker impedance, also creates a high-pass filter. Choose the value of the dc blocking capacitor ensuring that the low audio frequencies are not attenuated.

$$f_C = \frac{1}{2 \times \pi \times C_{OUT} \times R_{LOAD}}$$

In this example, with the output capacitor, C_{OUT}, set at a value of 68 µF, the resultant cutoff frequency is 146 Hz, so that it is close to the cutoff frequency of the input high-pass filter.

3 The Bridge-Tied Load (BTL) Audio Power Amplifier

3.1 Design

The BTL configuration differs from the SE configuration in that it includes an inverter follower to double the voltage across the load. This type of audio power amplifier is used when using a single supply voltage and maximizing the power to the load from that single supply. Figure 3 illustrates the block diagram for such an amplifier.

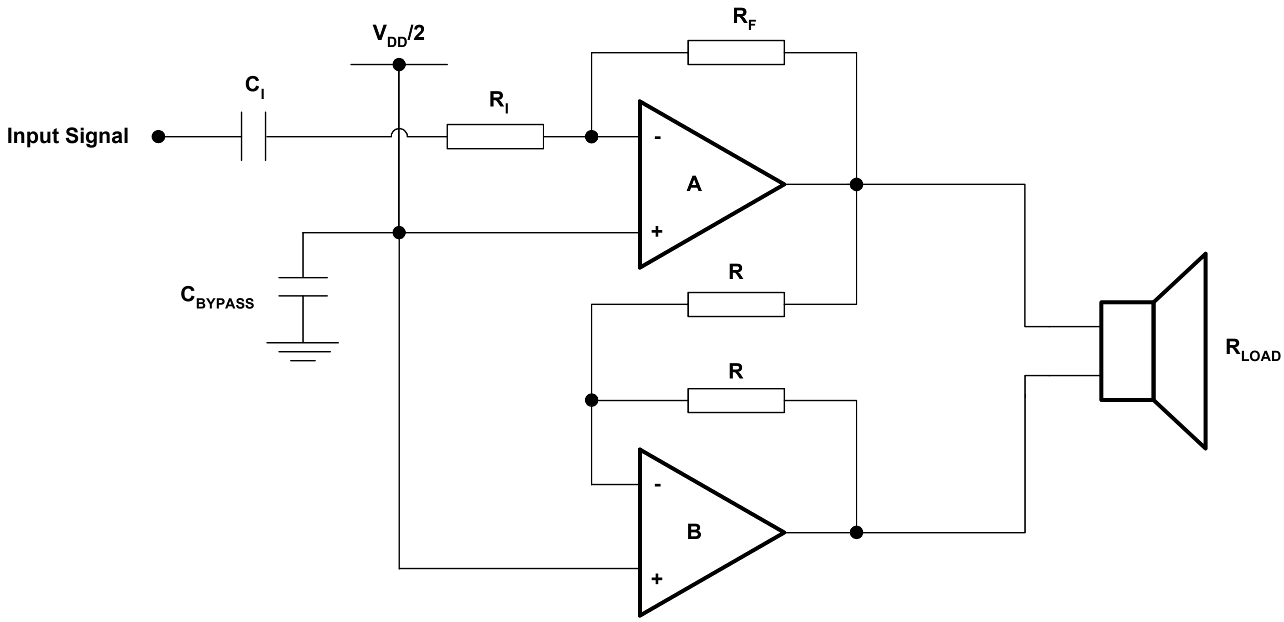

Figure 3. The BTL Audio Power Amplifier

As illustrated in Figure 3, this type of amplifier has the same inverting amplifier that provided the gain for the SE amplifier, but an inverter follower has been added to invert the output signal from the gaining amplifier, hence, doubling the voltage across the load. This results in a quadrupling of the power to the load, compared to the SE configuration mentioned previously.

3.2 Equation

The input resistor R_I and the feedback resistor R_F still provide the voltage gain of the amplifier. But in the case of the BTL amplifier, relationship has changed to:

$$|\text{Gain}| = 2\frac{R_F}{R_I}$$ *(Output signal is 180^O out of phase, versus the input signal)*

Therefore, for a voltage gain of 10 V/V or 20 dB, R_F must only be 5 times larger than R_I . Following is an example for the gain calculation for a BTL audio power amplifier.

3.3 BTL Example

Question:

An engineer's design requires that 2 W of RMS output power be driven into his 4-Ω speaker. The audio amplifier runs off a 5.0-V supply and is driven by an audio CODEC that has a maximum (peak-to-peak) output voltage of 3.0 V. What must the gain of the amplifier be to ensure that the amplifier can deliver the required power into the load, and what values of resistors should be used?

Answer:

Starting from the output power requirements, the first thing to do is to calculate the output voltage across the load that allows 2 W to drive the speaker. Using the following equation,

$$\text{Output Power }(P_O) = \frac{[\text{Output Voltage}(V_{O(RMS)})]^2}{\text{Load Impedance }(R_L)}$$

$$2\text{ W} = \frac{[V_{O(RMS)}]^2}{4\,\Omega}$$ *, therefore,*

$V_{O(RMS)} = \sqrt{2 \times 4}$ *, which means that the RMS output voltage from the audio power amplifier must be 2.83 V.*

Since the peak-to-peak output voltage of the CODEC is 3.0 V, convert this to RMS voltage,

$V_{O(RMS)} = \frac{V_{O(PP)}}{2\sqrt{2}}$ *, substituting in the numbers from this example,* $V_{O(RMS)} = \frac{3}{2\sqrt{2}}$ *= 1.06 V.*

Therefore, the RMS output voltage from the CODEC is 1.06 V and the RMS output voltage needed from the amplifier is 2.83 V. The gain of the amplifier must be 2.67 V/V or 8.5 dB. Using Equation 4, as illustrated earlier,

$\left|\text{Gain}\right| = 2\frac{R_F}{R_I}$ *, substituting in the number from this example,* $R_F = 1.33R_I$.

This means that R_I is approximately 10 kΩ and R_F is approximately 13.3 kΩ. This results in the following block diagram illustrated in Figure 4.

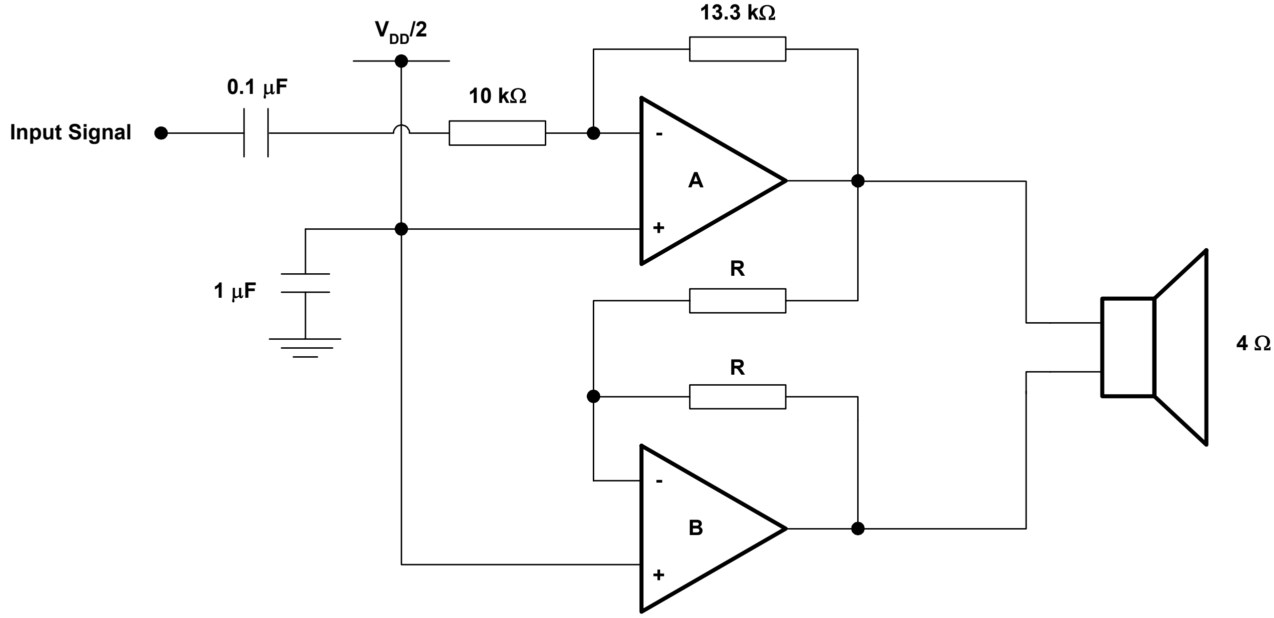

Figure 4. The BTL Audio Power Amplifier Example

Note: The input coupling capacitor, C_I, and the input resistor, R_I, form a high-pass filter. The values of C_I and R_I should be chosen to ensure that the high-pass filter does not attenuate the wanted audio frequencies.

In this example, the input capacitor is set to 0.1 µF to provide a cut-off frequency of 169 Hz.

Note that in Figure 4, the dc blocking capacitor used in the SE configuration has been omitted. Since both outputs are biased to the same dc voltage and the speaker is no longer referenced to ground, the dc blocking capacitor is no longer required. Only the input capacitor and resistor limit the low frequency response of the system.

4 The Fully Differential Audio Power Amplifier

4.1 Design

The fully differential configuration is very different from the typical BTL configuration. There is no inverter-follower to double the voltage across the load. However, since this is a differential amplifier, the output power to the load is the same as for the typical BTL amplifier, with the benefit that it is more immune to noise, both on the inputs and the outputs. This type of audio power amplifier maximizes the power to the load from a single supply in a similar way to the typical BTL amplifier mentioned earlier and performs very well in noisy environments, such as a cell phone or smart phone. Figure 5 illustrates the block diagram for such an amplifier.

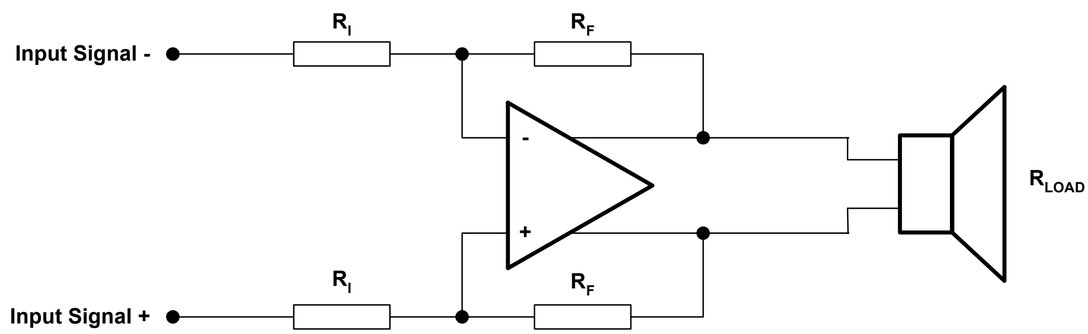

Figure 5. The Fully Differential Audio Power Amplifier

As illustrated in Figure 5, this amplifier consists of a fully-differential amplifier that provides the gain. As mentioned previously, the differential voltage swing across the load, results in a quadrupling of the power to the load, as in the case of the typical BTL amplifier.

4.2 Equation

The input resistor R_I and the feedback resistor R_F still provide the voltage gain of the amplifier. But in the case of the fully differential amplifier, the relationship has changed to:

$$\text{Gain} = \frac{R_F}{R_I}$$

Therefore, for a voltage gain of 10 V/V or 20 dB, R_F only must be 10 times larger than R_I. Following is an example for the gain calculation for a fully differential audio power amplifier.

4.3 Fully Differential Example

Questions:

An engineer's design requires the maximum RMS power from the TPA6203A1 be driven into a standard 8 Ω speaker while keeping the THD+N less than 10%. The audio amplifier runs off a battery that varies from 4.2 V down to 3.0 V. The input to the amplifier is an audio CODEC that has a maximum (peak-to-peak) output voltage of 1.8 V. What gain should be used to ensure that the TPA6203A1 can deliver the maximum power into the load while keeping the THD+N less than 10%?

Answer:

First, calculate the output power at 10% THD+N at 3.0 V supply. It is important to choose the minimum supply voltage, since, if calculating the gain at a 4.2 V supply, and the battery drops to 3.0 V, then it is likely that the output signal for the amplifier will clip and cause higher THD+N than originally expected.

Obtain the required output power from the Output Power versus Supply Voltage graph illustrated in Figure 6, which at 10% THD+N and 3.0 V supply is 550 mW.

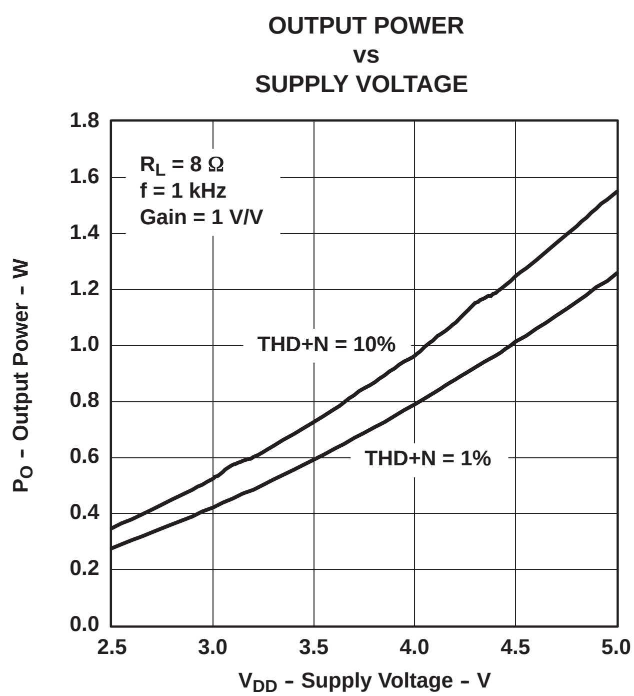

Figure 6. Output Power vs Supply Voltage Graphs for the TPA6203A1

Once the output power has been determined, calculating the required output voltage of the amplifier is done as in the previous sections using the following equation:

$$\text{Output Power } (P_O) = \frac{[\text{Output Voltage}(V_{O(RMS)})]^2}{\text{Load Impedance } (R_L)}$$

$$0.55\text{ W} = \frac{[V_{O(RMS)}]^2}{8\,\Omega}$$, therefore

$V_{O(RMS)} = \sqrt{4.4}$, which means that the RMS output voltage from the audio power amplifier must be 2.10 V.

Since the peak-to-peak output voltage of the CODEC is now 1.8V, convert this to RMS voltage,

$$V_{O(RMS)} = \frac{V_{O(PP)}}{2\sqrt{2}}$$, substituting in the numbers from this example

$$V_{O(RMS)} = \frac{1.8}{2\sqrt{2}} = 0.64\text{ V}$$

Therefore, the RMS output voltage from the CODEC is 0.64 V and the RMS output voltage needed from the amplifier is 2.10 V. The gain of the amplifier will be 3.82 V/V or 11.6 dB. Using Equation 5, as illustrated earlier,

$$\text{Gain} = \frac{R_F}{R_I}$$, substituting in the number from this example, $R_F = 3.82 R_I$.

This means that R_I is 10 kΩ and R_F is approximately 38.2 kΩ. Realizing that 38.2 kΩ is not a standard value, the nearest value available should be 38.3 kΩ. This results in the following block diagram:

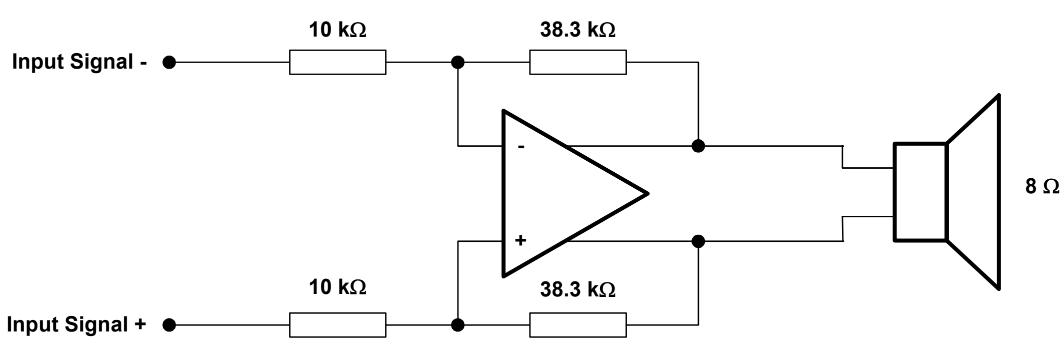

Figure 7. The Fully Differential Audio Power Amplifier Example

Note: In the case that R_F is integrated into the amplifier, which is typical of good audio power amplifiers, then obviously R_F is set to whatever value is in the data sheet and R_I is chosen to provide the necessary gain.

The resistors also typically need to be matched to 1% or better, since the better the matching of these components, then the better the power supply rejection ratio (PSRR) of the amplifier.

5 Conclusion

In calculating the gain of an audio power amplifier, it is important to ensure that the correct RMS values are used when calculating the necessary gain for the amplifier. It is also important to note, that when using input or output coupling capacitors, a high-pass filter is formed. R_I, C_I or C_{OUT} should be chosen to ensure that the wanted audio frequencies are passed through this filter.

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