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NCS2211 Audio Design Note

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APPLICATION NOTE

Introduction

System engineers require basic knowledge of a device to understand its performance and tradeoffs in their designs. The NCS2211 is a 1 W monaural amplifier designed to support singled−ended (SE) or bridge−tied load (BTL) configurations for desktop and portable computing. This design note will review and examine these two popular configurations in relation to specific design parameters such as gain dependent configuration, frequency response due to capacitive coupling, and efficiency.

Single−Ended Configuration

The single−ended (SE) amplifier is the basic configuration in audio applications. The SE configuration is often used to drive two speaker loads or headphones. The block diagram in Figure 1 illustrates an SE configuration since the load is connected to both amplifier outputs.

The signal gain for a single−ended configuration is:

$$A_V = \frac{R_F}{R_G} \angle 180 \qquad \text{(eq. 1)}$$

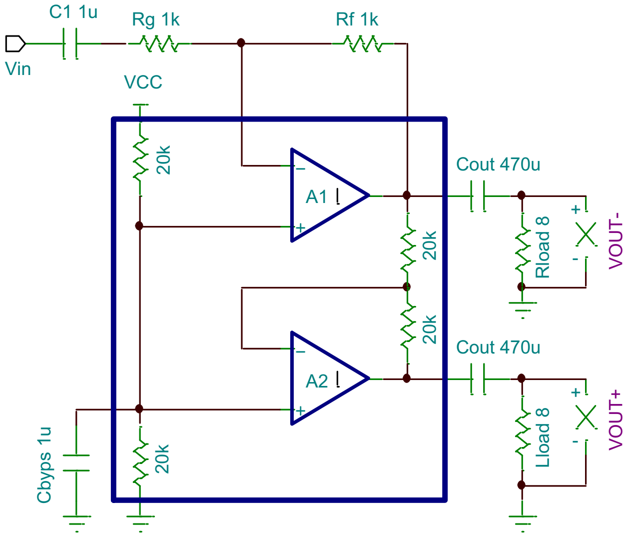

Figure 1. NCS2211 Single−ended (SE) Configuration

The ratio of the gain and feedback resistors may be adjusted to meet the necessary gain requirements for the application. For the following simulations the gain resistor, R_G, and feedback resistor, R_F, are set equal to one another to simply the results. The gain for each SE output is 0dB or 1 V/V, and is illustrated in Figure 2 below.

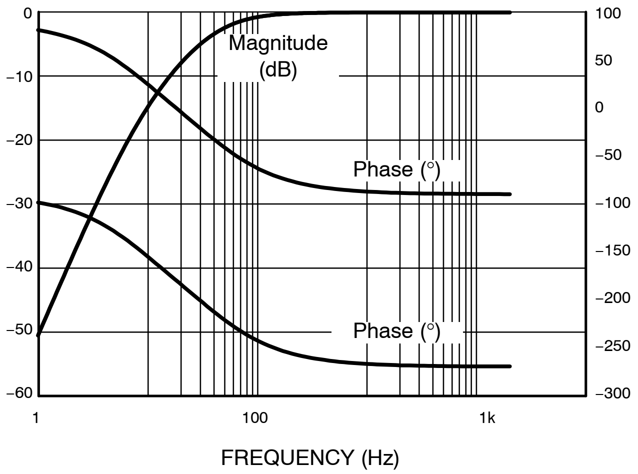

Figure 2. Gain and Phase vs. Frequency for SE Amplifier

The inverting amplifiers, A1 and A2, change the magnitude of the input signal polarity which induces a 180° phase shift from input to output. In comparing the phase shift of OUT+ and OUT−, as shown in Figure 2, the difference is approximately 180°. This is because the output of the first amplifier, A1, is the input to the second amplifier, A2.

Input and Output Coupling Capacitors

The amplifier shown in Figure 1 uses a single supply connection in conjunction with two internal 25 kΩ resistors to create a DC bias, equivalent to $V_{DD}/2$, on the non−inverting inputs of amplifiers A1 and A2. This allows a bipolar signal to swing around this common DC bias point.

Unfortunately for single−supply designs, input and output coupling capacitors are required to block any DC voltage.

Often the DC voltage from the input source will be biased at a different voltage level than the amplifier, so the input coupling capacitor allows the NCS2211 to bias according to its own midpoint voltage. Similarly, the output coupling capacitor isolates the DC bias of the NCS2211 from the speaker load. A speaker is not designed to handle any DC current as this will increase power dissipation, reduce dynamic range, and possibly damage the voice coil.

The frequency response must also be considered when using coupling capacitors. Referring back to Figure 1, C_{IN} and Rg create a high pass filter network. The gain and feedback resistors may be sized to allow a small value capacitor to be used where a typical value for C_{IN} is 1 μF. In order to avoid attenuating the lower frequencies of the audio range, the input network must be sized appropriately according to the following equation:

$$f_C = \frac{1}{2\pi R_G C_{IN}} \quad \text{(eq. 2)}$$

Keeping in mind the audio range is 20 Hz to 20 kHz.

Similarly, the output coupling capacitor and the speaker load also create a high pass filter. The cutoff frequency is also determined by Equation 2; however, the main concern with the output coupling capacitor is that it will be a large value, typically 470 μF when an 8 Ω speaker is being driven. A capacitor of this value is physically large and costly which are often critical considerations for system designers.

The last consideration when sizing both input and output coupling capacitors is the desire to design both cutoff frequencies to be equal. Figure 3 highlights the input cutoff frequency using a 1 μF and 20 kΩ input impedance and an output coupling capacitor value ranging from 68 μF, 100 μF, and 470 μF capacitors with an 8 Ω load.

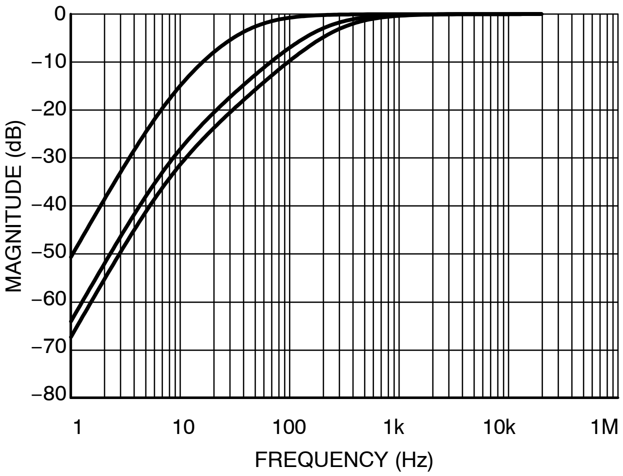

Figure 3. Input and Output Frequency Response − SE Amplifier

SE Efficiency

Efficiency is an important design goal especially in portable applications due to concerns for battery life. Efficiency, η, is the ratio of power delivered to the load to the power delivered from the supply as shown in Equation 3. Equation 4 is the total power supplied to the system is the sum of the power delivered to the load and the internal power dissipation.

$$\eta = \frac{P_{OUT}}{P_{SUPPLY}} \quad \text{(eq. 3)}$$

$$P_{SUPPLY} = P_{OUT} + P_{DISS} \quad \text{(eq. 4)}$$

In a single−ended configuration the power delivered to the load is straight forward. It is the ratio of the root−mean−square (RMS) value of the output voltage waveform to the load resistance:

$$P_{LOAD} = \frac{\left(V_{RMS}\right)^2}{R_{LOAD}} \quad \text{(eq. 5)}$$

The power delivered by the supply is more involved since the current and voltage waveforms are not proportional to one another. In the case of the SE amplifier Equation 6 shows, the power delivered by the supply is the product of the average current and the DC supply voltage:

$$P_{SUPPLY} = V_{DC} \times I_{DD(SE-AVG)} \quad \text{(eq. 6)}$$

For the case of the SE amplifier, only a half cycle of an assumed sinusoidal input waveform will pull current from the supply as shown in Figure 4:

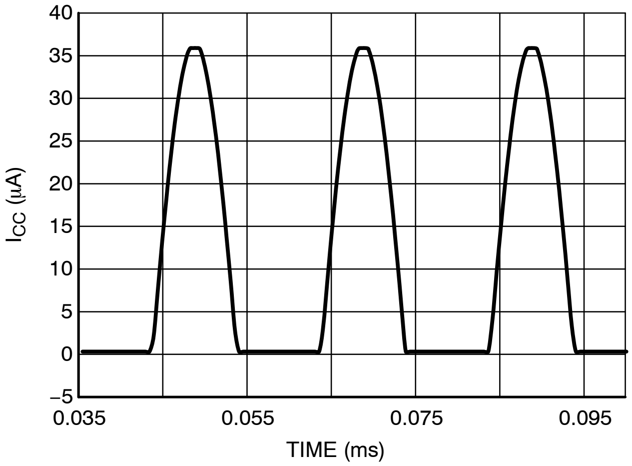

Figure 4. Supply Current Waveform − SE Amplifier

Current is only delivered for a half cycle in an SE configuration due to the nature of the half bridge output.

Figure 5 is a simplified representation of a half bridge circuit:

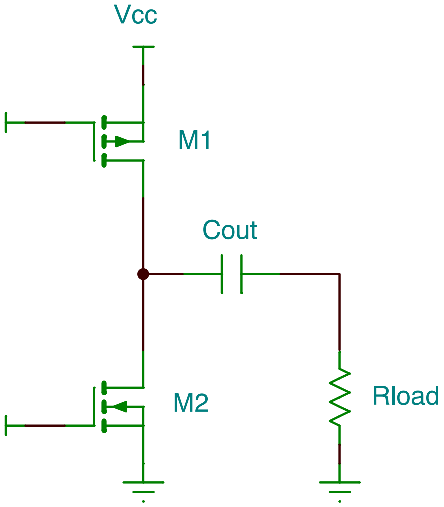

Figure 5. Class B Output Stage – SE Amplifier

During the positive cycle of a sinusoidal input, M1 conducts causing C_{out} to store charge across its plates. During the negative cycle of a sinusoidal input M1 is high impedance and M2 conducts. The current through the load during this cycle delivered by the charge stored across C_{out}; therefore no current is delivered by the supply.

To calculate the average current from the DC supply, integration under the current curve is required.

$$\frac{1}{\pi}\int_{0}^{\pi}\frac{I_P}{2}\theta dt \qquad \text{(eq. 7)}$$

$$\text{Since } I_P = \frac{V_{P(SE)}}{R_{LOAD}} \qquad \text{(eq. 8)}$$

It follows that $I_{DD(avg)}$ for a SE amplifier is proportional to:

$$\frac{I_P}{\pi} \qquad \text{(eq. 9)}$$

The supply power is calculated to be:

$$P_{SUPPLY} = V_{DC} \times \frac{I_P}{\pi} \qquad \text{(eq. 10)}$$

Finally, the efficiency of an SE amplifier can be calculated as:

$$\eta = \frac{\frac{\left(V_{RMS}\right)^2}{R_{LOAD}}}{V_{DC} \times \frac{I_P}{\pi}} \qquad \text{(eq. 11)}$$

Bridge–Tied Load Configuration

The bridge–tied load (BTL) configuration shown in Figure 6 is often used to obtain higher output powers compared to the SE configuration when all other variables are equal; i.e., load and supply voltage.

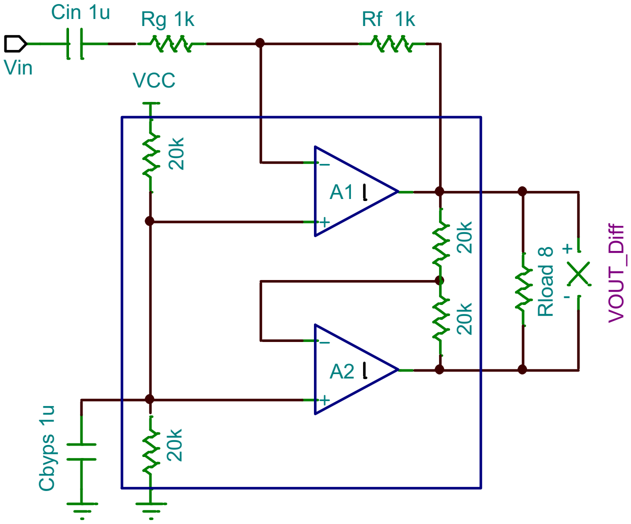

Figure 6. Bridge Tied Load (BTL) Amplifier

Since the load is connected between two SE (half–bridge) amplifiers there are two important benefits the BTL amplifier over the SE configuration. First, both sides of the load will be biased to $V_{DD}/2$ provided by the internal voltage divider network of the NCS2211 eliminating the need for output coupling capacitors. Second, the peak voltage swing across the load is twice that of an SE amplifier, thus the gain is actually twice that of the SE amplifier. The gain of a BTL amplifier can be expressed as:

$$A_{VDIFF} = 2\frac{R_F}{R_G} \qquad \text{(eq. 12)}$$

Figure 7 highlights the gain of the BTL configuration. The gain is 6 dB or 2 V/V higher than that of the SE configuration. The attenuation in the lower frequency range of the audio band is due to the high−pass input network:

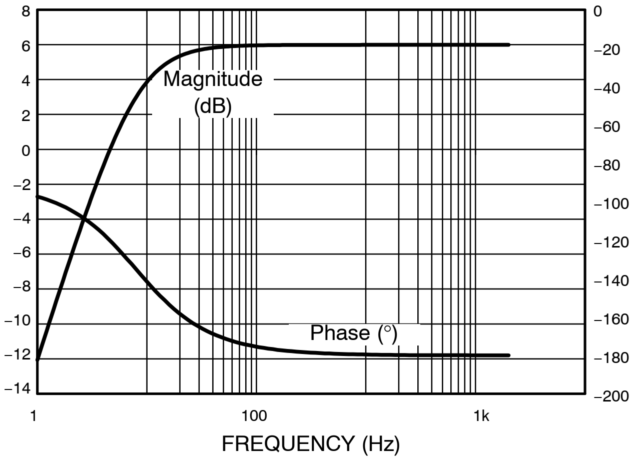

Figure 7. Input and Output Frequency Response − BTL Amplifier

To further understand how the voltage across the load doubles, Figure 8 illustrates the voltage waveforms of Figure 4. The peak−to−peak voltage is defined as $V_{p1} - V_{p2}$. It must be understood that the voltages are only ‘negative’ in respect to one another rather than common. The output voltage waveforms never swing below the common reference point of the circuit.

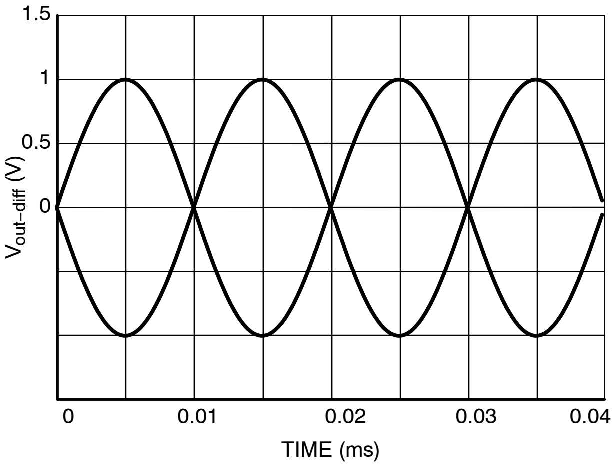

Figure 8. Output Voltage Waveforms – BTL Amplifier

Coupling Capacitors

As stated earlier, the input coupling capacitor creates a high pass filter with the same critical frequency calculated in Equation 2. As before, the same care must be taken to ensure that the input coupling network does not attenuate the low end of the audio range.

BTL Efficiency

The efficiency of a BTL amplifier shares the same ratio to that of a SE amplifier; reference Equation 3.

The power delivered by the supply for a BTL amplifier is also the product of the DC supply voltage and average current; however, current is pulled from the supply during both positive and negative cycles as shown in Figure 9.

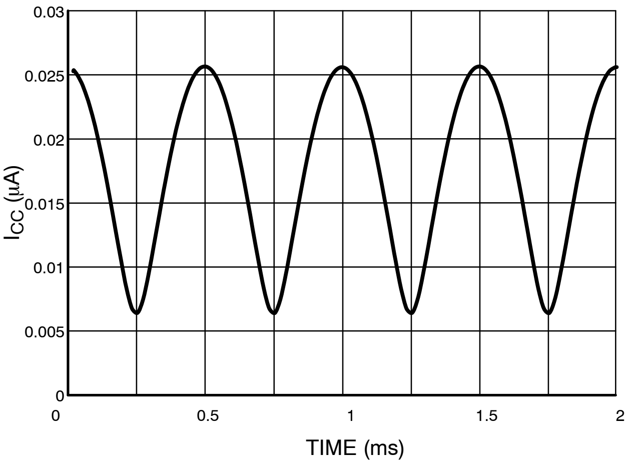

Figure 9. ICC Waveform − BTL Amplifier

Figure 10 is a simplified BTL circuit illustrating the current path during both positive and negative cycles. During the positive cycle M1 and M4 conduct while M3 and M2 are high impedance providing current path I1. During the negative cycle, the opposite is true thus providing current path I2.

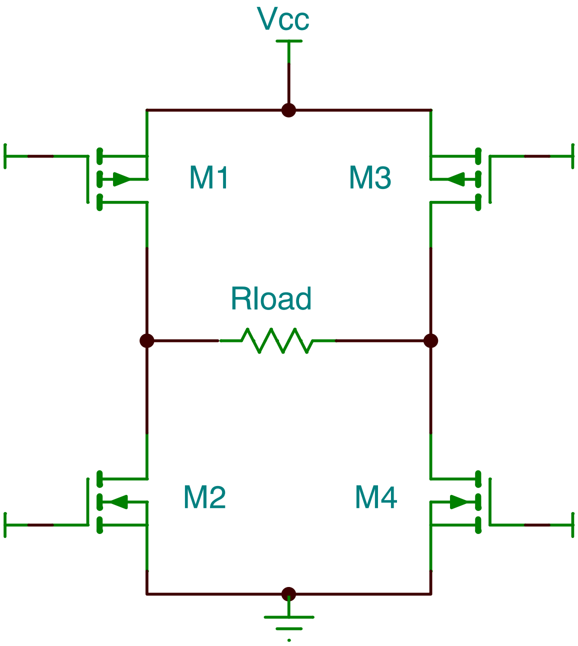

Figure 10. Simplified BTL Output Stage

Similar to the SE amplifier, integration is required under the current curve. For a BTL amplifier the average current is defined as:

$$\frac{1}{\pi}\int_{0}^{\pi} I_P \sin\theta dt \qquad \text{(eq. 13)}$$

Where

$$I_P = \frac{V_{P(DIFF)}}{R_{LOAD}} \qquad \text{(eq. 14)}$$

Therefore $I_{DD(avg)}$ for a BTL amplifier is:

$$\frac{2I_P}{\pi} \qquad \text{(eq. 15)}$$

The supply power is calculated to be:

$$P_{SUPPLY} = V_{DC} \times \frac{2I_P}{\pi} \qquad \text{(eq. 16)}$$

Finally, the efficiency calculation for a BTL amplifier is shown below:

$$\eta = \frac{\frac{\left(v_{RMS}\right)^2}{R_{LOAD}}}{V_{DC} \times \frac{2I_P}{\pi}} \qquad \text{(eq. 17)}$$

Summary

In audio applications it is important to maintain the quality of the single to ensure sound clarity. The use of capacitors can cause distortion; therefore, eliminating the output capacitors as in the BTL configuration is a great improvement over the SE configuration. Another important parameter is the power consumption and overall efficiency, especially in portable applications. The supplied power in an SE configuration is half of the power required for a BTL configuration. However, because the gain in a BTL configuration is taken differentially the overall gain is doubled. Doubling the gain results in an output power of four times the SE configuration and twice the efficiency. It has been shown that there are more advantages to utilizing the bridged configuration. However, depending on the specific application it may be more beneficial to use the SE setup. To simply things ON Semiconductor, a low distortion, class AB audio amplifier capable of both SE and BTL configurations. To learn more refer to the NCS2211/D datasheet.

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