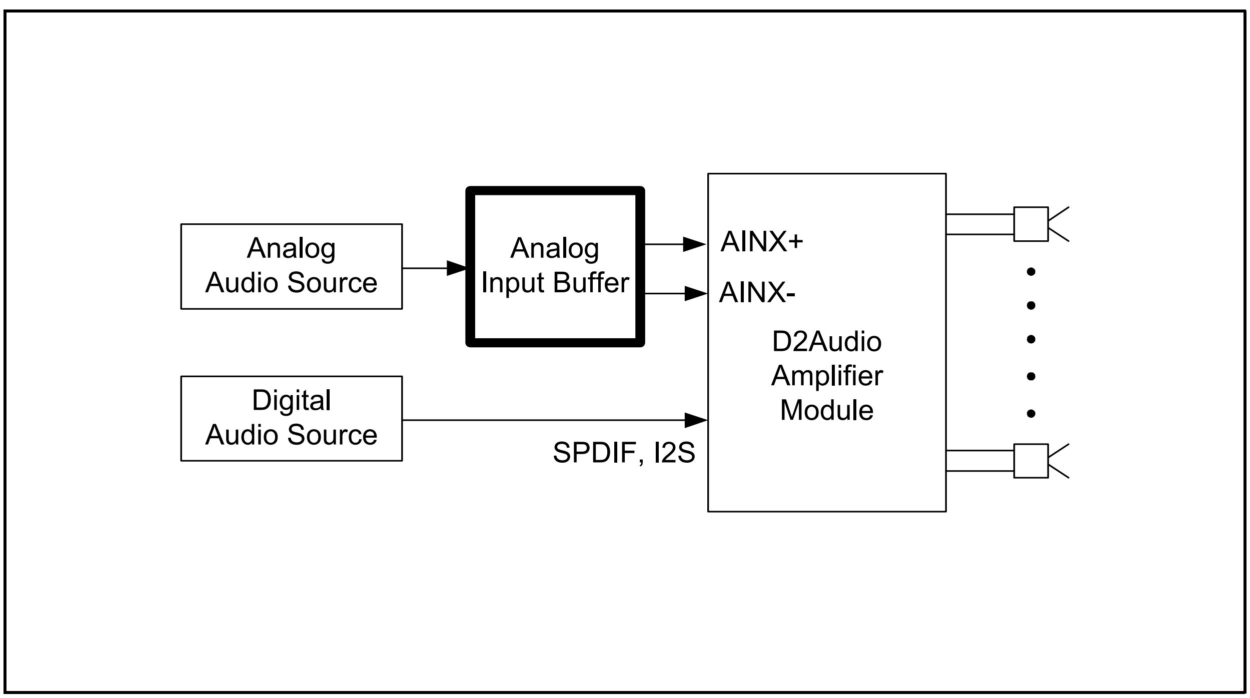
APPLICATION NOTE AN05

Analog Input Buffer Amplifiers

INTRODUCTION

The preferred audio input type for D2Audio® Class D amplifier modules is digital. For applications that require analog input signals and the best possible performance, the use of external Analog-to-Digital Converters (ADCs) is recommended. For applications that require analog input signals and medium performance at lowest cost, D2Audio modules include optional internal Analog to Digital Converters (ADC). To realize the best and most repeatable performance from the module when using the internal ADC analog inputs, D2Audio recommends that an input buffer circuit be used to drive the analog input pins. This application note discusses the various options involved in the design of the input buffer circuit. Topics discussed include the internal structure of the module analog input, the external buffer amplifier architecture choices, some example schematics, PCB layout guidelines and finally a design checklist. Designers can use the checklist to make sure all of the important factors have been included in their own buffer amplifier design.



1 Overview

The basic analog input buffer function is to drive the amplifier module with a low impedance signal and to adjust the signal level to the match input level range of the internal module ADC. There is no generic solution to this issue. The amplifier design is a balanced trade-off of the technical requirements, performance, cost, and physical implementation issues.

A good input buffer design meets several qualitative specifications:

- Provide gain or attenuation to match the analog input level to amplifier output full power.
- Does not alter the audio band signal characteristics.
- Immune to EMI and does not generate any interfering signals.
- Tolerant of electrical overstress and incidental short circuits to signals within the vicinity.
- Constructed from commonly available and reasonably priced components.
- Has stable characteristics over operating temperature range and supply voltage range.
- Behaves gracefully when operating conditions are exceeded.
- Adaptable to various manufacturing technologies.

The input buffer should have basic electrical specifications which match the D2Audio amplifier module analog input specifications. The buffer specifications include input and output impedance, maximum input and output levels, dynamic range, frequency response, THD and noise.

The following discussion illustrates the impact of these specifications on the buffer amplifier design. Maximum performance is obtained from the amplifier with a differential analog input source, driving a differential input buffer that is gain matched to the ADC full scale. The ADC inside the amplifier module uses differential inputs for maximum dynamic range.

For a system where the analog inputs are single-ended and maximum performance from the ADC is not required, the ADC may be driven single-ended. In such a system the following example buffers are simplified by deleting the AINX- stage and grounding the AINX- input pin on the amplifier module. The ADC dynamic range will be reduced by theoretically 6dB from the differential performance.

It is not recommended to drive the amplifier analog inputs directly from an RCA phono socket. In this case, the source impedance will depend on the length and type of cable, and the output impedance of the source driving the cable. This could result in unpredictable performance from the amplifier module.

The gain of the input buffer needs to be set to allow for some headroom in the overall signal path. The amplifier dynamic range is greater than the dynamic range of the internal ADC. The internal ADC will clip if overloaded and the resulting digital signals may induce ringing in the downstream processing in the amplifier. The amplifier module contains overload protection and compression filters to soften any clipping. This argues for putting more headroom in the ADC (less gain in the input buffer) and not as much, or none, in the amplifier module itself. The input buffer gain should be set so that the ADC does not clip with the maximum signal level.

2 AMPLIFIER MODULE ANALOG INPUT CIRCUIT

Figure 1 shows a simplified version of the module analog input circuit. Input capacitors C1 and C2, along with inductors L1 and L2 form an RF filter blocking RF energy from entering the amplifier and corrupting the ADC performance. R3 provides the primary terminating resistance for the differential input of 20kΩ. R1, R2 and C5 form a single pole, low pass anti-aliasing filter for the input sampling stage of the A/D converter. C5 also provides a local reservoir of charge for the input sampling stage of the A/D converter. The input pins of the A/D converter, ADC_IN1+ and ADC_IN1-, are biased at a nominal 2.5VDC by the A/D converter. Diode pack D1 prevents excessive voltage excursions of the ADC pins under overdrive conditions. Capacitors C3 and C4 are for DC blocking.

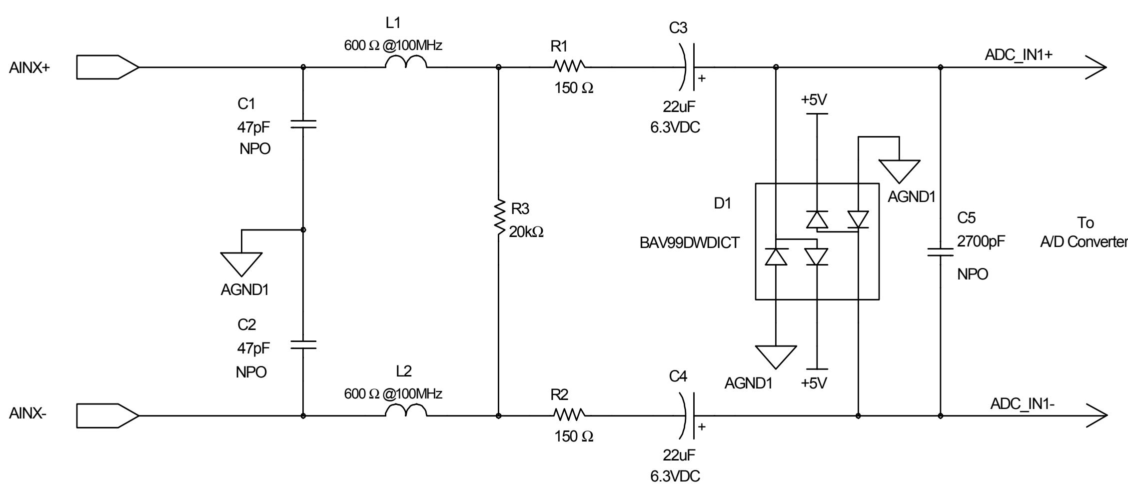


FIGURE 1: Input Circuit Inside Amplifier Module

Basic rules for driving the AINX+ and AINX- pins correctly are:

1) A low impedance source is required. While R1, R2 and C5 provide the optimum source impedance for the A/D converter, excessive external source impedance will degrade performance.

2) The DC level of the AINX+ and AINX- pins should be less than 2.5V and greater than -3.8V. This will avoid either reverse biasing or exceeding the maximum voltage rating of C3 and C4. If using op-amp supplies larger than +/-5V, and normal operation can cause a large DC offset, then diode protection must be used to clamp the input level on the AINX+ and AINX- pins.

3) Under overdrive conditions, the signal level of AINX+ and AINX- signals will be clamped by D1 at 0V or +5V. No external clamping diodes are necessary unless large a DC offset can occur (see above rule).

The ADC included in the D2Audio amplifier module uses differential inputs and needs 1Vrms, or 2.8V peak-to-peak, full scale input level, on each + and - pin, which is equivalent to 2Vrms differential on the input pair. The signal on the AINX- input should be identical to the signal on the

AINX+ input, except that it is inverted. The ADC contains a high pass filter which will remove any DC offset.

The amplifier module contains digital signal processing elements that can be configured to add gain to the signal. Applying full scale input voltage to the ADC will produce digital full scale output from the ADC. When the amplifier module is configured for 0dB, which is unity gain, this will result in full rated power at the amplifier output.

The ADC input must be low pass filtered to remove high frequencies that would alias into the audio band. The low pass filter must have adequate attenuation in the neighborhood of the ADC input sampling frequency. The ADC over-samples the analog input at 6.144MHz to generate a 48kHz PCM audio stream. Any signal or noise whose frequency is within +/- 20kHz of 6.144MHz, or multiples of 6.144MHz, will alias as audio signals with no rejection. A high order filter is not required. The simple filters illustrated in the buffer are adequate, providing about 24dB attenuation at 6MHz. However, care must be taken to ensure there are no large input signals around 6.144MHz or multiples of 6.144MHz.

3 Topology Choices

There are several top level choices to make when designing an input buffer. These choices include: single-ended to differential conversion or differential in to differential out, inverting or non-inverting configuration, capacitive or direct coupling, bipolar or uni-polar power supply, and choice of power supply voltage. The following paragraphs discuss the trade-offs when making these choices.

Single-Ended or Differential Input

For optimum performance, it is recommended to always drive the amplifier module differentially. This results in maximum dynamic range, minimum distortion, and increased noise immunity. The buffer amplifier provides a low impedance drive for the AIN+ and AINX- pins, and any attenuation or gain required. In many cases, the signal source will be single-ended, in which case a single-ended input to differential output buffer is needed. If the signal source is already differential, then a differential buffer amplifier must be used.

Single-ended inputs will typically swing around ground. Differential inputs may be ground referenced or floating. If the maximum input operating level and the ADC full scale input level are different, the buffer will require gain or attenuation. Small amounts of gain or attenuation, say +/-6dB, can be provided by the circuits described in the following section. Applications requiring significant attenuation must be carefully designed to accommodate the large maximum input operating level.

All analog inputs, single-ended and differential, should have a resistive termination to ground. If input attenuation is required before the buffer amplifier, then this termination resistance will be part of the input attenuator. The source output impedance must be considered when building an intentional input attenuator to ensure that the attenuation is correct and that the source amplifier can drive the load created by the input attenuator without distortion. The noise contribution of the input attenuation network must also be considered in the overall system noise budget.

Applications requiring attenuation should implement the attenuator at the buffer input as part of the input termination. The following circuit examples describe the input attenuator.

Inverting or Non-Inverting Op-amp Input Stage

This section compares single-ended input to differential output buffer topologies, one with a non-inverting op-amp input stage, the other with an inverting op-amp input stage. In either version, the signal polarity can be inverted by simply swapping the AINX+ and AINX- pins.

The benefits of the non-inverting input stage, Figure 2, are that the input impedance is determined solely by the input resistor to ground and the ability to use small value resistors resulting in better noise performance. The downsides of the non-inverting input stage include possible damage to input stage with high voltage inputs, possible increased distortion because of varying input current with + and - terminal voltage changes, and the inability to attenuate the input signal. The input stage gain is (R1+R2)/R1 which can vary from unity to whatever is practical. The input impedance is R3.

In contrast, the benefits of the inverting input stage, Figure 3, are immunity to high voltage input damage, no distortion caused by + and - terminal voltage changes and the ability to attenuate or amplify the input signal. The downsides of the inverting input stage include typically lower input impedance to avoid an unacceptably high noise penalty caused by large value input resistors, and the dependence of the input impedance on gain component selection. The lower input impedance means that the gain is more affected by the driver output impedance. The input stage gain is R2/R1 which can be less than or greater than unity. The input impedance is R1.

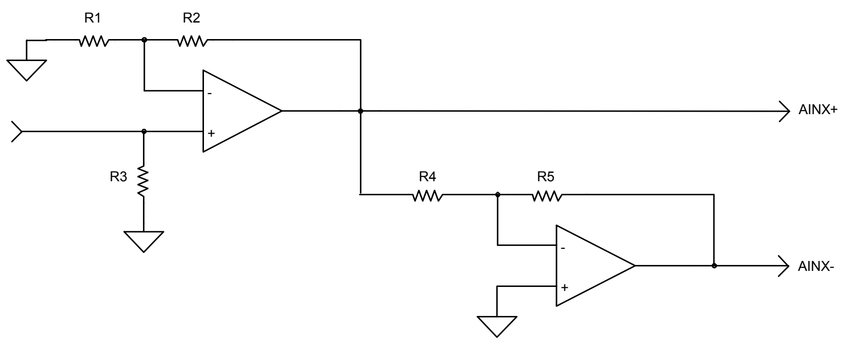


FIGURE 2: Single-ended to differential buffer, non-inverting topology

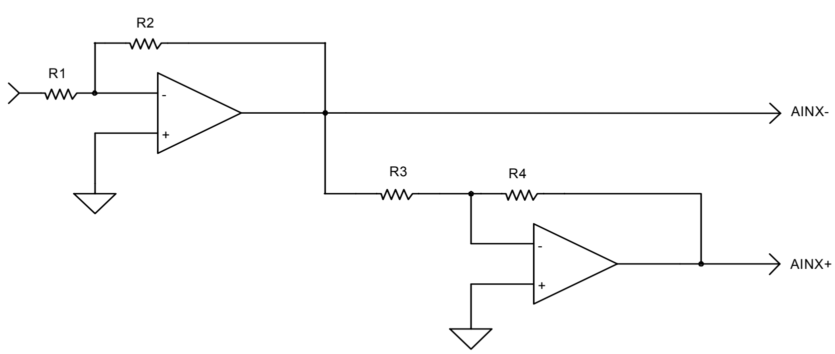


FIGURE 3: Single-ended to differential buffer, inverting topology

Capacitive or Direct Coupling

The amplifier module is capacitive coupled internally. It is recommended to also use capacitive coupling for the external buffer amplifier, which gives complete control over the DC level. If direct coupling is used, then the application of an unknown DC input level could cause the output DC level to exceed the maximum allowable DC input levels of the module. If the source DC offset is known and well controlled, then direct coupling may be used to reduce cost and reduce any possible distortion introduced by series capacitors.

Power Supply Considerations

D2Audio amplifier modules typically operate from +48V, +12V and +5V. Since no negative supply is required for the module, then the input buffer should preferably also operate from a unipolar positive supply. Using a unipolar supply requires biasing the buffer op-amps at an approximate mid-scale DC voltage level. If a negative supply is available for other reasons, then the buffer op-amps should operate from bipolar supplies, using 0V as the DC level and eliminating the need for bias components.

The voltage level of the power supply depends on the ability of the op-amps chosen to swing close to the power supply rails without adding distortion while driving the load. The signal swing needed by the module for full power is 2.9V pk-to-pk on each input pin. For a single +5V supply op-amp, this leaves 1V of headroom, assuming the signal is centered correctly, and the op-amp operates properly with a single supply.

If the op-amp power supplies are +5V or +/-5V then no over voltage protection components are needed to protect the amplifier module from excessive input voltages. If the power supplies exceed +5V or -5V, then additional protection components may be needed to guard against damaging components inside the amplifier module.

For overall power supply decoupling and layout guidelines, please refer to the D2Audio Amplifier Module power supply application note.

4 Example Single-Ended Buffer Amplifier Schematics

The next several figures show examples schematics for single-ended to differential buffers using different topologies and power supplies.

Figure 4 shows a non-inverting input stage op-amp with a unipolar +5V supply. R3 in parallel with R4+R8 determines the input impedance. C3 is large enough to ensure a flat low frequency response. The bass roll off corner frequency is given by:

$$\frac{R3 + R4 + R8}{2\pi C3R3(R4 + R8)}$$

R1, R2, R5 and R6 are low enough in value to yield low noise, while not exceeding the output drive capability of U1. R1 and R2 are set for a gain of 2, which yields full scale buffer input sensitivity of 0.5Vrms. U2A forms the bias generator buffer, which may be used to drive multiple channels. C2 and C4 are to ensure stability and provide additional high frequency filtering. R7 is chosen to present a similar source resistance to the + and - terminals of U1B to minimize the affects of any DC offset current. R4 and R8 form an input attenuator. If an overall input buffer gain of less than unity is required, components C1 and R1 should be omitted. This would set the op-amp gain at unity and the desired attenuation is determined by R4 and R8. If the overall gain is greater than unity, R1 and R2 set the gain, and R8 should be omitted. Capacitor C1 assures independent DC unity gain.

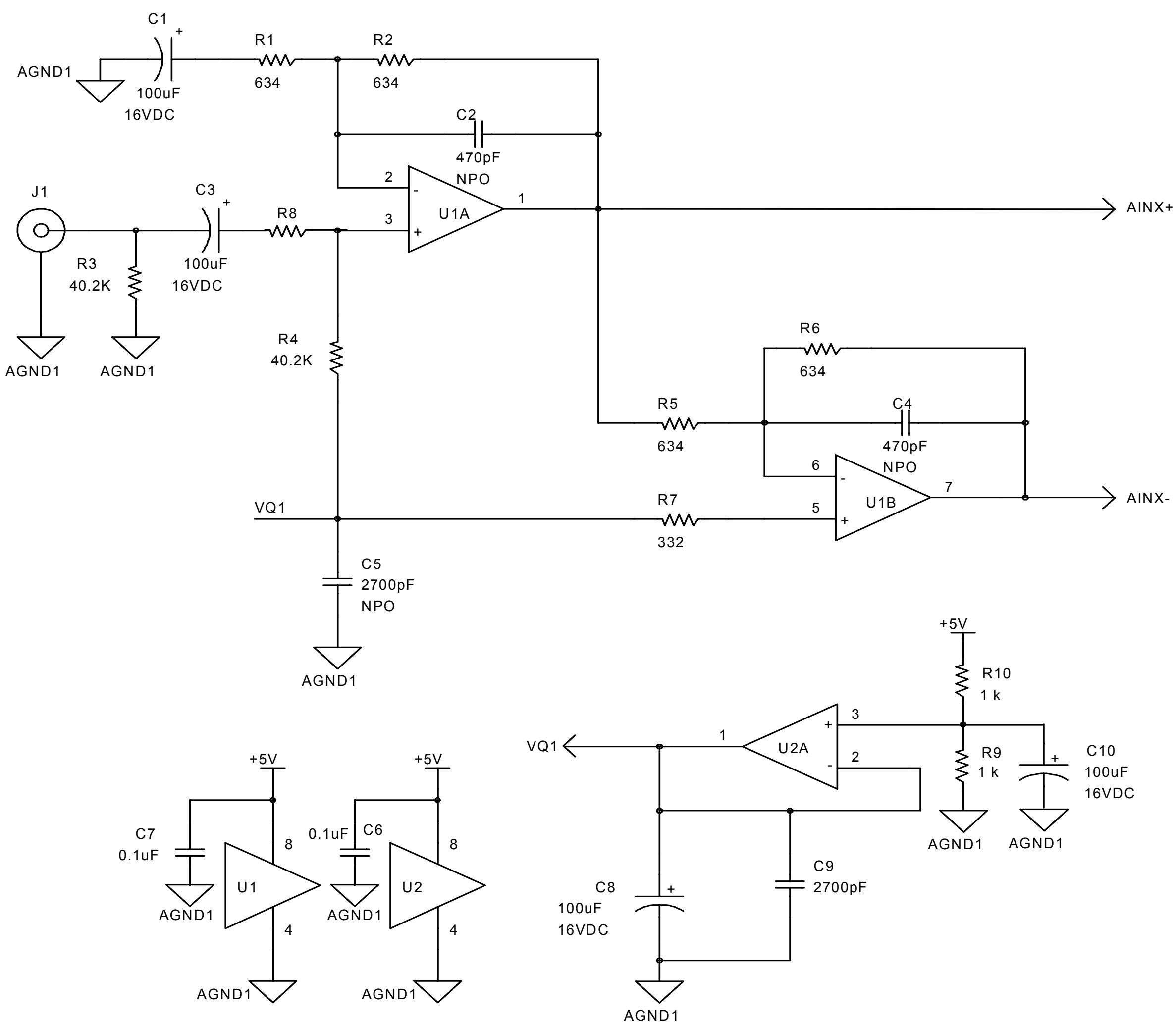


FIGURE 4: Single-ended to differential buffer using non-inverting input stage and unipolar supply

Figure 5 shows a non-inverting input stage op-amp with a bipolar +/- 5V supply. This is similar to the previous example, but with no bias components needed. R1 and R2 determine the overall gain, if R8 is much less than R4. With AGND1 used as a reference and gains of 0dB to +6dB, it is possible to eliminate the DC decoupling capacitor, C1, in the feedback loop. Even with 6dB of gain, the circuit will have enough headroom to accommodate input signals up to 1Vrms, but the output may overdrive the ADC input, depending on the signal source amplitude. For unity gain, omit R1 and short R8.

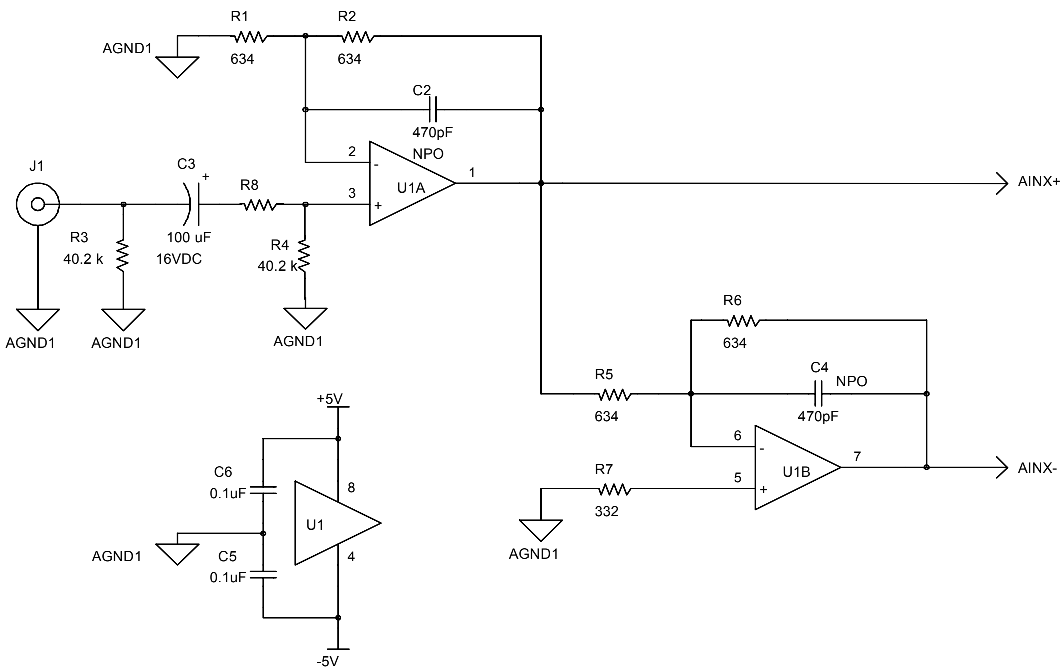


FIGURE 5: Single-ended to differential buffer using non-inverting input stage and bipolar supply

Figure 6 shows an inverting input stage op-amp with a unipolar +5V supply. R1 in parallel with R3 determines the input impedance. R3, R2, R5 and R6 are chosen to minimize noise contribution while not presenting a load impedance to the input that is too low. If the source can drive 600 ohms at 1Vrms, then reducing the value of R3, R2, R5 and R6 will lower the resistors' contribution to the noise floor. Input gain is set to 0.5, which gives full scale from the amplifier module with a 2Vrms input to the buffer. The main trade-off of this buffer implementation is that increasing the input resistance will result in greater noise.

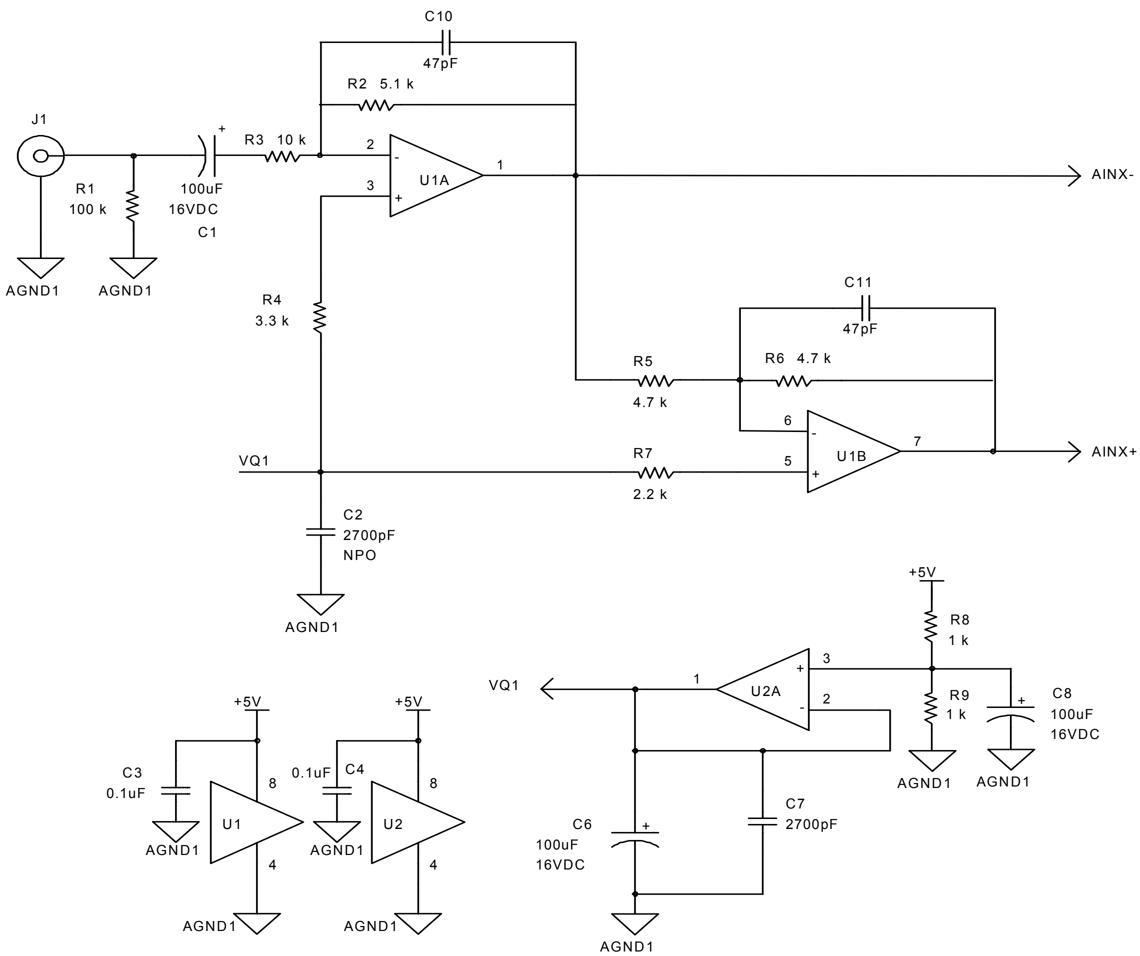


FIGURE 6: Single-ended to differential buffer using inverting input stage and unipolar supply

Figure 7 shows an inverting input stage op-amp with bipolar +/- 5V supplies. This is similar to the previous example, but with no bias components needed.

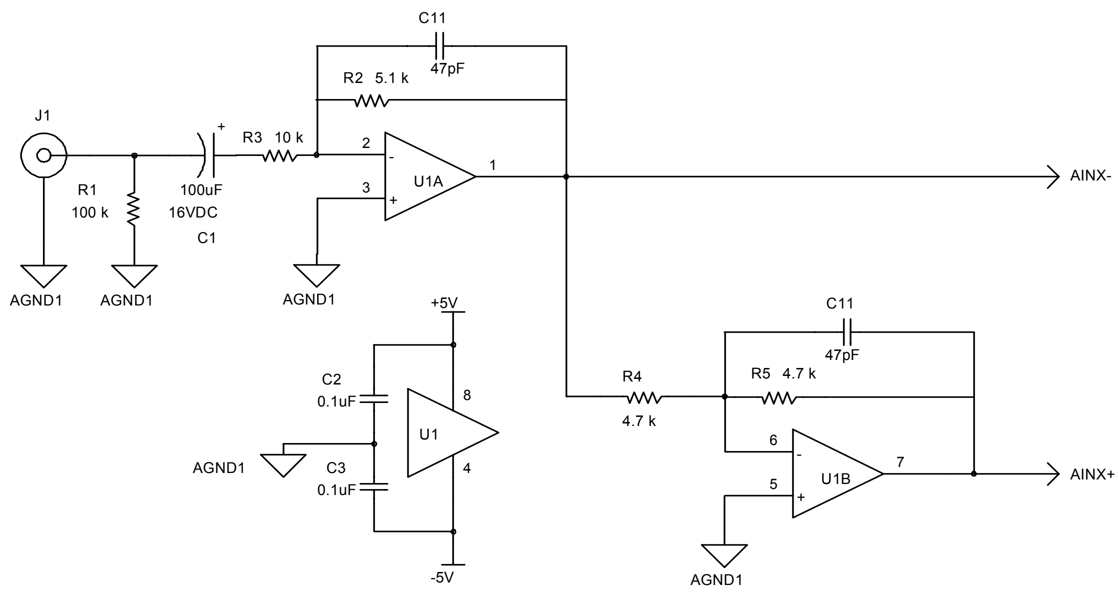


FIGURE 7: Single-ended to differential buffer using inverting input stage and bipolar supply

5 Example Differential Input Buffer Amplifier Schematic

Figure 8 shows a differential input buffer with a bipolar +/-5V supply. The op-amps are used in a non-inverting unity gain configuration. The input impedance is determined by the parallel combination of R3 and R4+R9 for the positive side, R7 and R8+R10 on the negative side. The overall buffer attenuation is established by the R4/R9 and R8/R10. Setting R9 and R10 to zero gives unity gain. Setting R9 and R10 to the same value as R4 and R8 gives 6dB attenuation.

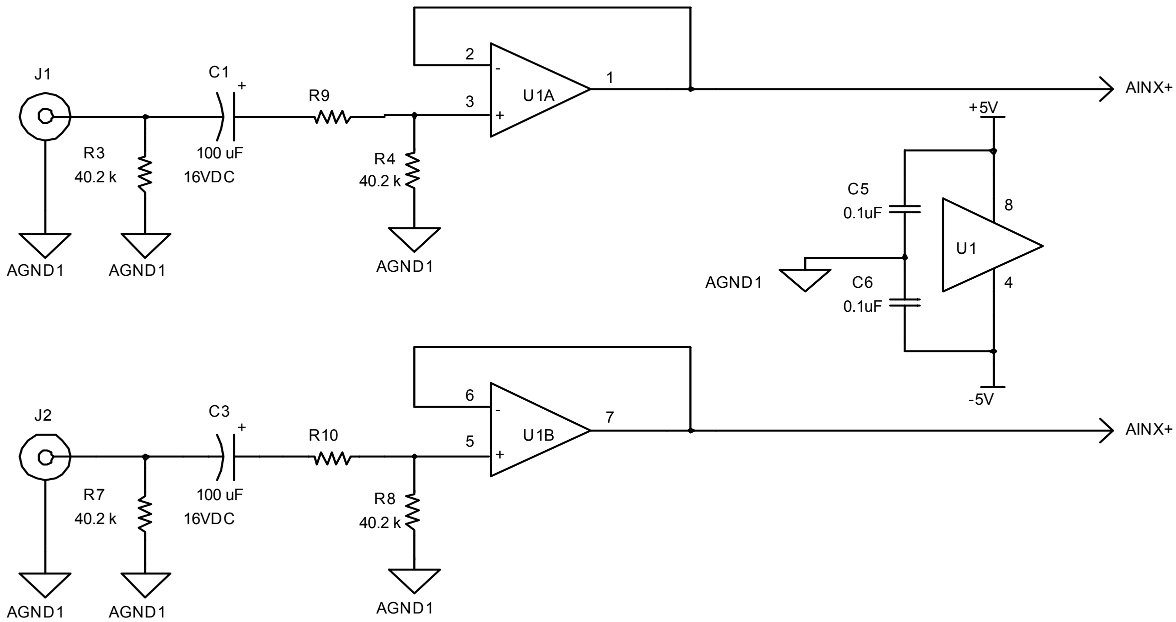


FIGURE 8: Differential input buffer with bipolar supply

6 Component Selection

Capacitors used in the audio signal path must have a low voltage coefficient and low leakage. Ceramic capacitors are generally not acceptable. Capacitors used for decoupling and anti-alias filtering must have good high frequency characteristics, such as NPO. Other capacitor considerations are microphonics, temperature sensitivity, and soakage (dielectric absorption).

Op-amps must be low noise, and operated with sufficient power supply levels to provide optimal bandwidth and headroom. Op-amps used as a non-inverting input stage will have the full input voltage swing at the input terminals. The supply voltage for these stages must exceed this input swing, and the selected op-amp should not cause distortion when driven with a varying voltage on the + and - inputs.

Resistors in the signal path must be metal film with as low value as practical to minimize thermal noise. Resistors uses for gain or attenuation setting must be of sufficient precision to meet the design tolerances.

7 Layout Guidelines

All signals must be referenced to the local ground. A balanced, or differential, input should be capacitively coupled and referenced to local ground. The analog input to the D2Audio amplifier module is differential and referenced to the analog ground terminal.

Ground differences between the input buffer and the audio source will cause problems. The ground voltage difference will add to the audio input signal. Ground currents must not be present in the ground shield of a single-ended input connection.

The buffer amplifier should be positioned close to the module analog input pins. Also, ground plane fill should be used around the buffer amplifier components and input and output signal traces. The buffer amplifier should not be close to digital signals or positioned over a digital ground or digital power plane.

Please refer to the D2Audio PCB Layout application note for further guidance on amplifier module motherboard layout.

8 Design Check List

This check list may be used by designers to make sure that their design meets the guidelines discussed in this application note.

- ❑ Signal gain: Check that the full scale input to the module is achieved, but not exceeded, when the maximum input voltage is applied.
- ❑ DC offset: Check that excessive DC offset is not applied to the module analog inputs: -3.8V < DC offset < 2.5V
- ❑ Switching: Check that when inputs are switched between analog sources, excessive transients are not applied to the analog inputs.
- ❑ Module inputs: Check that the module analog input pins are not connectly directly to a socket where users can plug in any signal using any cable with any source impedance.
- ❑ Power supplies: Check that the chosen op-amp can swing the required voltage range without distortion.
- ❑ Source impedance: Check that the source impedance has been taken into account in the gain calculations.
- ❑ Layout: Check that the buffer amplifier is close to the module analog input pins.
- ❑ Layout: Check that the buffer amplifier is not close to digital signals or positioned over a digital ground or digital power plane.
- ❑ Layout: Check that analog ground plane fill is used around the buffer amplifier components and input and output signal traces.
- ❑ Clock frequencies: Avoid clock frequencies that are within 24kHz of any integer multiples of 6.144MHz.
- ❑ Components: Check that any series capacitors are large enough to give the desired bass response.
- ❑ Components: Check that any capacitors used in the signal path are low voltage coefficient types.
- ❑ Noise: Check that noise added by the buffer is at least 6dB lower than the noise floor specification of the amplifer module when using the module analog inputs.

9 Performance Analysis

Noise and crosstalk analysis

Noise analysis evaluates the contribution of all the input components to the system noise floor. The expectation is a negligible increase in system noise due to the input buffer noise sources. For a detailed discussion of amplifier noise analysis, please refer to EDN articles “Noise 101”,Joshua Israelson, EDN, Jan 8 2004, and “Noise 102”,Joshua Israelson, EDN, March 18 2004, URL:http://www.reed-electronics.com/ednmag/archive/

Crosstalk analysis evaluates the coupling of signal energy from one channel into other channels. This is normally measured by driving one channel with a full scale signal and leaving all other channels with no input signal. The leakage of the active channel signal onto the idle channels is measured. Crosstalk occurs through many paths. The major crosstalk contributors are the common-mode bias of the amplifiers, ADC reference voltage, and power connections. The input buffer design goal is to keep the crosstalk contribution of the input buffer less than the crosstalk of the ADC and power amplifier. The expectation is for the input buffer crosstalk isolation to be better than -90dB. Power supply contributions to crosstalk are generally handled by good circuit layout, power distribution, and effective decoupling.

EMI considerations

The input buffer will not generate any EMI, as it is linear and uses no clocks, assuming it does not oscillate. The buffer may be exposed to excessive RF EMI, which may mix or demodulate into the audio band. RF chokes and decoupling must be used on the input terminals if the input source is exposed to RF energy.

ESD/EOS considerations

ESD tolerance is the ability of a device to withstand an electrostatic discharge without damage. The active devices, op-amps, will have their own internal ESD protection. Input topologies with a series input resistor will be more tolerant of ESD.

EOS tolerance is the ability of a device to withstand electrical stress outside of the normal operating conditions without damage. EOS specifications are frequently qualitative in nature, relating to input overdrive and output overload. Quantitative EOS limits are covered by the Absolute Maximum electrical specifications of the components in the circuit.

10 Glossary

Ambient temperature - free air temperature surrounding the component. For a system component in an enclosure, this is the air temperature outside the box away from any fans. For an internal component, this is the temperature of the air around the component.

Input impedance - The buffer amplifier analog input can be simplified to a series resistor and capacitor to ground, forming a low pass filter. The impedance of this filter combined with the output impedance of the analog source will attenuate the audio signal and cause a slight amplitude roll-off as frequency increases. To minimize this effect the buffer amplifier input impedance must be at least 10x higher than the source output impedance.

Nominal Input operating level - The input voltage level will be gained up or down to meet the overall output power specification. If we assume that the peak voltage input to the ADC produces maximum output power from the amplifier, then the input buffer gain is the peak ADC voltage divided by the peak input voltage that is expected to produce full power. The nominal operating level is the level for a normal level signal, which is usually set to be at least 6dB less than the maximum level to allow for some headroom.

Input common mode voltage (for differential inputs) - This is the signal voltage with respect to ground for the input pins. A input buffer with good common mode rejection ratio will reject signals which are common to both + and - input pins. Such signals are often noise.

Common mode rejection (for differential inputs) - The amount of signal at the output which results from inputting a common mode signal.

Maximum input operating level - The maximum input operating level is defined as the input level which results in the overall system outputting full power. If exceeded the power amplifier is expected to limit or clip. The difference between the nominal input level and the maximum input level is the operating headroom.

Full Scale input level - Input to an ADC where the ADC output value reaches digital saturation or the maximum numeric representation.

Absolute Maximum input voltage level - The maximum input voltage level is the voltage that the input buffer must tolerate without damage. This will be substantially greater than the maximum operating level and significant audio clipping and distortion is expected.

Output impedance - The buffer amplifier output impedance drives the input impedance of the amplifier module input stage. It must be as low as possible to avoid attenuation and roll-off.

Nominal output operating level - Typical analog operating level

Maximum output operating level - Level at the onset of analog clipping.

Operating temperature range - Temperature range over which the device will meet all performance specifications.

Noise floor - The noise floor is the output power when the input is zero or disconnected with a properly terminated input. If the input termination is the same impedance as the output impedance of the signal source, then the noise floor represents the noise floor when driven from the normal signal source.

Dynamic Range - the Dynamic Range is the ratio of the maximum output level, or full scale output power, to the noise floor.

Signal-to-noise ratio - The signal-to-noise ratio is ratio of the nominal output level to the noise floor. The difference between dynamic range and signal-to-noise is the headroom.

Headroom - The difference between dynamic range and signal-to-noise is the headroom.

Frequency response - The signal level versus frequency. Should be specified as a frequency range within attenuation limits, for example 20Hz to 20kHz +/- 0.5dB.

THD+N - Total Harmonic Distortion + Noise - This the ratio of the full scale signal to the sum of the remaining frequency components in the audio band, both harmonics of the test signal and noise. This is often specified at various signal levels.

Gain drift - Change in gain over time, temperature variations, or power supply variations.

Inter-Channel crosstalk - The amount of one channel’s signal which leaks across to another channel.

Inter-Channel phase deviation - The deviation in phase response between channels.

Inter-Channel gain error - The deviation in gain between channels.