Application Report

Optimizing Noise and Power with Super-Beta Fully Differential Amplifiers

Etsuji Iwata

ABSTRACT

Texas Instruments is recognized by many audio hardware engineers as the primary supplier for audio fully differential amplifiers (FDAs). TI's audio portfolio includes FDAs such as OPA1632 and LME49724. The differential analog front end of audio equipment requires high-fidelity audio performance. TI's FDAs are well-known in the audio design circles as premium solutions. Audio FDAs enable an easy solution for single-ended to differential conversion in audio signal chains such as the differential input of class-D power amps or audio ADCs.

In this application report we examine the impact of voltage and current noise in bipolar transistor technologies. An analysis is performed comparing the total noise performance across the audible frequency range with varying magnitudes of input impedance.

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1 Introduction

While ultra-low noise is always a focus of audio engineers, the input-referred voltage noise of the amplifier is often the only parameter that is considered. If impedances from the source and feedback network are low, this is a reasonable consideration. However, for a power-conscious system, such as one powered by battery or USB, low impedances may not be an option. The circuit designer must consider the noise contribution of the input resistor to the total noise of the system in order to determine the optimal balance of noise and power.

TI has launched the next generation audio FDA, the OPA1637. This device utilizes TI's novel analog bipolar process technology. Its use of super beta BJT devices can resolve the problems found in many audio applications.

2 Super-Beta BJT

The differentiating feature of OPA1637 from the prior generation is the bipolar junction transistor (BJT) of the long-tail pair in the input circuit. This technology is called *super-beta BJT*. TI's super-beta BJT is just a single BJT with high beta, that is, high current gain (Hfe).

The performance advantage of the OPA1637 comes from improvements in manufacturing technology. Precise manufacturing allows for its simple construction to achieve low noise and high frequency response with high current gain. This analog process technology improvement enables TI to design new op-amps that achieve both high DC and AC performance in bipolar op-amps. For example, BJT-input op-amps have higher input impedance with lower noise, higher bandwidth, and lower power than prior generations of transistors. While not quite as high input impedance as JFET-input op-amps, these op-amps can achieve high bandwidth while maintaining good DC precision.

This benefit is evident in not only the OPA1637 but also in other op-amps utilizing super-beta transistor technology such as the OPA2202, OPA2210, INA818, and INA819.

There are several benefits of the super-beta BJT in the input circuit of the op-amps.

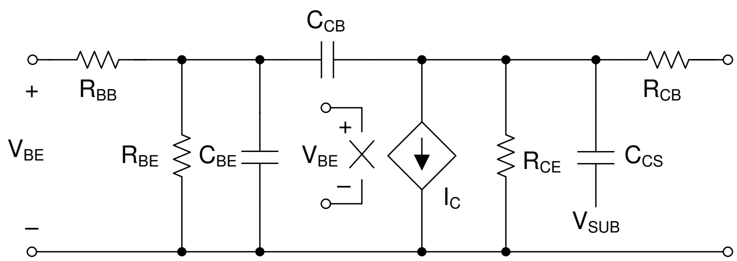

Figure 2-1. BJT small signal model

Figure 2-1 shows the small signal model of the BJT. The equation for its current gain is $I_B = I_C/\beta$.

This simple equation illustrates that the higher the beta, the lower the base current for a given collector current. When this transistor is part of the input differential pair of an op-amp, it amounts to a reduction of the input bias current for the op-amps. In addition, the super-beta can improve the input referred noise of the input long tail pair of op-amps with the expected and configured base current, I_B, as shown in the following calculations Equation 1, Equation 2, and Equation 4.

In the BJT small signal model, the input referred noise is also modeled. The input referred voltage noise, E_N, and the input referred current noise, I_N, in broadband range are represented with the parameters in the BJT small signal model.

$$E_n^2 = 4kTR_{bb} + 2qI_C R_e^2 = 4kT\left(R_{bb} + \frac{1}{2}\frac{I_C}{V_T}\left(\frac{1}{g_m}\right)^2\right) = 4qV_T\left(R_{bb} + \frac{1}{2}\frac{V_T}{\beta I_B}\right) \tag{1}$$

$$I_n^2 = 2qI_B \tag{2}$$

Where k is the Boltzmann constant as shown in the thermal voltage equation:

$$V_T = kT/q \quad (3)$$

- V_T is thermal voltage
- k is the Boltzmann constant
- T is temperature
- q is elementary charge

And g_m is the transconductance as shown in

$$g_m := \delta I_C / \delta V_{BE} = I_C / V_T \quad (4)$$

with respect to the Ebers-Moll model, V_{BE}=V_T exp(I_C/I_S), where Re is the equivalent emitter resistance and equivalent to 1/gm.

In conclusion, both the input referred voltage and current noise is kept low with the super-beta transistor.

3 Benefits of OPA1637

With reduced input bias current and input bias current noise, the OPA1637 with TI's super-beta BJT input enables a circuit designer to use higher input resistor values than the prior generation of audio FDAs. This translates to power savings in the end application. An example circuit is shown in Figure 3-1.

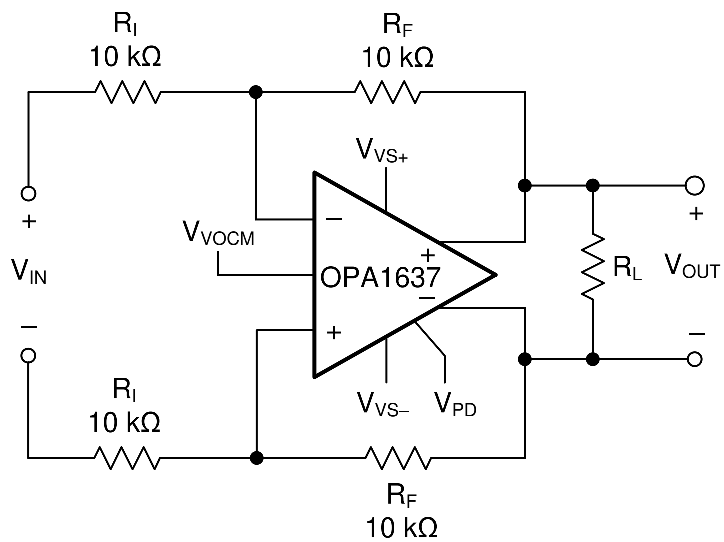

Figure 3-1. Typical application circuit for an OPA1637

It might appear that the OPA1637 has higher noise than the prior audio FDAs, such as OPA1632. Table 3-1 provides a detailed comparison of the two devices.

Table 3-1. Audio FDA Comparison of OPA1637 and OPA1632

Parameter	OPA1637	OPA1632
Number of channels	1	1
Total supply voltage (Min) (+5 V = 5, +/-5 V = 10)	3	5
Total supply voltage (Max) (+5 V = 5, +/-5 V= 10)	36	30
GBW (Typ) (MHz)	9.2	180
Slew rate (Typ) (V/us)	15	50
Rail-to-rail	RRO	NO
Vos (offset voltage @ 25 C) (Max) (mV)	0.2	3
I_q per channel (Typ) (mA)	0.95	14
I_q per GBW (Typ) (uA/MHz)	103	78
V_n at 1 kHz (Typ) (nV/rtHz)	3.7	1.5
V_n corner frequency (Typ) (Hz)	5	500
THD + N @ 1 kHz (Typ) (dB)	120	133

Table 3-1. Audio FDA Comparison of OPA1637 and OPA1632 (continued)

Parameter	OPA1637	OPA1632
CMRR (Typ) (dB)	140	90
Input bias current (Max) (nA)	2	200
In at 1 kHz (Typ) (pA/rtHz)	0.3	0.6
In corner frequency (Typ) (Hz)	10	1000
Output current (Typ) (mA)	31	85
Operating temperature range (C)	-40 to 125	-40 to 85

In the actual application circuit shown in Figure 3-1, it is evident that those parameters do not dominate the total noise. Figure 3-2 shows that in the case of higher input resistor values such as 10 kΩ, an OPA1637 has lower noise than an OPA1632 in the entire audible frequency range due to its lower current noise. Even with lower input resistor values, such as 1 kΩ, the difference in total noise is insignificant (less than 0.5 uV).

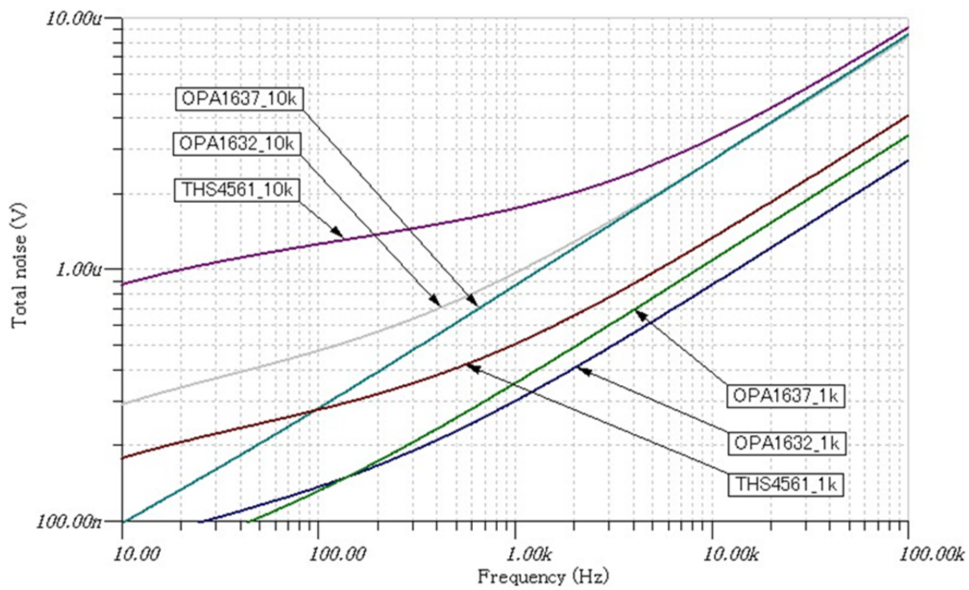

Figure 3-2. Total noise comparison with respect to the input resistor value for FDAs

The OPA1637 and OPA1632 have similar input topology, a differential pair BJT (Equation 3). The broadband input referred voltage and the current noise are dominated by the collector current and the current gain (β) .

$$E_n^2 = 4qV_T\left(R_{bb} + \frac{1}{2}\frac{V_T}{I_C}\right) \quad (5)$$

$$I_n^2 = 2qI_B = 2q\frac{I_C}{\beta} \quad (6)$$

The OPA1637 achieves superior performance with the super-beta BJT. It reduces the supply current by 10x compared to the OPA1632. The OPA1637 has a much lower 1/f corner frequency than the OPA1632 and other audio FDAs. In conclusion, the OPA1637 is the one of the best suited FDAs for audio applications due to its low noise and power consumption.

4 Typical Applications of OPA1637

An example use case of the OPA1637 is driving a differential input audio ADC such as the TLV320ADC5140. This is shown in Figure 4-1. A circuit designer can easily optimize the circuit by using the full scale input range of the ADC to achieve improved audio performance. This ADC has an improved THD+N performance in a differential input configuration when compared to a single-ended input configuration. The OPA1637 can implement the conversion circuit from single–ended to differential while maintaining high input impedance, minimizing loading on any previous circuitry.

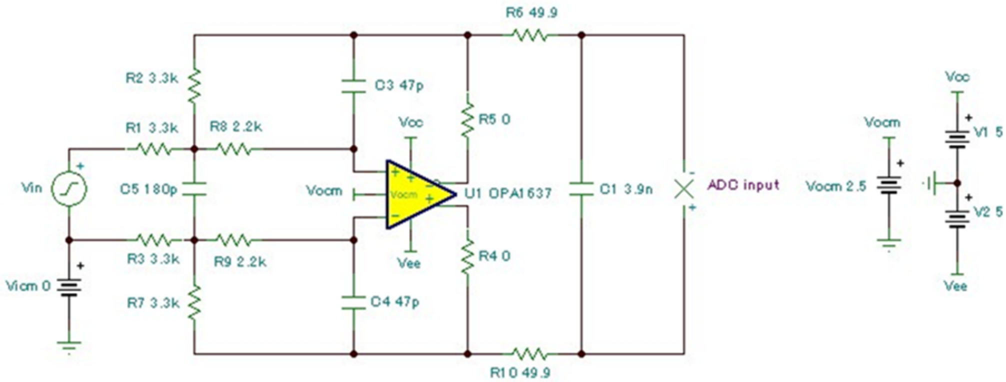

Figure 4-1. Differential input front end example for audio ADCs

5 Summary

The OPA1637 achieves novel audio performance in differential audio signal chains. This is due to its input structure which uses TI's super-beta BJT technology. A circuit designer can construct various audio front-ends with improved performance over the prior generation of available audio FDAs.

6 References

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