Application Brief

Super-beta Input Amplifiers: Features and Benefits

Brendan Hess, Soufiane Bendaoud, and Daniel Terrazas

Introduction

Texas Instruments (TI) new generation of bipolar amplifiers are built on a precision complementary bipolar semiconductor technology that incorporates *super-beta* bipolar transistors. *Super-beta* transistors are optimized for high current gain ($\beta > 1000$) which helps reduce the device's input bias current and input bias current drift over temperature.

This technology also incorporates advancements leading to better transistor matching and temperature stability yielding higher precision. This tech note will explain how *super-beta* transistors improve precision performance in bipolar amplifiers.

What is *super-beta?*

The beta (β) of a transistor, or transistor current gain, is the ratio of the transistor's collector current (I_c) to its base current (I_b), as shown in Equation 1.

$$\beta = I_c/I_b \tag{1}$$

The β value is fixed for a given transistor and operating condition. Figure 1 shows a simplified amplifier input stage using bipolar transistors.

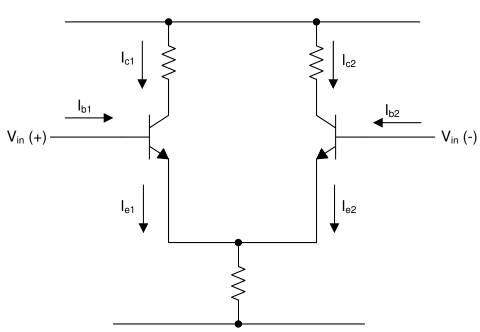

Figure 1. Simplified differential amplifier input stage

The value of β for traditional bipolar transistors typically ranges from 50 to 200 which may lead to a sizeable base current for a given collector current. For example, a transistor with a β value of 100 and I_c of 10 µA will require 100 nA of I_b.

In contrast, transistors with *super-beta* technology have a much higher β value, often well over 1000, greatly reducing the I_b needed for a given I_c. Revisiting the example above, for a transistor with a β value of 1000, the required I_b is decreased to only 10 nA. This is a 10x improvement over traditional bipolar transistors

Why do we care about base current?

In an amplifier, base current of the input transistors translates to input bias current (I_B). Traditional bipolar amplifiers offer better speed-to-power ratio and lower noise, however, they tend to suffer from higher I_B when compared to other silicon technologies like CMOS. The higher I_B may be unsuitable for high source impedance applications.

While CMOS and JFET amplifiers offer a clear advantage on I_B, new *super-beta* bipolar amplifiers offer significantly lower I_B while still providing the same benefits as the traditional process (speed-to-power ratio, lower voltage noise, lower 1/f noise, and lower open loop output impedance). To learn more about bipolar process advantages take look at the *Trade-offs Between CMOS, JFET, and Bipolar Input Stage Technology* application report.

What are the benefits of lower I_B?

Lower I_B translates to lower input current noise. The relationship between I_B and current noise is best described by Equation 2. The current noise (i_n) of a bipolar amplifier is given by

$$i_n = \sqrt{2 * q * I_B} \tag{2}$$

where q is the elementary charge (1.6 x 10-19 C). It follows that the lower I_B of a *super-beta* amplifier results in lower current noise.

In addition, lower I_B translates to higher input resistance (r_{in}). The small signal relationship between I_B and r_{in} is given by Equation 3.

$$r_{in} = \beta/g_m = I_c/I_b * V_T/I_c = V_T/I_B \tag{3}$$

Where g_m is the transconductance and V_T is the thermal voltage (equal to about 25 mV at 25ºC). Equation 3 can be simplified to show the inverse relationship between r_{in} and I_B. It follows that the lower I_B of a *super-beta* amplifier will result in higher r_{in}.

System level noise benefits

Unlike DC offset which can be calibrated out, filtering noise is not a trivial task. In applications with high source impedance, i_n translates to high input voltage noise density (e_n). For example, 2 pA/√Hz of i_n typically found in traditional bipolar amplifiers may seem acceptable. However, with a 1 MΩ source impedance the i_n translates to 2 μV/√Hz of e_n, which may be inadequate for many applications. On the other hand, a *super-beta* amplifier like the OPA2205 and OPA2206 with an i_n of 200 fA/√Hz yields 0.2 μV/√Hz. An order of magnitude improvement.

A traditional bipolar amplifier with ultra-low noise of 1 nV/√Hz with the i_n from the example above in a 10 kHz filter bandwidth and a circuit gain of 10 yields 350 μV_{rms} of total noise (e_n + i_n). In contrast, a *super-beta* amplifier like OPA2205 with a higher noise floor (7.2 nV/√Hz) results in 41 μV_{rms} under the same conditions, an 8.5x improvement.

Applications such as medical instrumentation, life sciences, and vibration sensing often require the use of high resolution analog-to-digital converters (ADCs) at rather low frequencies. *Super-beta* amplifiers such as TI's OPA2210 with low 1/f noise (90 nV_{pp}) and OPA2202 with an ultra-low 1/f noise corner (0.1 Hz) help reduce total errors at the output of the amplifier interfacing the ADC.

How about a comparison?

Texas Instruments offers an extensive portfolio of precision bipolar devices. Table 1-1 compares the INA118, an instrumentation amplifier with traditional bipolar transistors, to the INA818, a precision instrumentation amplifier with *super-beta* transistors. Thanks to the *super-beta* inputs of INA818 the current noise is reduced by a factor of almost 20, and I_B is reduced by a factor of about 10.

A new level of precision with *super-beta*

In addition to a reduction in I_B and i_n, TI's *super-beta* technology results in better transistor matching and better temperature stability, yielding higher precision. Improved DC precision specifications include lower input offset voltage and offset voltage drift over temperature. Table 1-2 shows a comparison between two high voltage precision operational amplifiers: the OPA2209, with traditional bipolar transistor input stage and the OPA2210, with *super-beta* transistor input stage. These devices both have the same pinout and functionality, but OPA2210 has improved specifications due to the implementation of *super-beta* technology.

Where can I get a *super-beta* amplifier?

Table 1-3 highlights some of TI's precision amplifiers with *super-beta* technology. For a full list, see our parametric search tool results by visiting ti.com/amps

Table 1-1. *Super-beta* vs. traditional bipolar instrumentation amplifiers

Device	Attribute	I_B (nA)	i_n (pA_{pp})
INA818 (super-beta)	Typical	0.15	4.7
	Maximum	0.50	-
INA118 (traditional)	Typical	1.00	80.0
	Maximum	5.00	-

Table 1-2. *Super-beta* vs. traditional bipolar op amps

Device	Attribute	I_B (nA)	i_n (fA/√Hz)	Z_{in} (Ω)	V_{os} (μV)	V_{os} Drift (μV/°C)
OPA2210 (*super-beta*)	Typical	0.3	400	400	5	0.1
	Maximum	2.0	-	-	35	0.6
OPA2209 (traditional)	Typical	1.0	500	200	35	1.0
	Maximum	4.5	-	-	150	-

Table 1-3. *Super-beta* devices

***Super-beta* devices**	**Description**
THP210 (3 V to 36 V)	Industry's first high voltage fully-differential, low noise (3.7 nV/√Hz) amplifier and ADC driver.
INA848 (8 V to 36 V)	Ultra-low noise (1.3 n/√Hz), high speed (45V/µs, 2.8 MHz), high precision amplifier with fixed gain of 2000.
INA818 (4.5 V to 36 V)	Low power (350 µA), high precision (35 µV), low noise instrumentation amp with over-voltage protection (gain pins 1, 8).
INA819 (4.5 V to 36 V)	Low power (350 µA), high precision (35 µV), low noise instrumentation amp with over-voltage protection (gain pins 2, 3). Now available in 3 mm x 3 mm QFN package.
INA821 (4.5 V to 36 V)	Wide bandwidth (4.7 MHz), low noise (7 nV/√Hz), high precision (35 µV) instrumentation amp with over-voltage protection. Now available in 3 mm x 3 mm QFN package.
OPA1637 (3 V to 36 V)	Fully differential, Burr-Brown™ Audio amp with low noise easily filters and drives fully differential audio signal chains.
OPA2210 (4.5 V to 36 V)	Ultra-low noise (2.2 nV/√Hz), high precision (35 µV), wide bandwidth amplifier (18 MHz).
OPA2205 (4.5 V to 36 V)	High precision (25 µV), low power (250 µA), low noise, e-Trim™ amplifier.
OPA2202 (4.5 V to 36 V)	High capacitive drive (25 nF), ultra-low 1/f noise corner (0.1 Hz), precision, dual amplifier.
OPA207 (4.5 V to 36 V)	Precision, low noise amp replaces industry standard OP-07, OP-77, and OP-177 with higher speed (1 MHz) and lower power (375 µA).