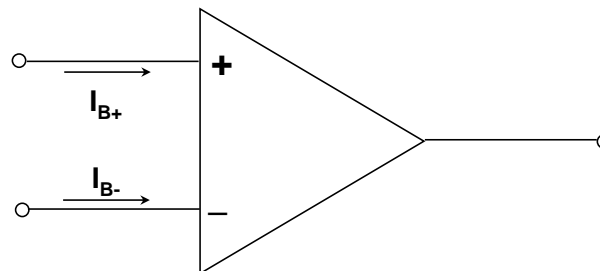


Op Amp Input Bias Current

DEFINITION OF INPUT BIAS CURRENT

Ideally, no current flows into the input terminals of an op amp. In practice, there are always two *input bias currents*, I_{B+} and I_{B-} . (see Figure 1).



- ◆ **A very variable parameter!**
- ◆ I_B can vary from 60 fA (1 electron every 3 μ s) to many μ A, depending on the device.
- ◆ Some structures have well-matched I_B , others do not.
- ◆ Some structures' I_B varies little with temperature, but a FET op amp's I_B doubles with every 10°C rise in temperature.
- ◆ Some structures have I_B which may flow in either direction.

Figure 1: Op Amp Input Bias Current

Values of I_B range from 60 fA (about one electron every three microseconds) in the [AD549](#) electrometer, to tens of microamperes in some high speed op amps. Op amps with simple input structures using bipolar junction transistors (BJT) or FET long-tailed pair have bias currents that flow in one direction. More complex input structures (bias-compensated and current feedback op amps) may have bias currents that are the difference between two or more internal current sources, and may flow in either direction.

Bias current is a problem to the op amp user because it flows in external impedances and produces voltages, which add to system errors. Consider a non-inverting unity gain buffer driven from a source impedance of 1 M Ω . If I_B is 10 nA, it will introduce an additional 10 mV of error. This degree of error is not trivial in any system.

Or, if the designer simply forgets about I_B and uses capacitive coupling, the circuit won't work—at all! Or, if I_B is low enough, it may work momentarily while the capacitor charges, giving even

more misleading results. The moral here is not to neglect the effects of I_B , in any op amp circuit. The same admonition goes for in-amp circuits.

INPUT OFFSET CURRENT

The *input offset current*, I_{OS} , is the difference between I_{B-} and I_{B+} , or $I_{OS} = I_{B+} - I_{B-}$. Note also that I_{OS} is only meaningful where the two individual bias currents are fundamentally reasonably well-matched, to begin with. This is true for most voltage feedback (VFB) op amps. However, it wouldn't for example be meaningful to speak of I_{OS} for a current feedback (CFB) op amp, as the currents are radically un-matched.

It should be noted that rail-to-rail input stages comprised of two parallel stages have bias currents that change direction as the common-mode voltage passes through the transition region. Bias and offset currents for these devices are especially difficult to specify, other than simply giving a maximum positive/negative value.

INTERNAL BIAS CURRENT CANCELLATION CIRCUITS

By providing this necessary bias currents via an internal current source, as in Figure 2 below, the only *external* current then flowing in the input terminals is the difference current between the base current and the current source, which can be quite small.

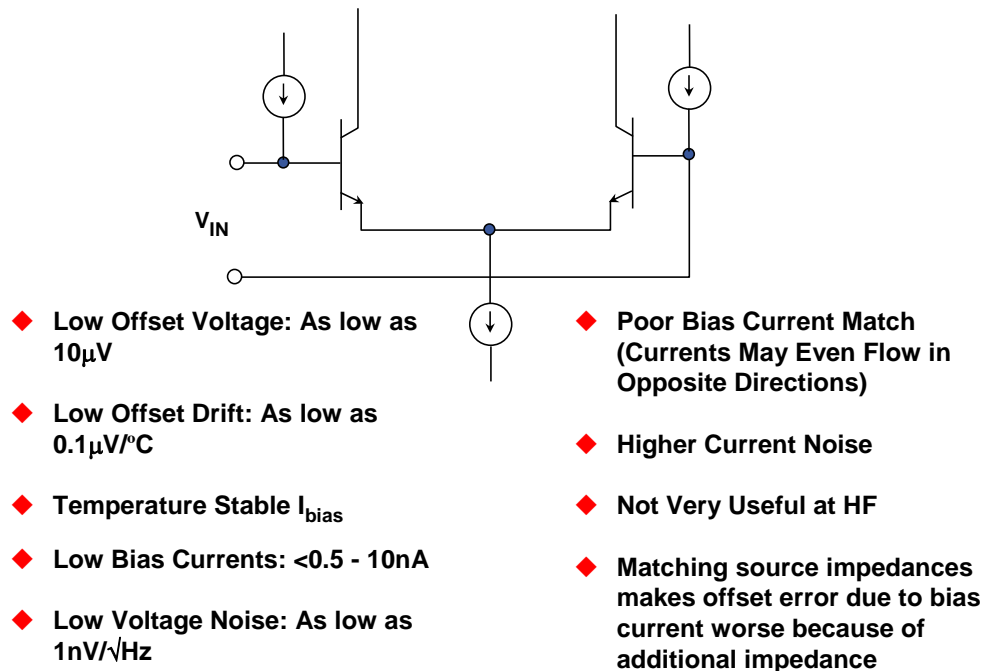


Figure 2: A Bias Current Compensated Bipolar Input Stage

Most modern precision bipolar input stage op amps use some means of internal bias current compensation, examples would be the familiar [OP07](#) and [OP27](#) series.

Bias current compensated input stages have many of the good features of the simple bipolar input stage, namely: low voltage noise, low offset, and low drift. Additionally, they have low bias current which is fairly stable with temperature. However, their current noise is not very good, and their bias current matching is poor.

These latter two undesired side effects result from the external bias current being the *difference* between the compensating current source and the input transistor base current. Both of these currents inevitably have noise. Since they are uncorrelated, the two noises add in a root-sum-of-squares fashion (even though the dc currents subtract).

Since the resulting external bias current is the difference between two nearly equal currents, there is no reason why the net current should have a defined polarity. As a result, the bias currents of a bias-compensated op amp may not only be mismatched, they can actually flow in opposite directions! In most applications this isn't important, but in some it can have unexpected effects (for example the droop of a sample-and-hold (SHA) built with a bias-compensated op amp may have either polarity).

In many cases, the bias current compensation feature is not mentioned on an op amp data sheet, and a simplified schematic isn't supplied. It is easy to determine if bias current compensation is used by examining the bias current specification. If the bias current is specified as a " \pm " value, the op amp is most likely compensated for bias current. Note that this can easily be verified, by examining the *offset current* specification (the difference in the bias currents). If internal bias current compensation exists, the offset current will be of the same magnitude as the bias current. Without bias current compensation, the offset current will generally be at least a factor of 10 smaller than the bias current. Note that these relationships generally hold, regardless of the exact magnitude of the bias currents.

As previously mentioned, rail-to-rail input stages have bias currents that change direction as the common-mode voltage passes through the transition region. Bias and offset currents for these devices are especially difficult to specify, other than simply giving a maximum positive/negative value.

CANCELING THE EFFECTS OF BIAS CURRENT (EXTERNAL TO THE OP AMP)

When the bias currents of an op amp are well matched (the case with simple bipolar input stage op amps, but *not* internally bias compensated ones, as noted previously), a bias compensation resistor, R_3 , ($R_3=R_1||R_2$) introduces a voltage drop in the non-inverting input to match and thus compensate the drop in the parallel combination of R_1 and R_2 in the inverting input. This minimizes additional offset voltage error, as in Figure 3. Note that if R_3 is more than 1 k Ω or so, it should be bypassed with a capacitor to prevent noise pickup. Also note that this form of bias cancellation is useless where bias currents are not well-matched, and will, in fact, make matters worse.

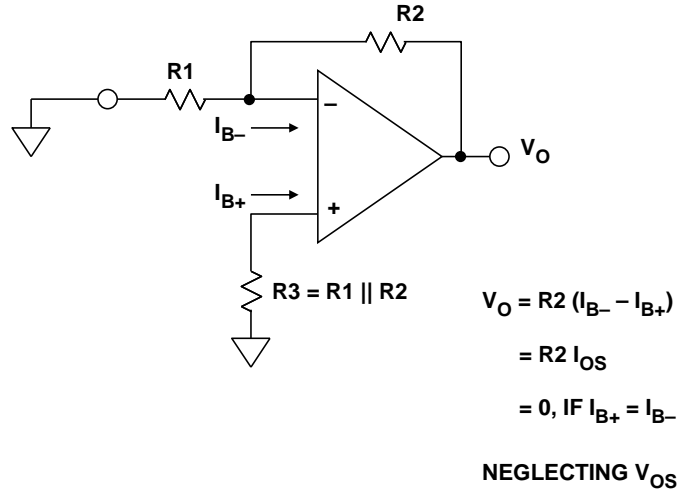
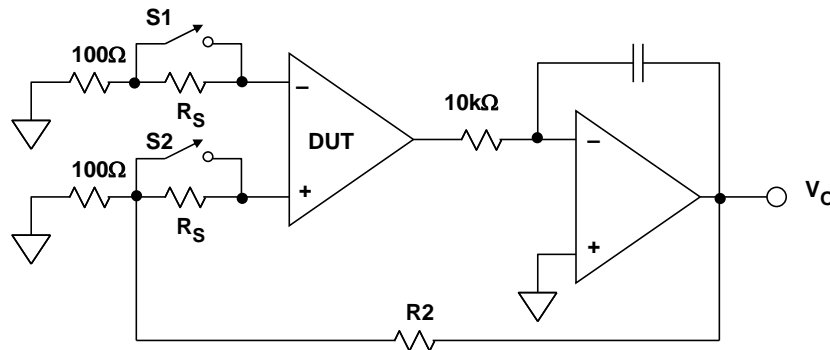


Figure 3: Canceling the Effects of Input Bias Current within an Application

MEASURING INPUT OFFSET AND INPUT BIAS CURRENT

Input bias current (or input offset voltage) may be measured using the test circuit of Figure 4. To measure I_B , a large resistance, R_S , is inserted in series with the input under test, creating an apparent additional offset voltage equal to $I_B \times R_S$. If the actual V_{OS} has previously been measured and recorded, the change in apparent V_{OS} due to the change in R_S can be determined, and I_B is then easily computed. This yields values for I_{B+} and I_{B-} . The rated value of I_B is the average of the two currents, or $I_B = (I_{B+} + I_{B-})/2$.

Typical useful R_S values vary from 100 k Ω for bipolar op amps to 1000 M Ω for some FET input devices.



$R_S \gg 100\Omega$ (100k Ω TO 1G Ω)
S1 CLOSED TO TEST I_{B+}
S2 CLOSED TO TEST I_{B-}
BOTH CLOSED TO TEST V_{OS}
BOTH OPEN TO TEST I_{OS}

$$V_O = \left[1 + \frac{R_2}{100} \right] V_{OS} + \left[1 + \frac{R_2}{100} \right] I_{B+} R_S - \left[1 + \frac{R_2}{100} \right] I_{B-} R_S$$

Figure 4: Measuring Input Bias Current

Extremely low input bias currents must be measured by integration techniques. The bias current in question is used to charge a capacitor, and the rate of voltage change is measured. If the capacitor and general circuit leakage is negligible (this is very difficult for currents under 10 fA), the current may be calculated directly from the rate of change of the output of the test circuit. Figure 5 below illustrates the general concept. With one switch open and the opposite closed, either I_{B+} or I_{B-} is measured.

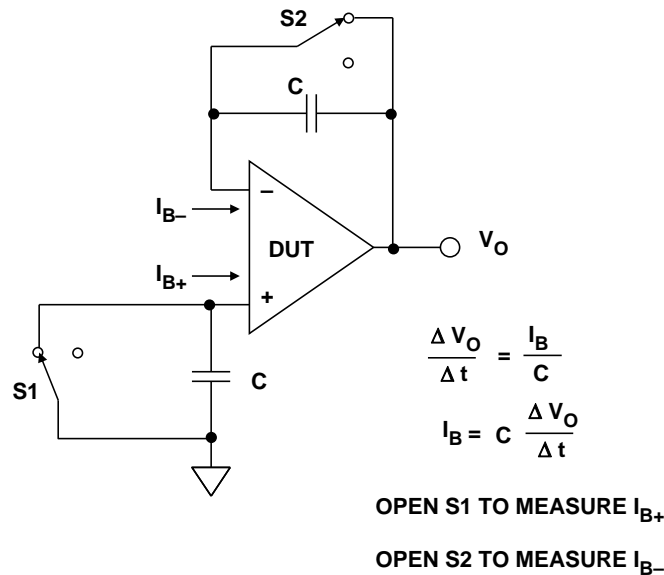


Figure 5: Measuring Very Low Bias Currents

It should be obvious that only a premium capacitor dielectric can be used for C, for example Teflon or polypropylene types.

REFERENCES:

1. Hank Zumbahlen, *Basic Linear Design*, Analog Devices, 2006, ISBN: 0-915550-28-1. Also available as [Linear Circuit Design Handbook](#), Elsevier-Newnes, 2008, ISBN-10: 0750687037, ISBN-13: 978-0750687034. Chapter 1.
2. Walter G. Jung, *Op Amp Applications*, Analog Devices, 2002, ISBN 0-916550-26-5, Also available as [Op Amp Applications Handbook](#), Elsevier/Newnes, 2005, ISBN 0-7506-7844-5. Chapter 1.
- 3.

Copyright 2009, Analog Devices, Inc. All rights reserved. Analog Devices assumes no responsibility for customer product design or the use or application of customers' products or for any infringements of patents or rights of others which may result from Analog Devices assistance. All trademarks and logos are property of their respective holders. Information furnished by Analog Devices applications and development tools engineers is believed to be accurate and reliable, however no responsibility is assumed by Analog Devices regarding technical accuracy and topicality of the content provided in Analog Devices Tutorials.