AOI UEDA, Field Applications Engineer

Electronic Design.

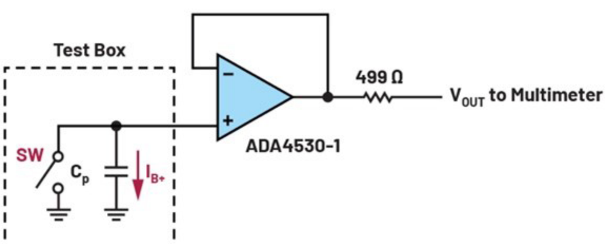
# Tips for Measuring Ultra-Low Bias Current with Commercial Lab Equipment

**Equipment like jigs, shields, cables, and connectors can impact femtoampere-level current measurements. This article offers methodology on how to work around those issues.**

In applications that require low leakage current, it's important to select a low-input-bias-current ($I_B$) operational amplifier. The application note AN-1373 describes how to measure ultra-low bias current using the ADA4530-1 evaluation board. However, due to the nature of handling femtoampere-level currents, the measurement environment—equipment such as jigs, shields, cables, and connectors—also affect the measurement results.

This article will introduce a trial to recreate the measurement in AN-1373 using commonly available commercial-grade lab equipment, jigs, and materials, and includes some workarounds to improve the measurement to finally achieve 50 fA.

First, we measure the input capacitance for bias current and the variation of output voltage with charging of the input capacitance under the condition of 125°C. We also attempt to derive the bias-current value from the measured output voltage. Finally, we will try to improve the measurement environment based on the measurement results.




**1. A diagram of the capacitive integration measurement method.**

### Capacitive Integration Measurement

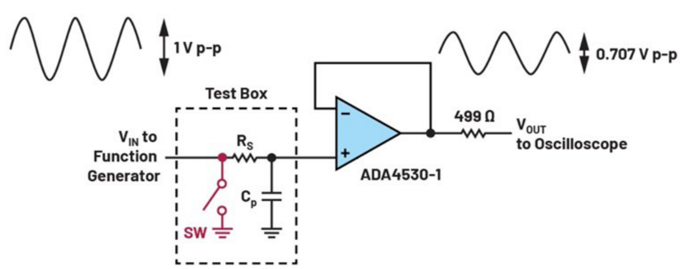
According to AN-1373, the input capacitance ($C_p$) of the ADA4530-1 must be measured first in order to use the capacitance integral measurement method. We will perform this experiment using the ADA4530-1R-EBZ-BUF,with the ADA4530-1 configured in buffer mode.

Next, we calculate the input current ($I_{B+}$). Specifically, using the circuit configuration shown in *Figure 1*, $I_{B+}$ flows into the $C_p$ when the SW in the test box is turned from ON (grounded to GND) to OFF (open). The output voltage rises as $I_{B+}$ charges $C_p$, so that the value of $I_{B+}$ can be calculated by monitoring and substituting it into Equation 1.

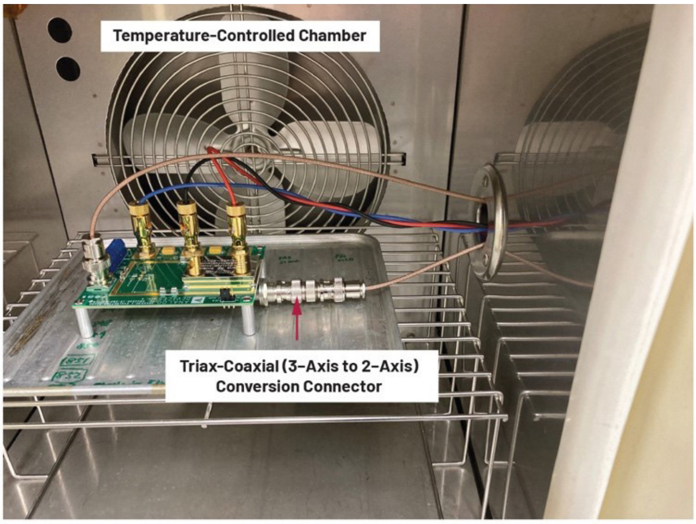
$$I_{B+} = \frac{C_p dV_{OUT}}{dt} \quad (1)$$

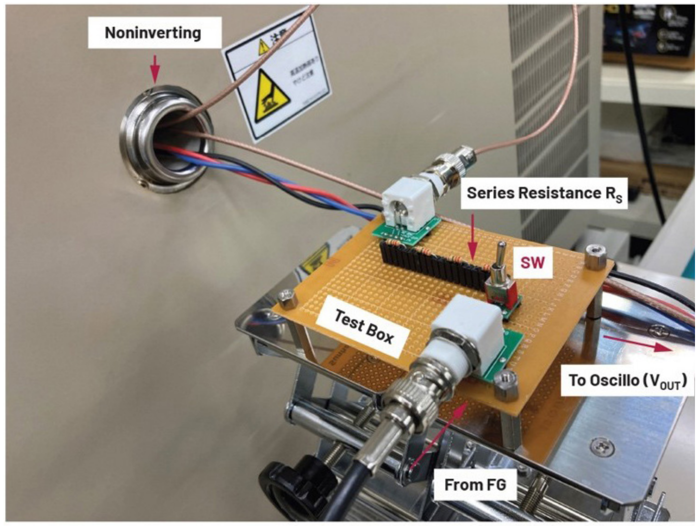
### Measuring Total Input Capacitance with an Input Series Resistor

To calculate $C_p$, this experiment adopts a method using series resistance. *Figure 2* shows a simple circuit diagram.




**2. Calculation of $C_p$ using series resistance of the input.**




(a) (b)

**3. $C_p$ measurement setup: Inside the temperature-controlled chamber—the evaluation board of ADA4530-1 is shown (a)—and setup of the test box side (b).**

The value of the series resistance is based on the measurement guidelines found on page 6 of AN-1373. The actual value is $R_s$ = 8.68 MΩ. An SW also is mounted in the test box for later experiments (SW is open at this time).

The frequency at which the waveform from the function generator is attenuated to –3 dB can be measured; use Equation 2 to calculate the input capacitance.

$$C_p = \frac{1}{2 \times \pi \times R_S \times f_{-3\ dB}} \tag{2}$$

*Figure 3* shows the setup. Since the temperature in the temperature-controlled chamber rises to 125°C in the experiment described in the section "Measuring $I_{B+}$ with Known Input Capacitance" (page 6 of AN-1373), we utilize materials that can withstand such a temperature. RG-316U was used as the material for the coaxial cable.

Furthermore, the noninverting inputs of the ADA4530-1 on the evaluation board are triaxial connectors. For this reason, a triax-to-coaxial conversion connector (BJ-TXP-1 from the Axis Company) was employed. In this configuration, the guard terminal on the triax side was left floating.

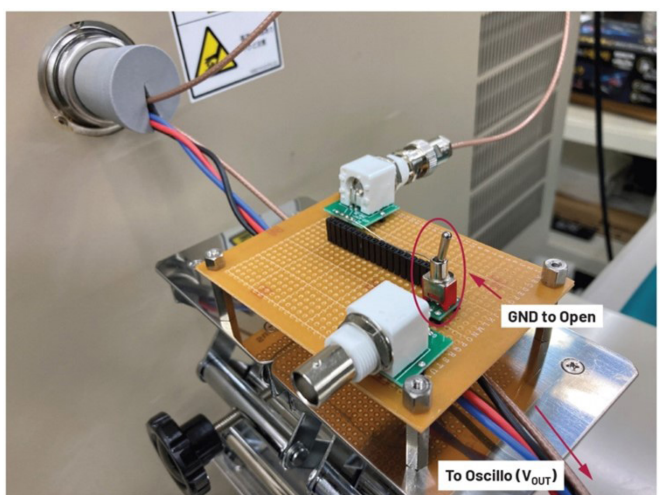
As a result of the measurement, $C_p$ = 73.6 pF was obtained, which is a relatively large value since the actual measurement, according to AN-1373, is about 2 pF. The reason for this is related to the cable length from the test box—which looks more like a test board—to the noninverting input.

**Measuring $I_{B+}$ with Known Input Capacitance**

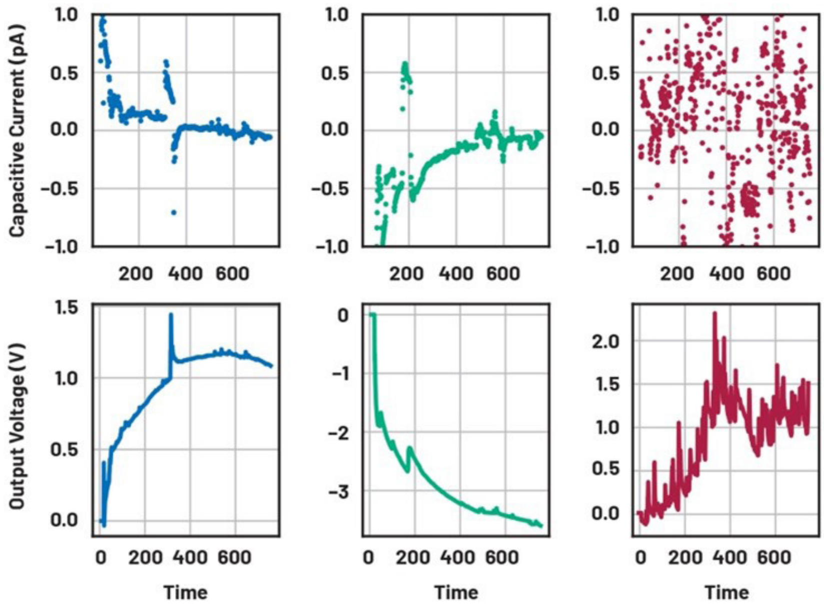
Finally, we start to measure the bias current. The circuit configuration is shown in *Figure 1*, and *Figure 4* illustrates the mounted test box. Note that the input resistor used in the section "Measuring Total Input Capacitive with an Input Series Resistor" is removed.

As described in AN-1373 (the capacitive integration measurement method, page 7), short-circuit the SW to GND, then open it and monitor the output voltage fluctuation with a digital multimeter (DMM) for a few minutes (we used the 34401A DMM from Keysight Technologies). Finally, calculate the $I_{B+}$ by substituting $V_{OUT}$ into Equation 1.

The results of three measurements under the same conditions are revealed in *Figure 5*. The lower part of the figure shows the output voltage fluctuation of the ADA4530-1 measured by the DMM, and the upper part shows the current value calculated using Equation 1. For all three instances, there's no repeatability in the measured voltage values. Therefore, the waveform of the calculated current value also has a different shape from the result described in AN-1373




**4. Setup of the capacitive integration measurement.**




**5. Measurement results: The lower side shows the output voltage of ADA4530-1 measured by the DMM, and the upper side reveals the current value calculated using Equation 1. The blue, green, and red lines are the first, second, and third measurements, respectively.**

(see figures 13 and 14 in AN-1373).

**How to Improve the Measurement Environment**

In the section "Capacitive Integration Measurement," we measured $I_{B+}$ based on the AN-1373, but the results differed. In this section, we share the steps to improve the measurement environment and thus, the accuracy of the measurements.

*Mount a Shield Box and Shorten the Input Cable*

First, we made the following two improvements:

- A shield box was installed on the evaluation board inside the thermostatic chamber *(Fig. 6)*.
- The coaxial cable connected to the noninverting input terminal was shortened to reduce the $C_p$ *(Fig. 7)*.

For one, we expect to reduce the effect of external noise, and secondly, we expect to reduce the small leakage current in the cable (the recalculated $C_p$ is 35.2 pF). However, although these measures were taken and remeasured, no reproducibility was observed, similar to the results obtained in "Capacitive Integration Measurement." The waveforms differed significantly from what was expected.

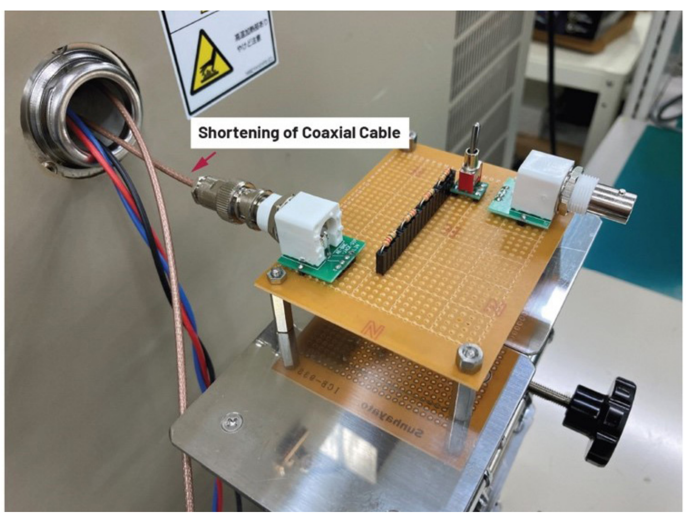
*Remove the Test Box*

The test box was removed, and the SW was changed by directly shorting and opening the ground *(Fig. 8)*. In other words, the conductance component called the test box was removed and the measurement was performed. As a result, we were able to obtain the waveform as shown in *Figure 9*.

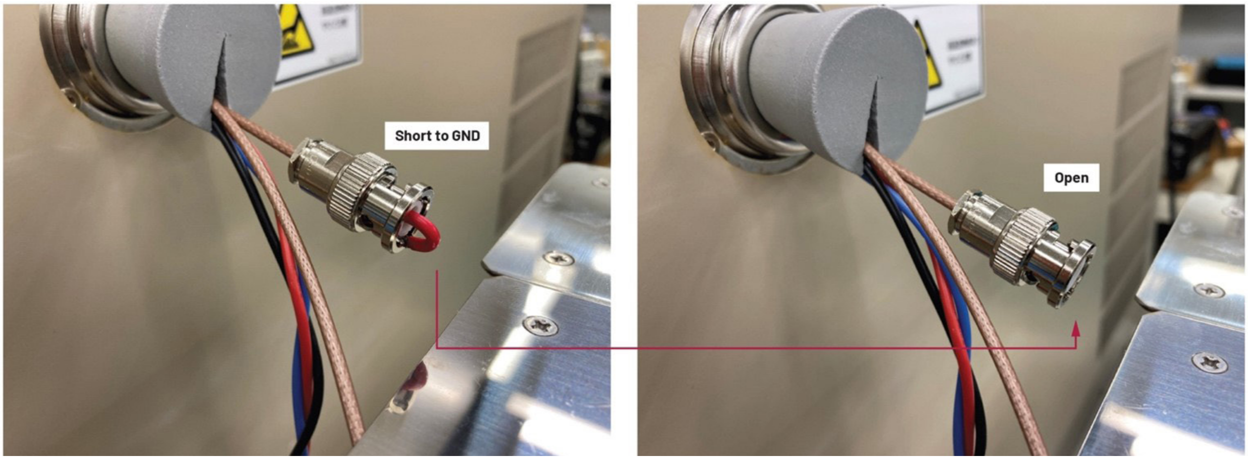
The output voltage measured by the DMM increased with a constant slope and reached around 4.16 V in all measurements. The corresponding current shows a value of about 50 fA.

Furthermore, the red line in *Figure 9* shows the waveform of the remeasurement with a shorter coaxial cable connected to the noninverting input terminal ($C_p$ = 26.5 pF). The slope of the voltage rise is as large as the theoretical calculation. From these measurement results, it was found that the conduc-

**6. Installing the shield box.**




**7. Shortening the coaxial cable.**




**8. Measurement with test box removed. Short and open operation by hand instead of the SW.**

tance component on the input side has a significant adverse effect on measurement accuracy.

### Conclusion

Although the femtoampere-level measurement can be performed in a general lab environment, the path of the leakage current on the input side of the operational amplifier needs to be carefully considered.

To improve the accuracy of the measurement, it's recommended to use a Teflon terminal block on the input side or a triaxial cable together with the evaluation board.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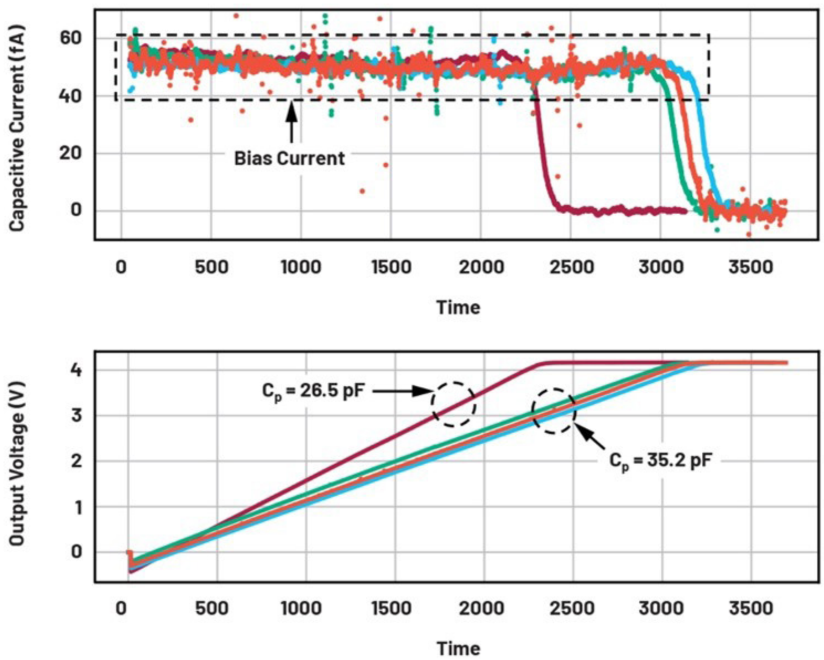


**9. Measurement results after removing the test box. The blue, orange, and green lines are measurement results at $C_p$** = 35.2 pF. The red line is the measurement result when $C_p$ = 26.5 pF.


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### Reference


Wong, Vicky. "AN-1373 Application Note: ADA4530-1 Femtoampere Level Input Bias Current Measurement." Analog Devices, Inc., October 2015.