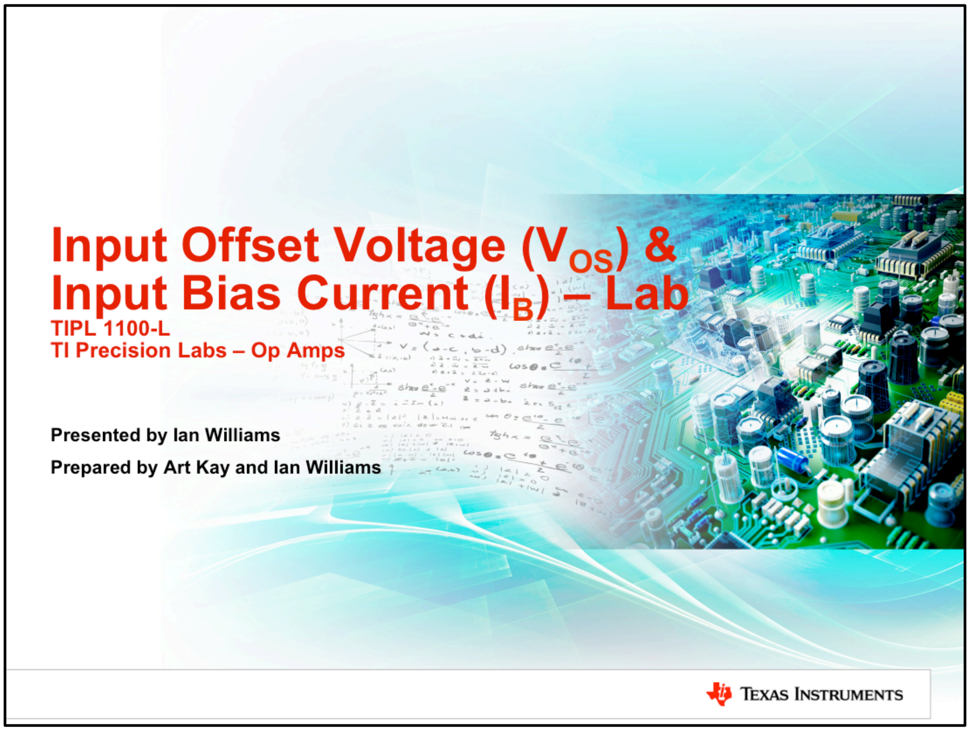
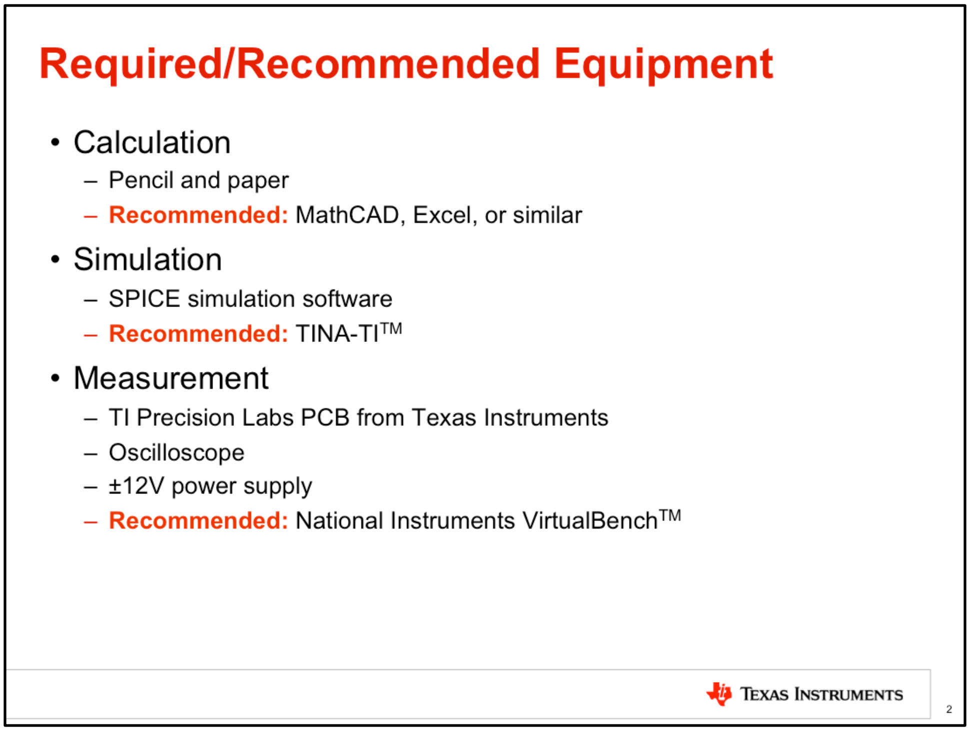


Hello, and welcome to the TI Precision Lab supplement for op amp input offset voltage (VOS) and input bias current (IB). This lab will walk through detailed calculations, SPICE simulations, and real-world measurements that greatly help to reinforce the concepts established in the op amp VOS and IB lecture.



The detailed calculation portion of this lab can be done by hand, but calculation tools such as MathCAD or Excel can help greatly.

The simulation exercises can be performed in any SPICE simulator, since Texas Instruments provides generic SPICE models of the op amps used in this lab. However, the simulations are most conveniently done in TINA-TI, which is a free SPICE simulator available from the Texas Instruments website. TINA simulation schematics are embedded in the presentation.

Finally, the real-world measurements are made using a printed circuit board, or PCB, provided by Texas Instruments. If you have access to standard lab equipment, you can make the necessary measurements with any oscilloscope and ±12V power supply. However, we highly recommend the VirtualBench from National Instruments. The VirtualBench is an all-in-one test equipment solution which connects to a computer over USB or Wi-Fi and provides power supply rails, analog signal generator and oscilloscope channels, and a 5 ½ digit multimeter for convenient and accurate measurements. This lab is optimized for use with the VirtualBench.

Experiment 1
R_{IN} = 0Ω

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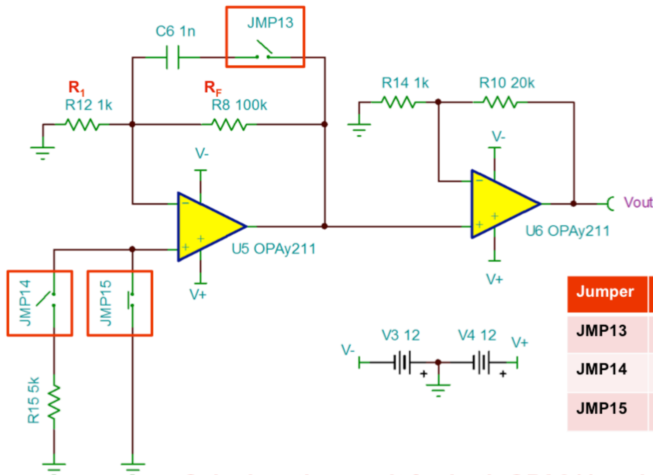
Texas Instruments

In experiment 1, we'll determine the effects of VOS and IB in a circuit where the input resistance, RIN, is equal to 0 ohms.

Calculation – R_{IN} = 0Ω

Calculate the total output voltage due to V_{OS} and I_B for the circuit shown below. Use the typical and maximum values for V_{OS} and I_B given on the next slide.



Jumper	Position	Description
JMP13	OPEN	C5 disconnected
JMP14	OPEN	R15 disconnected
JMP15	CLOSED	VIN+ connected to GND

Calculate the result for both OPA211 and OPA188!

Texas Instruments 4

First, calculate the expected total output voltage due to VOS and IB for the circuit shown here, using the techniques and equations given in the VOS and IB lecture. Take note of the jumper positions in the table. JMP13 and JMP14 are open, and JMP15 is closed. JMP15 shorts the non-inverting input of U5 to ground, causing RIN to be 0 ohms.

Calculate the output voltage twice – first with the OPA211 selected for U5 and U6, then with the OPA188. The different parameters of these op amps will give you different results.

Calculation – R_{IN} = 0Ω

PARAMETER		OPA211			
		MIN	TYP	MAX	UNIT
Input Offset Voltage	V_{OS}		±30	±125	µV
Input Bias Current	I_B		±60	±175	nA

PARAMETER		OPA188			
		MIN	TYP	MAX	UNIT
Input Offset Voltage	V_{OS}		±6	±25	µV
Input Bias Current	I_B		±160	±1400	pA

Device	Typical Output	Maximum Output
OPA188	±13mV	±56mV
OPA211	±191mV	±635mV

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TEXAS INSTRUMENTS

In order to perform the calculations, you need to know the typical and maximum values of VOS and IB for each op amp. Those values are given here.

Enter your answers in the table at the bottom of the slide. The solutions are already provided to allow you to check your work.

Calculation – $R_{IN} = 0\Omega$

OPA211

Calculate typical output error from Vos & Ib

$i_b = \pm 60\text{nA}$

$R_{eq} = \dfrac{R_f R_1}{R_f + R_1} \approx 1\text{k}\Omega$

$V_{ib} = i_b R_{eq} = \pm 60\mu\text{V}$

$V_{os} = \pm 30\mu\text{V}$

$V_{out\_error} = G_1 G_2 (V_{os} + V_{ib})$

$V_{out\_error} = 101 * 21(\pm 30\mu\text{V} + \pm 60\mu\text{V})$

$V_{out\_error} = \pm 191\text{mV or } \pm 64\text{mV}$

$V_{out\_error} = \pm 191\text{mV}$ Choose the largest

Calculate maximum output error from Vos & Ib

$i_b = \pm 175\text{nA}$

$R_{eq} = \dfrac{R_f R_1}{R_f + R_1} \approx 1\text{k}\Omega$

$V_{ib} = i_b R_{eq} = \pm 175\mu\text{V}$

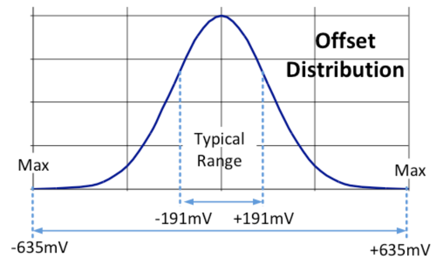
$V_{os} = \pm 125\mu\text{V}$

$V_{out\_error} = G_1 G_2 (V_{os} + V_{ib})$

$V_{out\_error} = 101 * 21(\pm 125\mu\text{V} + \pm 175\mu\text{V})$

$V_{out\_error} = \pm 106\text{mV or } \pm 636\text{mV}$

$V_{out\_error} = \pm 635\text{mV}$ Choose the largest



One important point to note is that IB and VOS can be positive or negative. This means that there are different possibilities for the output voltage due to VOS and IB which must all be considered.

First, calculate R_EQ, the equivalent input resistance, then multiply R_EQ by IB to determine the input voltage due to IB. Next, use the equation Vout = G1, gain of the first stage, times G2, gain of the second stage, times the sum of VOS and VIB to calculate the total output. Again, there are four possibilities. Pick the largest value.

Repeat the same steps, using the maximum values instead of the typical values. The plot on the bottom shows the Gaussian distribution of possible output values.

Calculation – $R_{IN} = 0\Omega$

OPA188

Calculate typical output error from Vos & Ib

$i_b = \pm 160\text{pA}$

$R_{eq} = \frac{R_f R_1}{R_f + R_1} \approx 1\text{k}\Omega$

$V_{ib} = i_b R_{eq} = \pm 0.16\mu\text{V}$

$V_{os} = \pm 6\mu\text{V}$

$V_{out\_error} = G_1 G_2 (V_{os} + V_{ib})$

$V_{out\_error} = 101 * 21(\pm 6\mu\text{V} + \pm 0.16\mu\text{V})$

$V_{out\_error} = \pm 13\text{mV or } \pm 12\text{mV}$

$V_{out\_error} = \pm 13\text{mV}$ Choose the largest

Calculate maximum output error from Vos & Ib

$i_b = \pm 1400\text{pA}$

$R_{eq} = \frac{R_f R_1}{R_f + R_1} \approx 1\text{k}\Omega$

$V_{ib} = i_b R_{eq} = \pm 1.4\mu\text{V}$

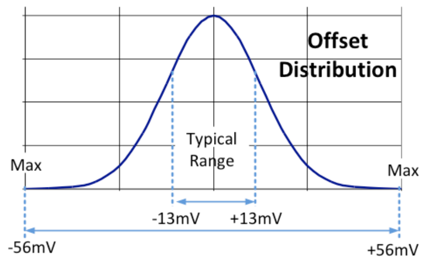
$V_{os} = \pm 25\mu\text{V}$

$V_{out\_error} = G_1 G_2 (V_{os} + V_{ib})$

$V_{out\_error} = 101 * 21(\pm 25\mu\text{V} + \pm 1.4\mu\text{V})$

$V_{out\_error} = \pm 56\text{mV or } \pm 50\text{mV}$

$V_{out\_error} = \pm 56\text{mV}$ Choose the largest



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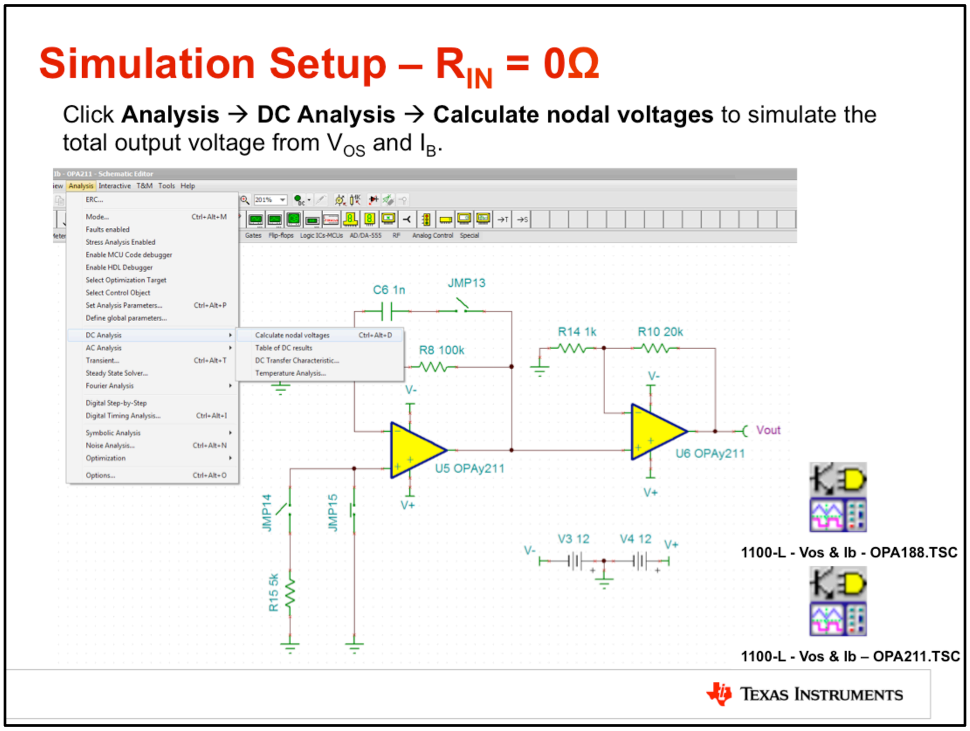
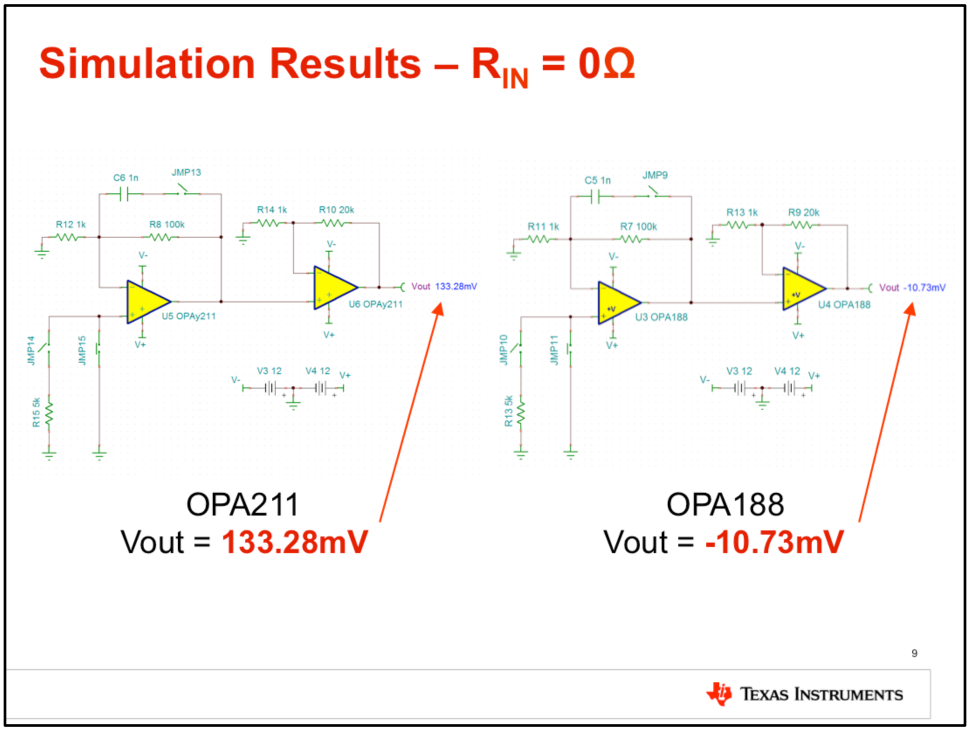
TEXAS INSTRUMENTS

Repeat the same procedure for the OPA188. The different specifications of the OPA188 will give a different output voltage result in both the typical and maximum case.

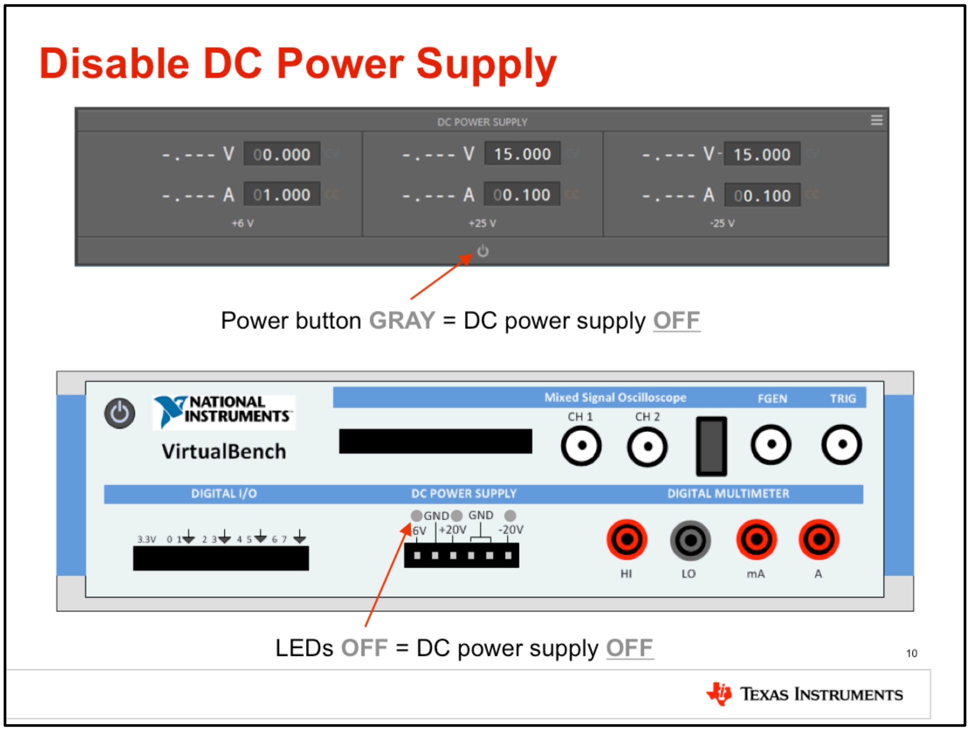


The next step is to run a SPICE simulation analysis for the total DC output voltage. The necessary TINA-TI simulation schematics are embedded in this slide set – simply double-click the icons to open them. Ensure that the jumpers are set correctly. In the OPA211 circuit, JMP13 and JMP14 are open, and JMP15 is closed. In the OPA188 circuit, JMP9 and JMP10 are open, and JMP11 is closed.

To simulate the output voltage, click Analysis → DC Analysis → Calculate nodal voltages.

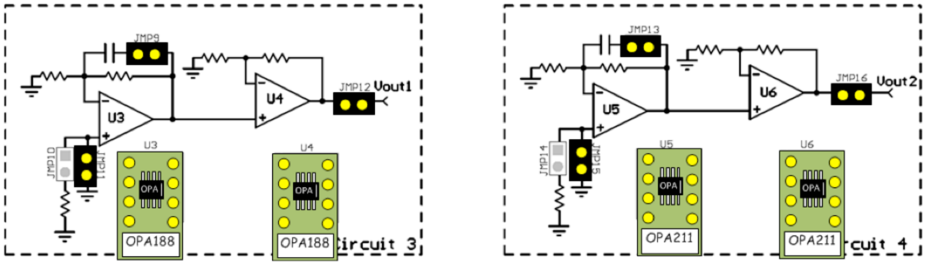


For the OPA211, you should get a result of around 133.28mV. For the OPA188, you should get a result of about -10.73mV.



Make sure to disable the DC power supply before setting up the test PCB! In the VirtualBench software, click the power button in the DC Power Supply area to turn off the power. Check the front panel of the VirtualBench unit to make sure the LEDs are OFF! Also make sure that the Function Generator is OFF.

Test Board Setup – Jumpers



Jumper, Device	Description
JMP9, JMP13	Filter noise with feedback capacitor
JMP11, JMP15	Connect VIN+ to GND
JMP12, JMP16	Connect Circuit 3 to Vout1, connect Circuit 4 to Vout2
U3, U4	Install OPA188
U5, U6	Install OPA211

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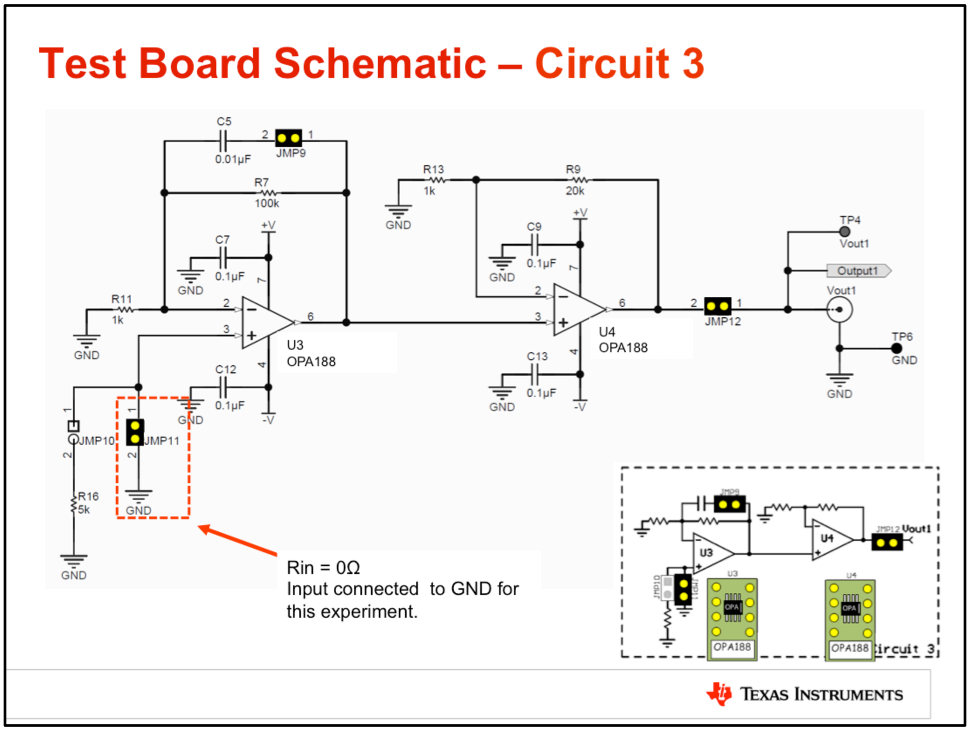
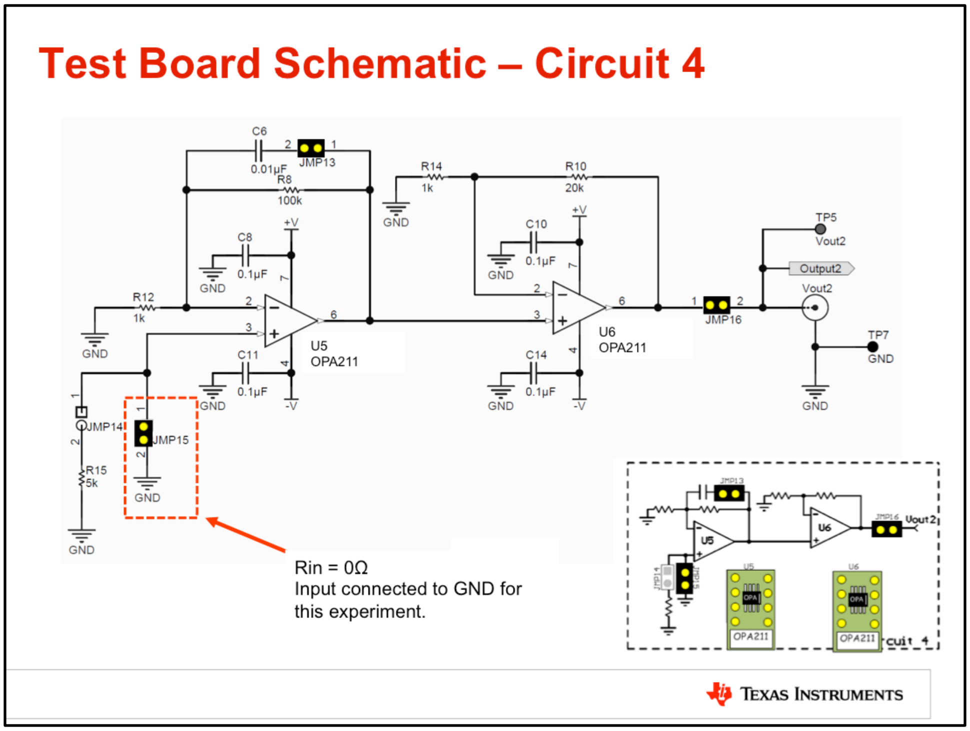
Texas Instruments

To prepare the test board for the measurement, install the jumpers and devices on circuit 3 and circuit 4 as shown here.

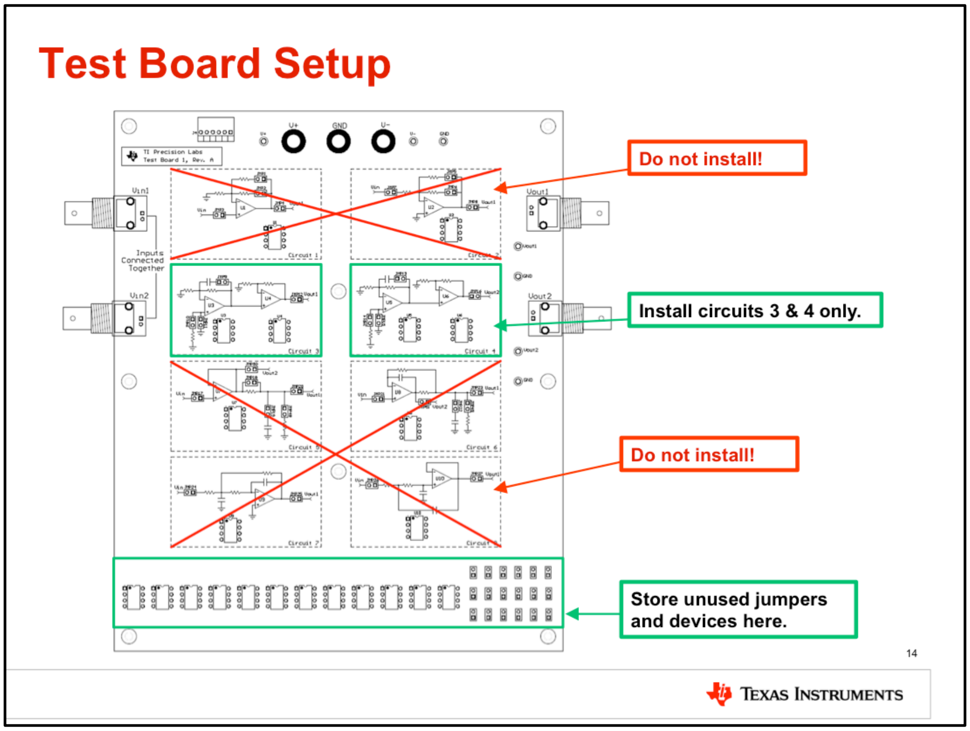
On circuit 3, install JMP9, JMP11, and JMP12, as well as the OPA188 in sockets U3 and U4. On circuit 4, install JMP13, JMP15, and JMP16, as well as the OPA211 in sockets U5 and U6.



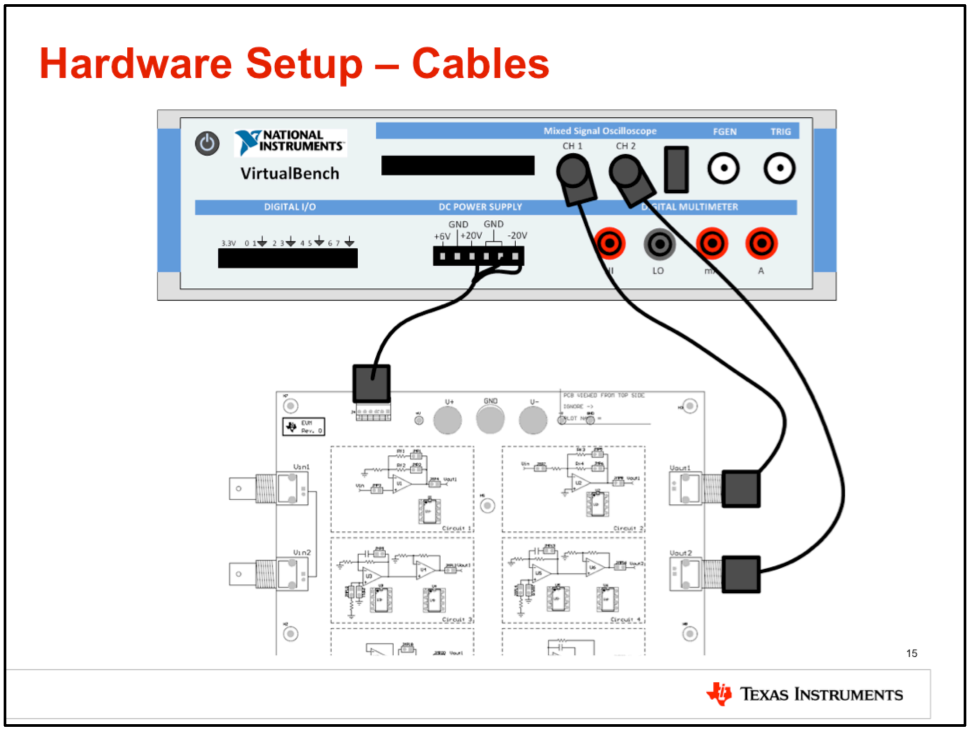
This slide shows the full schematic for Circuit 3 on the TI Precision Labs test board. You will use this circuit to measure the effects of VOS and IB on the OPA188.



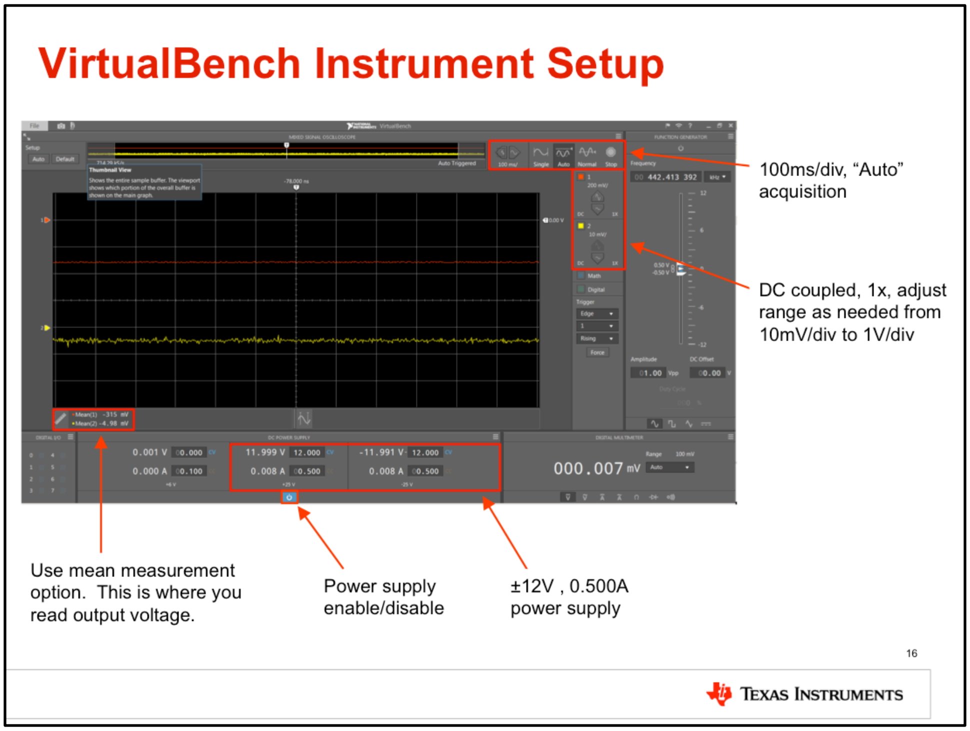
This slide shows the full schematic for Circuit 4 on the TI Precision Labs test board. You will use this circuit to measure the effects of VOS and IB on the OPA211.



For the test board to function properly, it is important that you only install jumpers and devices in circuits 3 and 4. Do not install any jumpers or devices in any other circuits on the PCB! Remove any jumpers or devices from the unused circuits and store them in the storage area at the bottom of the test board.



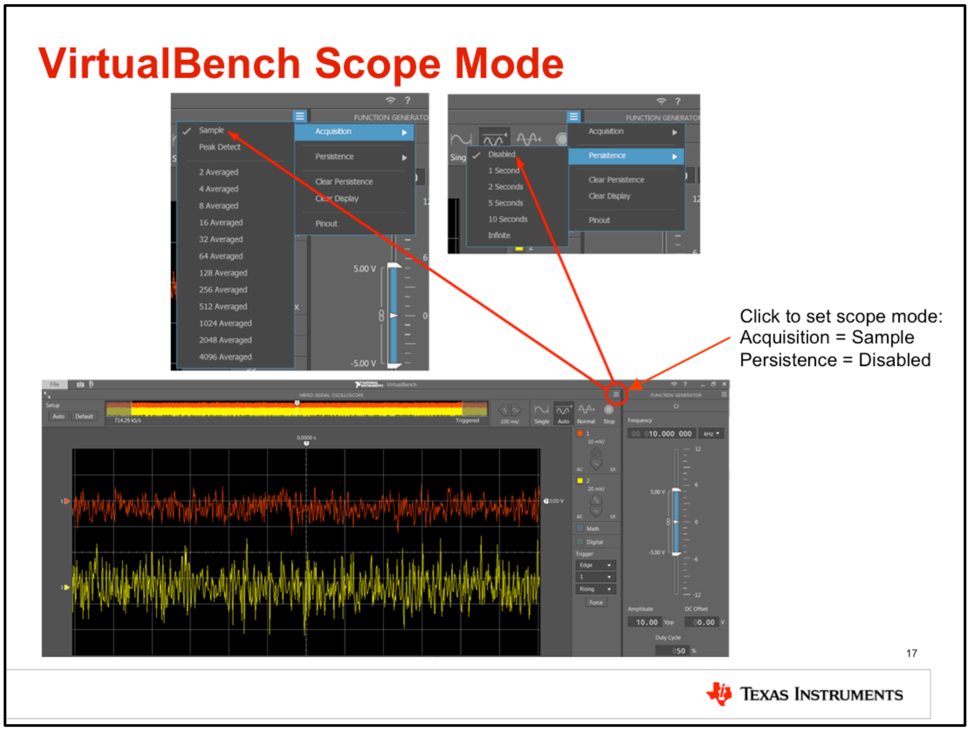
This slide gives the connection diagram between the TI Precision Labs test board and the National Instruments VirtualBench. Connect the provided power cable to the DC power supply of the Virtual Bench and power connector J4 on the test board. Connect Vout1 on the test board to VirtualBench oscilloscope channel 1, and Vout2 on the test board to Virtual Bench oscilloscope channel 2, using BNC cables.



Next apply power to the National Instruments VirtualBench and connect it to your computer with a USB cable. The hardware should be detected as a virtual CD drive, and you can run the VirtualBench software directly from the drive. Once the software opens, configure the software as follows:

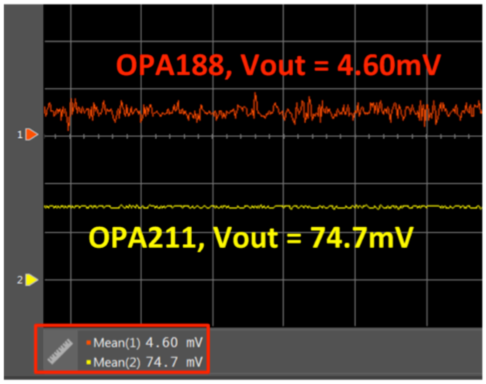
Set the time scale to 100ms per division, with the acquisition mode set to "Auto." Enable channels 1 and 2 on the oscilloscope, and set them to 1x, DC-coupled mode. Adjust the vertical scale as needed from 10mV/div to 1V/div. Set the +25V power supply to +12V, 0.500A. Set the -25V power supply to -12V, 0.500A. Press the power button to turn on the power supply rails.

Enable "mean" measurements on both channels in order to read the output voltage of each circuit.



You must also set the mode of the Virtual Bench oscilloscope. Click the button shown on the front panel, then set Acquisition to "Sample" and Persistence to "Disabled."

Measurement Results – R_{IN} = 0Ω



Measured result should be less than calculated maximum

Device	Calculated Maximum	Calculated Typical	Simulated Typical	Measured
OPA188	±56mV	±13mV	-10.73mV	4.60mV
OPA211	±635mV	±191mV	+133.28mV	74.7mV

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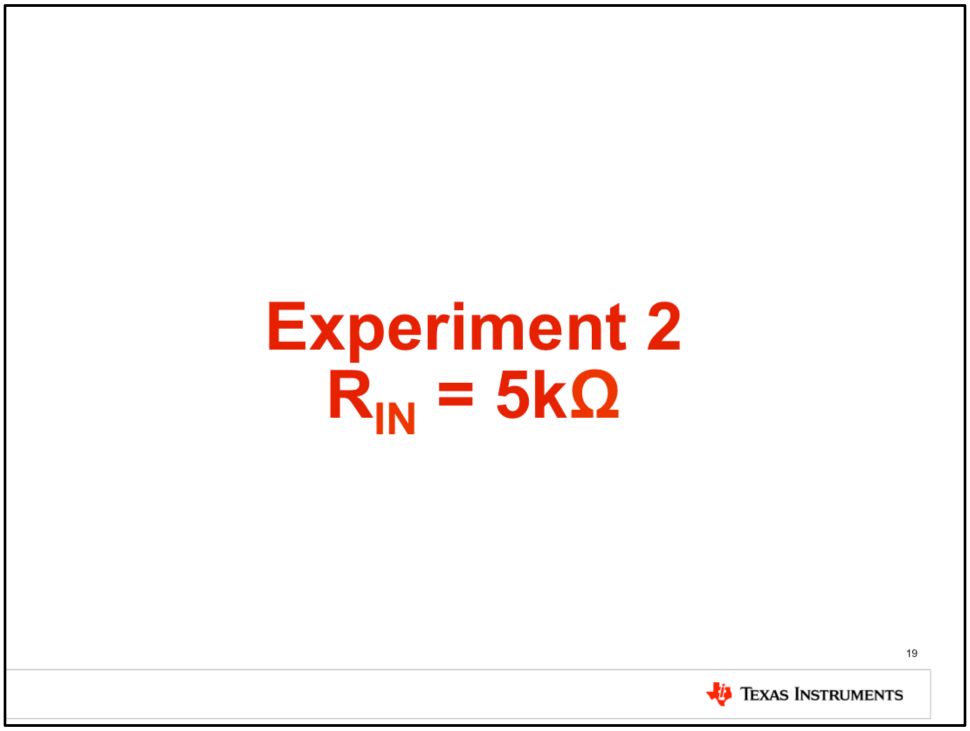
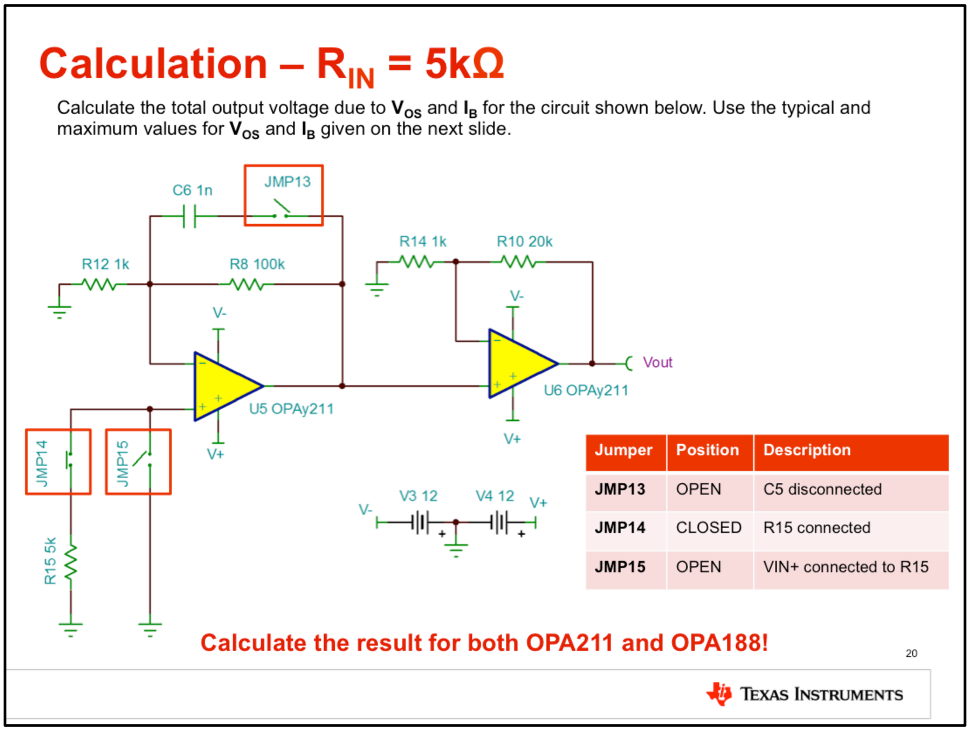
TEXAS INSTRUMENTS

The expected output voltage results from the measurement are shown here. The OPA211 has a measured output voltage of 74.7mV, and the OPA188 has a measured output voltage of 4.60mV. You may have different results in your experiment.

How did the measured and simulated results compare to the typical hand calculated results? Take a moment to look over the previous results and draw your own conclusions.



For the next part of the lab, we'll repeat the same procedure as experiment 1, but this time with 5kΩ of input resistance. This will emphasize the effects of input bias current, IB.



As shown in the schematic, jumper JMP15 shorting the positive input of U5 to ground is now removed. Jumper JMP14 is now installed in order to connect the positive input of U5 to a 5kΩ resistor. The IB of U5 will now flow through this resistor, developing a DC voltage due to Ohm's law and increasing the amount of offset voltage.

As before, calculate the total output voltage due to VOS and IB for this circuit, using both the OPA211 and OPA188.

Calculation – R_{IN} = 5kΩ

PARAMETER		OPA211			
		MIN	TYP	MAX	UNIT
Input Offset Voltage	V_{OS}		±30	±125	µV
Input Bias Current	I_B		±60	±175	nA

PARAMETER		OPA188			
		MIN	TYP	MAX	UNIT
Input Offset Voltage	V_{OS}		±6	±25	µV
Input Bias Current	I_B		±160	±1400	pA

Device	Typical Output	Maximum Output
OPA188	±15mV	±71mV
OPA211	±191mV	±2492mV

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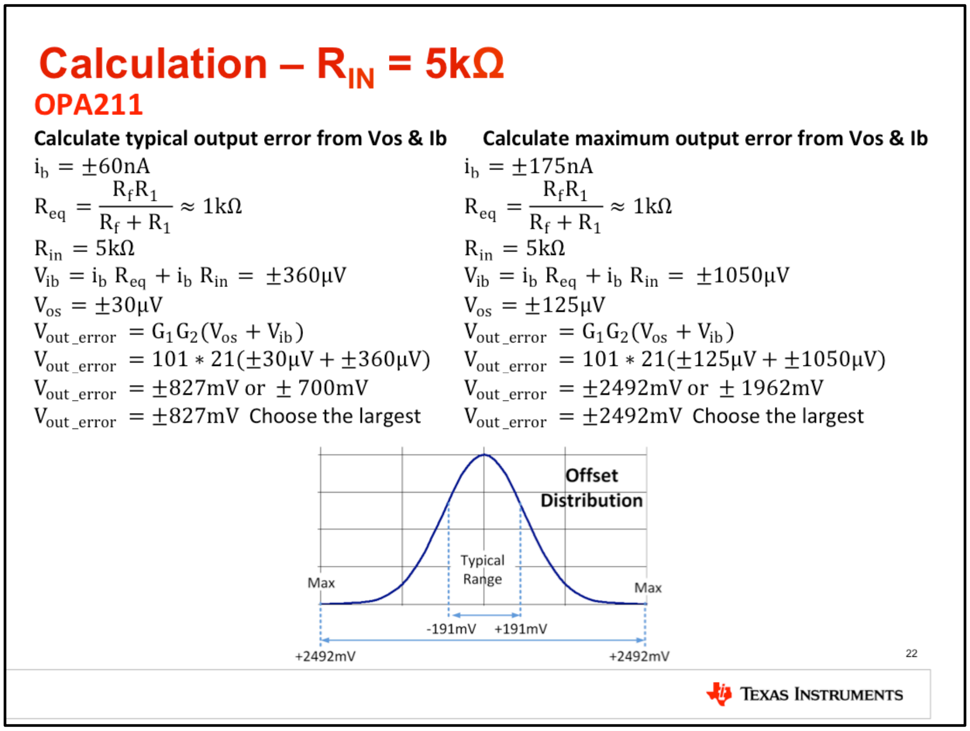
Texas Instruments

The data sheet parameters for both devices are provided again for reference. Enter your calculated results in the lower table. The answers have been provided so that you can check your work.



With RIN = 5k, the calculations change slightly since the voltage caused by IB is now affected by R_IN. Use the new equation VIB = IB*R_EQ + IB*R_IN. Otherwise, the steps are the same as in experiment 1. Repeat the calculations for the maximum values.

Calculation – $R_{IN} = 5k\Omega$

OPA188

Calculate typical output error from Vos & Ib

$i_b = \pm 160pA$

$R_{eq} = \dfrac{R_f R_1}{R_f + R_1} \approx 1k\Omega$

$R_{in} = 5k\Omega$

$V_{ib} = i_b\, R_{eq} + i_b\, R_{in} = \pm 0.96\mu V$

$V_{os} = \pm 6\mu V$

$V_{out\_error} = G_1 G_2 (V_{os} + V_{ib})$

$V_{out\_error} = 101 * 21(\pm 6\mu V + \pm 0.96\mu V)$

$V_{out\_error} = \pm 15mV \text{ or } \pm 11mV$

$V_{out\_error} = \pm 15mV$ Choose the largest

Calculate maximum output error from Vos & Ib

$i_b = \pm 1400pA$

$R_{eq} = \dfrac{R_f R_1}{R_f + R_1} \approx 1k\Omega$

$R_{in} = 5k\Omega$

$V_{ib} = i_b\, R_{eq} + i_b\, R_{in} = \pm 8.4\mu V$

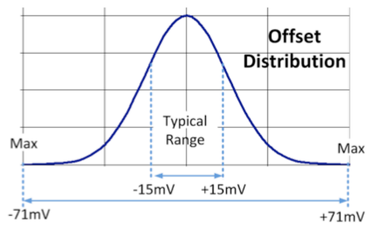
$V_{os} = \pm 25\mu V$

$V_{out\_error} = G_1 G_2 (V_{os} + V_{ib})$

$V_{out\_error} = 101 * 21(\pm 25\mu V + \pm 8.4\mu V)$

$V_{out\_error} = \pm 71mV \text{ or } \pm 35mV$

$V_{out\_error} = \pm 71mV$ Choose the largest



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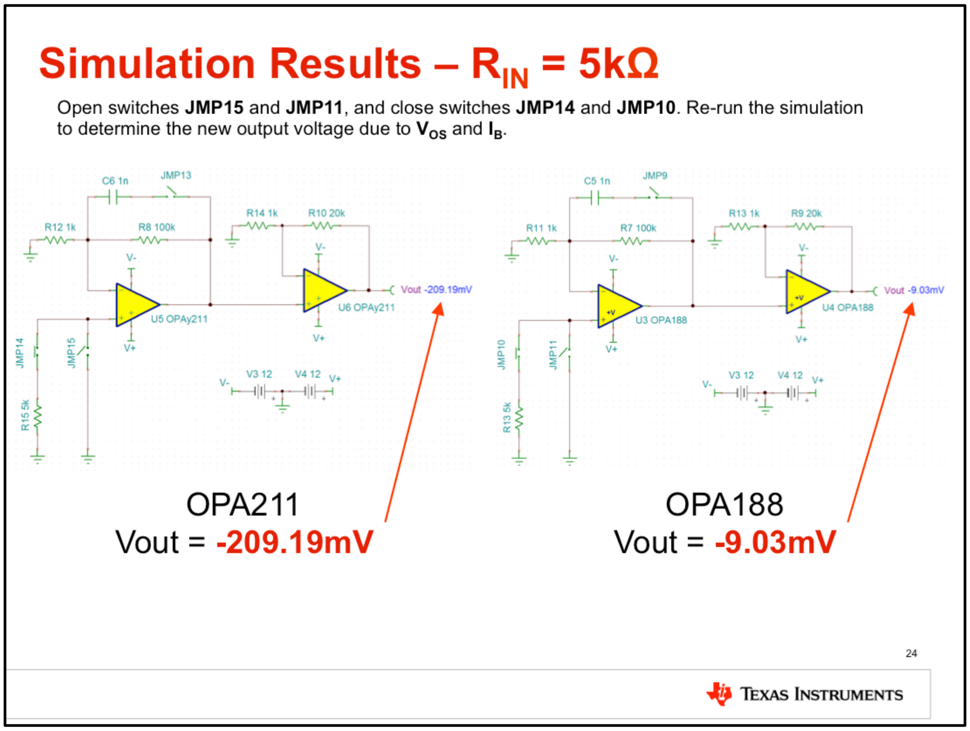
TEXAS INSTRUMENTS

Repeat both sets of calculations for the OPA188, again using typical and maximum values. As before, the different electrical characteristics of the OPA188 will result in different output voltage calculations.

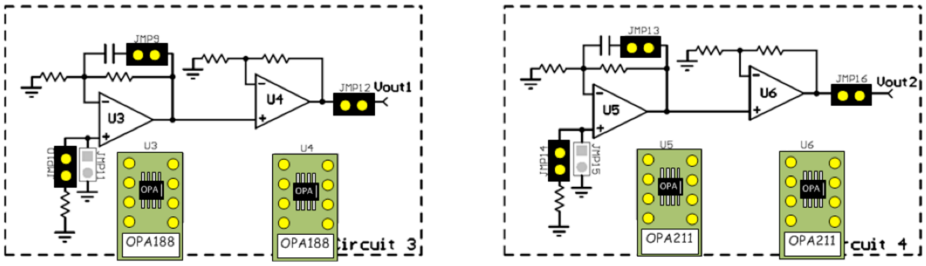


Re-run the simulated DC nodal voltage analysis, making sure to use the proper jumper settings.

In the OPA211 circuit, JMP13 and JMP15 are open, and JMP14 is closed.
In the OPA188 circuit, JMP9 and JMP11 are open, and JMP10 is closed.

Test Board Setup – Jumpers

Remove jumpers **JMP11** and **JMP15**, and install jumpers **JMP10** and **JMP14**.



Jumper, Device	Description
JMP9, JMP13	Filter noise with feedback capacitor
JMP10, JMP14	Connect VIN+ to 5kΩ
JMP12, JMP13	Connect Circuit 3 to Vout1, connect Circuit 4 to Vout2
U3, U4	Install OPA188
U5, U6	Install OPA211

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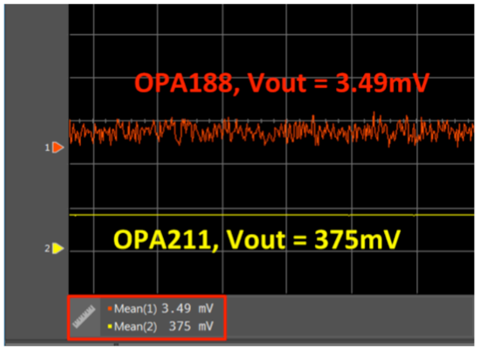
TEXAS INSTRUMENTS

The jumper settings on the test board must be modified before re-running the bench measurement. Remove jumpers JMP11 and JMP15, and install jumpers JMP10 and JMP14. All other jumpers and devices remain the same from the previous experiment.

Measurement Results – R_{IN} = 5kΩ



Measured result should be less than calculated maximum

Device	Calculated Maximum	Calculated Typical	Simulated Typical	Measured
OPA188	±71mV	±15mV	-9.03mV	3.49mV
OPA211	±2492mV	±827mV	-209.19mV	375mV

In experiment 2, the OPA188 has a measured output voltage of 3.49mV, and the OPA211 has a measured output voltage of 375mV. You may have different results in your experiment.

How did the measured and simulated results compare to the hand calculated results? In this example, the OPA211 output was greater than the calculated and simulated typical values, but less than the calculated maximum value. The OPA188 output was less than the calculated and simulated typical values.

Final Results

How did the change in input resistance affect the output voltage measurement?

Device Rin = 0Ω	Calculated Maximum	Calculated Typical	Simulated Typical	Measured
OPA188	±56mV	±13mV	-10.73mV	4.60mV
OPA211	±635mV	±191mV	133.28mV	74.7mV

Device Rin = 5kΩ	Calculated Maximum	Calculated Typical	Simulated Typical	Measured With Rin
OPA188	±71mV	±15mV	-9.03mV	3.94mV
OPA211	±2492mV	±191mV	-209.19mV	375mV

Answer:	Dramatic increase for the OPA211, small change for OPA188. This is due to the OPA211 having much larger I_B than the OPA188.

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TEXAS INSTRUMENTS

Let's now compare the results of both experiments. How did the change in input resistance affect the output voltage measurement?

In the OPA211, increasing the input resistance caused a dramatic increase in output voltage. However, the OPA188 did not see such a large increase. This is because the OPA211 has a much larger input bias current (IB), than the OPA188.

That concludes this lab – thank you for your time!