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StudentZone—ADALM2000 Activity: BJT Differential Pair

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Objective

The objective of this activity is to investigate a simple differential amplifier using NPN transistors. First, we need to make a few notes on hardware limitation issues. The waveform generator in the ADALM2000 system has a high output bandwidth and with that high bandwidth comes wideband noise. The input signal level needed for the measurements in this lab activity is rather small because of the gain of the differential amplifier. If the waveform generator output were used directly, the signal-to-noise ratio of its output would not be high enough. The signal-to-noise ratio can be improved by increasing the signal level and then placing an attenuator and filter (Figure 1) between the generator outputs and the circuit inputs. The materials needed for this activity are:

- Two 100 Ω resistors
- Two 1 kΩ resistors
- Two 0.1 µF capacitors (marked 104)

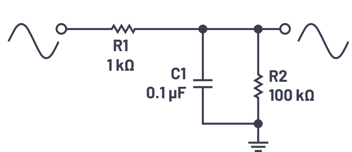


Figure 1. 11:1 attenuator and filter.

This attenuator and filter will be used in all parts of this lab.

Differential Pair with Tail Resistor

Materials

ADALM2000 Active Learning Module

- Solderless breadboard
- Jumper wires
- Two 10 kΩ resistors
- One 15 kΩ resistor (use a 10 kΩ resistor in series with a 4.7 kΩ resistor)
- Two small signal NPN transistors (2N3904 or SSM2212 NPN matched pair)

Directions

The breadboard connections are shown in Figure 3. Q1 and Q2 should be selected from your available transistors with the best matching of V_{BE}. The emitters of Q1 and Q2 share a common connection with one end of R3. The other end of R3 is connected to the Vn (–5 V) and supplies the tail current. The base of Q1 is connected to the output of the first arbitrary waveform generator, and the base of Q2 is connected to the output of the second arbitrary waveform generator. The two collector load resistors R1 and R2 connect between the collectors respectively of Q1 and Q2 and the positive supply Vp (5 V). The Differential Scope Input (2+ and 2–) is used to measure the differential output as seen across the two 10 kΩ load resistors.

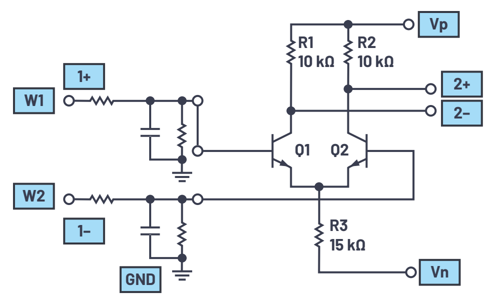


Figure 2. Differential pair with tail resistor.

Hardware Setup

The first waveform generator should be configured for a 200 Hz triangle wave with 4 V amplitude peak-to-peak and 0 offset. The second generator should be configured for a 200 Hz triangle wave with 4 V amplitude peak-to-peak and 0 V offset but with 180° phase. The resistor dividers will reduce the signal amplitude seen at the bases of Q1 and Q2 to slightly less than 200 mV. Channel 1 of the oscilloscope should be connected with 1+ to the output of the first generator, W1, and 1– connected to W2. Channel 2 should be connected to display 2+ and 2– and set to 1 V per division.

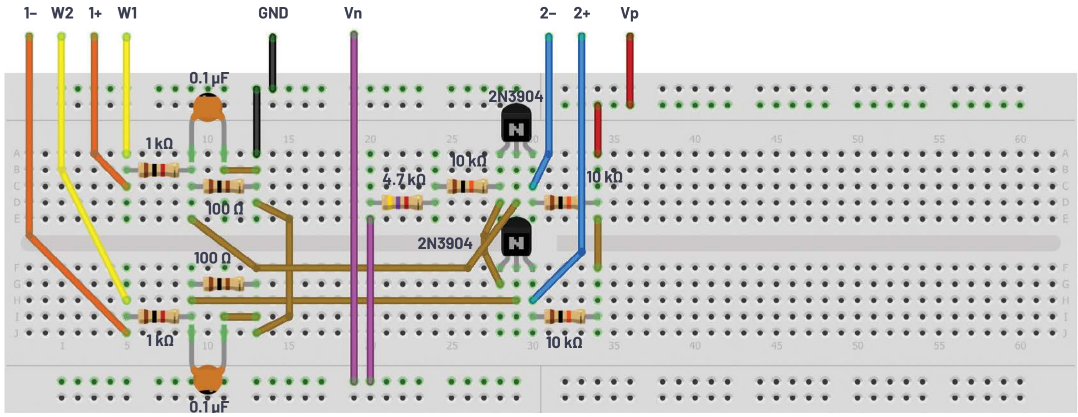


Figure 3. Differential pair with tail resistor breadboard circuit.

Procedure

The following data should be taken: the x-axis is the output of the arbitrary waveform generator and the y-axis is Scope Channel 2 using both the 2+ and 2– inputs. By changing the value of R3, you should explore the effects of the level of the tail current on the gain of the circuit (as seen in the slope of the line as it passed through the origin) and the linear input range and the shape of the nonlinear fall off in the gain as the circuit saturates. With minor additions to the basic circuit, such as emitter degeneration resistors, you should also explore techniques to extend and linearize the range of the input swing and the effects on circuit gain.

Configure the oscilloscope instrument to capture several periods of the two signals being measured. An xy plot example is presented in Figure 4.

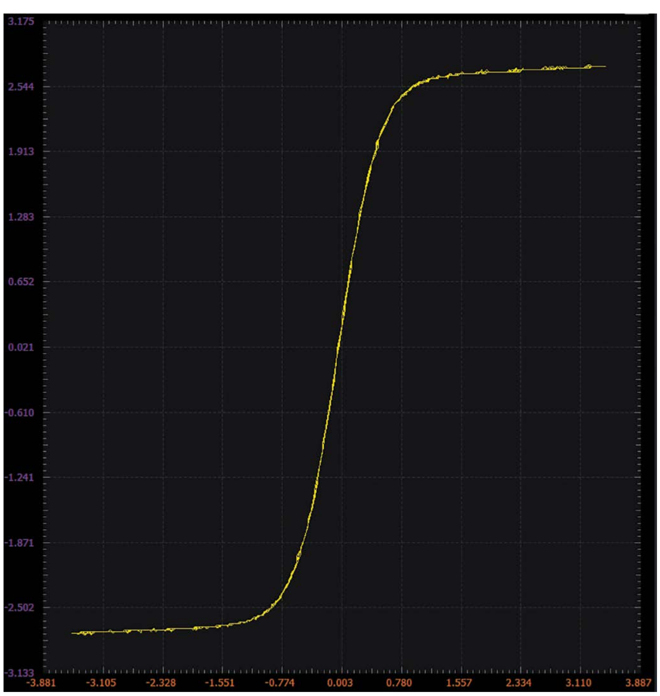


Figure 4. Differential pair with a tail resistor xy plot.

Using a Current Source as the Tail Current

The use of a simple resistor as the tail current has limitations. You should explore ways to construct a current source to bias the differential pair. These could be made with a couple of additional transistors and resistors, as shown in the previous ADALM2000 activity, "Stabilized Current Source."

Additional Materials

- Two small signal NPN transistors (Q3, Q4 = either 2N3904 or SSM2212)

Directions

The breadboard connections are shown in Figure 6.

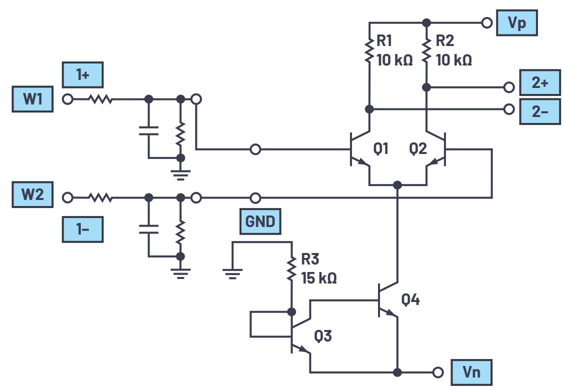


Figure 5. Differential pair with a tail current source.

Hardware Setup

The first waveform generator should be configured for a 200 Hz triangle wave with 4 V amplitude peak-to-peak and 0 offset. The second generator should also be configured for a 200 Hz triangle wave with 4 V amplitude peak-to-peak and 0 V offset but with 180° phase. The resistor dividers will reduce the signal amplitude seen at the bases of Q1 and Q2 to slightly less than 200 mV. Channel 1 of the oscilloscope should be connected with 1+ to the output of the first generator, W1, and 1– connected to W2. Channel 2 should be connected to display 2+ and 2– and set to 1 V per division.

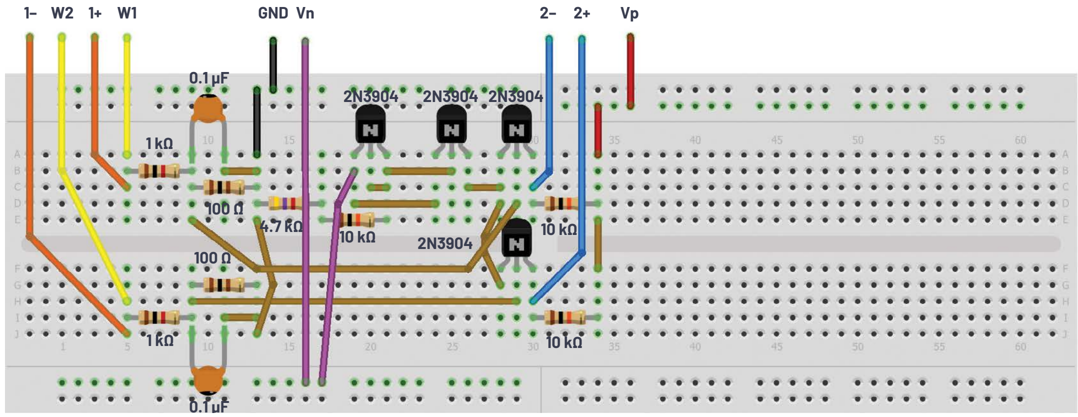


Figure 6. Differential pair with a tail current source breadboard circuit.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. An xy plot example is presented in Figure 7.

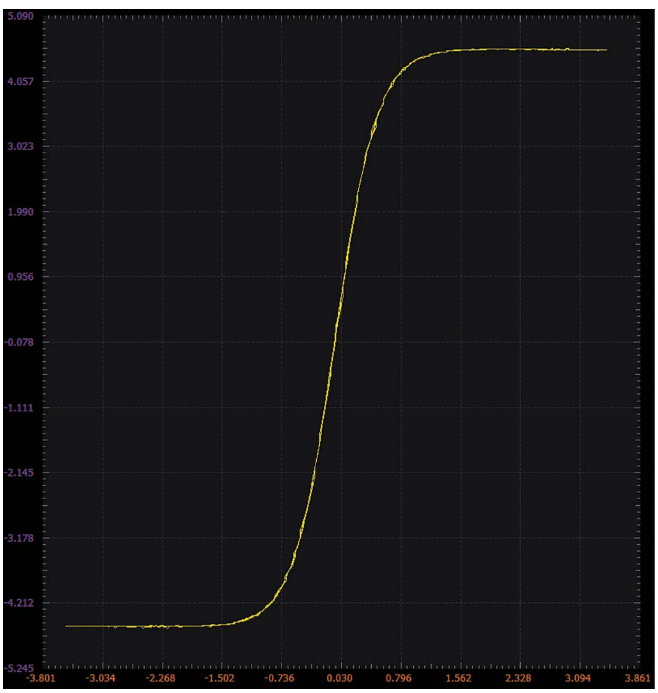


Figure 7. Differential pair with a tail current source xy plot.

Measuring Common-Mode Gain

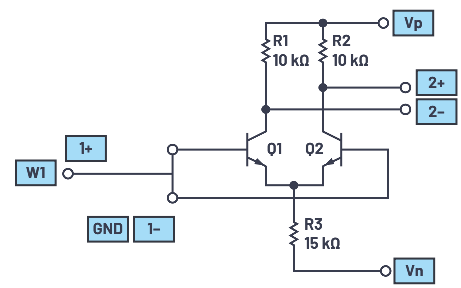


Figure 8. Common-mode gain configuration.

Common-mode rejection is a key aspect of the differential amplifier. CMR can be measured by connecting the base of both transistors Q1 and Q2 to the same input source. The plot in Figure 10 shows the differential output for both the resistively biased and current source biased differential pair as the common-mode voltage from W1 is swept from +2.9 V to –4.5 V around ground. The maximum positive swing on the input is limited to the point where the base voltage of the transistors exceeds the collector voltage and the transistors saturate. This can be checked by observing that the collector voltage of the transistors is single ended with respect to ground (that is, grounding the 2– scope input.)

Hardware Setup

The waveform generator should be configured for a 100 Hz sine wave with 8 V amplitude peak-to-peak and 0 offset. Channel 1 of the oscilloscope should be connected with 1+ to the output of the first generator, W1, and 1– to the ground. Channel 2 should be connected to display 2+ and 2– and set to 1 V per division.

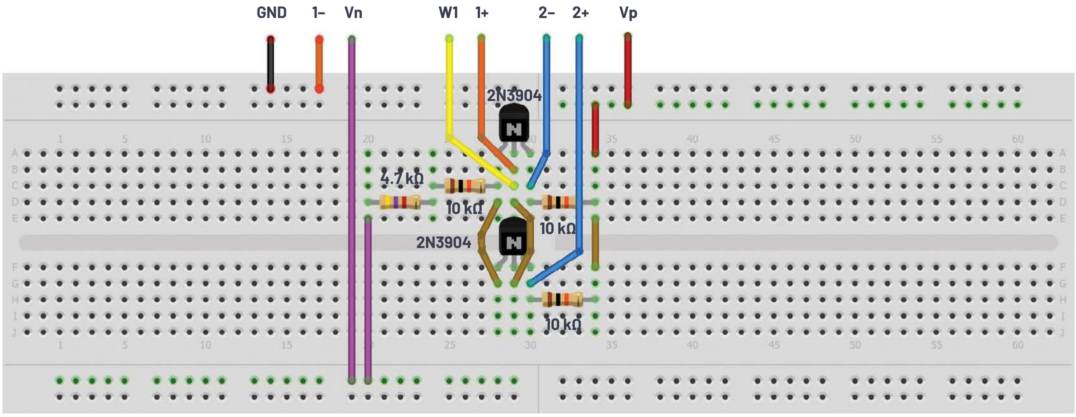


Figure 9. Common-mode gain breadboard circuit.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 10.

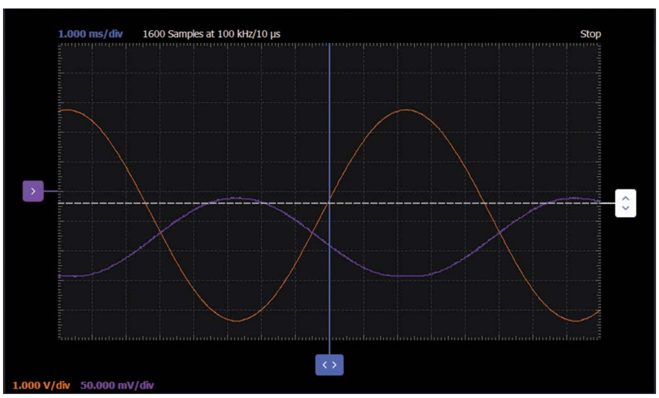


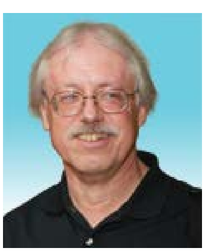
Figure 10. Common-mode gain waveform.

Question:

For the circuit in Figure 8, would you characterize this transistor amplifier as being inverting or noninverting to outputs 2+ and 2– with the base terminal of transistor Q1 being considered the input?

For the same circuit, describe what happens to each of the output voltages (2+ and 2–) as the input voltage (W1) increases. Also describe what happens as it decreases.

You can find the answers at the StudentZone blog.



About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and he holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a Fellow Emeritus contributing to the Active Learning Program. In 2016 he was named Engineer in Residence within the ECSE department at RPI. He can be reached at doug.mercer@analog.com.

About the Author

Antoniu Miclaus is a system applications engineer at Analog Devices, where he works on ADI academic programs, as well as embedded software for Circuits from the Lab®, QA automation, and process management. He started working at Analog Devices in February 2017 in Cluj-Napoca, Romania. He is currently an M.Sc. student in the software engineering master's program at Babes-Bolyai University and he has a B.Eng. in electronics and telecommunications from Technical University of Cluj-Napoca. He can be reached at antoniu.miclaus@analog.com.