ANALOG DEVICES

AN-0990
APPLICATION NOTE

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Terminating a Differential Amplifier in Single-Ended Input Applications

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Properly terminating differential amplifiers for single-ended input applications can be challenging. This application note simplifies the process by walking through the calculations from start to finish. The first step is to determine the input impedance of the amplifier.

CALCULATING THE INPUT IMPEDANCE

The effective input impedance of a circuit depends on whether the amplifier is being driven by a single-ended or differential signal source. For balanced differential input signals, as shown in Figure 1, the input impedance ($R_{IN,\ dm}$) between the inputs ($+D_{IN}$ and $-D_{IN}$) is simply

$$R_{IN,\ dm} = 2 \times R_G$$

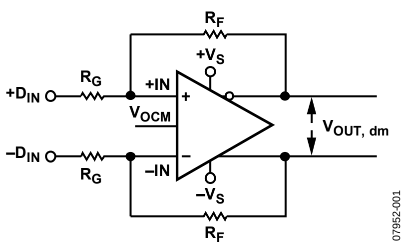

Figure 1. Differential Amplifier Configured for Balanced (Differential) Inputs

For an unbalanced, single-ended input signal (see Figure 2), calculate the input impedance using Equation 1.

$$R_{IN,\ cm} = \left(\frac{R_G}{1 - \dfrac{R_F}{2 \times (R_G + R_F)}} \right) \quad (1)$$

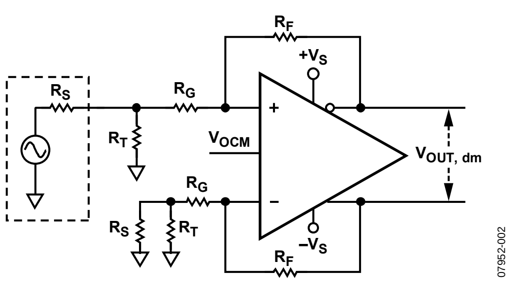

Figure 2. Differential Amplifier Configured for Unbalanced (Single-Ended) Input

The input impedance of the circuit is effectively higher than it would be for a conventional op amp connected as an inverter. This is because a fraction of the differential output voltage appears at the inputs as a common-mode signal, partially bootstrapping the voltage across the input resistor R_G.

Terminating a Single-Ended Input

In this example, the circuit features an ADA4937-1, configured for unity gain. Note that this approach can be used with any differential amplifier.

The gain of the amplifier can be calculated using the gain equation

$$G = \frac{R_F}{R_G}$$

The Analog Devices, Inc., ADA4937-1 data sheet recommends using 200 Ω resistors. The signal source applied to the circuit is 2 V, with a source resistor of 50 Ω. The input termination can now be calculated by following these four simple steps.

1. Calculate the input impedance using Equation 1.

$$R_{IN} = \left(\frac{R_G}{1 - \dfrac{R_F}{2 \times (R_G + R_F)}} \right) = \left(\frac{200}{1 - \dfrac{200}{2 \times (200 + 200)}} \right) = 267\ \Omega$$

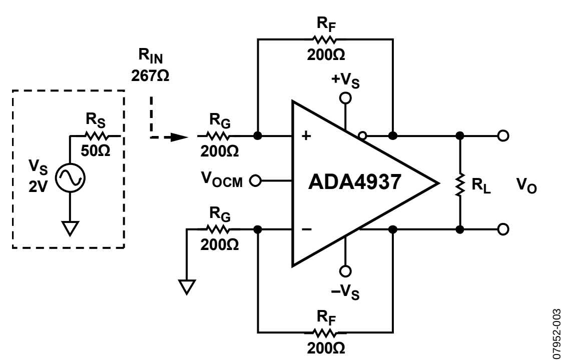

Figure 3. Single-Ended Input Impedance R_{IN}

2. For the source termination to be 50 Ω, calculate the termination resistor (R_T) using $R_T || R_{IN} = 50\ \Omega$, which makes R_T equal to 61.9 Ω.

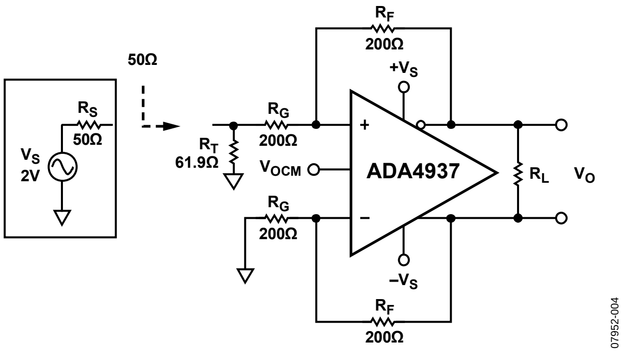

Figure 4. Adding Termination Resistor R_T

3. To compensate for the imbalance of the gain resistors, a correction resistor (R_{TS}) is added in series with the inverting input gain resistor R_G. R_{TS} is equal to the Thevenin equivalent of the source resistance $R_S||R_T$.

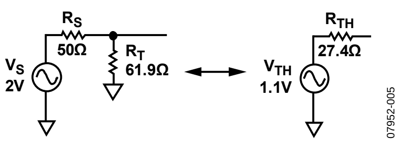

Figure 5. Calculating the Thevenin Equivalent

$R_{TS} = R_{TH} = R_S||R_T = 27.4\ \Omega$.

Note that V_{TH} is not equal to $V_S/2$, which would be the case if the termination were not affected by the amplifier circuit input impedance R_{IN}.

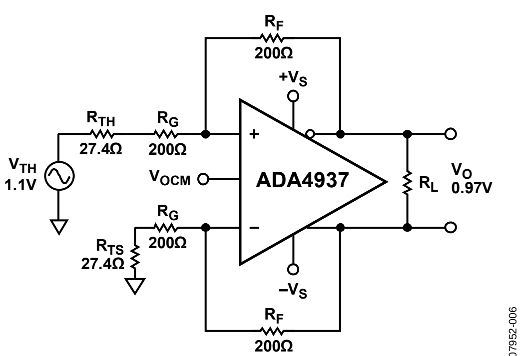

Figure 6. Balancing Gain Resistor R_G

4. The feedback resistor must be recalculated to adjust the output voltage as shown below.

   To make the output voltage V_{OUT} = 1 V, recalculate R_F using the following formula:

$$R_F = \left(\frac{V_{OUT} \times (R_G + R_{TS})}{V_{TH}}\right) = \left(\frac{1 \times (200 + 27.4)}{1.1}\right) = 207\ \Omega$$

   To make $V_O = V_S = 2$ V to recover the loss due to the input termination, R_F should be

$$R_F = \left(\frac{V_{OUT} \times (R_G + R_{TS})}{V_{TH}}\right) = \left(\frac{2 \times (200 + 27.4)}{1.1}\right) = 414\ \Omega$$

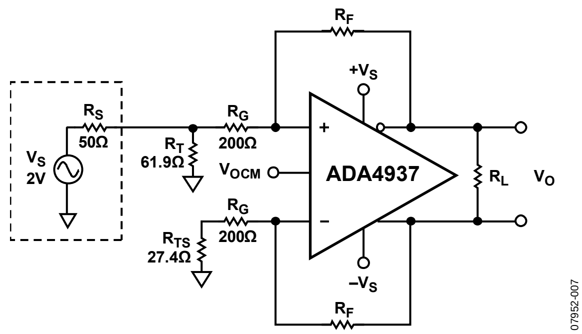

Figure 7. Complete Single-Ended-to-Differential System

CONCLUSION

Calculating the input termination for a single-ended input differential amplifier is accomplished in four steps. First, calculate the amplifier input impedance R_{IN}, then calculate the termination resistor R_T. Rebalance the amplifier gain paths, by adding R_{TS} in series with the inverting input gain resistor. Finally, calculate and adjust the feedback resistor for the correct gain. More information on differential amplifiers is available at www.analog.com.

REFERENCES

ADA4927-1 Data Sheet. Analog Devices, Inc., 2008.

AN-584 Application Note. Analog Devices, Inc., 2002.