# Terminating a differential-input signal

A PREVIOUS COLUMN explains that terminating transmission lines at the driving and receiving ends minimizes signal reflections (**Reference 1**). You must calculate termination-resistor values for single-ended and fully differential circuits. The calculations for single-ended circuits are simple; the noninverting-circuit configuration separates the termination and gain-setting resistors. The calculations in fully differential circuits are complicated, because you can't separate the termination and gain-setting resistors (**Figure 1**).

Assuming that you're dealing with an ideal op amp simplifies the calculations; doing so makes the amplifier gain infinite with no frequency degradation. Under these assumptions, $V_N=V_P$, causing a virtual short across the op-amp inputs. Thus, $R_1$ is effectively in series with $R_3$, and the series combination is in parallel with $R_T$. The equation for the terminating-resistor value follows:

$$R_T = \frac{R_S(R_1+R_3)}{(R_1+R_3-R_S)},$$

where $R_S$ is the driver/source termination resistor.

You must account for the source output impedance, $R_S$, and the cable-termination resistance, $R_T$, in the gain equation, because they are parts of gain-setting resistors $R_1$ and $R_3$ ($R_G$ in the general case). Begin the gain-resistor calculations by using Thevenin's theorem to obtain a series-equivalent circuit to replace $R_T$ and $R_S$. Thevenin-equivalent voltage and resistance equations for a series model follow:

$$V_{TH} = V_S\frac{R_T}{R_T+R_S}.$$

$$R_{TH} = \frac{R_SR_T}{R_S+R_T}.$$

Substituting these three equations into the ideal gain equation, $V_{OUT}=V_{IN}$ $(R_F/R_G)$, yields the gain equation for a circuit with significant source/termination impedance. This equation applies to fully differential inputs and outputs; hence, $R_G=R_1=R_3$, and $R_F=R_2=R_4$.

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_F}{R_G+\dfrac{R_SR_T}{2(R_S+R_T)}}\frac{R_T}{R_T+R_S}.$$

A design example calculates resistor values for a common circuit with a 50Ω differential-balance source and an overall differential gain of one (**Reference 2**). First, choose a value for $R_G$, use that value to calculate $R_T$, and then use the values for $R_T$ and $R_G$ to calculate the feedback-resistor value. An appropriate feedback-resistor value for an op amp in this frequency range is 500Ω. $R_T$ approximately equals $R_S$, so the gain through the termination resistors is about 0.5. The op-amp gain must be two to achieve an overall gain of one, so begin the calculations with $R_G=(R_F/2)=249\Omega$ (closest 1% standard value). Now, use the first equation to calculate $R_T=55.6\Omega$ and select $R_T$ as the closest 1% standard value, 56.2Ω. An algebraically manipulated equation follows, which solves for $R_F=495.5\Omega$, and the closest 1% standard value is 499Ω.

$$R_T = \left(R_G+\frac{R_SR_T}{2(R_S+R_T)}\right)\left(\frac{R_S+R_T}{R_T}\right).$$

**Figure 2** shows the complete circuit with the calculated resistor values.□

## REFERENCES


1. Mancini, Ron, "Fully differential amplifiers and transmission lines," *EDN*, Aug 7, 2003, pg 20.
2. Karki, James, Fully Differential Amplifiers, SLOA054D, Texas Instruments, January 2002.


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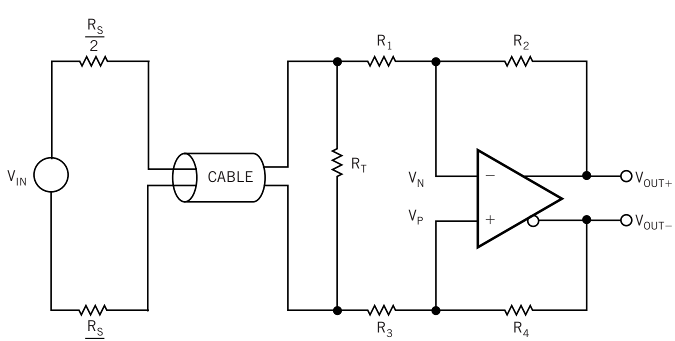


**Figure 1** Fully differential termination is more complicated than the single-ended scheme, because you must take the gain-setting resistors into account when doing the calculations.

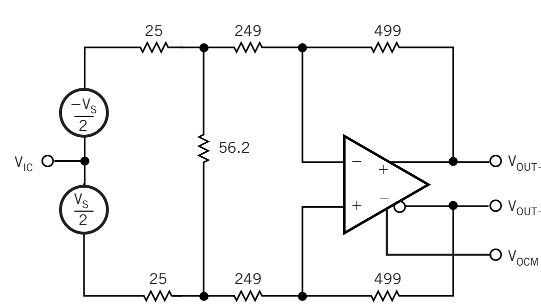


**Figure 2** The calculated resistor values for the completed circuit differ from the intuitive values because $R_T$ and $R_S$ affect the calculations.