Developing equations for fully differential amplifiers

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Fully differential amplifiers and op amps are similar, but they are not identical. You must consider the input voltages and both output voltages when developing fully-differential-amplifier transfer equations. (This column later addresses the development of the common-mode-voltage equation.) You use the fully-differential-amplifier circuit in Figure 1 to develop the transfer equations. **Equation 1** is the amplifier equation, where a is the amplifier gain, and **equations 2 and 3** are the amplifier-input-node equations.

\[ V_{\text{OUT}+} - V_{\text{OUT}-} = a(V_p - V_n). \]  
**EQUATION 1**

\[
V_n = V_{\text{IN}+} \left( \frac{R_2}{R_1 + R_2} \right) + \\
V_{\text{OUT}+} \left( \frac{R_1}{R_1 + R_2} \right). 
\]

**EQUATION 2**

\[
V_p = V_{\text{IN}+} \left( \frac{R_4}{R_3 + R_4} \right) + \\
V_{\text{OUT}+} \left( \frac{R_3}{R_3 + R_4} \right). 
\]

**EQUATION 3**

Substituting **equations 2 and 3** into **Equation 1**, combining terms, and assuming that \( R_1 = R_3 \) and \( R_2 = R_4 \) yields **Equation 4**:

\[
V_{\text{OUT}+} - V_{\text{OUT}-} = \frac{(V_{\text{IN}+} - V_{\text{IN}+})R_2}{R_1 + R_2 + R_1} \cdot \frac{a}{a}. 
\]

**EQUATION 4**

When \( a \) is much greater than \( (R_1 + R_2) \), **Equation 4** reduces to **Equation 5**:
When you use both inputs, the circuit functions as a differential-input/differential-output amplifier. When you use one input (either input, with the remaining input grounded), the circuit functions as a single-ended-input/differential-output amplifier. Equation 5 illustrates the ease of making the single-ended-to-differential-signal conversion: Just connect four resistors, and you obtain signal gain by manipulating the $R_2/R_1$ resistor ratio. The fully differential amplifier eliminates the need for complex two- and three-op-amp versions of single-ended-to-differential-output converters. It has several other advantages over op-amp configurations: higher speed, cheaper cost, smaller space requirement, and lower power consumption.

You calculate the common-mode output voltage, $V_{OCM}$, with the aid of Equation 6 (See Reference 1 below):

$$V_{OCM} = \frac{(V_{OUT+} - V_{OUT-})_{CM}}{2V_{OCM} \frac{R_1 - R_2}{R_1 + R_2}}.$$  

**EQUATION 6**

Notice that the common-mode output voltage goes to zero when $R_1$ and $R_2$ match. It is best to implement the fully differential amplifier with matched resistors to eliminate common-mode voltages. Film resistors are the best source of inexpensive matched resistors. Low-cost matched-film-resistor sets may become readily available in different gain configurations as the popularity of fully differential amplifiers increases.

Reference