Defining an op amp’s dynamic range

It is extremely hard to define dynamic range for an op amp. A good place to start is with a DAC that defines dynamic range as the ratio of the maximum output voltage to the smallest output voltage that the DAC can produce (the least significant bit). You usually express dynamic range in decibels using the formula in Equation 1:

\[
\text{DYNAMIC RANGE} = 20 \text{LOG}_{10} \left( \frac{V_{\text{OUTMAX}}}{V_{\text{OUTMIN}}} \right). \tag{1}
\]

You can use the same definition of dynamic range for an op amp, and the maximum-output-voltage swing equals \(V_{\text{OUTMAX}}\). You define this output voltage swing as the maximum output voltage that the op amp can achieve (\(V_{\text{OH}}\)) minus the minimum output voltage it can achieve (\(V_{\text{OL}}\)). You can easily obtain \(V_{\text{OH}}\) and \(V_{\text{OL}}\) from an op-amp-IC data sheet. Normally, \(V_{\text{OH}}\) and \(V_{\text{OL}}\) are guaranteed minimum and maximum parameters, respectively. These parameters yield Equation 2:

\[
V_{\text{OUTMAX}} = V_{\text{OH(MIN)}} - V_{\text{OL(MAX)}}. \tag{2}
\]

Equation 2 illustrates the role that power-supply voltage plays in limiting the dynamic range. \(V_{\text{OH(MIN)}}\) is the most positive power-supply voltage minus the voltage across the upper output transistor; thus, \(V_{\text{OH(MIN)}}\) is directly proportional to the most positive power-supply voltage. For any op amp, the output voltage swing is directly proportional to the power-supply voltage; thus, in the same op amp, the dynamic range is directly proportional to the power-supply voltage.

At first, you might think that the smallest output voltage that an op amp can have is zero, and the natural conclusion—based on this assumption—is that the dynamic range is equal to infinity. However, this situation is never the case, because op-amp and external-circuit imperfections ensure that the smallest op-amp output voltage is greater than zero. A series of error terms actually determine \(V_{\text{OUTMIN}}\). These error terms are the op amp’s internal noise (\(V_n\) and \(I_n\)), external resistor noise (\(V_{nR}\)), power-supply rejection ratio (\(k_{SVR}\)), voltage offset (\(V_{\text{IO}}\)), current offset (\(I_{\text{IO}}\)), common-mode rejection ratio (CMRR), and closed-loop gain (\(G\)). You calculate each of these error terms at the op-amp input, so you must multiply each of them by \(G\) to make them output parameters.

\[
V_{\text{OUTMIN}} = G_{\text{CL}} V_{\text{IO}} + I_{\text{IO}} R_p + \alpha V_{\text{IO}} \Delta T + \frac{V_{\text{IN}} + I_{\text{BR}} R_p}{k_{SVR}} + \frac{\Delta V}{k_{SVR}} + V_n + I_n R_{\text{EQ}} + I_n R. \tag{3}
\]

Equation 3 takes the error sources into account, and this equation refers them to the op-amp output by multiplying them by the op amp’s \(G\).

\[
\text{DYNAMIC RANGE} = 20 \text{LOG}_{10} \left( \frac{V_{\text{OH(MIN)}} - V_{\text{OL(MAX)}}}{V_{\text{OUTMIN}}} \right) = 20 \text{LOG}_{10} \frac{V_{\text{OUTMAX}}}{V_{\text{OUTMIN}}}. \tag{4}
\]

The dynamic range decreases by the sum of the error terms, so you can properly conclude that the maximum power-supply voltage and the op-amp choice (this choice defines the error magnitude) both establish the dynamic range of an op amp. The first two terms in Equation 3 are dc error terms; thus, you can adjust them to zero by one of several methods that this column doesn’t cover. The input-offset-current and input-bias-current error terms were big factors with older generation ICs, but today’s technology renders them much less significant.

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Ron Mancini is an applications engineer at Texas Instruments. You can reach him at 1-352-568-1040, rmancini@ti.com.