Op-amp bandwidth and accuracy

Op-amp gain begins decreasing at low frequencies, and this effect causes errors because op-amp gain relates to accuracy. Bandwidth-related performance is the hardest op-amp parameter to compensate for because the data sheet never fully specifies it. Some engineers ignore the bandwidth problem by selecting an op amp with much more bandwidth than the application requires to accurately amplify the signal. Choosing an op amp with extra bandwidth causes wideband noise amplification, increased op-amp cost, and increased susceptibility to instability.

In the following response and error equations for a feedback circuit, A is the forward gain, E is the error, and β is the feedback factor:

$$\frac{E}{V_{IN}}=\frac{1}{1+A\beta},$$

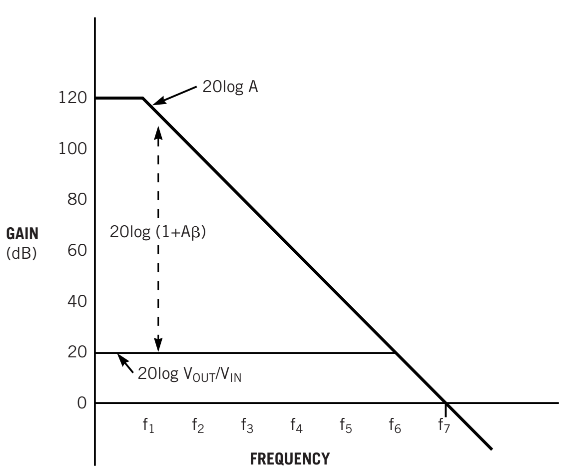
and

$$\frac{V_{OUT}}{V_{IN}}=\frac{A}{1+A\beta}.$$

The loop gain, Aβ, is identical for inverting and noninverting circuits; therefore, the forward gain can't be equal for both circuits. The forward gain, A, equals the op-amp gain, a, for noninverting circuits. The forward gain, A, equals the op-amp gain, a, multiplied by a resistive divider, $R_F/(R_F+R_G)$, for inverting circuits. The forward gain in inverting circuits equals $a(R_F/(R_F+R_G))$.The feedback factor in amplifier circuits is passive and resistive; thus, it is independent of frequency.

A log plot of the op-amp equation shows that the difference between the closed-loop gain and the forward gain is the error factor, 1+Aβ (**Figure 1**). When the input-signal frequency is below f_1, the error is $E/V_{IN}=1/1{,}000{,}000=10^{-6}$. When the input-signal frequency is below f_4, the error is $E/V_{IN}=10^{-3}$, which is a thousand times greater. The error increases when the input-signal frequency increases because the forward gain decreases. The bandwidth specification that you normally find on data sheets is the unity-gain bandwidth, and **Figure 1** shows this bandwidth occurring at f_7.

BEWARE OF OP-AMP-GAIN PLOTS, BECAUSE THEY ARE ALMOST ALWAYS TYPICAL RATHER THAN GUARANTEED DATA.



An op-amp-equation plot reveals that the error increases with increasing frequency.

Now, if you need an amplifier with an error of $10^{-3.5}$ at f_3, an op amp with the forward gain in the **figure** is adequate, but if you require an error of $10^{-4.5}$ at f_3, this op amp is inadequate. To select an op amp that performs with less than a specified error at f_x, start at the unity-gain-bandwidth specification, back up a decade in frequency, and accumulate 10^{-1} error. Repeat this procedure, reducing the error 10^{-1} for each decade in frequency that you back up. When you meet the error specification, note the frequency, and, if it exceeds f_x, the op amp is adequate for the job. This analysis procedure yields good circuits when the manufacturer guarantees the unity-gain-bandwidth specification. The circuit is not guaranteed when the manufacturer doesn't guarantee the unity-gain-bandwidth specification. Beware of op-amp-gain plots, because they are almost always typical rather than guaranteed data.

This procedure is simple to implement when the input signal is a sine wave, but few input signals are sine waves. When the input signal is complex, you must analyze it to determine what frequencies it contains and how an inaccuracy in the amplification of the high frequencies affects the distortion. Because the solution to this problem is complicated, I will address it in my next column.□

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