How to Determine the Op-Amp Open-Loop Output Impedance

Applying phase compensation to amplifier circuits using op-amps requires knowledge about the open-loop output impedance of the device, Z_O. As this parameter is rarely specified in datasheets, this application note explains one of many ways to determine Z_O for a given capacitive load condition.

Loading the output of the non-inverting amplifier in Figure 1 with a large capacitance causes a gain peak in the frequency response. This is because C_L forms a pole with Z_O at frequency f_p, causing the unload open-loop gain, A_{ul}, to change its roll off from -20 to -40dB/decade (Figure 2). This section is denoted as the loaded open-loop gain, A_{ld}. At the frequency, where the closed-loop gain, 1/β, crosses A_{ld}, the gain peak occurs. Therefore, this frequency becomes the peak frequency, f_{pk}.

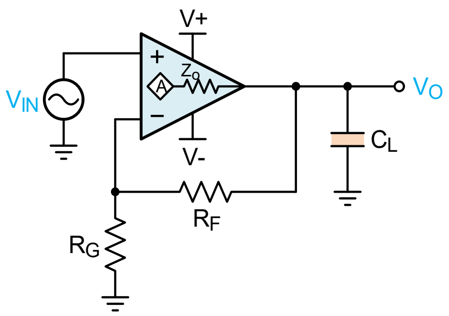

Figure 1.

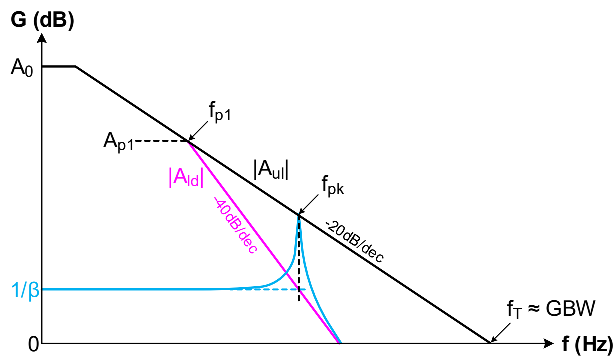

Figure 2.

To find the value for Z_O under this load condition, only two parameters must be known by the designer: f_{pk}, which can be measured with a network analyzer or oscilloscope, and f_T, which is the unity-gain bandwidth of the op-amp, and in most cases also the gain bandwidth, GBW: $f_T \approx$ GBW.

As the open-loop gain at f_{p1}, denoted as A_{p1}, is equal for both roll offs, you can establish the constant gain-bandwidth equation for each slope:

for the -20dB/dec roll off: $f_{p1} \cdot A_{p1} = f_T \quad \Rightarrow \quad A_{p1} = \dfrac{f_T}{f_{p1}}$

for the -40dB/dec roll off: $f_{p1}^2 \cdot A_{p1} = f_{pk}^2 \cdot 1/\beta \quad \Rightarrow \quad A_{p1} = \dfrac{f_{pk}^2}{f_{p1}^2 \cdot \beta}$.

Setting both A_{p1} terms equal and solving for f_{p1}, gives: $f_{p1} = \dfrac{f_{pk}^2}{f_T \cdot \beta}$

Then, substituting f_{p1} with $1/(2\pi Z_O C_L)$ and solving for Z_O, provides the open-loop output impedance:

(EQ. 1) $$Z_O = \frac{f_T \beta}{2\pi f_{pk}^2 C_L} \qquad \text{with} \qquad f_T \approx \text{GBW} \qquad \text{and} \qquad \beta = \frac{R_G}{R_G + R_F}$$

Revision History

Revision	Date	Description
1.00	May 10, 2022	Initial release.

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