

# OpAmp Output Protection: White Paper - Amatek Design 2016

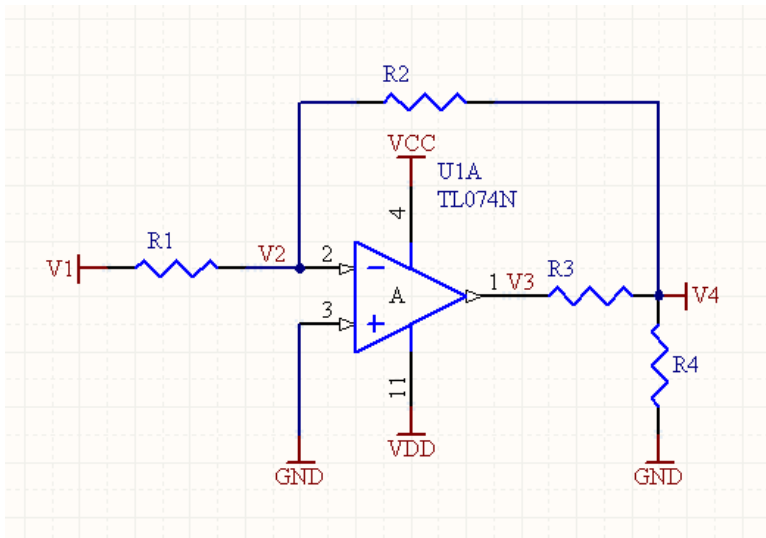
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Operational Amplifiers are often used as output drivers and can be subject to output overload, especially when driving loads outside the box. This overload may damage the output driver of the op-amp.

An often used circuit includes an output resistor placed between the op amp and the feedback loop as shown in Figure 1. But how does this output resistor affect the performance of the circuit?

The answer can found from first principles by using nodal analysis and including the open loop amplifier gain  $A$  in the analysis. Cramer's rule is used to find the equation for the output  $V_4$ . The ideal case for this circuit can be seen if the limit to infinity of  $A$  is taken.

Further circuit insight can be developed by solving for the differential input voltage,  $V_2$ , and again taking the limit.



The first step is to analyze the current leaving each node yielding the following equations:

$$V_3 = A(V_+ - V_-) = A(0 - V_2) = -AV_2 \quad (1)$$

$$\frac{V_2 - V_1}{R_1} + \frac{V_2 - V_4}{R_2} = 0 \quad (2)$$

$$\frac{V_4 - V_2}{R_2} + \frac{V_4 - V_3}{R_3} + \frac{V_4}{R_4} = 0 \quad (3)$$

From equations (1), (2) and (3) the following matrix can be constructed:

$$\begin{bmatrix} \frac{1}{R_1} + \frac{1}{R_2} & -\frac{1}{R_2} \\ \frac{A}{R_3} - \frac{1}{R_2} & \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \end{bmatrix} \begin{bmatrix} V_2 \\ V_4 \end{bmatrix} = \begin{bmatrix} \frac{V_1}{R_1} \\ 0 \end{bmatrix} \quad (5)$$

Cramer's Rule can be used to solve for the output as a function of the input.

The next step is to use Cramer's Rule to find the output voltage  $V_4$ :

$$V_4 = \frac{\Delta_4}{\Delta} = \frac{-\frac{V_1}{R_1} \left( \frac{A}{R_3} - \frac{1}{R_2} \right)}{\left( \frac{1}{R_1} + \frac{1}{R_2} \right) \left( \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \right) + \frac{1}{R_2} \left( \frac{A}{R_3} - \frac{1}{R_2} \right)}$$

Next divide top and bottom by  $A$  and then take the limit as  $A \rightarrow \infty$ , which yields the ideal case for  $V_4$ :

$$V_4 = \frac{-\frac{V_1}{R_1} \left( \frac{1}{R_3} \right)}{\frac{1}{R_2} \cdot \frac{1}{R_3}} = -V_1 \cdot \frac{R_2}{R_1}$$

From this result we can conclude that the output at  $V_4$  is independent of the value of the load resistor  $R_4$ ; though practically the op amp can be protected with a small value of 50 or 100 ohms depending on the output drive capability of the selected device.

This method also can be used to verify that as  $A \rightarrow \infty$  the voltage between the input terminals also tends to zero.

Find  $V_2$ :

$$V_2 = \frac{\Delta_2}{\Delta} = \frac{\frac{V_1}{R_1} \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)}{\left( \frac{1}{R_1} + \frac{1}{R_2} \right) \left( \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \right) + \frac{1}{R_2} \left( \frac{A}{R_3} - \frac{1}{R_2} \right)}$$

Again divide top and bottom by  $A$  and then take the limit as  $A \rightarrow \infty$

$$V_2 = \frac{0}{\frac{1}{R_2} \cdot \frac{1}{R_3}} = 0$$

From this analysis we can see that the output of a generic op amp device can be protected by the series insertion of a small resistor before the feedback pick up point without affecting the voltage transfer function and gain. The analysis also verifies that in the limiting case the voltage between the two op amp input terminals tends towards zero.