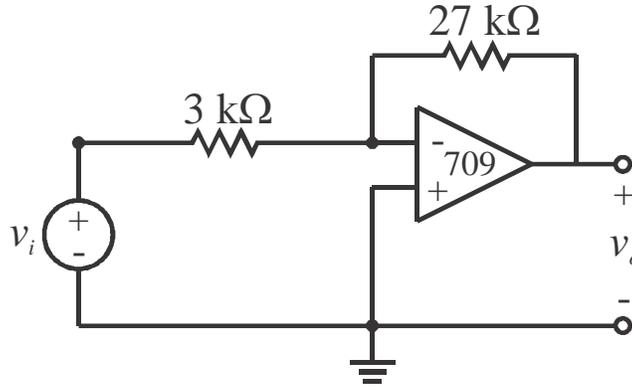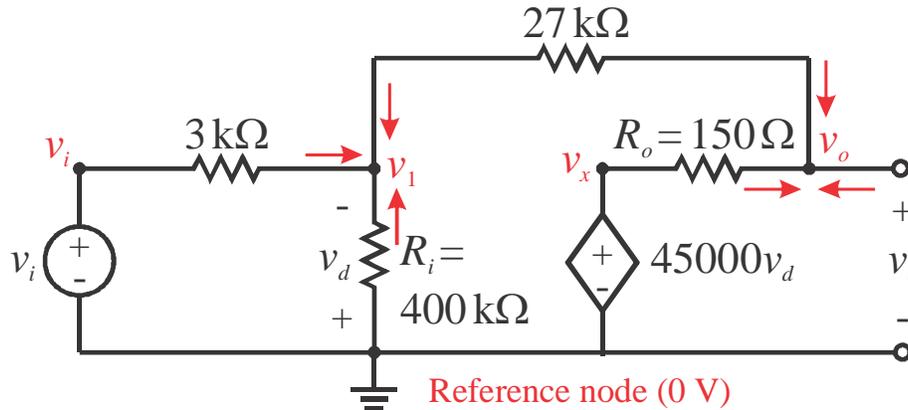# LM709 Op-Amp

- Inferior predecessor to very popular LM741 op-amp developed ~1968 by Dave Fullagar at Fairchild Semiconductor
- Consists of ~14 BJTs and 15 resistors
- $A = 45{,}000$, $R_i = 400\,\text{k}\Omega$, and $R_o = 150\;\Omega$

Find the closed loop gain $A_v = v_o/v_i$ for the circuit below.

Replace op-amp with equivalent circuit model.

Reference node (0 V)

Apply nodal analysis-

Input node: $v_i = v_i$

Node 1: $\dfrac{v_i - v_1}{3000} + \dfrac{0 - v_1}{400000} + \dfrac{v_o - v_1}{27000} = 0$

Node x: $v_x = \mathbf{45000}v_d$

Output node: $\dfrac{v_1 - v_o}{27000} + \dfrac{v_x - v_o}{150} + 0 = 0$

From the circuit, note that $v_1 = -v_d$.

$\Rightarrow$ **Modify output node equation** $\dfrac{-v_d - v_o}{27000} + \dfrac{45000v_d - v_o}{150} = 0$ **and**

solve for difference voltage to get:

$$v_d = \left(\dfrac{\dfrac{1}{27000} + \dfrac{1}{150}}{\dfrac{45000}{150} - \dfrac{1}{27000}} \right) v_o = \left(\dfrac{1 + 180}{8100000 - 1} \right) v_o = \left(\dfrac{181}{8099999} \right) v_o$$

$\Rightarrow$ **Modify node 1 equation** $\dfrac{v_i + v_d}{3000} + \dfrac{v_d}{400000} + \dfrac{v_o + v_d}{27000} = 0$

$\Rightarrow$ **Substitute for difference voltage in the modified node 1 equation to get an equation solely in terms of v_i and v_o:**

$$\dfrac{v_i + \left(\dfrac{181}{8099999}\right) v_o}{3000} + \dfrac{\left(\dfrac{181}{8099999}\right) v_o}{400000} + \dfrac{v_o + \left(\dfrac{181}{8099999}\right) v_o}{27000} = 0$$

Solve for the closed loop gain-

$$\dfrac{1 + \left(\dfrac{181}{8099999}\right)\dfrac{v_o}{v_i}}{3000} + \dfrac{\left(\dfrac{181}{8099999}\right)\dfrac{v_o}{v_i}}{400000} + \dfrac{\dfrac{v_o}{v_i} + \left(\dfrac{181}{8099999}\right)\dfrac{v_o}{v_i}}{27000} = 0$$

$$\dfrac{v_o}{v_i}\left(\dfrac{181}{8099999}\right)\left[\dfrac{1}{3000} + \dfrac{1}{400000} + \dfrac{\dfrac{8099999}{181} + 1}{27000}\right] = \dfrac{-1}{3000}$$

$$A_v = \dfrac{v_o}{v_i} = \dfrac{\dfrac{-1}{3000}\left(\dfrac{8099999}{181}\right)}{\dfrac{1}{3000} + \dfrac{1}{400000} + \dfrac{\dfrac{8099999}{181} + 1}{27000}}$$

$\underline{A_v = -8.997975771}$