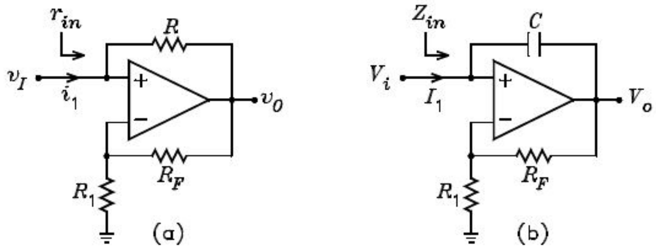
<u>Tutorial 7 Solution</u>

Question 1



Circuit (a)

Assuming ideal op-amp in linear mode with negative feedback, we can write

$$v_O = \left(1 + \frac{R_F}{R_1}\right) v_I.$$

Now,

$$\begin{aligned} i_I &= \frac{v_I - v_O}{R} \\ &= \frac{R_F}{R_1 R} v_I \\ \therefore r_{in} = \frac{v_I}{i_I} &= -\frac{R1}{R_F} R \end{aligned}$$

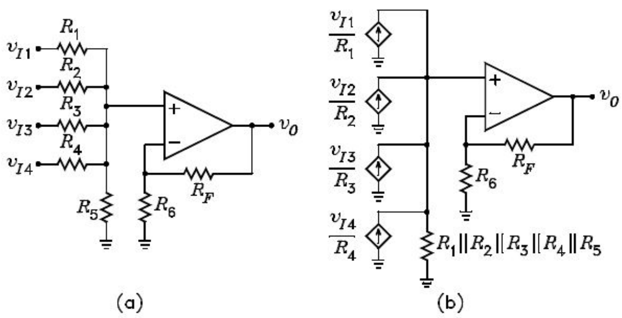
Circuit (b)

Similar results will be obtained as circuit (a) with replacing R with reactance $\frac{1}{j\omega C}$.

$$Z_{in} = -\frac{R_1}{R_F}\frac{1}{j\omega C} = j\omega \frac{R_1}{\omega^2 R_F C} = j\omega L_{eq}$$

Note: This circuit results in inductive behavior with frequency dependent inductance L_{eq}.

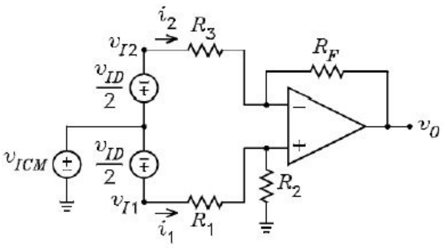
Question 2



All voltage sources can be converted to their equivalent Norton's circuit as shown in part (b). Now,

$$v_O = \left(1 + \frac{R_F}{R_6}\right) v_+ \qquad = \left(\frac{v_{I1}}{R_1} + \frac{v_{I2}}{R_2} + \frac{v_{I3}}{R_3} + \frac{v_{I4}}{R_4}\right)(R_1 \parallel R_2 \parallel R_3 \parallel R_4 \parallel R_5)\left(1 + \frac{R_F}{R_6}\right)$$

Question 3



$$v_{I1} = v_{CM} + \frac{v_D}{2}$$

$$v_{I2} = v_{CM} - \frac{v_D}{2}$$

The voltages v_{CM} and v_D can be expressed in terms of input voltages as

$$v_{CM} = \frac{v_{I1} + v_{I2}}{2}$$

$$v_D = v_{I1} - v_{I2}$$

Now writing expression for output in terms of input voltages v_{I1} and v_{I2},

$$V_o = \left(1 + \frac{R_F}{R_3}\right)\left(\frac{R_2}{R_1 + R_2}\right) v_{I1} - \frac{R_F}{R_3} v_{I2}$$

writing in terms of common mode and differential voltages yields

$$\begin{aligned} V_o &= \left(1 + \frac{R_F}{R_3}\right)\left(\frac{R_2}{R_1 + R_2}\right)\left(v_{CM} + \frac{v_D}{2}\right) - \frac{R_F}{R_3}\left(v_{CM} - \frac{v_D}{2}\right) \\ &= \left(1 - \frac{R_F R_1}{R_2 R_3}\right)\left(\frac{R_2}{R_1 + R_2}\right) v_{CM} + \frac{R_F}{2R_3}\left[1 + \frac{R_2(R_3 + R_F)}{R_F(R_1 + R_2)}\right] v_D \end{aligned}$$

Now, common mode and differential mode gain are obtained as below.

$$A_{cm} = \frac{V_o}{v_{CM}}|_{v_D=0} = \left(1 - \frac{R_F R_1}{R_2 R_3}\right)\left(\frac{R_2}{R_1 + R_2}\right)$$

$$A_d = \frac{V_o}{v_D}|_{v_{CM}=0} = \frac{R_F}{2R_3}\left[1 + \frac{R_2(R_3 + R_F)}{R_F(R_1 + R_2)}\right]$$

With $\frac{R_F}{R_2} = \frac{R_3}{R_1}$, we get

$$A_{cm} = 0 \qquad \text{and} \qquad A_d = \frac{R_F}{R_3}$$
