Tutorial 3, Sep 27, 2023

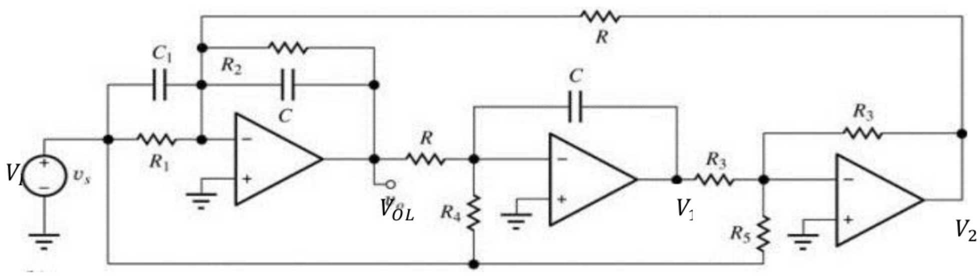

Figure 1: Example problem: two integrator biquad.

- Example: find the transfer function of the above
  - Replace C_1, R_1 by impedance $Z_a = \dfrac{R}{sR_1C_1+1}$
  - Replace C, R_2 by impedance $Z_2 = \dfrac{R_2}{sR_2C+1}$
  - Replace R by impedance Z_b
  - At the first op-amp we have an inverting summing amplifier
    * We don't need to worry about R_4 and R_5 since they just contribute to V_I
    * $V_{OL} = -\dfrac{Z_2}{Z_a}V_I - \dfrac{Z_2}{Z_b}V_2 = -\dfrac{R_2(sR_2C_1+1)}{(sR_2C+1)R_1}V_I - \dfrac{R_2}{(sR_2C+1)R}V_2$
  - $V_2 = -\dfrac{R_3}{R_3}V_1 - \dfrac{R_3}{R_5}V_I$
    * Sub in V_2 to get V_{OL} in terms of V_1 and V_I
  - $V_1 = -\dfrac{\frac{1}{sC}}{R}V_{OL} - \dfrac{\frac{1}{sC}}{R_4}V_I$
  - ... a bunch of nasty algebra later

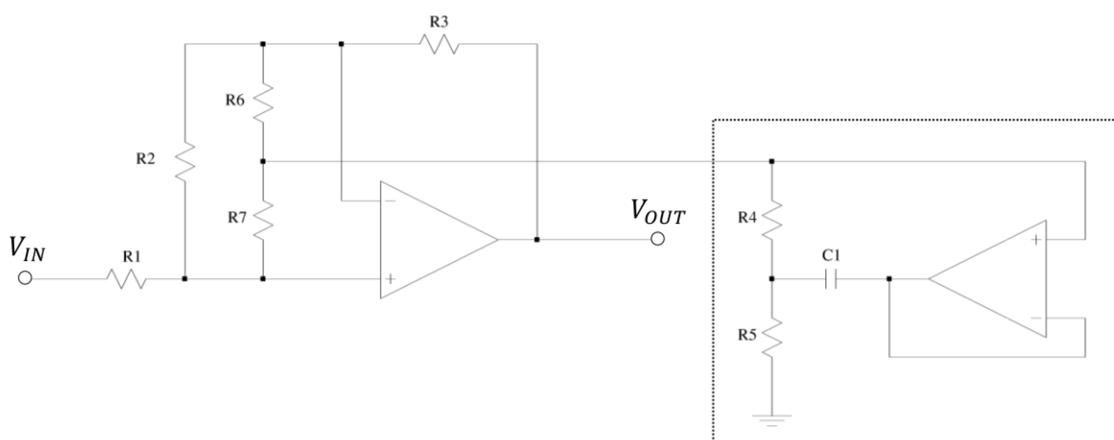

Figure 2: Example problem.

- Example: find the transfer function of the circuit above
  - We will model the sub-circuit in the box as an equivalent impedance connected to ground
  - First find Z_{eq}
    * Assume a voltage of V_{in} at the top node
    * Since this is an ideal op-amp, the inverting input and output are also at V_{in} and no current flows into the noninverting input
    * Node equation at A, the node between the resistors: $\dfrac{V_A - V_{in}}{R_4} + \dfrac{V_A}{R_5} + \dfrac{V_A - V_{in}}{\frac{1}{sC_1}}$

* $V_A \left(\frac{R_5 + R_4 + sR_4R_5C_1}{R_5R_4} \right) = V_{in} \left(\frac{1 + sR_4C_1}{R_4} \right)$
* $\frac{V_A}{V_{in}} = \frac{R_5 + sR_4C_1R_5}{R_5 + R_4 + sR_4R_5C_1}$
* If we have an input current I_{in}, then $I_{in} = \frac{V_{in} - V_A}{R_4}$ which we can substitute V_A
* $Z_{eq} = \frac{V_{in}}{I_{in}} = \frac{1}{R_5 + R_4 + sR_4R_5C_1}$