#### UNIVERSITY OF CALIFORNIA, BERKELEY College of Engineering Department of Electrical Engineering and Computer Sciences st modified on Oct 16th, 2003 by Jia Zhou (jiazhou@aacs barkalay a

Last modified on Oct 16th, 2003 by Jie Zhou (jiezhou@eecs.berkeley.edu)

Prof. Neureuther

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**Homework 7 Solutions** 

### 7.1 Dependent Sources

a) There three steps to lead you to the answer; first, we can see that Vin is equal to V- in magnitude. Then if A goes to infinity, the actual circuit resembles a voltage divider for V- and Vo. So the last step is to solve for V<sub>0</sub> in terms of  $V_{IN}$ .

$$\begin{split} \mathbf{V}_0 = \mathbf{V}_{\mathrm{IN}} \frac{\mathbf{A}(\mathbf{R}_1 + \mathbf{R}_2)}{(\mathbf{A} + 1)\mathbf{R}_1 + \mathbf{R}_2} &\cong \mathbf{V}_{\mathrm{IN}} \frac{\mathbf{R}_1 + \mathbf{R}_2}{\mathbf{R}_1} = 10 \mathbf{V}_{\mathrm{IN}} \\ & \text{if } \mathbf{A} \rightarrow \infty \end{split}$$

b) The gain  $(Vo/V_{IN})$  is greater than unity as shown in part a.

# 7.2 Ideal Op-Amp

a) Assuming ideal op amp, 1) V+ = V-; 2) no current into + and - terminals, so V- = V+ = V2 holds.

KCL at node V-, we get: 
$$\frac{V2 - V1}{R1} + \frac{V2 - Vout}{R3} = 0$$

Solve, we have: Vout = V2 
$$\cdot \left(1 + \frac{R3}{R1}\right) - V1 \cdot \frac{R3}{R1}$$

b) VCVS (Voltage controlled voltage source) is a voltage source, so  $R_L$  at the output in parallel to the VCVS will not affect the voltage.

c) The Op amp is ideal, therefore by definition, there is no current that is flowing through  $R_2$ , So Vo is independent of the value of  $R_2$ .

# 7.3 Cascade Op-Amps

a) Let's look at the first stage, which consists of the first Op-Amp with two resistors. For ideal Op-Amps, the two inputs are equal, so the voltage on the negative input V\_ is equal to V1. We can use voltage divider to find an expression for Vo<sub>l</sub> and we get:

$$Vo1 = V1 \cdot \left(1 + \frac{R2}{R1}\right)$$

b) The output of the second Op-Amp is dependent on the output of the first Op-Amp, so we can derive an expression of Vo2 in terms of Vo1, V2, R3 and R4. Then we can plug

in the result we obtained for Vo1 in part a) into the equation that we have derived for Vo2.

$$\operatorname{Vo2} = \operatorname{Vo1} \cdot \left(1 + \frac{R4}{R3}\right) - \operatorname{V2} \cdot \frac{R4}{R3} = \operatorname{V1} \cdot \left(1 + \frac{R2}{R1}\right) \cdot \left(1 + \frac{R4}{R3}\right) - \operatorname{V2} \cdot \frac{R4}{R3}$$

#### 7.4 Dependent Sources

a) Do KCL at node VE, we find VE =  $\beta$  ib\* RE + ib\* RE VE =  $(\beta + 1)ibRE$ 

b) VTEST is the sum of two voltages, VE and the voltage drop across RIN. Thus: VTEST = ibRIN + VE. Plug the answer from part a) into this equation, we have: <u>VTEST =  $ibRIN + (\beta + 1)ibRE$ </u>

c) The current flowing between the terminals AA' is ib, and the voltage across AA' is VTEST, thus the resistance seen looking into AA' is VTEST/ib and it is equal to: <u>VTEST/ib = RIN + ( $\beta$  +1) RE</u>