EECS 42 Introduction to Digital Electronics

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Lecture # 14 Circuit analysis with dependent sources (4.1-4.3)

A) Node Equations

B) Equivalent Sources

C) Amplifier Parameters:
Gain, R_{IN}, R_{OUT}

D) Non-Ideal Op-Amp Model

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The 4 Basic Linear Dependent Sources

Constant of proportionality

Parameter being sensed

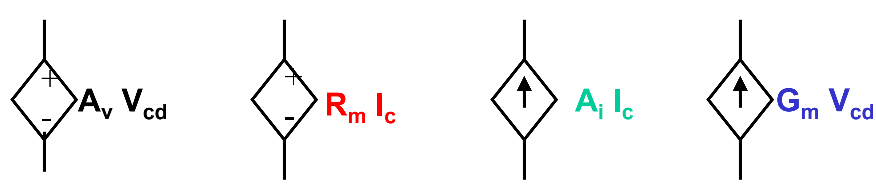
Output

Voltage-controlled voltage source … $V = A_v \; V_{cd}$

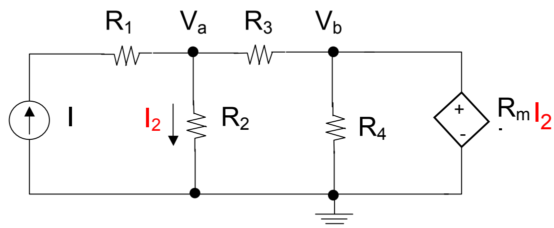
Current-controlled voltage source … $V = R_m \; I_c$

Current-controlled current source … $I = A_i \; I_c$

Voltage-controlled current source … $I = G_m \; V_{cd}$



EXAMPLE OF NODAL ANALYSIS WITH DEPENDENT SOURCES



Standard technique, except an additional equation is needed if the dependent variable is an unknown current as here. Note Vb is redundant.

$I = V_a / R_2 + (V_a - R_m I_2)/ R_3$ and $I_2 = V_a / R_2$

Solving: $I = V_a (1/R_2 + 1/R_3 - R_m /R_2 R_3)$

So $V_a = I R_2 R_3 /(R_2 + R_3 - R_m)$

THEVENIN EQUIVALENT WITH DEPENDENT SOURCES

Method 1: Use V_{oc} and I_{sc} as usual to find V_T and R_T (and I_N as well)

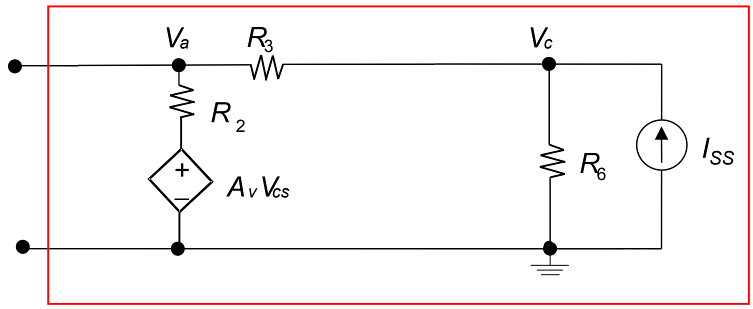
Method 2: To find R_T by the "ohmmeter method" turn off only the *independent* sources; let the dependent sources just do their thing.

See examples in text (such as Example 4.3).

This method also works when computing incremental signals such as a change in the source V_S (given by ΔV_S or v_S) produces a change in V_{IN} or V_{OUT}, (given by ΔV_{IN} or ΔV_{OUT} also written v_{IN} and v_{OUT}), and their ratio called the small-signal gain $(\Delta V_{OUT} / \Delta V_S)$ or (v_{OUT}/ v_S)

NODAL ANALYSIS WITH DEPENDENT SOURCES

Example : Find Thévenin equivalent of stuff in red box.

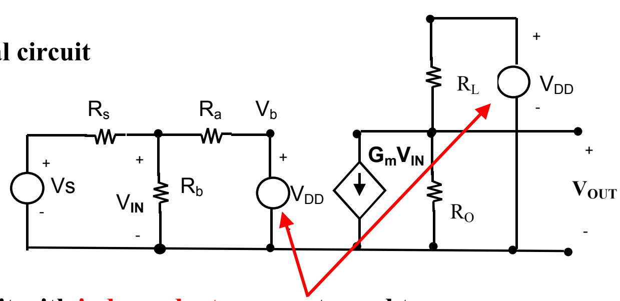


With method 2 we first find open circuit voltage (V_T) and then we "measure" input resistance with source I_{SS} turned off.

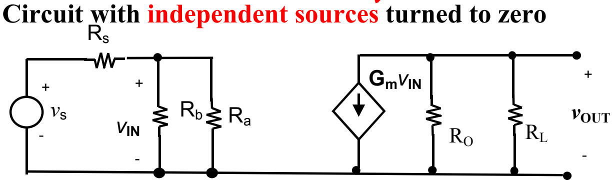
You verify the solution: $V_{TH} = \dfrac{I_{SS}R_6(R_2 + AR_3)}{R_2 + R_3 + R_6(1-A)}$ $R_{TH} = \dfrac{R_2(R_6 + R_3)}{R_2 + R_3 + R_6(1-A)}$

EXAMPLE CIRCUIT WITH MULTIPLE SOURCES

Original circuit

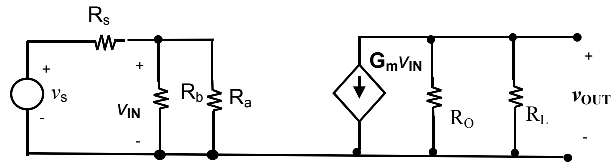


Circuit with independent sources turned to zero



Note R_L has been rotated down.

EXAMPLE CIRCUIT: GAIN = ($\Delta V_{OUT} / \Delta V_S$) = ($v_{OUT}/v_S$)

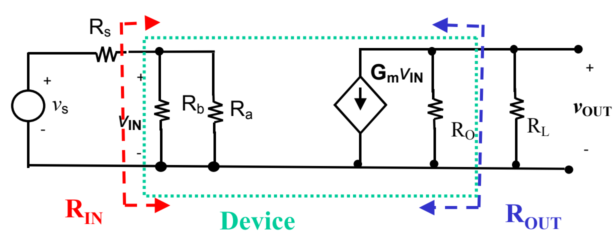


$$R_{IN} = \frac{R_a R_b}{R_a + R_b} \qquad v_{IN} = \frac{R_{IN}}{R_S + R_{IN}} v_s$$

$$v_{OUT} = -G_m v_{IN} \frac{R_O R_L}{R_O + R_L} = -G_m \frac{R_{IN}}{R_S + R_{IN}} \frac{R_O R_L}{R_O + R_L} v_S$$

Input voltage divider and output current divider reduce the gain

EXAMPLE CIRCUIT: INPUT/OUTPUT RESISTANCE



$$R_{IN} = \frac{R_a R_b}{R_a + R_b}$$

Output does not feed back to input

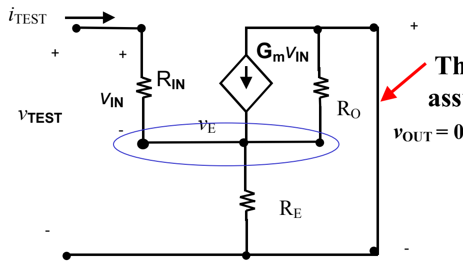
$$R_{OUT} = R_O$$

Assume $v_S = 0 \Rightarrow v_{IN} = 0 \Rightarrow$ no current in dependent source

Can circuit design improve R_{IN} and R_{OUT} or do we need better devices?

EXAMPLE CIRCUIT: INCREASED INPUT RESISTANCE

Add resistor R_E



The output has been assumed to be shorted

Analysis: apply i_{TEST} and evaluate v_{TEST}

$$v_{IN} = R_{IN} i_{TEST} \qquad v_{TEST} = R_{IN} i_{TEST} + v_E$$

Finish this in the homework

KCL $$\frac{v_E}{R_E} + \frac{v_E}{R_0} - i_{TEST} - G_m R_{IN} i_{TEST} = 0$$

Check for special case for R_0 infinite $$\frac{v_{TEST}}{i_{TEST}} = R_{IN} + (1 + G_m R_{IN}) R_E$$

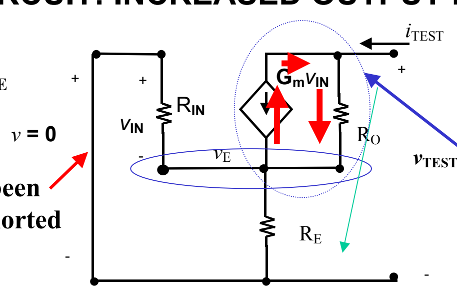
Intuitive Explanation: R_E puts R_{IN} on a node whose voltage increases in response to current in R_{IN}.

EXAMPLE CIRCUIT: INCREASED OUTPUT RESISTANCE

Add resistor R_E

v = 0

The input has been assumed to be shorted



Try a bag. It is even easier

Analysis: apply i_{TEST} and evaluate v_{TEST}

Unknowns: i_{TEST}, v_{TEST}, v_{IN}, v_E

Need 3 equations to find the ratio of i_{TEST} / v_{TEST}

$v_{IN} = -v_E$ and is not zero!

KCL at v_E

KVL at v_{OUT}

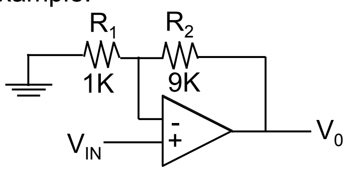
Intuitive Explanation: GmV_{IN} burps current which has to also go through R_0. This raises v_{TEST} and the output impedance v_{TEST}/i_{TEST}

Finish this in the homework

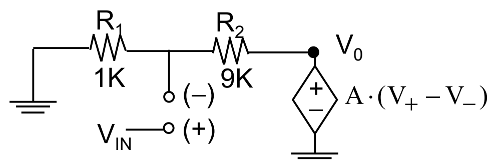
NON-IDEAL OP-AMPS

JUST ANOTHER CASE OF ANALYSIS WITH DEPENDENT SOURCES

Example:



Circuit (assume $R_{IN} \cong \infty$)



Analysis: **Outline your circuit analysis strategy here.**

Hint: 1) Find V_- in terms of V_0, 2) plug into expression for V_0 and then 3) solve for V_0 which appears on both sides of the equation.

Answer:

$$V_0 = V_{IN}\frac{A(R_1+R_2)}{(A+1)R_1+R_2} \cong V_{IN}\frac{R_1+R_2}{R_1} = 10V_{IN}$$

$$\text{if } A \to \infty$$