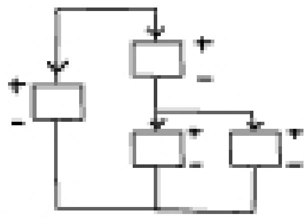
Lecture 7

Last Time: The Circuit Abstraction

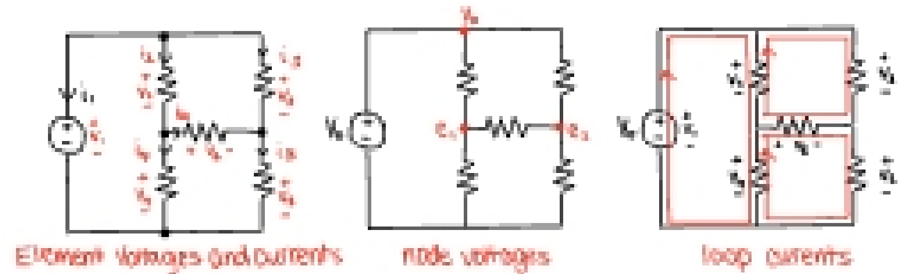
Circuits represent systems as connections of elements
- through which currents (through variables) flow
- across which voltages (across variables) develop



Last Time: Analyzing Circuits

Circuits are analyzed by combining three types of equations
KVL: sum of voltages around any closed path is zero
KCL: sum of currents out of any closed surface is zero
Element (constitutive) equations
- Resistor: V = IR
- Voltage Source: V = V
- Current Source: I = I

Many KVL and KCL equations are redundant
We looked at three methods to systematically identify a linearly independent set



Check yourself: Analyzing Circuits
Correct answer: 2 and 3
How many of the following are true?
- $V_0 - e_1 = i_6 R_2 = -i_4 R_2$
- $i_1 + i_2 + i_4 = 0$
- $v_2 + v_6 + v_3 = v_4 + v_6 + v_4$
- $i_2 - i_4 = i_3 - i_5$
- $\frac{e_1 - V_0}{R_2} + \frac{e_2 - V_0}{R_3} + \frac{e_1}{R_4} + \frac{e_2}{R_5} = 0$

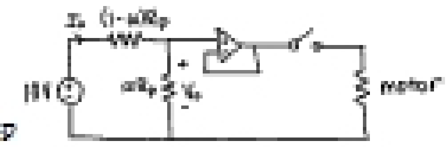
Interaction of Circuit Elements

Circuit design is complicated by interactions among the elements
Adding an element changes voltages and currents throughout the circuit
Example: closing a switch is equivalent to adding a new element

Concept Question: Closing a switch
Correct answer: 3
By closing the switch, V decreased by more than a factor of 1000

Buffering with Op-Amps

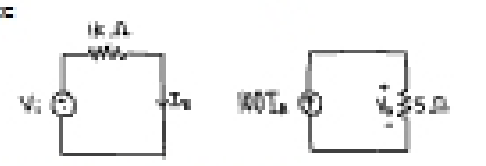
Interactions between elements can be reduced (or eliminated) by using an op-amp as a buffer
Opening and closing the switch has no effect on I or V
When the switch is closed, the voltage across the motor is the same as the voltage at the input to the op-amp



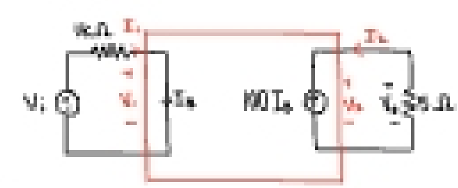
Dependent Sources

To analyze op-amps, we must introduce a new kind of element: a dependent source
A dependent source generates a voltage or current whose value depends on another voltage or current
Example: current-controlled current source

Check yourself: Dependent Sources
Correct answer: 4
$V_o/V_i = 1/2$

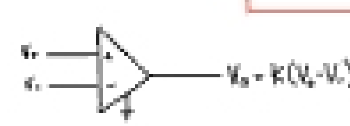


Dependent sources are two-ports: characterized by two equations
By contrast, one-ports (resistors, voltage sources, current sources) are characterized by a single equation



Op-Amp

An op-amp (operational amplifier) can be represented by a voltage-controlled voltage sources
A voltage-controlled voltage source is a two-port
Example: Find V /V for the following circuit

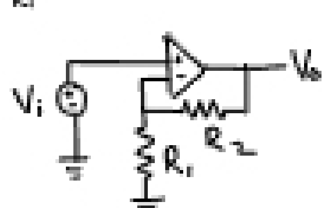


$V_+ = V_i$ $V_- = \frac{R_1}{R_1+R_2}V_o$ $V_o = K(V_+ - V_-) \rightarrow V_o = K(V_i - \frac{R_1}{R_1+R_2}V_o)$

$\frac{V_o}{V_i} = \frac{K}{1+\frac{KR_1}{R_1+R_2}} = \frac{K(R_1+R_2)}{R_1+R_2+KR_1}$ Assuming that K is large we get $\frac{V_o}{V_i} = \frac{R_1+R_2}{R_1}$

Non-Inverting Amplifier

This circuit implements a gain
For large K, the gain is always greater than or equal to one
We call this a non-inverting amplifier



Check yourself: Non-Inverting Amplifier
Correct answer: 4
$V_o = V_i$ when R_1 is infinity and or R_2 is zero

The Ideal Op-Amp

The approximation that $V_+ = V_-$ is referred to as the idea op-amp approximation