EIT Review

Electrical Circuits – DC Circuits

Lecturer: Russ Tatro

Presented by Tau Beta Pi
The Engineering Honor Society

Session Outline

- Basic Concepts
- Basic Laws
- Methods of Analysis
- Circuit Theorems
- Operational Amplifiers
- Capacitors and Inductors
- Summary and Questions

Basic Concepts

Linear, Lumped parameter systems.

Linear – response is proportional to V or I

(no higher order terms needed)

Lumped Parameter

Electrical effects happen instantaneously in the system.

Low frequency or small size (about 1/10 of the wavelength).

Basic Concepts

Circuit Elements

Voltage Source

Current Source

Resistor

capacitor

Inductor

Basic Concepts - Units

Volt – The Potential difference is the energy required to move a unit charge (the electron) through an element (such as a resistor).

Amp – Electric current is the time rate of change of the charge, measured in amperes (A).

A direct Current (dc) is a current that remains constant with time.

An alternating current (ac) is a current that varies sinusoidally with time.

Ohm – the resistance R of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).

Basic Concepts - Units

Farad – Capacitance is the ratio of the charge on one plate of a capacitor to the voltage difference between the two plates, measured in farads (F).

Henry – Inductance is the property whereby an inductor exhibits opposition to the charge of current flowing through it; measured in henrys (H).

Basic Concepts - Volts

Symbol: V or E (electromotive force)

Circuit usage: V
or v(t) when voltage may vary.

Voltage is a measure of the DIFFERENCE in electrical potential between two points.

I say again!
Voltage ACROSS two points.

Basic Concepts - Amps

Symbol: A (Coulomb per second)

Circuit usage: I

or i(t) when current may vary with time.

Amperage is a measure of the current flow past a point.

I say again!

Current THRU a circuit element.

Basic Concepts - Ohms

Symbol: Ω

Circuit usage: R

Resistance is the capacity of a component to oppose the flow of electrical current.

$R = V/I$

Basic Concepts - Farad

Symbol: F

Circuit usage: C for capacitor

Capacitor resists CHANGE in voltage across it.

Passive charge storage by separation of charge.

Electric field energy.

Basic Concepts - Henrys

Symbol: H

Circuit usage: L for inductor

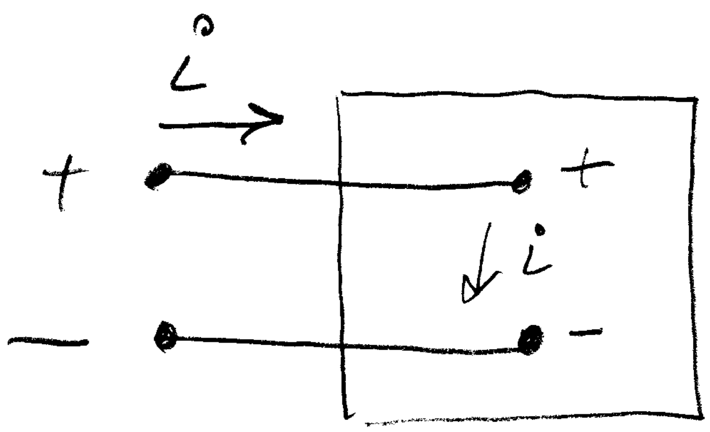
Inductor resists CHANGE in current thru it.

Passive energy storage by creation of magnetic field.

Basic Concepts – Passive Sign Convention

Use a positive sign when:

Current is the direction of voltage drop.



Basic Concepts – Power

$p = (+/-)\ vi = i^2R = v^2/R$

p = the power in watts

v = the voltage in volts

I = the current in amperes

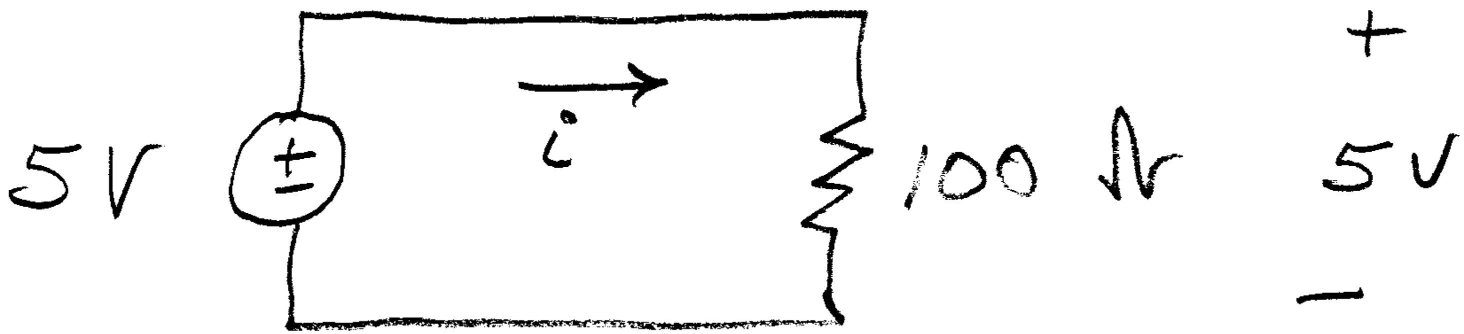
I.A.W. with Passive Sign Convention

+ (positive) – element is absorbing power.

- (negative) – element is delivering power.

Basic Concepts - Example

Power delivered/absorbed.



Basic Concepts

End of Basic Concepts.

Questions?

Basic Laws

Circuit Connections:

Nodes – point of connection of two or more branches.

Branches – single element.

Loops – any CLOSED path in a circuit.

Basic Laws – Ohm's Law

Ohms Law: $v = iR$

$R = v/i$

$1\ \Omega = 1\ \text{V/A}$

Short Circuit when $R = 0\ \Omega$

Open Circuit when $R = \infty\ \Omega$

Basic Laws - Kirchhoff's Laws

KVL: Kirchhoff's Voltage Law

- Sum of all voltages around a closed path is zero.

KCL: Kirchhoff's Current Law

- Sum of all currents = zero
- sum all currents in = sum all currents out

Based on conservation of charge:

Basic Laws – Series/Parallel

Series Resistors:

Req = R1 + R2 + ……

Parallel Resistors:

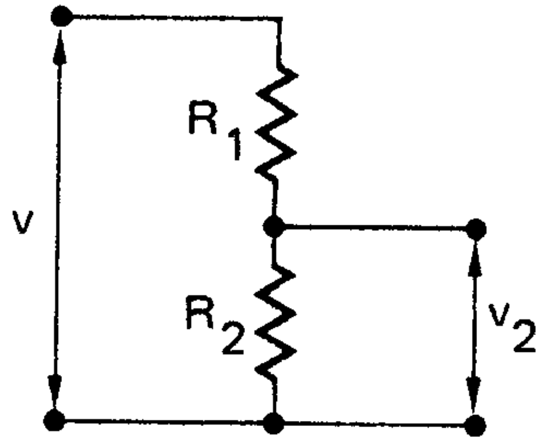
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots$$

For Two Resistors in Parallel:

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

Basic Laws – Voltage Divider

Voltage Divider for Series Resistors:



(a) voltage

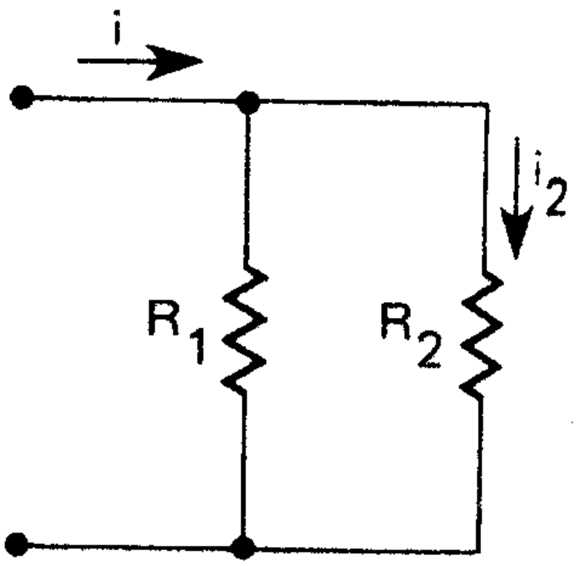
$$v_1 = \frac{R_1}{R_1 + R_2} v$$

$$v_2 = \frac{R_2}{R_1 + R_2} v$$

Basic Laws – Current Divider

Current Divider for Parallel Resistors:

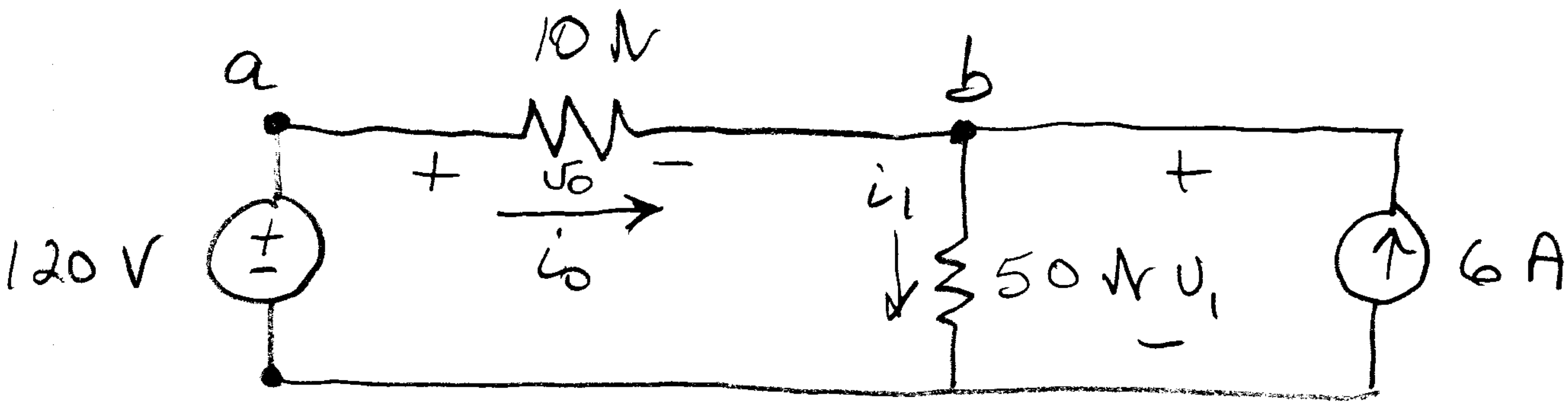
$$i_1 = \frac{R_2}{R_1 + R_2} i$$



$$i_2 = \frac{R_1}{R_1 + R_2} i$$

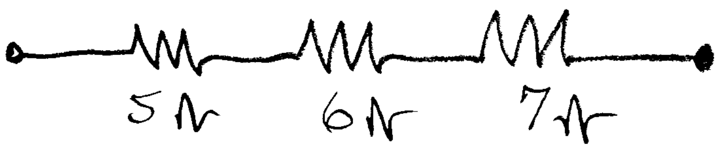
Basic Laws – Example

KCL/KVL Example

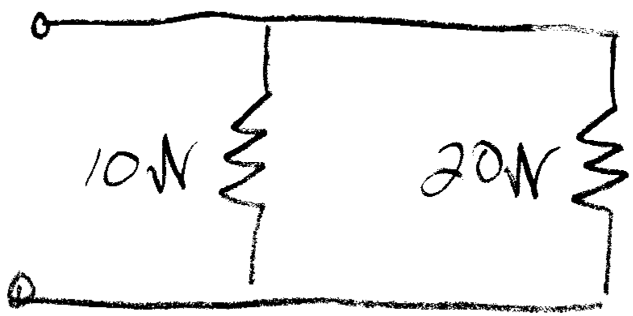


Basic Laws – Example

Calculating Resistance



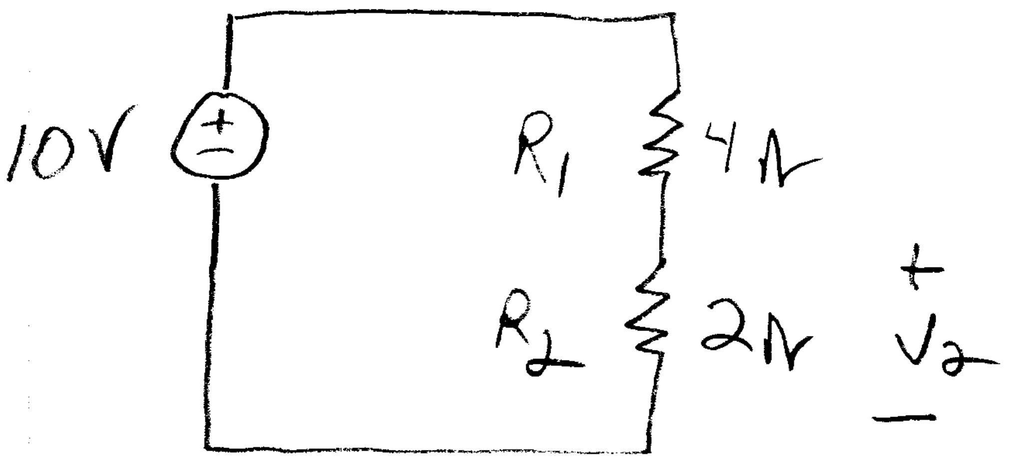
R_{eq} = ?



R_{eq} = ?

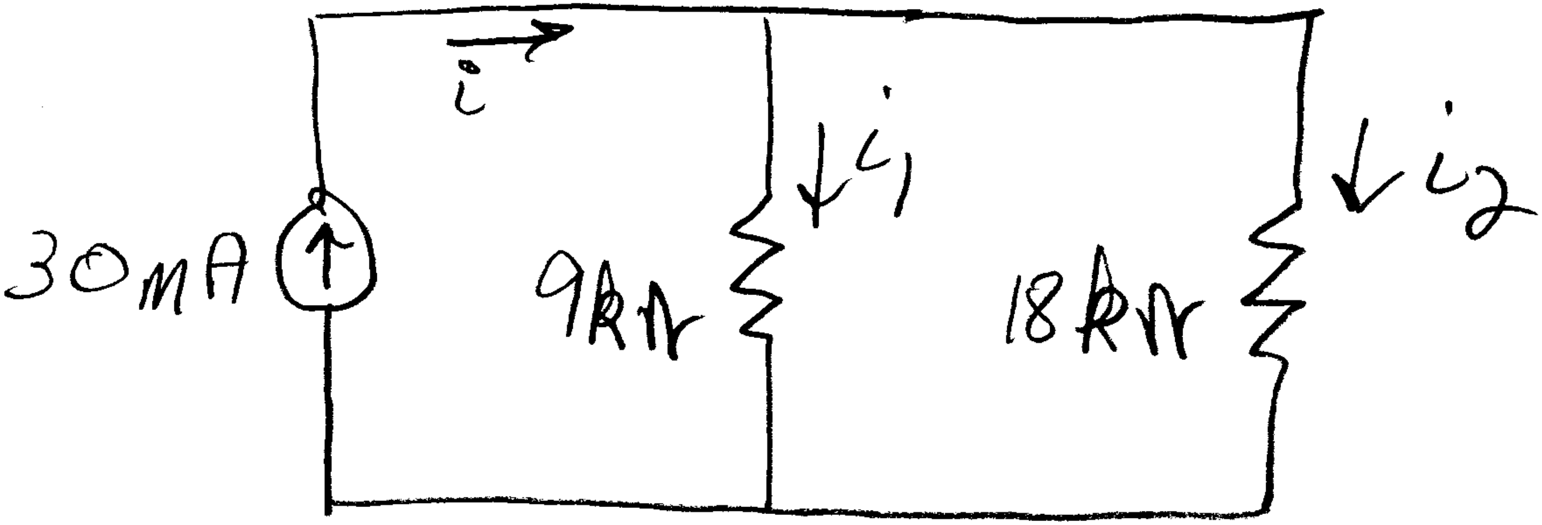
Basic Laws – Example

Voltage Divider



Basic Laws – Example

Current Divider



Basic Laws

Questions?

Break for 5 minutes.

Chinese Proverb: This too shall pass.

Or as the Kidney stone patient hopes:

This too shall pass,

but not soon enough!

Methods of Analysis

Nodal Analysis –

assign voltages in branches and find currents.

Mesh Analysis –

assign currents in a loop and find voltages.

Methods of Analysis

Node Analysis:

1. Select a reference node.
2. Apply KCL to each of the nonreference nodes.
3. Solve the resulting simultaneous equations.

   Number of equations = # of nodes - 1

Methods of Analysis

Node Analysis:

Select a reference node.

This becomes the “zero” reference.

All voltages become a rise in voltage from this reference node.

Methods of Analysis

Node Analysis:

Apply KCL:

There are a number of slightly different approaches in applying KCL.

The approach you use MUST be consistent!

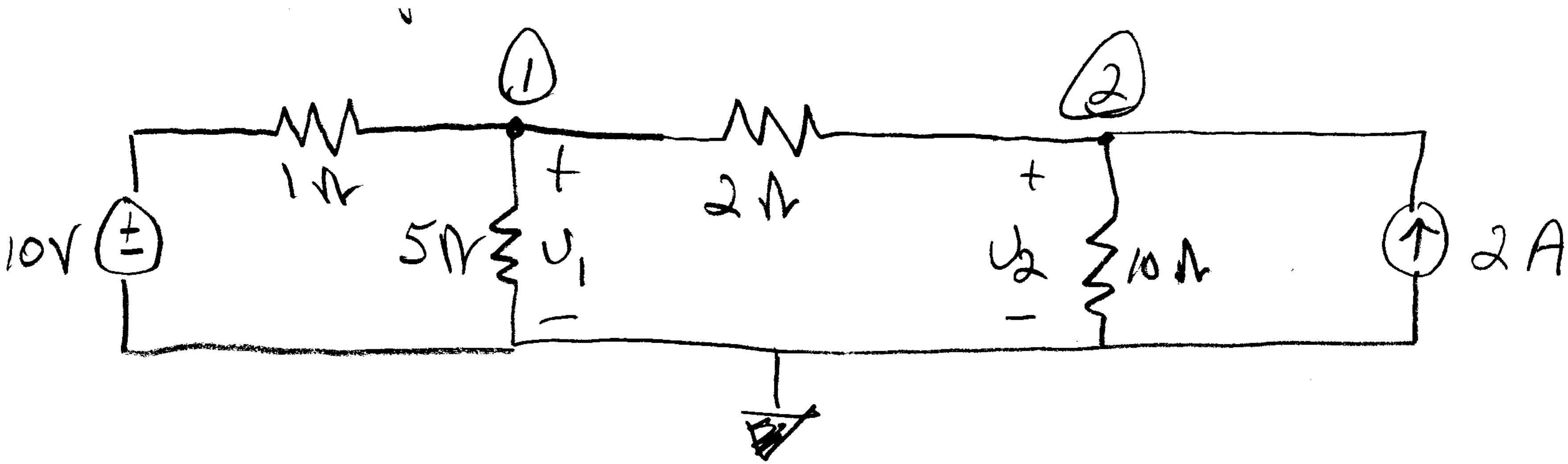
IMHO – assume voltage drop away from node.

This means the current is leaving the node.

IMHO – in my humble opinion

Methods of Analysis – Example

Let us work a node problem.



Methods of Analysis

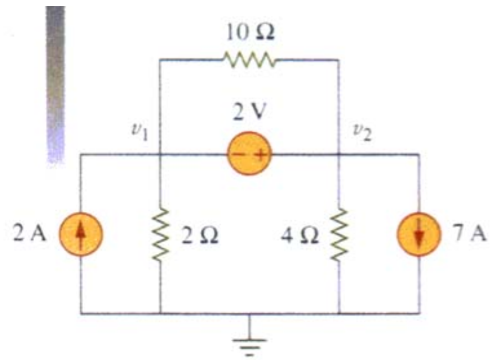
Supernode: when a voltage source connects to nonreference nodes.

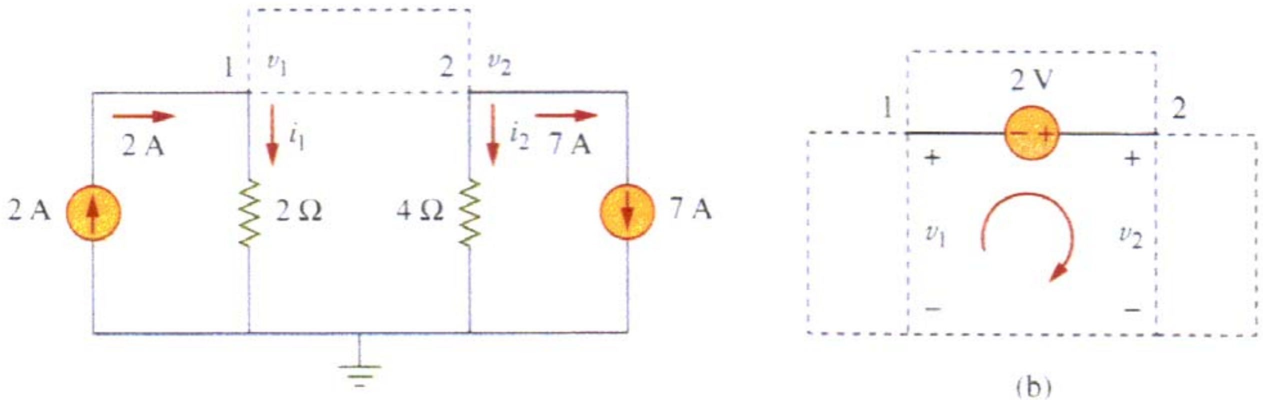
Recall that a ideal voltage source provides WHATEVER current the circuit requires.

Procedure:

1. Short the voltage source. That is: form a single node of the ends of the voltage source.
2. Write the constraint equation for the voltages.
3. Write the standard node equations for the supernode.

Methods of Analysis





(b)

Remember the constraint equation!

$$v_1 - 2V = v_2$$

Methods of Analysis

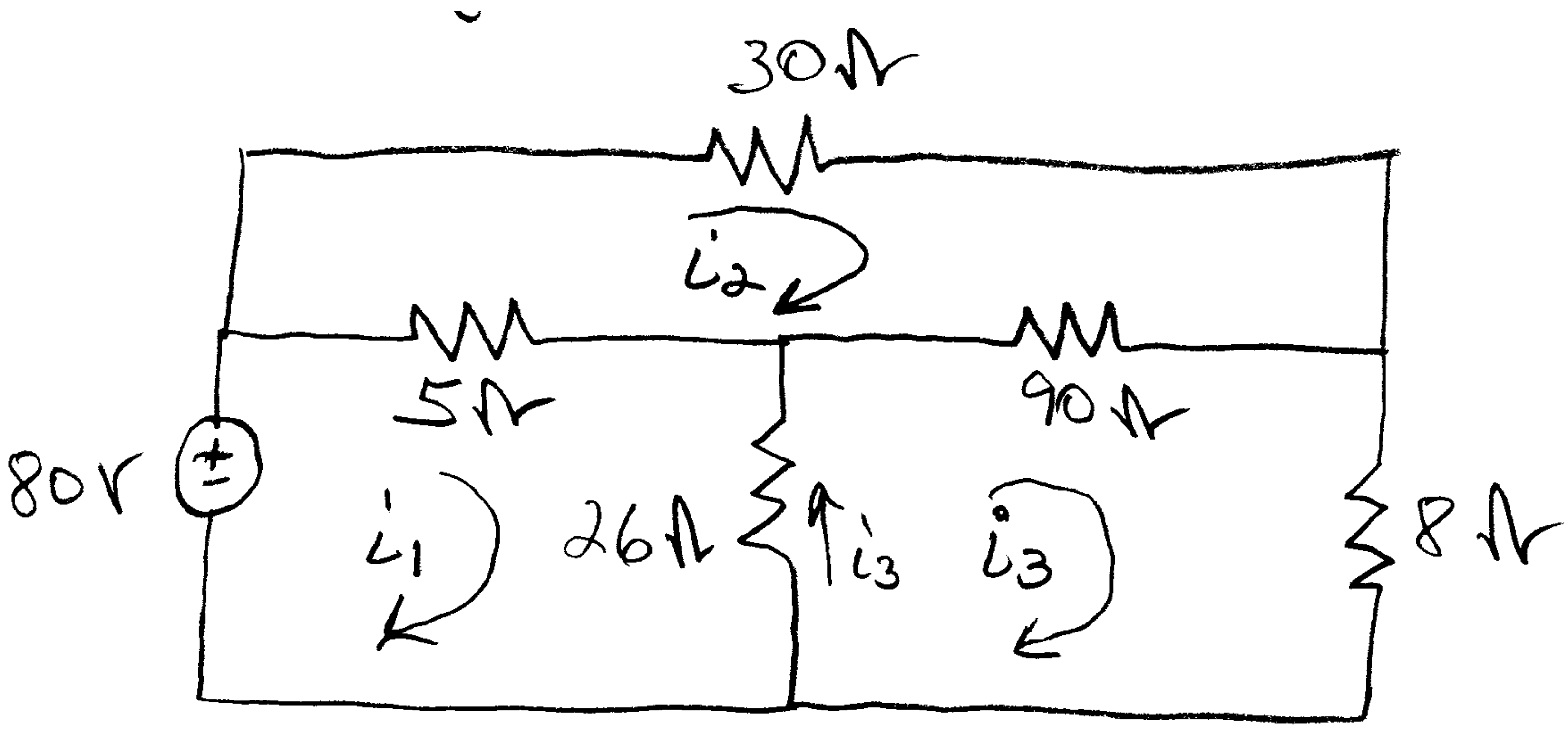
Mesh Analysis:

A mesh is a loop which does not contain any other loops within it.

1. Assign mesh currents to the n meshes.
2. Apply KVL to each mesh. Express the voltages in terms of Ohm's law.
3. Solve the resulting n simultaneous equations.

Methods of Analysis – Example

Let us work a mesh problem.



Methods of Analysis

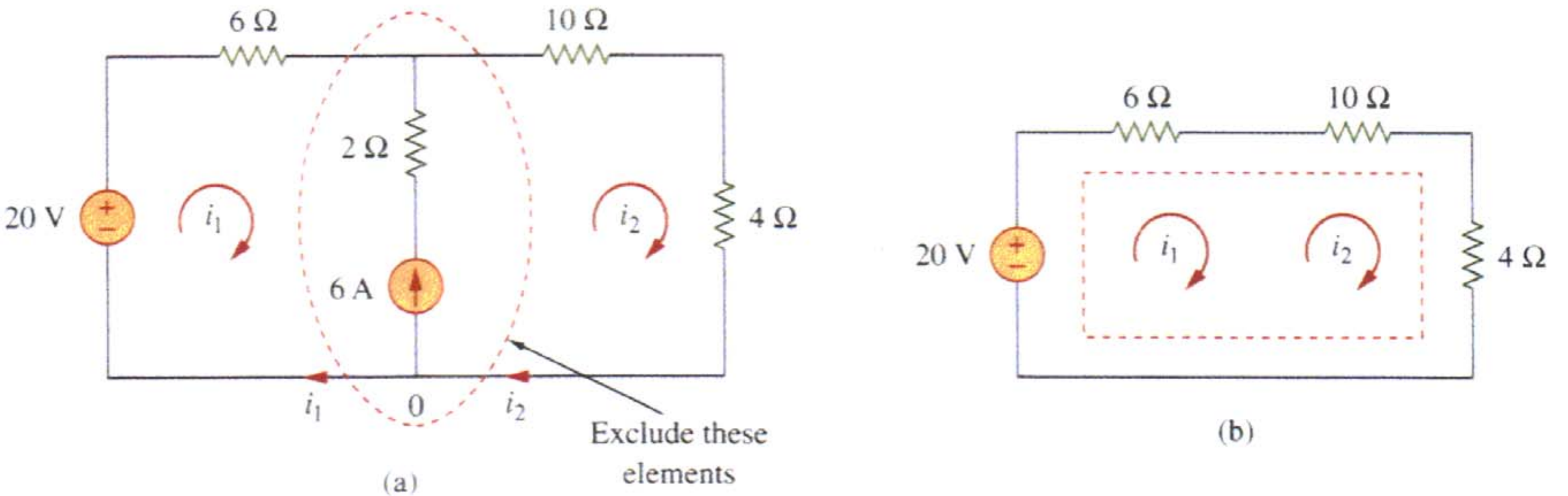
Supermesh: when two meshes share a current source.

Recall that a ideal current source provides WHATEVER voltage the circuit requires.

Procedure:

1. Open the current source. That is form a single mesh for the two mesh sharing the current source.
2. Write the constraint equation for the currents.
3. Write the standard mesh equation for the supermesh.

Methods of Analysis



Remember to write the constraint equation!

$i_1 - 6A - i_2 = 0$

Methods of Analysis

Supermesh or Supernode?

1. Do what the test tells you!

2. Pick the approach with the least equations.

3. Node equations are usually easier.

Methods of Analysis

End of Methods of Analysis.

Questions?

Circuit Theorems

1. Superposition
2. Source Transformation
3. Thevenin’s Theorem
4. Norton’s Theorem
5. Maximum Power Transfer

Circuit Theorems - Superposition

Determine the contribution of each independent source to the variable in question. Then sum these “responses” to find the total response.

Circuit Theorems - Superposition

1. Turn off all independent sources except one.

   Voltage source V = 0 when shorted.

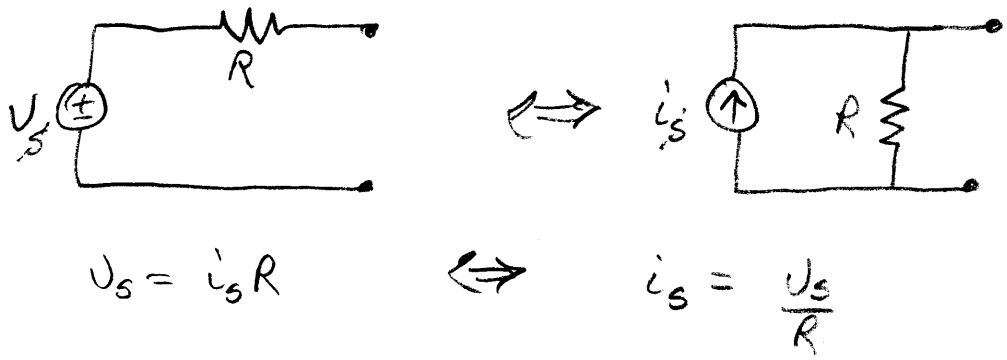
   Current source A = 0 when opened.

2. Solve the circuit.
3. Repeat until all sources handled.
4. Sum the individual responses to get the total response.

Circuit Theorems – Source Transforms

A source transformation exchanges a voltage source with a series resistor with a current source and a parallel resistor.

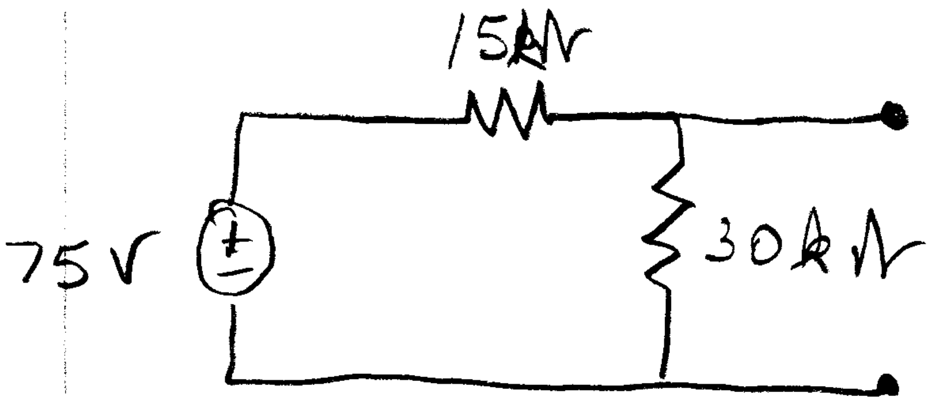
$$v_s = i_s R$$



$$i_s = \frac{v_s}{R}$$

Circuit Theorems – Example

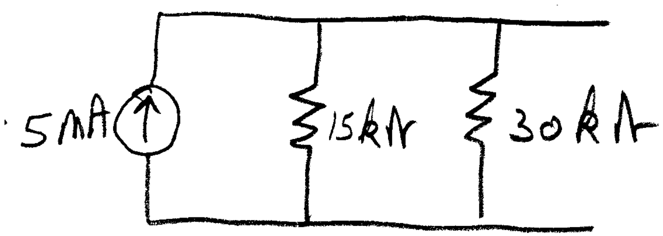
Let us work a source transformation problem.

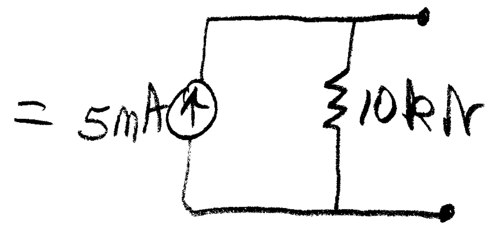


$$i_s = \frac{75\ \text{V}}{15\ \text{k}\Omega} = 5\ \text{mA}$$

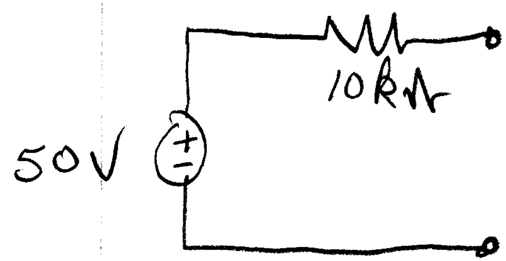
Circuit Theorems – Example

Let us work a source transformation problem.





$$v_s = i_s R = (5mA)(10k\Omega)$$
$$= 50V$$



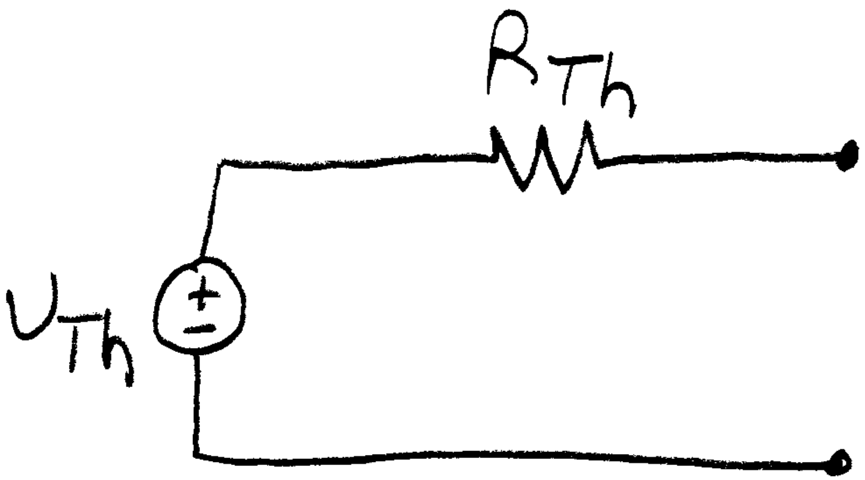
Circuit Theorems – Thevenin's Theorem

Thevenin's Theorem: a linear two-terminal network can be replaced with an equivalent circuit of a single voltage source and a series resistor.

V_{TH} is the open circuit voltage

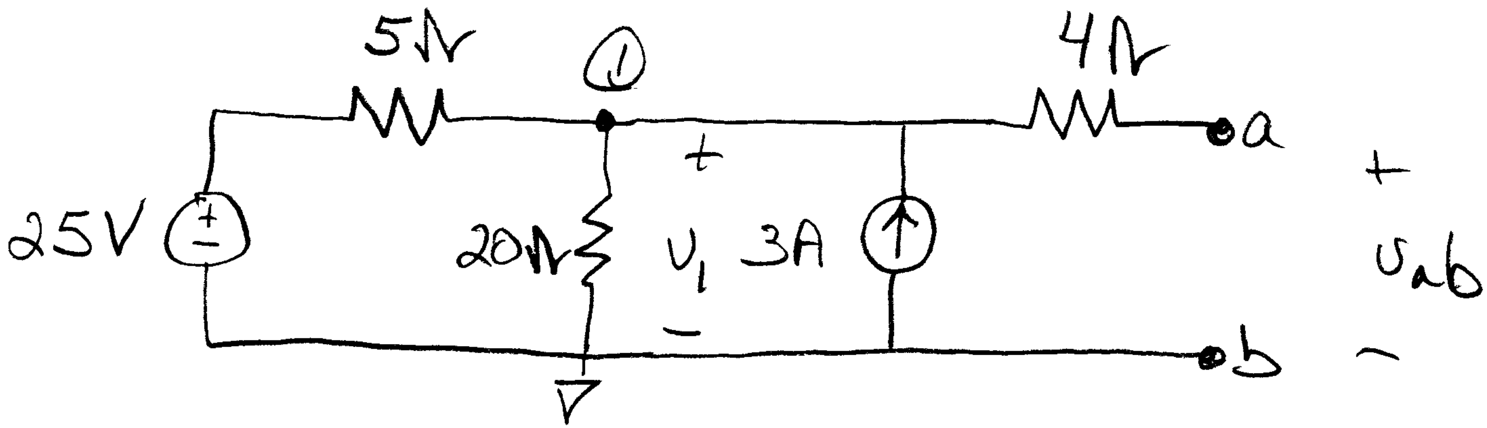
R_{TH} is the equivalent resistance of the circuit.

Circuit Theorems – Thevenin's Theorem



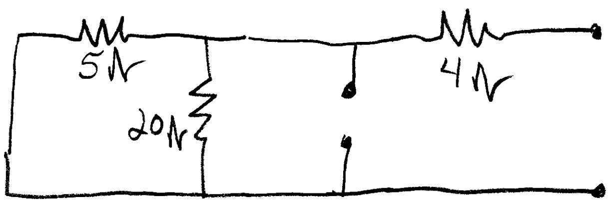
Circuit Theorems – Example

Let us work a Thevenin problem.

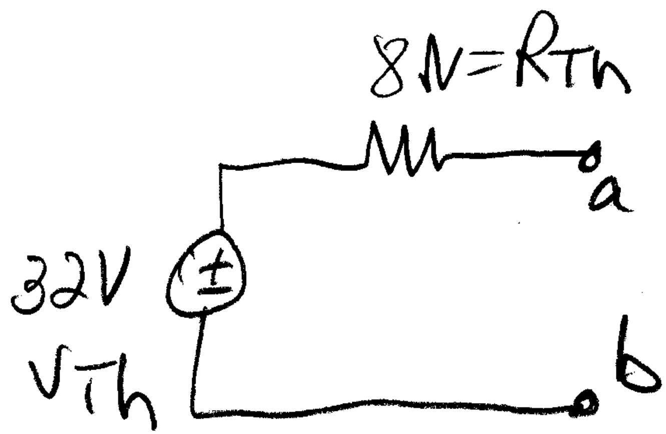


Circuit Theorems – Example

Let us work a Thevenin problem.



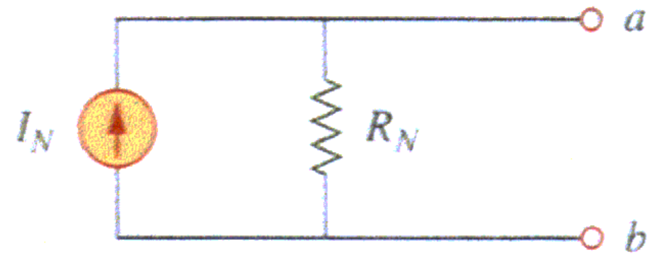
$$5 \| 20 + 4 = 4 + 4 = 8\,\Omega$$



Circuit Theorems – Norton's Theorem

Norton's Theorem: a linear two-terminal network can be replaced with an equivalent circuit of a single current source and a parallel resistor.

$$I_N = \frac{V_{TH}}{R_{TH}}$$

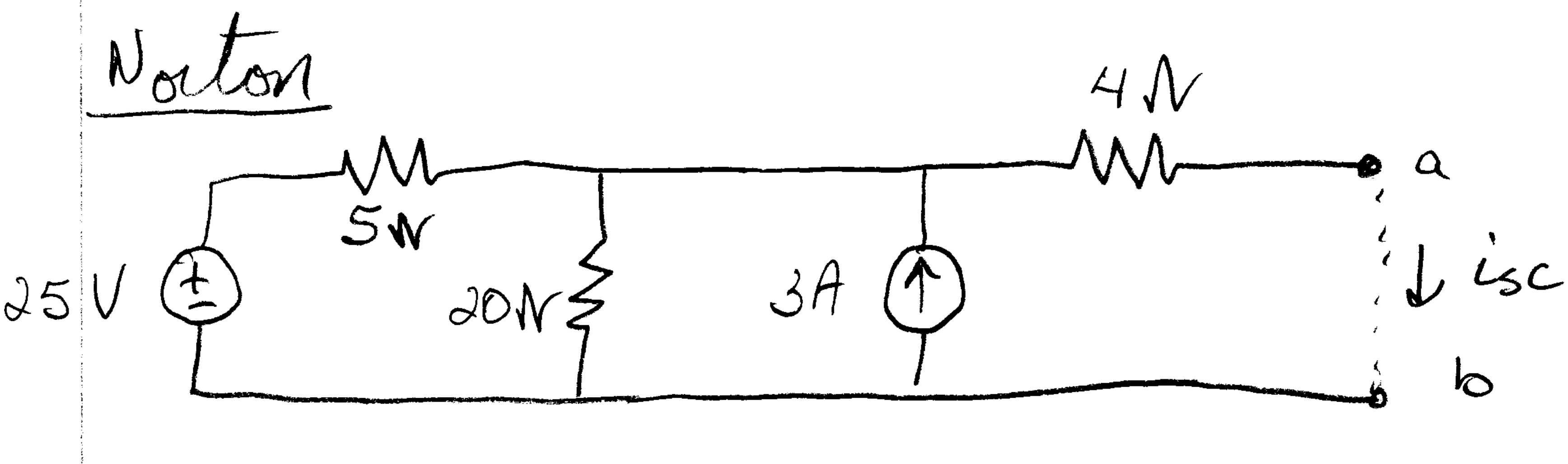


I_N is the short circuit current.

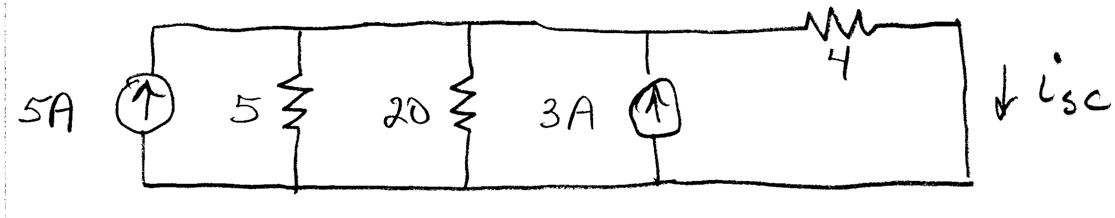
R_{TH} is the equivalent resistance of the circuit.

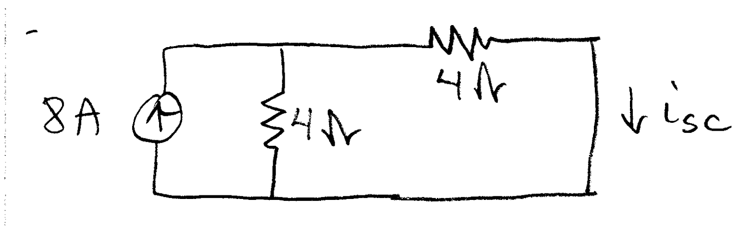
Circuit Theorems – Example

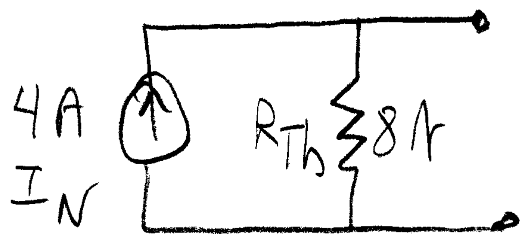
Let us work a Norton problem.



Circuit Theorems – Example







By confirmation

$$I_N = \frac{V_{Th}}{R_{Th}} = \frac{32\,V}{8\,\Omega} = \underline{4\,A}$$

Circuit Theorems – Maximum Power Transfer

The maximum power delivered to a load is when the load resistance equals the Thevenin resistance as seen from the load.

$$R_L = R_{TH}$$

Circuit Theorems – Maximum Power Transfer

When $$R_L = R_{TH}$$

Then

$$p_{\max} = \frac{V_{TH}^2}{4R_{TH}}$$

Circuit Theorems

End of Circuit Theorems.

Questions?

Break for 5 minutes.

Nerves and butterflies are fine - they're a physical sign that you're mentally ready and eager. You have to get the butterflies to fly in formation, that's the trick.

~Steve Bull

Operational Amplifiers

OP Amp – name derived from this circuits ability to perform various mathematical operations.

Why us? Another chance to use Node Analysis!

When not? Op Amp with capacitor or inductor? No Laplace skills? Then guess an answer and move along.

Operational Amplifiers

Ideal Op Amp assumptions:

1. $i_n = i_p$ = zero

2. $v_n = v_p$

3. V_{out} is equal to or less than the input power voltage.

$$V_{out} \le \pm V_{CC}$$

Operational Amplifiers

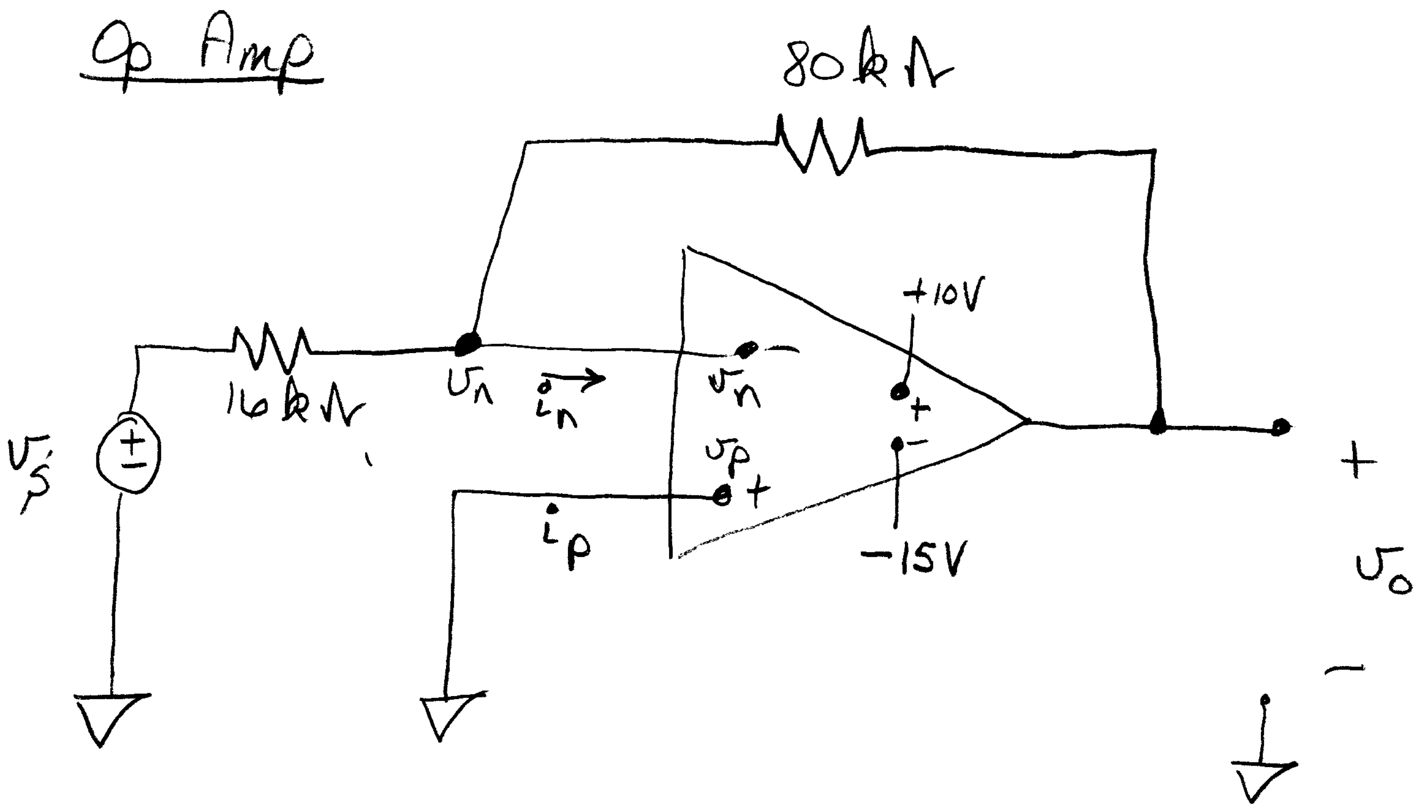
Use node analysis to solve the problem. If you recognize the type and like to memorize:

Inverting Op Amp: $$V_{out} = -\frac{R_{feedback}}{R_{input}} V_{input}$$

Noninverting Op Amp: $$V_{out} = \left(1 + \frac{R_{feedback}}{R_{input}}\right) V_{input}$$

Operational Amplifiers – Example

Let us work an Op Amp problem.



Operational Amplifiers

End of Operational Amplifiers.

Questions?

Capacitors and Inductors

A Capacitor consists of two conducting plates separated by an insulator.

Capacitance is the ratio of the charge on one plate of a capacitor to the voltage difference between the two plates. Capacitance is measured in Farads.

Capacitors and Inductors

The voltage across a capacitor cannot change abruptly.

$$i = C\frac{dv}{dt}$$

A capacitor is an open circuit to dc.

Capacitors and Inductors

Capacitors add in parallel - CAP

$$C_{eq} = C_1 + C_2 + \ldots$$

Series Capacitance

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$$

Capacitors and Inductors

An Inductor consists of a coil of conducting wire.

Inductance is the property where an inductor opposes change to current flow. Inductance is measured in Henrys.

Capacitors and Inductors

The current thru an inductor cannot change abruptly.

$$v = L\frac{di}{dt}$$

An inductor is a short circuit to dc.

Capacitors and Inductors

Inductors add in series.

$$L_{eq} = L_1 + L_2 + \ldots$$

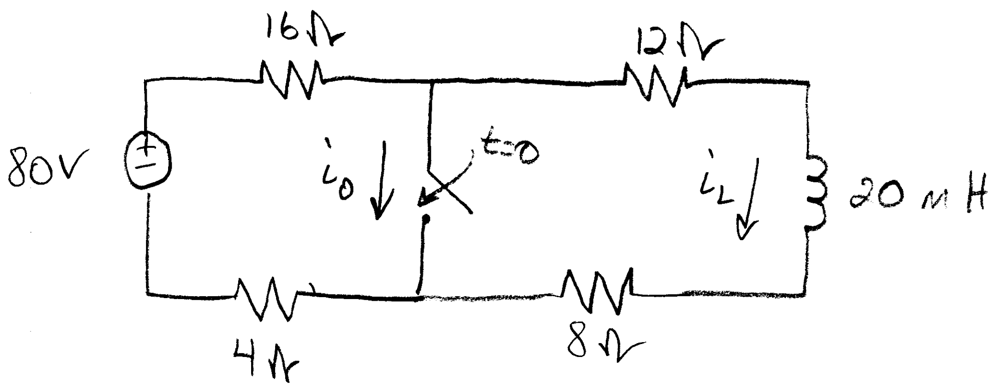
Parallel Inductance

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \ldots$$

Capacitors and Inductors – Example

Overall behavior of an inductor

Inductor

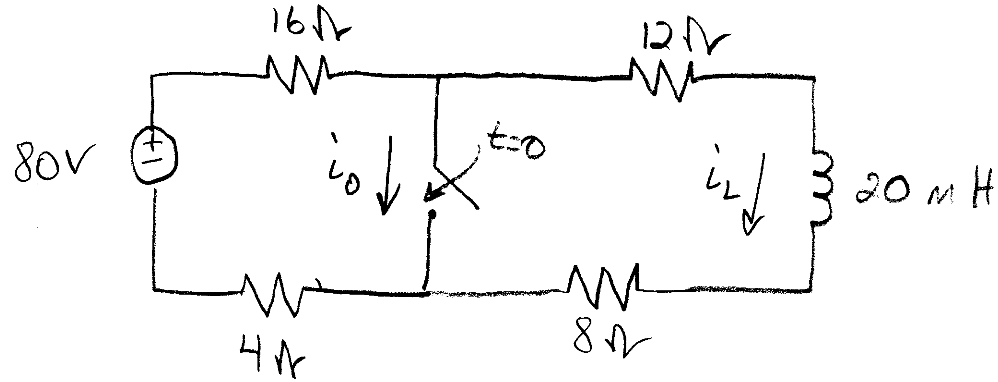


at $t<0$ $\quad v_L = 0$ since $\frac{di}{dt} = 0$

$$i_L(0^-) = \frac{80V}{(16+12+4+8)\Omega} = \frac{80V}{40\Omega} = \underline{\underline{2A}}$$

Capacitors and Inductors – Example

Overall behavior of an inductor



at $t \to \infty$ "short out" the voltage source

thus $i_L = 0$

at $t=0$

inductor cannot change abruptly

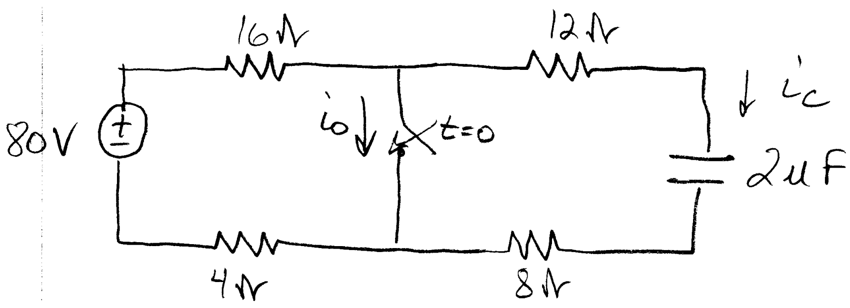
$$i_o(0^+) = \frac{80V}{16\Omega + 4\Omega} - 2A = \frac{80V}{20\Omega} = 4A - 2A = \underline{2A}$$

at $t \to \infty$

$$i_o(\infty) = \underline{4A}$$

Capacitors and Inductors – Example

Overall behavior of a capacitor



at $t < 0$ $\quad v_c = 80V$

$i_c = 0A$

at $t \to \infty$ $\quad v_c = 0V$

$i_c = 0A$

at $t = 0$ $\quad$ left loop + right loop

left $\quad i_{left} = \frac{80V}{20\Omega} = 4A$

Right $\quad i_{rt} = \frac{80V}{20\Omega} = 4A$

total $i_o(t=0^+) = 4A + 4A = \underline{8A}$

Capacitors and Inductors

End of Capacitors and Inductors.

Questions?

Summary

- Passive Sign
- Power: $p = vi$
- Ohm's Law $v = ir = i^2R = V^2/R$
- KCL – Sum of currents = zero
- KVL – Sum of voltage in loop = zero
- Series/Parallel Elements
- Voltage/Current Divider

Summary

- Source Transformation
- Thevenin Equivalent
- Norton Equivalent
- Ideal Op Amp
- Capacitor
- Inductor

Summary

What we did not cover:

- Response of 1^{st} order RC/RL circuits
- Unbounded response
- Response of 2^{nd} order RLC circuits
- Sinusoidal Steady-State analysis
- 3 Phase AC power

Be sure to study these areas as time permits.

Good Luck on the EIT Exam!

- It is a timed exam. Answer what you know. Mark what you might know and come back later. Do not get bogged down on a few questions. Move along!
- Remember that it is a multiple choice exam. Look for hints in the answers.
- If totally in doubt – Guess by using your intuition and science.

EIT Review

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