BME2312 - Analog Electronics

The Instructors:

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LECTURE 1

Assesment

• Midterm 1	:	15%
• Midterm 2	:	15%
• Lab	:	15%
• Project	:	10%
• Quizzes	:	5%
• Final	:	40%

Course Outline

ELECTRICAL CICRUITS AND COMPONENTS

Basic Electrical circuits and components, Measurement of Voltages and Currents, Resistance and DC Circuits, Capacitance and Electric Fields, Inductance and Magnetic Fields, Alternating Voltages and Currents, Power in AC Circuits, Frequency Characteristics of AC Circuits, Transient Behaviour

ELECTRONIC SYSTEMS

Electronic Systems, Sensors, Actuators, Amplification, Control and Feedback, Operational Amplifiers

SEMICONDUCTOR DEVICES AND CIRCUITS

Semiconductors and Diodes, Diode Applications, Bipolar Junction Transistors, Field-effect Transistors, Power Electronics, Operational Amplifiers, Digital Systems

Recommended books…

- **Electronic Devices and Circuit Theory** by Robert L. Boylestad and Louis Nashelsky
- **Electronics a Systems Approach** by Neil Storey
- **Electronic Circuits - Fundamentals & Applications** by Michael H. Tooley
- **The Art of Electronics** by Paul Horowitz and Winfield Hill
- **Schaum's Outline of Electronic Devices and Circuits** by Jimmie J. Cathey
- **Electronic Devices and Circuits** by Theodore F. Bogart, Jeffrey S. Beasley, and Guillermo Rico

…Recommended books

- **Electronic Devices and Circuits: Discrete and Integrated** by Denton J. Dailey
- **Electronics Fundamentals: Circuits, Devices & Applications** by Thomas L. Floyd and David Buchla
- **Electronic Devices and Circuits I** by A.P.Godse and U.A.Bakshi
- **Electronic Devices: Circuits and Applications** by William D. Stanley
- **Electronic Devices and Circuits** by David A. Bell
- **Microelectronic Circuits** by Adel Sedra and Kenneth Smith

Main course book

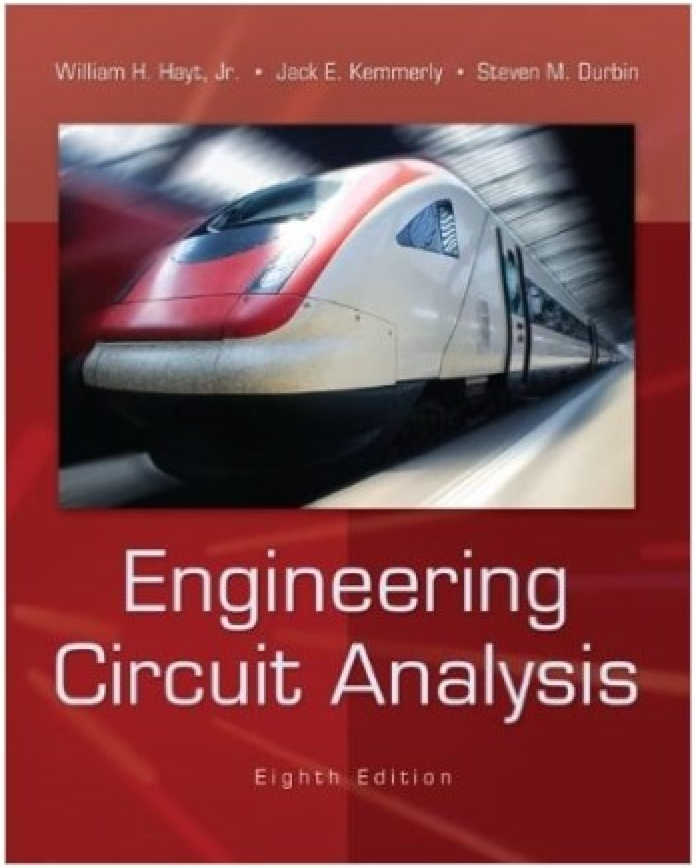
Frequency Response and Filters Part

Engineering Circuit Analysis

by William Hayt, Jack Kemmerly, Steven Durbin.

Published by McGraw-Hill.

Isbn: 0073529575



Main Course Book (Electronic Components)

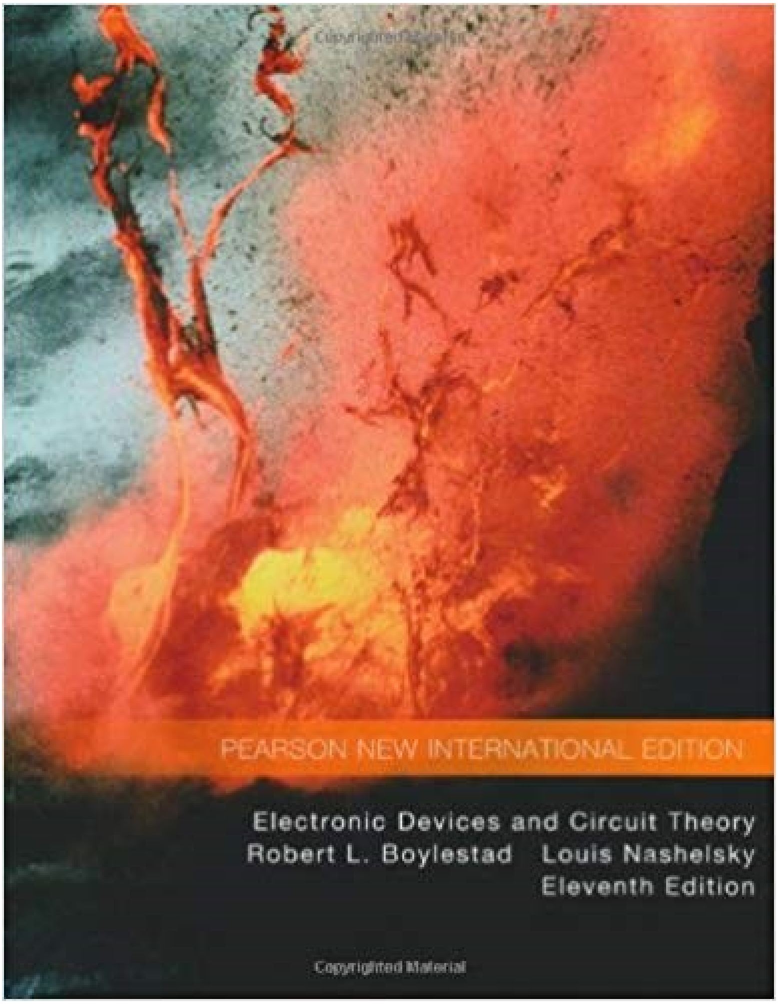
Electronic Devices and Circuit Theory

by Robert L. Boylestad

Published by Pearson

ISBN-10: 1292025638

ISBN-13: 978-1292025636



Rules of the Conduct

- No eating /drinking in class
  - *except water*
- Cell phones must be kept outside of class or switched-off during class
  - *If your cell-phone rings during class or you use it in any way, you will be asked to leave and counted as unexcused absent.*
- No web surfing and/or unrelated use of computers,
  - when computers are used in class or lab.

Rules of the Conduct

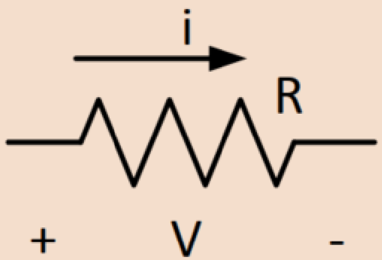
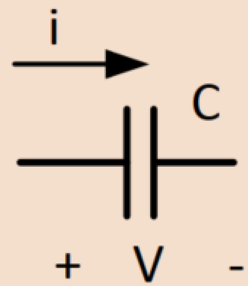
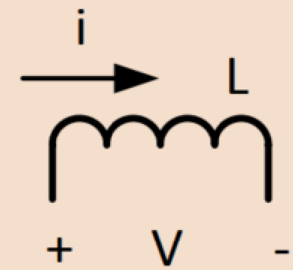
- You are responsible for checking the class web page often for announcements.
- Academic dishonesty and cheating will not be tolerated and will be dealt with according to university rules and regulations
  - *Presenting any work, or a portion thereof, that does not belong to you is considered academic dishonesty.*
- University rules and regulations:
  - http://www.ogi.yildiz.edu.tr/category.php?id=17
  - https://www.yok.gov.tr/content/view/544/230/lang,tr_TR/

Attendance Policy

- The requirement for attendance is **70%**.
  - *Hospital reports are not accepted to fulfill the requirement for attendance.*
  - *The students, who fail to fulfill the attendance requirement, will be excluded from the final exams and the grade of* F0 *will be given.*

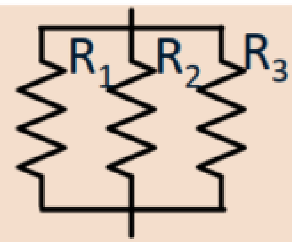
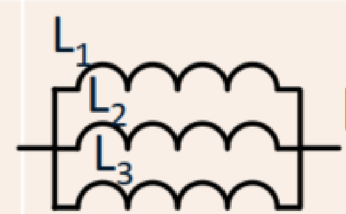
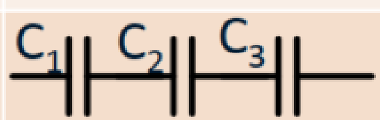
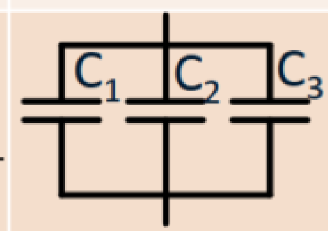
Review of Circuit Elements

Passive Elements

Resistor	Capacitor	Inductor
		
$V = iR$	$i = C\frac{dV}{dt}$	$V = L\frac{di}{dt}$

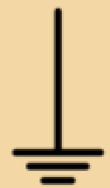
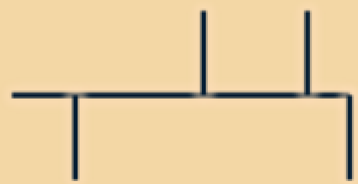
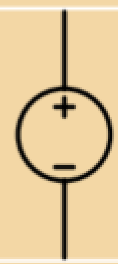
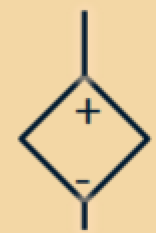
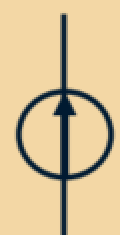
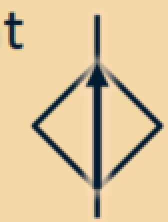
Review of Circuit Elements (cont.)

Series and Parallel Connections

	Series	Parallel
Resistors	 $R = R_1 + R_2$	 $R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$
Inductors	 $L = L_1 + L_2$	 $L = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$
Capacitors	 $C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$	 $C = C_1 + C_2 + C_3$

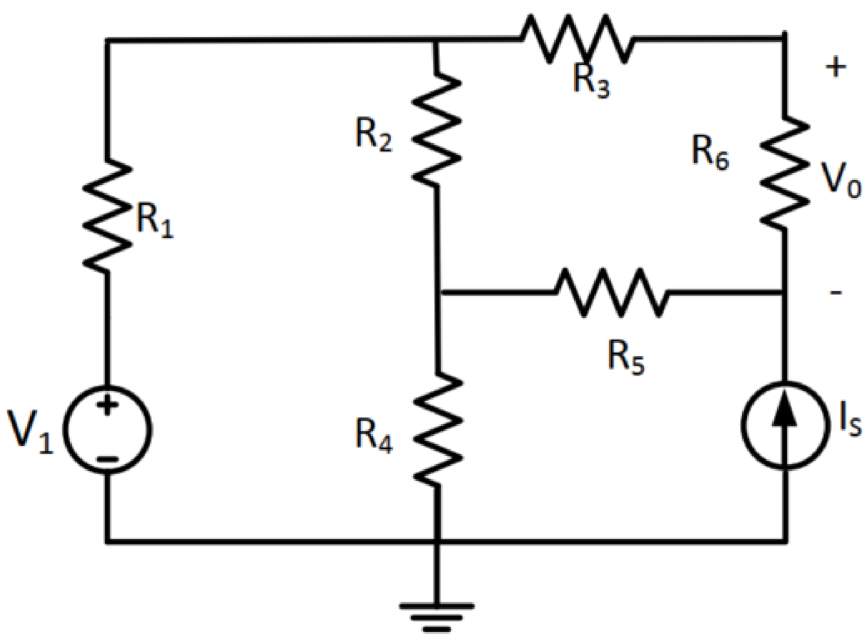
Review of Circuit Elements (cont.)

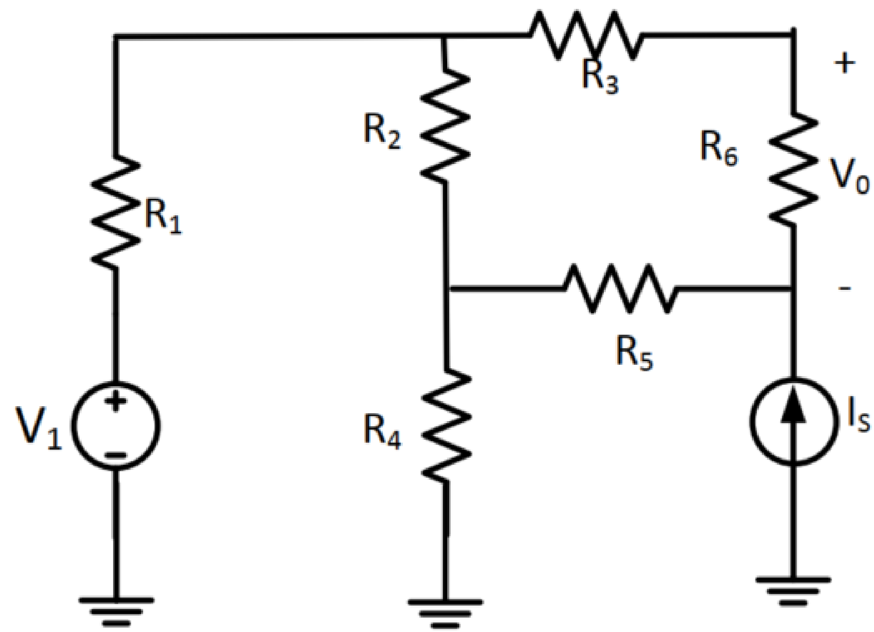
Connections and Sources

Ground		Reference for 0 volts
Node		Voltage level the same everywhere on the node
Voltage Source	Independent 	Dependent 
Current Source	Independent 	Dependent 

Review of Circuit Elements (cont.)

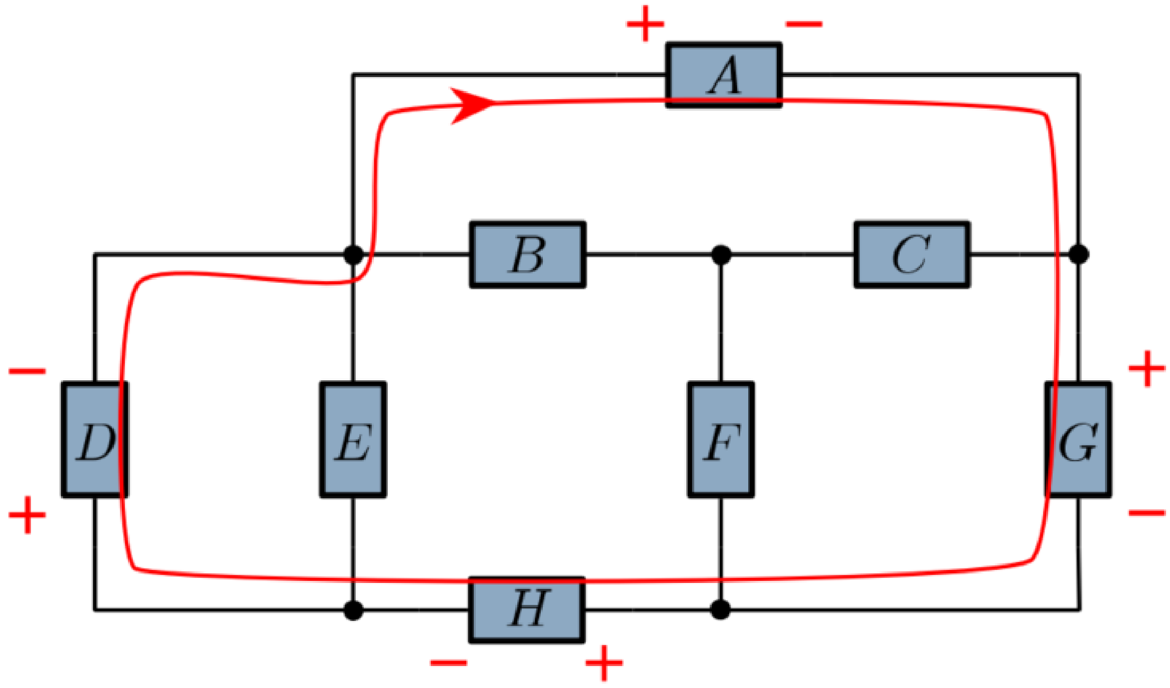
Circuit Connections





Review of Kirchhoff's Laws

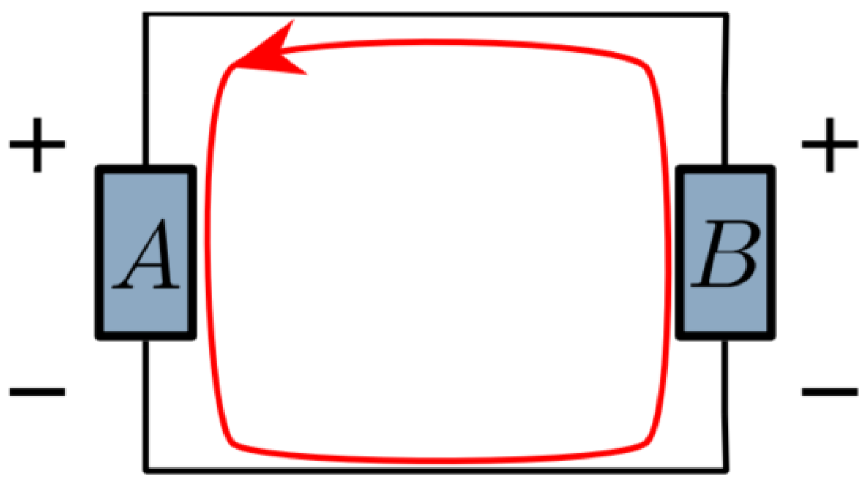
Kirchhoff's Voltage Law (KVL)



The sum of voltages around any closed loop is zero.

Review of Kirchhoff's Laws (cont.)

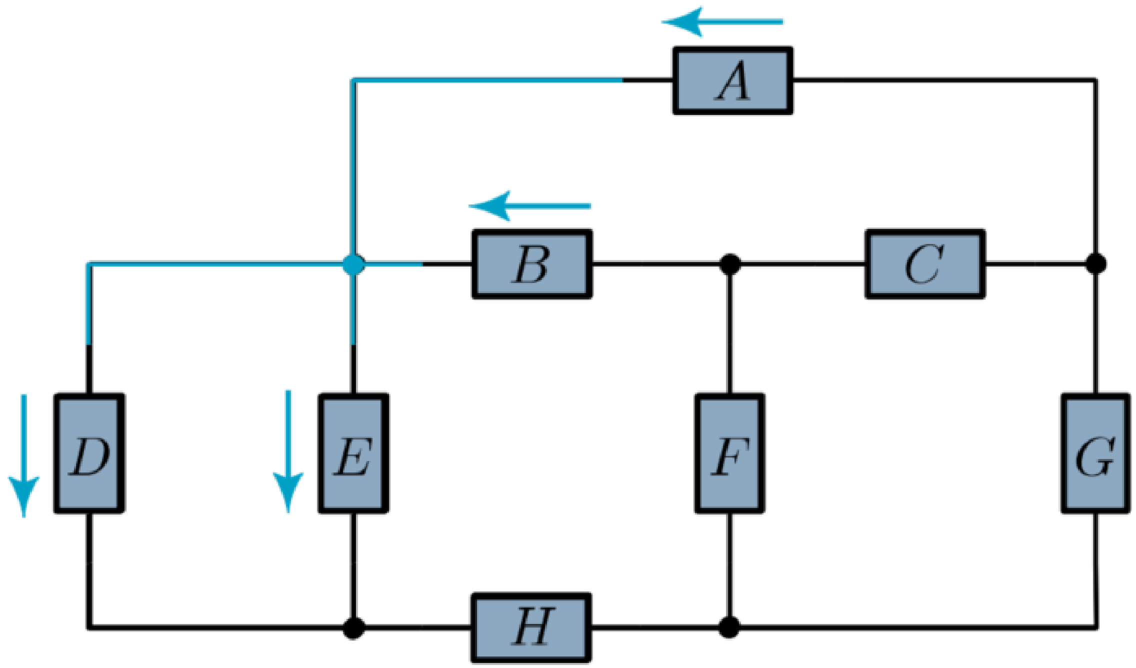
KVL and Parallel Circuits



$$v_A - v_B = 0$$
$$v_A = v_B$$

Review of Kirchhoff's Laws (cont.)

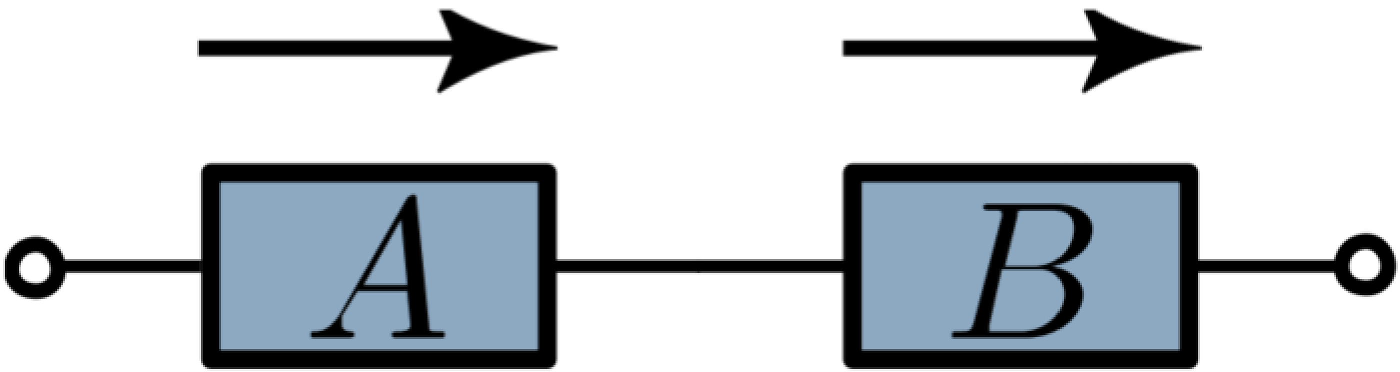
Kirchhoff's Current Law (KCL)



$$\sum i_{entering} = \sum i_{leaving}$$

Review of Kirchhoff's Laws (cont.)

KCL and Series Circuits



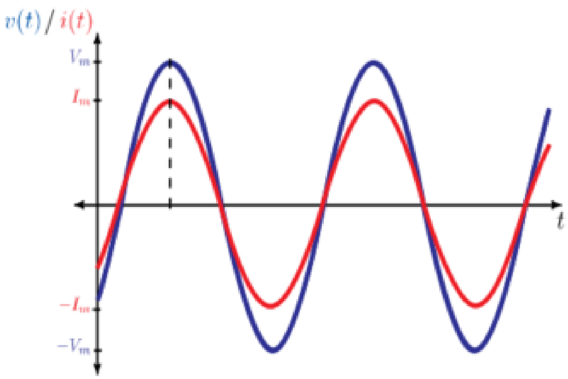
$$i_A = i_B$$

Review of Impedance

Impedances

R

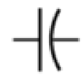
$$Z_R = R$$



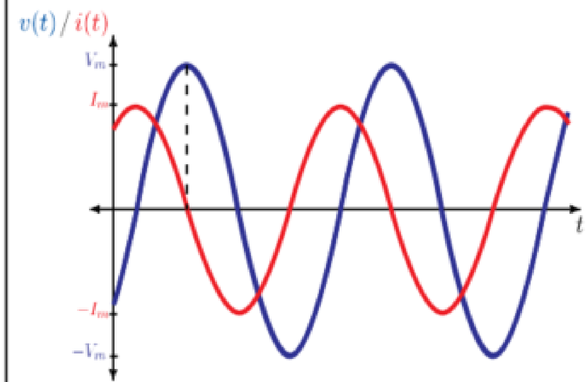
In-phase

Frequency invariant

C



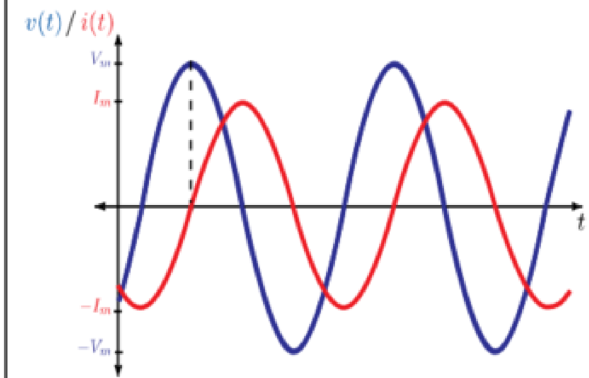
$$Z_C = \frac{1}{j\omega C}$$



Current leads voltage

L

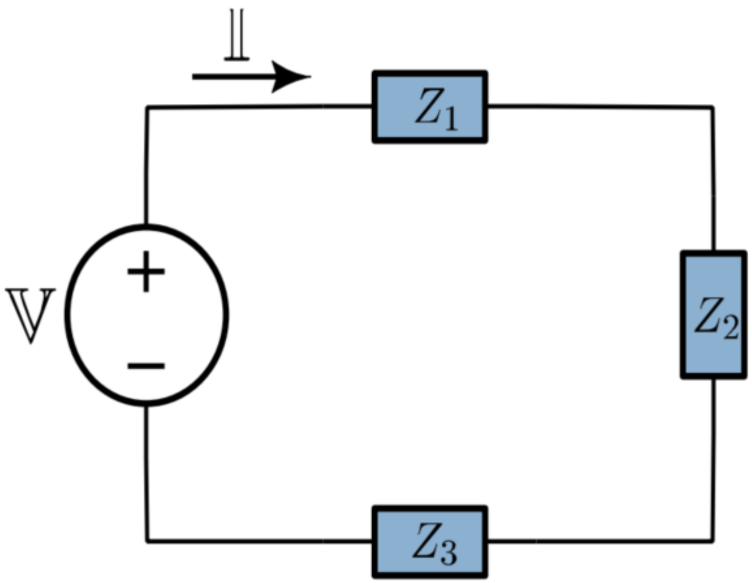
$$Z_L = j\omega L$$



Current lags voltage

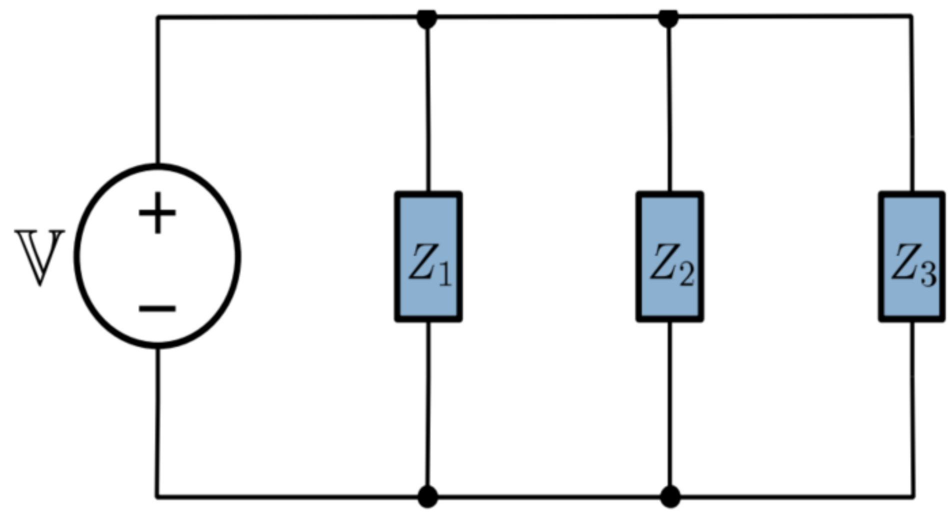
Review of Impedance (cont.)

Impedances in Series



$$Z_{\mathrm{cq}} = \sum_i Z_i$$

Impedances in Parallel

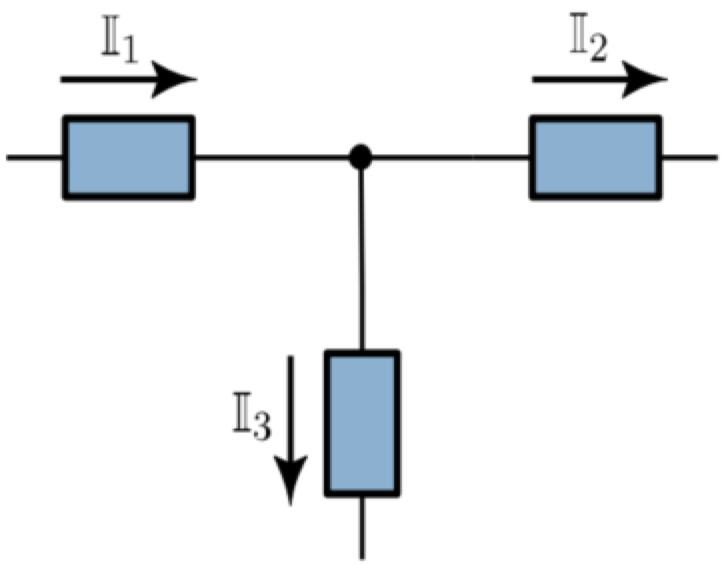


$$Z_{\mathrm{eq}} = \left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}\right]^{-1}$$

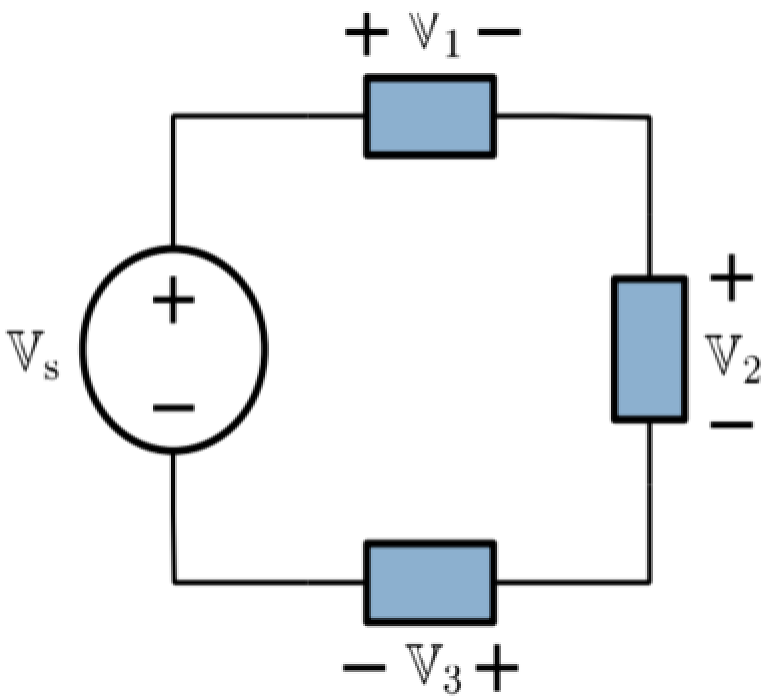
$$Z_{\mathrm{eq}} = \left[\sum_i \frac{1}{Z_i}\right]^{-1}$$

Review of Impedance (cont.)

Kirchhoff's Laws



$$\mathbb{I}_1 = \mathbb{I}_2 + \mathbb{I}_3$$



$$\mathbb{V}_s = \mathbb{V}_1 + \mathbb{V}_2 + \mathbb{V}_3$$

Review of Circuit Analysis with AC Impedances

Builds Upon:

- Phasors and impedances
- Resistive circuit methods
  - Foundational methods:
    - Series and parallel resistors
    - Kirchhoff's Laws: KVL, KCL
    - Voltage divider, current divider
  - Systematic Solution methods
    - Mesh analysis
    - Node analysis
    - Thévenin and Norton Equivalent Circuits
    - Superposition

Review of Circuit Analysis with AC Impedances (Cont)

1. Redraw circuit, replacing
   - Sources with their phasors
   - Components with their impedances

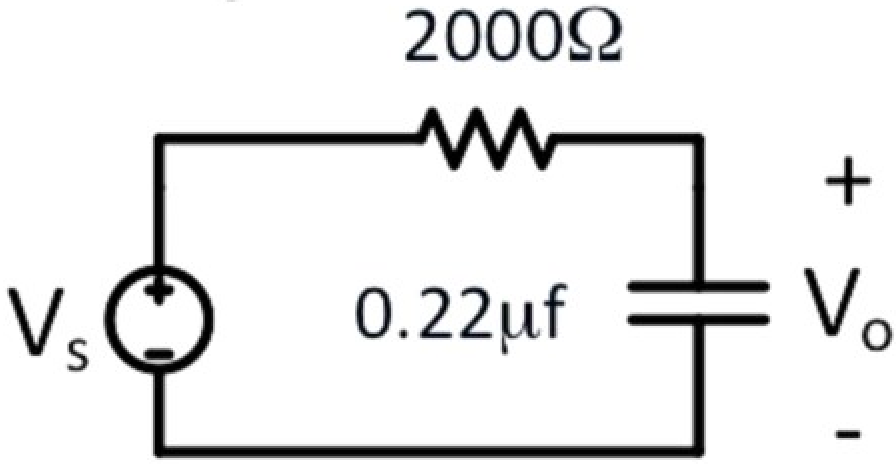
$$Z_R = R \qquad Z_c = \frac{1}{j\omega C} \qquad Z_L = j\omega L$$

2. Use circuit analysis methods to solve the circuit, treating impedances like complex resistors
3. Convert the output phasor to its sinusoidal equivalent

$$V\angle\theta \Rightarrow V\cos(\omega t + \theta)$$

Example 1

Example



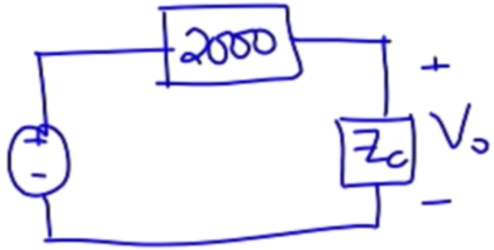
$V_s = 2\cos(2000t+30^\circ)$

Find Vo

Example 1 (Cont.)

$V_s = 2\cos(\underbrace{2000}_{\omega}t + 30^o)$

1. 1) $2\angle 30^\circ$



$$Z_c = \frac{1}{j\omega C} = \frac{1}{j2000(.22\times10^{-6})}$$

$$= \frac{2272.7}{j}\cdot\frac{j}{j} = -2272.7j$$

2. Voltage Divider

$$V_o = \frac{Z_c}{2000 + Z_c}\, 2\angle 30^\circ$$

$$V_o = \frac{-2272.7j}{2000 - 2272.7j}\, 2\angle 30^\circ$$

$$= \frac{2272.7\angle -90^\circ}{3027\angle -48.6}\, 2\angle 30^\circ$$

$$= 1.5\angle -41.3^\circ + 30^\circ$$

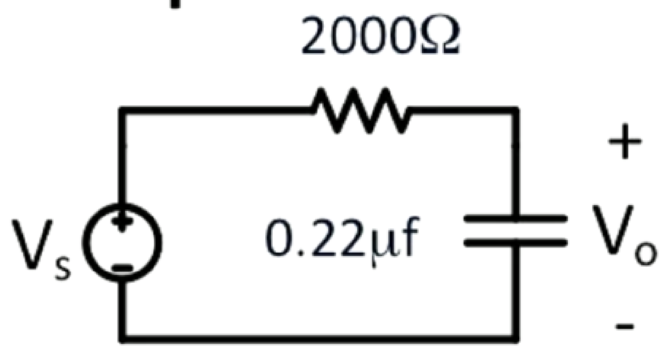
$$= 1.5\angle -11.3^\circ$$

3. Go back to time-domain

$$V_o = 1.5\cos(2000t - 11.3^\circ)$$

Example 1 (Cont.)

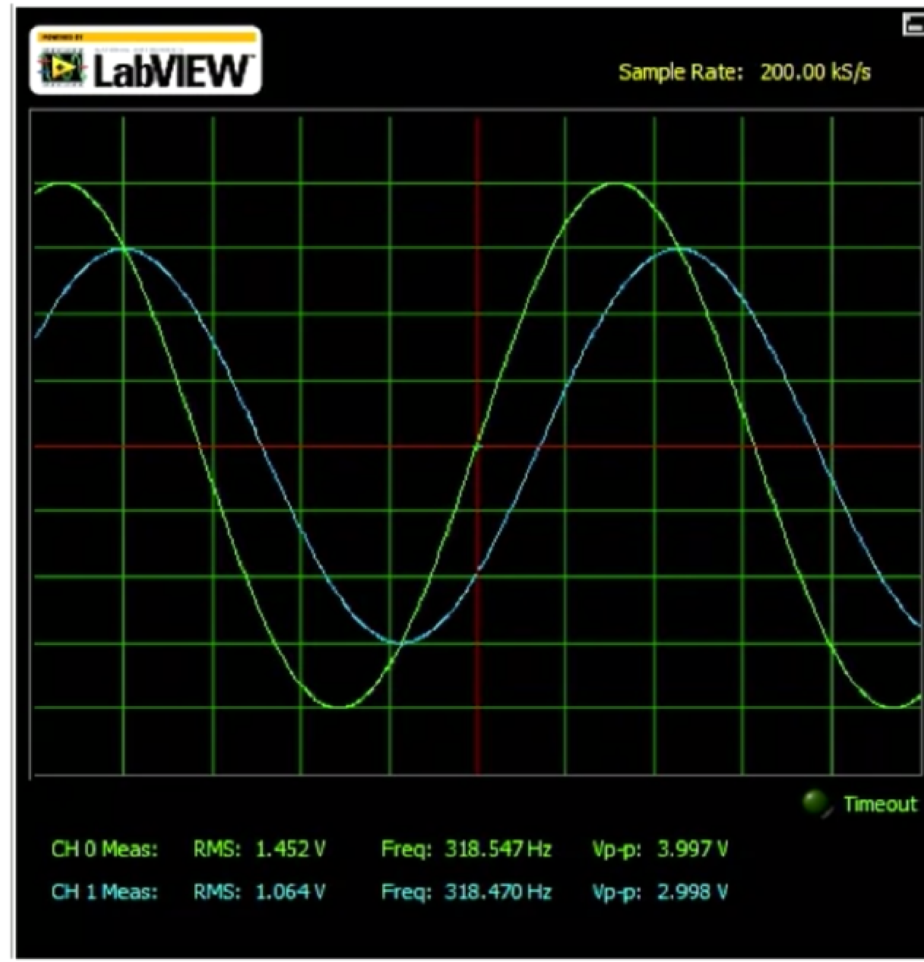
Example



$V_s = 2\cos(2000t+30^o)$

$$\mathbf{V_o} = 1.5\angle -11.3^o$$

$V_o = 1.5\cos(2000t-11.3^o)$

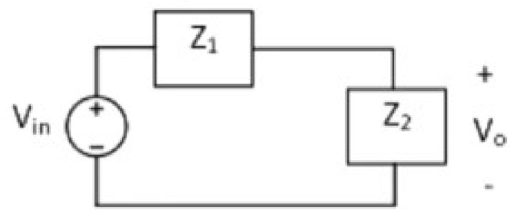


Review of Circuit Analysis with AC Impedances (Cont)

Key Concepts

Impedance Method for solving AC circuit problems:

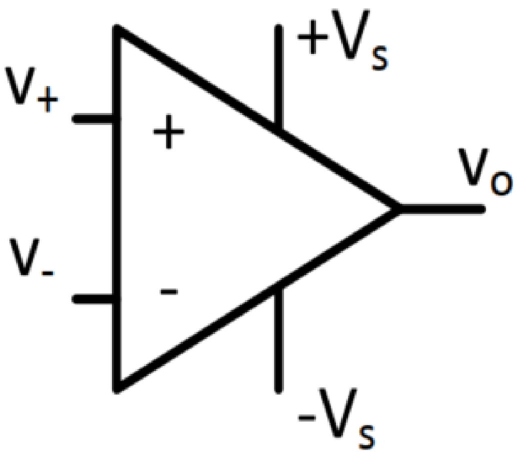
1. Redraw circuit with its impedance equivalent



2. Use standard circuit methods to solve
3. Convert the output phasor to sinusoidal form

Review of Op-Amp Behaviour

Operational Amplifiers (Op Amps)



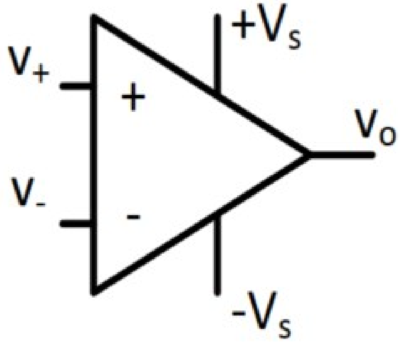
Specialized circuit made up of transistors, resistors, and capacitors fabricated on an integrated chip

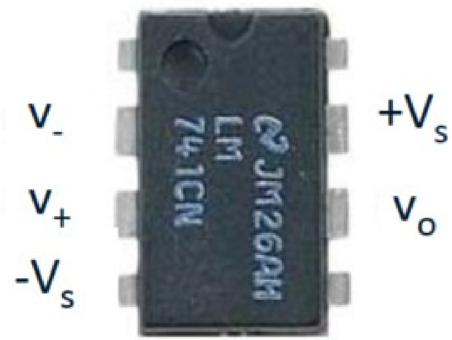
Uses:

- Amplifiers
- Active Filters
- Analog Computers

Review of Op-Amp Behaviour (Cont.)

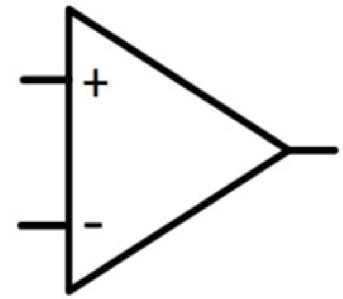
Op Amps in Circuits





V_s = 10V, 15V

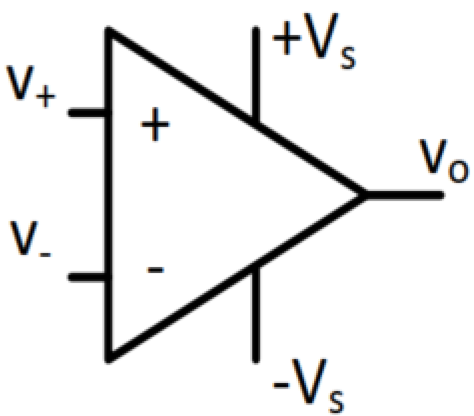
Symbol:



- Active Element: has its own power supply
- Symbol ignores the +/- V_s in the symbol since it does not affect circuit behavior

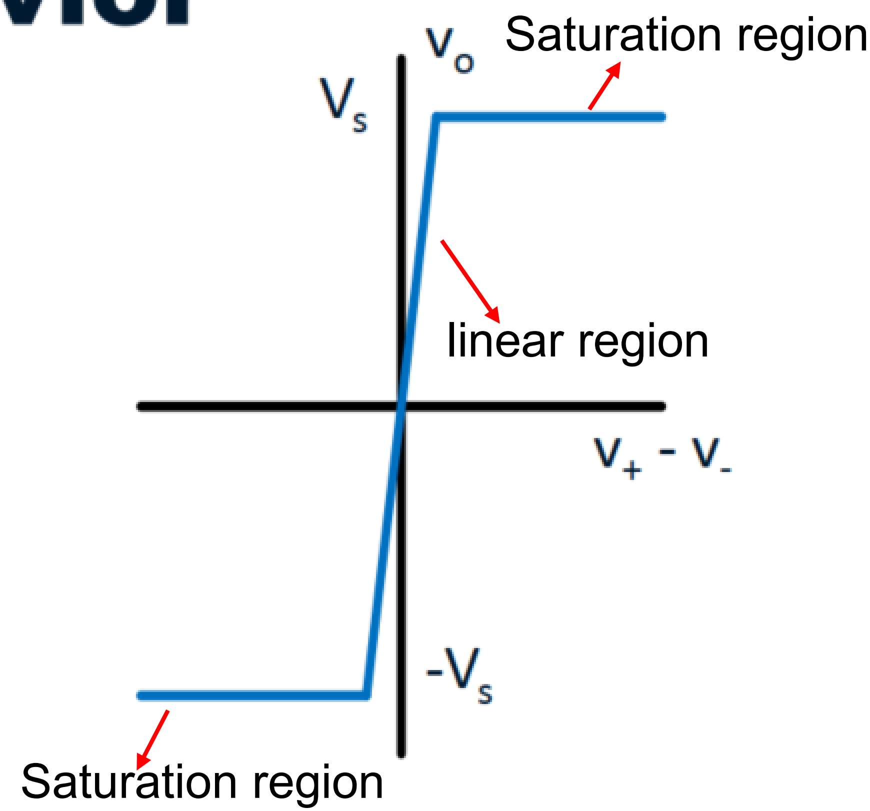
Review of Op-Amp Behaviour (Cont.)

Open Loop Behavior



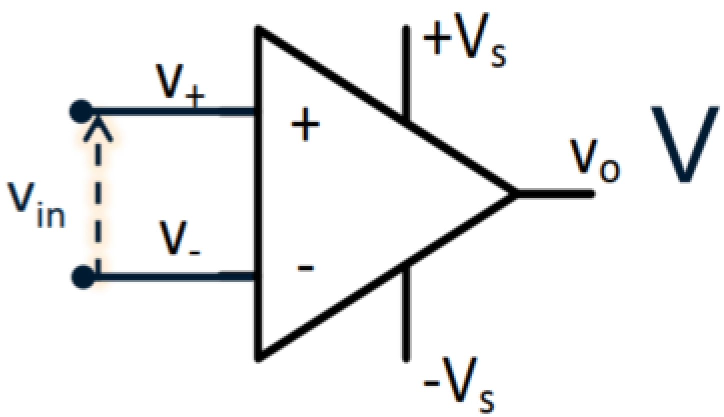
$v_o = A(v_+ - v_-)$

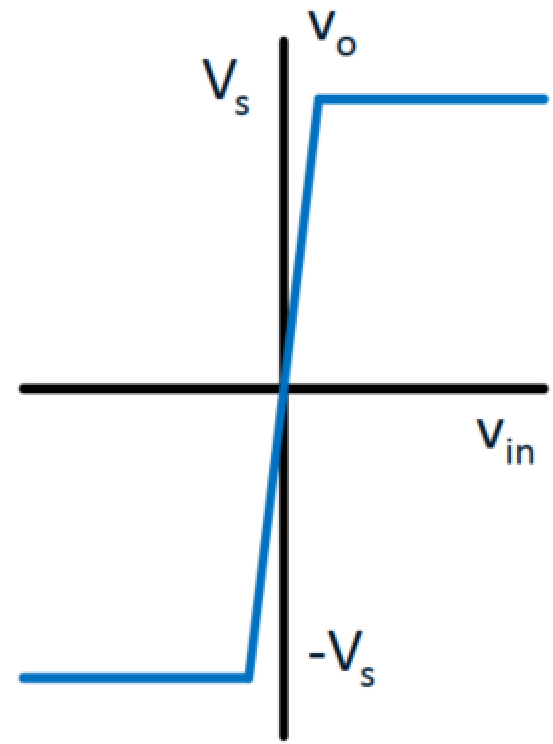
Open loop gain
(A very large value)



Review of Op-Amp Behaviour (Cont.)

Comparator Circuit

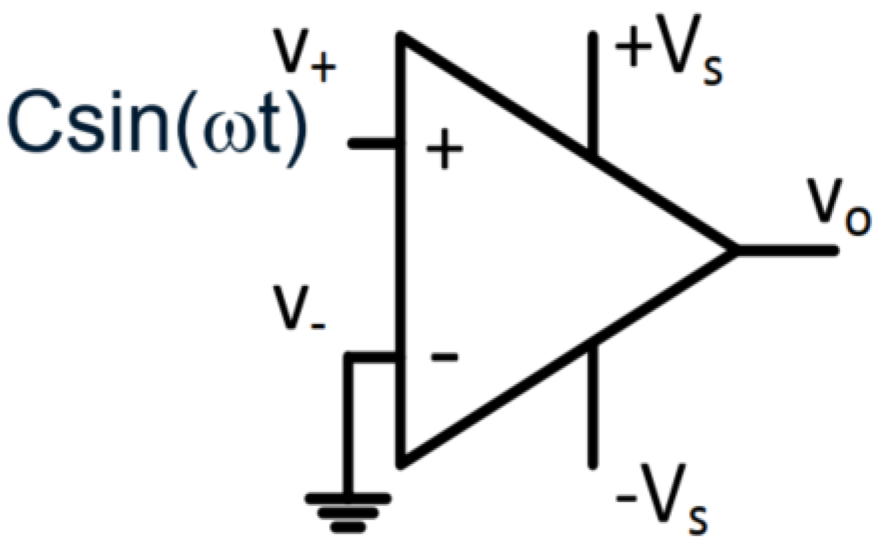


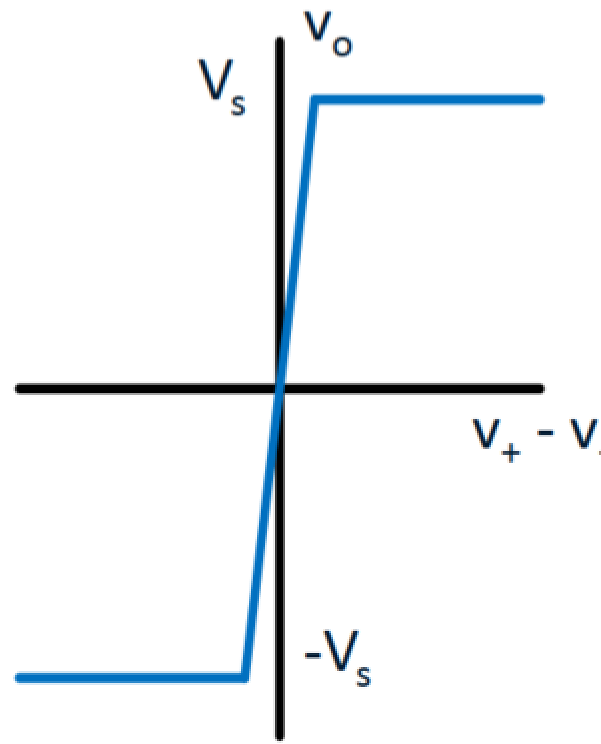


$$V_o = \begin{cases} V_s & \text{if } v_{in} > 0 \\ -V_s & \text{if } v_{in} < 0 \end{cases}$$

Review of Op-Amp Behaviour (Cont.)

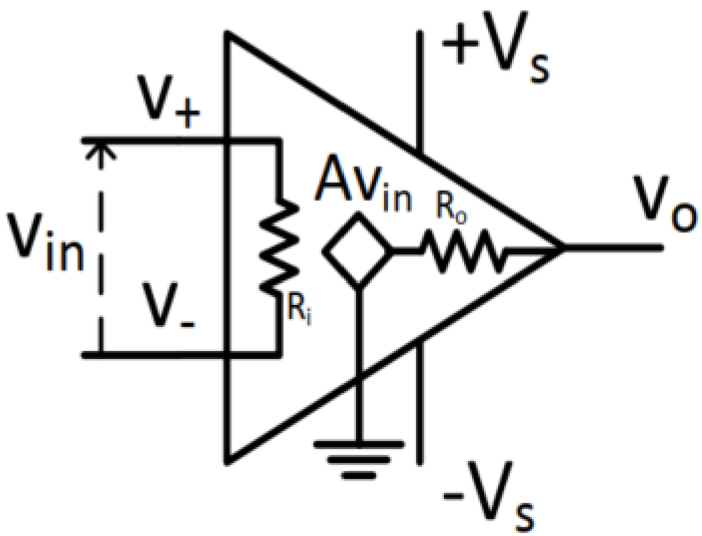
Example





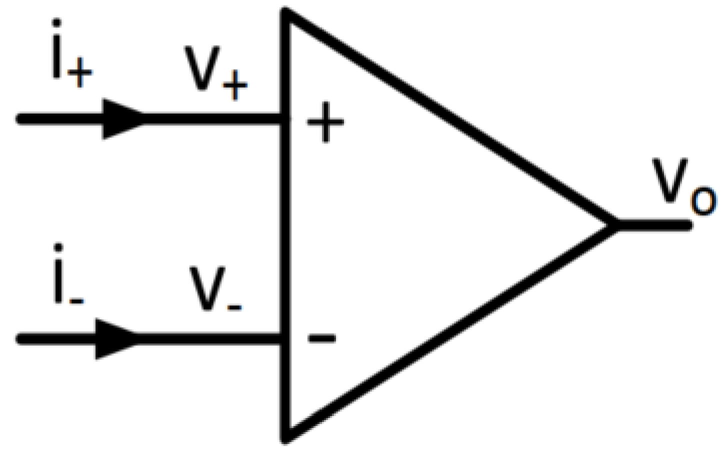
Review of Op-Amp Behaviour (Cont.)

Op-Amp Model



R_i is the input resistance
(A very large value)

Ideal Op-Amp Behavior

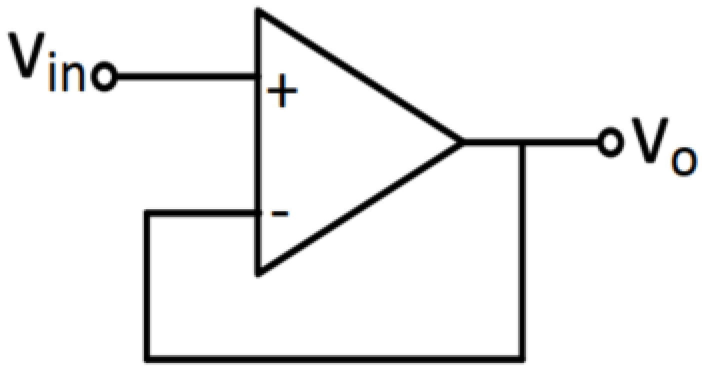


$i_+ = i_- = 0$

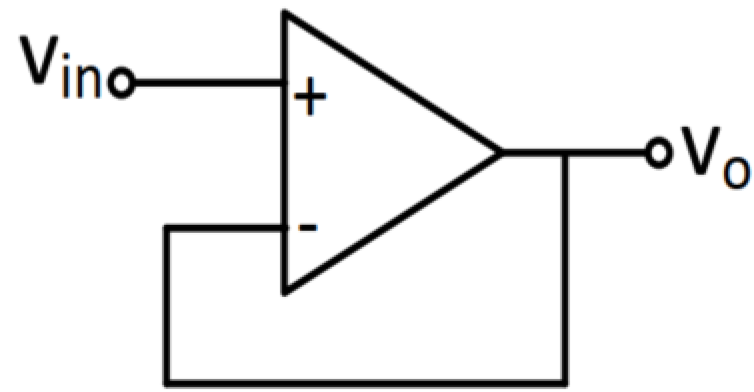
$v_+ - v_- = 0$

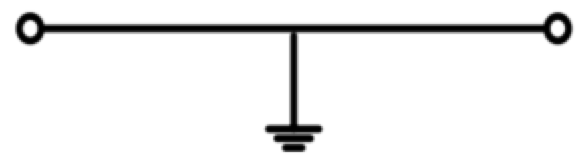
Review of Op-Amp Behaviour (Cont.)

Buffer Circuit



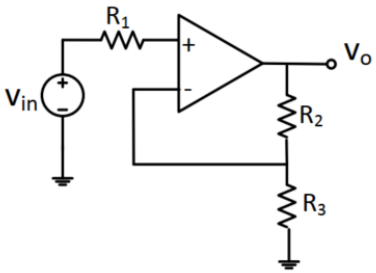
$V_{in} = V_o$





Review of Basic Op-Amp Circuits

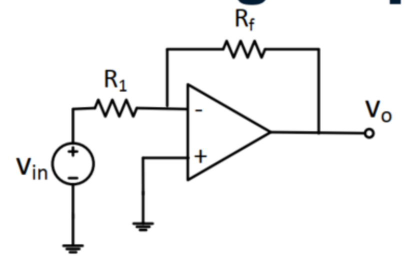
Non-Inverting Amplifiers



$$V_o = \frac{R_2 + R_3}{R_3} V_{in}$$

$V_o = GV_{in}$ Gain: $G = \frac{R_2 + R_3}{R_3}$

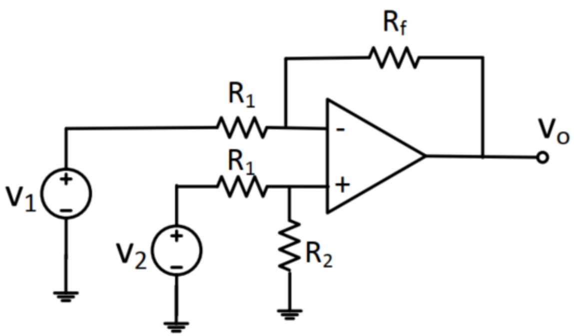
Inverting Amplifier



$$V_o = -\frac{R_f}{R_1} V_{in}$$

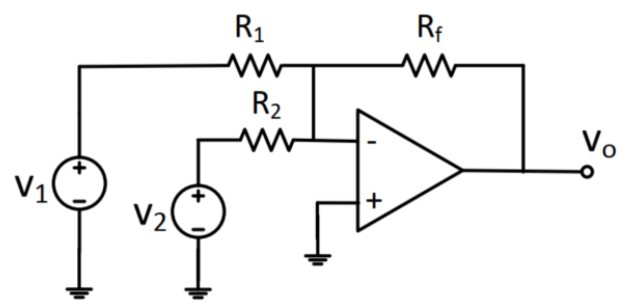
$V_o = GV_{in}$

Difference Circuit



$$V_o = \frac{R_F}{R_1}(V_2 - V_1)$$

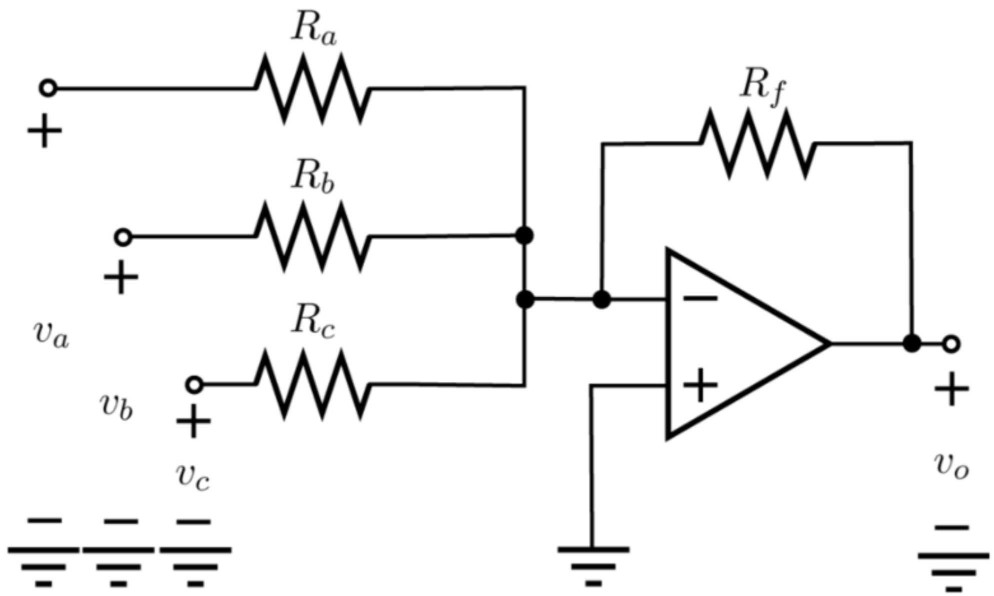
Summing Amplifier



$$V_o = G_1 V_1 + G_2 V_2$$

$$G_1 = -\frac{R_F}{R_1} \quad G_2 = -\frac{R_F}{R_2}$$

Example 2



In the figure above, R_a=1kΩ, R_b=2kΩ, R_c=3kΩ. R_f=12kΩ. The sources are v_a=−4V, v_b=+2V, and v_c=1V. The power supplies for the op-amp are +15V and −15V. What is the value of v_o? Notice that this op amp circuit might saturate, and you need to consider that possibility in your answer.

What must be R_a be changed to so that v_o is 13 V? Give your answer in kilo-ohms

Example 2 (Cont.)

① $R_a = 1k\Omega$, $R_b = 2k\Omega$, $R_c = 3k\Omega$, $R_f = 12k\Omega$.

$V_a = -4V$, $V_b = 2V$, $V_c = 1V$

$$\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} = \frac{0 - V_o}{R_f} \Rightarrow V_o = -\left[\frac{R_f}{R_a}V_a + \frac{R_f}{R_b}V_b + \frac{R_f}{R_c}V_c\right]$$

$$V_o = -\left[\frac{12k\Omega}{1k\Omega}(-4V) + \frac{12k\Omega}{2k\Omega}(2V) + \frac{12k\Omega}{3k\Omega}(1V)\right] = -[-48 + 12 + 4]V$$

$$= 32V$$

V_o is greater than so it saturates @ 15V

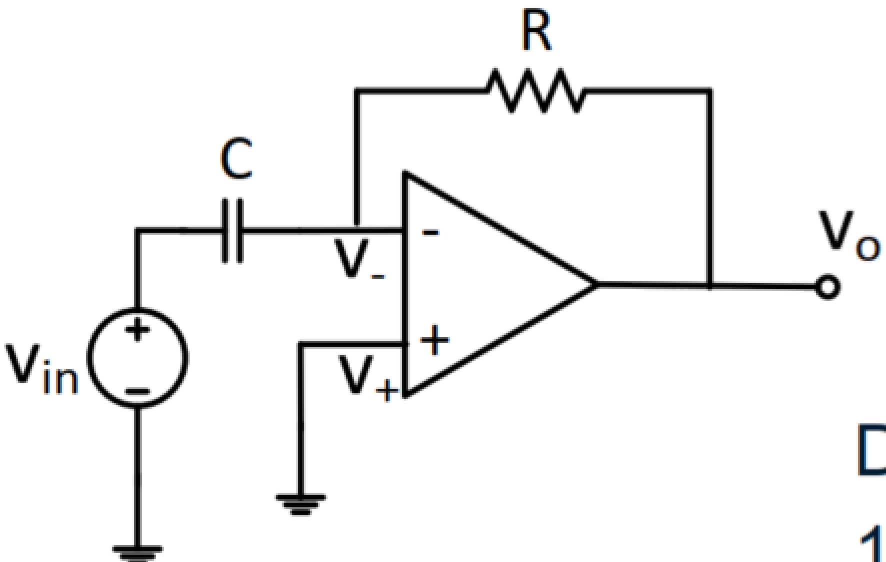
② By using above equation

$$13V = -\left[\frac{12k\Omega}{R_a}(-4V) + \underbrace{\frac{12k\Omega}{2k\Omega}(2V)}_{12V} + \underbrace{\frac{12k\Omega}{3k\Omega}(1V)}_{4V}\right]$$

$$\frac{(13V + 16V)}{4V} = \frac{12k\Omega}{R_a} \Rightarrow \frac{12k\Omega \times 4V}{29V} = \boxed{R_a \Rightarrow 1.6552k\Omega}$$

Review of Differentiators and Integrators

Differentiator Circuit



$$i = C\frac{dV_c}{dt}V_c$$

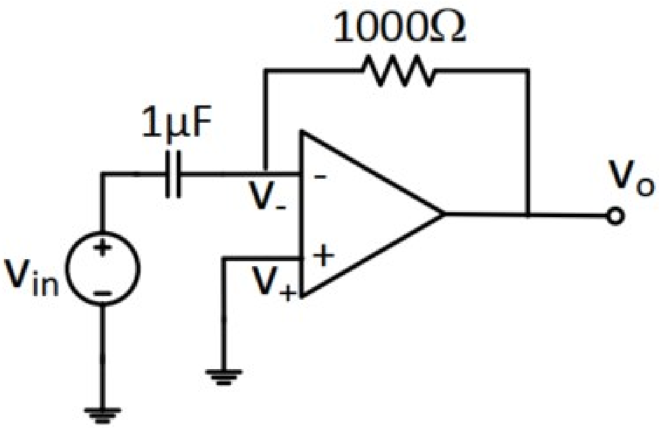
$$V_o = -RC\frac{dV_{in}}{dt}$$

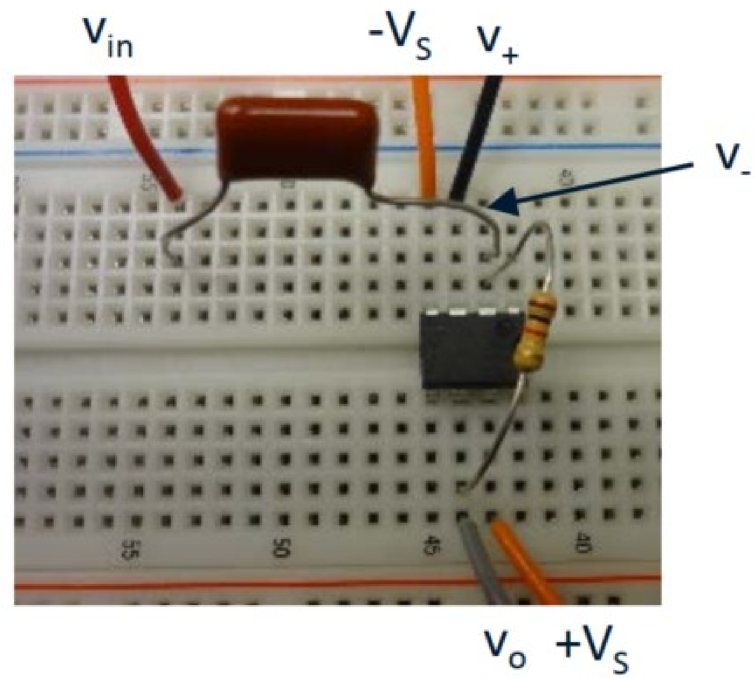
Derivation:

1. KVL: $V_{in} = V_c + Ri + V_o$
2. $V_{in} = V_c$
3. $V_o = -Ri = -RC(dV_{in} / dt)$

Review of Differentiators and Integrators (Cont.)

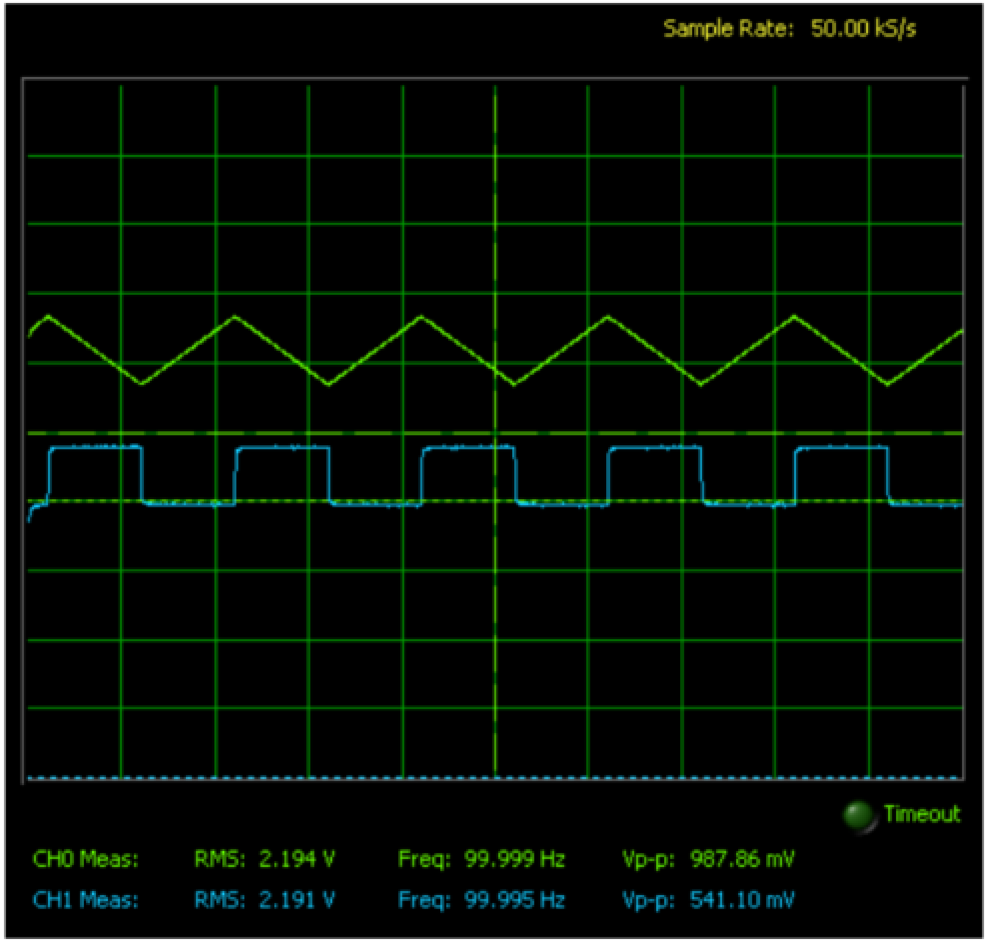
Differentiator Example





Review of Differentiators and Integrators (Cont.)

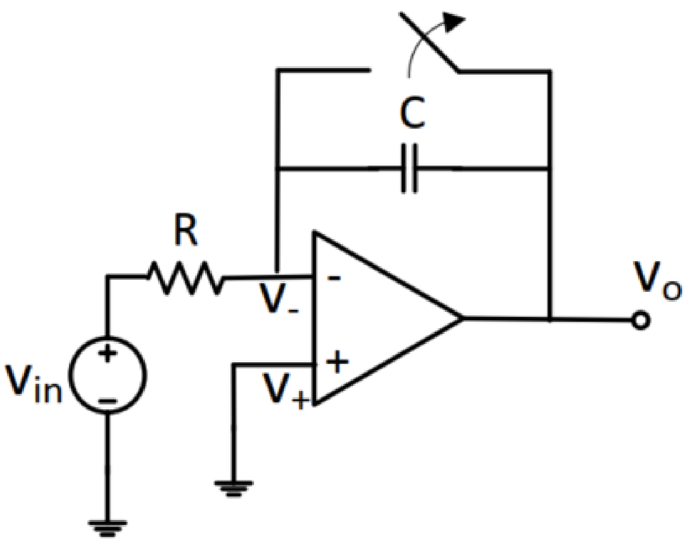
Results



$$V_o = -RC\frac{dV_{in}}{dt}$$

Review of Differentiators and Integrators (Cont.)

Integrator Circuit



$$V_o = \frac{-1}{RC}\int_0^t V_{in}dt$$

$$i = C\frac{dV_c}{dt}V_c \qquad V_c = \frac{1}{C}\int_0^t i\,dt$$

Derivation:

For t<0: $V_{in} = iR$ and $V_o = 0$

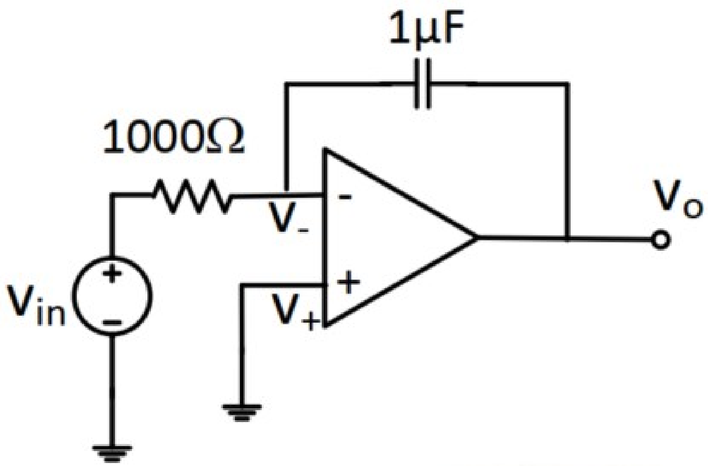
For t>0: $V_{in} = iR$ $\qquad i = V_{in}/R$

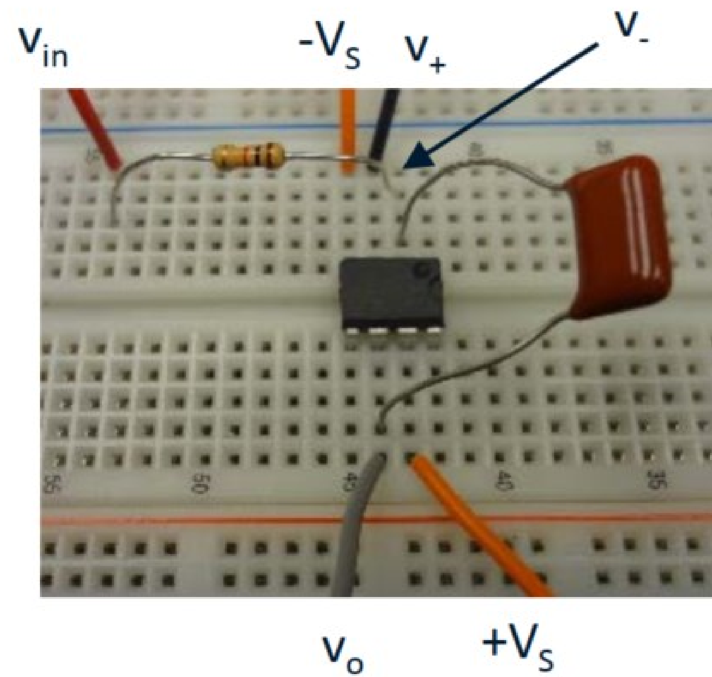
$V_{in} = iR + V_c + V_o$

$V_o = -V_c = -1/C \int_0^t V_{in}/R\ dt$

Review of Differentiators and Integrators (Cont.)

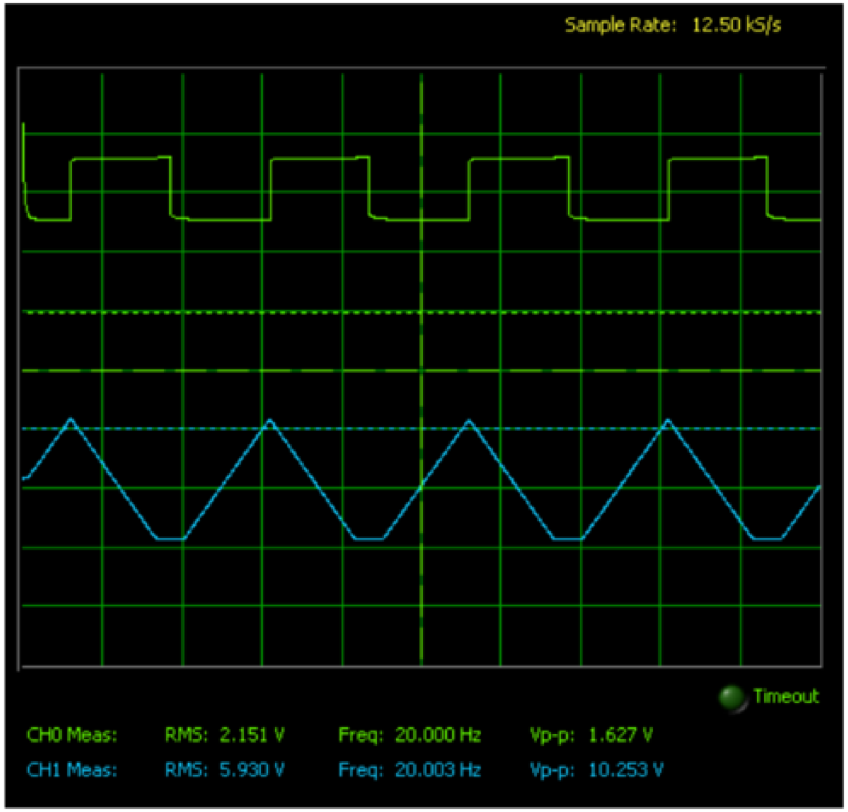
Integrator Example





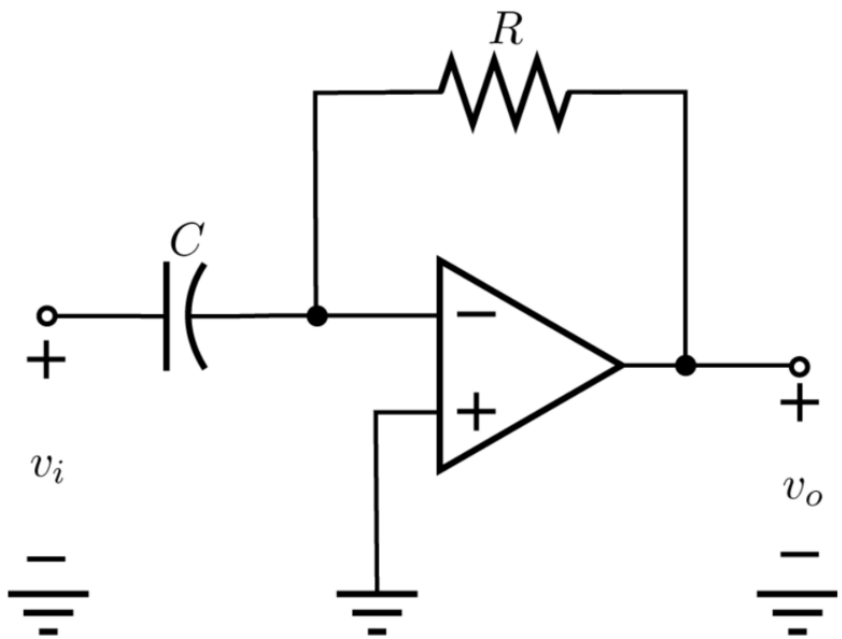
Review of Differentiators and Integrators (Cont.)

Results



$$V_o = \frac{-1}{RC}\int_0^t V_{in}\,dt$$

Example 3



For the circuit above, R=5kΩ and C=2μF. If v_i=sin(1000t)V, what is the value of v_o at t=4π/3 ms?

Example 3 (Cont.)

$R = 5\,k\Omega$, $C = 2\,\mu F$, $V_i = \sin(1000t)$, $V_o = ?$ @ $t = \frac{4\pi}{3}\,ms$

$$V_o = -RC\frac{dV_i}{dt} \Rightarrow -5\times10^{3}\times 2\times10^{-6}\,\frac{d(\sin(1000t))}{dt}$$

$$\Rightarrow -10\times\cancel{10^{-3}}\times\cancel{10^{3}}\cos(1000t)$$

$$V_o(t) \Rightarrow -10\cos(1000t)$$

@ $t_o = \frac{4\pi}{3}\,ms \Rightarrow V_o(t_o) = -10\left[\cos\left(\cancel{10^{3}}\times\frac{4\pi}{3}\times\cancel{10^{-3}}\right)\right]$

$$= -10\cos\left(\frac{4\pi}{3}\right) \Rightarrow 5\,V$$

Derivative Rules

$$f(x)=k\in\mathbb{R}\Rightarrow f'(x)=0$$

$$f(x)=x\Rightarrow f'(x)=1$$

$$f(x)=x^k\Rightarrow f'(x)=kx^{k-1}$$

$$f(x)=\frac{1}{x}\Rightarrow f'(x)=-\frac{1}{x^2}$$

$$f(x)=\sqrt{x}\Rightarrow f'(x)=\frac{1}{2\sqrt{x}}$$

$$f(x)=\ln x\Rightarrow f'(x)=\frac{1}{x}$$

$$f(x)=\log_a x\Rightarrow f'(x)=\frac{1}{x\ln a}$$

$$f(x)=e^x\Rightarrow f'(x)=e^x$$

$$f(x)=a^x\Rightarrow f'(x)=a^x\ln a$$

$$f(x)=\sin x\Rightarrow f'(x)=\cos x$$

$$f(x)=\cos x\Rightarrow f'(x)=-\sin x$$

$$f(x)=\tan x\Rightarrow f'(x)=\sec^2 x=1+\tan^2 x$$

$$f(x)=\arcsin x\Rightarrow f'(x)=\frac{1}{\sqrt{1-x^2}}$$

$$f(x)=\arctan x\Rightarrow f'(x)=\frac{1}{1+x^2}$$