

Announcements:

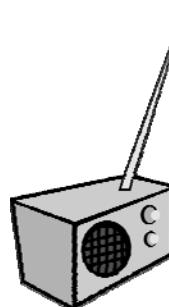
1. Announcement

# EECS 70A: Network Analysis

## Lecture 13

# Wireless Communications

Broadcast Radio:



Telecom:



Internet:



3G data:



*All use sine waves (phasors) as way to describe signals and circuits.*

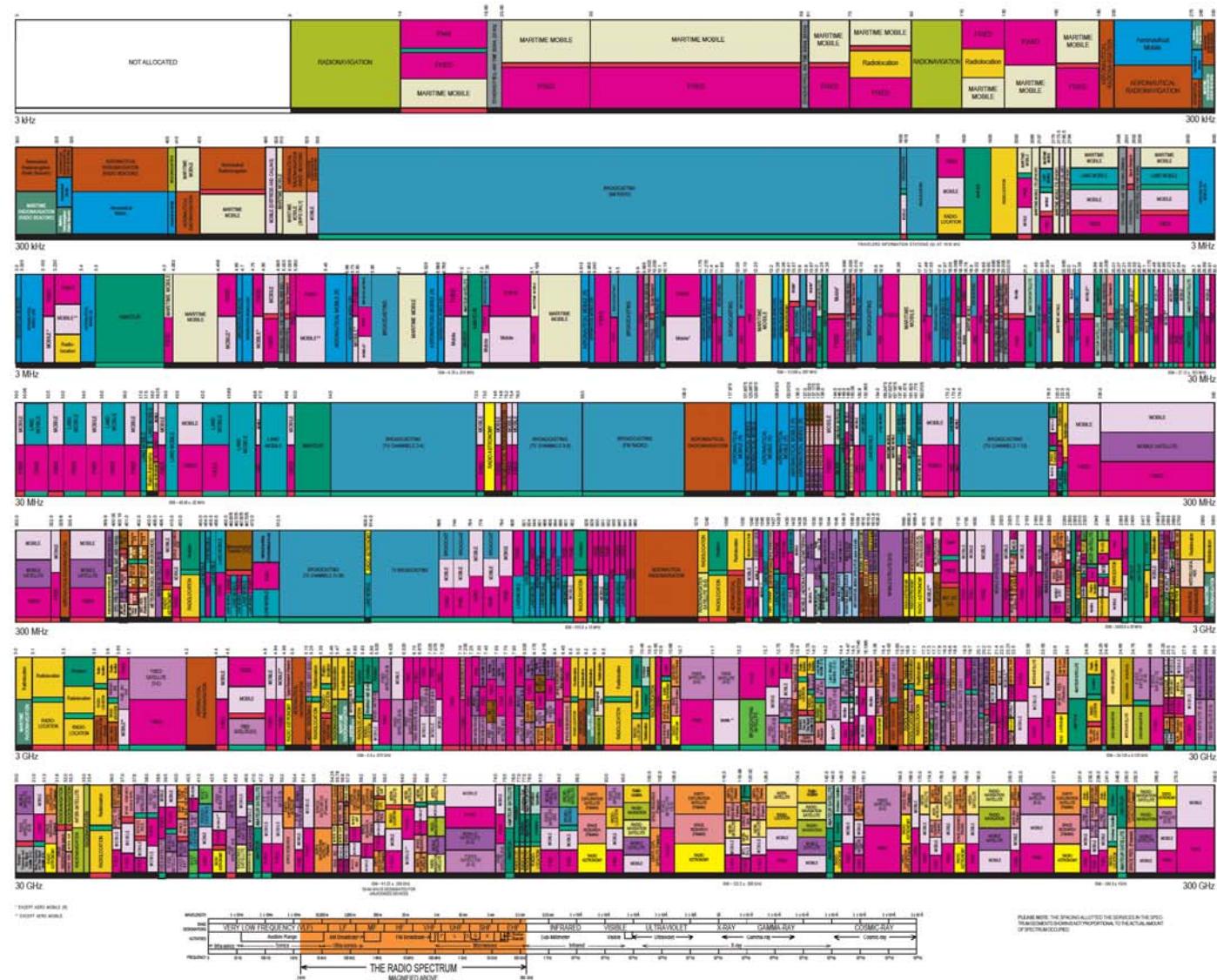
# UNITED STATES FREQUENCY ALLOCATIONS

## THE RADIO SPECTRUM



This chart is a graphic representation of the U.S. Frequency Allocations used by the FCC and NTIA. No such chart can completely reflect all aspects, i.e., technical and legal changes. For more detailed information, refer to the source documents cited at the bottom of this chart.

U.S. DEPARTMENT OF COMMERCE  
National Telecommunications and Information Administration  
Office of Spectrum Management  
October 2003



<http://www.ntia.doc.gov/osmhome/allochrt.PDF>

# *Phasors*

$$V(t) = V_m \cos(\omega t + \phi) = \operatorname{Re} \left( V_m e^{j(\omega t + \phi)} \right)$$

$$= \operatorname{Re} \left( V_m e^{j\phi} e^{j\omega t} \right)$$


“Voltage Phasor” **V**  
(Complex #)

$$i(t) = I_m \cos(\omega t + \phi) = \operatorname{Re} \left( I_m e^{j(\omega t + \phi)} \right)$$

$$= \operatorname{Re} \left( I_m e^{j\phi} e^{j\omega t} \right)$$


“Current Phasor” **I**

# Circuits

The diagram shows three circuit elements: a resistor ( $R$ ), a capacitor ( $C$ ), and an inductor ( $L$ ). Each element is shown with its symbol and a voltage drop  $V$  indicated across it. The resistor has a blue zigzag symbol with a green label  $R$ . The capacitor has a blue parallel plate symbol with a green label  $C$ . The inductor has a blue coil symbol with a green label  $L$ . The voltage drops are labeled  $V = I R$ ,  $V = I / j\omega C$ , and  $V = j\omega L I$  respectively.

“Impedance”

$$Z = R$$

$$Z = 1/j\omega C$$

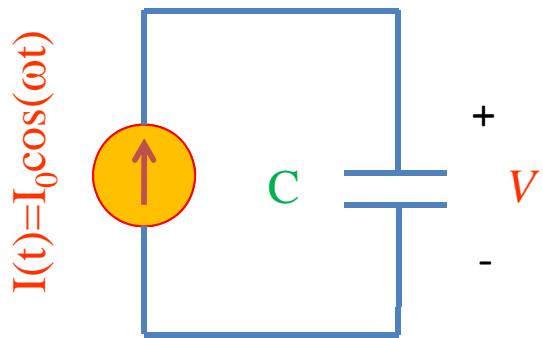
$$Z = j\omega L$$

*Can think of this as a “generalized Ohm’s law for ac circuits”*

KCL, KVL hold for relationship  
between  $V$ ,  $I$ .

# Phasor to voltage conversion

Find  $V(t)$ ,  $q(t)$



Problem gives us:

$$I(t) = I_0 \cos(\omega t)$$

Compare to definition of current phasor:

$$i(t) = I_m \cos(\omega t + \phi) = \operatorname{Re}(I_m e^{j\phi} e^{j\omega t}) = \operatorname{Re}(I e^{j\omega t})$$
$$\Rightarrow \mathbf{I} = I_0$$

Find voltage phasor using generalized Ohm's law:

$$\mathbf{V} = \mathbf{I}/j\omega C$$

Find  $v(t)$  from voltage phasor:

$$v(t) = \operatorname{Re}[\mathbf{V} e^{j\omega t}] = \operatorname{Re}\left[\left(\frac{\mathbf{I}}{j\omega C}\right) e^{j\omega t}\right] = \operatorname{Re}\left[\left(\frac{I_0}{j\omega C}\right) e^{j\omega t}\right]$$
$$= \frac{I_0}{\omega C} \operatorname{Re}\left[\left(\frac{1}{j}\right) e^{j\omega t}\right] = \frac{I_0}{\omega C} \operatorname{Re}[-je^{j\omega t}] = \frac{I_0}{\omega C} \operatorname{Re}[-j(\cos(\omega t) + j \sin(\omega t))]$$
$$= \frac{I_0}{\omega C} \operatorname{Re}[-j \cos(\omega t) + (-j) j \sin(\omega t)] = \frac{I_0}{\omega C} \operatorname{Re}[\sin(\omega t) - j \cos(\omega t)] = \frac{I_0}{\omega C} \sin(\omega t)$$

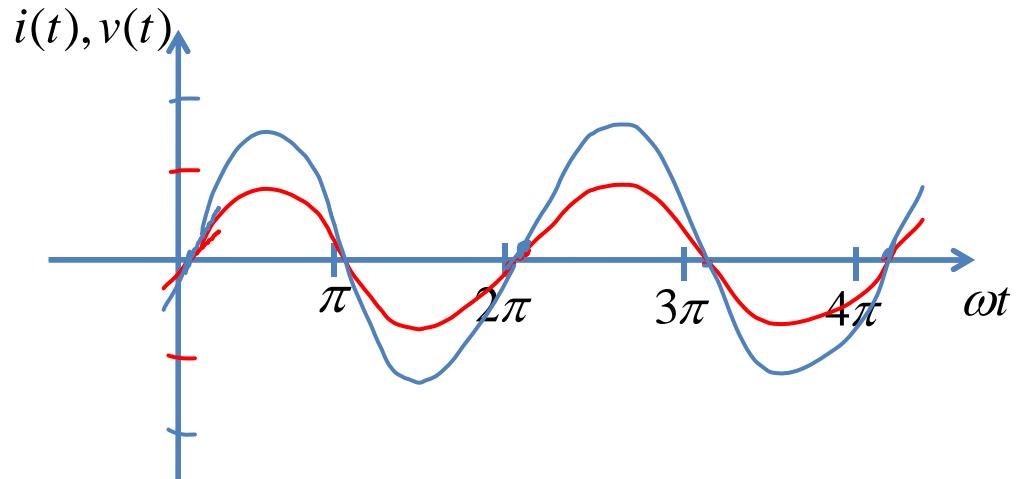
# Phase vs. impedance (Z)

In general:

Z real i.e.  $Z = x + jy$

$$\begin{array}{cc} \uparrow & \uparrow \\ \neq 0 & = 0 \end{array}$$

$\Rightarrow i(t), v(t)$  “in phase”

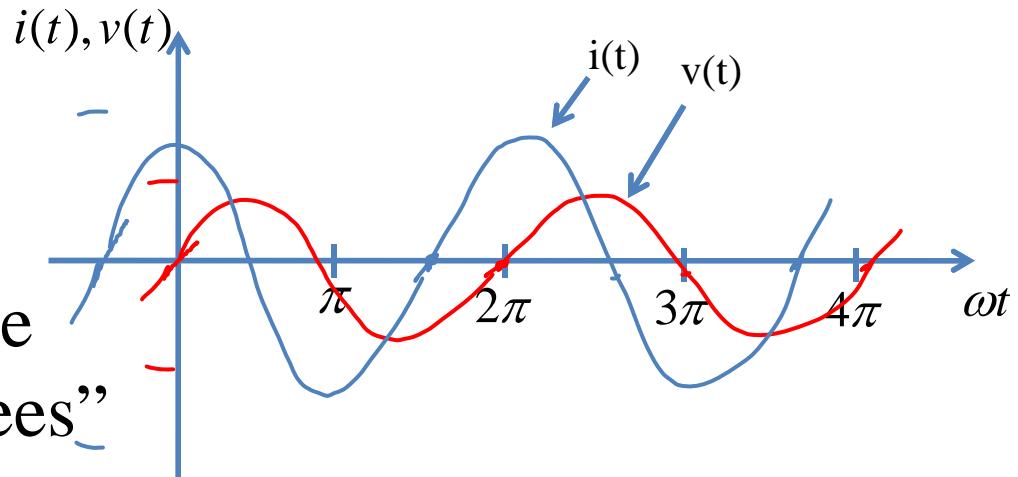


In general:

Z imag i.e.  $Z = x + jy$

$$\begin{array}{cc} \uparrow & \uparrow \\ = 0 & \neq 0 \end{array}$$

$\Rightarrow i(t), v(t)$  “out of phase by 90 degrees”

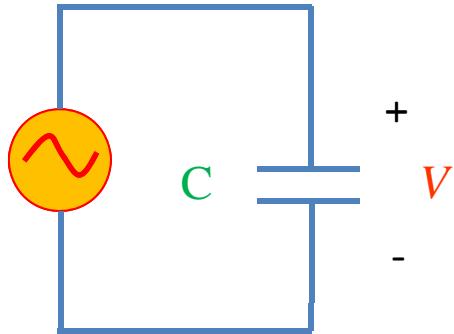


HW problem: Find relationship between phase shift and impedance (Z).

# Example phasor problem

Find  $i(t)$  (students)

$$v(t) = 3 \cos(10t + 30^\circ) \text{ Volts}$$



Problem gives us:

$$v(t) = 3 \cos(10t + 30^\circ) \text{ Volts}$$

Compare to definition of voltage phasor:

$$v(t) = V_m \cos(\omega t + \phi) = \operatorname{Re}(V_m e^{j\phi} e^{j\omega t}) = \operatorname{Re}[\mathbf{V} e^{j\omega t}]$$
$$\Rightarrow \mathbf{V} = ?$$

Find current phasor using generalized Ohm's law:

$$\mathbf{I} = j\omega C \mathbf{V} = \dots$$

Find  $i(t)$  from current phasor:

$$i(t) = \operatorname{Re}(\mathbf{I} e^{j\omega t}) = \dots$$

# Example problem #3

Find  $\underline{i(t)}$ ,  $V_1(t)$ ,  $V_2(t)$  for this circuit: (instructor)

$$V = V_0 \cos(\omega t)$$

$$V_1$$

$$V_2$$

$$Z_{eq} = (R + \frac{1}{j\omega C}) \frac{j\omega L}{j\omega L} = \frac{j\omega RL}{j\omega RC + j\omega L^2}$$

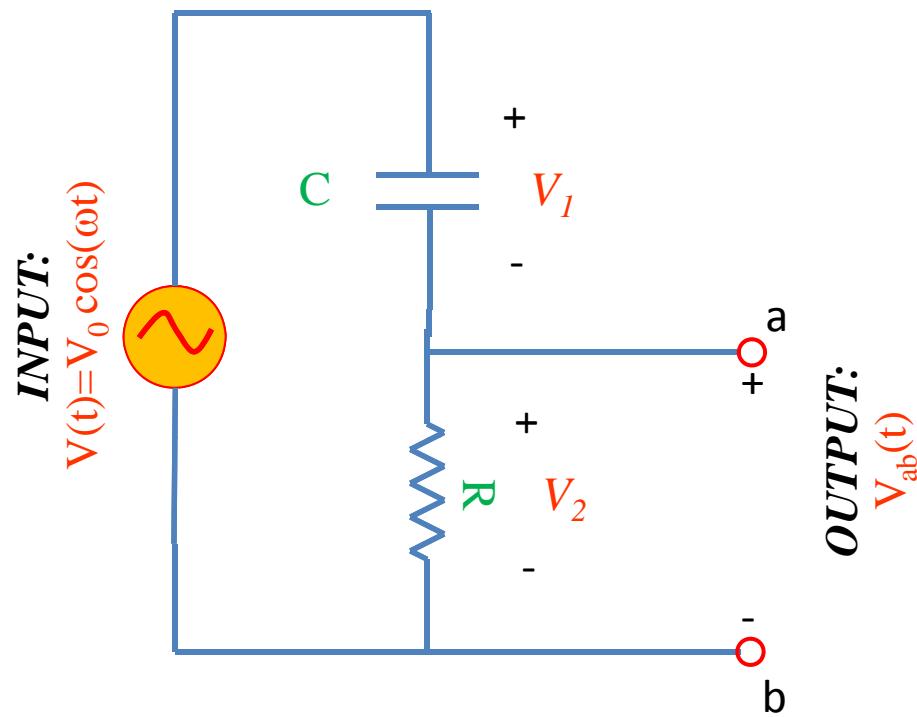
$$I = \frac{V}{Z_{eq}}$$

$$i(t) = \operatorname{Re}[I e^{j\omega t}] = \operatorname{Re}\left[\frac{V}{Z_{eq}} e^{j\omega t}\right]$$

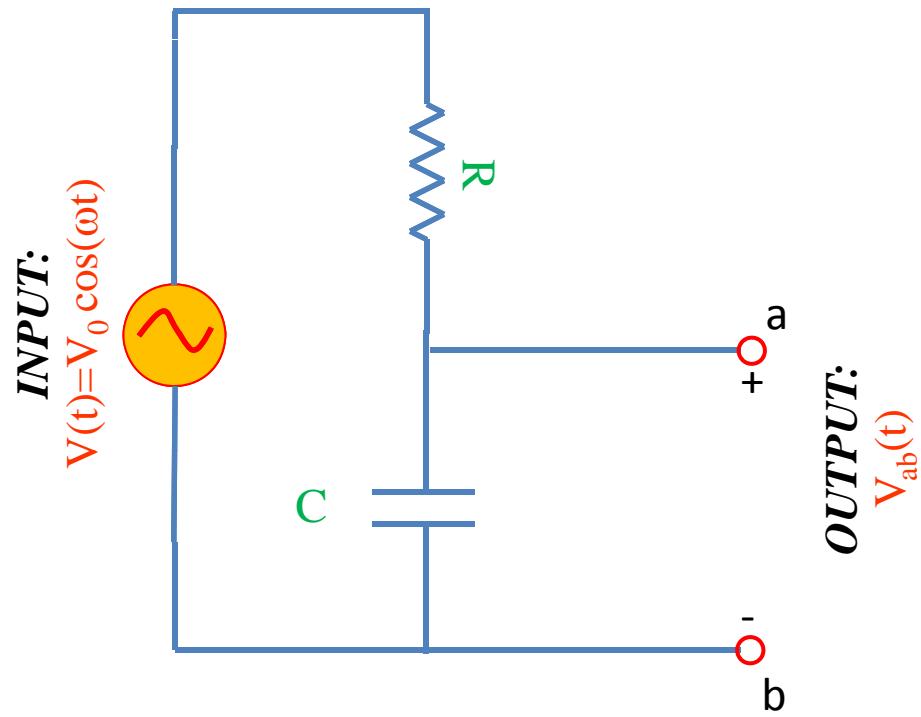
$$= \operatorname{Re}\left[\frac{V_0}{R + j\omega C} e^{j\omega t}\right] = \operatorname{Re}\left[\frac{V_0 j\omega RC}{1 + j\omega RC} e^{j\omega t}\right]$$

$$\cos \omega t + j \sin \omega t$$

# High pass filter



# Low pass filter

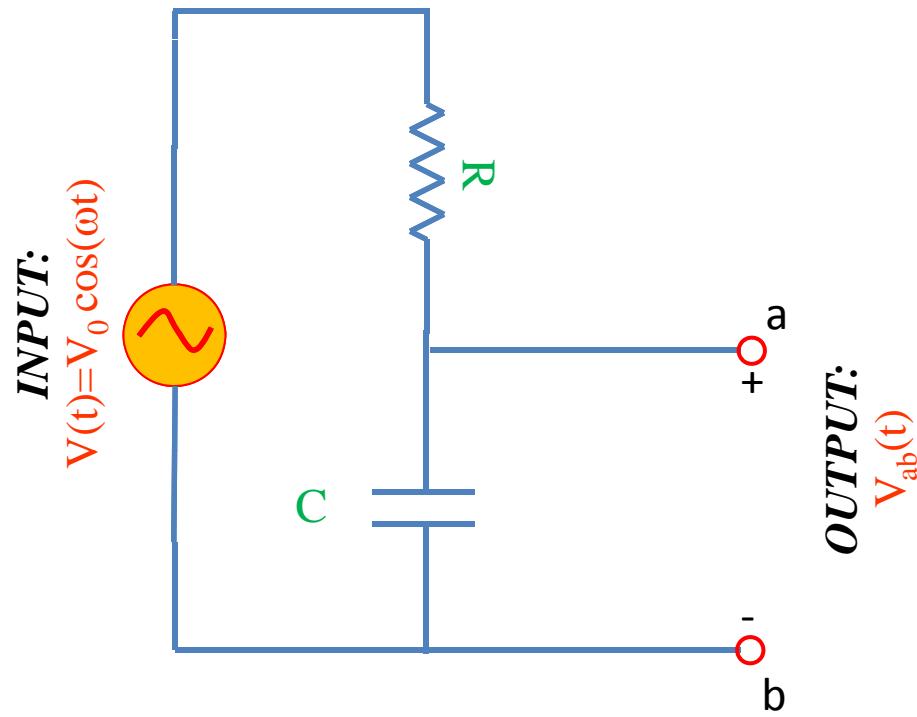


# “Transfer function”



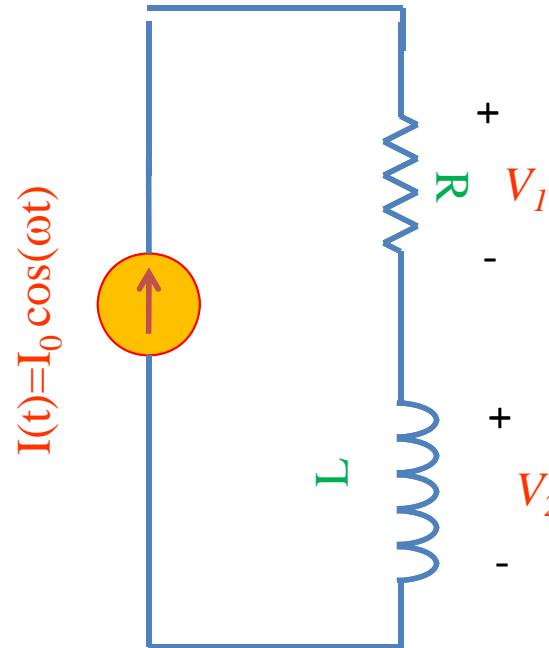
*demo*

# RC transfer function

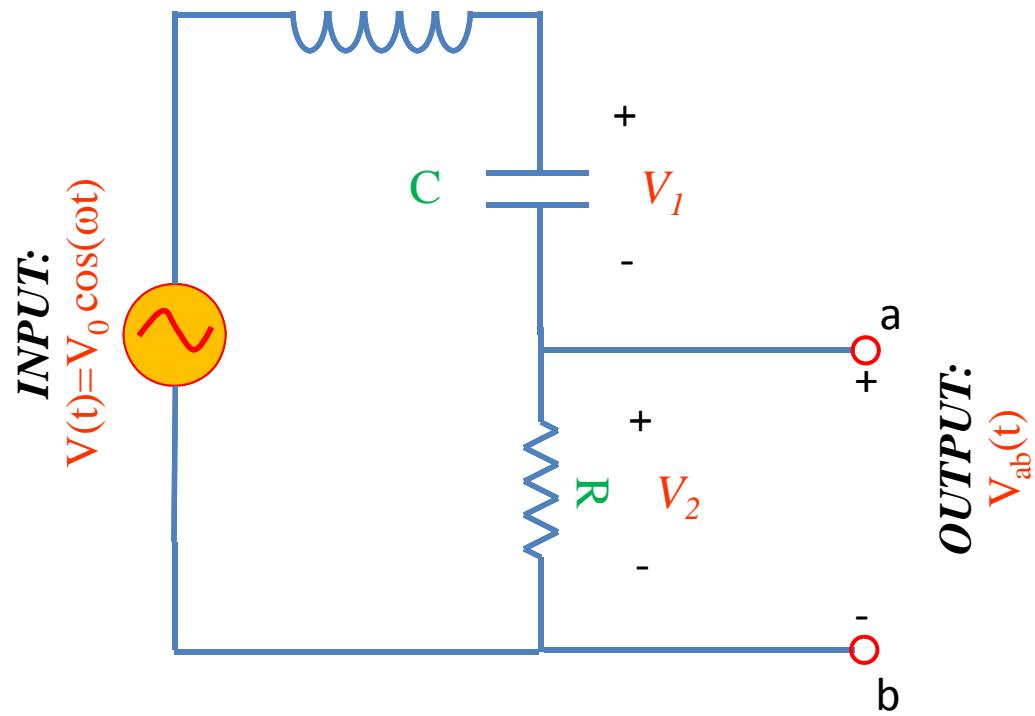


# Example problem #4

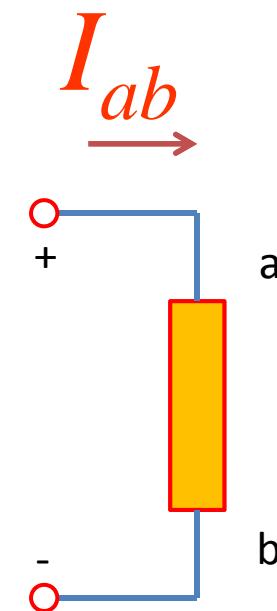
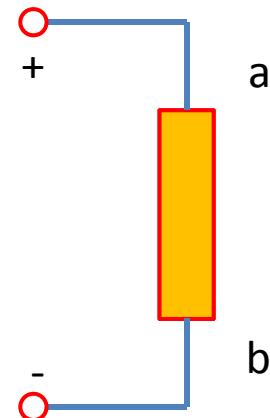
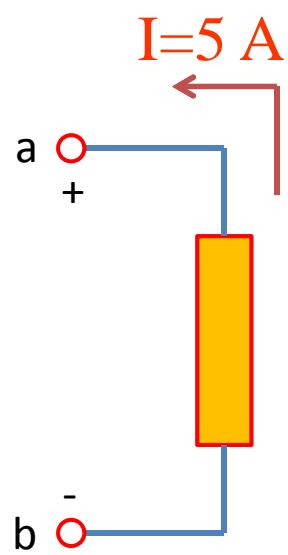
Find  $i(t)$ ,  $V_1(t)$ ,  $V_2(t)$  for this circuit: (students)



# Band pass filter (RLC)



# Symbol library



# Symbol library

