

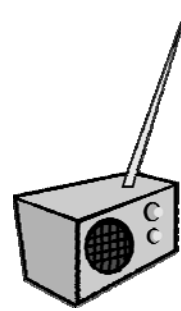
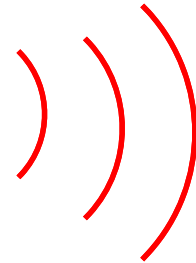
- Announcements:
1. Announcement

EECS 70A: Network Analysis

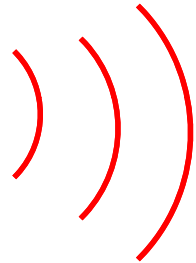
Lecture 13

Wireless Communications

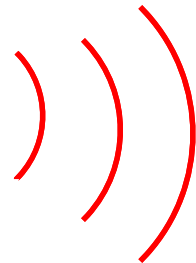
Broadcast Radio:



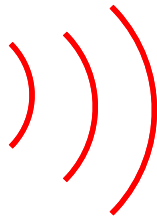
Telecom:



Internet:



3G data:



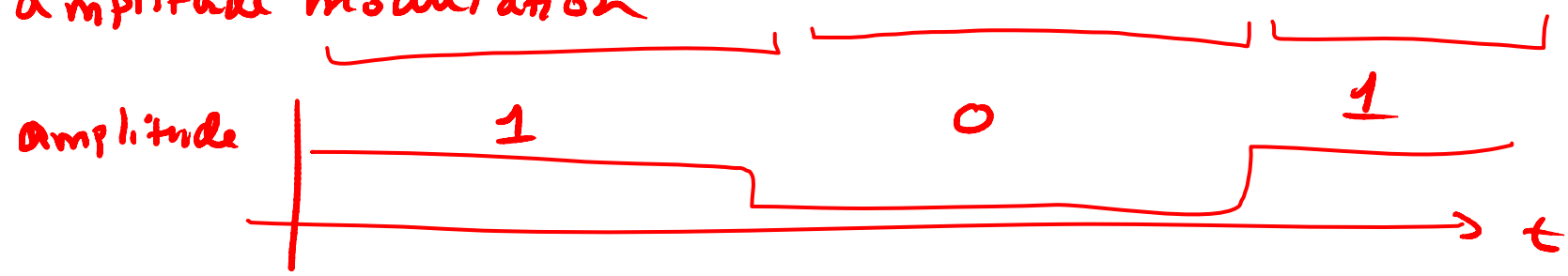
*All use sine waves
(phasors) as way to
describe signals and
circuits.*

$$Z = r e^{i\theta}$$

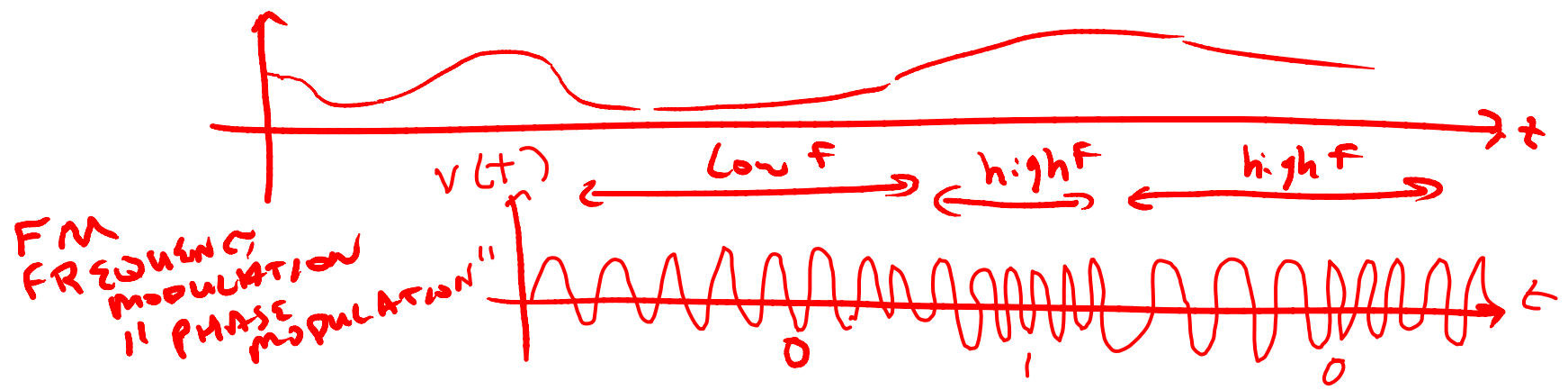
Modulation schemes



amplitude modulation



Am RADIO



Frequency Allocations

UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- INTER SATELLITE
- RADIO ASTRONOMY
- AERONAUTICAL MOBILE SATELLITE
- LAND MOBILE
- RADIO DETERMINATION SATELLITE
- AERONAUTICAL RADIONAVIGATION
- LAND MOBILE SATELLITE
- RADIONAVIGATION
- AMATEUR
- MARITIME MOBILE
- RADIONAVIGATION SATELLITE
- AMATEUR SATELLITE
- MARITIME MOBILE SATELLITE
- RADIONAVIGATION
- MARITIME RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- BROADCASTING SATELLITE
- METEOROLOGICAL AID
- SPACE OPERATION
- EARTH EXPLORATION SATELLITE
- METEOROLOGICAL SATELLITE
- SPACE RESEARCH
- FIXED
- MOBILE
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE
- MOBILE SATELLITE

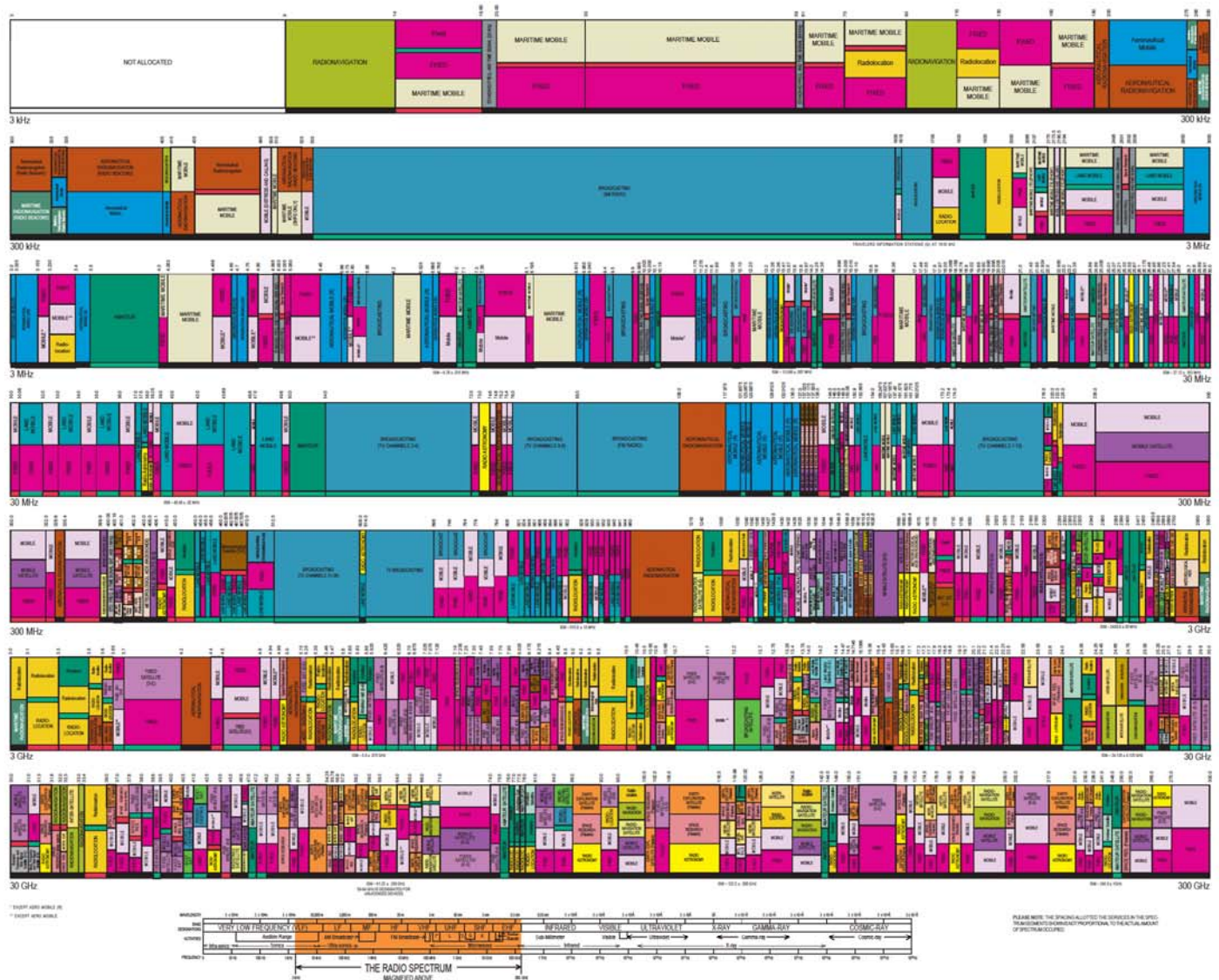
ACTIVITY CODE

- GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

This chart is a graphic interpretation of the Table of Frequency Allocations used by the FCC and is not a substitute for the actual Table of Frequency Allocations. It does not completely reflect all details, i.e., bandwidth and power standards, which are found in the Table of Frequency Allocations. Bandwidths for frequency allocations were derived from the Table of Frequency Allocations. Bandwidths for frequency allocations were derived from the Table of Frequency Allocations.



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

Phasors

Euler

$$\cos\theta + j\sin\theta = e^{j\theta}$$

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

$$= \text{Re}\left(\underbrace{V_m e^{j\phi}}_{\text{Voltage Phasor}} e^{j\omega t}\right)$$

“Voltage Phasor”

V

(Complex #)

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

$$= \text{Re}\left(\underbrace{I_m e^{j\phi}}_{\text{Current Phasor}} e^{j\omega t}\right)$$

“Current Phasor”

I

Circuits

$$v(t) = R i(t)$$

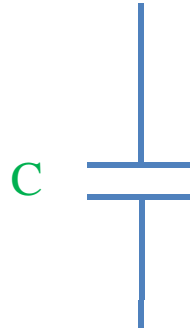
$$q(t) = C v(t)$$

$$i(t) = C \frac{dv(t)}{dt}$$



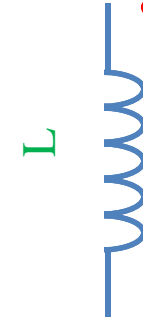
$$\mathbf{V} = \mathbf{I} R$$

$$V = IR$$



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

$$V = I \left(\frac{1}{j\omega C} \right)$$



$$\mathbf{V} = j\omega L \mathbf{I}$$

“Impedance”

$$Z = R$$

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

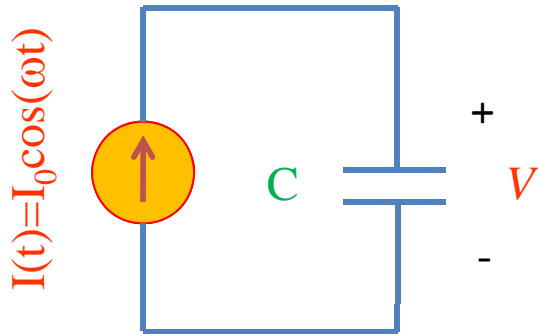
$$Z = j\omega L$$

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

KCL, KVL hold for relationship between \mathbf{V} , \mathbf{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:

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

$$\Rightarrow \mathbf{I} = I_0$$

Find voltage phasor using generalized Ohm's law:

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

Find $v(t)$ from voltage phasor:

$$v(t) = \text{Re} \left[\mathbf{V} e^{j\omega t} \right] = \text{Re} \left[\left(\frac{\mathbf{I}}{j\omega C} \right) e^{j\omega t} \right] = \text{Re} \left[\left(\frac{I_0}{j\omega C} \right) e^{j\omega t} \right]$$

$$= \frac{I_0}{\omega C} \text{Re} \left[\left(\frac{1}{j} \right) e^{j\omega t} \right] = \frac{I_0}{\omega C} \text{Re} \left[-j e^{j\omega t} \right] = \frac{I_0}{\omega C} \text{Re} \left[-j (\cos(\omega t) + j \sin(\omega t)) \right]$$

$$= \frac{I_0}{\omega C} \text{Re} \left[-j \cos(\omega t) + (-j) j \sin(\omega t) \right] = \frac{I_0}{\omega C} \text{Re} \left[\sin(\omega t) - j \cos(\omega t) \right] = \frac{I_0}{\omega C} \sin(\omega t)$$

Phase vs. impedance (Z)

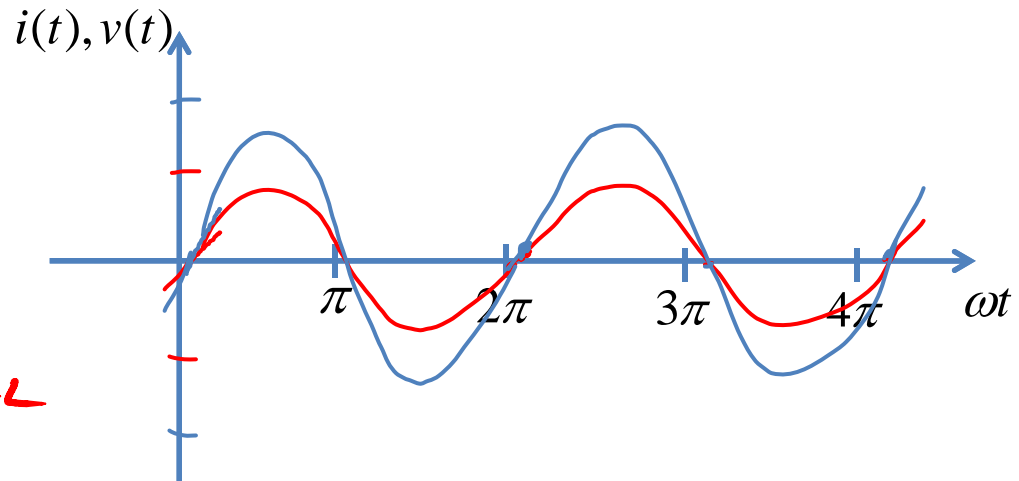
In general:

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

\uparrow \uparrow
 $\neq 0$ $= 0$

$\Rightarrow i(t), v(t)$ "in phase"

PROOF: TRIVIAL



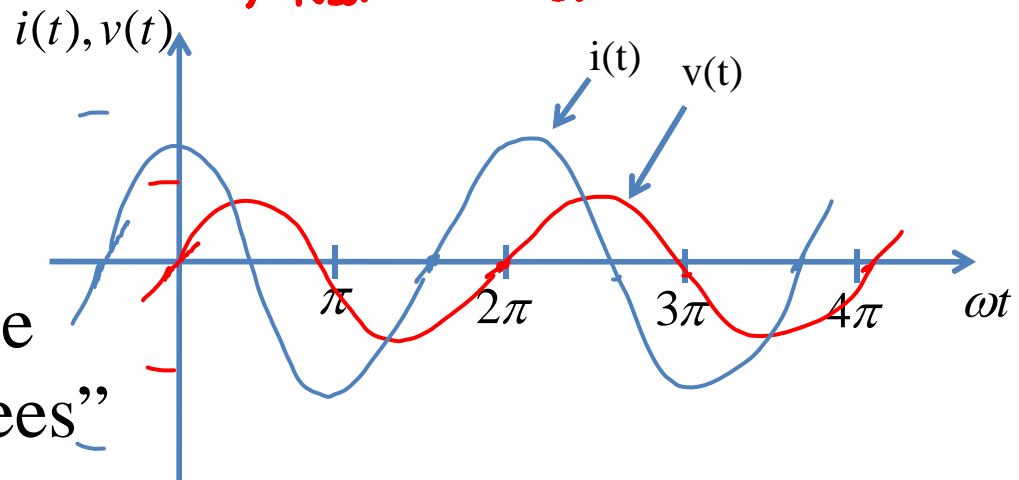
In general:

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

\uparrow \uparrow
 $= 0$ $\neq 0$

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

PROOF: EXERCISE

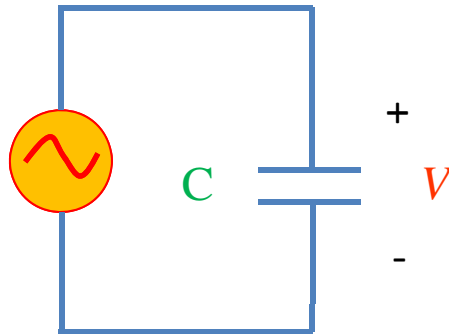


HW problem: Find relationship between phase shift and impedance (Z).

Example phasor problem

Find $i(t)$ (students)

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



Problem gives us:

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

Compare to definition of voltage phasor:

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

$$\Rightarrow \underline{V} = ? \quad (3) e^{j(30^\circ)}$$

\uparrow phasor
 \uparrow RADIANs
 \uparrow time dependence

Find current phasor using generalized Ohm's law:

$$\underline{I} = j\omega C \underline{V} = \dots \quad (10jC) e^{j30^\circ}$$

Find $i(t)$ from current phasor:

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

$$\begin{aligned}
 &= \text{Re}[10jC \cdot 3 e^{j30^\circ} e^{j\omega t}] = \\
 &= 10 \times 3 \times C \text{Re}[j e^{j30^\circ} e^{j\omega t}] = \\
 &= 10 \times 3 \times C \text{Re}[e^{j\frac{\pi}{2}} e^{j30^\circ} e^{j\omega t}] = \\
 &= 10 \times 3 \times C \text{Re}[e^{j\frac{\pi}{2}} e^{j\frac{\pi}{6}} e^{j\omega t}] = 30C \text{Re}[e^{j(\frac{2\pi}{3} + \omega t)}] \\
 &= 30C \cos\left[\omega t + \frac{2\pi}{3}\right] \checkmark
 \end{aligned}$$

TRICK:

$$j = e^{j\frac{\pi}{2}} = \frac{\cos\frac{\pi}{2} + j\sin\frac{\pi}{2}}{0 + j1} = j$$

TODAY!!!
 PHASOR CONSTANT
 IS DOES NOT
 DEPEND ON
 TIME

Trick #1

Euler

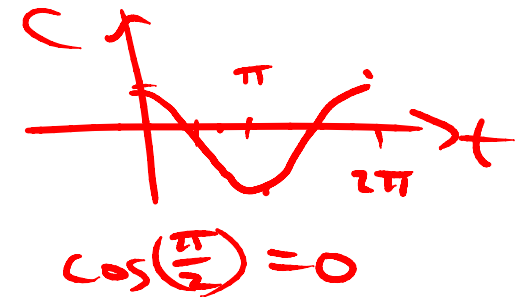
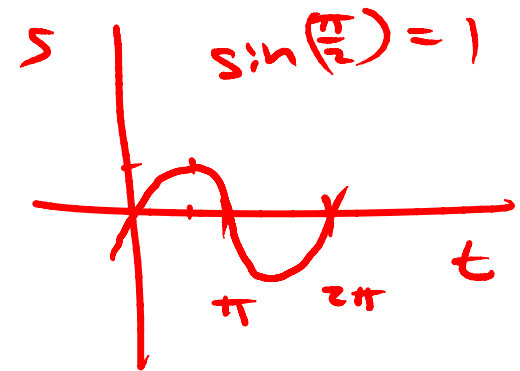
$$e^{j\theta} = \cos \theta + j \sin \theta$$

"Consider" $\theta = \frac{F}{2}$

$$e^{j \frac{F}{2}} = \cos \frac{F}{2} + j \sin \frac{F}{2}$$

$$= 0 + j(1) = j$$

$$\Rightarrow j = e^{j \frac{F}{2}}$$



Example problem #3

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

$V(t) = V_0 \cos(\omega t)$
 $V = V_0$
 $Z_{eq} = R + \frac{1}{j\omega C}$
 $V = Z_{eq} I \Rightarrow I = \frac{V}{Z_{eq}}$
 $i(t) = \text{Re} \left[I e^{j\omega t} \right] = \text{Re} \left[\frac{V}{Z_{eq}} e^{j\omega t} \right]$
 $= \text{Re} \left[\frac{V_0}{R + \frac{1}{j\omega C}} e^{j\omega t} \right] = \text{Re} \left[\frac{j\omega R C V_0}{R + j\omega R C} e^{j\omega t} \right]$
 $= \frac{V_0}{R} \frac{\omega R C}{\sqrt{1 + (\omega R C)^2}} \cos(\omega t + \tan^{-1} \frac{1}{\omega R C})$
 CASE 1: $\omega \rightarrow 0$ CASE 2: $\omega \rightarrow \infty$ $L = RC$ $\cos \omega t + j \sin \omega t$

$$i(t) = \text{Re} \left[\frac{1}{R} \frac{V_0 j\omega (R)}{1 + j\omega RC} e^{j\omega t} \right] = \frac{V_0}{R} \text{Re} \left[\frac{j\omega L}{1 + j\omega L} e^{j\omega t} \right]$$

want

$$\frac{j\omega L}{1 + j\omega L} \text{ as } r e^{j\phi}$$

$$\frac{1 - j\omega L}{(1 + j\omega L)(1 - j\omega L)} = \frac{1 - j\omega L}{1 + (\omega L)^2}$$

$$\frac{j\omega L}{1 + j\omega L} = \frac{j\omega L (1 - j\omega L)}{1 + (\omega L)^2} = \frac{j\omega L - (\omega L)^2}{1 + (\omega L)^2}$$

$$= \omega L \frac{\omega L + j}{1 + (\omega L)^2}$$

$$i(t) = \frac{V_0}{R} \text{Re} \left[\omega L \frac{\omega L + j}{1 + (\omega L)^2} e^{j\omega t} \right]$$

$$= \frac{V_0}{R} \frac{\omega L}{1 + (\omega L)^2} \text{Re} \left[(\omega L + j) e^{j\omega t} \right]$$

$$= \frac{V_0}{R} \frac{\omega L}{1 + (\omega L)^2} \text{Re} \left[\sqrt{(\omega L)^2 + 1} e^{j\phi} e^{j\omega t} \right]$$

$$\omega\tau + j = |\omega\tau + j| e^{j\phi} = \sqrt{(\omega\tau)^2 + 1} e^{j\phi}$$

$$\phi \equiv \tan^{-1} \frac{\text{Im}(\omega\tau + j)}{\text{Re}(\omega\tau + j)} \equiv \tan^{-1}\left(\frac{j}{\omega\tau}\right)$$

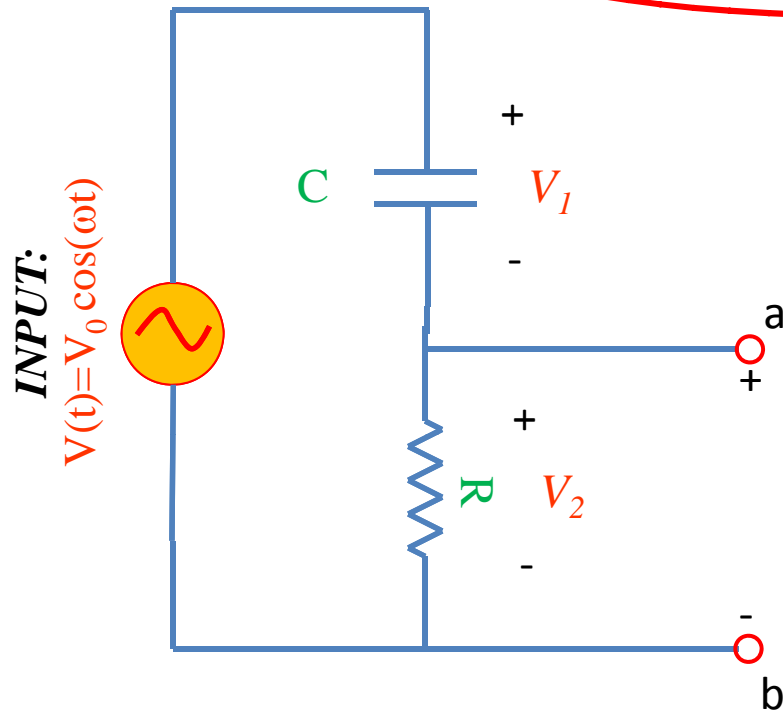
$$|\omega\tau + j| = \sqrt{(\omega\tau)^2 + 1}$$

$$i(t) = \frac{V_0}{R} \frac{\omega\tau}{\sqrt{1 + (\omega\tau)^2}} \text{Re} \left[e^{j\phi} e^{j\omega t} \right]$$

$$= \frac{V_0}{R} \frac{\omega\tau}{\sqrt{1 + (\omega\tau)^2}} \cos(\omega t + \phi)$$

$$\phi \equiv \tan^{-1}\left(\frac{j}{\omega\tau}\right)$$

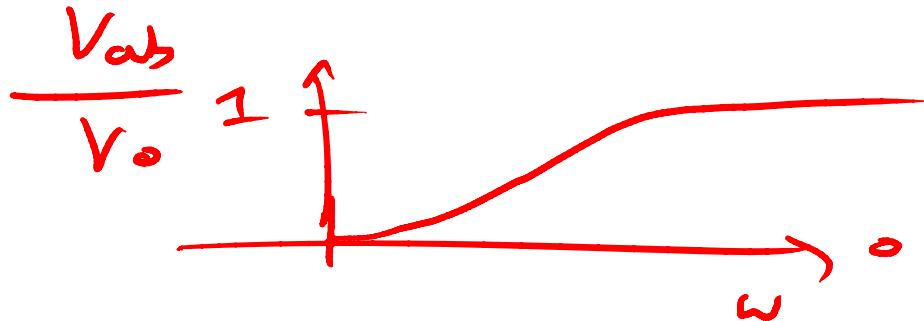
High pass filter



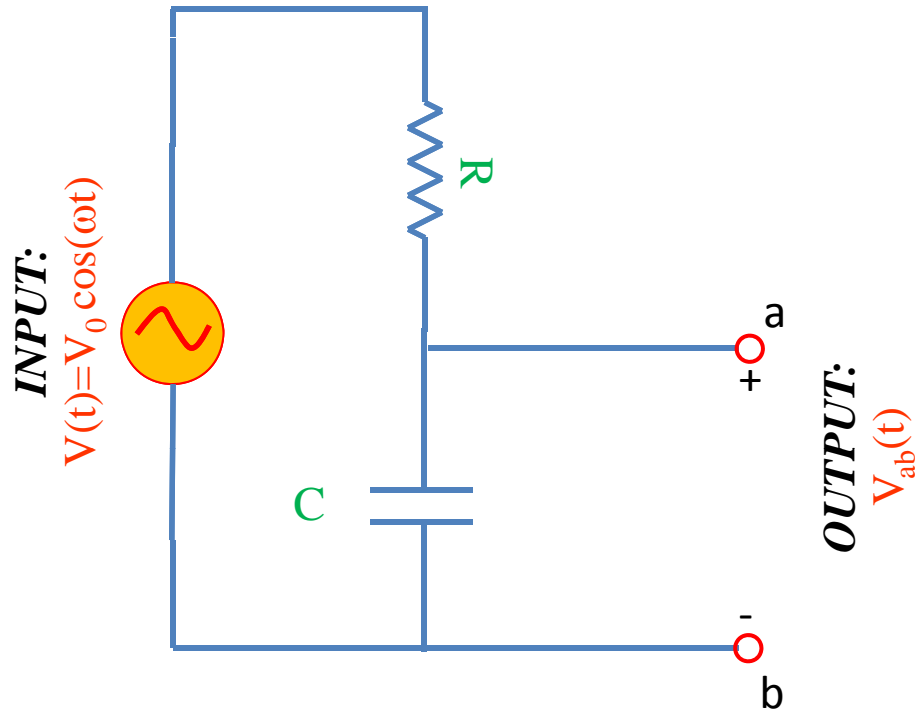
$$V_{ab}(t) = R i(t)$$

$$= R \frac{V_0}{R} \frac{\omega \tau}{\sqrt{1 + (\omega \tau)^2}} \cos(\omega t + \phi)$$

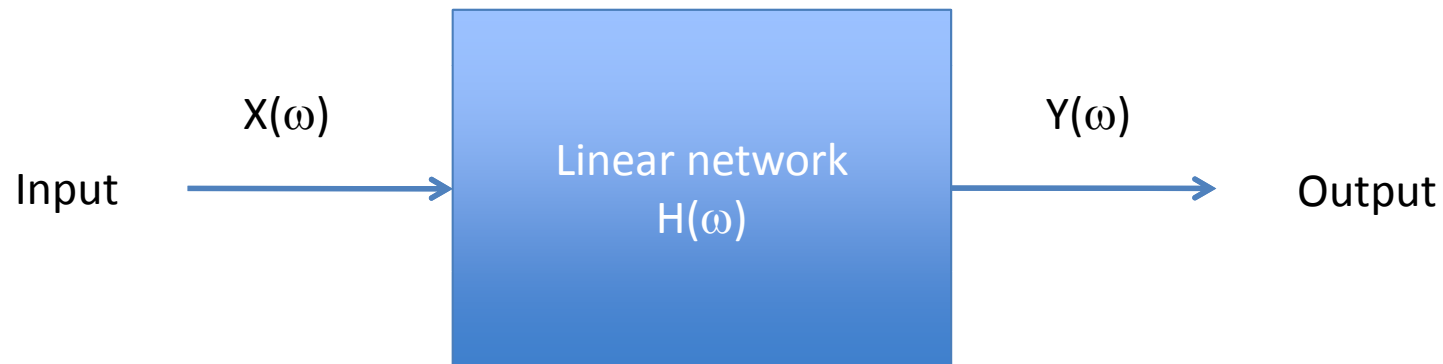
$$\frac{V_{ab}}{V_0} = \frac{\omega \tau}{\sqrt{1 + (\omega \tau)^2}} \cos(\omega t + \phi)$$



Low pass filter

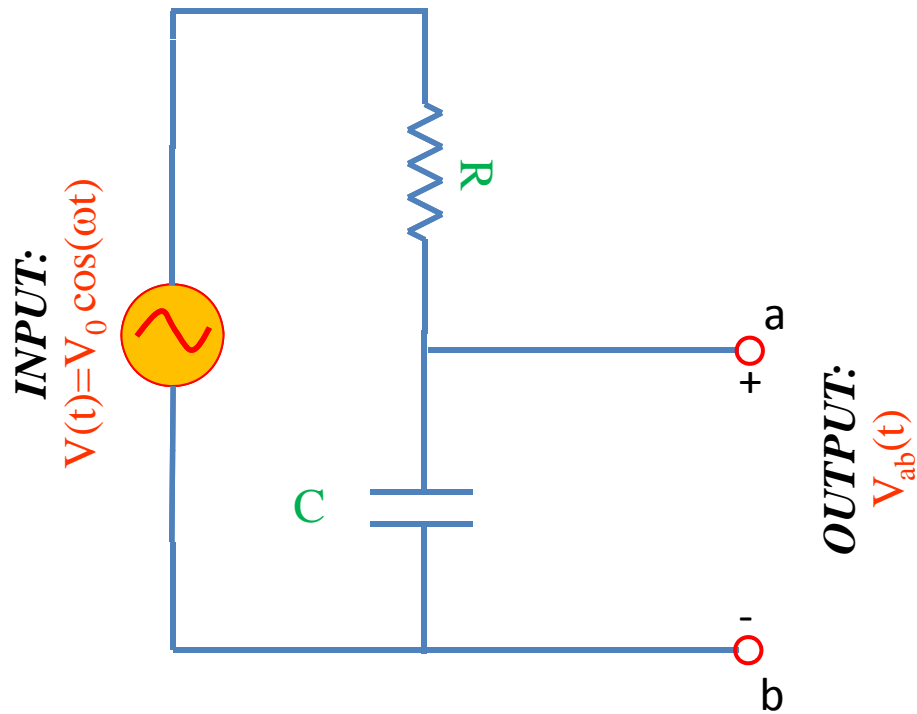


“Transfer function”



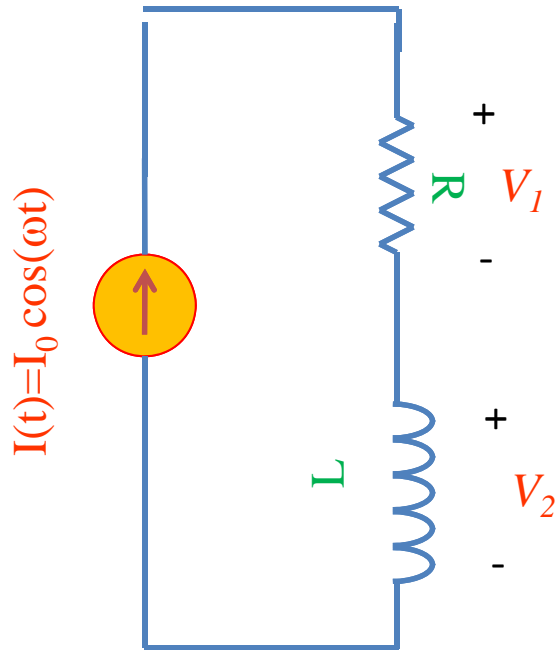
demo

RC transfer function

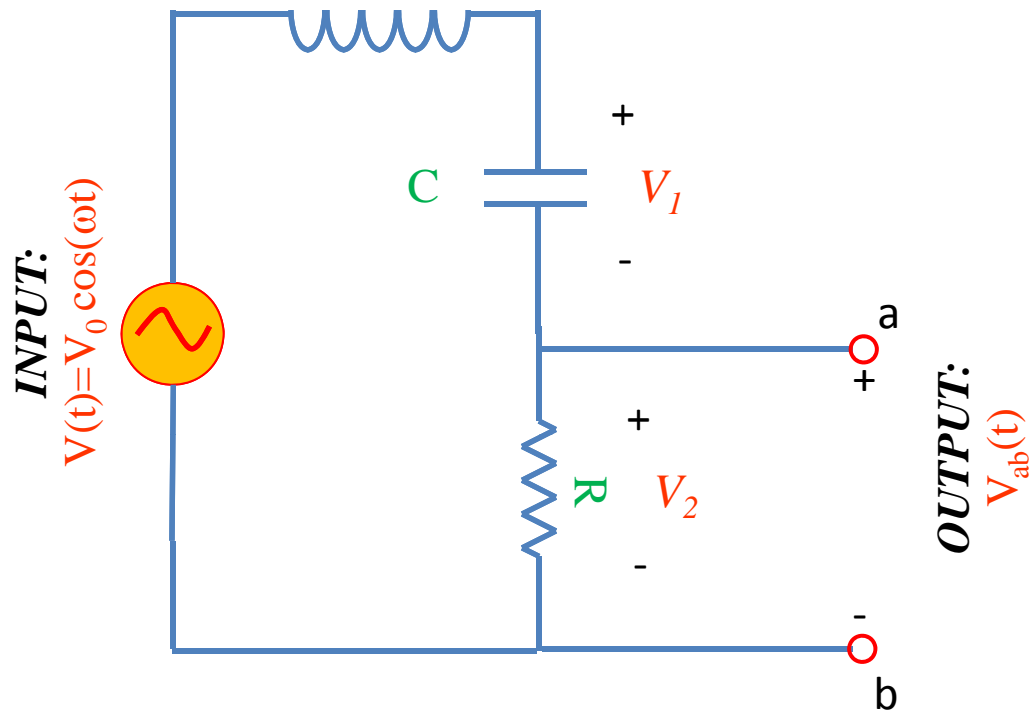


Example problem #4

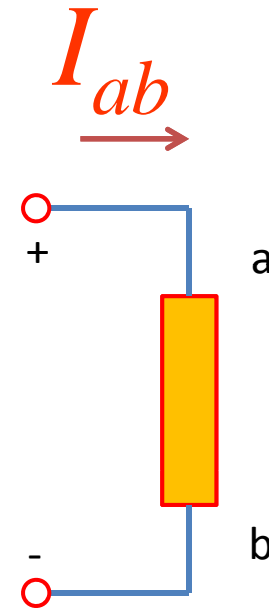
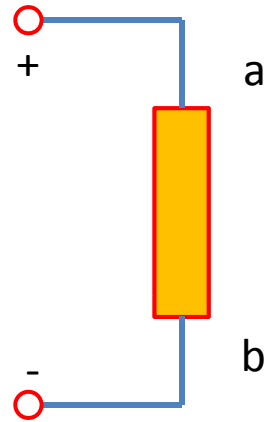
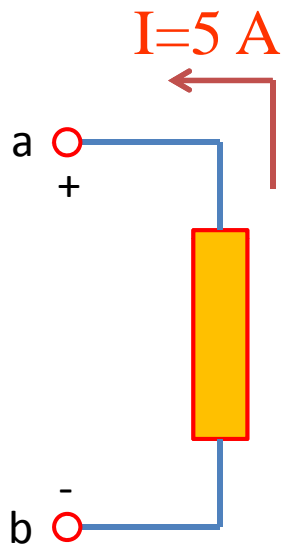
Find $i(t)$, $V_1(t)$, $V_2(t)$ for this circuit: (students)



Band pass filter (RLC)



Symbol library



Symbol library

