EE1C2 “Linear Circuits B”

Week 2.1

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Faculty of Electrical Engineering,
Mathematics and Computer Science

TU Delft

The EE1C2 team…

Wishes you a lot of success!!!


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Today

- Recapitulation of Q1
- New topics:
  - Sinusoidal voltages and currents
  - Phasors, phasor relations for R, L and C
  - Impedance, admittance
  - Analysis examples
  - Exam exercise example
- Summary of the day
- Next tasks

Recapitulation of Q1

- You became conversant in the full battery of circuit analysis methods
- You have a full dictionary of circuit elements: sources, resistances, capacitances, inductances and op amps
- Capacitances and inductances react to changes in circuits → you examined transients in first- and second-order circuits (transition from a steady-state to another steady-state)
- But what will happen if (smooth) change ***is*** the steady-state?

Sinusoidal voltages and currents

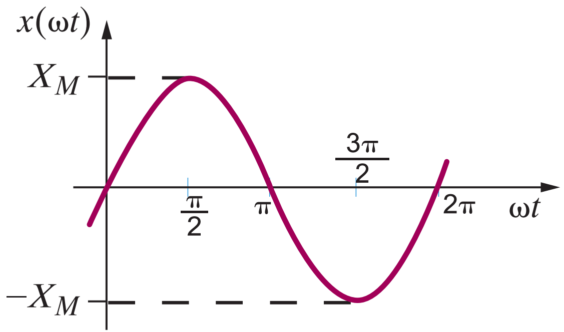
Sinusoids / sinusoidal functions

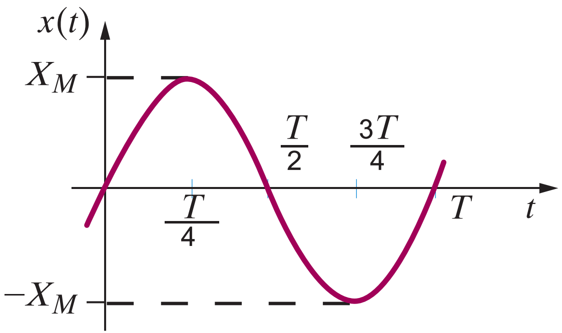
- Sinusoidal function

$$x(t) = X_M \sin \omega t \qquad\qquad x[\omega(t+T)] = x(\omega t)$$

  - X_{M} = the amplitude
  - ω = the angular frequency ⟶ ωt = the argument

- The plot as a function of ωt or as a function of t



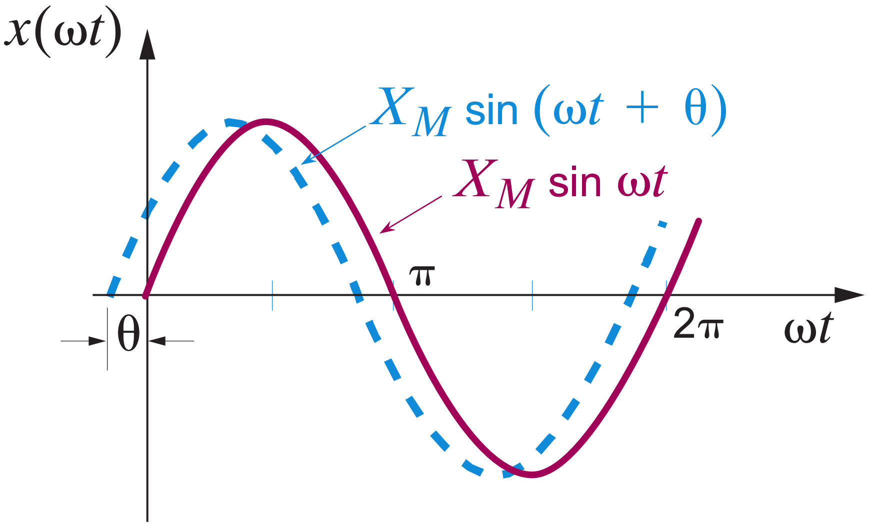


Sinusoids / sinusoidal functions

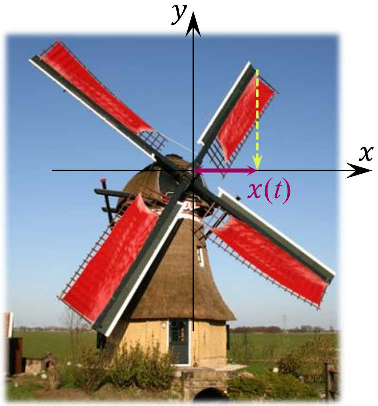
- Basic features: (angular) frequency $f = \dfrac{1}{T} \longrightarrow \omega = \dfrac{2\pi}{T} = 2\pi f$

- Phase (argument):

$$x(t) = X_M \sin(\underbrace{\omega t + \theta}_{\text{phase}})$$



Sinusoids / sinusoidal functions

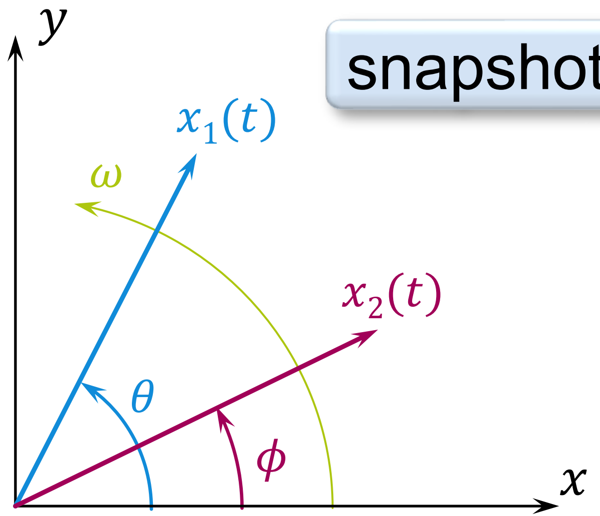


- Important:

$$x_1(t) = X_M \sin(\omega t + \theta) \qquad x_2(t) = X_M \sin(\omega t + \phi)$$

snapshot!

- Assume that $\theta > \phi$; we say that:
  - x_1 leads x_2 by $\theta - \phi$ radians
  - x_2 lags x_1 by $\phi - \theta$ radians



$\sin(\omega t) = \cos(\omega t - \pi/2)$

$$a\cos(\omega t) + b\sin(\omega t) = \frac{a}{\cos(\theta)}\cos(\omega t - \theta)$$

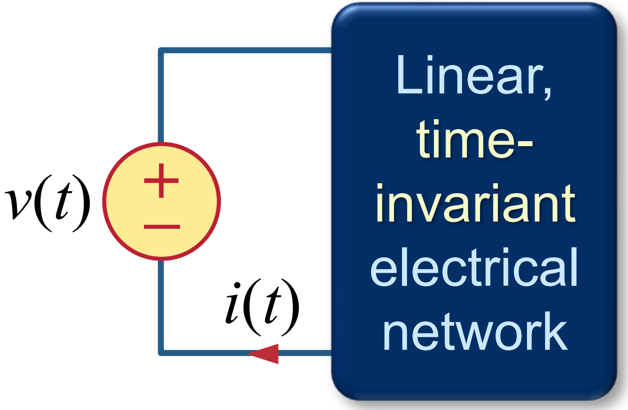
with $\theta = \arctan(b/a)$, $(a \neq 0)$ …more in the book

Sinusoidal and complex sources

- The steady-state voltages and currents in circuits fed by sinusoidal sources are themselves sinusoidal

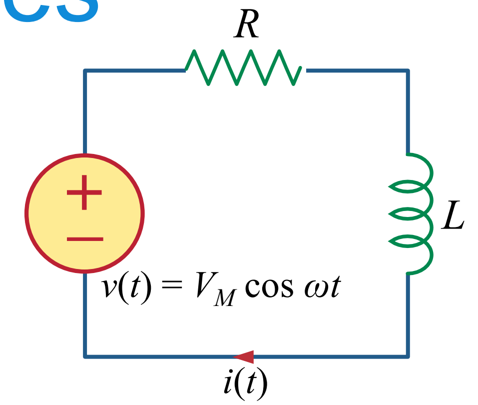
Consequence of KVL and KCL

- If $v(t) = A\sin(\omega t + \theta)$
  then the current must be of the form
  $i(t) = B\sin(\omega t + \phi)$



The basis for analysing steady-state AC circuits

Sinusoidal and complex sources



- Example: RL circuit:

  differential equation: $L\frac{di(t)}{dt} + Ri(t) = V_M \cos \omega t$

$$i(t) = \frac{V_M}{\sqrt{R^2 + \omega^2 L^2}} \cos\left(\omega t - \tan^{-1}\frac{\omega L}{R}\right)$$

- Phase shift:
  - if $L = 0$ → $i(t)$ is in phase with $v(t)$
  - if $R = 0$ → $i(t)$ lags behind $v(t)$ by 90°
  - if L and R are both non-zero → $i(t)$ lags behind $v(t)$ by a value between 0° and 90°

Sinusoidal and complex sources

- It is abundantly clear: even a simple RL circuit involves a lot of work

- This can be simpler!

  via the relation between sinusoidal functions and complex functions

- Euler relation:

$$e^{j\omega t} = \cos\omega t + j\sin\omega t = \mathrm{Re}\left\{e^{j\omega t}\right\} + j\,\mathrm{Im}\left\{e^{j\omega t}\right\}$$

Leonhard Euler
15 April 1707 –
18 September 1783

Sinusoidal and complex sources

- Assume a non-physical voltage source $v(t) = V_M e^{j\omega t}$

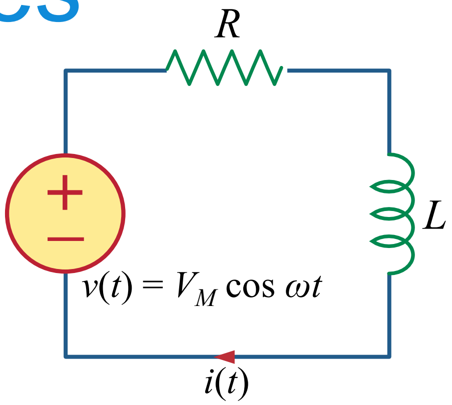
$$v(t) = V_M \cos \omega t + jV_M \sin \omega t$$

- The current response can be written by making use of linearity and superposition

$$i(t) = I_M \cos(\omega t + \phi) + jI_M \sin(\omega t + \phi)$$

- And thus: $i(t) = I_M e^{j(\omega t + \phi)}$

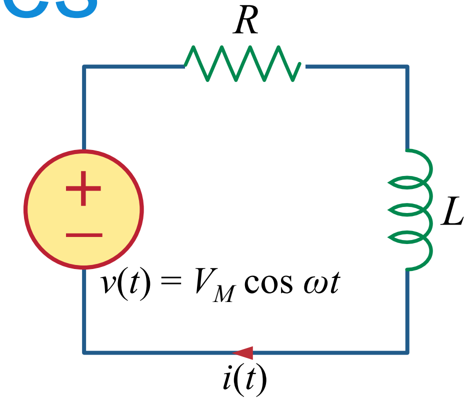
Sinusoidal and complex sources



Is this really easier?

- Assume again $L\dfrac{di(t)}{dt} + Ri(t) = V_M \cos \omega t$
- We now apply $V_\mathrm{M} e^{j\omega t}$ instead of $V_\mathrm{M}\cos(\omega t)$
- The current response must be of the form $i(t) = I_M e^{j(\omega t+\phi)}$

Sinusoidal and complex sources



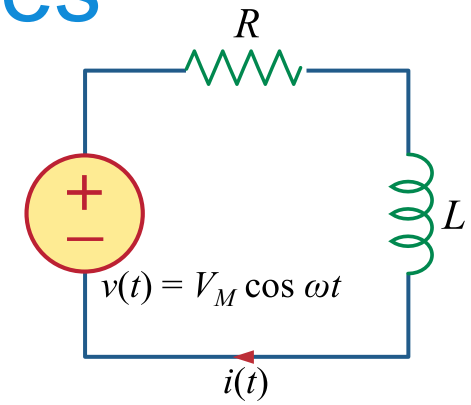
- By filling in the quantities in the differential equation $L\frac{di(t)}{dt}+Ri(t)=V_M\cos\omega t$

$$I_M e^{j(\omega t+\phi)} \qquad V_M e^{j\omega t}$$

- It is found that:

$$j\omega L I_M e^{j(\omega t+\phi)}+RI_M e^{j(\omega t+\phi)}=V_M e^{j\omega t}$$

Sinusoidal and complex sources



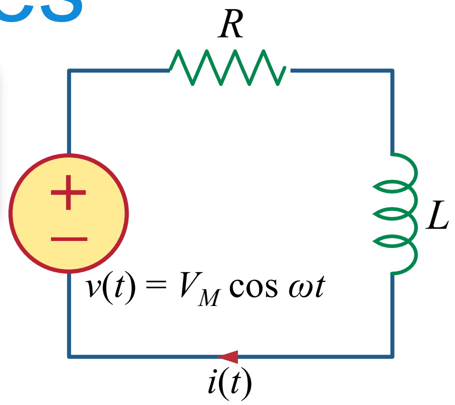
- Divide by $e^{j\omega t}$ → $j\omega L I_M e^{j\phi} + R I_M e^{j\phi} = V_M$

  and do the algebra → $I_M e^{j\phi} = \dfrac{V_M}{R + j\omega L}$

- Express the complex result in polar coordinates:

$$I_M e^{j\phi} = \frac{V_M}{\sqrt{R^2 + \omega^2 L^2}} e^{j\left[-\tan^{-1}(\omega L / R)\right]}$$

Sinusoidal and complex sources



- Thus $I_M = \dfrac{V_M}{\sqrt{R^2 + \omega^2 L^2}}$ & $\phi = -\tan^{-1} \dfrac{\omega L}{R}$
- But $I_M e^{j\phi} = \dfrac{V_M}{\sqrt{R^2 + \omega^2 L^2}} e^{j\left[-\tan^{-1}(\omega L / R)\right]}$

  is complex ⟶ non-physical!
- We put back the $e^{j\omega t}$ part and take the real part of the result

$$i(t) = I_M \cos(\omega t + \phi) = \frac{V_M}{\sqrt{R^2 + \omega^2 L^2}} \cos\left(\omega t - \tan^{-1} \frac{\omega L}{R}\right)$$

Phasors

Phasors

- We observed that $e^{j\omega t}$ occurs overall without itself changing
  - we can ignore this term and only keep in mind the frequency
  - we then carry on in terms of the magnitude and phase, only
- We write $v(t) = V_M \cos(\omega t + \theta) = \mathrm{Re}\left[V_M e^{j(\omega t + \theta)}\right]$

  as $v(t) = \mathrm{Re}\left(V_M \angle \theta \;\; e^{j\omega t}\right)$ and ignore (for now) $e^{j\omega t}$

The direct phasor transform

$V_M \angle \theta$

Phasors

- Phasors are usually typeset as boldface letters $\mathbf{V} = V_M \angle \theta$
- The differential equation in the example

$$L\frac{di(t)}{dt} + Ri(t) = V_M \cos \omega t \xrightarrow[\text{substitution}]{\text{formal}} L\frac{d}{dt}\left(\mathbf{I} e^{j\omega t}\right) + R\mathbf{I} e^{j\omega t} = \mathbf{V} e^{j\omega t}$$

becomes after dividing by $e^{j\omega t}$: $j\omega L\mathbf{I} + R\mathbf{I} = \mathbf{V}$

- Rules for operating with phasors:
  - derivative: $\mathrm{d}/\mathrm{dt} \longrightarrow (\mathrm{j}\omega)$
  - integral: $\int ...\mathrm{dt} \longrightarrow (1/\mathrm{j}\omega)$

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Phasors

- Applying these rules entails that

$$\mathbf{I} = \frac{\mathbf{V}}{j\omega L + R} = I_M \angle \phi = \frac{V_M}{\sqrt{R^2 + \omega^2 L^2}} \angle - \tan^{-1} \frac{\omega L}{R}$$

- The real current can then be expressed as

$$i(t) = \frac{V_M}{\sqrt{R^2 + \omega^2 L^2}} \cos\left(\omega t - \tan^{-1} \frac{\omega L}{R} \right)$$

The inverse phasor transform

Phasors

- Summarising:
  - at a first glance, this method seems more intricate
  - but it allows replacing differential equations by algebraic equations that are clearly easier to handle
- Algorithm:
  1) Write the differential equations and transform them into algebraic ones by making use of phasors and the derivative/integral rules
  2) Solve the algebraic equations
  3) Transform the derived phasors back to the time-domain

Phasors

- Summarising
  - at a first glanc
  - but it allows r
    that are clear
- Algorithm:
  1) Write the di
     ones by ma
  2) Solve the a
  3) Transform t

COMPLEX QUANTITIES AND THEIR USE IN ELECTRICAL ENGINEERING.

BY CHAS. PROTEUS STEINMETZ.

I.—INTRODUCTION.

In the following, I shall outline a method of calculating alternate current phenomena, which, I believe, differs from former methods essentially in so far, as it allows us to represent the alternate current, the sine-function of time, by a *constant* numerical quantity, and thereby eliminates the independent variable "time" altogether from the calculation of alternate current phenomena. Herefrom results a considerable simplification of methods.

C.P. Steinmetz, "Complex quantities and their use in electrical engineering," 1893

Phasors

- Summarising:

A (not so) small detail concerning the phasor electrical quantities $\mathbf{V} = V_\mathrm{M}\,\angle\theta_v$ and $\mathbf{I} = I_\mathrm{M}\,\angle\theta_i$

- V_M, I_M = magnitudes (amenable to measurement)
- θ_v, θ_i = phases (actually, time delays)
- the combination of the two = a complex number

Assigning a measure unit to a phasor (or any complex number) makes no physical sense! (still, it is often done…)

Phasor relations

- We now want to deal with circuits by using phasors
- We also want to establish in this way relations between R, L and C

Phasor relations

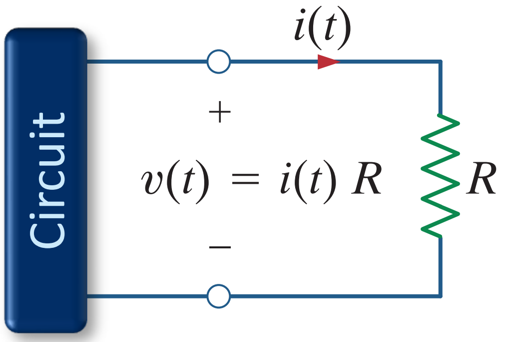
- Resistances: $v(t) = Ri(t)$

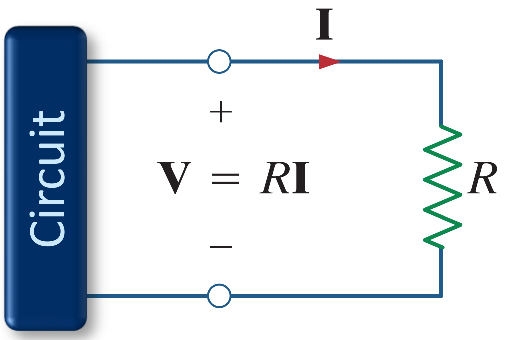
$$V_M e^{j(\omega t+\theta_v)} = RI_M e^{j(\omega t+\theta_i)}$$

$$V_M e^{j\theta_v} = RI_M e^{j\theta_i}$$

- In phasor form: $\mathbf{V} = R\mathbf{I}$

$$\mathbf{V} = V_M e^{j\theta_v} = V_M \angle \theta_v \qquad \mathbf{I} = I_M e^{j\theta_i} = I_M \angle \theta_i$$



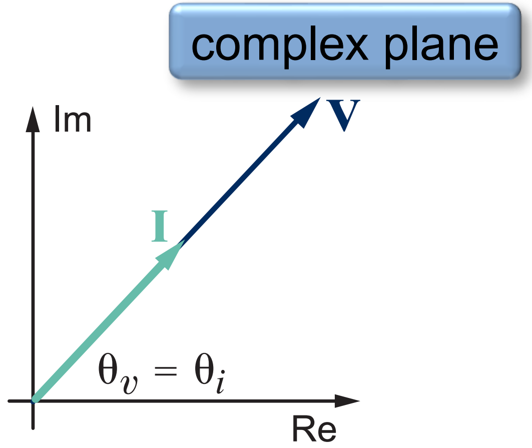


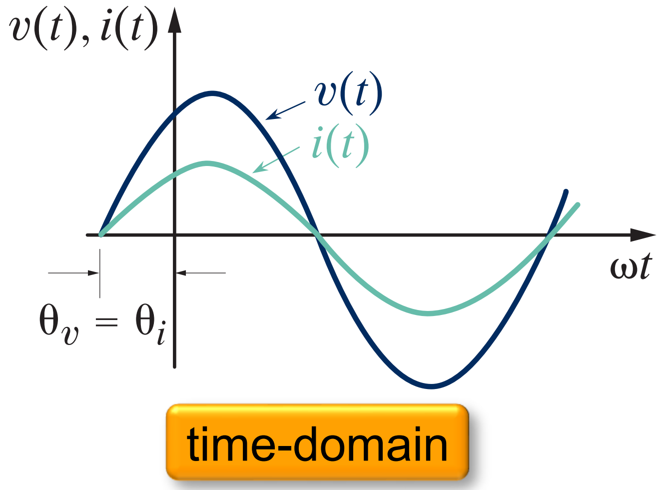
Phasor relations

$$\mathbf{V} = R\mathbf{I} \;\; (\mathbf{V} = V_M e^{j\theta_v} = V_M \angle \theta_v ,\;\; \mathbf{I} = I_M e^{j\theta_i} = I_M \angle \theta_i \;)$$

- The phases θ_v and θ_i are equal →
  V and I are "in phase"

- This can be cast into a phasor diagram
  - amplitude ratios
  - phase shifts
  - which phasor leads or lags?





Phasor relations

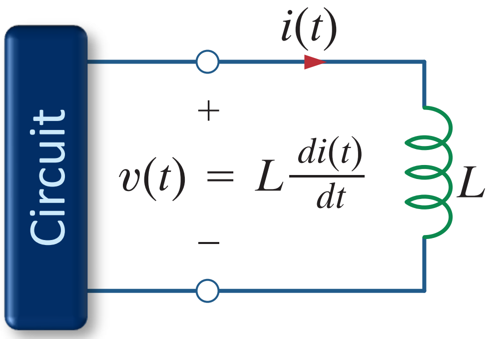
- Inductances: $v(t) = L\frac{di(t)}{dt}$
- Again, the same steps:

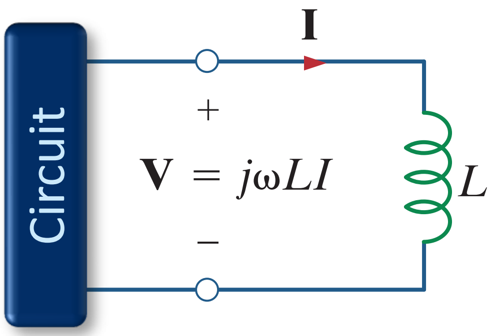
$$V_M e^{j(\omega t+\theta_v)} = L\frac{d}{dt} I_M e^{j(\omega t+\theta_i)}$$

$$\Downarrow$$

$$V_M e^{j\theta_v} = j\omega L I_M e^{j\theta_i}$$

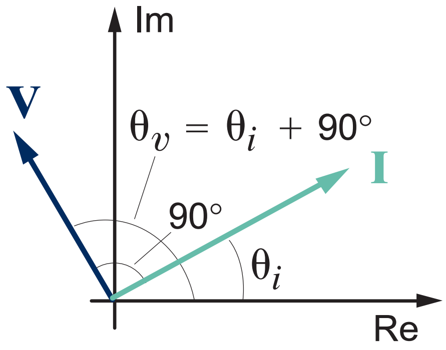
$$\mathbf{V} = j\omega L\mathbf{I}$$

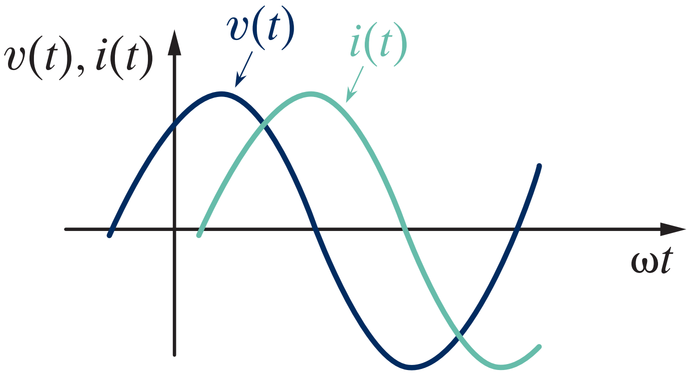




Phasor relations

- For j it holds that $j = 1e^{j90°} = 1\angle 90°$
- $V_M e^{j\theta_v} = j\omega L I_M e^{j\theta_i}$ then becomes $V_M e^{j\theta_v} = \omega L I_M e^{j(\theta_i + 90°)}$
- The voltage thus leads the current by 90°





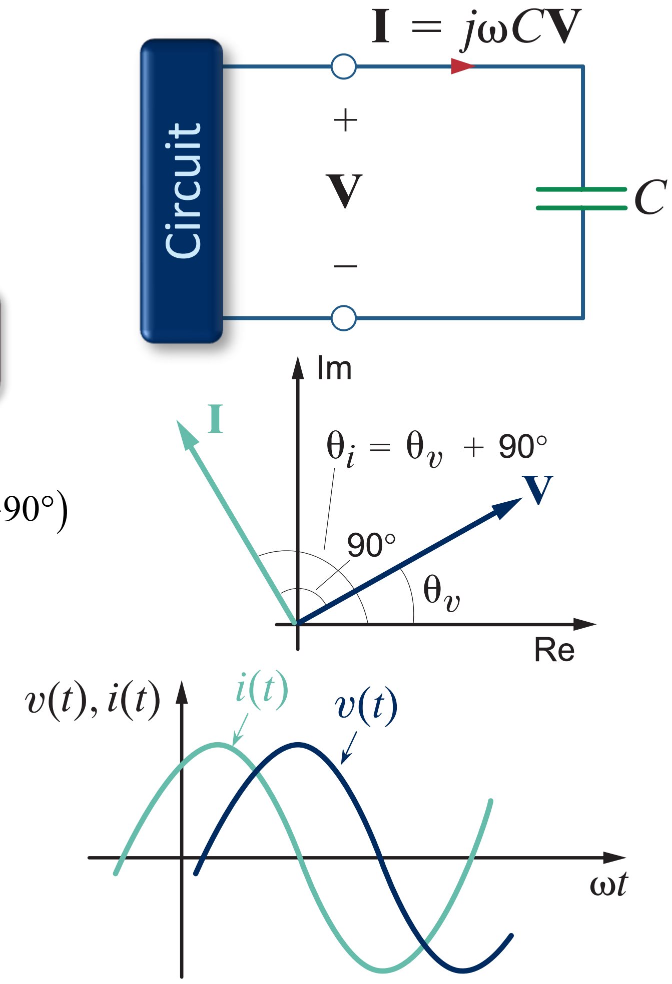
Phasor relations

- Capacities: similar derivation

$$I_M e^{j\theta_i} = j\omega C V_M e^{j\theta_v} \longrightarrow \boxed{\mathbf{I} = j\omega C\mathbf{V}}$$

- Here, it holds that $I_M e^{j\theta_i} = \omega C V_M e^{j(\theta_v + 90°)}$

- The current thus leads the voltage by 90°



Phasors ⟷ phasor transform

- Sinusoidal feeding ⟶ sinusoidal response
- The term $e^{j\omega t}$ occurs in all equations without changing
  - we ignore this term and only keep in mind the frequency
  - calculations are done for the magnitude and phase, only
- We then write:

Direct phasor transform

$$v(t) = V_M \cos(\omega t + \theta) = \mathrm{Re}\left[V_M e^{j(\omega t + \theta)}\right] = \mathrm{Re}\left(V_M \angle \theta \cdot e^{j\omega t}\right)$$

Inverse phasor transform

Phasors ⟷ phasor transform

- Sinusoidal feeding ⟶ sinusoidal response
- The term $e^{j\omega t}$ occurs in all equations without changing

The phasor transform applies to time-depending quantities, only

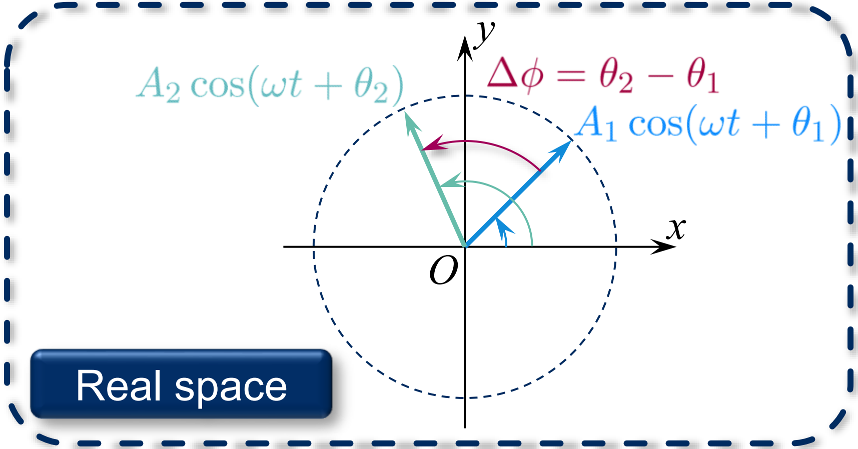
- We then write:

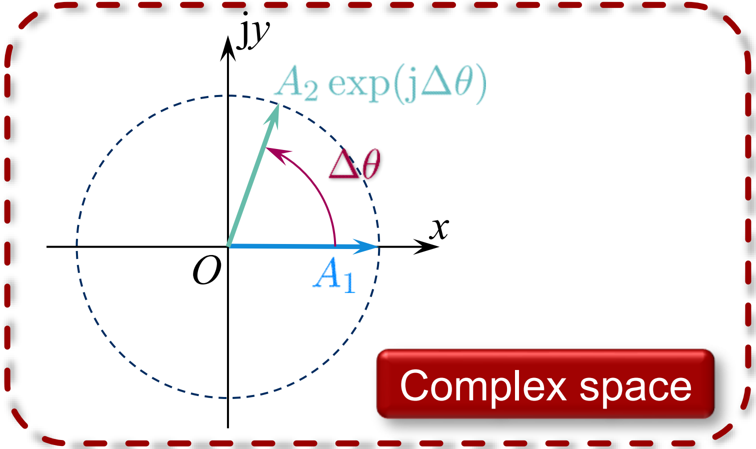
Direct phasor transform

$$v(t) = V_M \cos(\omega t + \theta) = \mathrm{Re}\left[V_M e^{j(\omega t+\theta)}\right] = \mathrm{Re}\left(V_M \angle \theta \cdot e^{j\omega t}\right)$$

Inverse phasor transform

Phasors ⟷ phasor transform





No complex value (no j)

No ωt

Impedances

Impedances and admittances

- Impedance = an analogous of the time-domain resistance that is valid in the frequency-domain

$$\mathbf{Z} = \frac{\mathbf{V}}{\mathbf{I}}$$

- Since V and I are both complex → Z is also complex

$$\mathbf{Z} = \frac{V_M \angle \theta_v}{I_M \angle \theta_i} = \frac{V_M}{I_M} \angle \theta_v - \theta_i = Z \angle \theta_z$$

- The measure unit of $Z = |\mathbf{Z}|$ is ohm

Impedances and admittances

- In Cartesian coordinates, the impedance reads

$$\mathbf{Z}(\omega) = R(\omega) + jX(\omega)$$

  with $R(\omega)$ being the resistive component (real part) and $X(\omega)$ the reactive component (imaginary part)

- $R(\omega)$ and $X(\omega)$ are real functions of ω → $\boldsymbol{Z}$ is also a function of ω

- $\boldsymbol{Z}$ is not a phasor → the phasor transform applies to time-dependent quantities, whereas $\boldsymbol{Z}$ is a ratio (a constant)

Impedances and admittances

- Impedance parameters:

$$Z\angle\theta_z = R + jX \longrightarrow Z = \sqrt{R^2 + X^2} \ \& \ \theta_z = \tan^{-1}\frac{X}{R}$$

- Impedances (AC) ⟷ Resistances (DC) ⟶ for series and parallel impedances it holds that

$$\mathbf{Z}_\mathrm{S} = \mathbf{Z}_1 + \mathbf{Z}_2 + \mathbf{Z}_3 + \mathbf{Z}_4 + \ldots + \mathbf{Z}_\mathrm{n}$$

$$\frac{1}{\mathbf{Z}_\mathrm{P}} = \frac{1}{\mathbf{Z}_1} + \frac{1}{\mathbf{Z}_2} + \frac{1}{\mathbf{Z}_3} + \frac{1}{\mathbf{Z}_4} + \ldots + \frac{1}{\mathbf{Z}_\mathrm{n}}$$

Impedances and admittances

By accounting for phasor relations, resistances, inductances and capacities entail the following impedances

Element	Phasor Equation	Impedance
R	$\mathbf{V} = R\mathbf{I}$	$\mathbf{Z} = R$
L	$\mathbf{V} = j\omega L\mathbf{I}$	$\mathbf{Z} = j\omega L$
C	$\mathbf{V} = \frac{1}{j\omega C}\mathbf{I}$	$\mathbf{Z} = \frac{1}{j\omega C}$

Impedances and admittances

- The resistance's inverse is the conductance → the impedance's inverse is the admittance

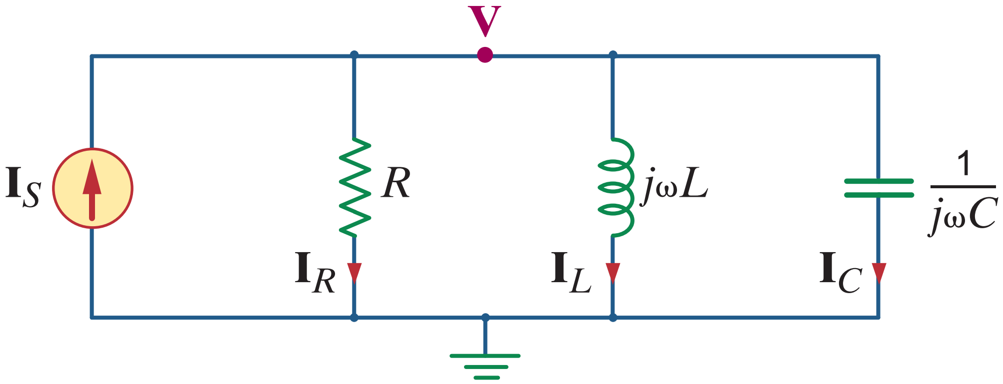
$$\mathbf{Y} = \frac{1}{\mathbf{Z}} = \frac{\mathbf{I}}{\mathbf{V}}$$

  – the measure unit of $Y = |\boldsymbol{Y}|$ is siemens
  – it is spilt-up as $\boldsymbol{Y} = Y\angle\theta_y = G + \mathrm{j}B$ in which $G(\omega)$ is the conductance and $B(\omega)$ is the susceptance

- The same rules for series/parallel connections hold

Phasor diagrams

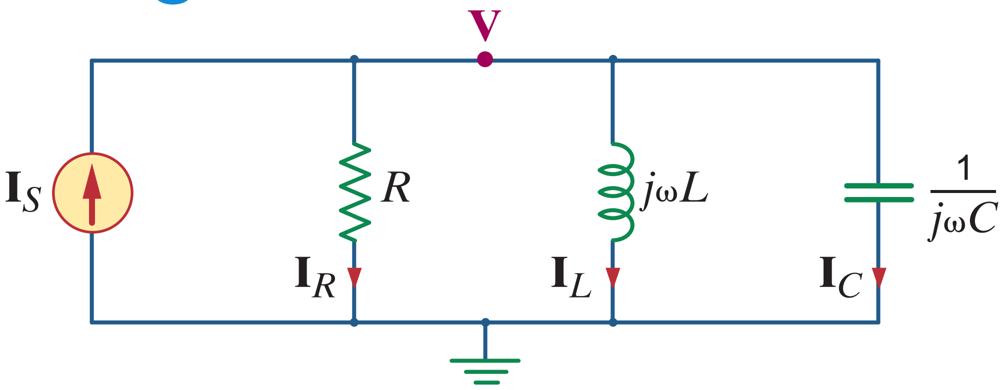
- Impedances and admittances are frequency dependent → so are the voltage ↔ current relations in the network



- For the upper node it holds via KCL:

$$\mathbf{I}_S = \mathbf{I}_R + \mathbf{I}_L + \mathbf{I}_C = \frac{\mathbf{V}}{Z_R} + \frac{\mathbf{V}}{Z_L} + \frac{\mathbf{V}}{Z_C} = \frac{\mathbf{V}}{R} + \frac{\mathbf{V}}{j\omega L} + \frac{\mathbf{V}}{1/\,j\omega C}$$

Phasor diagrams



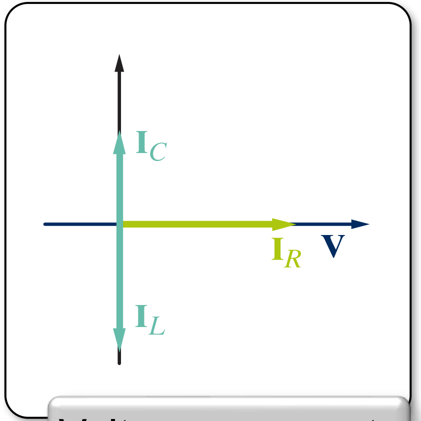
$$\mathbf{V} = V_M \angle 0°$$

- We take: $\boldsymbol{V} = V_\mathrm{M} \angle 0°$ (origin of the phase)
- It then follows that: $\mathbf{I}_S = \dfrac{V_M \angle 0°}{R} + \dfrac{V_M \angle -90°}{\omega L} + V_M \omega C \angle 90°$

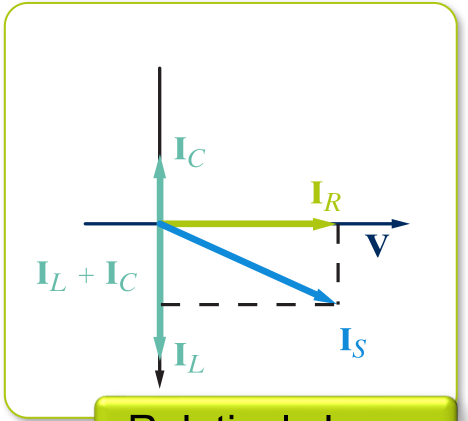
Phasor diagrams

$$\mathbf{I}_S = \frac{V_M\angle 0^\circ}{R} + \frac{V_M\angle -90^\circ}{\omega L} + V_M \omega C \angle 90^\circ$$

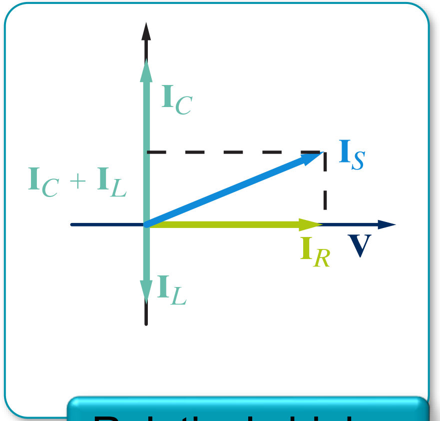
- This can be represented graphically as phasor diagrams



Voltages, currents



Relatively low ω



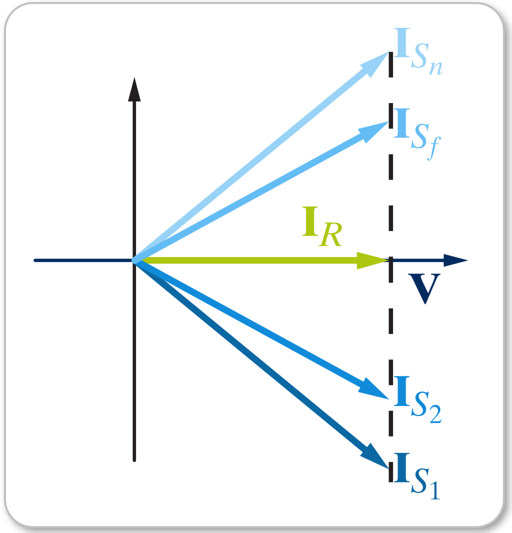
Relatively high ω

Phasor diagrams

$$\mathbf{I}_S = \frac{V_M \angle 0°}{R} + \frac{V_M \angle -90°}{\omega L} + V_M \omega C \angle 90°$$

- As frequency increases, $\boldsymbol{I}_{\mathrm{S}}$ moves from bottom to the top
- When $\boldsymbol{I}_C = \boldsymbol{I}_L$, then $\boldsymbol{I}_{\mathrm{S}}$ and $\boldsymbol{V}$ are in phase
  - this occurs at $\omega = \frac{1}{\sqrt{LC}}$
  - this can also be derived from KCL

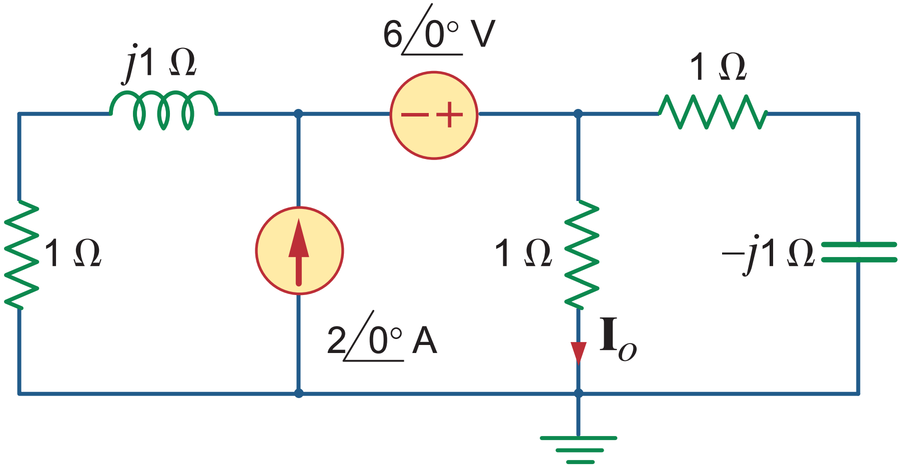
$$\mathbf{I}_S = \left[\frac{1}{R} + j\left(\omega C - \frac{1}{\omega L}\right)\right]\mathbf{V}$$



Examples

Example 1

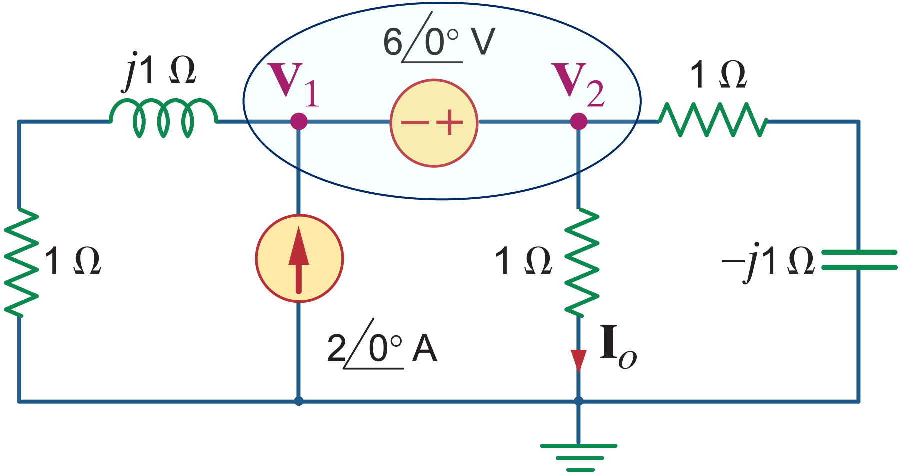
Consider the circuit at the right. Determine I_o.



- Preliminaries:
  - sources transformed to the phasor domain (extract ω, the two sources are in phase)
  - calculate the values of the impedances: $R \rightarrow R$, $L \rightarrow \mathrm{j}\omega L$, $C \rightarrow 1/\mathrm{j}\omega C = -\mathrm{j}/\omega C$
  - these operations are part of the exercise!

Example 1

Consider the circuit at the right. Determine I_o.



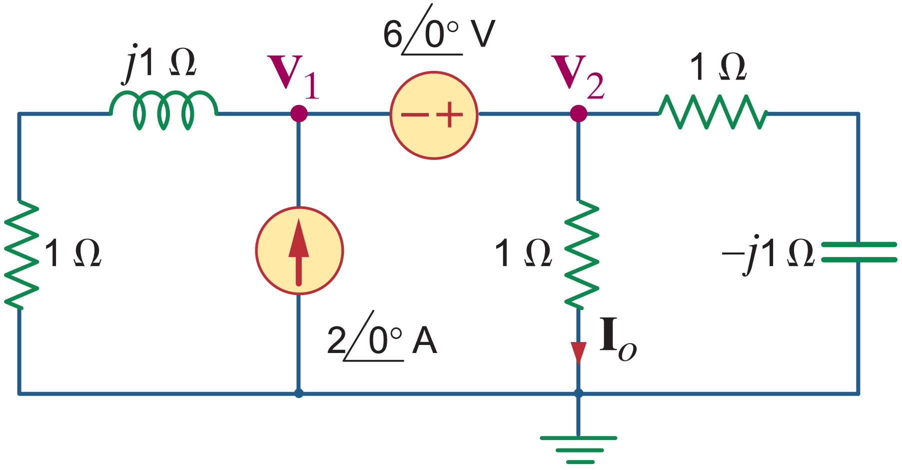
- One can opt for various solution techniques

  choice: nodal analysis

- Super-node: $\dfrac{\mathbf{V}_1}{1+j} - 2\angle 0° + \dfrac{\mathbf{V}_2}{1} + \dfrac{\mathbf{V}_2}{1-j} = 0$ & $\mathbf{V}_1 + 6\angle 0° = \mathbf{V}_2$

- Substitution: $\dfrac{\mathbf{V}_2 - 6\angle 0°}{1+j} - 2\angle 0° + \mathbf{V}_2 + \dfrac{\mathbf{V}_2}{1-j} = 0$

Example 1



- Algebraic manipulation:

$$\frac{\mathbf{V}_2 - 6\angle 0°}{1+j} - 2\angle 0° + \mathbf{V}_2 + \frac{\mathbf{V}_2}{1-j} = 0$$

$$\mathbf{V}_2\left[\underbrace{\frac{1}{1+j} + 1 + \frac{1}{1-j}}_{=2}\right] = \frac{6+2+2j}{1+j}$$

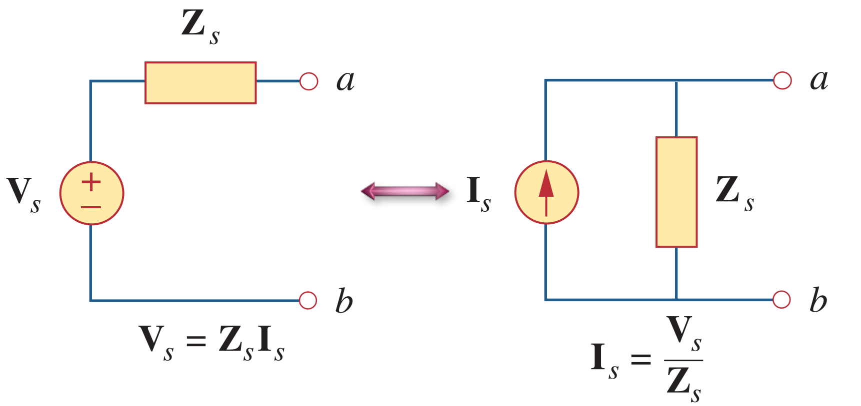
  – this entails: $\mathbf{V}_2 = \left(\frac{4+j}{1+j}\right)$

- Thus: $\mathbf{I}_o = \left(\frac{4+j}{1+j}\right) = \frac{\sqrt{4^2+1^2}}{\sqrt{1^2+1^2}}\angle\left(\tan^{-1}\tfrac{1}{4} - \tan^{-1}\tfrac{1}{1}\right) = \sqrt{8.5}\angle -31°$ (A)

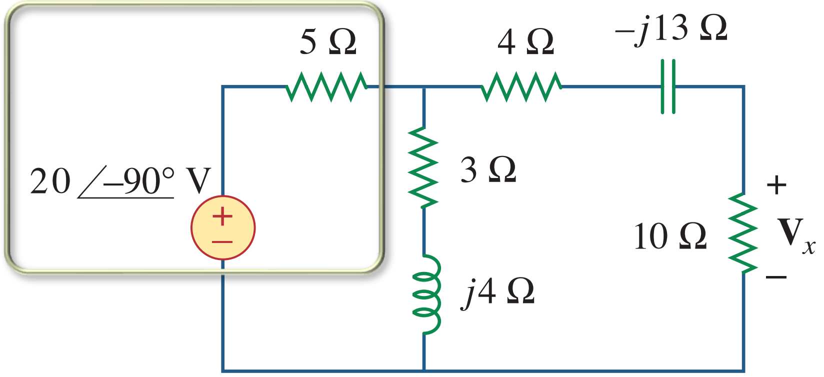
Example 2

- Source transformation

$$\mathbf{V}_s = \mathbf{Z}_s\mathbf{I}_s \longleftrightarrow \mathbf{I}_s = \frac{\mathbf{V}_s}{\mathbf{Z}_s}$$



- Consider the circuit at the right. Determine $\boldsymbol{V}_{\text{x}}$.



- Source transformation: $\boldsymbol{V}_{\text{s}} \rightarrow \boldsymbol{I}_{\text{s}}$

$$\mathbf{I}_s = \frac{20\angle{-90^\circ}}{5} = 4\angle{-90^\circ} = -j4\ \text{A}$$

Example 2

- Parallel impedances:

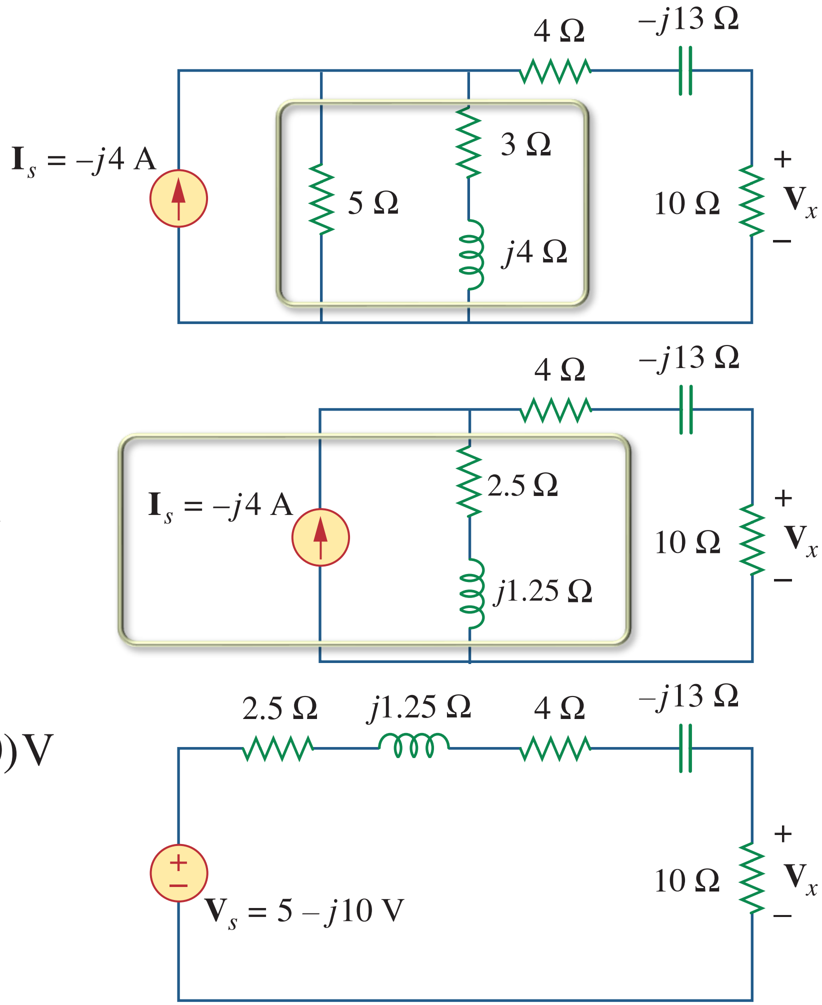
$$\mathbf{Z}_1 = \frac{5(3 + j4)}{8 + j4} = 2.5 + j1.25\ \Omega$$

- Back to Thévenin: $\boldsymbol{V}_\mathrm{s} \rightarrow \boldsymbol{I}_\mathrm{s}$

$$\mathbf{V}_s = \mathbf{I}_s\mathbf{Z}_1 = -j4(2.5 + j1.25) = 5 - j10\ \mathrm{V}$$

- Voltage division:

$$\mathbf{V}_x = \frac{10}{10 + 2.5 + j1.25 + 4 - j13}(5 - j10)\mathrm{V}$$



Example 2

- Algebraic manipulation:

$$\mathbf{V}_x = \frac{10}{10+2.5+j1.25+4-j13}(5-j10) = \frac{50-j100}{16.5-j11.75}$$

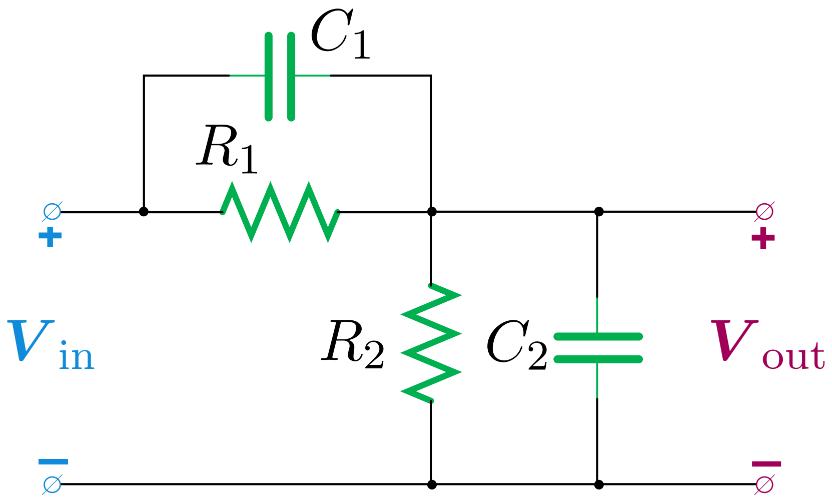
$$= \frac{\sqrt{50^2+100^2}}{\sqrt{16.5^2+11.75^2}}\left(\tan^{-1}\tfrac{-100}{50} - \tan^{-1}\tfrac{-11.75}{16.5}\right)$$

$$= 5.52\angle -28^\circ \; (\text{V})$$

Exam exercise example

Exam(ple)

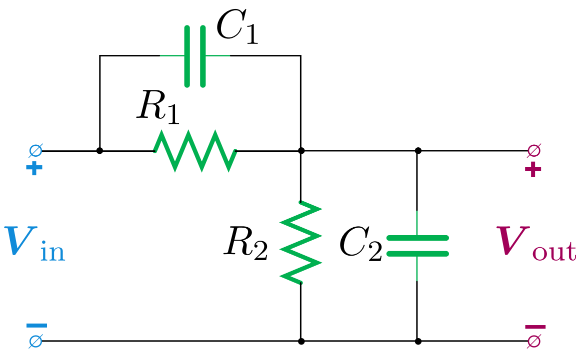
- Consider the circuit in the figure at the right:



a) Determine $\dfrac{V_{\mathrm{out}}}{V_{\mathrm{in}}}$.

b) For which condition is $\dfrac{V_{\mathrm{out}}}{V_{\mathrm{in}}}$ frequency independent?

Exam(ple)



a) Determine $\frac{\boldsymbol{V}_{\text{out}}}{\boldsymbol{V}_{\text{in}}}$.

- Calculate the partial impedances:
  - $\boldsymbol{Z}_1 = (R_1 \parallel C_1) = \frac{R_1 \frac{1}{\mathrm{j}\omega C_1}}{R_1 + \frac{1}{\mathrm{j}\omega C_1}} = \frac{R_1}{1 + \mathrm{j}\omega R_1 C_1}$
  - $\boldsymbol{Z}_2 = (R_2 \parallel C_2) = \frac{R_2}{1 + \mathrm{j}\omega R_2 C_2}$
- Determine the transfer:

$$\frac{\boldsymbol{V}_{\text{out}}}{\boldsymbol{V}_{\text{in}}} = \frac{\boldsymbol{Z}_2}{\boldsymbol{Z}_1 + \boldsymbol{Z}_2} = \frac{R_2(1 + \mathrm{j}\omega R_1 C_1)}{R_1(1 + \mathrm{j}\omega R_2 C_2) + R_2(1 + \mathrm{j}\omega R_1 C_1)}$$

Exam(ple)

b) For which condition is $\frac{\boldsymbol{V}_{\text{out}}}{\boldsymbol{V}_{\text{in}}}$ frequency independent?

$$\frac{\boldsymbol{V}_{\text{out}}}{\boldsymbol{V}_{\text{in}}} = \frac{R_2(1 + \mathrm{j}\omega R_1 C_1)}{R_1(1 + \mathrm{j}\omega R_2 C_2) + R_2(1 + \mathrm{j}\omega R_1 C_1)}$$

- For obtaining frequency independence, the terms containing ω must vanish from the expression
- By taking $R_1 C_1 = R_2 C_2 \longrightarrow \frac{\boldsymbol{V}_{\text{out}}}{\boldsymbol{V}_{\text{in}}} = \frac{R_2}{R_1 + R_2}$ which is indeed frequency independent

Summary of the day

- Sinusoidal voltages and currents
- Phasors, phasor relations for R, L and C
- Impedance, admittance, phasor diagrams
- Analysis examples

Next tasks

- Please do the SGH1
- Seminars of Tuesday and Friday
- Next week: transfer functions

Thank you!