

# Lecture 18

## Phasors – 4 of 9

using phasors;  
variation with frequency

# Phasor Review

- Extend sinusoidal voltages/currents to phasors (complex)
- Convert components (R,L,C) to impedances
- Solve the problem using Ohm's Law, KVL/KCL, ...
- Convert back

$$V_s \cos(\omega t + \phi) \Rightarrow \mathbf{V} = V_s e^{j\phi}$$

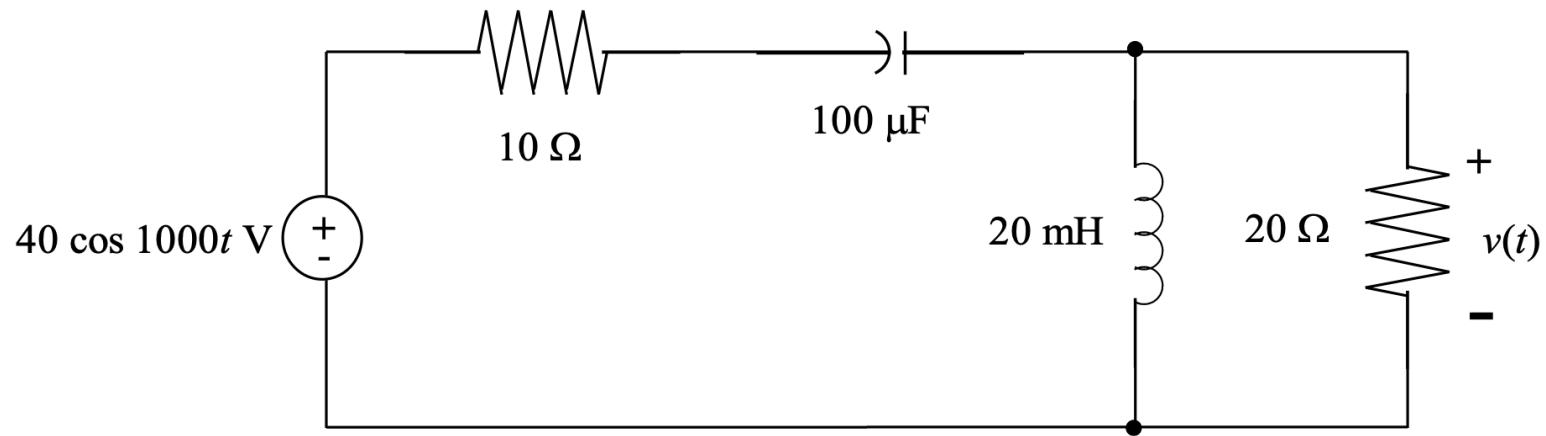
$$I_s \cos(\omega t + \phi) \Rightarrow \mathbf{I} = I_s e^{j\phi}$$

$$Z = \begin{cases} R & \text{resistor} \\ j\omega L & \text{inductor} \\ \frac{1}{j\omega C} = -j \frac{1}{\omega C} & \text{capacitor} \end{cases}$$

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

# Common Usage

- Find the voltage  $v(t)$

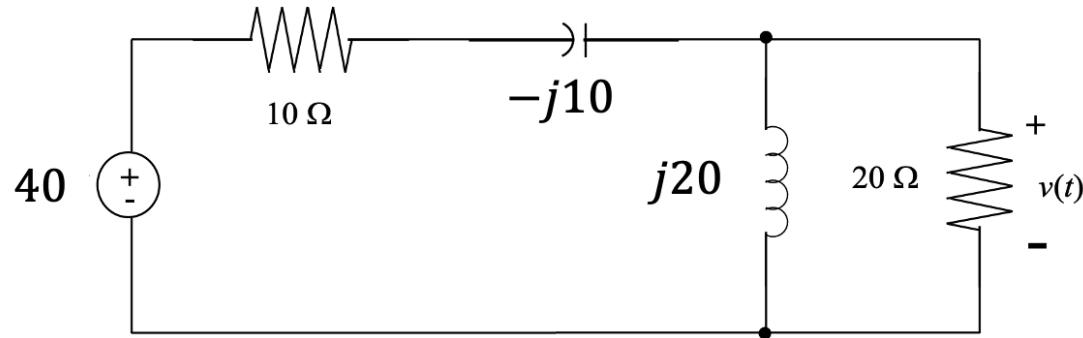


- Convert:

$$40 \cos 1000 t \rightarrow 40$$

$$20 \text{ mH} \rightarrow j\omega L = j20$$

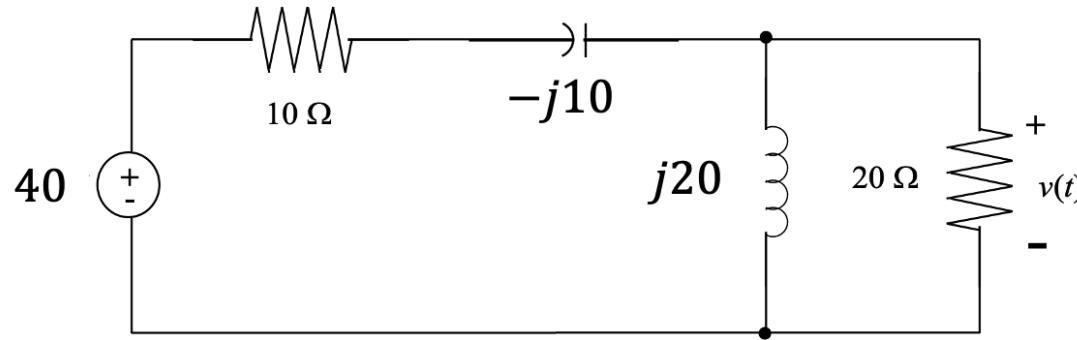
$$100 \mu\text{F} \rightarrow -j \frac{1}{\omega C} = -j10$$



- Solve: series/parallel combining, voltage division

$$Z_s = 10 - j10 = 10(1 - j) \quad Z_p = \frac{(20)(j20)}{20 + j20} = \frac{j20}{1 + j}$$

$$V = 40 \frac{Z_p}{Z_s + Z_p}$$



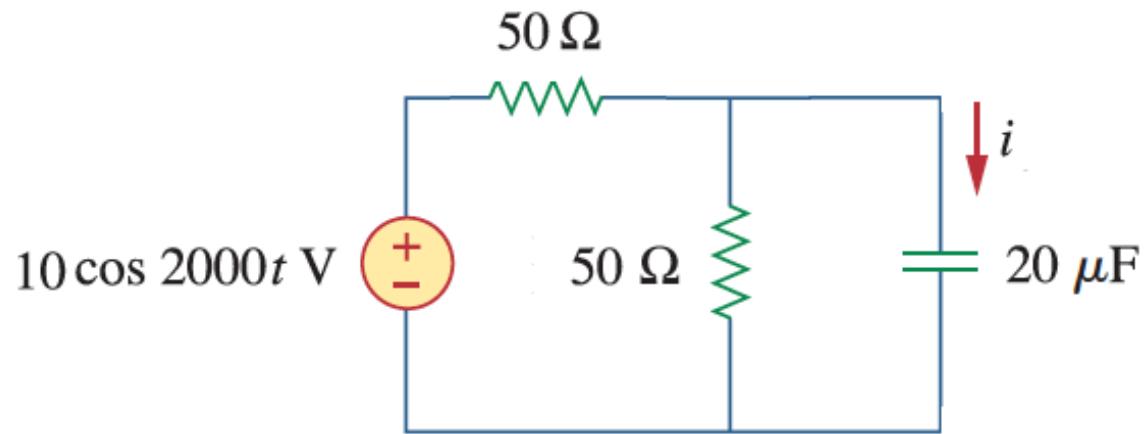
- Simplify and convert to polar form

$$V = 40 \frac{\frac{j20}{1+j}}{10(1-j) + \frac{j20}{1+j}} = \frac{40(1+j)}{2} = 28.3 \angle 45^\circ$$

- Convert to a time function

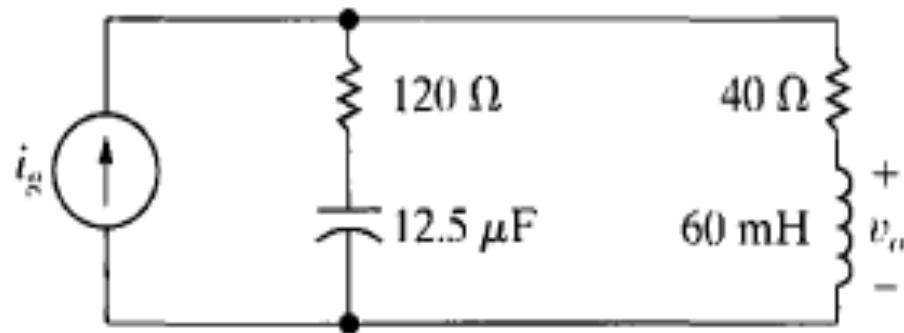
$$v(t) = 28.3 \cos(1000t + 45^\circ) V$$

- **Example:** find  $i(t)$



$$141\cos(2000t+45^\circ)~mA$$

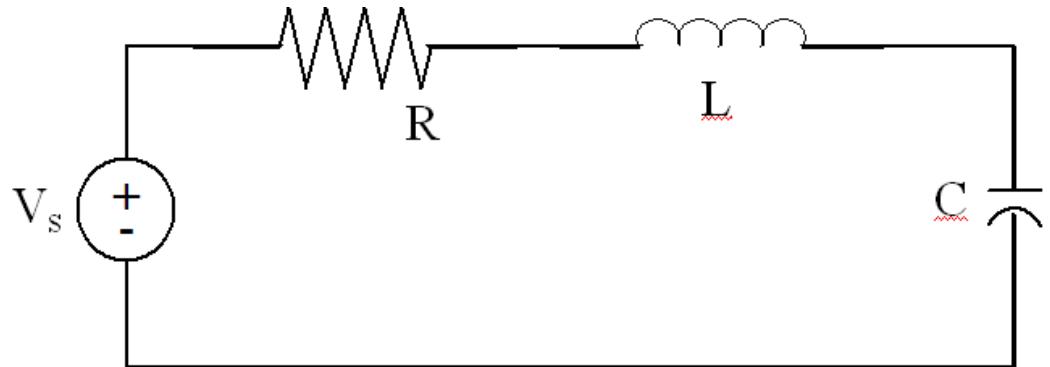
**Example:** find  $v_o(t)$  if  $i_g(t) = 500 \cos 2000 t$  mA



$$1.59\,\cos(2000t-17.0^\circ)\,\mathrm{V}$$

# Consider Variation with Frequency

Consider voltage division:



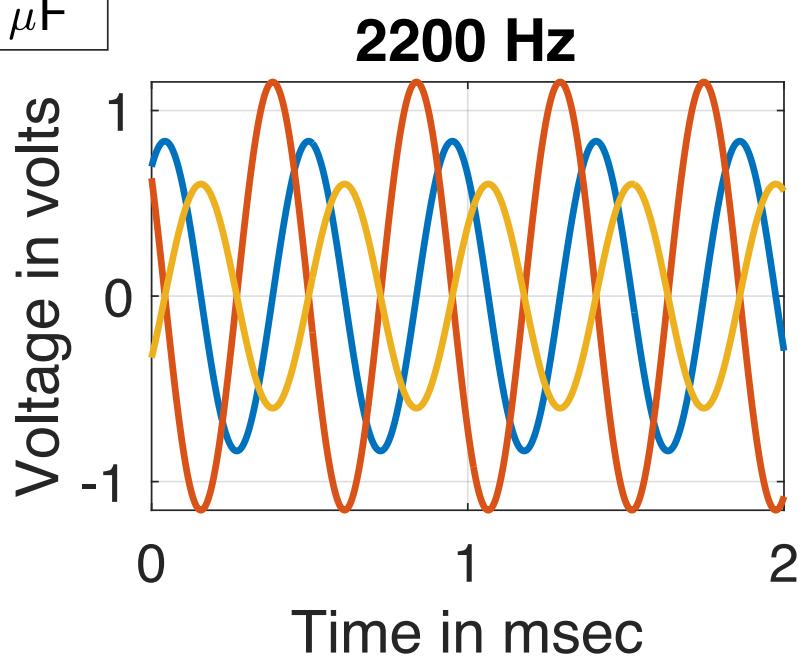
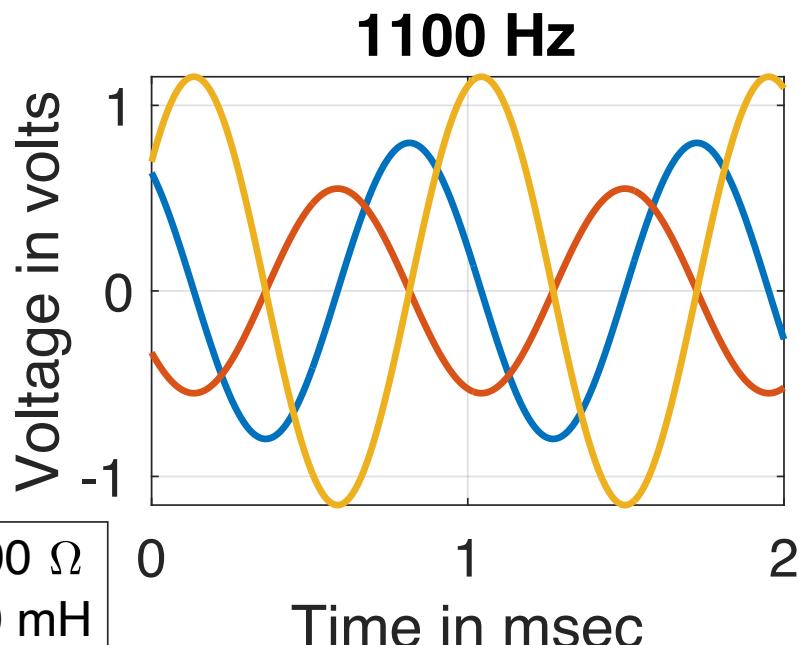
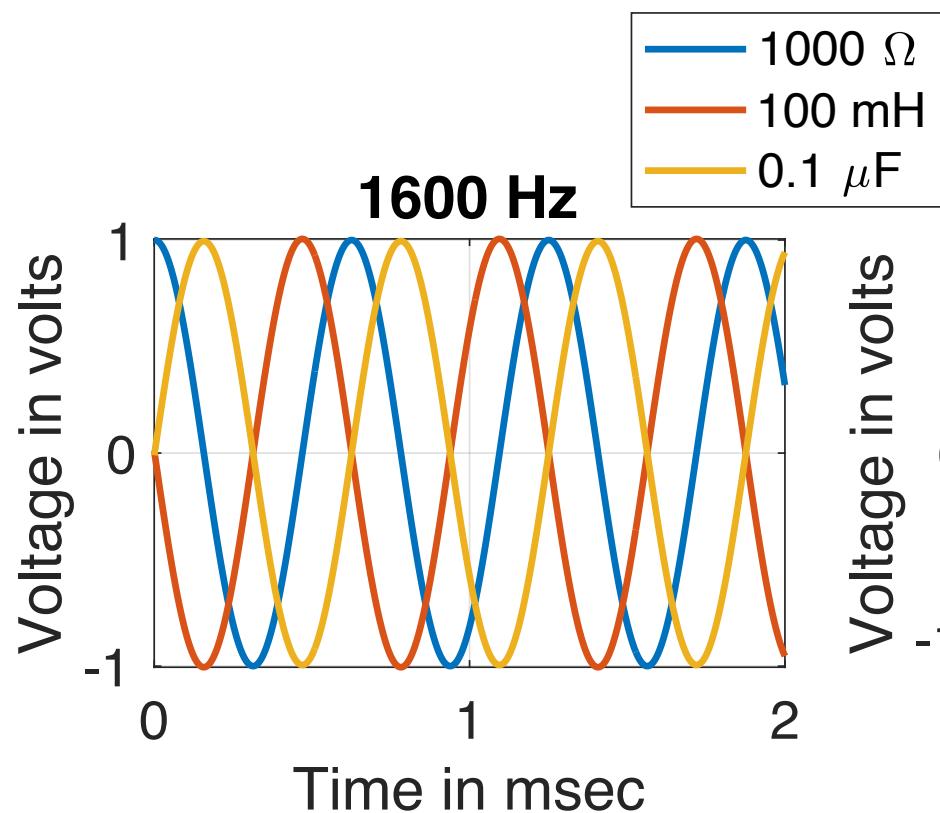
$$V_R = \frac{RV_s}{R + j\omega L + \frac{1}{j\omega C}} = \frac{j\omega RC}{1 - \omega^2 LC + j\omega RC} V_s$$

Similarly

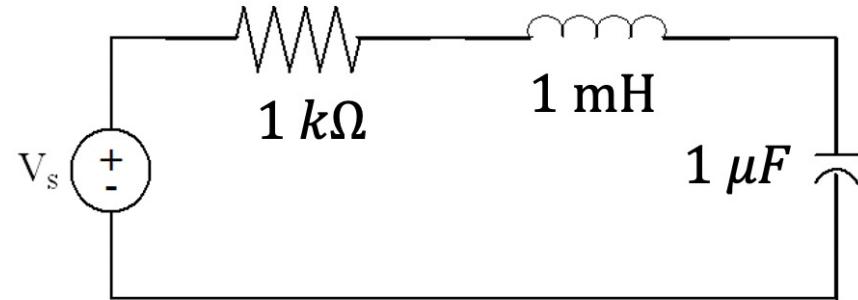
$$V_L = \frac{-\omega^2 LC}{1 - \omega^2 LC + j\omega RC} V_s$$

$$V_C = \frac{1}{1 - \omega^2 LC + j\omega RC} V_s$$

- Comparison of the component voltages for different frequencies ( $V_s = 1$ )



Consider combined impedance variation

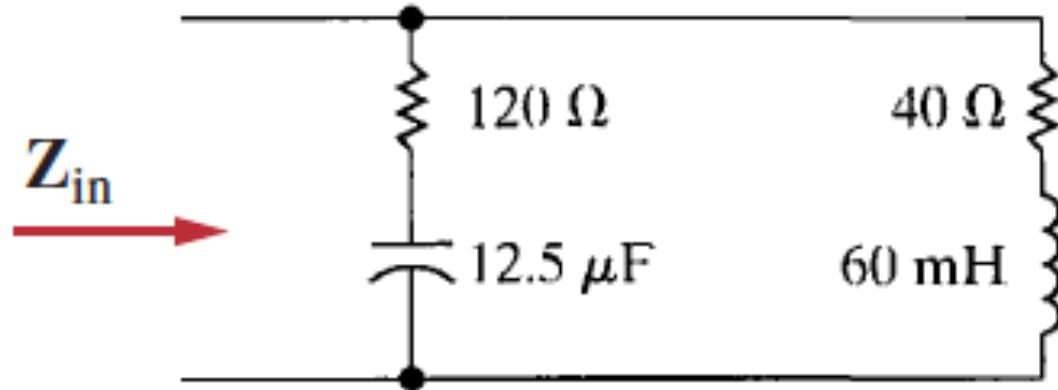


$$\begin{aligned} Z &= R + j\omega L + \frac{1}{j\omega C} = R + j \left( \omega L - \frac{1}{\omega C} \right) \\ &= 1000 + j \left( \frac{\omega}{100} - \frac{10^6}{\omega} \right) \end{aligned}$$

Questions:

- At what frequency does this “appear” purely resistive?
- What happens at small frequency? Large frequency?

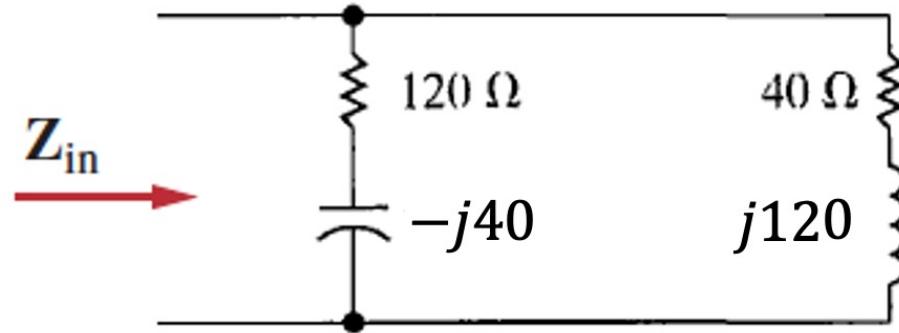
**Example:** find  $Z_{in}$  if  $\omega = 2000$  rad/sec



- Convert:

$$60 \text{ mH} \rightarrow j\omega L = j120$$

$$12.5 \mu F \rightarrow -j \frac{1}{\omega C} = -j40$$



- Solve: series/parallel combining

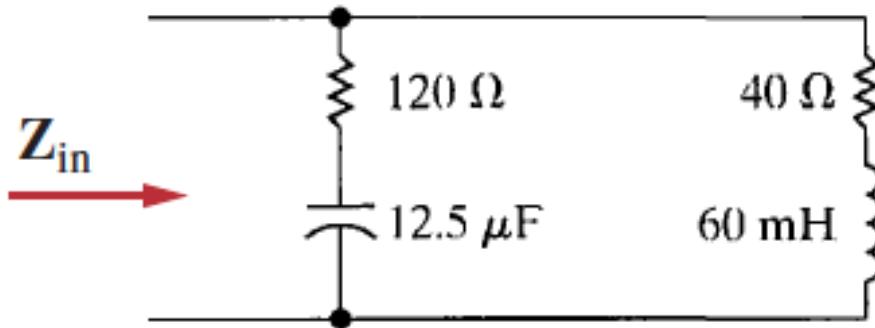
$$Z_{s, left} = 120 - j40 = 40(3 - j) \quad Z_{s, right} = 40 + j120 = 40(1 + j3)$$

$$Z_{in} = \frac{40(3 - j)40(1 + j3)}{40(3 - j) + 40(1 + j3)} = \frac{40(6 + j8)}{4 + j2} = \frac{40(3 + j4)}{2 + j}$$

$$= \frac{40(3 + j4)(2 - j)}{5} = 80 + j40$$

80 ohm resistor in series with 20 mH inductor !!

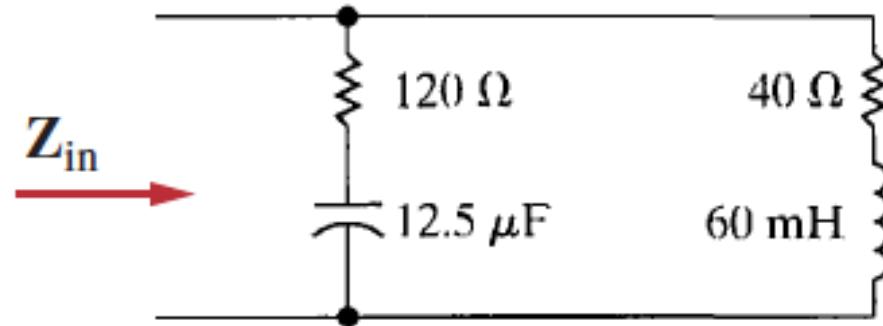
**Example:** How does  $Z_{in}$  vary with frequency? Is it ever purely real?



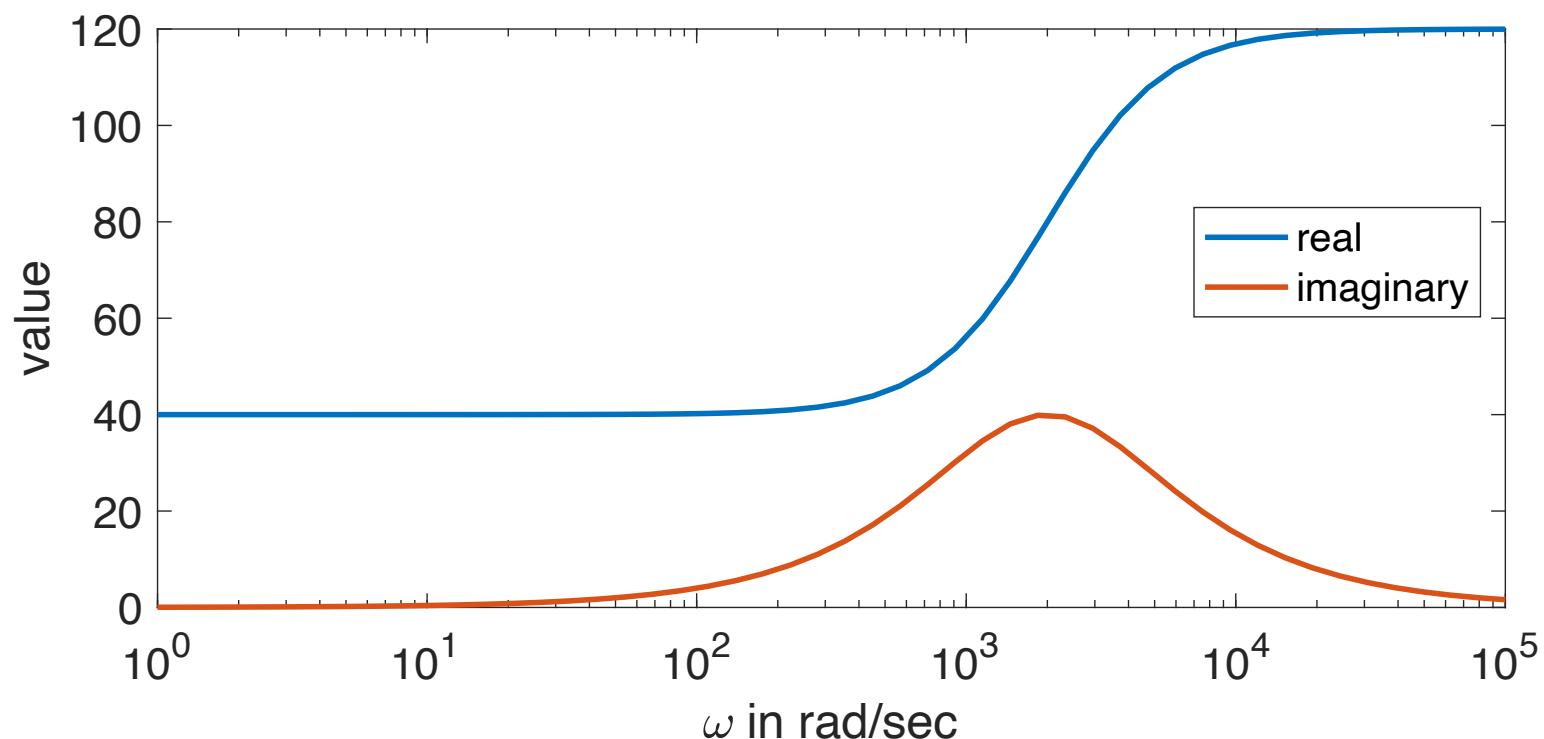
- Solve: series/parallel combining

$$Z_{s,left} = 120 - j \frac{80,000}{\omega} \quad Z_{s,right} = 40 + j60\omega$$

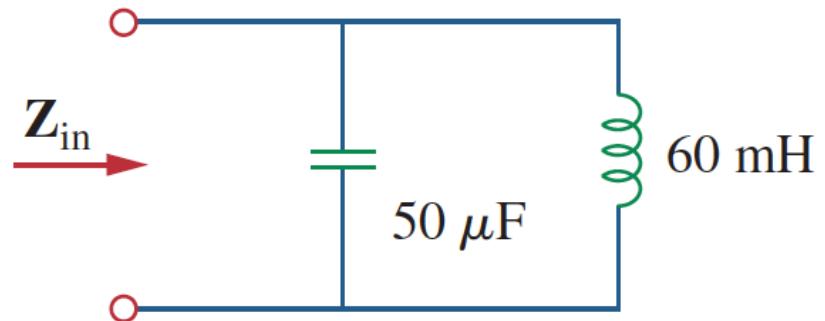
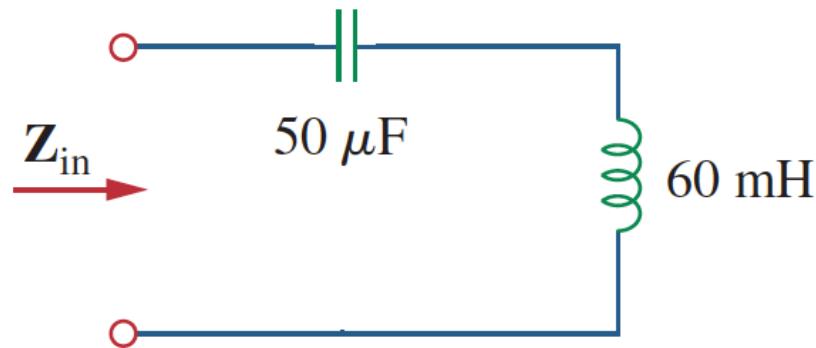
$$Z_{in} = \frac{Z_{s,left} \times Z_{s,right}}{Z_{s,left} + Z_{s,right}} = \frac{(120 - j \frac{80,000}{\omega})(40 + j60\omega)}{120 - j \frac{80,000}{\omega} + 40 + j60\omega} = \dots$$



$$Z_{in} = \frac{120\omega^2 + 160 \times 10^6}{\omega^2 + 4 \times 10^6} + j \frac{160,000\omega}{\omega^2 + 4 \times 10^6}$$

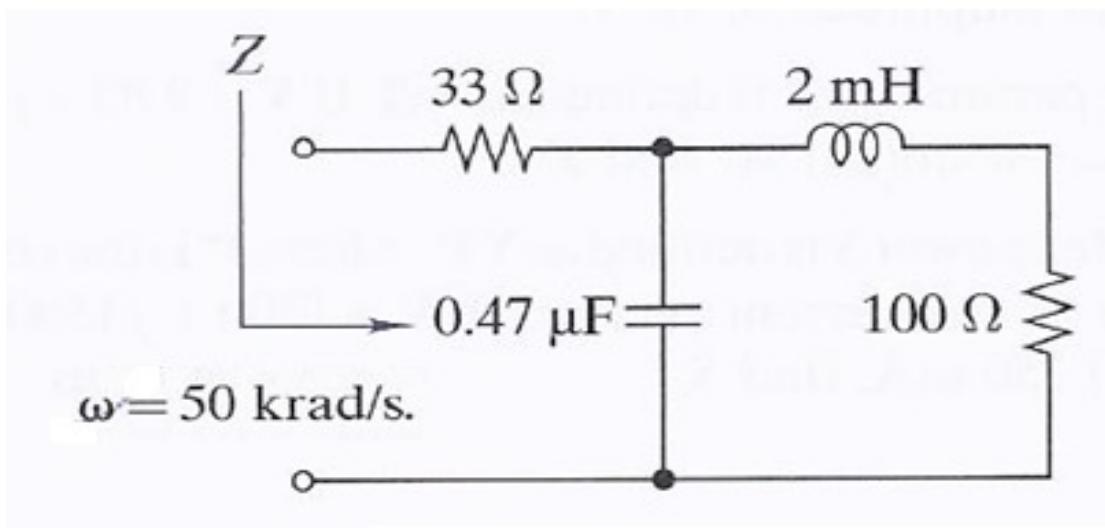


**Example:** How do these vary with frequency?



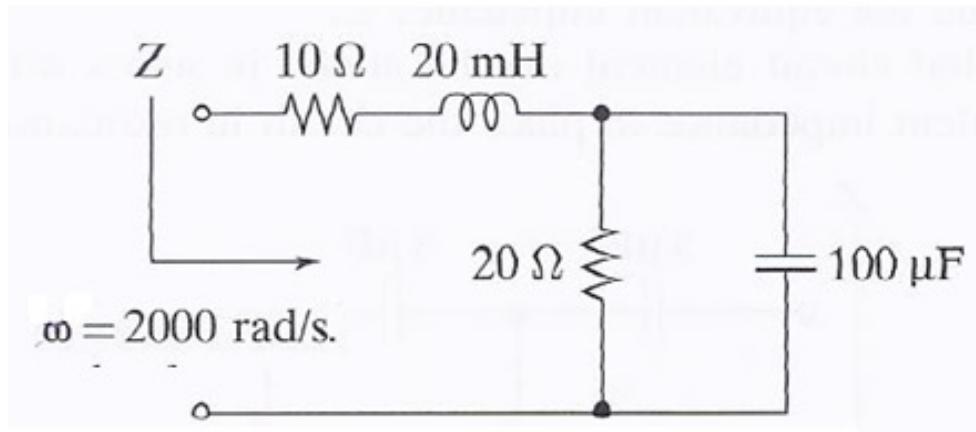
**Practice problem:** find  $Z$

$$46.4 - j50.4; \\ 46.4 \Omega \ 0.397 \mu F$$

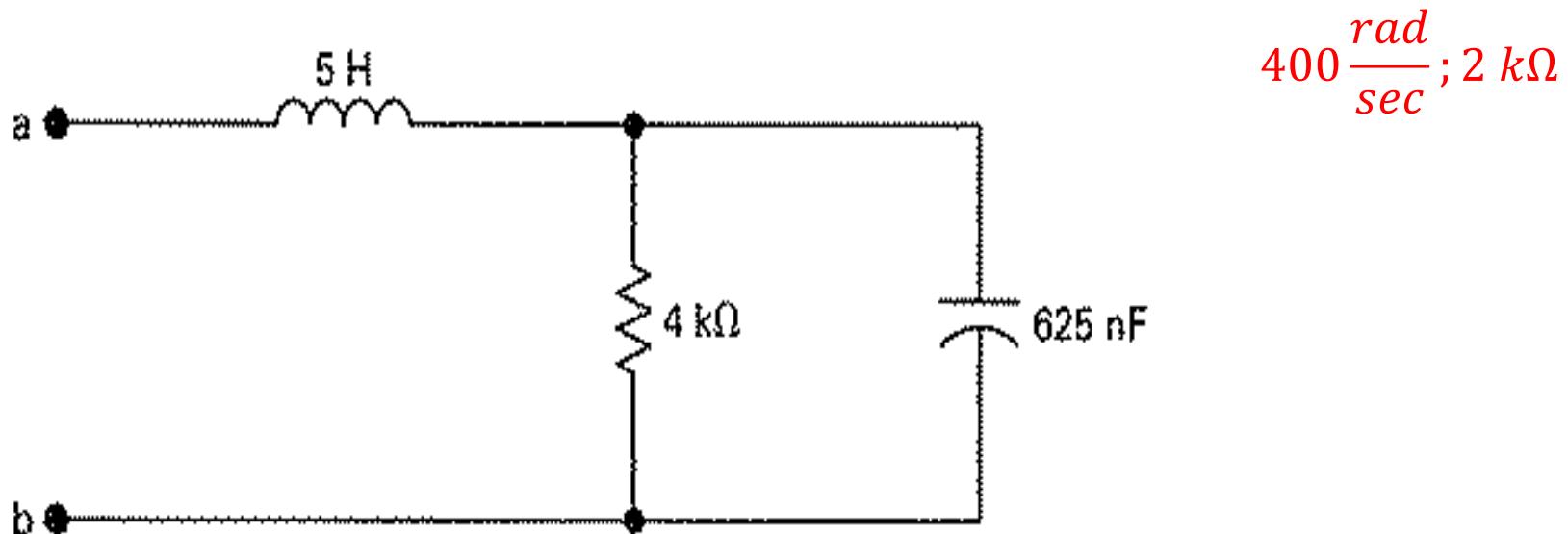


**Practice problem:** find  $Z$

$$11.2 + j35.3;$$
$$11.2 \Omega \ 17.6 mH$$



**Practice problem:** at what frequency does this circuit seem purely resistive? What is the resistance?



- **Practice problem:** consider the parallel connection of a  $220 \Omega$  resistor, a  $0.5 \mu\text{F}$  capacitor, and a  $5 \text{ mH}$  inductor.
  - What is the equivalent impedance of this circuit at 1000 Hz?
  - At 5000 Hz?
  - At what frequency is the impedance purely real?

$$11.6 + j49.2 \Omega; 1.42 - j17.6 \Omega; 1.59 \text{ kHz}$$

**Practice problem:** Find the time expression for  $v_o(t)$ .

Note that  $\sin \omega t = \cos(\omega t - 90^\circ)$

$$17.1 \cos 200t \text{ V}$$

