Your Comments

Thus far, Physics 212 has been a bit like tubing. It's possible to stay on the tube, but only if you cling to it for dear life. Eventually, though, there's just that one wave that the boat hits, and you get thrown into the water. This lecture was a bit like that, so I'm hoping that we get a bit of clarification in the actual lecture. The resonance I understand, the transformer is slightly more befuddling.

Lot of hand-waving in this lecture. And really? Q? They couldn't have picked ANY other letter? I mean seriously, even a russian or a greek letter would've been better than choosing Q! Or X! Anything but Q! Q is charge....usually..... Sigh. E&M, why you do this to me? T_T

I want to go over more examples on how to visualize RLC ciruits as phasors, and how to interpret them more clearly.

Can we slow this down? There were a lot of new variables introduced, and it seemed that they were introduced arbitrarily. What exactly is "resonance" and how does a transformer really work?

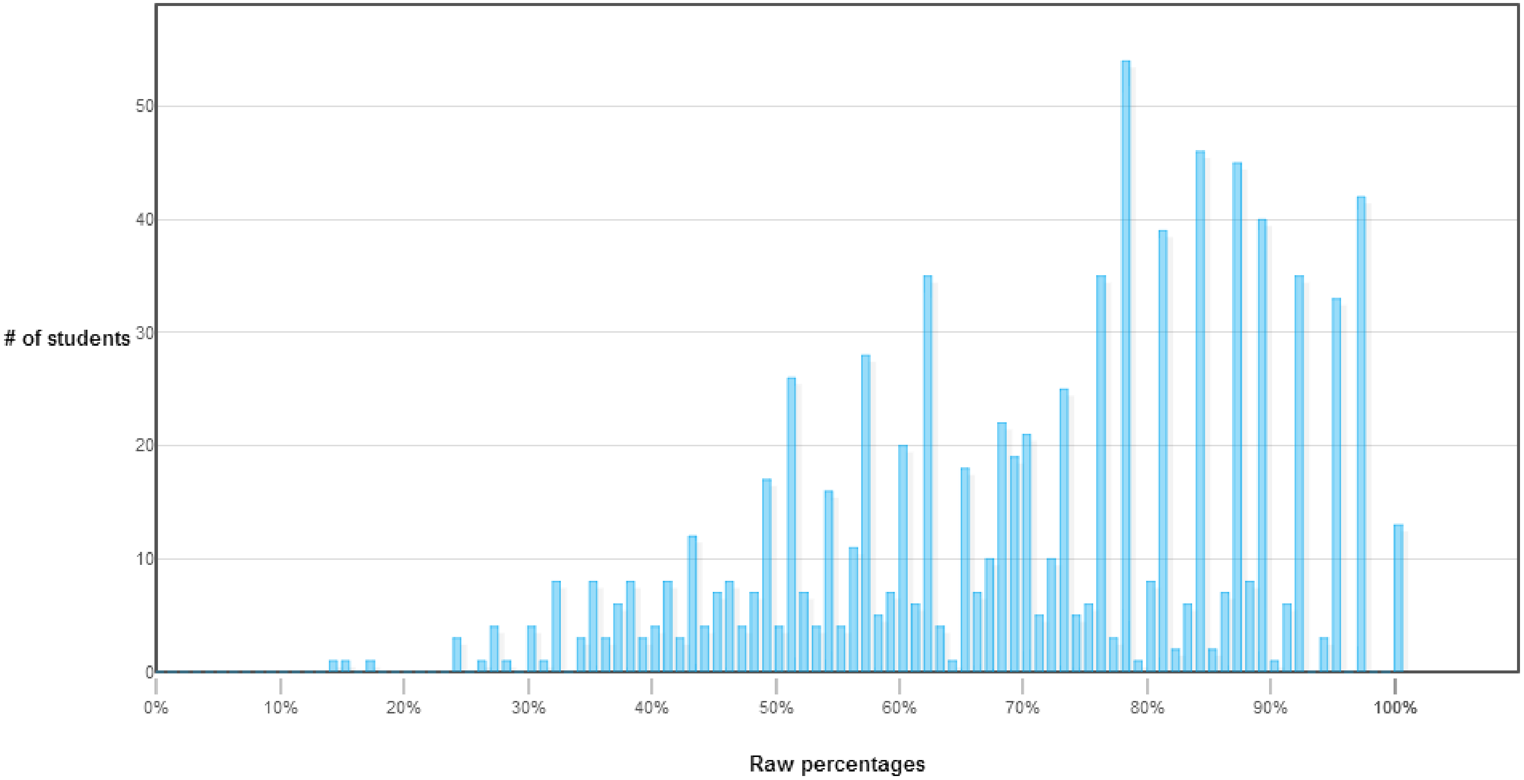
Ya know, the first half of this prelecture was just a bunch of mumbo-jumbo mental gymnastics math. Like Im sure its important, but it just doesn't have any meaning yet: Its just scary functions that look like theyre gonna be a bad time. The second part wasn't too bad tho. Its cool to know what a transformer - of the variety that is not robots in disguise - do.

Can you explain how dB/dt=V/N? Other than that the ideas on the whole were clear, yet confusing. I bet the examples in class will clear confusion up.

Too many new variables, formulas, derivations, etc. No idea what's going on at this point. I've been confused many times before but this prelecture takes the cake.

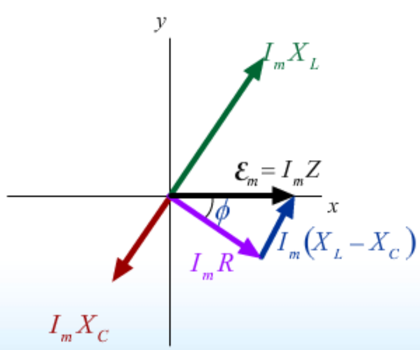
Nice work on hour exam 2

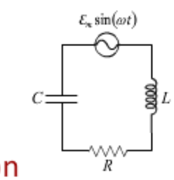
Raw average score 71%
Scaled average score 76%



Physics 212
Lecture 21

Voltage Phasor Diagram





Phase Relation

$$\tan\phi = \frac{X_L - X_C}{R}$$

Impedance

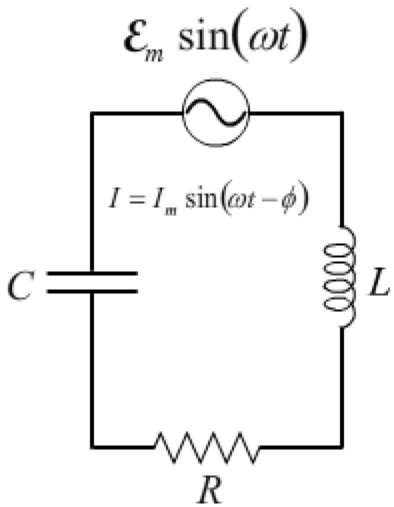
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Maximum Current

$$I_m = \frac{\mathcal{E}_m}{Z}$$

Looks intimidating, but isn't bad!

The Driven LCR Circuit



Frequency Dependence of Maximum Current

$$I_m = \frac{\mathcal{E}_m}{R} \frac{1}{\sqrt{1 + Q^2 \frac{(x^2-1)^2}{x^2}}}$$

Average Power per Cycle

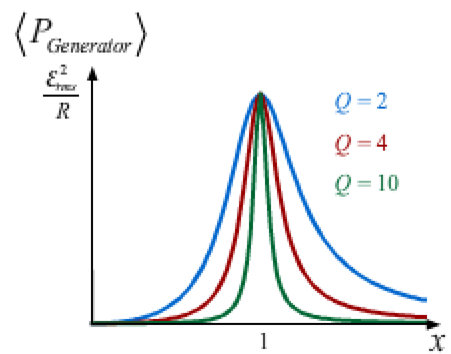
$$\langle P_{Generator} \rangle = \frac{\mathcal{E}_{rms}^2}{R} \frac{x^2}{x^2 + Q^2(x^2-1)^2}$$

where $x \equiv \frac{\omega}{\omega_o}$ & $Q^2 = \frac{L}{R^2 C}$

Quality Factor

$$Q \equiv 2\pi \left[\frac{U_{max}}{\Delta U}\right]_{cycle}$$

evaluate at $\omega = \omega_o$



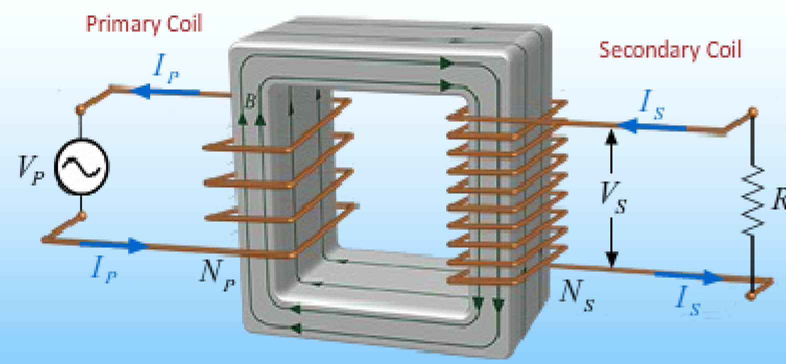
Transformers

Voltage Relation

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Current Relation

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}$$



Peak AC Problems

"Ohms" Law for each element

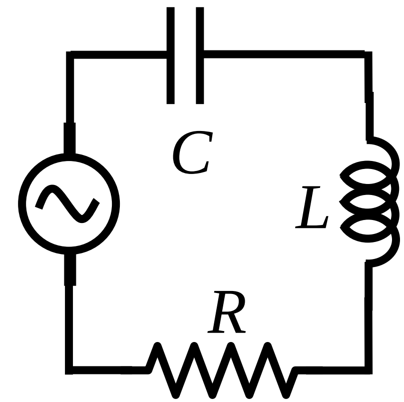
NOTE: Good for PEAK values only)

$$V_{gen} = I_{max} Z$$
$$V_{Resistor} = I_{max} R$$
$$V_{inductor} = I_{max} X_L$$
$$V_{Capacitor} = I_{max} X_C$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

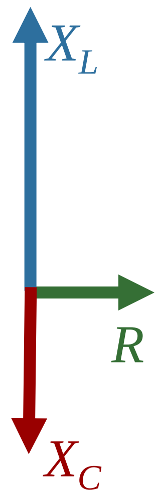
$$X_L = \omega L$$

$$X_C = \frac{1}{\omega C}$$



Typical Problem

A generator with peak voltage 15 volts and angular frequency 25 rad/sec is connected in series with an 8 Henry inductor, a 0.4 mF capacitor and a 50 ohm resistor. What is the peak current through the circuit?



$$X_L = \omega L = 200\Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = 122\Omega$$

$$X_C = \frac{1}{\omega C} = 100\Omega$$

$$I_{max} = \frac{V_{gen}}{Z} = 0.13A$$

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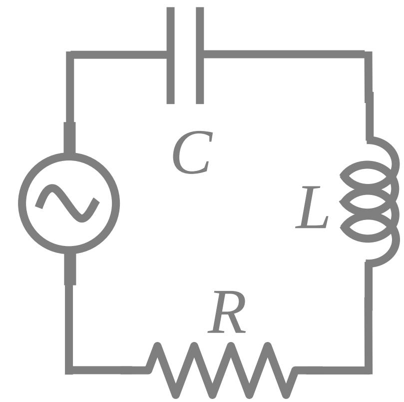


Typical Problem

A generator with peak voltage 15 volts and angular frequency 25 rad/sec is connected in series with an 8 Henry inductor, a 0.4 mF capacitor and a 50 ohm resistor. What is the peak current through the circuit?

Which element has the largest peak voltage across it?

A) Generator

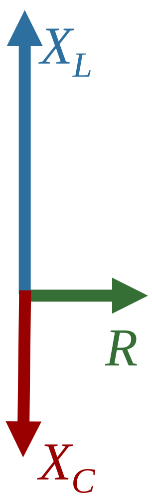
B) Inductor

C) Resistor

D) Capacitor

E) All the same.

$$V_{max} = I_{max} X$$



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Peak AC Problems

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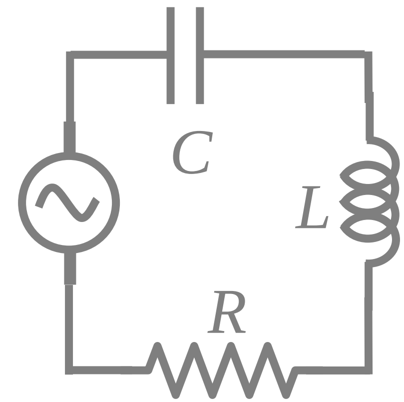


Typical Problem

A generator with peak voltage 15 volts and angular frequency 25 rad/sec is connected in series with an 8 Henry inductor, a 0.4 mF capacitor and a 50 ohm resistor. What is the peak current through the circuit?

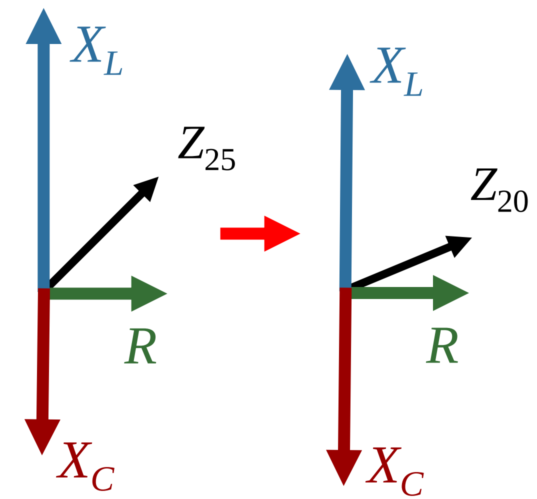
What happens to the impedance if we decrease the angular frequency to 20 rad/sec?

A) *Z* increases

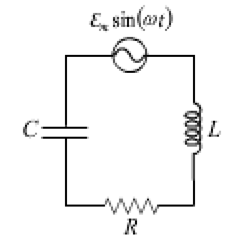
B) *Z* remains the same

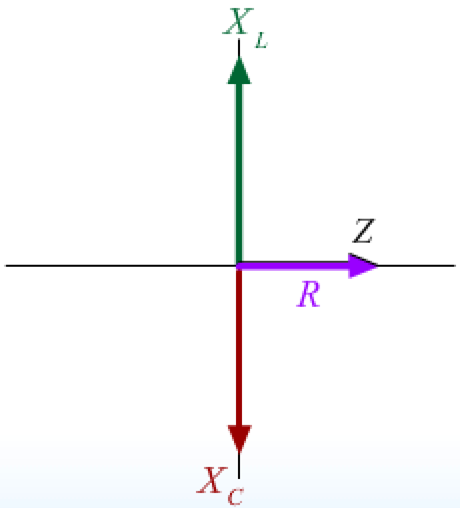
C) *Z* decreases

$(X_L - X_C)$: (200 – 100) -> (160 – 125)



Resonance





Resonance

I_m is a maximum $\longrightarrow$ $I_m = \dfrac{\mathcal{E}_m}{R}$

$\omega = \omega_o$

Z minimized $\longrightarrow$ $X_L = X_C$

$\phi = 0^{o}$

$$\omega_o = \frac{1}{\sqrt{LC}}$$

Light-bulb Demo

Resonance

Frequency at which voltage across inductor and capacitor cancel

R is independent of ω

X_L increases with ω

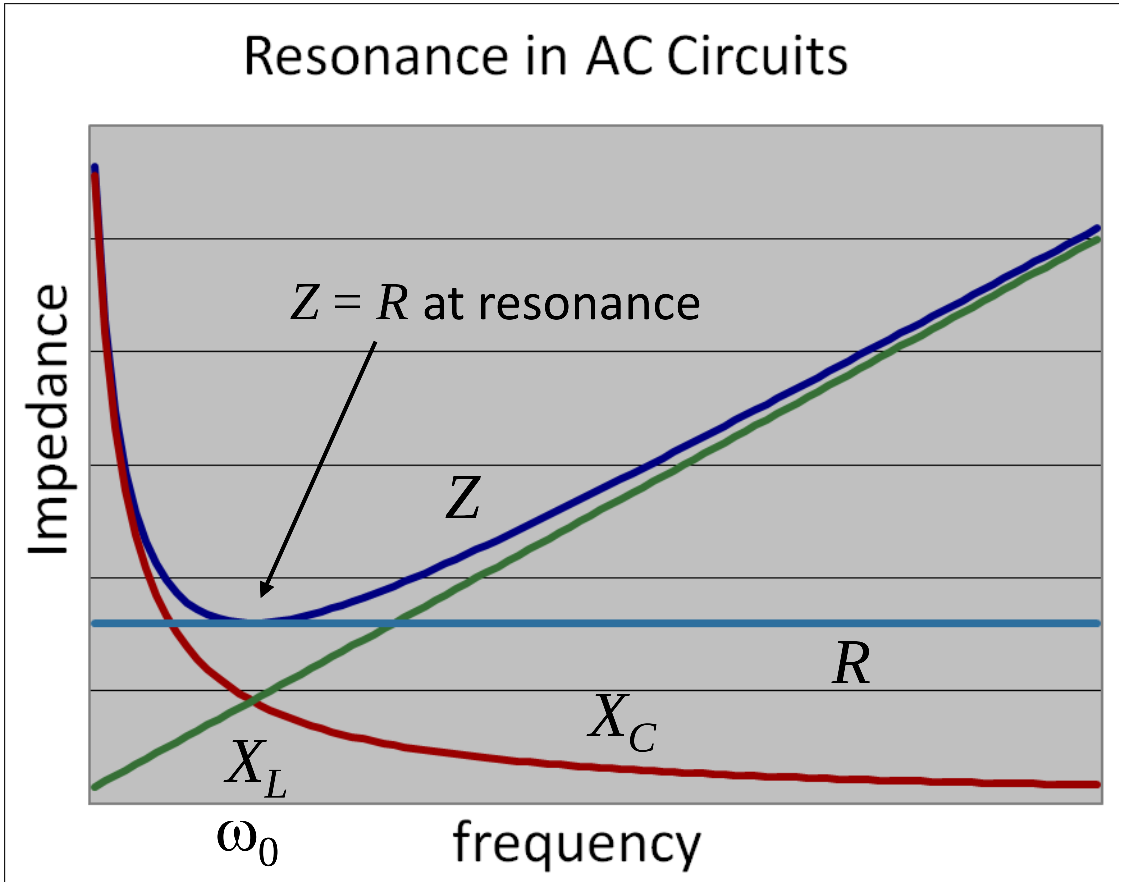
$$X_L = \omega \mathrm{L}$$

X_C increases with $1/\omega$

$$X_C = \frac{1}{\omega C}$$

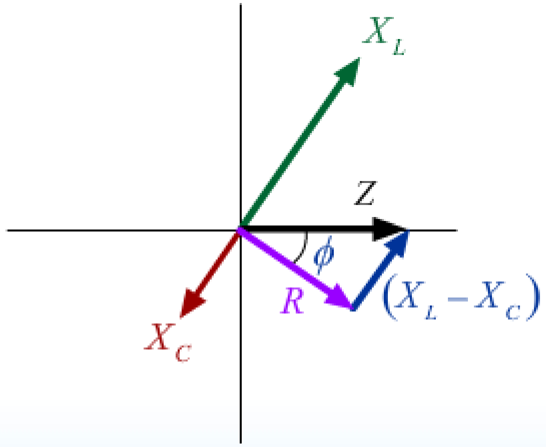
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

is minimum at resonance



Resonance: $X_L = X_C$ $\quad \omega_0 = \frac{1}{\sqrt{LC}}$

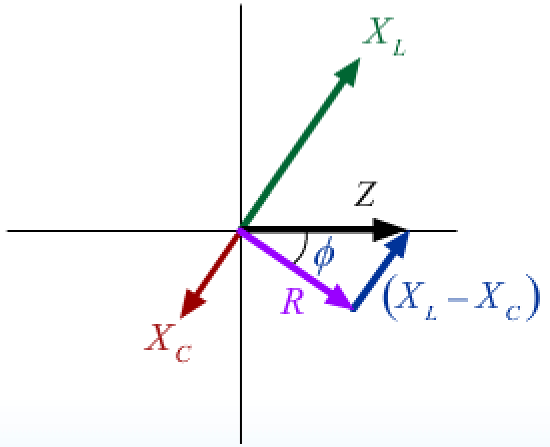
Off Resonance



$$I_m = \frac{\mathcal{E}_m}{Z}$$

$$I_m = \frac{\mathcal{E}_m}{R} \frac{R}{\sqrt{R^2 + (\omega L - 1/\omega C)^2}}$$

Z



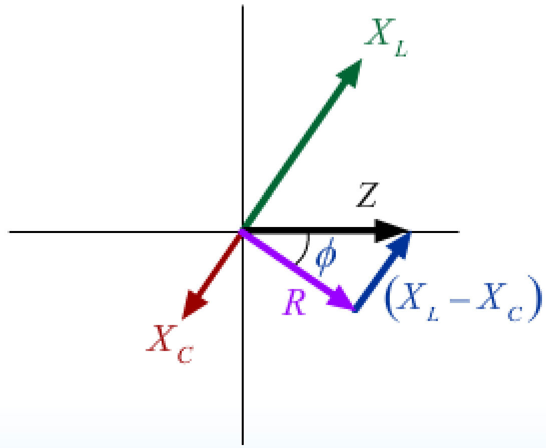
$$x \equiv \frac{\omega}{\omega_o} \qquad Q^2 \equiv \frac{L}{R^2 C}$$

$$Q \equiv 2\pi \frac{U_{\max}}{\Delta U}$$

$$I_m = \frac{\mathcal{E}_m}{R} \frac{1}{\sqrt{1 + Q^2 \frac{(x^2 - 1)^2}{x^2}}}$$

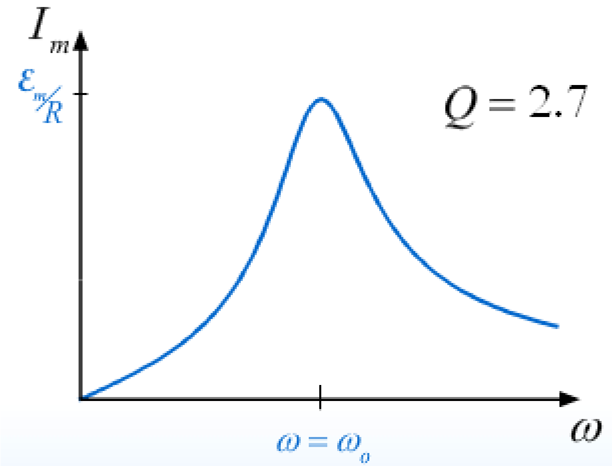
U_{max} = max energy stored
ΔU = energy dissipated
in one cycle at resonance

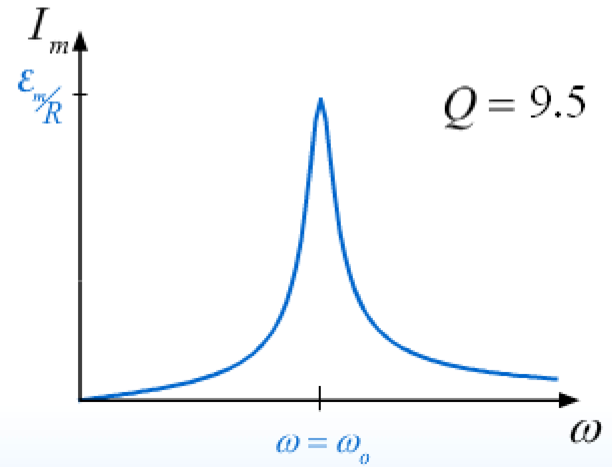
Off Resonance



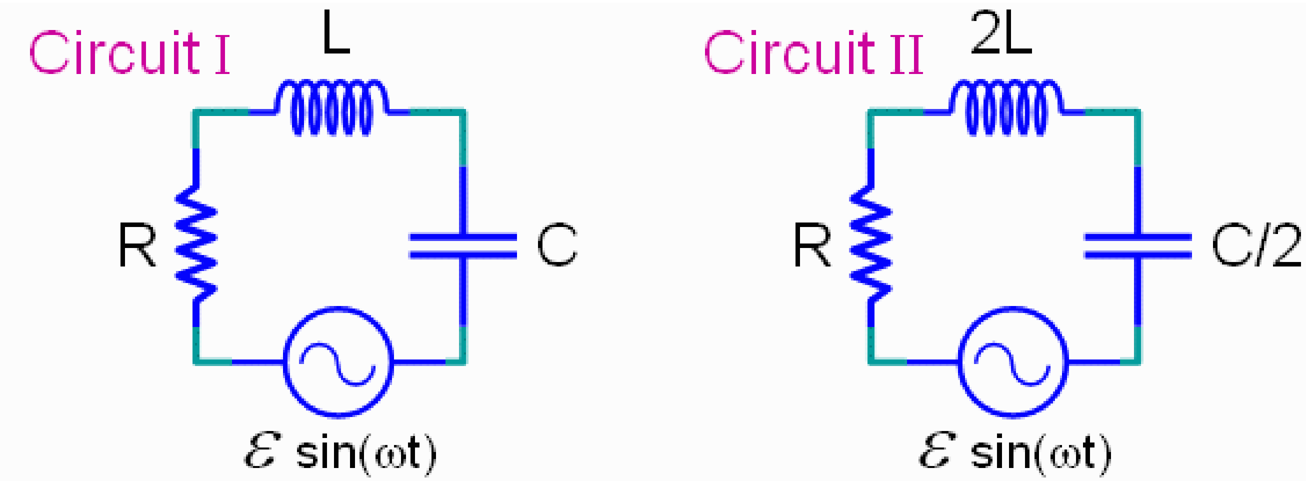
$$x \equiv \frac{\omega}{\omega_o} \qquad Q^2 \equiv \frac{L}{R^2 C}$$

$$I_m = \frac{\varepsilon_m}{R} \frac{1}{\sqrt{1 + Q^2 \frac{\left(x^2 - 1\right)^2}{x^2}}}$$





CheckPoint 1a



Consider two RLC circuits with identical generators and resistors. Both circuits are driven at the resonant frequency. Circuit II has twice the inductance and 1/2 the capacitance of circuit I as shown above.

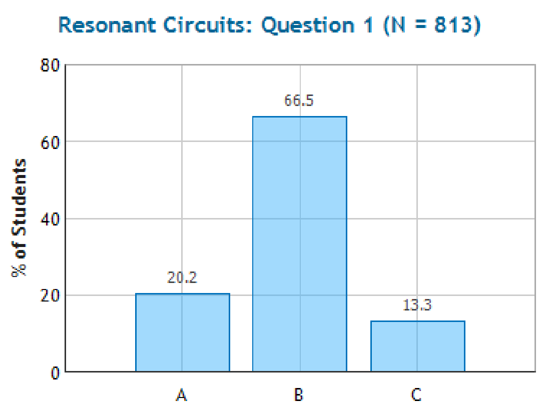
Compare the peak voltage across the resistor in the two circuits

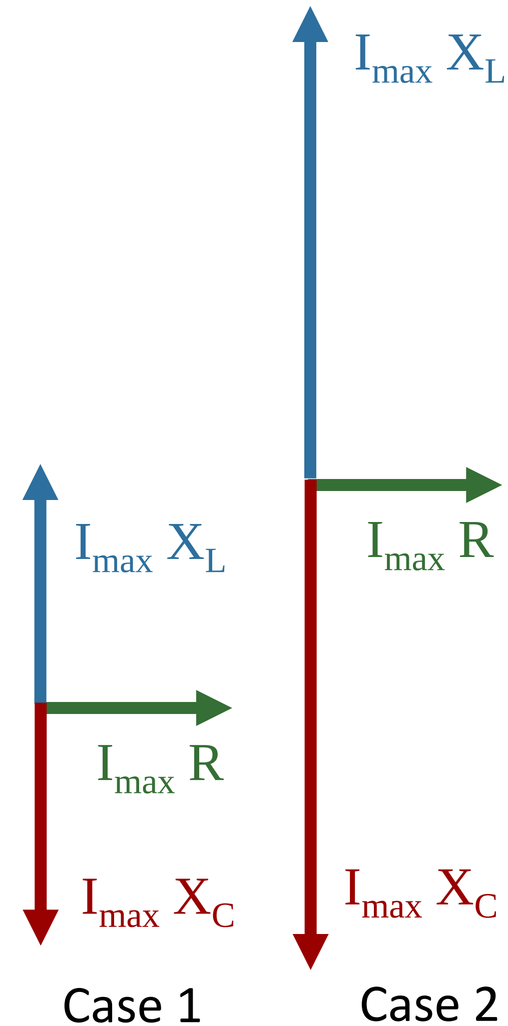
A. $V_I > V_{II}$ ***B.*** $V_I = V_{II}$ ***C.*** $V_I < V_{II}$

Resonance: $X_L = X_C$

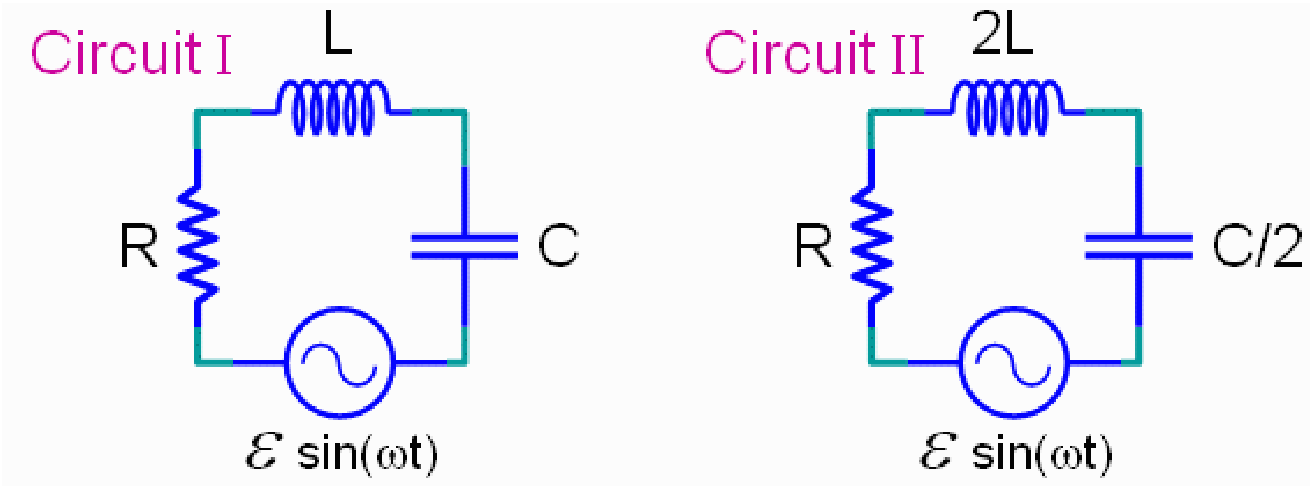
$Z = R$

Same since R doesn't change





CheckPoint 1b

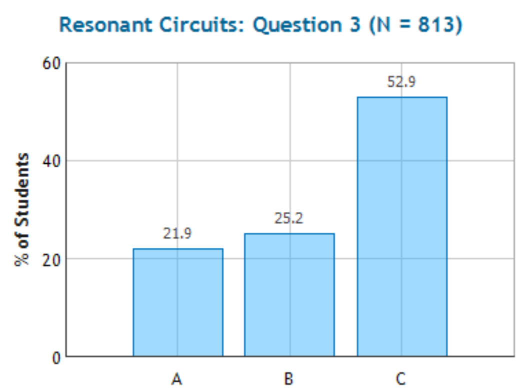


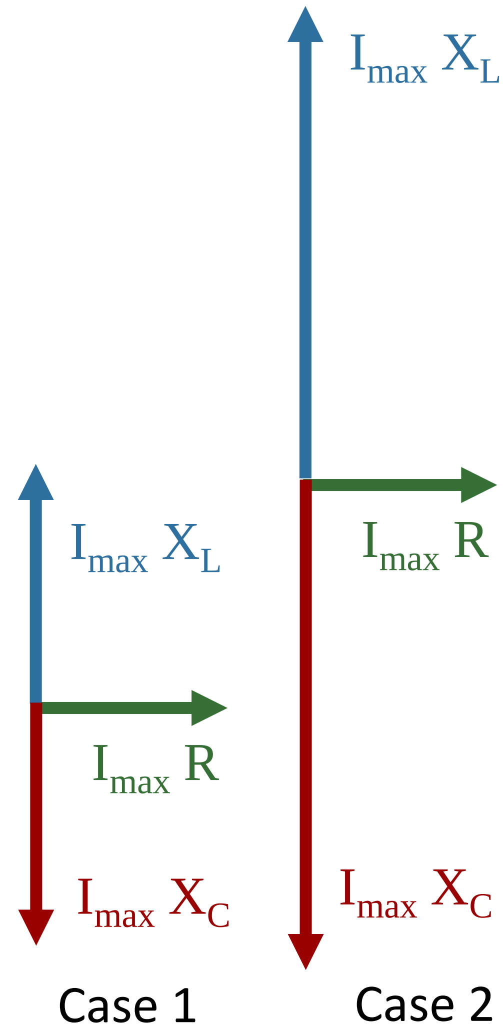
Consider two RLC circuits with identical generators and resistors. Both circuits are driven at the resonant frequency. Circuit II has twice the inductance and 1/2 the capacitance of circuit I as shown

Compare the peak voltage across the inductor in the two circuits

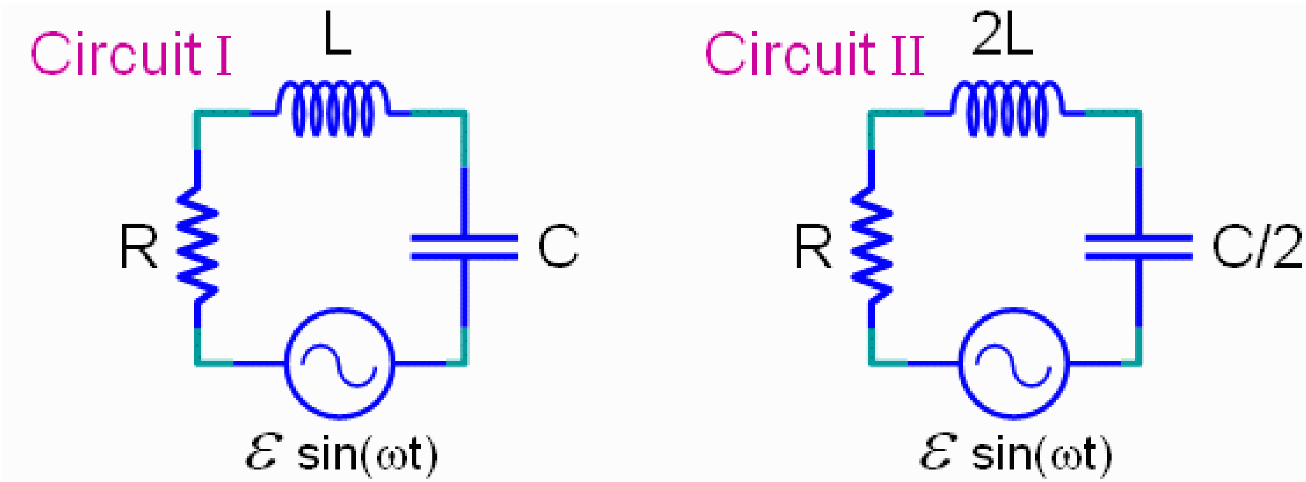
A. $V_I > V_{II}$ **B.** $V_I = V_{II}$ **C.** $V_I < V_{II}$

Voltage in second circuit will be twice that of the first because of the $2L$ compared to L.





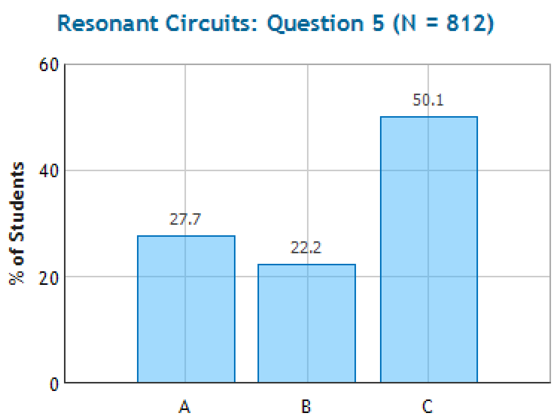
CheckPoint 1c



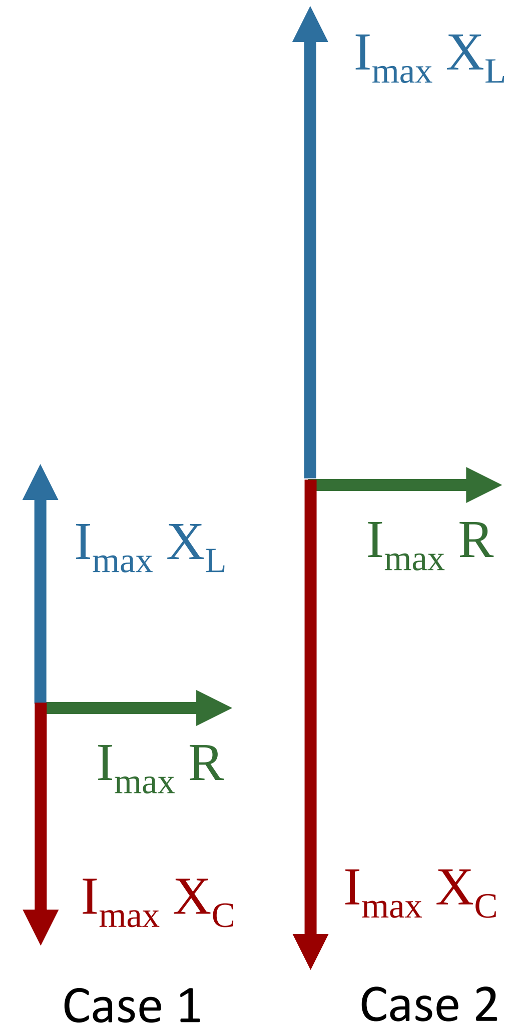
Consider two RLC circuits with identical generators and resistors. Both circuits are driven at the resonant frequency. Circuit II has twice the inductance and 1/2 the capacitance of circuit I as shown

Compare the peak voltage across the capacitor in the two circuits

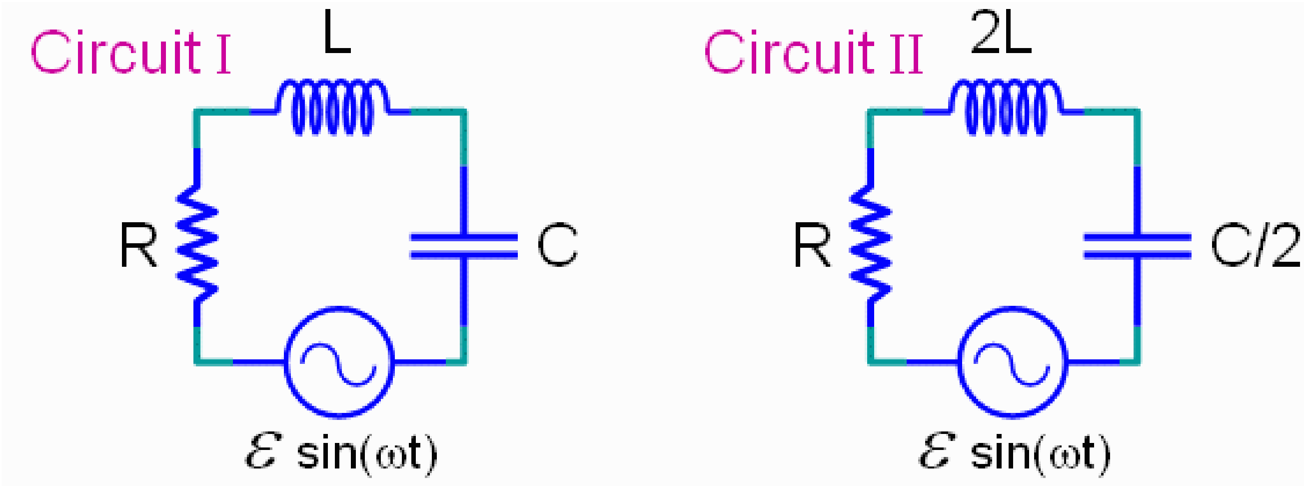
A. $V_I > V_{II}$ **B.** $V_I = V_{II}$ **C.** $V_I < V_{II}$



The peak voltage will be greater in circuit 2 because the value of X_C doubles.



CheckPoint 1D



Consider two RLC circuits with identical generators and resistors. Both circuits are driven at the resonant frequency. Circuit II has twice the inductance and 1/2 the capacitance of circuit I as shown

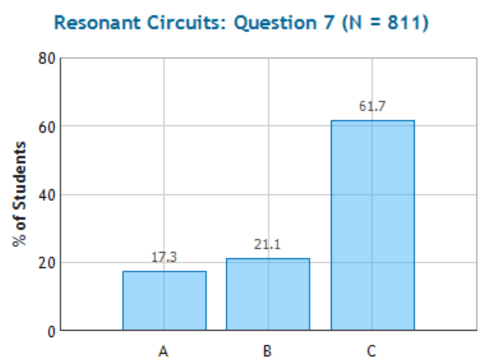
At the resonant frequency, which of the following is true?

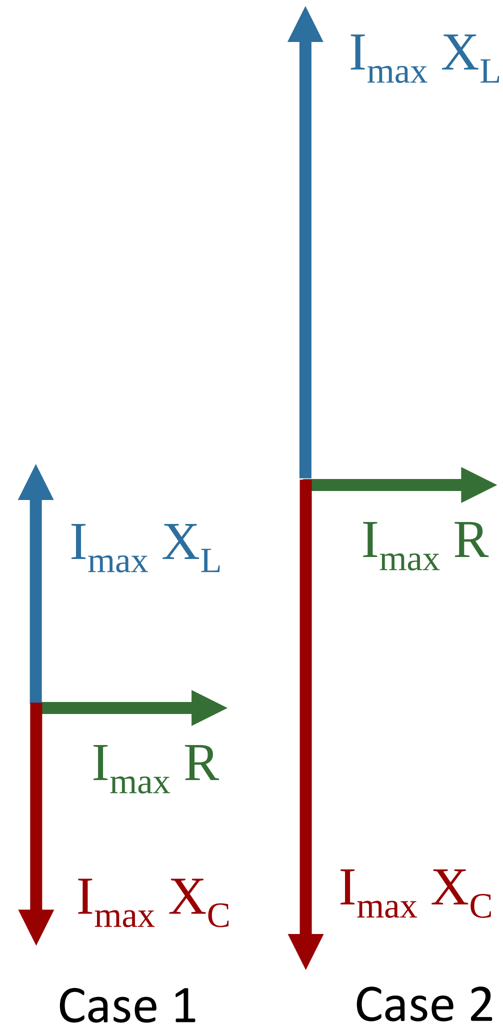
A. Current leads voltage across the generator

B. Current lags voltage across the generator

C. Current is in phase with voltage across the generator

The voltage across the inductor and the capacitor are equal when at resonant frequency, so there is no lag or lead.

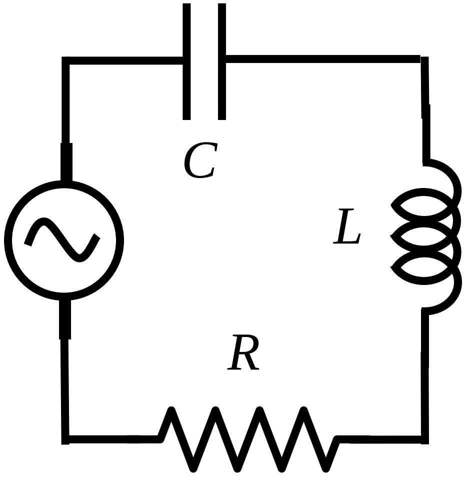




Power

$P = IV$ instantaneous always true

- Difficult for Generator, Inductor and Capacitor because of phase
- Resistor I,V are always in phase!



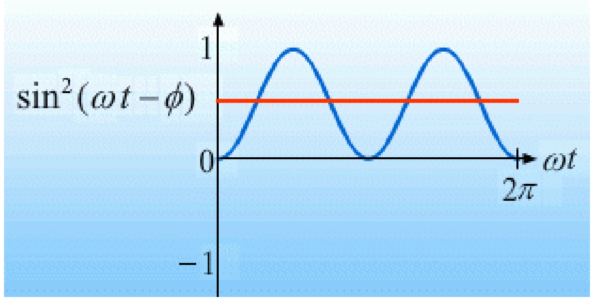
$$P = IV$$
$$= I^2 R$$

Average Power

Inductor and Capacitor = 0 ($< \sin(\omega t) \cos(\omega t) > = 0$)

Resistor

$$<I^2R> = <I^2> R = ½\, I^2_{peak}\, R$$



RMS = Root Mean Square

$I_{peak} = I_{rms}$ sqrt(2)

→ $< I^2 R > = I_{rms}{}^2 R$

Power Line Calculation

If you want to deliver 1,500 Watts at 100 Volts over transmission lines w/ resistance of 5 Ohms. How much power is lost in the lines?

- Current Delivered: $I = P/V = 15$ Amps
- Loss $= IV$ (on line) $= I^2 R = 15*15 * 5 = 1{,}125$ Watts!

If you deliver 1,500 Watts at 10,000 Volts over the same transmission lines. How much power is lost?

- Current Delivered: $I = P/V = .15$ Amps
- Loss $= IV$ (on line) $= I^2 R = 0.125$ Watts

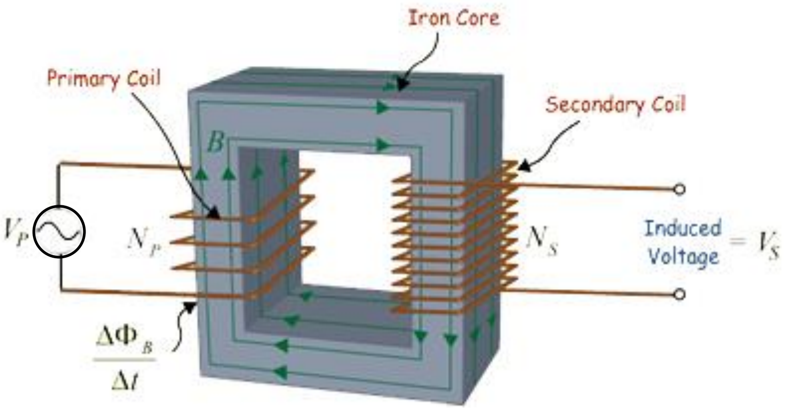
DEMO

Transformers

Application of Faraday's Law

- Changing EMF in Primary creates changing flux
- Changing flux, creates EMF in secondary

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$



Efficient method to change voltage for AC.

Power Transmission Loss $= I^2 R$

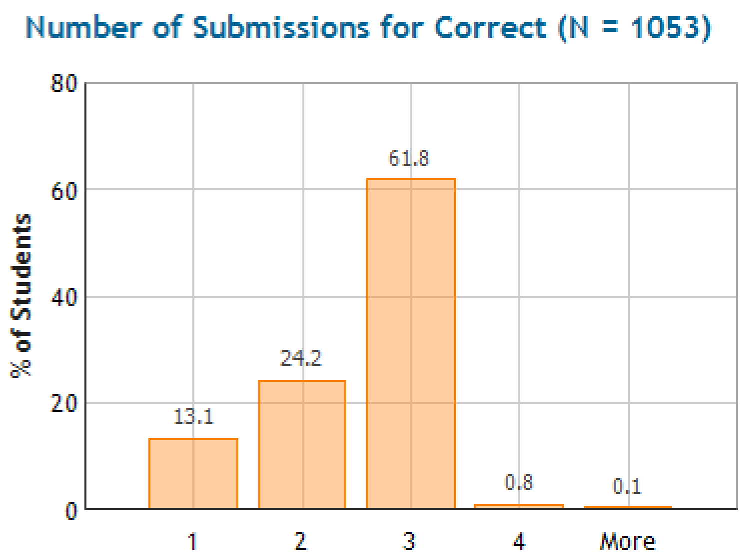
Power electronics

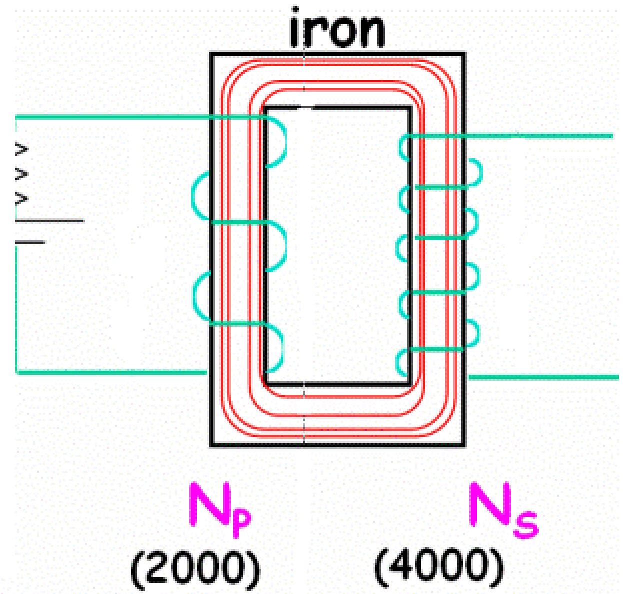
Demo

Tranformers

I don't understand the second question of the prelecture. It said something about the changing currents...like changing flux?

A) 0 Volts
B) 6 Volts
C) 12 Volts





Wrong Answer: 2 ✗

Feedback: Actually if this was connected to an AC source, the secondary would have twice the primary voltage. However, the battery voltage does not change in time, so after the battery has been connected for a while, there will not be a changing current to create a voltage across the secondary.

Follow-Up from last lecture

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100\ V$

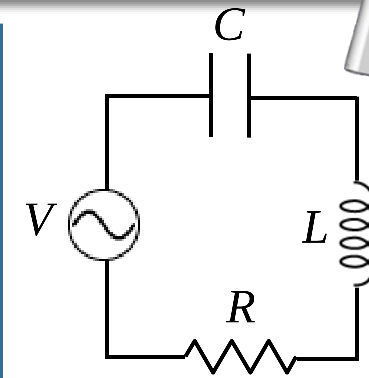
$I_{max} = 2\ mA$

$V_{Cmax} = 113\ V$ (= 80 sqrt(2))

The current leads generator voltage by 45^o (cos = sin = 1/sqrt(2))

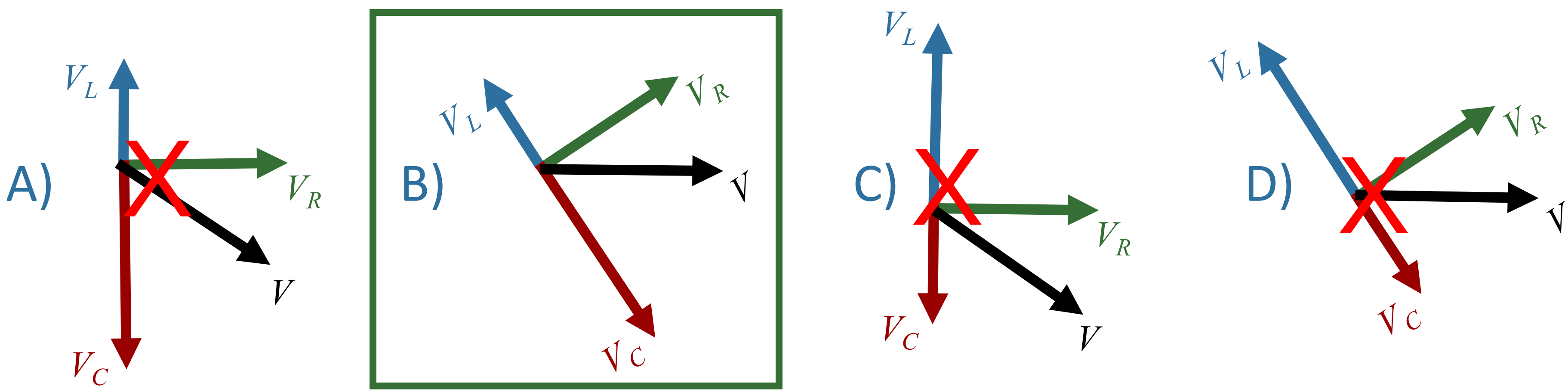
L and R are unknown.

What does the phasor diagram look like at t = 0? (assume $V = V_{max}\sin\omega t$)



$$R = 25\sqrt{2}\ k\Omega$$

$$X_L = 15\sqrt{2}\ k\Omega$$



$V = V_{max} \sin\omega t$ -> V is horizontal at $t = 0$ ($V = 0$)

$\vec{V} = \vec{V}_L + \vec{V}_C + \vec{V}_R$ → $V_L < V_C$ if current leads generator voltage

Follow-Up from Last Lecture

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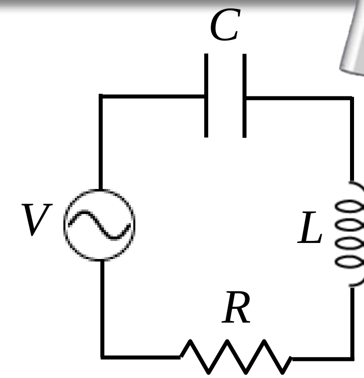


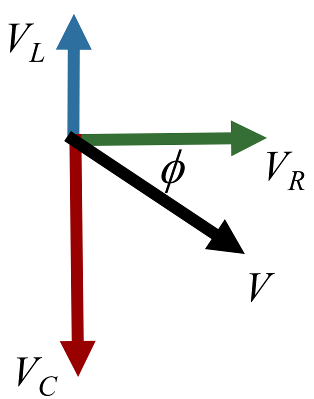
How should we change ω to bring circuit to resonance?

A) decrease ω

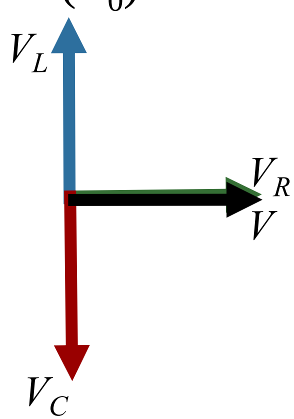
B) increase ω

C) Not enough info

Original ω



At resonance (ω_0)



At resonance

$X_L = X_C$

↓

X_L increases

X_C decreases

→ ω increases

More Follow-Up

Consider the harmonically driven series LCR circuit shown.

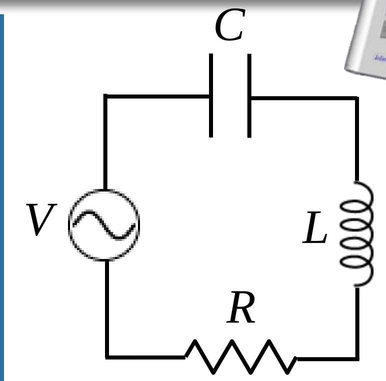
$V_{max} = 100\ V$

$I_{max} = 2\ mA$

$V_{Cmax} = 113\ V\ (= 80\ \text{sqrt}(2))$ → $X_C = 40\sqrt{2}\ k\Omega$

The current leads generator voltage by 45^o $(\cos = \sin = 1/\text{sqrt}(2))$

L and R are unknown.



$R = 25\sqrt{2}\ k\Omega$

$X_L = 15\sqrt{2}\ k\Omega$

By what factor should we increase ω to bring circuit to resonance?
i.e. if $\omega_0 = f\omega$, what is f?

A) $f = \sqrt{2}$

B) $f = 2\sqrt{2}$

C) $f = \sqrt{\frac{8}{3}}$

D) $f = \sqrt{\frac{8}{5}}$

If ω is increased by a factor of f:

X_L increases by factor of f

X_C decreases by factor of f

→

$X_L \to f \cdot 15\sqrt{2}$

$X_C \to (1/f) \cdot 40\sqrt{2}$

At resonance $X_L = X_C$ → $15 f = \frac{40}{f}$ → $f^2 = \frac{40}{15}$ → $f = \sqrt{\frac{8}{3}}$

Current Follow-Up

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100\ V$

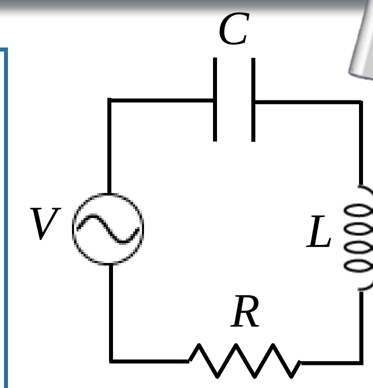
$I_{max} = 2\ mA$

$V_{Cmax} = 113\ V\ (= 80\ \mathrm{sqrt}(2))$ → $X_C = 40\sqrt{2}\ k\Omega$

The current leads generator voltage by 45^o (cos = sin = 1/sqrt(2))

L and R are unknown.

What is the maximum current at resonance



$$R = 25\sqrt{2}\ k\Omega$$

$$X_L = 15\sqrt{2}\ k\Omega$$

$$\omega_0 = \sqrt{\frac{8}{3}}\,\omega$$

A) $I_{\max}(\omega_0) = \sqrt{2}\,mA$

B) $I_{\max}(\omega_0) = 2\sqrt{2}\,mA$

C) $I_{\max}(\omega_0) = \sqrt{\frac{8}{3}}\,mA$

At resonance
$X_L = X_C$ → $Z = R$ → $I_{\max}(\omega_0) = \frac{V_{\max}}{R} = \frac{100}{25\sqrt{2}} = 2\sqrt{2}\,mA$