Oscilações EM e Corrente Alternada

Profa. Hilde Harb Buzzá

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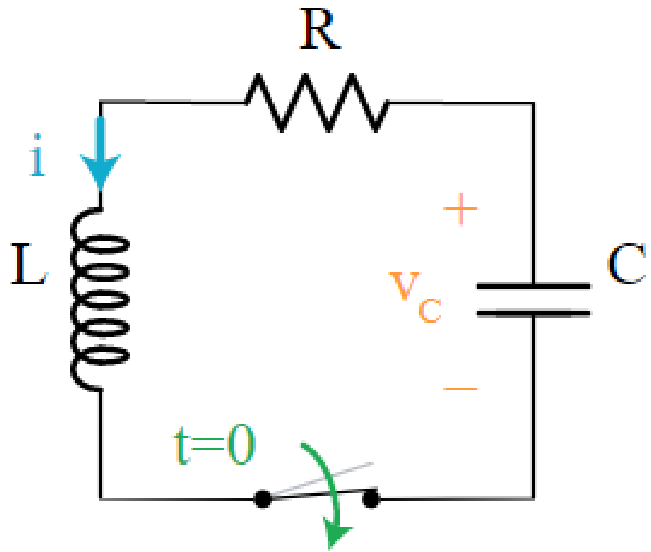
Parte II – o supra-sumo do sabor

Circuito RLC

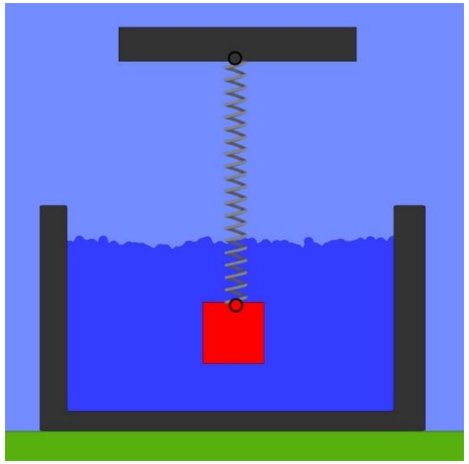


$$L\frac{d^2q}{dt^2}+R\frac{dq}{dt}+\frac{q}{C}=0$$

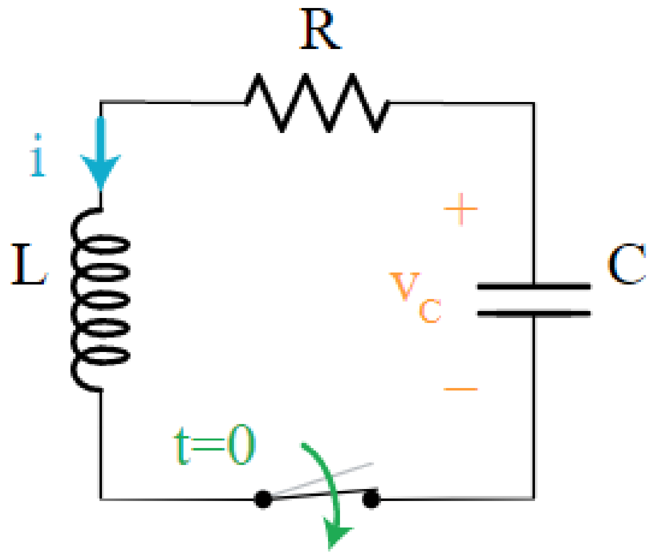
$$\frac{d^2q}{dt^2}+\frac{R}{L}\frac{dq}{dt}+\frac{1}{LC}q=0$$

Oscilador amortecido

$$\frac{d^2x}{dt^2}+\frac{b}{m}\frac{dx}{dt}+\frac{k}{m}x=0$$



Circuito RLC



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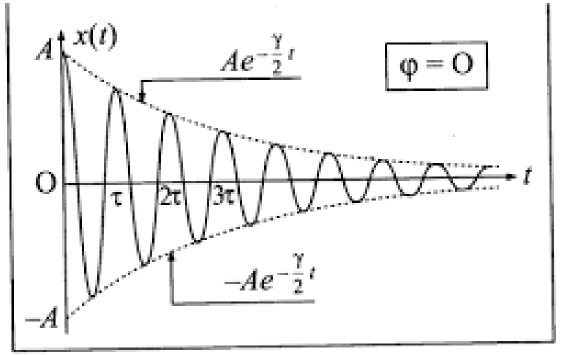
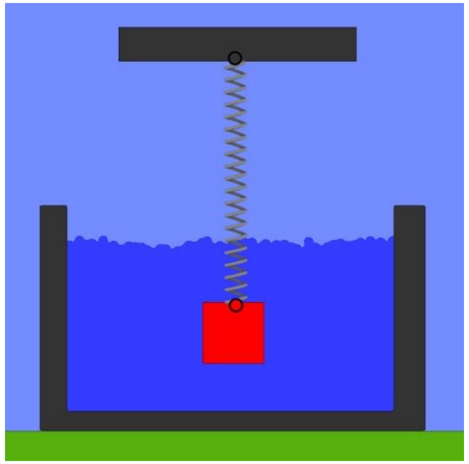


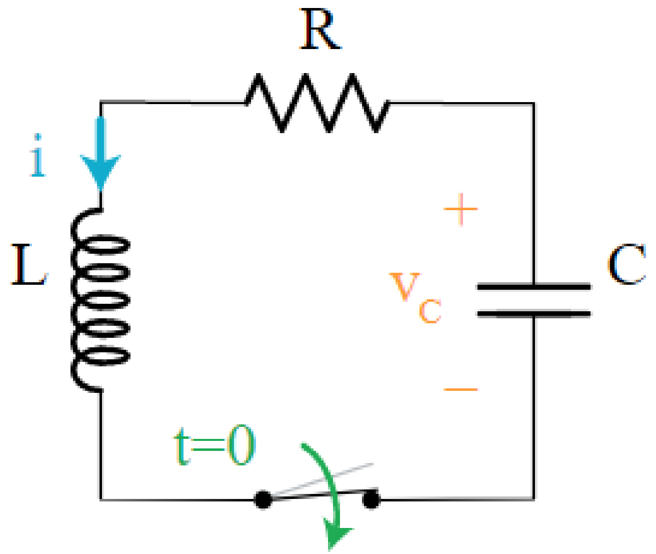
Figura 4.1 — *Oscilações amortecidas*

Oscilador amortecido

$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = 0$$



Circuito RLC



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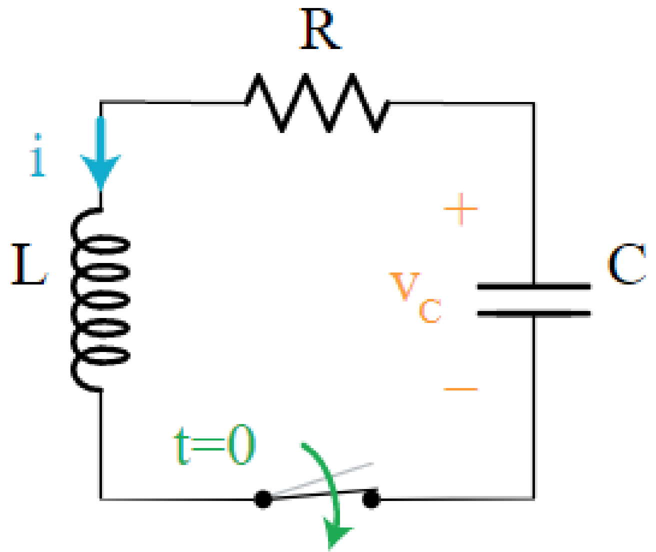
Lousa!

Circuito RLC



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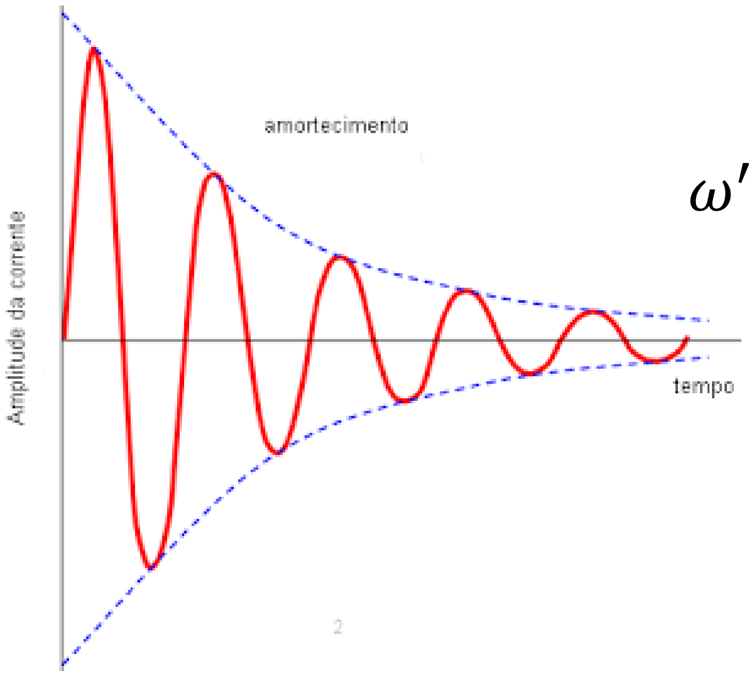
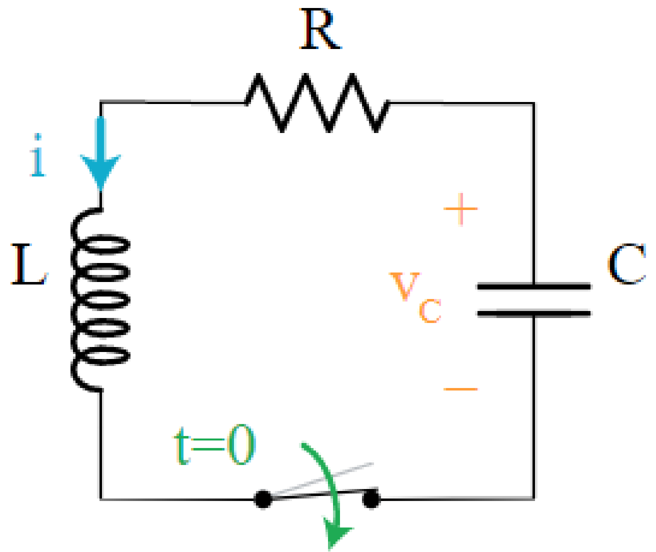
$$q = Qe^{-Rt/2L}\cos(\omega' t + \emptyset)$$



$$\omega' = \sqrt{\omega_0^2 - (\frac{R}{2L})^2}$$

Circuito RLC



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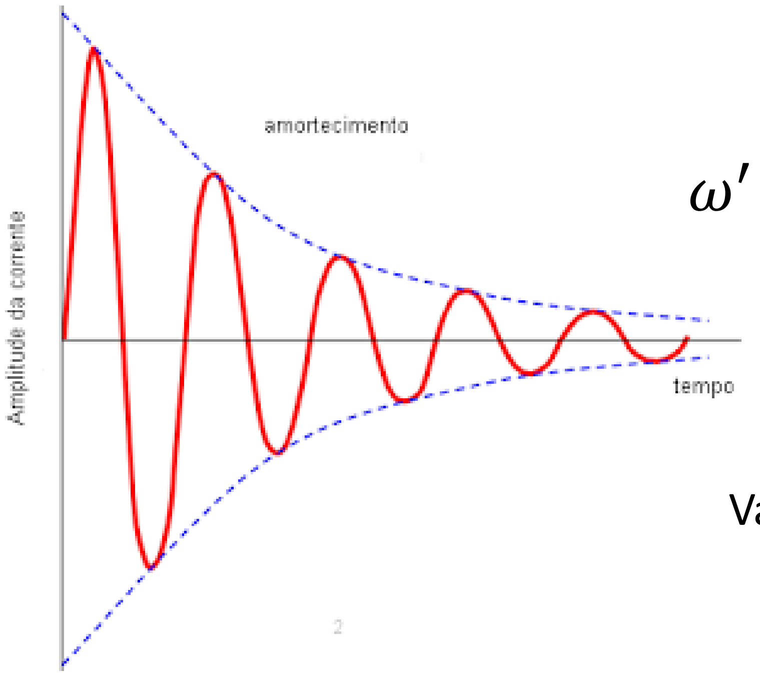
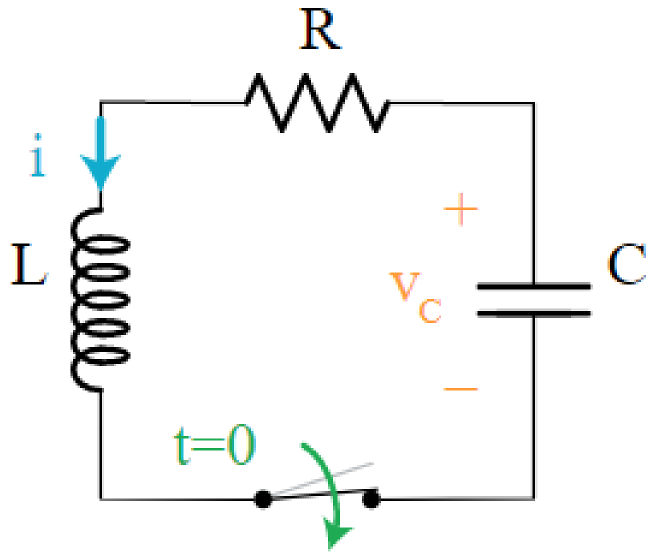


$$\omega' = \sqrt{\omega_0^2 - (\frac{R}{2L})^2}$$

Valores muito pequenos de R?

Circuito RLC



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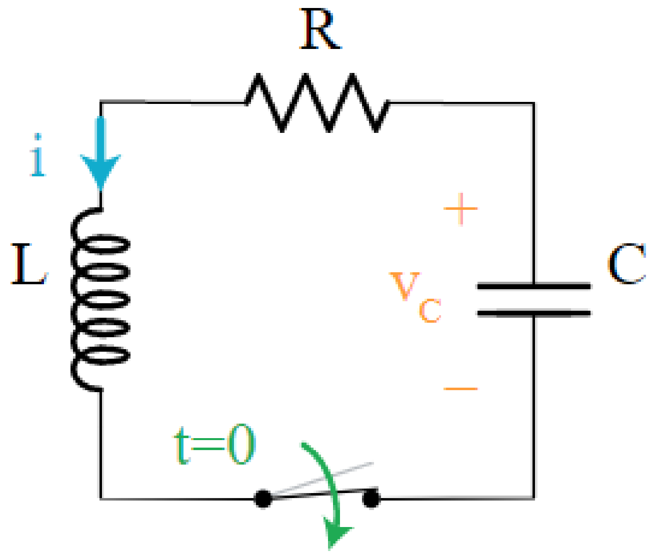
$$U_E = \frac{q^2}{2C}$$

Circuito RLC



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$$\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q = 0$$

$$q = Qe^{-Rt/2L}\cos(\omega' t + \emptyset)$$

$$U_E = \frac{q^2}{2C} = \frac{Q^2}{2C}e^{-Rt/L}\cos^2(\omega' t + \emptyset)$$

Corrente Alternada

Se fornecermos tensão externa pra compensar a energia dissipada pela R → não há amortecimento!

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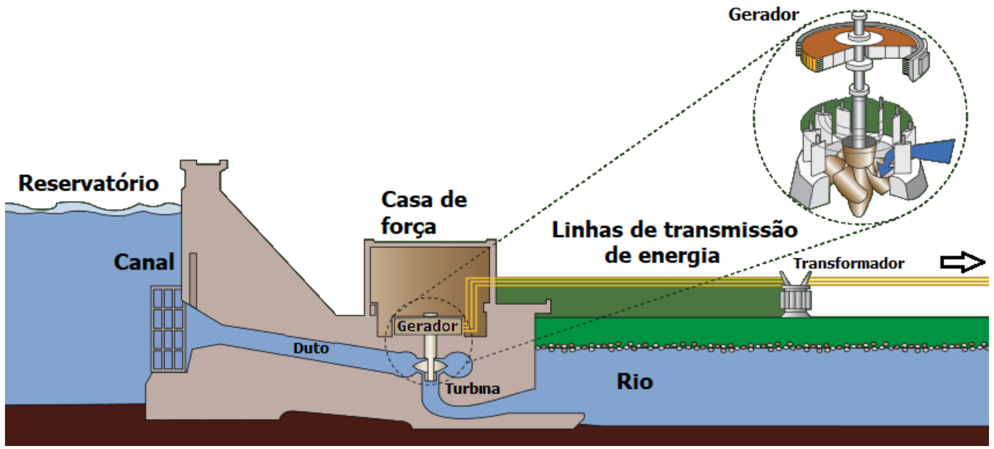

Corrente Alternada

Se fornecermos tensão externa pra compensar a energia dissipada pela R → não há amortecimento!

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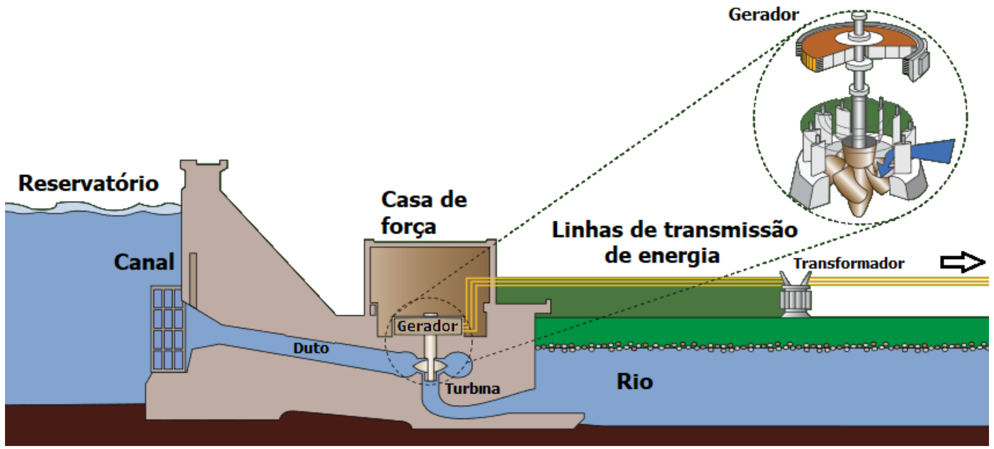
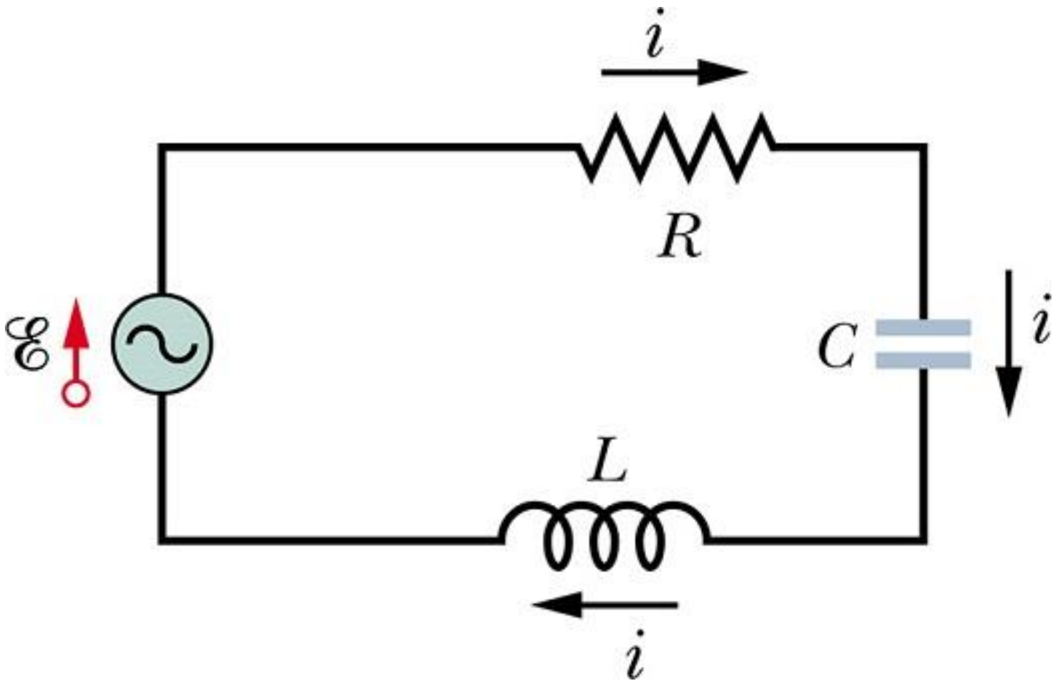
$$i = I sen(\omega_d t - \emptyset)$$

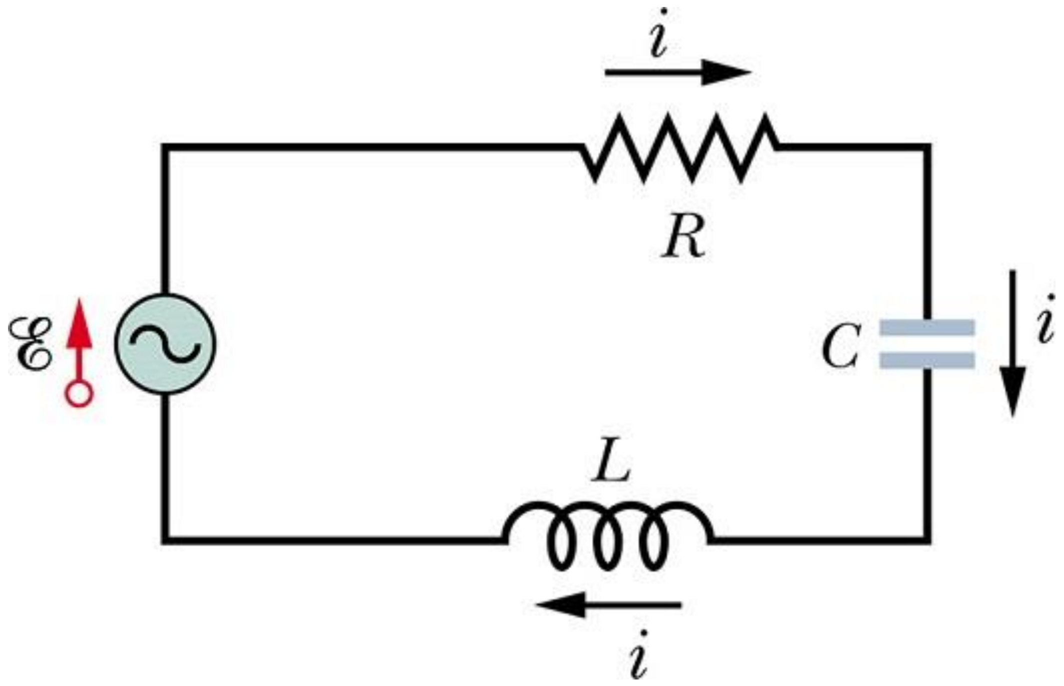


Oscilação forçada



https://wiki.ifsc.edu.br/mediawiki/index.php/AULA_7_-_Circuitos_2_-_Engenharia

Oscilação forçada



$$\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q =$$

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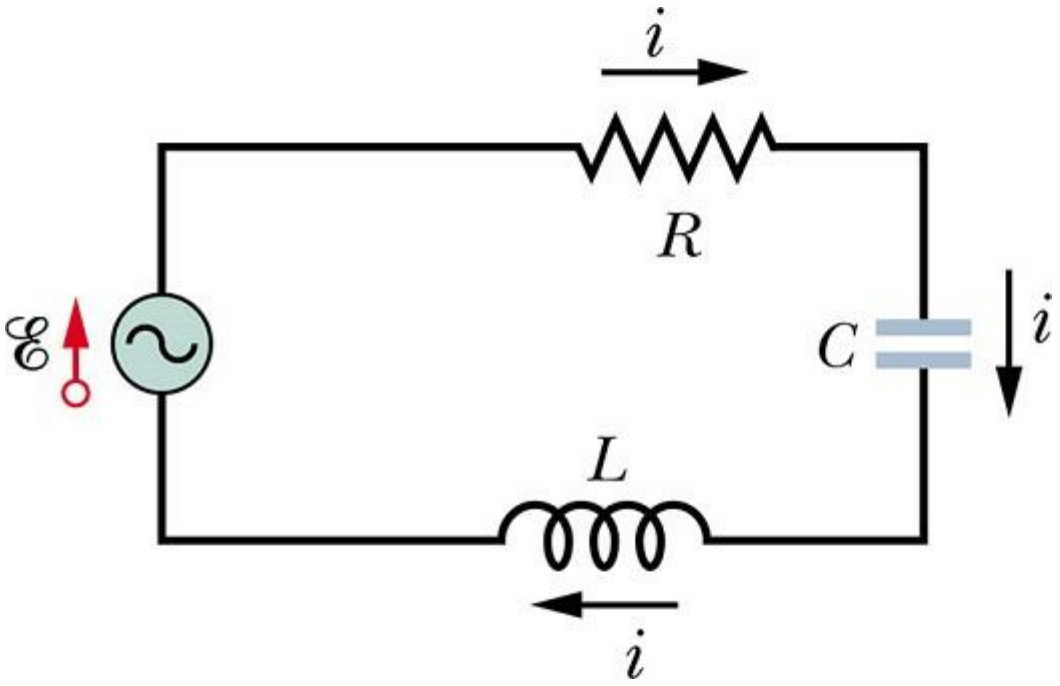

$$\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q = \varepsilon_{max} sen(\omega_d t)$$

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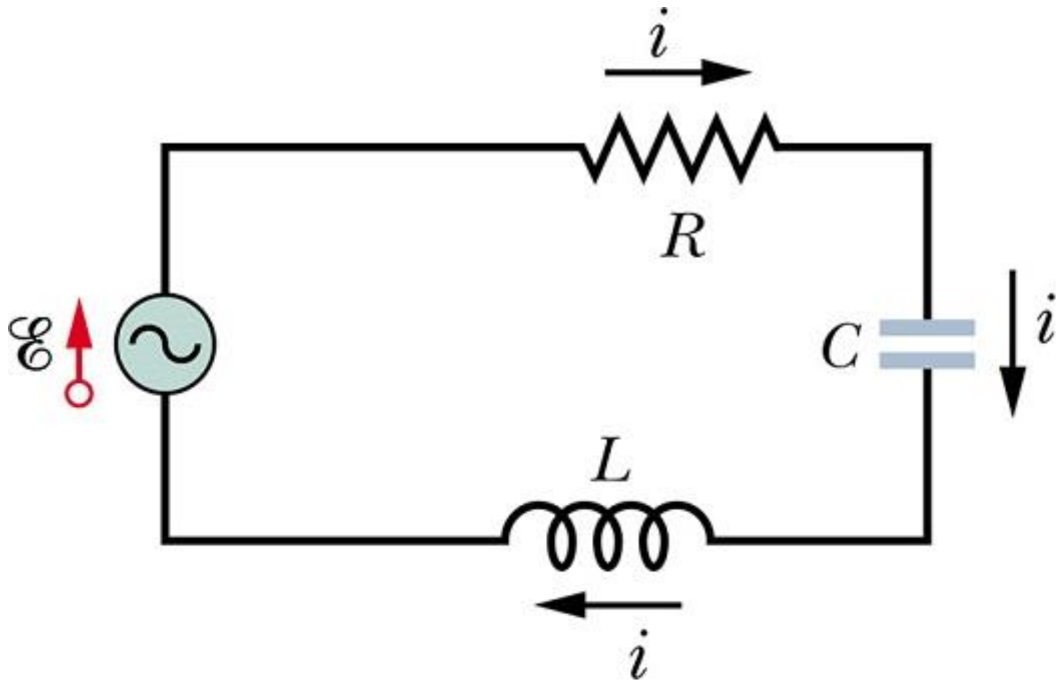

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Antes, circuitos mais simples!

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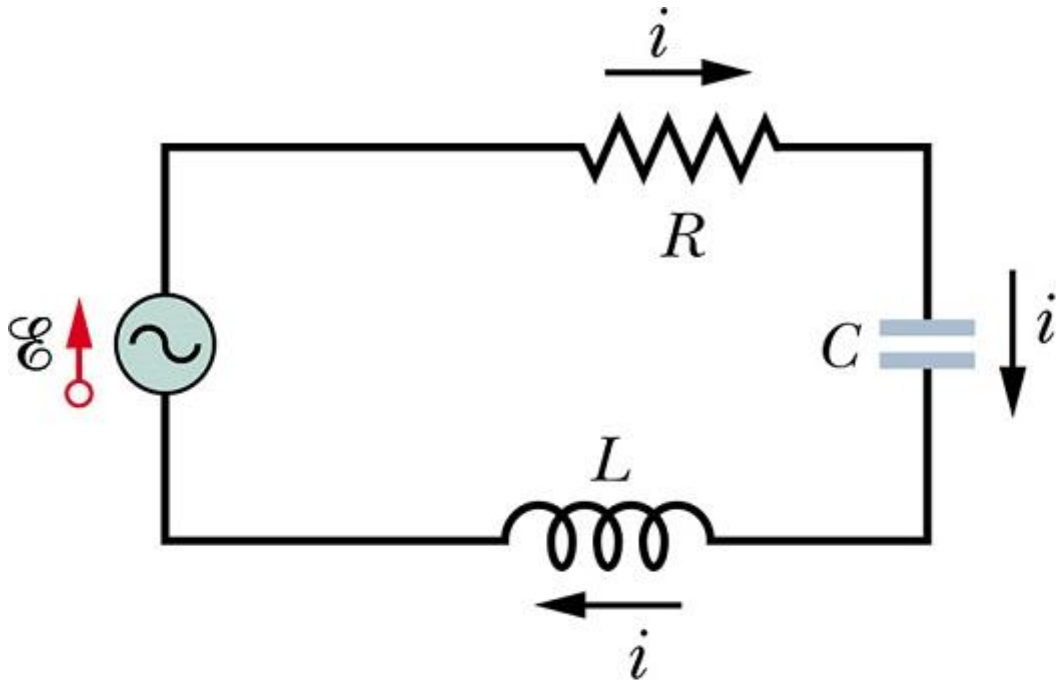

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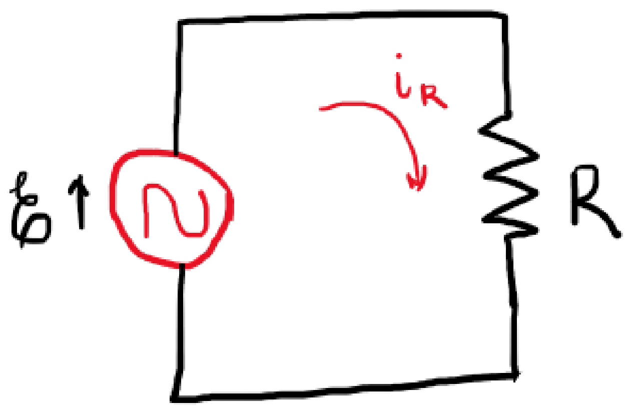
Circuito AC-R



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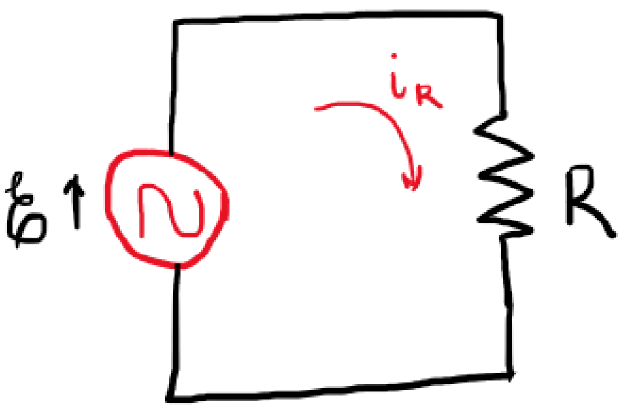
Circuito AC-R



$$\varepsilon = \varepsilon_{max} sen(\omega_d t)$$

$$\varepsilon - v_R = 0$$

$$\varepsilon - R i_R = 0$$

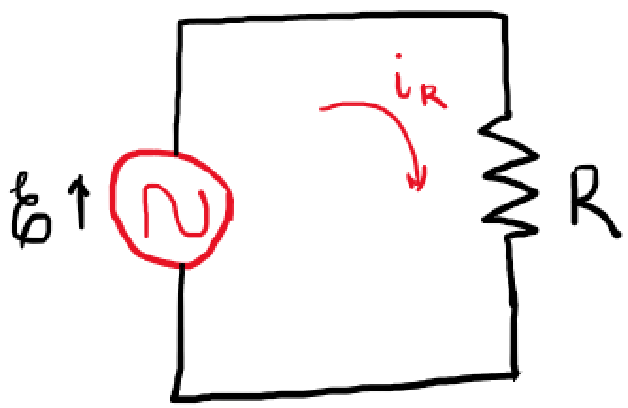
$$\varepsilon_{max} sen(\omega_d t) = R i_R$$

$$V_R sen(\omega_d t) = R i_R \rightarrow d.d.p \; em \; R$$

$$i_R = \frac{V_R}{R} sen(\omega_d t) = I_R sen(\omega_d t)$$

$$V_R = R.I_R$$ Amplitudes!

Circuito AC-R



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Corrente e tensão em fase!

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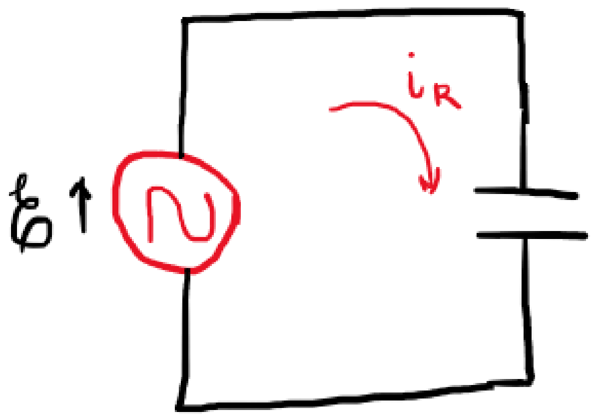
Circuito AC-C

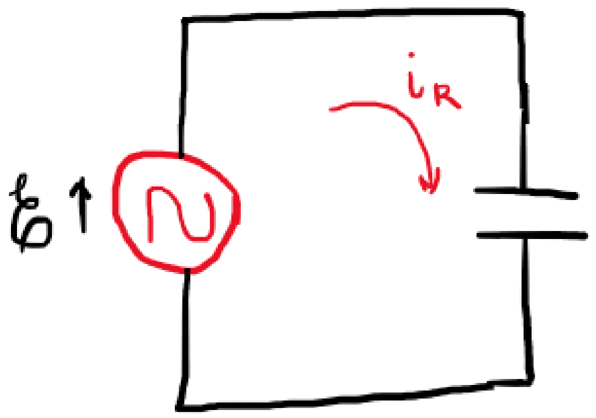


$$v_C = V_C sen(\omega_d t)$$

$$\frac{q_C}{C} = v_C \rightarrow q_C = CV_C sen(\omega_d t)$$

$$i_C = \frac{dq}{dt} = \omega_d C V_C cos(\omega_d t)$$

Circuito AC-C



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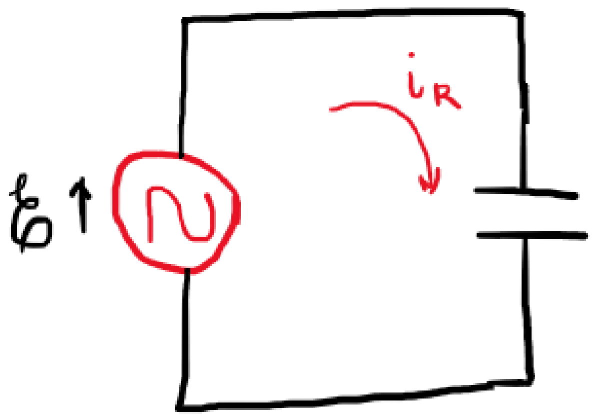

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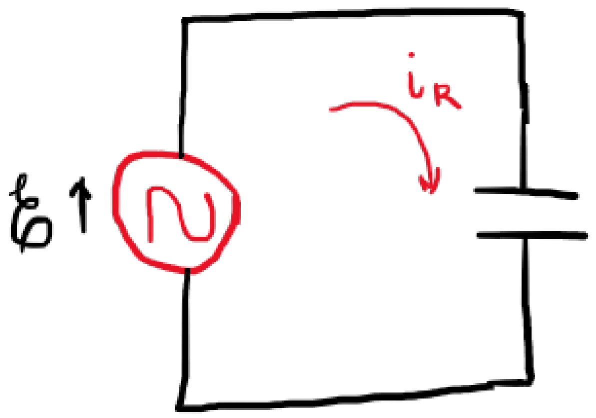
Definimos: $X_C = \dfrac{1}{\omega_d C}$ Reatância capacitiva

Circuito AC-C



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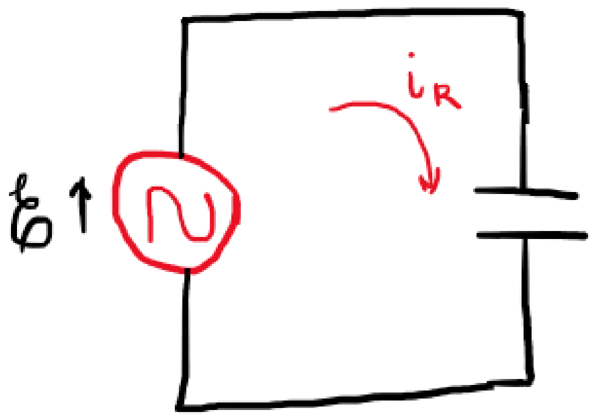
$$i_C = \frac{V_C}{X_C}.sen(\omega_d t + \pi/2)$$

Circuito AC-C



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Circuito AC-C

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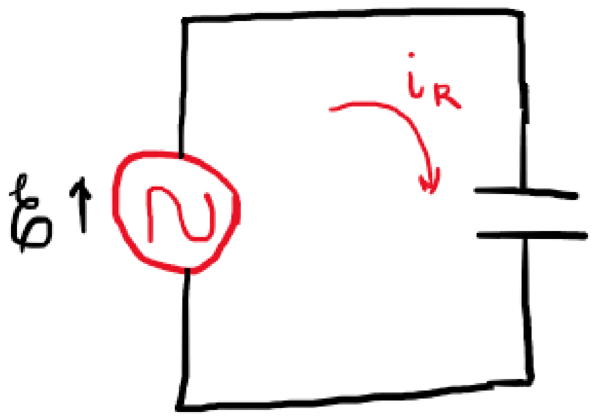

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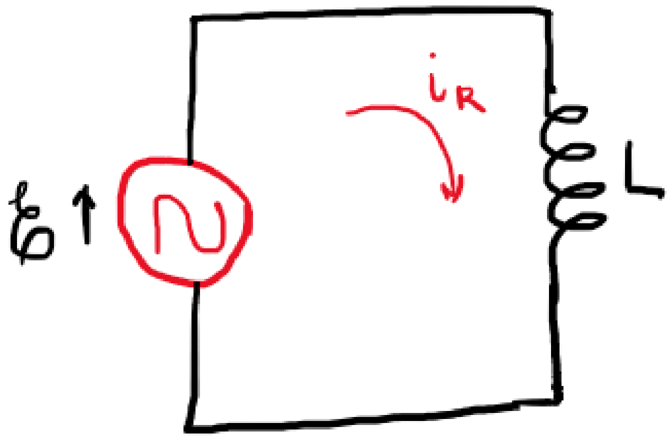
Amplitude $V_C = I_C X_C$

$$i_C = I_C sen(\omega_d t + \pi/2)$$

Circuito AC-L



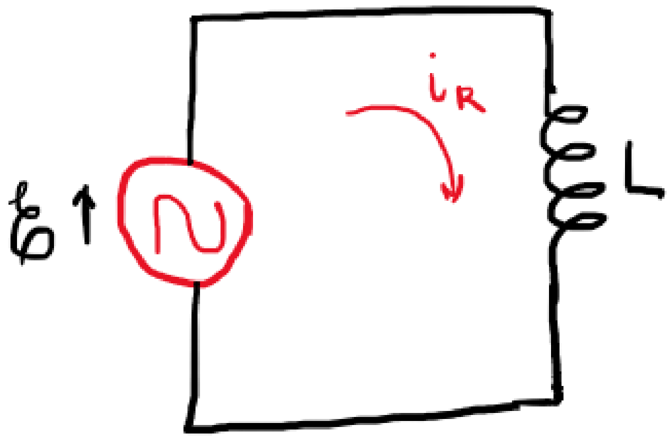
$$v_L = V_L sen(\omega_d t)$$

$$L.\frac{di}{dt} = v_L \rightarrow \frac{di_L}{dt} = \frac{V_L}{L} sen(\omega_d t)$$

$$\int di_L = \frac{V_L}{L} \int sen(\omega_d t) dt$$

$$i_L = -\frac{V_L}{\omega_d L} cos(\omega_d t)$$

Circuito AC-L



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Definimos: $X_L = \omega_d L$ Reatância indutiva

Circuito AC-L

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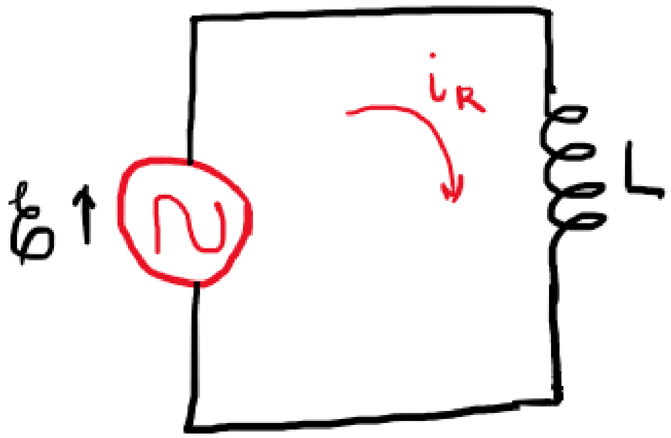

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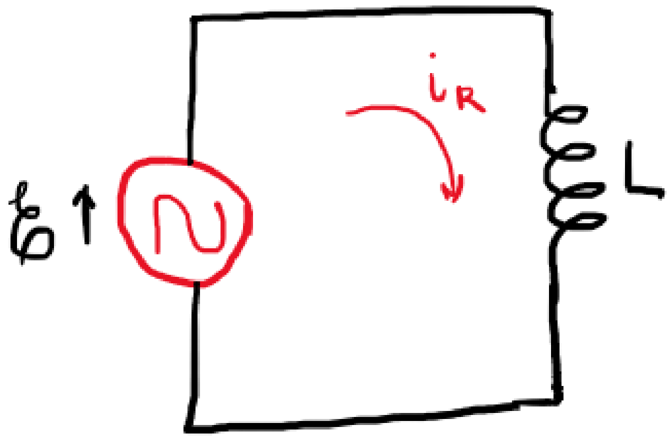

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Circuito AC-L

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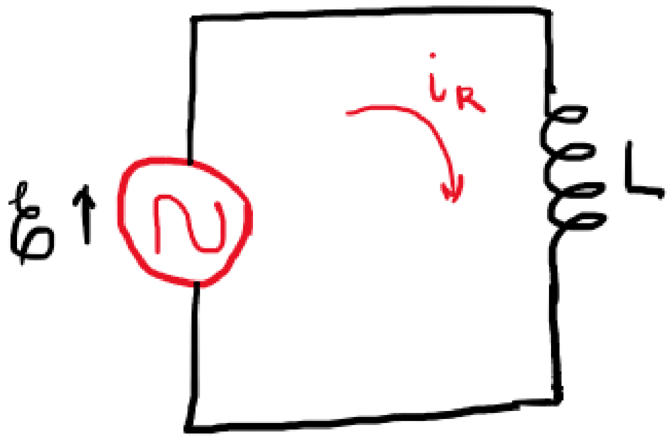

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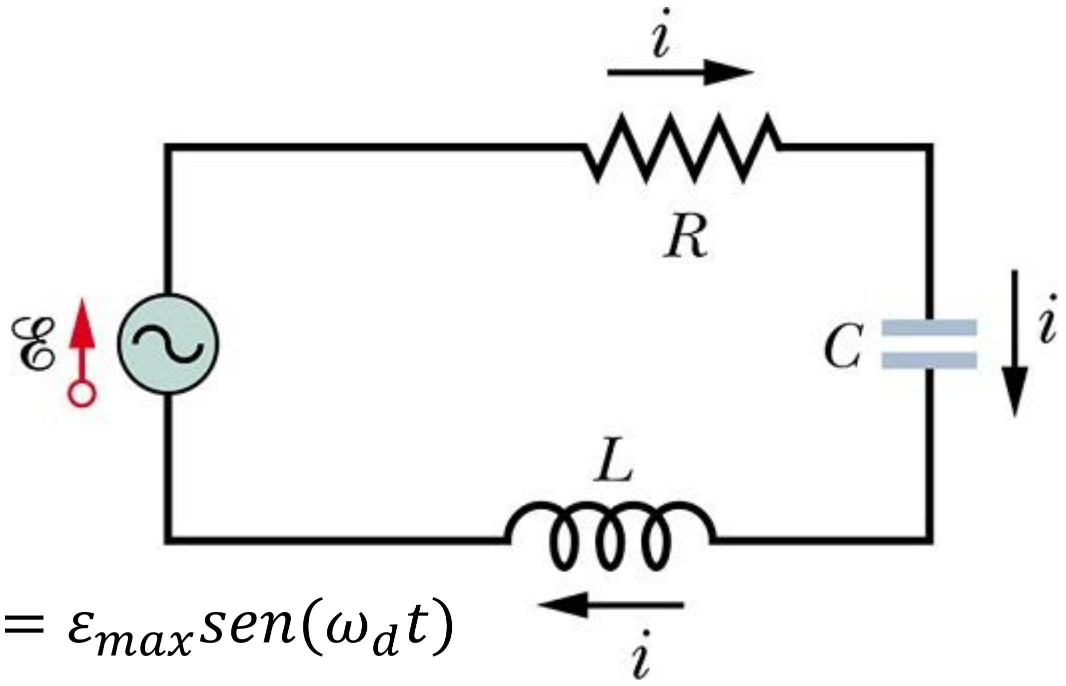
$$i_L = -\frac{V_L}{\omega_d L} cos(\omega_d t)$$

Amplitude $V_L = I_L X_L$

$$i_L = \frac{V_L}{X_L} sen(\omega_d t - \pi/2)$$

Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$

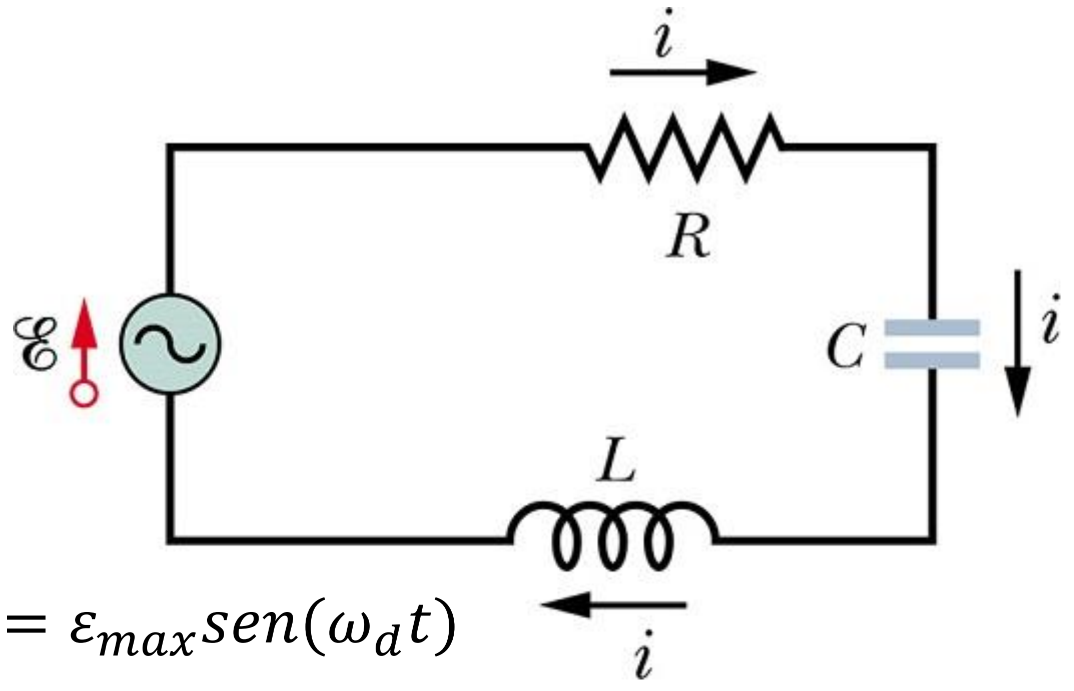


$$\varepsilon = \varepsilon_{max} sen(\omega_d t)$$

$$i = I sen(\omega_d t - \emptyset)$$

Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



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$$V_R = R.I_R$$

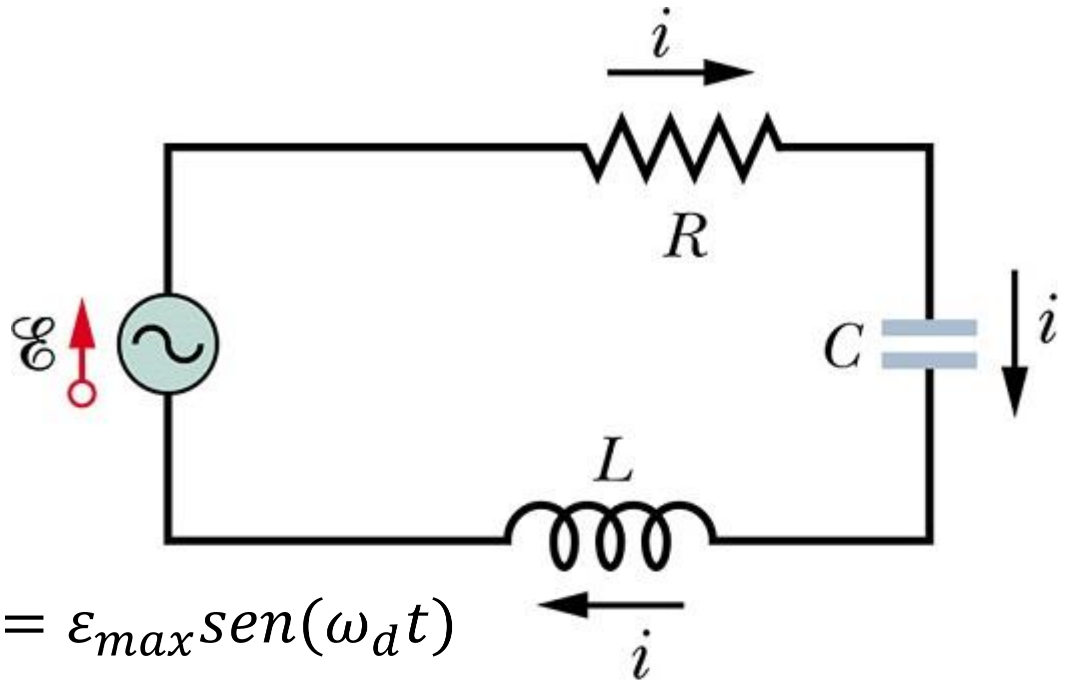
$$v_C = V_C sen(\omega_d t)$$
$$i_C = I_C sen(\omega_d t + \pi/2)$$
$$V_C = I_C X_C$$

$$v_L = V_L sen(\omega_d t)$$
$$i_L = \frac{V_L}{X_L} sen(\omega_d t - \pi/2)$$
$$V_L = I_L X_L$$

Fasores – lousa!

Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



$$V_R = R.I_R$$

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$$V_L = I_L X_L$$

$$\varepsilon = \varepsilon_{max} sen(\omega_d t)$$

$$\varepsilon_{max}{}^2 = v_R^2 + (v_L - v_C)^2$$

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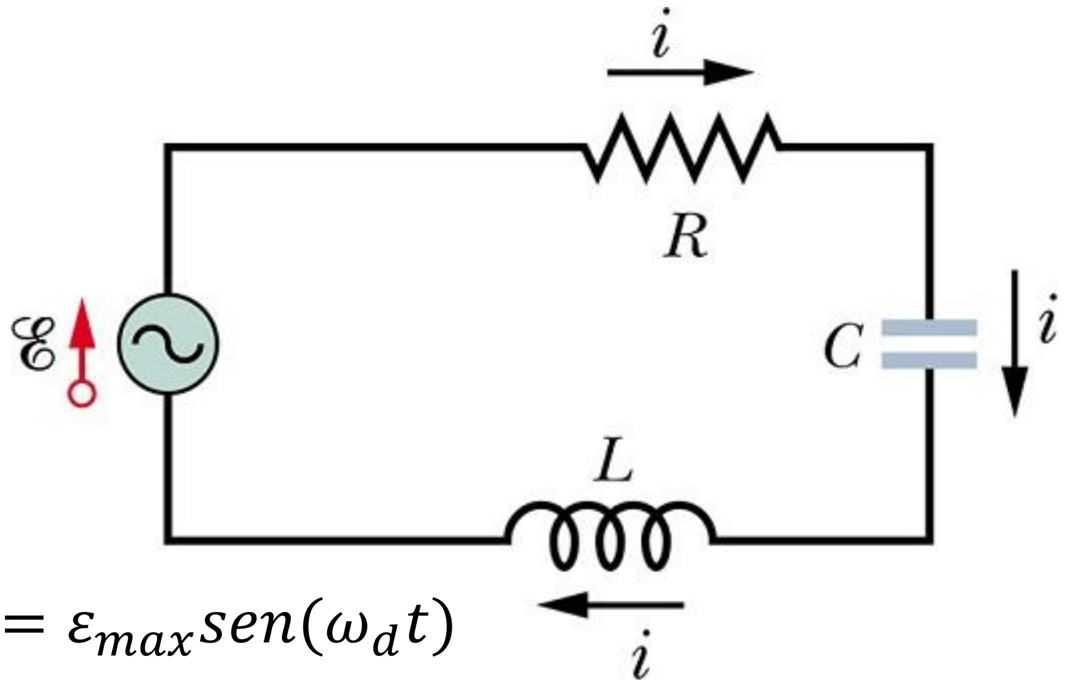
Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



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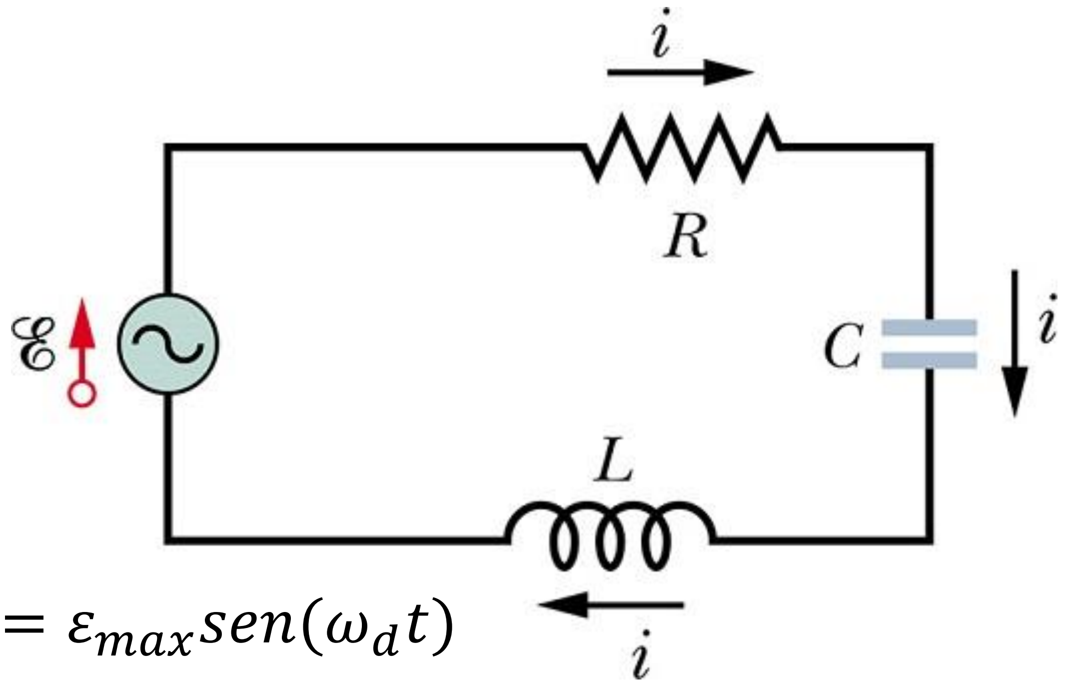
Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



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$$V_R = R.I_R$$

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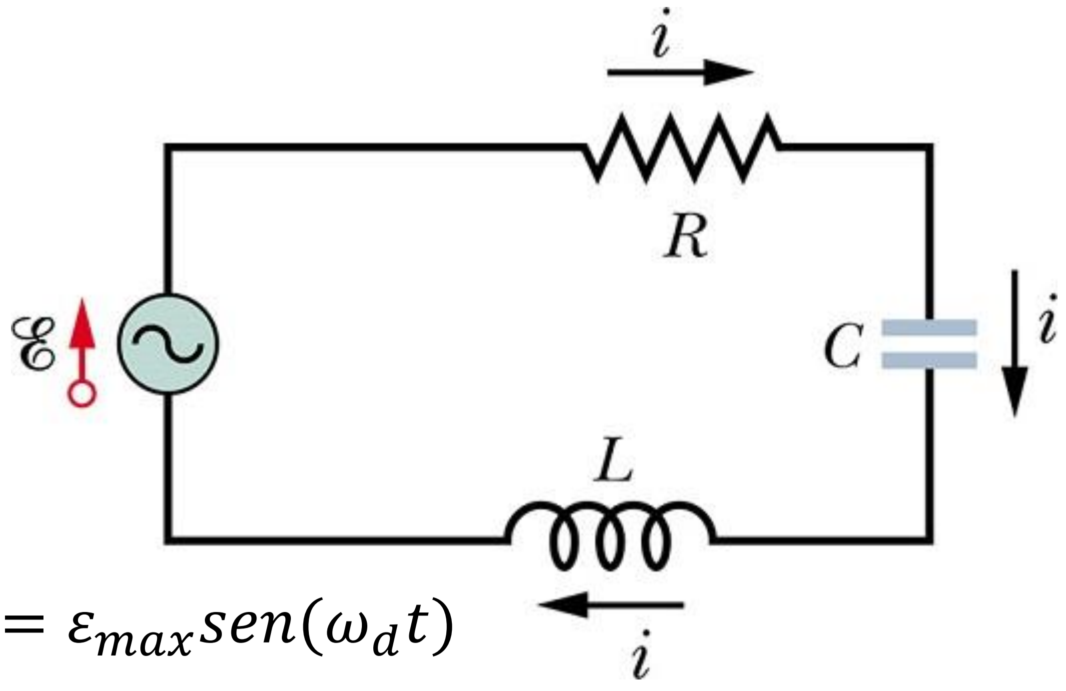
$$\varepsilon_{max}{}^2 = v_R^2 + (v_L - v_C)^2$$

$$\varepsilon_{max}{}^2 = (IR)^2 + (IX_L - IX_C)^2$$

$$I = \frac{\varepsilon_{max}}{\sqrt{(R)^2 + (X_L - X_C)^2}}$$

Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



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$$V_C = I_C X_C$$

$$V_L = I_L X_L$$

$$\varepsilon = \varepsilon_{max} sen(\omega_d t)$$

$$\varepsilon_{max}{}^2 = v_R^2 + (v_L - v_C)^2$$

$$\varepsilon_{max}{}^2 = (IR)^2 + (IX_L - IX_C)^2$$

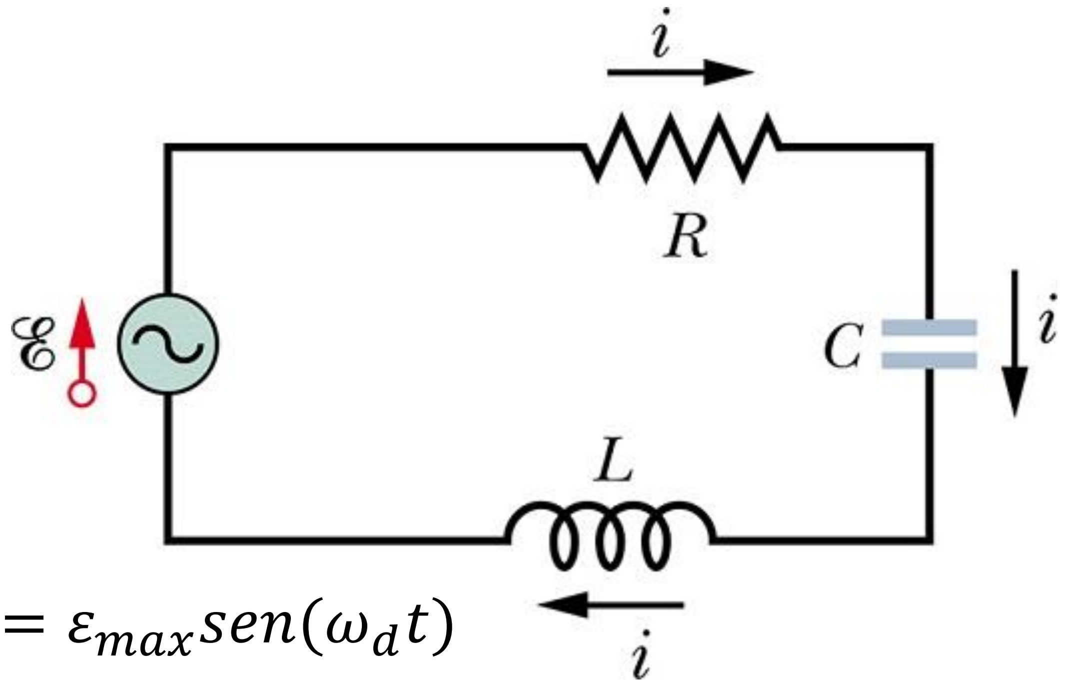
$$i = Isen(\omega_d t - \emptyset)$$

$$I = \frac{\varepsilon_{max}}{\sqrt{(R)^2 + (X_L - X_C)^2}}$$

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

Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



$$V_R = R.I_R$$

$$V_C = I_C X_C$$

$$V_L = I_L X_L$$

$$\varepsilon = \varepsilon_{max} sen(\omega_d t)$$

$${\varepsilon_{max}}^2 = v_R^2 + (v_L - v_C)^2$$

$${\varepsilon_{max}}^2 = (IR)^2 + (IX_L - IX_C)^2$$

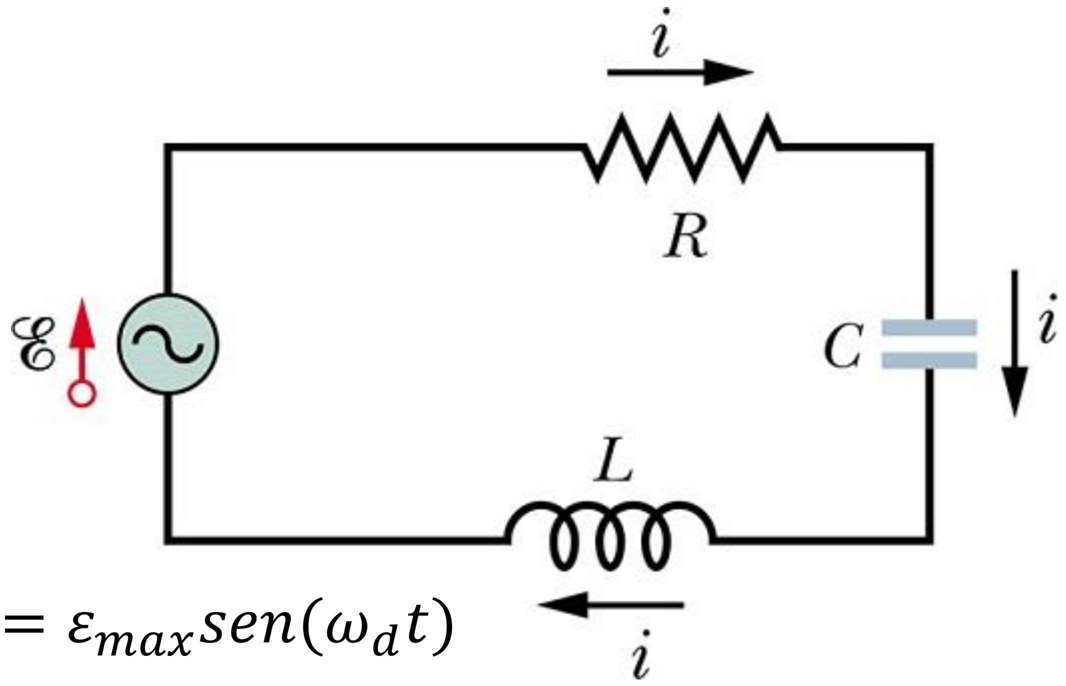
$$i = Isen(\omega_d t - \emptyset)$$

$$I = \frac{\varepsilon_{max}}{Z}$$

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

Circuito RLC em série

$$\varepsilon = v_R + v_C + v_L$$



$$\varepsilon = \varepsilon_{max} sen(\omega_d t)$$

$$i = Isen(\omega_d t - \emptyset)$$

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

$$V_R = R.I_R$$

$$V_C = I_C X_C$$

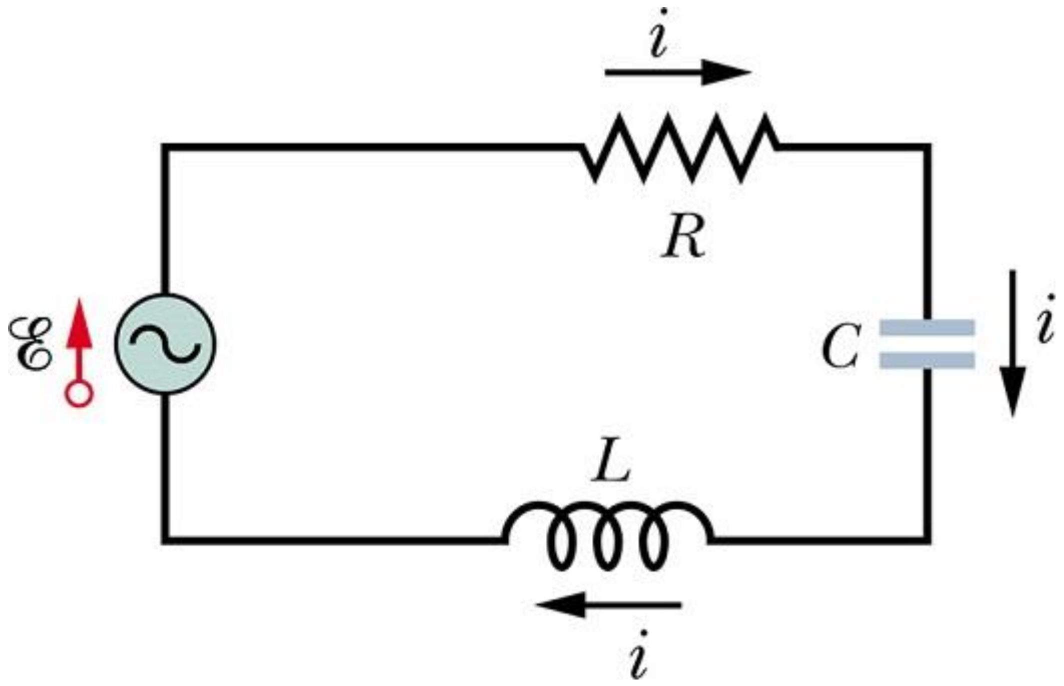
$$V_L = I_L X_L$$

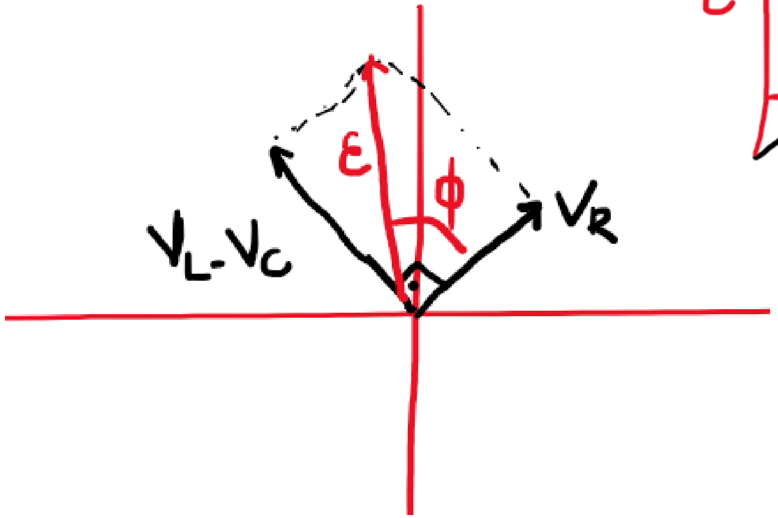
$$\varepsilon_{max}{}^2 = v_R^2 + (v_L - v_C)^2$$

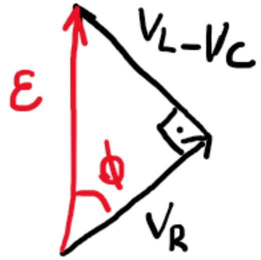
$$\varepsilon_{max}{}^2 = (IR)^2 + (IX_L - IX_C)^2$$

$$I = \frac{\varepsilon_{max}}{Z} = \frac{\varepsilon_{max}}{\sqrt{(R)^2 + (\omega_d L - 1/(\omega_d C)^2}}$$

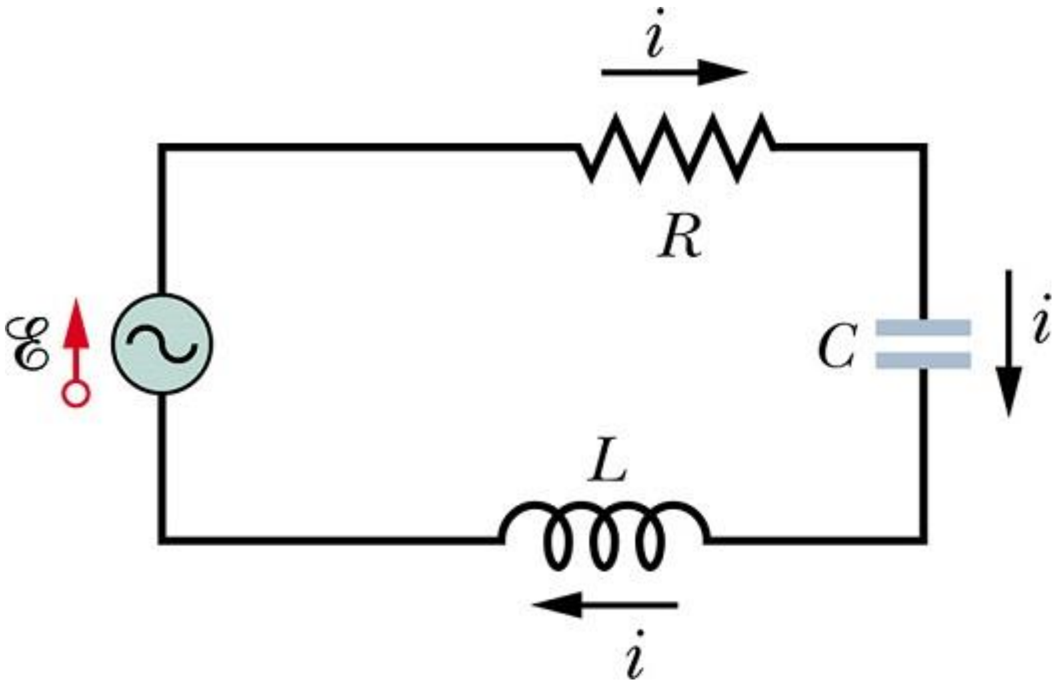
Circuito RLC em série

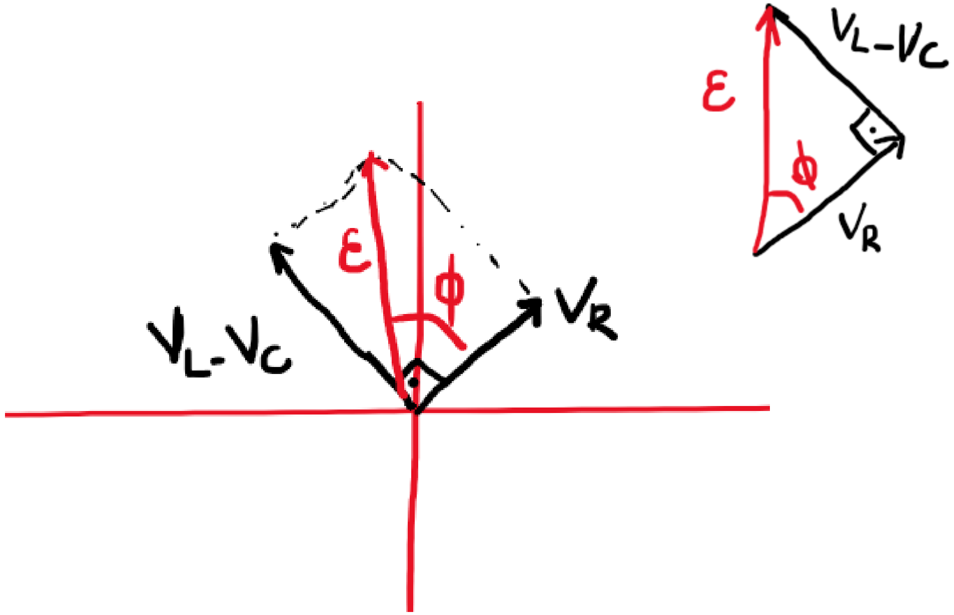






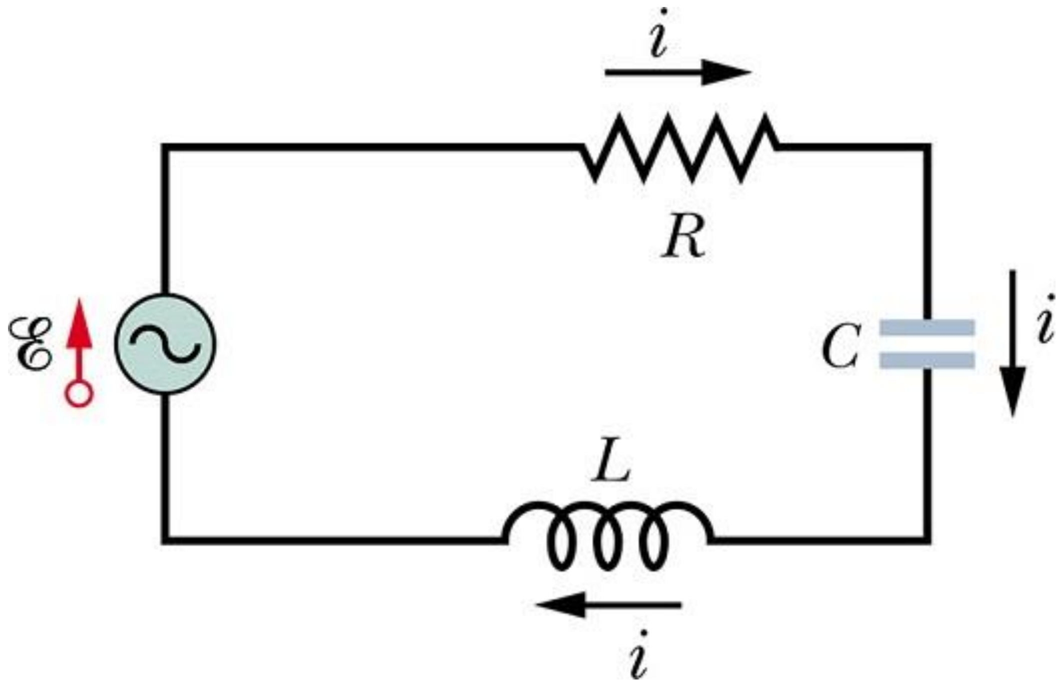
Circuito RLC em série

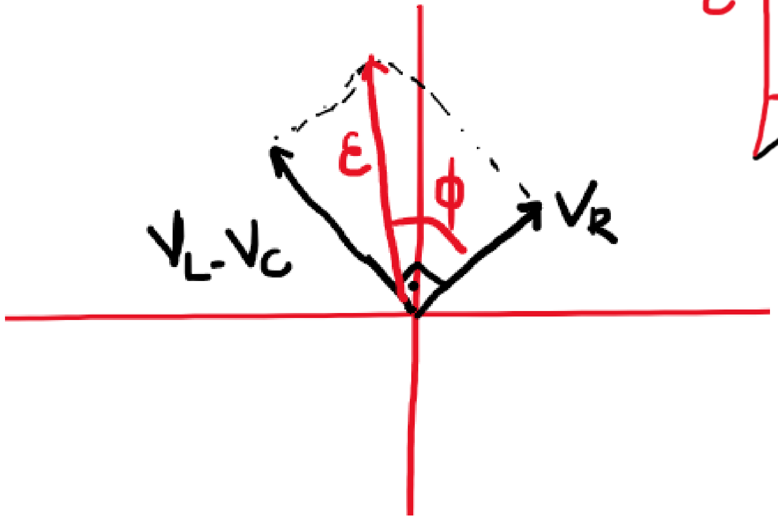


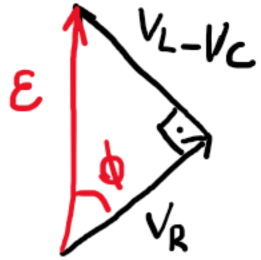


$$tg\emptyset = \frac{V_L - V_C}{R}$$

Circuito RLC em série

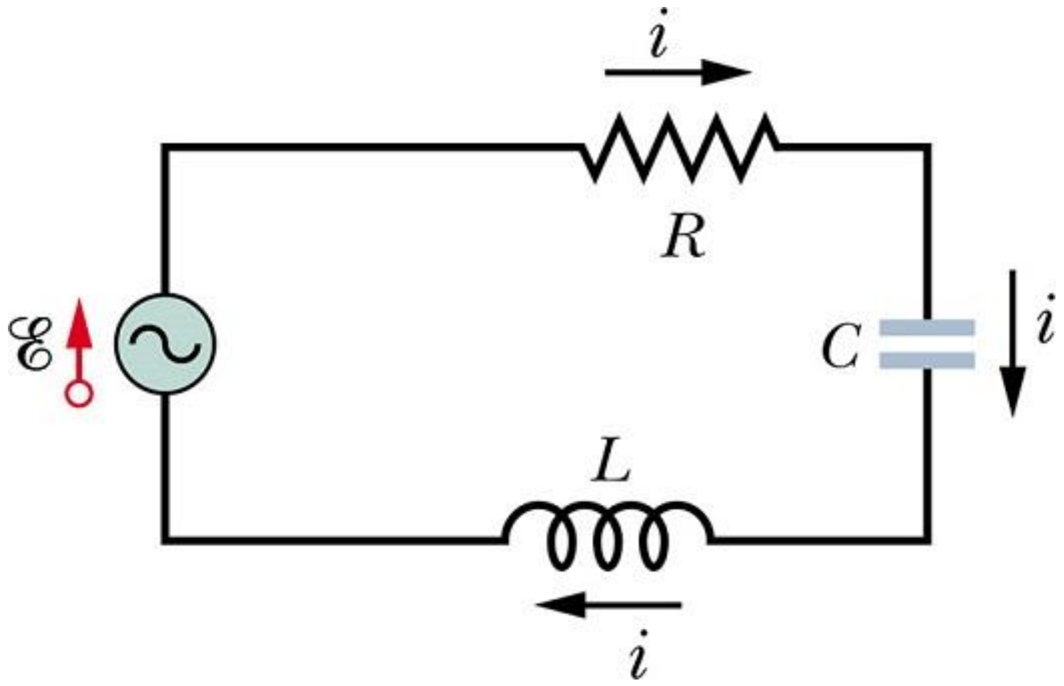


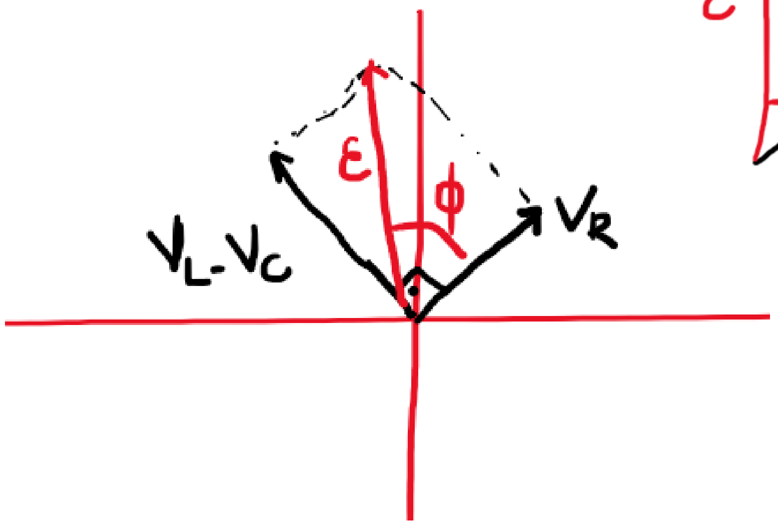


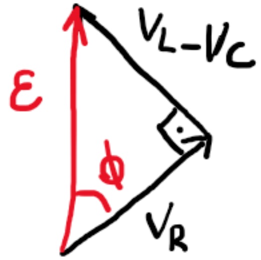


$$tg\emptyset = \frac{V_L - V_C}{V_R} = \frac{(IX_L - IX_C)}{IR}$$

Circuito RLC em série



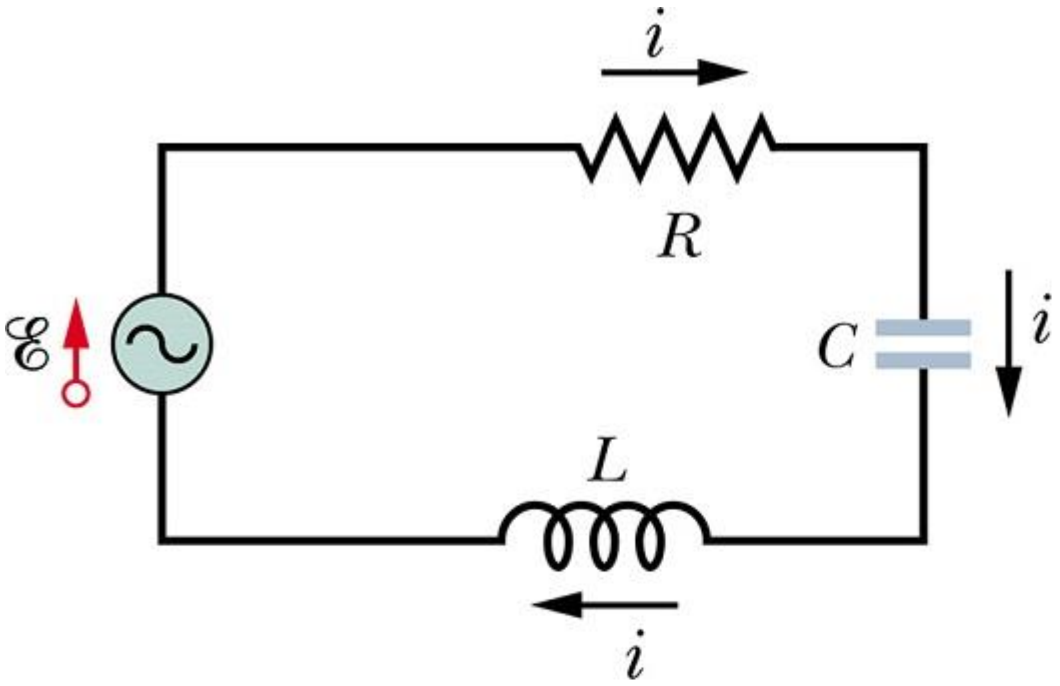


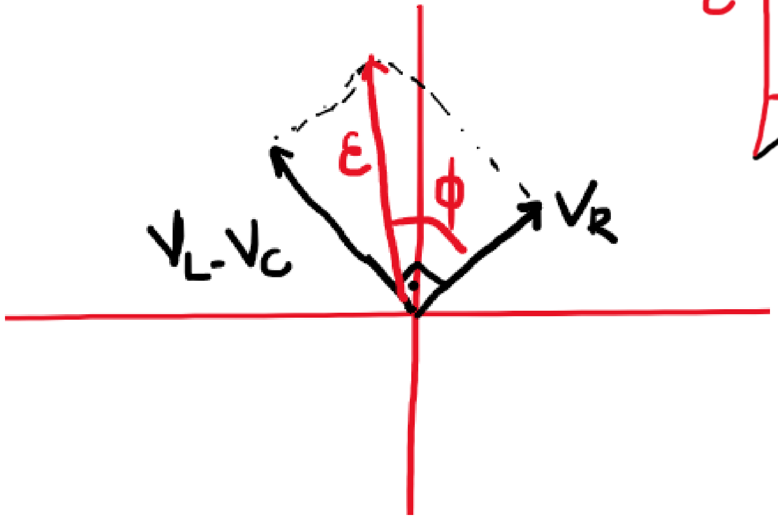


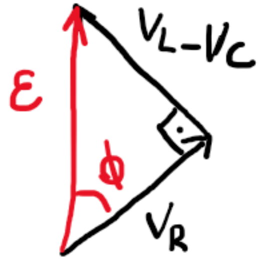
$$tg\emptyset = \frac{V_L - V_C}{V_R} = \frac{(IX_L - IX_C)}{IR}$$

$$tg\emptyset = \frac{(X_L - X_C)}{R}$$

Circuito RLC em série







$$tg\emptyset = \frac{V_L - V_C}{V_R} = \frac{(IX_L - IX_C)}{IR}$$

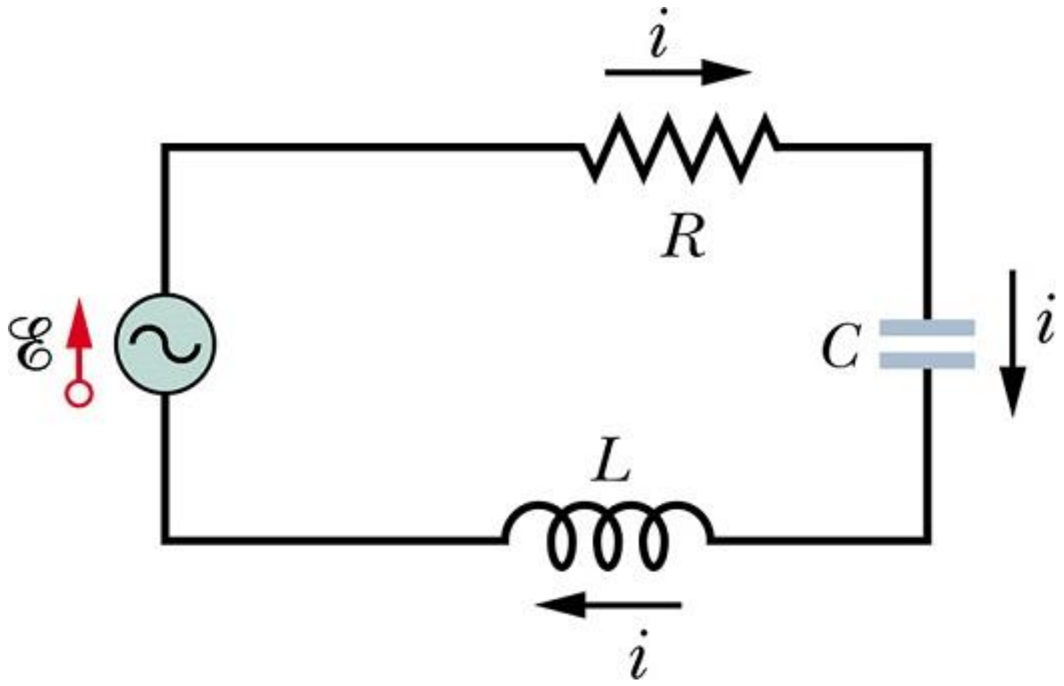
$$tg\emptyset = \frac{(X_L - X_C)}{R}$$

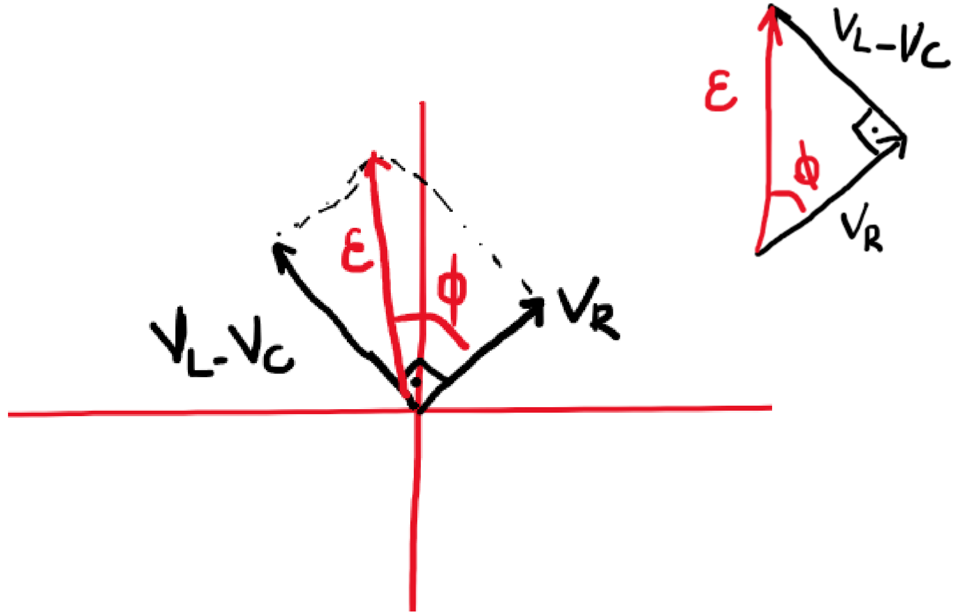
$X_L > X_C?$

$X_L < X_C?$

$X_L = X_C?$

Circuito RLC em série





$$tg\emptyset = \frac{V_L - V_C}{V_R} = \frac{(IX_L - IX_C)}{IR}$$

$$tg\emptyset = \frac{(X_L - X_C)}{R}$$

$X_L > X_C \rightarrow circuito\ mais\ indutivo$

$X_L < X_C \rightarrow circuito\ mais\ capacitivo$

$X_L = X_C \rightarrow$ ressonância

Circuito RLC em série - Ressonância

$X_L = X_C \rightarrow \text{ressonância}$

$$tg\emptyset = \frac{(X_L - X_C)}{R}$$

Circuito RLC em série - Ressonância

$X_L = X_C \rightarrow \text{ressonância}$

$$tg\emptyset = \frac{(X_L - X_C)}{R} = 0 \ \rightarrow \emptyset = 0$$

Circuito RLC em série - Ressonância

$X_L = X_C \rightarrow \text{ressonância}$

$$tg\emptyset = \frac{(X_L - X_C)}{R} = 0 \ \rightarrow \emptyset = 0$$

$$L\omega_d = 1/C\omega_d$$

Circuito RLC em série - Ressonância

$X_L = X_C \rightarrow$ ressonância

$$tg\emptyset = \frac{(X_L - X_C)}{R} = 0 \ \rightarrow \emptyset = 0$$

$$L\omega_d = 1/C\omega_d$$

$$\omega_d{}^2 = 1/LC$$

Circuito RLC em série - Ressonância

$X_L = X_C \rightarrow$ ressonância

$$tg\emptyset = \frac{(X_L - X_C)}{R} = 0 \rightarrow \emptyset = 0$$

$$L\omega_d = 1/C\omega_d$$

$$\omega_d^2 = \frac{1}{LC} = \omega_0^2$$

Circuito RLC em série - Ressonância

$X_L = X_C \rightarrow$ ressonância

$$I = \frac{\varepsilon_{max}}{\sqrt{(R)^2 + (X_L - X_C)^2}}$$

$$tg\emptyset = \frac{(X_L - X_C)}{R} = 0 \rightarrow \emptyset = 0$$

$$L\omega_d = 1/C\omega_d$$

$$\omega_d^2 = \frac{1}{LC} = \omega_0^2$$

Circuito RLC em série - Ressonância

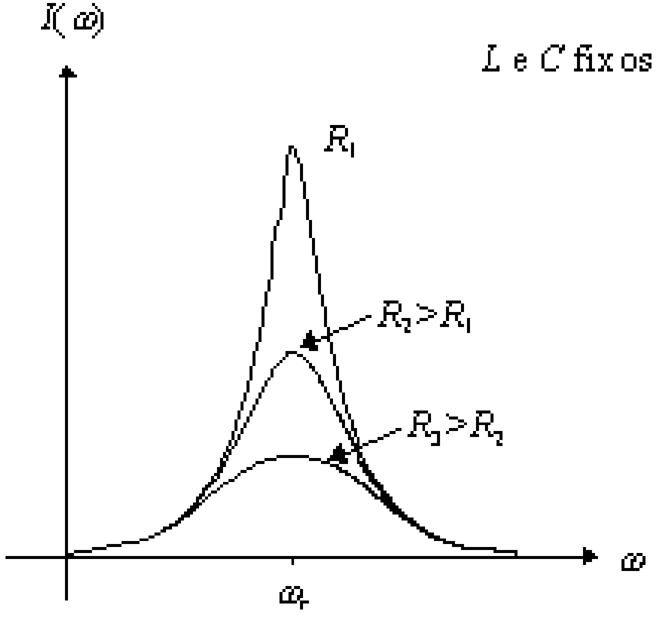
$X_L = X_C \rightarrow$ ressonância

$$tg\emptyset = \frac{(X_L - X_C)}{R} = 0 \rightarrow \emptyset = 0$$

$$L\omega_d = 1/C\omega_d$$

$$\omega_d^2 = \frac{1}{LC} = \omega_0^2$$

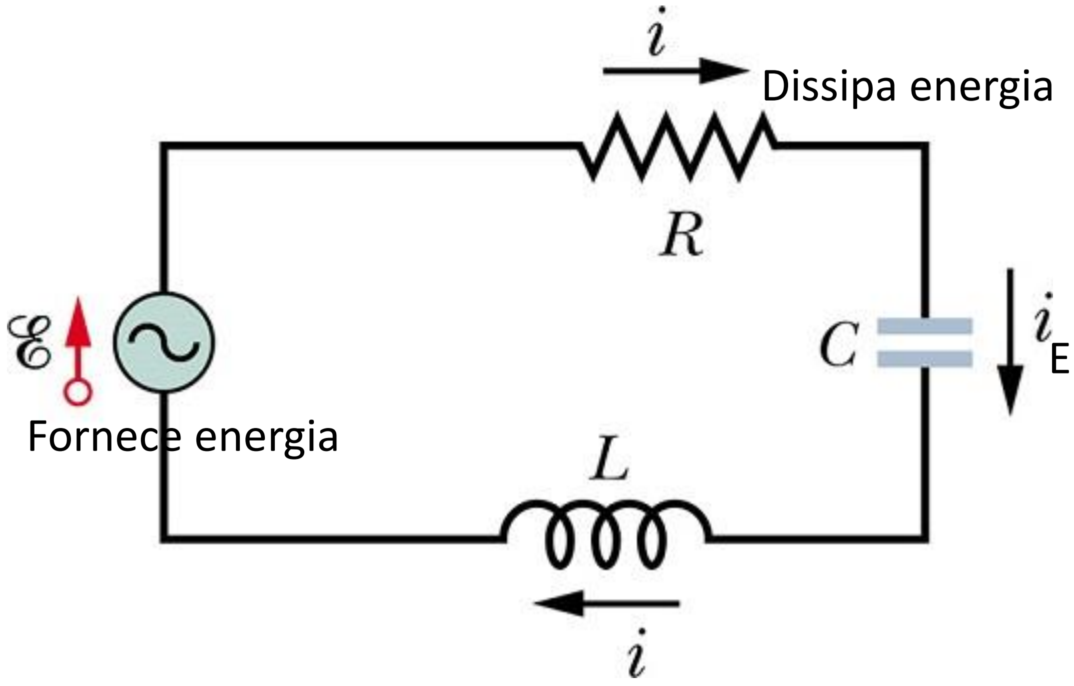
$$I = \frac{\varepsilon_{max}}{\sqrt{(R)^2 + (X_L - X_C)^2}}$$



(a)

Potência em AC

No regime estacionário!



Dissipa energia

Energia permanece constante

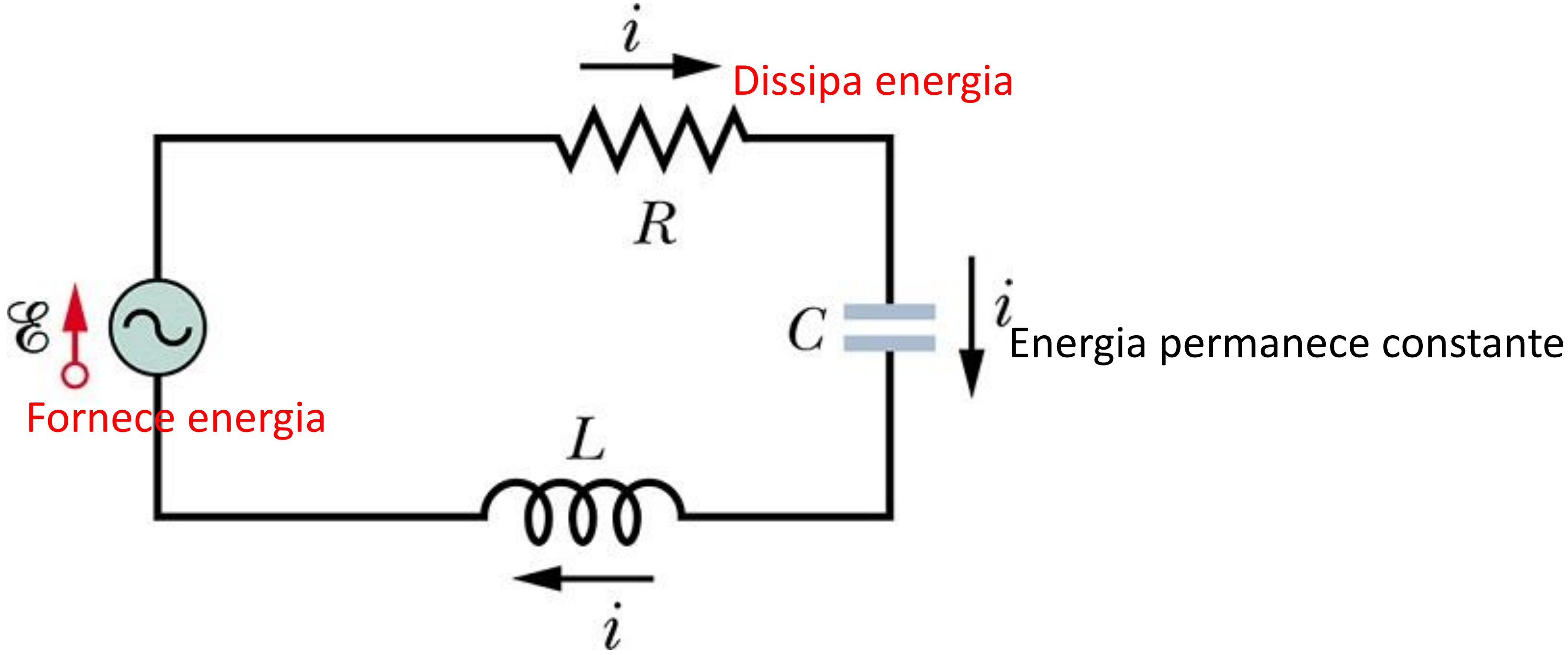
Fornece energia

Energia permanece constante

Potência em AC

No regime estacionário!

$$Pot = i^2 R = \left(I sen(\omega_d t - \emptyset)\right)^2 R$$

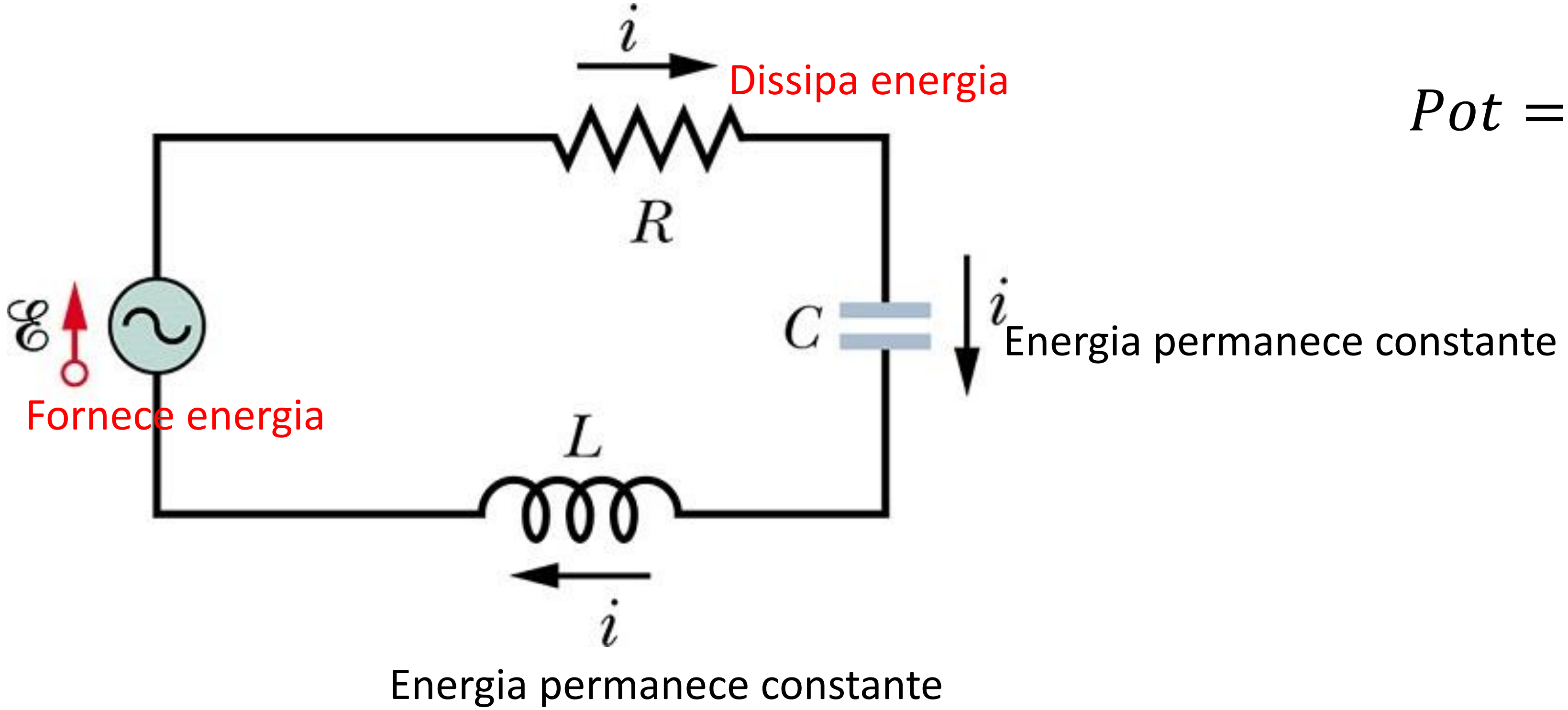


Energia permanece constante

$$i = I sen(\omega_d t - \emptyset)$$

Potência em AC

No regime estacionário!



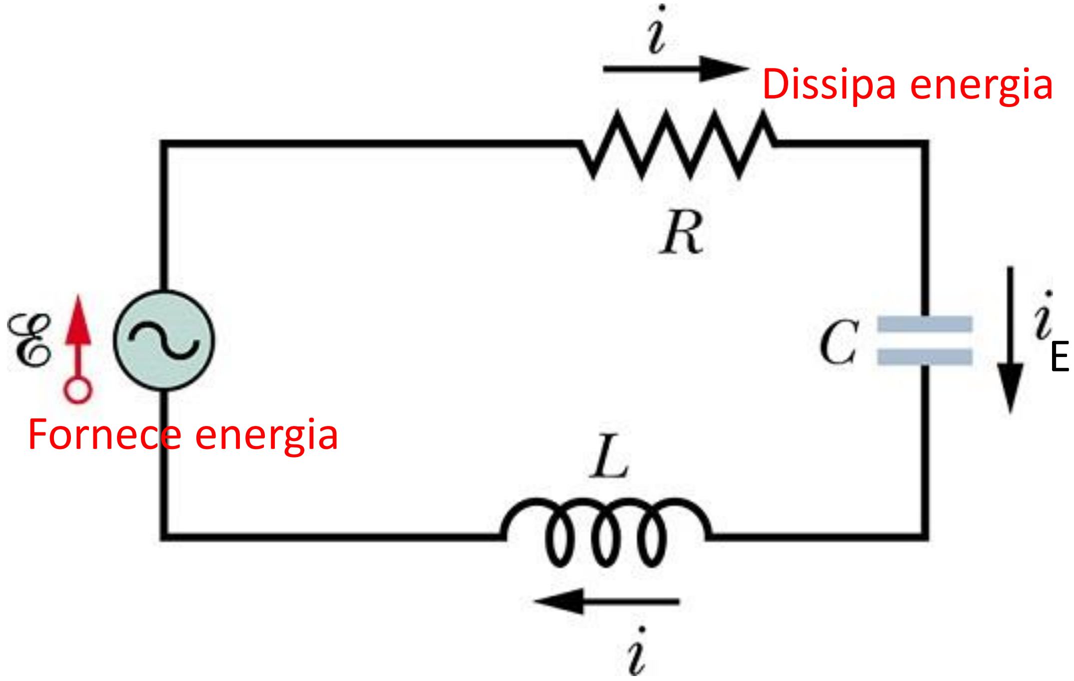
$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

$$i = Isen(\omega_d t - \emptyset)$$

Potência em AC

No regime estacionário!



Energia permanece constante

$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

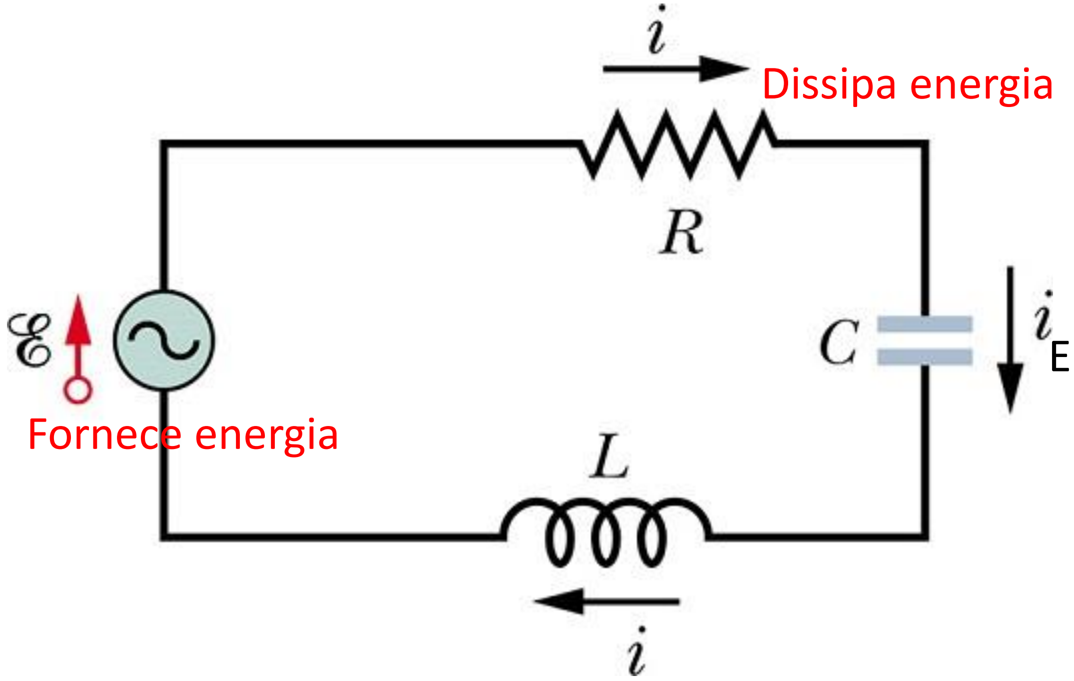
$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

$$Pot_{média} = I^2R\left(\frac{1}{2}\right)$$

$$i = Isen(\omega_d t - \emptyset)$$

Potência em AC

No regime estacionário!



Dissipa energia

Energia permanece constante

Fornece energia

Energia permanece constante

$$i = Isen(\omega_d t - \emptyset)$$

$$Pot = i^2 R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

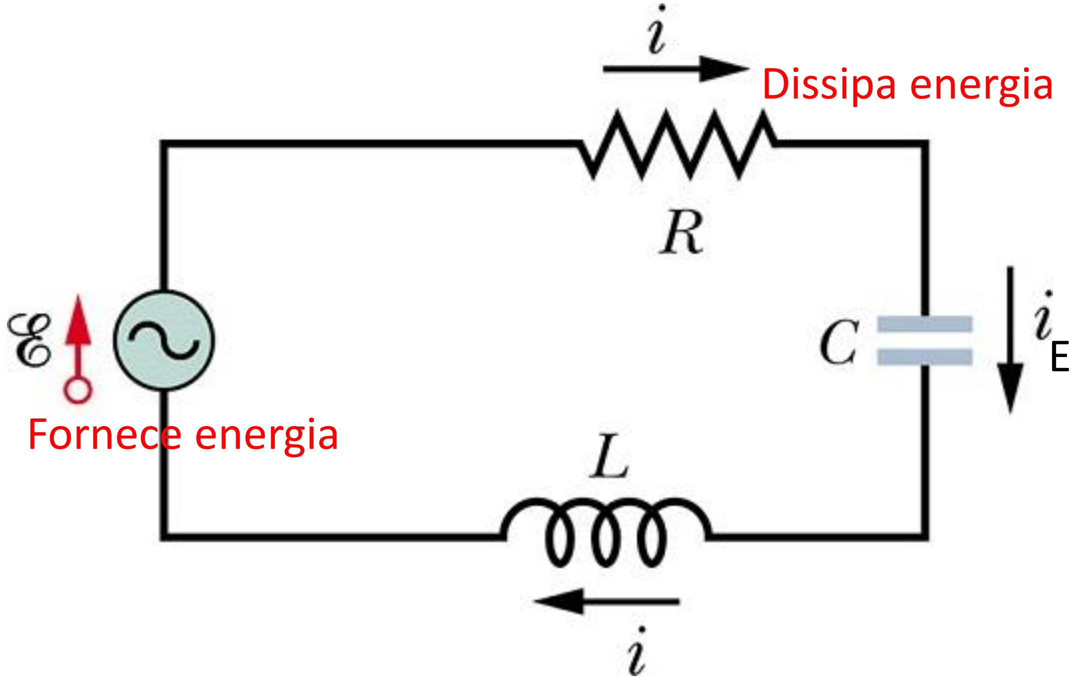
$$Pot = I^2 Rsen^2(\omega_d t - \emptyset)$$

$$Pot_{média} = I^2 R\left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R$$

Potência em AC

No regime estacionário!



Dissipa energia

Fornece energia

Energia permanece constante

Energia permanece constante

$$i = Isen(\omega_d t - \emptyset)$$

$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

$$Pot_{média} = I^2R\left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio →rms

Potência em AC

$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$Pot_{média} = I^2R\left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio →rms

Potência em AC

$$Pot = i^2 R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2 R sen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$V_{rms} = \frac{V}{\sqrt{2}}$$

$$Pot_{média} = I^2 R \left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio → rms

Potência em AC

$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$V_{rms} = \frac{V}{\sqrt{2}}$$

Máximo 170 V

Tomada 120 V

$$Pot_{média} = I^2R\left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio →rms

Potência em AC

$$Pot = i^2 R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2 R sen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$V_{rms} = \frac{V}{\sqrt{2}}$$

$$\varepsilon_{rms} = \frac{\varepsilon_{max}}{\sqrt{2}}$$

$$I_{rms} = \frac{\varepsilon_{rms}}{Z}$$

$$Pot_{média} = I^2 R \left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio →rms

Potência em AC

$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$V_{rms} = \frac{V}{\sqrt{2}}$$

$$Pot_{média} = \frac{\varepsilon_{rms}}{Z} I_{rms} R$$

$$\varepsilon_{rms} = \frac{\varepsilon_{max}}{\sqrt{2}}$$

$$Pot_{média} = \varepsilon_{rms} I_{rms} \frac{R}{Z}$$

$$Pot_{média} = I^2R\left(\frac{1}{2}\right)$$

$$I_{rms} = \frac{\varepsilon_{rms}}{Z}$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio → rms

Potência em AC

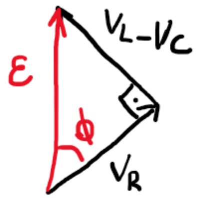
$$Pot = i^2 R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2 R sen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$V_{rms} = \frac{V}{\sqrt{2}}$$

$$Pot_{média} = \frac{\varepsilon_{rms}}{Z} I_{rms} R$$



$$cos(\emptyset) = \frac{V_R}{\varepsilon} = \frac{IR}{IZ} = \frac{R}{Z}$$

$$\varepsilon_{rms} = \frac{\varepsilon_{max}}{\sqrt{2}}$$

$$Pot_{média} = \varepsilon_{rms} I_{rms} \frac{R}{Z}$$

$$Pot_{média} = I^2 R \left(\frac{1}{2}\right)$$

$$I_{rms} = \frac{\varepsilon_{rms}}{Z}$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio →rms

Potência em AC

$$Pot = i^2R = \left(Isen(\omega_d t - \emptyset)\right)^2 R$$

$$Pot = I^2Rsen^2(\omega_d t - \emptyset)$$

Podemos calcular a taxa média de dissipação de energia em AC!

$$V_{rms} = \frac{V}{\sqrt{2}}$$

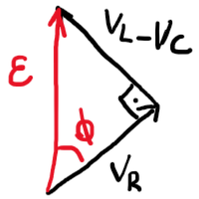
$$\varepsilon_{rms} = \frac{\varepsilon_{max}}{\sqrt{2}}$$

$$I_{rms} = \frac{\varepsilon_{rms}}{Z}$$

$$Pot_{média} = \frac{\varepsilon_{rms}}{Z} I_{rms} R$$

$$Pot_{média} = \varepsilon_{rms} I_{rms} \frac{R}{Z}$$

$$\boldsymbol{Pot_{média} = \varepsilon_{rms} I_{rms} cos\emptyset}$$



$$cos(\emptyset) = \frac{V_R}{\varepsilon} = \frac{IR}{IZ} = \frac{R}{Z}$$

Fator de potência

$$Pot_{média} = I^2R\left(\frac{1}{2}\right)$$

$$Pot_{média} = \left(\frac{I}{\sqrt{2}}\right)^2 R = I_{rms}^2 R$$

Valor quadrático médio →rms

Transformadores

Equações de Maxwell

Nome	Forma diferencial	Forma integral
Lei de Gauss	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$	$\oiint_{\partial V} \mathbf{E} \cdot \mathrm{d}\mathbf{A} = \frac{Q(V)}{\varepsilon_0}$
Lei de Gauss para o magnetismo	$\nabla \cdot \mathbf{B} = 0$	$\oiint_{\partial V} \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
Lei de Faraday da indução	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint_{\partial S} \mathbf{E} \cdot \mathrm{d}\mathbf{l} = -\frac{\partial \Phi_{B,S}}{\partial t}$
Lei de Ampère (com a correção de Maxwell)	$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$	$\oint_{\partial S} \mathbf{B} \cdot \mathrm{d}\mathbf{l} = \mu_0 I_S + \mu_0 \varepsilon_0 \frac{\partial \Phi_{E,S}}{\partial t}$