Resistor-Inductor-Capacitor (RLC) Circuits

Session 3e for Basic Electricity
A Fairfield University E-Course
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Module: Basic Electronics (AC Circuits and Impedance: two parts)

- Text: "Electricity One-Seven," Harry Mileaf, Prentice-Hall, 1996, ISBN 0-13-889585-6 (Covers much more material than this section)
- References:
  - "Digital Mini Test: Principles of Electricity Lessons One and Two," SNET Home Study Coordinator, (203) 771-5400
  - Electronics Tutorial (Thanks to Alex Pounds)
  - Electronics Tutorial (Thanks to Mark Sokos)
  - Basic Math Tutorial (Thanks to George Mason University)
  - Vector Math Tutorial (Thanks to California Polytec at atom.physics.calpoly.edu)
- Alternating Current and Impedance
  - 5 on-line sessions plus one lab
- Resonance and Filters
  - 5 on-line sessions plus one lab

Section 3:
AC, Inductors and Capacitors

- 0BJECTIVES: This section introduces AC voltage / current and their effects on circuit components (resistors, inductors, transformers and capacitors). The concept of impedance and the use of the vector analogy for computations is also introduced.

Section 3 Schedule:

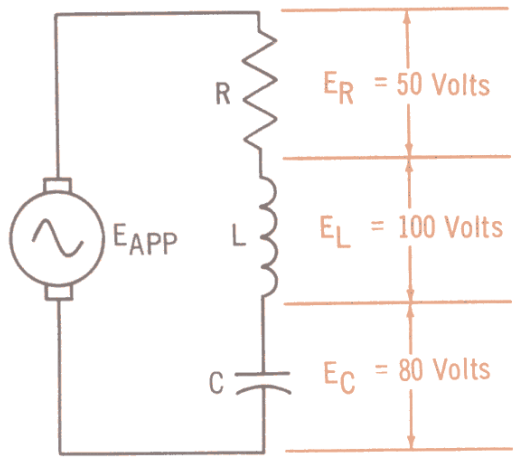
Session 3a	– 05/13	Sine Waves, Magnitude, Phase and Vectors (again)	Text 4.1 – 4.24
3a continued	– 05/20	Complete 3a	
Session 3b	– 05/22	R-L Circuits (no class on 05/27)	Text 4.25 – 4.54
3b continued	– 05/29	Complete 3b	
Session 3c	– 06/03	R-C Circuits	Text 4.55 – 4.76
Session 3d	– 06/05	Series LC Circuits	Text 4.77 – 4.88
(lab - 06/08, Sat.)			
(lab - 06/10, Mon.)			
Session 3e	**– 06/12**	**Series RLC Circuits**	
(Quiz 3 due 06/16)			**Text 4.89 – 4.113**
Session 3f	– 06/17	Review (Discuss Quiz 3)	
3e continued	– 06/17	Series RLC Circuits	

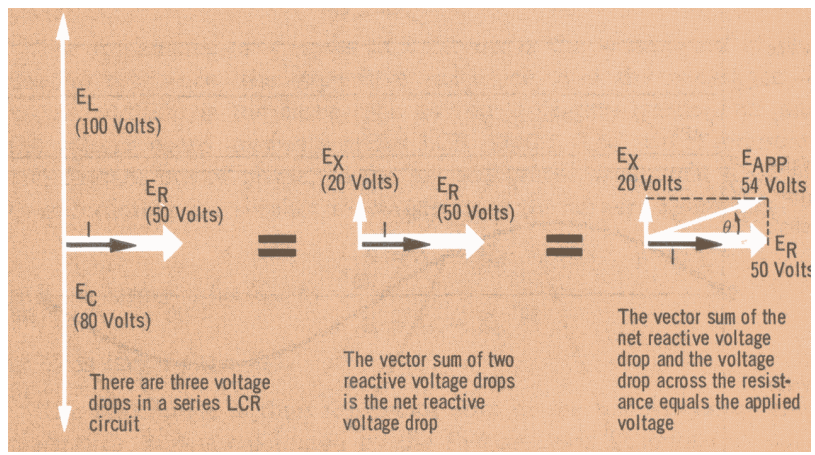
Session 3d (L-C) Review

- Capacitive reactance $X_C = 1/2\pi fC$ at -90º
- Inductive reactance$X_L = 2\pi fL$ at 90º
- Impedances (R, X_L, X_C) in series add as vectors (Phasors).
- Impedances in parallel add as inverses
  - Adding Vectors
    - Separately add their horizontal and vertical components
    - Graphically: head-to-tail or parallelogram
  - Multiplying Vectors
    - Multiply their magnitudes (lengths)
    - Add their phases
  - Dividing Vectors
    - Divide their magnitudes (lengths)
    - Subtract their phases
- Ohm's and Kirchoff's laws still work with AC
- Inductive and capacitive reactances are both vertical and exactly 180º out of phase; They subtract!

Series RLC- Voltage

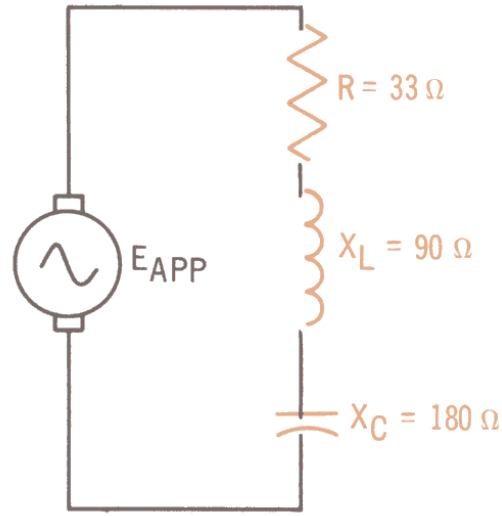
- AC voltages always add as vectors
- Current (ref. Phase) is the same in all series components
- Inductor - E_L points up (leads current by 90º)
- Capacitor - E_C points down (lags current by 90º)
- Add E_L and E_C (they subtract) to get E_X
  - $E_L = 100\angle 90º$
  - $E_C = 80\angle -90º = -80\angle 90º$
  - $E_X = -20\angle 90º = 20\angle 90º$ (inductive circuit)
- Now add the vectors E_R and E_X to get E_{APP}
  - $50\angle 0º + 20\angle 90º$
  - $54\angle 21.8º$ { $\tan^{-1}(20/50)$ }

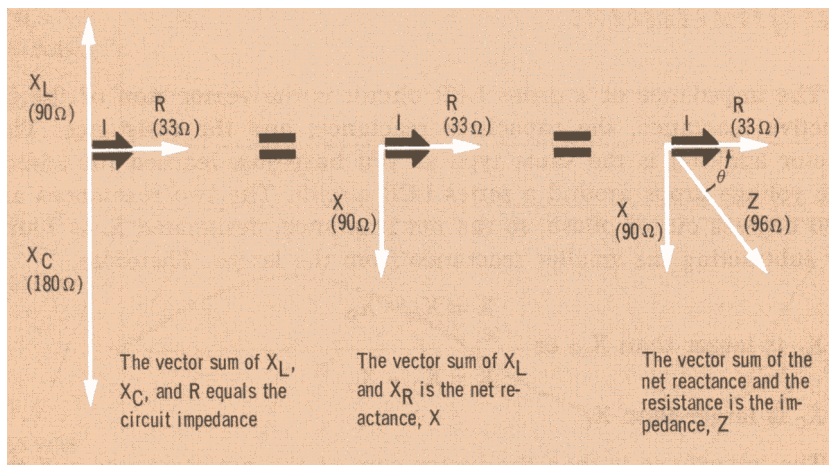




Series RLC - Impedance

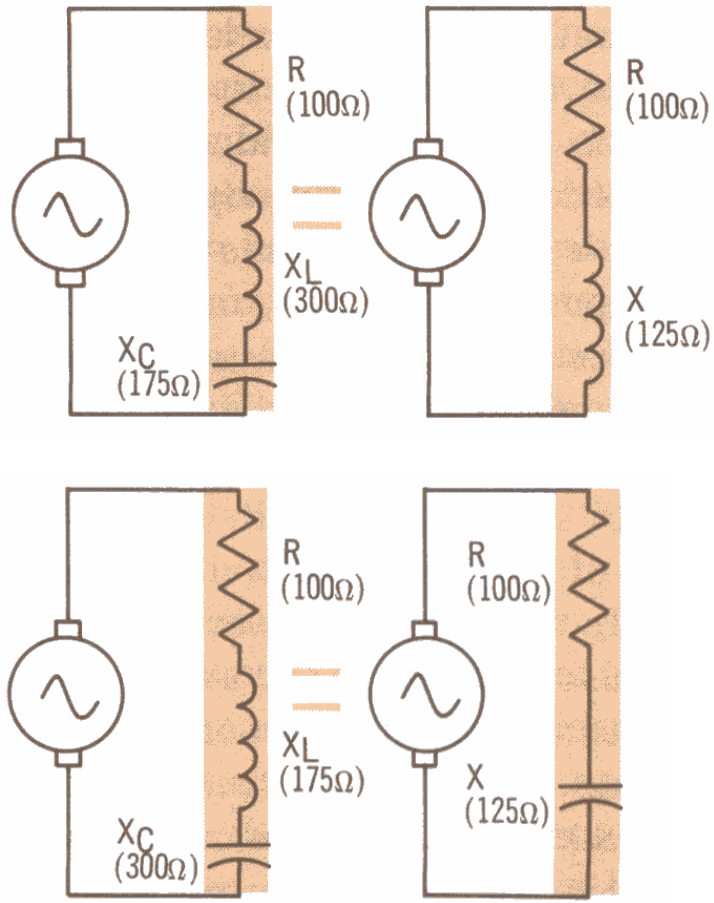
- Impedances in series add as vectors
- X_L and X_C are in opposite directions
  - Magnitudes subtract
  - $X = 90\angle -90^\circ$ (Capacitive)
- $Z = X_R + X$
  - $Z = 33\angle 0^\circ + 90\angle -90^\circ$
  - $|Z| = (33^2 + 90^2)^{1/2}$
  - $\angle Z = \tan^{-1}(-90/33) = \tan^{-1}(-2.72) = -69.8^\circ$
  - $Z = 96\angle -69.8^\circ$





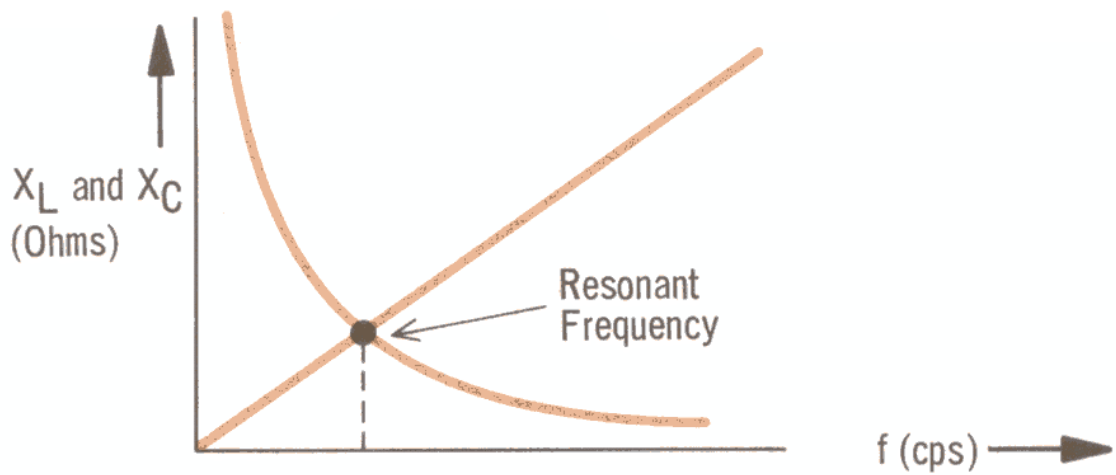
Series LC: Current

- $I = E_{app} / Z$
- Top (inductive)
  - $Z = 100\angle 0^{o} + 125\angle 90^{o}$
- Bottom (capacitive)
  - $Z = 100\angle 0^{o} + 125\angle -90^{o}$

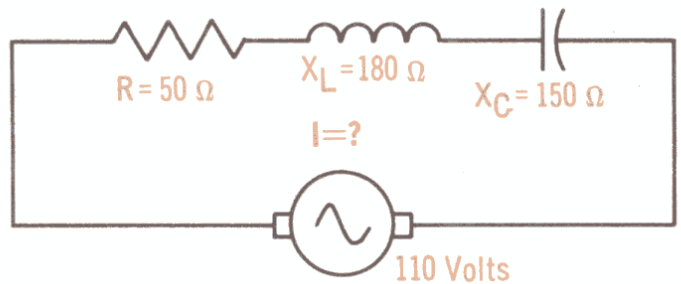


The Effect of Frequency

- $Z_L = 2\pi fL$ (rises linearly with frequency)
- $Z_C = 1/2\pi fL$ (decreases with frequency)
- Resonance is when they are equal and cancel; the impedance is then just the resistance



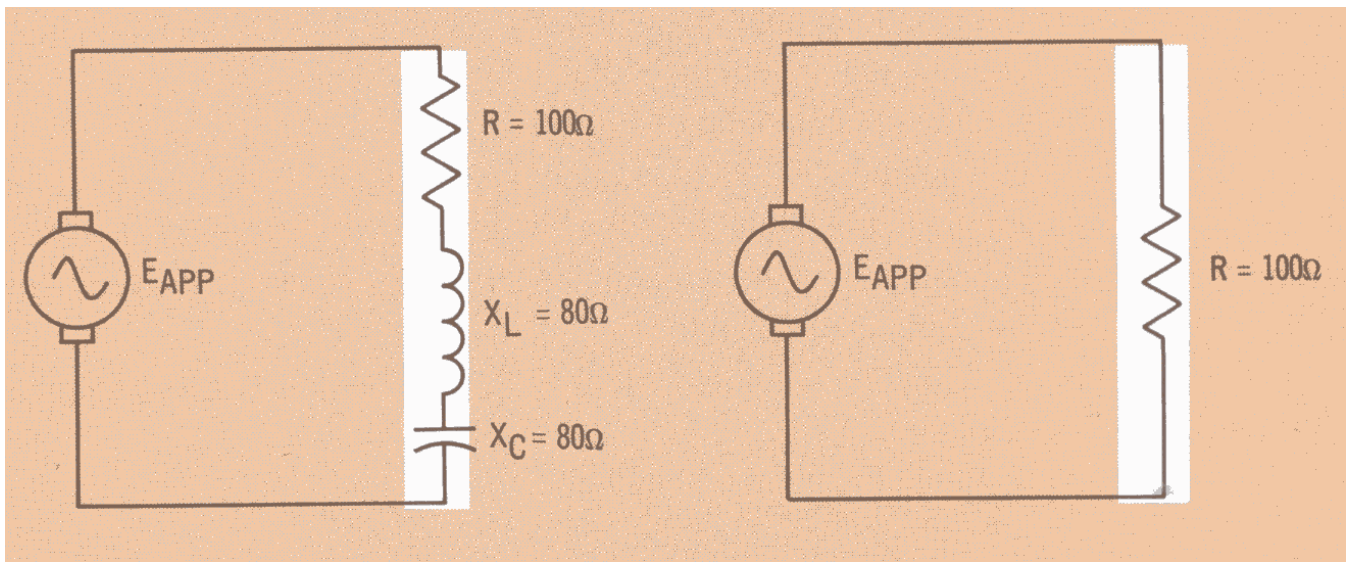
Series RLC Example



- $X = (180 - 150)\angle 90^o$
  $= 30\angle 90^o$
- $Z = 50\angle 0^o + 30\angle 90^o$
  - $|Z| = (33^2 + 90^2)^{1/2} = 58$
  - $\angle Z = \tan^{-1}(30/50) = \tan^{-1}(0.6) = 31^o$
- $I = 110\angle 0 / 58\angle 31^o$
  $I = 1.9$ amps at -31^o or
  $I = 1.9*\cos(2\pi ft - 0.541)$
  (I'm assuming that E_{APP} is a peak voltage at zero phase)
- $E_L = 1.9\angle -31^o * 180\angle 90^o = 342$ volts at 90^o
- $E_C = 1.9\angle -31^o * 150\angle -90^o = 285$ volts at -90^o
- $E_R = 1.9\angle -31^o * 50\angle 0^o = 95$ volts at -31^o

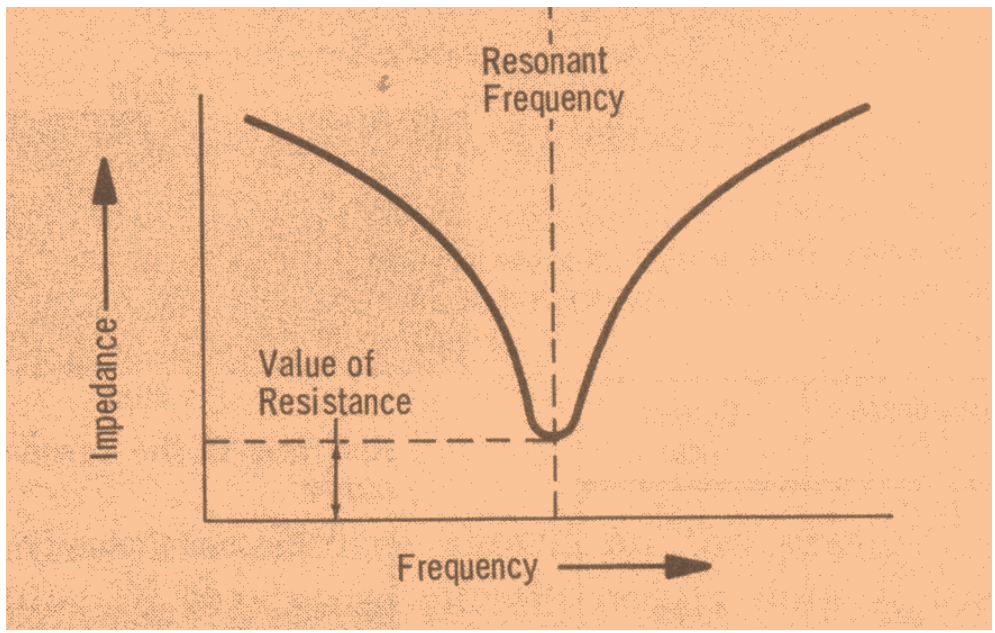
RLC Series Resonance

- Resonance: X_L and X_C cancel leaving only a series R

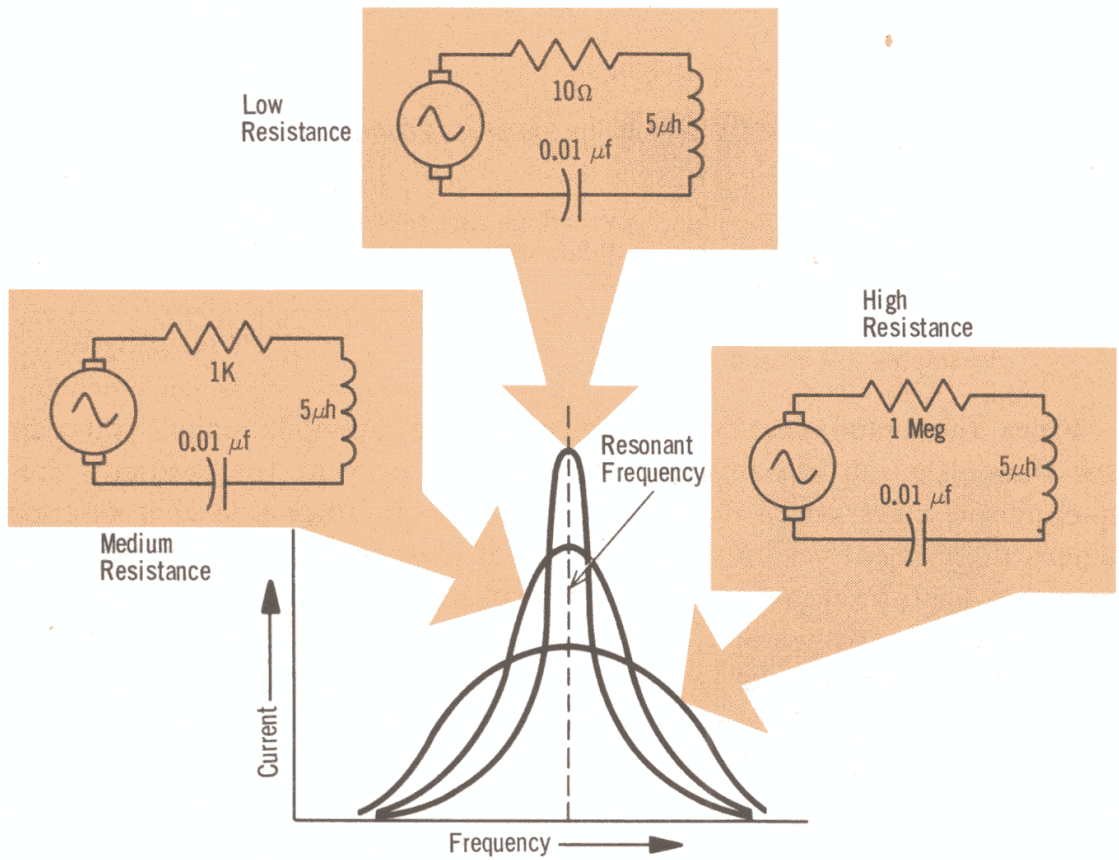


RLC Series Resonance:
Impedance

- At series resonance the magnitude of the impedance is a minimum

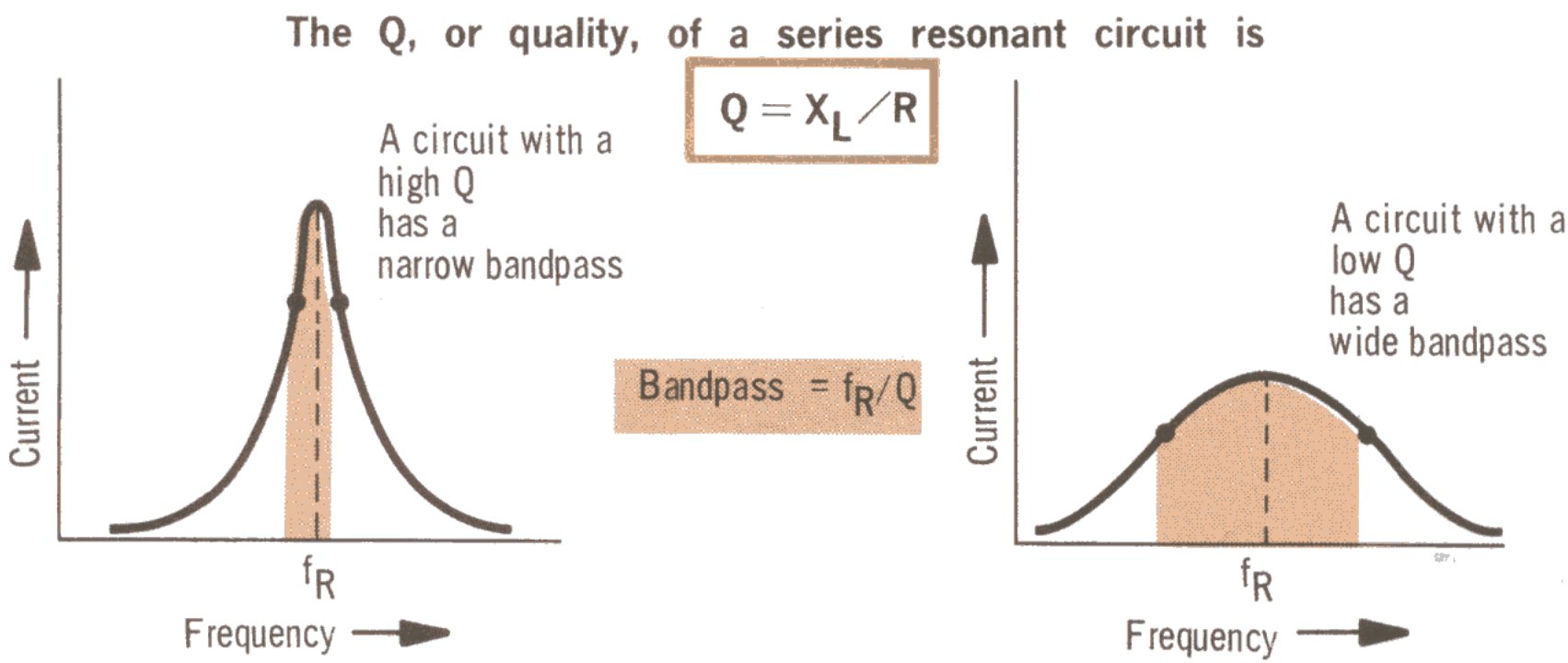


RLC Series Resonance:
Current

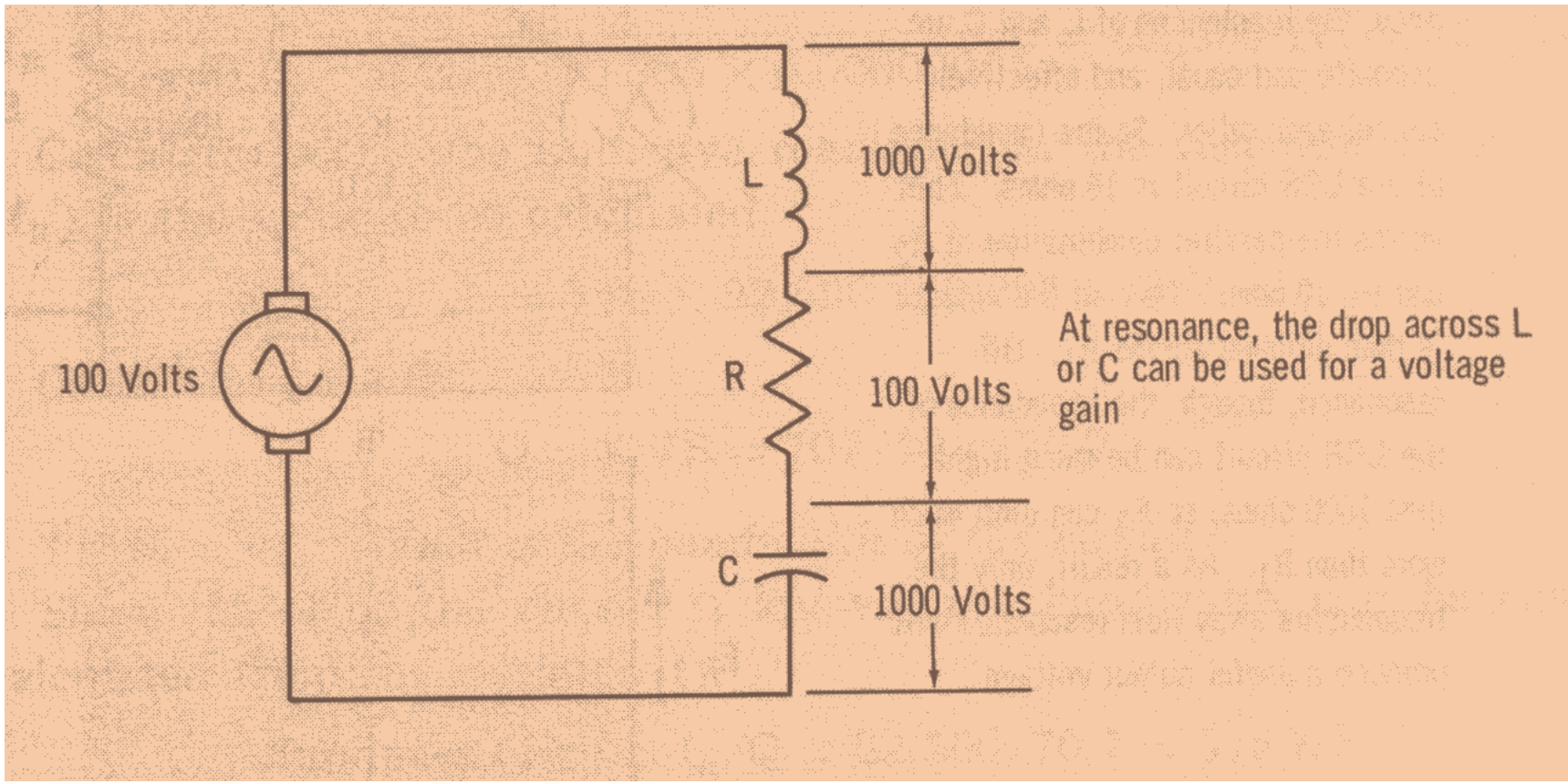


The circuit resistance determines the height and flatness of the resonance curve

RLC Series Resonance: Q

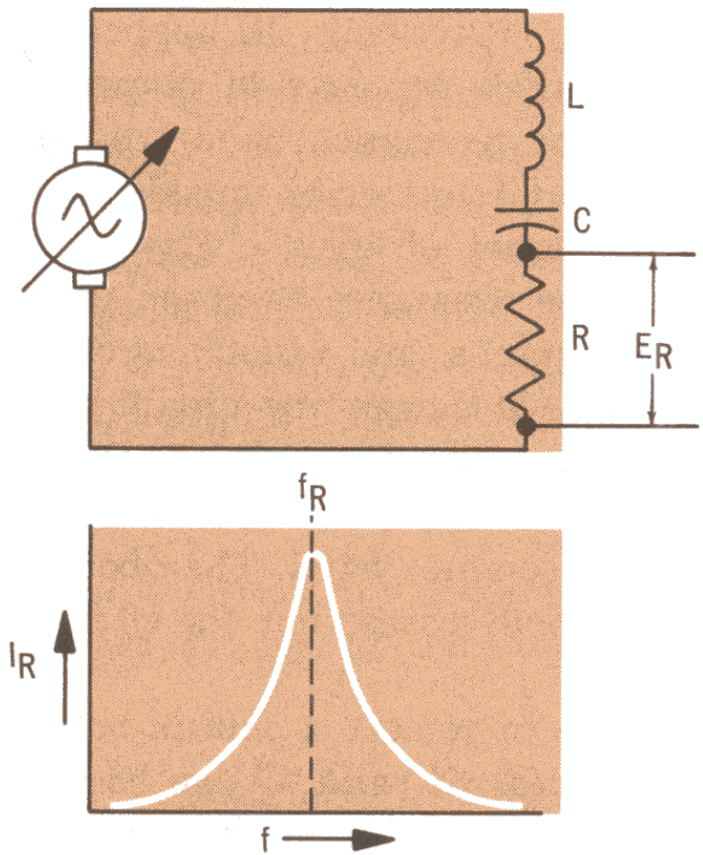


RLC Series Resonance:
Voltage Gain



RLC Series Resonance:
Band-Pass Filter

- The current is a maximum at resonance and falls off at frequencies above and below resonance
- The voltage across the resistor behaves the same. (Ohm's Law)
- This is therefore a Band-Pass filter – passes only energy at frequencies around resonance and reduces the energy of signals at other frequencies



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(Quiz 3 due 06/16)			**(** Section 4: parallel
Session 3f	**– 06/17**	**Review (Discuss Quiz 3)**	RLC, resonance, filters - then MT2)
3e continued	**– 06/19**	Series RLC Circuits	

Section 4 Preliminary Schedule:

Session 4a	– 06/24	Parallel L-R-C Circuits	Text 4.114 – 4.132
Session 4b	– 06/26	Parallel L-R-C Circuits Cont.	
(have a nice July 4)		(no class on 05/27)	
Session 4c	– 07/08	Parallel Resonance	Text 4.133 – 4.146
Session 4d	– 07/10	Tuning and Filters	Text 4.147 – 4.151
(break for a week)			
Session 4e	– 07/22	Transformers and Impedance	Text 4.152 – 4.160
(Quiz 4 due 07/28)		Matching	
(lab - 07/27, Sat.)			
Session 4f	– 07/29	Review (Discuss Quiz 4)	
	07/31	MT2 Review	
		MT2 – AC Circuits	