Resistor-Capacitor (RC) Circuits

Session 3c 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 Series RLC Circuits	Text 4.77 – 4.88, 4.89 – 4.113
(lab - 06/08, Sat.)			
Session 3e (Quiz 3 due 06/16)	– 06/10	Parallel LC Circuits Parallel RLC Circuits	Text 4.114 – 4.122, 4.123 – 4.146
Session 3f	– 06/17	Review (Discuss Quiz 3)	

Session 3b (R-L) Review

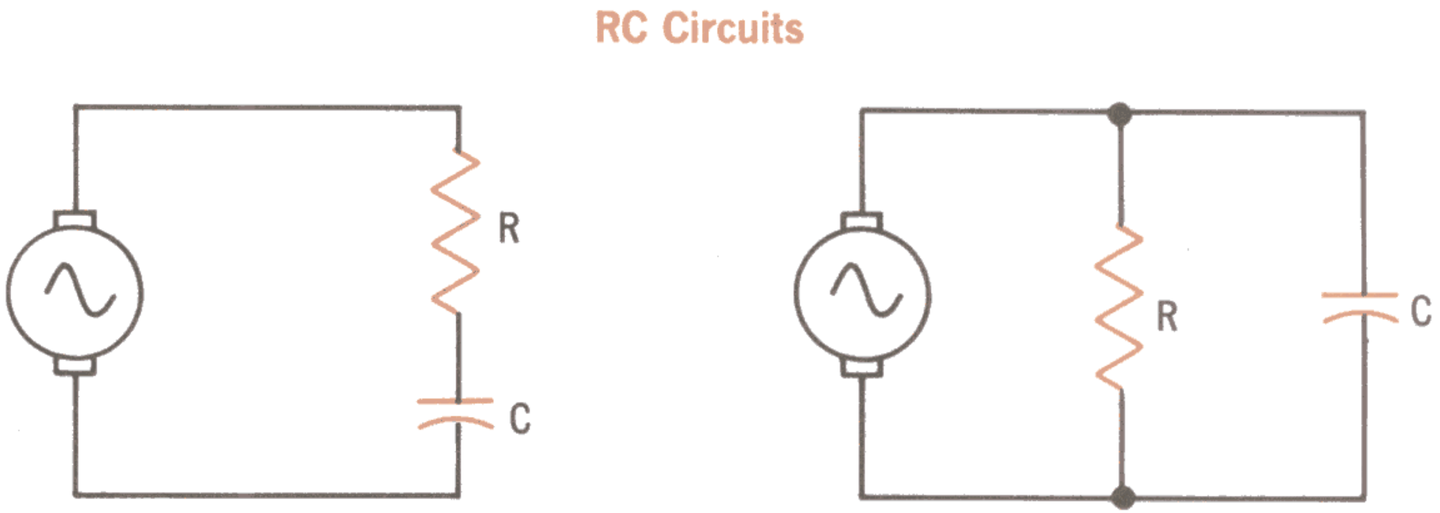
- Inductive reactance $X_L = 2\pi fL$ at 90º
- Impedances (R, X_L) in series add as vectors (Phasors).
- Impedances in parallel add as inverses
- Multiplying Vectors
  - Multiply their magnitudes (lengths)
  - Add their phases
- Dividing Vectors
  - Divide their magnitudes (lengths)
  - Subtract their phases
- Ohm's and Kirchoff's laws still work

Session 3a (Vectors) Review

- Vector Analogy (frequency is not shown, corresponds to rotation)
  - Vector length corresponds to signal amplitude
  - Vector angle corresponds to phase (need a reference phase)
  - $\sin(2\pi ft)$: vertical vector (points up)
  - $\cos(2\pi ft)$: horizontal vector (points right)
- Vector Addition
  - Head-to-Tail
  - Parallelogram
- Vector Components (θ is the angle w.r.t. the horizontal axis)
  - Horizontal component: $A*\cos(\theta)$
  - Vertical component : $A*\sin(\theta)$
- You can add vectors by adding their corresponding components!

R-C Circuits

- 10:1 Ratio
  - If the effect of resistance (reactance) is 10 time larger than reactance (resistance), the smaller can be generally ignored in computations

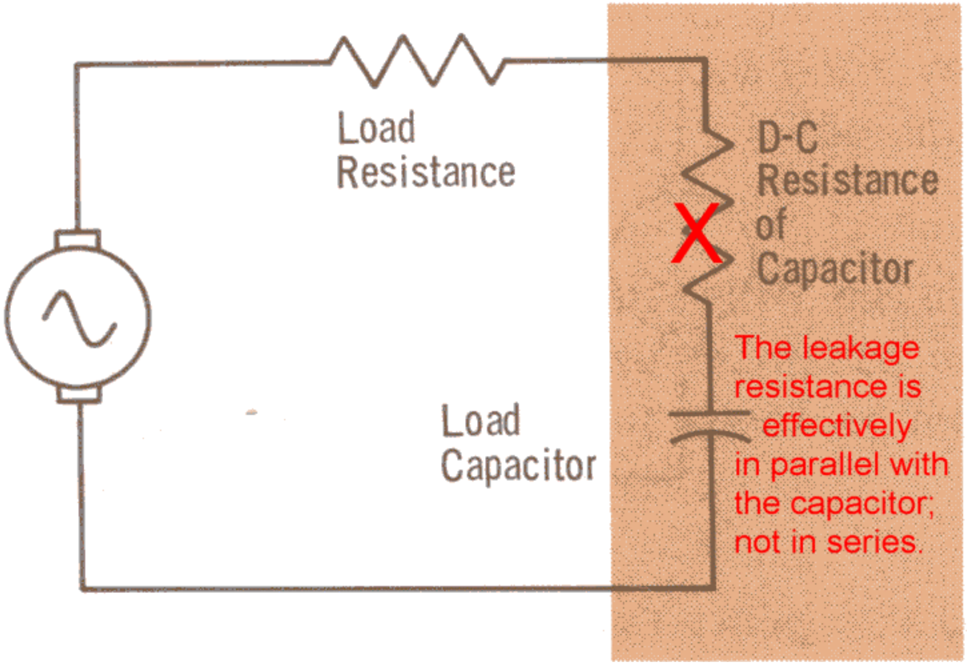


Series RC

Parallel RC

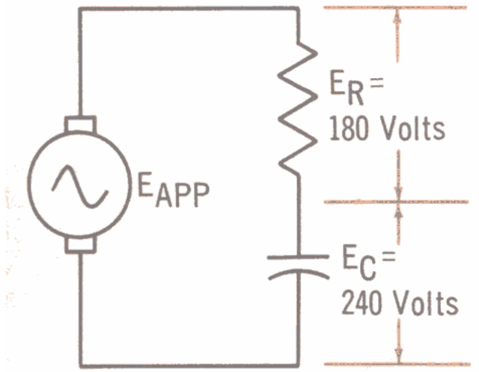
Capacitor Leakage Resistance

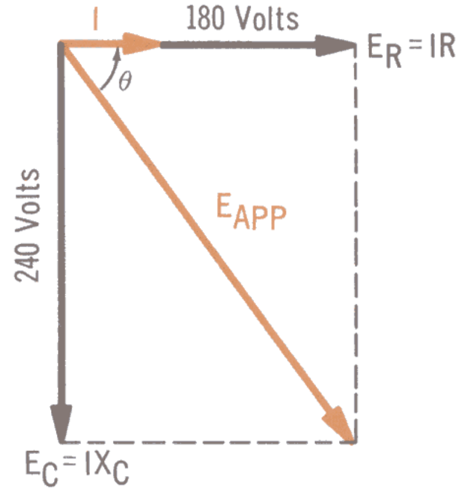
- DC leakage resistance is in parallel with the capacitor. (**Text Error**)



Series RC Voltages

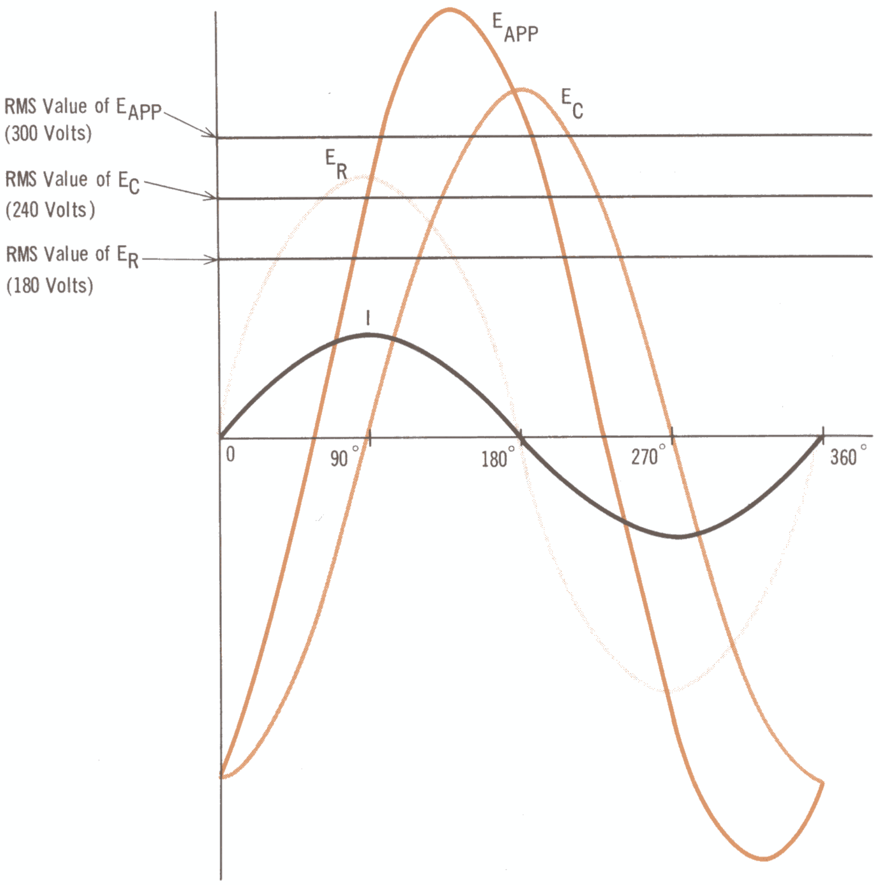
- Current is the same in all components; Use it as the reference.
- Voltage across the resistor is in phase with the current.
- Voltage across the capacitor lags (ICE) by 90º (*minus* π/2).
- E_{app} is the vector sum.
  - $|Z| = (180^2 + 240^2)^{½} = 300\ \Omega$
  - $\angle Z$ = arctan(-240/180) = arctan(-1.33)
    = -0.93 radians or –53.1º





Series RC Voltage Waveforms

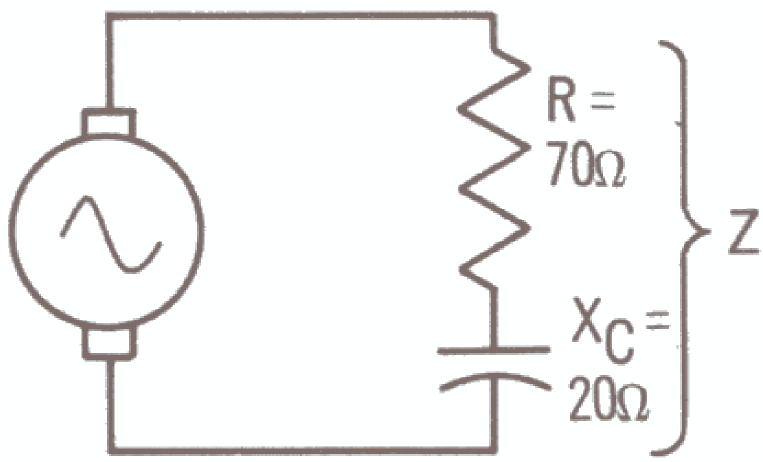
- Current is again the reference phase (shown as a sine wave).
- Capacitor voltage is –cos (lagging by 90º)
- Every point on E_{app} is the sum of the instantaneous values of E_R and E_C

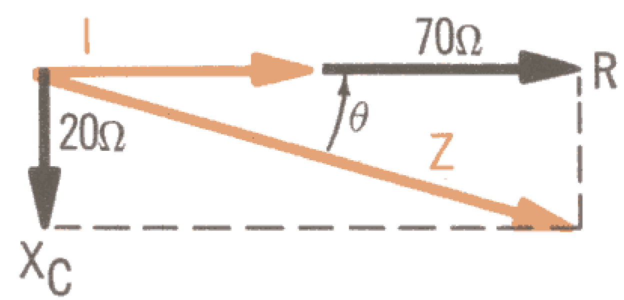


Series RC Impedance

- Resistance is always treated as zero phase (to the right).
- Capacitive reactance, X_C, is then at -90º (down).
- Total impedance, Z, is then the vector sum of R and X_C.
  - $|Z| = (70^2 + 20^2)^{½} = 72.8\ \Omega$
  - $\angle Z = \arctan(-20/70)$
    $= \arctan(-0.2857)$
    $= -0.2783$ radians or –16º

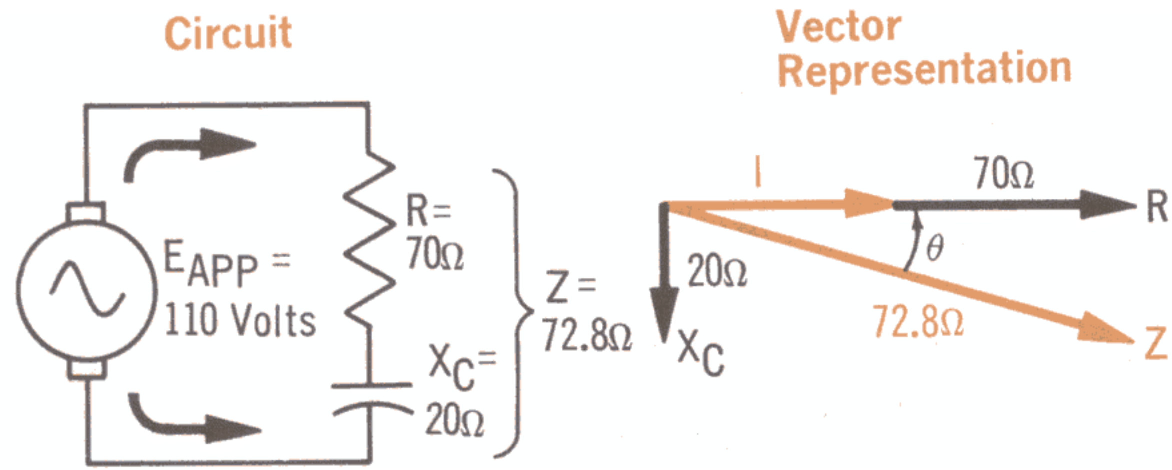
  note: the picture shows θ backwards





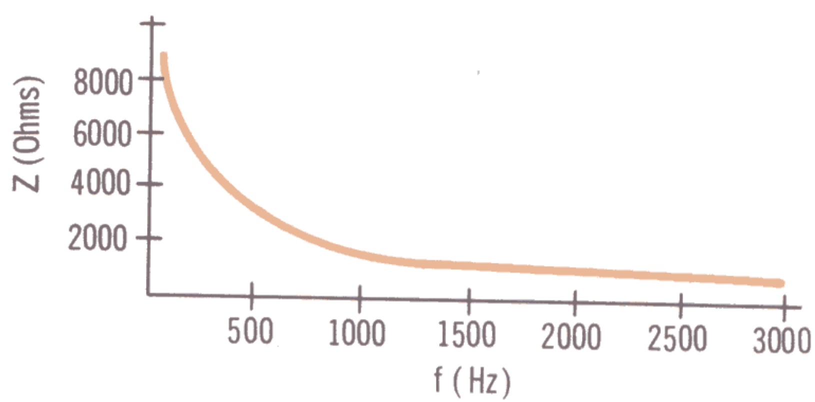
Ohm's Law Again

- $Z = 72.8\angle{-16^o}$
- $V = 110\angle 0^o$ (using E_{app} as the reference phase)
  (if I is the reference, then V is at -16^o)
- $I = V / Z = 110/72.8\angle 16^o = 1.51\angle 16^o$



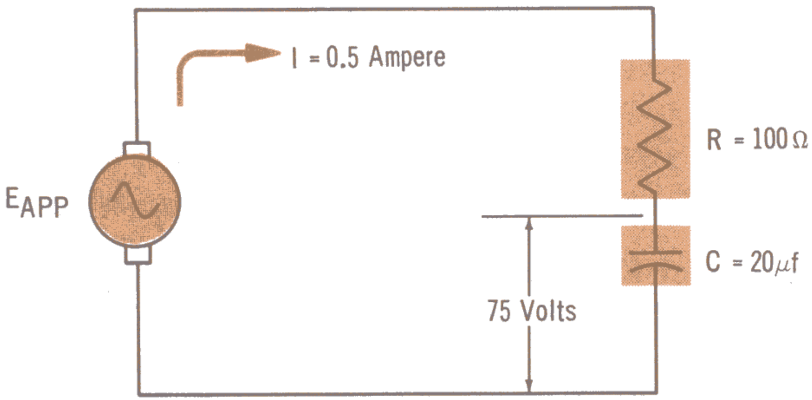
Effect of Changing Frequency

- At low frequency the capacitive reactance is high and dominates the impedance.
- At high frequencies the capacitive reactance goes to zero and the resistor dominates the impedance.

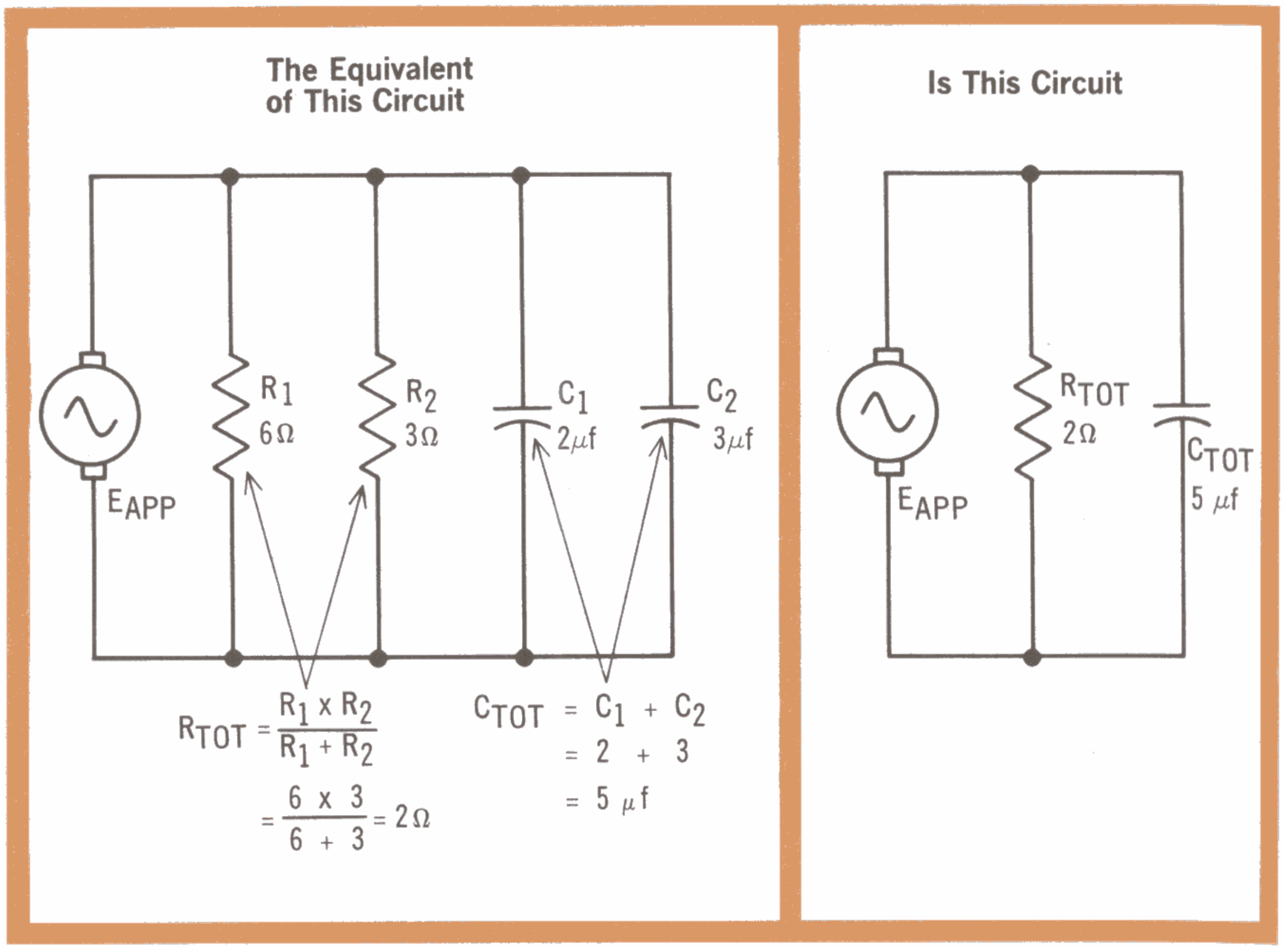


Serial RC Exercise

- $X_C = E_C / I$
  $= 150\Omega$ (at -90º)
- $|Z| = (100^2 + 150^2)^{½}$
  $= 180\Omega$
- $\angle Z = \arctan(-150/100)$
  $= \arctan(-1.5)$
  $= -56.3º$
- $E_{app} = I * Z = 90\angle -56.3º$
- $f = 1/(2\pi C X_C)$
  $=1/(6.28*0.00002*150)$
  $= 53$ Hz

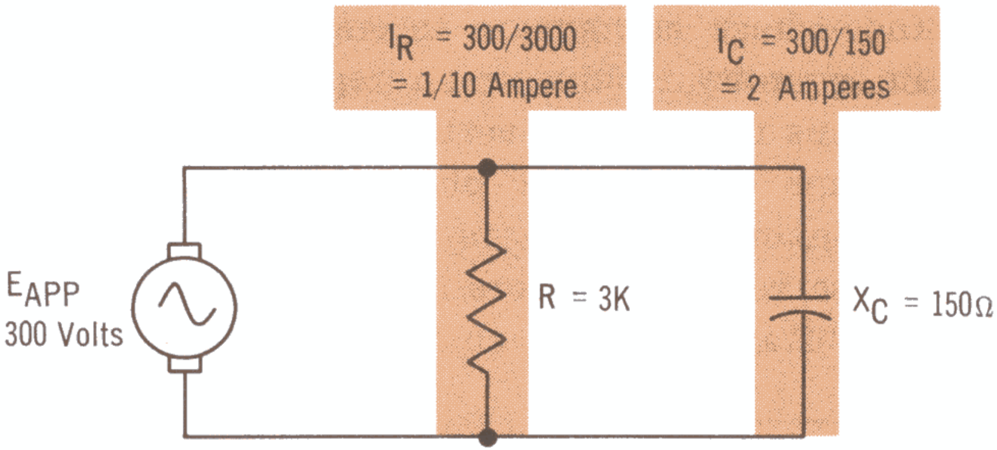


Parallel RC Circuits



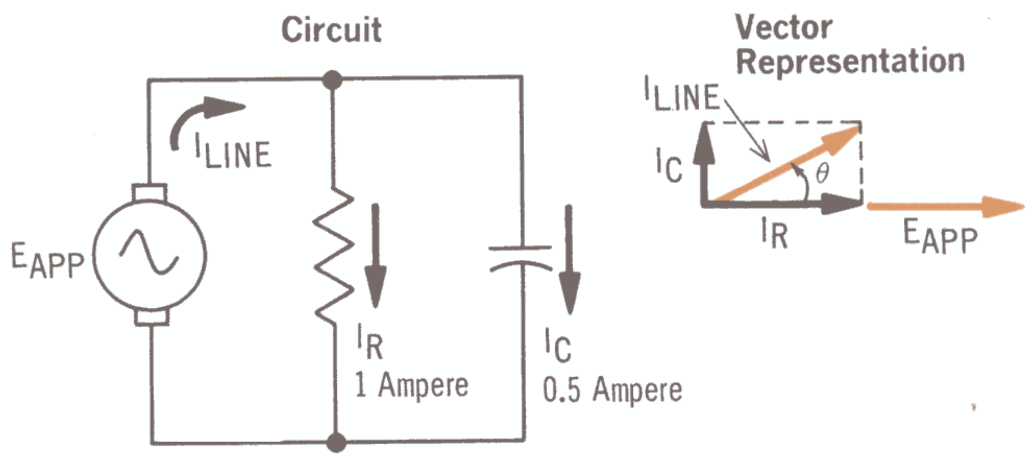
Branch Currents

- Voltages are the same across all branches.
- Calculate currents independently.
- Note that I_C is at 90º. (E_{app} is the reference phase)



Line Current

- The total or Line current is the vector sum of the branch currents (Kirchoff's Current Law)



Parallel RC Impedance

- Impedances in parallel add as inverses

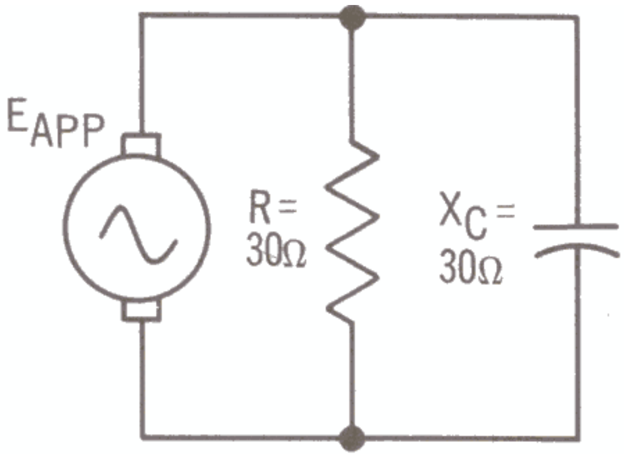
$$\frac{1}{Z} = \frac{1}{R} + \frac{1}{X_C}$$

$$\frac{1}{Z} = \frac{1}{30} + \frac{1}{30\angle -90^0}$$

$$\frac{1}{Z} = .0333 + 0.0333\angle 90^0$$

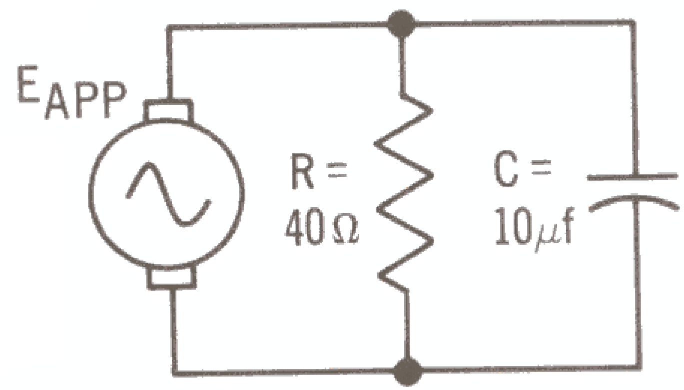
$$\frac{1}{Z} = 0.047\angle 45^0$$

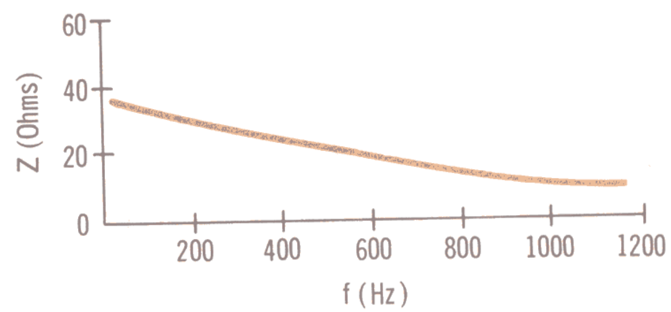
$$Z = 21\angle -45^0$$



The Effect of Frequency

- At low frequencies the capacitance is high so the resistance dominates.
- At high frequencies the capacitance goes to zero and dominates.





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