ECE 2210 / 00 Lecture 8 Notes Basic AC

A. Stolp
1/27/03,
9/9/20

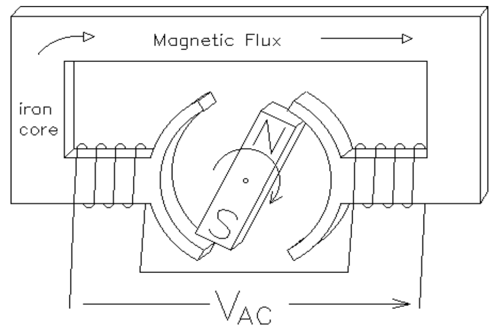
AC stands for **A**lternating **C**urrent as opposed to DC, **D**irect **C**urrent. AC refers to voltages and currents that change with time, usually the voltage is + sometimes and - at other times. This results in currents with go one direction when the voltage is + and the reverse direction when the voltage is -.

AC is important for two reasons.
Power is created and distributed as AC. Signals are AC.

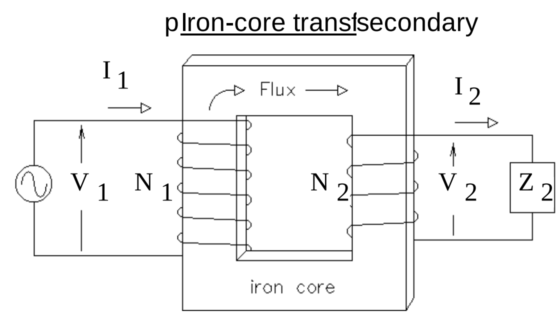
AC Power

Power is generated by rotating magnetic fields.
This naturally produces sinusoidal AC waveforms.

It is easier to make AC motors than DC motors.



AC Power allows use of transformers to reduce line losses



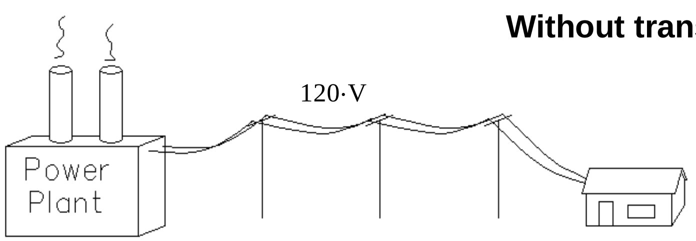
Transformers work with AC, but not DC. Transformers can be used to raise or lower AC voltages (with an opposite change of current). This can be very useful in power distribution systems. Power is voltage times current. You can distribute the same amount of power with high voltage and low current as you can with low voltage and high current. However, the lower the current, the lower the I^2R loses in the wires (all real wires have some resistance). So you'd like to distribute power at the highest possible voltage. Transformers allow you to do this with AC, but won't work with DC.

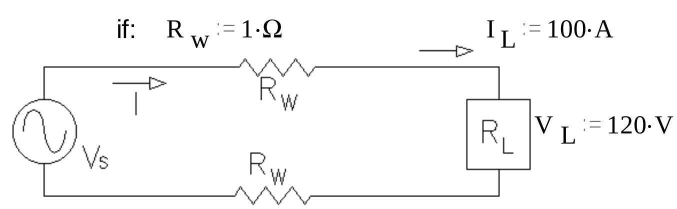
Ideal: power in = power out

Ideal transformation of voltage and current: $\frac{N_1}{N_2} = \frac{\mathbf{V_1}}{\mathbf{V_2}} = \frac{\mathbf{I_2}}{\mathbf{I_1}}$

Example:

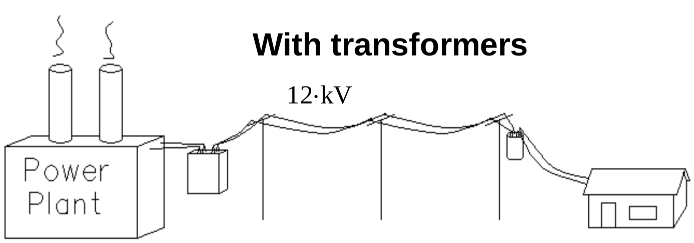
Without transformers

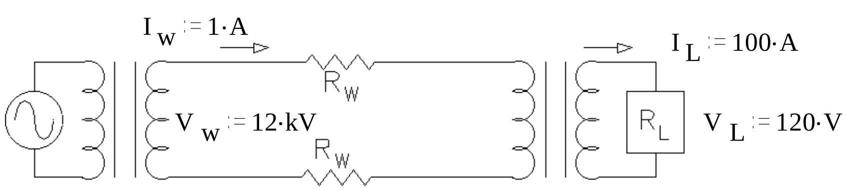




Wire loss: $P_W = I_L^2 \cdot 2 \cdot R_w = 20 \bullet kW$

With transformers





Wire loss: $P_W = I_w^2 \cdot 2 \cdot R_w = 2 \bullet W$

In this example, the power lost in the transmission lines is only 1/10,000th what it is without transformers.

That's why they raise the voltage in transmission lines to the point where they crackle and buzz. That crackle is the sound of the losses into the surrounding air and can become significant if the voltage is *too* high.

Signals

A time-varying voltage or current that carriers information. If it varies in time, then it has an AC component.

| — In some unpredictable fashion

| — Audio, video, position, temperature, digital data, etc...

DC is not a signal, Neither is a pure sine wave. If you can predict it, what information can it provide?
Neither DC nor pure sine wave have any "bandwidth". In fact, no periodic waveform is a signal & no periodic waveform has bandwidth. You need bandwidth to transmit information.

Signal sources

Microphone	Audio
Camera	Video
Thermistor or other thermal sensor	Temperature
Potentiometer	Position
LVDT (Linear Variable Differential Transformer)	Position
Light sensor	
Computer	
switch	
etc...	

A transducer is a device which transforms one form of energy to another. Some sensors are transducers, many are not

Most often a signal comes from some other system.

Periodic waveforms: Waveshape repeats

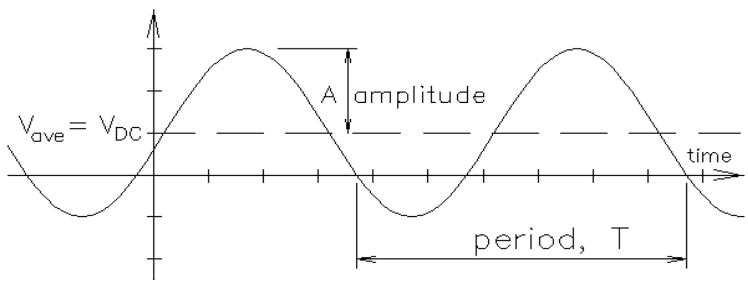
T = Period = repeat time

f = frequency, cycles / second $\quad f = \frac{1}{T} = \frac{\omega}{2\cdot\pi}$

ω = radian frequency, radians/sec $\quad \omega = 2\cdot\pi\cdot f$

A = amplitude

DC = average



Sinusoidal AC

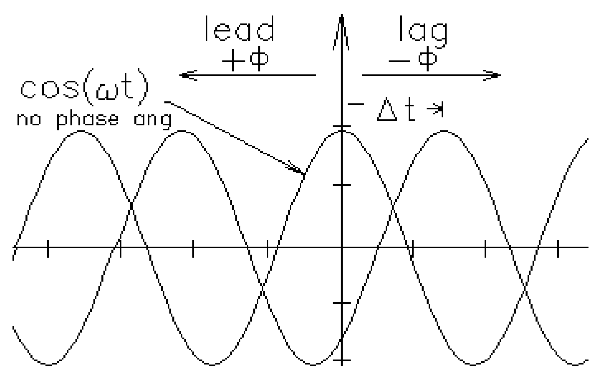
$y(t) = A\cdot\cos(\omega\cdot t + \phi)$

voltage: $v(t) = V_p\cdot\cos(\omega\cdot t + \phi)$

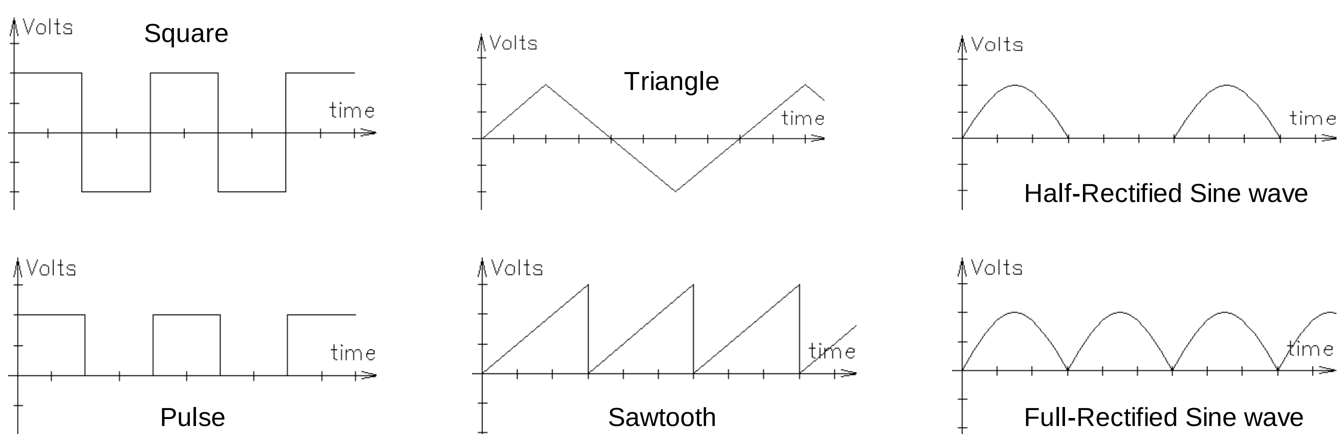
current: $i(t) = I_p\cdot\cos(\omega\cdot t + \phi)$

Phase: $\phi = -\frac{\Delta t}{T}\cdot 360\cdot deg$ or: $\phi = -\frac{\Delta t}{T}\cdot 2\cdot\pi\cdot rad$

Phase:



Other common periodic waveforms



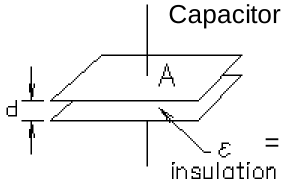
All but the square and triangle waves have a DC component as well as AC.

Capacitor Lecture Notes

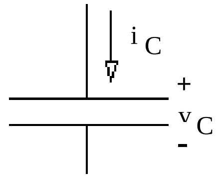
A. Stolp
2/17/03
rev 9/16/09
12/15 & 9/19

Now that we have voltages and currents which can be functions of time, it's time to introduce the capacitor and the inductor.

Electrical equivalent:

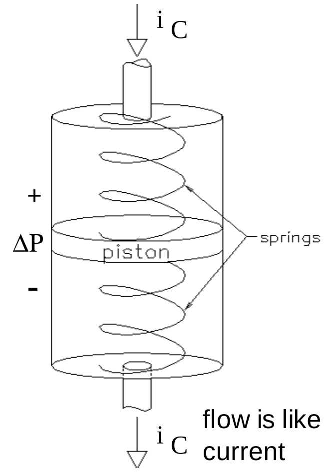


ε = permittivity



v_C like pressure ΔP

Fluid Model:



flow is like current

$$C = \varepsilon\cdot\frac{A}{d} = \frac{Q}{V} = \frac{dq}{dv}$$

Units: $\text{farad} = \frac{\text{coul}}{\text{volt}} = \frac{\text{amp}\cdot\text{sec}}{\text{volt}}$ $\qquad \mu F = 1 \cdot 10^{-6}\ \cdot\text{farad} \qquad pF = 1\cdot 10^{-12}\ \cdot\text{farad}$

For drawings of capacitors and info about tolerances, see Ch.3 of textbook.

Basic equations you should know: $C = \frac{Q}{V}$

$$v_C = \frac{1}{C}\cdot\int_{-\infty}^{t} i_C\,dt$$

$$i_C = C\cdot\frac{d}{dt}v_C$$

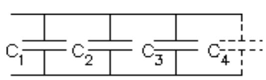
Or... $v_C = \frac{1}{C}\cdot\int_0^t i_C\,dt + v_C(0)$ ← initial voltage

Or... $\Delta v_C = \frac{1}{C}\cdot\int_{t_1}^{t_2} i_C\,dt$

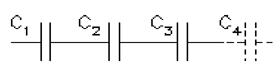
Energy stored in electric field: $W_C = \frac{1}{2}\cdot C\cdot V_C^{\,2}$

Capacitor voltage **cannot** change instantaneously

parallel: $C_{eq} = C_1 + C_2 + C_3 + \ldots$



series: $C_{eq} = \dfrac{1}{\dfrac{1}{C_1}+\dfrac{1}{C_2}+\dfrac{1}{C_3}+\ldots}$



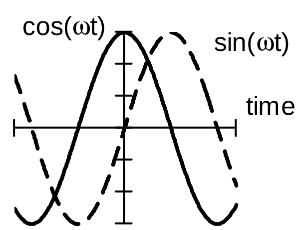
Capacitors are the only "backwards" components.

Sinusoids

$i_C(t) = I_p\cdot\cos(\omega\cdot t)$

$$v_C(t) = \frac{1}{C}\cdot\int i_C\,dt = \underbrace{\frac{1}{C}\cdot\frac{1}{\omega}\cdot I_p}_{V_p}\cdot\sin(\omega\cdot t) = \underbrace{\frac{1}{C}\cdot\frac{1}{\omega}\cdot I_p}_{V_p}\cdot\cos(\omega\cdot t - 90\cdot\text{deg})$$

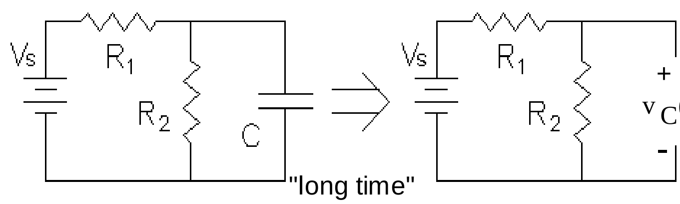
indefinite integral



Voltage "lags" current, makes sense, current has to flow in first to charge capacitor.

Steady-state or Final conditions

If a circuit has been connected for "a long time", then it has reached a steady state condition. that means the currents and voltages are no longer changing.



"long time"

$$v_C(\infty) = V_S\cdot\frac{R_2}{R_1+R_2}$$

$\frac{d}{dt}v_C = 0 \qquad i_C = C\cdot\frac{d}{dt}v_C = 0$

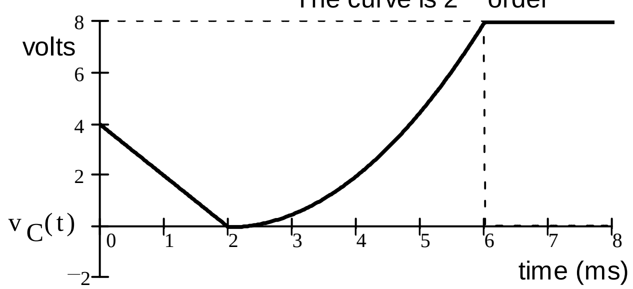
no current means it looks like an open

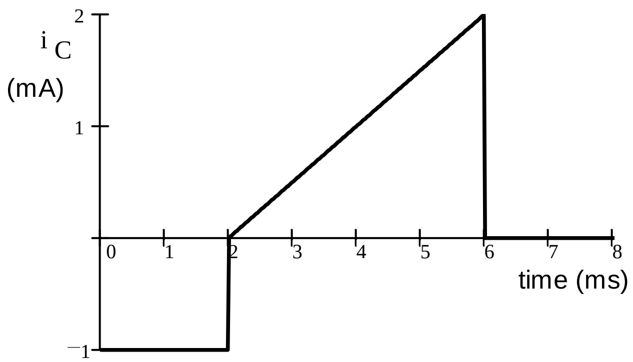
Example

The voltage across a 0.5 μF capacitor is shown below. Make an accurate drawing of the capacitor current. Label the y-axis of your graph (I've already done the time-axis).

The accuracy of your plot at 0, 2, 6, and 8 ms is important, so calculate those values and plot or label them carefully. Between those points your plot must simply be the correct shape.

$C := 0.5\cdot\mu F$





1 - 2ms: $i_C = C\cdot\frac{\Delta V}{\Delta t} = 0.5\cdot\mu F\cdot\frac{-4\cdot V}{2\cdot ms} = -1\cdot mA$

2ms - 6ms: Initial slope is zero and the final slope is positive, so the current must be a triangle that starts at zero and ends at some height.

$$\Delta v_C(t) = \frac{1}{C}\cdot\int_0^t i_C(t)\,dt$$

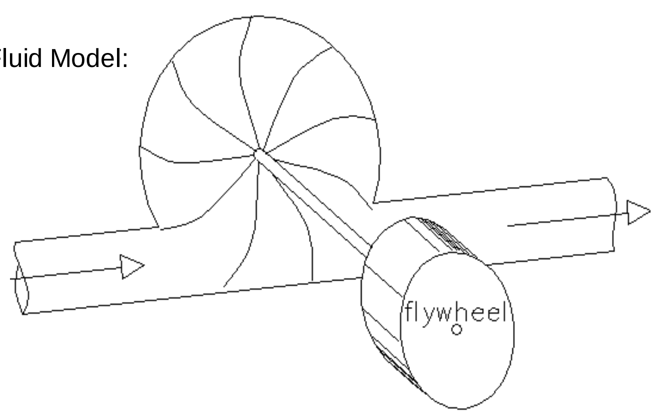
$$8\cdot V = \frac{1}{C}\cdot\left(\frac{4\cdot ms\cdot height}{2}\right)$$

$$height = 8\cdot V\cdot\frac{C\cdot 2}{4\cdot ms} = 2\cdot mA$$

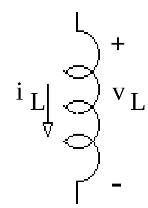
6ms - 8ms: Slope is zero, so the current must be zero.

ECE 2210 / 00 Inductor Lecture Notes

Fluid Model:



Electrical equivalent:



$L = \mu_o\cdot N^2\cdot K$

μ is the permeability of the inductor core

K is a constant which depends on the inductor geometry

N is the number of turns of wire

Basic equations you should know: $v_L = L\cdot\frac{d}{dt}i_L$

$$i_L = \frac{1}{L}\cdot\int_{-\infty}^t v_L\,dt$$

Or... $i_L = \frac{1}{L}\cdot\int_0^t v_L\,dt + i_L(0)$ (initial current)

Or... $\Delta i_L = \frac{1}{L}\cdot\int_{t_1}^{t_2} v_L\,dt$

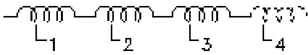
Energy stored in electric field: $W_L = \frac{1}{2}\cdot L\cdot I_L^2$

Inductor current **cannot** change instantaneously

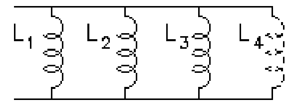
Units: $henry = \frac{volt\cdot sec}{amp}$

$mH = 10^{-3}\cdot H$ $\qquad$ $\mu H = 10^{-6}\cdot H$

series: $L_{eq} = L_1 + L_2 + L_3 + \ldots$



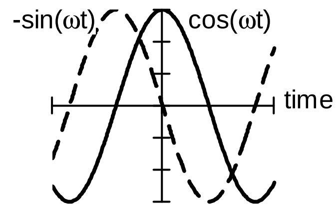
parallel: $L_{eq} = \dfrac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2} + \dfrac{1}{L_3} + \ldots}$



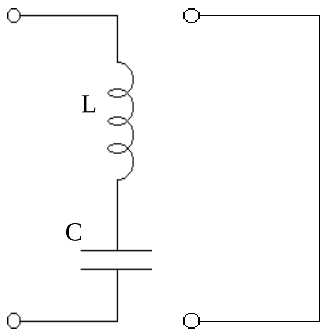
Sinusoids $i_L(t) = I_p \cdot \cos(\omega \cdot t)$

$$v_L(t) = L \cdot \frac{d}{dt} i_L = \underbrace{L \cdot \omega \cdot}_{V_p} \left(-I_p \cdot \sin(\omega \cdot t)\right) = \underbrace{L \cdot \omega \cdot I_p}_{V_p} \cdot \cos(\omega \cdot t + 90 \cdot deg)$$

Voltage "leads" current, makes sense, voltage has to present to make current change, so voltage comes first.

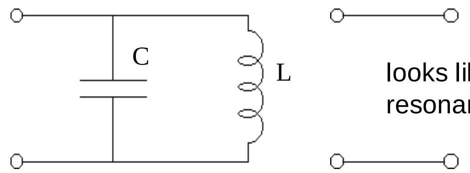


Resonance Series resonance



looks like a short at resonance frequency

Parallel resonance



looks like an open at resonance frequency

The resonance frequency is calculated the same way for either case:

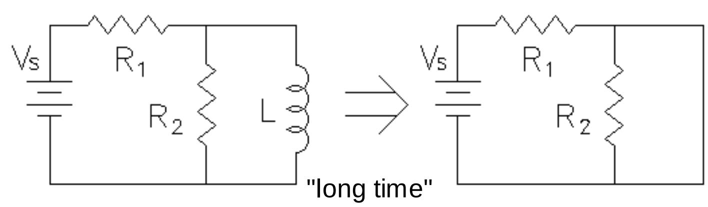
$\omega_o = \dfrac{1}{\sqrt{L \cdot C}} \left(\dfrac{rad}{sec}\right)$ OR.. $\omega_o = \dfrac{1}{\sqrt{L_{eq} \cdot C_{eq}}}$ If you have multiple capacitors or inductors which can be combined. $f_o = \dfrac{\omega_o}{2 \cdot \pi}$ (Hz)

Steady-state of Final conditions

If a circuit has been connected for "a long time", then it has reached a steady state condition. that means the currents and voltages are no longer changing.

$\dfrac{d}{dt} i_L = 0$ $v_L = L \cdot \dfrac{d}{dt} i_L = 0$

no voltage means it looks like a short



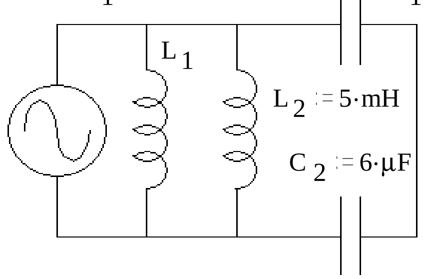
$i_L(\infty) = \dfrac{V_S}{R_1}$

Examples

Ex 1

Find the resonant frequency (or frequencies) of the circuit shown (in cycles/sec or Hz).

$L_1 := 5 \cdot mH$ $C_1 := 6 \cdot \mu F$



$L_2 := 5 \cdot mH$ $C_2 := 6 \cdot \mu F$

$L_{eq} := \dfrac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2}}$ $L_{eq} = 2.5 \cdot mH$

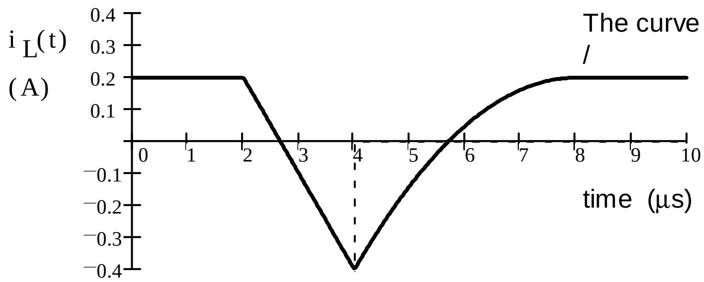
$C_{eq} := \dfrac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2}}$ $C_{eq} = 3 \cdot \mu F$

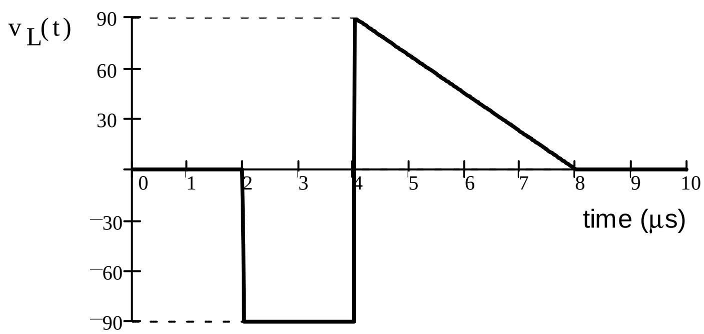
$\omega_o := \dfrac{1}{\sqrt{L_{eq} \cdot C_{eq}}}$ $\omega_o = 11547 \cdot \dfrac{rad}{sec}$ $f_o = \dfrac{\omega_o}{2 \cdot \pi} = 1838 \cdot Hz$

Ex 2

The current through a 0.3mH inductor is shown below. Make an accurate drawing of the inductor voltage. Make reasonable assumptions where necessary. Label your graph.

$L := 0.3\cdot mH$





0 - 2μs: No change in current, so: $v_L = 0$

2μs - 4μs: $v_L = L\cdot\frac{\Delta I}{\Delta t} = 0.3\cdot mH\cdot\frac{-0.6\cdot A}{2\cdot\mu s} = -90\cdot V$

4μs - 8μs: Initial slope is positive and the final slope is zero, so the voltage must be a triangle that starts at some height and ends at zero.

$$\Delta i_L(t) = \frac{1}{L}\cdot\int_0^t v_L(t)\,dt$$

$$0.6\cdot A = \frac{1}{0.3\cdot mH}\cdot\left(\frac{4\cdot\mu s\cdot height}{2}\right)$$

$$height = 0.6\cdot A\cdot\frac{0.3\cdot mH\cdot 2}{4\cdot\mu s} = 90\cdot V$$

8μs - 10μs: No change in current, so: $v_L = 0$

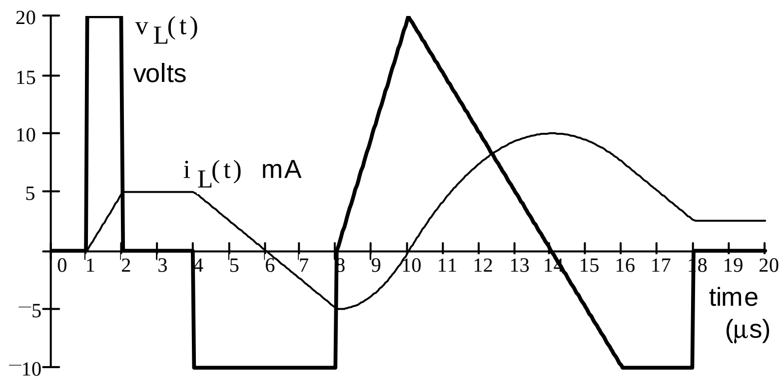
Ex 3 Given a voltage, find the current, $L := 4\cdot mH$

$$\Delta i_L(t) = \frac{1}{L}\cdot\int_{1\cdot\mu s}^{2\cdot\mu s} 20\cdot V\,dt = 5\cdot mA$$

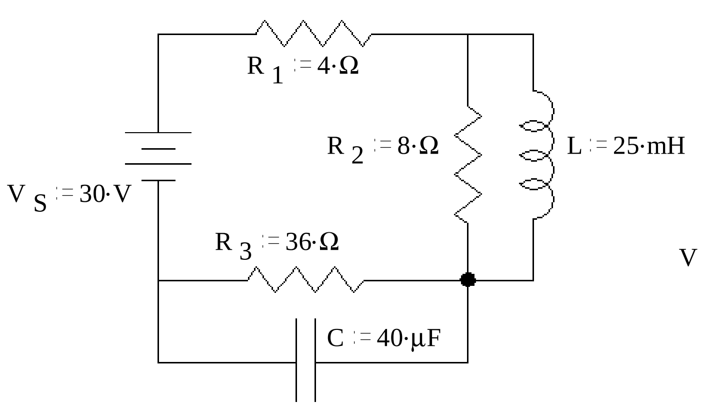
$$\frac{1}{L}\cdot\int_{4\cdot\mu s}^{8\cdot\mu s} -10\cdot V\,dt + 5\cdot mA = -5\cdot mA$$

$$\frac{1}{L}\cdot\int_{8\cdot\mu s}^{10\cdot\mu s} V(t)\,dt + -5\cdot mA$$

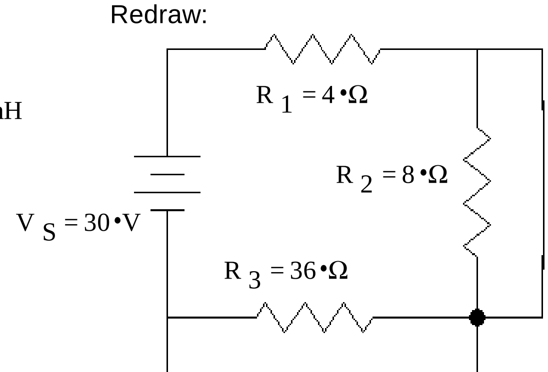
$$= \frac{1}{L}\cdot\frac{20\cdot V\cdot 2\cdot\mu s}{2} - 5\cdot mA = 0\cdot mA \quad \text{etc...}$$



Ex 4 The following circuit has been connected as shown for a long time. Find the energy stored in the capacitor and the inductor.



Redraw:



$V_C := I_L\cdot R_3$

$V_C = 27\cdot V$

$W_C := \frac{1}{2}\cdot C\cdot V_C^{\,2}$ $\qquad W_C = 14.58\cdot mJ$

$I_L := \frac{V_S}{R_1 + R_3}$

$I_L = 0.75\cdot A$

$W_L := \frac{1}{2}\cdot L\cdot I_L^{\,2}$

$W_L = 7.031\cdot mJ$

Capacitor, Inductor Notes

ECE 2210 / 00

A.Stolp
2/27/00,
9/13/05

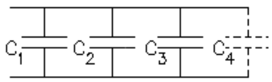
Capacitors

$C = \frac{Q}{V}$ $\quad$ $\text{farad} = \frac{\text{coul}}{\text{volt}} = \frac{\text{amp}\cdot\text{sec}}{\text{volt}}$ $\quad$ $v_C = \frac{1}{C}\cdot\int_{-\infty}^{t} i_C\,dt = \frac{1}{C}\cdot\int_{0}^{t} i_C\,dt + v_C(0)$ (initial voltage) $\quad$ $i_C = C\cdot\frac{d}{dt}v_C$

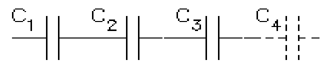
Energy stored in electric field: $W_C = \frac{1}{2}\cdot C\cdot V_C^{\,2}$

Capacitor voltage **cannot** change instantaneously

parallel: $C_{eq} = C_1 + C_2 + C_3 + \ldots$



series: $C_{eq} = \dfrac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} + \ldots}$



Steady-state sinusoids:

Impedance: $Z_C = \frac{1}{j\cdot\omega\cdot C} = \frac{-j}{\omega\cdot C}$ $\quad$ Current leads voltage by 90 deg

Inductors

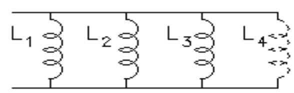
$\text{henry} = \frac{\text{volt}\cdot\text{sec}}{\text{amp}}$ $\quad$ $i_L = \frac{1}{L}\cdot\int_{-\infty}^{t} v_L\,dt = \frac{1}{L}\cdot\int_{0}^{t} v_L\,dt + i_L(0)$ (initial current) $\quad$ $v_L = L\cdot\frac{d}{dt}i_L$

Energy stored in magnetic field: $W_L = \frac{1}{2}\cdot L\cdot I_L^{\,2}$

Inductor current **cannot** change instantaneously

series: $L_{eq} = L_1 + L_2 + L_3 + \ldots$

parallel: $L_{eq} = \dfrac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2} + \dfrac{1}{L_3} + \ldots}$



Steady-state sinusoids:

Impedance: $Z_L = j\cdot\omega\cdot L$ $\quad$ Current lags voltage by 90 deg

RC and RL first-order transient circuits

For all first order transients: $v_X(t) = v_X(\infty) + \left(v_X(0) - v_X(\infty)\right)\cdot e^{-\frac{t}{\tau}}$ $\quad$ $i_X(t) = i_X(\infty) + \left(i_X(0) - i_X(\infty)\right)\cdot e^{-\frac{t}{\tau}}$

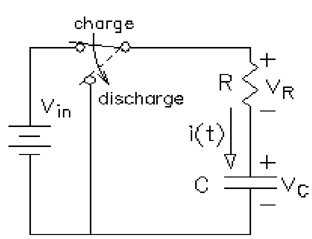
Find initial Conditions (v_C and/or i_L)

Find conditions just before time t = 0, $v_C(0-)$ and $i_L(0-)$. These will be the same just after time t = 0, $v_C(0+)$ and $i_L(0+)$ and will be your initial conditions. (If initial conditions are zero: Capacitors are shorts, Inductors are opens.) Use normal circuit analysis to find your desired variable: $v_X(0)$ or $i_X(0)$

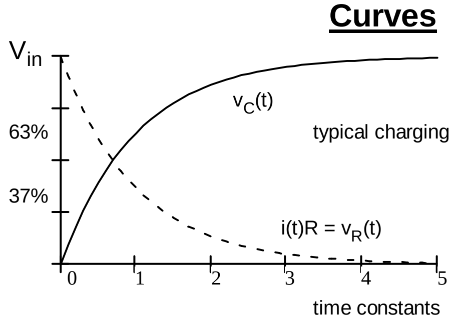
Find final conditions ("steady-state" or "forced" solution)

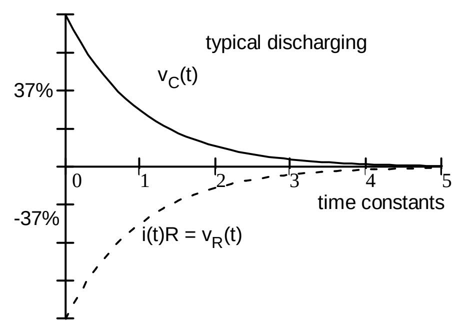
Inductors are shorts Capacitors are opens Solve by DC analysis $v_X(\infty)$ or $i_X(\infty)$

RC Time constant $= \tau = RC$

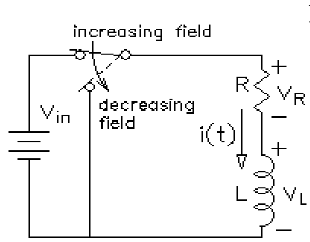


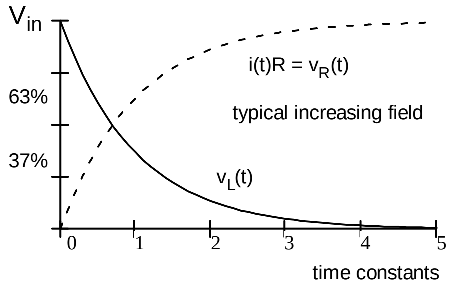
Curves

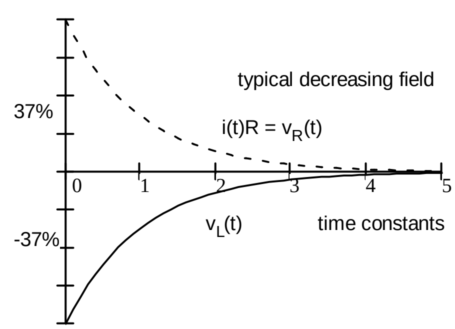




RL Time constant $= \tau = \frac{L}{R}$







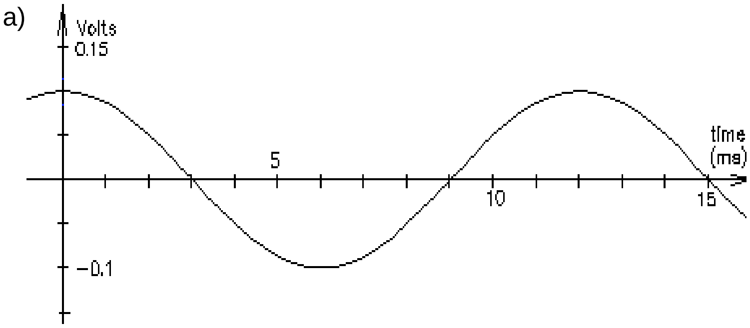
$e^{-1} = 0.368$ $\quad$ $1 - e^{-1} = 0.632$

ECE 2210 / 00   homework # 7   Due: Tue, 2/16/21   a

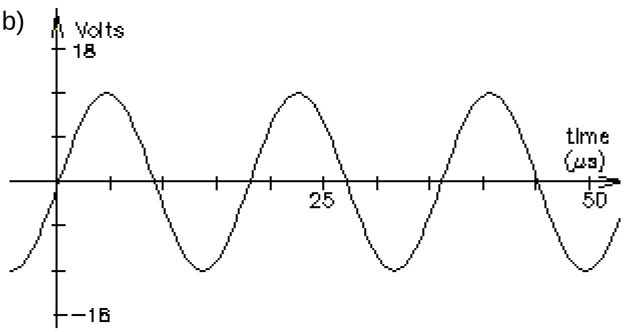
Answer the following problems on your own paper.

1. For each of the following sinusoidal waves, find:
   1) peak-to-peak voltage or current, V_{pp} or I_{pp}
   2) amplitude, A, V_p, or I_p
   3) period, T
   4) frequency f in cycles/sec or Hz
   5) an expression for $v(t)$ or $i(t)$ in terms of $A\cos(\omega t + \phi)$
      the frequency ω is in radians/sec
      the phase angle ϕ is in rad/sec or degrees

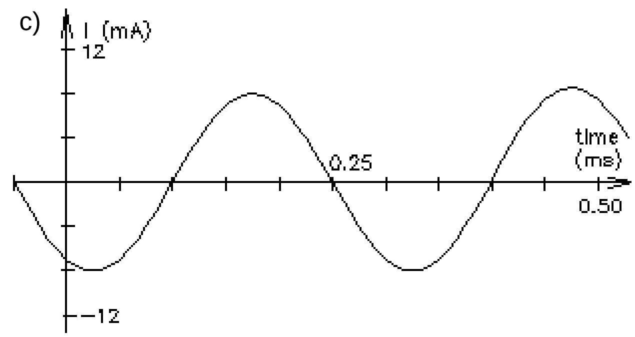
a)



b)

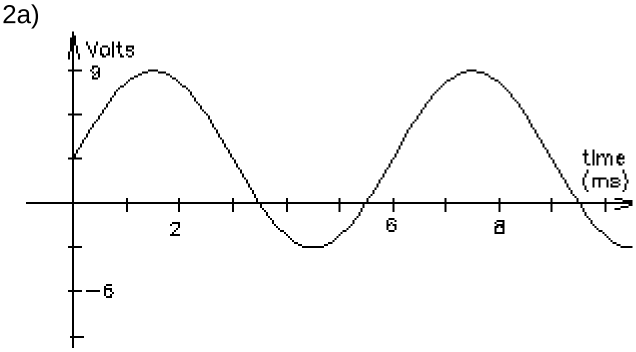


c)

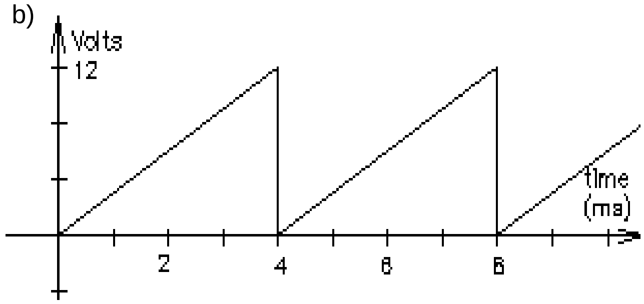


2. For each of the following waveforms, find:
   1) Peak-to-peak voltage or current, V_{pp} or I_{pp}
   2) Average, (V_{DC}, I_{DC}, V_{ave}, or I_{ave})
   3) Period, T
   4) Frequency f in cycles/sec or Hz

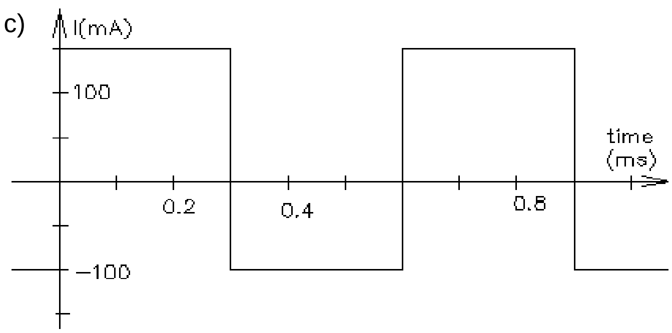
2a)



b)



c)



3. For problem 2a above, write a full expression for $v(t)$ in terms of $v(t) = A\cos(\omega t + \phi) + V_{DC}$

Answers

1. a) $0.2\cdot V$ $0.1\cdot V$ $12\cdot ms$ $83.3\cdot Hz$ $0.1\cdot V\cdot\cos(523.6\cdot t)$

   b) $24\cdot V$ $12\cdot V$ $0.018\cdot ms$ $55.6\cdot kHz$
   $v(t) := 12\cdot V\cdot\cos(349100\cdot t - 90\cdot deg)$

   c) $16\cdot mA$ $8\cdot mA$ $0.3\cdot ms$ $3333\cdot Hz$
   $8\cdot mA\cdot\cos(20940\cdot t + 150\cdot deg)$

2. a) $12\cdot V$ $3\cdot V$ $6\cdot ms$ $167\cdot Hz$

   b) $12\cdot V$ $6\cdot V$ $4\cdot ms$ $250\cdot Hz$

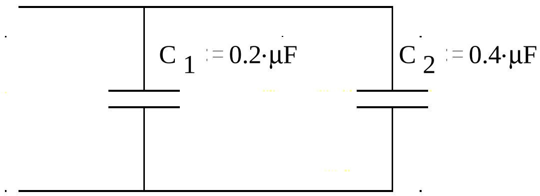
   c) $250\cdot mA$ $25\cdot mA$ $0.6\cdot ms$ $1.667\cdot kHz$

3. $v(t) := 6\cdot V\cdot\cos(1047\cdot t - 90\cdot deg) + 3\cdot V$

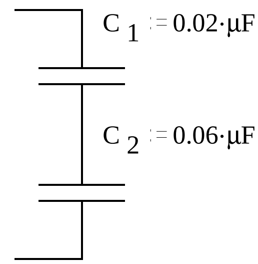
ECE 2210 / 00 homework # 8 Due: Sat, 2/20/21 a2

1) Find C_{eq} in each case

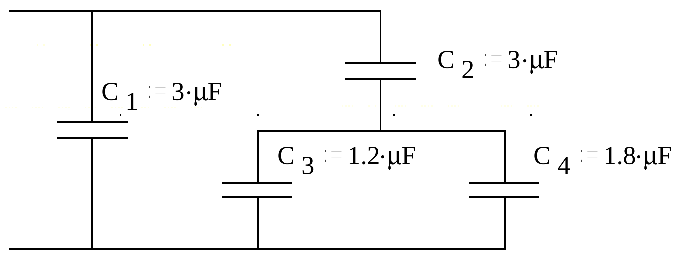
a)



b)

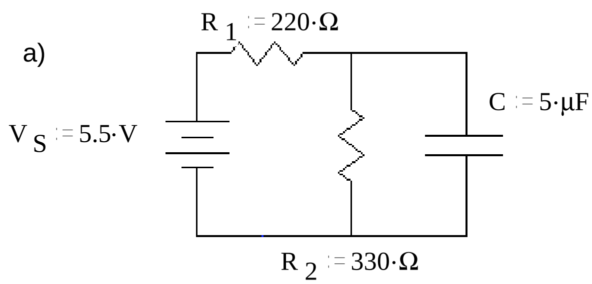


c)

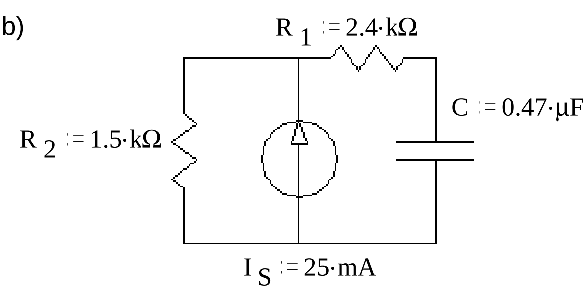


2. Each of the following circuits have been connected as shown for a long time.
Find the voltage across each capacitor and the energy stored in each.

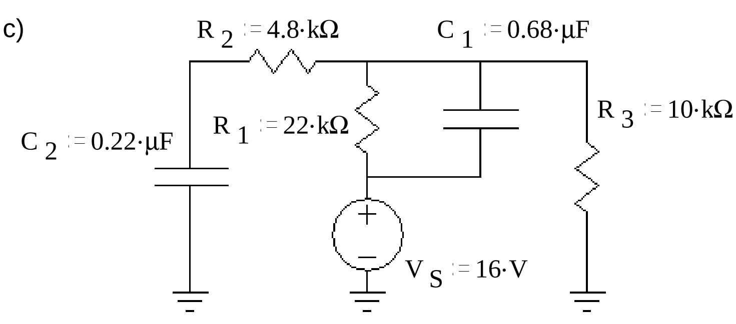
a)



b)

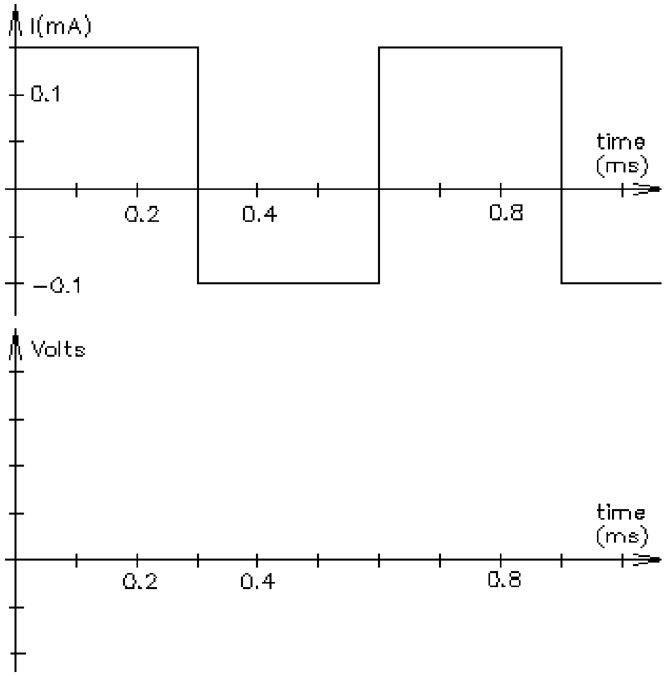


c)

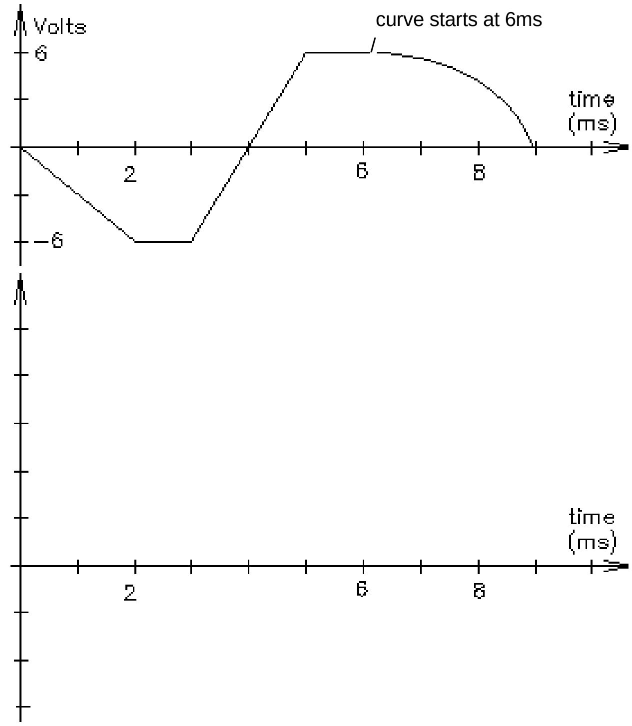


Name: ___________________________________You may want to hand in this page with answers to problems 3 & 4.

3. The current waveform shown below flows through a $0.025\ \mu F$ capacitor. Make an accurate drawing of the voltage across it. Label your graph. Assume the initial voltage across the capacitor is $0\ V$.



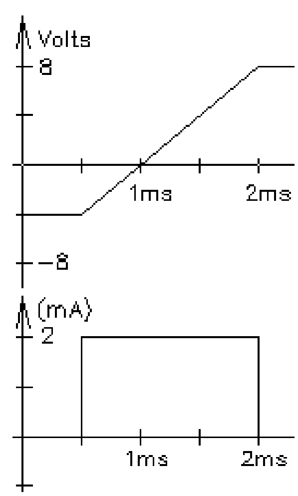
4. The voltage across a $2\ \mu F$ capacitor is shown below. Make an accurate drawing of the capacitor current. Label your graph.



5. The voltage across a $0.68\ \mu F$ capacitor is $v_C = 6 \cdot V \cdot \cos\left(200 \cdot t + \frac{\pi}{2}\right)$ find i_c.

6. The current through a $0.0047\ \mu F$ capacitor is $i_C = 18 \cdot \mu A \cdot \cos\left(628 \cdot t - \frac{\pi}{4}\right)$ find v_c.

7. A capacitor voltage and current are shown at right. What value is the capacitor?



Answers

1. a) $0.6 \cdot \mu F$ b) $0.015 \cdot \mu F$ c) $4.5 \cdot \mu F$

2. a) $3.3V$ $0.027 \cdot mJ$ b) $37.5 \cdot V$ $0.33 \cdot mJ$ c) $11 \cdot V$ $0.0411 \cdot mJ$ $5 \cdot V$ $2.75 \cdot \mu J$

3. $1.8 \cdot V$ $0.6 \cdot V$ $2.4 \cdot V$ 4. $-6 \cdot mA$ $12 \cdot mA$ ramp to $-8mA$

5. $i_c = 0.816 \cdot mA \cdot \cos(200 \cdot t + \pi)$ 6. $v_c = 6.1 \cdot V \cdot \cos\left(628 \cdot t - \frac{3 \cdot \pi}{4}\right)$ 7. $0.25 \cdot \mu F$

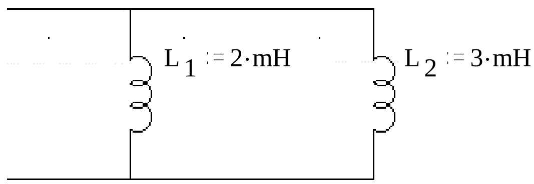
Name: ________________________________

ECE 2210 / 00   hw # 9   Due: Tue, 2/23/21

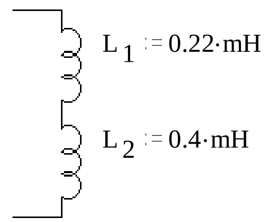
You will need another paper for your calculations, but you may want to hand this sheet in with your drawings.

1. Find L_{eq} in each case

a)

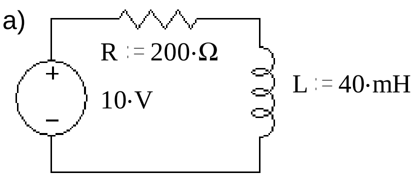


b)

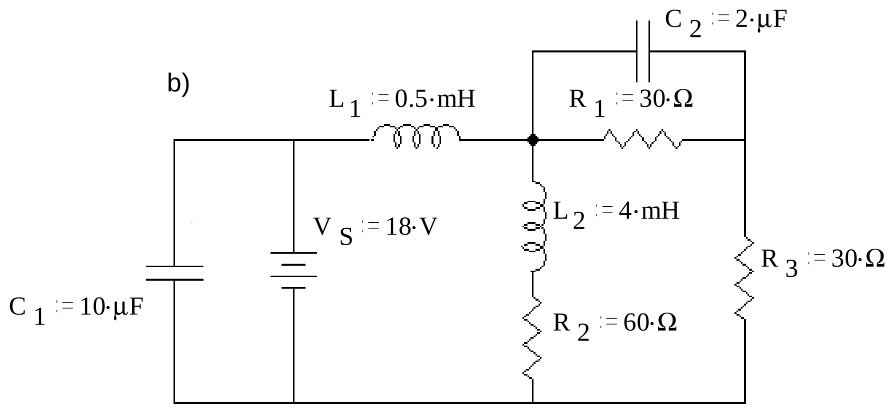


2. Find the stored energy in each capacitor and/or inductor under steady-state conditions. Note: Treat caps as opens and inductors as shorts to find DC voltages and currents.

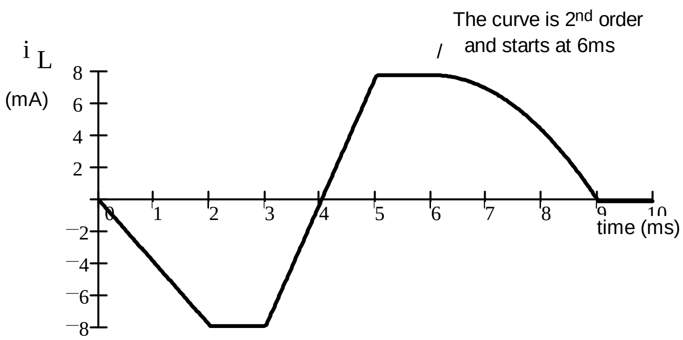
a)

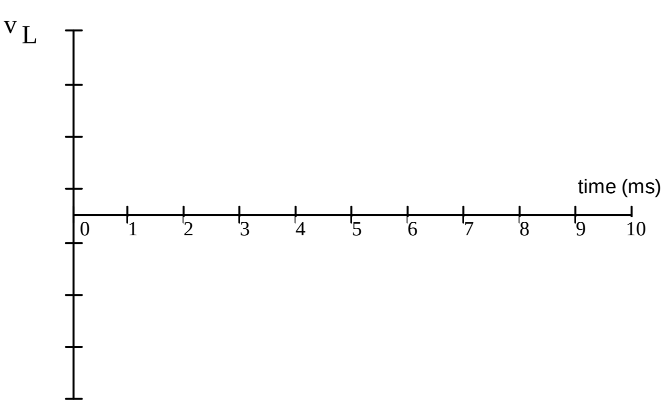


b)

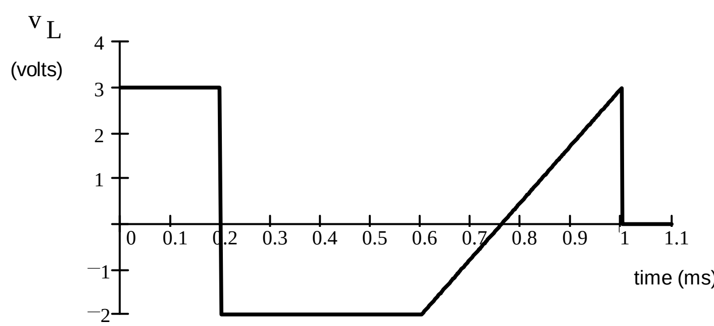


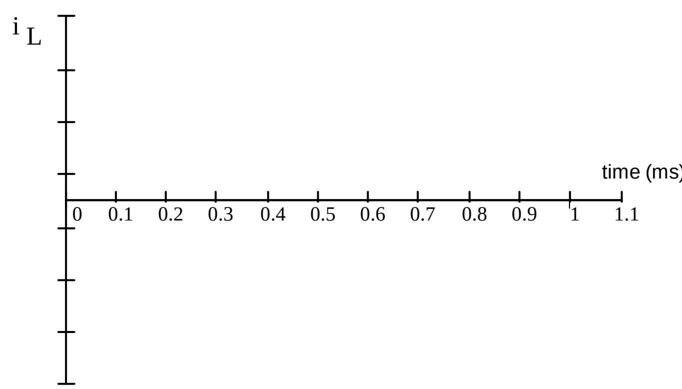
3. The current waveform shown below flows through a 2 mH inductor. Make an accurate drawing of the voltage across it. Label your graph.





4. The voltage across a 0.5 mH inductor is shown below. Make an accurate drawing of the inductor current. Label your graph. Assume the initial current is 0 mA.





ECE 2210 / 00 homework # 9

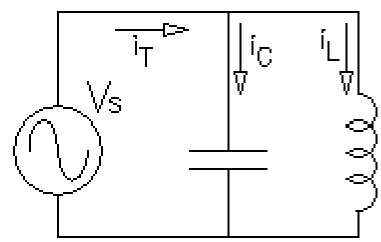
5. The voltage across a 1.2 mH inductor is $v_L = 4 \cdot mV \cdot \cos(300 \cdot t)$ find i_L.

6. The current through a 0.08 mH inductor is $i_L = 20 \cdot mA \cdot \cos\left(628 \cdot t - \frac{\pi}{4}\right)$ find v_L.

7. Refer to the circuit shown. Assume that V_s is a sinusoidal input voltage whose frequency can be adjusted. At some frequency of V_s this circuit can resonate. At that frequency $i_C(t) = -i_L(t)$. ($i_C(t)$ is 180 degrees out-of-phase with $i_L(t)$).

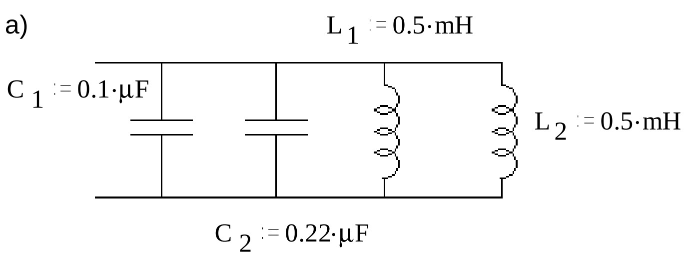
   Show that resonance occurs at this frequency:

$$\omega_o = \frac{1}{\sqrt{L \cdot C}} \quad , \qquad f_o = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

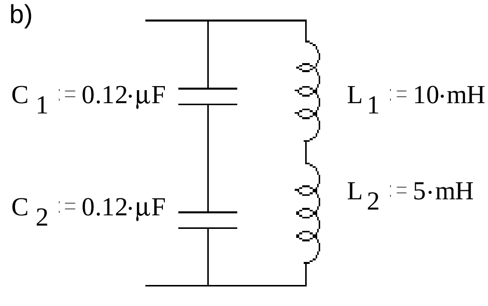


8. Find the resonant frequency, f_o in each case.

   a)



   b)



Answers

1. $1.2 \cdot mH$ $\quad 0.62 \cdot mH$
2. a) $0.05 \cdot mJ$ $\quad$ b) $1.62 \cdot mJ$ $\quad 0.081 \cdot mJ$ $\quad 0.09 \cdot mJ$ $\quad 0.18 \cdot mJ$
3. Straight lines between the following points: (0ms,-8mV), (2ms,-8mV), (2ms,0mV), (3ms,0mV), (3ms,16mV), (5ms,16mV), (5ms,0mV), (6ms,0mV), (9ms,-10.67mV), (9ms,0mV), (10ms,0mV)
4. Straight lines between the following points: (0ms,0A), (0.2ms,1.2A), (0.6ms,-0.4A), curves until it's flat at (0.76ms, -0.72A), continues to curve up to (1ms, 0A), (1.1ms,0A)
5. $i_L = 11.1 \cdot mA \cdot \cos(300 \cdot t - 90 \cdot deg)$
6. $v_L = 1 \cdot mV \cdot \cos\left(628 \cdot t + \frac{1}{4} \cdot \pi\right)$
7. Assume a sinusoidal voltage, find i_C and i_L by integration and differentiation, and show that they are equal and opposite at the resonant frequency.
8. a) $17.79 \cdot kHz$ $\quad$ b) $5305 \cdot Hz$