EE 5220 - Lecture 3 Fri Jan 10, 2024

Topics for Today:

- Startup
    - Web page: https://pages.mtu.edu/~bamork/ee5220/
    - Book, references, syllabus, more are on web page.
    - Software - ATP/EMTP, Matlab. License - www.emtp.org
    - EE5220-L@mtu.edu (participation = min half letter grade)
    - Lectures - new videostreams, some archived videos also
    - Daily lecture notes scanned and .pdf file archived
    - Exercises posted as pdf on web page.
    - Grading: grad students must achieve BC (75%) or higher.
    - Prereqs: - Circuit Analysis RLC Responses, EE5200
- Chapters 1 and 2, probs 1.2, 1.3, 2.2, 2.3, 2.7 due Tues 9am ET.
- Basic use of ATP (tutorials from EE5200), see https://mtu.instructure.com/courses/1487599/modules
- Forced response of RL, RLC circuits.

EE 5220 Assn: ______________ Date: ______

Name	Problems Worked	Partner's Approval
__________________	__________________________	______________
__________________	__________________________	______________

Note! If working together, turn in <u>ONE</u> homework set, else the first one encountered will be graded! You and your homework partner shall in any case receive the same grade.

ASSIGNMENT GUIDELINES:

Assignments will be given out regularly - typically one larger one each week. You will typically have 2-7 days to complete an assignment, depending on how long it is. **Late penalties may be assigned - typically 10% off for each day of inconvenience.** If there is not already enough room on the assignment sheet, attach additional sheets of 8½ x 11 engineering grid paper (not notebook paper), stapled in upper left corner. Show all work, illustrate by schematic or a diagram, provide assumptions, give equations before substitution, show all units and underline or circle all answers. If attaching computer simulation results, highlight important results and provide complete annotations so that the significance of the results is clear - let's develop the documentation habits of a design engineer - could someone else reconstruct your work? **Neatness and clarity of the documentation are important.** You are strongly encouraged to discuss concepts and theory related to homework via the course e-mail forum, send e-mail to ee5220-L@mtu.edu (not yet in operation) to reach all of us and start a discussion.

In some cases you will work together in <u>pairs</u>. Remote students may have to work alone if they are the only one at their site. Although it's not recommended, each of you may work alone on your part of the exercise, meeting and tutoring each other on the details prior to handing in the homework. Partners are to sign off on each other's work. Your approval signifies that:

- you've checked your partner's calculations for correctness,
- you understand the theory, concepts, and solutions method of your partner's work, and
- your partner has done a proportionate share of the work.

Answers (but not necessarily the solutions) will be posted or marked on the graded homework.

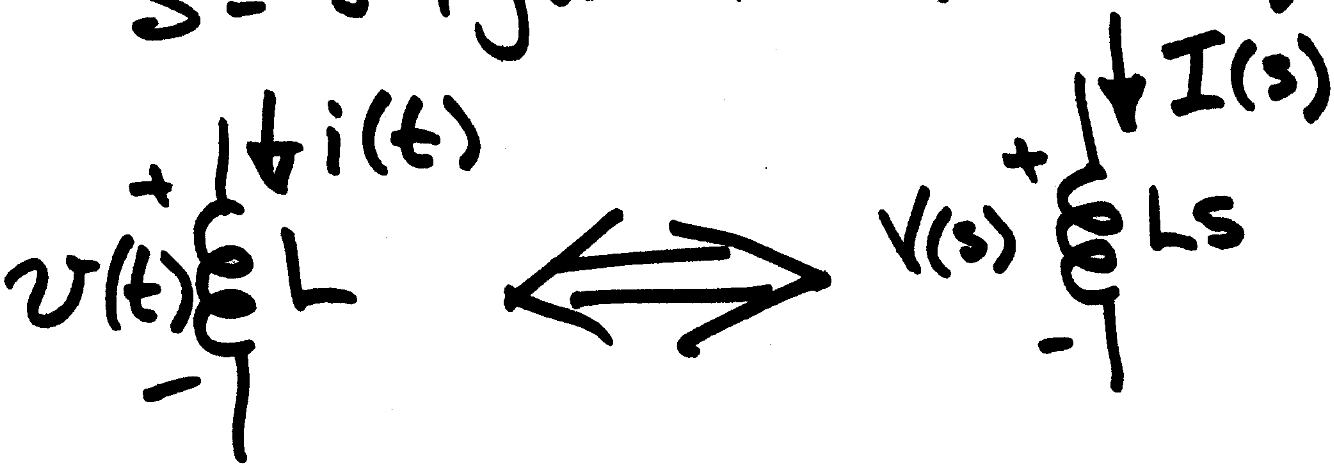
Local Students: Put your homework in Drop Box #34 on the 7th Floor of EERC. [Online students: scan and e-mail to bamork@mtu.edu and mjagtap@mtu.edu as .pdf attachment (max 150-300 dpi gray scale is recommended, otherwise files are huge!), or fax to 906.487.2949 (high-res mode).]

Graded homework may be claimed in the box outside of your instructor's office (EERC 614). [Remote students: your work will be returned via mail.] After claiming your returned homework, please follow up on any incorrect solutions.

Your professor is typically available for office hours help from 3:05-3:55pm Mon,Wed,Fri, plus other times by arrangement. E-mail: bamork@mtu.edu; Office: 487-2857; A classroom office hour can be scheduled on demand, this works extremely well. Contact your professor.

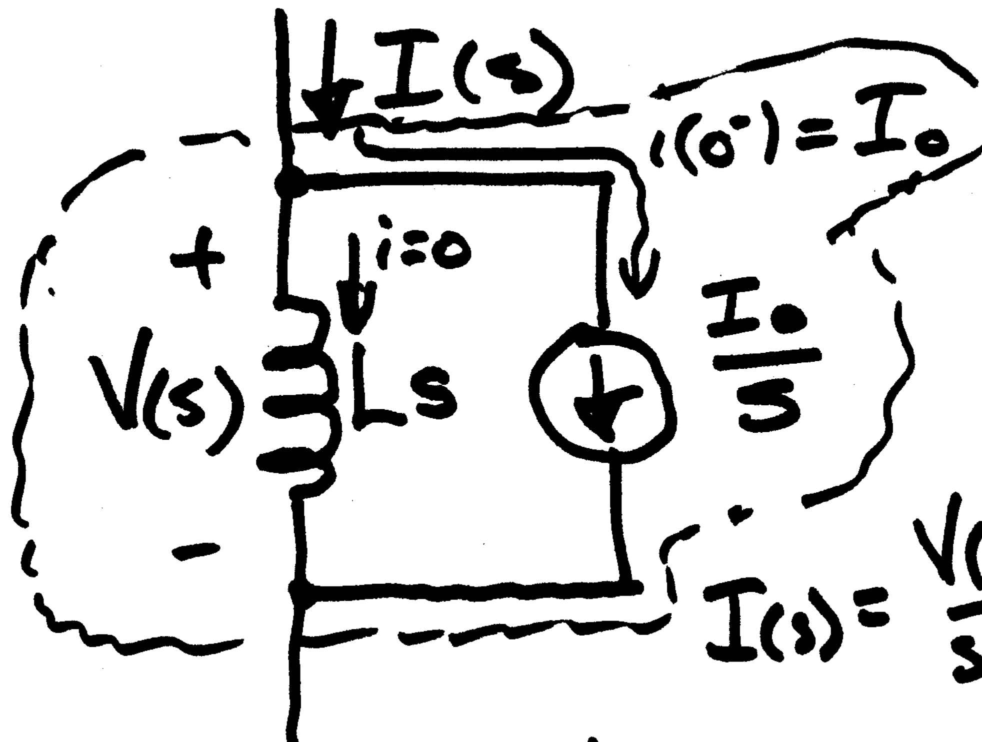
Laplace Review

$s = \sigma + j\omega$ (complex freq)



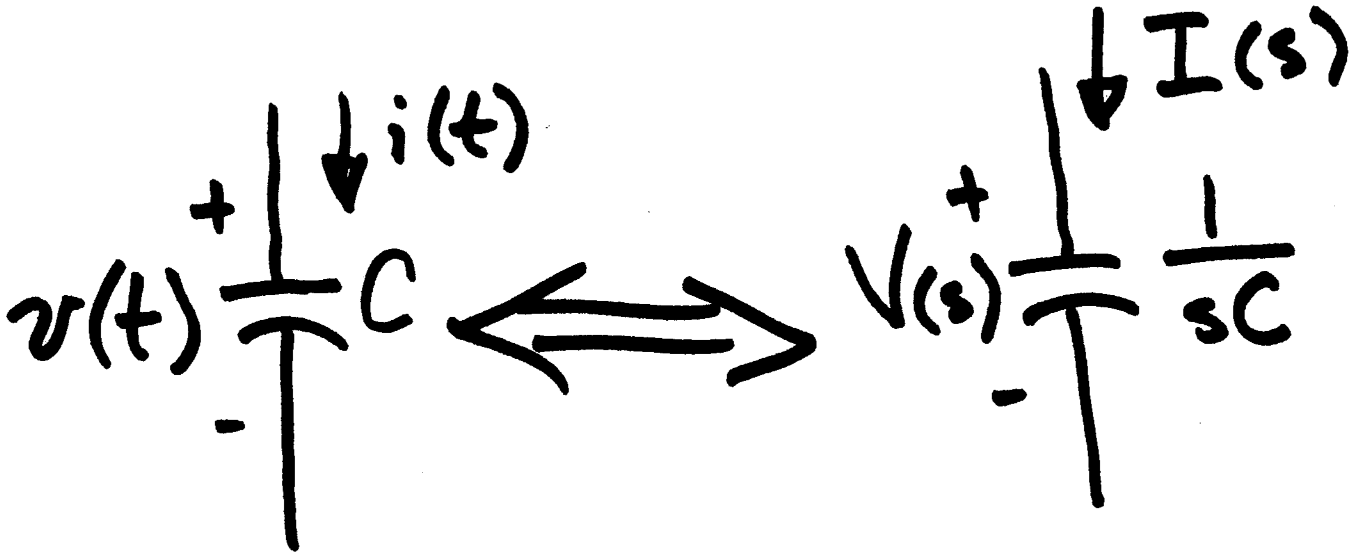
Initial Conditions:

if $i(0^-) = I_0$ then



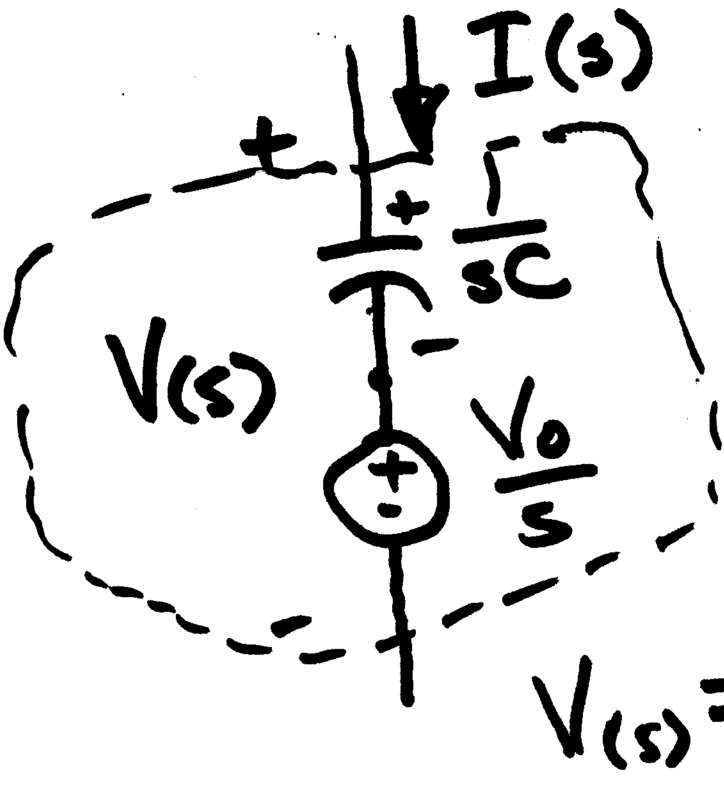
$$I(s) = \frac{V(s)}{sL} + \frac{I_0}{s}$$

$$V(s) = sL\left(I(s) - \frac{I_0}{s}\right) = sLI(s) - LI_0$$



Initial Conditions:

if $v(0^-) = V_0$ then



$$V(s) = \frac{I(s)}{sC} + \frac{V_0}{s}$$

$$I(s) = sCV(s) - CV_0$$

Approach:

- Solve circuit, i.e. $V(s)$ & $I(s)$
- Take inverse transform to get time-domain soln.

$$f(t) = \frac{1}{2\pi j} \int_{\sigma - j\infty}^{\sigma + j\infty} e^{st} F(s)\, ds$$

$$= \underline{\underline{\mathcal{L}^{-1}(F(s))}}$$

$$F(s) = \int_0^{\infty} e^{-st} f(t)\, dt = \underline{\underline{\mathcal{L}(f(t))}}$$

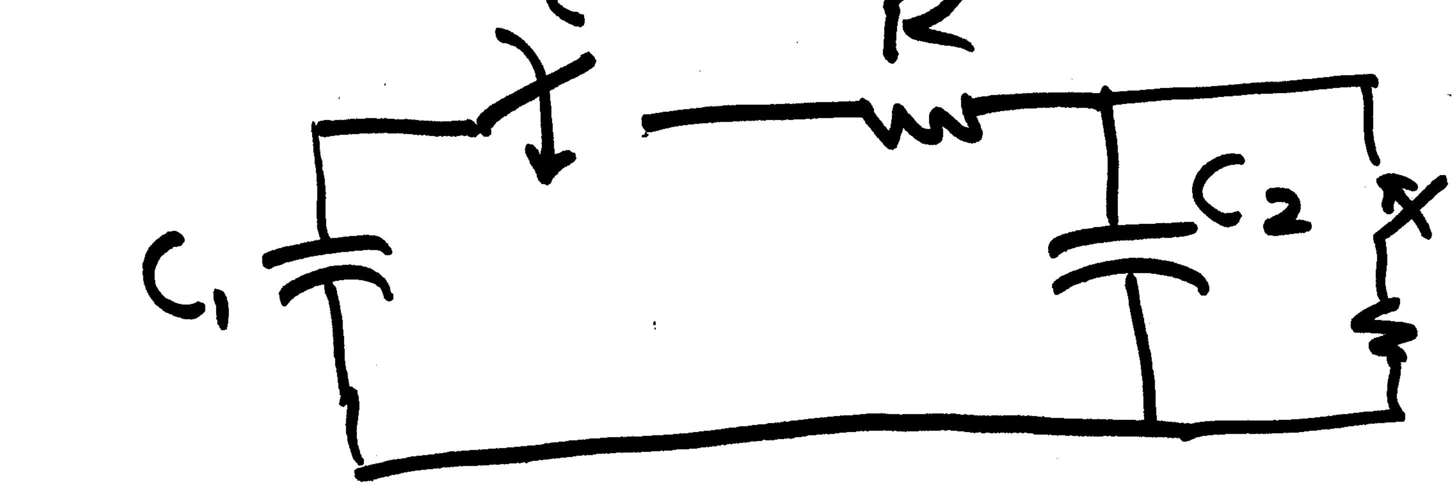
Or, use transform tables

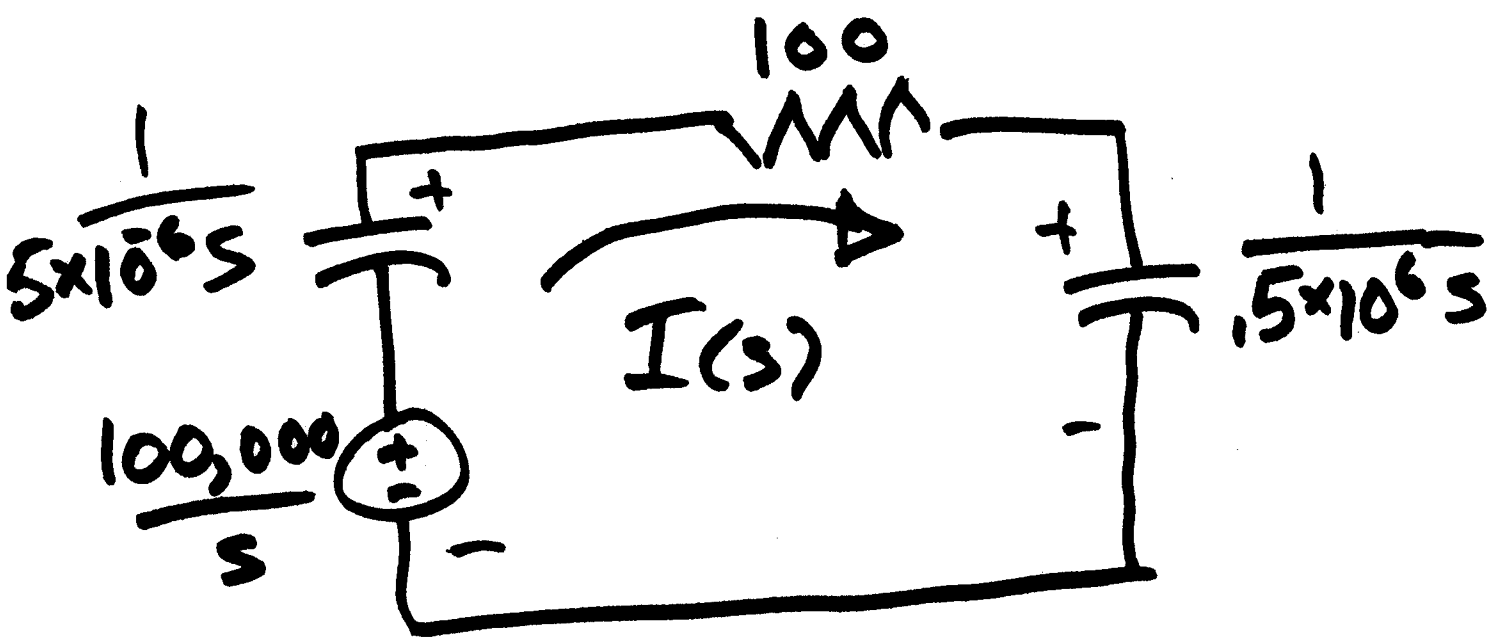
* $V u(t) \Leftrightarrow \frac{V}{s}$ $\qquad e^{\alpha t} \Leftrightarrow \frac{1}{s-\alpha}$

$I' t \Leftrightarrow \frac{I'}{s^2}$ $\qquad e^{-\alpha t} \Leftrightarrow \frac{1}{s+\alpha}$

* $\sin \omega t \Leftrightarrow \frac{\omega}{s^2+\omega^2}$ $\qquad \cos \omega t \Leftrightarrow \frac{s}{s^2+\omega^2}$

Ex: 1.3





$$I(s) = \frac{\frac{100,000}{s}}{100 + \frac{1}{5\times10^{6}s} + \frac{1}{.5\times10^{6}s}}$$

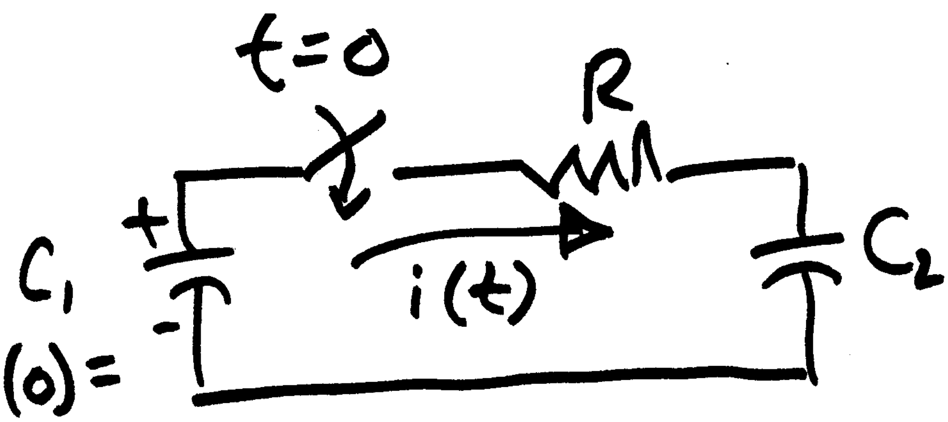
$$= \frac{100,000}{100s + 2,200,000}$$

$$= \frac{1000}{S + 22{,}000} = 1000\left(\frac{1}{S+22{,}000}\right.$$

since $\frac{1}{s+\alpha} \Longleftrightarrow e^{-\alpha t}$

$$\boxed{i(t) = 1000\, e^{-22{,}000 t}} \text{ A}$$

use this soln up until SW2 (Arc Gap) closes at $t = 40\,\mu S$

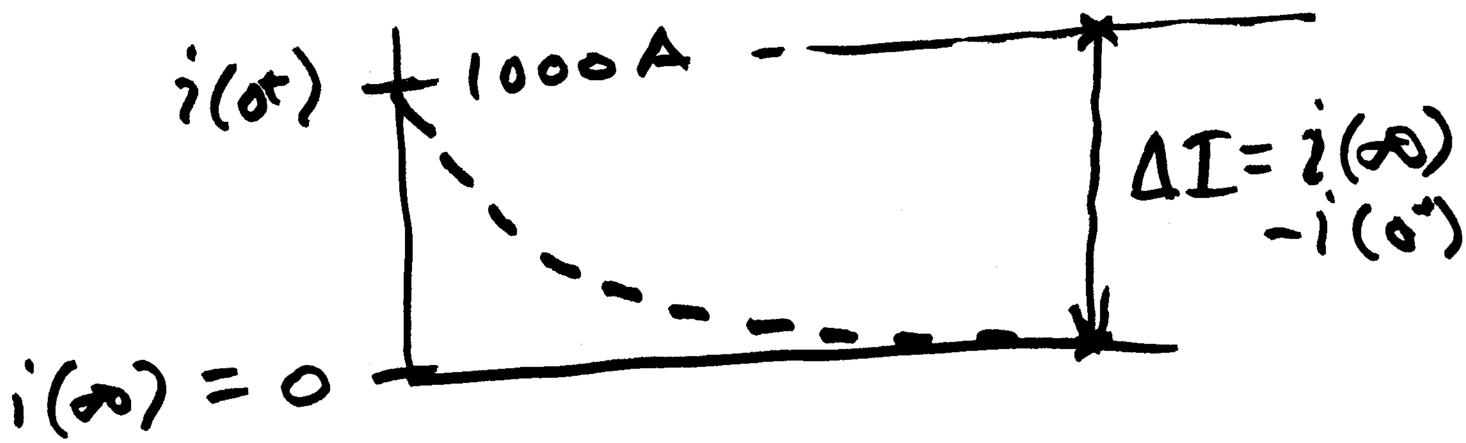


$V_{C_1}(0) =$ 100,000V

$$\tau = RC_{EQ} = R\frac{C_1C_2}{C_1+C_2}$$

$$i(0^+) = \frac{100{,}000}{100} = \underline{1000\,A}$$

$$\underline{i(\infty) = 0} \quad (V_{C1} = V_{C2})$$



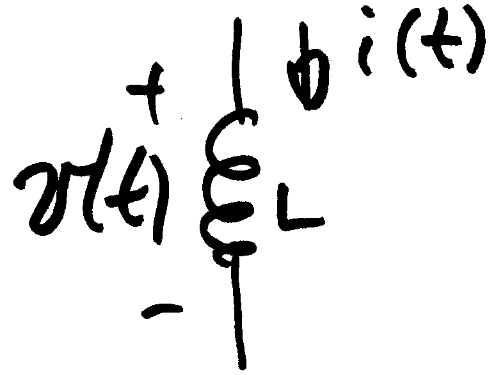
$$i(t) = 1000\,e^{-\frac{t}{\tau}}$$

$$\tau = RC_{EQ} = \frac{1}{22{,}000}\,s$$

C_{EQ} = "Operative" capacitanc

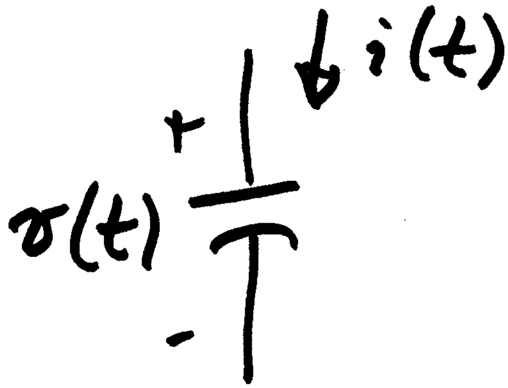
$$C_{EQ} = C_1 \not\parallel C_2 \;\; = \frac{C_1C_2}{C_1+C_2}$$

Basic Circuits



$$v(t) = L\frac{di(t)}{dt}$$

$$i(t) = \frac{1}{L}\int_0^t v(t)\,dt + \underline{\underline{I_0}}$$



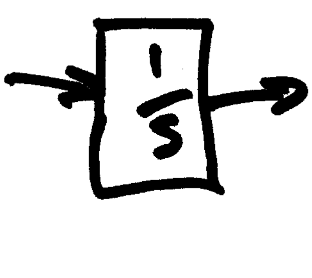
$$i(t) = C\frac{dv(t)}{dt}$$

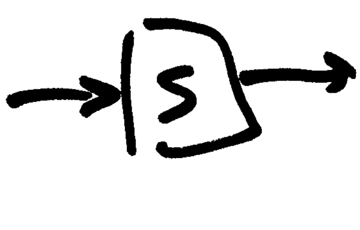
$$v(t) = \frac{1}{C}\int_0^t i(t)\,dt + \underline{\underline{V_0}}$$

In s-domain:

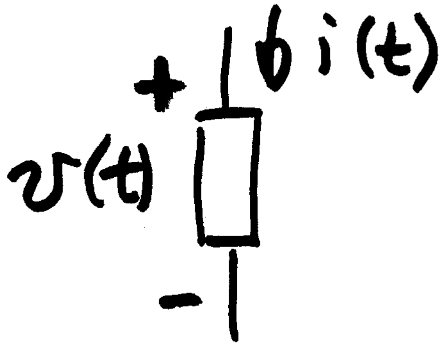
derrivative $\Rightarrow$ $\times s$

integrate $\Rightarrow$ $\div s$

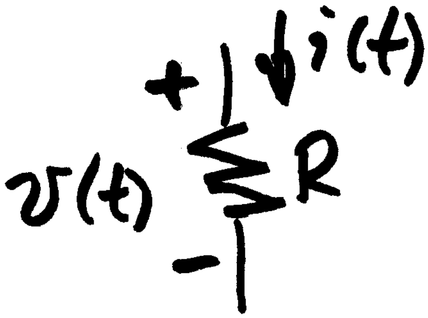




Instantaneous Power



$$p(t) = v(t)\,i(t)$$



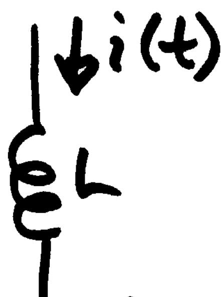
$$p(t) = i^2(t) \times R$$

$$= \frac{v^2(t)}{R}$$

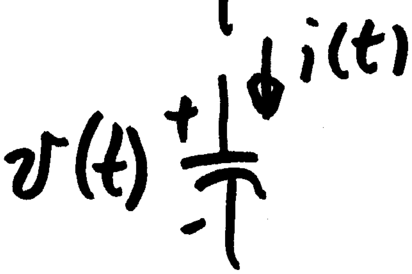
Energy: $J(t) = \int_0^t p(t)\,dt$

Stored Energy

- At any instant of time, t



$$J = \frac{1}{2} L\, i^2(t) + J_0$$

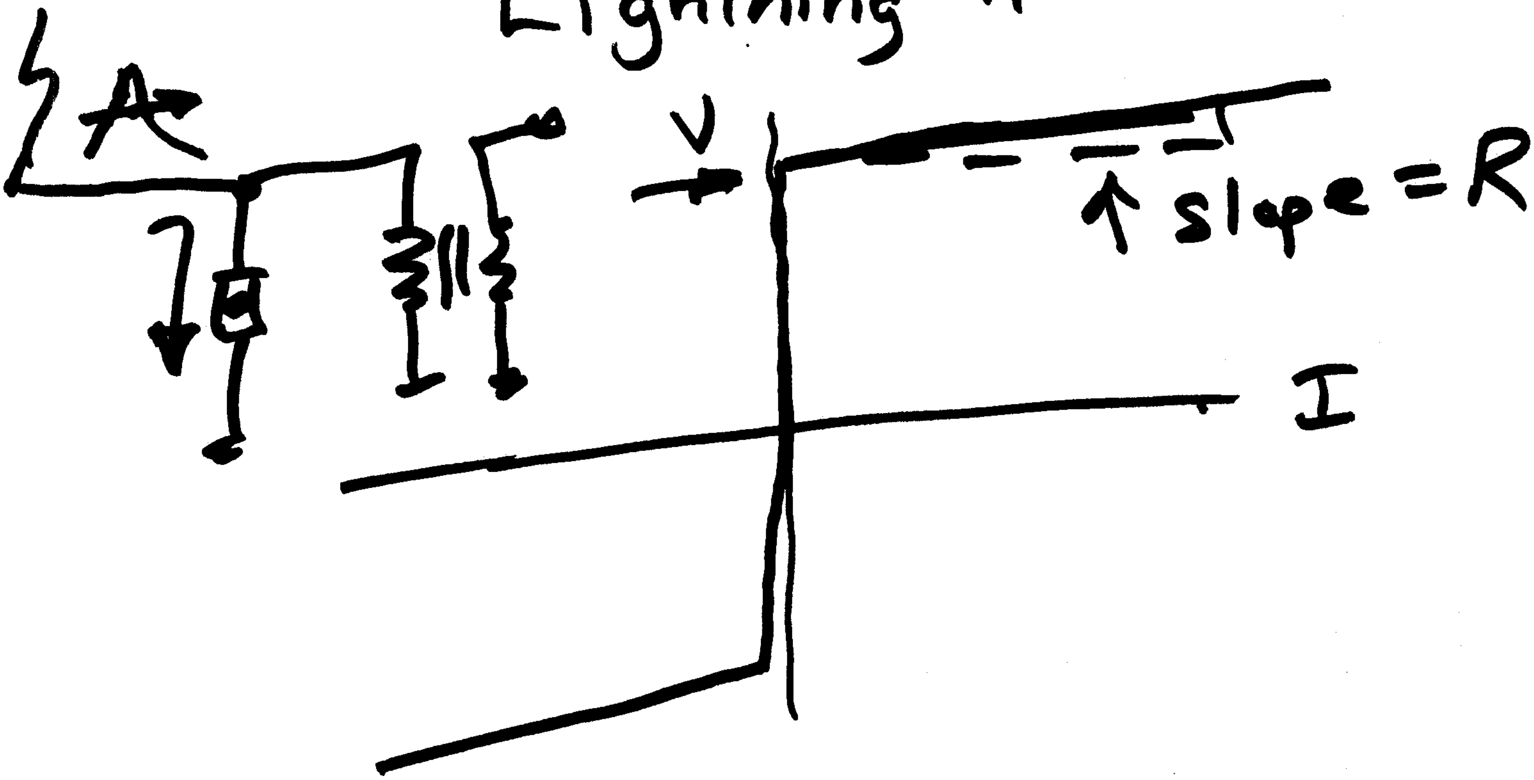


$$J = \frac{1}{2} C\, v^2(t) + J_0$$

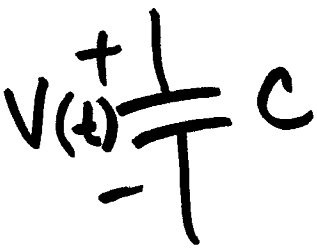
Energy Dissipated in R

$$J = \int_0^\infty \underbrace{R\, i^2(t)}_{p_{inst}}\, dt$$

Lightning Arrester



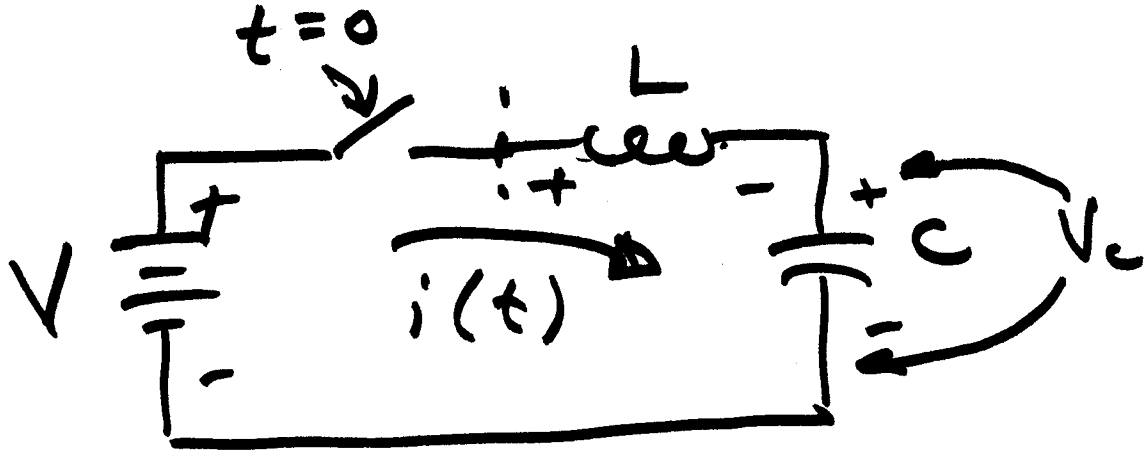
Charge on a Capacitor



$$q(t) = v(t)\, C$$

$$Q = CV \quad \text{(steady state)}$$

RLC circuits



KVL → $V = L\frac{di(t)}{dt} + V_c$

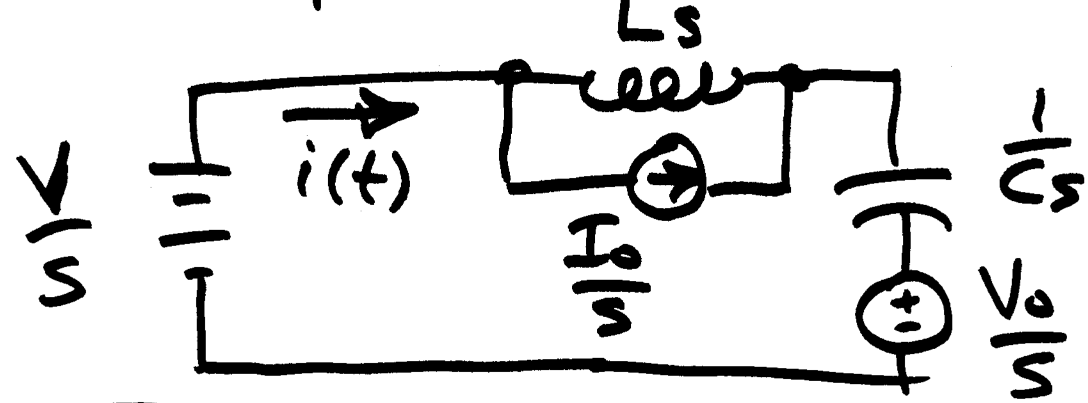
$i(t) = C\frac{dv_c}{dt}$

$$V = L\frac{di(t)}{dt} + \frac{1}{C}\underbrace{\int i(t)\,dt}_{q(t)}$$

Note:

$$\left.\begin{aligned} q(t) &= \int_0^t i(t)\,dt \\ i(t) &= \frac{dq(t)}{dt} \end{aligned}\right\}$$

With Laplace,

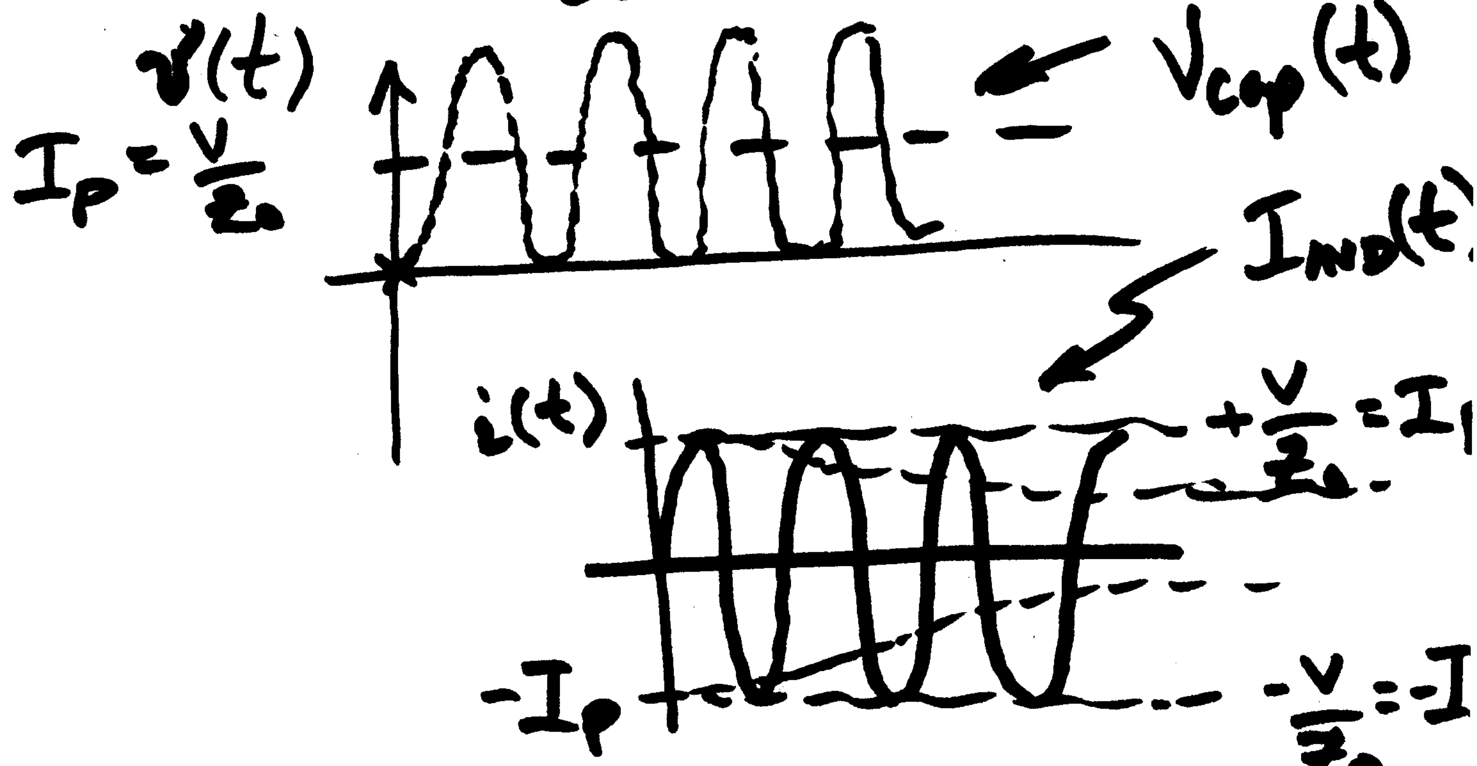


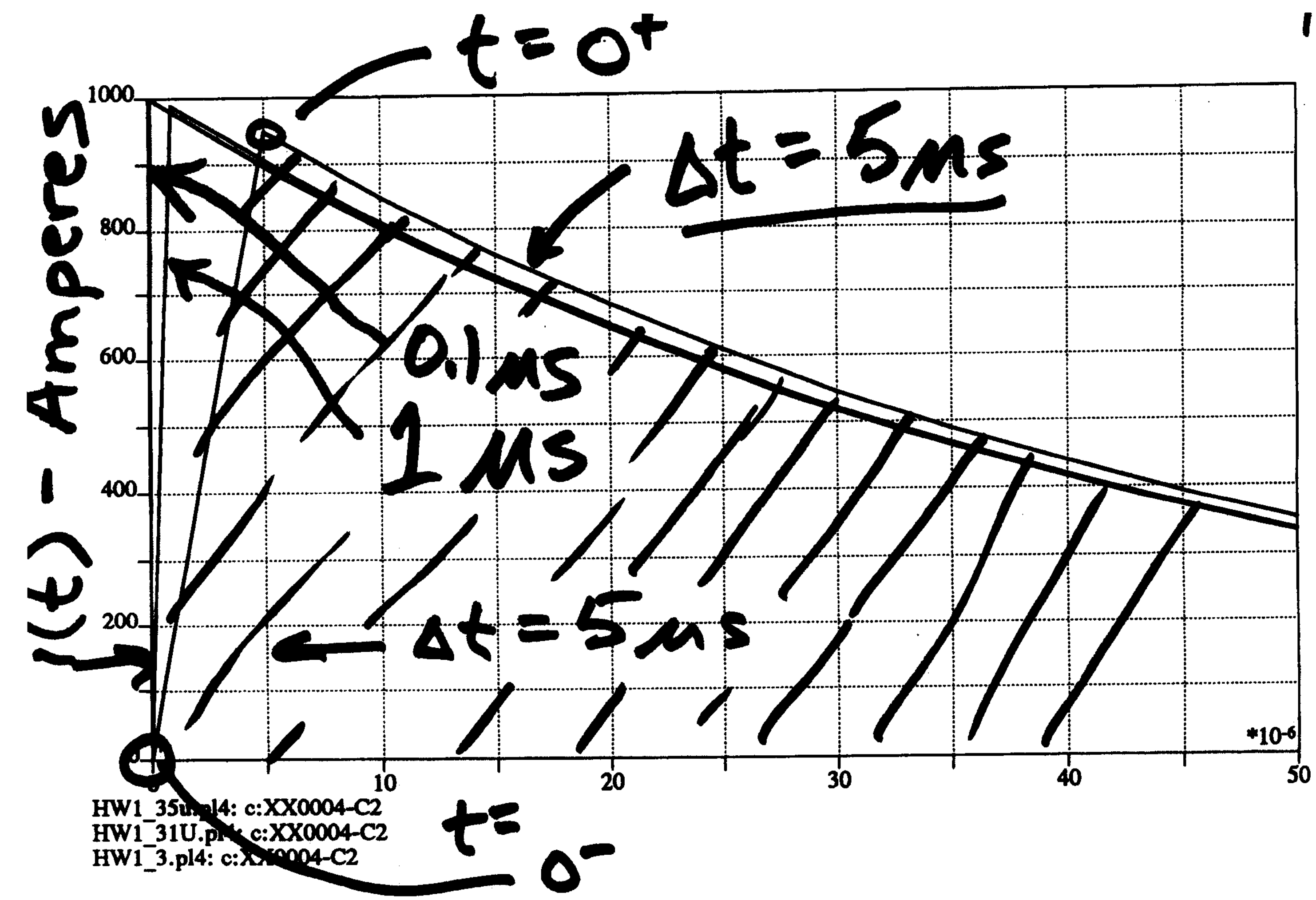
Short-Cut Observations

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad \text{or} \quad f_0 = \frac{1}{2\pi\sqrt{LC}}$$

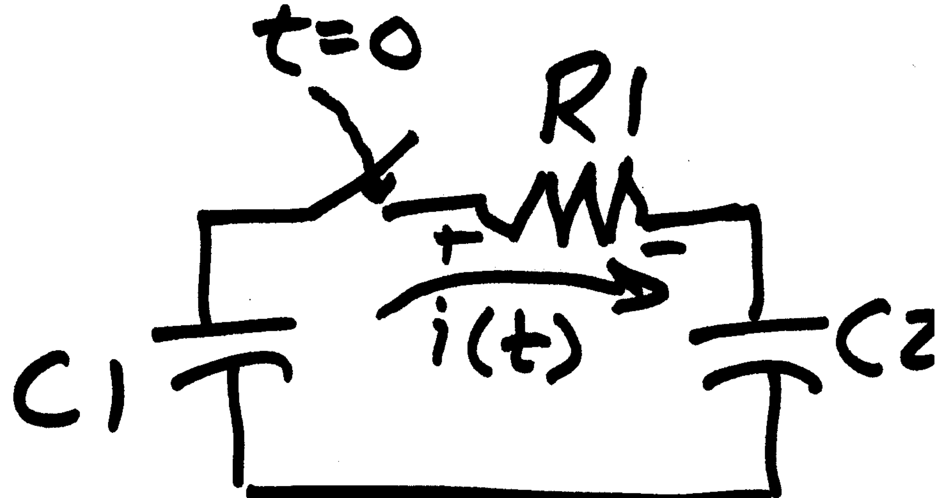
Operative ~~[illegible]~~ Impedance

$$Z_0 = \sqrt{\frac{L}{C}} \Rightarrow I_p = \frac{V}{Z_0}$$





Prob 1.3



$$i(0^+) = \frac{v_{C1}(0)}{R1}$$

$$= 1000\,A$$

Make Δt small enough to resemble step function!