EE 5220 - Lecture 6 Fri Jan 19, 2024

Topics for Today:

- Startup
  - Web page: https://pages.mtu.edu/~bamork/ee5220/
  - Book, references, syllabus, more are on web page.
  - Software - Matlab. ATP/EMTP [License - www.emtp.org]
  - **ATP tutorials posted on course web page. DO THEM!**
  - Circuit analysis tutorials posted, "Pre-Req Material"
  - EE5220-L@mtu.edu (participation = min half letter grade)

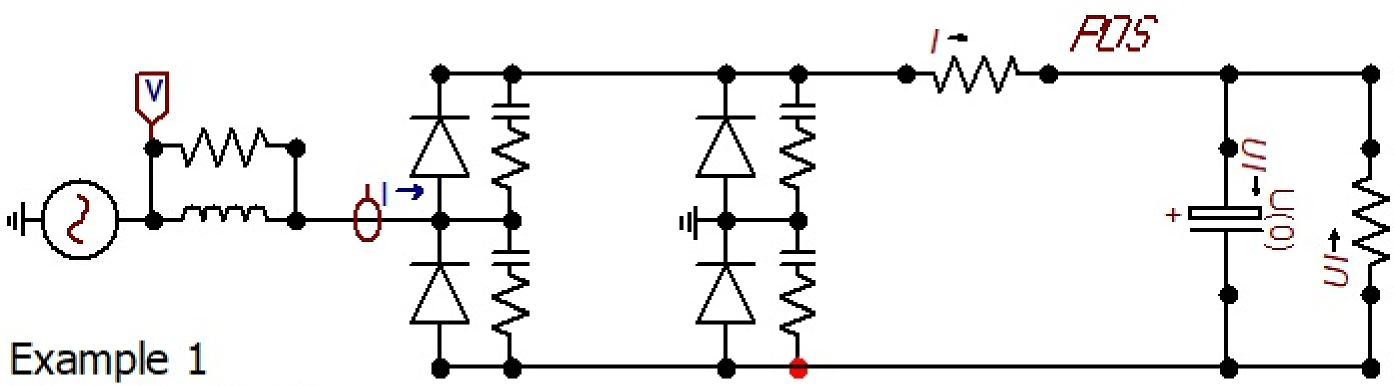
- HW#3 probs 3.2, 3.3, 3.4, 3.6, 3.12 due Tues Jan 30th.
- ATP Simulation pointers
- Cap Bank Switching (continued)
  - First (single) bank energization
  - Back-to-back switching
  - Outrush
  - TRV
  - Voltage Magnification

ATP Pointers

Your simulation circuit from *.acp file and PlotXY plot of *.pl4 file can be easily pasted into a .doc file for homework or writing a report.

Circuit diagram:

- Select/drag window around circuit diagram
- File > Save metafile (.wmf format)
- Insert graphics/file into your .docx file.

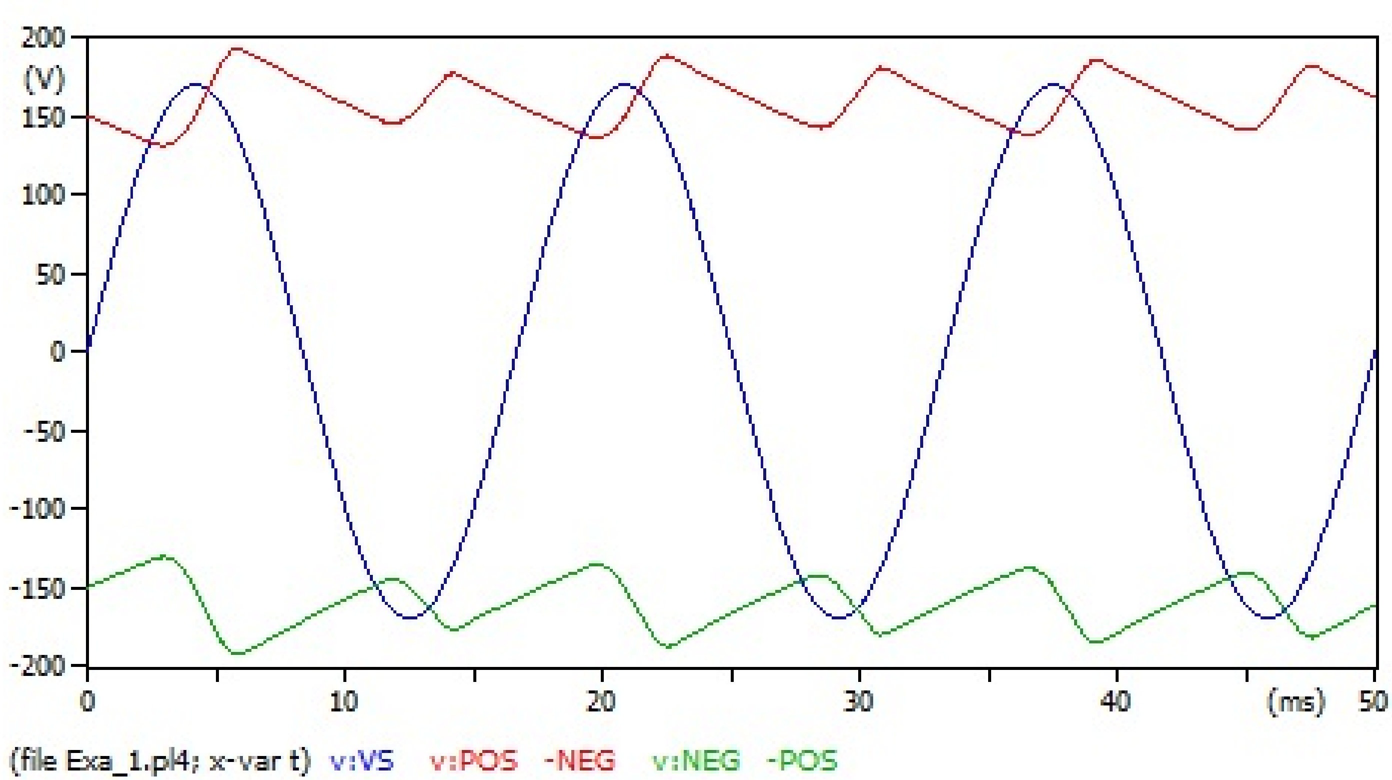


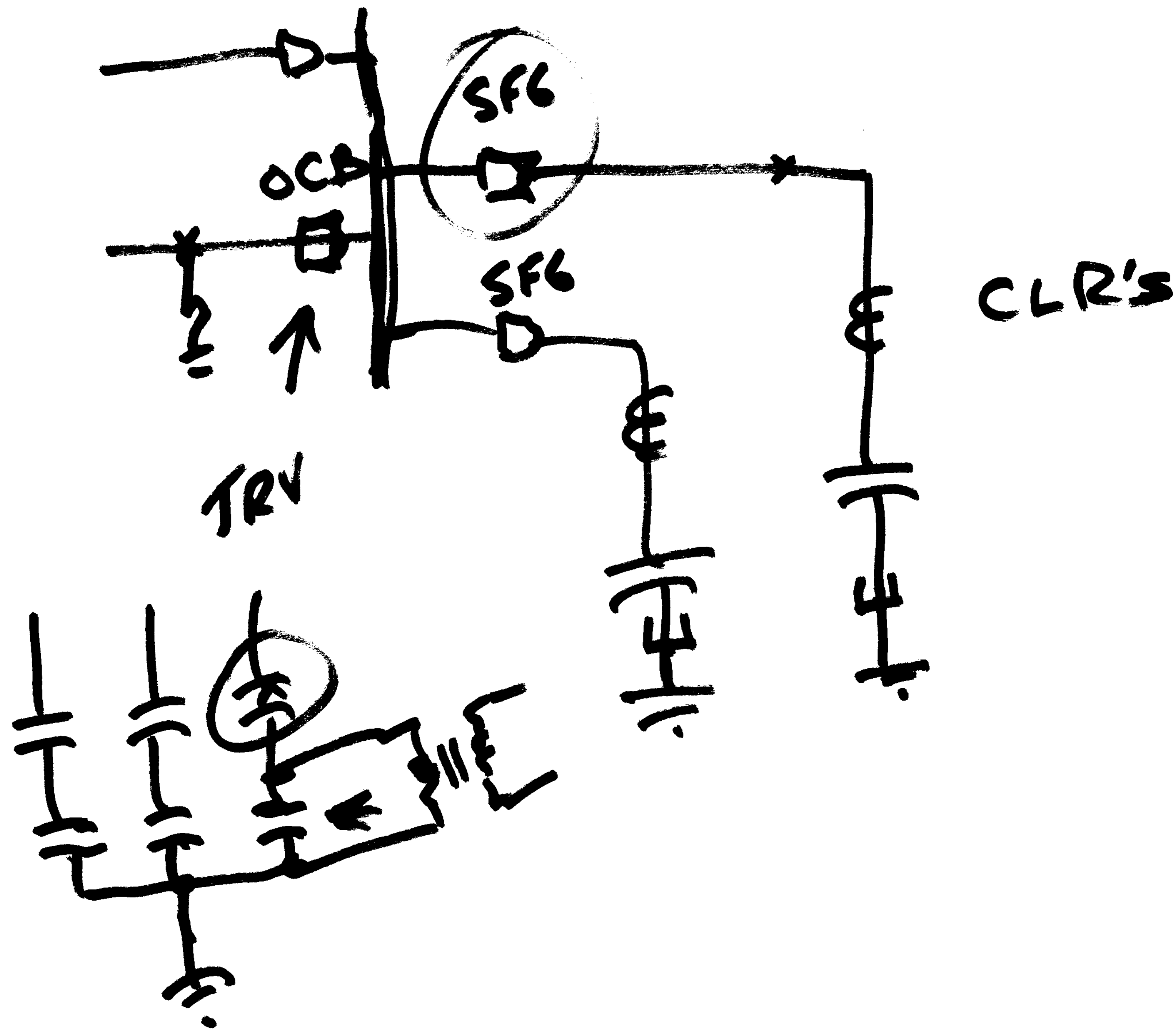
Example 1
Your first circuit
Rectifier bridge

What is the difference between vector graphics (.wmf) and raster/dot (.bmp)?

Plot file from PlotXY:

Copy plot into clipboard (lower right corner of Plot Window).
Paste into your .docx file. This will be a bit-map file, low resolution. Can also save as *.svg (Scalable Vector Graphics, similar to metafile *.wmf) or *.png (raster/dot/pixel graphics).

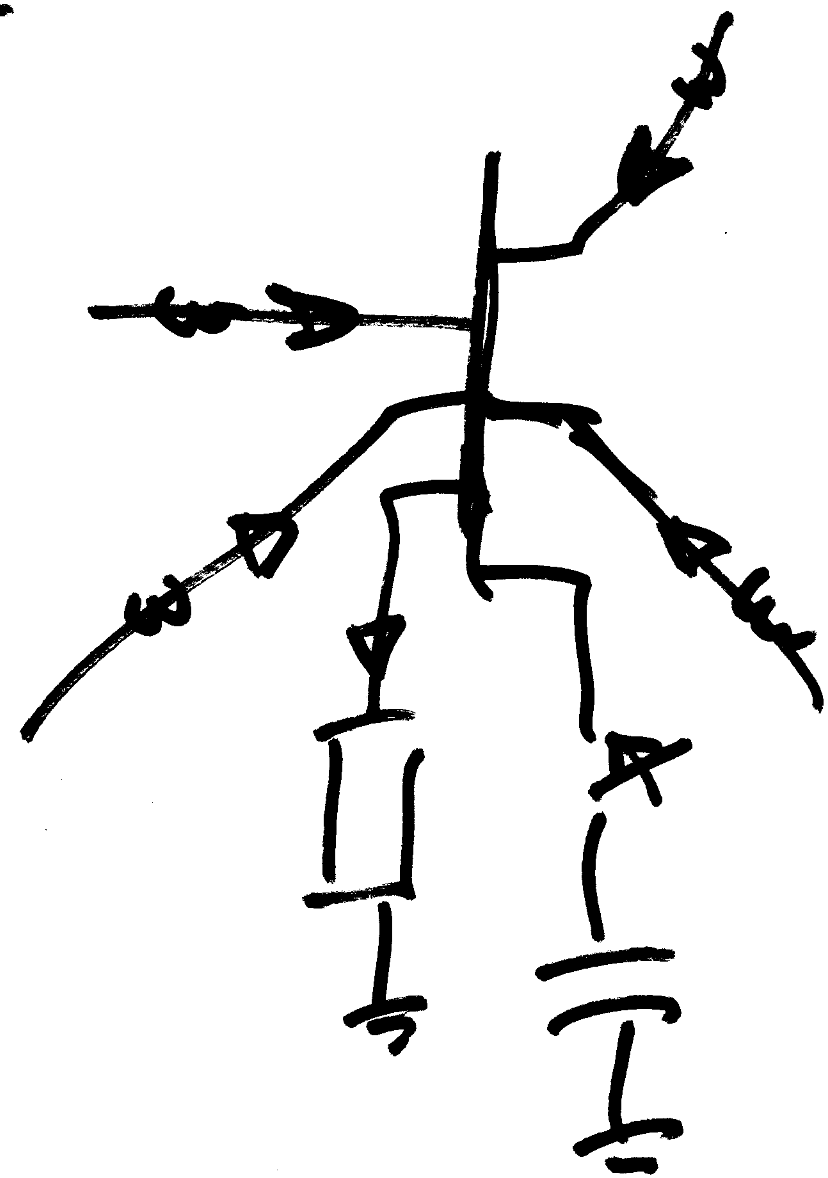



SF6
OCB
SF6
CLR's
TRV

Shunt Cap Banks

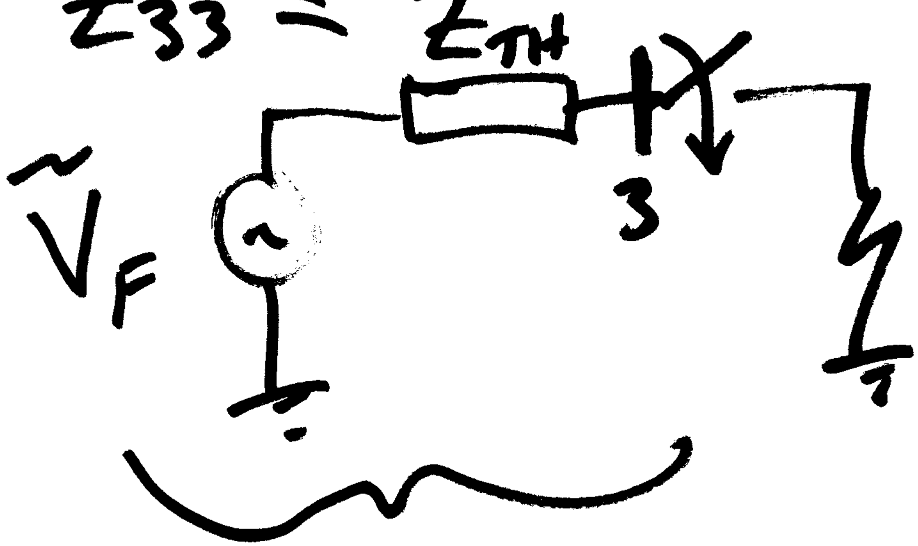
- Voltage Support
- Var
- Power Flow

$$P_M = \frac{V_1 V_2}{X} \qquad \uparrow \underline{21\%}$$

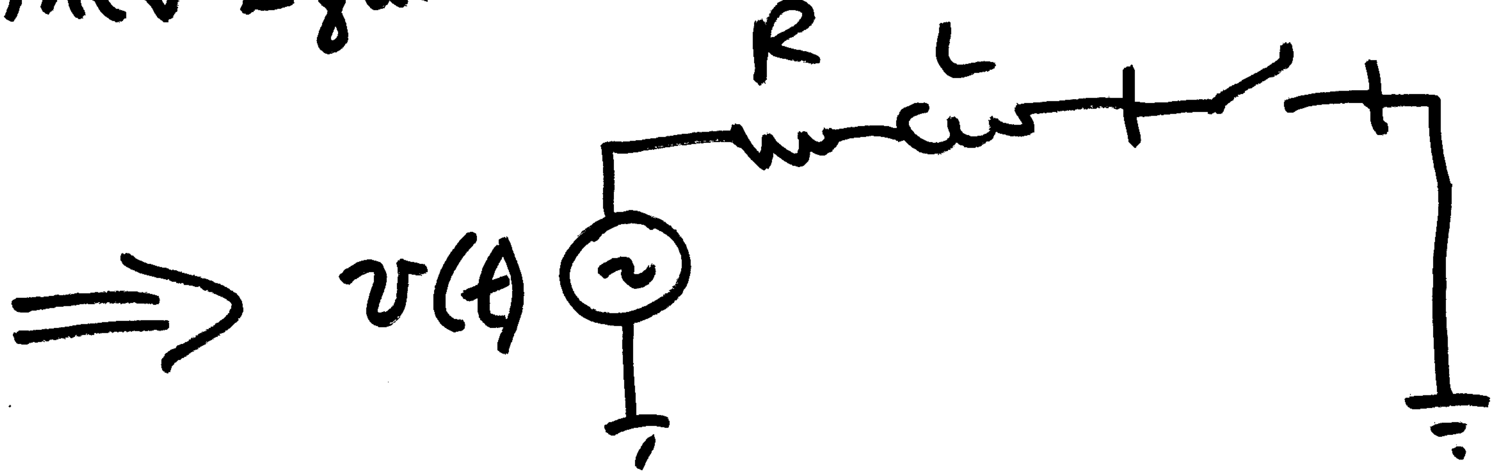


Short Circuit Calcs/Sims

$\bar{Z}_{33} = Z_{TH}$



Thev Equiv

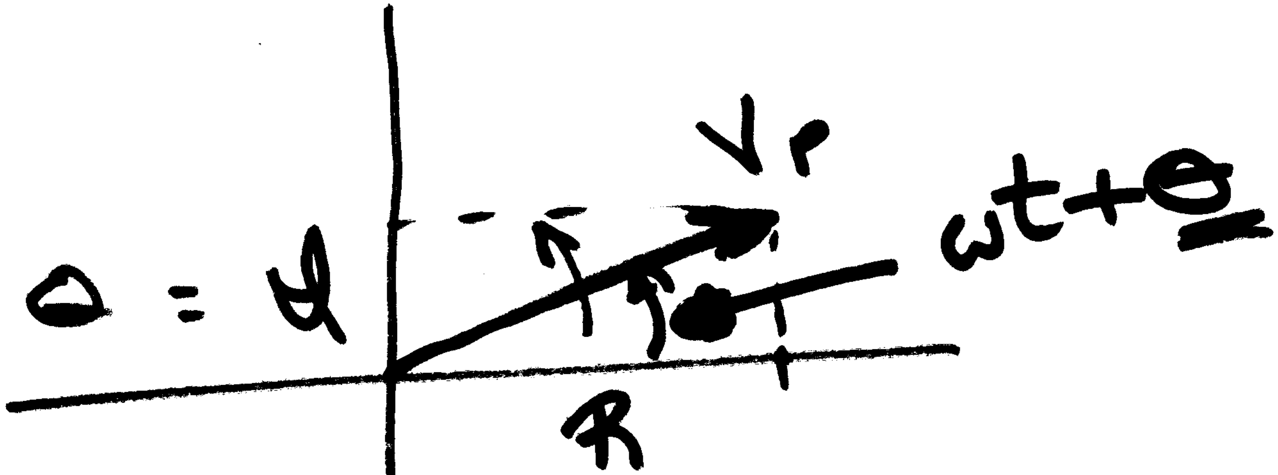


$v(t) = V_p \cos(\omega t + \theta)$

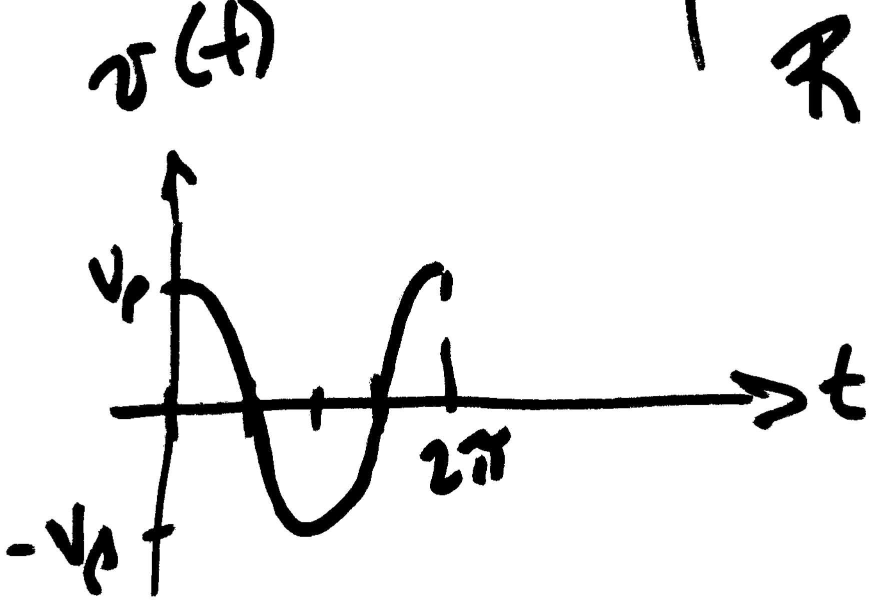
Euler's Identity

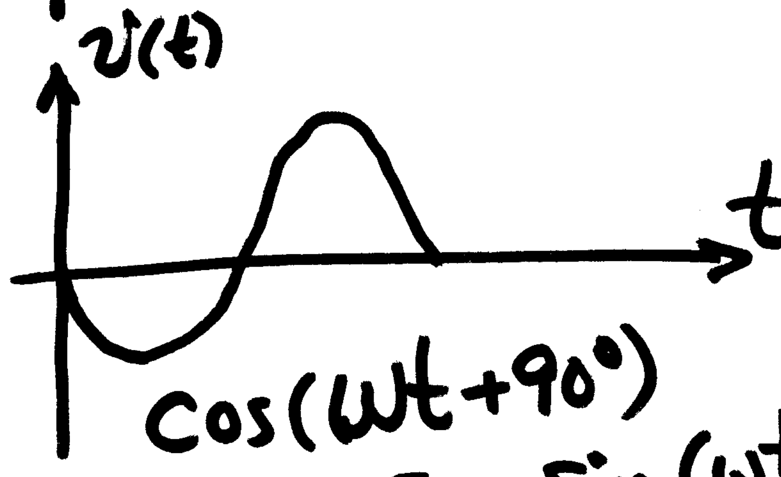
ccw rotation

$V_p \sin\theta = \mathcal{I}$

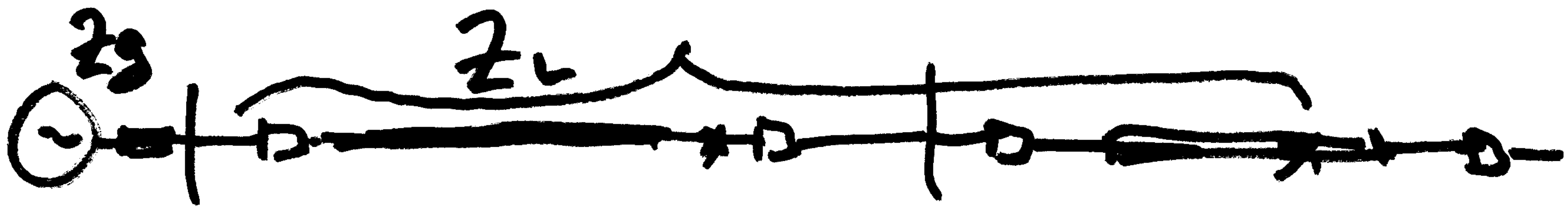


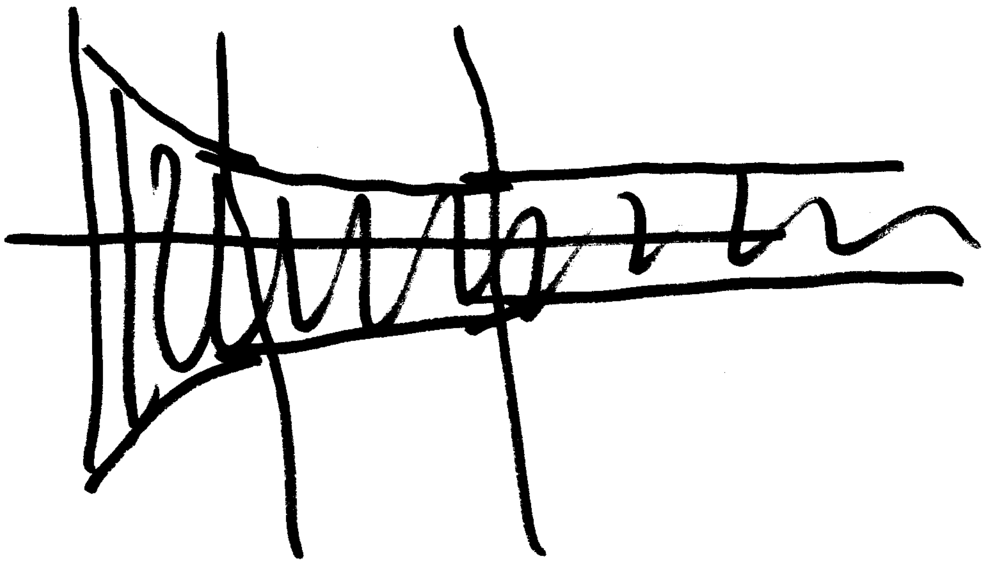
$\mathcal{R} = V_p \cos\theta$





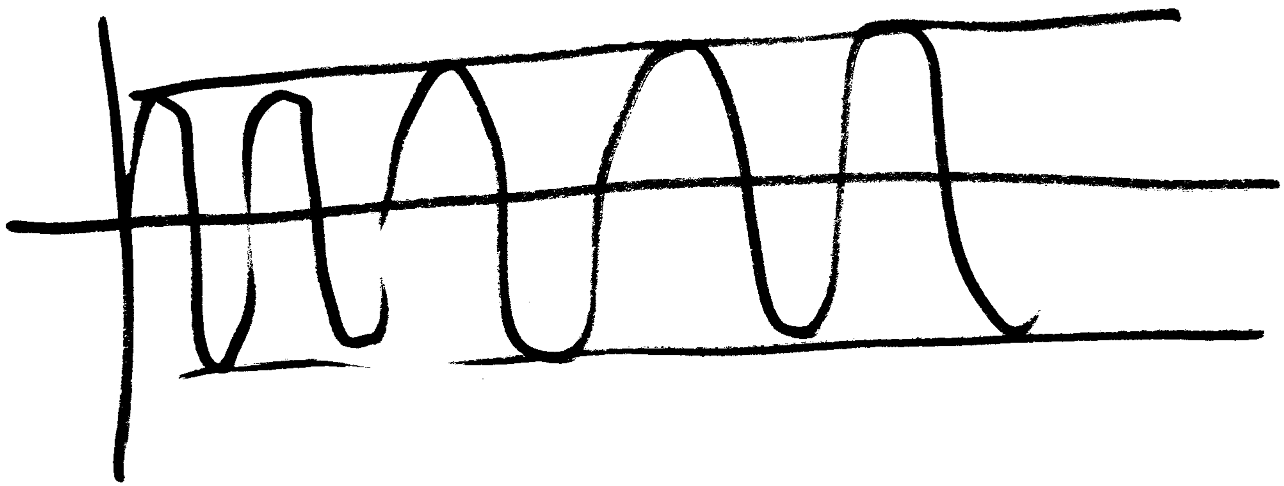
$\cos(\omega t + 90°)$
$= -\sin(\omega t)$

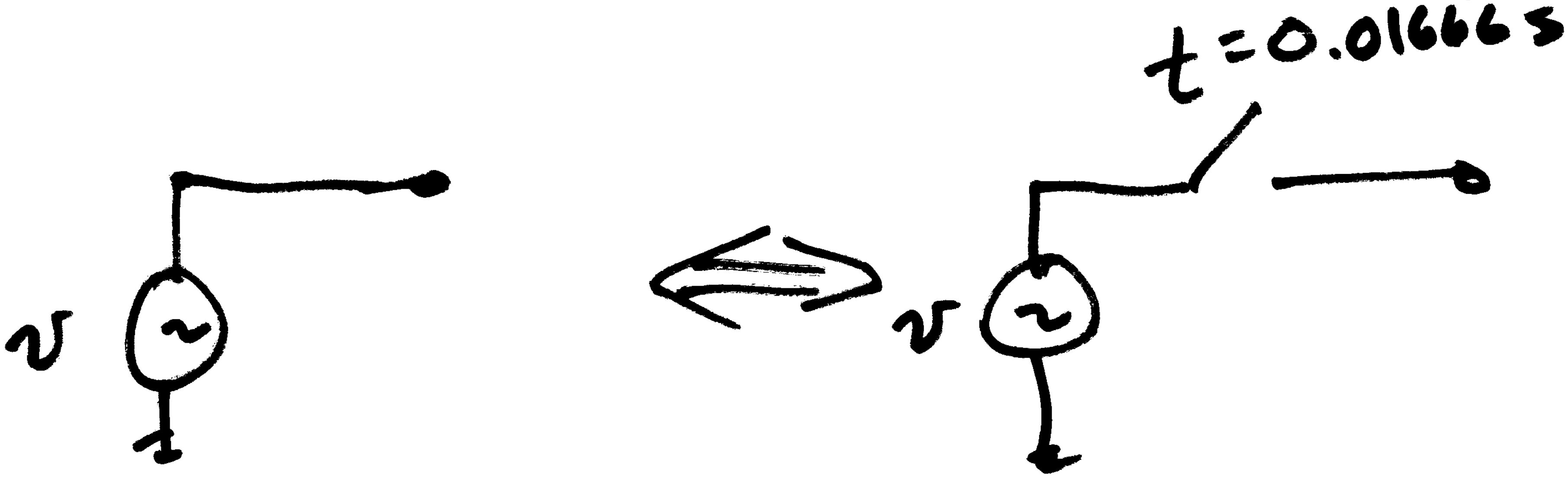




$Z_g \simeq Z_L$

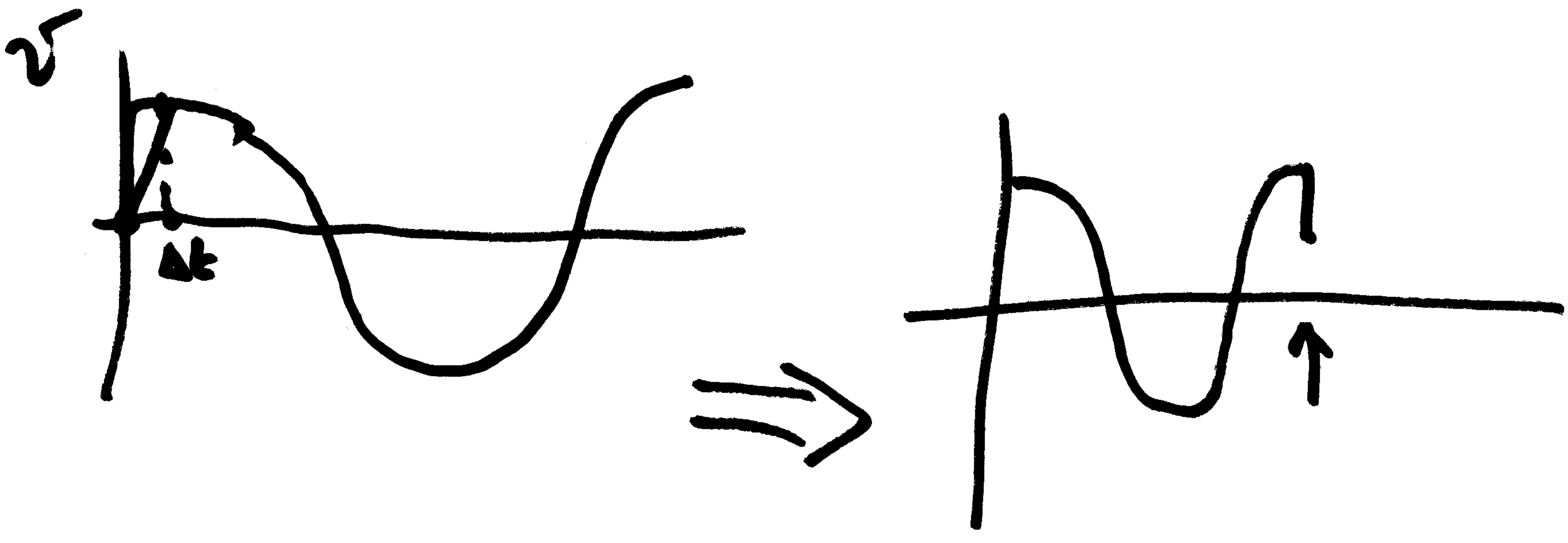
$Z_L >> Z_g$

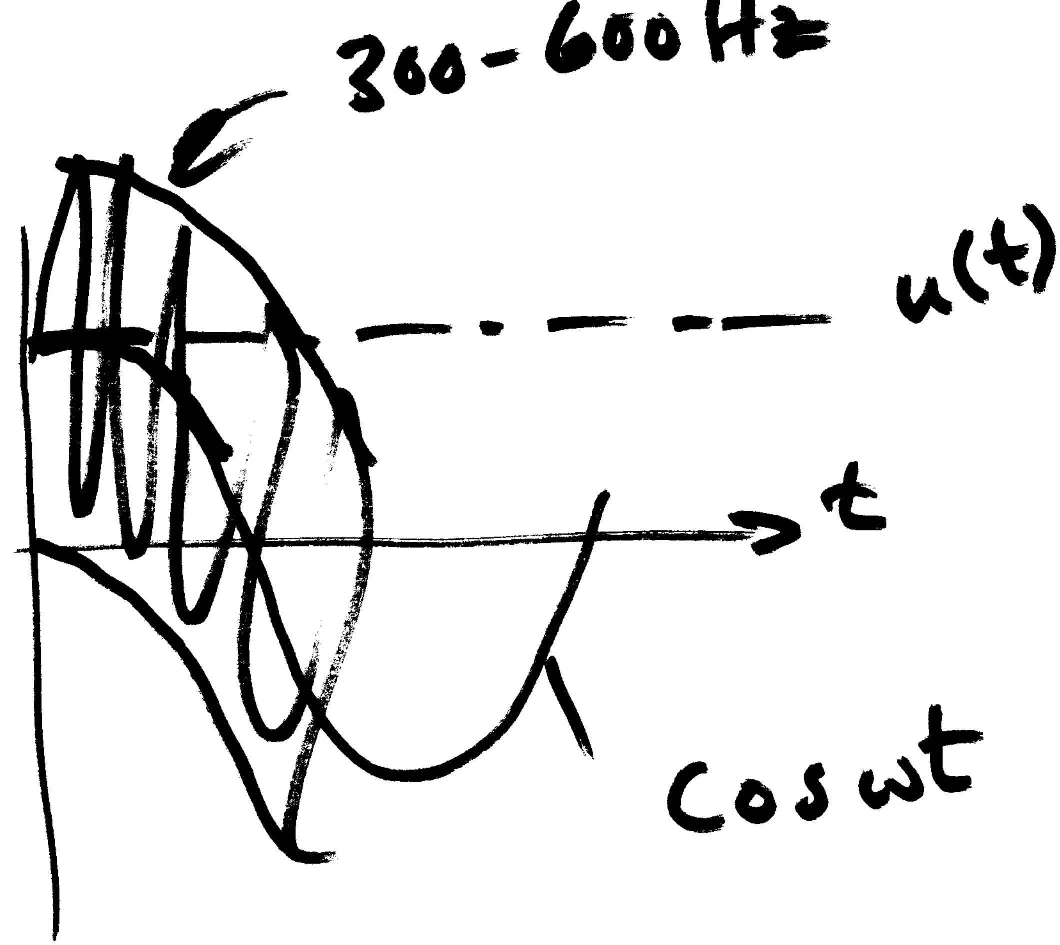




Tstart = 0.0

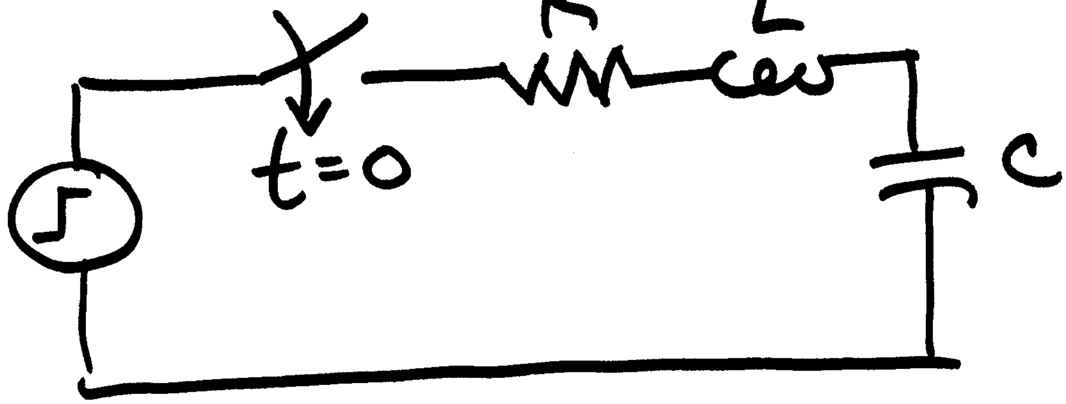
Tstart = -1.0



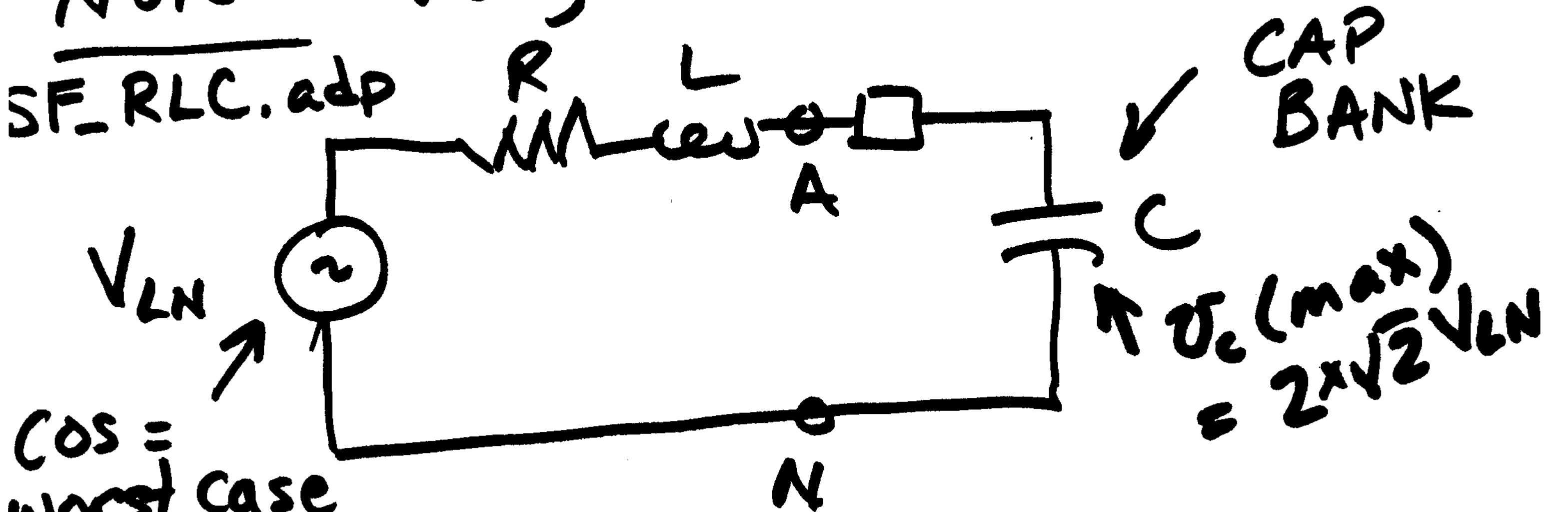

300-600 Hz
u(t)
t
Cos ωt

Forced RLC Responses

ERLC



Note: Very similar to



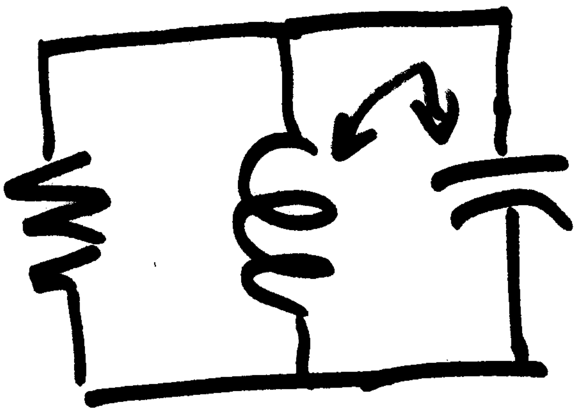
since L is very small and C is sizeable

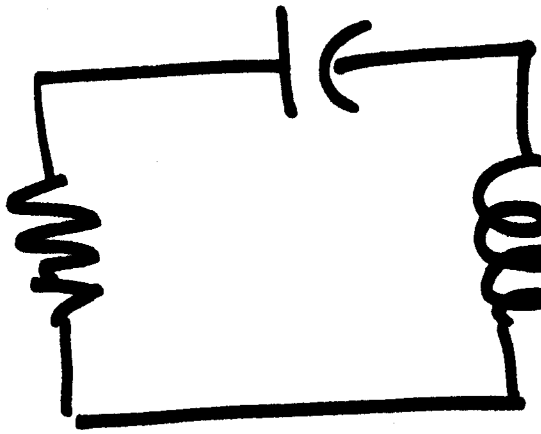
Then $\boxed{\omega_0 >> 377}$

Then we can assume that

$V_p \cos 377t \iff V_p$

PARALLEL RLC - SERIES RLC





Resonant freq:

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad \omega_0 = \frac{1}{\sqrt{LC}}$$

Exponential Damping Coefficient
(or Neper freq)

$$\alpha = \frac{1}{2RC} \qquad \alpha = \frac{R}{2L}$$

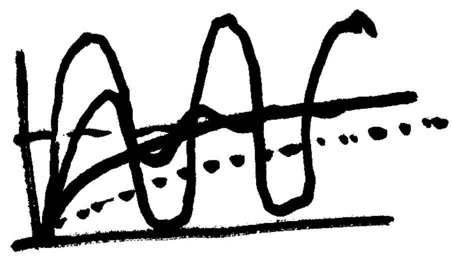
Damped or "Natural" Resonant freq

$$\omega_d = \sqrt{\omega_0^2 - \alpha^2}$$

Damping:

Critical Damping: $\alpha = \omega_0$

$$\omega_d = \sqrt{\omega_0^2 - \alpha^2} = 0$$



Overdamped:

$$\alpha > \omega_0$$

Underdamped:

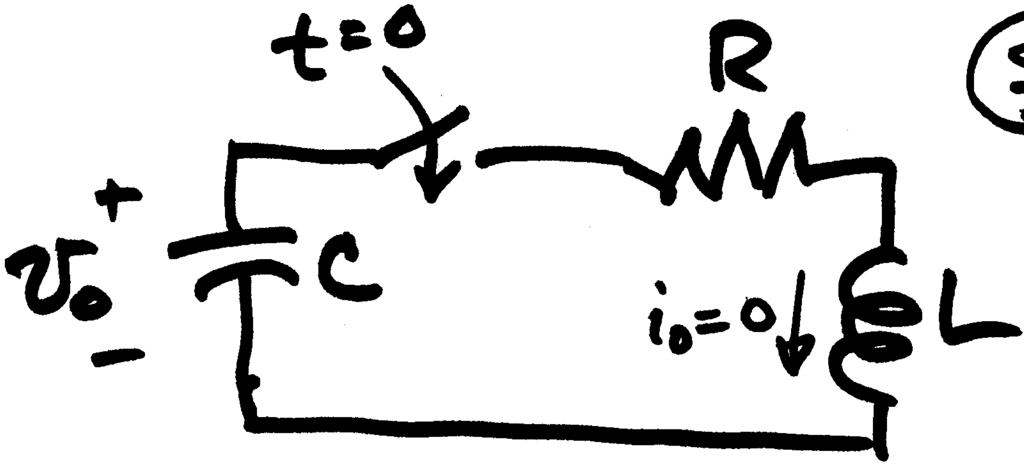
$$\omega_0 > \alpha$$

Undamped: $\alpha = 0$

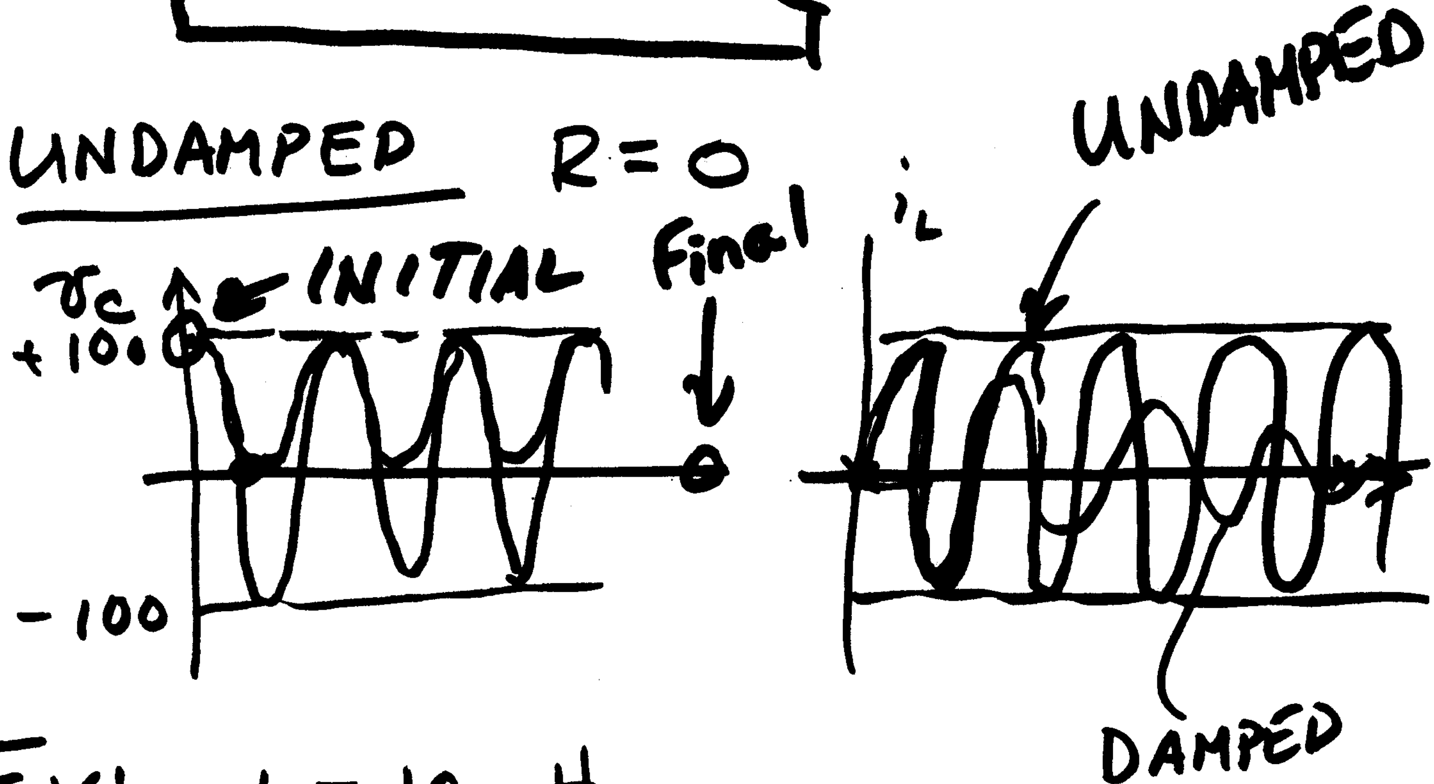
$$\omega_d = \omega_0$$

Look at Series RLC

SER_RLC.adp



UNDAMPED $R=0$



Ex:

$L = 10\,mH$

$C = 1\,\mu F$

$R \cong 0$

(1)

$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{.01}{10^{-6}}} = 100\,\Omega$

$\boxed{I_p = \frac{\Delta V}{Z_0}}$

(2)

$\omega_0 = 10{,}000\ s^{-1}$

$f = 1591\ Hz$

$T = 0.63\ ms$

$\Delta t \cong 20\,\mu s$

$T_{END} =$

Read Ch. ~~3~~ 4 – § 4.3 - Damping

Make transistion from

$\alpha, \omega_0, \omega_d$

to $\boxed{s = \sigma + j\omega}$

~~int~~ in terms of Z_0, R, λ, η

More on simulation:

Critically damped:

$$\alpha = \omega_0 = \cancel{\frac{10{,}000}{2}} \; \frac{R}{2L}$$

Check: decrease R

$$\alpha = 10{,}000 = \frac{R}{(2)(.01)}$$

$\Rightarrow$ <u>$R = 200\,\Omega$</u>

$$R = 190\,\Omega \Rightarrow \alpha = \frac{R}{2L}$$

$$= \frac{190}{(2)(.01)}$$

$$= 9500$$

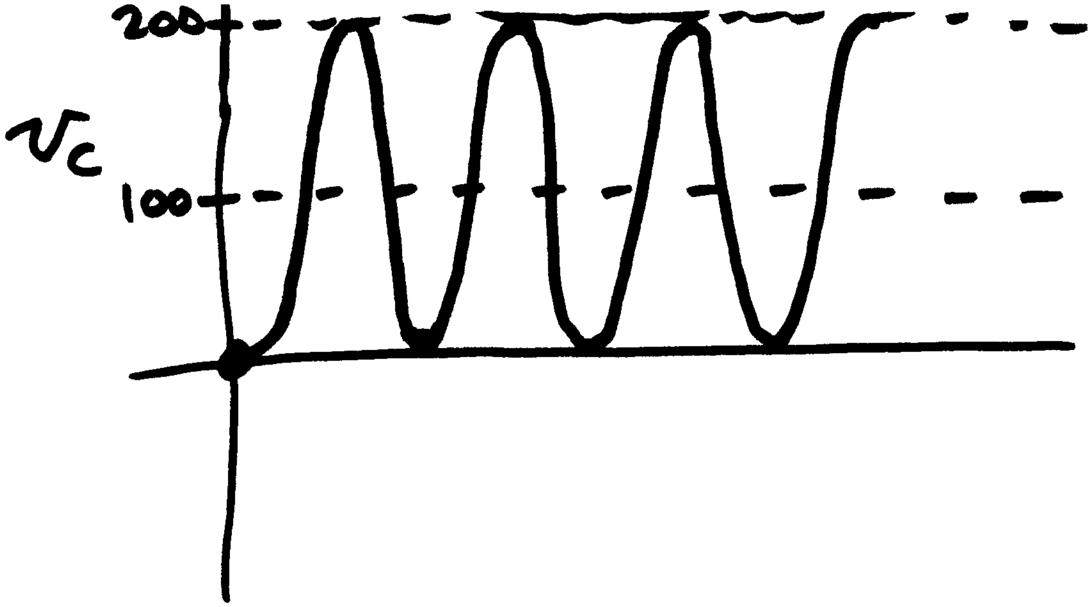
$$\omega_d = \sqrt{\omega_0^2 - \alpha^2}$$

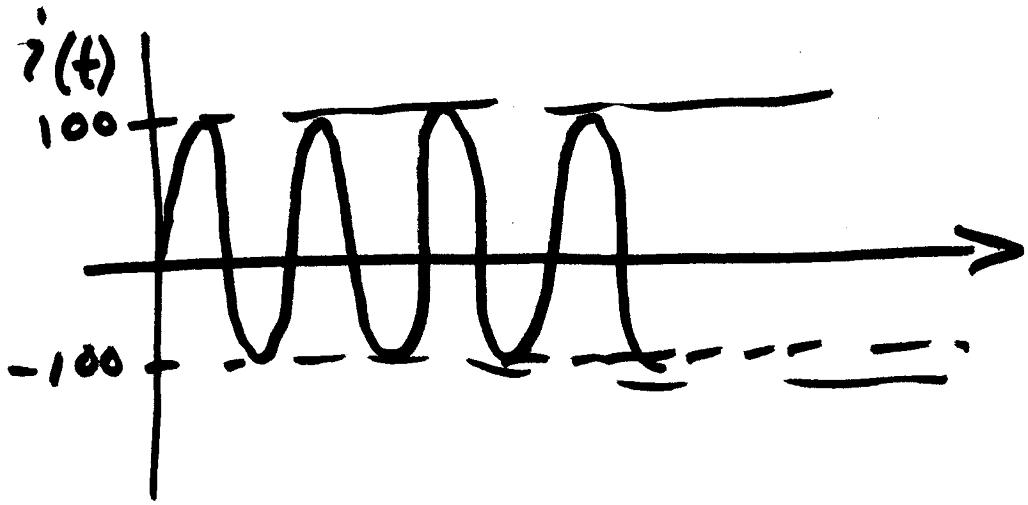
$$= \sqrt{10{,}000^2 - 9500^2} = 3122\ s^{-1}$$

$$= 497\ Hz$$

$$T = 2\ ms$$

$R = 10{,}000 \rightarrow$ overdamped





<u>If</u> $\frac{X}{R}$ ratio is 10, then

$$R = \frac{X}{10} = \frac{377L}{10} = \underline{0.377\,\Omega}$$

CAP BANK SWITCHING

1 - Energization Inrush - Bus OV

2 - Back-to-Back Energization

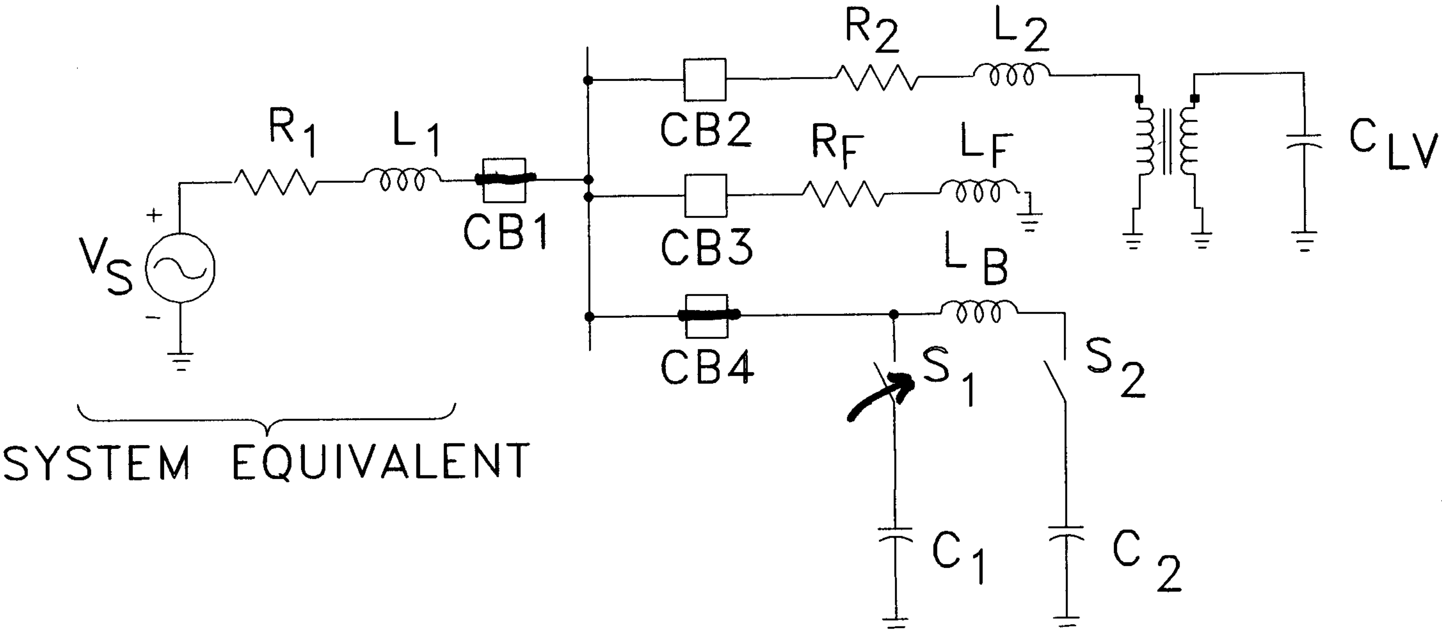
HF I thru CBs.

3 - Outrush

4 - Voltage Magnification

5 - TRV - Transient Recovery Voltage

Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.



R_1 = 0.5 Ohms L_1 = 3 mH R_2 = 0.001 Ohms L_2 = 12 mH

C_1 = 40.1 μF (18 MVAR) C_2 = 22.3 uF (10 MVAR) C_{LV} = 601 μF

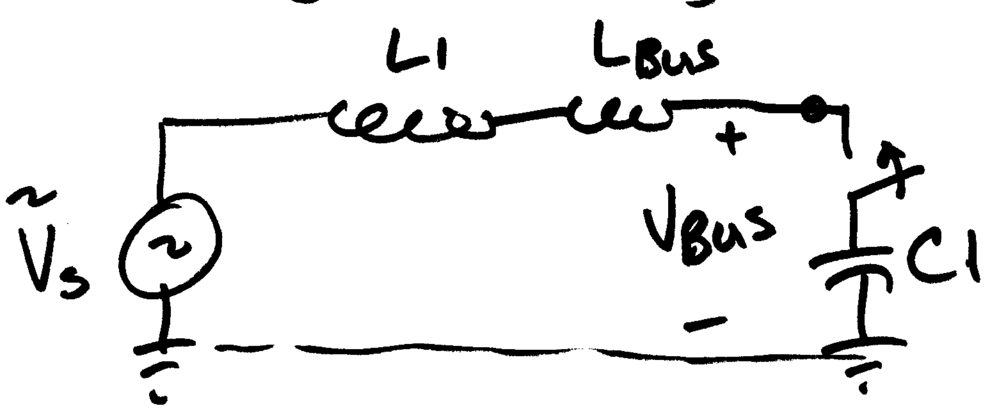
Dist. Transformer: 4:1 ratio L_B = 19 μH C_{BUSH} = 300 pF (see p.437)

Typical: 0.2 - 0.4 μH/ft

Tube Bus Strain Bus

1

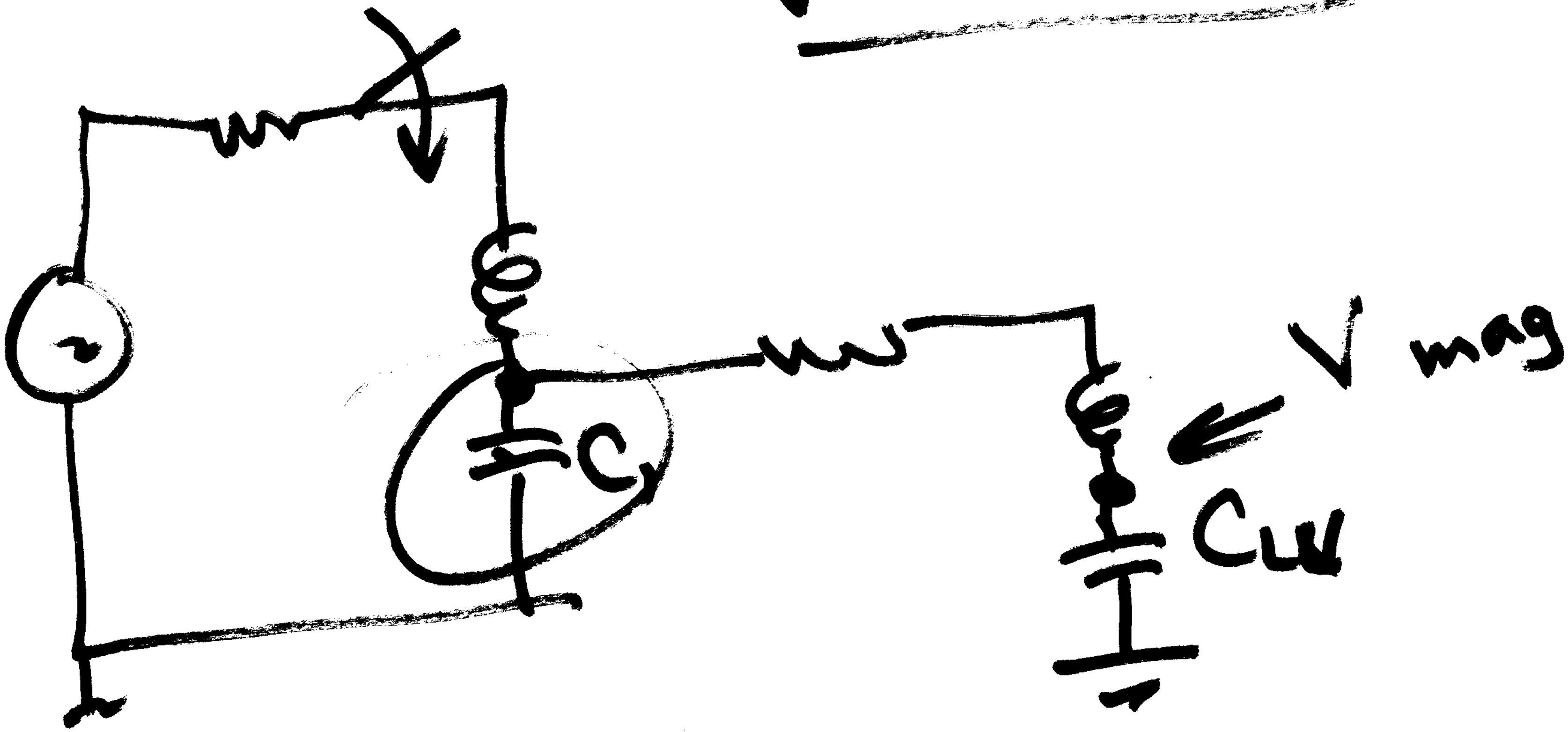
Inrush - CB1 - Closed
CB4 - Closed
SW1 - Closing

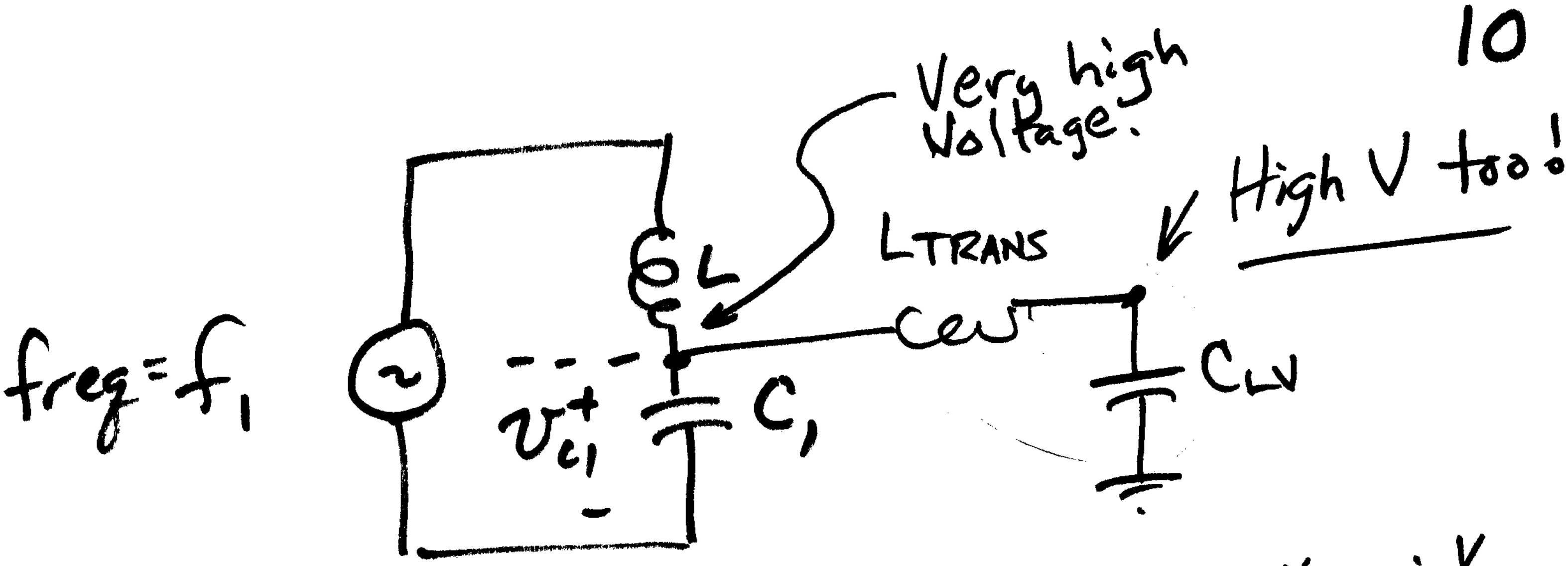


@ $t = 0^+$

$V_{Bus} \downarrow 0V$

VOLT MAG





Series resonance: $Z_{TOT} = jX_L - jX_c$

$= 0$

$$X_L = X_{C1}$$

$$2\pi f_1 L = \frac{1}{2\pi f_1 C_1}$$

$I \to \infty$

$V_L \to \infty$

$V_C \to \infty$

Per Unit voltage at C_{LV} is higher than at C_1, thus the name "voltage magnification."