EE 5220 - Lecture 8+9 (over 2 days)

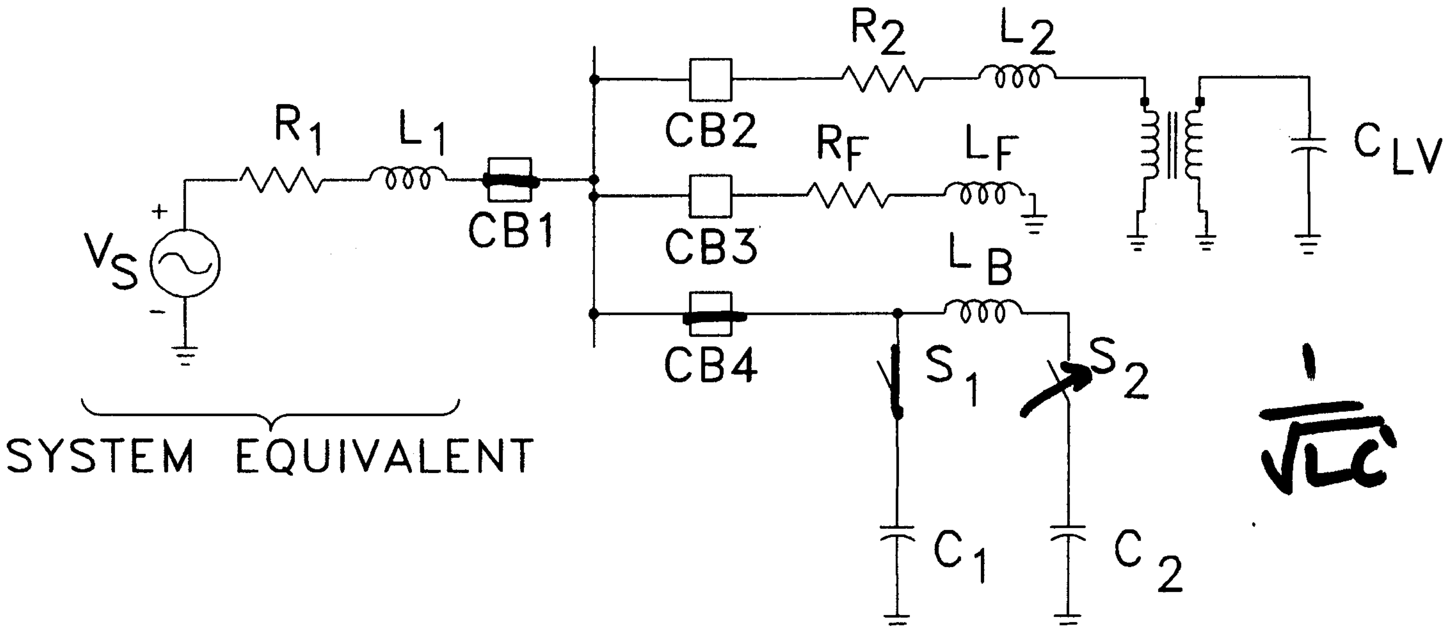
Wednesday Jan 26, 2022
Friday Jan 28, 2022

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 our course web page
  - EE5220-L@mtu.edu (participation = half letter grade, 5%)

- Next week focus: Get up to speed with ATP!
- HW#4 updated/posted soon. Partnered. Due Tues Feb 15th.
- ATP Simulation pointers
- Cap Bank Switching (continued)
  - Back-to-back switching
  - Outrush
  - TRV
  - Voltage Magnification
- Discussion - how to carry out HW#4

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



$$\frac{1}{\sqrt{LC}}$$

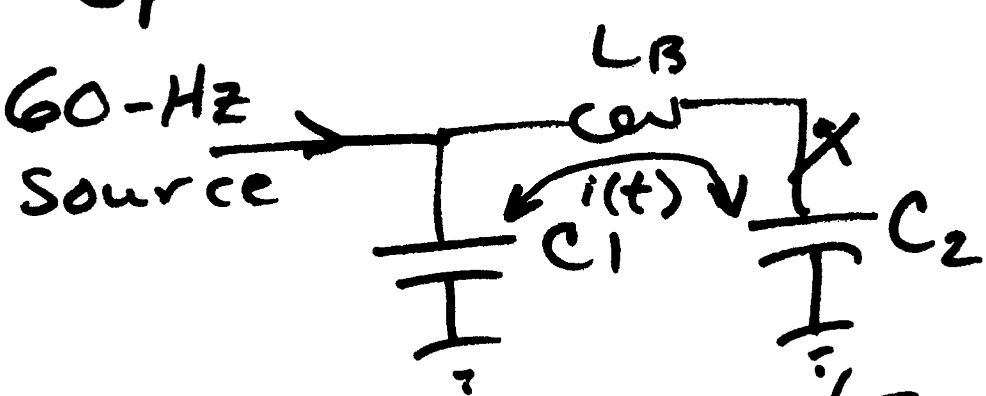
R_1 = 0.5 Ohms L_1 = 3 mH R_2 = 0.001 Ohms L_2 = 12 mH

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)

Back-to-Back

Operative Circuit:



$$\omega_0 = \frac{1}{\sqrt{L_B \cdot \frac{C_1 C_2}{C_1 + C_2}}}$$

$$Z_0 = \sqrt{\frac{L_B}{\frac{C_1 C_2}{C_1 + C_2}}}$$

(Typ f_0: 3-15 KHz)

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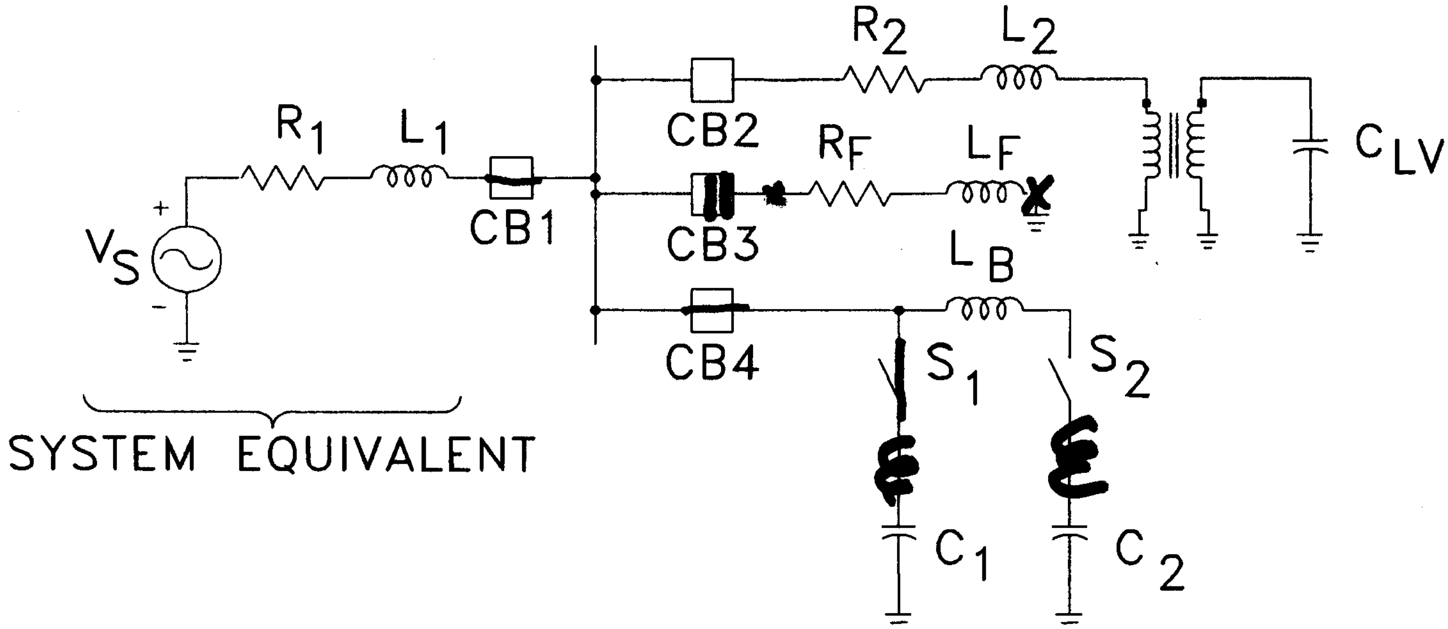

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Dist. Transformer: 4:1 ratio L_B = 19 μH C_{BUSH} = 300 pF (see p.437)

Outrush – Cap banks discharge into nearby fault

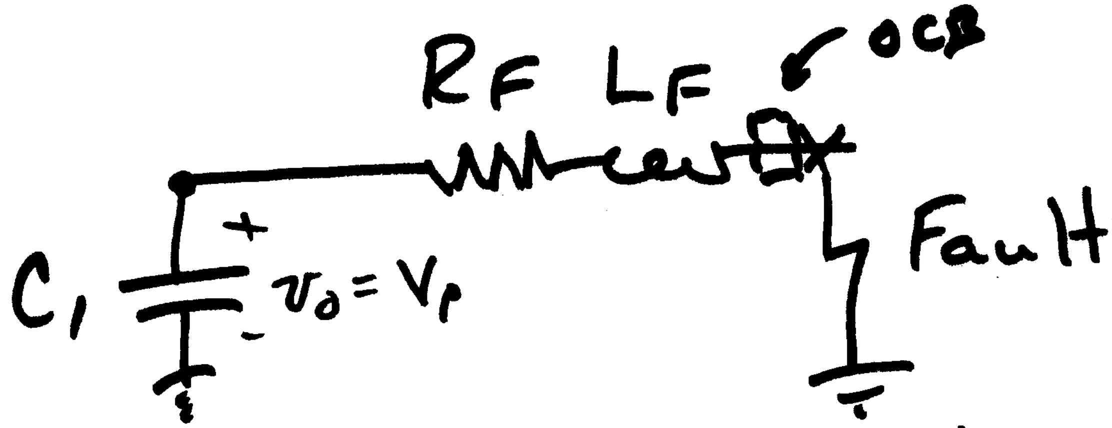
(Close CB3)

CBs may not handle it.

Ratings of CB's: $I_p \times f_0$

i) General Purpose $I_p \times f_0 \leq 2\times10^7$

ii) Definite Purpose: see IEEE Stds!



$$\omega_0 = \frac{1}{\sqrt{C_1 L_F}} \;*\; \text{or} \; \frac{1}{\sqrt{(C_1+C_2)L_F}}$$

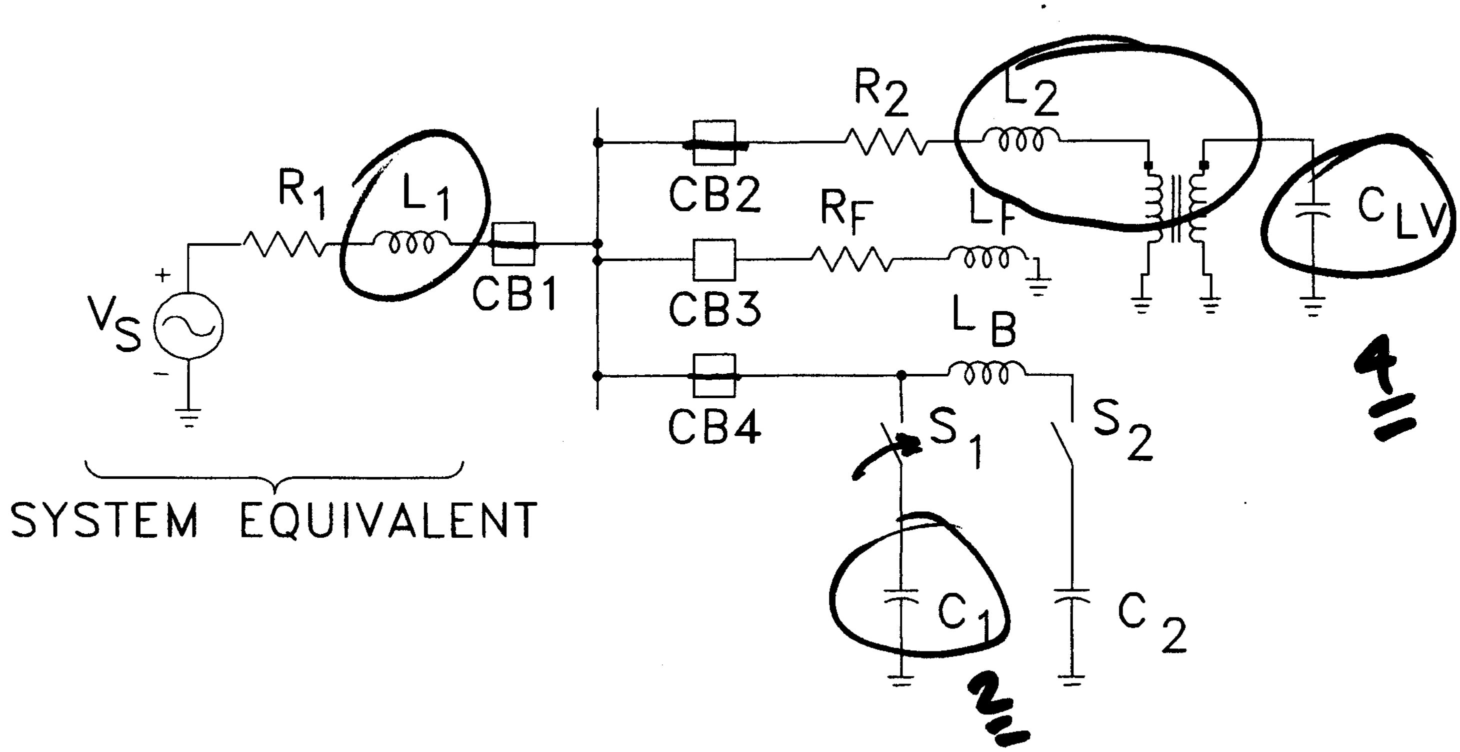
$$Z_0 = \sqrt{\frac{L_F}{C_1}} \quad \text{or} \quad \sqrt{\frac{L_F}{C_1+C_2}}$$

(one Bank) (Both Banks)

$$I_p = \frac{V(0)}{Z_0}$$

$$\underline{I_p \times f_0} = ?$$

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

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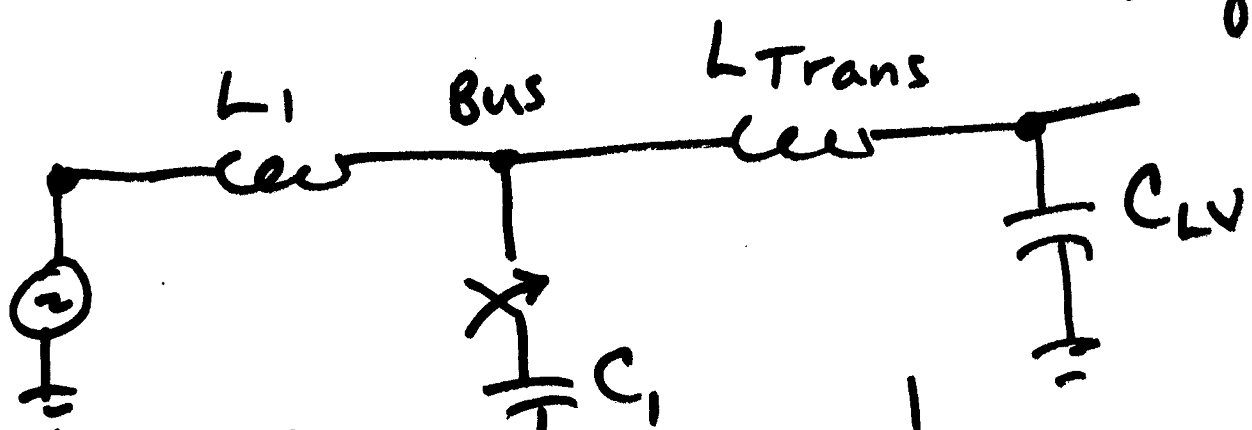
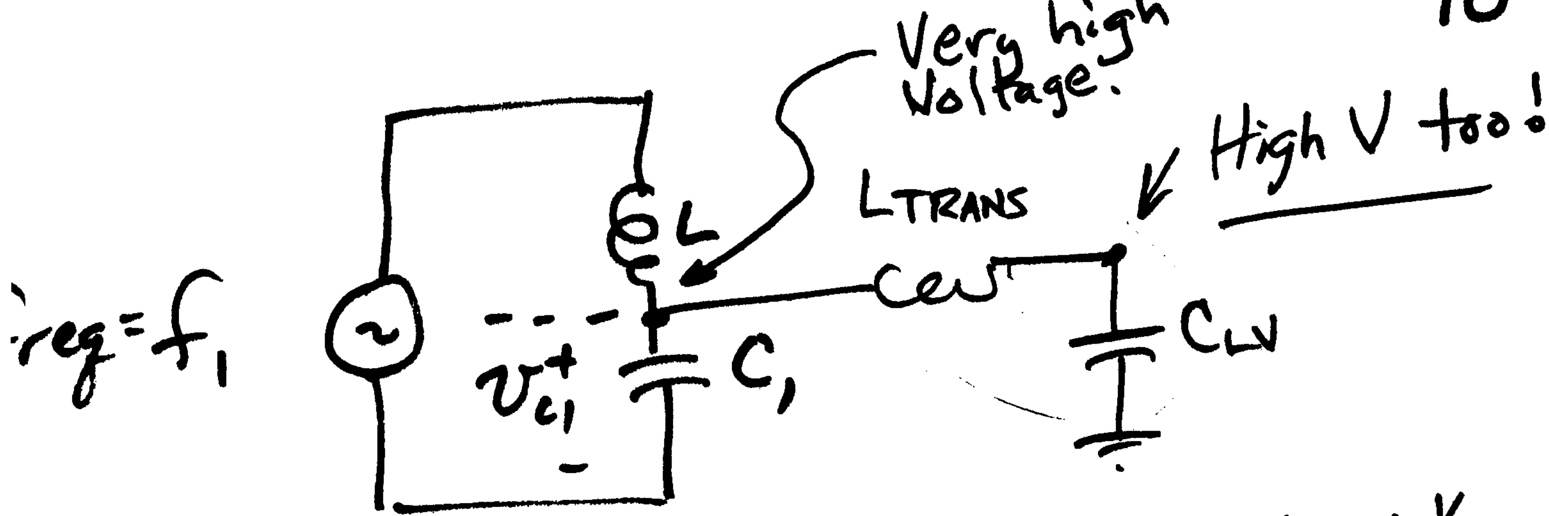
Dist. Transformer: 4:1 ratio L_B = 19 μH C_{BUSH} = 300 pF (see p.437)

5) Voltage Magnification – Usually Low Freq



$$f_1 = \frac{1}{2\pi\sqrt{L_1 C_1}} \qquad f_2 = \frac{1}{2\pi\sqrt{L_T C_{LV}}}$$



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."

TRV –

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

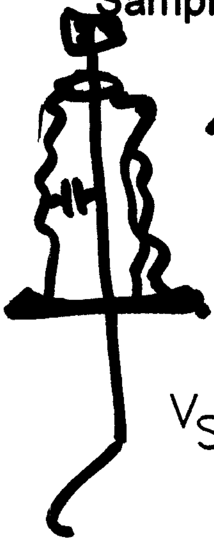
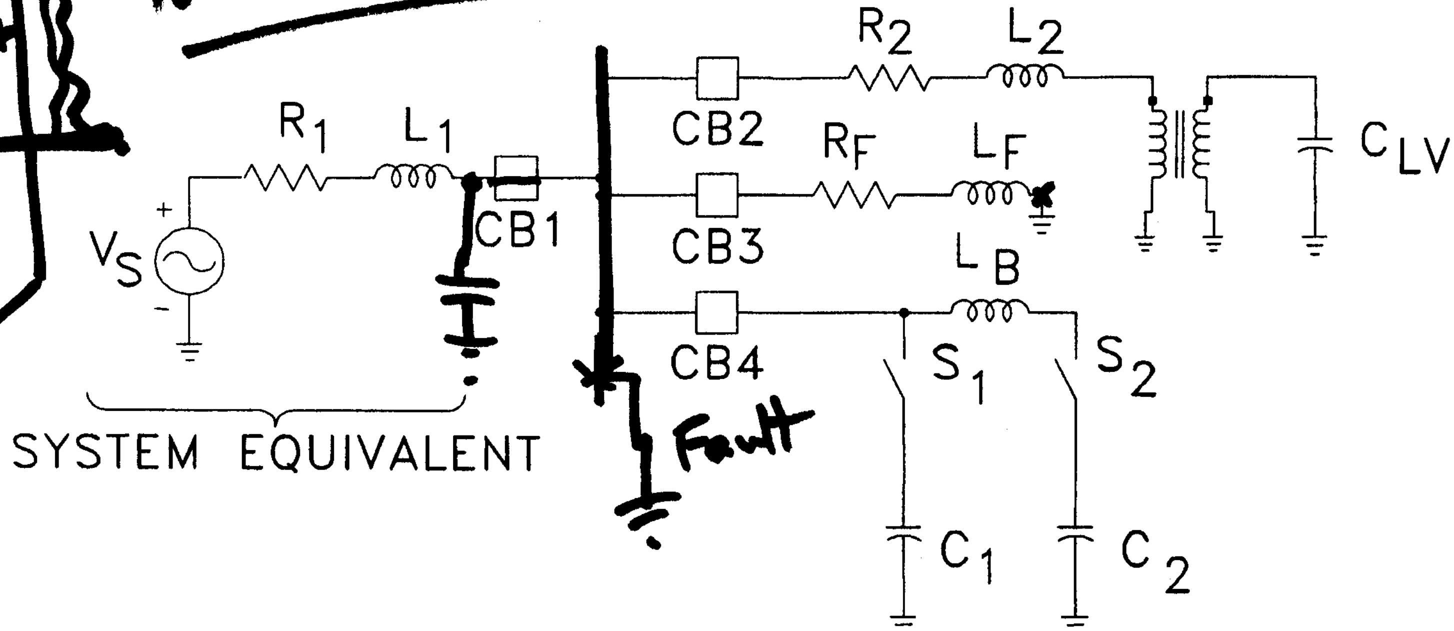


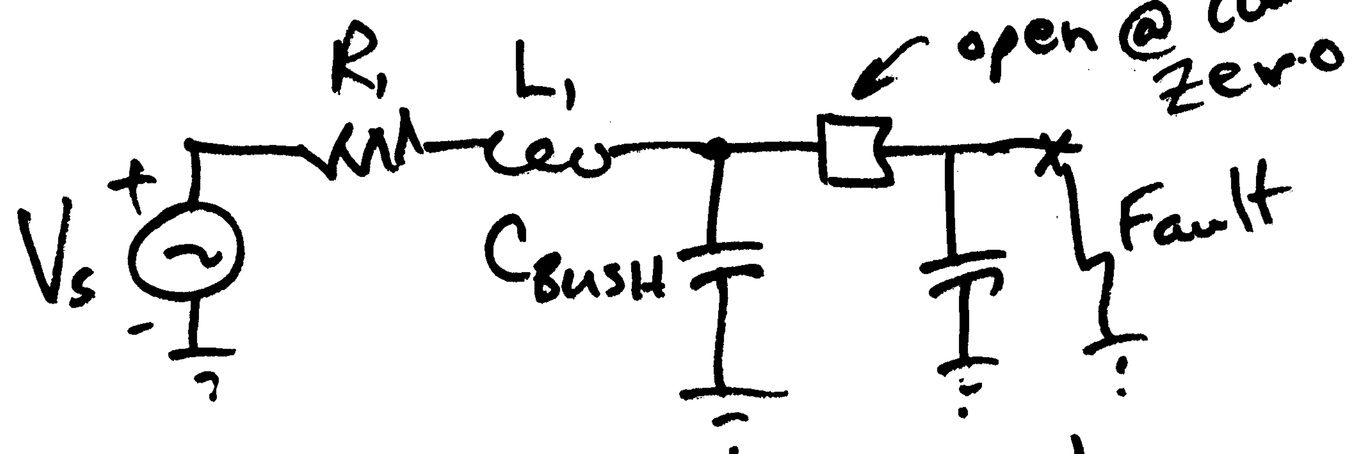
Table 13.4



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)



$$\omega_0 = \frac{1}{\sqrt{L_1 C_{BUSH}}} = \frac{1}{\sqrt{(.003)(300\times10^{-12})}}$$

$V_{peak} = 39.64\ KV$

$$V_{peak,\,Base} = \frac{(34{,}500)(\sqrt{2})}{\sqrt{3}} = 28.1\ KV$$

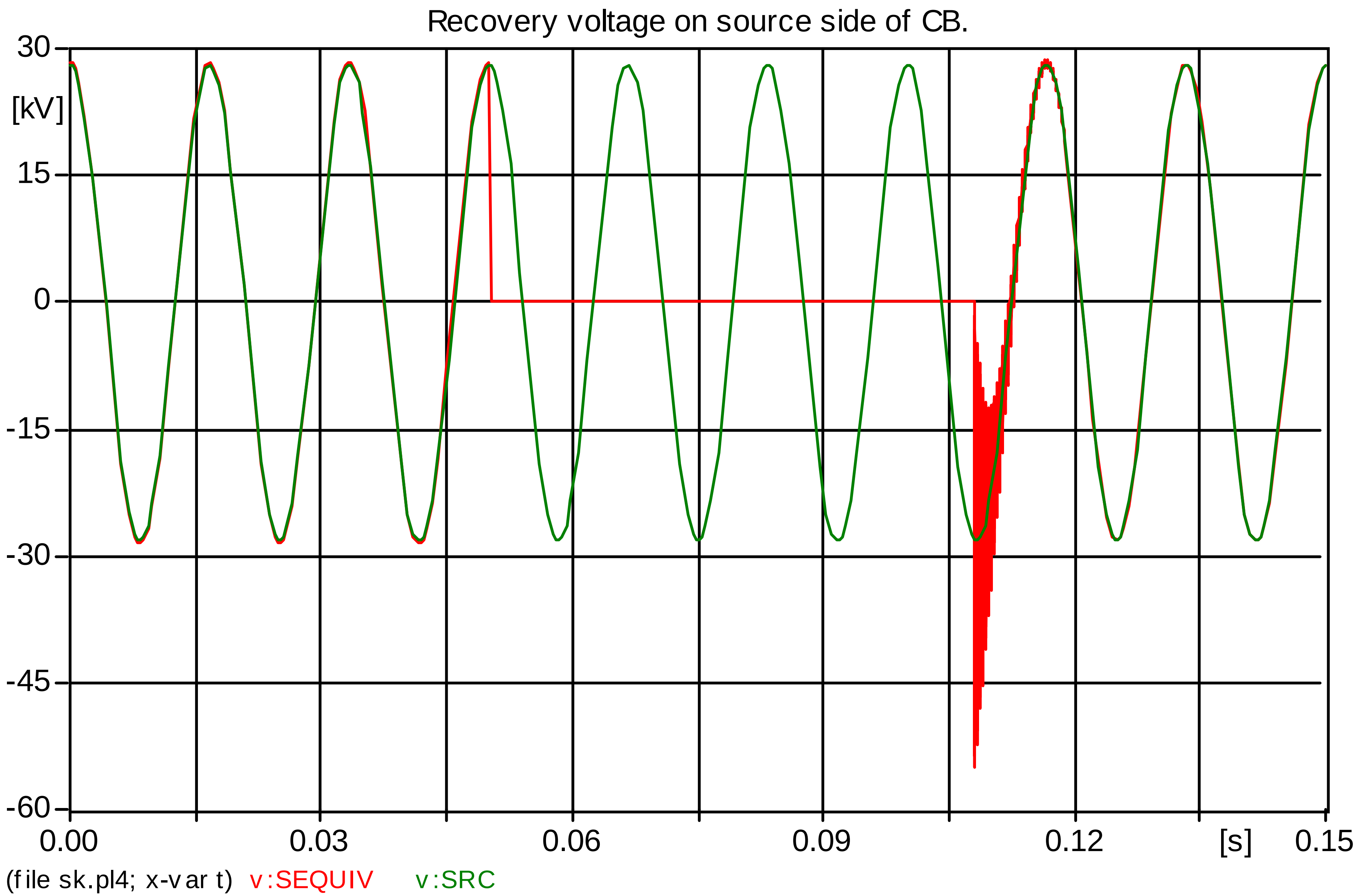
$$V_{pu} = \frac{39.64}{28.1} = 1.4\ p.u.$$

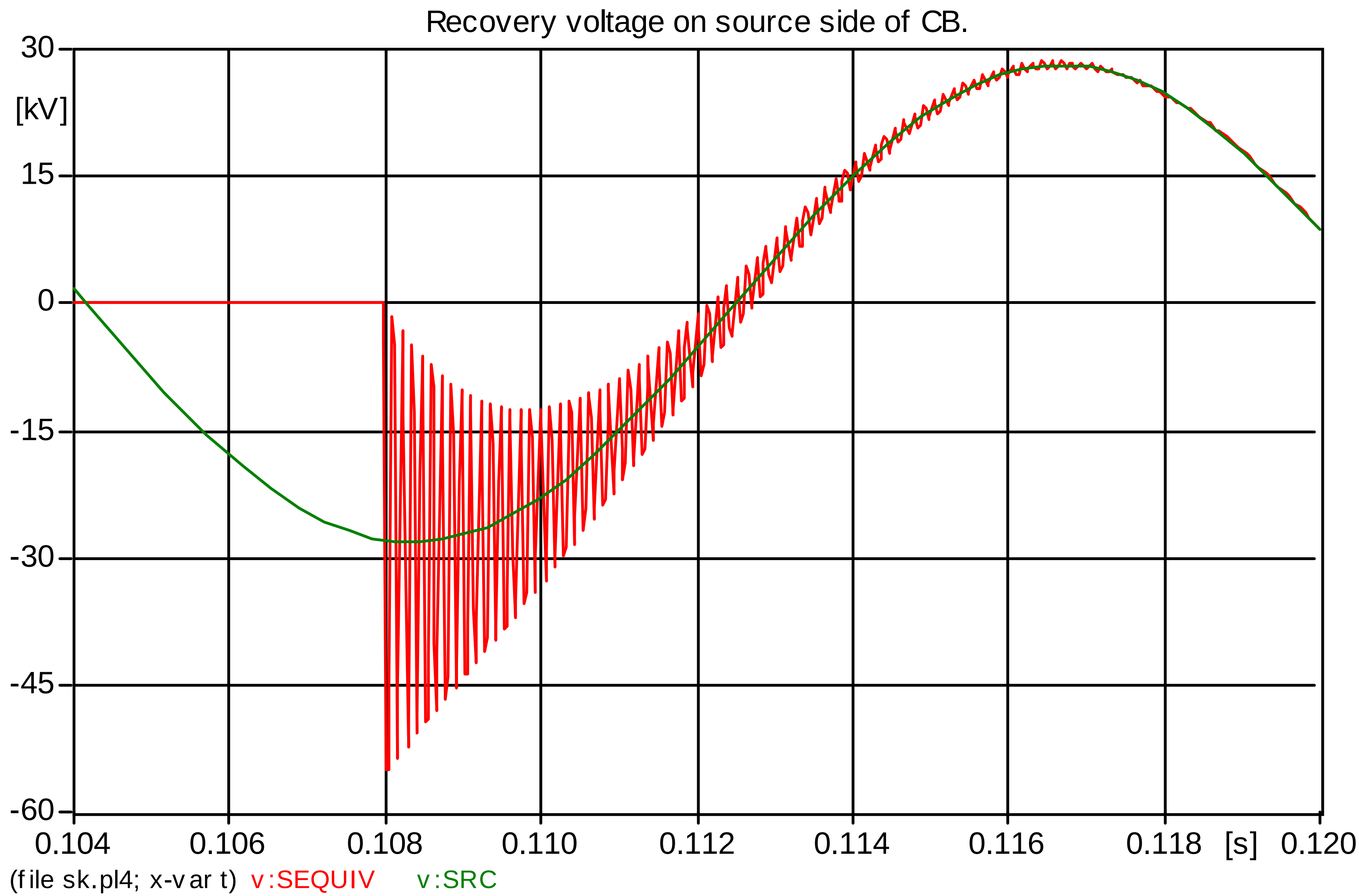
$$W_0 = \frac{1}{\sqrt{L_1 C_{BUSH}}} = 167\ KHZ$$ = 300pF

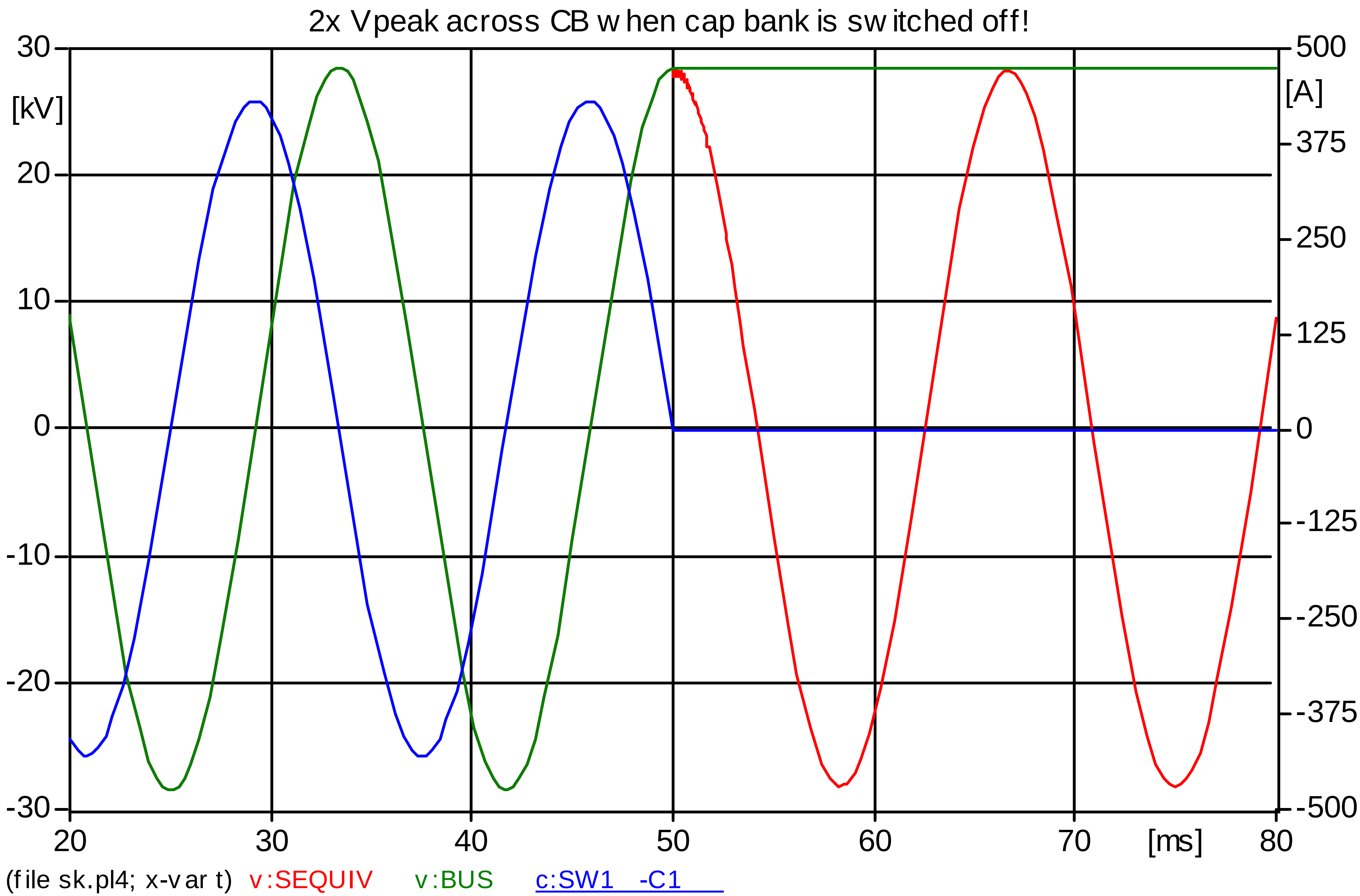
W_{SIM} = 5 KHZ (@ 200nF)

Capacitances other than C_{BUSH} may be present.

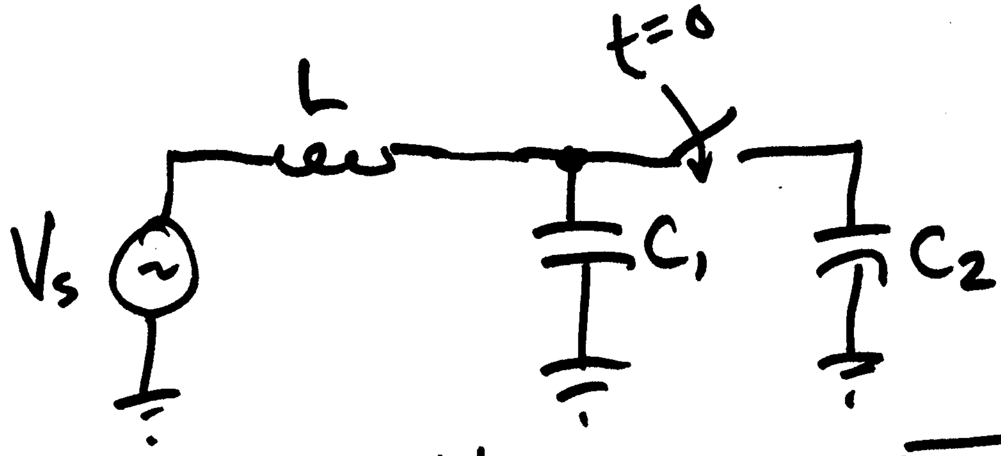
- Cap Bank (like single-Bank energization)
- Transformer Coil Capacitances.
- Transformer Bushing Cap.


Recovery voltage on source side of CB.
30
[kV]
15
0
-15
-30
-45
-60
0.00
0.03
0.06
0.09
0.12
[s]
0.15
(file sk.pl4; x-var t)
v:SEQUIV
v:SRC


Recovery voltage on source side of CB.
30
[kV]
15
0
-15
-30
-45
-60
0.104
0.106
0.108
0.110
0.112
0.114
0.116
0.118
[s]
0.120
(file sk.pl4; x-var t)
v:SEQUIV
v:SRC

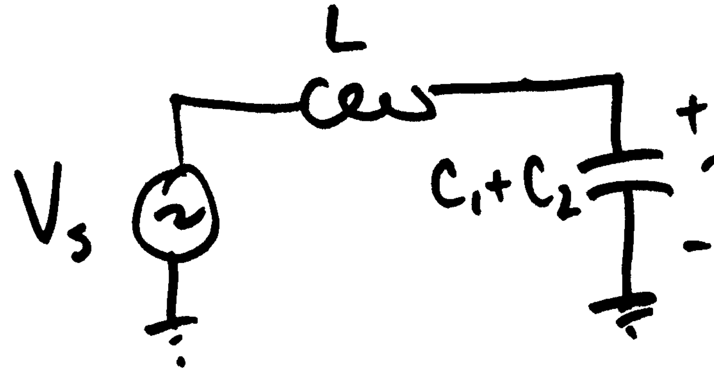

2x Vpeak across CB when cap bank is switched off!
[kV]
30
20
10
0
-10
-20
-30
[A]
500
375
250
125
0
-125
-250
-375
-500
20
30
40
50
60
70
80
[ms]
(file sk.pl4; x-var t) v:SEQUIV v:BUS c:SW1 -C1

Problem 3.3 - Recovery Voltage



$\Downarrow$

$$\boxed{Q = CV}$$



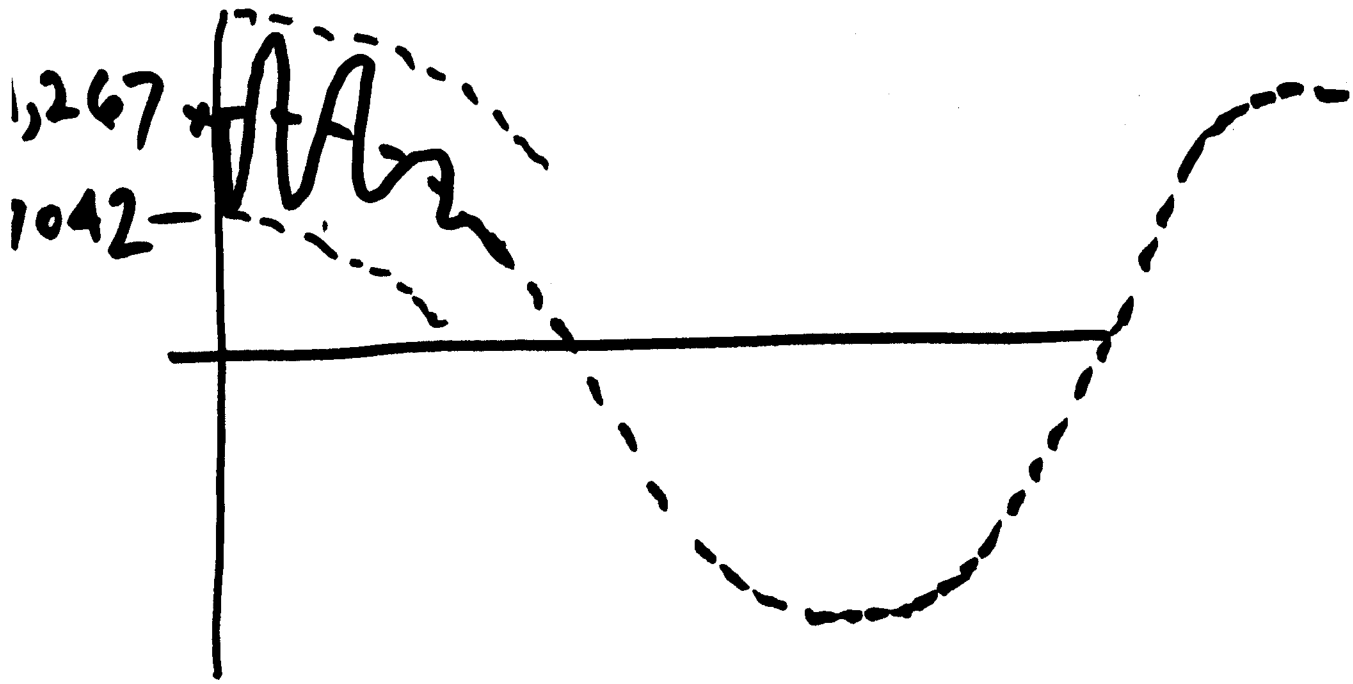
$C_1 = 69.64\,\mu F$
$C_2 = 41.79\,\mu F$

Conservation of charge:

$$Q(0^-) = Q(0^+) = (C_1)(V_{s\text{-}PEAK})$$

$$= (69.64\,\mu F)\left(\frac{\sqrt{2}\times 13{,}800}{\sqrt{3}}\right)$$

$$v(0^+) = \frac{Q}{C_1+C_2} \Longrightarrow v(0^+) = \underline{7042\text{ V}}$$

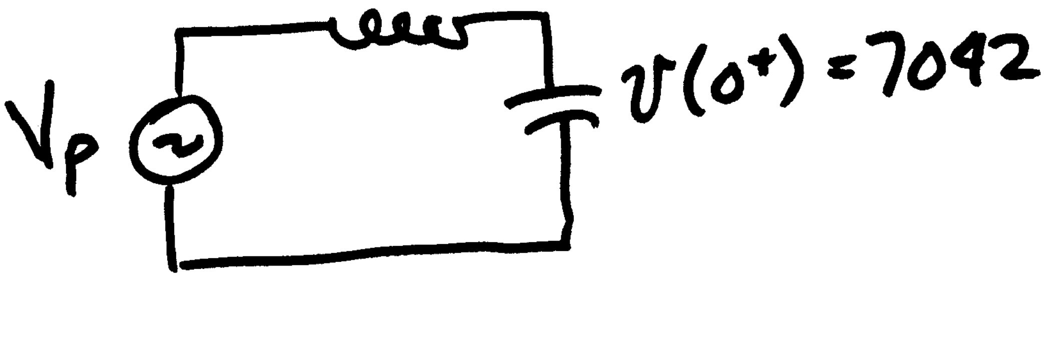


Voltage oscillations : $\pm\,(11{,}267 - 7042$

$= \boxed{\pm\ 4225\ \mathrm{V}}$

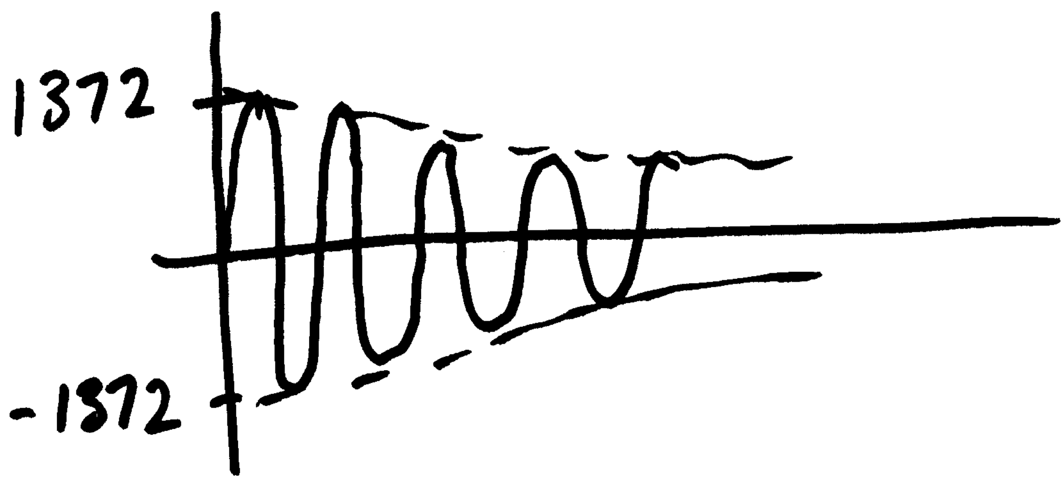
$$\omega_0 = \frac{1}{\sqrt{L_1(C_1+C_2)}} \qquad Z_0 = \sqrt{\frac{L_1}{(C_1+C_2)}}$$

What about current oscillations?



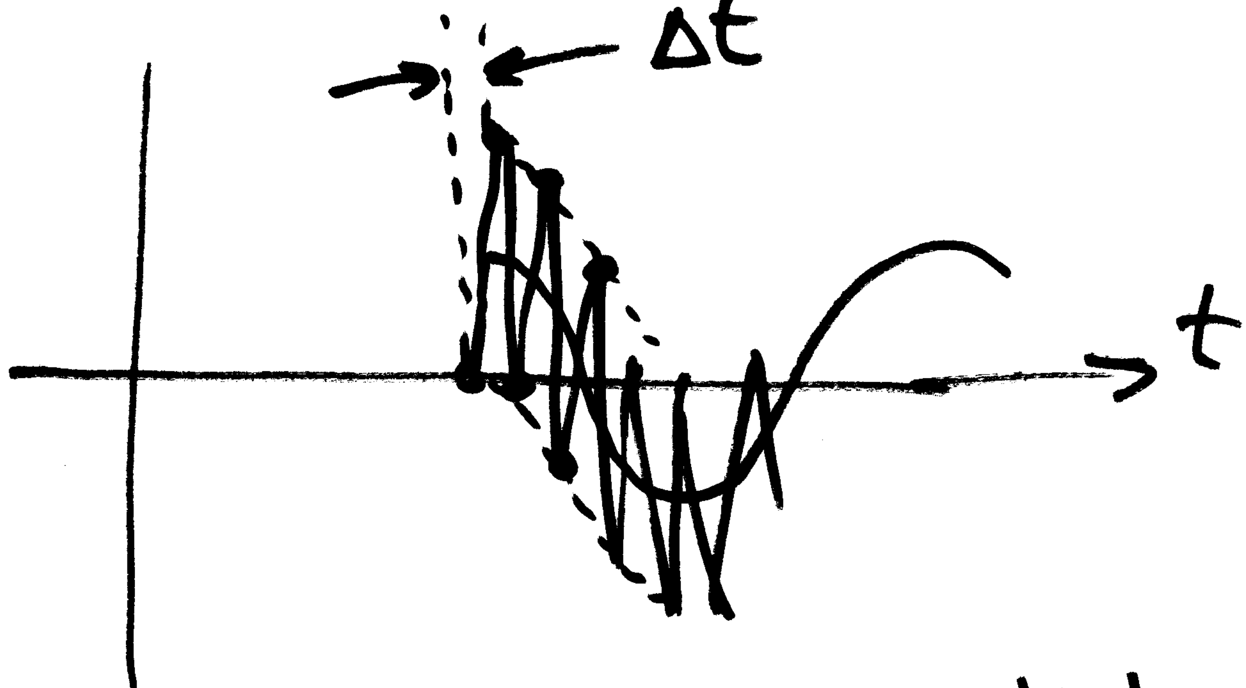
$$\Delta V = V(\infty) - v(0^+)$$
$$= 11267 - 7042$$
$$= 4225\text{V}$$

$$I_p = \frac{\Delta V}{Z_0} = \frac{4225}{3.08} = \boxed{1372\text{ A}}$$



Bus Overvoltages

- Not usually a concern with B-2-B energization.
- Bigger ~~word~~ worry with single Bank.

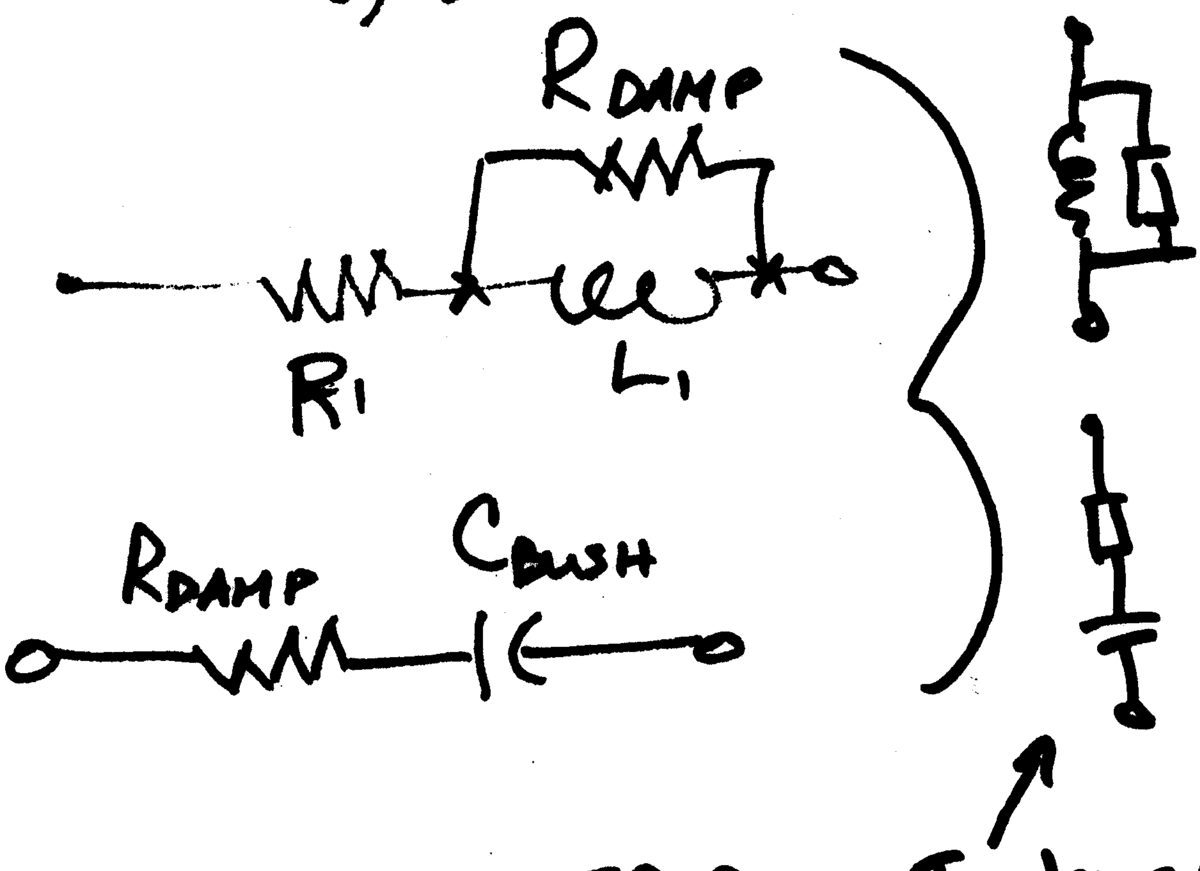


- time-step oscillation, or
- numerical instability

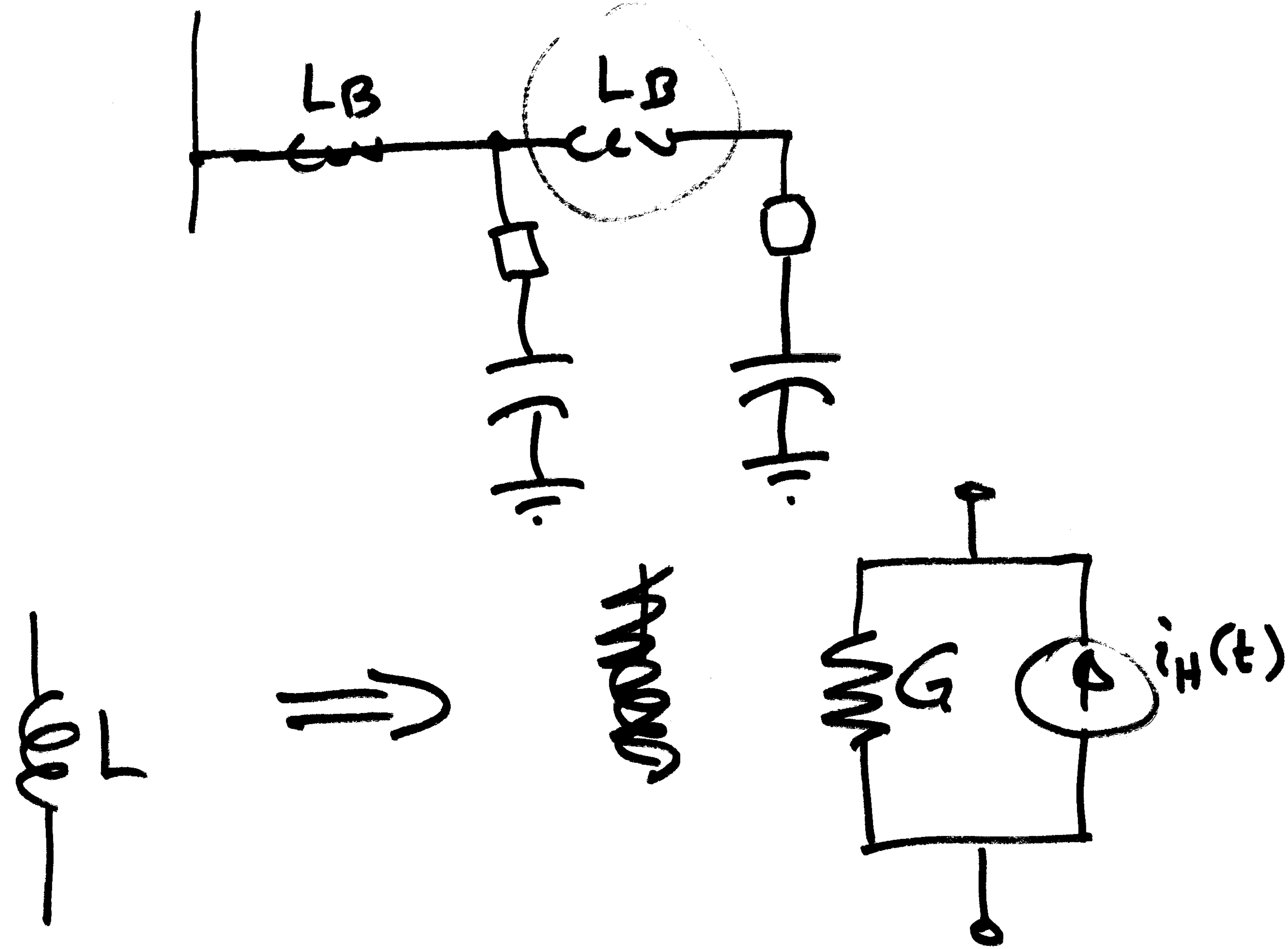
Numerical Oscillations –
(Trapezoidal Method in EMTP)

Typical: Very small L's
Very large C's.

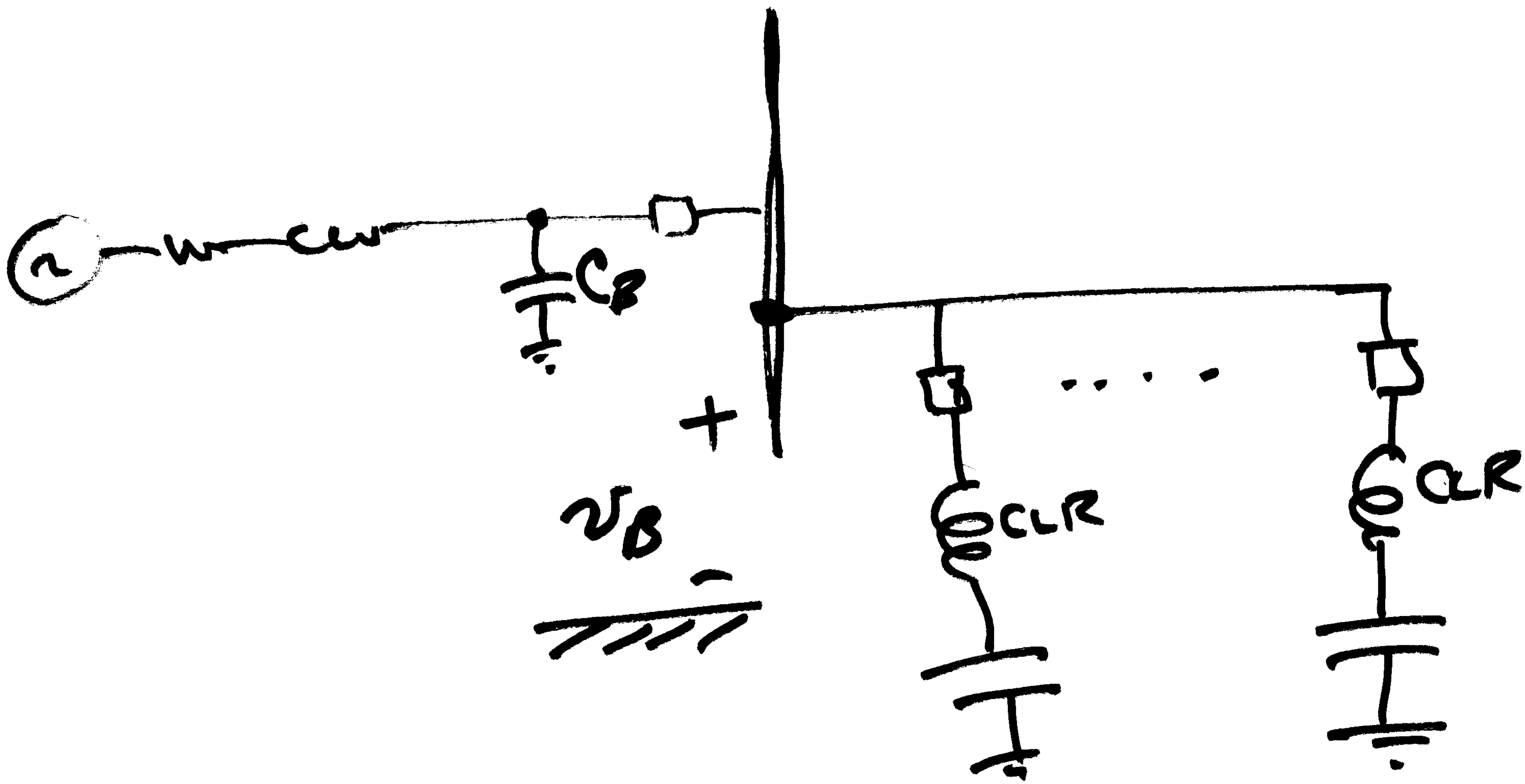
<u>Solution</u>: Place a numerical damping resistor
a) In parallel w/ L
b) In series w/ C



<u>ATP Draw Implementation</u>



(<u>EES240</u>, EES220)



C_B
+
v_B
−
CLR
CLR