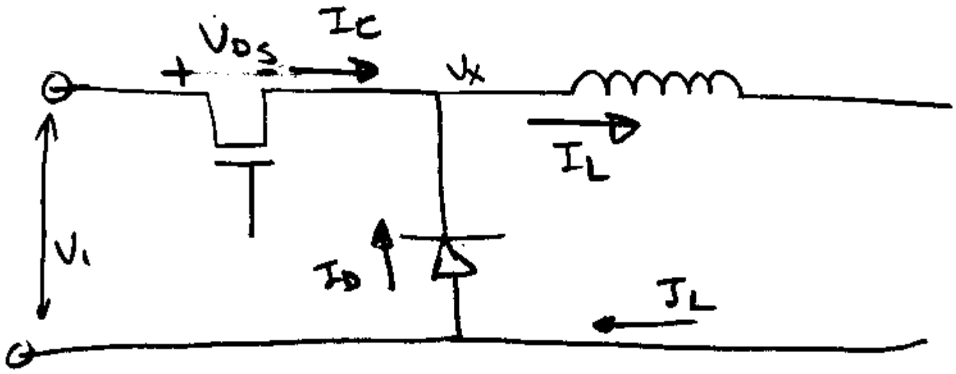
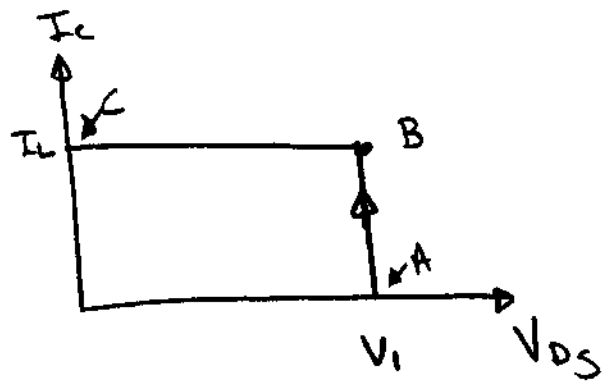
Turn-on problems with Buck transistors





- while mosfet is off
  - I_L flows through the free-wheel diode
  - $V_{DS} = V_1$

- as mosfet turns on $I_C \uparrow$, $I_D \downarrow$

$$I_L = I_D + I_C$$

- as $I_C \uparrow$
  - I_C goes from 0 to I_L
  - I_D goes from I_L to 0

  ⇒ while I_C $0 \to I_L$, $I_D \neq 0$
  - since $I_D = 0$, $V_D = V_\gamma$ and $V_{DS} = V_1 - V_\gamma$

⇒ as mosfet turns on

$V_{DS} \cong V_1$

I_C $0 \to I_L$

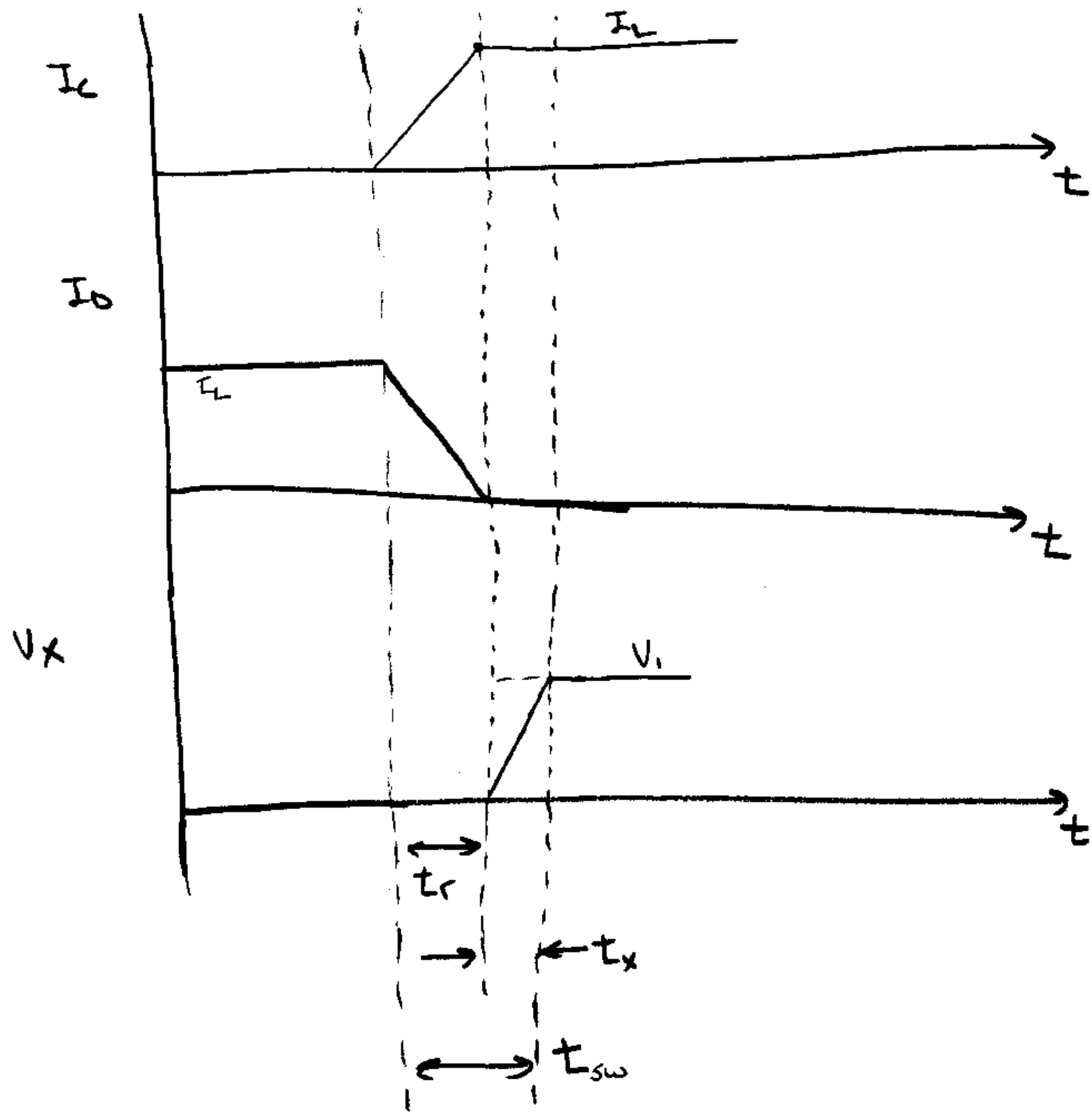
⇒ on graph, Transition from Ⓐ to Ⓑ.

⇒ once $I_D = 0$, V_X is free to rise to V_1

$I_C = I_L$

V_{DS} $V_1 \to 0$

⇒ on graph, Transition from $B \to C$.



During t_R, $V_{DS} = V_1$, $\langle I_C \rangle \frac{I_L}{2}$

$$\langle P \rangle = V_{DS} \langle I_C \rangle = \frac{V_1 I_L}{2}$$

$$\langle p \rangle \text{ per cycle} = \langle p \rangle \frac{t_r}{T_s} = \frac{V_1 I_L}{2} \frac{t_r}{T_s}$$

During t_x, $I_L = I_L$, $\langle V_{DS} \rangle = \frac{V_1}{2}$

$$\langle p \rangle = \langle V_{DS} \rangle I_L = \frac{V_1 I_L}{2}$$

$$\langle p \rangle \text{ per cycle} = \langle p \rangle \frac{t_x}{T_s} = \frac{V_1 I_L}{2} \frac{t_x}{T_s}$$

So Total switching power dissipation

$$\langle p \rangle_{sw} = \frac{V_1 I_L}{2} \left(\frac{t_x + t_r}{T_s} \right) = \frac{V_1 I_L}{2} \frac{t_{sw}}{T_s}$$

Turn-on switching loss

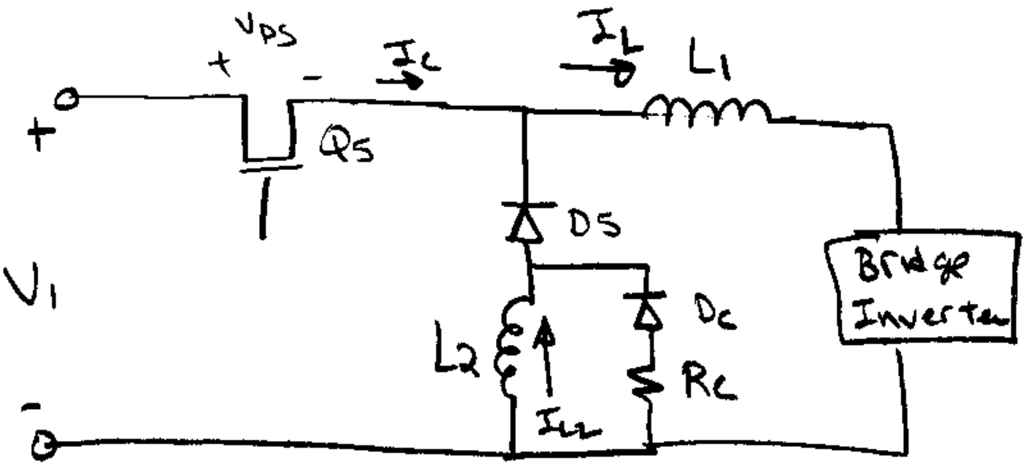
Note: Book states that $t_x \ll t_r$ so

$$\langle p \rangle_{sw} \cong \frac{V_1 I_L}{2} \frac{t_r}{T_s}$$

- For turn-off, we would trace out path
  C → B – A

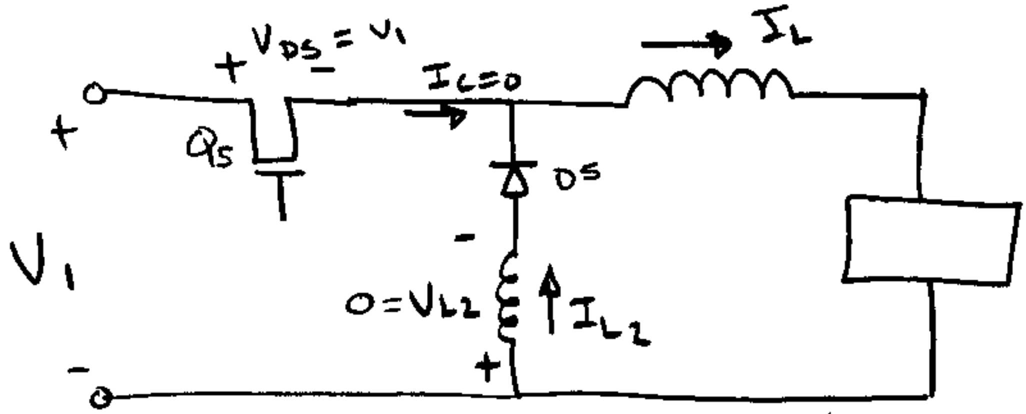
- Same equation for $\langle p \rangle_{sw}$ except that the switching times would be numerically different.

Buck Turn-on snubber



- Idea, while $I_C \rightarrow 0$ to I_L, Keep V_1 = Small

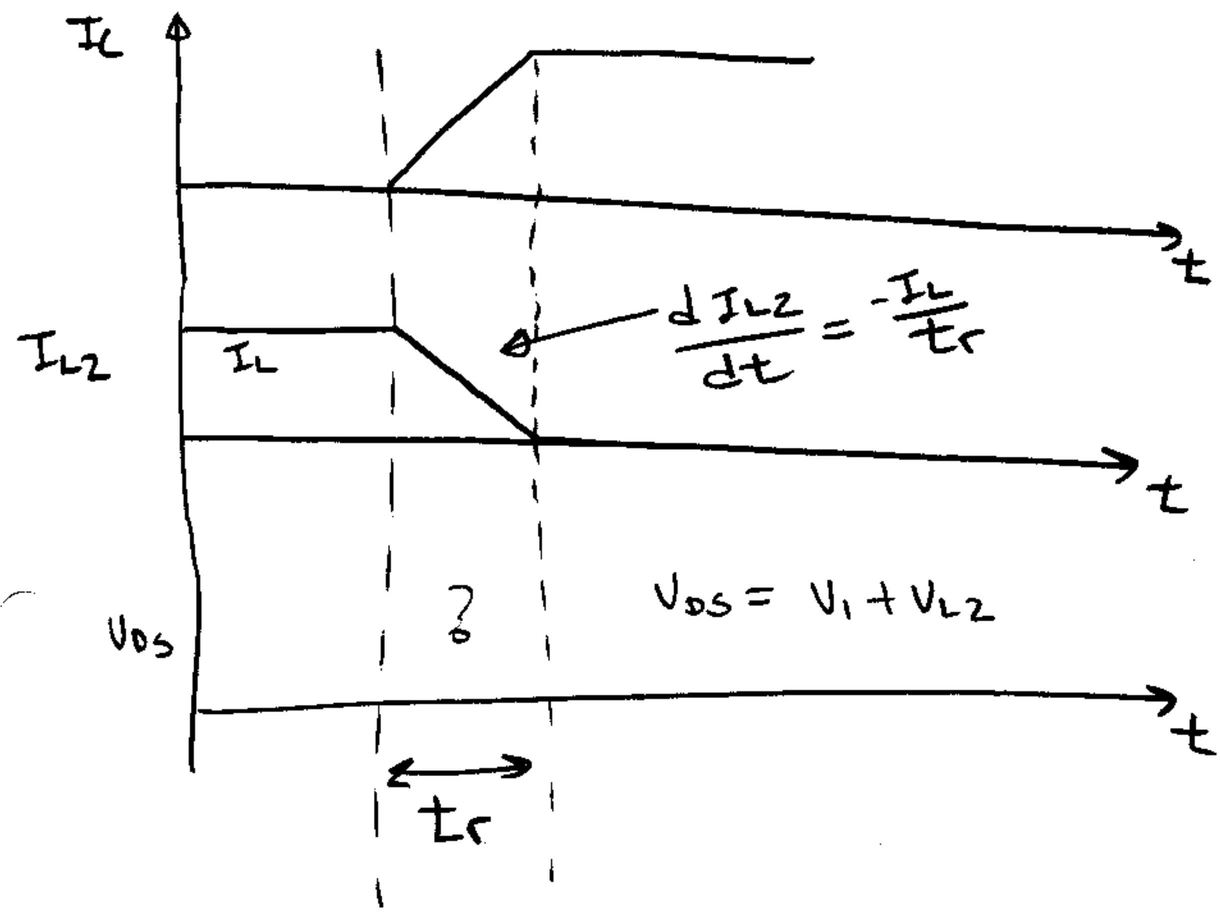
- while Q_S = OFF we have



$I_L = I_{L2}$, $V_{L2} = 0$ ⇒ short

$I_C = 0$

- Now look at when Q_5 turns on



$$V_{L2} = L_2 \frac{di_L}{dt} = -L_2 \frac{I_L}{t_r}$$

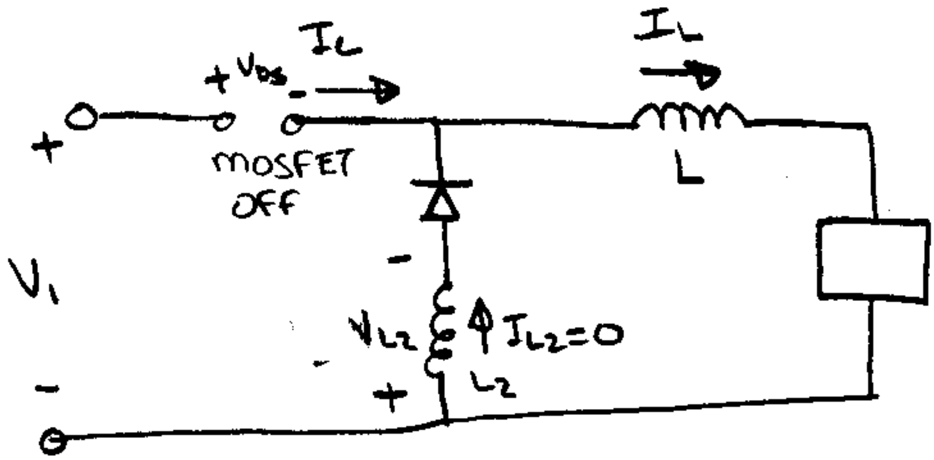
Choose L_2 so that $V_{DS} = 0$

$$0 = V_1 + V_{L2} = V_1 - L_2 \frac{I_L}{t_r}$$

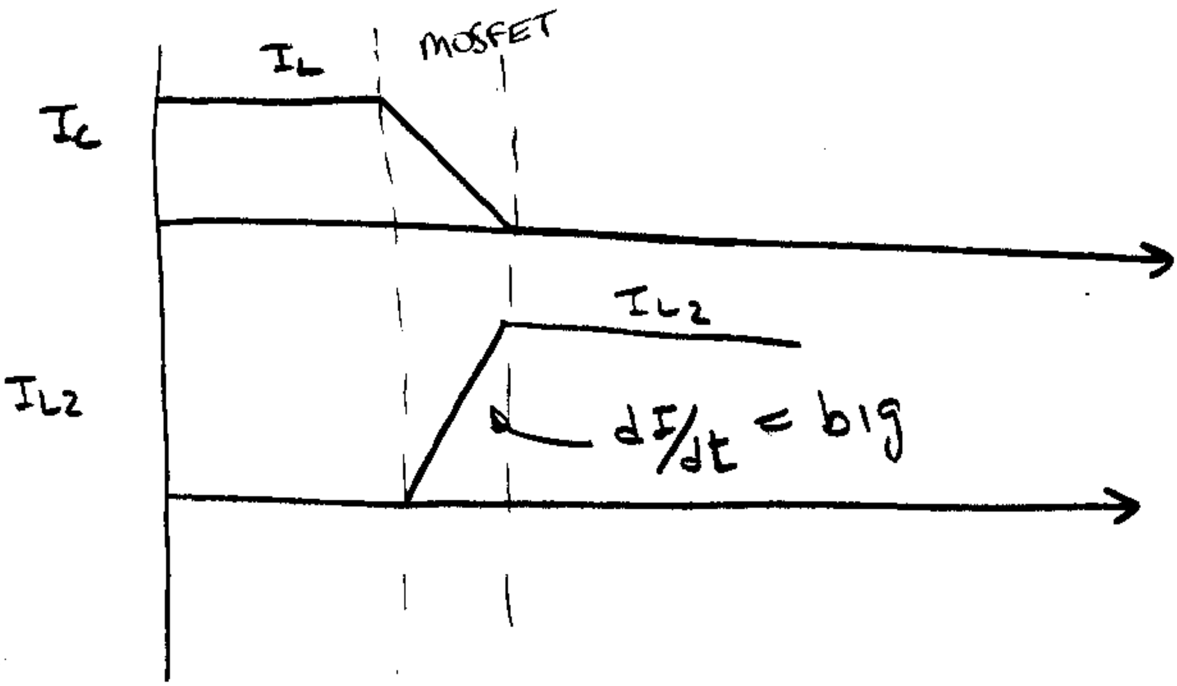
$$\Rightarrow \boxed{L_2 = \frac{V_1 t_r}{I_L}}$$

- what is the purpose of R ?

Look at turn-off



I_L must flow through L_2



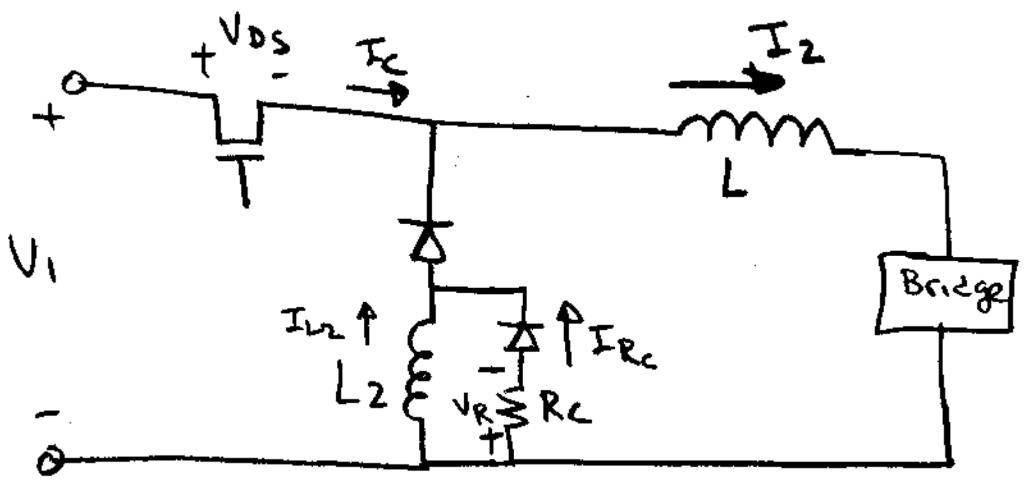
- The large $\frac{dI}{dt}$ causes a big V_{L2}

- $V_{DS} = V_1 + V_{L2}$

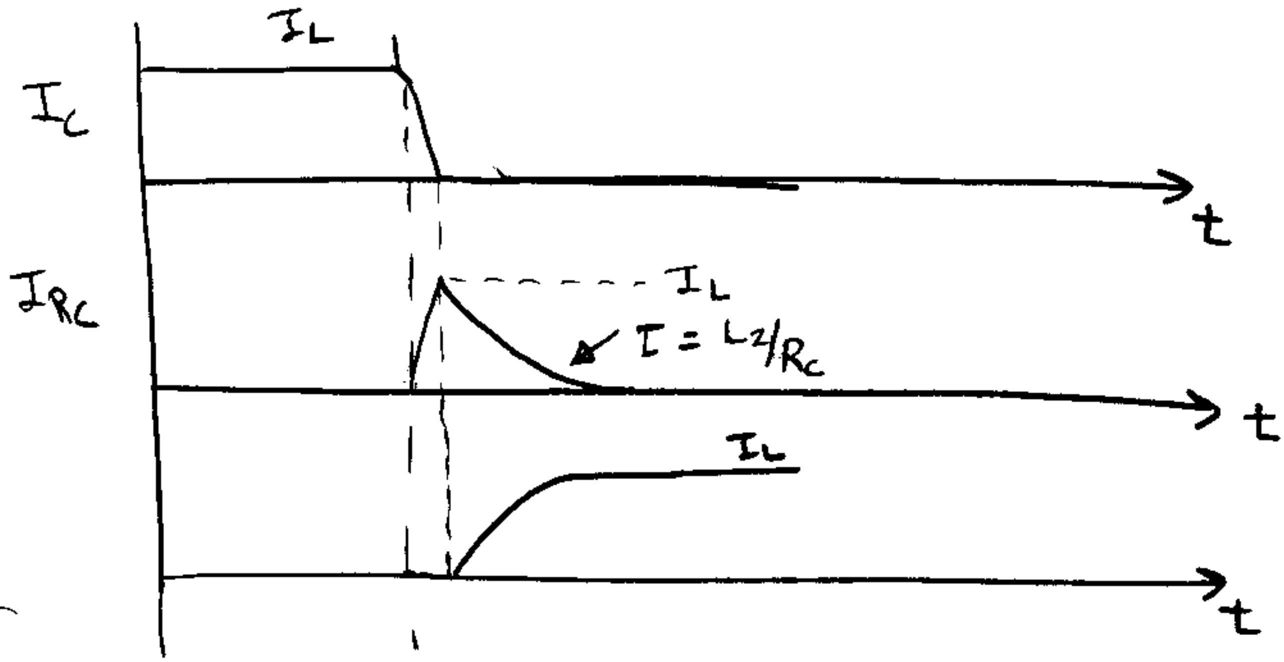
$$= V_1 + L_2 \frac{dI}{dt} \Rightarrow \text{big}$$

$\Rightarrow$ Kill MOSFET switch

- add a parallel Resistor to snub Voltage Spike.

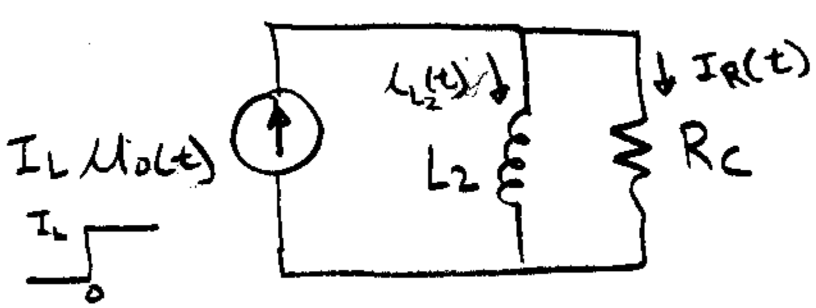


- At the instant of turn-off, there is no current through L_2

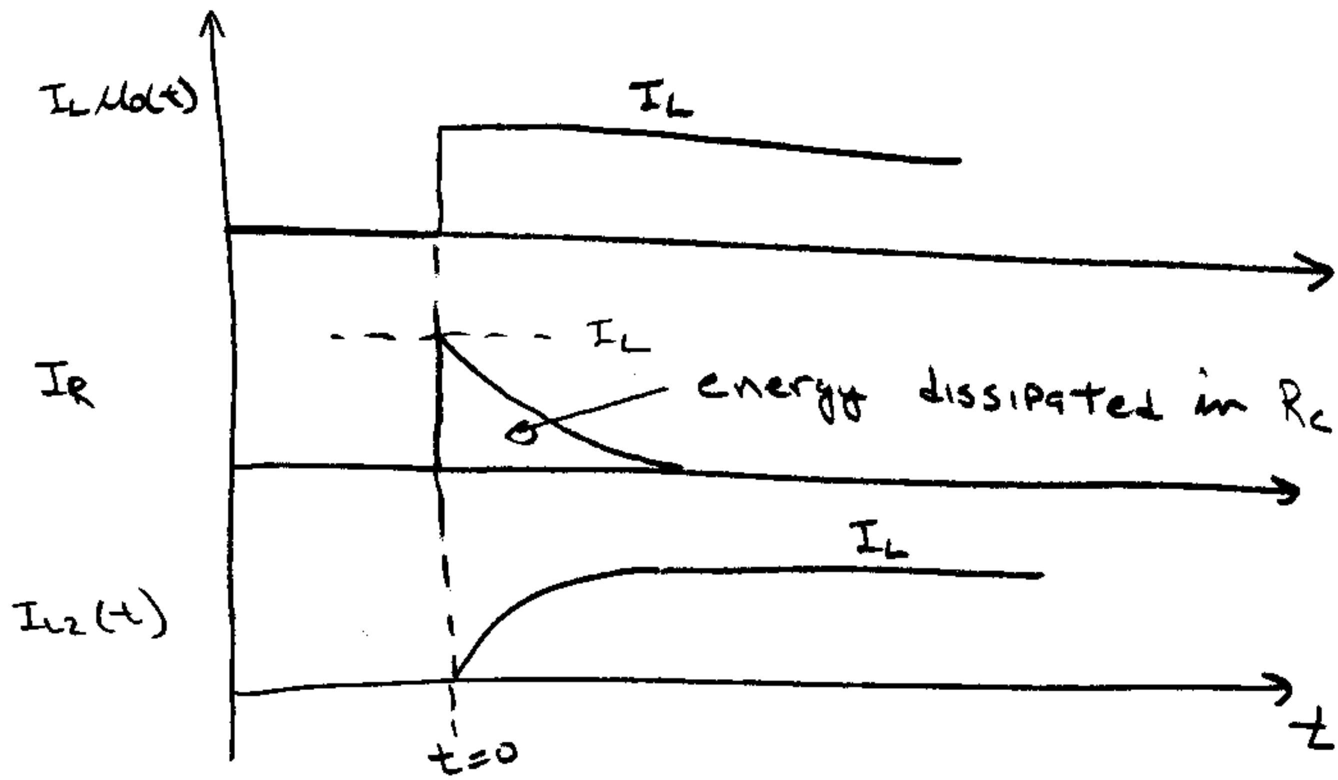


How much power is dissipated in R_c?

Equivalent Circuit



- How much Energy is dissipated in R_c



$$I_R(t) = I_L e^{-t/\tau} \quad ; \quad \tau = L_2/R_c$$

$$P_R = I_R^2(t) R_c$$

$$P_R(t) = I_L^2 R_c e^{-2t/\tau}$$

$$E_R = \int_0^\infty P_R(t)\,dt = \int_0^\infty I_L^2 R_c e^{-2t/\tau}\,dt$$

$$= \Big[-I_L^2 R_c \frac{\tau}{2} e^{-2t/\tau} \Big]_0^\infty = \frac{I_L^2 R_c \tau}{2}$$

$$E_R = \frac{I_L^2 R_C}{2} \frac{L_2}{R_C} = \underbrace{\frac{1}{2} L_2 I_L^2}$$

I_L = peak current through L_2

$E_R = \frac{1}{2} L_2 I_L^2$ = Energy dissipated per cycle.

$$P_R\Big|_{Avg} = E_R F_S$$

$$\boxed{P_R\Big|_{Avg} = \frac{1}{2} L_2 I_L^2 \; F_S}$$

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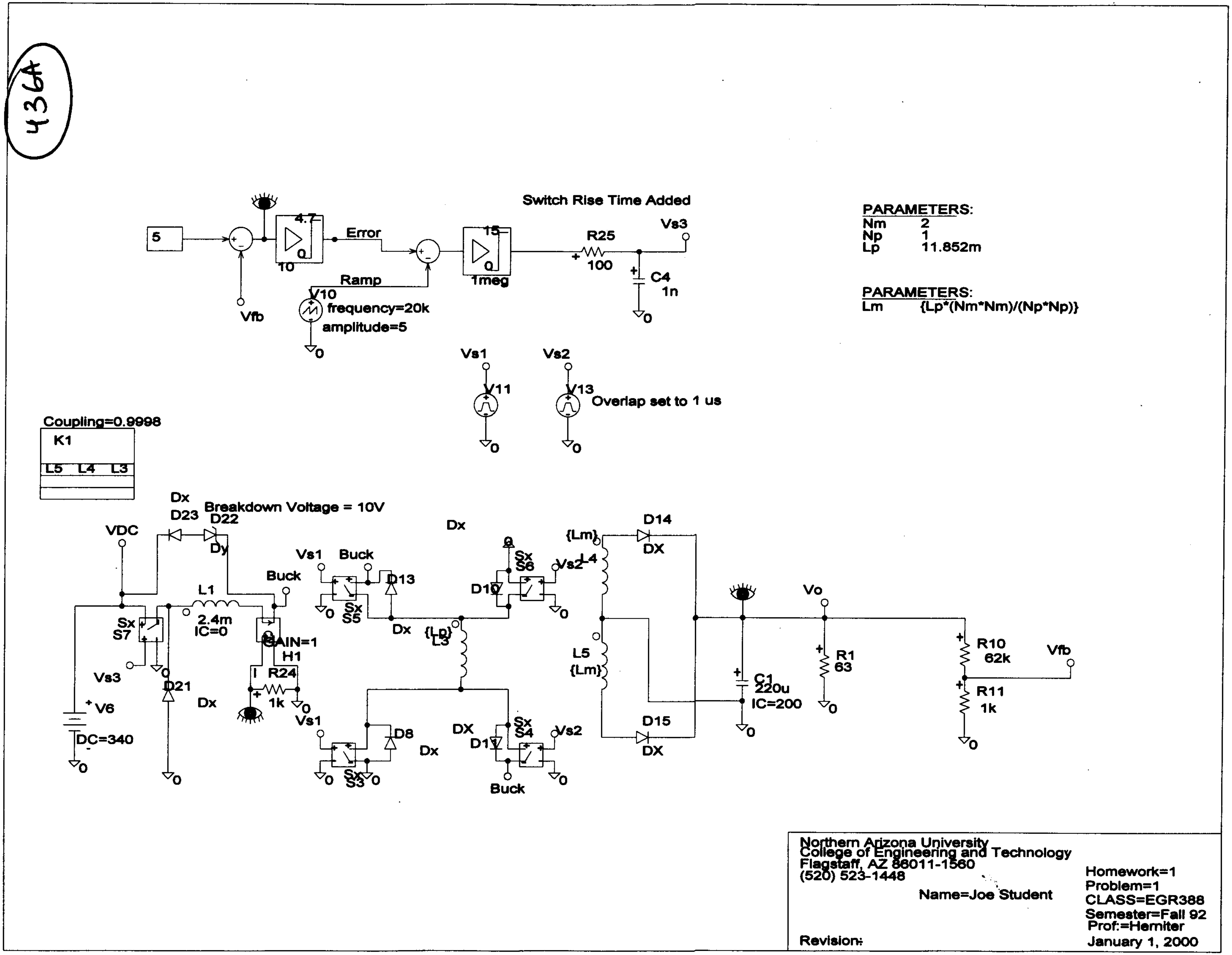

Switch Rise Time Added
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4.7
10
Error
Ramp
Vfb
V10
frequency=20k
amplitude=5
15
1meg
R25
100
Vs3
C4
1n
PARAMETERS:
Nm 2
Np 1
Lp 11.852m
PARAMETERS:
Lm {Lp*(Nm*Nm)/(Np*Np)}
Vs1
V11
Vs2
V13
Overlap set to 1 us
Coupling=0.9998
K1
L5 L4 L3
Dx
D23
D22
Dy
Breakdown Voltage = 10V
VDC
L1
2.4m
IC=0
Sx
S7
Vs3
V6
DC=340
D21
Buck
GAIN=1
H1
R24
1k
Vs1
Buck
D13
Sx
S5
{Lp}
L3
D10
Sx
S6
D8
Sx
S3
DX
D11
Sx
S4
Vs2
{Lm}
L4
L5
{Lm}
D14
DX
D15
DX
C1
220u
IC=200
Vo
R1
63
R10
62k
R11
1k
Vfb
Northern Arizona University
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Name=Joe Student
Homework=1
Problem=1
CLASS=EGR388
Semester=Fall 92
Prof:=Herniter
January 1, 2000
Revision:

B

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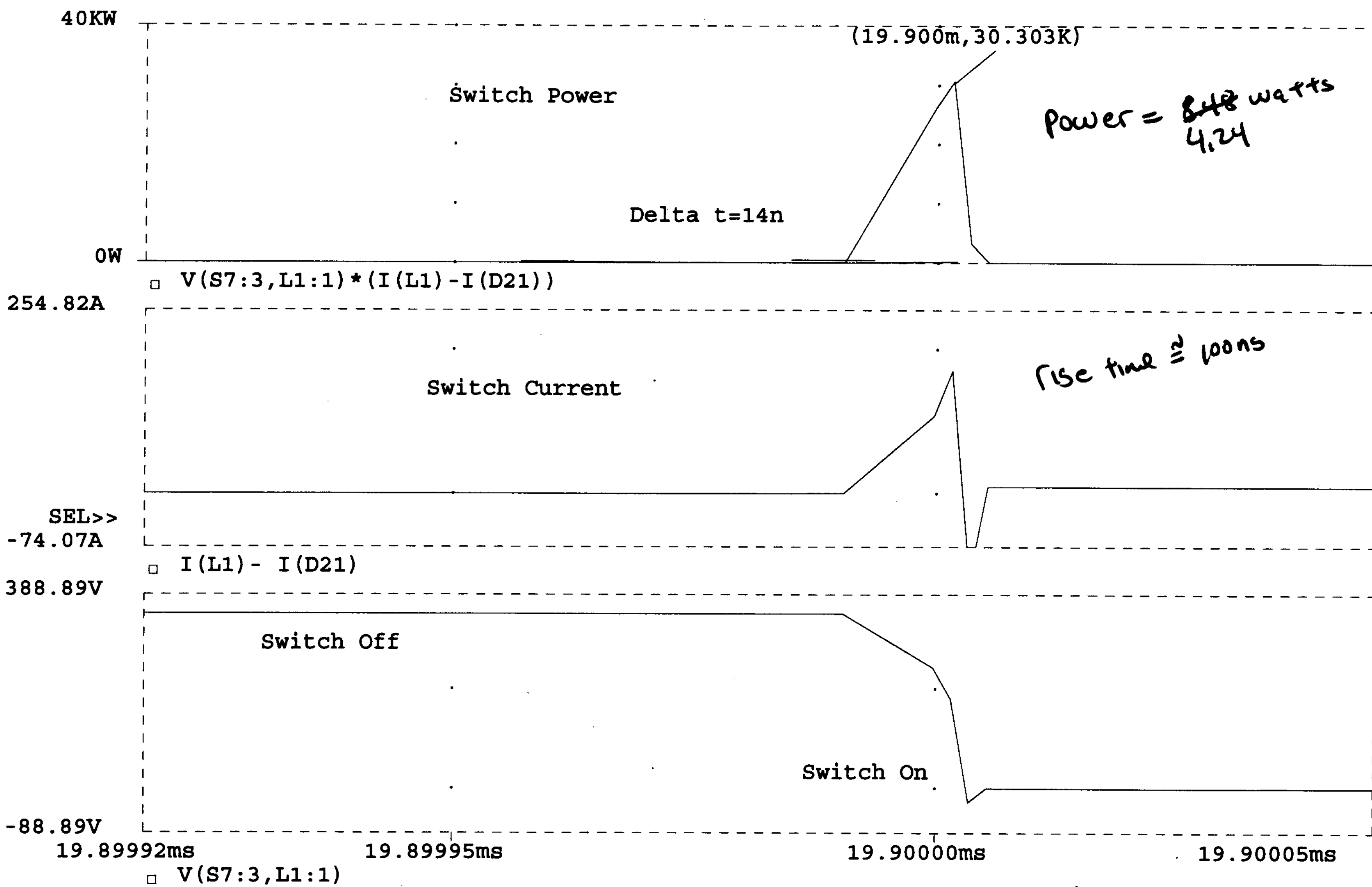

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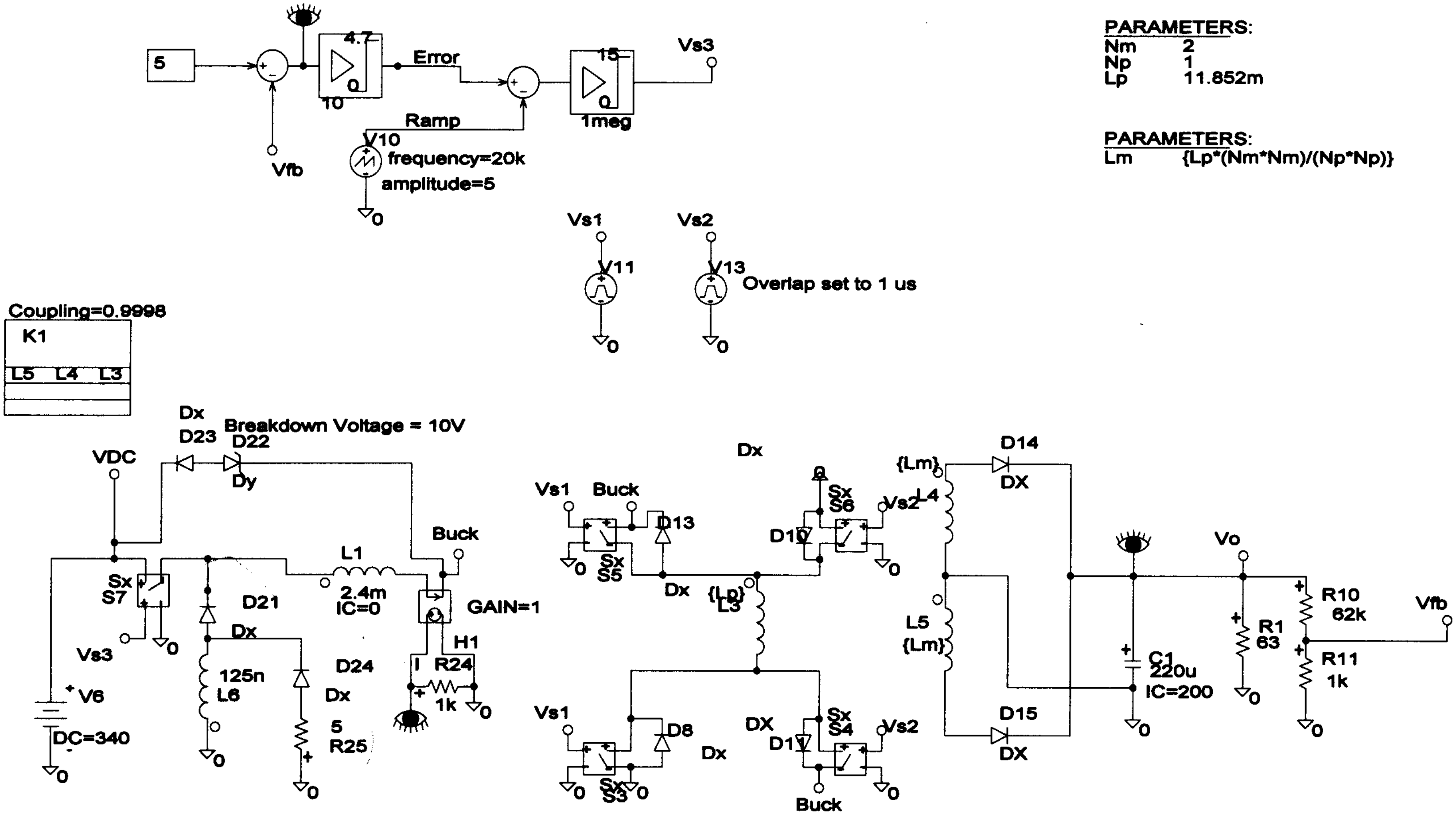

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D

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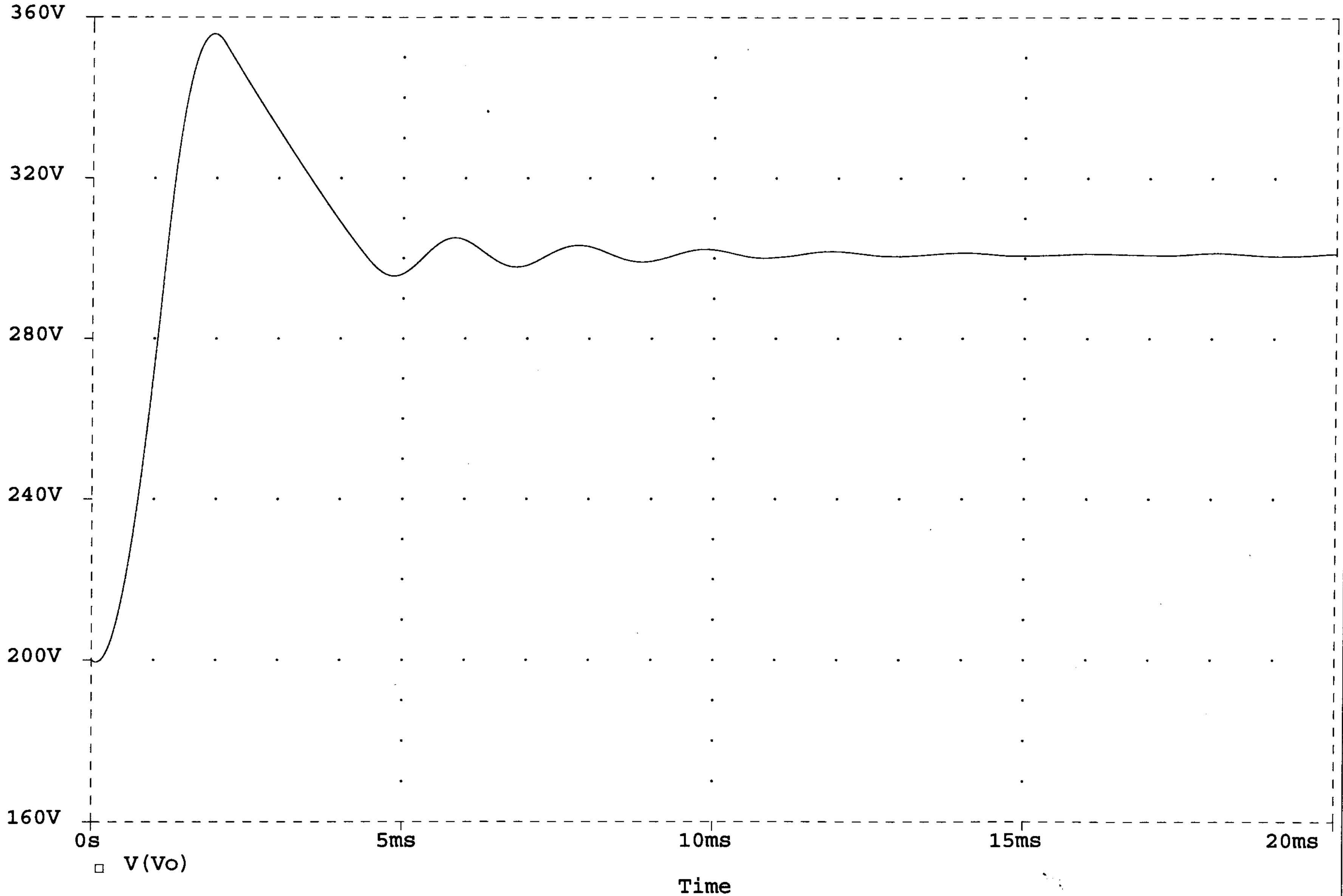

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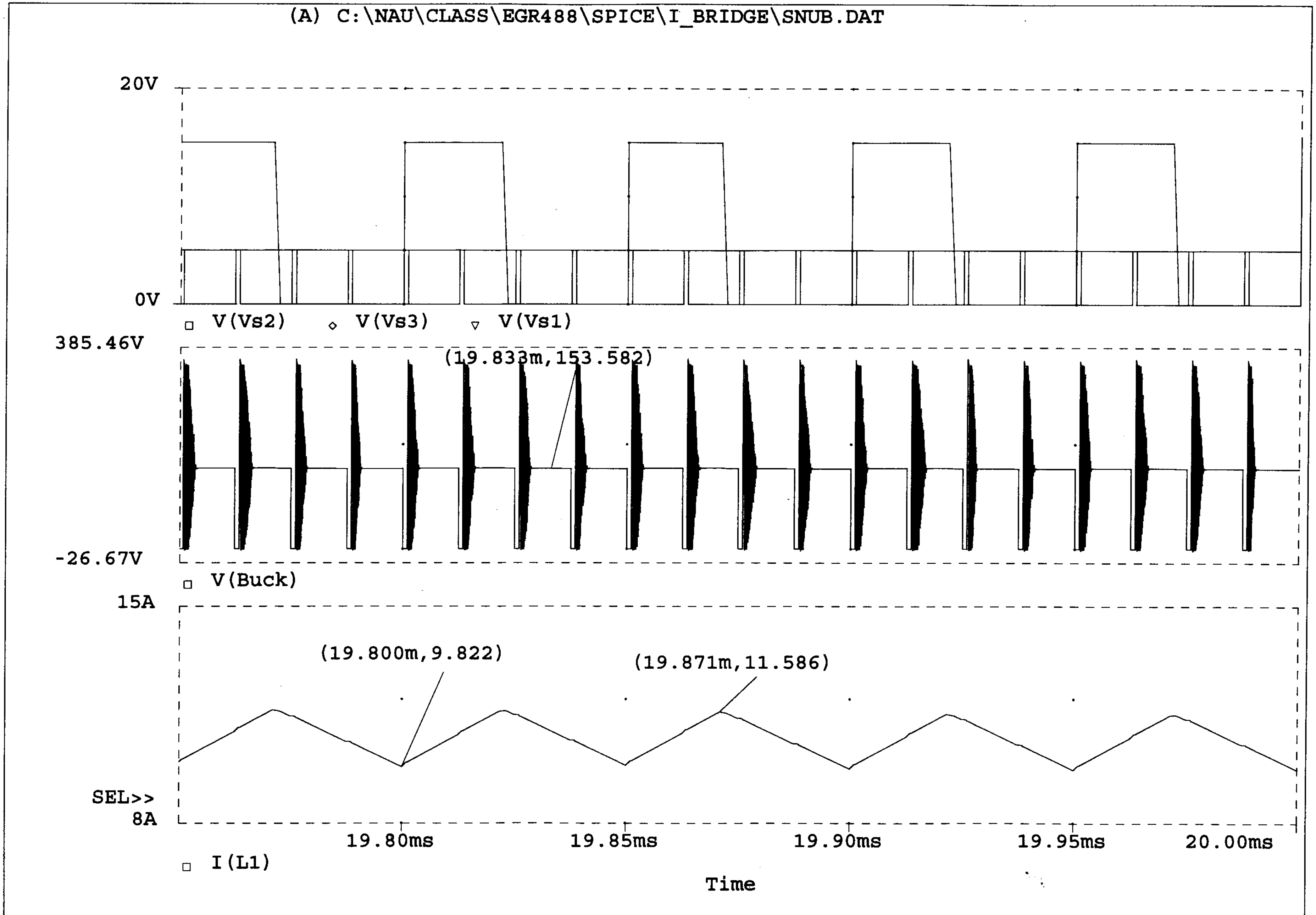

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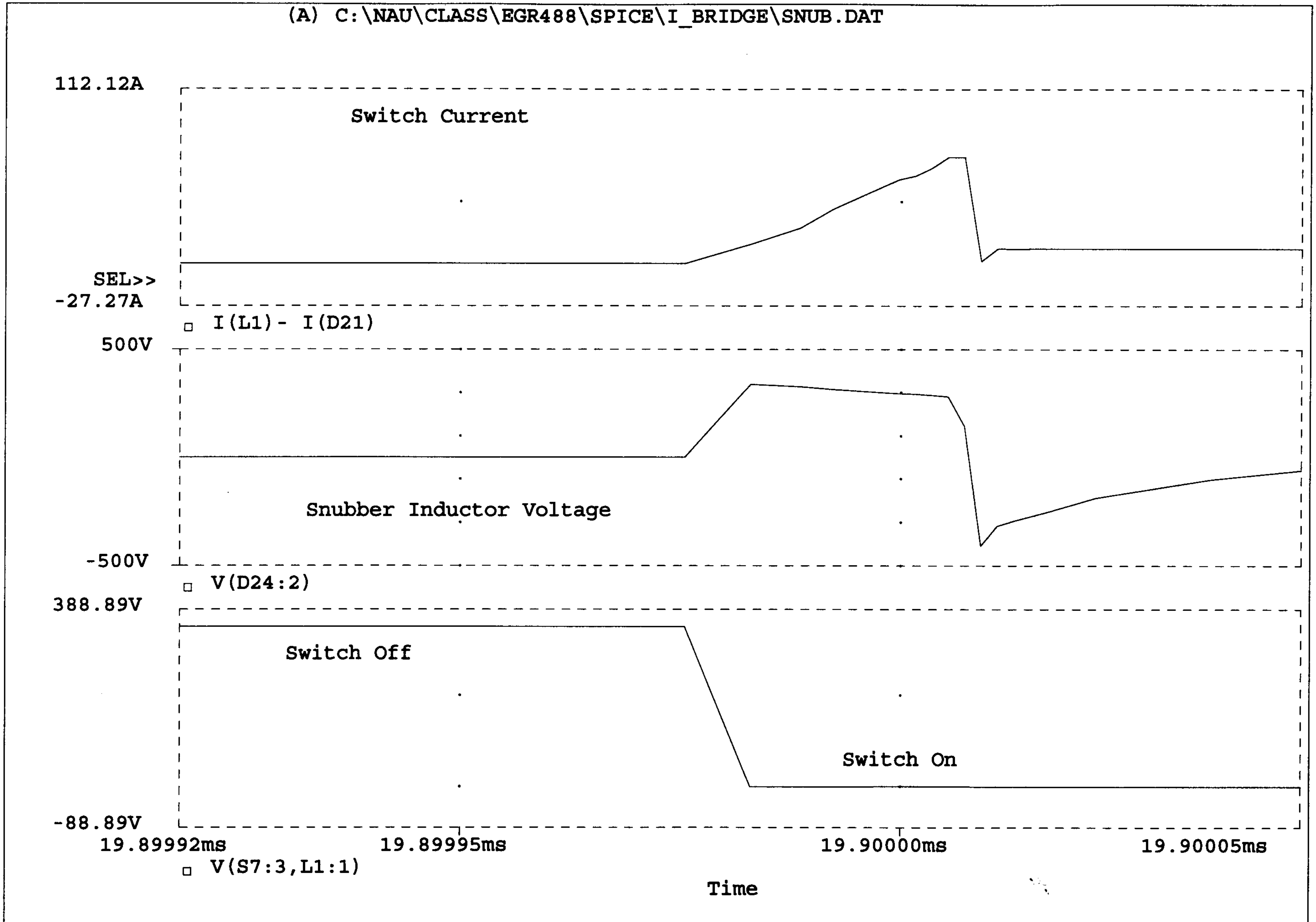

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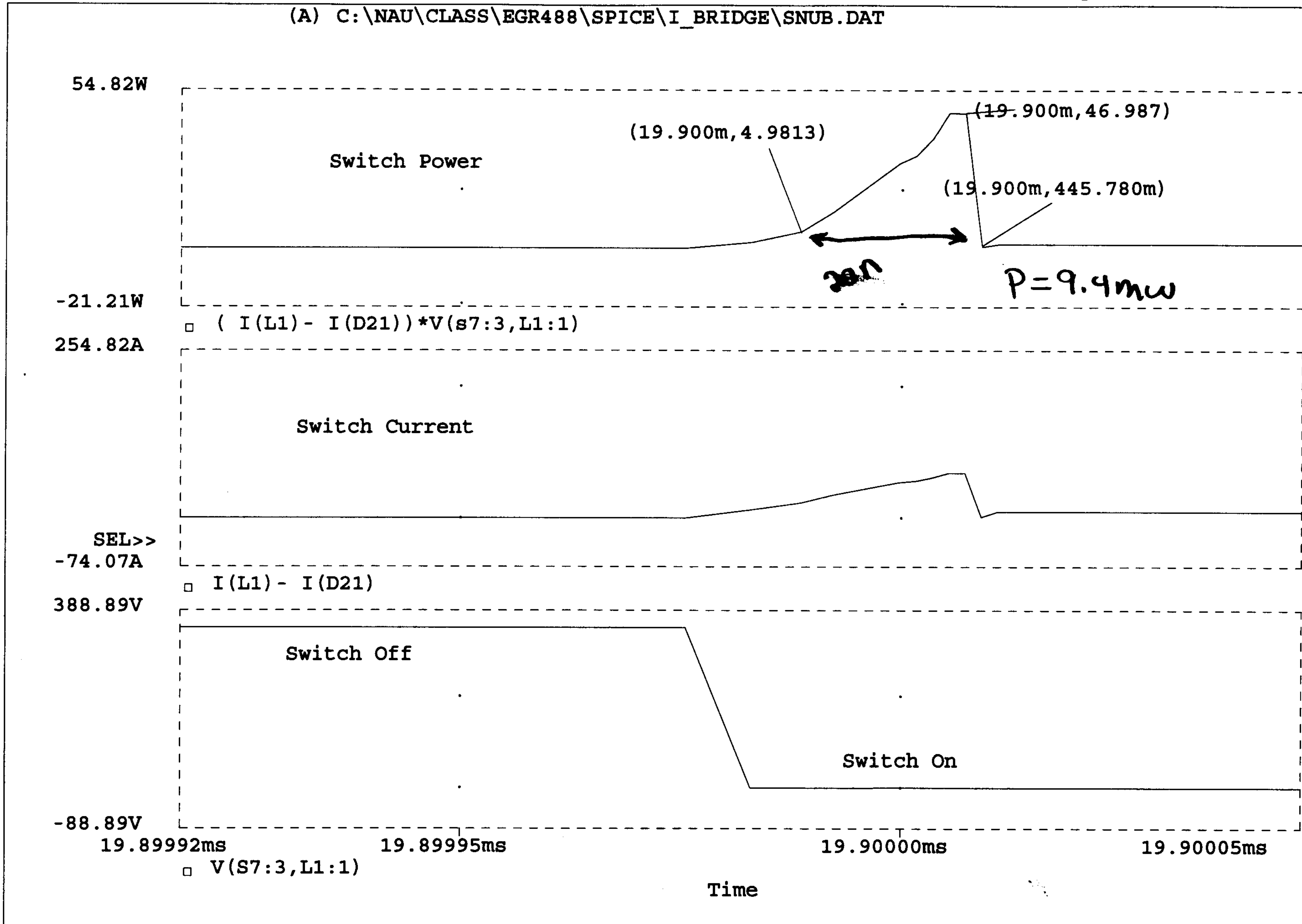

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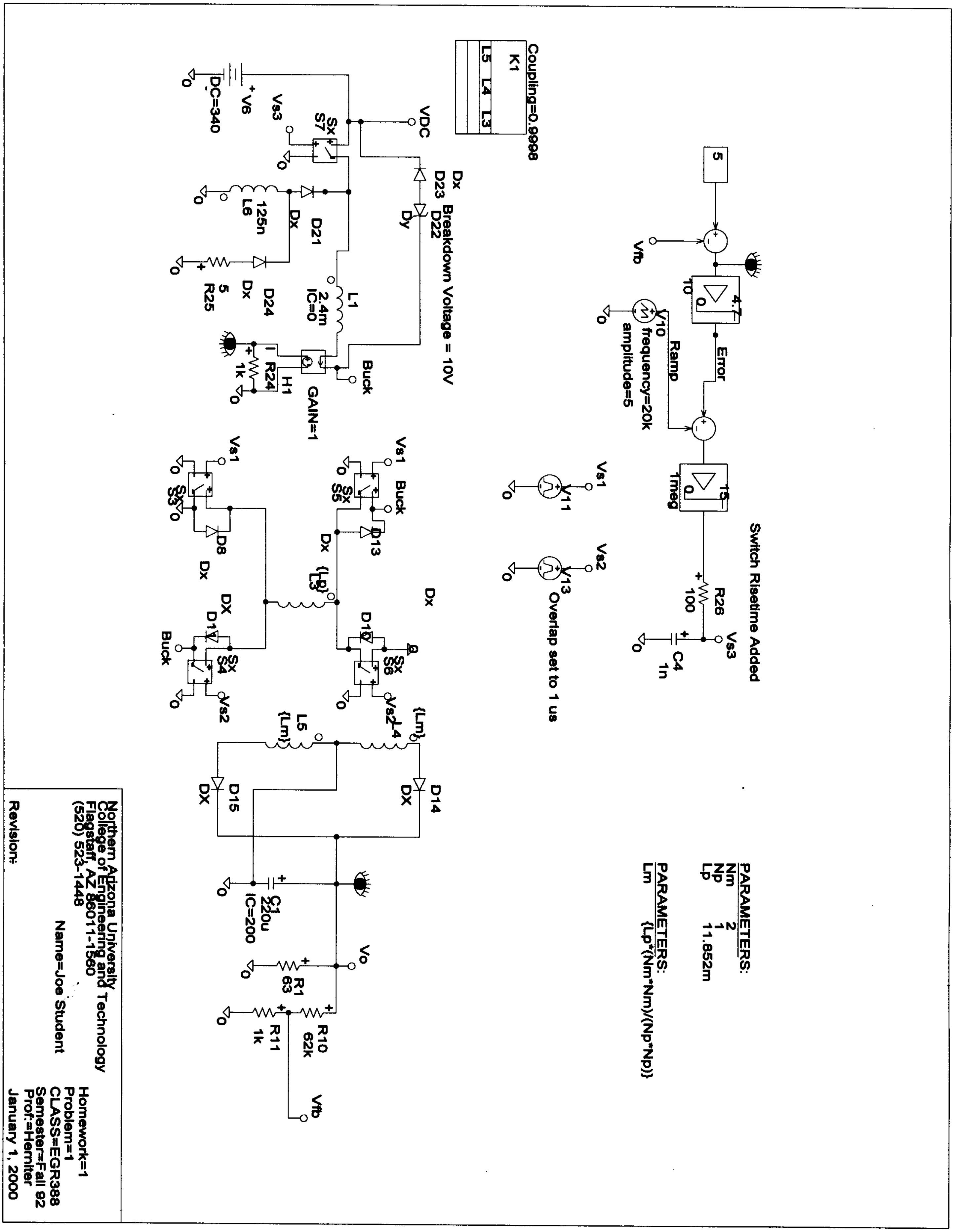

Switch Risetime Added
Error
Ramp
V10
frequency=20k
amplitude=5
Vfb
fmeg
R26
100
C4
1n
Vs3
V11
Vs1
V13
Vs2
Overlap set to 1 us
PARAMETERS:
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Np 1
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Dy
Breakdown Voltage = 10V
D21
L6
125n
D24
R25
5
L1
2.4m
IC=0
Buck
H1
GAIN=1
R24
1k
S5
S3
D13
D8
L3
{Lp}
D10
D11
S6
S4
L4
L5
{Lm}
D14
D15
DX
C1
220u
IC=200
Vo
R1
63
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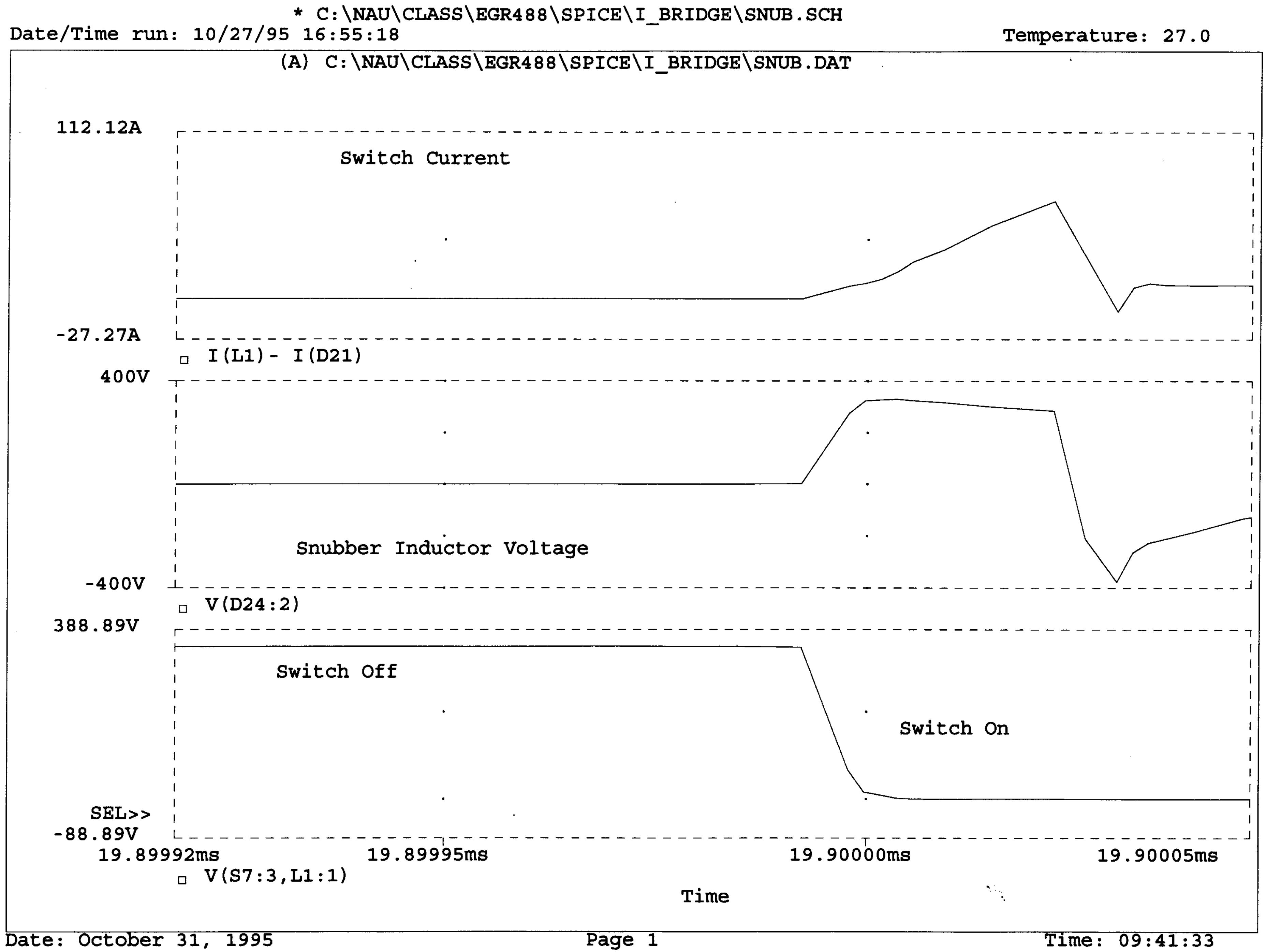

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Switch Current
-27.27A
I(L1)- I(D21)
400V
Snubber Inductor Voltage
-400V
V(D24:2)
388.89V
Switch Off
Switch On
SEL>>
-88.89V
19.89992ms
19.89995ms
19.90000ms
19.90005ms
V(S7:3,L1:1)
Time
Date: October 31, 1995
Page 1
Time: 09:41:33

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