Question #1

Buck Converter DCM

Conditions

$V_g = 5[\mathrm{V}]$

$R_{load} = 4[\Omega]$

$freq = 250[\mathrm{kHz}]$

$L = 2.2[\mu\mathrm{H}]$

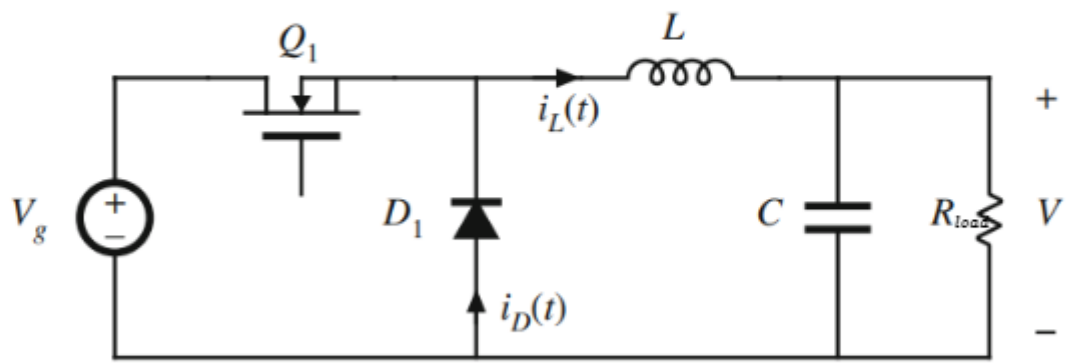
$C = 47[\mu\mathrm{F}]$

$K = \frac{2L}{RT_s}$

Problems

아래 회로가 DCM으로 동작할 때 왼쪽의 조건을 고려하여 문제를 푸시오

1) $K_{crit}(D)$ & 입출력 관계식 V/V_g
2) $D_1 = 0.3$ 일때 출력전압 V 계산
3) 2)의 결과를 PSIM simulation 결과와 비교
4) PSIM simulation으로 인덕터 리플 전류 Δi_L, 평균전류 I, 시간 D_3확인



$$I_L = \frac{V}{R} = \frac{DV_g}{R} \quad \cdots ①$$

$$\Delta i_L = \frac{(V_g - V)}{2L} DT_S \qquad V = DV_g$$

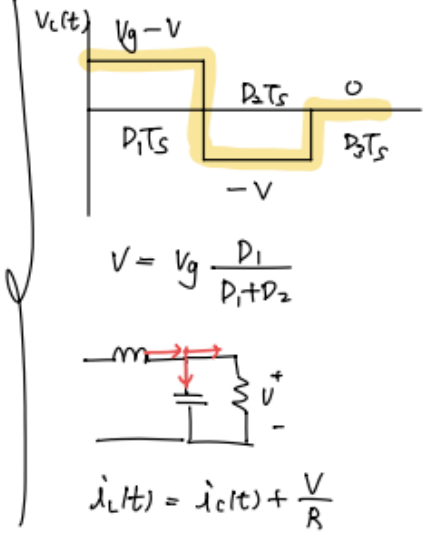
$$\cdots ②$$

$$= \frac{V_g D D' T_S}{2L}$$

① = ②

$$\frac{DV_g}{R} < \frac{V_g D D' T_S}{2L}$$

$$\frac{2L}{RT_S} < D' \quad \therefore \; K_{crit} = D'$$

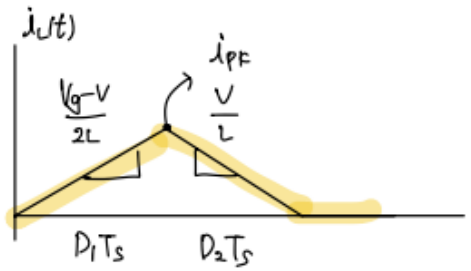


$$V = V_g \frac{D_1}{D_1 + D_2}$$

$$i_L(t) = i_c(t) + \frac{V}{R}$$

$$\langle i_c(t) \rangle = 0$$

$$\langle i_L \rangle = \frac{V}{R}$$



$$i_{pk} = \frac{V_g - V}{L} D_1 T_S$$

삼각형의 넓이

$$\langle i_L \rangle = \frac{1}{2}(D_1 + D_2) T_S \cdot \frac{V_g - V}{L}$$

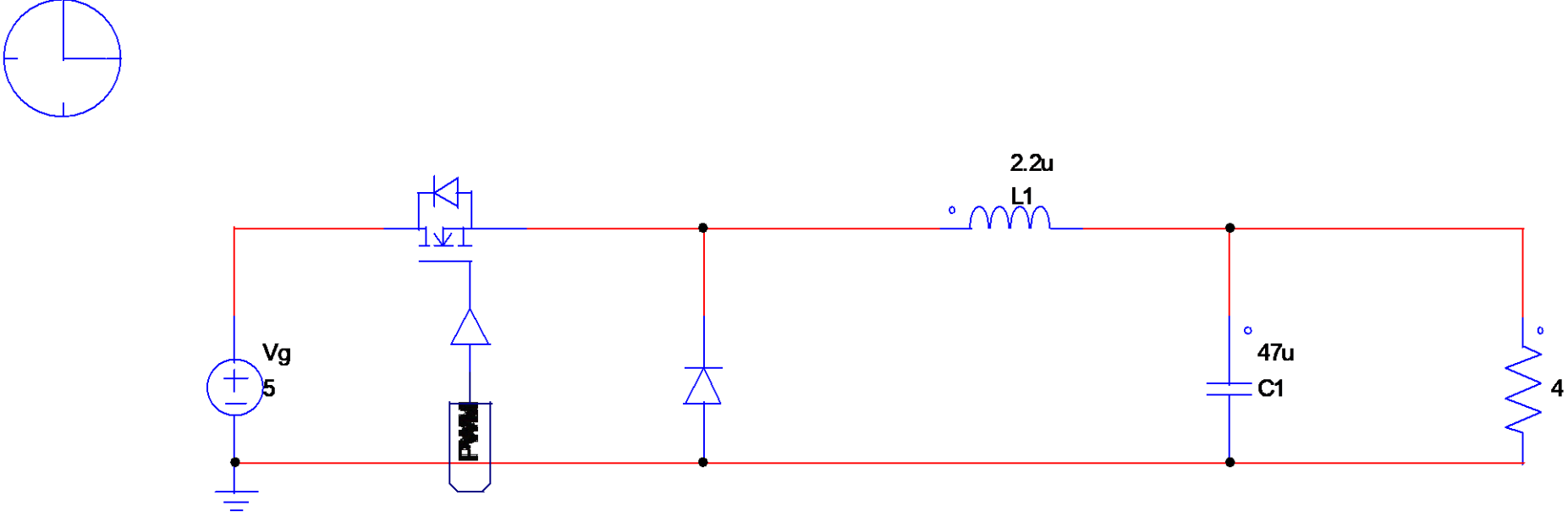
$$\frac{V}{R} = \frac{T_S}{2L}(D_1 + D_2)(V_g - V)$$

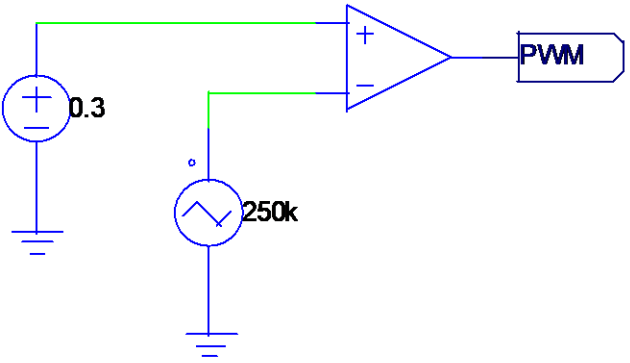
$$V = \frac{1}{K}(D_1 + D_2)(V_g - V)$$

$$\frac{V}{V_g} = \frac{2}{1 + \sqrt{1 + \frac{4K}{D_1^2}}}$$

$D_1 = 0.3$, $K = 0.25$

$$\rightarrow \frac{V}{V_g} = \frac{2}{1 + \sqrt{1 + \frac{4 \times 0.25}{0.3^2}}} = 0.4314 \quad \therefore \; V = 2.157\,[V]$$





Simulation Control

PSIM | SPICE | SimCoder | Color

Solver Type: Fixed-step / Variable-step (dual) — Help

		Time Step Ratio	Smaller Time Step
Time Step	1E-07	4	2.5e-08
Total Time	0.1	Free Run	
Print Time	0		
Print Step	1		
Load Flag	0		
Save Flag	0		

Engine Default Values

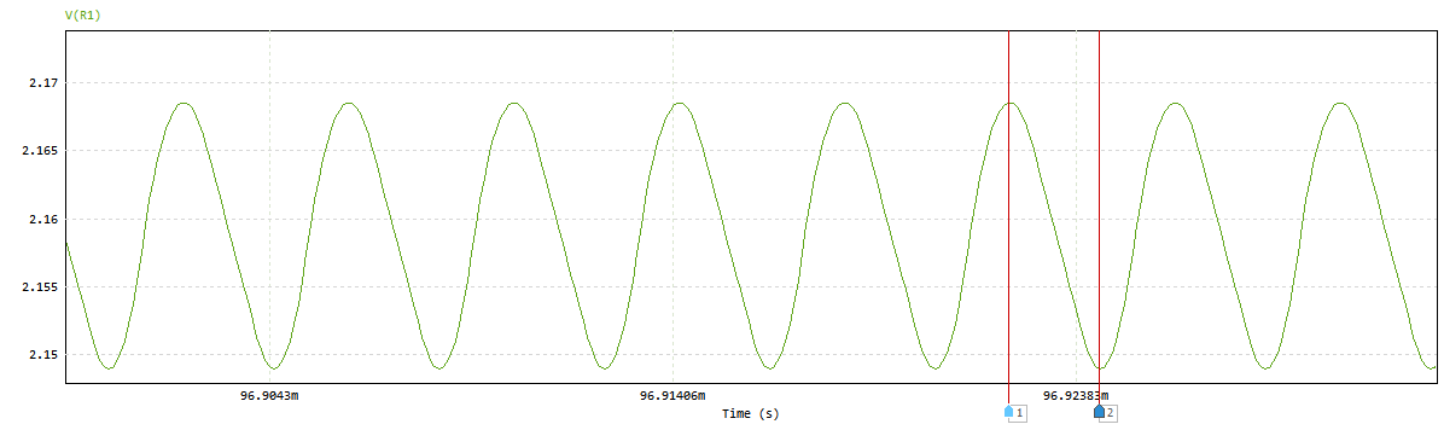
R_switch_on	1E-05
R_switch_off	1E+007

Triangular : VTRI1

Parameters | Color

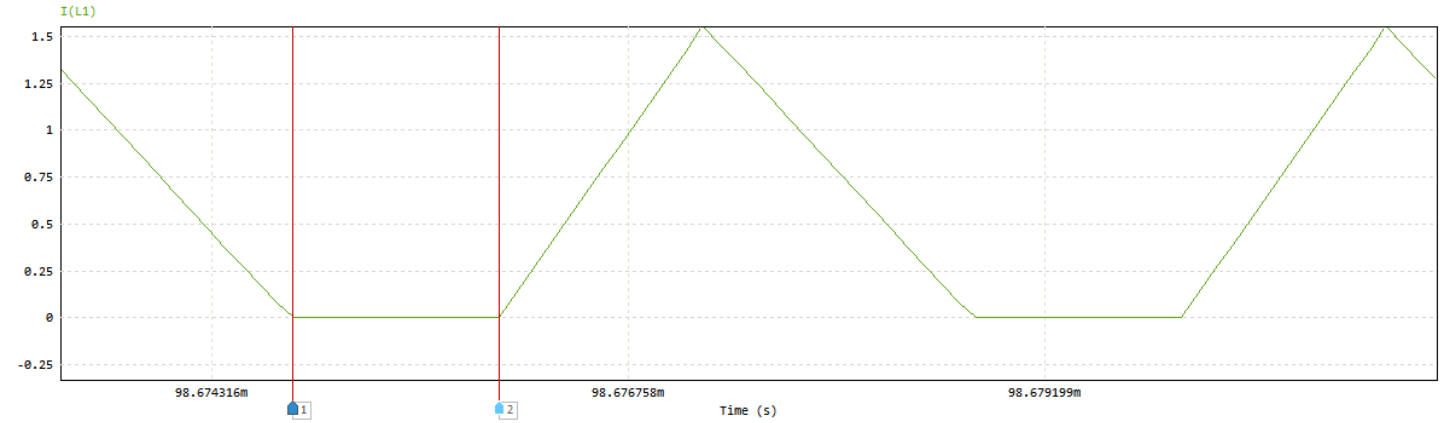
Triangular-wave voltage source — Help

		Display
Name	VTRI1	
V_peak_to_peak	1	
Frequency	250k	✓
Duty Cycle	1	
DC Offset	-0	
Tstart	0	
Phase Delay	0	



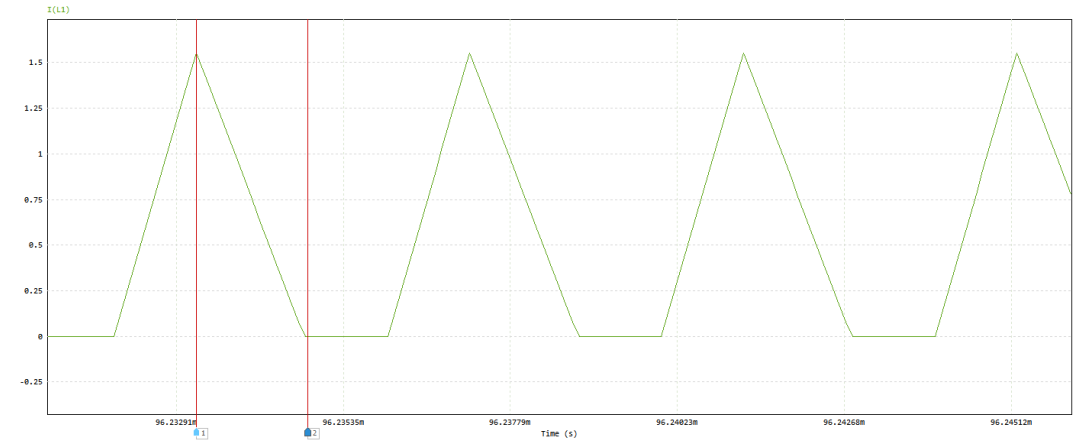
Measure	X1	X2	Δ	Average
Time	9.69222e-02	9.69244e-02	2.20000e-06	
V(R1)	2.16853e+00	2.14896e+00	-1.95726e-02	2.15919e+00

$$Average\ V_{out} = 2.1519[V]$$



Measure	X1	X2	Δ	Average
Time	9.86748e-02	9.86760e-02	1.20358e-06	
I(L1)	2.76892e-03	-7.53132e-06	-2.77646e-03	2.97256e-03

$$D_3 = X2 - X1 = 1.2 * 10^{-6} = 1.2[\mu s]$$



Measure	X1	X2	Δ	Average
Time	9.90612e-02	9.90640e-02	2.80000e-06	
I(L1)	1.55396e+00	-7.51737e-06	-1.55397e+00	4.38583e-01

$$I_L = 0.43858[A]$$

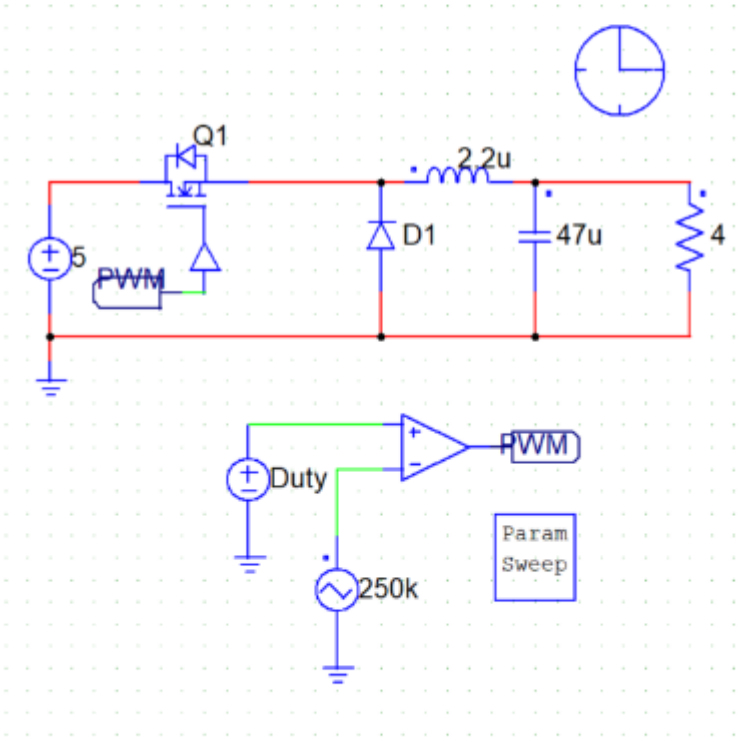
$$\Delta i_L = 1.55397[A]$$

Question #2

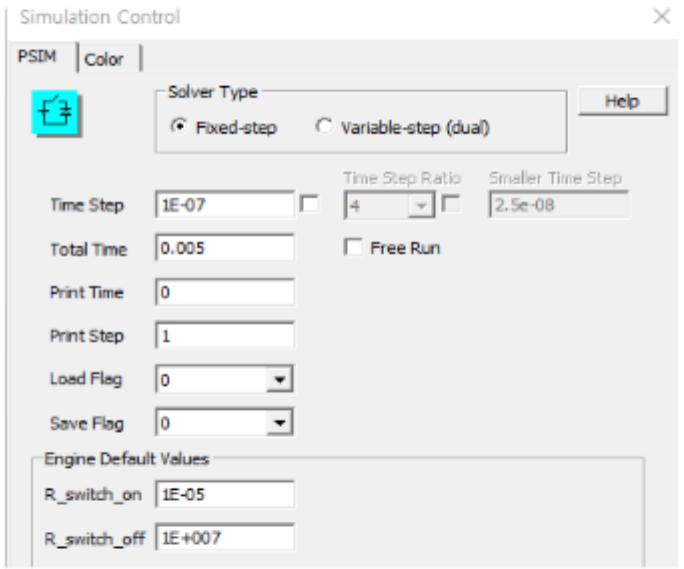
Buck converter DCM

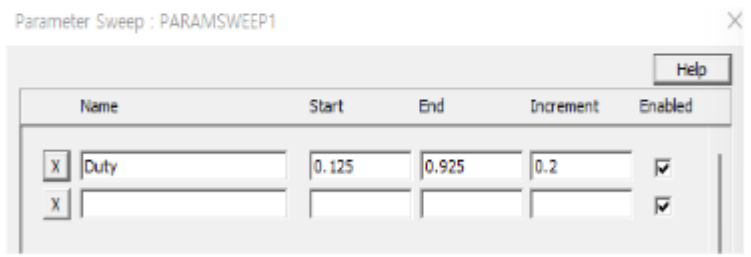
Problems

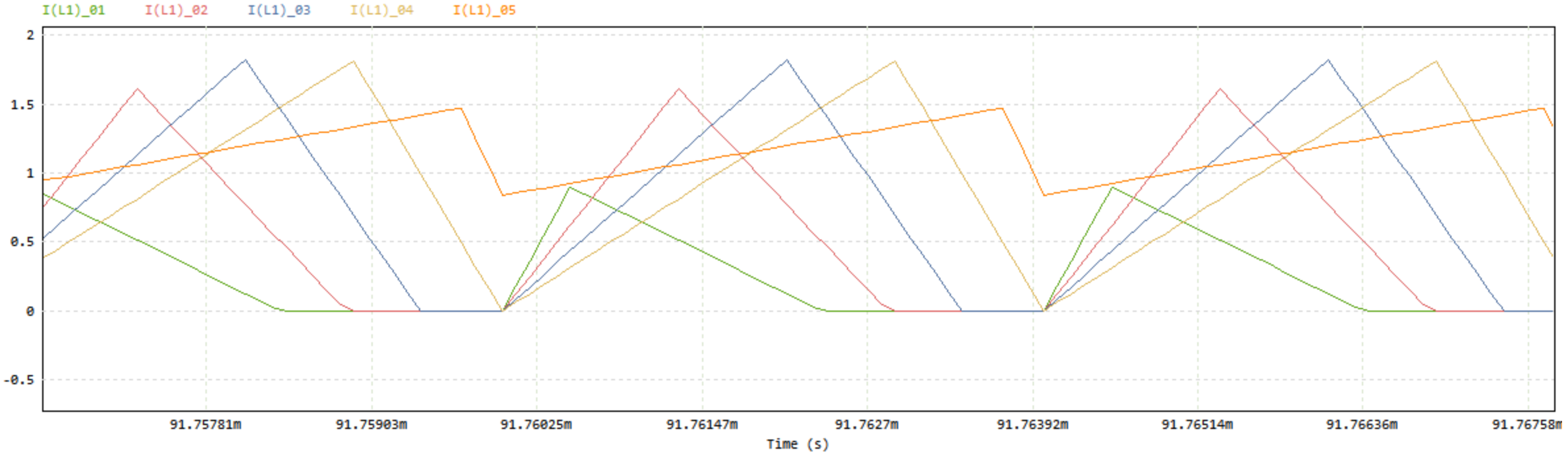
Question #1에 대해 PSIM의 Parameter Sweep을 이용하여 (Duty를 변경하여) CCM에서 DCM으로 변경되는 구간을 확인하시오 (DCM: $\Delta i_L > I$)



$$K = 0.275, \quad K_{crit} = (1 - D)$$







$K_{crit} = (1 - D) = 0.275$가 되는 지점인 $I(L1)04$부터 CCM 모드가 시작되는 것을 확인

Question #3

Boost Converter DCM

Conditions

$V_g = 100[\mathrm{V}]$

$R_{load} = 100[\Omega]$

$freq = 5[\mathrm{kHz}]$

$L = 1[\mathrm{mH}]$

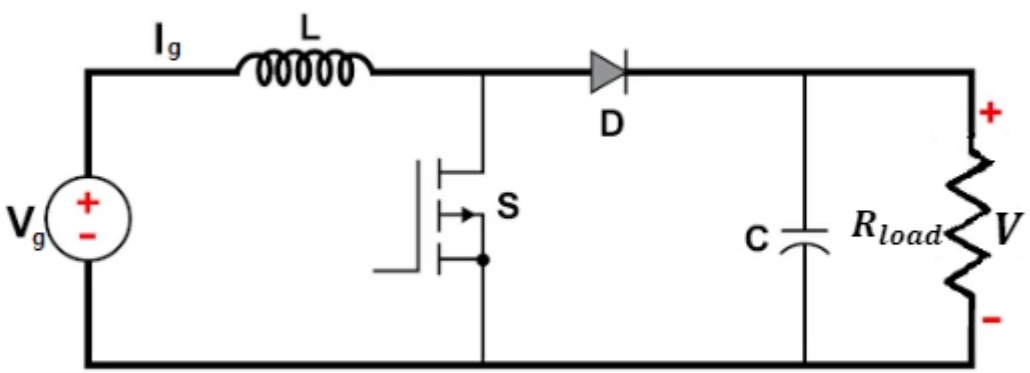
$C = 100[\mu\mathrm{F}]$

$K = \frac{2L}{RT_s}$

Problems

아래 회로가 DCM으로 동작할 때 왼쪽의 조건을 고려하여 문제를 푸시오

1) $K_{crit}(D)$ & 입출력 관계식 V/V_g
2) $D_1 = 0.25$ 일때 출력전압 V 계산
3) 2)의 결과를 PSIM simulation 결과와 비교
4) PSIM simulation으로 인덕터 리플 전류 Δi_L, 평균전류 I, 시간 D_3확인



$I = \frac{V_g}{D'^2 R}$, $\Delta i_L = \frac{V_g}{2L} D T_s$

$\frac{V_g}{D'^2 R} < \frac{V_g}{2L} D T_s$

$\frac{2L}{R T_s} > D'^2 D$ $\quad K = \frac{2L}{R T_s}$

$K_{crit}(D) = D D'^2$

① $v_L(t) = V_g$

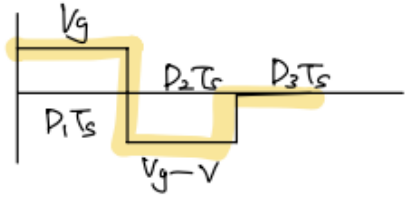
$i_c(t) = \frac{V}{R}$

② $v_L(t) = V_g - V$

$i_c(t) = i(t) - \frac{V}{R}$

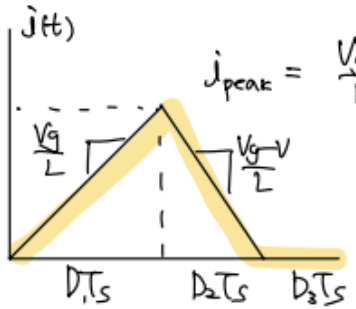
③ $v_L(t) = 0$

$i_c(t) = -\frac{V}{R}$



$D_1 V_g + D_2 (V_g - V) = 0$

$V = \frac{(D_1 + D_2) V_g}{D_2}$



$i_{peak} = \frac{V_g}{L} D_1 T_s$

Average Diode Current

$i_D = \frac{1}{T_s} \int_0^{T_s} i_D(t)\, dt$

$\int_0^{T_s} i_D(t)\, dt = \frac{1}{2} i_{pk} D_2 T_s$

$\langle i_D \rangle = \frac{1}{2} \cdot \frac{V_g}{L} D_1 D_2 T_s$

$\frac{V}{R} = \frac{V_g D_1 D_2 T_s}{2L}$

$D_2 V = D_1 V_g + D_2 V_g$

$D_2 (V - V_g) = D_1 V_g$

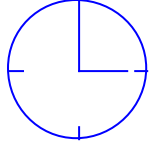
$D_2 = \frac{D_1 V_g}{V - V_g}$

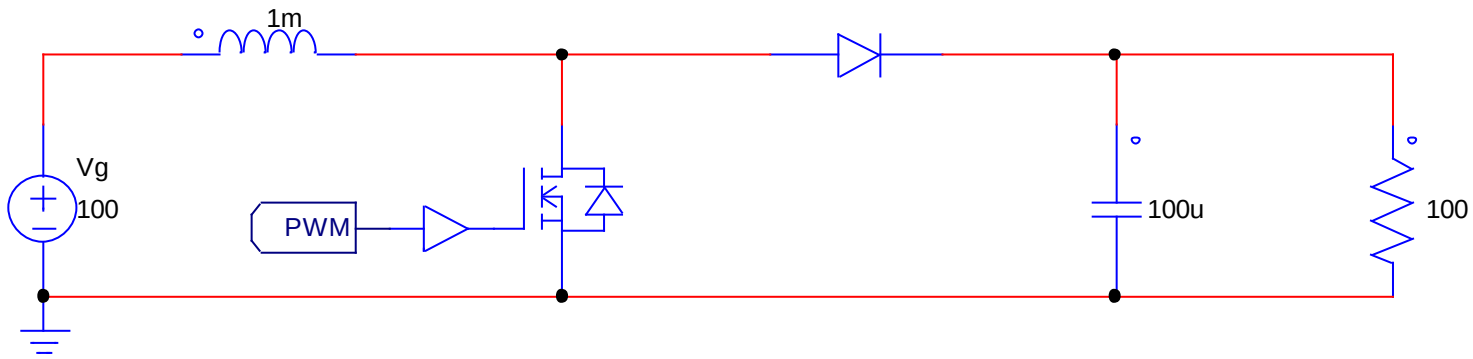
$V^2 - V V_g - \frac{V_g^2 D_1^2}{K} = 0$

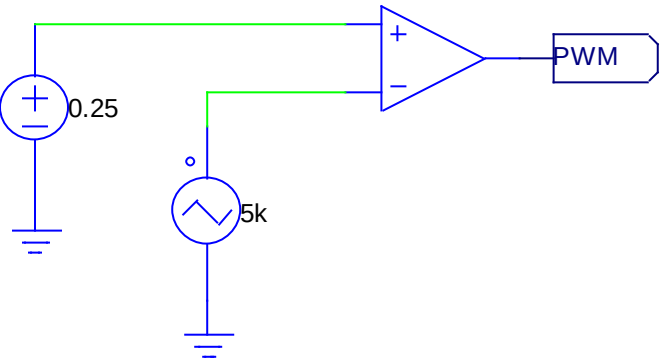
$\frac{V}{V_g} = \frac{1 + \sqrt{1 + 4 D_1^2 / K}}{2}$

$\frac{V}{V_g} = \frac{1 \pm \sqrt{1 + 4 \cdot 0.25^2 / 0.1}}{2} = 1.4354$

$V = 143.5414\,[V]$







Simulation Control

PSIM | SPICE | SimCoder | Color

Solver Type: Fixed-step / Variable-step (dual) — Help

		Time Step Ratio	Smaller Time Step
Time Step	1E-07	4	2.5e-08
Total Time	0.1	Free Run	
Print Time	0		
Print Step	1		
Load Flag	0		
Save Flag	0		

Engine Default Values

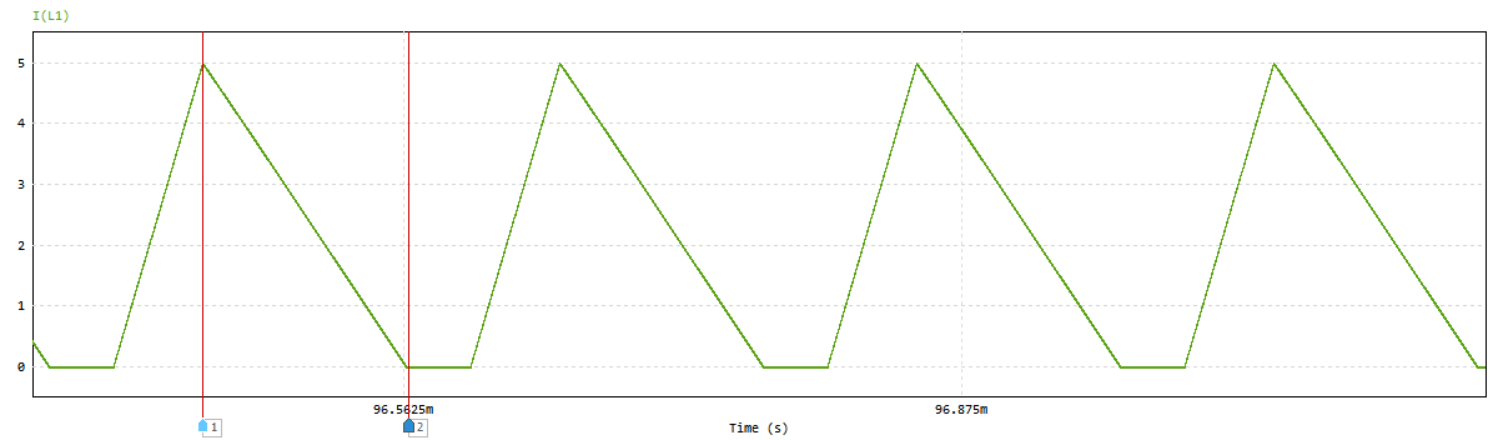
R_switch_on	1E-05
R_switch_off	1E+007

Triangular : VTRI1

Parameters | Color

Triangular-wave voltage source — Help

		Display
Name	VTRI1	
V_peak_to_peak	1	
Frequency	5k	✓
Duty Cycle	1	
DC Offset	0	
Tstart	0	
Phase Delay	0	

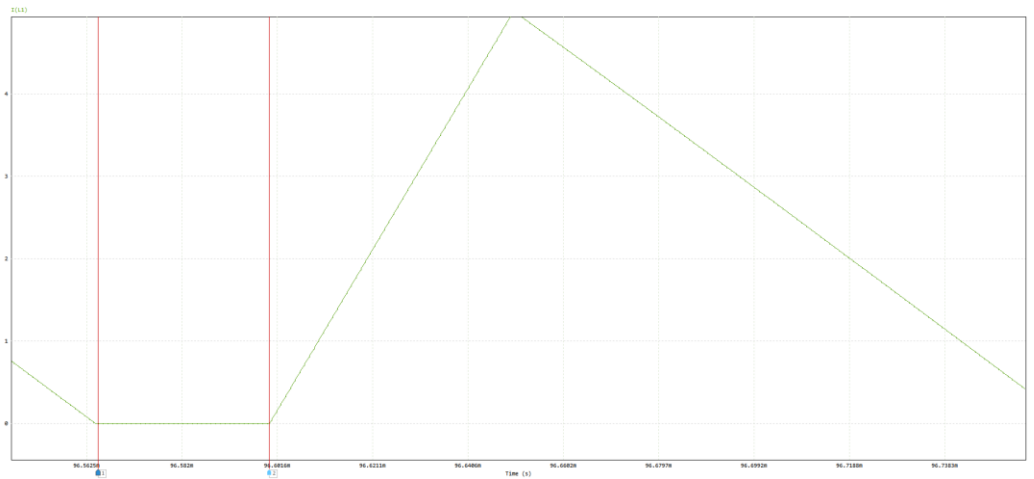


Measure

	X1	X2	Δ	Average
Time	9.64500e-02	9.65658e-02	1.15758e-04	
I(L1)	4.99940e+00	0.00000e+00	-4.99940e+00	2.47899e+00

$$I_L = 1.915[A]$$

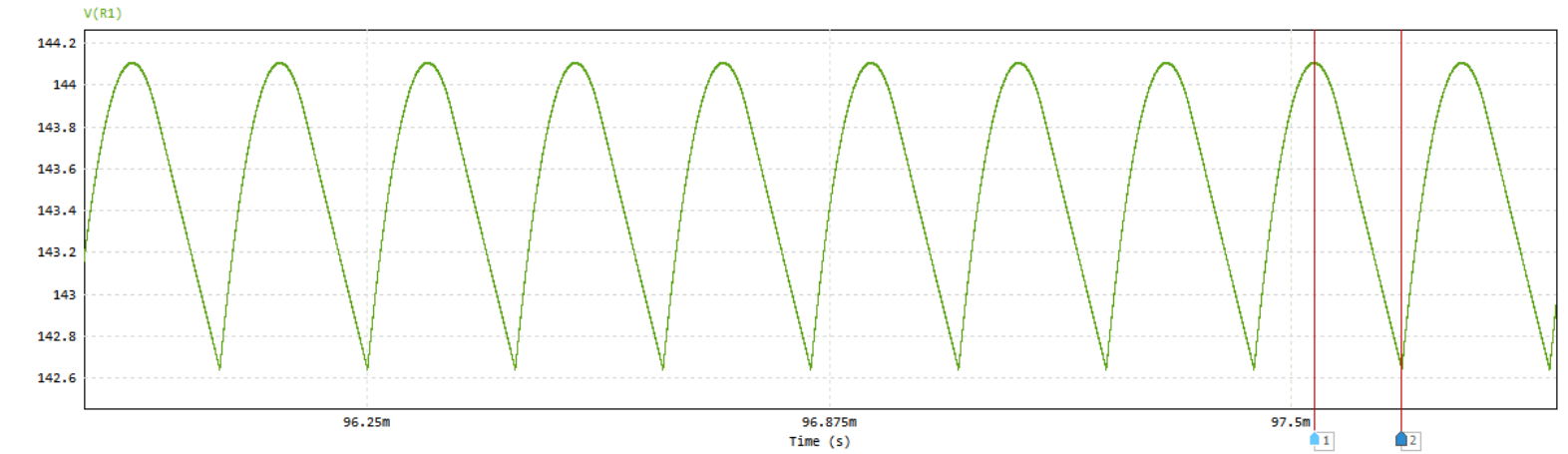
$$\Delta i_L = 5[A]$$



Measure

	X1	X2	Δ	Average
Time	9.65648e-02	9.65999e-02	3.51000e-05	
I(L1)	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00

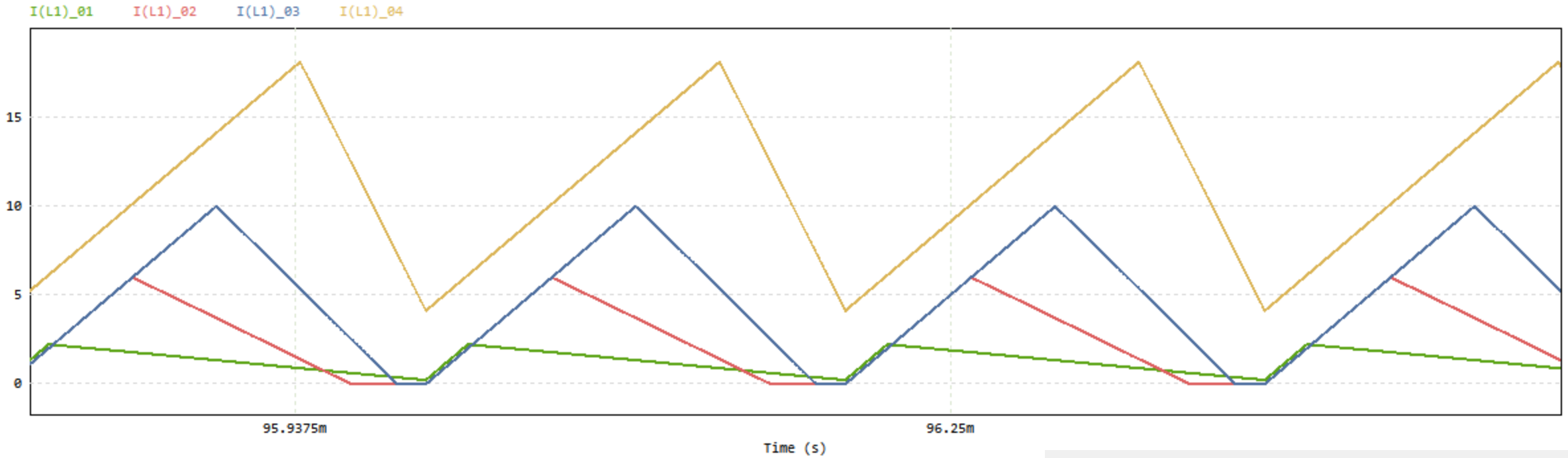
$$D_3 = 0.351[\mu s]$$



Measure

	X1	X2	Δ	Average
Time	9.75316e-02	9.76500e-02	1.18400e-04	
V(R1)	1.44109e+02	1.42645e+02	-1.46345e+00	1.43471e+02

$$V_R = 143.47[V]$$



$I(L_1)01, D = 0.1$로 CCM으로 동작
$I(L_2)02, D = 0.3$로 DCM으로 동작
$I(L_3)03, D = 0.5$로 DCM으로 동작
$I(L_4)014\ D = 0.7$로 CCM으로 동작

왜 boost는 CCM과 DCM이 섞여서 나오는가?

$K = 0.1$을 기준으로 Duty에 따라 CCM으로 동작하다가
DCM으로 동작하다 다시 CCM으로 동작한다.

즉 boost converter는 buck converte와 달리 K_{crit}는 $D(1-D)^2$로
3차 방정식이므로 K값을 기준으로 두 번 바뀌기 때문이다.