BUCK CONVERTER

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목차

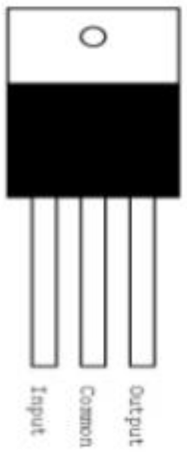
BUCK CONVERTER

* 설계 진행 방향 추가

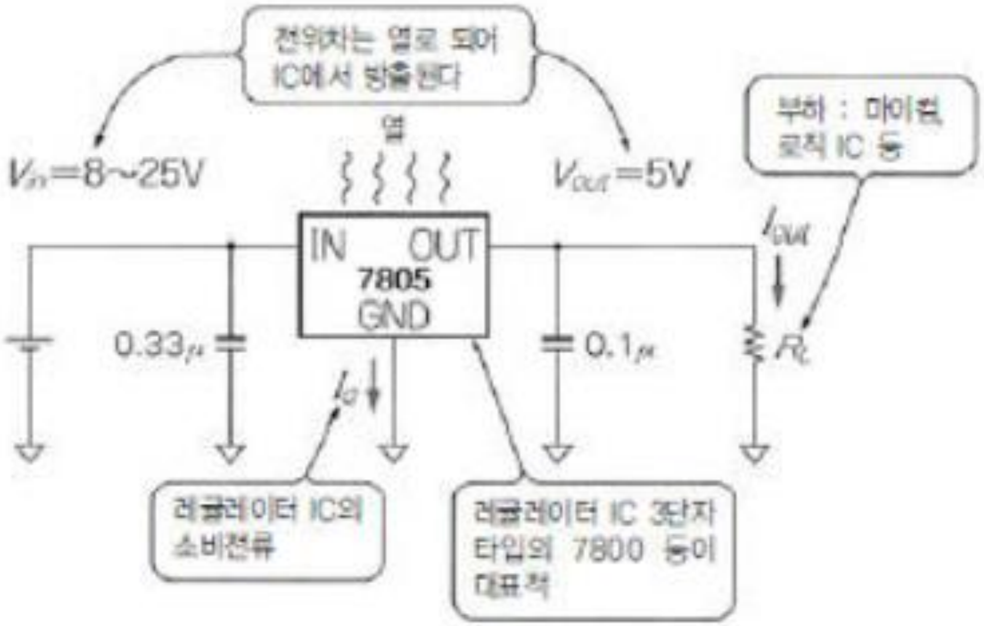
1) BUCK CONVERTER를 쓰는 이유

78XX basic features

IC No	Voltage
7805	5V
7806	6V
7808	8V
7809	9V
7810	10V
7812	12V
7815	15V
7818	18V
7824	24V



- **Features**
- 3 terminal positive voltage regulator with nine voltage options
- High Output Current - typically 1.5A
- Short circuit current limit - 750mA at 5v
- Max input voltage = 35v
- Minimum Input Voltage = V_{out} + 2.5



▲ 그림 1. 시리즈 레귤레이터의 회로 예와 발열

증상 1) 통상적인 회로 동작 시, 시리즈 레귤레이터의 발열이 크다

원인 1-1) 전원 회로의 입출력 전압 차가 커서, 출력전류가 크다

2) 기본 DC/DC 컨버터 SWITCHING 원리 1

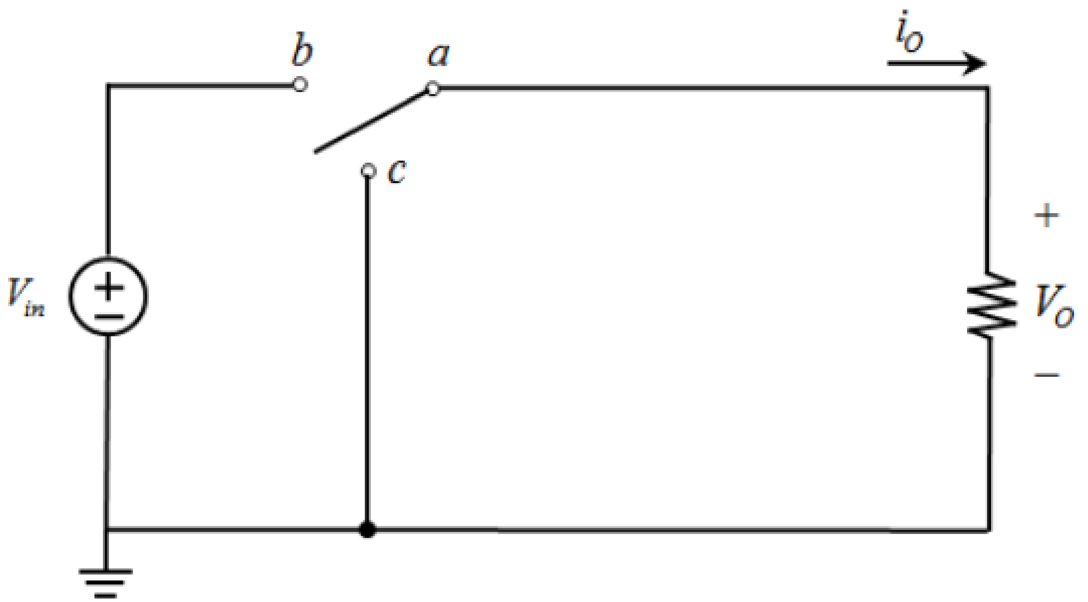


그림 1 : 기본적인 DC/DC 컨버터 회로

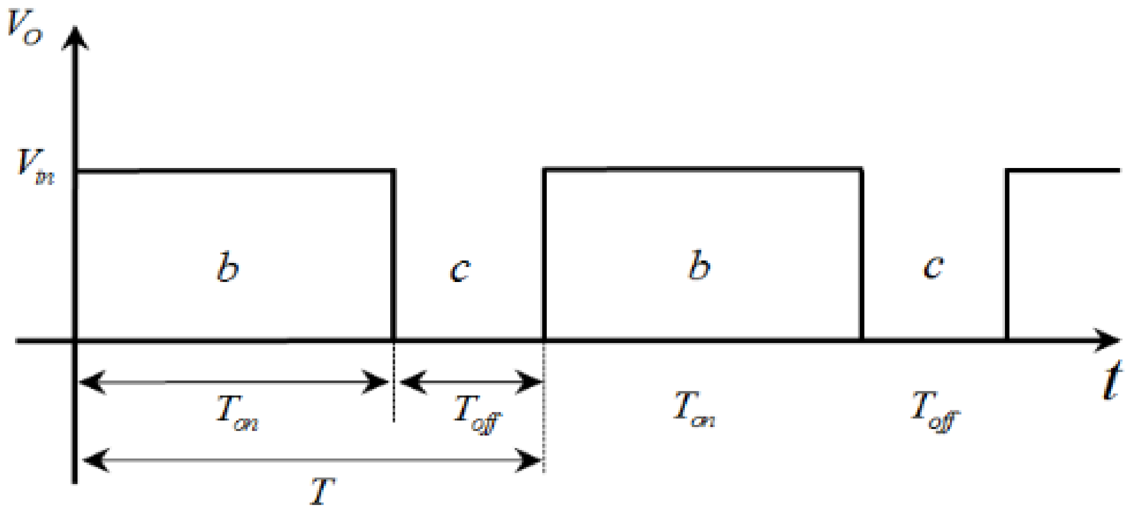


그림 2 : 출력 전압 파형

$$D = \frac{T_{on}}{T}$$

$$T_{on} = DT$$

$$T_{off} = (T - T_{on}) = (1 - D)T$$

$$V_O = \frac{1}{T}(V_{in} \cdot T_{on} + 0 \cdot T_{off}) = V_{in} \cdot \frac{T_{on}}{T} + 0 \cdot \frac{T_{off}}{T}$$

$$= V_{in} \cdot D + 0 \cdot (1 - D)$$

$$= V_{in} \cdot D$$

$$P_O = \frac{1}{T}\left(\frac{V_{in}^2}{R} \cdot T_{on} + 0 \cdot T_{off}\right) = \frac{V_{in}^2}{R} \cdot D$$

2) 기본 DC/DC 컨버터 SWITCHING 원리 2

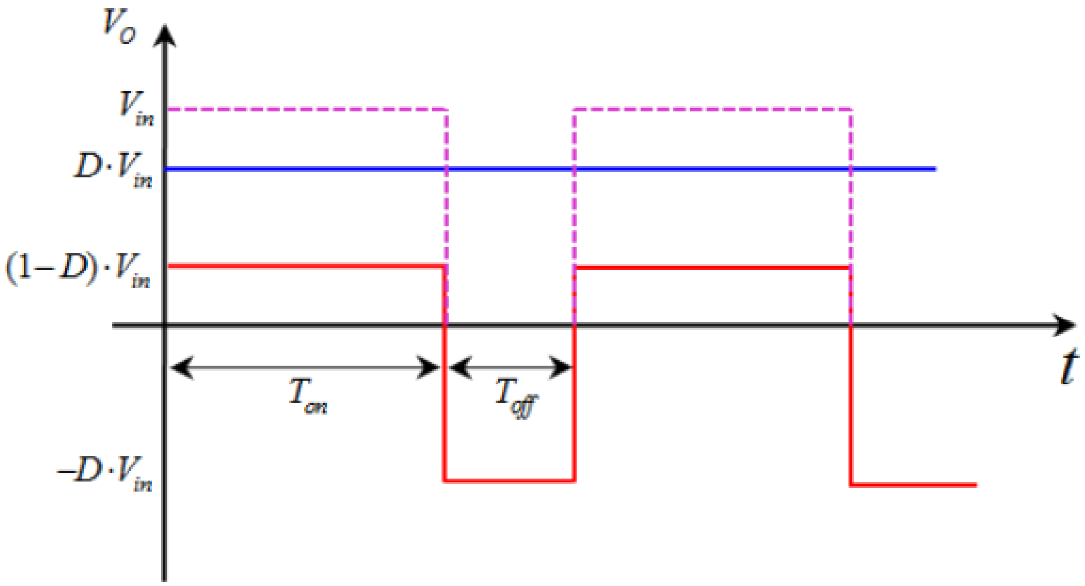


그림 3 : 출력 전압 파형의 직/교류 성분

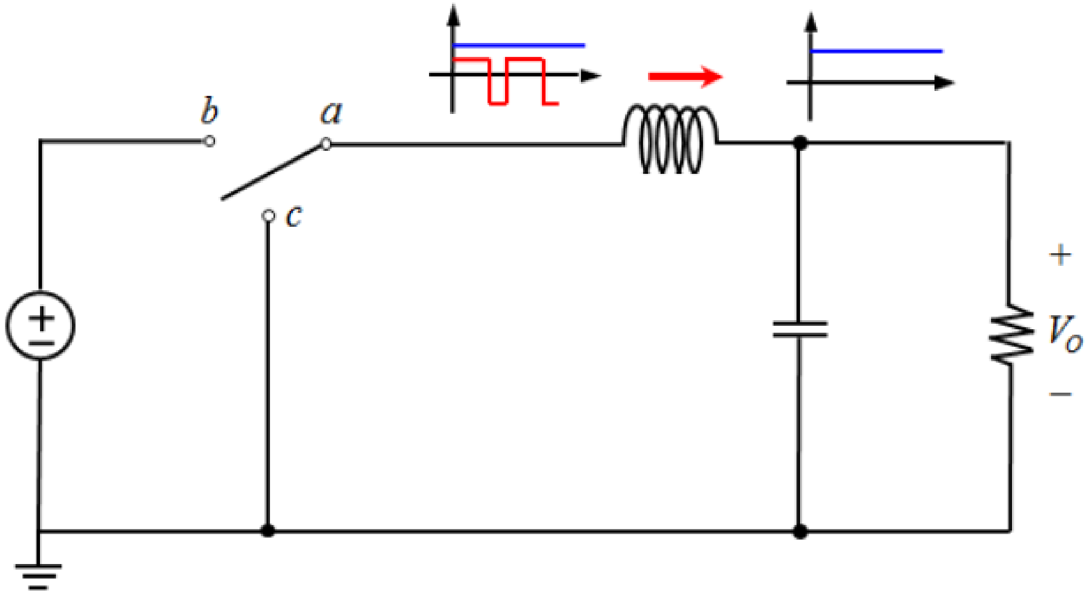
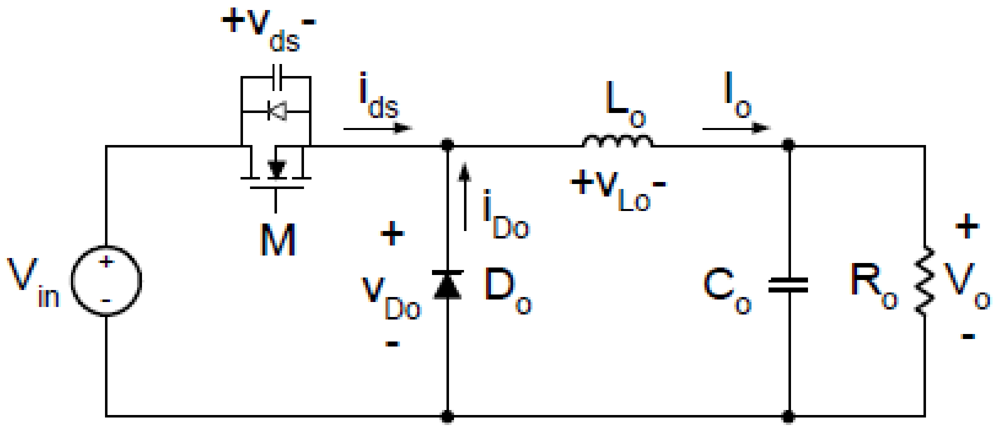


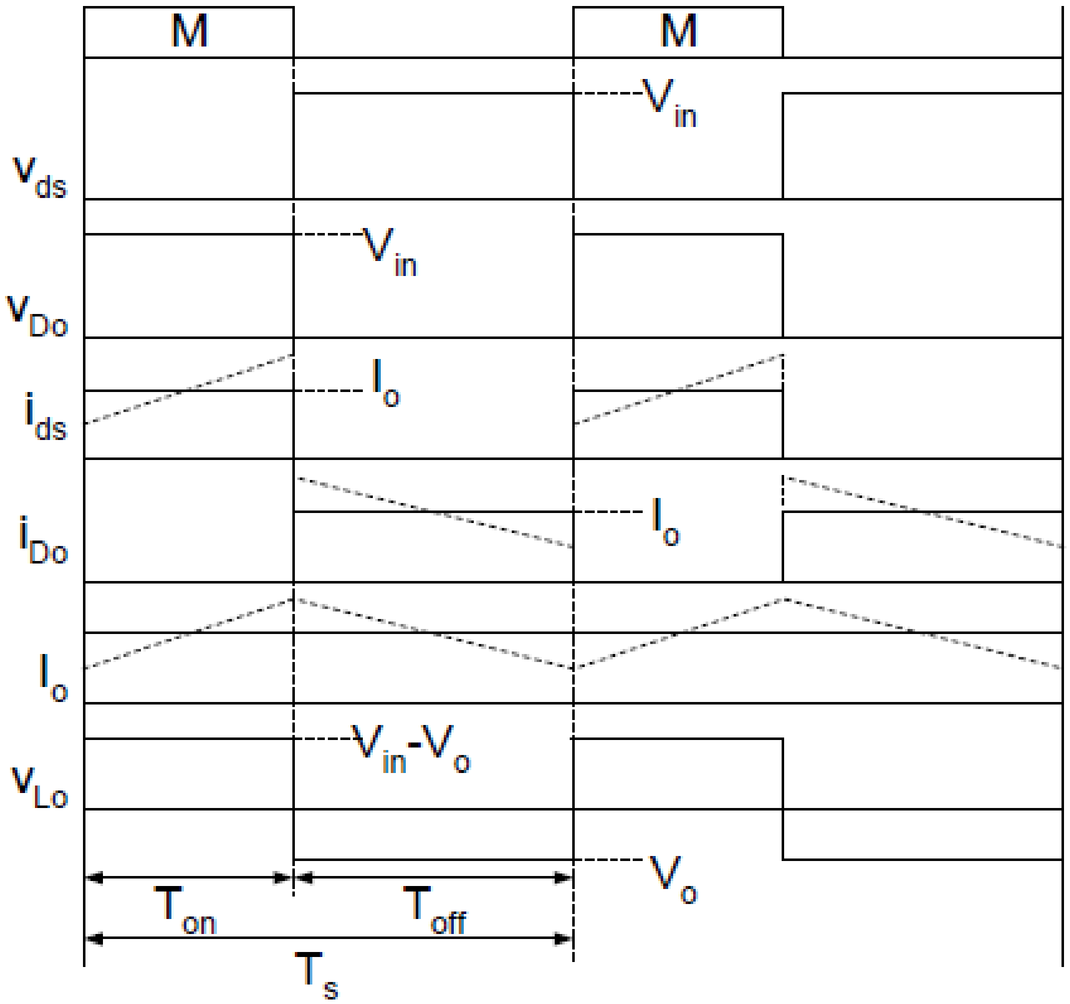
그림 4 : LC 필터를 추가한 기본적인 DC/DC 컨버터 회로

$$G_V = \frac{V_o}{V_i} = \frac{D \cdot V_i}{V_i} = D$$

3) BUCK CONVERTER 개념 1

- Assumptions
  - V_o: constant
  - I_o: constant ($=V_o/R_o$)



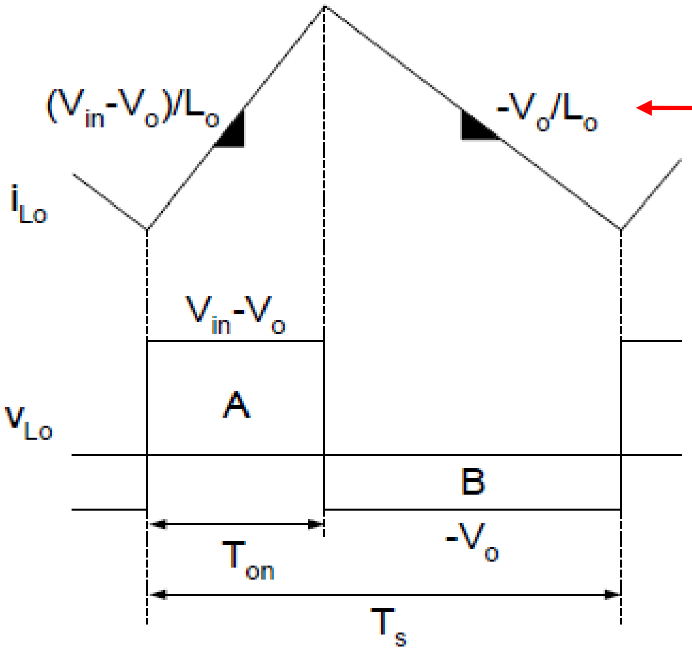


- Mode 1 (during DT_s) powering
- Mode 2(during $(1\text{-}D)T_s$) freewheeling

3) BUCK CONVERTER 개념 2

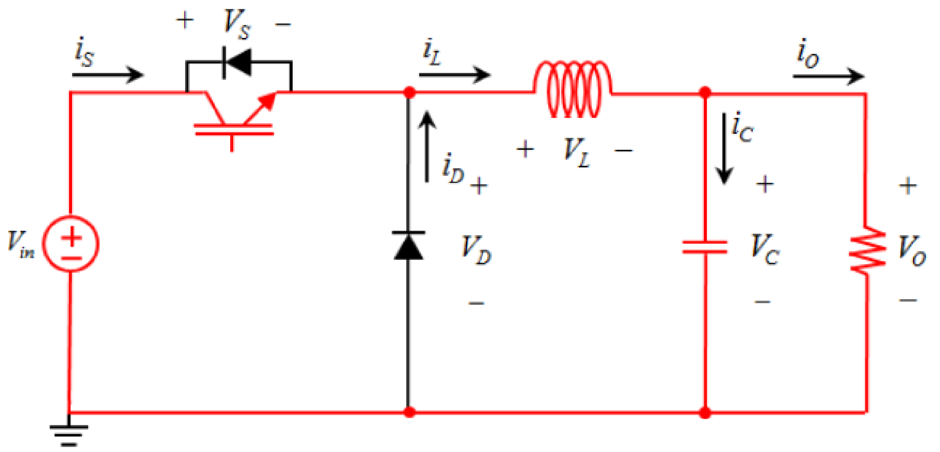
- Voltage-second balance
  - At steady state,
    - Rising amplitude=Falling amplitude: $\frac{V_{in} - V_o}{L_o} T_{on} = \frac{V_o}{L_o}(T_s - T_{on})$
    - Area of A=Area of B: $(V_{in} - V_o) T_{on} = V_o (T_s - T_{on})$ **Voltage-second balance**
    - Voltage conversion ratio: $V_o = DV_{in} \le V_{in}$
    - **<u>Average voltage across the inductor = 0</u>**

$$i_L = \frac{1}{L}\int (V_i - V_o)\,dt$$

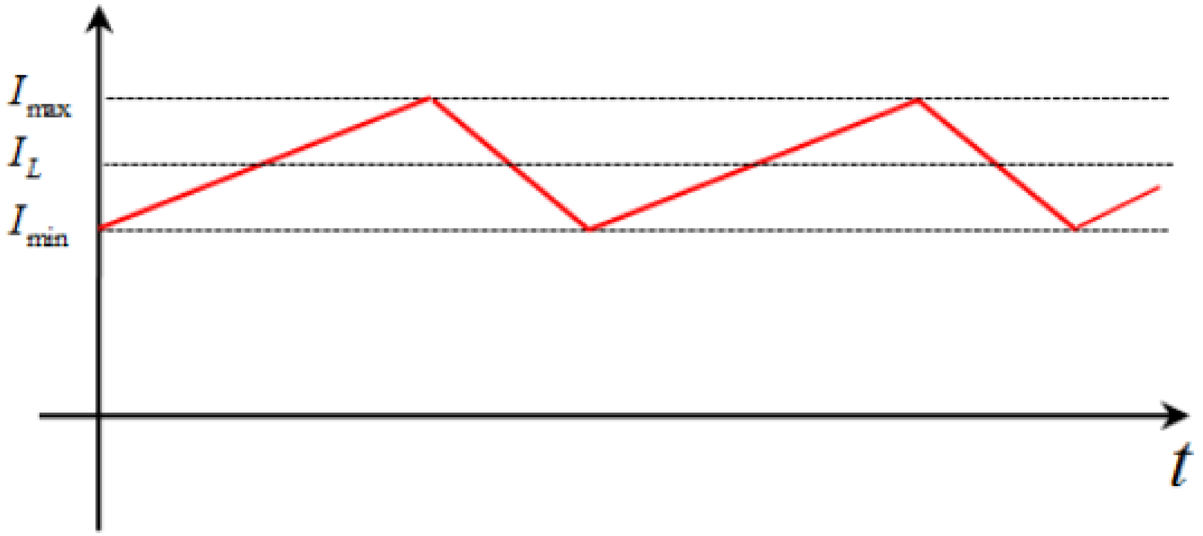


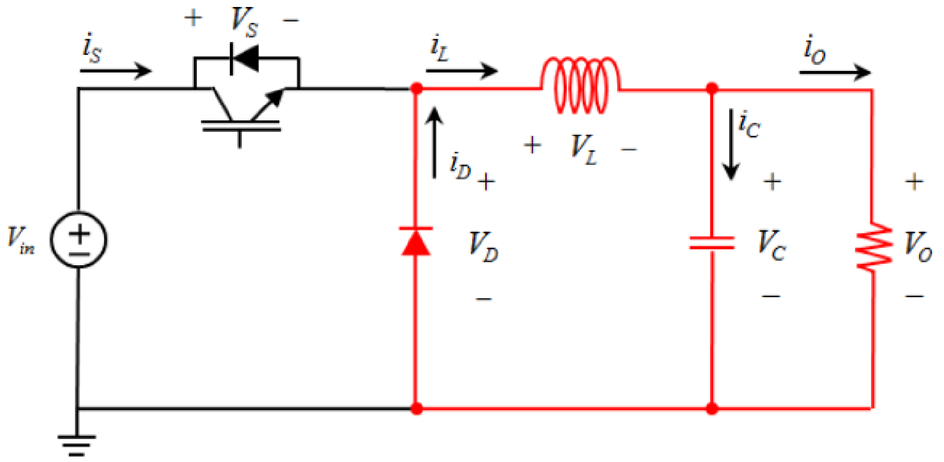
$$i_L = \frac{1}{L}\int (0 - V_o)\,dt$$

3) BUCK CONVERTER 개념 3



a) SW/ON 상태의 전류 Path





b) SW/OFF 상태의 전류 Path
그림 6 : Swith 상태에 따른 전류의 흐름

$$i_L = i_C + i_O$$

$I_L = I_O$ DC 성분 -> ic = 0

$$v_L = L\frac{di_L}{dt}$$

$$\frac{di_L}{dt} = \frac{V_i - V_o}{L}$$

$$\Delta i_L = \frac{V_i - V_o}{L} \cdot T_{on}$$

$$i_{max} = I_L + \frac{1}{2}\cdot \Delta i_L = I_L + \frac{V_i - V_o}{2L}\cdot DT$$

$$= I_L + \frac{V_i - V_i D}{2L}\cdot DT = I_L + \frac{V_i}{\boxed{2L}}\cdot(1-\boxed{D})\cdot DT$$

$$i_{Min} = I_L - \frac{1}{2}\cdot \Delta i_L = I_L - \frac{V_i - \boxed{V_o}}{2L}\cdot DT$$

$$= I_L - \frac{V_i - V_i D}{2L}\cdot DT = I_L - \frac{V_i}{\boxed{2L}}\cdot(1-\boxed{D})\cdot DT$$

3) BUCK CONVERTER 개념 4

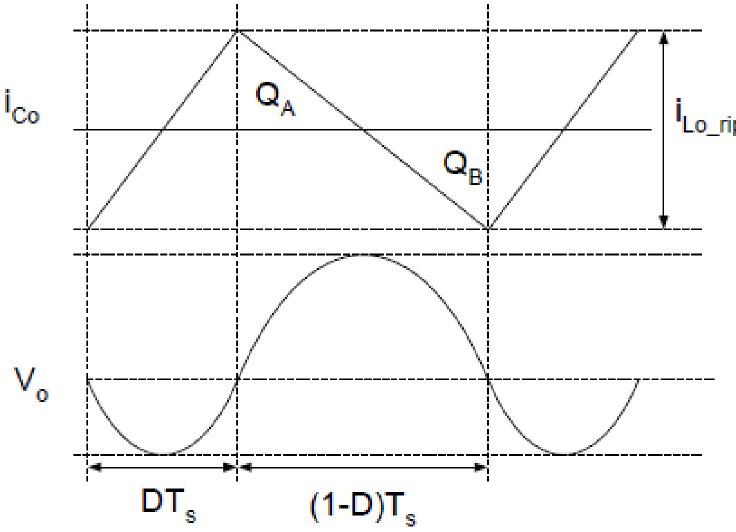
- Output Voltage Ripple **(ignoring the effect of capacitor ESR)**
  - Area of Q_A(charging Charge)=Area of Q_B(discharging charge)
  - Charge=current x time

$$Q_A = Q_B = \Delta Q = C_o \Delta V_o$$

$$V_{o\_ripple} = \Delta V_o = \frac{\Delta Q}{C_o} = \frac{1}{C_o}\left(\frac{1}{2}\frac{T_s}{2}\frac{i_{Lo\_ripple}}{2}\right) = \frac{1}{C_o}\left(\frac{1}{2}\frac{T_s}{2}\frac{1}{2}\frac{V_o}{L_o}(1-D)T_s\right)$$

$$= \frac{T_s^2}{8L_oC_o}V_o(1-D)$$

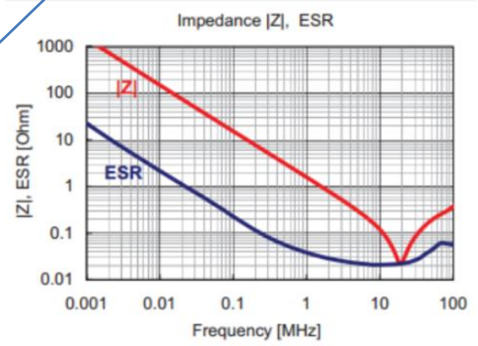
$$\text{Voltage Ripple Ratio (ROV)} = \frac{V_{o\_ripple}}{V_o}100[\%]$$



$i_{Lo\_ripple} = DT_s(V_{in}\text{-}V_o)/L_o$
$= (1\text{-}D)T_sV_o/L_o$

$$Z = \sqrt{ESR^2 + (X_C + (-X_L))^2}$$

100nF 혹은 104 라고 부르는 콘덴서의 ESR 그래프

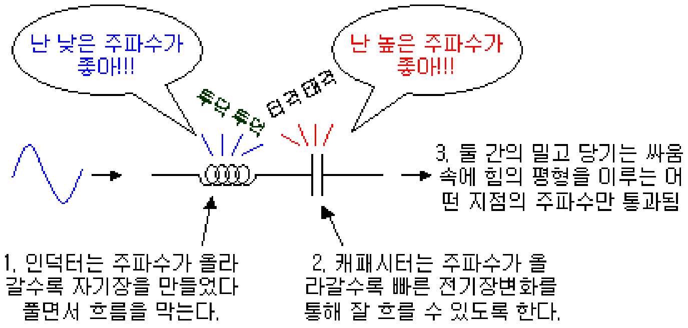


-Practically, output voltage ripple is determined mainly by ESR

$$\Delta V_o = \frac{T_s^2}{8L_oC_o}V_o(1-D) + R_{esr}\, i_{Lo\_ripple}$$

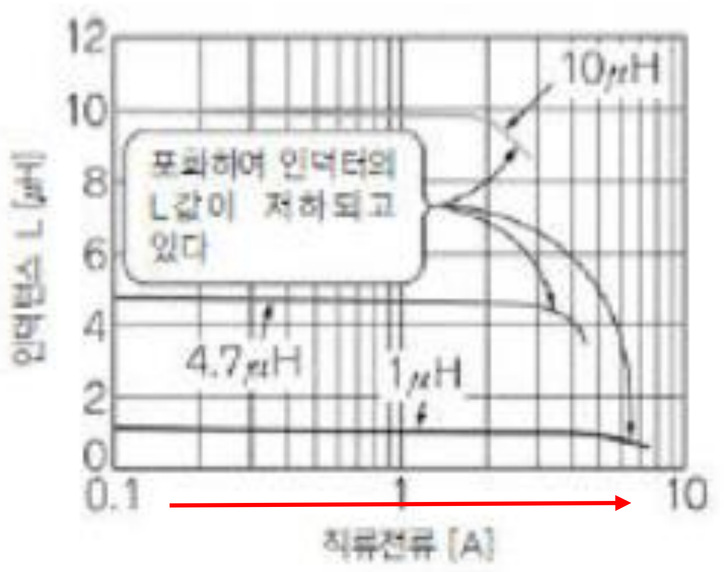
ESR : Equivalent Series Resistance

4) BUCK CONVERTER 설계 시 주의사항 1 (전류 리플 설계 시)



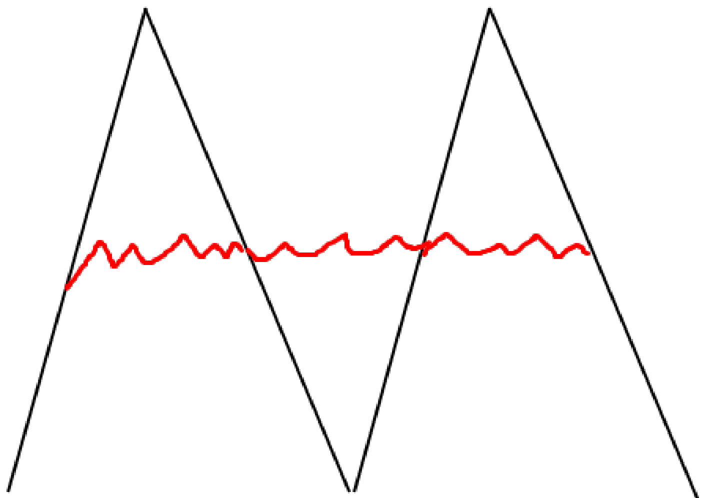
i(ripple)을 줄이기 위한 방법

1) L값 증가 2) 주파수 증가



전류량을 증가시키면 어느 순간 과포화하여 L값 급격하게 저하.

▲ 그림 5. 인덕터의 직류 중첩 특성 예



주파수 높일 시 문제점

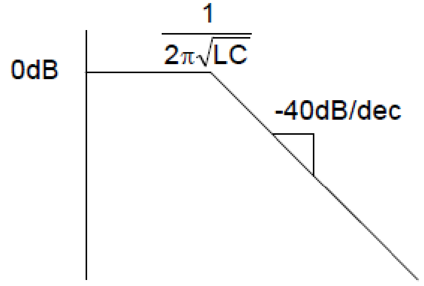
$$Z = R + jX = R + j\omega L + \frac{1}{j\omega C}$$

이중에서 허수임피던스가 0이 되어 없어지는 주파수가 공진주파수입니다.

$$X = \omega L - \frac{1}{\omega C} = 2\pi f L - \frac{1}{2\pi f C} = 0$$

이 식을 뒤집어서 f를 구하면 아래와 같이 공진주파수가 정해집니다.

$$resonance frequency = \frac{1}{2\pi\sqrt{LC}}$$



L=1mH, C=1mF

f_c=159Hz

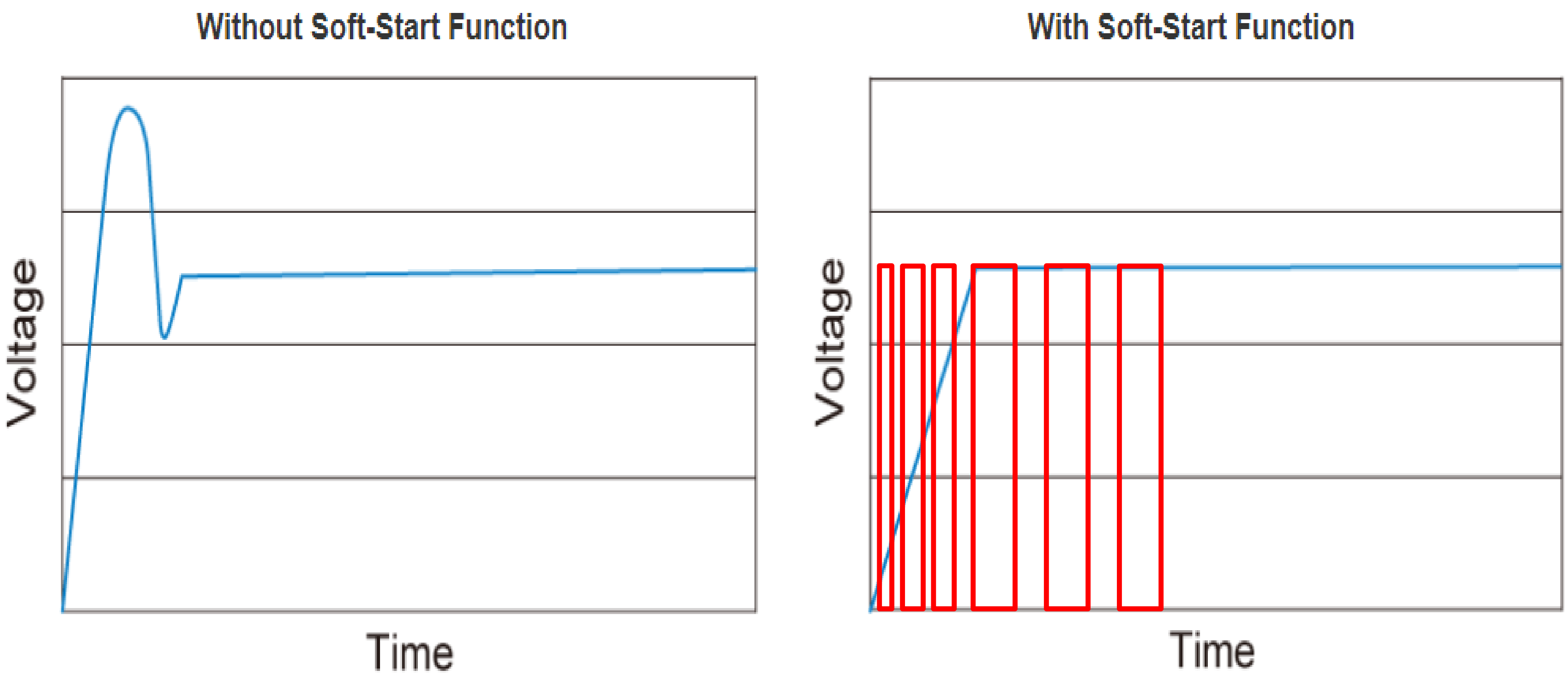
증상 3) 인덕터의 발열이 크다

원인 3) 인덕터가 과포화를 일으켜 에너지를 모을 수 없게 되었다

4) BUCK CONVERTER 설계 시 주의사항 2 (IC 선정 또는 PWM 설계 시)

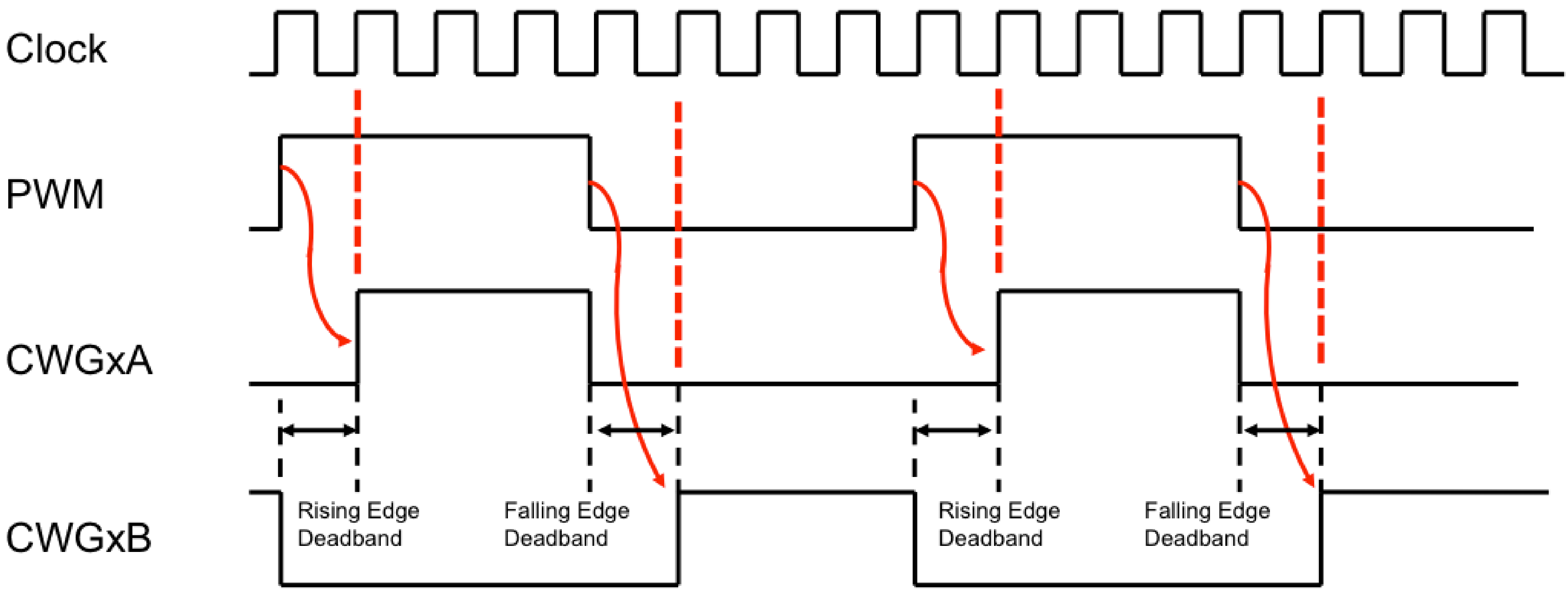
Soft start에 필요성

DCDC Converters (Switching Regulators)



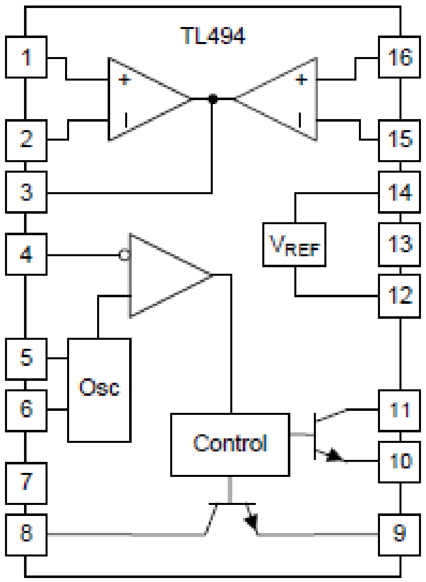
4) BUCK CONVERTER 설계 시 주의사항 3 (IR2110 사용 또는 PWM 설계 시)

PWM Dead-Band



5) TL494 동작원리 이해 1

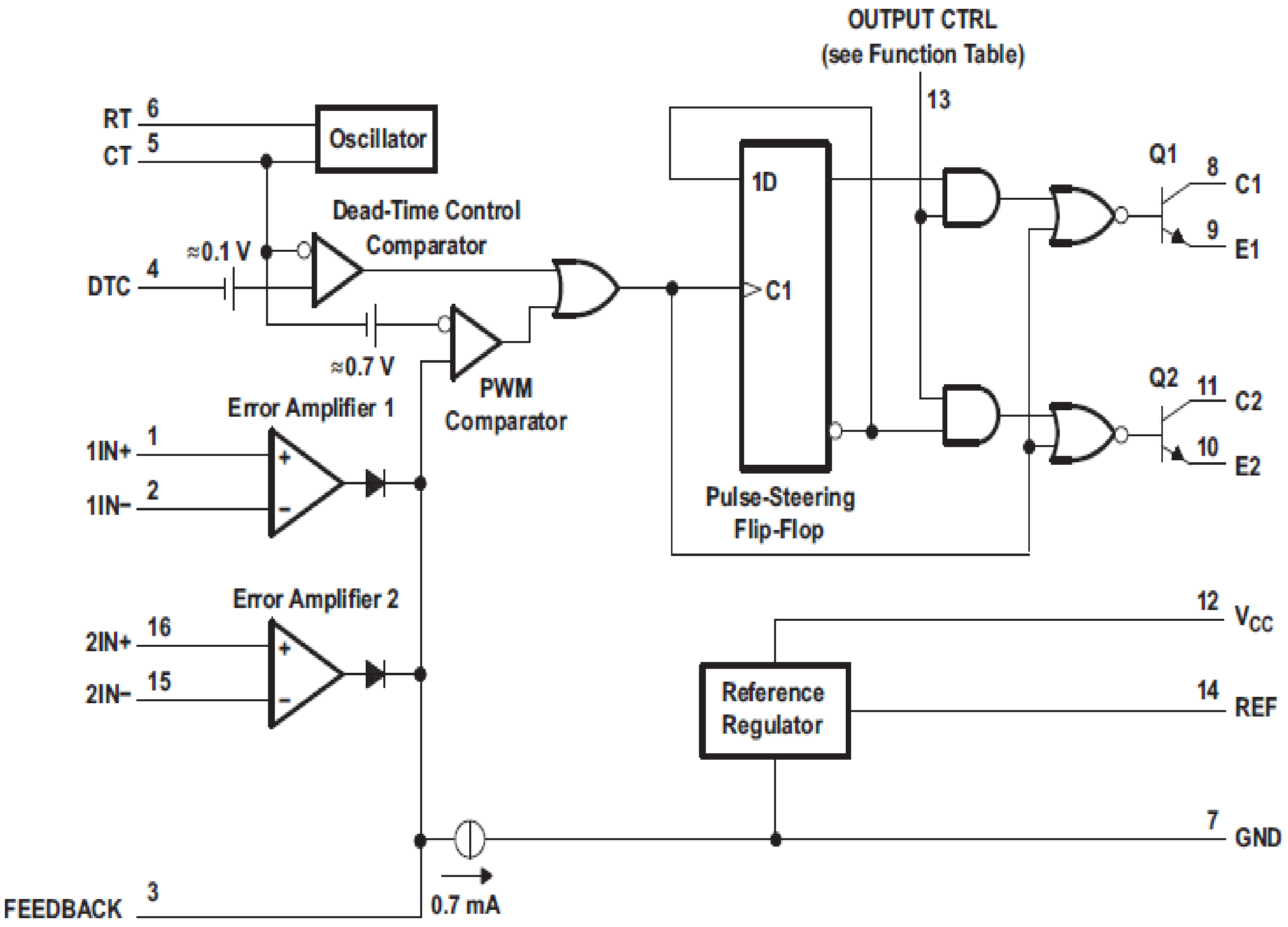
4 Simplified Block Diagram



Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
1IN+	1	I	Noninverting input to error amplifier 1
1IN-	2	I	Inverting input to error amplifier 1
2IN+	16	I	Noninverting input to error amplifier 2
2IN-	15	I	Inverting input to error amplifier 2
C1	8	O	Collector terminal of BJT output 1
C2	11	O	Collector terminal of BJT output 2
CT	5	—	Capacitor terminal used to set oscillator frequency
DTC	4	I	Dead-time control comparator input
E1	9	O	Emitter terminal of BJT output 1
E2	10	O	Emitter terminal of BJT output 2
FEEDBACK	3	I	Input pin for feedback
GND	7	—	Ground
OUTPUT CTRL	13	I	Selects single-ended/parallel output or push-pull operation
REF	14	O	5-V reference regulator output
RT	6	—	Resistor terminal used to set oscillator frequency
V_{CC}	12	—	Positive Supply

9.2 Functional Block Diagram



5) TL494 동작원리 이해 2

10.2 Typical Application

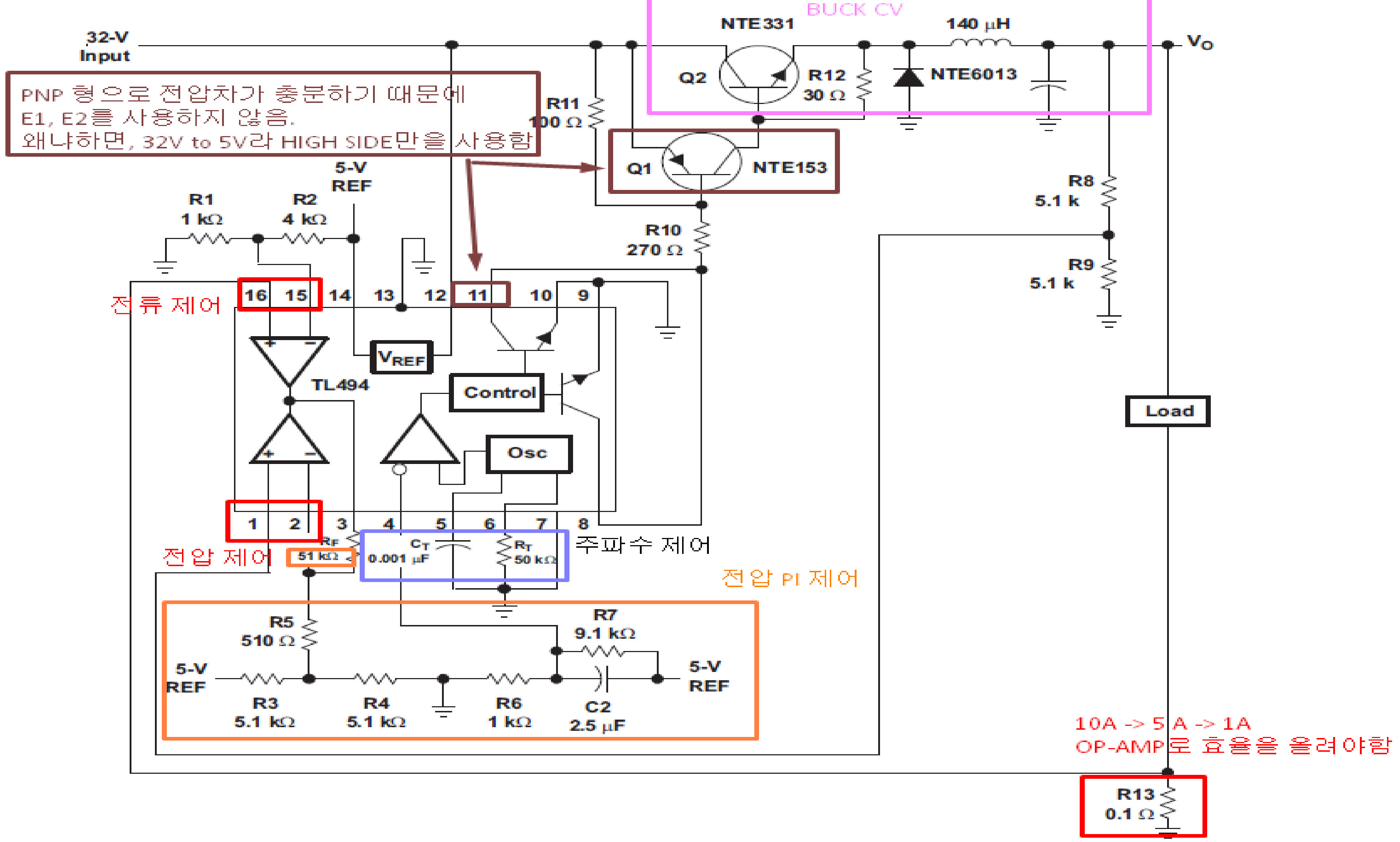
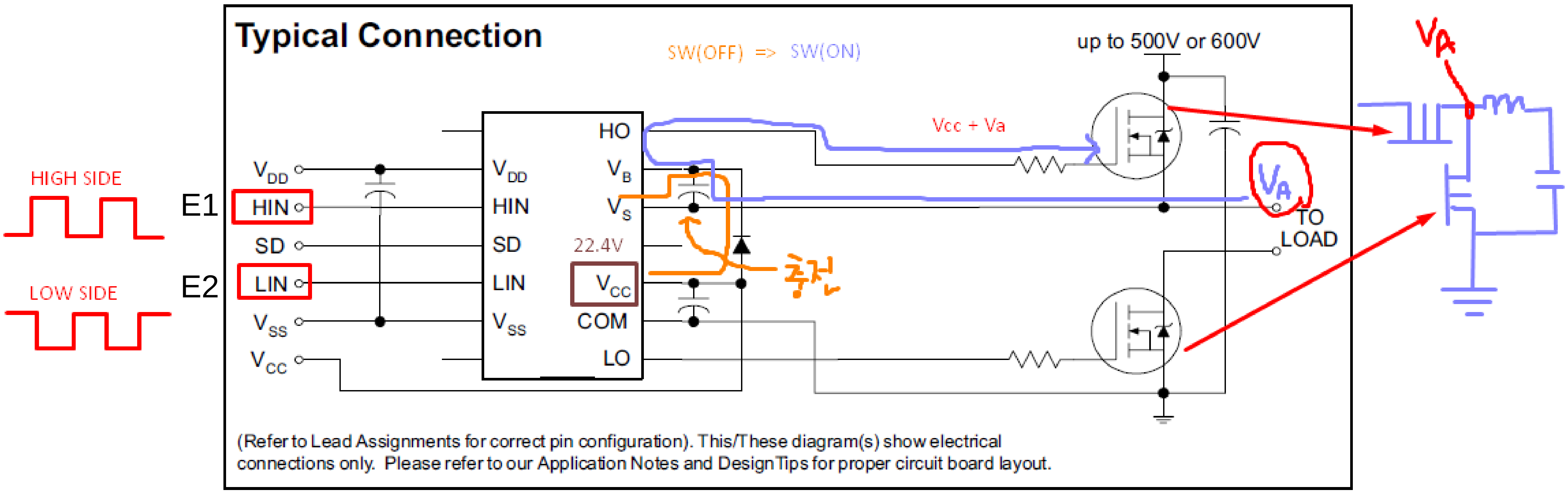


Figure 9. Switching and Control Sections

6) IR2110 작동원리 이해



7) BUCK SIMULATION 1

- Specifications
  - V_{in}:24V
  - V_o=5V (output voltage ripple (ROV) V_{o_ripple}/V_o=+-2%)
  - I_o=10A (Ripple ratio (ROA) =20%)
  - Switching frequency fsw=50kHz(=20usec)

1. Determining Max Duty Ratio
   - From $V_o=DV_{in}$, D=5/24=0.2083

2. Determining L_o:
   - $i_{Lo\_ripple}= I_o \cdot ROA \rightarrow I_{o\_ripple}= I_o \cdot 0.2 = 2(A)$
   - $(1\text{-}D)T_sV_o/L_o= I_{o\_ripple} \rightarrow L_o= (1\text{-} 0.2083)x20x10^{-6}x5/2=39.58(uH)$

3. Determining C_o:
   - From spec., $V_{o\_ripple}=V_ox4\% \rightarrow V_{o\_ripple}=5x0.04=0.2(V)$
   - From $V_{o\_ripple} = \dfrac{T_s^2}{8L_oC_o}V_o(1-D)$, $C_o = \dfrac{T_s^2}{8L_oV_{o\_ripple}}V_o(1-D)$
   - $C_o=(20x10^{-6})^2x(24x\ 0.2083^{2}\text{-}2x5x\ 0.2083 +5)/(8x39.58x10^{-6}x0.2)=25(uF)$

Practically, V_{o_ripple} is determined mainly by $i_{Lo\_ripple} \cdot R_{esr}$
To reduce the V_{o_ripple}, C_o must be parallel connected with several number of capacitors

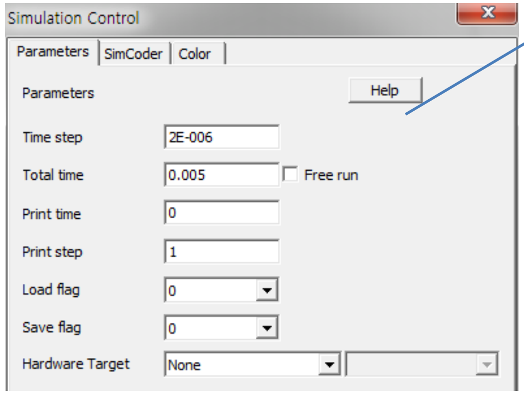
4. Calculating voltage and current stresses of Semiconductors
   - MOSFET switch:
     1. Voltage stress: 24(V)
     2. Current stress: $I_o+0.5I_{o\_ripple}$=10+1=11(A)
   - Diode:
     1. Voltage stress: 24(V)
     2. Current stress:$I_o+0.5I_{o\_ripple}$=10+1=11(A)

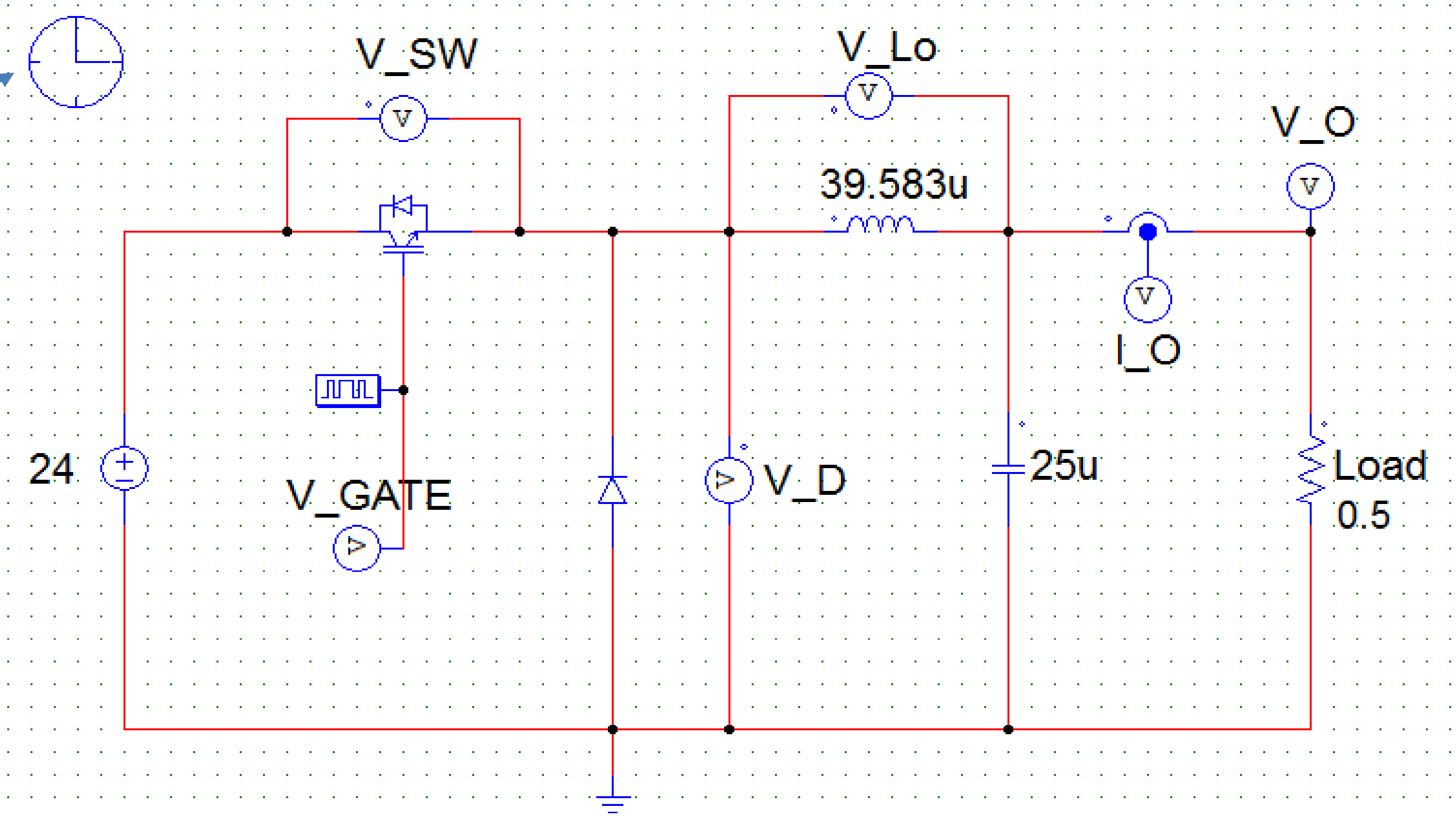
5. Selecting MOSFET and Diode
   - Voltage ratings of MOSFET and Diode: **50~100% Margin**
     1. Voltage rating: (max voltage stress)x2 → over 48(V)
   - Current ratings of MOSFET and Diode: **100% Margin**
     1. Current rating: (max current stress)x2 → over 22 (A)

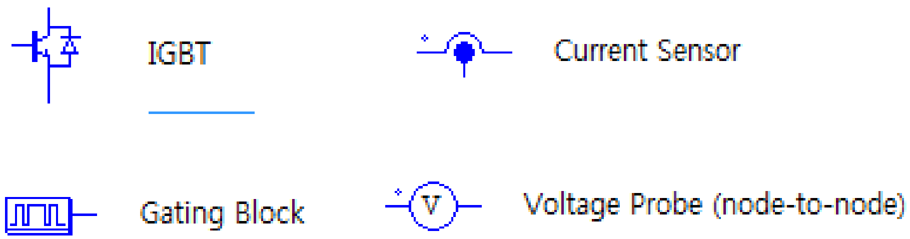
→ MOSFET: STD30NF06 (60V, 28A, Coss=290pF, Rds=0.02ohm)
→ Diode: MBR3050PT (50V, 30A, VF=0.75V)

- Related Web site:
  1. www.irf.com
  2. www.fairchildsemi.com
  3. www.st.com
  4. www.alldatasheet.com

7) BUCK SIMULATION 2

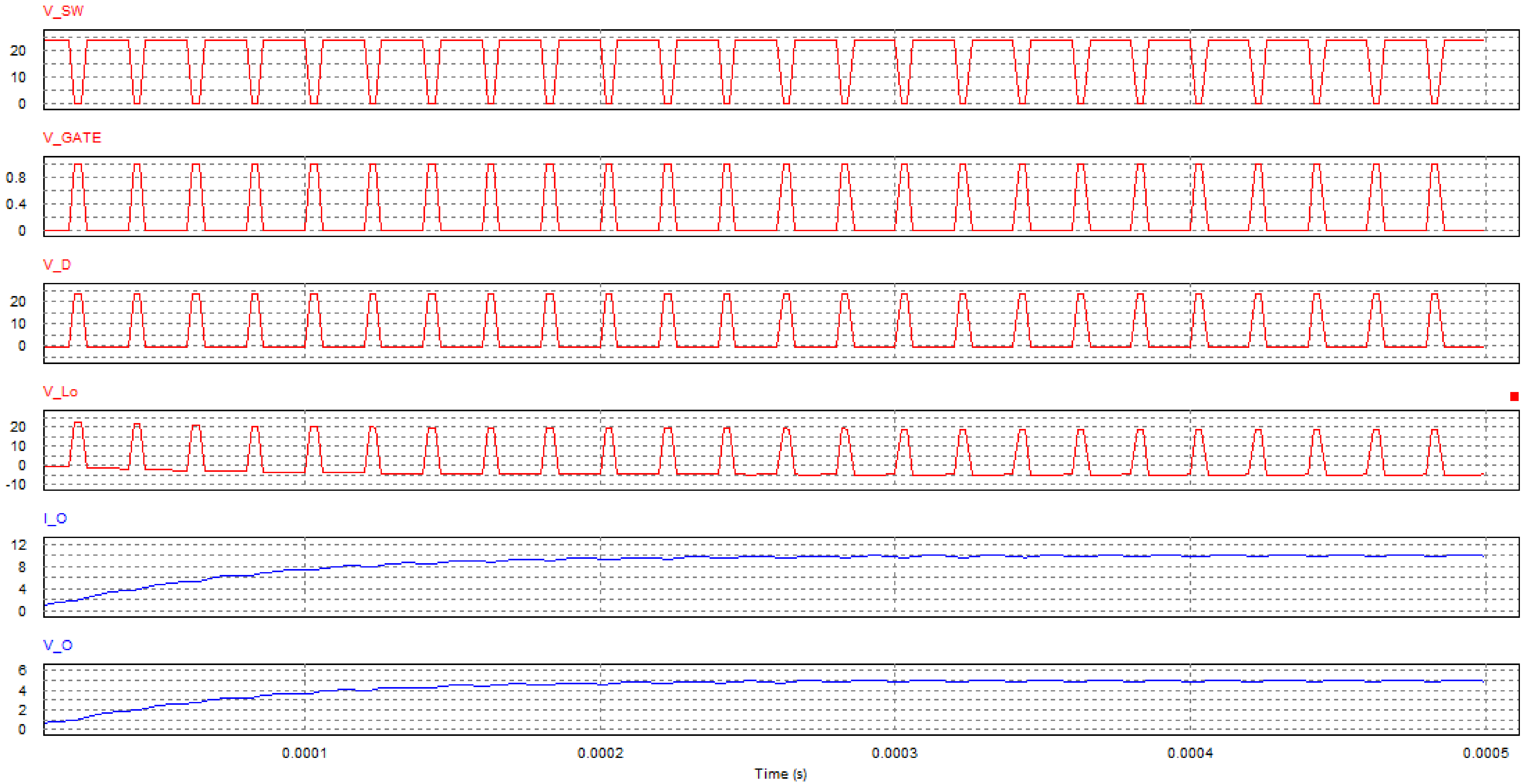






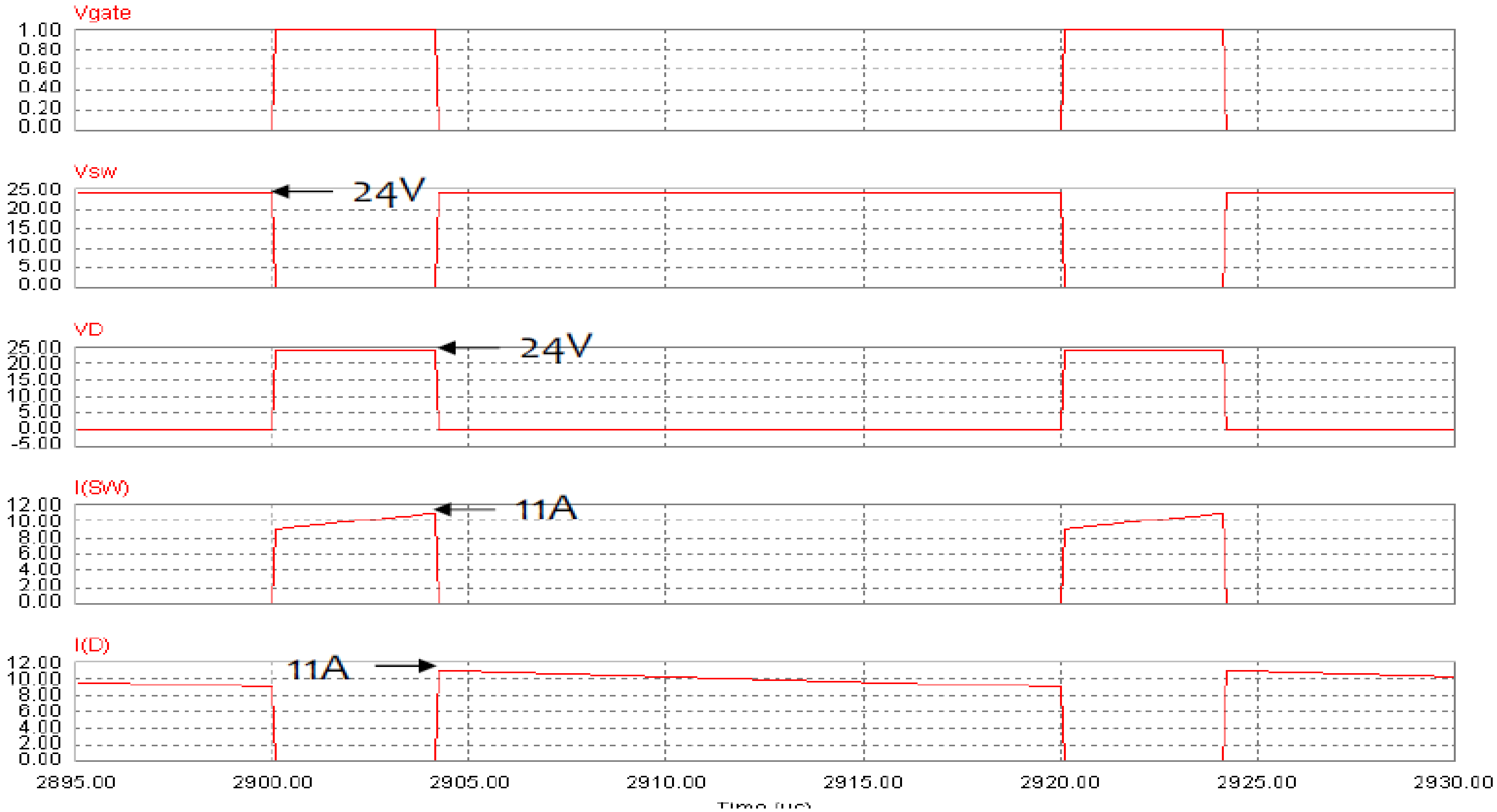
- Specifications
  - V_{in}:24V
  - V_o=5V (output voltage ripple (ROV) V_{o_ripple}/V_o=+-2%)
  - I_o=10A (Ripple ratio (ROA) = 20%)
  - Switching frequency fsw=50kHz(=20usec)
  - L_o=39.583uH
  - C_o=25uF

7) BUCK SIMULATION 3



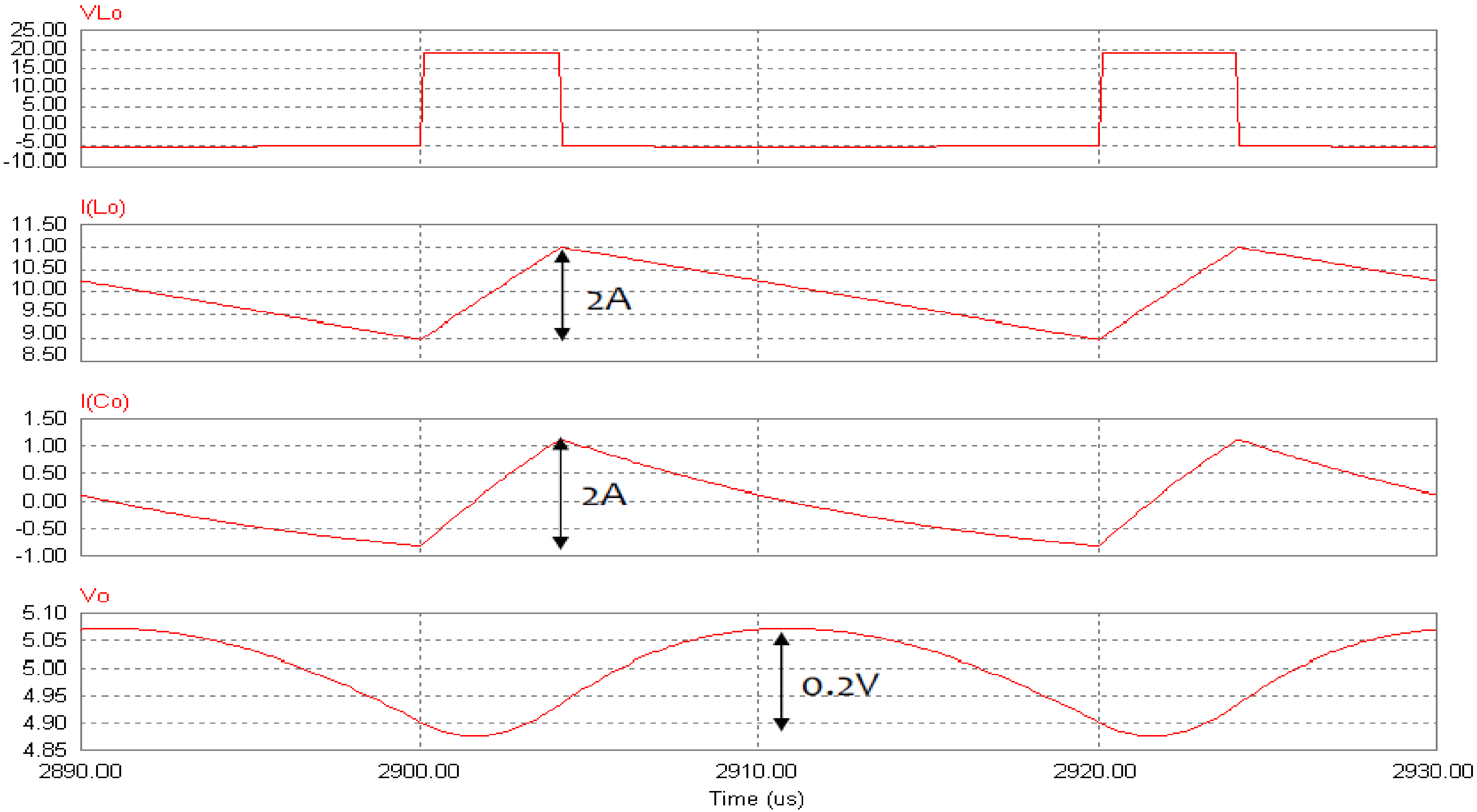
7) BUCK SIMULATION 3

- Gate signal, v_{ds}, v_D, i_{ds}, i_D



7) BUCK SIMULATION 4

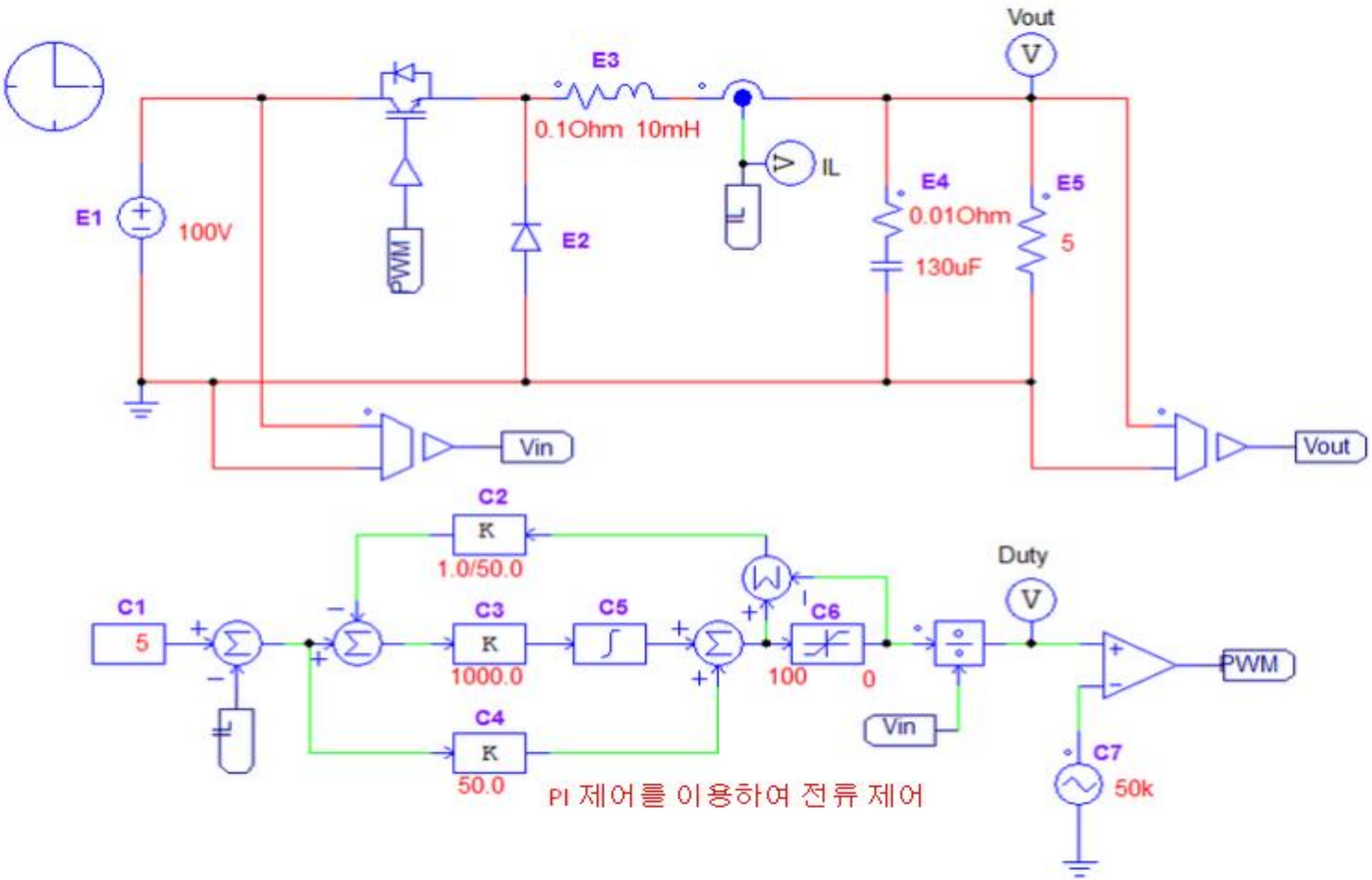
- v_{Lo}, i_{Lo}, i_{co}, v_o



7) BUCK SIMULATION 5

- 10% load

7) BUCK SIMULATION 6 (제어 공학을 개념을 추가하면 PID 제어까지 가능)



* 설계 진행 방향

1. DC – DC 컨버터 SPEC 작성, L, C 값, SWITCH 선정

2. TL494(H/W) 또는 MCU(S/W) 제어기 설계

3. 실제 구동 회로 설계 (소자 FIX)