Power Electronics
No. 6: Step-up, Step-up/down choppers

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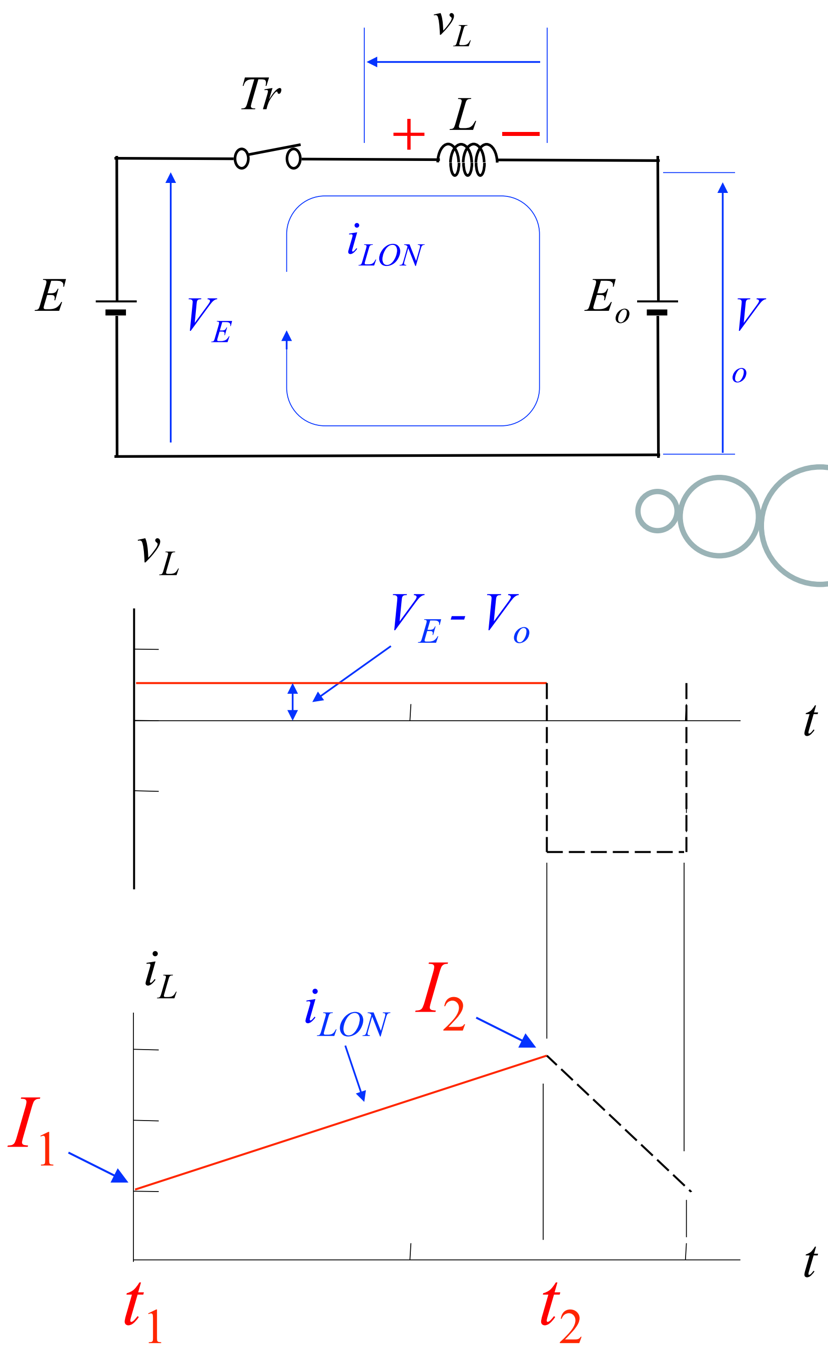
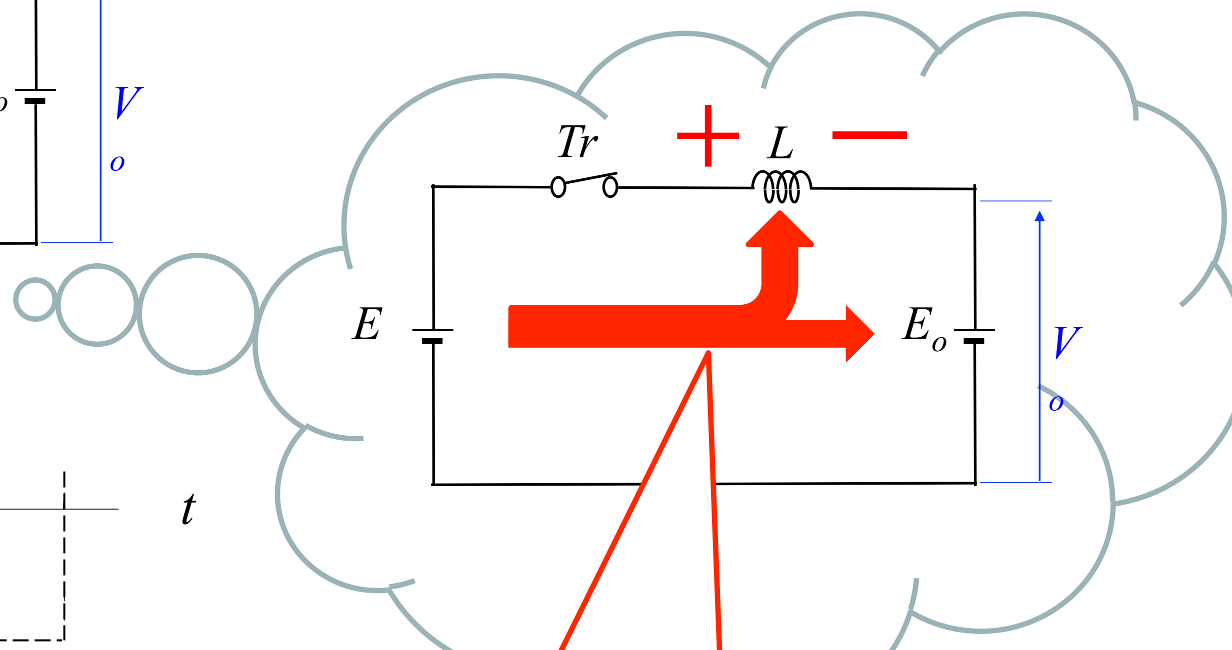
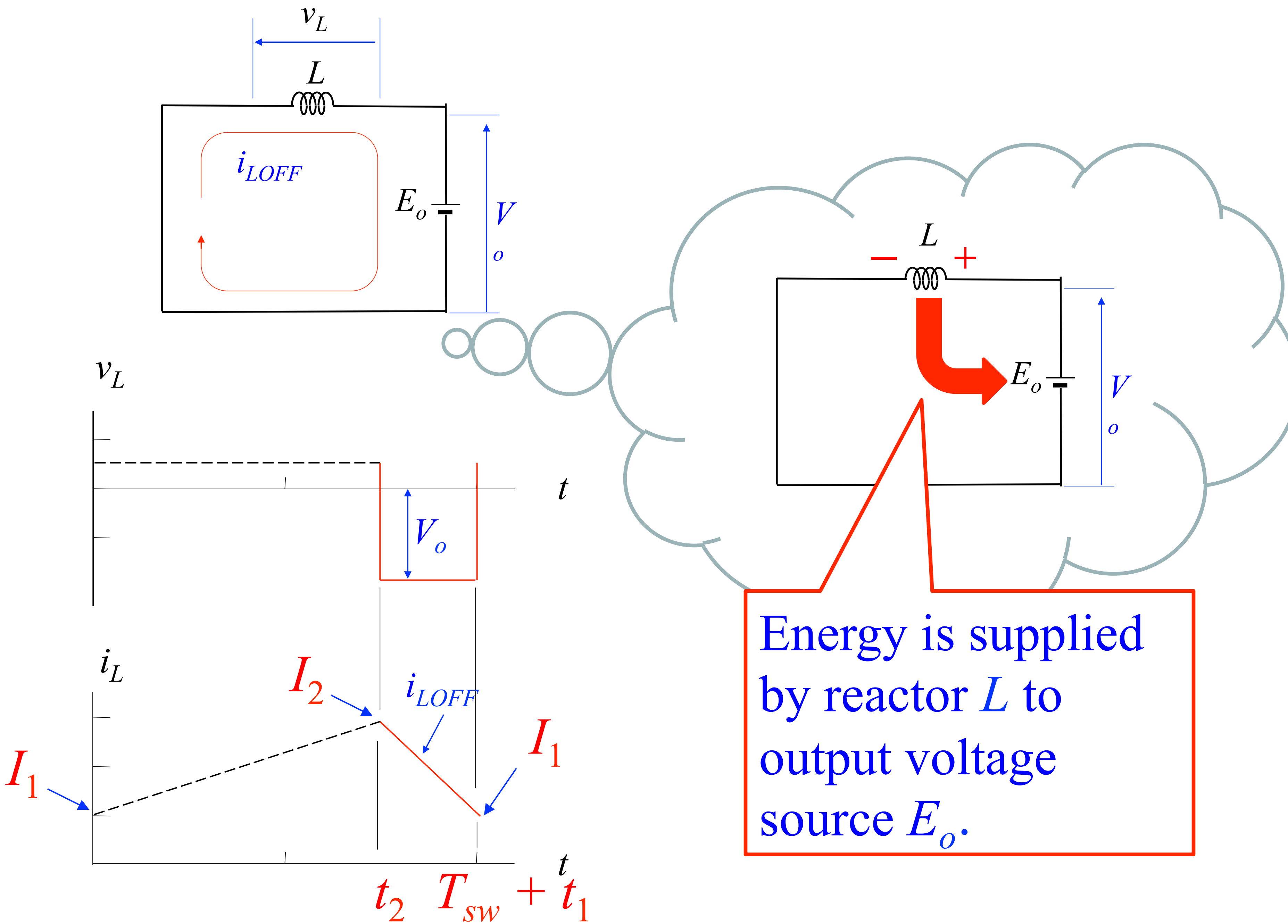
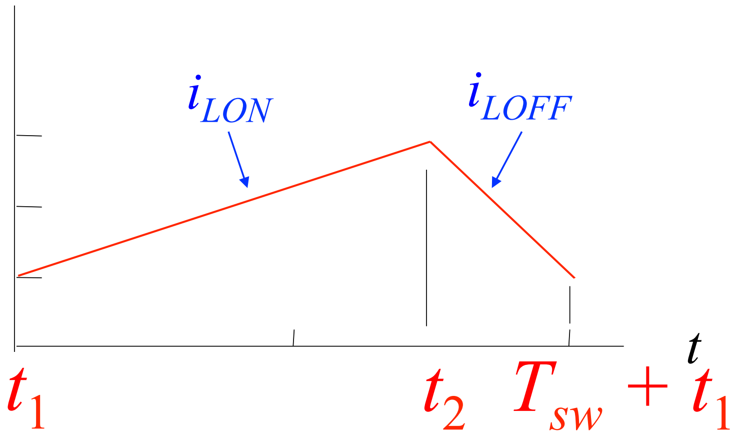




Energy is supplied from the power source to reactor L and output voltage source E_o.



v_L
L
i_{LOFF}
E_o
V_o
v_L
t
V_o
i_L
I_2
i_{LOFF}
I_1
I_1
t
t_2
$T_{sw} + t_1$
L
$-$
$+$
E_o
V_o
Energy is supplied by reactor L to output voltage source E_o.



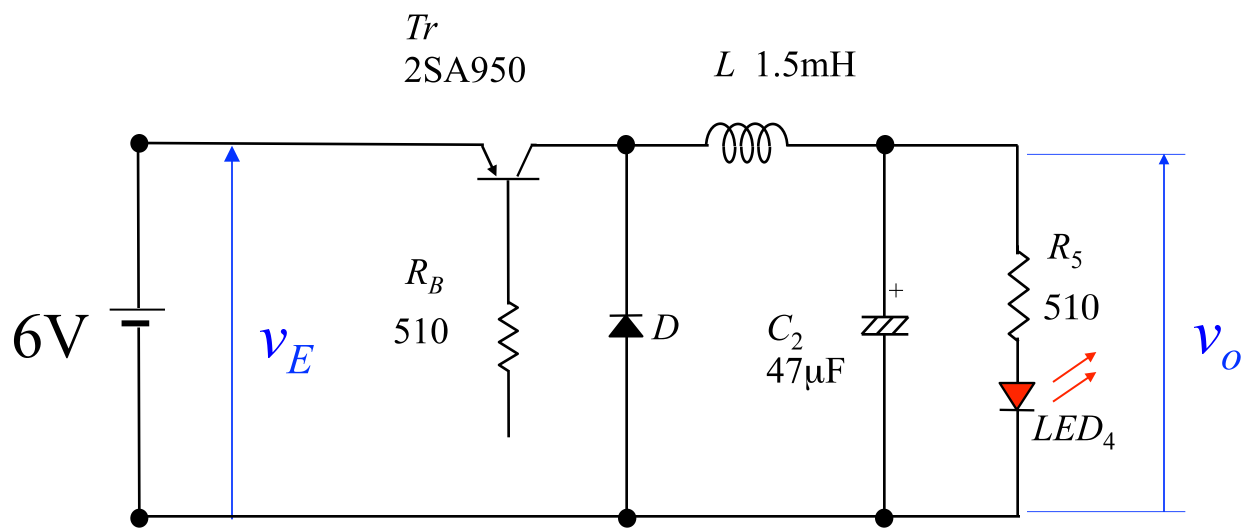
$$\Delta I = I_2 - I_1 = \frac{V_E - V_o}{L} \delta T_{SW}$$

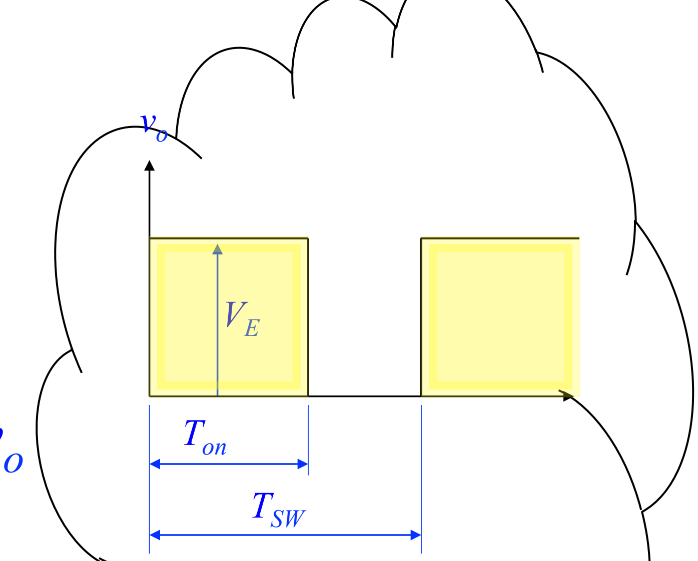
$$\Delta I = I_2 - I_1 = \frac{V_o}{L} T_{SW} (1 - \delta)$$

The right hand side of both equations are equal.

$$\frac{V_E - V_o}{L} \delta \, T_{SW} = \frac{V_o}{L} T_{SW} (1 - \delta)$$

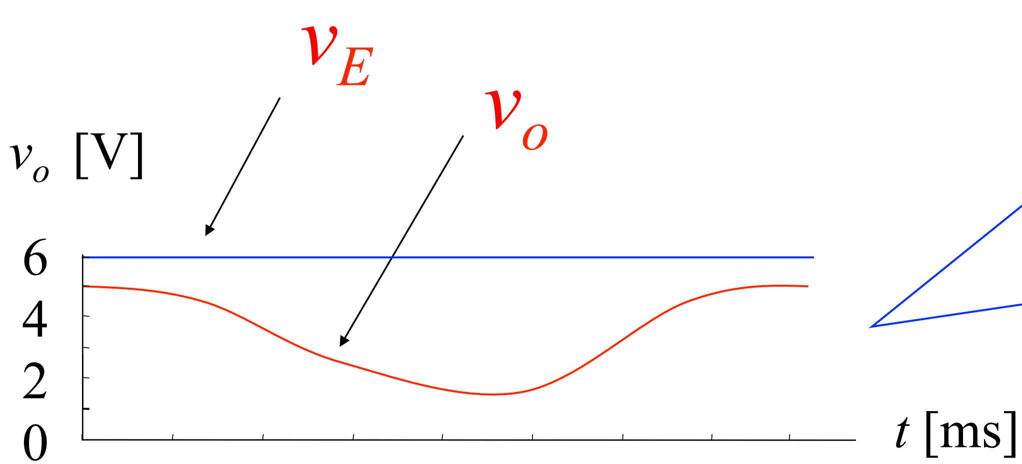
$$V_o = \delta V_E$$





Duty ratio

$$\delta = T_{on} / T_{sw}$$

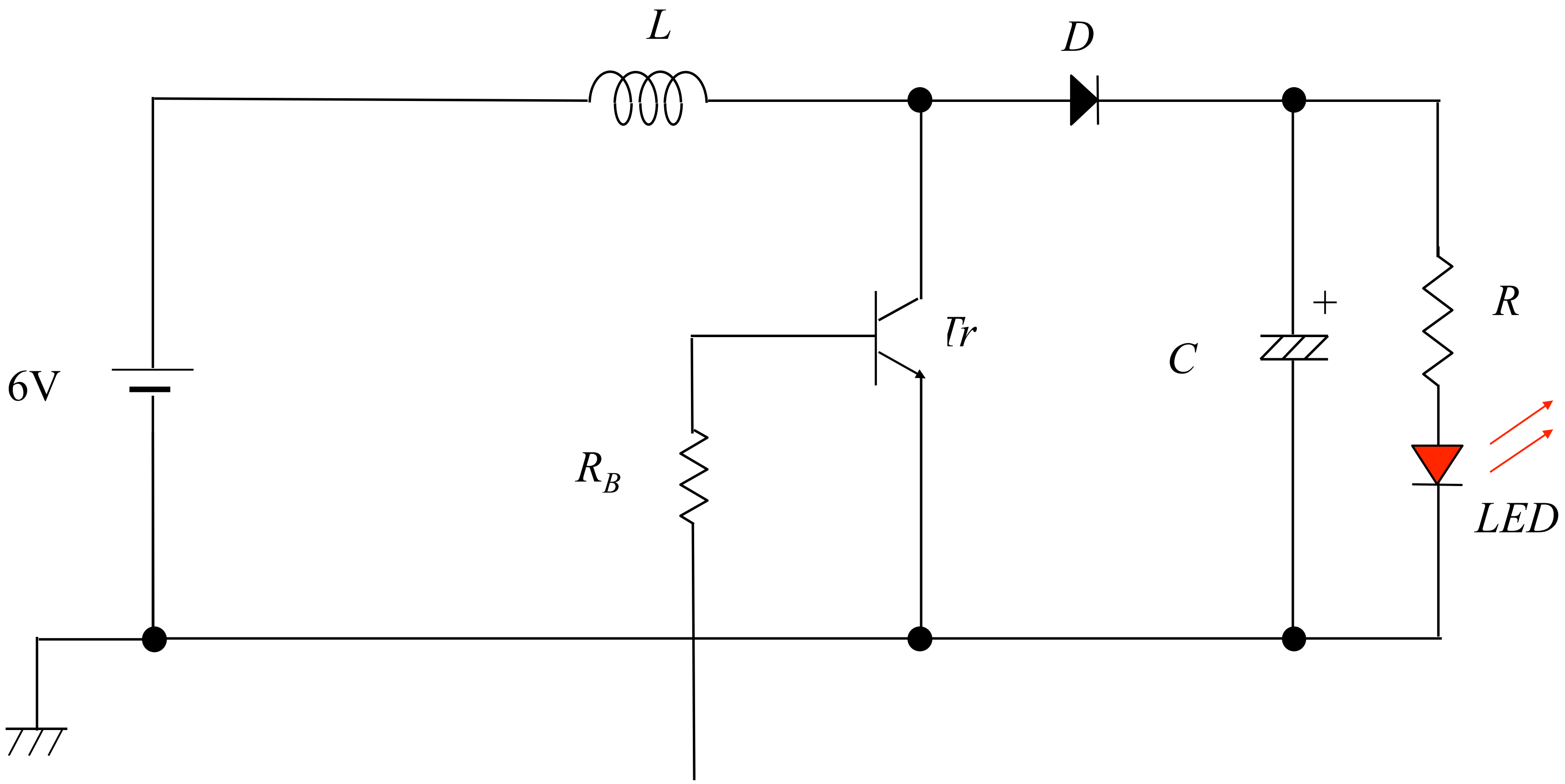


$$V_o = \delta V_E$$

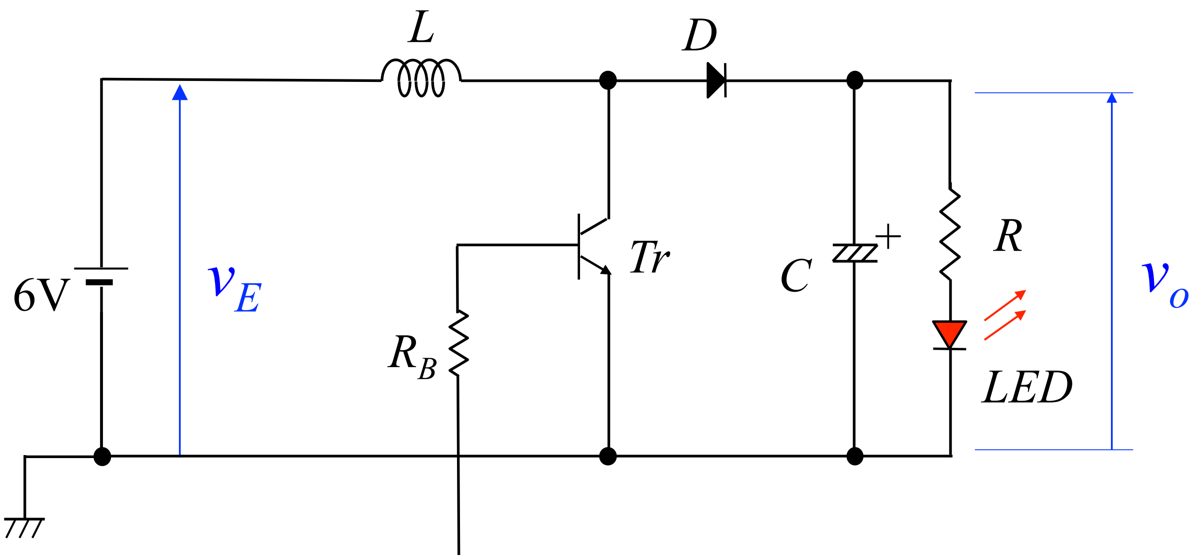
$$0 \leq \delta \leq 1$$

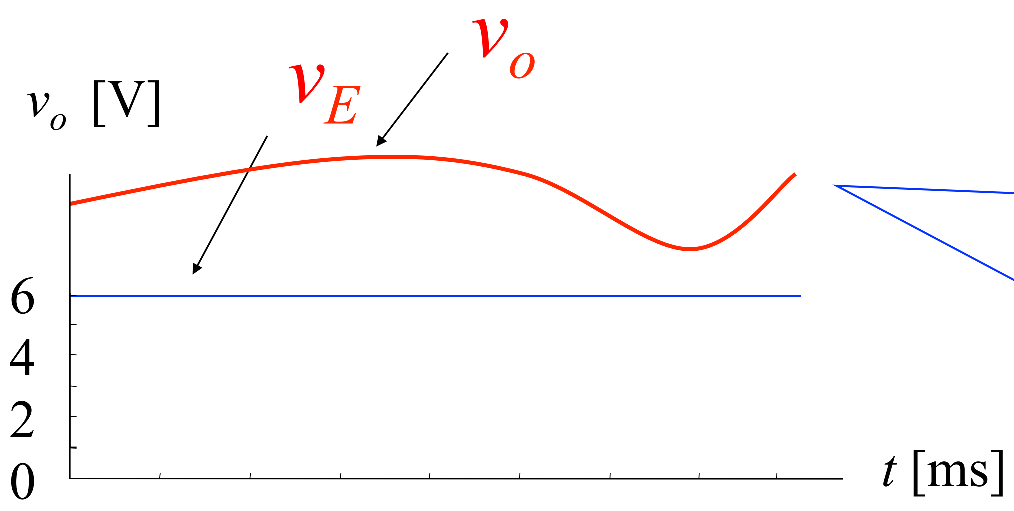
The output volatge is not larger than the source voltage.

Step-up chopper



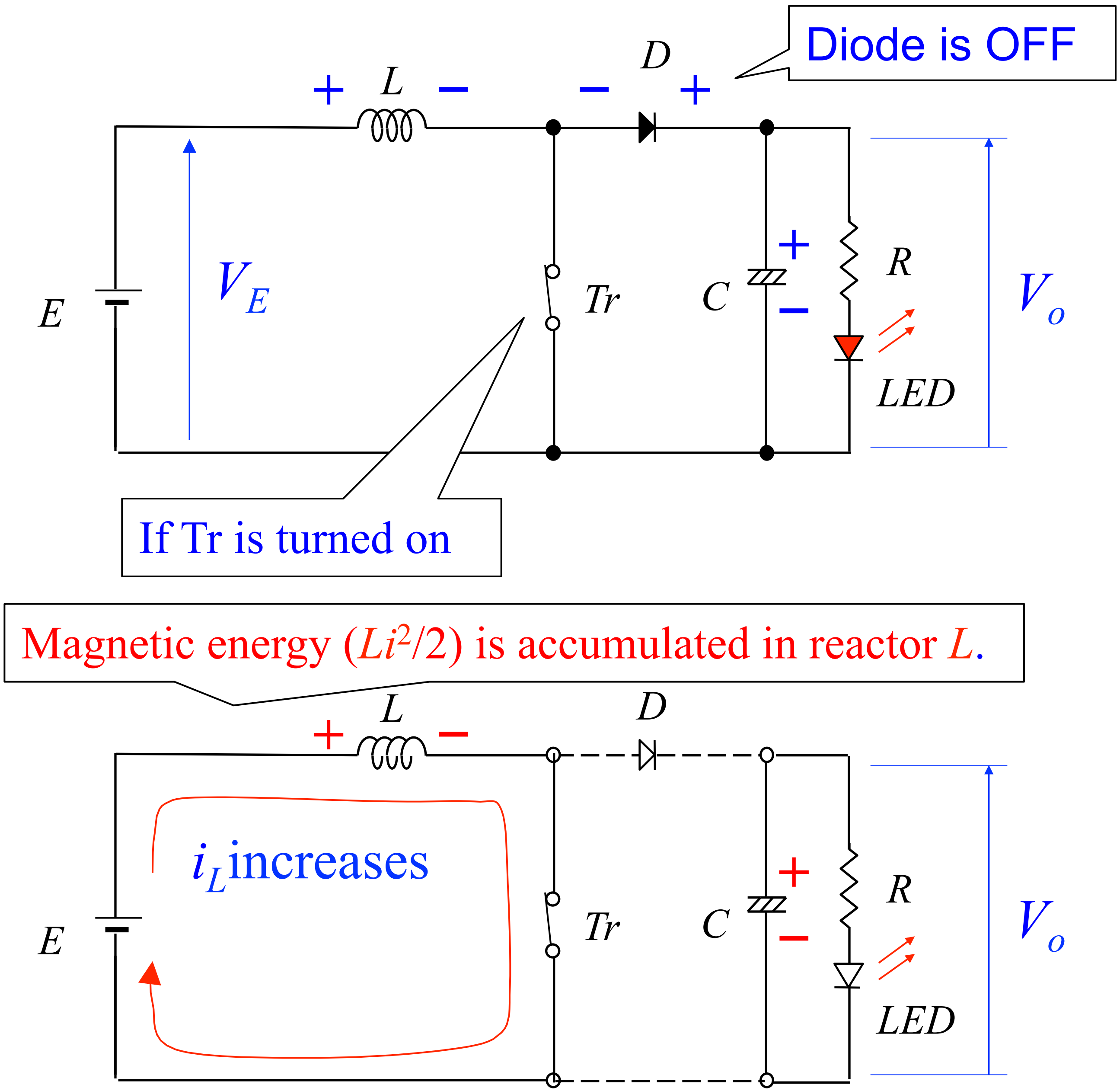
Step-up chopper





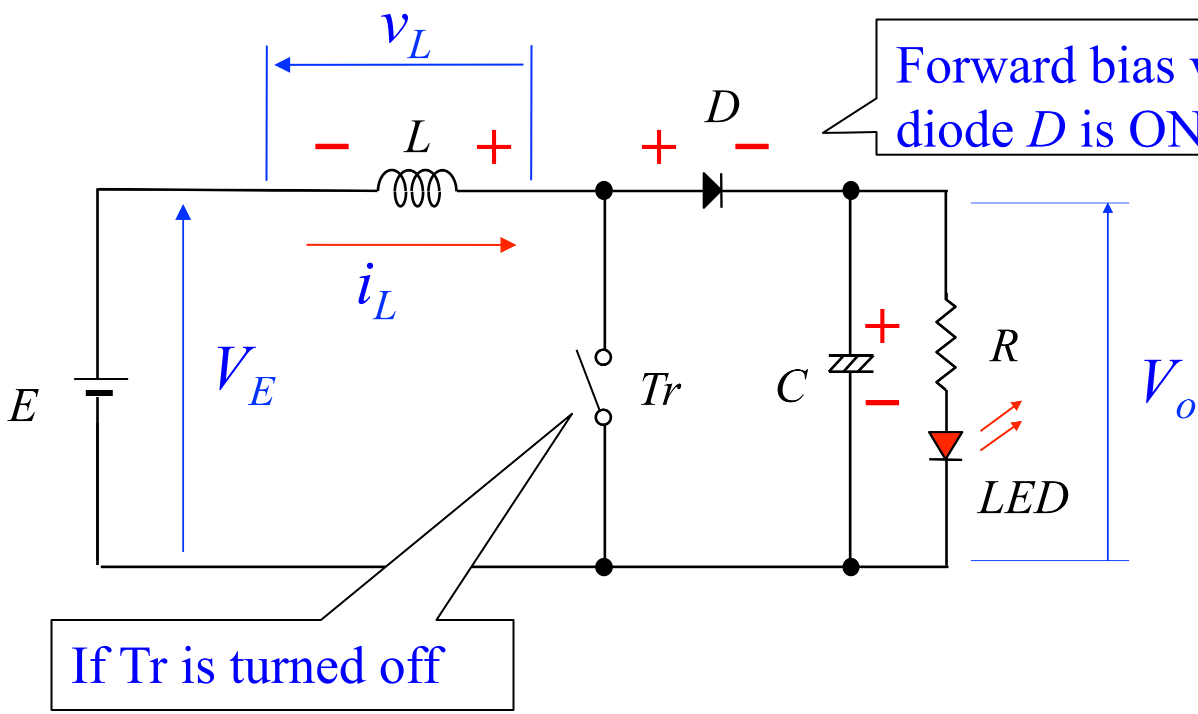
The output voltage is larger than the source voltage.

Operating principle of the step-up chopper



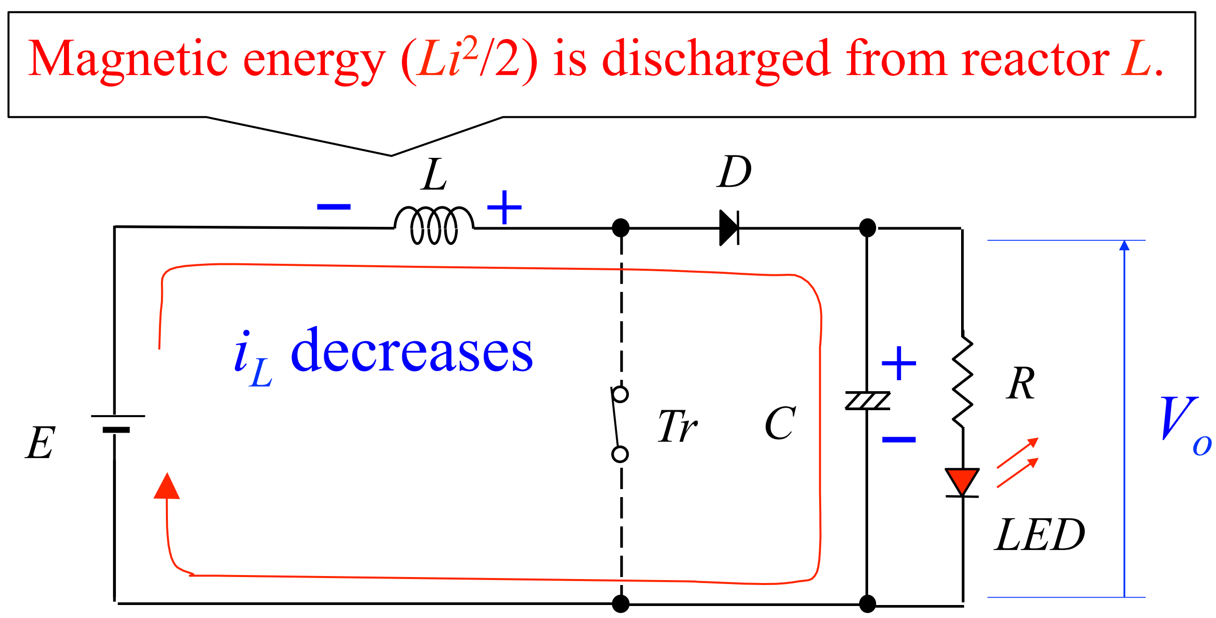
Assume that $V_o > V_E > 0$

While Tr is turned off, current from the voltage source E to the capacitor C does not flow.



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

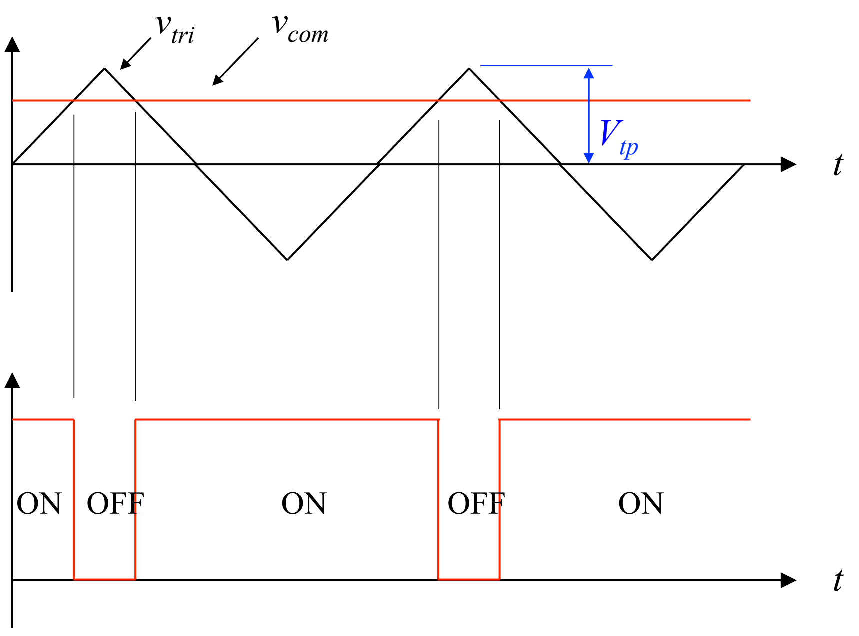
When i_L decreases, $v_L < 0$. In this case, $V_E - v_L > V_o$.

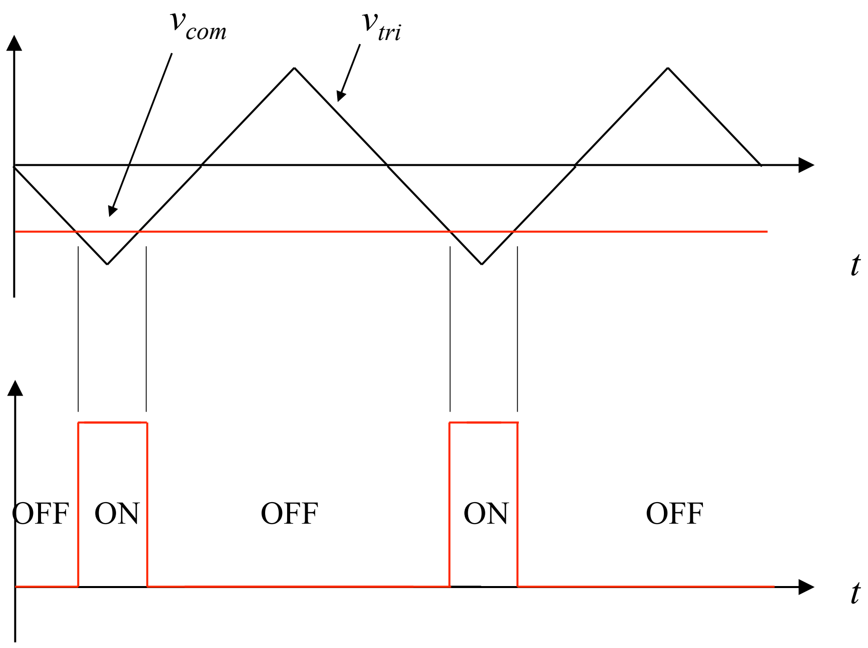


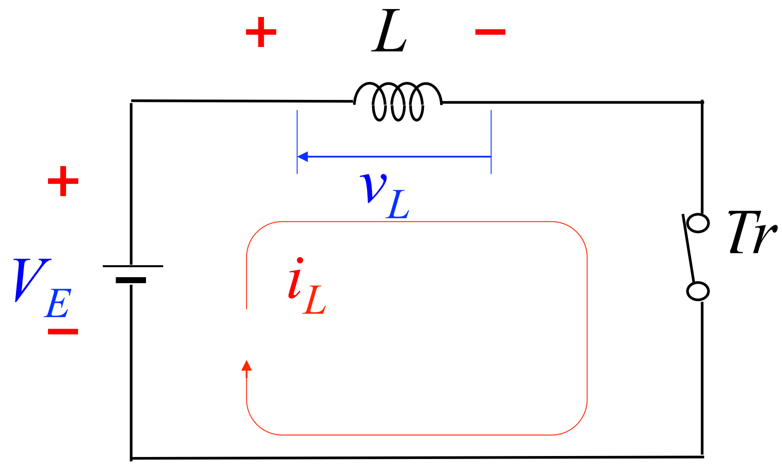
PWM control method

$$\text{If } v_{com} \geq v_{tri}\text{, then Tr is turned on.}$$

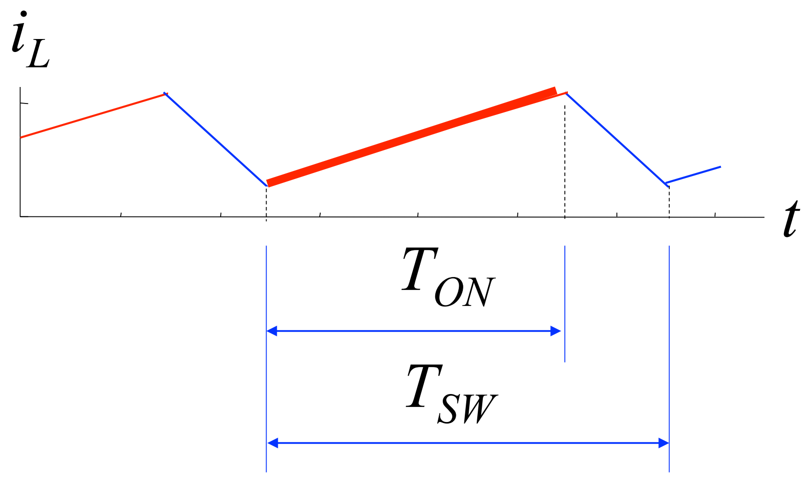
$$\text{If } v_{com} < v_{tri}\text{, then Tr is turned off.}$$







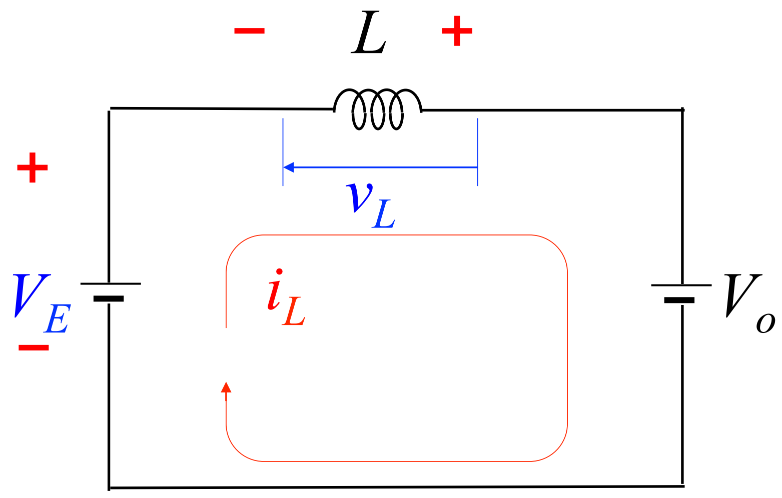
(a) Tr: ON



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

$$v_L = V_E$$

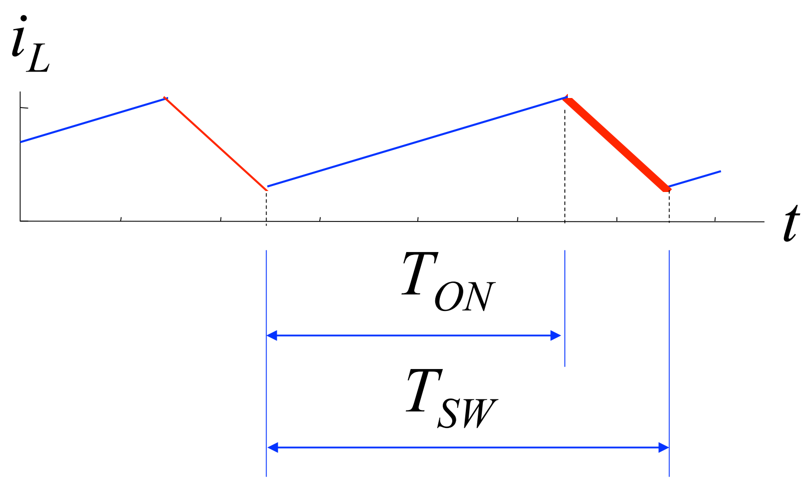
Current flowing through reactor *L*



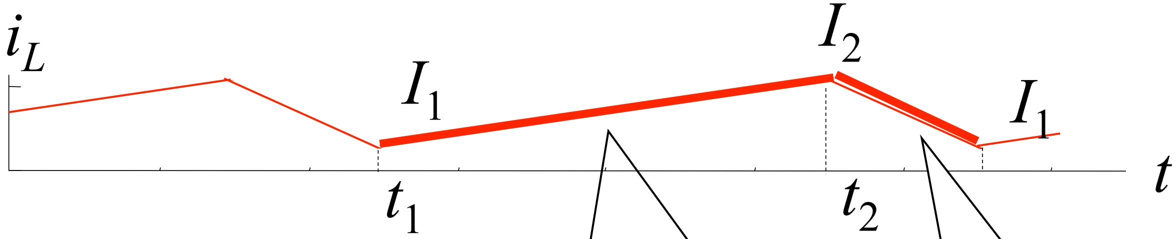
(b) Tr: OFF

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

$$v_L = V_E - V_o$$



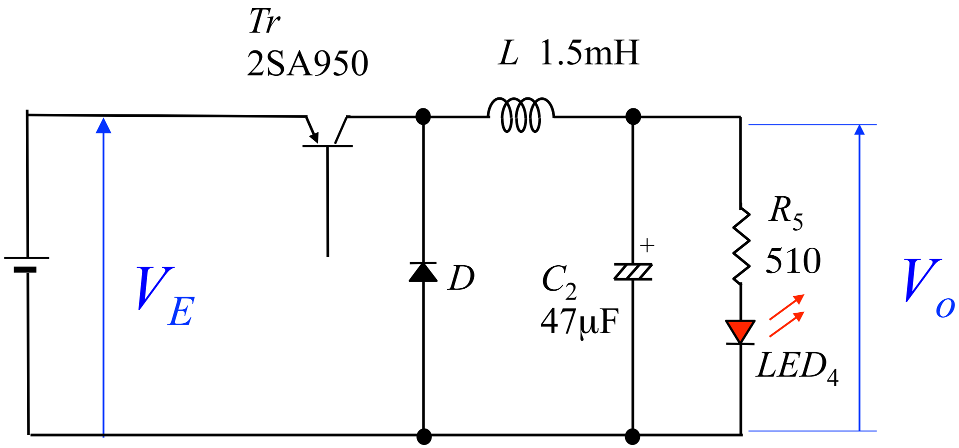
Current flowing through reactor *L*



$$\Delta I_L = I_2 - I_1 = \frac{V_E}{L}\delta T_{SW}$$

$$\Delta I_L = I_2 - I_1 = -\frac{V_E - V_o}{L} T_{SW}(1-\delta)$$

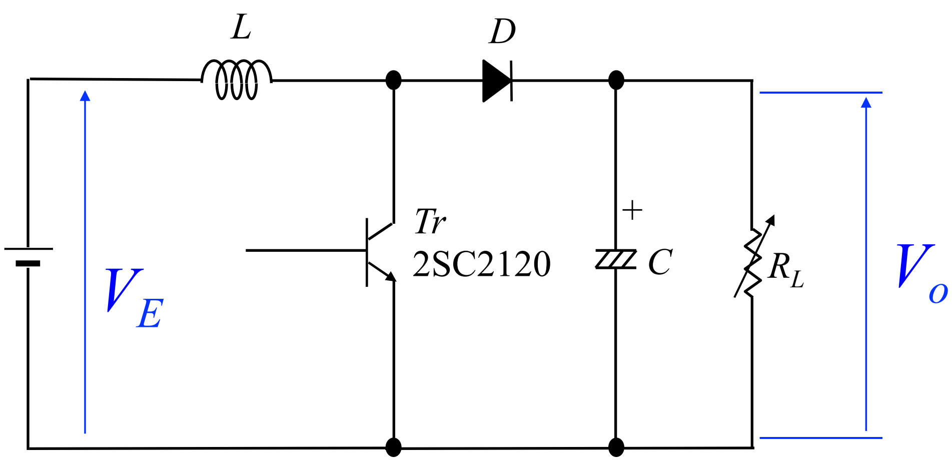
$$V_o = \frac{1}{1-\delta} V_E \qquad 0 \le \delta < 1$$



Step-down chopper

$$V_o \leq V_E$$

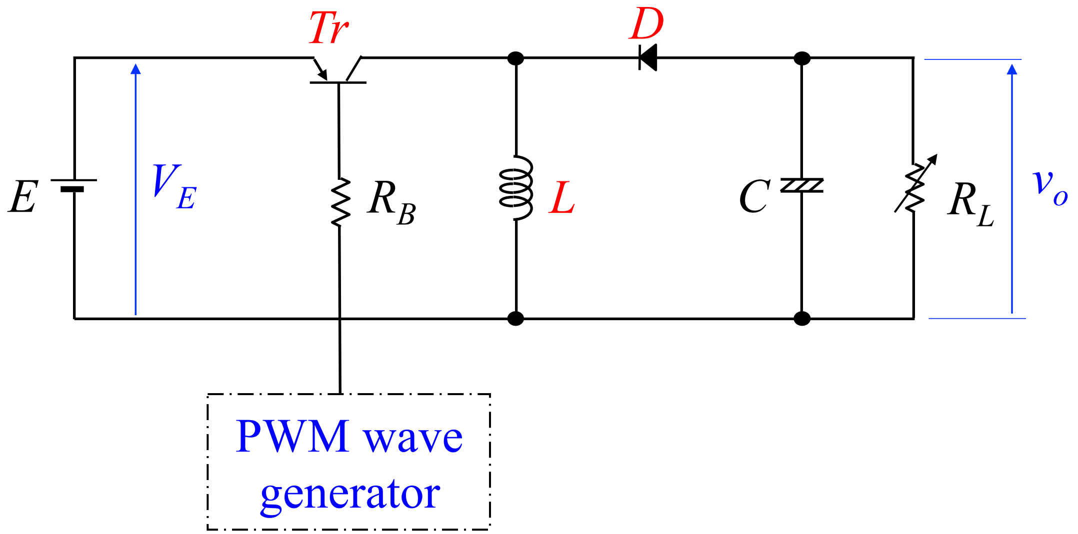
Which configuration's output voltage range covers both regions?

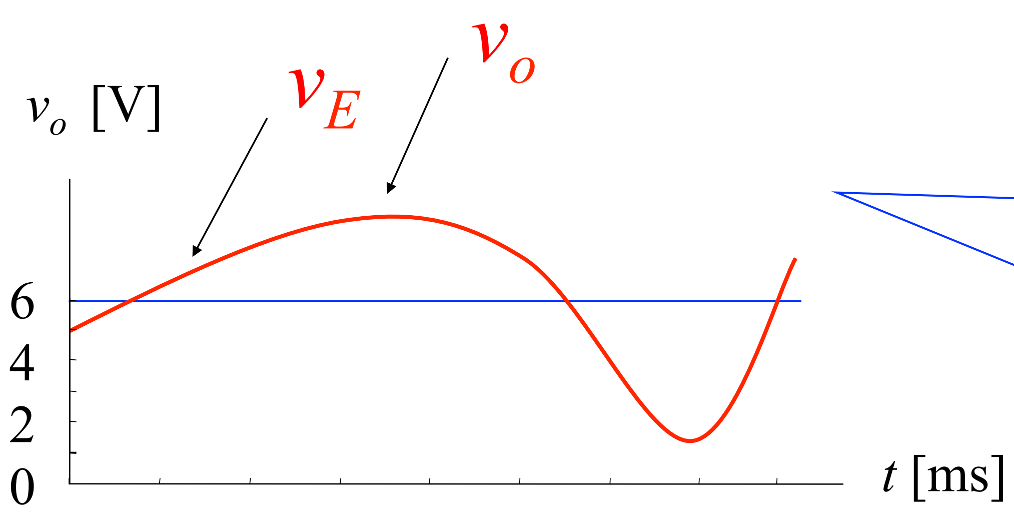


Step-up chopper

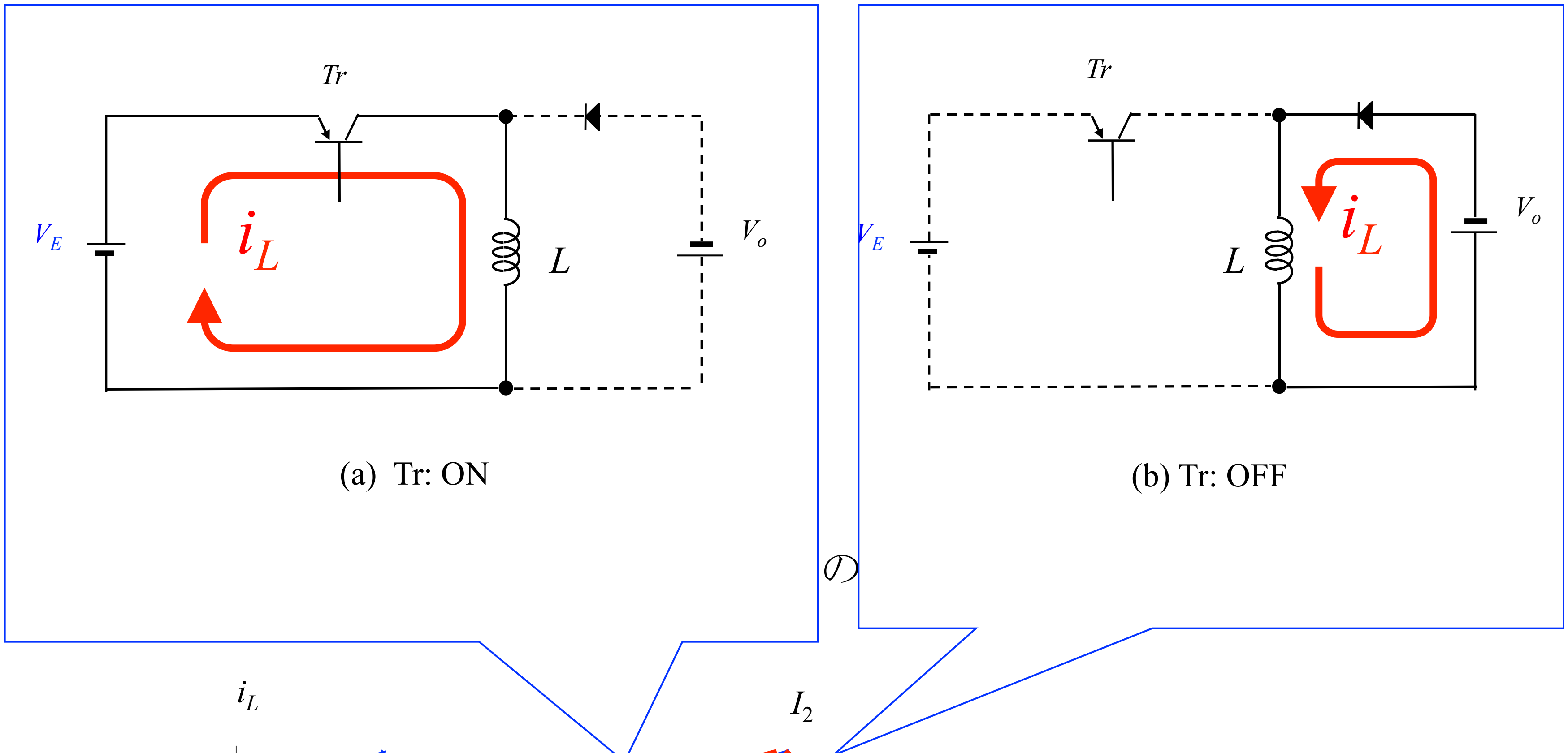
$$V_E \leq V_o$$

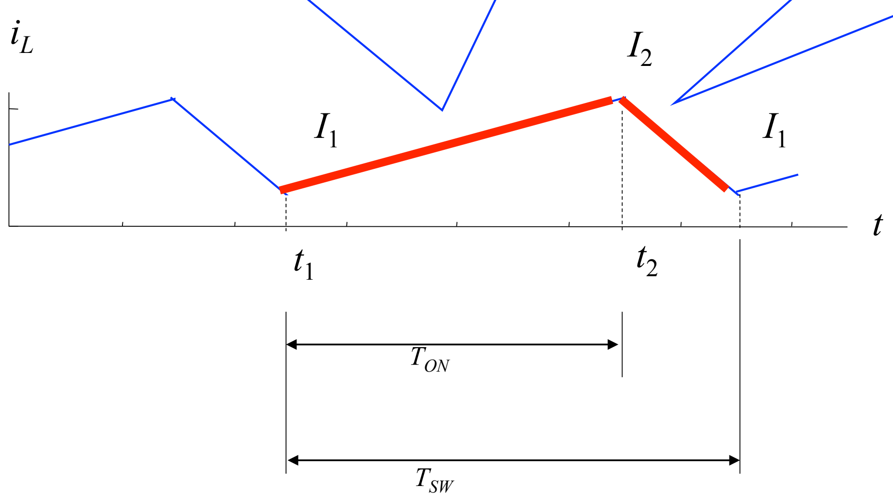
Step-up/down chopper





The output voltage is smaller/larger than the source voltage.



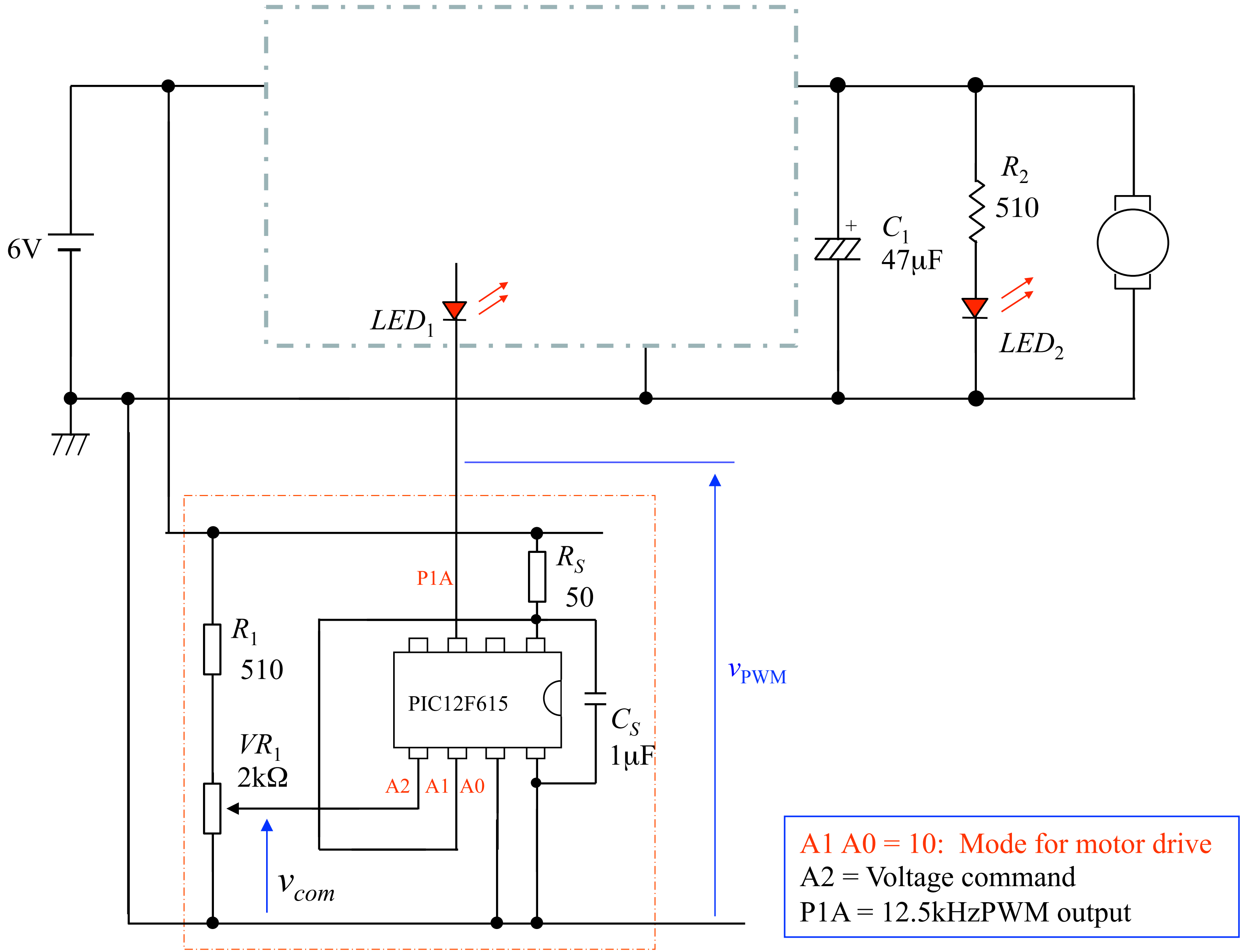


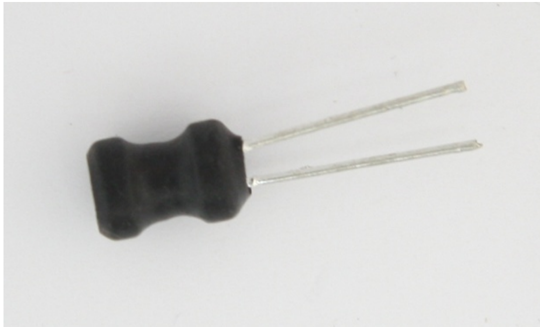
$$V_o = \frac{\delta}{1-\delta} V_E$$

$$0 \leq \delta < 1$$

Current flowing through reactor *L*

STEP 5. Circuit construction practice Construct a step-down chopper with a smoothing circuit that includes a reactor, Schottky barrier diode, and electrolytic capacitor. After rotating the motor at a low speed for a few minutes, check the temperature of the transistor by touching it.

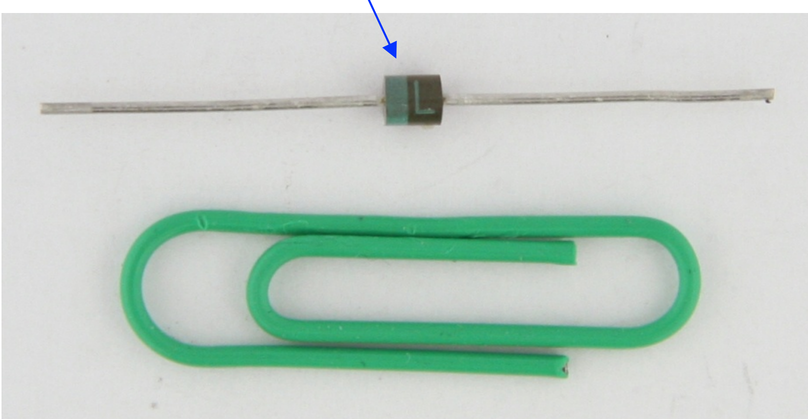




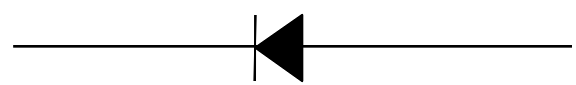
Reactor (1.5 mH)

Reactor symbol

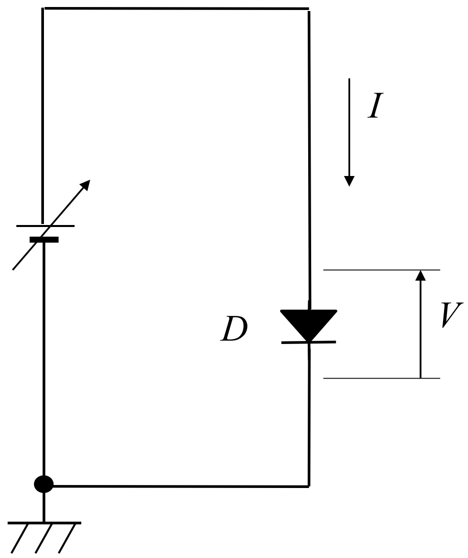
The stripe indicates cathode.



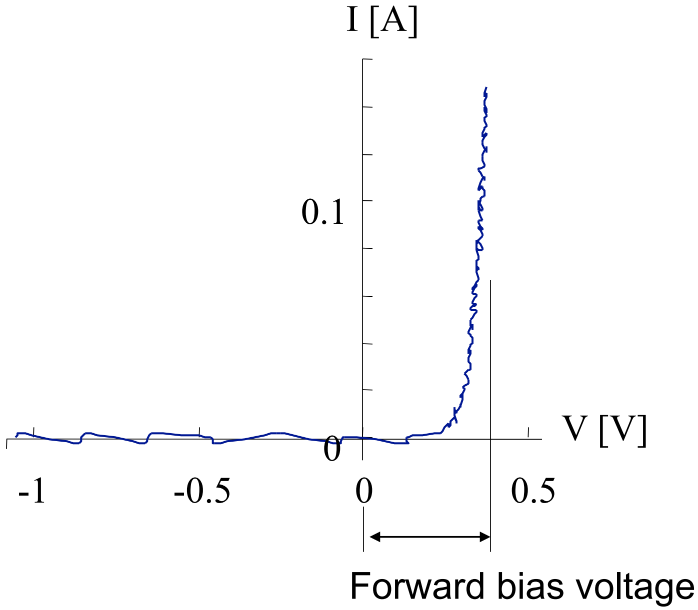
Schottky barrier diode (30V, 1A)



Diode symbol

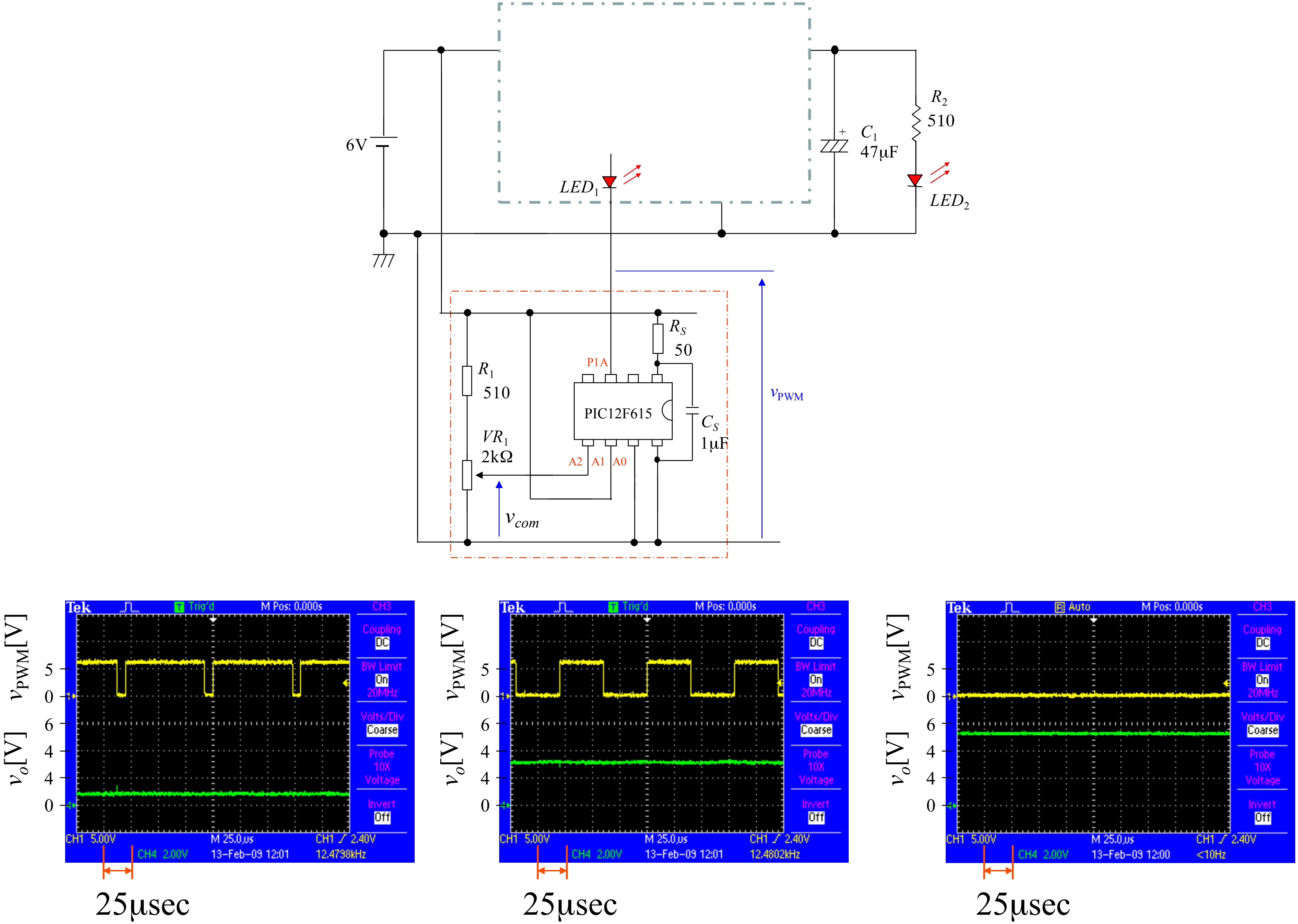


(a) Definitions of voltage direction across diode V and current direction into diode I



(b) Characteristic of the Schottky barrier diode

Characteristic of the Schottky barrier diode



(a) $v_{ref} = 0.5$ [V]

(b) $v_{ref} = 3$ [V]

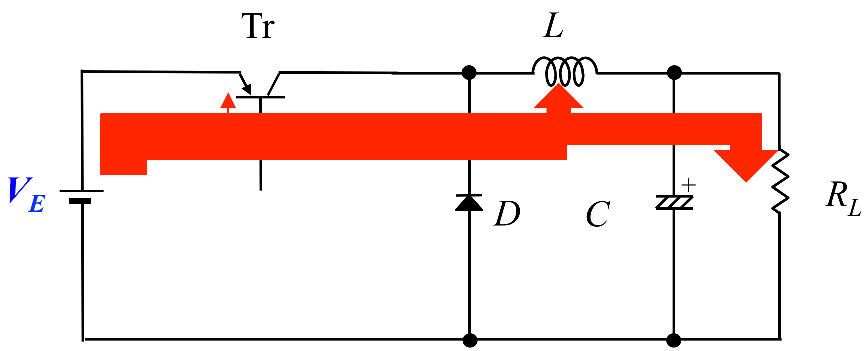
(c) $v_{ref} = 6$ [V]

Step 5. problem 1

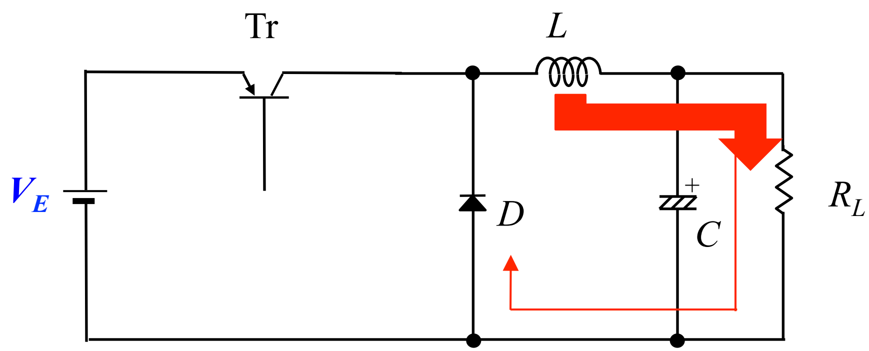
(a) Draw the energy flow in the case where Tr is ON in a step-up chopper.

(b) Draw the energy flow in the case where Tr is OFF in a step-up chopper.

(hint) Energy flow in a step-down chopper.
Small amounts of energy are consumed in transistor Tr and diode *D*.



Tr: ON



Tr: OFF