Power Electronics
No. 5: Step-down chopper with smoothing circuit

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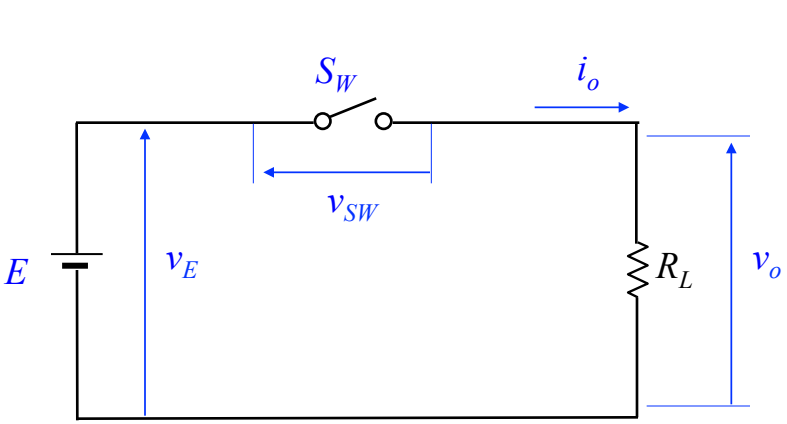
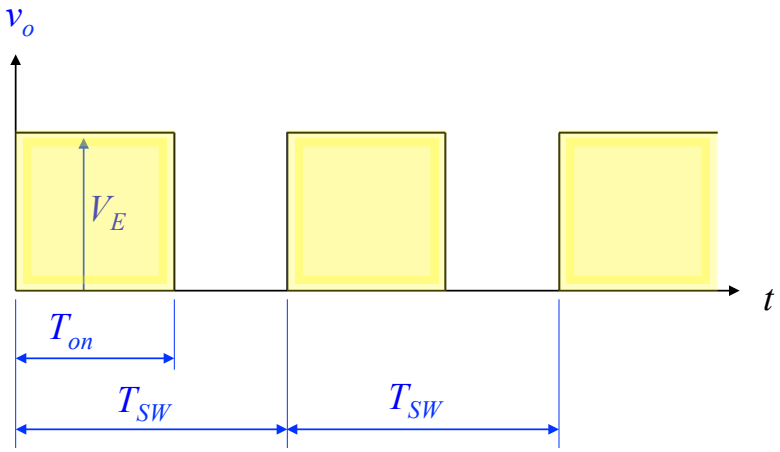
Output voltage control



(a) Switching circuit

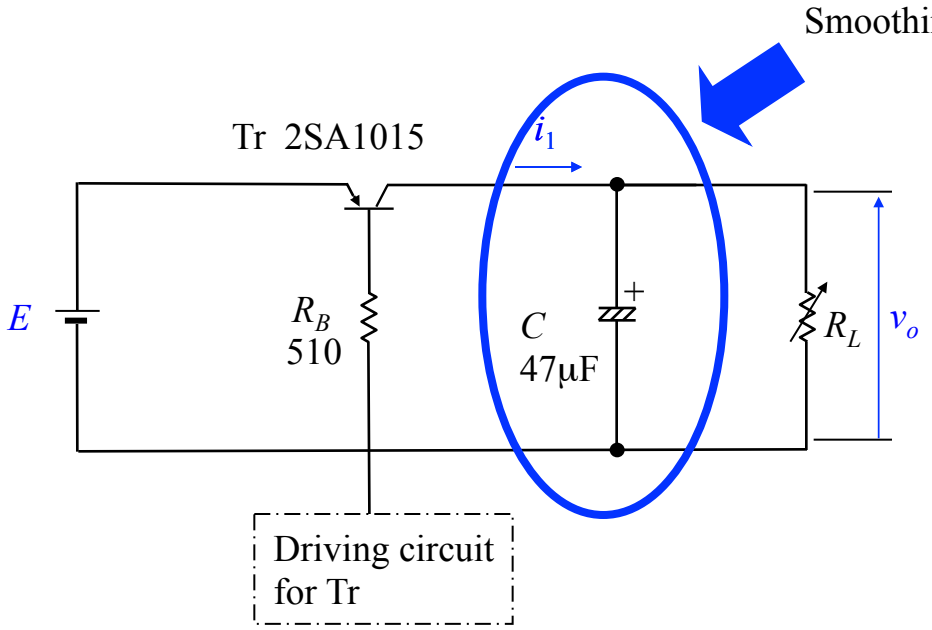


(b) Waveform of output voltage

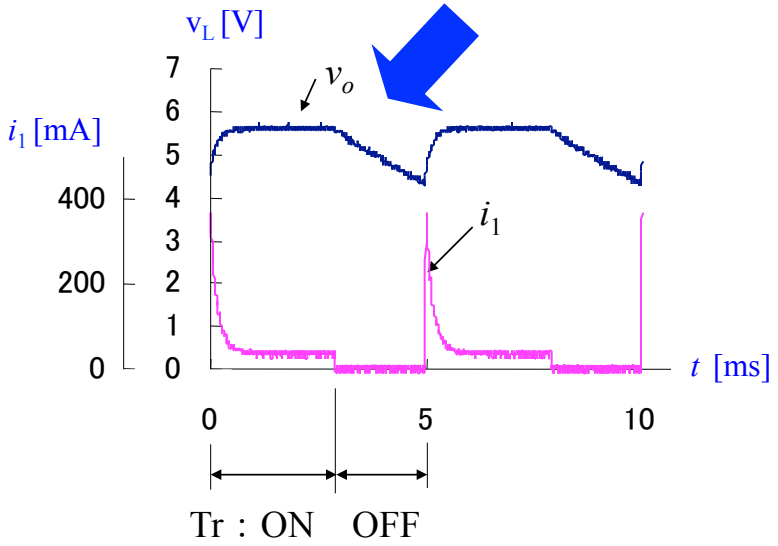
Switching power supply

The voltage fluctuation is too large to be used for electronic circuits.

Voltage v_o still fluctuates and there is an inrush current i_1 into the capacitor



(a) Switching circuit

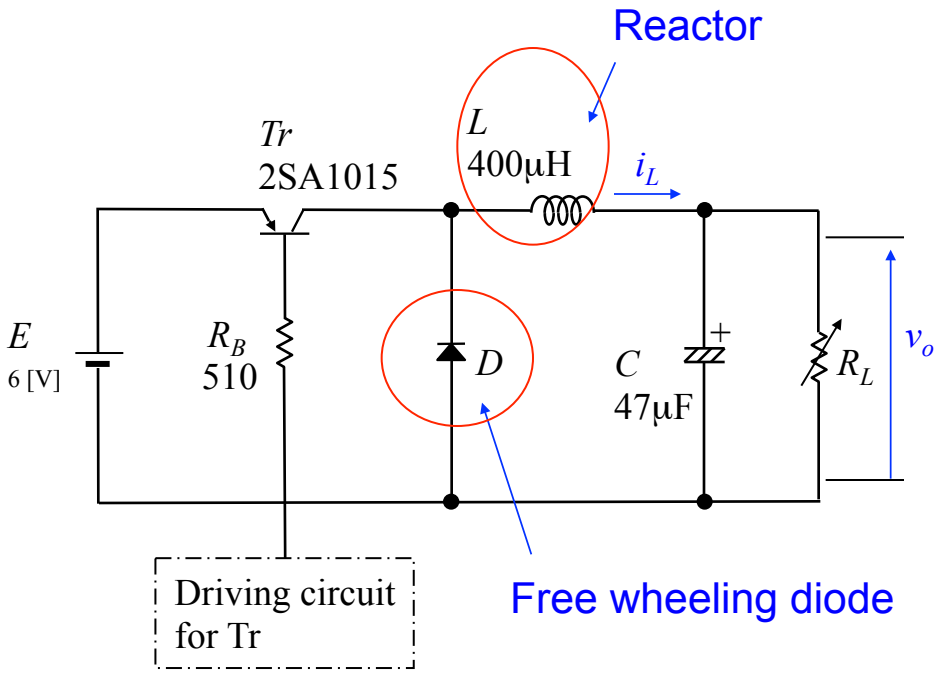


(b) Waveforms of the output voltage v_o and the input current of capacitor i_1

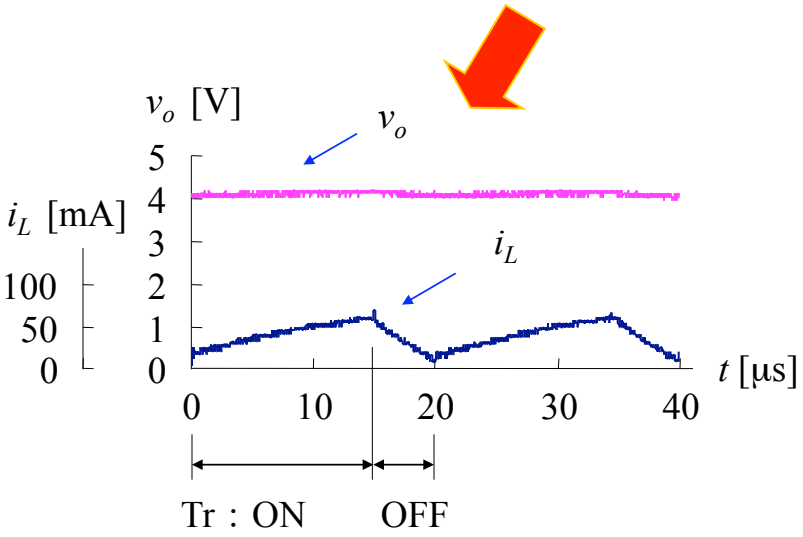
Switching power supply with smoothing capacitor

Smoothing is possible not only by capacitor.

The voltage ripple and inrush current are suppressed.



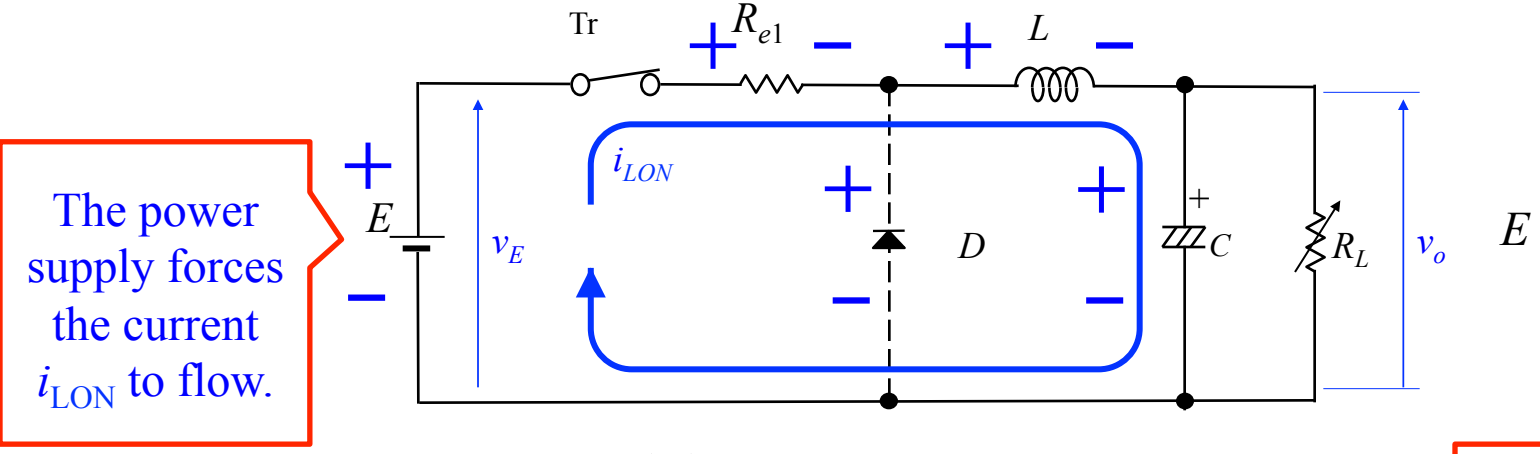
(a) Circuit diagram



(b) Waveforms of output voltage v_o and reactor current i_L

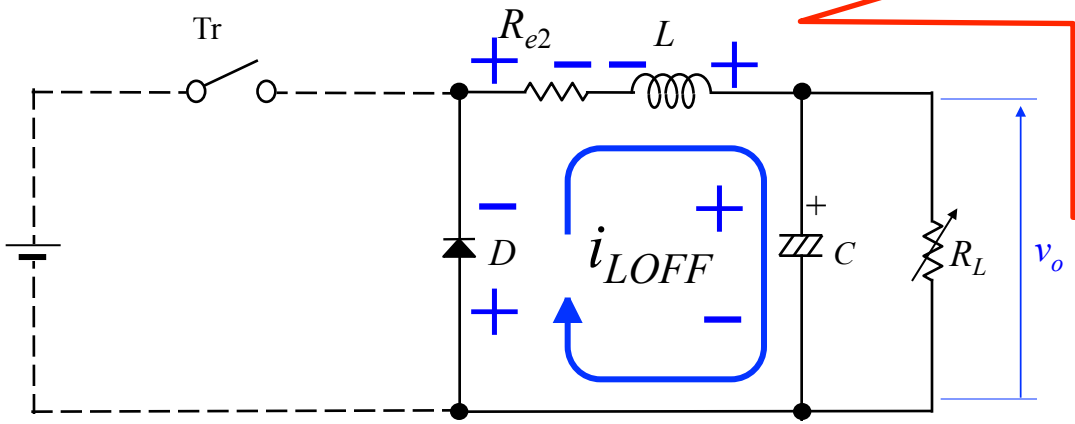
Step-down chopper circuit

Operating principle of the step-down chopper



The power supply forces the current i_{LON} to flow.

(a) Tr ON

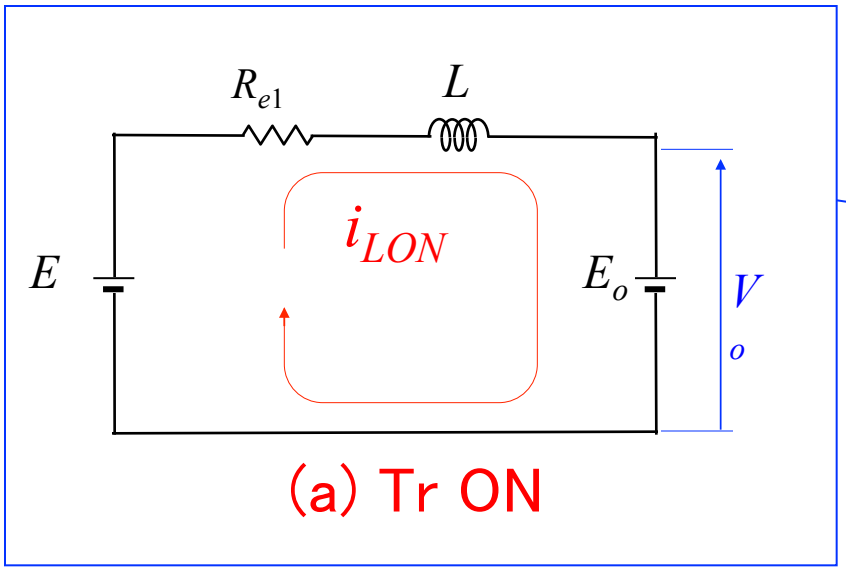


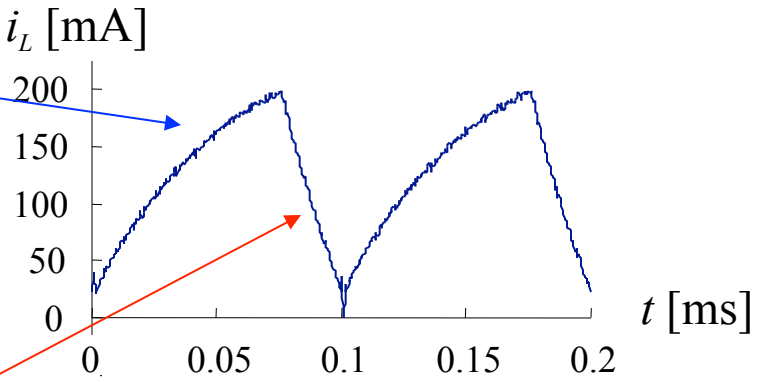
Reactor L forces the current i_{LOFF} to flow.

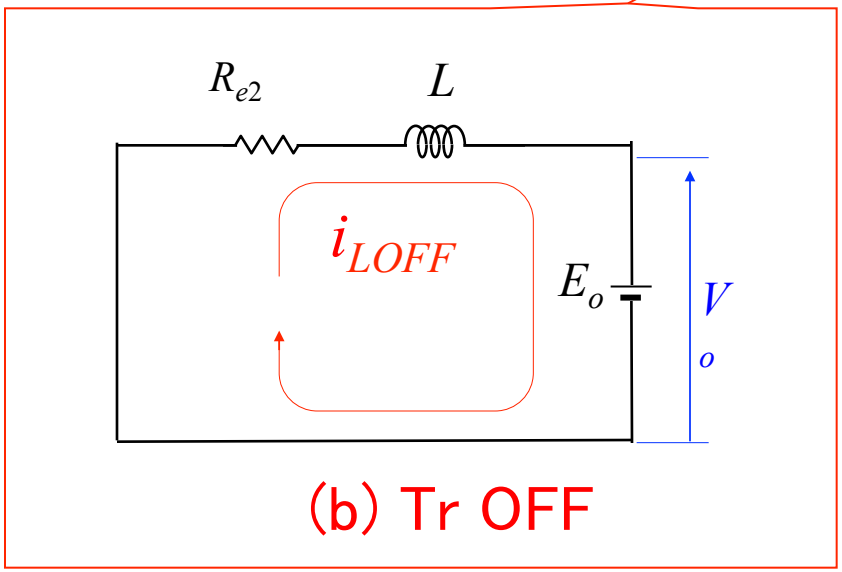
(b) Tr OFF

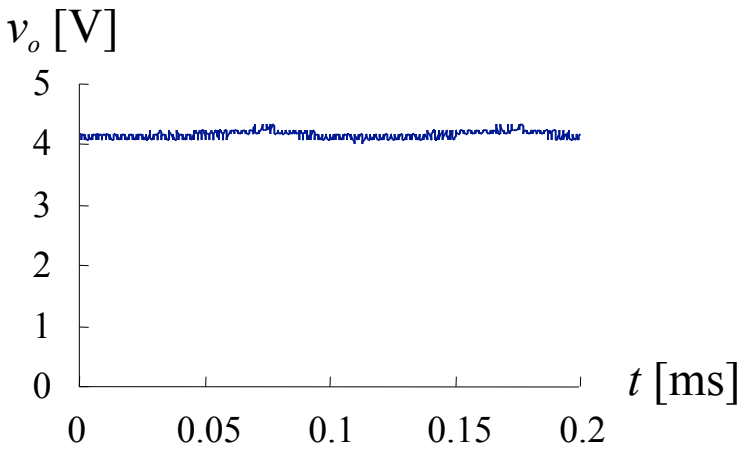
Equivalent circuit of the step-down chopper

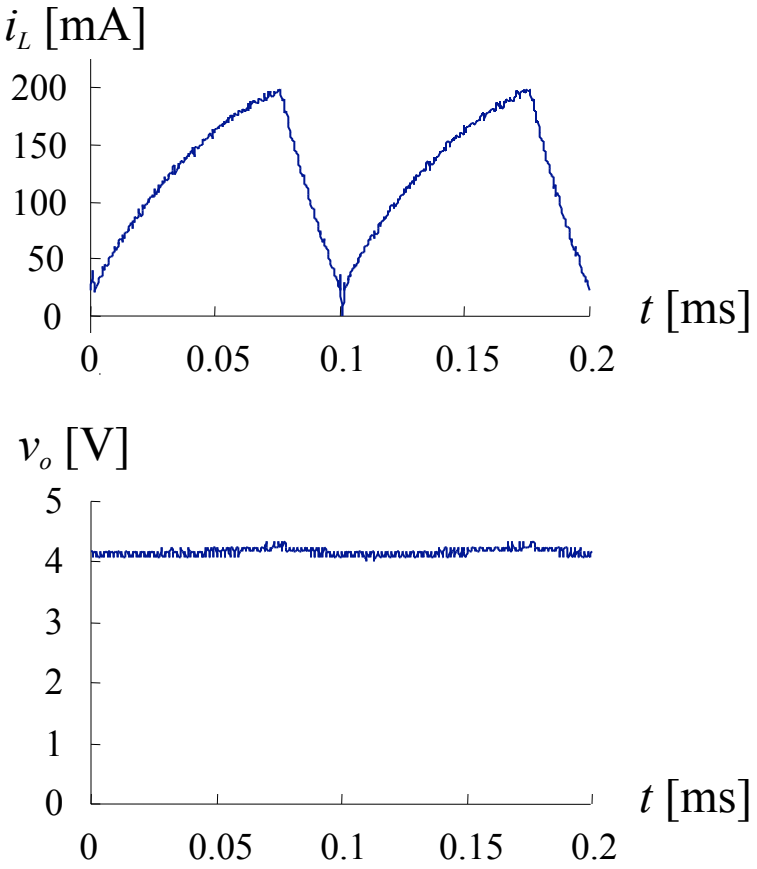
V_E = 6 [V], V_o = 4.1 [V], L = 400 [μH],
R_{e1} = 7 [Ω], f_{SW} = 10 [kHz]





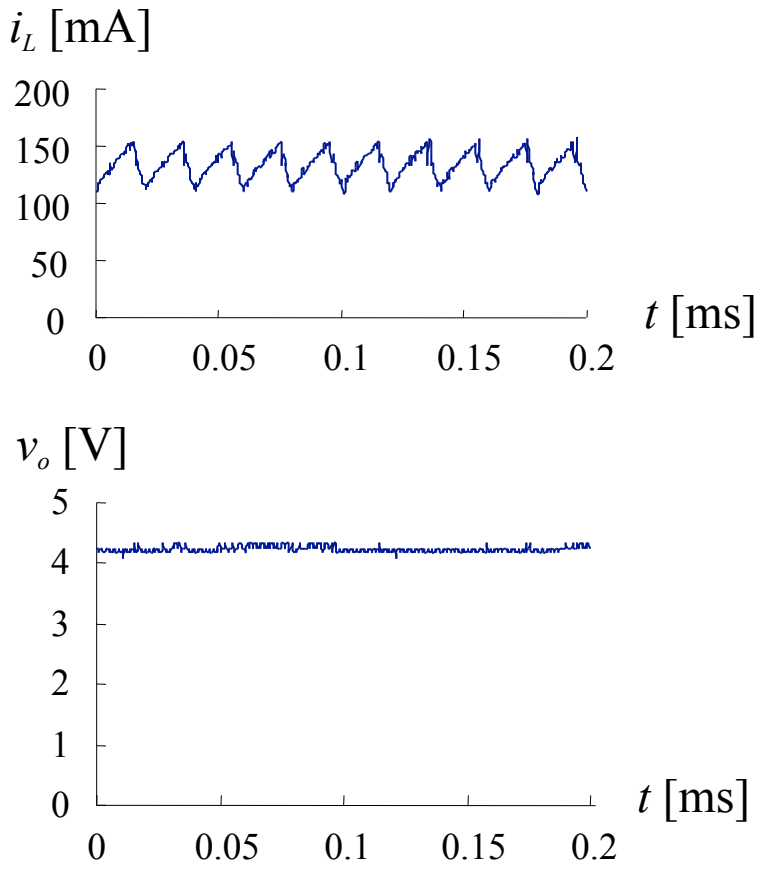






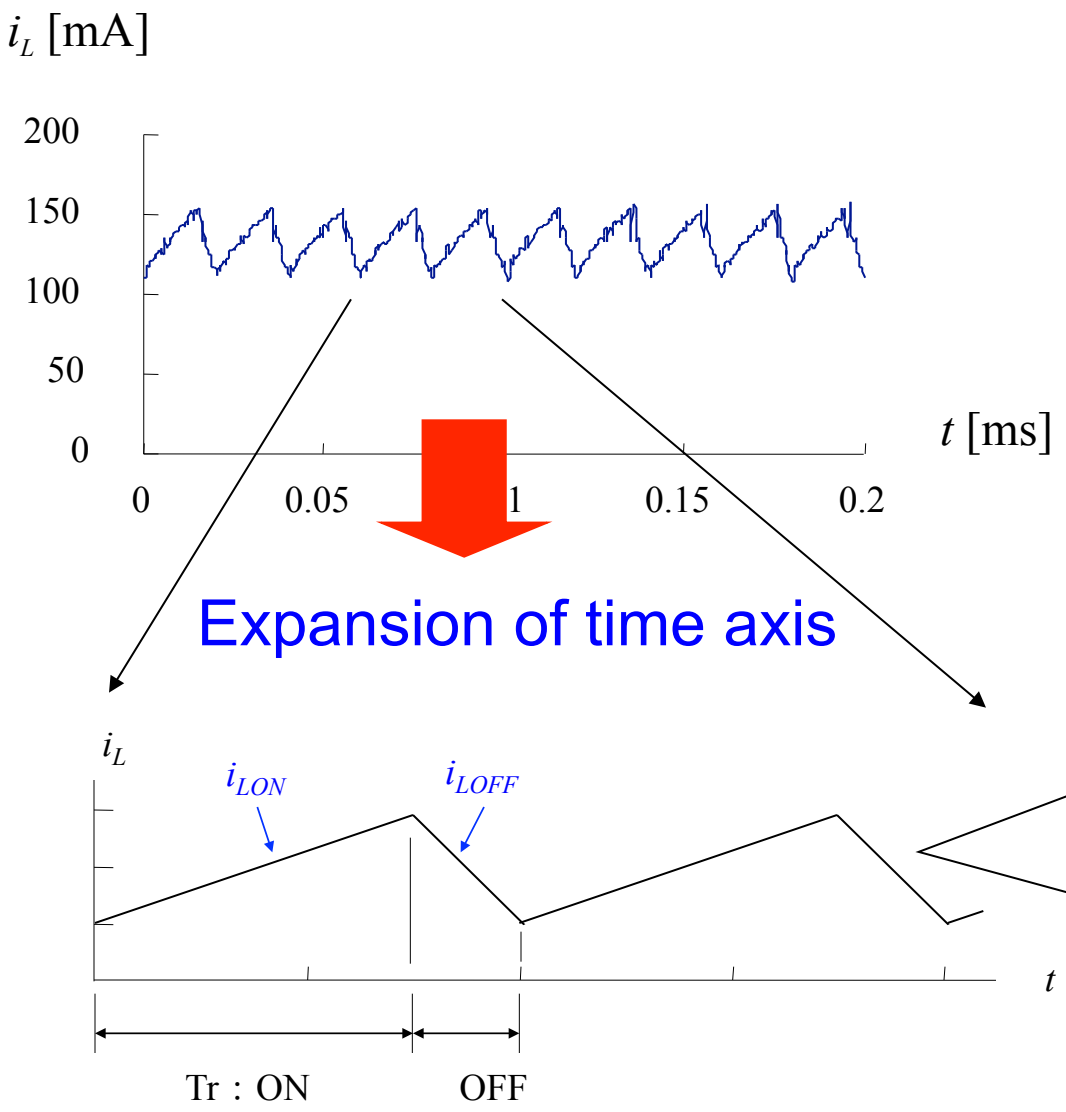
(a) Switching frequency

$f_{SW} = 10$ [kHz]



(b) $f_{SW} = 50$ [kHz]

Waveforms of reactor current i_L and output voltage v_o



Approximation by straight lines

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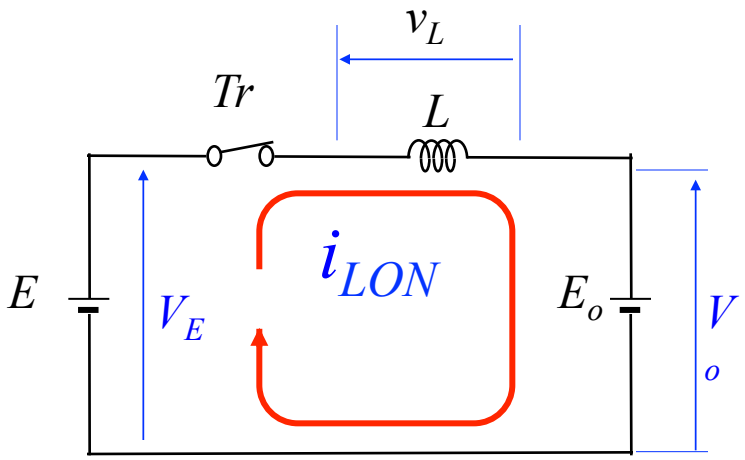
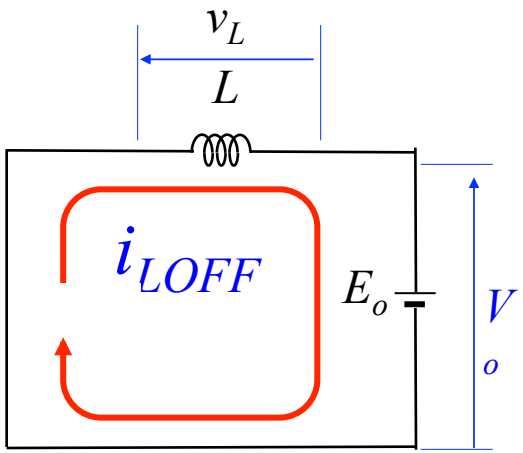
Resistance in the circuit is negligible.

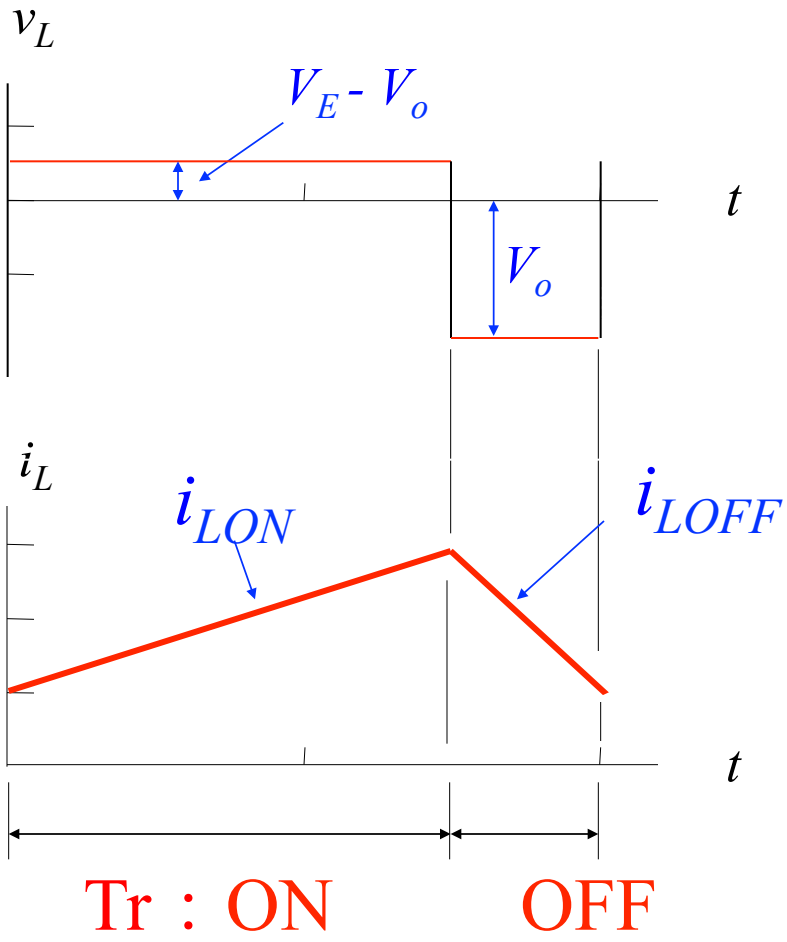
Reactor current i_L



(a) Tr ON



(b) Tr OFF

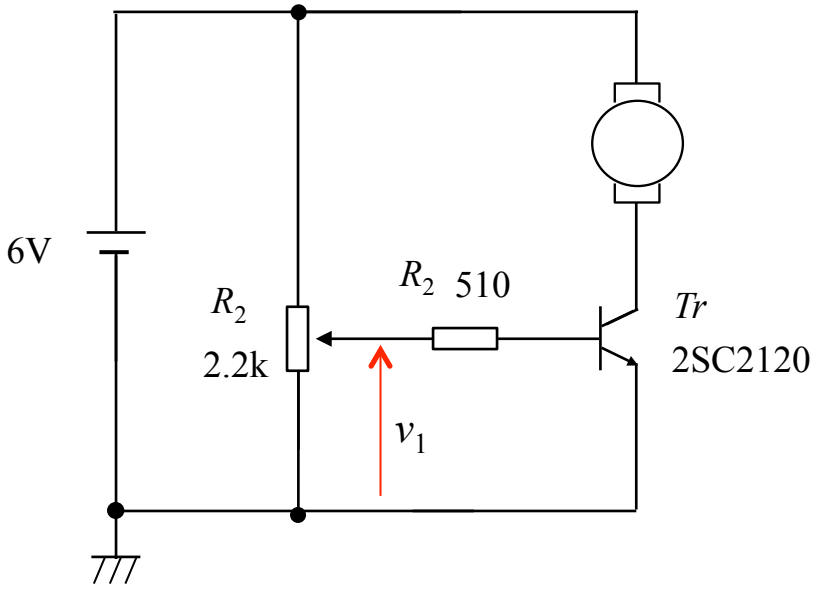


Waveforms of voltage across reactor L and reactor current i_L.

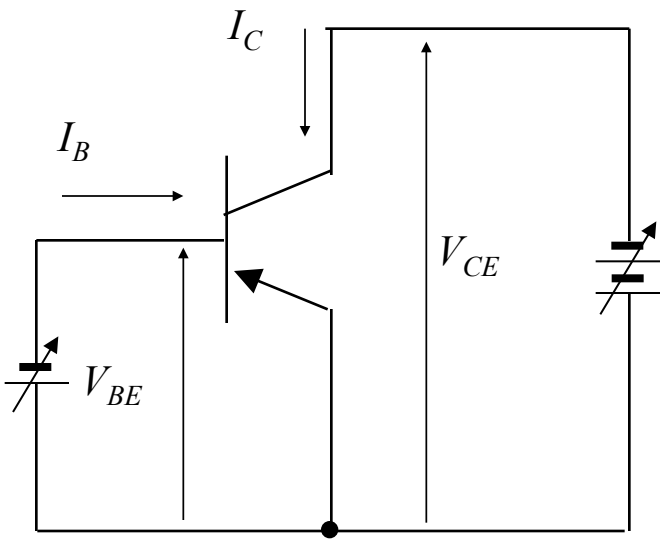
STEP 4. Circuit construction practice

Construct a motor control circuit.

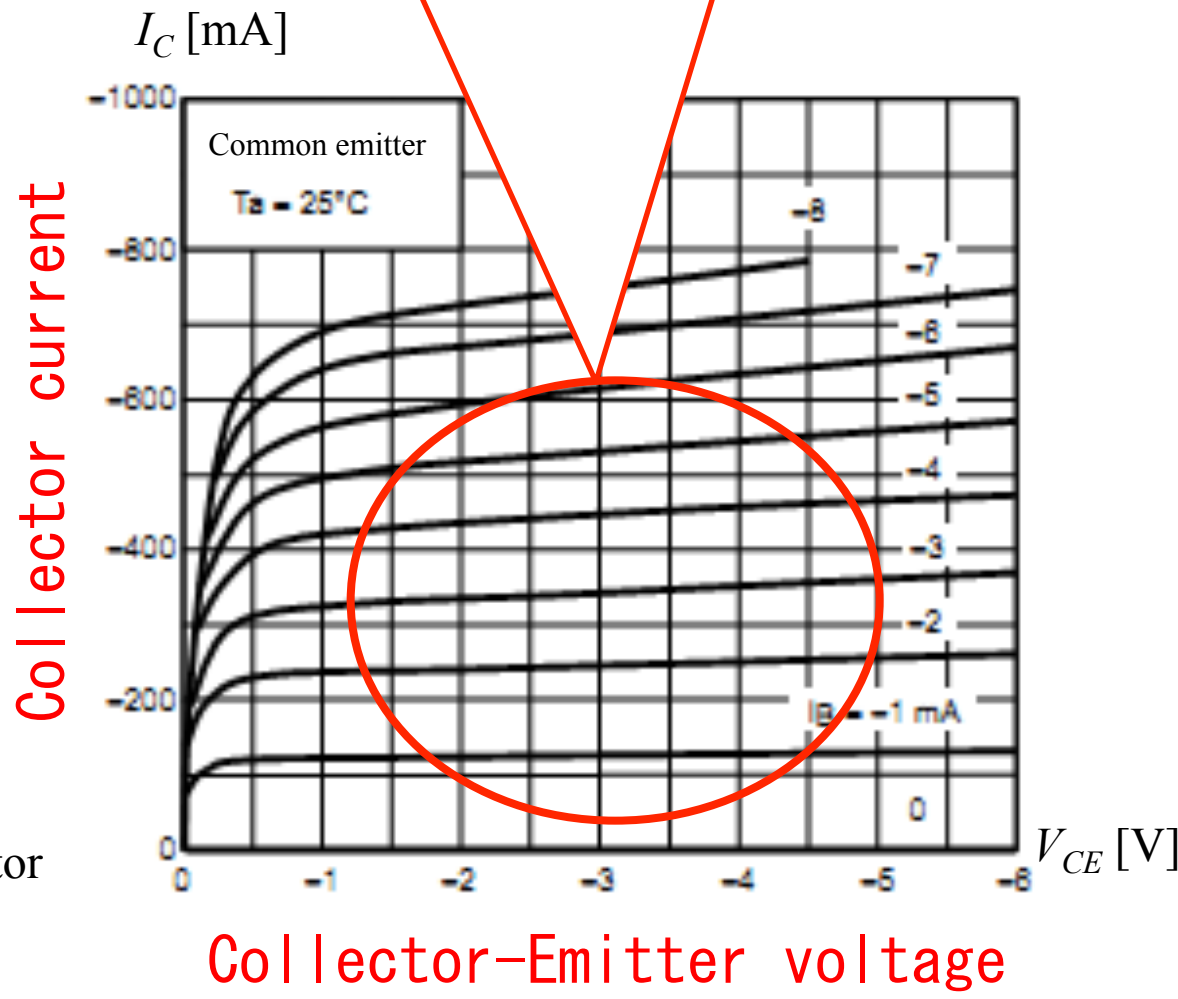
Control the motor speed by changing the voltage v_1. After rotating the motor at a low speed for a few minutes, check the temperature of the transistor by touching it. Be careful not to burn your finger.



Operating region of the transistor in an A-class amplifier



Amplifier using an NPN-type transistor



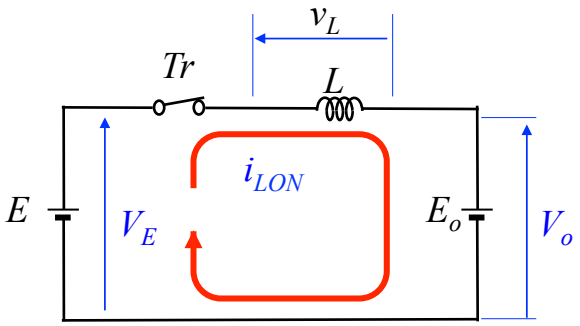
STEP 4. problem 1 The circuits below are equivalent circuits in the case where Tr is ON and OFF, respectively. The switching frequency of transistor Tr is high enough that resistance components in the circuits are negligible. Answer the following questions.

(a) Write the differential equations in the case of Tr-ON/OFF, respectively.

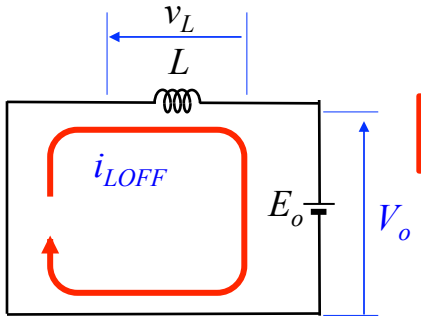
(b) Assuming that current $i_{LON} = I_1$ at $t = t_1$, $i_{LON} = I_2$ at $t = t_2$, $i_{LOFF} = I_2$ at $t = t_2$, and $i_{LOFF} = I_1$ at $t = t_1 + T_{SW}$, solve the differential equations.

(c) From the solutions in (b), derive two expressions of the relationship between I_2 - I_1 and duty ratio δ and switching period T_{SW}.

(d) Derive the relation between output voltage V_o and source voltage V_E.



(a) Tr ON



(b) Tr OFF