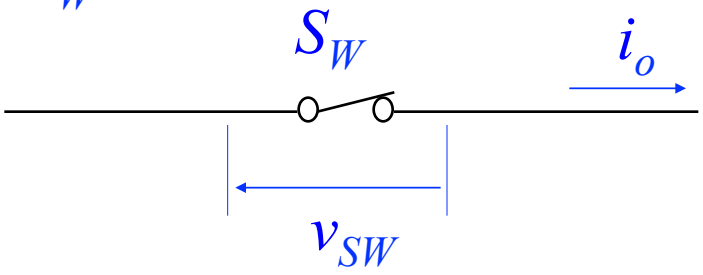
Power Electronics
No.4: Step-down Chopper

Takeshi Furuhashi
Furuhashi_at_cse.nagoya-u.ac.jp

Basic idea for high efficiency

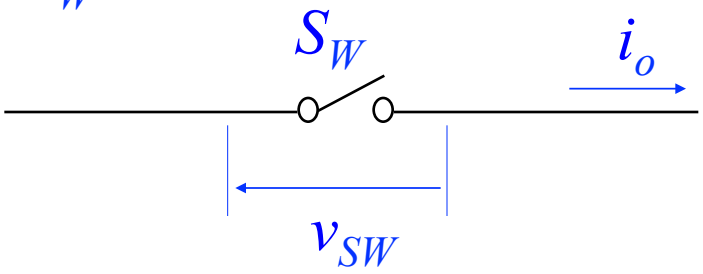
S_W ON



$$v_{SW} = 0$$

$$P_{SW} = v_{SW} i_o = 0$$

S_W OFF

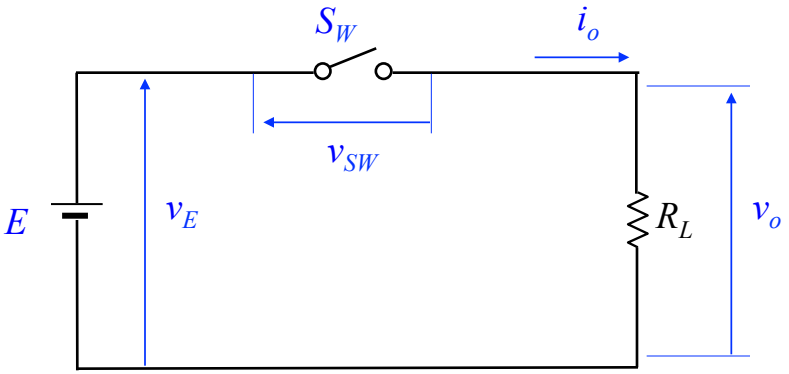


$$i_o = 0$$

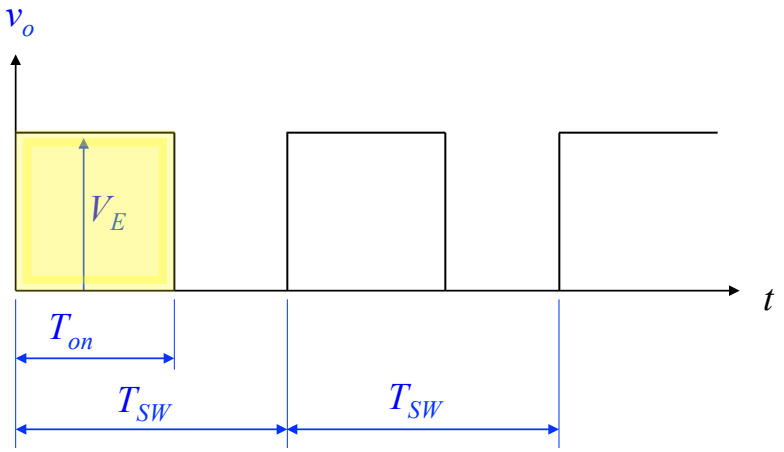
$$P_{SW} = v_{SW} i_o = 0$$

➡ Loss by S_W is zero.

Output voltage control by switching



(a) Switching circuit

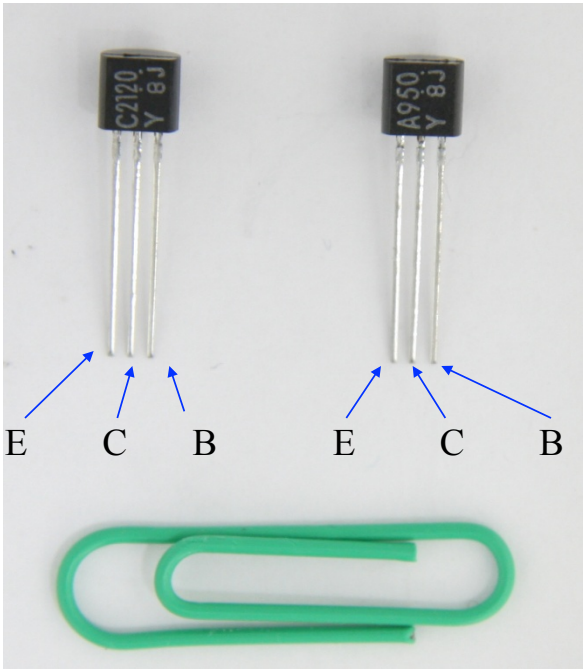


(b) Waveform of output voltage

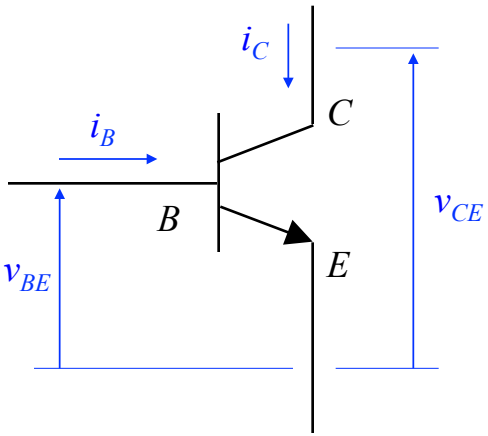
$$\bar{v}_o = \frac{1}{T_{SW}} \int_0^{T_{on}} V_E dt = \frac{T_{on}}{T_{SW}} V_E$$

T_{SW}: Switching period

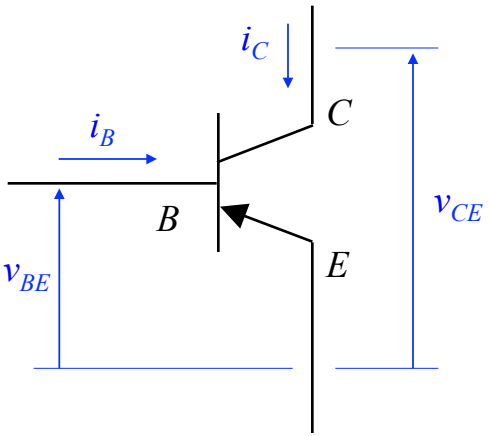
Transistor → used as a switching device



Transistor
(left: 2SC2120(NPN-type)
right: 2SA950(PNP-type))



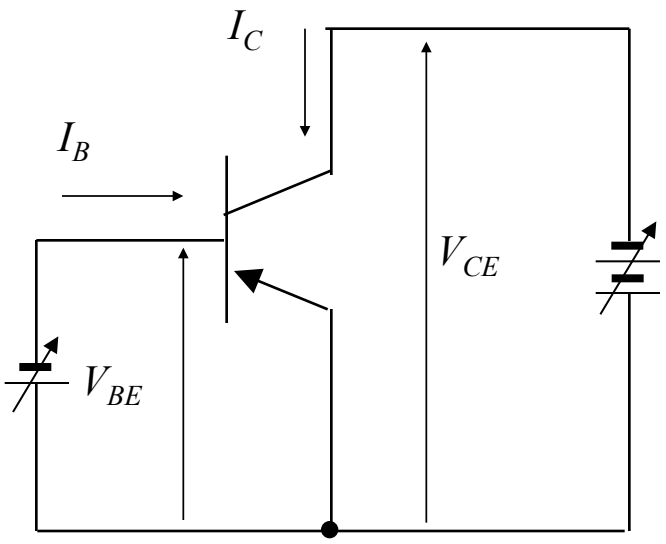
(a) NPN-type transistor



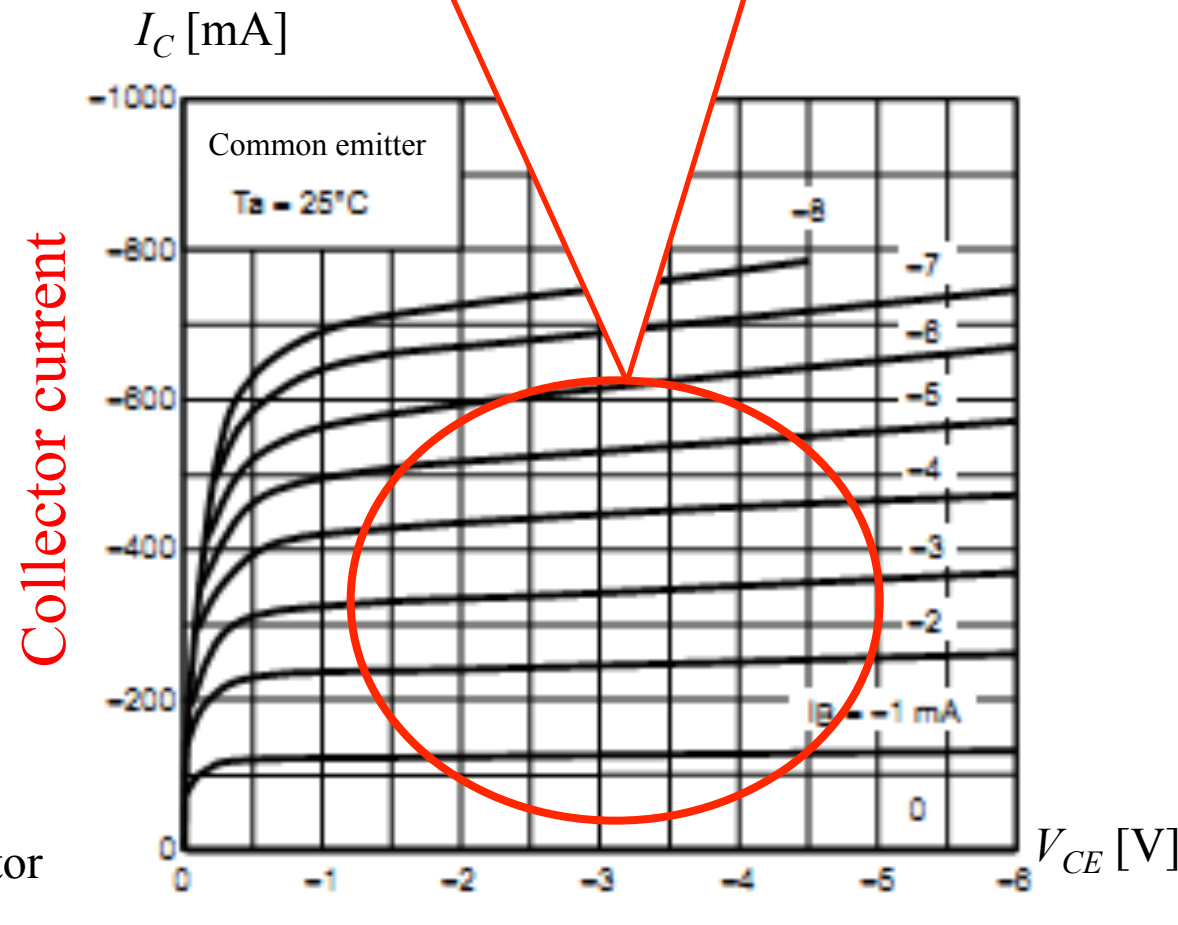
(b) PNP-type transistor

Voltage and current polarities definition

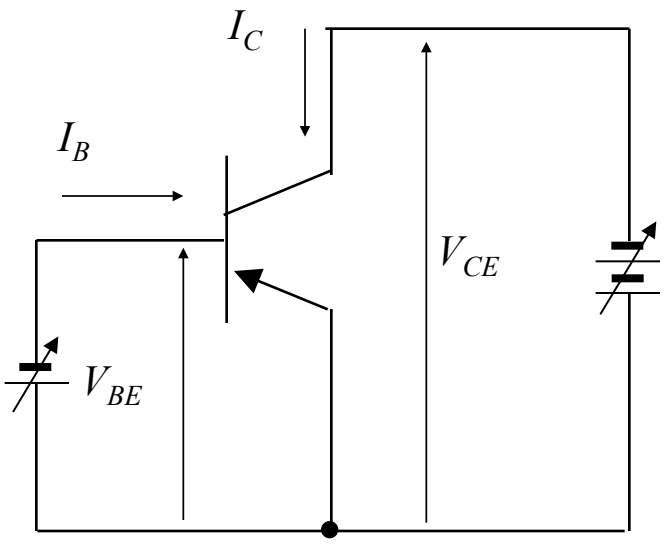
Operating region of the transistor in an A-class amplifier



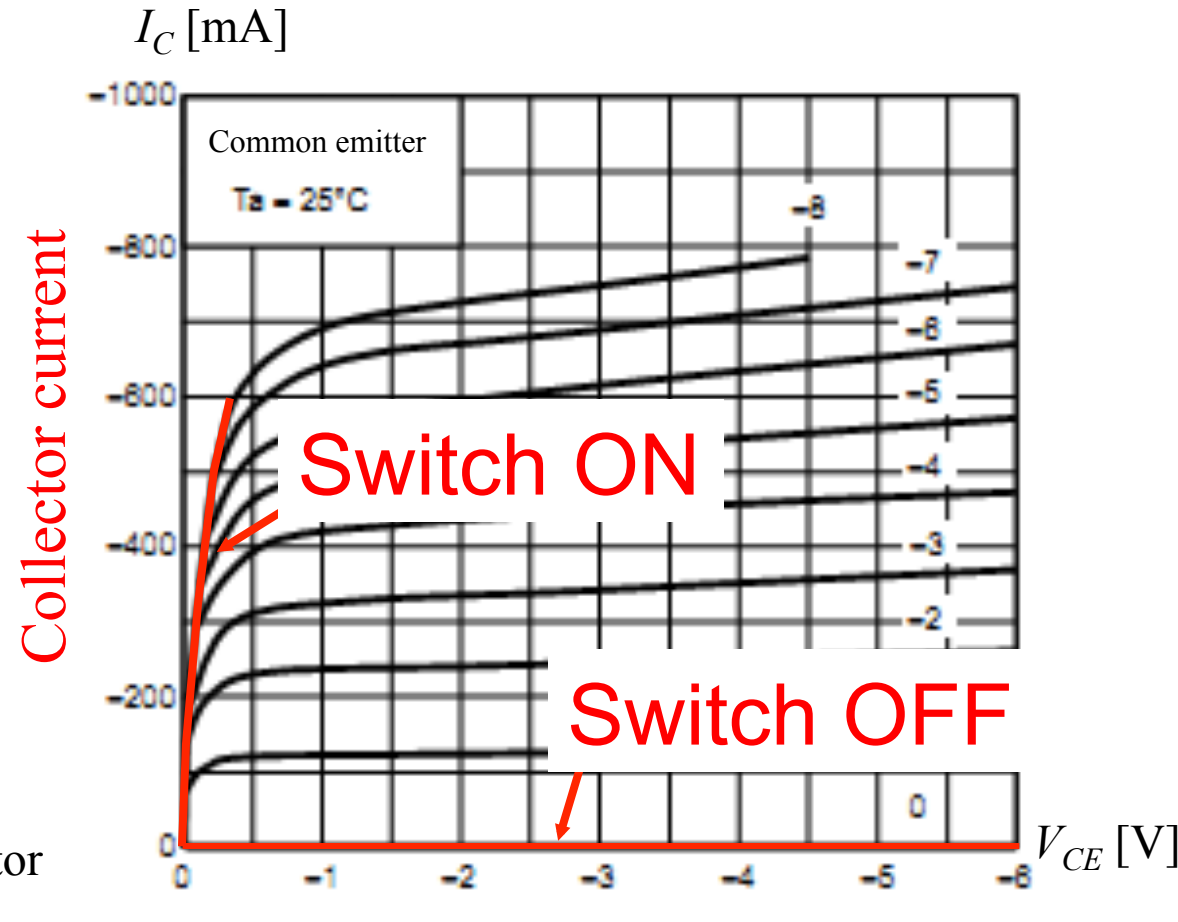
Amplifier using an NPN-type transistor



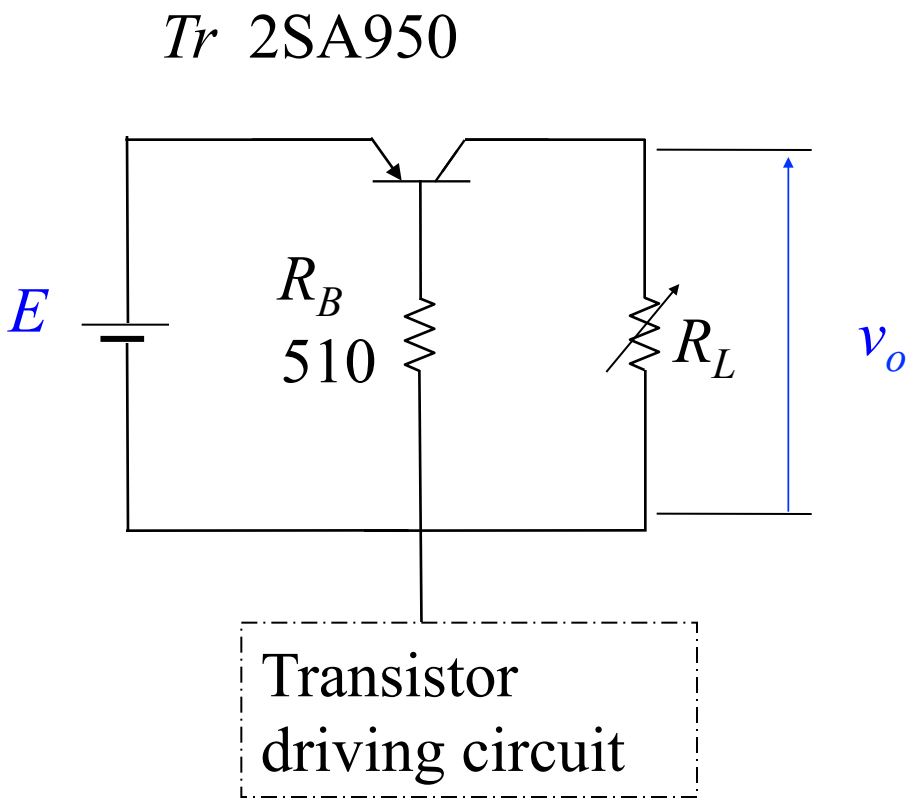
Operating region of a transistor used as a switch



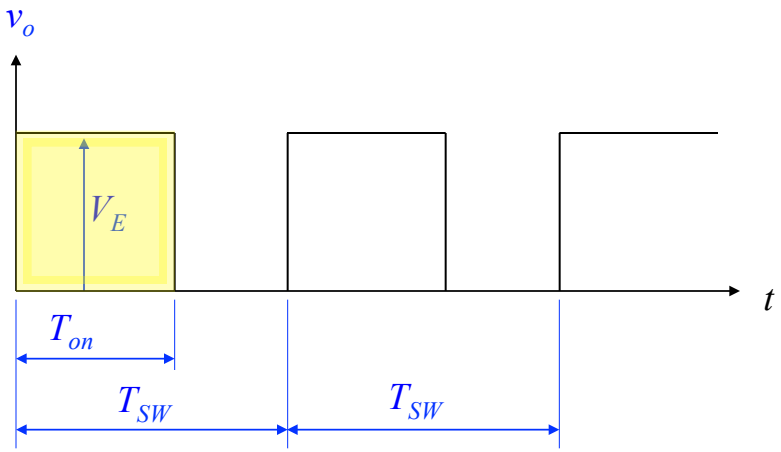
Amplifier using an NPN-type transistor



Drive transistor scheme



(a) Switching circuit

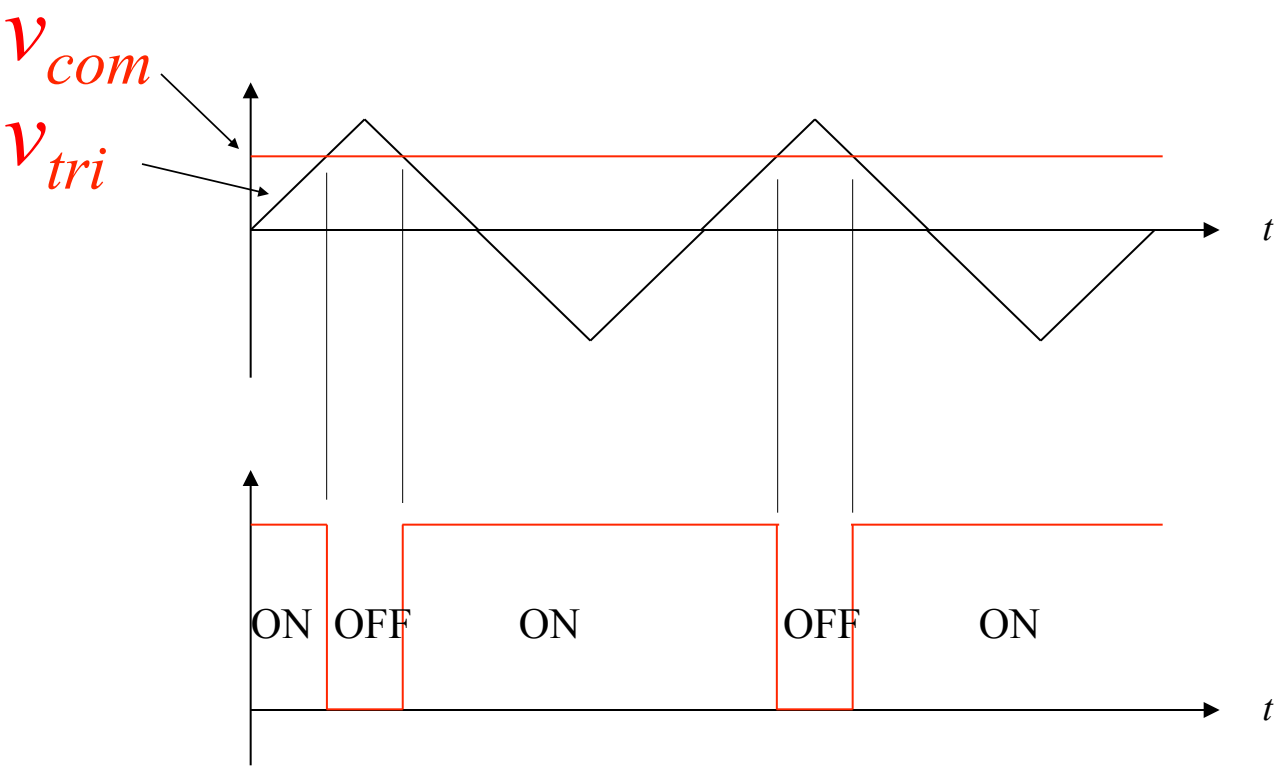


(b) Waveform of output voltage

PWM (Pulse Width Modulation) control method

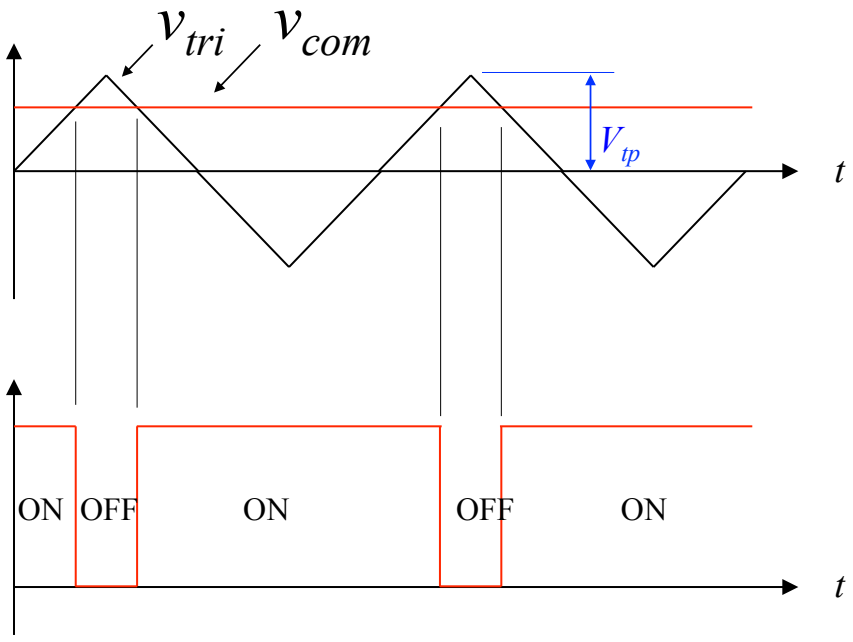
If $v_{com} \geq v_{tri}$, then Tr is turned on.

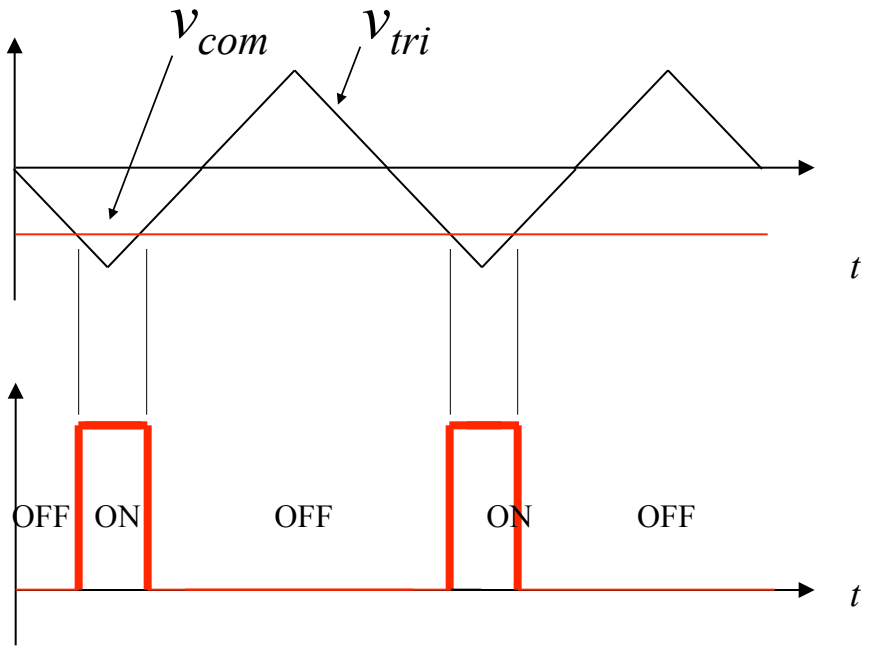
If $v_{com} < v_{tri}$, then Tr is turned off.



PWM control method

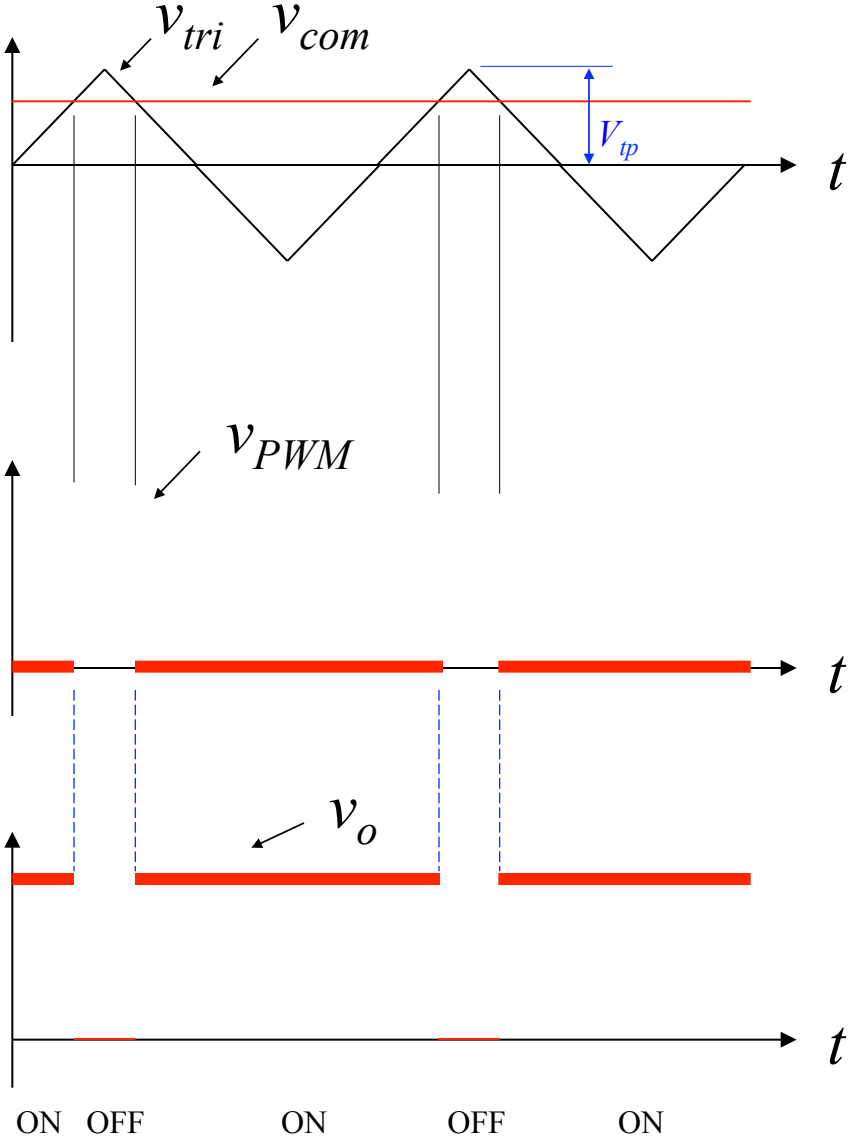
PWM (Pulse Width Modulation) control method

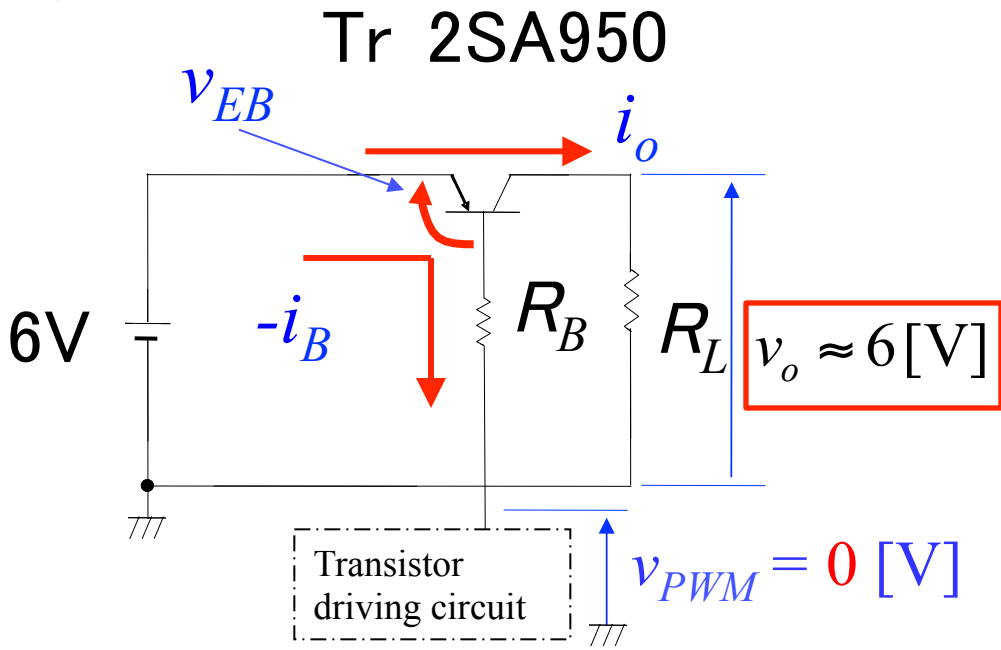




PWM control method

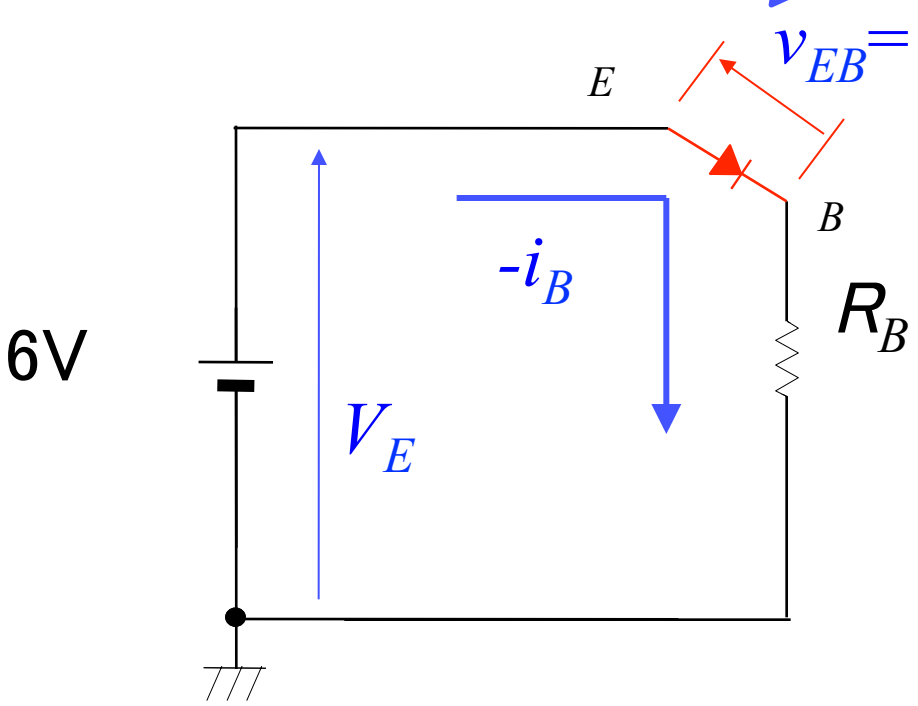
Drive transistor scheme (Tr:ON)





When $v_{PWM} = 0$ [V]

The emitter-base circuit of a PNP-type transistor such as 2SA950 can be modeled by a diode.

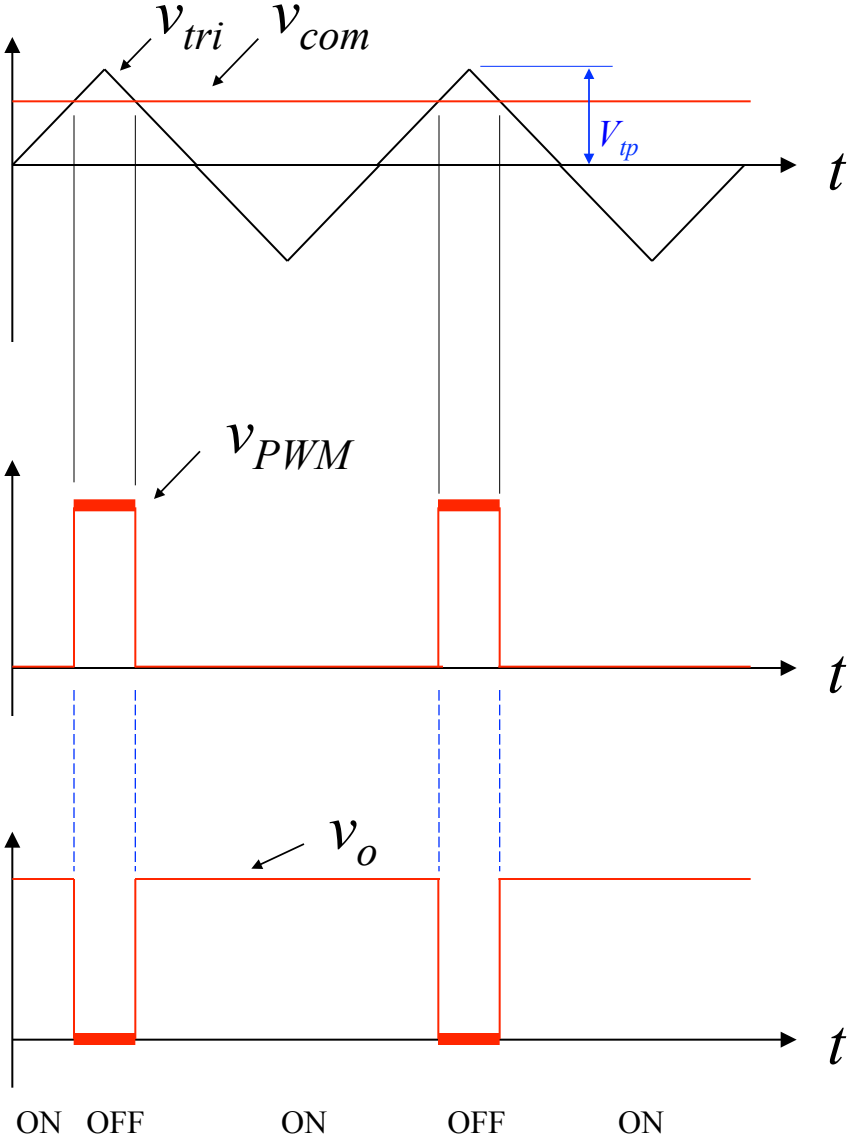


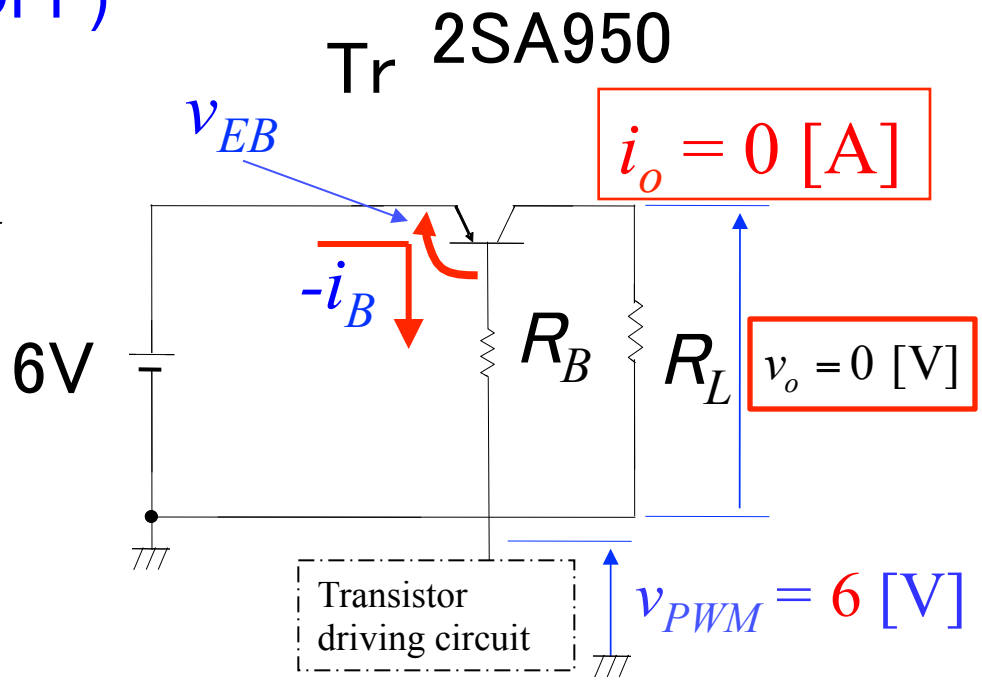
$$-i_B = \frac{V_E - v_{EB}}{R_B}$$

$$= \frac{6 - 0.7}{R_B} \approx \text{xx [mA]}$$

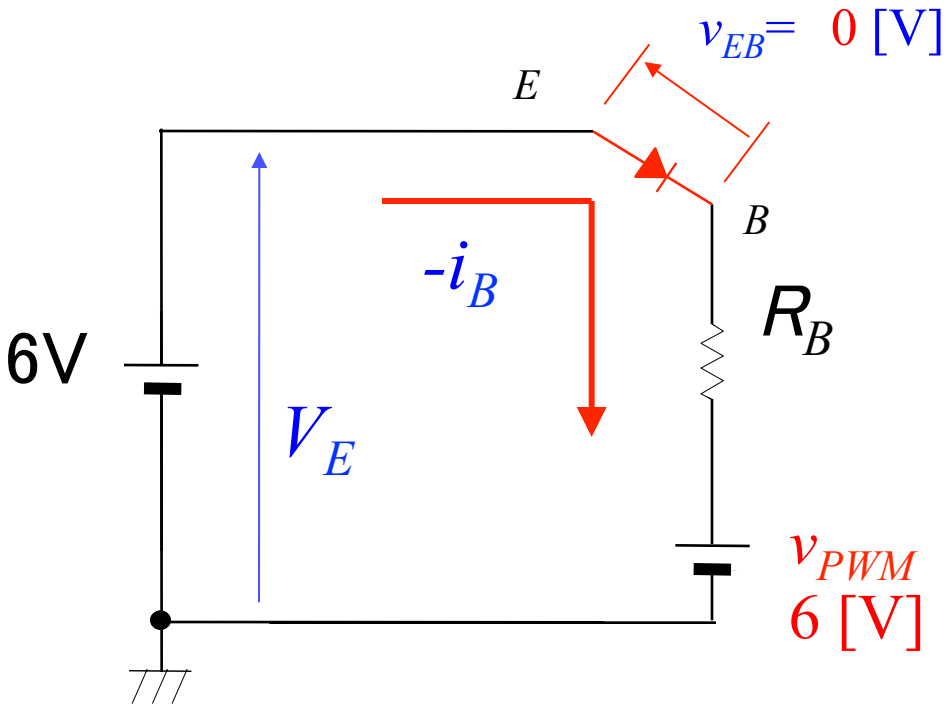
Equivalent circuit between emitter-base circuits

Drive transistor scheme (Tr:OFF)





When $v_{PWM} = 6$ [V]



$$-i_B = \frac{V_E - v_{BE} - v_{PWM}}{R_B}$$

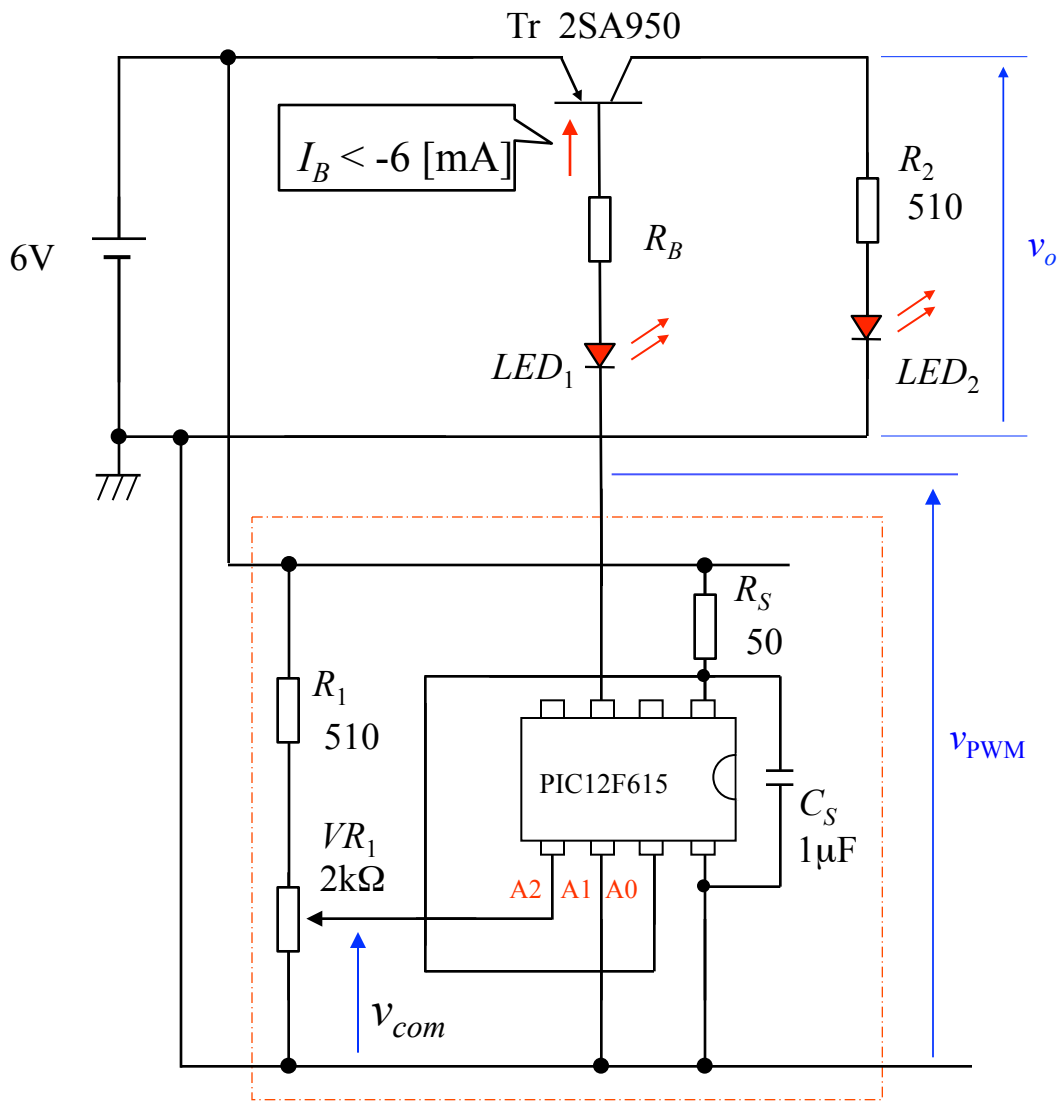
$$= \frac{6 - 0 - 6}{R_B} = 0\,[\mathrm{mA}]$$

$$i_B = 0\,[\mathrm{mA}]$$

Equivalent circuit between emitter-base circuits

STEP 3. Circuit construction practice (Step-down chopper)

Construct the step-down chopper shown below. Design the base resistance of transistor Tr, so that the base current I_B < -6 [mA] when Tr is ON.



(A1 A0 = 01)

The forward bias voltage of LED (LED_1) is approximately 1.7[V].

A1 A0 = 01: Mode for very slow PWM

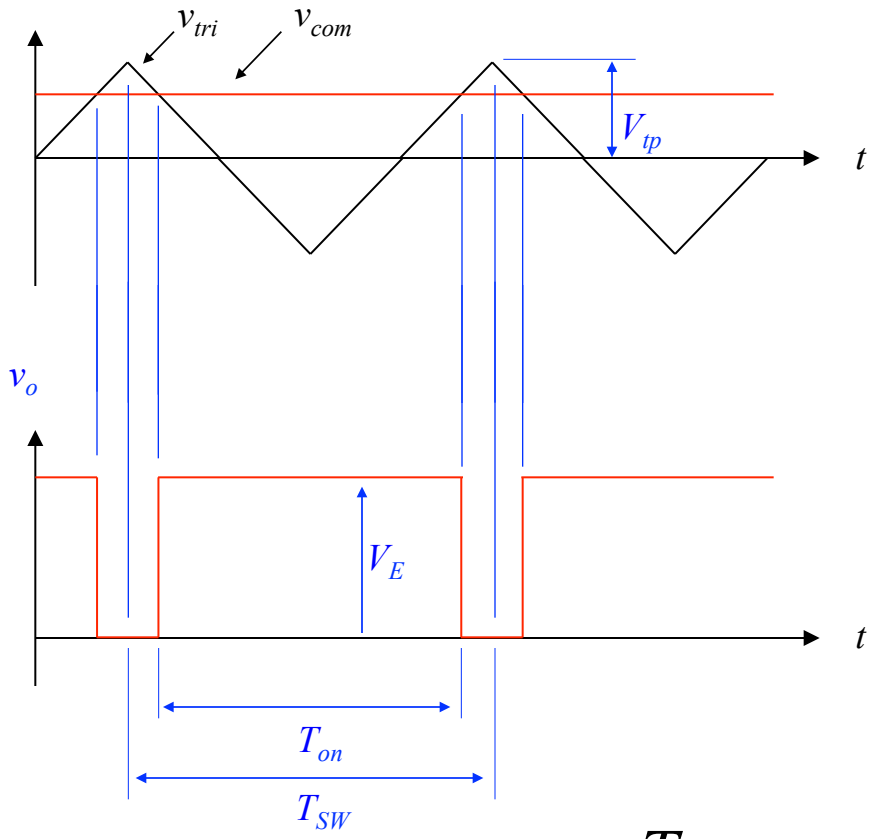
A2 = Voltage command input

P1A = 0.5HzPWM output

Step 3. Problem 1

The ratio between on-period T_{on} and switching period T_{sw} is called the "duty ratio," δ. Derive the following when the triangular voltage v_{tri}, command voltage v_{com}, and output voltage of chopper v_o are given in the right figure. The peak value of the triangular voltage is V_{tp}. The output voltage of the chopper is V_E when Tr is ON:

(a) Relation between δ and v_{com}.
(b) Relation between the average of output voltage V_o and v_{com}



$$\delta = \frac{T_{on}}{T_{SW}}$$

δ: duty ratio
T_{on}: on-period of transistor
T_{SW}: switching period

Step 3. Problem 2

The figure below shows a series circuit of resistor R and reactor L. Assume that switches SW_1 and SW_2 are OFF.
At $t = 0$, switch SW_1 is turned on, at $t = L/R$, switch SW_1 is turned off, and switch SW_2 is turned on. Then, at $t = 2L/R$, switch SW_1 is turned on, and switch SW_2 is turned off. At $t = 3L/R$, switch SW_1 is turned off, and switch SW_2 is turned on. This switching is repeated (i.e., at $t = (2n\text{-}1)L/R$ ($n = 1, 2, \ldots$), switch SW_1 is turned off, and switch SW_2 is turned on, and at $t = 2nL/R$ ($n = 1, 2, \ldots$), switch SW_1 is turned on, and switch SW_2 is turned off.
Draw the waveform of current i at $t \geq 0$.