Power Electronics
No. 9: Rotation speed control of DC motor using step-down converter

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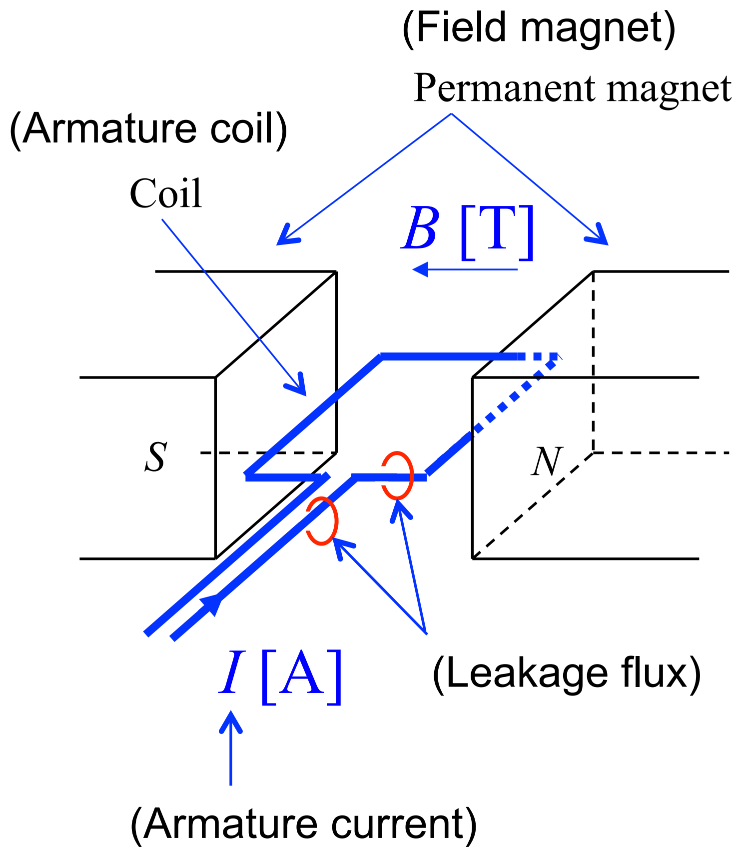
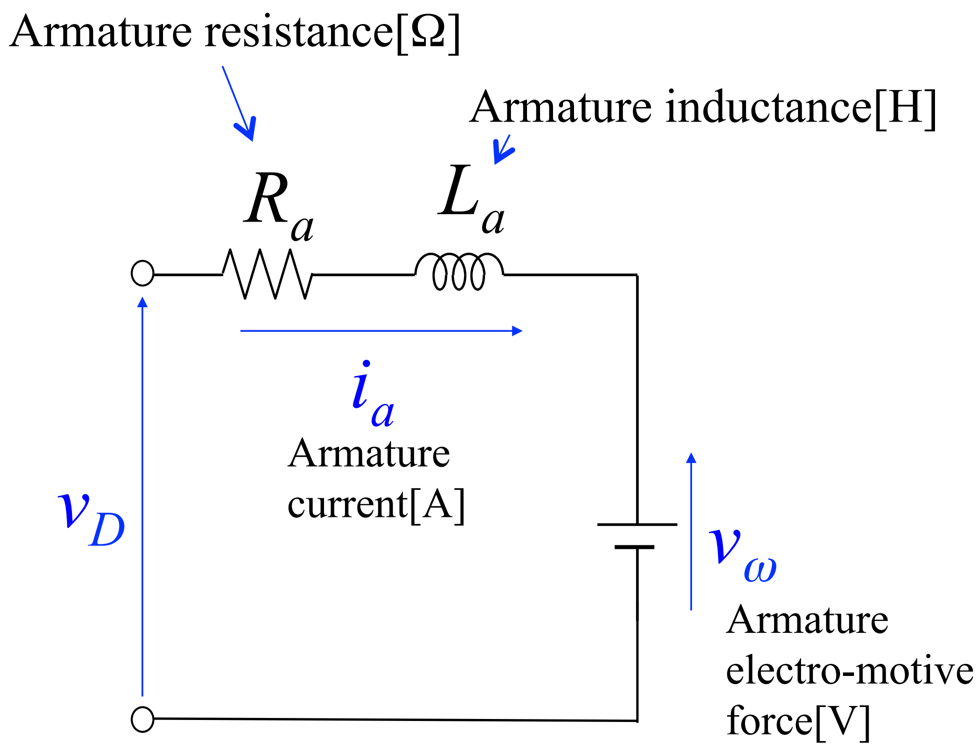


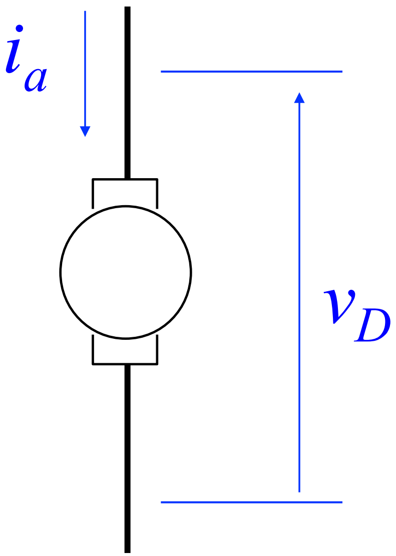


Equivalent circuit of a DC motor

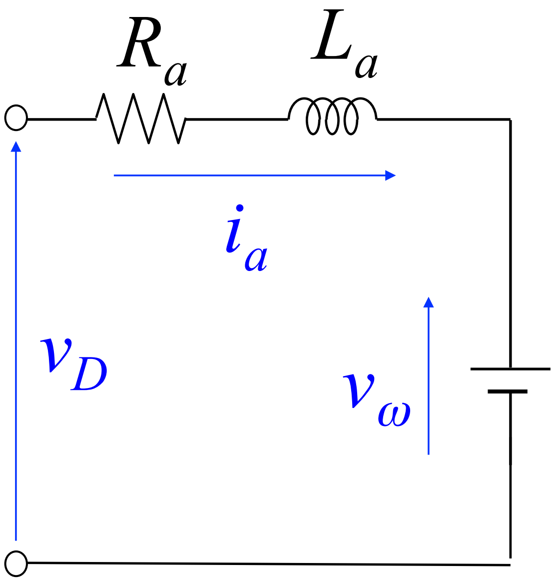
$v_\omega = K_e\,\omega$: armature electro-motive force

K_e : counter emf constant

$\omega = 2\pi\, n$



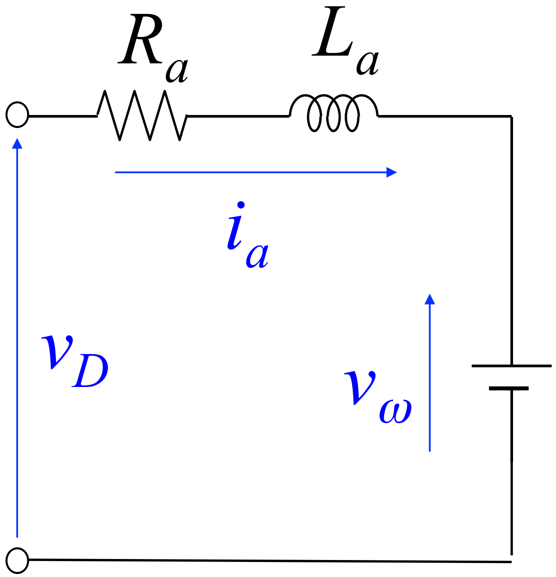
DC motor symbol



Equivalent circuit of DC motor

Differential equation of the electrical circuit of a DC motor

$$L_a \frac{\mathrm{d}\, i_a}{\mathrm{d}\, t} + R_a i_a = v_D - v_\omega$$



$$L_a \frac{\mathrm{d}\, i_a}{\mathrm{d}\, t} + R_a i_a = v_D - v_\omega$$

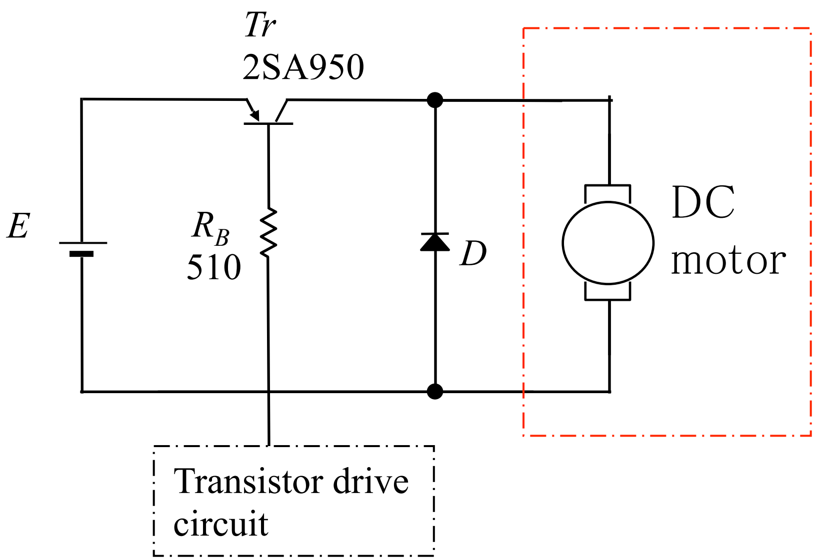
$v_D - v_\omega = E$ (constant),

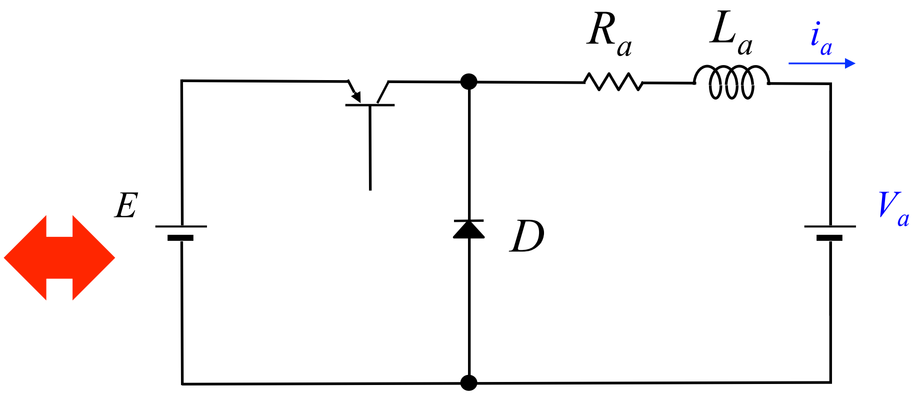
at $t = 0$, it is assumed that $i_a = 0$

$$i_a = \frac{E}{R_a}\left(1 - \exp\left(-\frac{R_a}{L_a}t\right)\right)$$

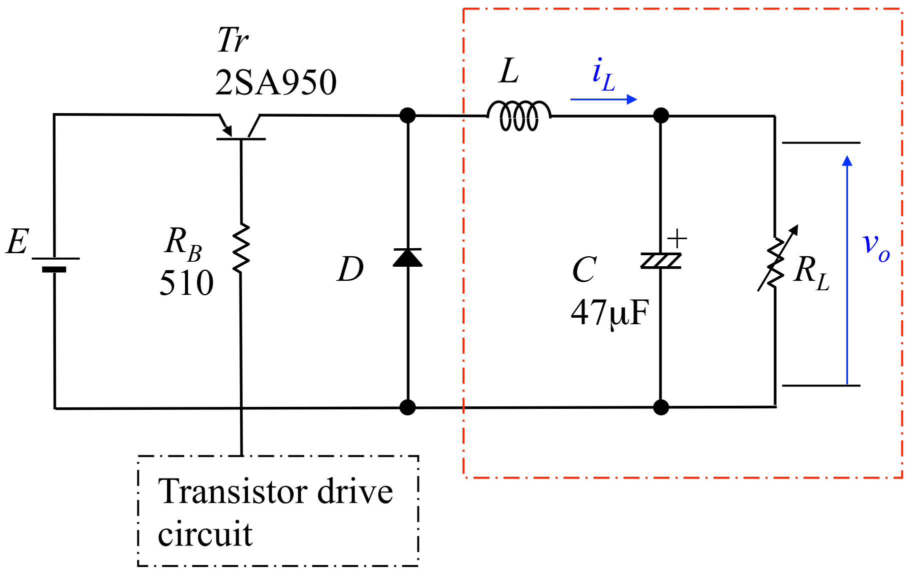
$$= \frac{E}{R_a}\left(1 - \exp\left(-\frac{t}{\tau}\right)\right)$$

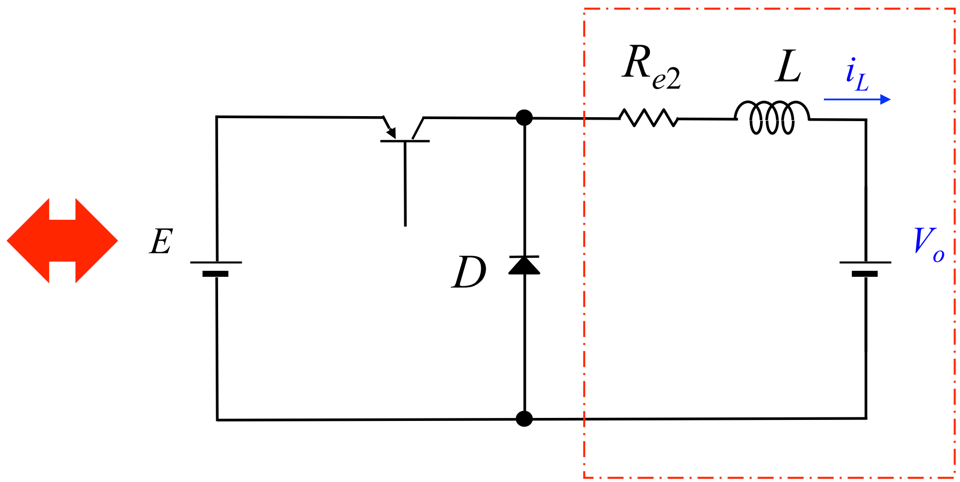
τ : time constant of an electrical circuit





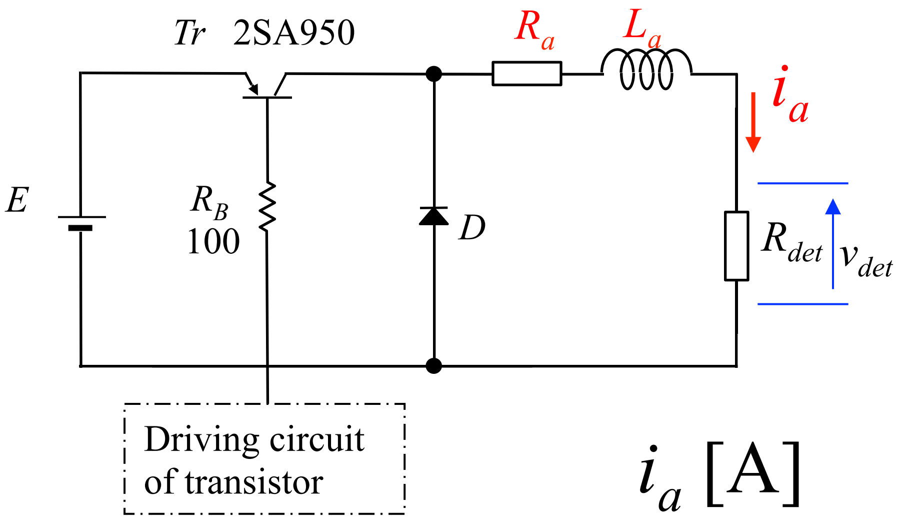
Equivalent circuit of a step-down chopper and DC motor





Equivalent circuit of a step-down chopper

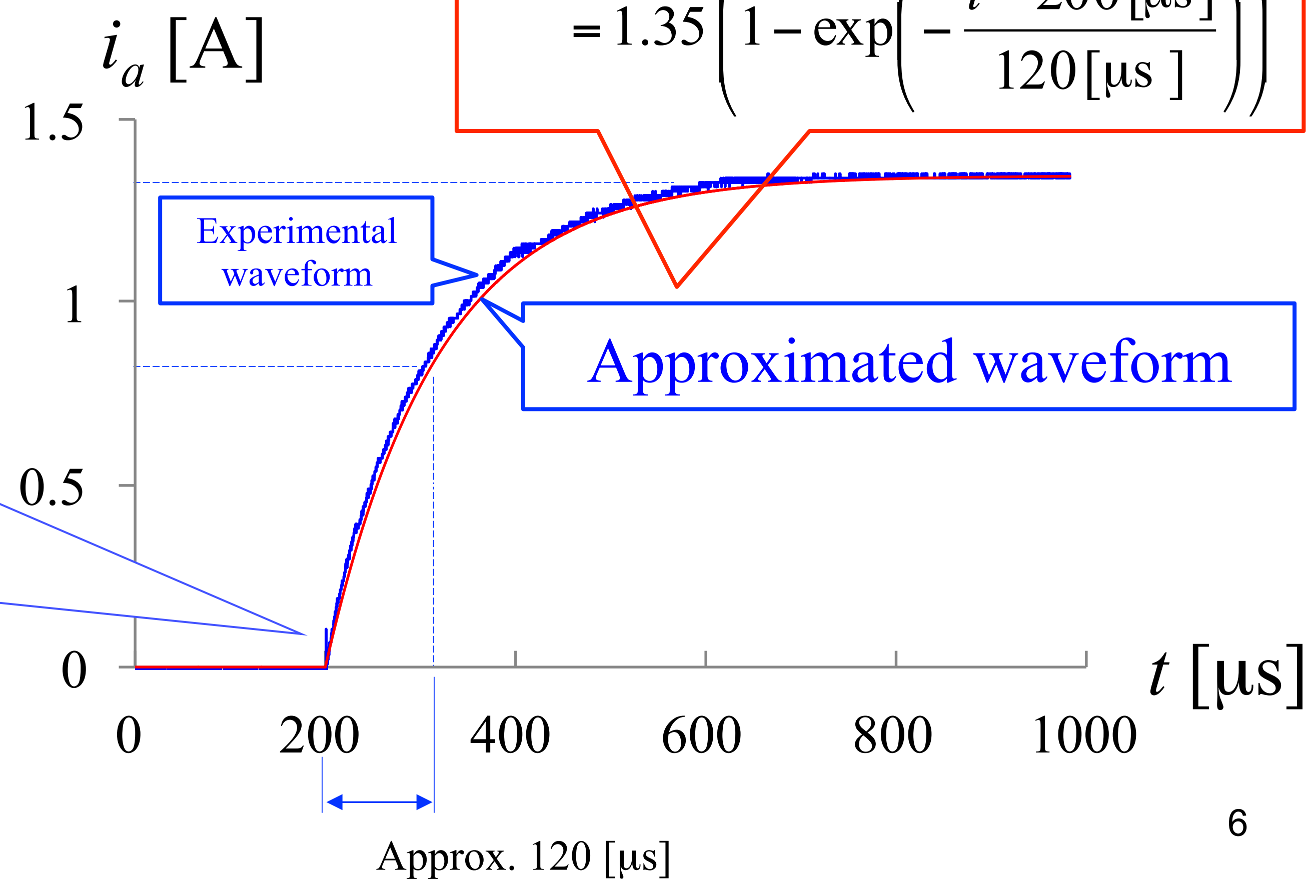
Experiment on the time constant of an electrical circuit of a DC motor



Armature resistance: R_a= 1.25 [Ω]
Resistor for detecting armature current: R_{det}= 1.2 [Ω]

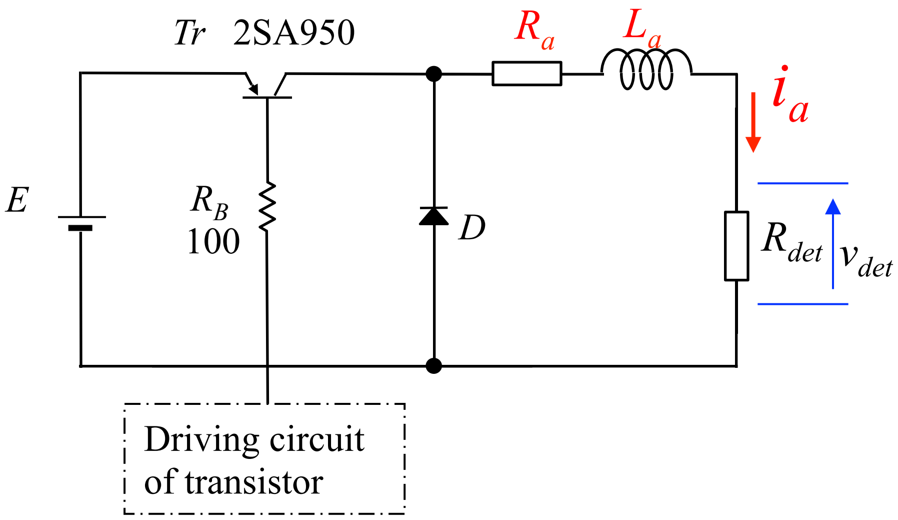
$$i_a = I_0\left(1-\exp\left(\frac{t-t_0}{\tau}\right)\right)$$

$$= 1.35\left(1-\exp\left(-\frac{t-200\,[\mu s]}{120\,[\mu s]}\right)\right)$$



At t = 0.2 [ms], step voltage was applied to the DC motor.
The rotor axis of the DC motor was locked to make v_ω = 0.

Experiment on the time constant of electrical circuit of a DC motor



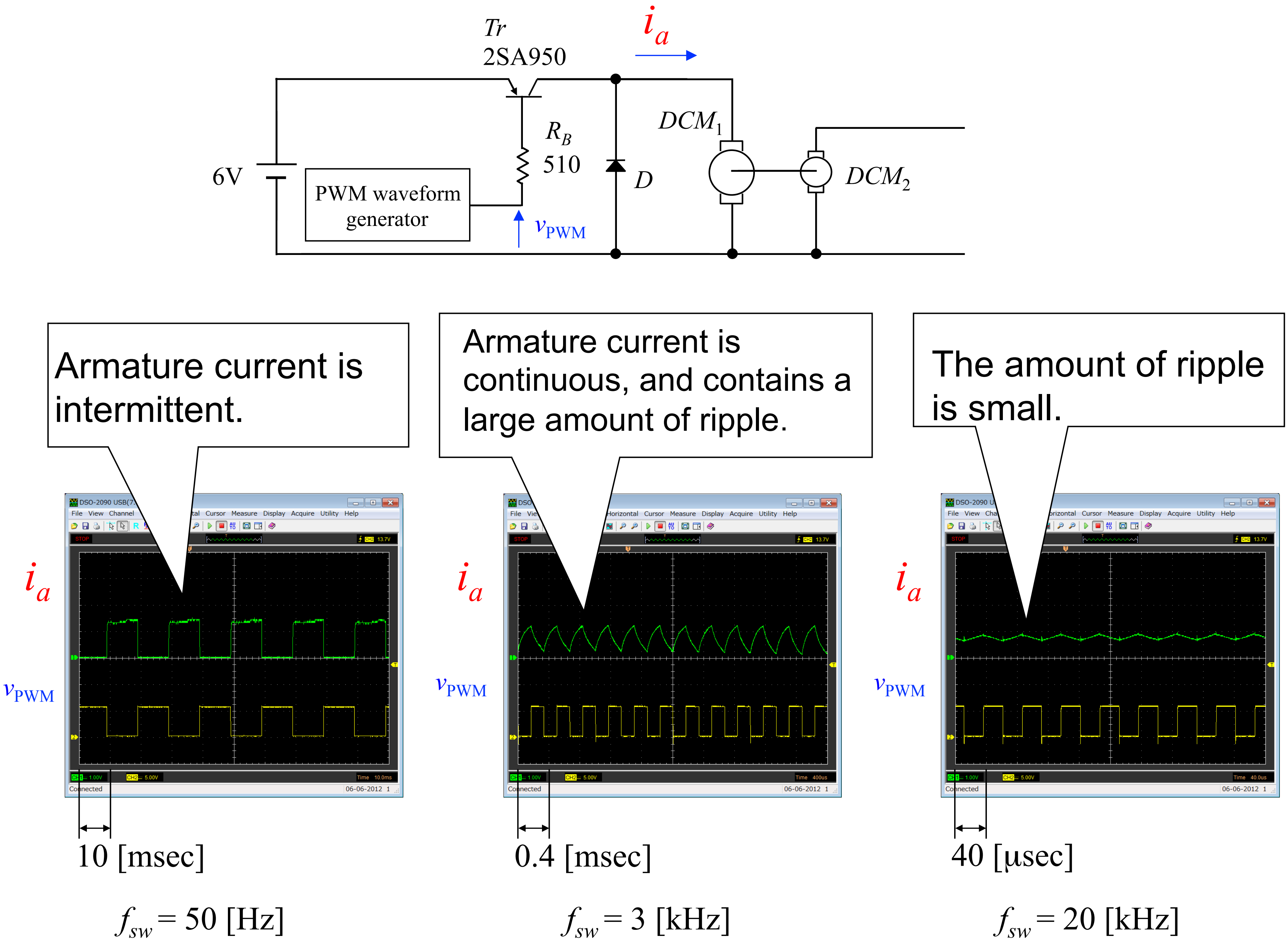
Armature resistance: R_a= 1.25 [Ω]
Resistor for detecting armature current: R_{det}= 1.2 [Ω]

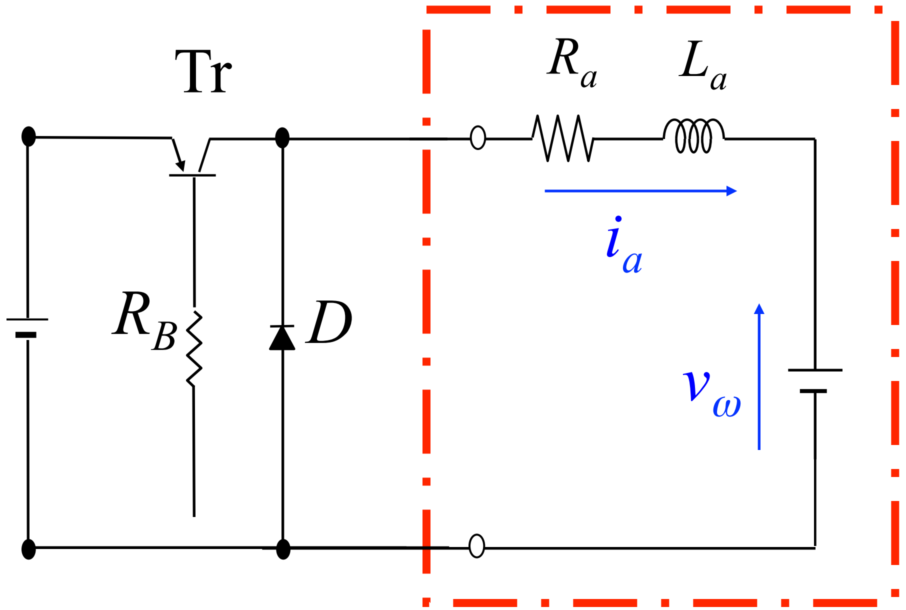
$$\tau = \frac{L}{R_a + R_{\text{det}}}$$

$$L = \tau\left(R_a + R_{\text{det}}\right)$$

$$\approx 120\,[\mu s] \times 2.5\,[\Omega]$$

$$= 0.3\,[\text{mH}]$$


Tr
2SA950
i_a
6V
PWM waveform generator
R_B
510
v_{PWM}
D
DCM_1
DCM_2
Armature current is intermittent.
Armature current is continuous, and contains a large amount of ripple.
The amount of ripple is small.
i_a
v_{PWM}
10 [msec]
0.4 [msec]
40 [μsec]
$f_{sw} = 50$ [Hz]
$f_{sw} = 3$ [kHz]
$f_{sw} = 20$ [kHz]



Armature resistance: R_a

$$T_{sw} << \tau$$

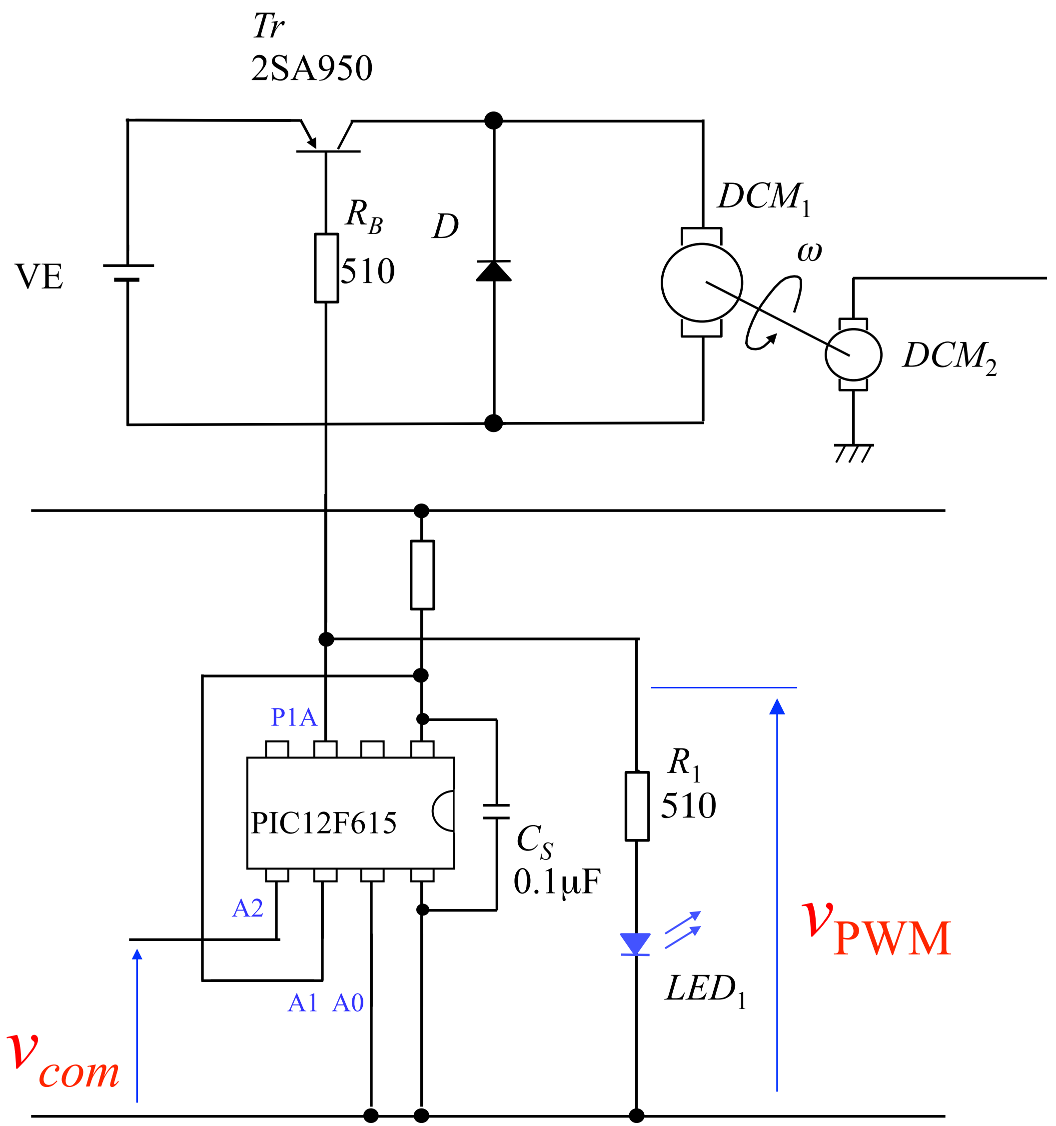
$L_a = 0.3$ [mH]

$R_a = 1.3$ [Ω]

$\tau = R_a / L_a = 0.23$ [ms]

$$T_{sw} = 0.08 \text{ [ms]}$$

$$\rightarrow f_{sw} = 12.5 \text{ [kHz]}$$

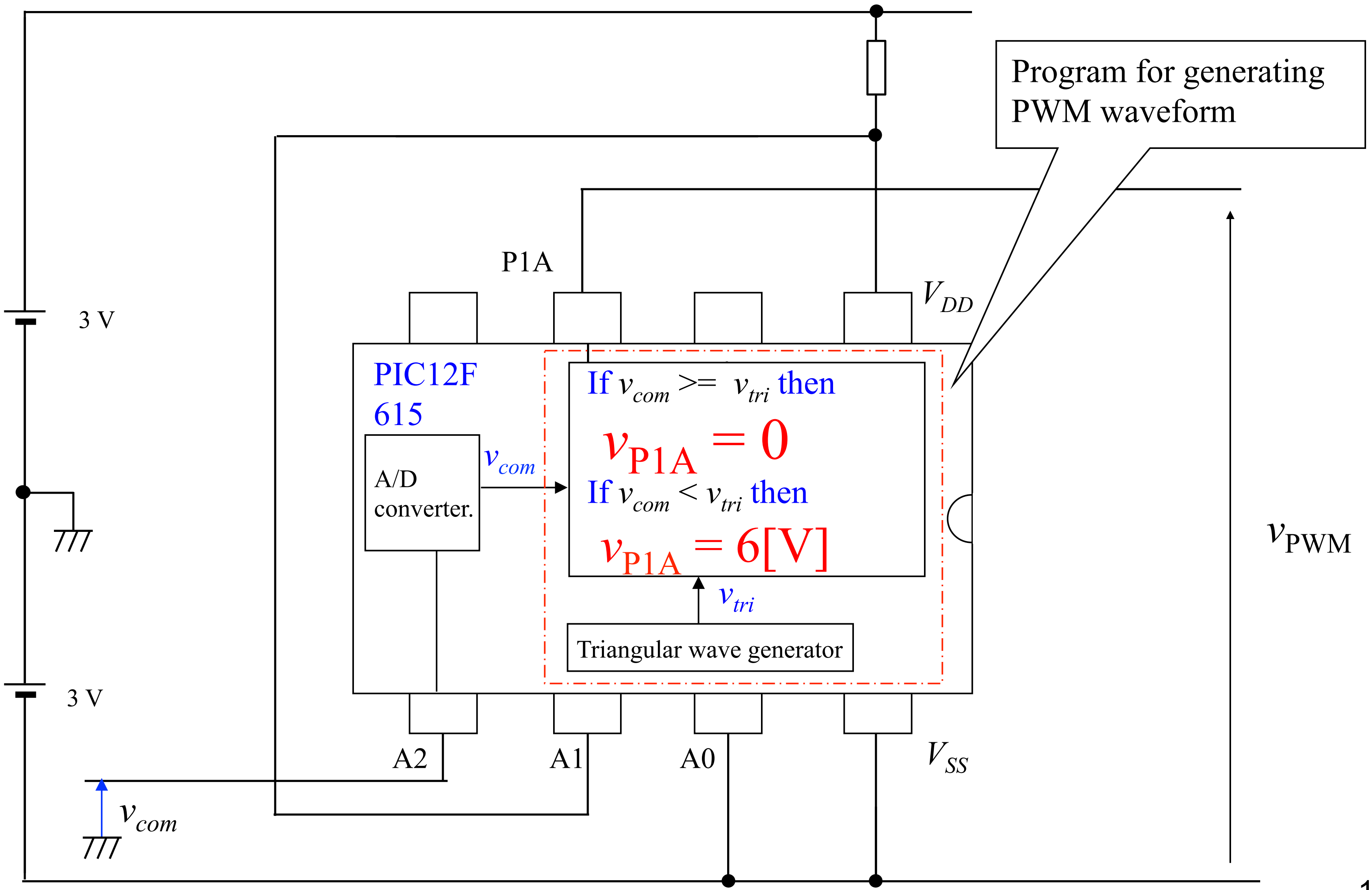


A1 A0 = 10: Mode for driving DC motor
P1A = 12.5kHzPWM output

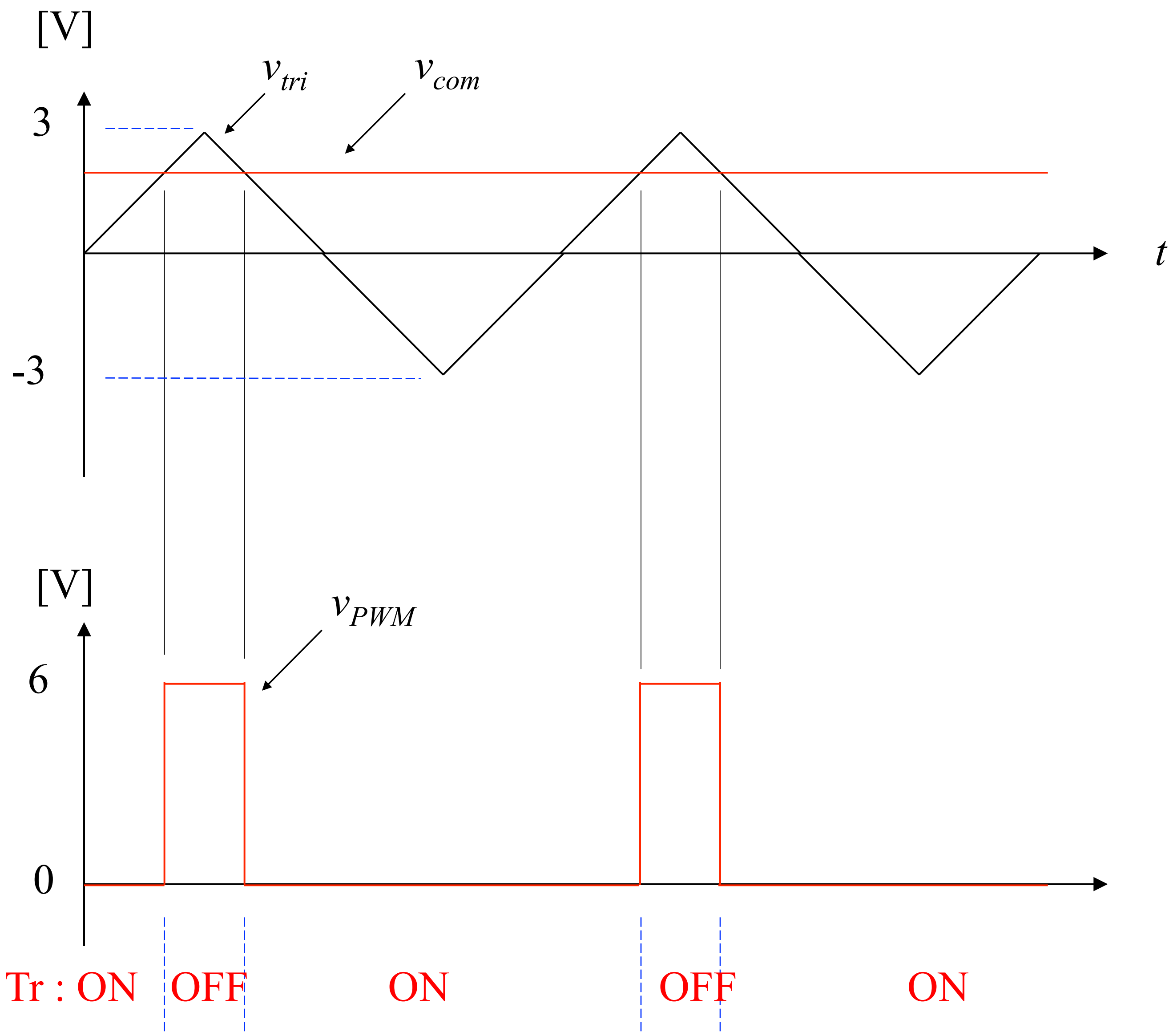
Drive of DC motor using step-down chopper

Micro computer program

(A1 A0 = 10 : mode for driving DC motor, f_{PWM} =12.5kHz)

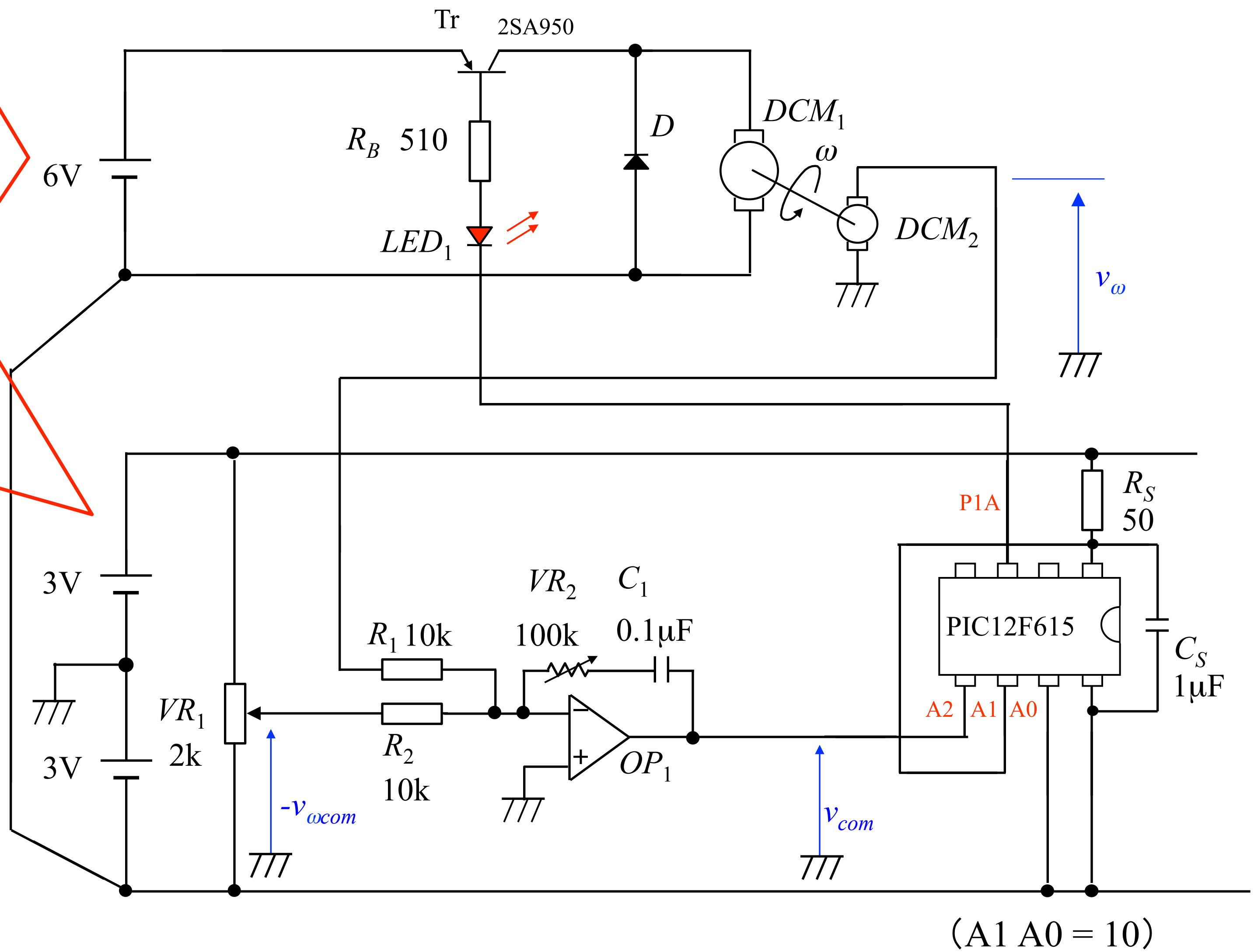


What the micro-computer does.



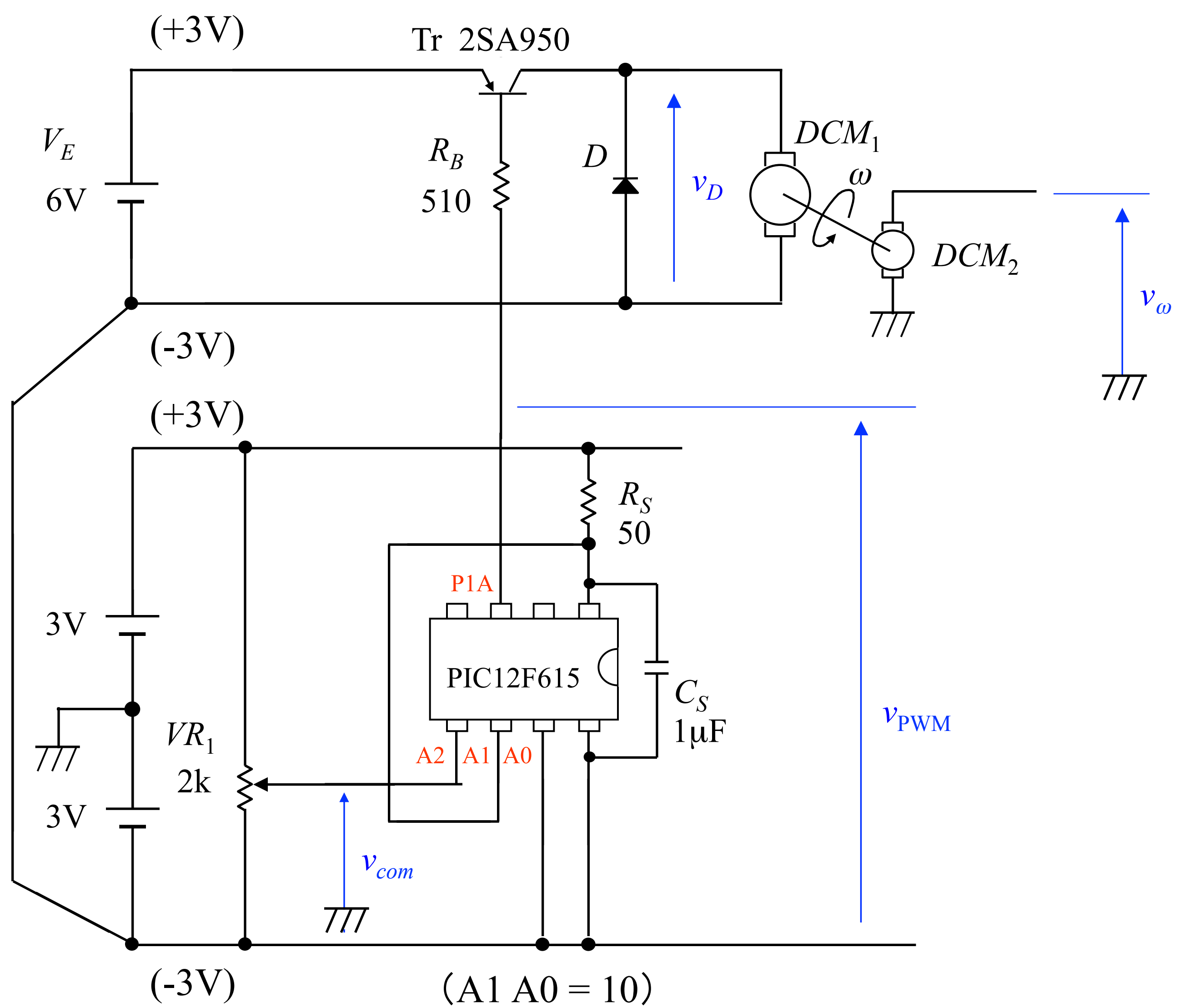
STEP 7. Circuit construction practice Construct the DC motor speed control system below. The source voltage of the op-amp should be set at ±3 [V].

Separate the battery for the chopper circuit from that for the op-amp and the micro controller. This will free the op-amp and mi-con from noise generated by the chopper circuit and motor



STEP 7. Problem 1

Answer questions (a) and (b) on the next page regarding why motor speed v_ω increases when voltage command v_{com} increases.



STEP 7. Problem 1 (continued)

The figure below shows how the PWM waveform is generated. The output voltage of micro-computer v_{PWM} is determined according to the difference between triangular waveform v_{tri} and command voltage v_{com}.

(a) In which periods is transistor Tr turned on/off?

(b) If v_{com} increases,

1) is the average voltage across diode v_D higher or lower?

2) does motor speed v_ω go up or down?