Power Electronics
No. 15: Three-phase Inverter II

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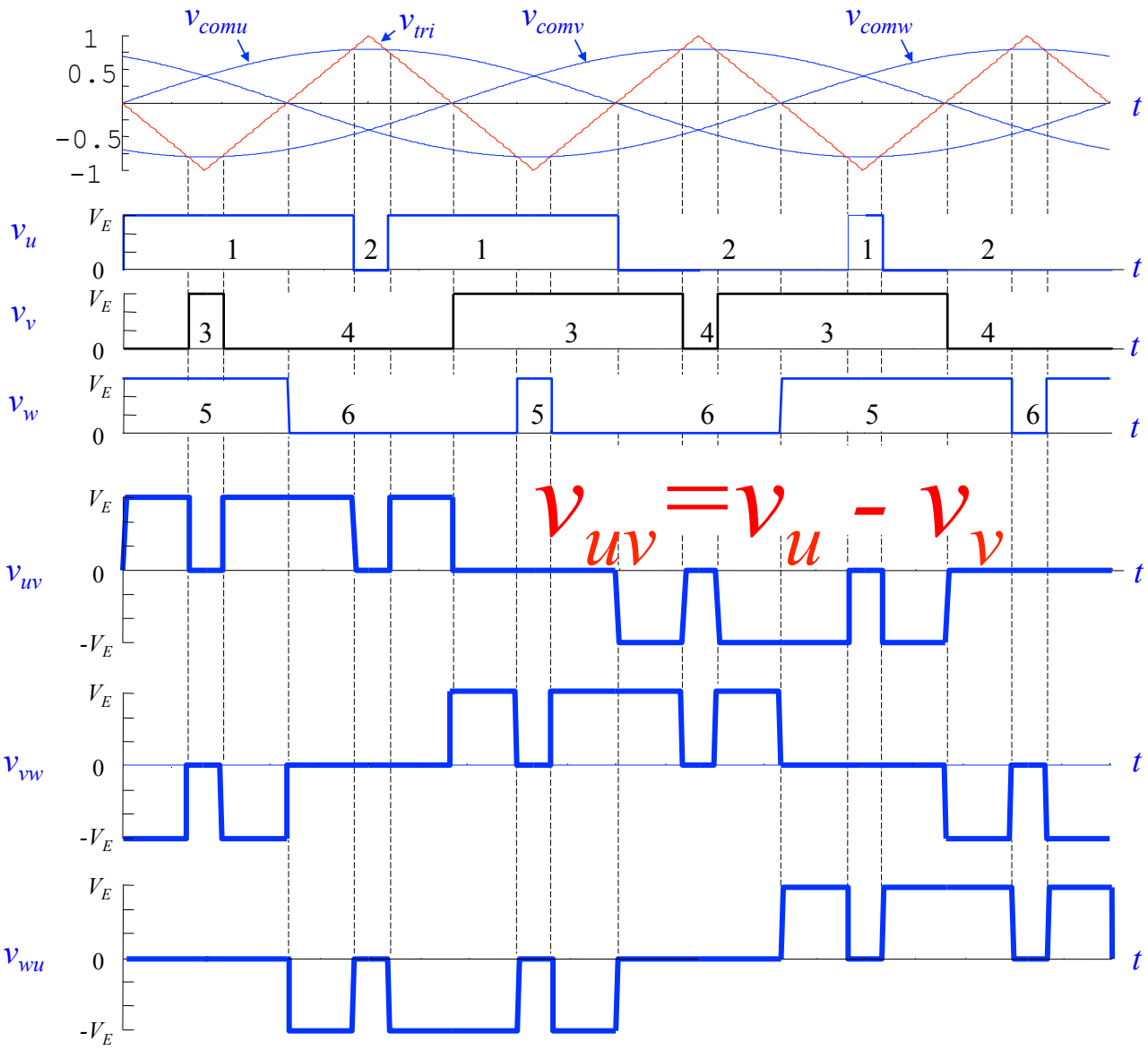
Three Pulse PWM

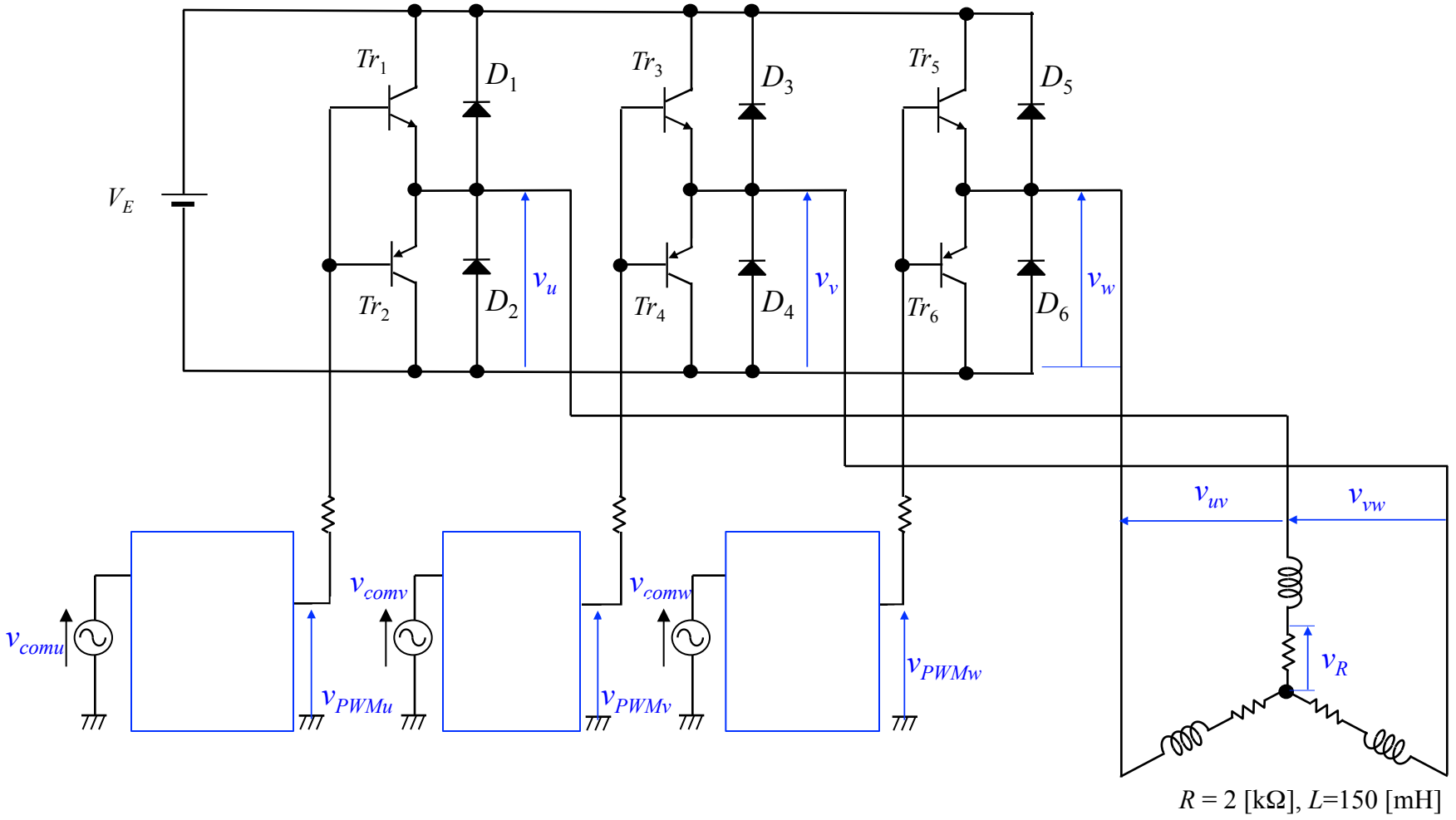


If $v_{comu} > v_{tri}$
Tr1 ON, Tr2 OFF
If $v_{comu} < v_{tri}$
Tr1 OFF, Tr2 ON

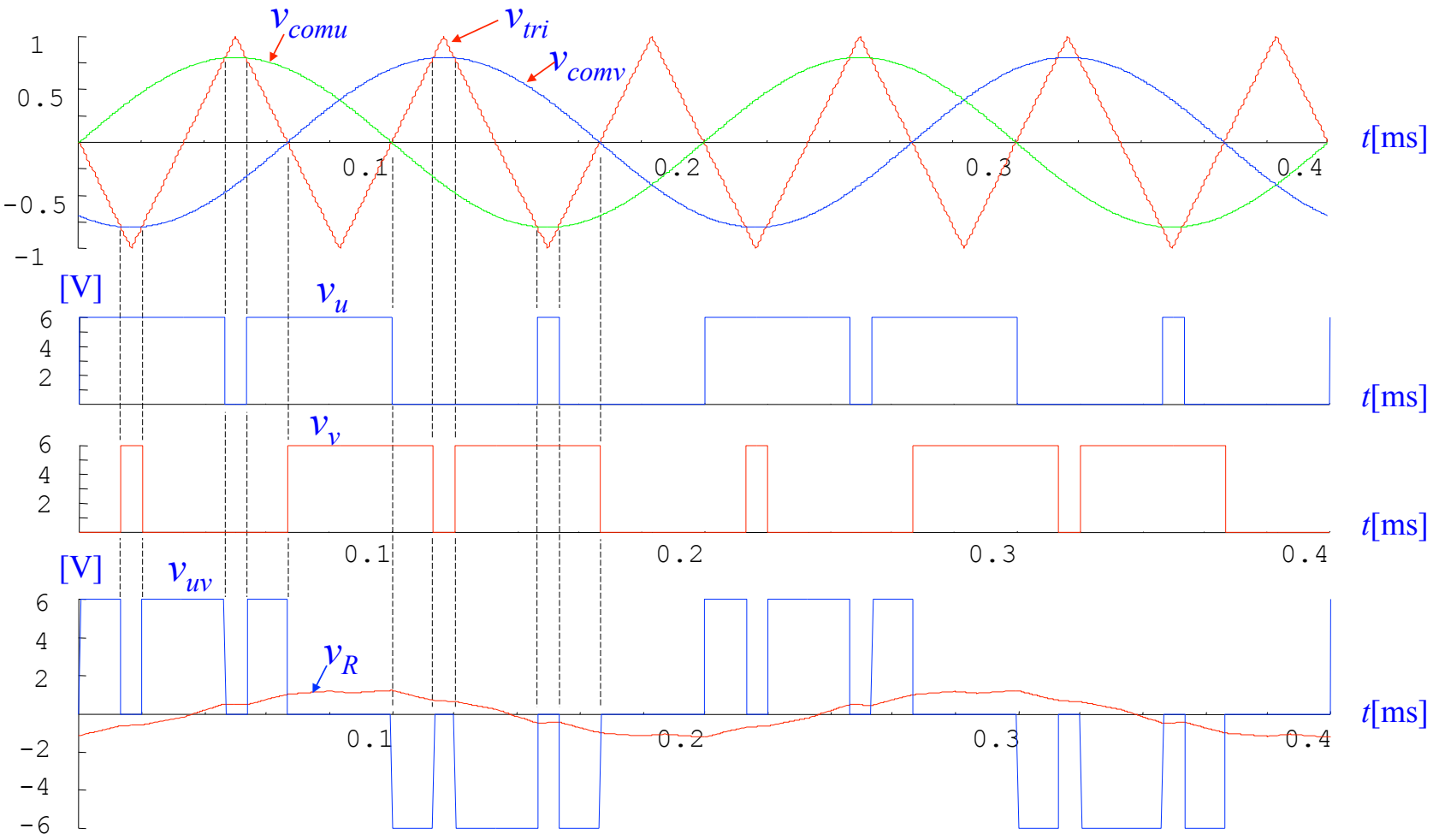
If $v_{comv} > v_{tri}$
Tr3 ON, Tr4 OFF
If $v_{comv} < v_{tri}$
Tr3 OFF, Tr4 ON

If $v_{comw} > v_{tri}$
Tr5 ON, Tr6 OFF
If $v_{comw} < v_{tri}$
Tr5 OFF, Tr6 ON

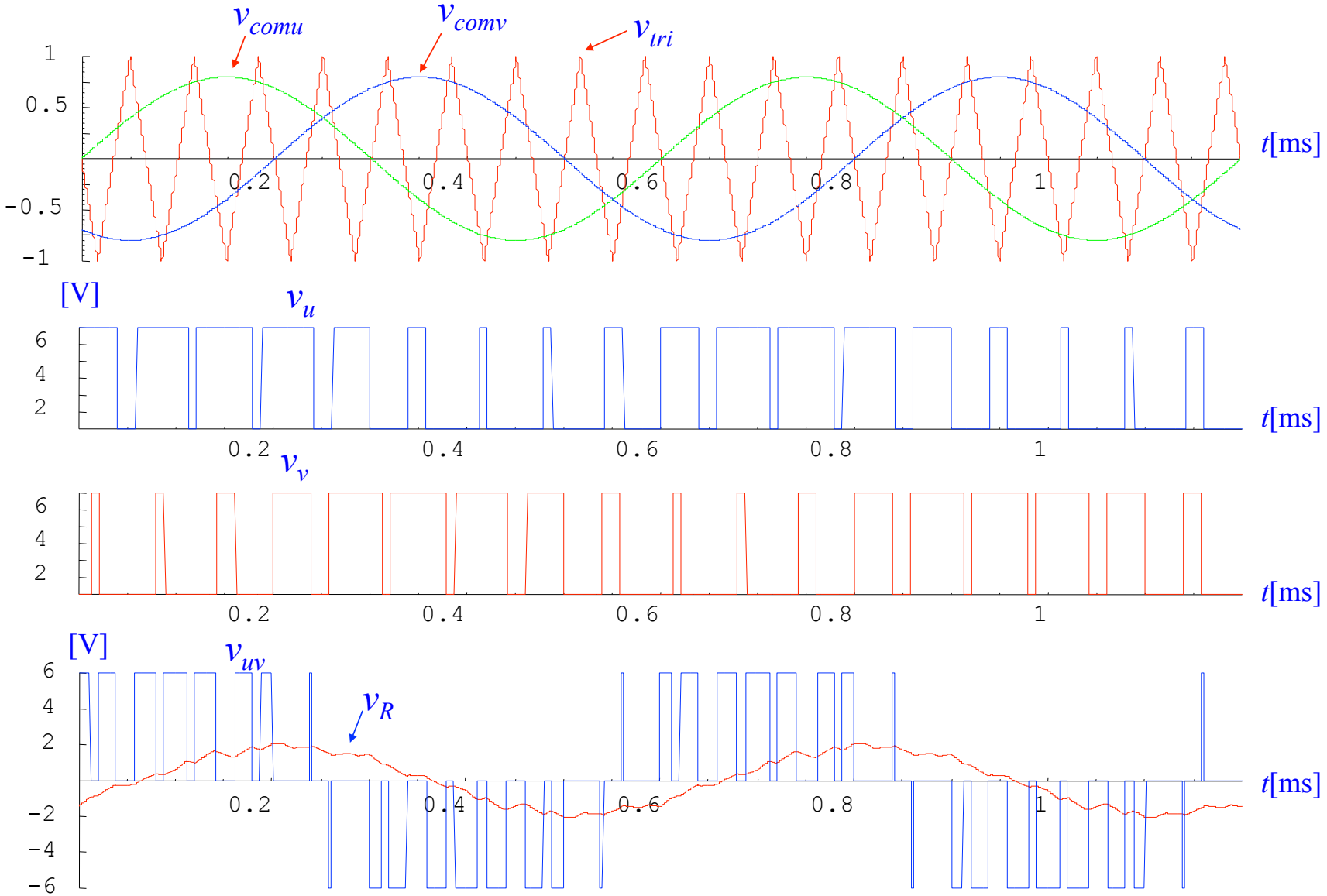
Experimental circuit of the three-phase inverter



R = 2 [kΩ], L=150 [mH]

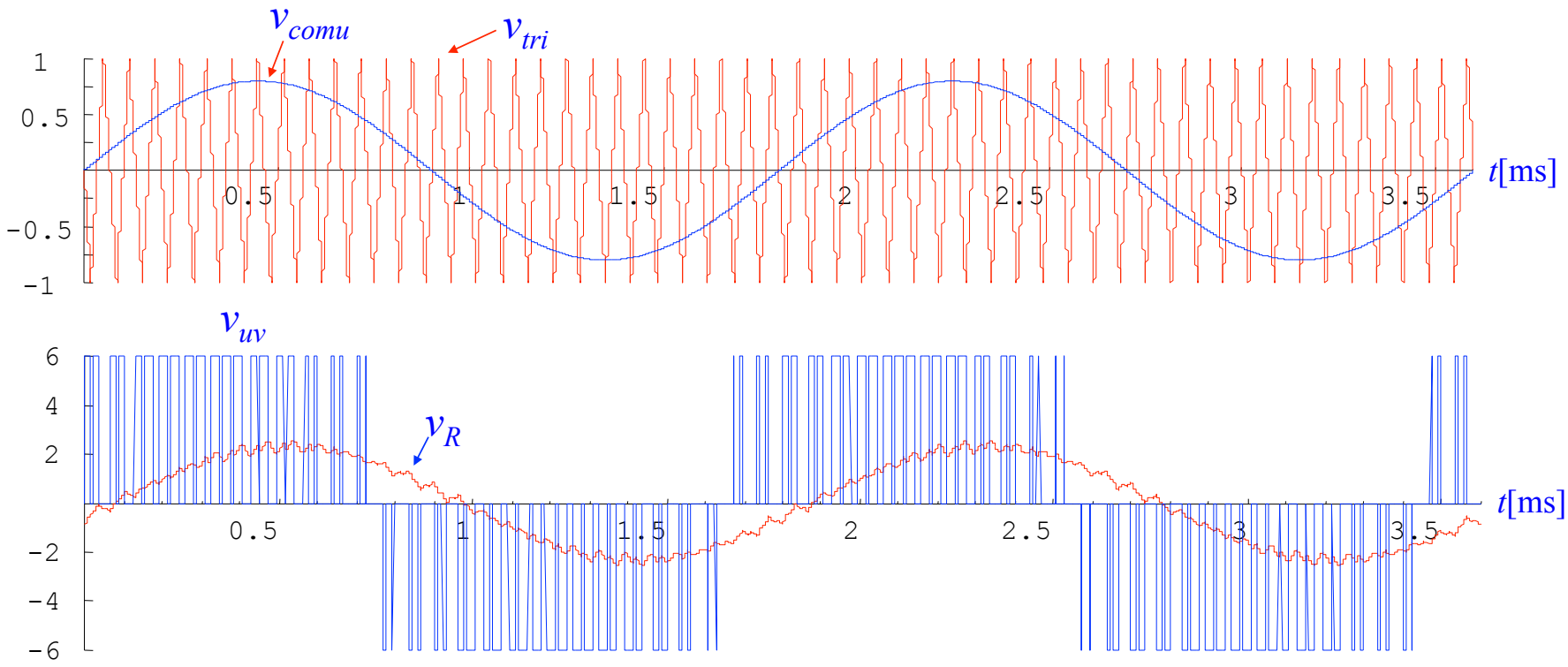


Waveforms of the output voltage and current in the case of a three-pulse PWM
f_{sw} = 15[kHz], R=2[kΩ], L150[mH], V_E = 6[V]

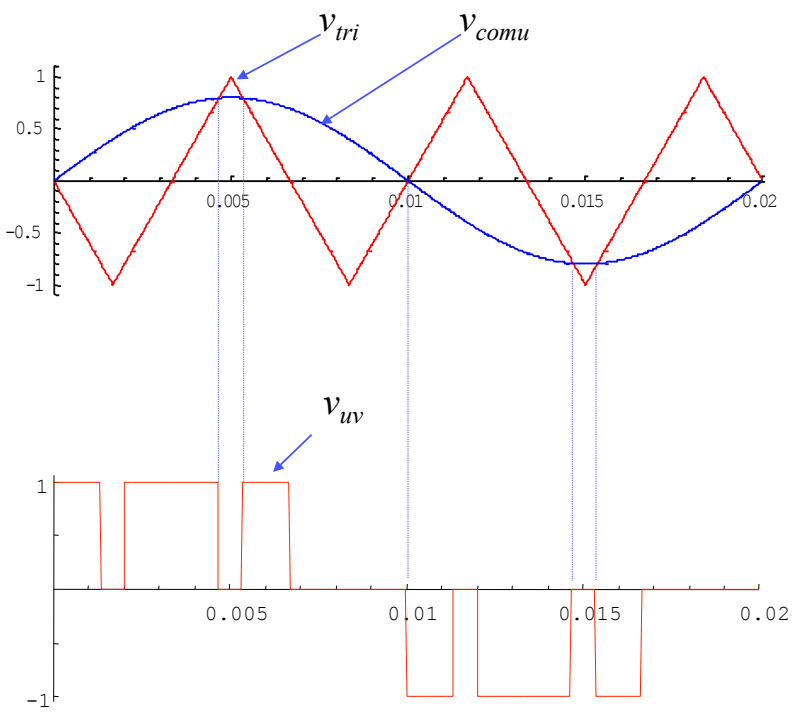


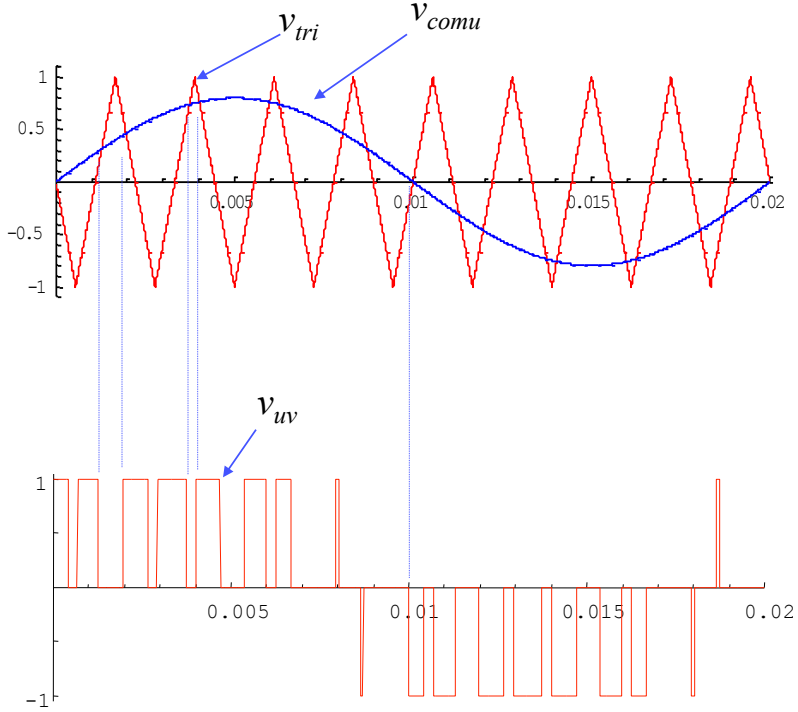
Waveforms of the output voltage and current in the case of a nine-pulse PWM

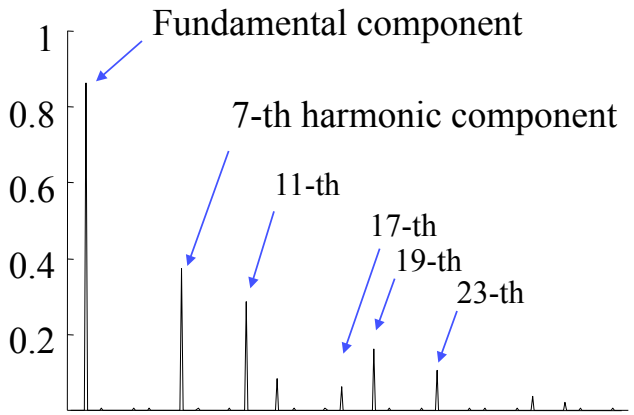
f_{sw} = 15[kHz], R=2[kΩ], L150[mH], V_E = 6[V]



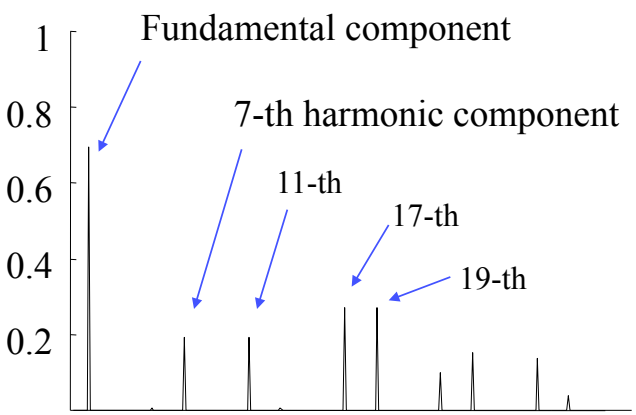
Waveforms of the output voltage and current in the case of a 27-pulse PWM
f_{sw} = 15[kHz], R=2[kΩ], L150[mH], V_E = 6[V]







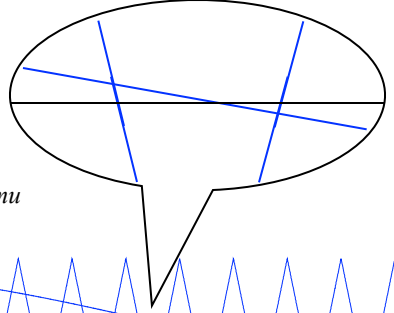
(a) 3-pulse



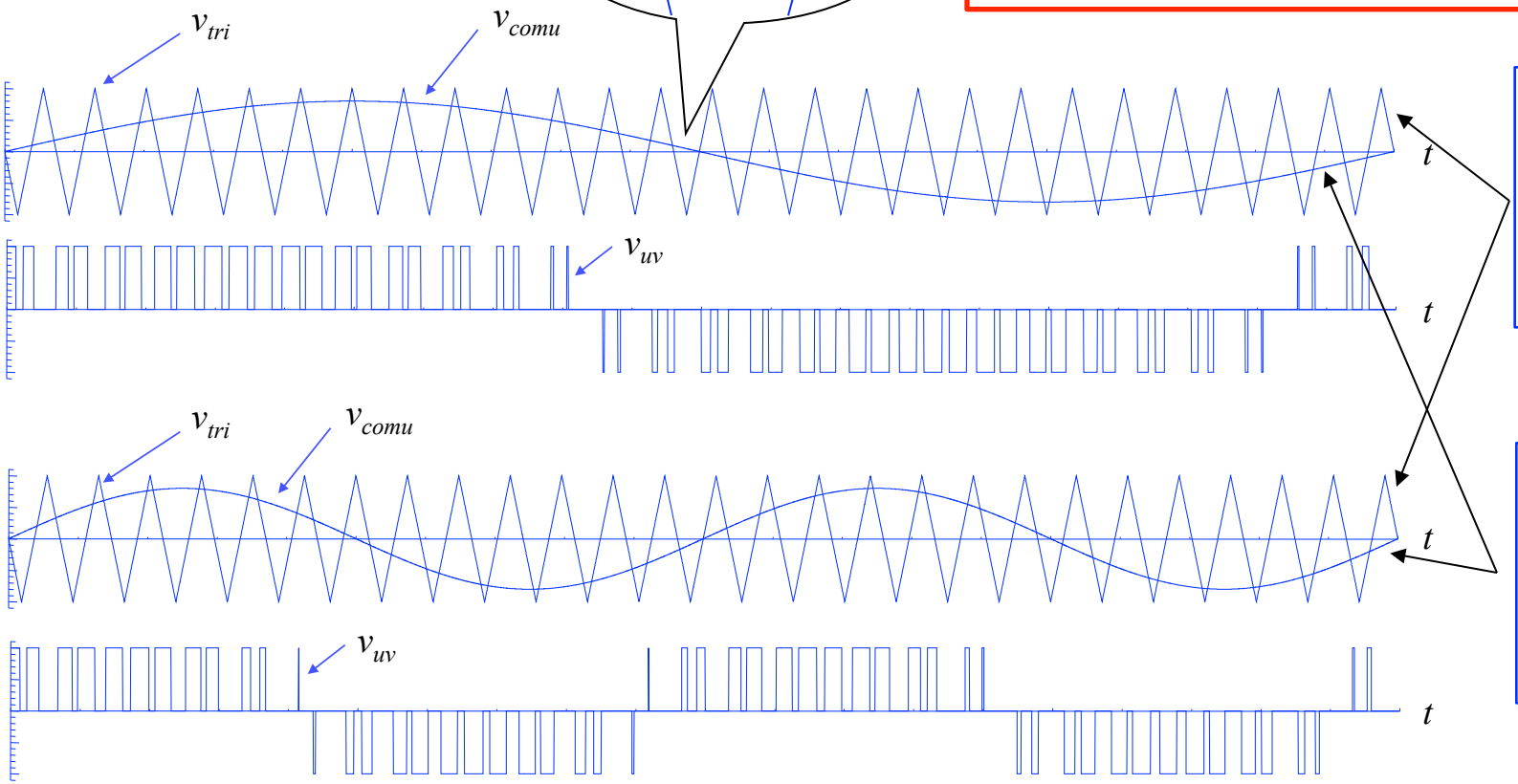
(b) 9-pulse

FFT analysis of line-to-line voltages

Asynchronous mode

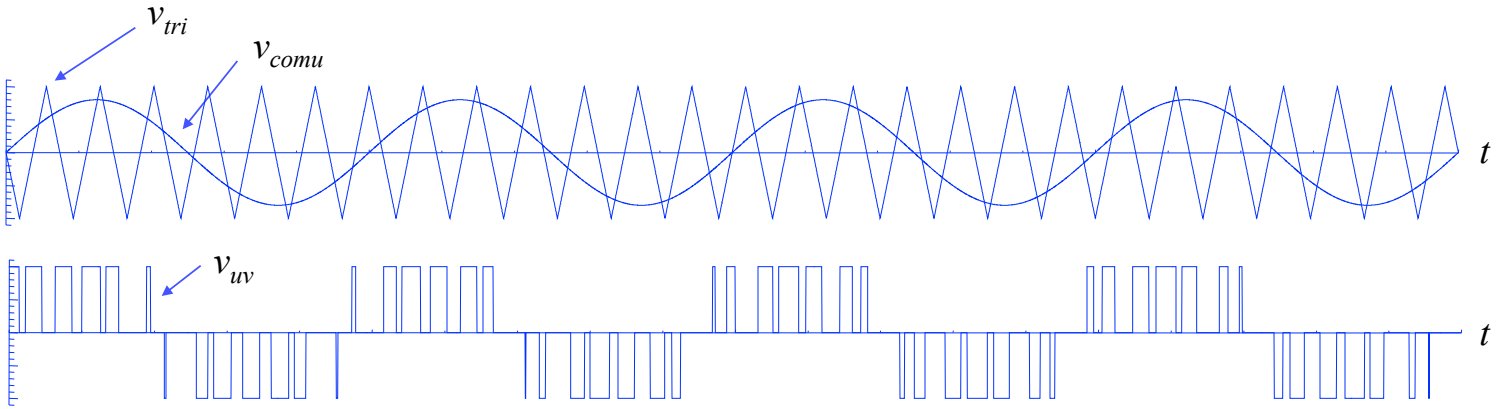


Zero crossing points of the command voltage and triangular voltage do not coincide.



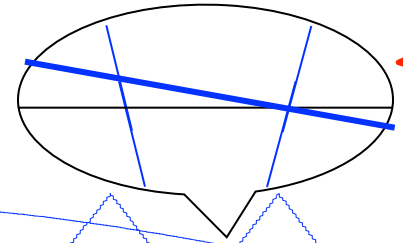
Freq of the triangular voltage is constant.

Freq of the command voltage is varying.

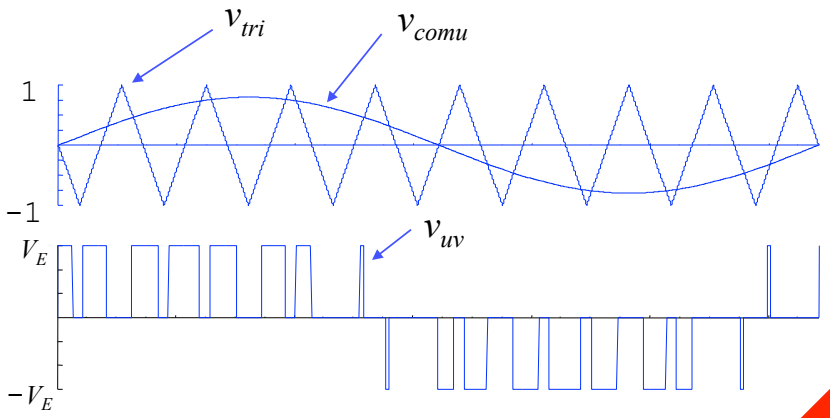


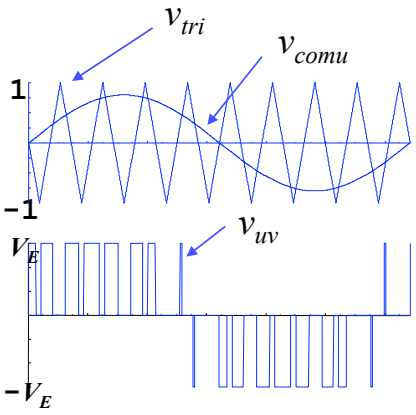
Switching frequency is constant.

Synchronous mode



Zero crossing points of the command voltage and triangular voltage always coincide.





$f_{com} / f_{tri} = 1/9$

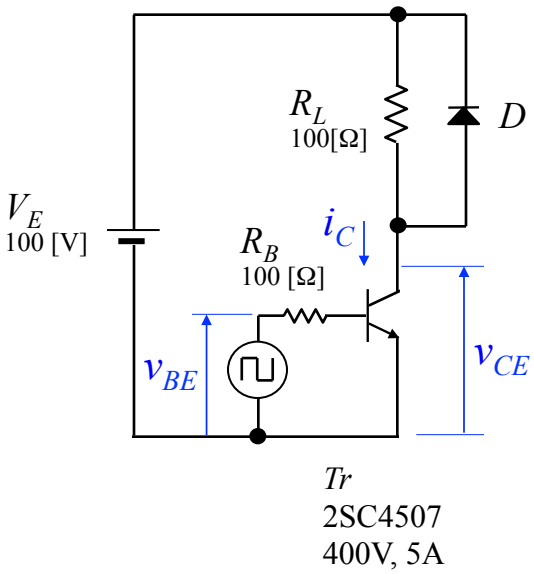
Increased frequency of voltage command

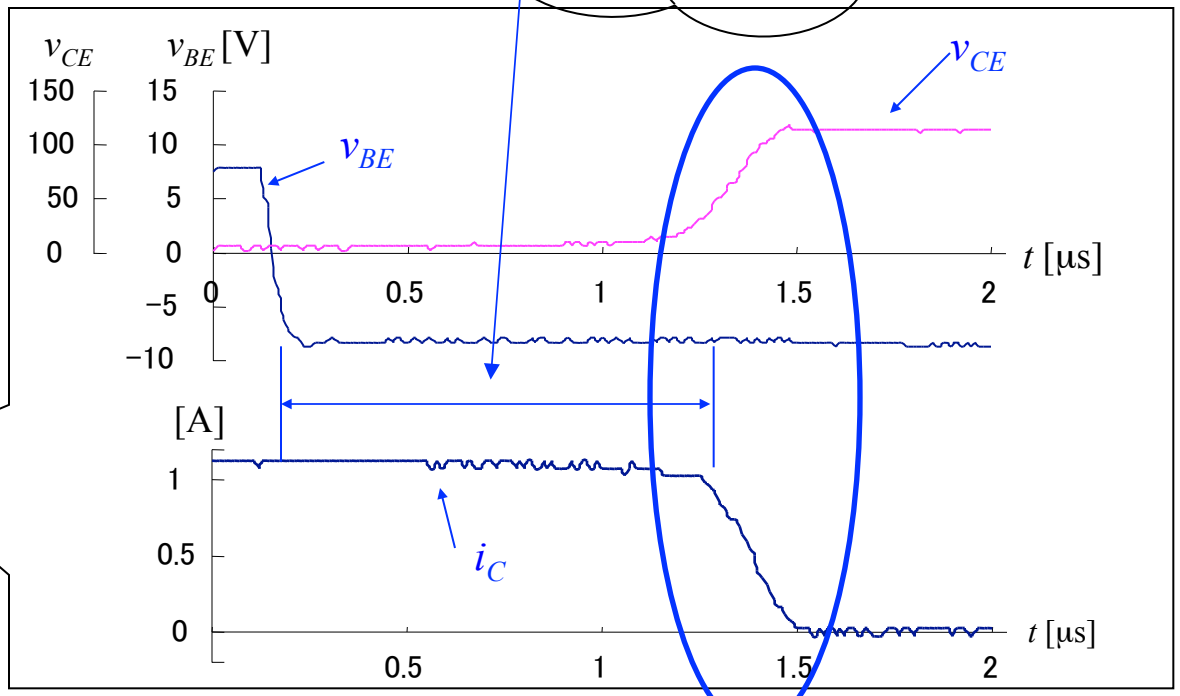
⇩

Increased switching frequency

Switching loss by transistor
(example of an experimental waveform)

Collector current i_C keeps flowing even though the voltage between the base and emitter v_{BE} is made negative.





Energy loss E_{loss} *occurs while* $v_{CE} > 0$ and $i_C > 0$.

$$E_{loss} = \int v_{CE} i_C dt \ \text{[J]}$$

Synchronous mode

Increase of f_{sw}

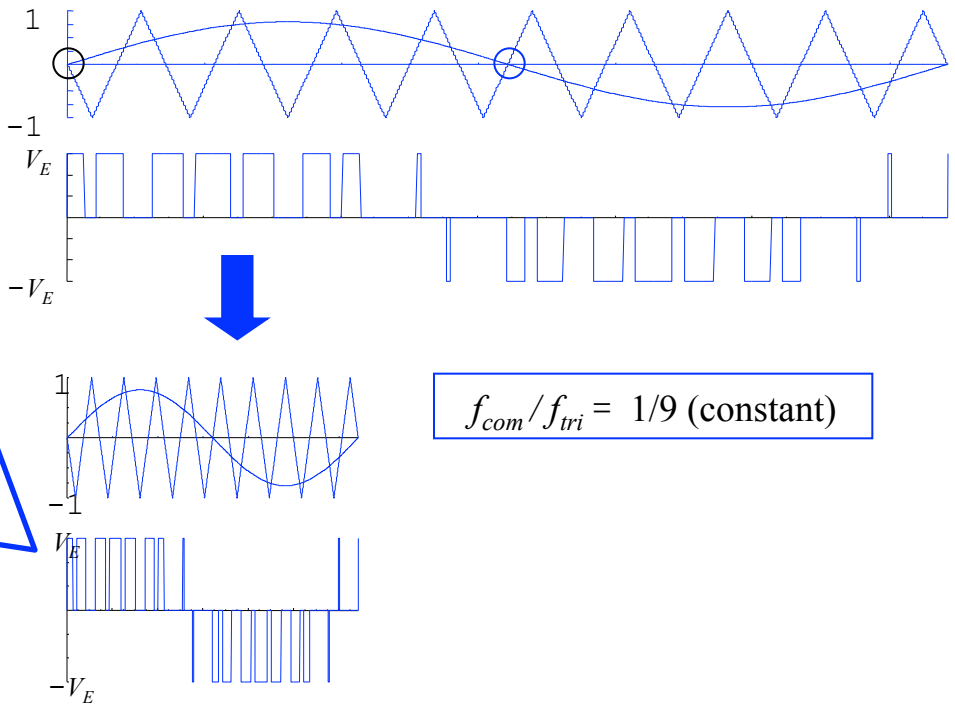
→ Increase of power loss

$$P_{loss} = E_{loss} \times f_{sw} \ [\mathrm{W}]$$

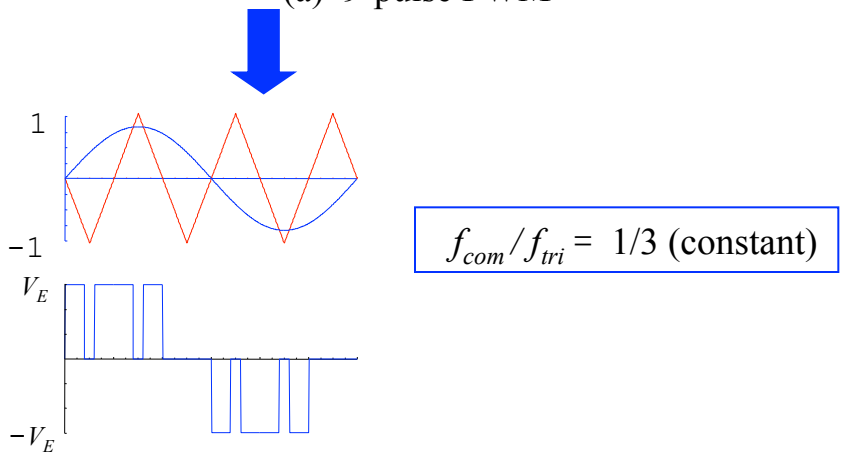
→ Upper limit of f_{sw}

Ex. Shinkansen train

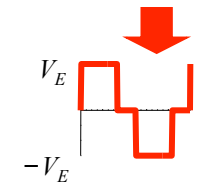
700-Series (1.5kHz)



(a) 9-pulse PWM

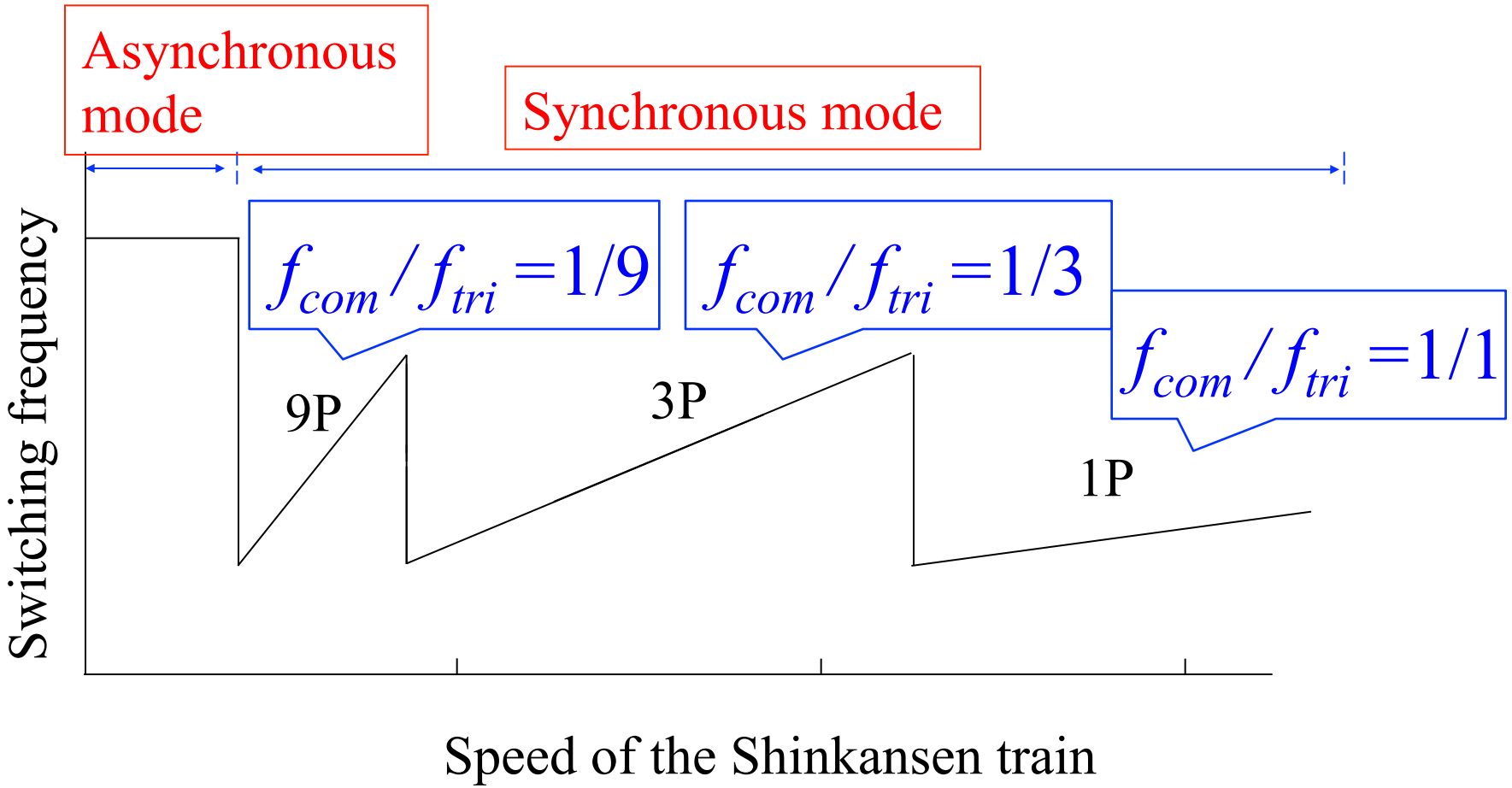


(b) 3-pulse PWM



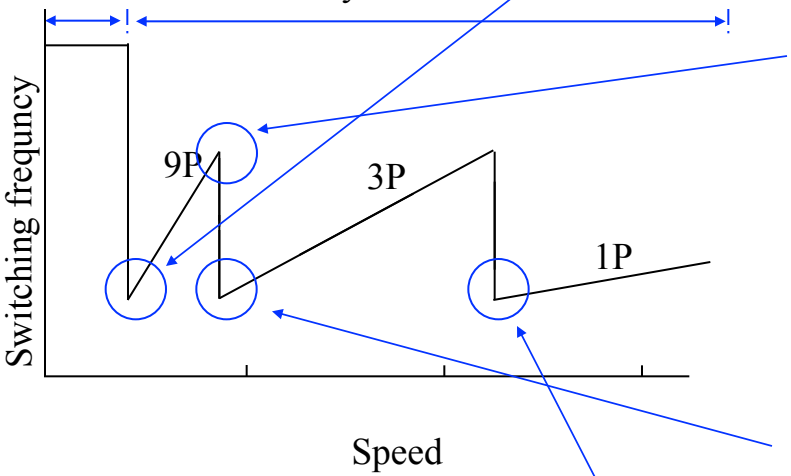
(c) 120 degree conduction mode

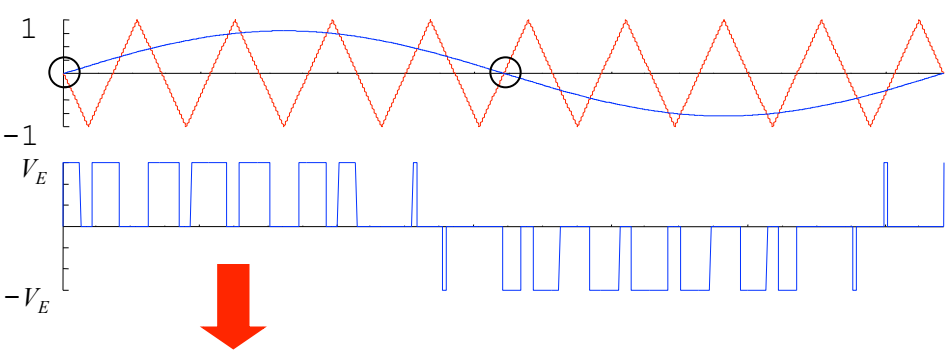
Example of switching between asynchronous mode and synchronous mode

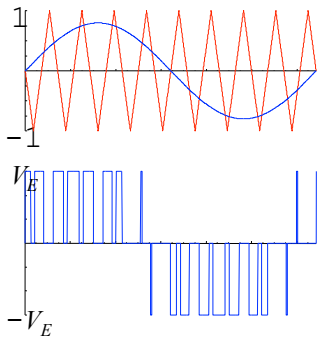


Synchronous mode at high speed

Zero crossing points of the voltage command and triangular waveform always coincide.

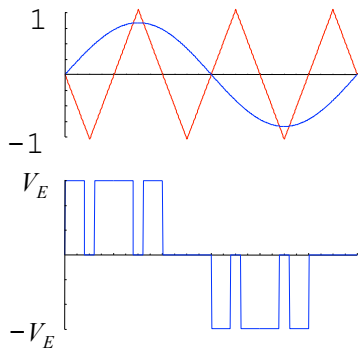






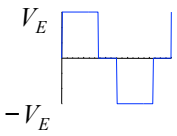
f_{com}/f_{tri} = 1/9 (constant)

(a) 9-pulse PWM



f_{com}/f_{tri} = 1/3 (constant)

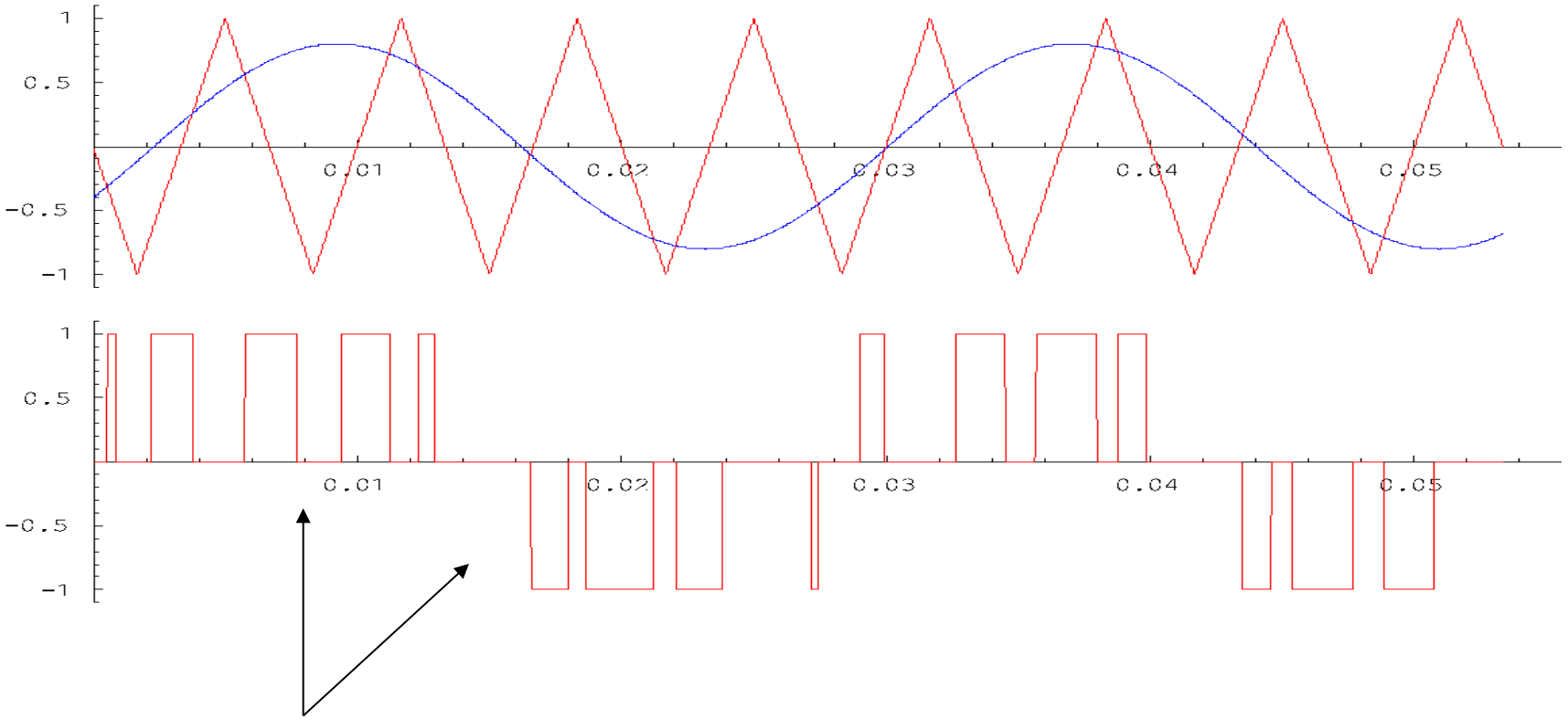
(b) 3-pulse PWM



f_{com}/f_{tri} = 1 (constant)

(c) 120 degree conduction mode

If not synchronized!



Asymmetry between positive side and negative side. Waveform varies at every cycle.

Over heating, vibration of motor noisy motor sound

Shinkansen

http://ja.wikipedia.org/wiki/新幹線100系電車

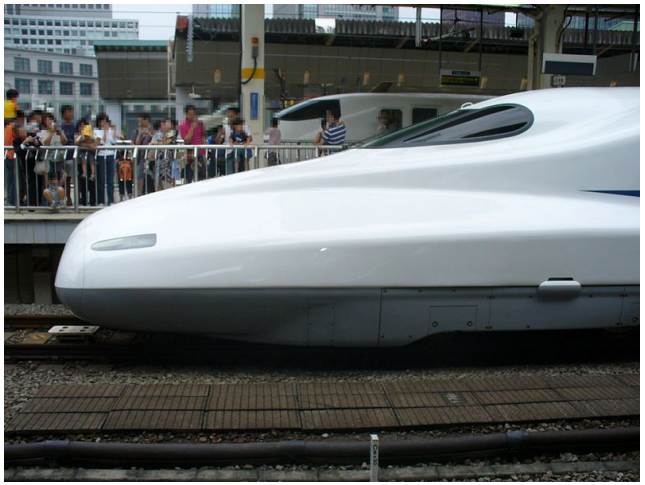
http://ja.wikipedia.org/wiki/新幹線300系電車

100-series（1985～）
Max speed: 275 km/h
Main motor: DC series wound motor
Power converter: Thyristor type
Braking method: Resistance braking

300-series (（1990～）
Max speed: 285 km/h
Main motor: Three phase induction motor
Power converter: VVVF Inverter (GTO Thyristor)
Switching frequency 420 [Hz]
Braking method: Regenerative braking

The induction motor’s output power is 130% and its weight is half of that of the DC motor.
Regenerative braking was first introduced to Shinkansen trains.

http://ja.wikipedia.org/wiki/新幹線500系電車



http://ja.wikipedia.org/wiki/新幹線N700系電車

500-series（1992～）
Max speed: 365km/h
Main motor: Three phase induction motor
Power converter: VVVF Inverter (GTO Thyristor)
Braking method: Regenerative braking

N700-series(2005～)

Main motor: Three phase induction motor
Power converter: VVVF Inverter (IGBT)
Switching frequency: 1.5 [kHz]
Braking method: Regenerative braking

・Asynchronous mode
From the time train leaves a station
300-series approx. 5 sec
500-series approx. 22 sec
N700-series approx. 25 sec
・Sound noise level
Sound noise from the motors of N700-series is less than from previous types of Shinkansen trains.