TAMPEREEN TEKNILLINEN YLIOPISTO

# Aspects on designing switched-mode power electronic converter for photovoltaic application

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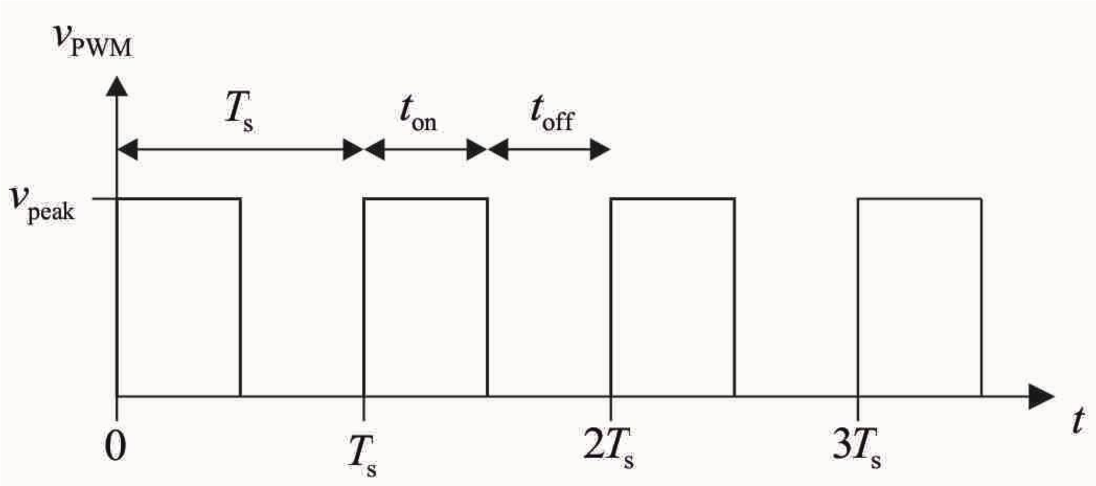
# Pulse-Width Modulation

- Controlling a dc-dc converter requires a steady pulse with adjustable width
- Usually a voltage signal
- Such method is referred as pulse-width-modulation or PWM
- Duty ratio is used to define the width of the pulse

$$D = \frac{t_{\mathrm{on}}}{T_{\mathrm{s}}}$$

$$t_{\mathrm{on}} = DT_{\mathrm{s}}$$

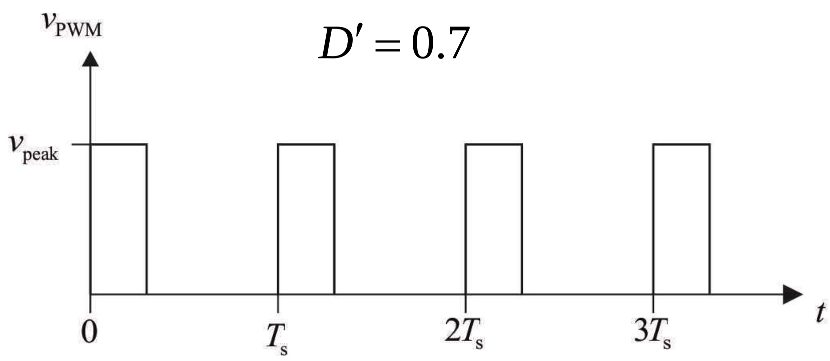
$$t_{\mathrm{off}} = (1 - D)T_{\mathrm{s}} = D'T_{\mathrm{s}}$$



# Pulse-Width Modulation

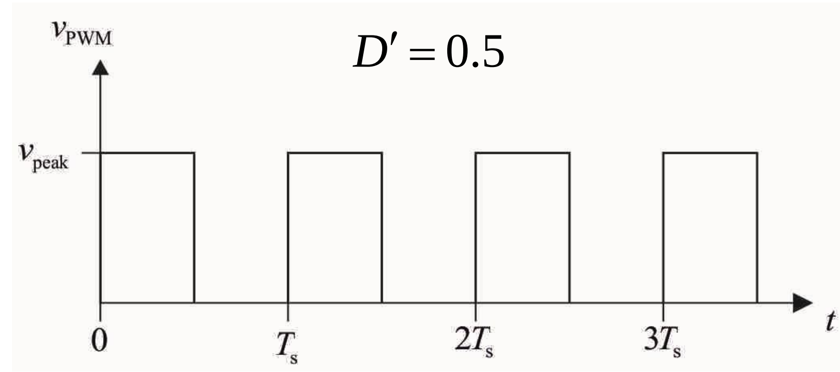
$D = 0.3$

$D' = 0.7$



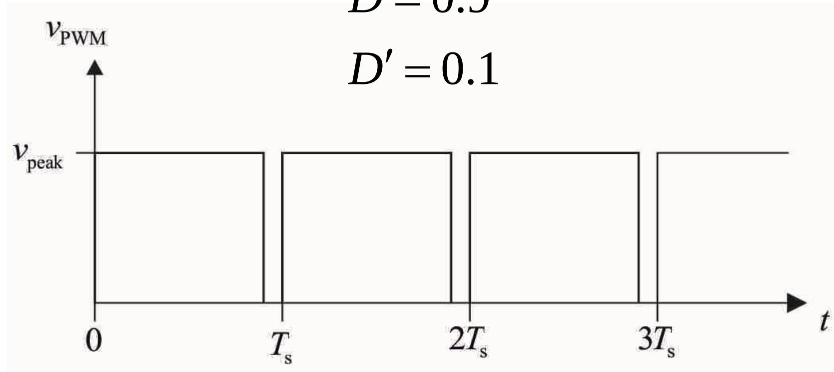

$D = 0.5$

$D' = 0.5$




$D = 0.9$

$D' = 0.1$

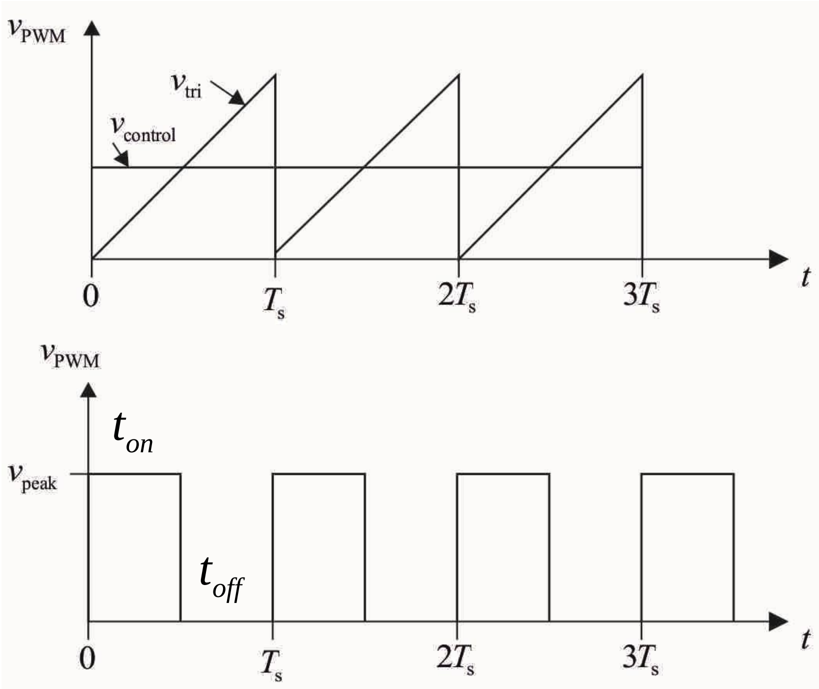


# Pulse-Width Modulation

- The most common method to realize PWM is to compare a saw-tooth waveform with a control value
- External circuit is used to generate a voltage when the control voltage is larger than the saw-tooth waveform

$$v_{\text{control}} > v_{\text{tri}}$$

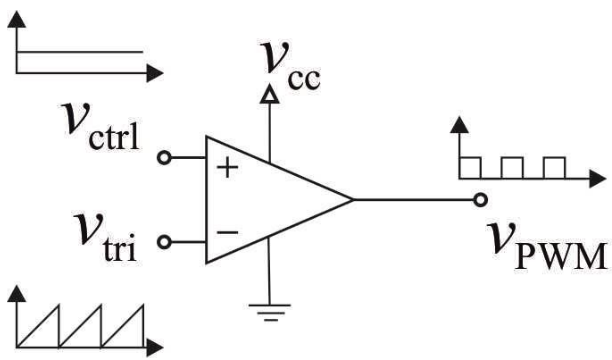
$$f_{sw} = \frac{1}{T_s}$$



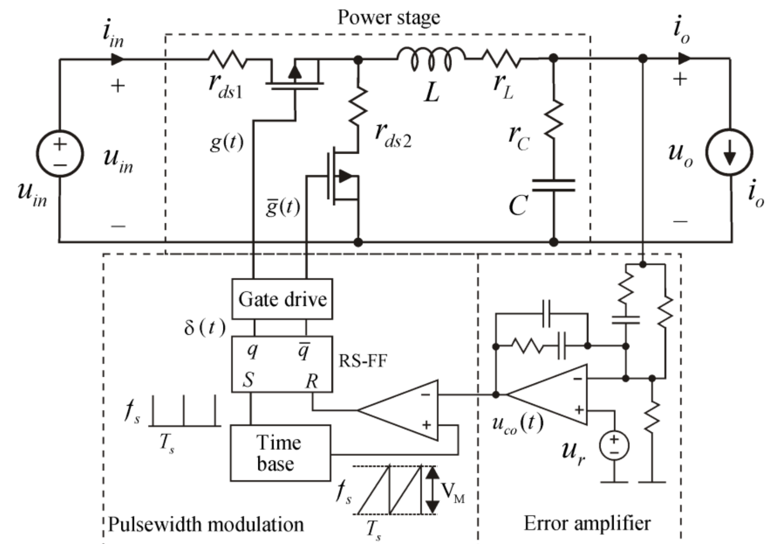

$$D = \frac{t_{on}}{T_s} = \frac{v_{control}}{\hat{v}_{tri}}$$

# Pulse-Width Modulation (analog)

- Comparison of two signals produces a pulse train
- Can be implemented using operational amplifier (comparator)



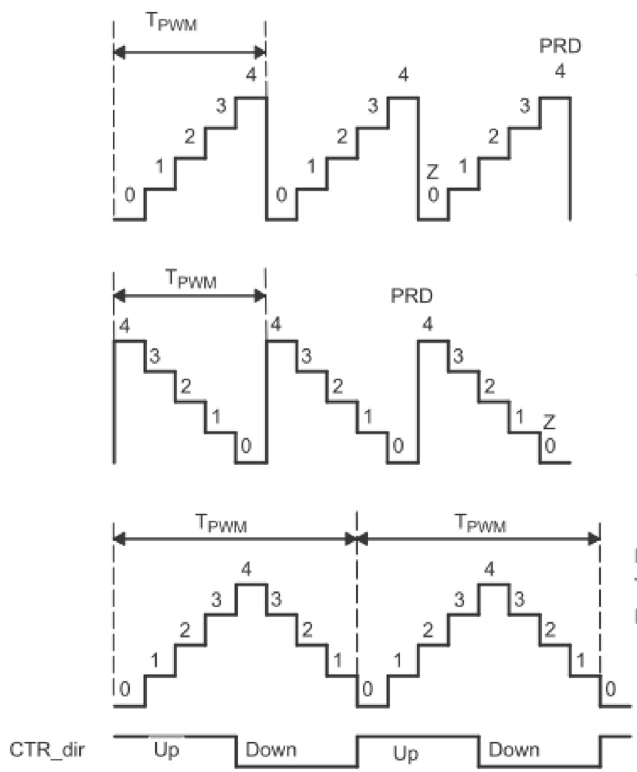

- Comparator switches its state between high and low
- Switching frequency depends on the saw-tooth waveform
- Width of the pulse depends on the dc level of the control signal




Picture: Professor Teuvo Suntio

# Pulse-Width Modulation (digital)

- PWM and control system can be implemented digitally using a digital signal processor (DSP)
- PWM-waveforms can have several shapes inside the DSP




For Up Count and Down Count

$T_{PWM} = (TBPRD + 1) \times T_{TBCLK}$

$F_{PWM} = 1/(T_{PWM})$

For Up and Down Count

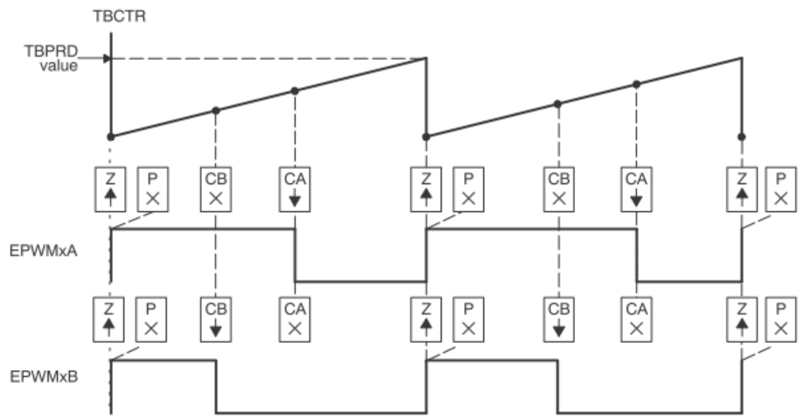
$T_{PWM} = 2 \times TBPRD \times T_{TBCLK}$

$F_{PWM} = 1/(T_{PWM})$

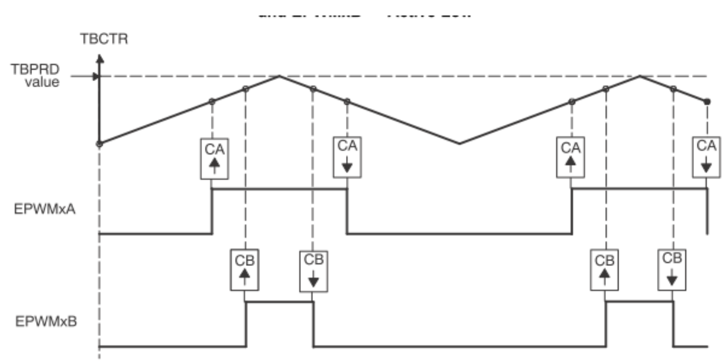

Texas Instruments

# Pulse-Width Modulation (digital)

- Output pin of the DSP is set to high state when compare value is less than the counter value → used in DC-DC converters



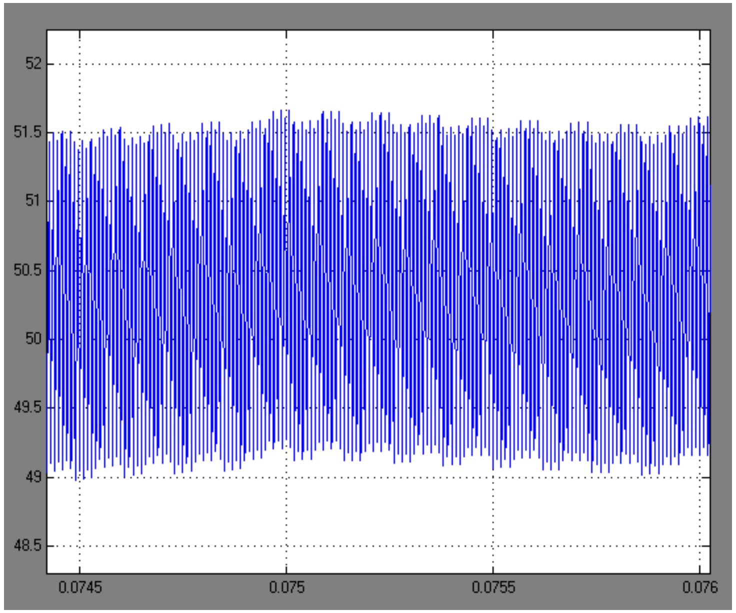

- Counter can also generate a triangle waveform → used in DC-AC converters

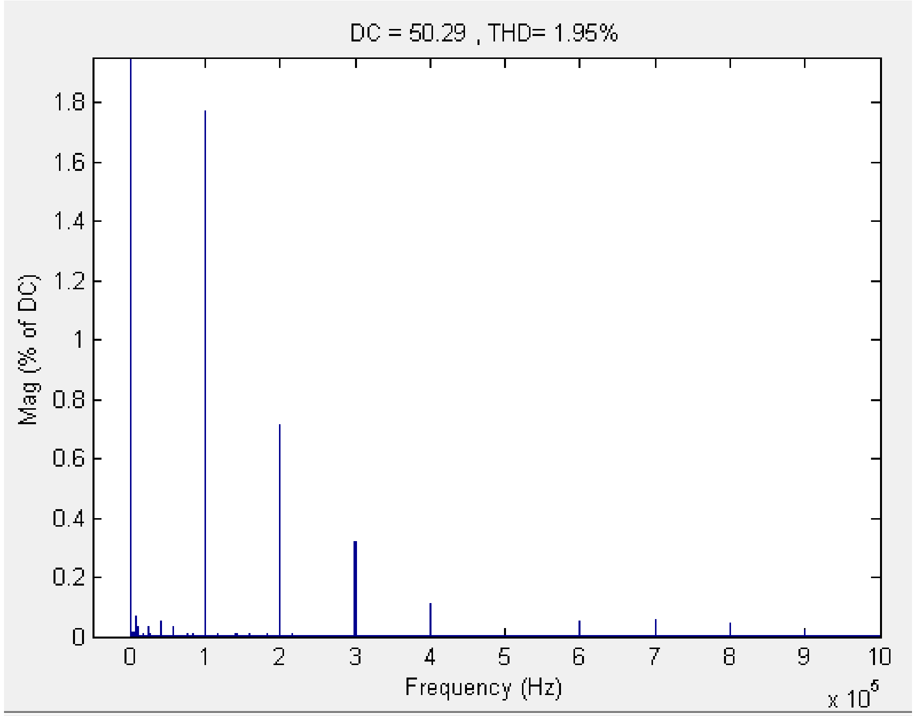



Picture: Texas Instruments

# Pulse-Width Modulation

- Produces high-frequency harmonics in converter currents and voltages
- Harmonics appear at the switching frequency and its multiples

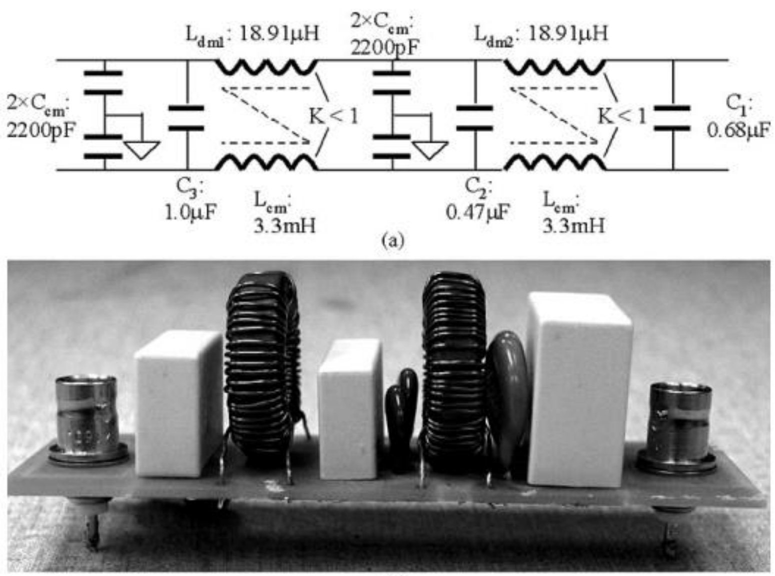


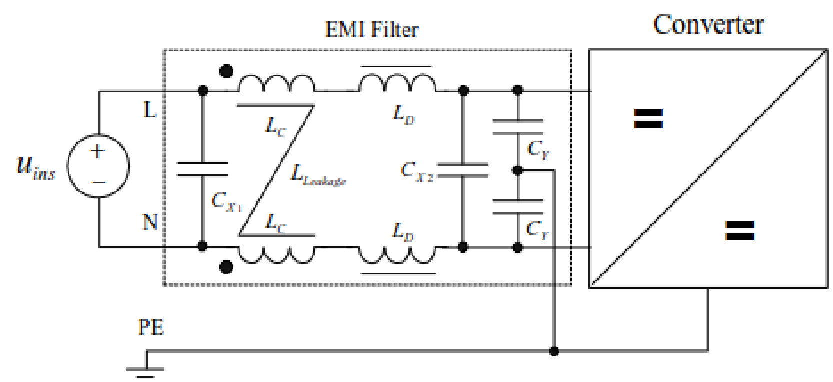




Buck FFT-Analysis simulation example

# Pulse-Width Modulation

- EMI-filters are required to filter out switching ripple



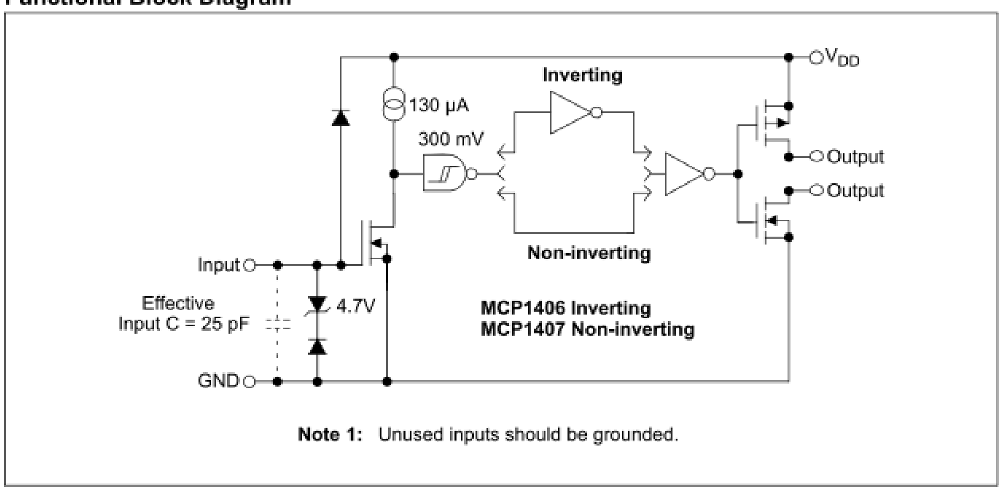

S. Wang et al, "Effects of Parasitic Parameters on EMI Filter Performance", IEEE Trans. Power Electron., vol 19, no 3, pp. 869-877, 2004

# Driver Circuit

- Driver circuit is needed to amplify the switch signal
- DSP / comparator cannot supply enough current to turn a transistor on
- Driver circuit has to supply or sink enough current to turn the switch on or off sufficiently fast

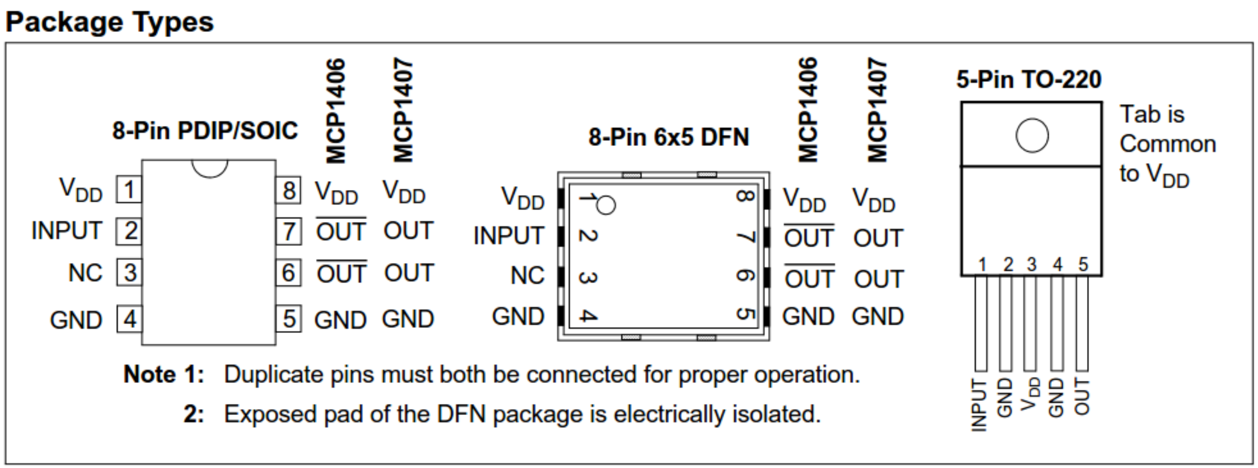
## MCP1406/07

Functional Block Diagram[1]



# Driver Circuit

- Driver circuit has to be connected to supply voltage to operate
- Driver circuit can have also inverted output
- Comes in different sizes and cases

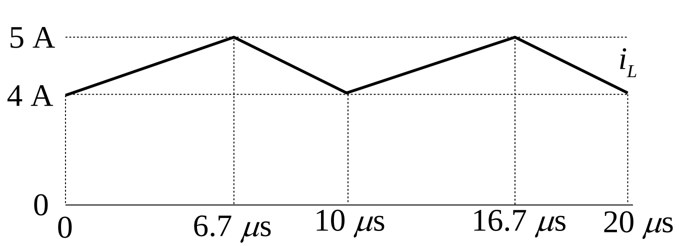


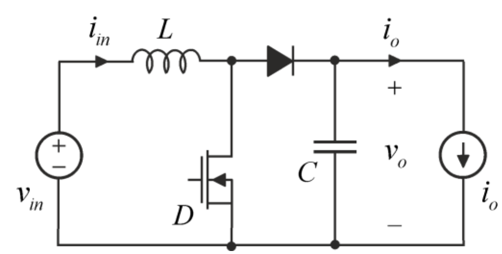
# Example

**Analyze the boost converter**

The output voltage is 50V.

a) What is the MOSFET switching frequency?
b) Draw the example of the converter PWM reference signal and the control signal
c) How large is the inductor current ripple if the inductor value will be doubled?
d) How large is the inductor current ripple if the switching frequency will be decreased to half?
e) What is the power level of the converter?



# Example solution

a) What is the MOSFET switching frequency?

$$f_{sw} = \frac{1}{T_s} = \frac{1}{10\mu s} = 100kHz$$

b) Draw the example of the converter PWM reference signal and the control signal

c) How large is the inductor current ripple if the inductor value will be doubled?

$$\hat{i}_{L-pp} = \frac{V_{in}}{L} \cdot DT_s = \frac{50V}{2 \cdot 335\mu H} \cdot 0,67 \cdot 10\mu s = 0,5A$$

d) How large is the inductor current ripple if the switching frequency will be decreased to half?

$$\hat{i}_{L-pp} = \frac{V_{in}}{L} \cdot DT_s = \frac{50V}{2 \cdot 335\mu H} \cdot 0,67 \cdot 20\mu s = 1A$$

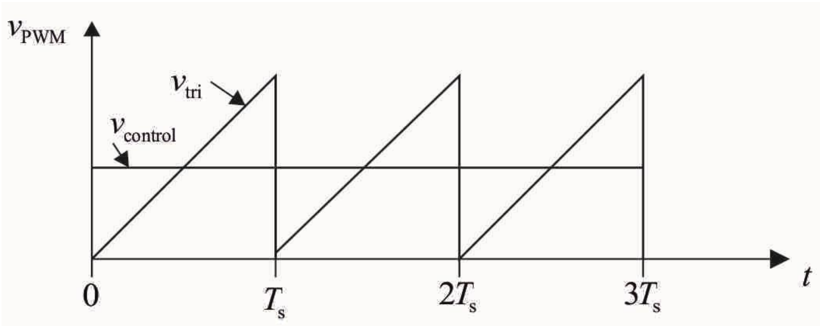
e) What is the power level of the converter?

$$P_{in} = V_{in} I_{in} = 50V \cdot 4,5A = 225W$$

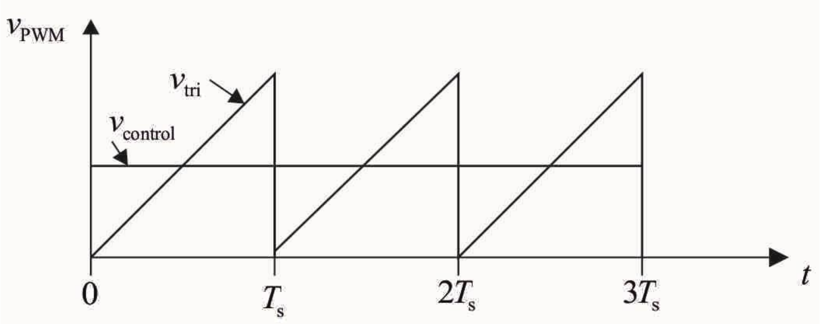
# Example

The buck converter is controlled with PWM signal shown in the figure. The amplitude of the control signal is 1,2 V and the amplitude of the sawtooth-waveform is 3V. The switching cycle $T_s$ is 10μs. The input voltage of the converter is 50 V.

a) What is the duty cycle D of the converter?
b) What is the MOSFET switching frequency?
c) What is the output voltage value?
d) How large the control signal amplitude should be if the output voltage value should be half of the previous value? What would be the duty cycle D value?



# Example solution




a) What is the duty cycle D of the converter?

$$D = \frac{v_{control}}{v_{tri}} = \frac{1,2V}{3V} = 0,4$$

a) What is the MOSFET switching frequency?

$$f_{sw} = \frac{1}{T_s} = \frac{1}{10\mu s} = 100kHz$$

a) What is the output voltage value?

$$V_{out} = DV_{in} = 0,4 \cdot 50V = 20V$$

b) How large the control signal amplitude should be if the output voltage value should be half of the previous value? What would be the duty cycle D value?

$$D = \frac{V_{out}}{V_{in}} = \frac{10V}{50V} = 0,2$$

$$v_{control} = Dv_{tri} = 0,2 \cdot 3V = 0,6V$$