

Wrocław University of Science and Technology

## DC-DC converters DC-DC controllers

Jerzy Krawczyk




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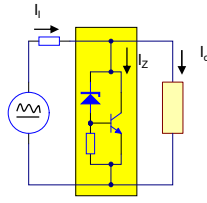
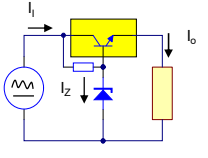
### Serial & parallel controller


$$I_1 = I_Z + I_O$$

$$P_{\text{loses}} = I_Z U_O + I_1 (E - U_O)$$

$$I_1 \approx I_O$$

$$P_{\text{loses}} = I_1 (E - U_O)$$

Smaller dissipation power  
Better efficiency 

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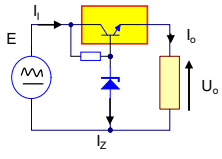
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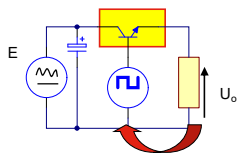
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### Linear vs. Pulse (switching) controller

$$P_{\text{strat}} \approx (E - U_O) I_O$$


Smaller dissipation power  
Better efficiency

$$P_{\text{strat}} \approx U_{\text{sat}} I_{\text{max}}$$


Even smaller dissipation power  
Even better efficiency 

$$U_O = U_{AV} = \frac{t_{\text{on}}}{t_{\text{on}} + t_{\text{off}}} E$$

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### The average value of the impulse waveform

$$U_{AV} = \frac{t_{on}}{T} E = \gamma E$$

$T = t_{on} + t_{off}$       T - period  
 $\gamma = t_{on}/T$  - duty factor

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### Step down converter

$$U_o = U_{AV} = \frac{t_{on}}{t_{on} + t_{off}} E = \gamma E$$


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### Choke

$$U(t) = L \frac{di(t)}{dt} \approx L \frac{\Delta i}{\Delta t}$$

$$i(t) - i(t_0) = \frac{U}{L} (t - t_0)$$

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## Choke

$$U(t) = L \frac{di(t)}{dt} \approx L \frac{\Delta i}{\Delta t}$$

$$i(t) - i(t_0) = \frac{U}{L} (t - t_0)$$

High inductance-  
Small voltage-  
Small current slope

Power stored = power transferred to output

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## Choke - some parameters

$B_{max} = 0.05 \dots 0.1 \dots 0.2 \dots 0.3$  [T] for ferrites  
and frequencies  $200 \dots 20 \dots 10$  [kHz] ..2[MHz]

when  $\mu_r/l \gg 1$

$$\frac{BSz}{l} = L = \mu_0 \mu_r \frac{z^2 S}{l_r \left(1 + \mu_r \frac{l_r}{l}\right)} = A_L z^2 \approx \mu_0 \frac{z^2 S}{l_r}$$

For sine waveforms:

$$\frac{U_{max}}{z} = 2\pi f B_{max} S = \frac{\sqrt{2} U_{skut}}{z}$$

For square wave:

$$\frac{U_{max}}{z} = \frac{1}{\gamma} f B_{max} S = \frac{1}{t_{on}} B_{max} S$$

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## Step down (buck) converter

$$U_o = \gamma E = \frac{t_{on}}{T} E$$

$$I_{L,max} \approx 2 I_{O,max}$$

$$I_{L,min} \geq \frac{E - U_o}{L} t_{on}$$

$$C > \frac{I_{O,max} T}{4 U_{O,rip}}$$

$U_o$  – output voltage,  
 $E$  – input voltage,  
 $t_{on}, t_{off}, T$  – turn on, off, period  
 $I_{L,peak}$  – peak current of choke and switch  
 $L_{min}$  – minimum inductance  
 $U_{O,rip}$  – ripple output voltage

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## simplified way of deriving equation of the output voltage of the step-down converter

chalk board or separate video



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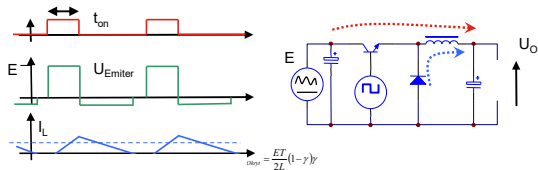
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## Step down converter (discontinuous mode)



Output voltage can reach the value E !!!



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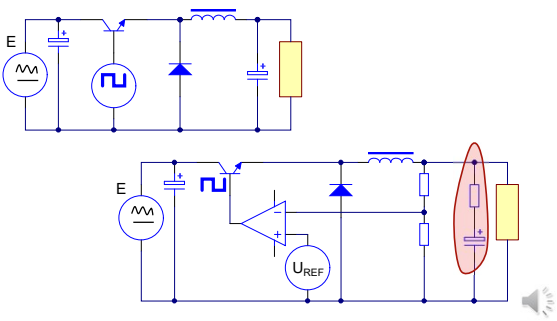
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## self-excited step-down controller



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### Step up (boost) converter

$$U_o = \frac{1}{1-\gamma} E$$

$$I_{L_{scryt}} \approx 2I_{Omax} \left( 1 + \frac{t_{on}}{T} \right)$$

$$L_{min} \geq \frac{E}{I_{L_{scryt}}} t_{on}$$

$$C > \frac{I_{Omax} T}{U_{Oripp}}$$

$U_o$  – output voltage,  
 $E$  – input voltage,  
 $t_{on}, t_{off}, T$  – turn on, off, period  
 $I_{L_{peak}}$  – peak current of choke and switch  
 $L_{min}$  – minimum inductance  
 $U_{Oripp}$  – ripple output voltage

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### simplified way of deriving equation of the output voltage of the step-up converter

chalk board or separate video

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### Inverter (buck-boost)

$$U_o = -\frac{\gamma}{1-\gamma} E$$

$$I_{L_{scryt}} \approx 2I_{Omax} \left( \frac{1}{1-\gamma} \right)$$

$$L_{min} \geq \frac{E}{I_{L_{scryt}}} t_{on}$$

$$C > \frac{I_{Omax} T}{U_{Oripp}}$$

$U_o$  – output voltage,  
 $E$  – input voltage,  
 $t_{on}, t_{off}, T$  – turn on, off, period  
 $I_{L_{peak}}$  – peak current of choke and switch  
 $L_{min}$  – minimum inductance  
 $U_{Oripp}$  – ripple output voltage

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## simplified way of deriving equation of the output voltage of the inverter

chalk board or separate video




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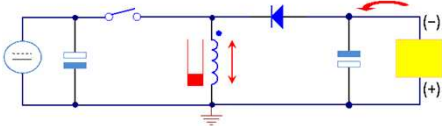
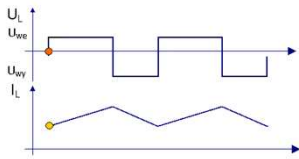
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## Inverter




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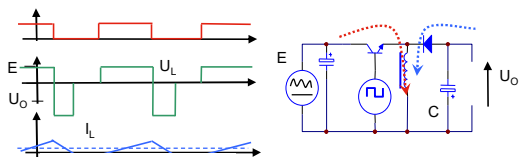
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## Inverter (discontinuous mode)



$$I_O < I_{Okryt} = \frac{E\gamma}{2L}(1-\gamma)T$$

Output voltage can ????? !!!




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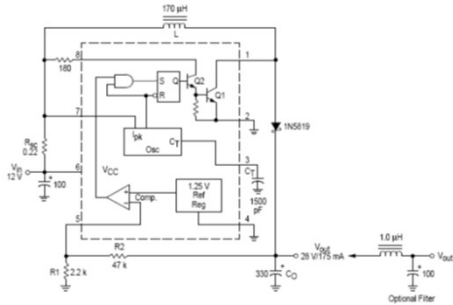
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## Step up MC34063



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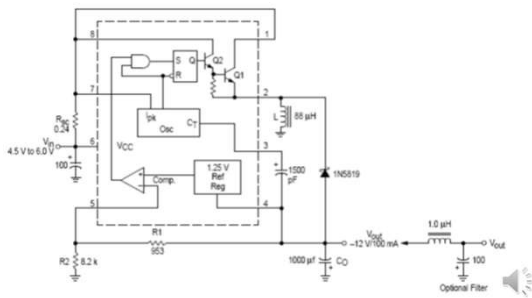
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## Inverting MC34063



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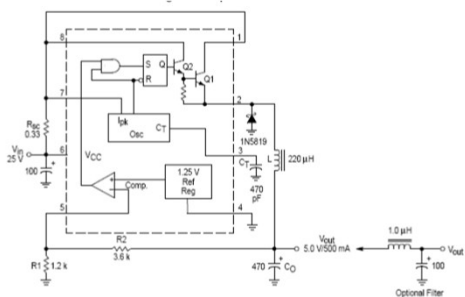
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## Step down MC34063



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## forward converter

**Flyback converter**

**Forward converter**

Primary current + secondary (negative)

3rd winding

Total magnetic flux

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## Choke vs. transformer

choke:  
only primary is conducting

transformer:  
both primary and secondary are  
conducting simultaneously;  
magnetic flux of both cancel out (almost)

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## Foreword converter

- In foreword converters:
- Energy is „transformed” (is not stored in magnetic field)
- Magnetization current is small
- Instead of choke a smaller transformer is used
- In symmetrical (push-pull, half-bridge, full-bridge, foreword converters average magnetization current is zero !

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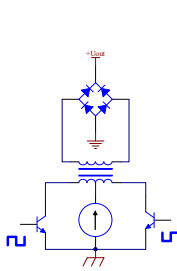
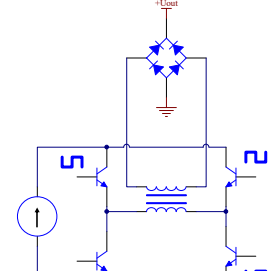
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## High power converters (foreword)

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## Converters - problems to overcome

High frequency (10-200kHz-2MHz) and short switching times (10-200ns):

- fast diodes and transistors
- distortions - noises
- voltage spikes
- parasitic capacitances (resonances)
- skin effect

Additional reference:  
I. Pressman, Switching Power Supply Design 3/e, McGraw-Hill Education Ltd.

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## Summary

Advantages:

- High efficiency
- Small dimensions

Drawbacks:

- Worse line and load regulation
- Interferences
- More expensive

*Capacitive converters (charge pump) - for self studies (n.ICL7660)*

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## Test problems

- simplified derivation of the output voltages for:
  - Step down (buck) converter
  - Step up (boost) converter
  - Inverter (buck-boost)
- Drawbacks and advantages of DC-DC converters



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