Wroclaw University of Science and Technology

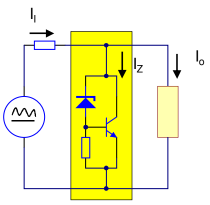
DC-DC converters
DC-DC controllers

Jerzy Witkowski

Serial & parallel controller

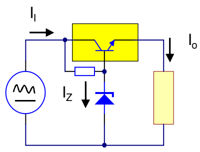
$I_I = I_Z + I_O$

$P_{loses} = I_Z U_O + I_I (E - U_O)$



$I_I \approx I_O$

$P_{loses} = I_I (E - U_O)$

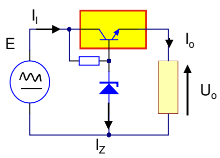


Smaller dissipation power

Better efficiency

Linear vs. Pulse (switching) controller

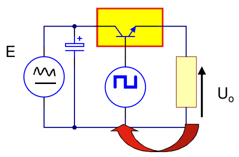
$P_{strat} \approx (E - U_O) I_O$



Smaller dissipation power

Better efficiency

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

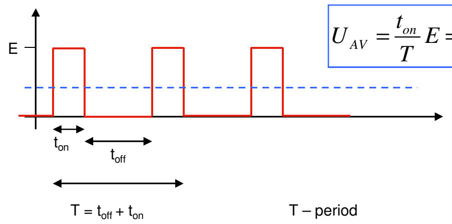


$$U_O = U_{AV} = \frac{t_{on}}{t_{on} + t_{off}} E$$

Even smaller dissipation power

Even better efficiency

The average value of the impulse waveform



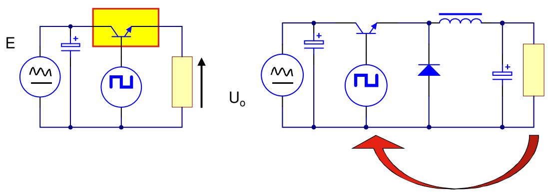
$$U_{AV} = \frac{t_{on}}{T} E = \gamma E$$

$T = t_{off} + t_{on}$

T – period

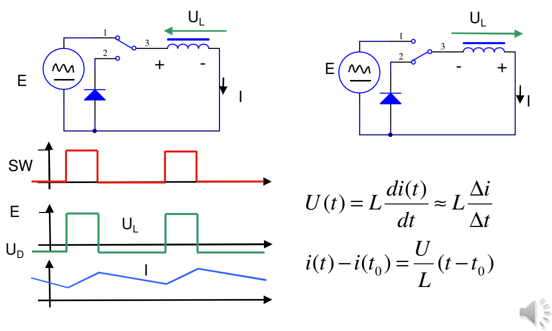
$\gamma = t_{on}/T$ – duty factor

Step down converter



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

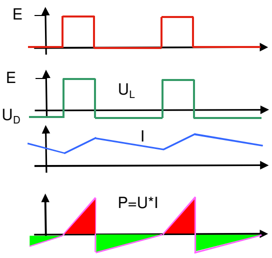
Choke



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

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

Choke



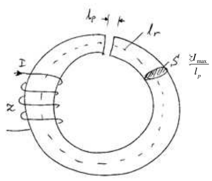
$$U(t) = L\frac{di(t)}{dt} \approx L\frac{\Delta i}{\Delta t}$$

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

High inductance-
Small voltage-
Small current slope

Power stored = power transfered to output

Choke - some parameters



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

when $\mu_w \frac{l_p}{l_r} >> 1$

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

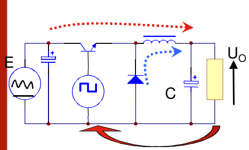
For sine waveforms:

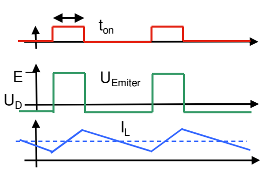
$$\frac{U_{max}}{z} = 2\pi f B_{max} S = \frac{\sqrt{2}U_{skut}}{z}$$

For square wave:

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

Step down (buck) converter





$$U_0 = \gamma E = \frac{t_{on}}{T} E$$

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

$$L_{\min} \geq \frac{E - U_0}{I_{L\max}} t_{on}$$

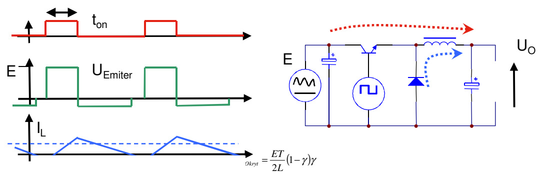
$$C > \frac{I_{O\max} T}{4 U_{Orip}}$$

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

simplified way of deriving equastion of the output voltage of the step-down converter

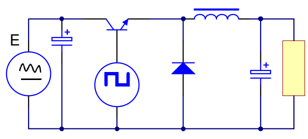
chalk board or separate video

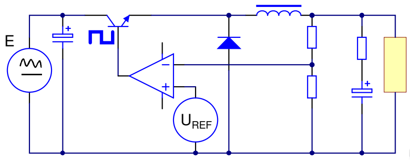
Step down converter (discontinues mode)



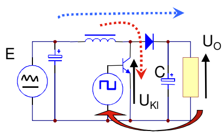
Output voltage can reach the value E !!!

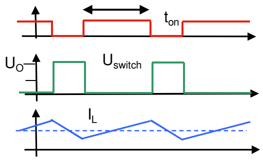
self-excited step-down controller





Step up (boost) converter





$$U_0 = \frac{1}{1-\gamma}E$$

$$I_{Lszczyt} \approx 2I_{O\max}\left(1+\frac{t_{on}}{t_{off}}\right)$$

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

$$C > \frac{I_{O\max}T}{U_{Otetnie\acute{n}}}$$

U_O – output voltage,

E – input voltage,

t_{on}, t_{off}, T – turn on, off, period

I_{Lpeak} – peak current of choke and switch

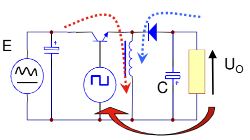
L_{min} – minimum inductance

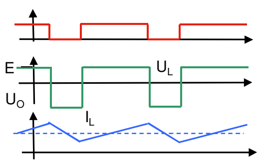
U_{Oripp} – ripple output voltage

simplified way of deriving equastion of the output voltage of the step-up converter

chalk board or separate video

Inverter (buck-boost)





$$U_0 = -\frac{\gamma}{1-\gamma}E$$

$$I_{Lszczyt} \approx 2I_{O\max}\left(\frac{1}{1-\gamma}\right)$$

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

$$C > \frac{I_{O\max}T}{U_{Otetnie\acute{n}}}$$

U_O – output voltage,

E – input voltage,

t_{on}, t_{off}, T – turn on, off, period

I_{Lpeak} – peak current of choke and switch

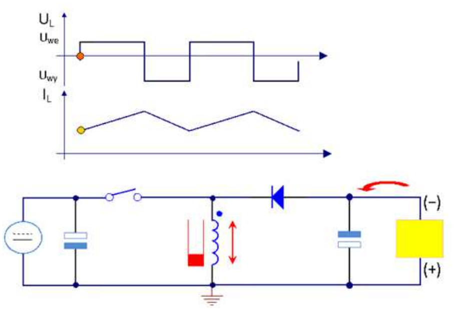
L_{min} – minimum inductance

U_{Oripp} – ripple output voltage

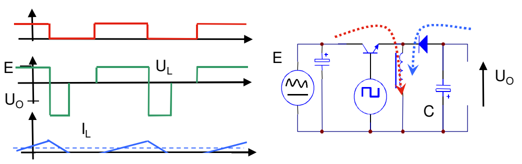
simplified way of deriving equastion of the output voltage of the inverter

chalk board or separate video

Inverter



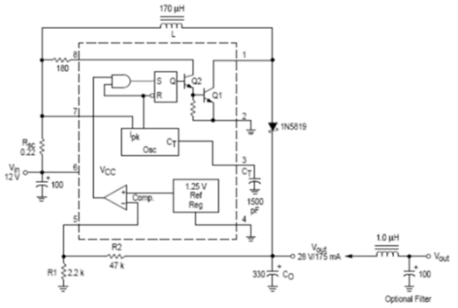
Inverter (discontinues mode)



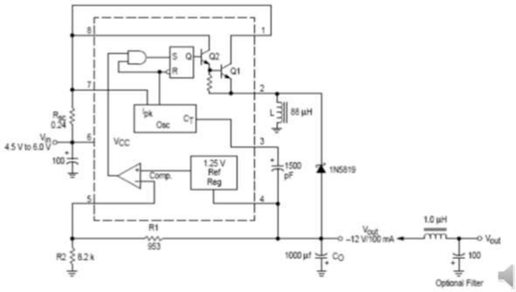
$$I_O < I_{Okryt} = \frac{E\gamma}{2L}(1-\gamma)T$$

Output voltage can ????∞ !!!

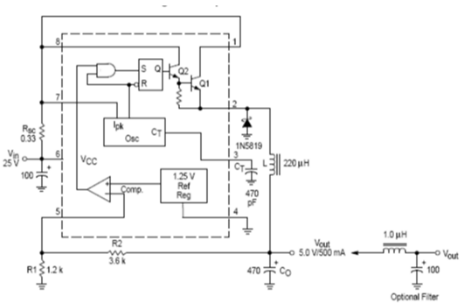
Step up MC34063



Inverting MC34063



Step down MC34063



MC34063 data sheet expressions

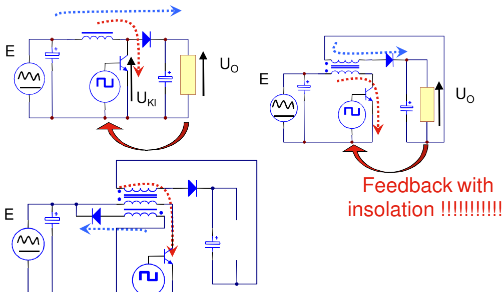
Calculation	Step–Up	Step–Down	Voltage–Inverting
t_{on}/t_{off}	$\frac{V_{out} + V_F - V_{in(min)}}{V_{in(min)} - V_{sat}}$	$\frac{V_{out} + V_F}{V_{in(min)} - V_{sat} - V_{out}}$	$\frac{\lvert V_{out}\rvert + V_F}{V_{in} - V_{sat}}$
$(t_{on} + t_{off})$	$\frac{1}{f}$	$\frac{1}{f}$	$\frac{1}{f}$
t_{off}	$\frac{t_{on} + t_{off}}{\frac{t_{on}}{t_{off}} + 1}$	$\frac{t_{on} + t_{off}}{\frac{t_{on}}{t_{off}} + 1}$	$\frac{t_{on} + t_{off}}{\frac{t_{on}}{t_{off}} + 1}$
t_{on}	$(t_{on} + t_{off}) - t_{off}$	$(t_{on} + t_{off}) - t_{off}$	$(t_{on} + t_{off}) - t_{off}$
C_T	$4.0 \times 10^{-5}\, t_{on}$	$4.0 \times 10^{-5}\, t_{on}$	$4.0 \times 10^{-5}\, t_{on}$
$I_{pk(switch)}$	$2I_{out(max)} \left(\frac{t_{on}}{t_{off}} + 1\right)$	$2I_{out(max)}$	$2I_{out(max)} \left(\frac{t_{on}}{t_{off}} + 1\right)$
R_{sc}	$0.3/I_{pk(switch)}$	$0.3/I_{pk(switch)}$	$0.3/I_{pk(switch)}$
$L_{(min)}$	$\left(\frac{V_{in(min)} - V_{sat}}{I_{pk(switch)}}\right) t_{on(max)}$	$\left(\frac{V_{in(min)} - V_{sat} - V_{out}}{I_{pk(switch)}}\right) t_{on(max)}$	$\left(\frac{V_{in(min)} - V_{sat}}{I_{pk(switch)}}\right) t_{on(max)}$
C_O	$9\frac{I_{out} t_{on}}{V_{ripple(pp)}}$	$\frac{I_{pk(switch)}(t_{on} + t_{off})}{8V_{ripple(pp)}}$	$9\frac{I_{out} t_{on}}{V_{ripple(pp)}}$

V_{sat} = Saturation voltage of the output switch.
V_F = Forward voltage drop of the output rectifier.

The following power supply characteristics must be chosen:

V_{in} – Nominal input voltage.
V_{out} – Desired output voltage, $\lvert V_{out}\rvert = 1.25\left(1 + \frac{R2}{R1}\right)$
I_{out} – Desired output current.
f_{min} – Minimum desired output switching frequency at the selected values of V_{in} and I_O.
$V_{ripple(pp)}$ – Desired peak–to–peak output ripple voltage. In practice, the calculated capacitor value will need to be increased due to its equivalent series resistance and board layout. The ripple voltage should be kept to a low value since it will directly affect the line and load regulation.

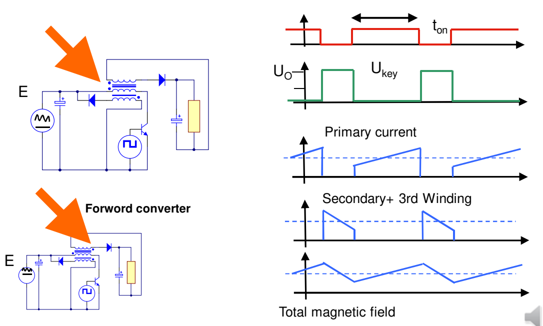
Choke converter (flyback)



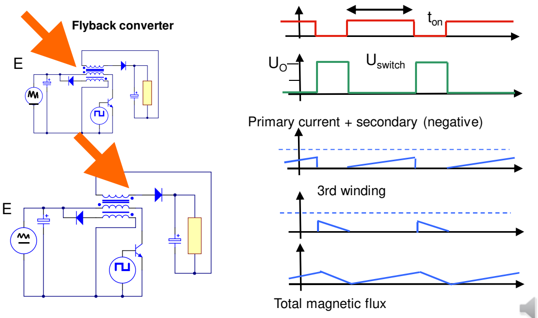
Feedback with insolation !!!!!!!!!!!!

3rd winding allows release the energy in the choke when there is no load

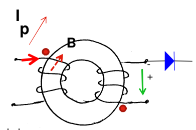
Flyback vs. Forword converter



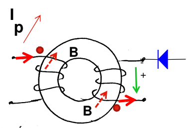
forward converter



Choke vs. transformer



choke:
only primary is conducting

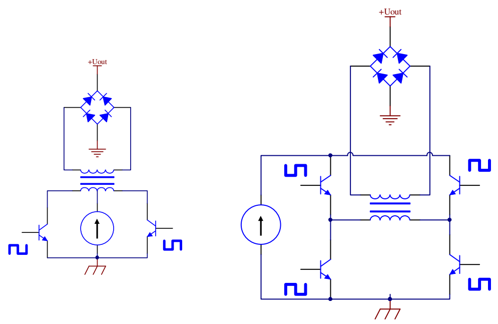


transformer:
both primary and secondary are conducting simultaneously;
magnetic flux of both cancel out (almost)

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 !

High power converters (foreword)



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.

Summary

Advantages:

- High efficiency
- Small dimensions

Drawbacks:

- Worse line and load regulation
- Interferences
- More expensive

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

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