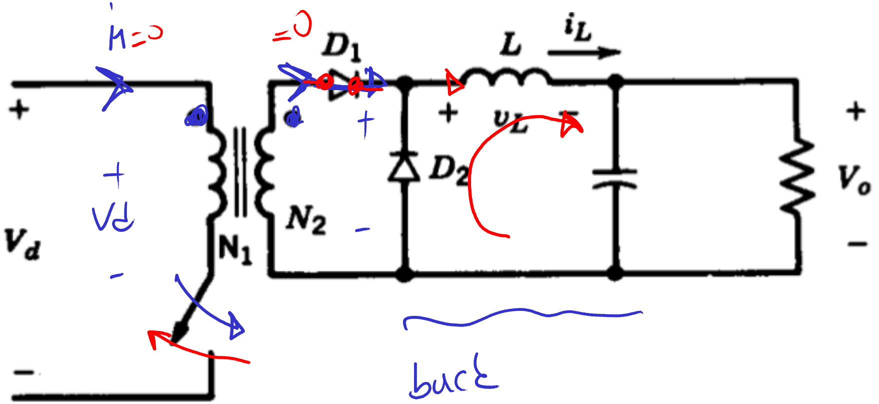
Forward Converter

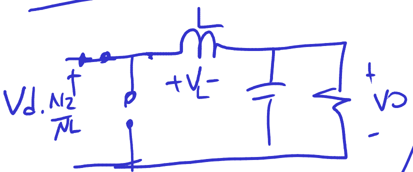
Derived from the Buck Converter



Forward Converter

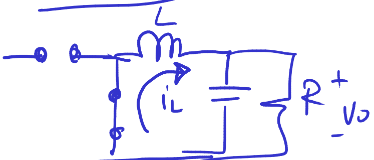
Let's obtain the output voltage characteristics

Switch is ON

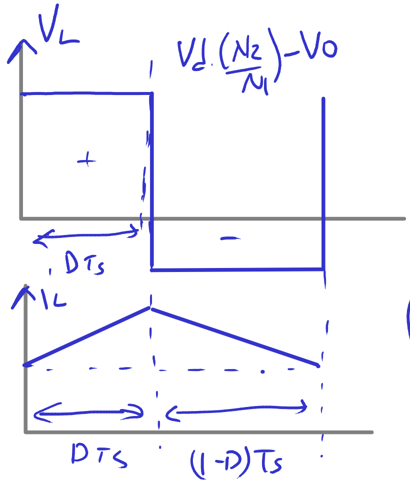


$$V_L = V_d \left(\frac{N_2}{N_1}\right) - V_o$$

switch is OFF



$$V_L = -V_o$$



$$\left(V_d \left(\frac{N_2}{N_1}\right) - V_o\right) \cdot D = V_o(1-D)$$

$$V_d \cdot \frac{N_2}{N_1} \cdot D - V_o D = V_o - V_o D$$

$$V_o = V_d \cdot \frac{N_2}{N_1} \cdot D$$

Forward Converter

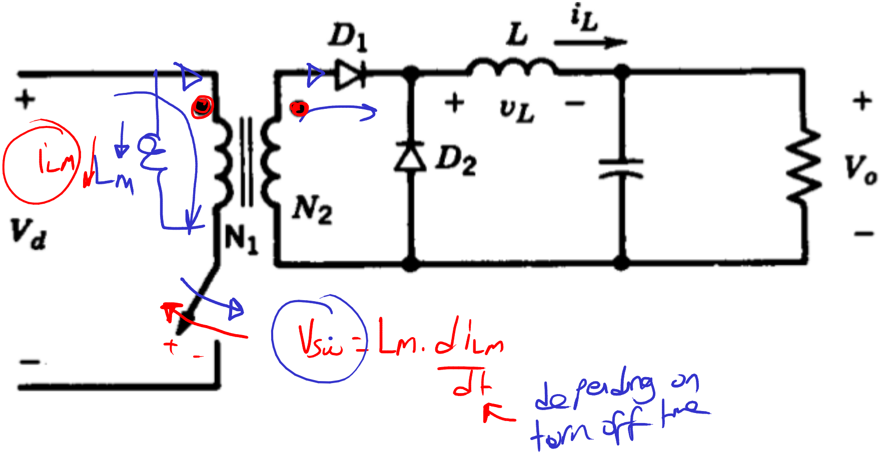
A buck converter with added turns ratio

$$\frac{V_o}{V_d} = \frac{N_2}{N_1} D$$

transformer ratio

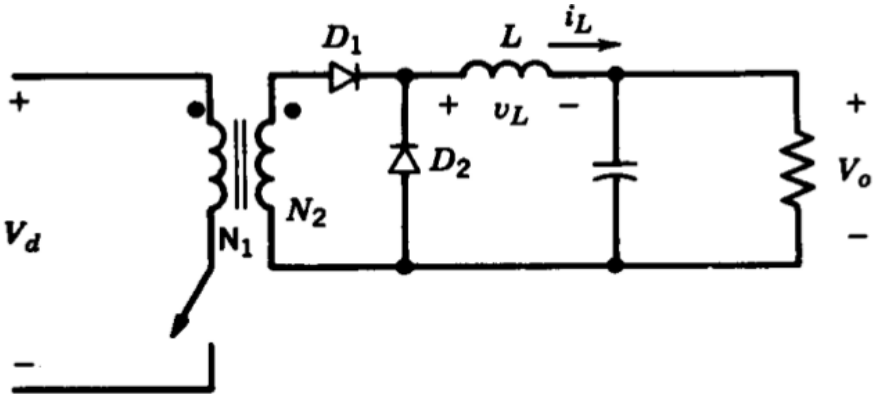
buck part

Forward Converter



What happens at the instant when the switch is turned-off, if the transformer is not ideal?

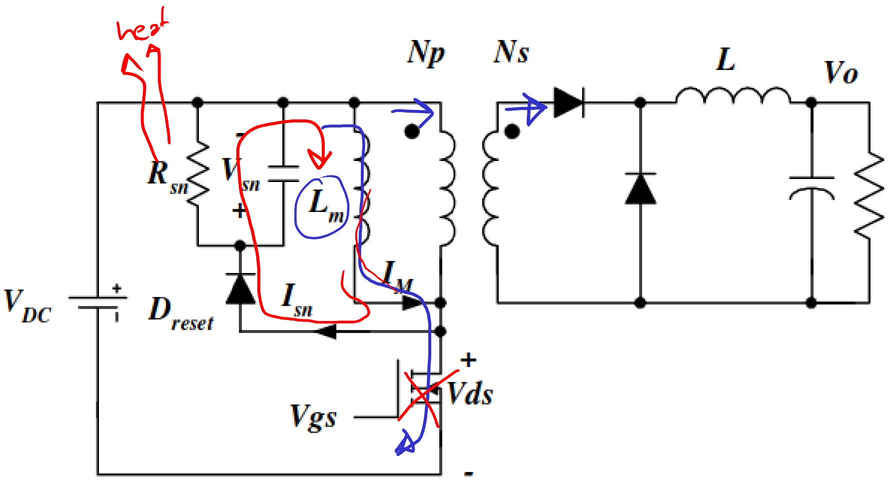
Forward Converter



A discharging path for Lm should be added.

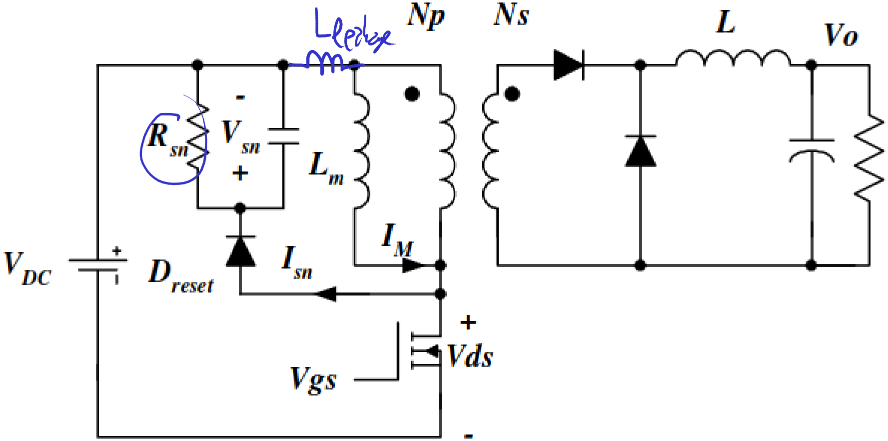
Simple Solution: RCD Reset Circuit

↳ Snubber Circuit



Magnetizing current dissipates through RCD circuit

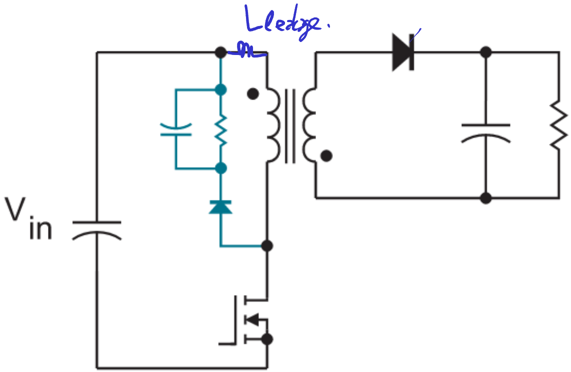
Simple Solution: RCD Reset Circuit



Cheap but inefficient

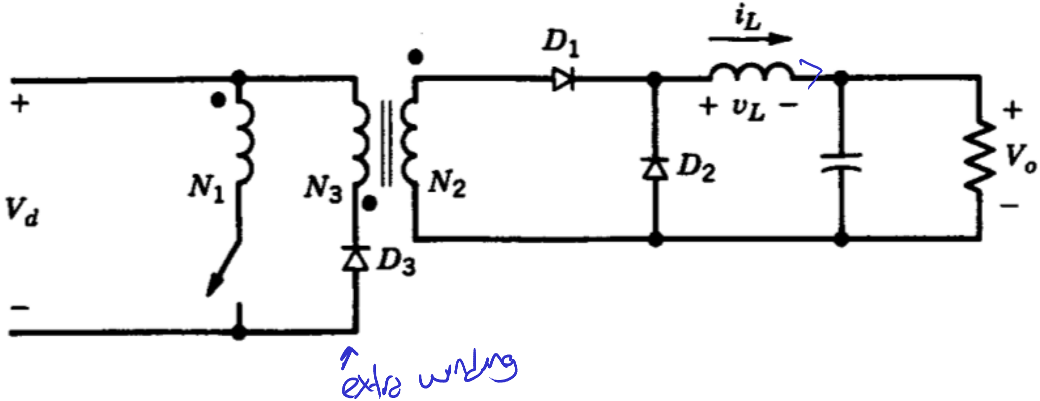
RCD Snubber

Note a similar circuit can be used for the Flyback converter (to reduce inductance leakage ringing)



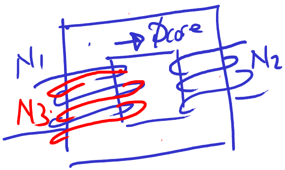
Suggested Reading: [Flyback Converter Snubber Design]

Practical Forward Converter

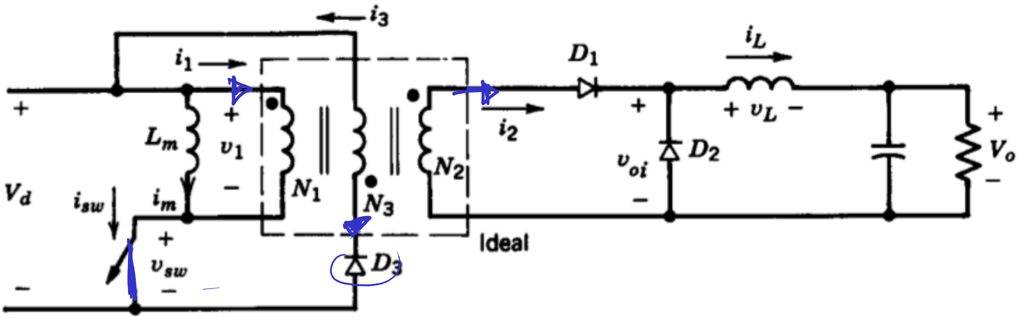


A transformer with two-primary windings

Third winding is added to discharge the energy stored in Lm



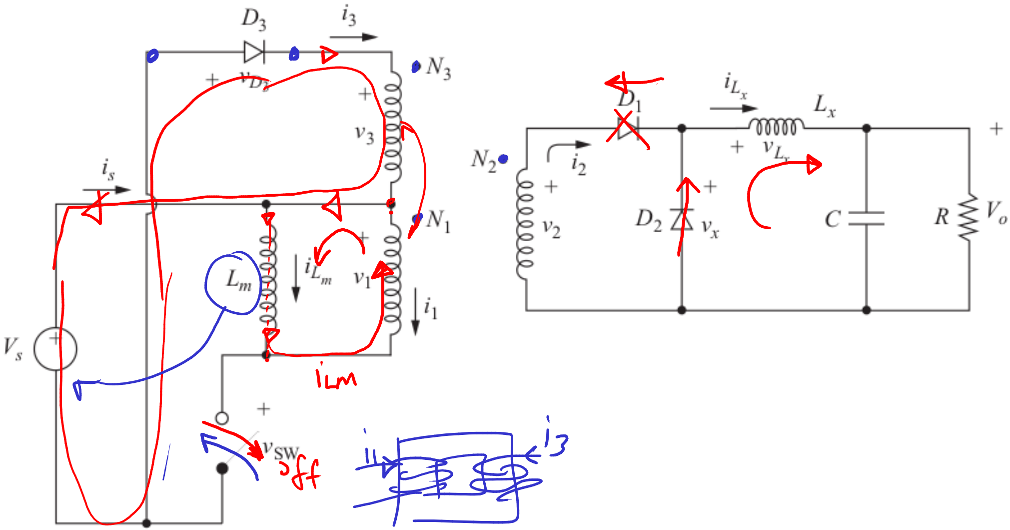
Practical Forward Converter



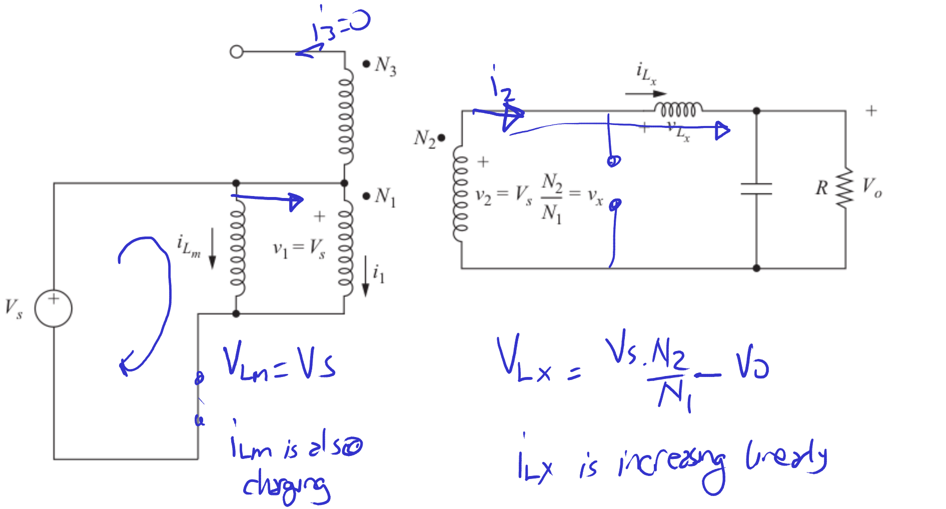
A transformer with two-primary windings

Third winding is added to discharge the energy store

Forward Converter



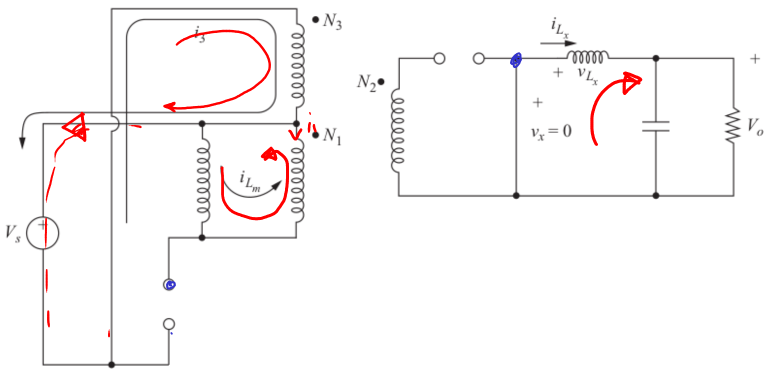
Forward Converter: Switch is ON



Lm is charged by input voltage, Lx is also charging

D1 On, D2 Off, D3 Off

Forward Converter: Switch is OFF



Lx feeds the load, Lm is discharged to the source: $i_1 = -i_{Lm}$

KCL: $N_1 i_1 = N_2 i_2 - N_3 i_3$

For proper operation the transformer should be "reset" before next ON period

Forward Converter: Switch is OFF

<u>switch ON</u> $\Rightarrow$ $V_1 = V_s$

$V_2 = V_1 . \frac{N_2}{N_1} = V_s . \frac{N_2}{N_1}$

$V_3 = V_1 . \frac{N_3}{N_1} = V_s . \frac{N_3}{N_1}$

$V_{D3} = -V_s - V_3 < 0 \Rightarrow D_3$ is off

$V_{Lm} = V_s$ (for DT_s)

✓ $\Delta i_{Lm} = \frac{V_s . DT_s}{L_m}$

$i_{sw} = i_1 + i_{Lm}$

<u>switch off</u>

$i_{Lm} = -i_1$ $\quad V_3 = -V_s$

$V_1 = V_3 . \left(\frac{N_1}{N_3}\right) = -V_s . \frac{N_1}{N_3}$

$V_2 = V_3 \left(\frac{N_2}{N_3}\right) = -V_s . \frac{N_2}{N_3}$

$N_1 . i_1 = N_2 . i_2 - N_3 . i_3$ ($i_2 = 0$)

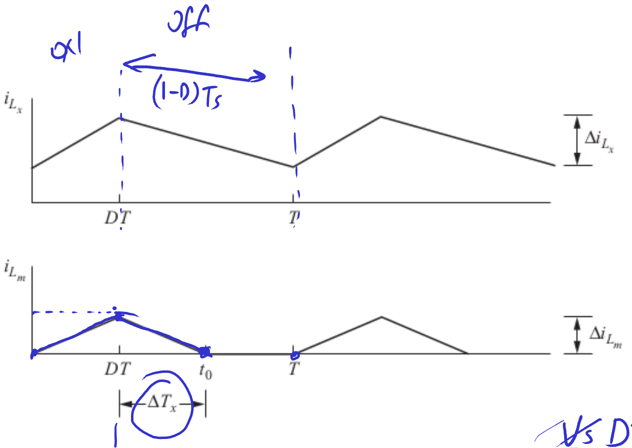
$N_1 i_1 = N_3 i_3$

$i_3 = \frac{-N_1}{N_3} i_1$

$V_{Lm} = V_1 = -V_s . \frac{N_1}{N_3} = L_m . \frac{di_{Lm}}{dt}$

$\frac{di_{Lm}}{dt} = \frac{-V_s}{L_m} . \left(\frac{N_1}{N_3}\right)$ ✓

Forward Converter



$$D\left(1+\frac{N_3}{N_1}\right) < 1$$

$N_1 = N_3$ (common practice)

$$D < 0,5$$

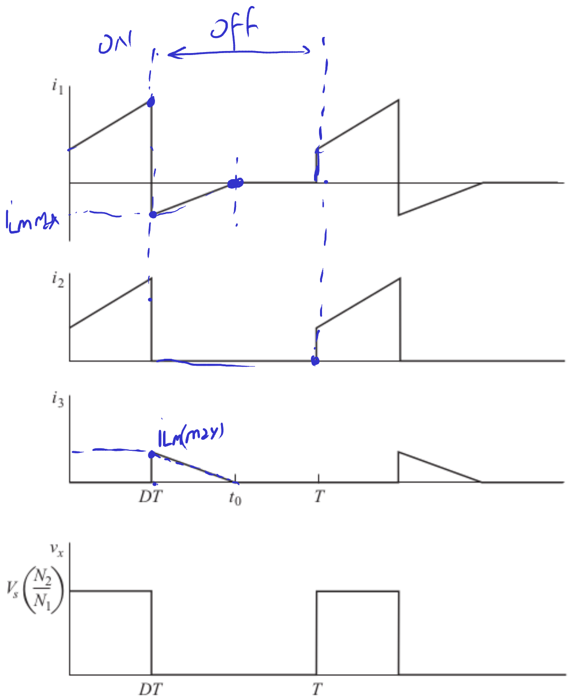
$$i_{Lm(max)} = \frac{V_s \cdot DT_s}{L_m}$$

$$\Delta T_x = \frac{\frac{V_s DT_s}{L_m}}{\frac{V_s}{L_m}\left(\frac{N_1}{N_3}\right)} = DT_s\left(\frac{N_3}{N_1}\right)$$

$$\Delta T_x < (1-D)\,T_s$$

$$\Delta T_x = DT_s\left(\frac{N_3}{N_1}\right) < (1-D)\,T_s$$

Forward Converter



Practical Forward Converter

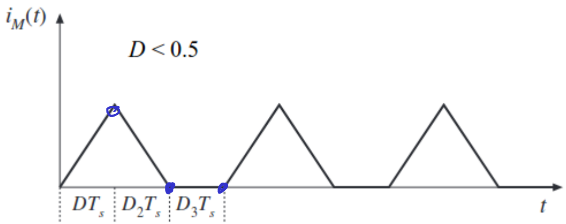
For proper operation the transformer should be "reset" before next ON period

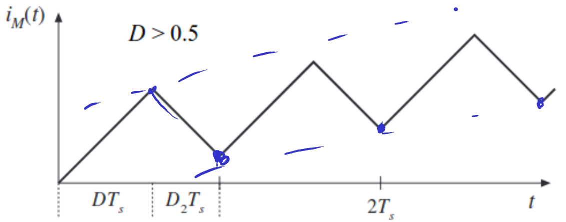
$$t_m < (1 - D)T_s$$

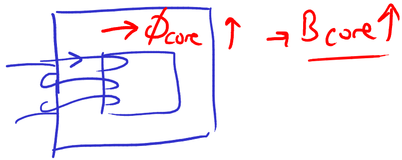
$$D_{max} = \frac{1}{1 + (N_3/N_1)}$$

if $N_3 = N_1 \Rightarrow D < 0,5$

What happens if D is large, and transformer does not reset completely?







In the figure Dmax=0.5

Saturation, increased core losses, reduced Lm, problem in power transfer

Advantages over Flyback

- Better utilization of transformer (direct power transfer, higher)

- A gapless core can be used (higher Lm, less ripple)

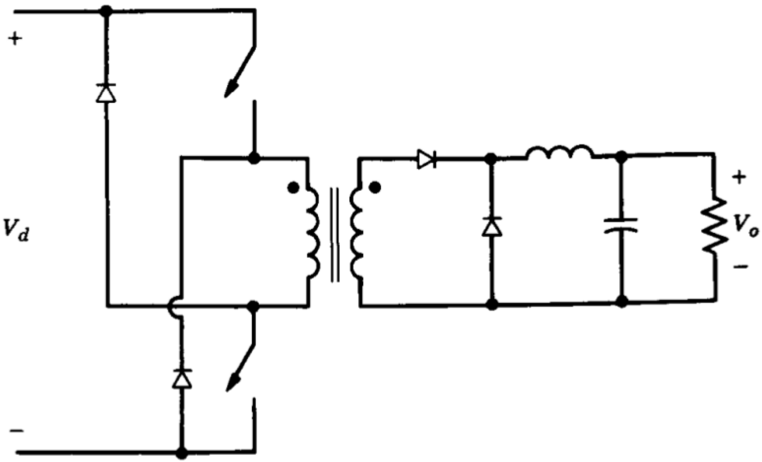
- Output inductor and diode ensures continuous output current

Drawbacks compared to Flyback

- Increased cost (extra diode and inductor)
- Gain changes a lot in DCM
- Higher voltage requirement for MOSFET

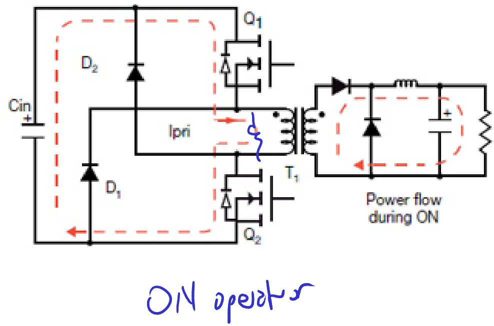
Forward Converter Alternatives

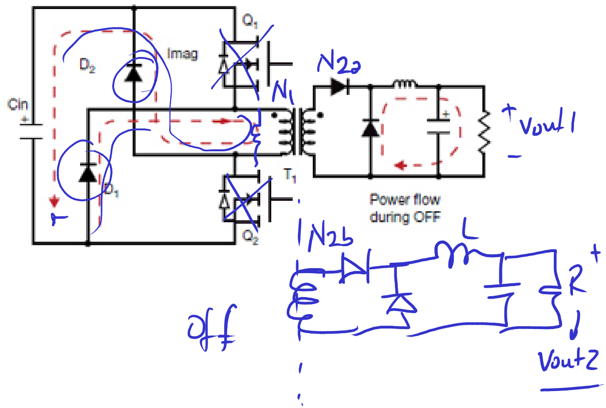
Two-switch forward converter



Forward Converter Alternatives

Two-switch forward converter





Two-switch forward converter

Advantages:

- Does not require a snubber circuit
- Less voltage stress on MOSFETs
- Can supply multiple isolated outputs
- Low power losses and noise

Two-switch forward converter

Disadvantages:

- Slightly more expensive
- Larger component count

Interleaved forward converter