EE-464 STATIC POWER CONVERSION-II

Switching Power Supplies

Ozan Keysan

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Regulated Power Supplies

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- Regulated Output Voltage

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- Electric Isolation

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- Minimum size, weight

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- Minimum cost
- Maximum efficiency

Linear Regulators

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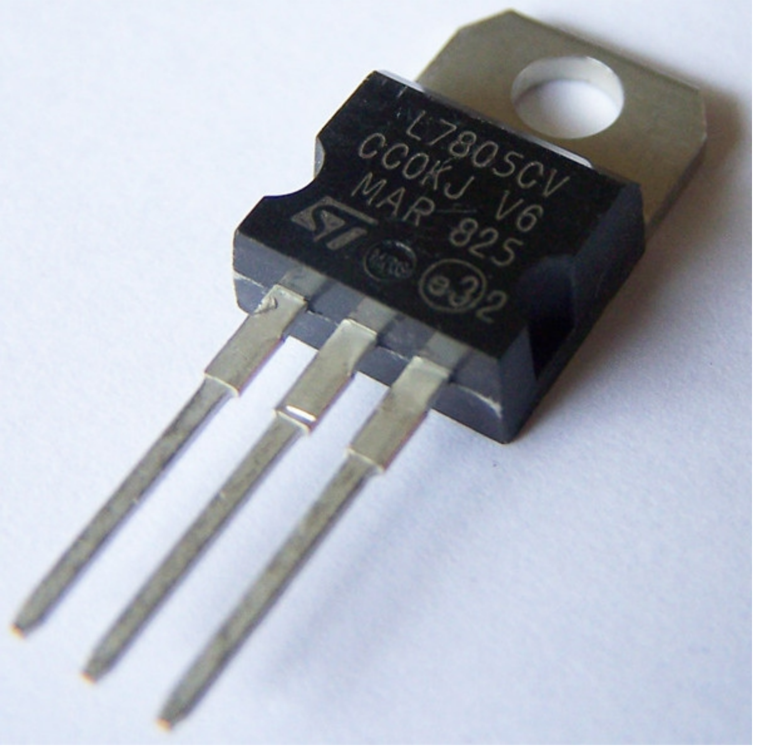

Linear Power Supplies

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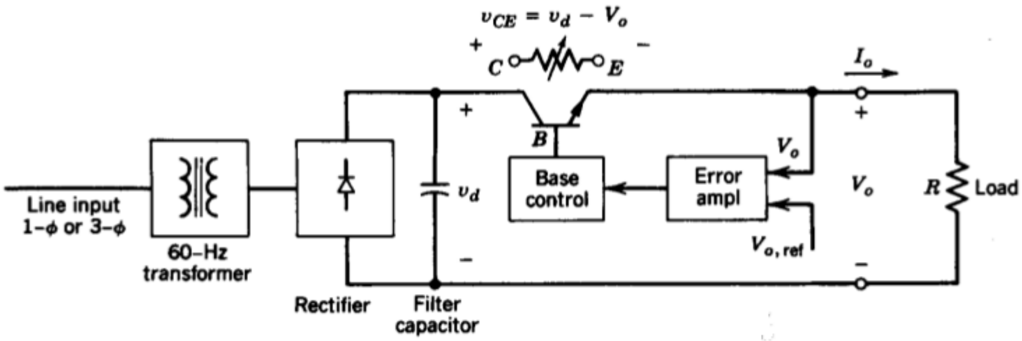
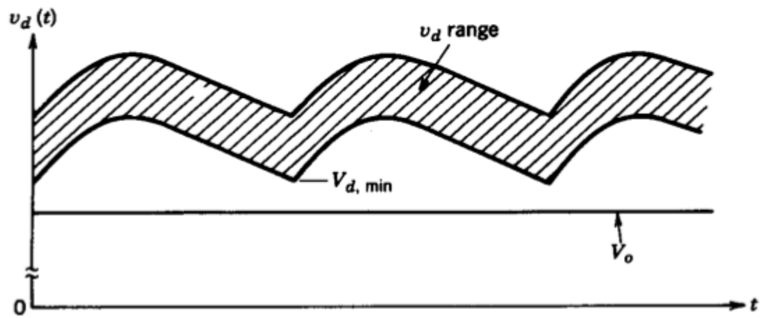


(a)



Linear Power Supplies

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- Low frequency transformer: large and heavy

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Switching DC Power Supply

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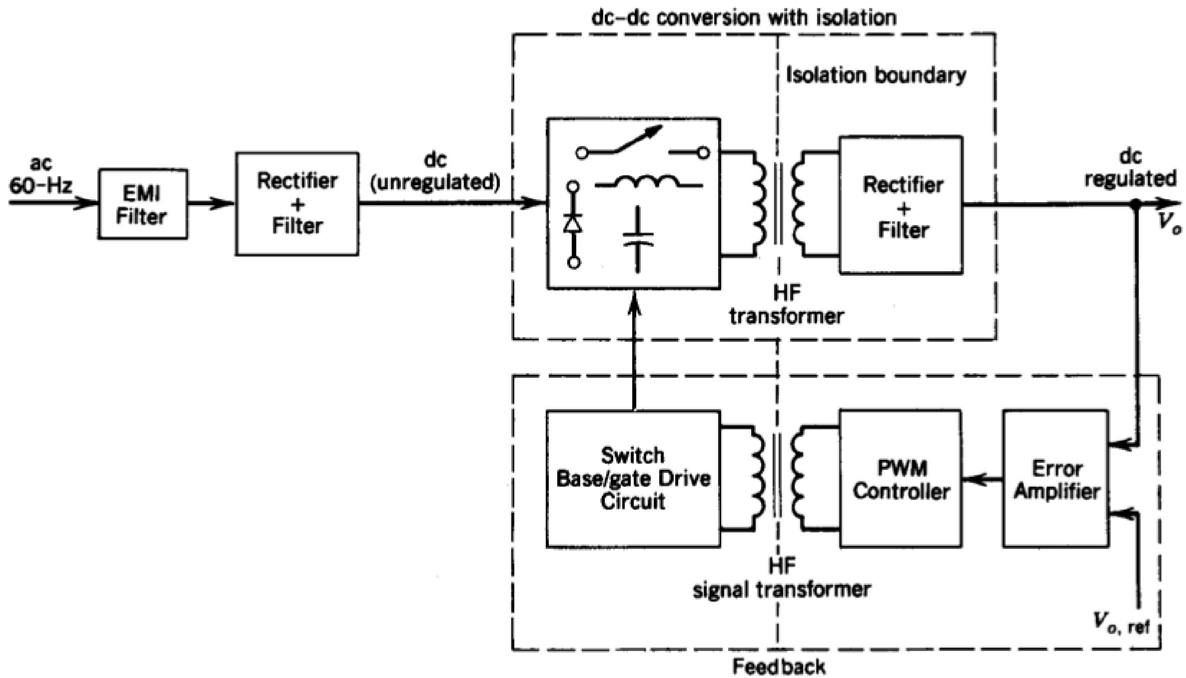
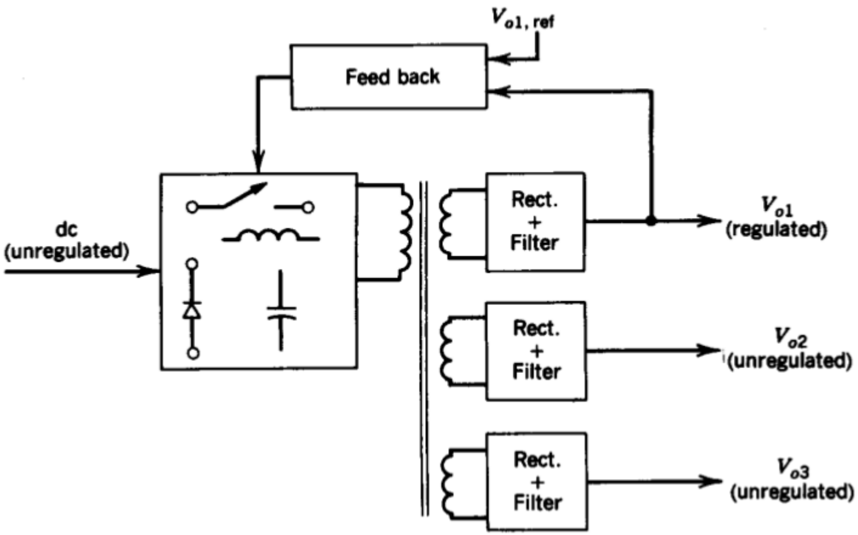


Switching DC Power Supply

Switching DC Power Supply

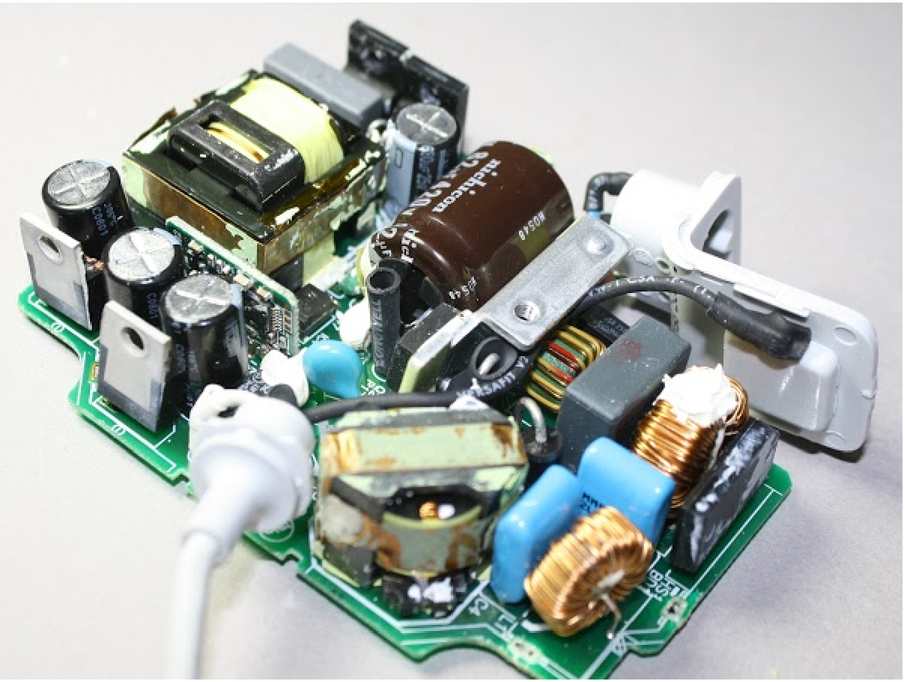
Multiple Output Case



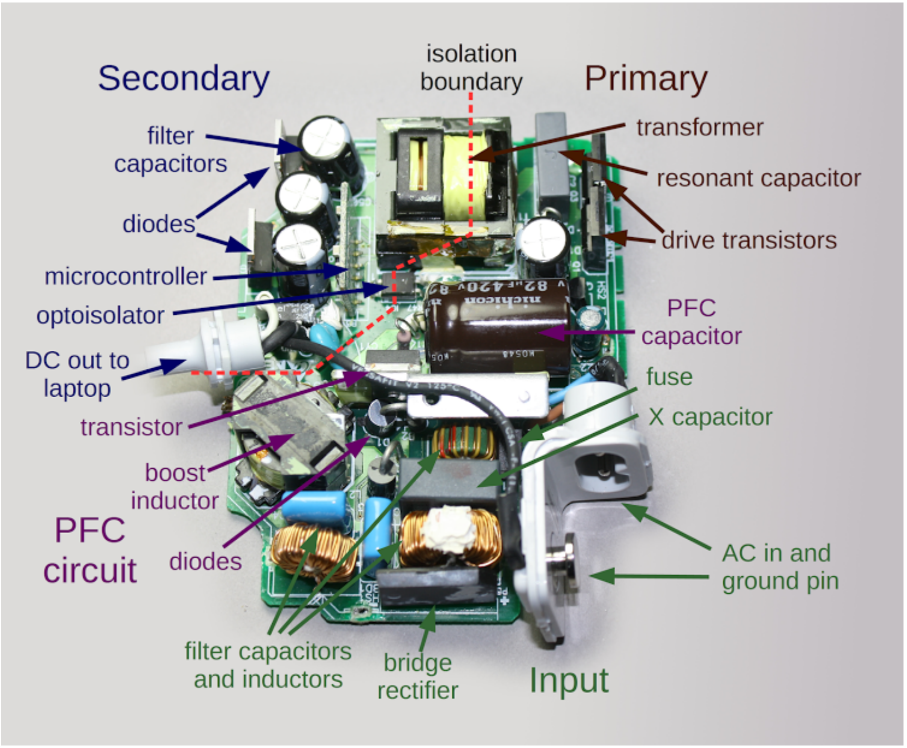
Case Study:

Case Study:

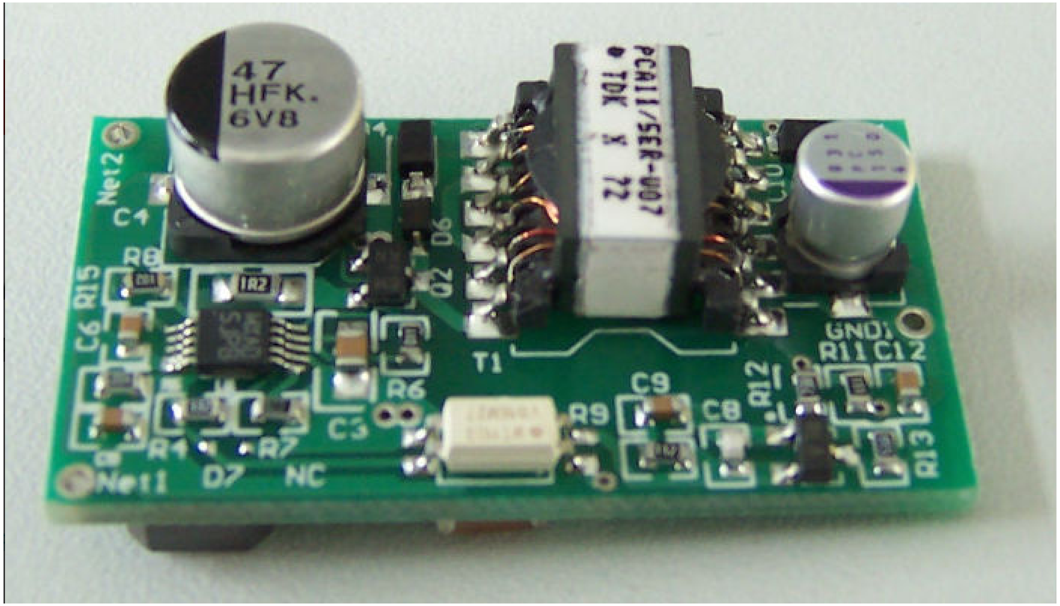
Apple Charger Teardown



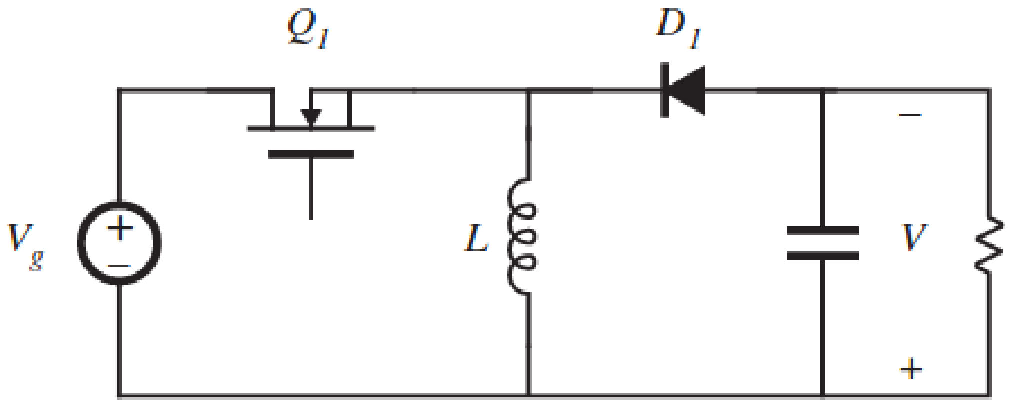
Apple Charger Teardown



Flyback Converter

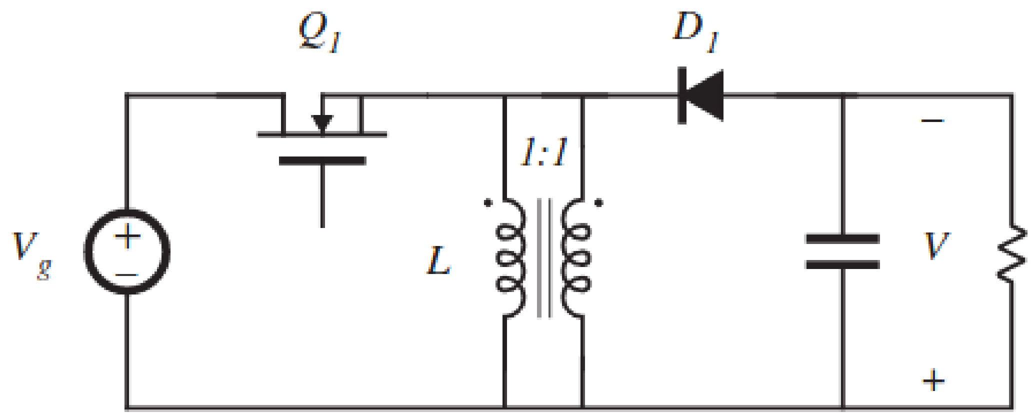


Flyback Converter Evolution



Start from the buck-boost converter

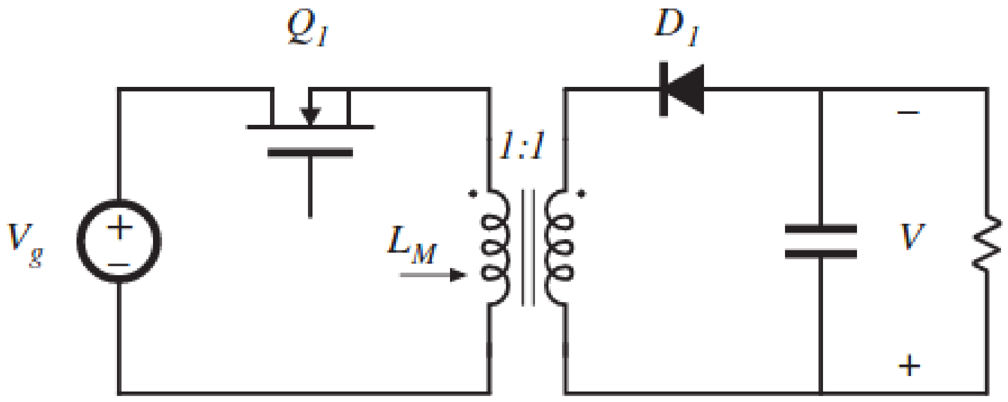
Flyback Converter Evolution



Wound the inductor with two parallel wires

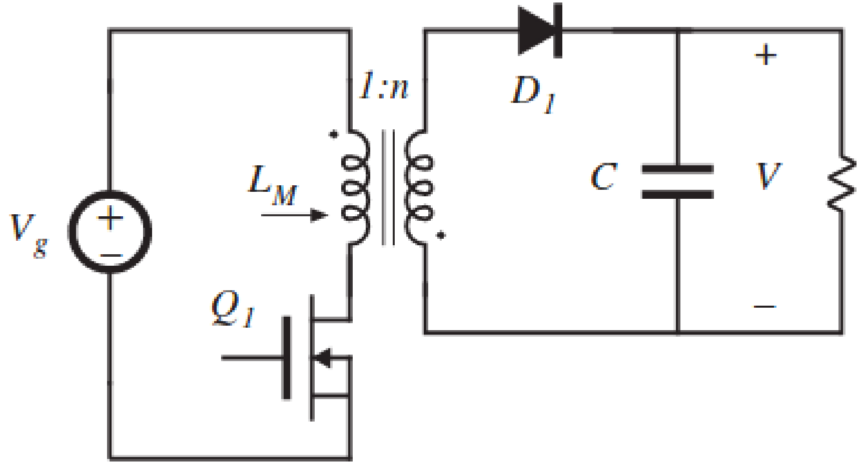
Don't get confused with the dots yet!

Flyback Converter Evolution



Isolate inductor wires (isolated converter)

Flyback Converter Evolution



Modify turns ratio to adjust output voltage and direction to get positive output

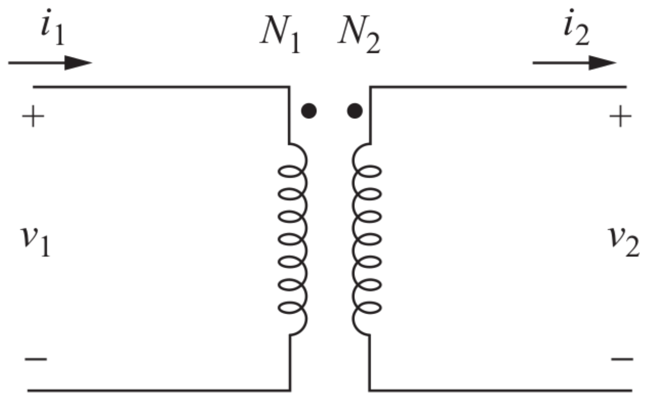
Back to EE361

Back to EE361

Ideal Transformer

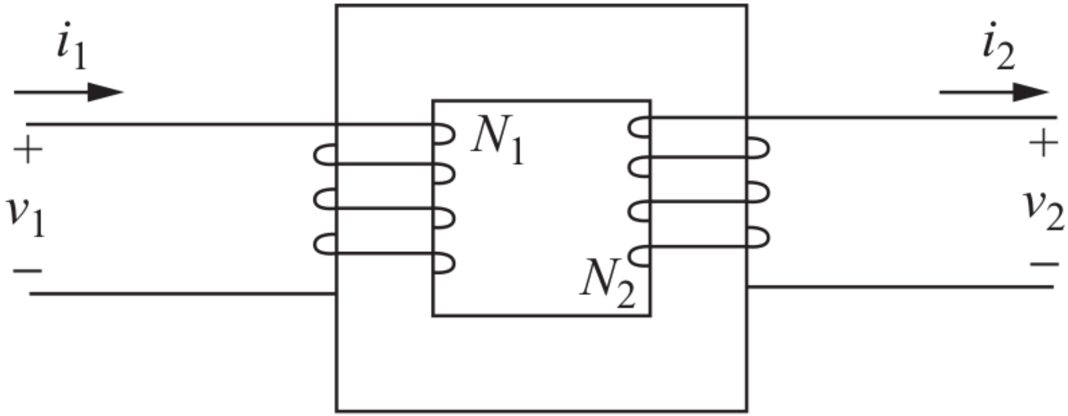
Back to EE361

Ideal Transformer



Back to EE361

Ideal Transformer



Back to EE361

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Realistic Transformer Equivalent Circuit

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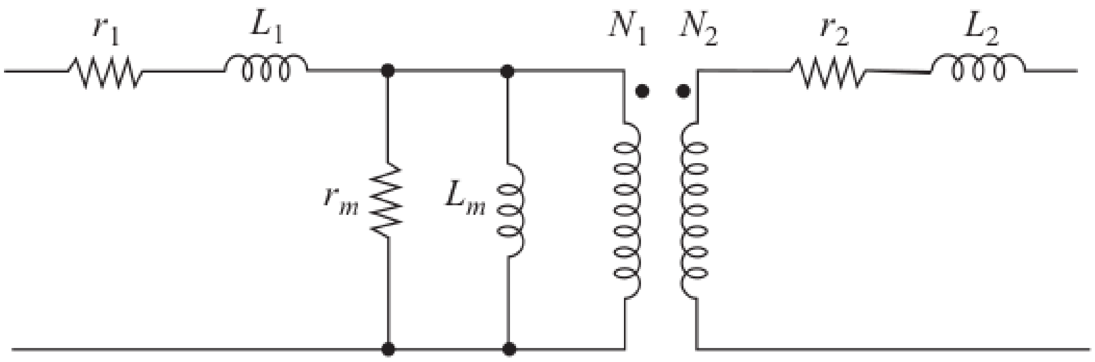
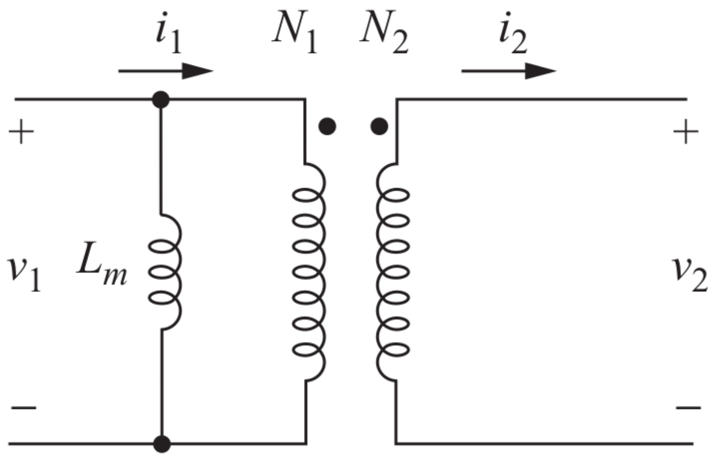
Realistic Transformer Equivalent Circuit

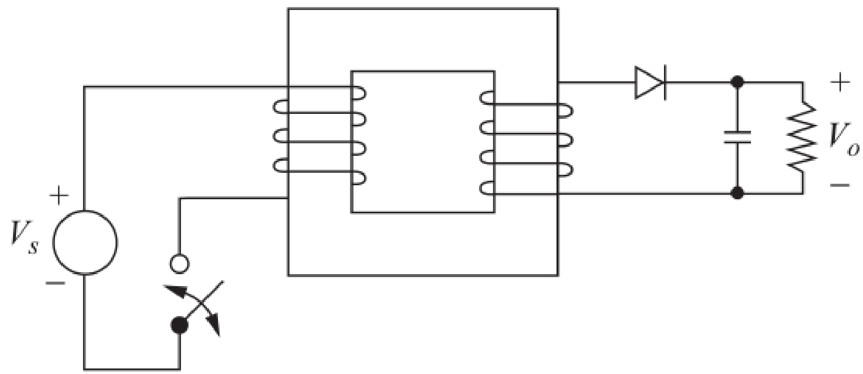


Flyback Converter

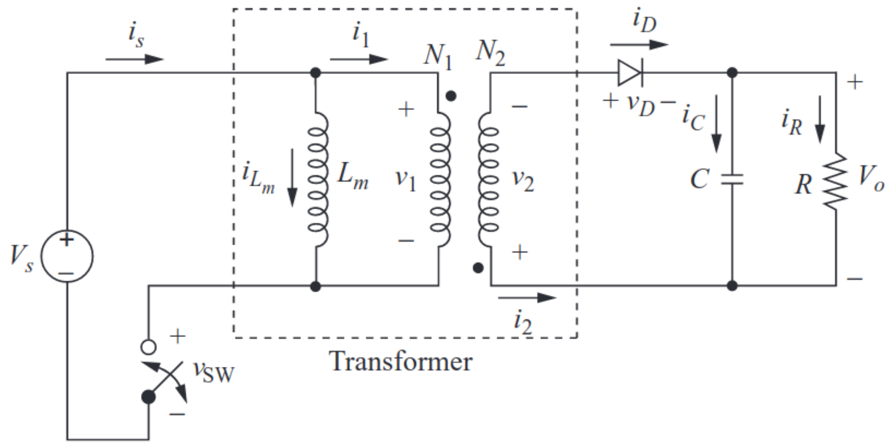
Let's ignore resistive parts and leakage flux for now



Flyback Converter with Transformer



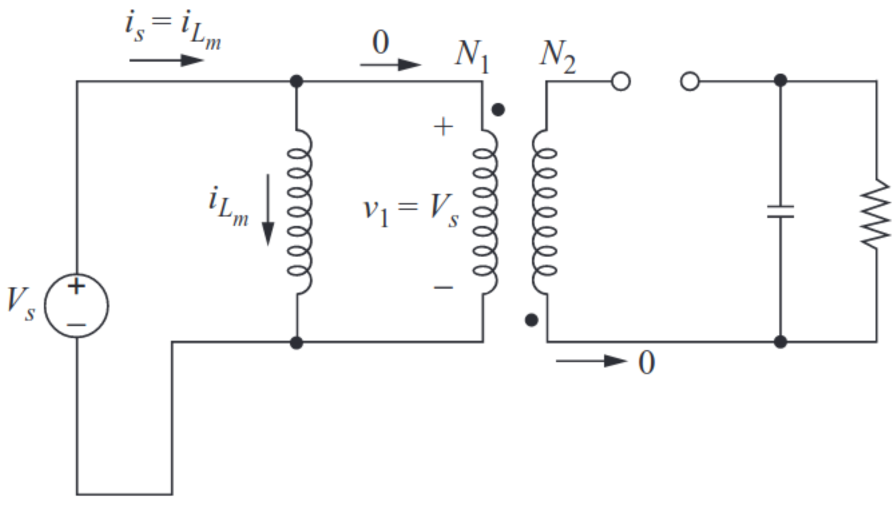
Flyback Converter with Transformer



Can you plot the operating modes?

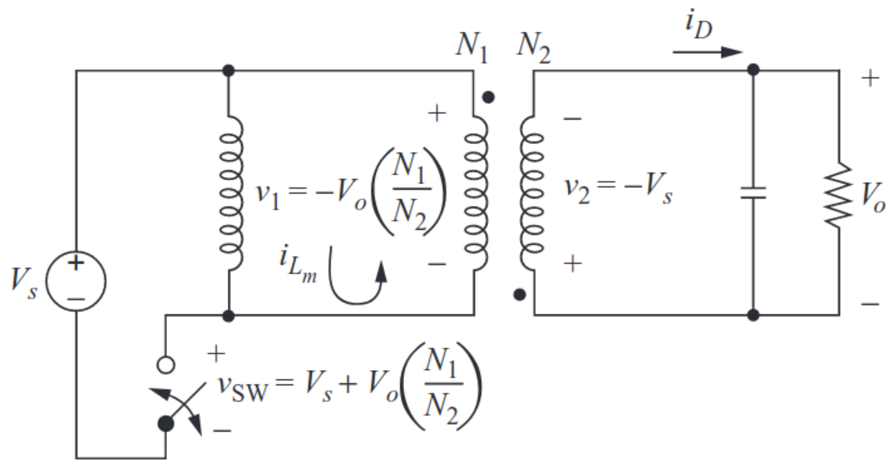
Flyback Converter

Switch ON

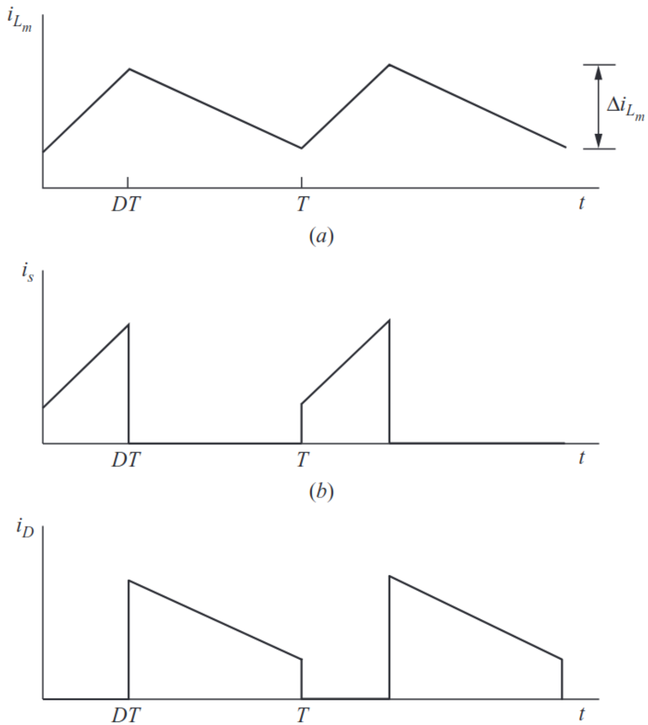


Flyback Converter

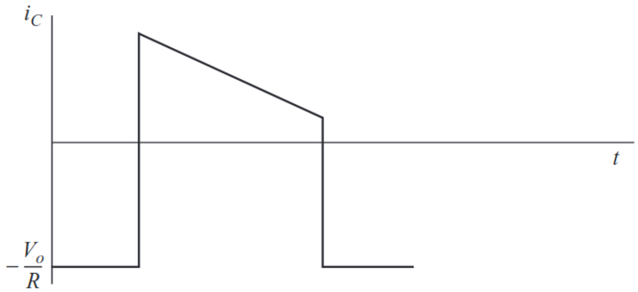
Switch OFF



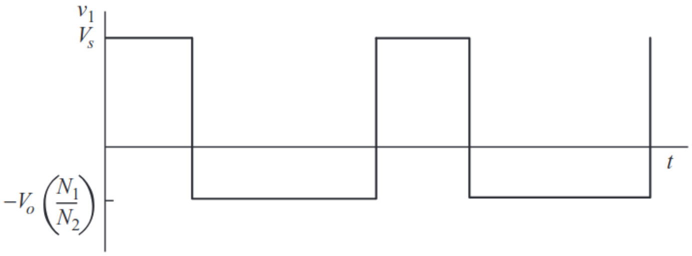
Flyback Converter



Flyback Converter



(d)



Flyback Converter

Conversion ratio can be calculated in three different ways:

- Magnetic Circuit: Transformer Flux
- Steady state current
- Graphically: Voltage-seconds area of the inductor

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

Switch Selection

Switch Selection

Peak Switch Current

Switch Selection

Peak Switch Current

$$\hat{I}_{sw} = \frac{1}{(1-D)} \frac{N_2}{N_1} I_o + \frac{N_1}{N_2} \frac{(1-D)T_s}{2L_m} V_o$$

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Peak Switch Voltage

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Peak Switch Voltage

$$\hat{V}_{sw} = V_d + \frac{N_1}{N_2} V_o$$

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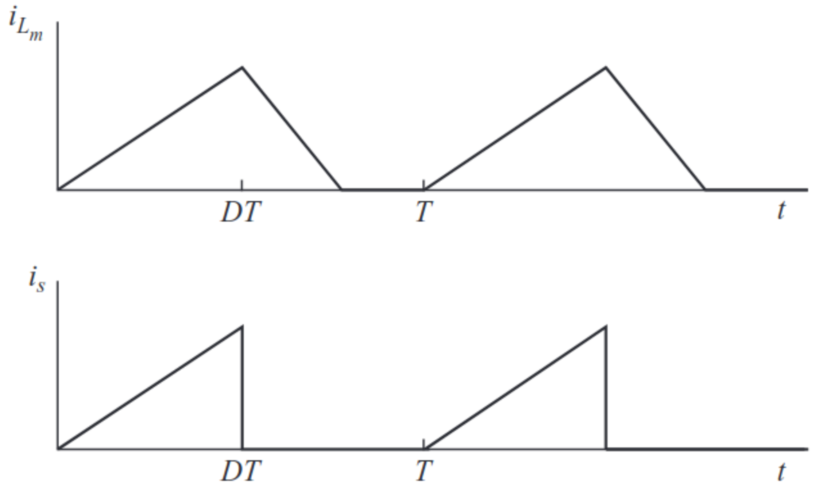
Peak Switch Voltage

$$\hat{V}_{sw} = V_d + \frac{N_1}{N_2}V_o = \frac{V_d}{(1-D)}$$

Flyback Converter: DCM



Reading Materials

- The Flyback Converter
- Flyback transformer tutorial: function and design
- Flyback Converter Video
- Designing a DCM flyback converter
- Flyback DCM vs CCM

Flyback Variations: Two Transistor Flyback

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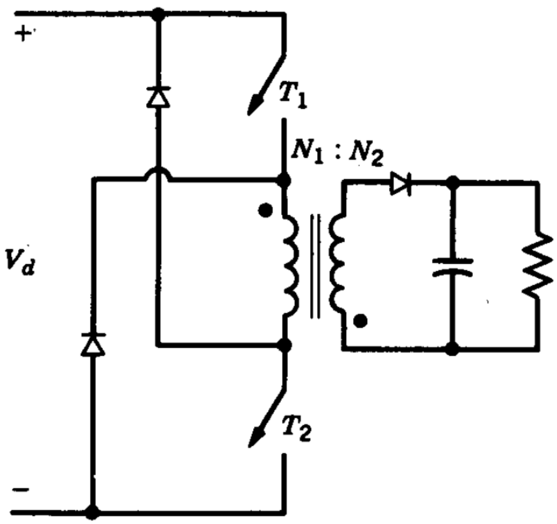

- [Improving the Performance of Traditional Flyback with Two Switch Approach]
- [Operation & Benefits of Two-Switch Forward/Flyback Power Converter Topologies]

Flyback Variations: Paralled Flyback

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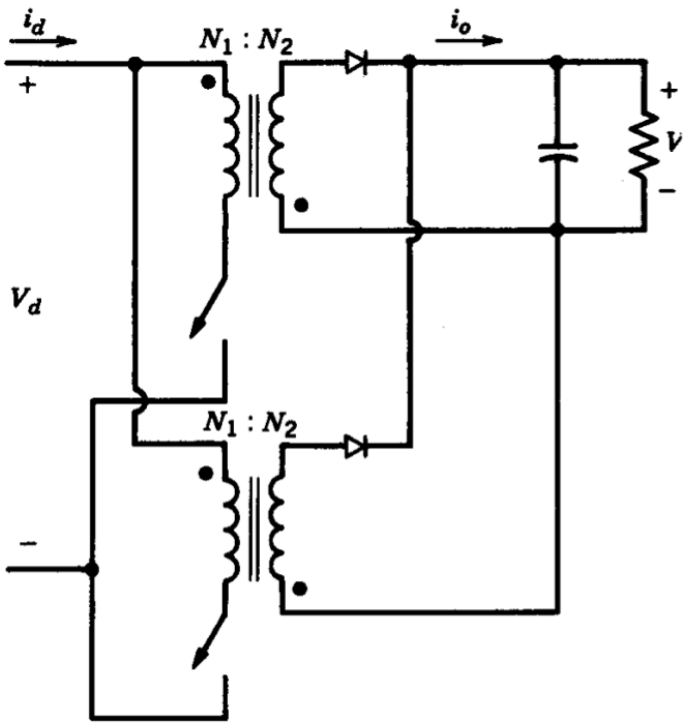
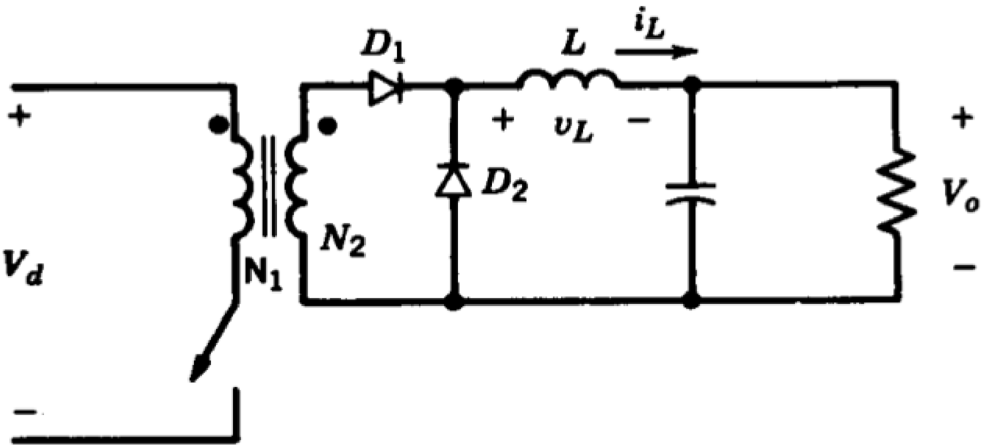


Forward Converter

Forward Converter

Derived from the Buck Converter



Forward Converter

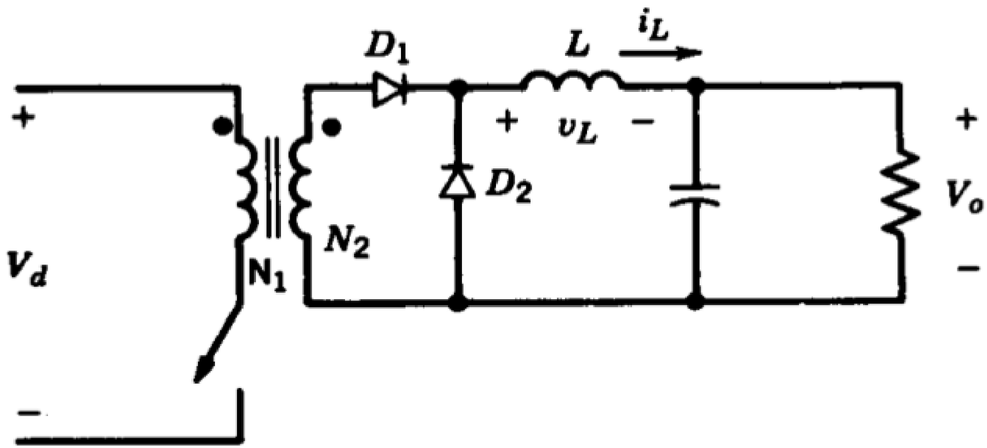
Let's obtain the output voltage characteristics

Forward Converter

A buck converter with added turns ratio

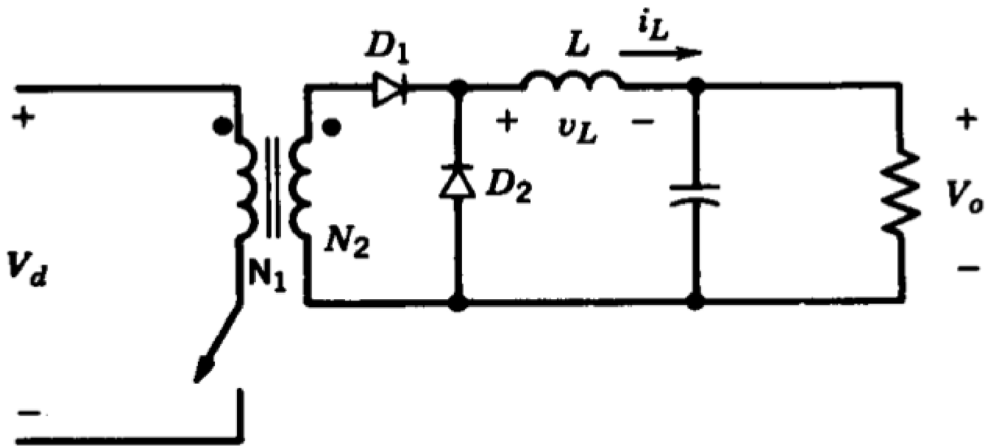
$$\frac{V_o}{V_d} = \frac{N_2}{N_1} D$$

Forward Converter



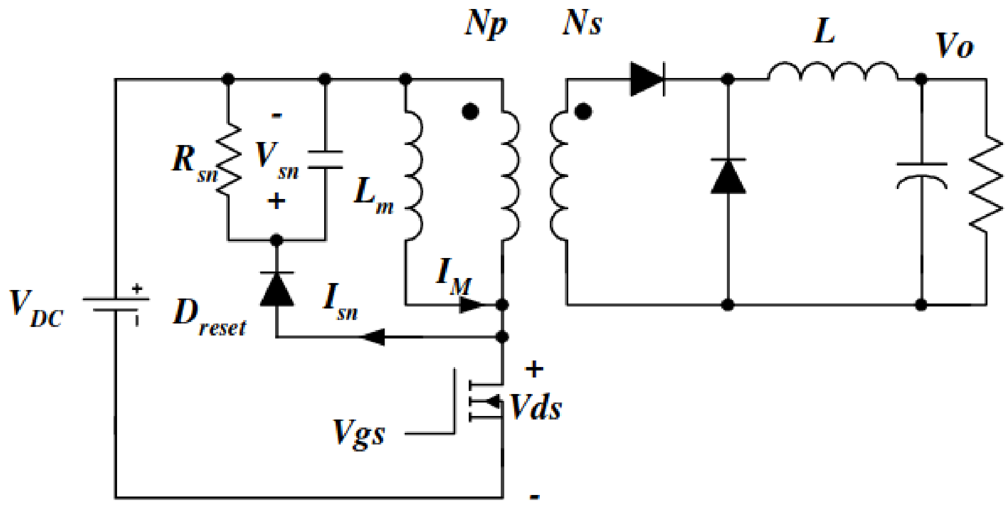
What happens at the instant when the switch is turned-off, if the transformer is not ideal?

Forward Converter



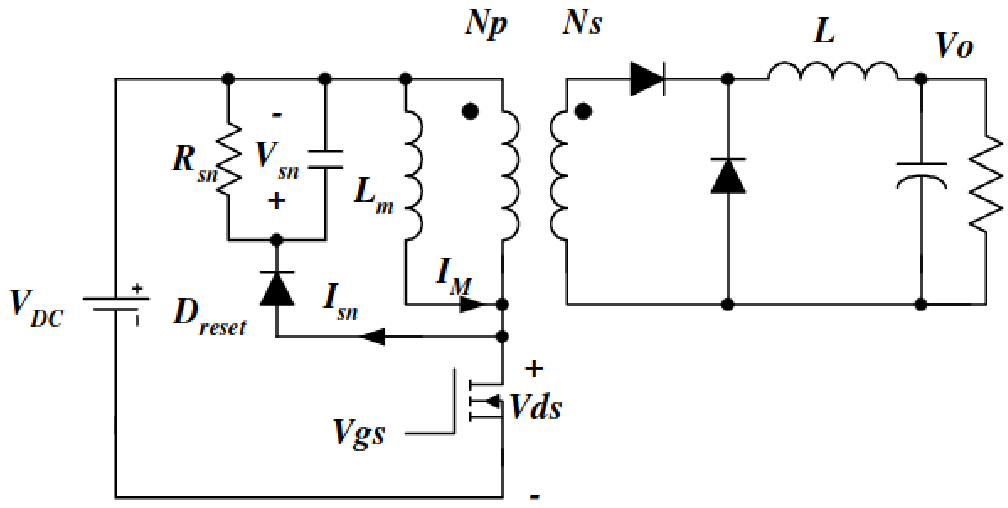
A discharging path for Lm should be added.

Simple Solution: RCD Reset Circuit



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)

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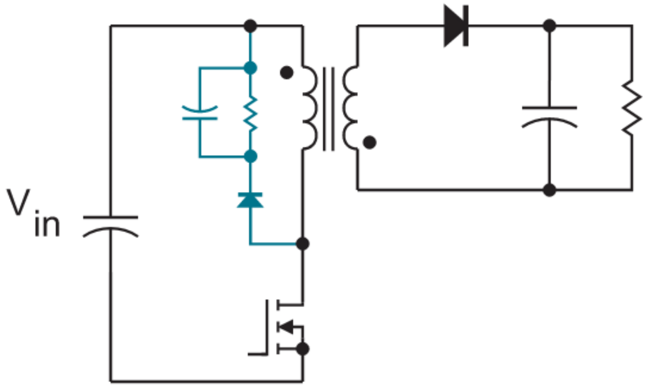
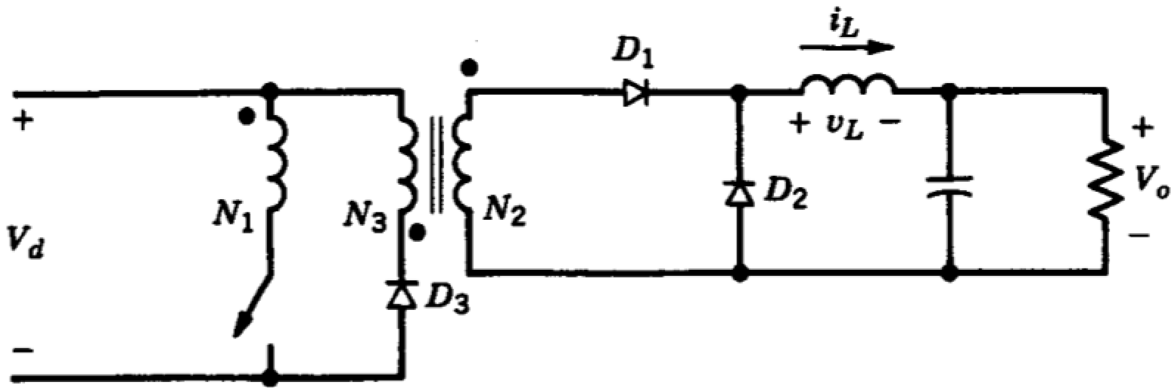


Suggested Reading: [Flyback Converter Snubber Design]

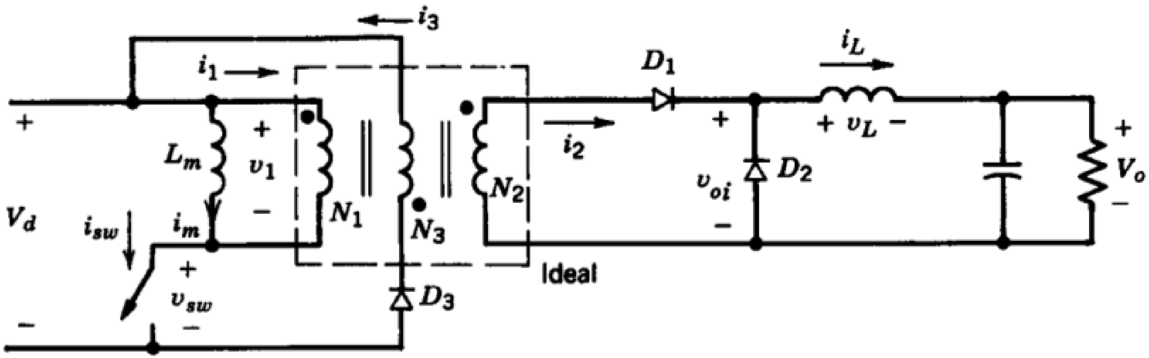
Practical Forward Converter



A transformer with two-primary windings

Third winding is added to discharge the energy stored in Lm

Practical Forward Converter



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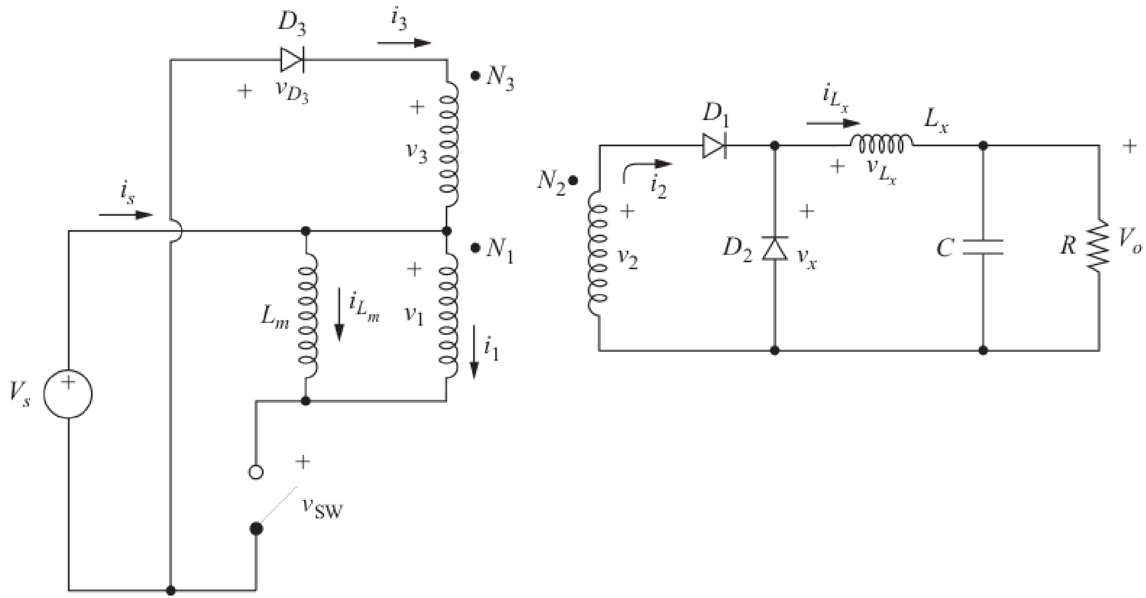
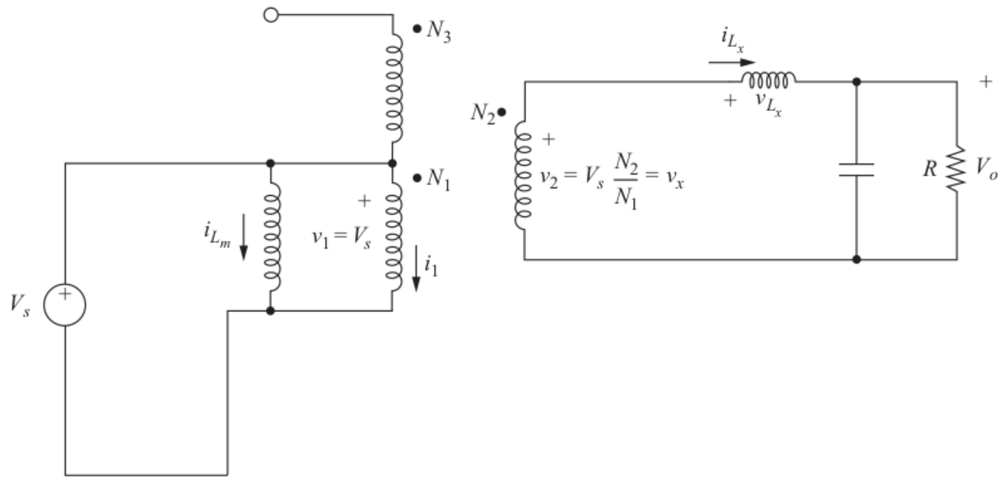
Forward Converter



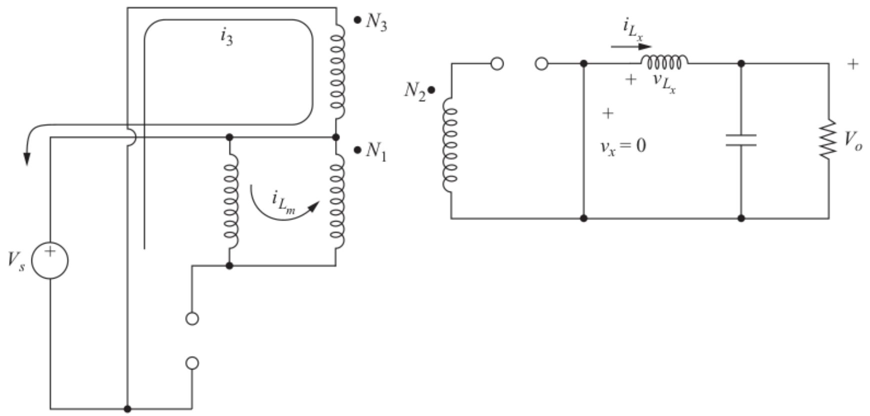
Forward Converter: Switch is ON



Lm is charged by input voltage, Lx is also charging

D1 On, D2 Off, D3 Off

Forward Converter: Switch is OFF



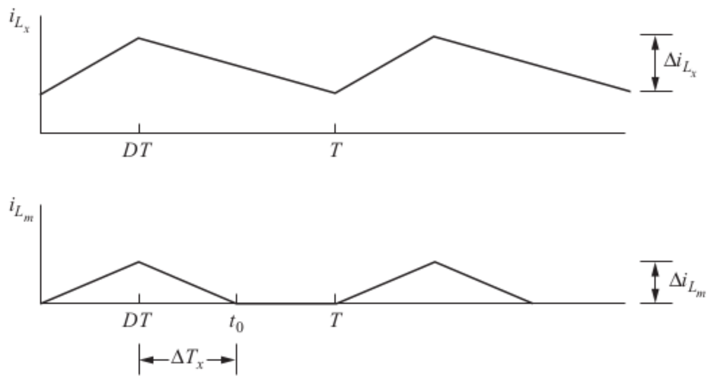
Lx feeds the load, Lm is discharged to the source: $i_1 = -i_{Lm}$

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

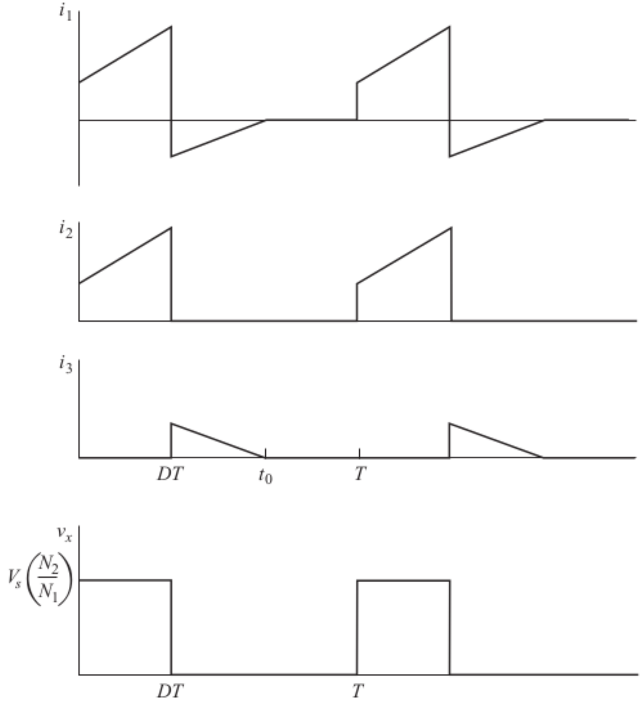
For proper operation the transformer should be "reset" before next ON period

Forward Converter: Switch is OFF

Forward Converter



Forward Converter



Practical Forward Converter

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

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

Practical Forward Converter

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$$D_{max}$$

Practical Forward Converter

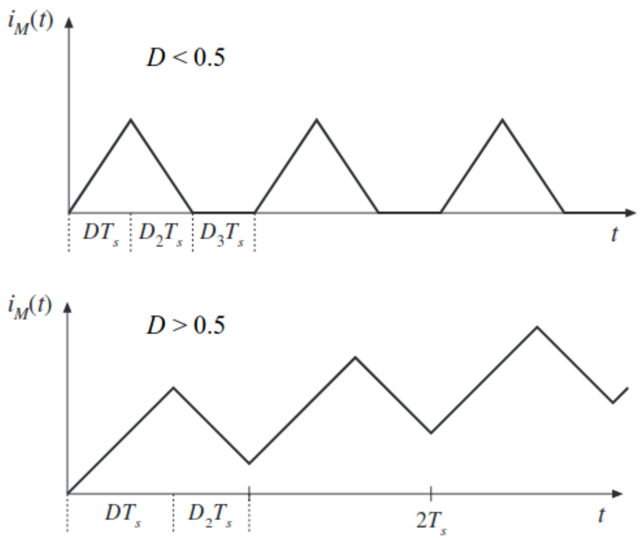
For proper operation the transformer should be "reset" before next ON period

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

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

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

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

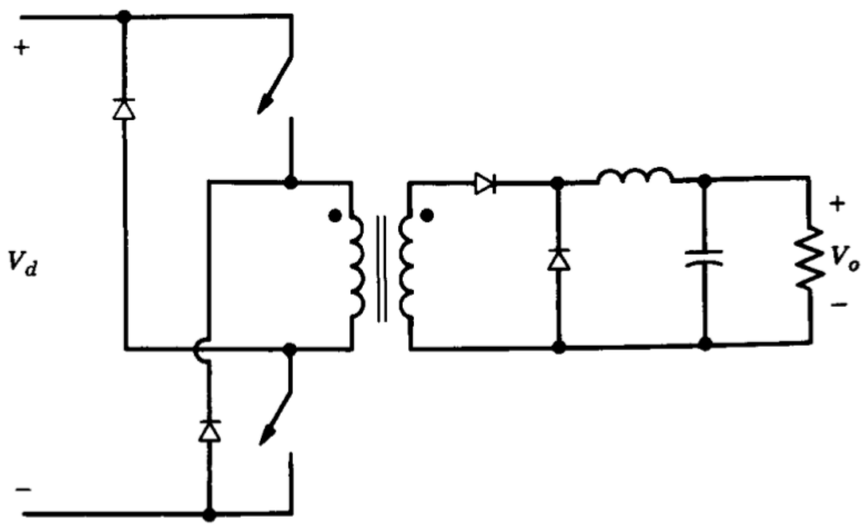
Drawbacks compared to Flyback

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

Forward Converter Alternatives

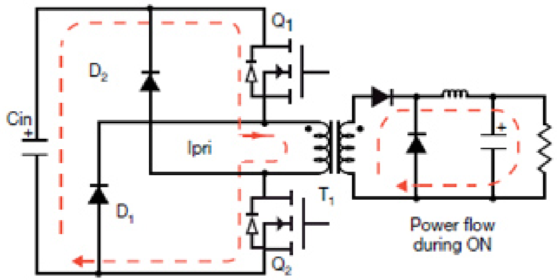
Forward Converter Alternatives

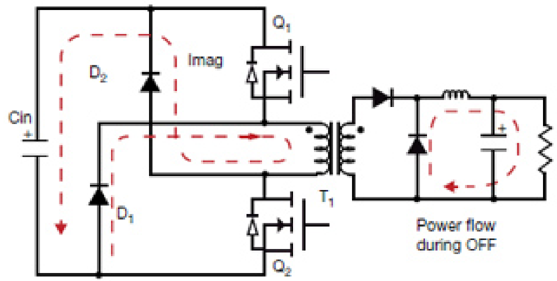
Two-switch forward converter



Forward Converter Alternatives

Two-switch forward converter





Two-switch forward converter

Advantages:

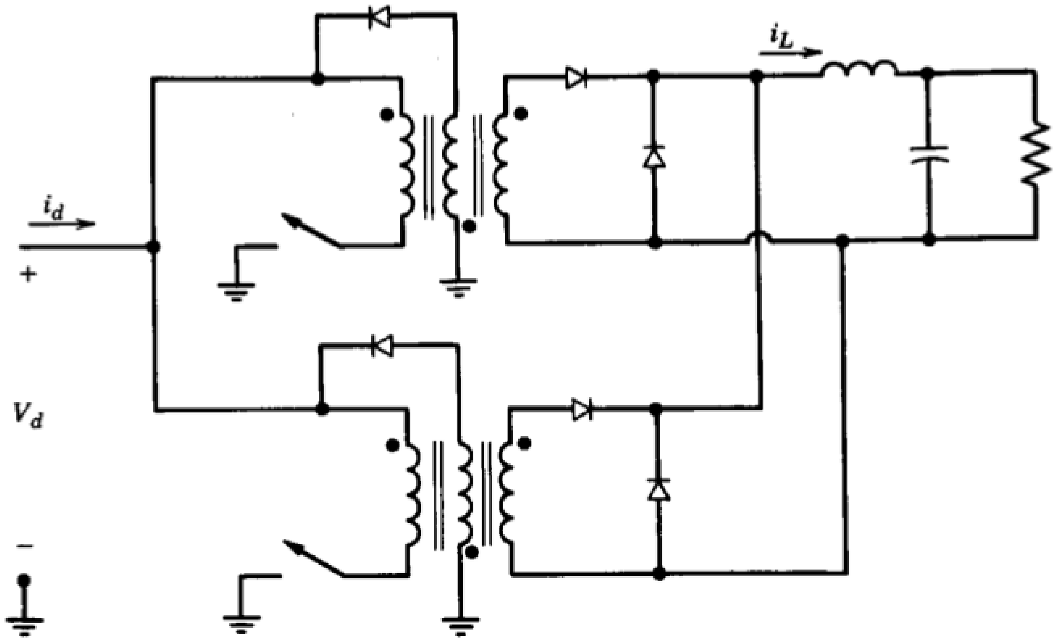
- Does not require a snubber circuit
- Less voltage stress on MOSFETs
- Can supply multiple isolated outputs
- Low power losses and noise

Two-switch forward converter

Disadvantages:

- Slightly more expensive
- Larger component count

Interleaved forward converter



Forward Converter Reading Materials

- [Infineon, Forward Converter Design Note]
- [Fairchild Forward Converter Application Note]

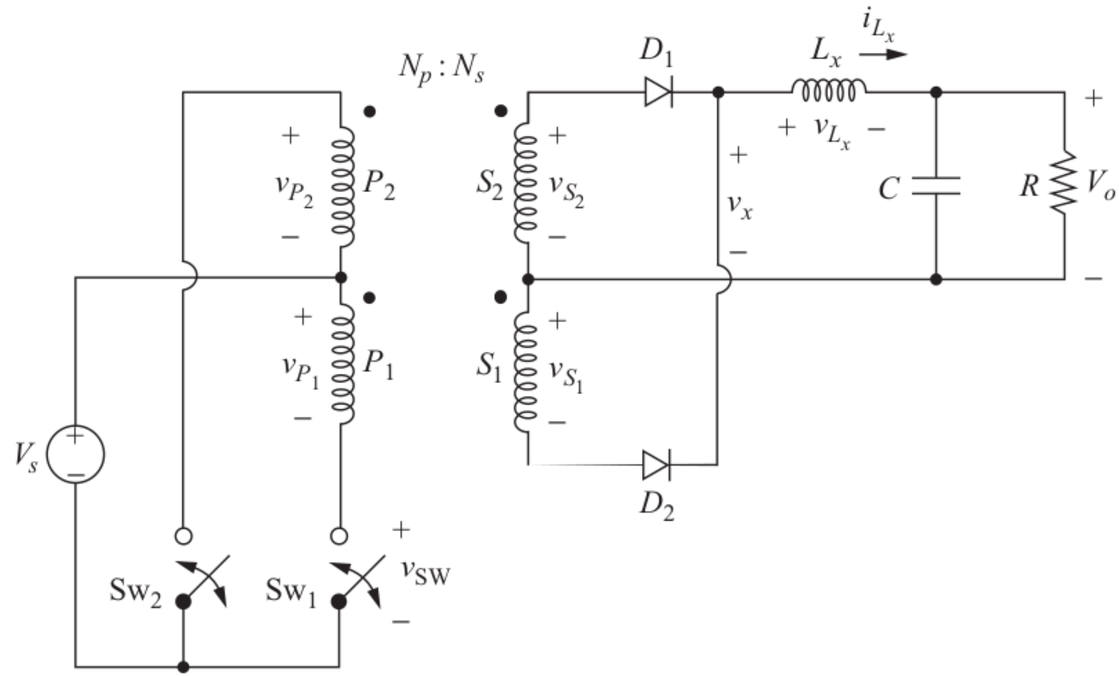
Example:

Hart - Power Electronics

Ex. 7-4

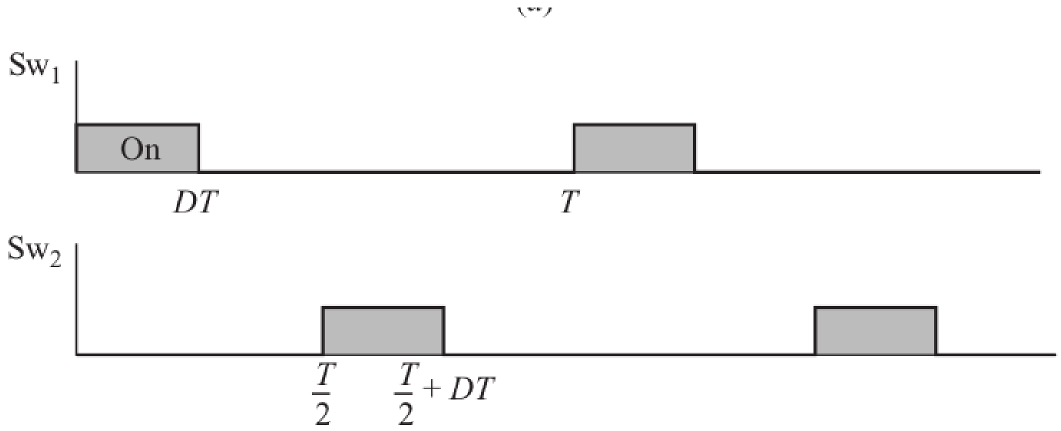
Push-Pull Converter

Push-Pull Converter



Uses a center-tapped transformer

Push-Pull Converter



Three operating sections

Push-Pull Converter

Switch(T1) ON, Switch(T2) OFF

D1 conducts, D2 reverse-biased

Push-Pull Converter

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D1 conducts, D2 reverse-biased

$$v_x = \frac{N_2}{N_1} V_s$$

Push-Pull Converter

Switch(T1) ON, Switch(T2) OFF

D1 conducts, D2 reverse-biased

$$v_x = \frac{N_2}{N_1} V_s$$

$$v_L = v_x - V_o = \frac{N_2}{N_1} V_s - V_o$$

i_L increases linearly

Push-Pull Converter

Switch(T2) ON, Switch(T1) OFF

Symmetrical operation with the previous

$$v_x = \frac{N_2}{N_1} V_s$$

Push-Pull Converter

Switch(T2) ON, Switch(T1) OFF

Symmetrical operation with the previous

$$v_x = \frac{N_2}{N_1} V_s$$

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i_L increases linearly

Push-Pull Converter

Both Switches are OFF

for a period of Δ

Push-Pull Converter

Both Switches are OFF

for a period of Δ

Both D1 and D2 conducts

$$I_{D1} = I_{D2} = 0.5 I_L$$

$$v_x = 0$$

Push-Pull Converter

Both Switches are OFF

for a period of Δ

Both D1 and D2 conducts

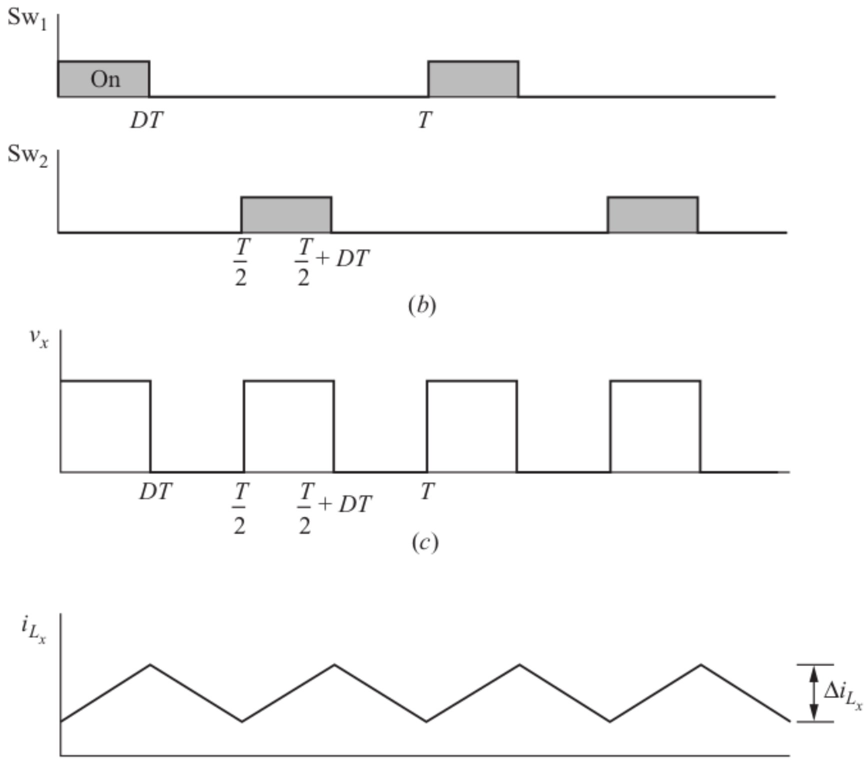
$$I_{D1} = I_{D2} = 0.5 I_L$$

$$v_x = 0$$

Therefore $v_L = -V_o$

Inductor discharges and feeds the load

Repeating waveforms for every Ts/2



Push-Pull Converter

Repeating waveforms for every Ts/2

$$DT_s + \Delta = \frac{T_s}{2}$$

$$\Delta = \frac{(1-2D)}{2} T_s$$

Push-Pull Converter

Output voltage characteristics?

Push-Pull Converter

Output voltage characteristics?

Use the inductor voltage

Push-Pull Converter

Output voltage characteristics?

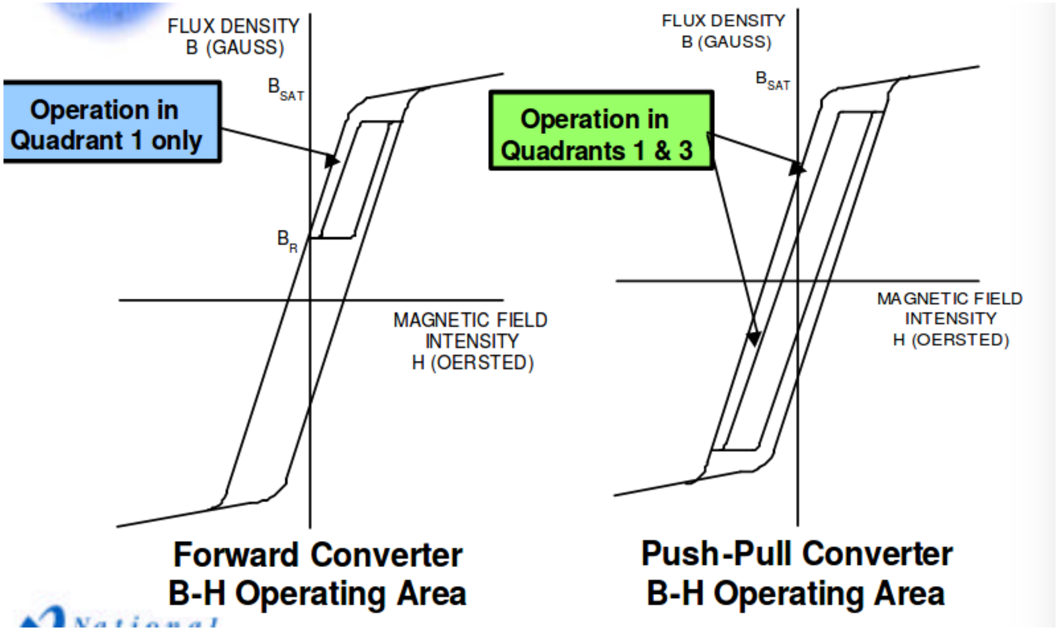
Use the inductor voltage

$$\frac{V_o}{V_d} = \frac{2N_2}{N_1}D$$

Twice of the forward converter

Push-Pull Converter

Comparison of Magnetic Flux in the Core



Extra Materials

Flyback Converter

ECEN4517 Lecture Notes

Flyback Transformer Tutorial

Optimised Flyback Design

Switch Mode Power Supply (SMPS) Topologies

ECE5797 SMPSs

Flyback Converter, Transformer Design

Design Guide Flyback Converter

Design Guidelines for Flyback Converter

Transformer Design Cookbook

Extra Materials

Forward Converter

Forward Converter, Transformer, Inductor Design

Forward Converter Design

Forward Converter Tutorial Video

Design Exercise

Design Exercise

[Forward Converter Design]

[ETD 34/17/11]

Design Exercise

[Forward Converter Design]

[ETD 34/17/11]

[Skin Effect Calculator]

[AWG Conductors]

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