DIGITAL WE DAYS 2023

DESIGN CONSIDERATIONS FOR FLYBACK TRANSFORMER

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

TODAY'S SPEAKERS

PRESENTATION
Khaled Elshafey
Design Engineer

MODERATION
Silas Zorn
Marketing Department

INFORMATION ABOUT THE WEBINAR

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However, you can ask us questions using the chat function.

Duration of the presentation 30 Min
Q&A: 10 – 15 Min

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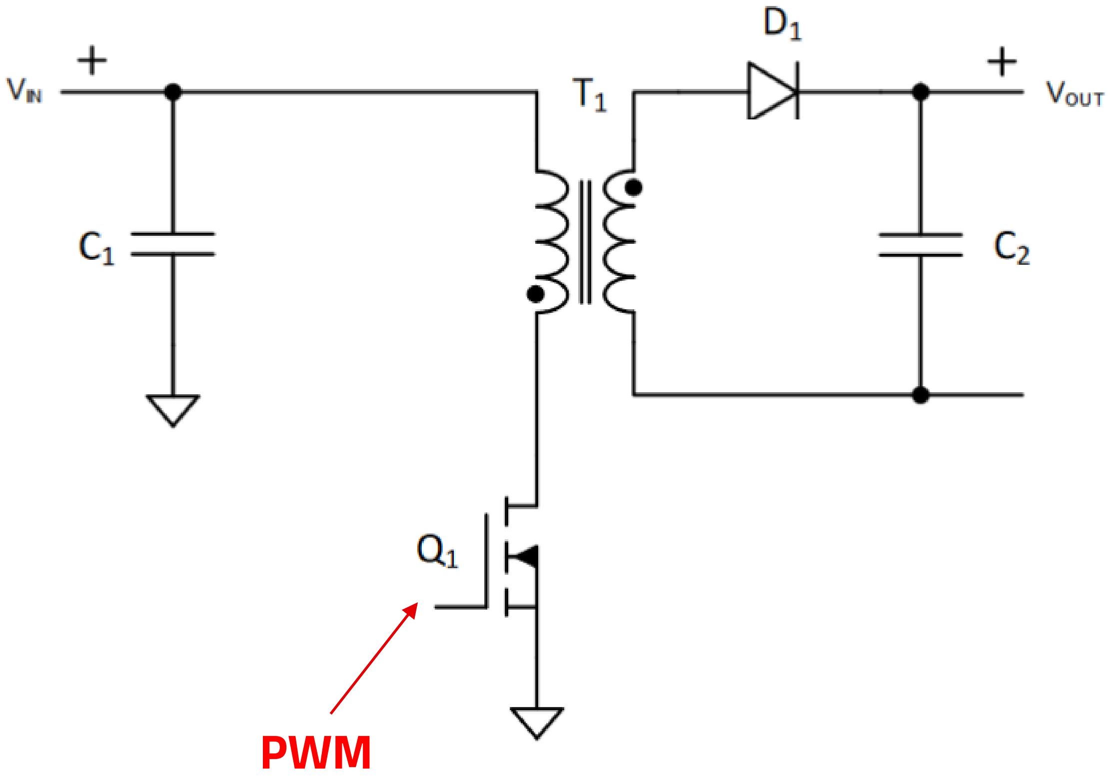
AGENDA

- Short overview -What is flyback topology
- Short overview - Mode of operation
- Flyback transformer – Design Requirements
- Methods to improve some of Flyback transformer characteristics
- Tips to improve EMI

SHORT OVERVIEW

What is Flyback Topology

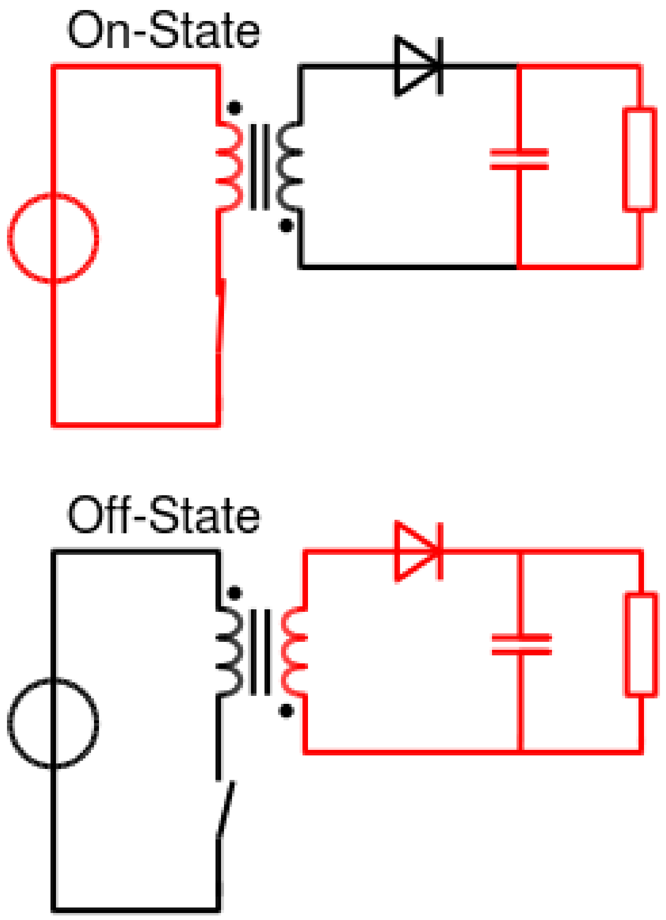
- It is one of modern SMPS topology uses PWM techniques
- It can provide isolation using transformer
- Controller is not complicated
- A few components needed to build the circuit
- Typically uses for power range < **100 watts**



SHORT OVERVIEW

What is Flyback Topology

- How does it work?
  - Two states of operation:
    - On state
    - Off state



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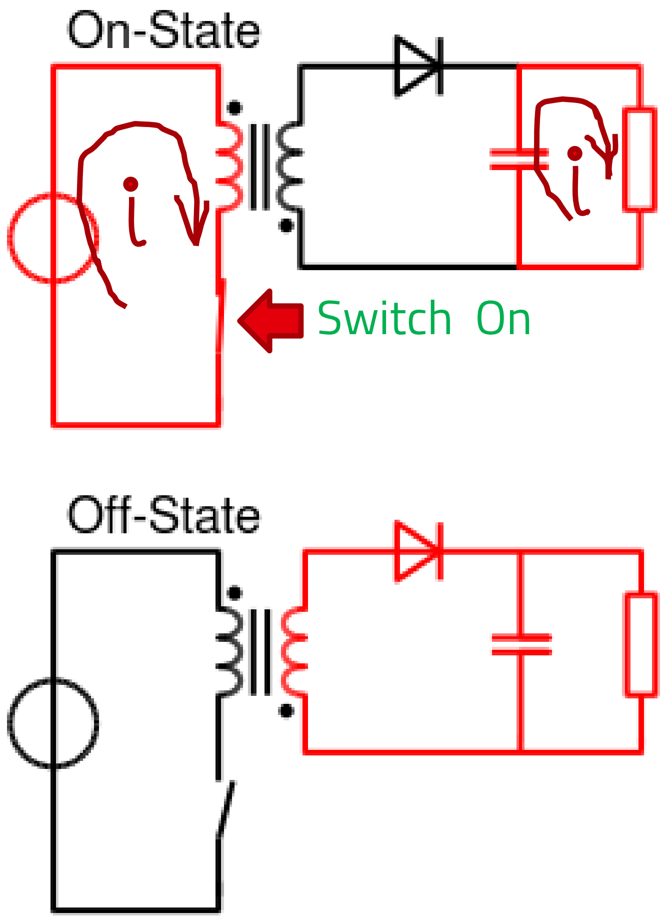

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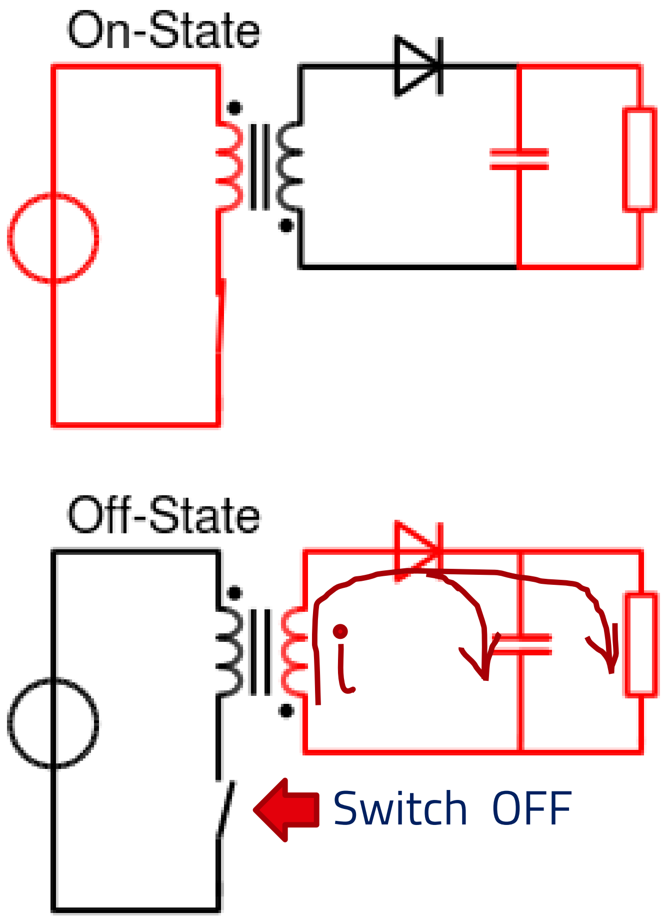

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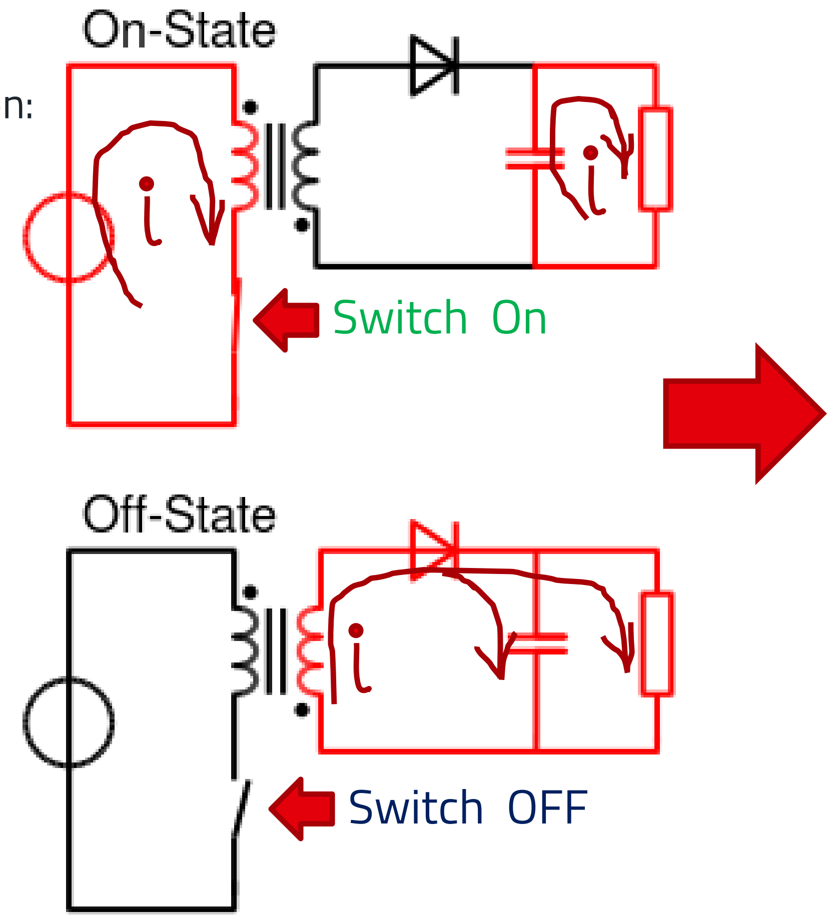


Flyback transformer is **NOT** a real transformer

No transfer energy **instantaneously**

Acts as inductor **store** energy then release it

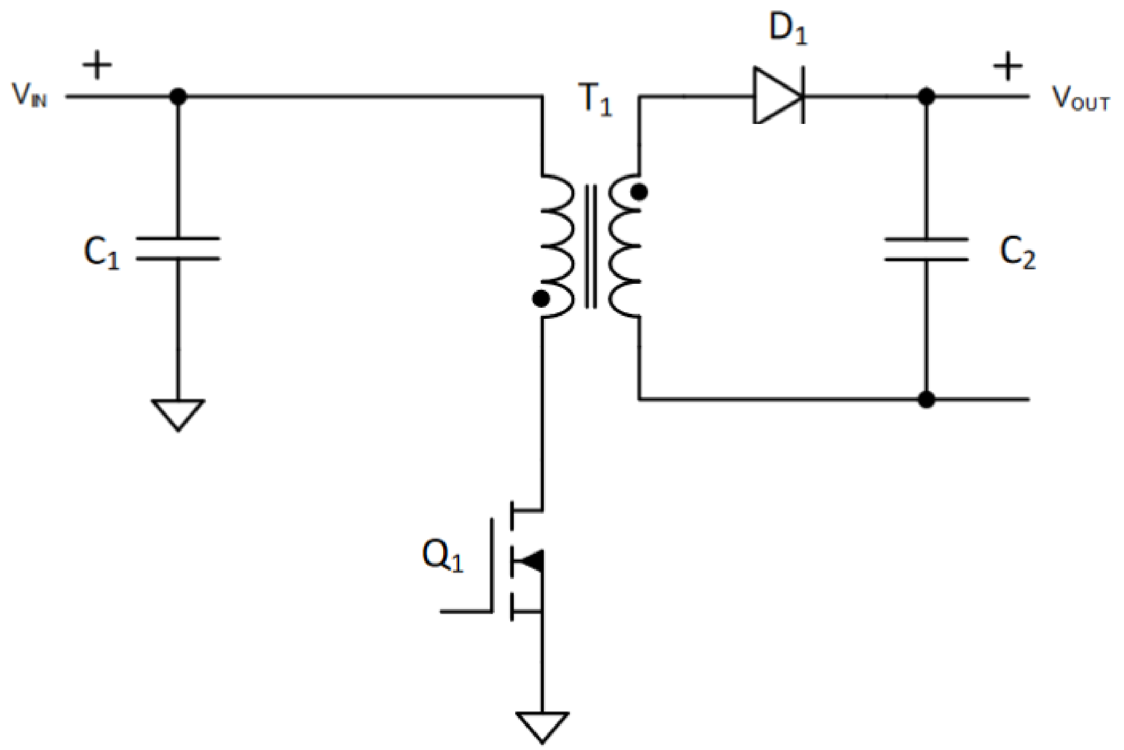
So sometimes called it a **Coupled Inductor**

SHORT OVERVIEW

What is Flyback Topology

- **Advantages**:
  - Controller is not complicated
  - A few components needed to build the circuit

- **Disavantages:**
  - Generate high ripples -> EMI issues
  - Montior leakage inductance -> to protect Mosfet
  - Not suitable for applications require high efficiency



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Mode of operation

- There are many text books and application notes talk and explain about Flyback operation mode
- Here is a summary about mode of operations:

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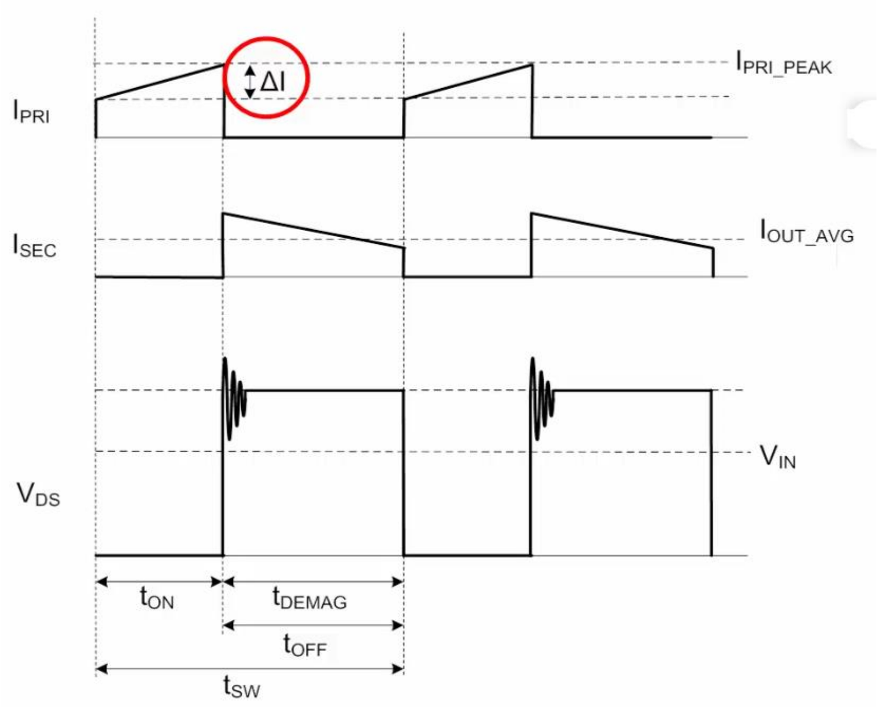

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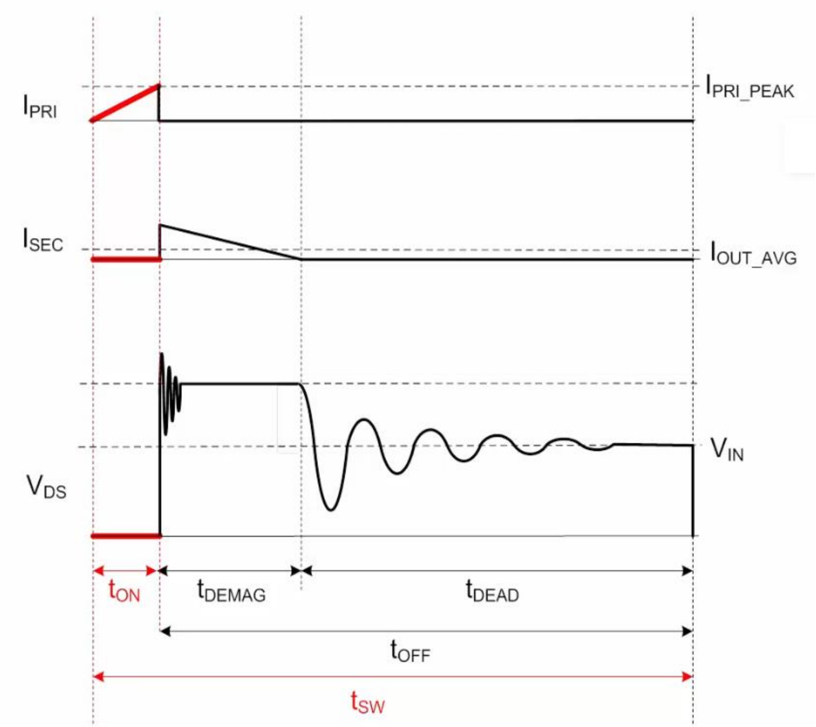

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      - Quasi-Resonant Mode or transition mode or Critical condition mode
      - Valley Switching

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Common mode of operation for ICs have a **P**rimary **S**ide **R**egulation feature
– **No feedback loop needed (Optocoupler)**

SHORT OVERVIEW

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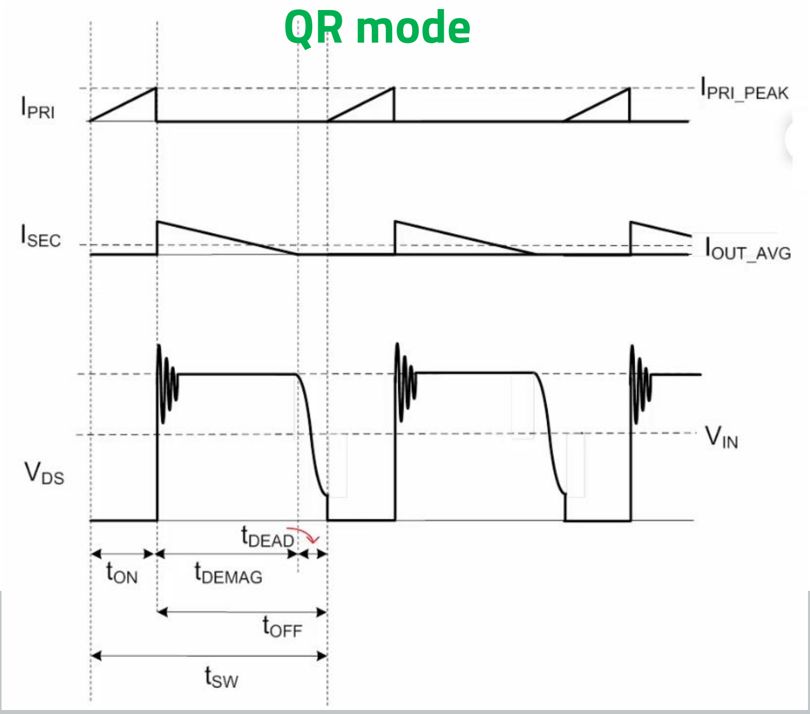

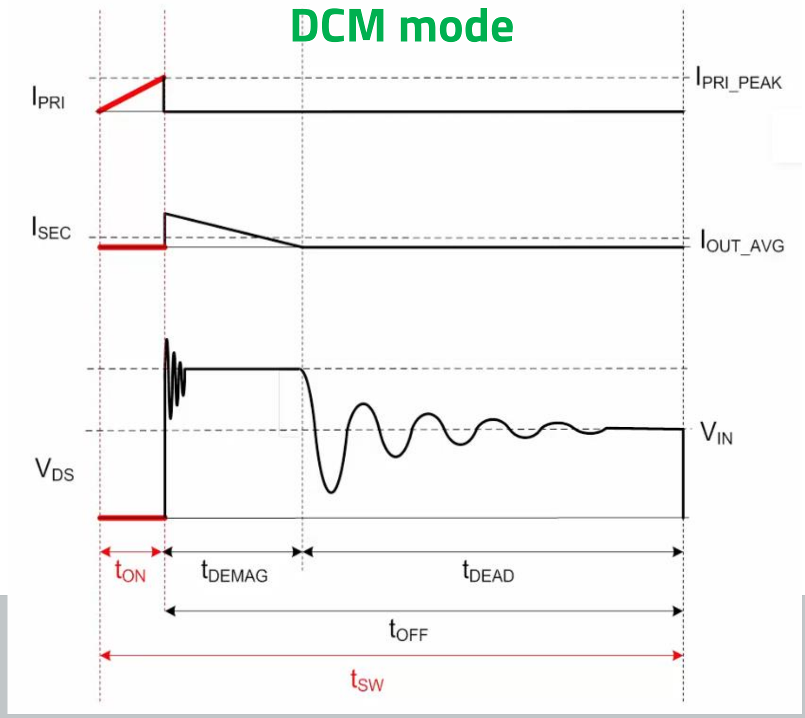

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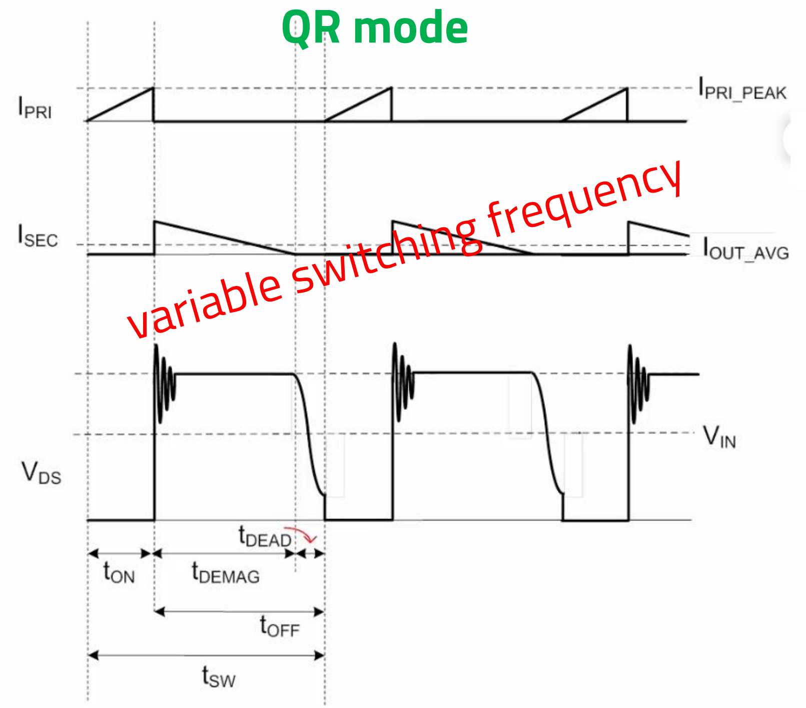
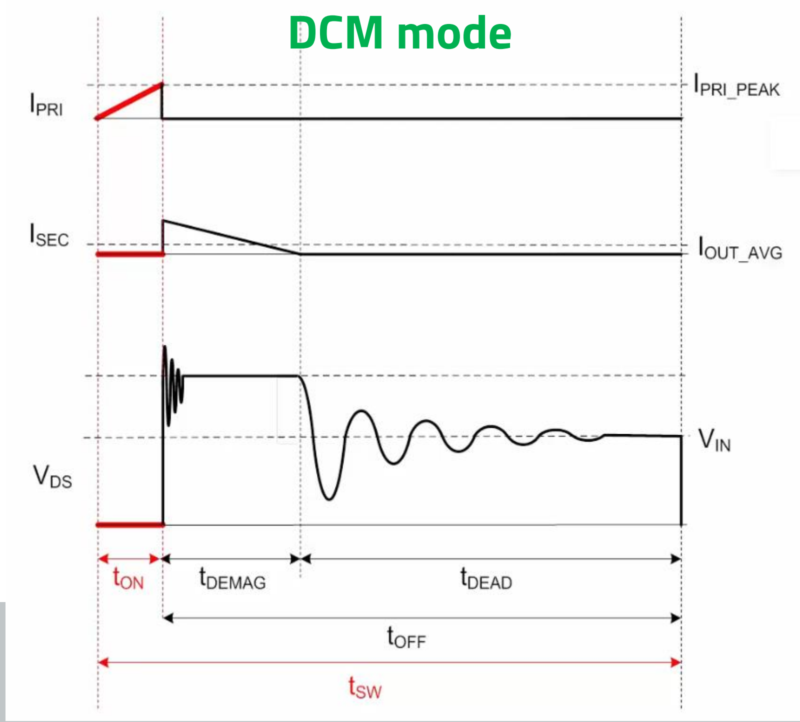




FLYBACK TRANSFORMER

Design Requirements

- You notice that Flyback transformer store energy on core then release it, So

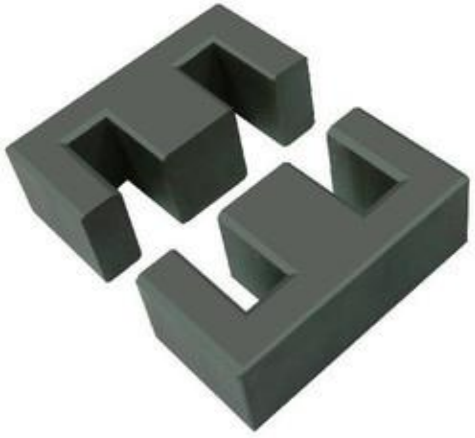
$$\text{Energy (store inside core)} = \frac{1}{2}\frac{B^2}{\mu_c}V_c \quad \text{unit J}$$

Where:

B: Flux density

μ_c: Core permeability

V_c: Core volume



$$\text{Energy} \propto \frac{V_c}{\mu_c}$$

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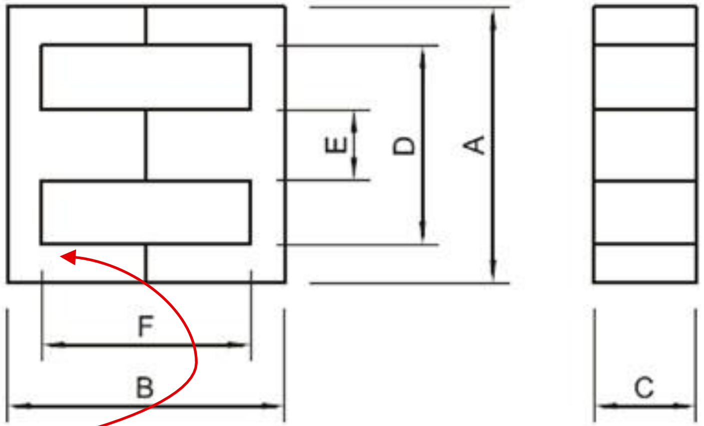

For un-gapped core, µc about 1500 to 6000

Reference: Switching Power Supply Design&Optimization – Sanjaya Maniktala

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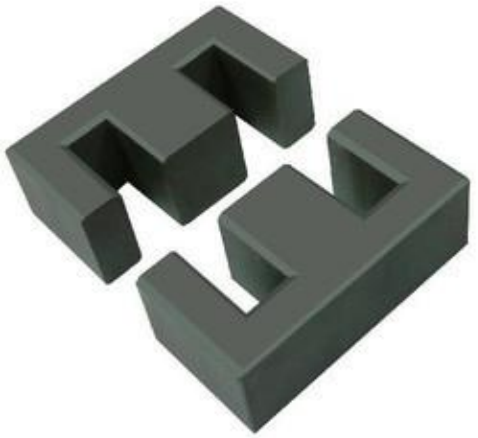
Design Requirements



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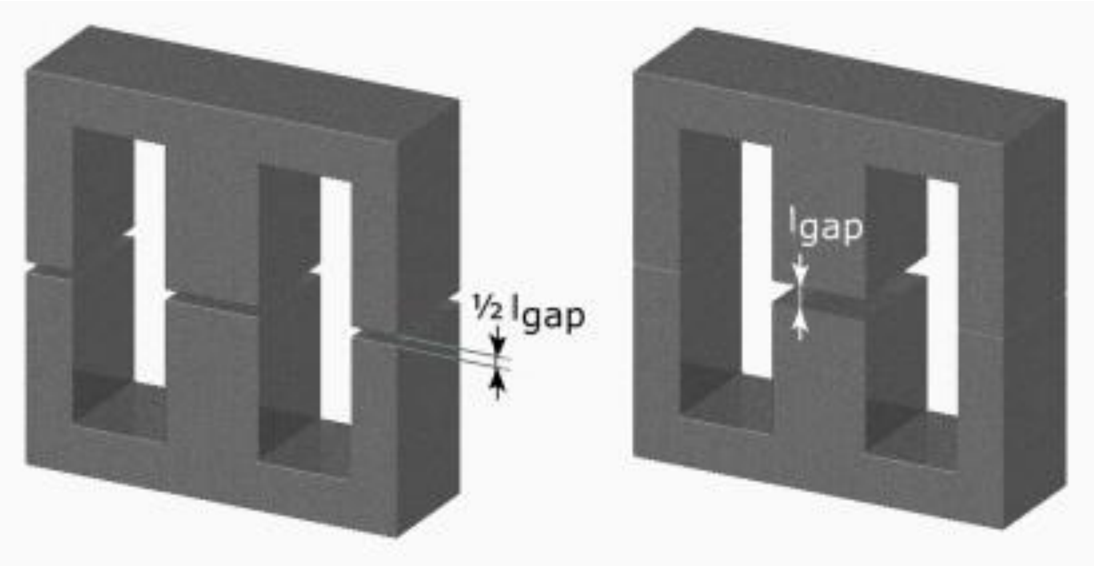
$$\uparrow \text{Energy} \propto \frac{V_c}{\downarrow \mu_c}$$

Add an air gap to core to reduce the equivalent permeability



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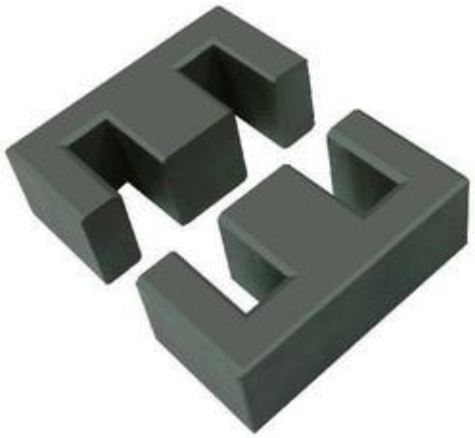
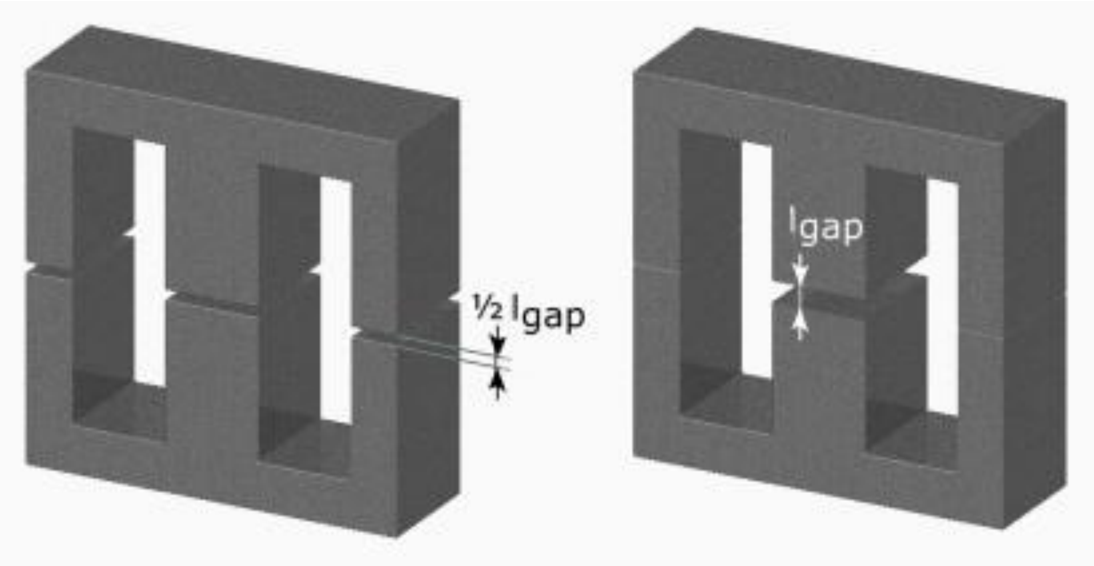


$$\text{Energy (store in an inductor)} = \frac{1}{2} L_{ind} I^2$$

$$\text{Max. Energy (store in an inductor)} \approx \frac{1}{2} L_{ind} {I_{sat}}^2$$

$$I_{sat-prim} \gg I_{Pri\ or\ required\ for\ design}$$



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Important requirement for Flyback transformer

6C ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	1–3	@20°C	3.15 ohms ±10%
D.C. RESISTANCE	5–4	@20°C	0.81 ohms ±10%
D.C. RESISTANCE	7–9	tie(6+7, 8+9), @20°C	0.021 ohms ±20%
INDUCTANCE	1–3	10kHz, 100mVAC, Ls	1.59mH ±10%
SATURATION CURRENT		20% rolloff from initial	480mA
LEAKAGE INDUCTANCE	1–3	tie(4+5, 6+7+8+9), 100kHz, 100mVAC, Ls	23uH typ., 34uH max.
6C DIELECTRIC	3–7	tie(3+4, 7+8), 4500VAC, 1 second	3600VAC, 1 minute
TURNS RATIO		(3–1):(7–9), tie(6+7, 8+9)	15:1, ±1%
TURNS RATIO		(3–1):(5–4)	8.571:1, ±1%

FLYBACK TRANSFORMER

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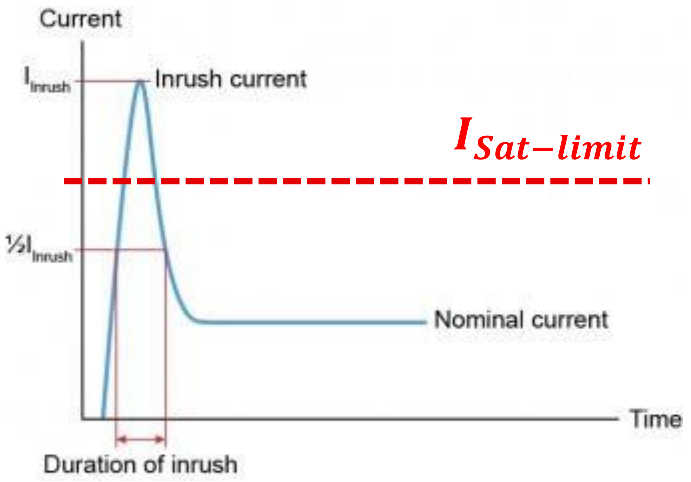
- **Very improtant note:**
  - During the start up of the power supply, Inrush current can exceed saturation current:



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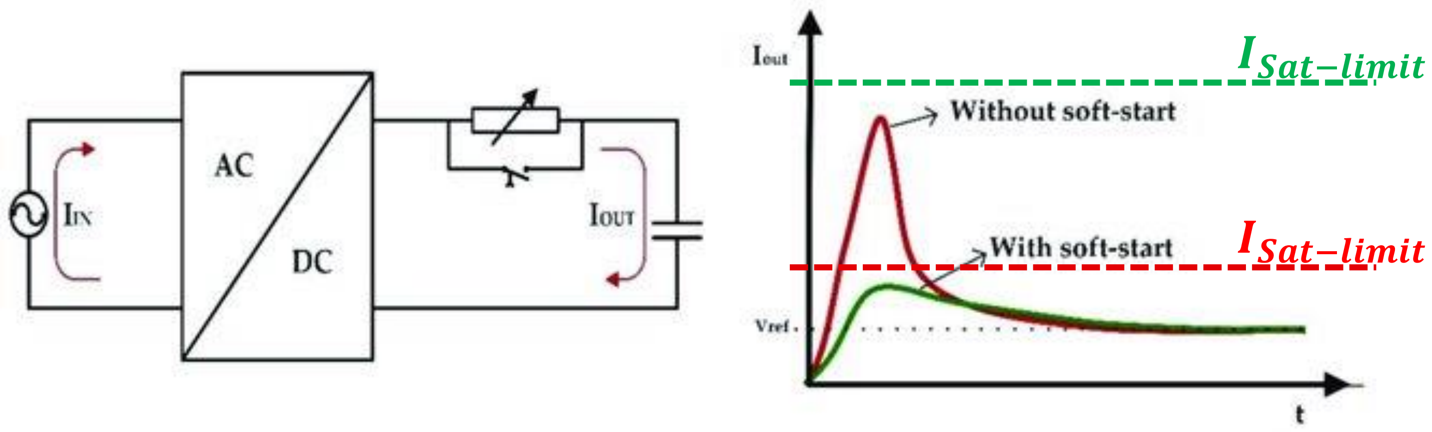

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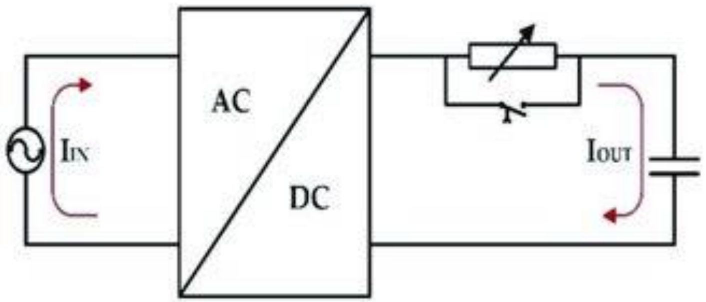

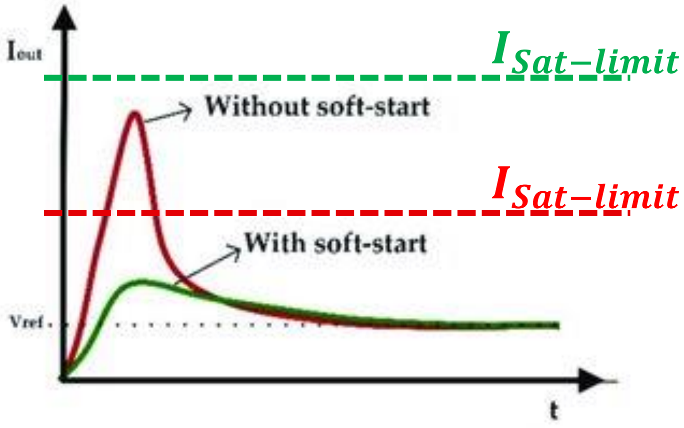

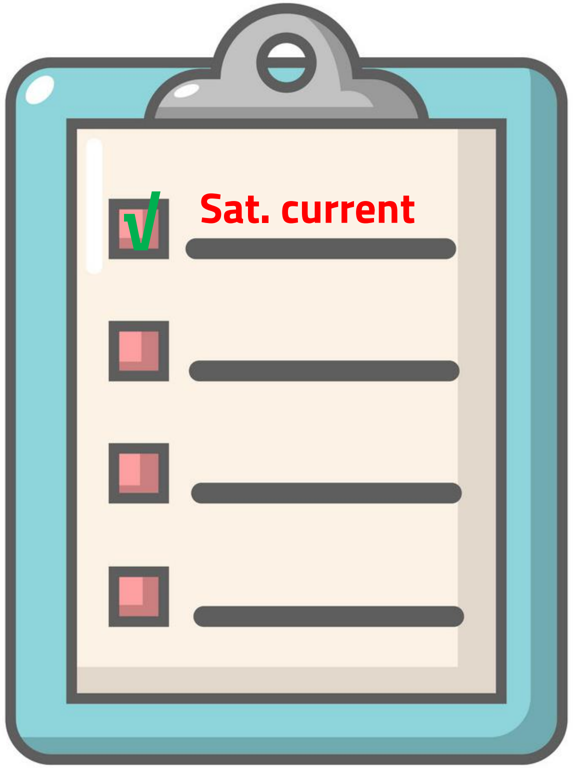

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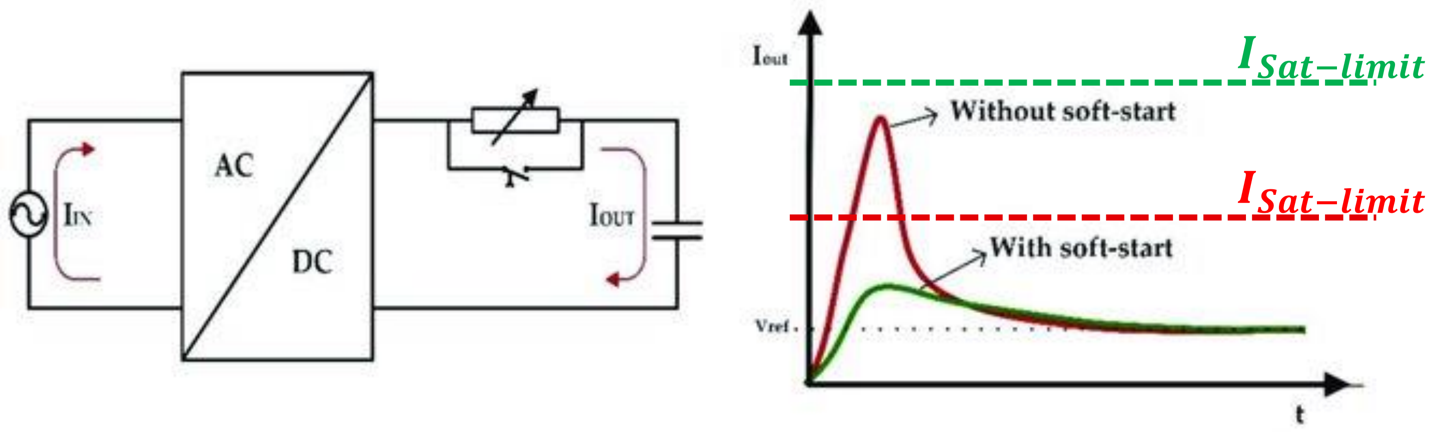

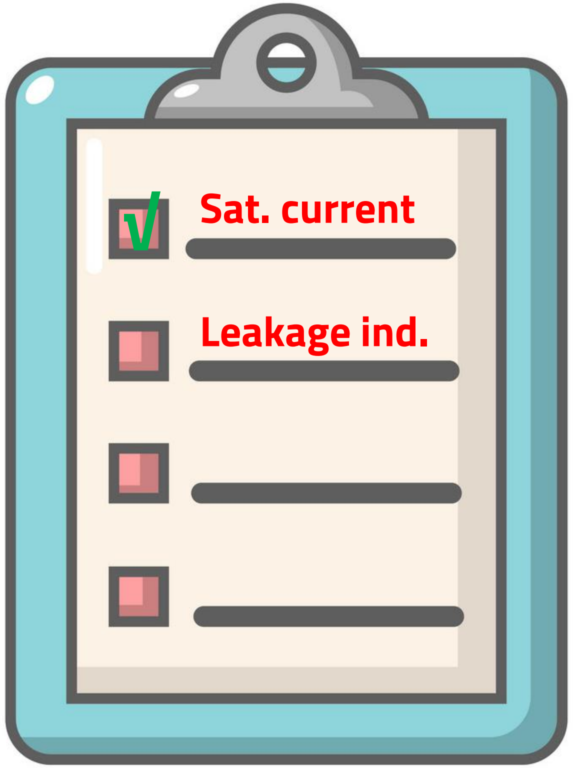

FLYBACK TRANSFORMER

Design Requirements

- Leakage inductance:
  - For most of IC's application notes, they set a rule of thumb for leakage inductance of Flyback to be between **3-5%** of main inductance. **Does that make sense?**

- Because of that, let's understand the effect of leakage inductance in Flyback topology

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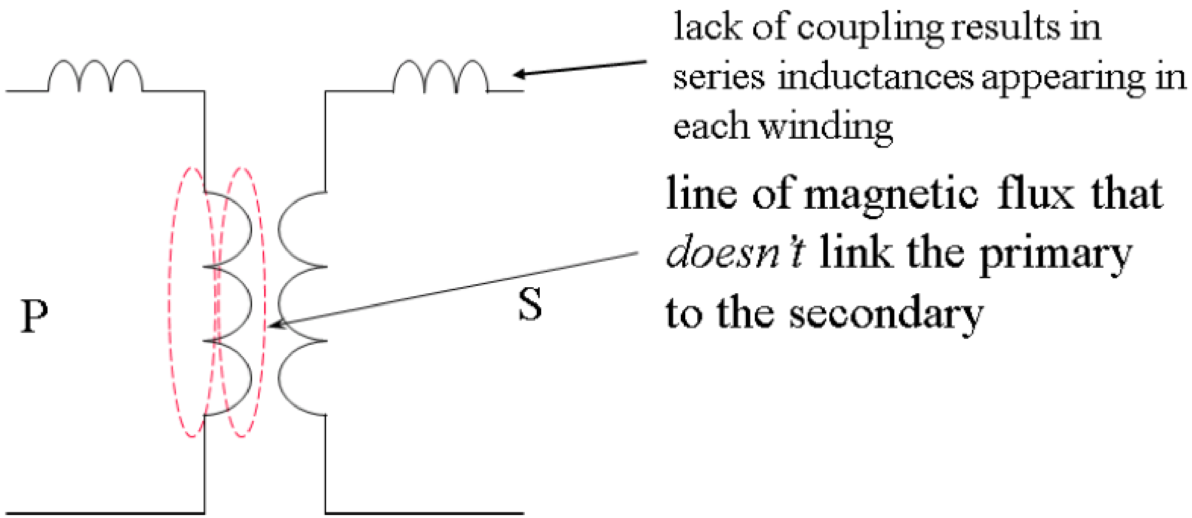
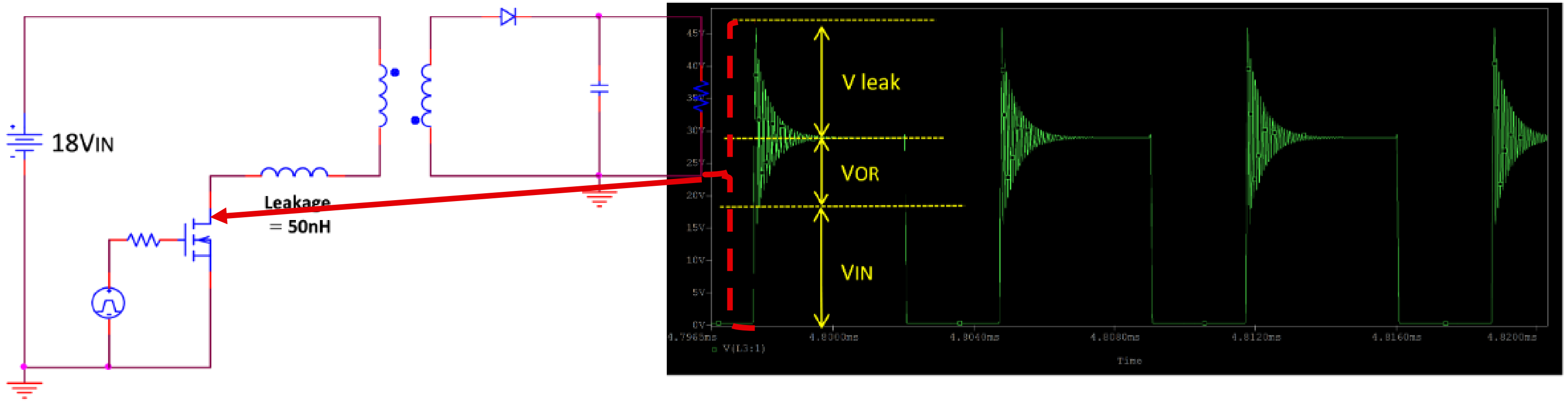


FLYBACK TRANSFORMER

Design Requirements

- Leakage inductance:
  - Acts as discrete indutance in Flyback where during Switch ON, it can store energy (charge) similar to Prim inductance but when the Switch is OFF, leakage inductance discharge all energy on switch node casuses high spike votlage on switch node:



Switch Note Waveform with Leakage Inductance

Reference: Application note SLVAF01, Texas Instruments

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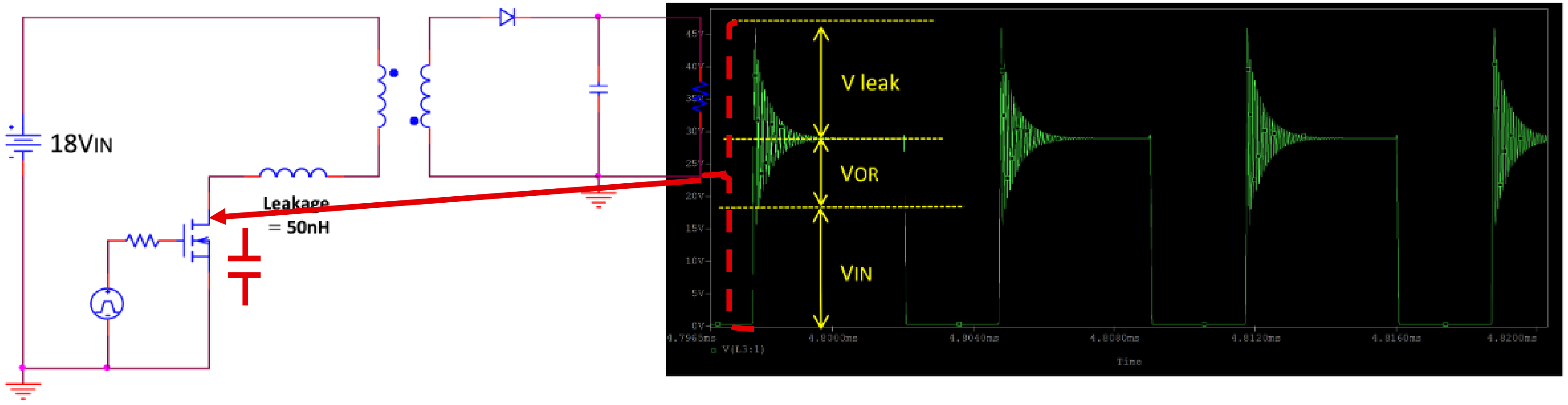

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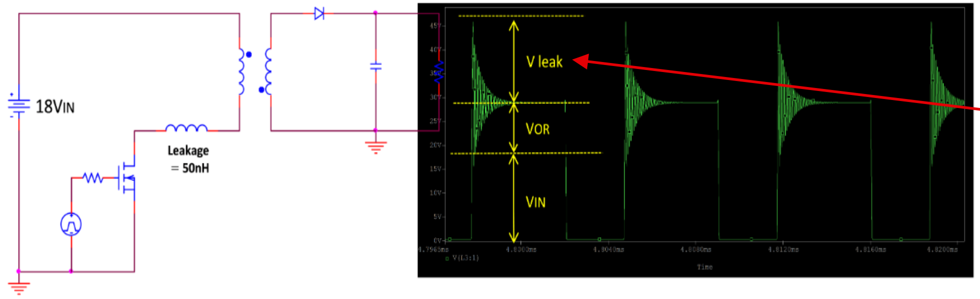

Switch Note Waveform with Leakage Inductance

$$V_{leak\ or\ Spike} = I_{Pri-peak}\sqrt{\frac{L_{leakage}}{(C_p + C_{ds})}}$$

Where:

$L_{leakage}$: Primary leakage inductance

C_p: Transformer primary capacitance

C_{ds}: Mosfet drain-source capacitance

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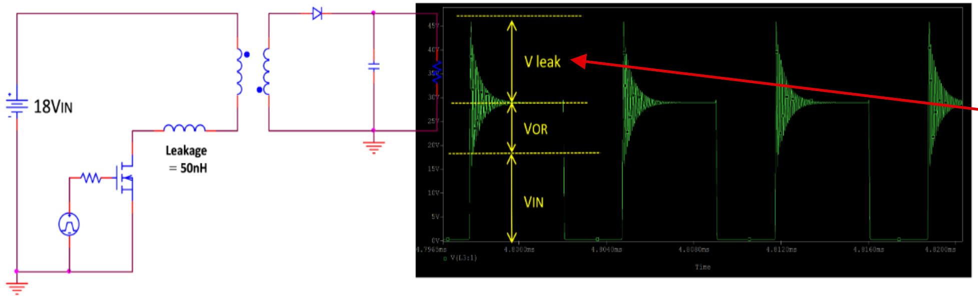

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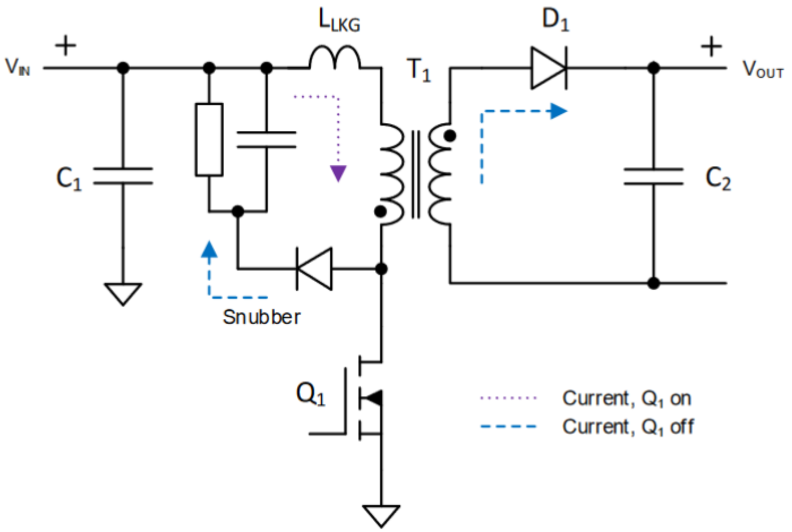
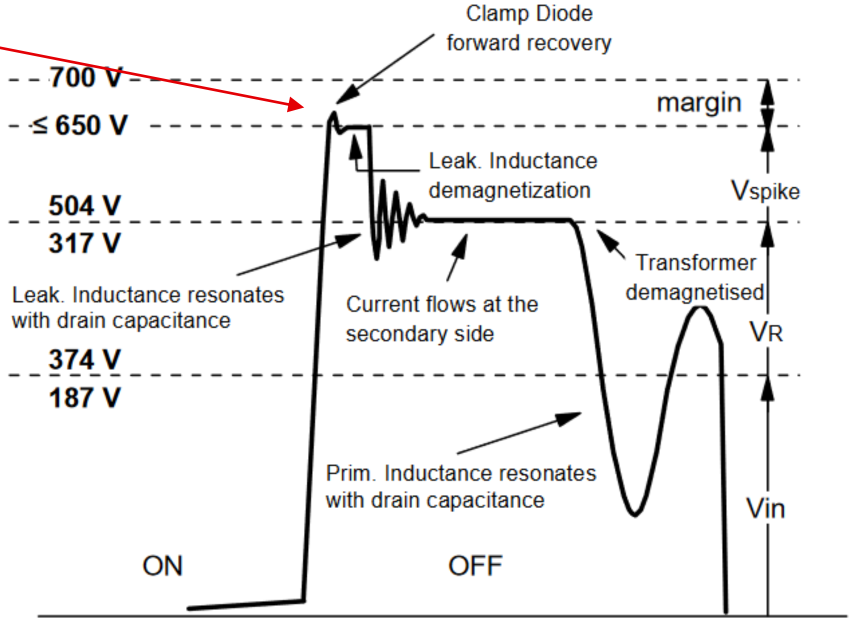
FLYBACK TRANSFORMER

Design Requirements

- Leakage inductance:
  - On system level solutions:
    - Snubber circuit
    - Or Zener/TVS clamping
    - Mosfet with higher breakdown voltage
    - …………



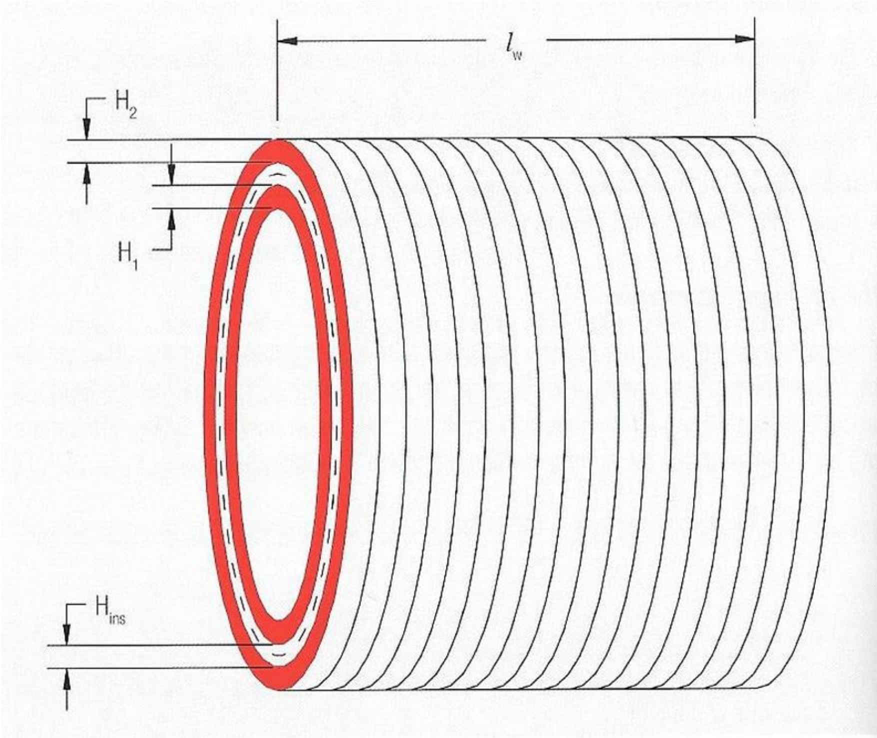


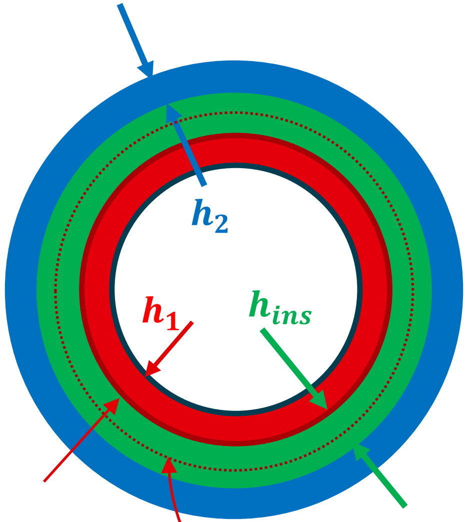
Reference: Application note AN1262, ST Micro

FLYBACK TRANSFORMER

Design Requirements

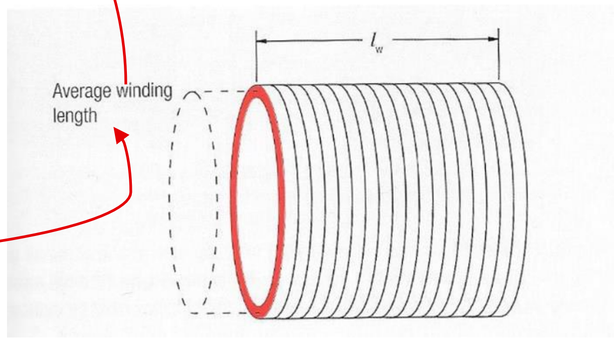
- Leakage inductance:
  - On component level:
    - **For Solenoid Structure with symmetrical turns ratio:**





$$L_{leakage} = \frac{\mu_0 N^2 A_{insulation}}{l_w}$$

$$A_{insulation} = MLT\left(h_{ins} + \frac{1}{3}h_1 + \frac{1}{3}h_2\right)$$



MLT: Mean length turn or average winding length

Reference: Würth Elektronik eiSos, Trilogy of Magnetics, handbook

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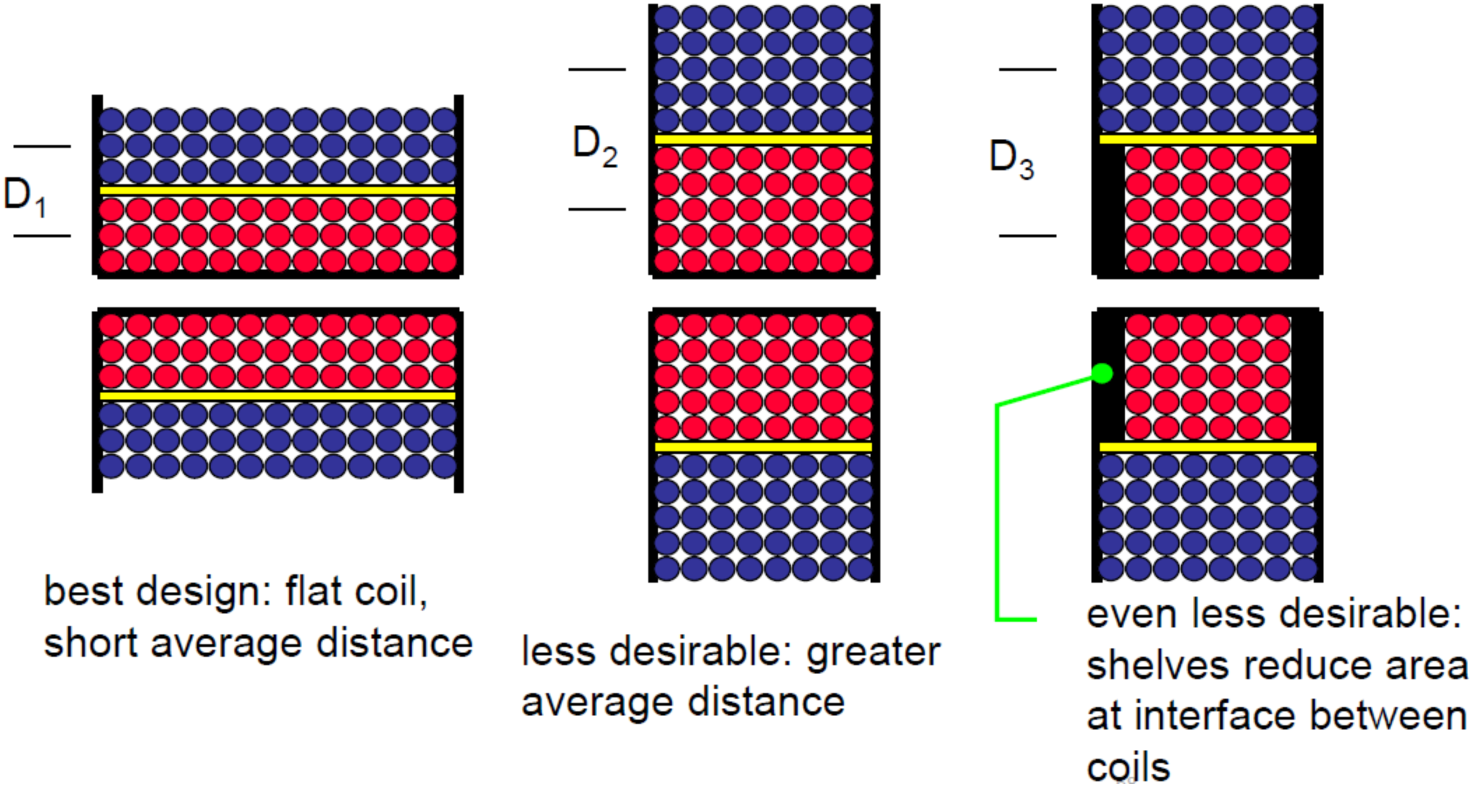
      - **Examples**



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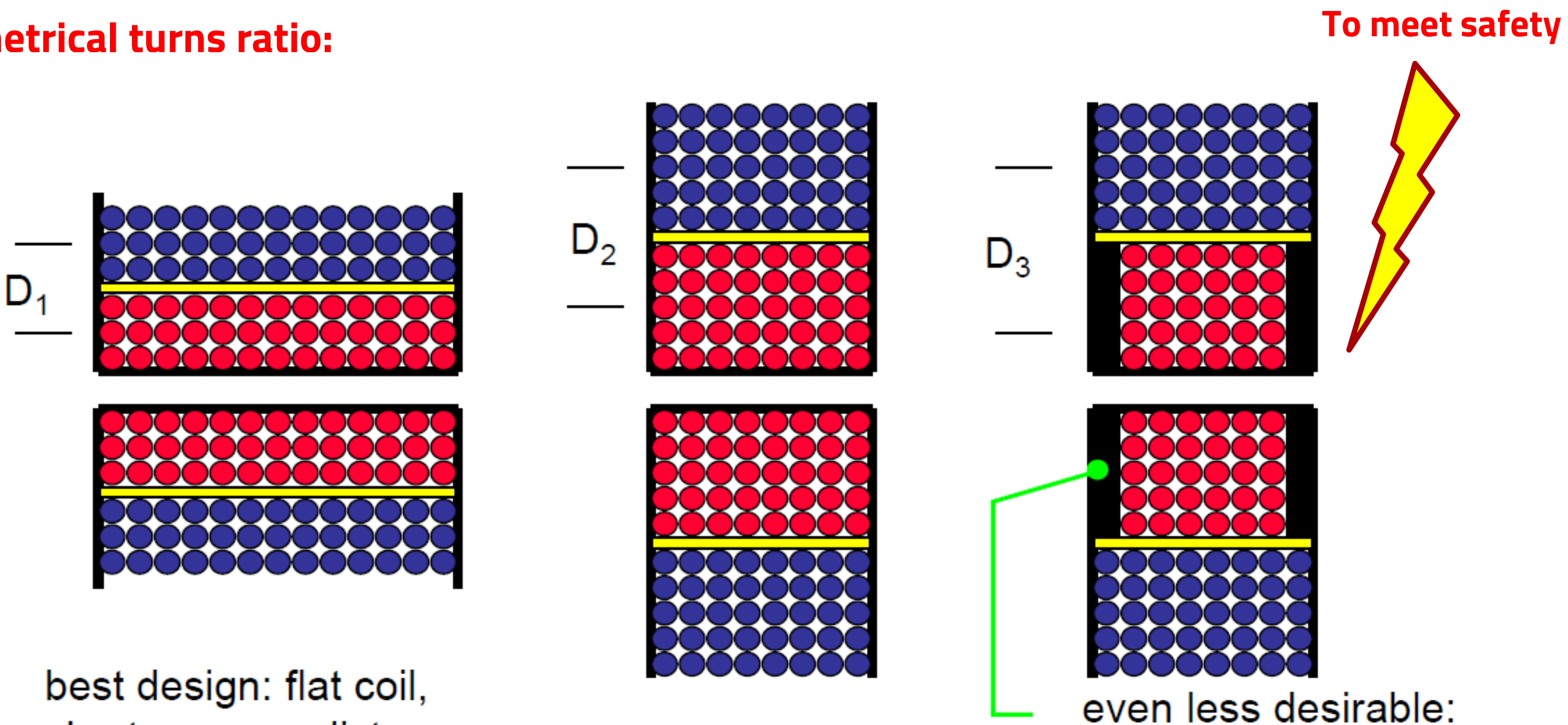

best design: flat coil, short average distance

less desirable: greater average distance

even less desirable: shelves reduce area at interface between coils

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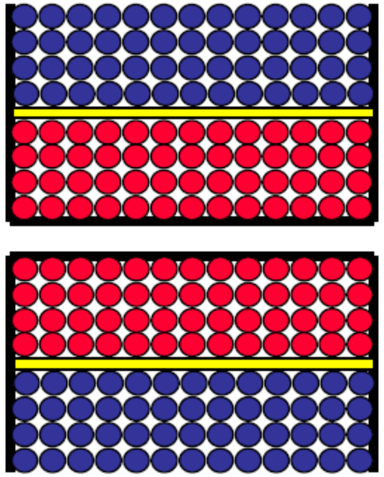

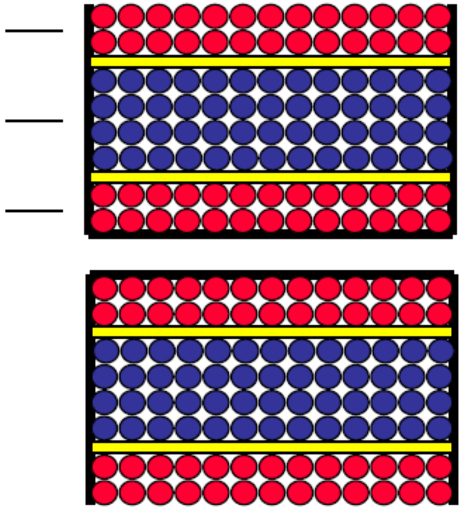

To improve the coupling between the windings we can sandwich the first winding around the second. This reduces the average distance between the windings and results in 1/4th the original value of leakage inductance –

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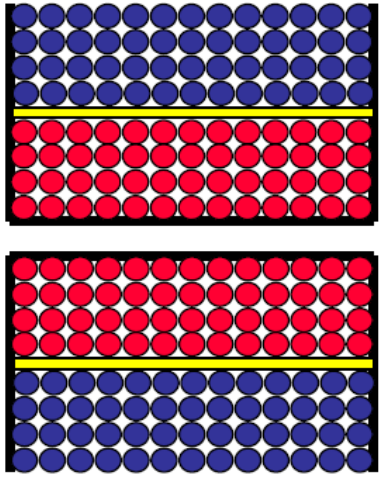
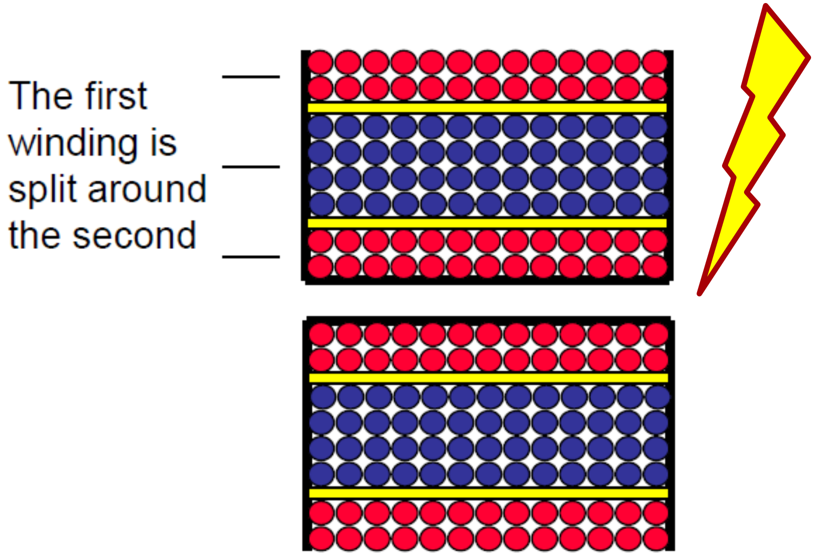
More winding labor - $$ cost





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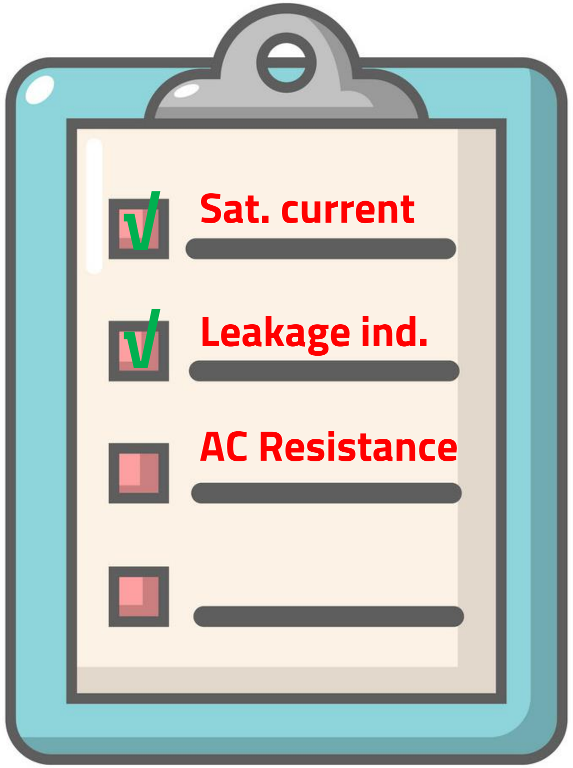
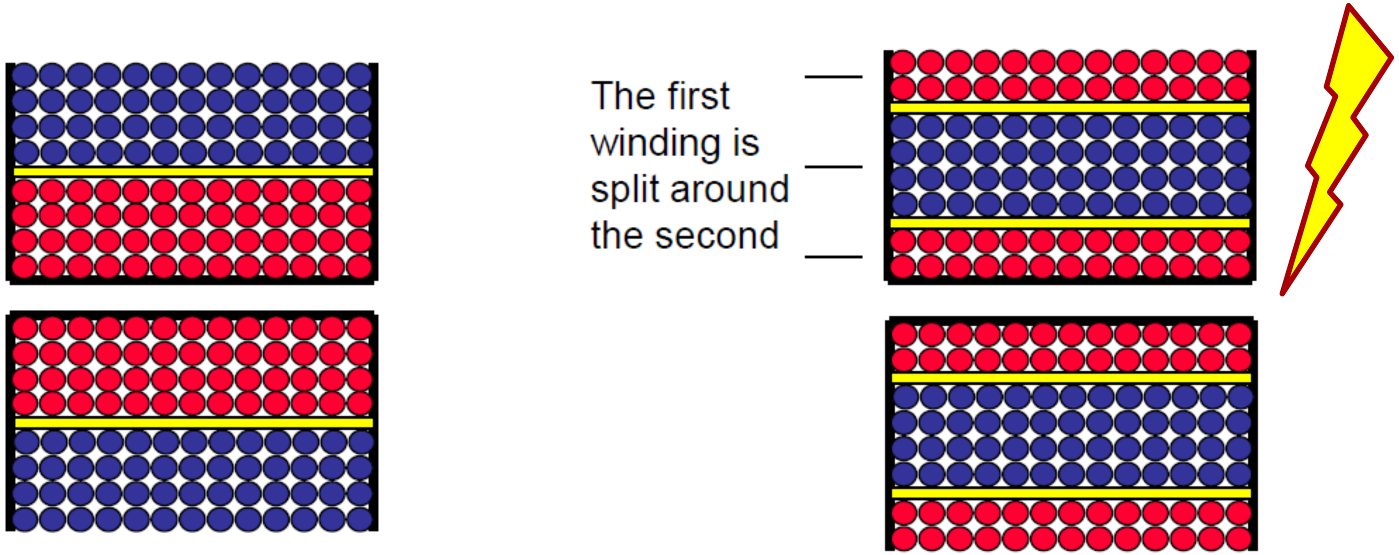
    - **For Solenoid Structure with symmetrical turns ratio:**
      - **Examples**



More winding labor - $$ cost

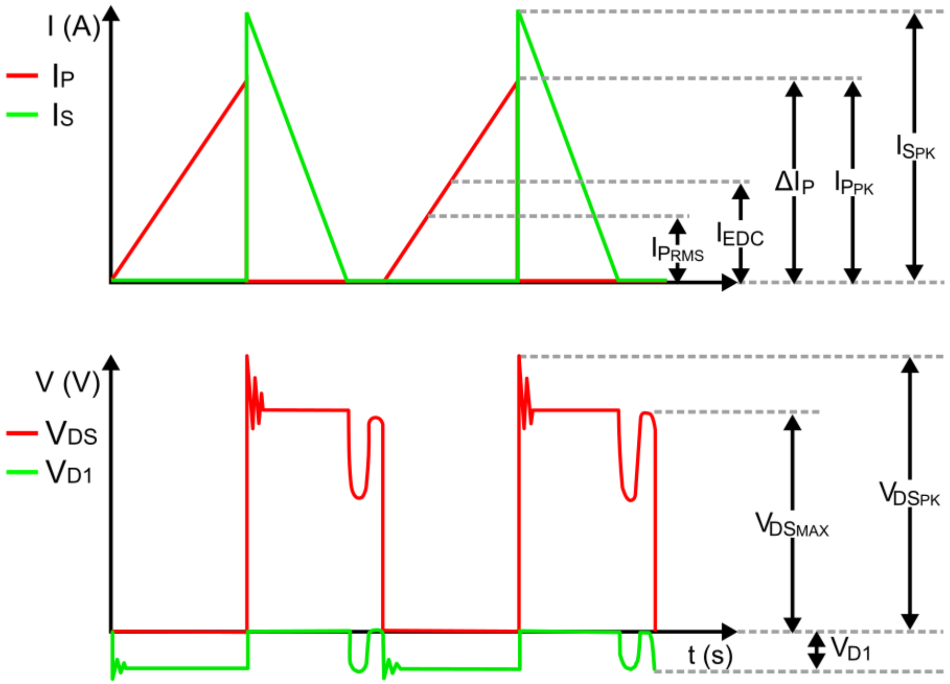


To improve the coupling between the windings we can sandwich the first winding around the second. This reduces the average distance between the windings and results in 1/4th the original value of leakage inductance –

FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Important of this resistance for DCM mode of operation.



Discontinuous Conduction Mode

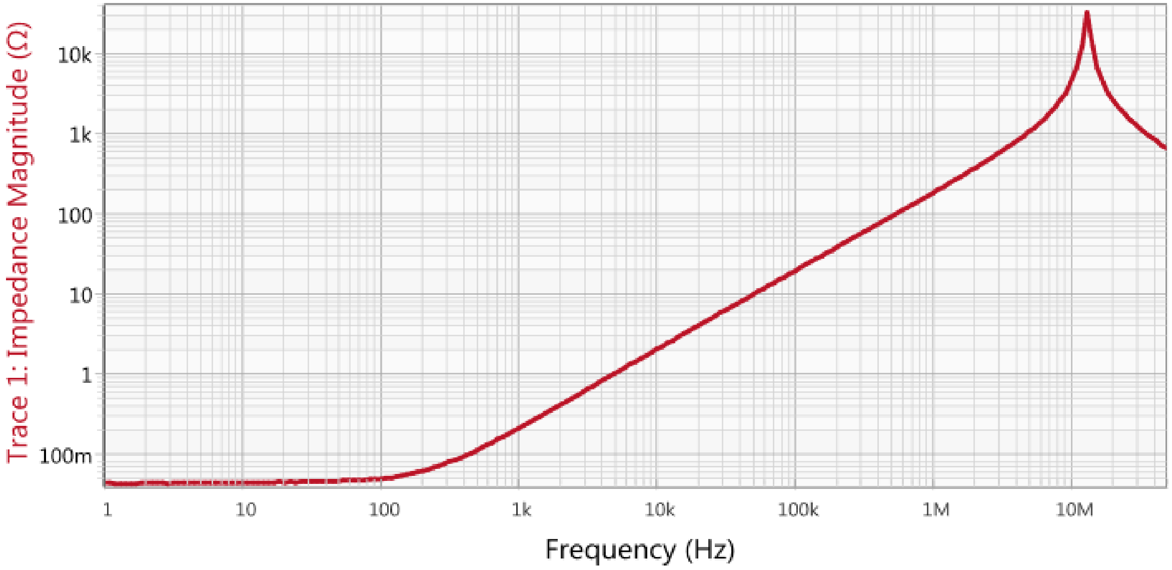
- **Sawtooth current waveform on PRI & SEC**
- **FFT of current waveform shows a fundamental @ switching frequency + harmonics**
- **So importance of AC resistance comes to the equation**

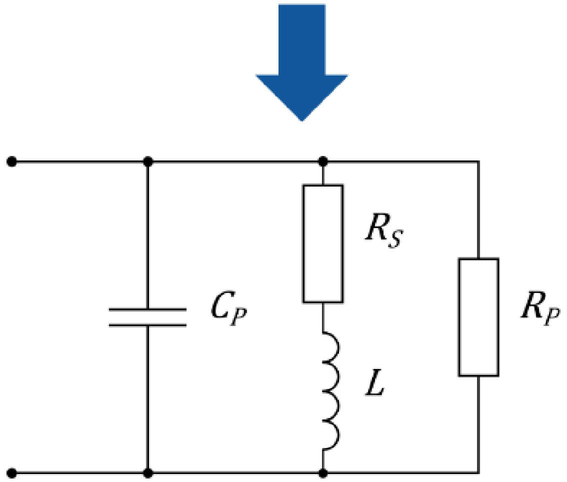
FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Important of this resistance appears in DCM mode of operation or high ripple current mode.
  - At higher frequencies, AC resistance is the dominant for copper losses

Inductor impedance





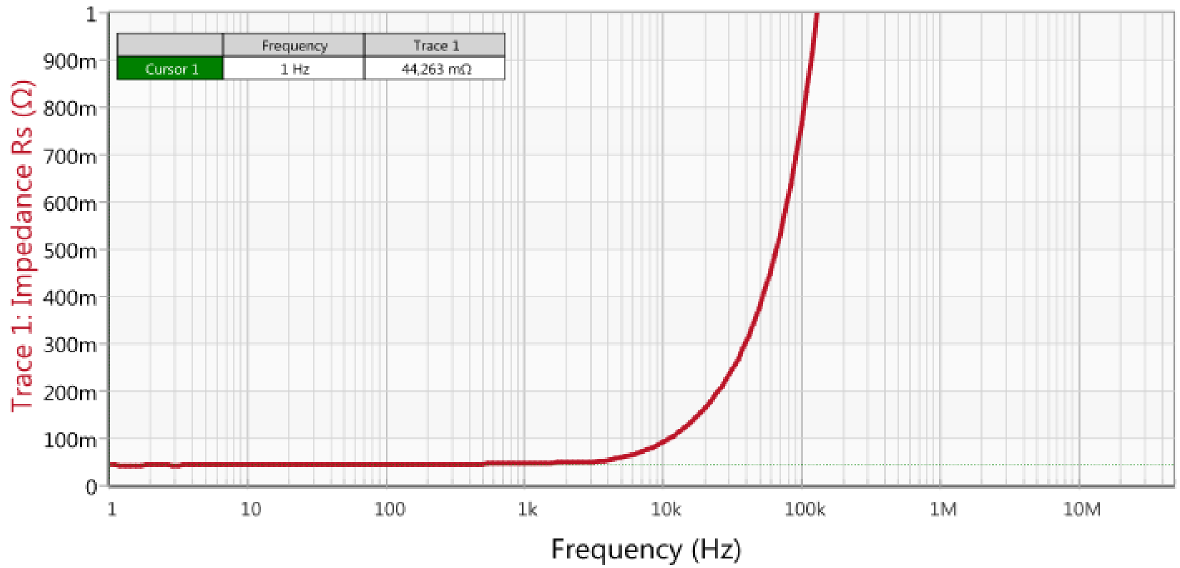
Reference: Bode 100 – Application note

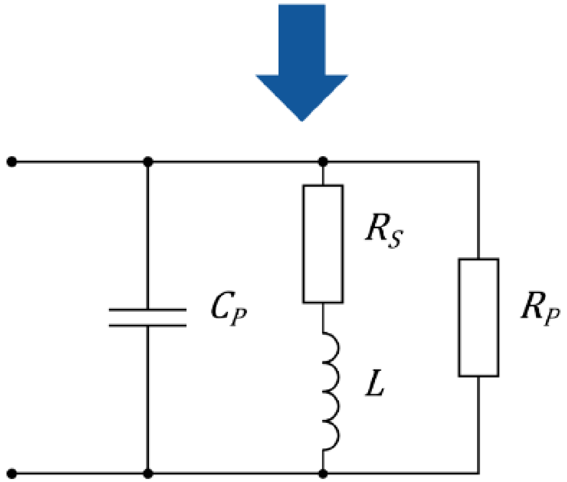
FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Important of this resistance appears in DCM mode of operation or high ripple current mode.
  - At higher frequencies, AC resistance is the dominant for copper losses

Rs (AC component)



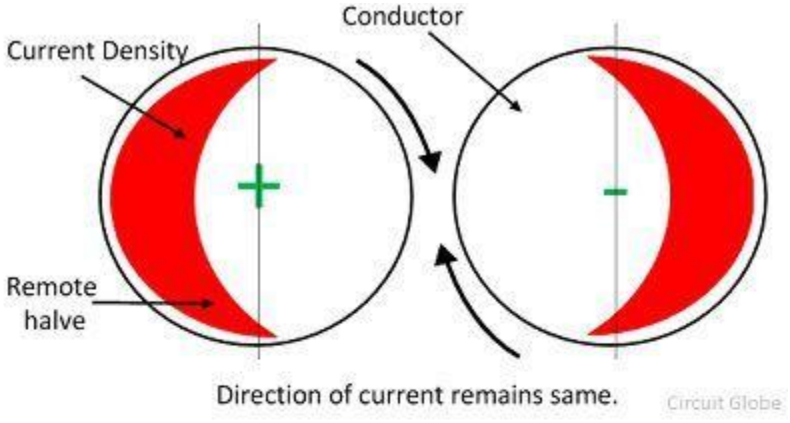


Reference: Bode 100 – Application note

FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Important of this resistance appears in DCM mode of operation.
  - At higher frequencies, AC resistance is the dominant for copper losses
  - Modeling of AC resistance:
    - Analytical or theoretical model -> **not easy (check text books)**
    - **Need to study the effect of:**
      - **Proximity effect**
      - **Skin depth**
    - **2D or 3D model using FEM:**
      - **Ansys -> Maxwell**



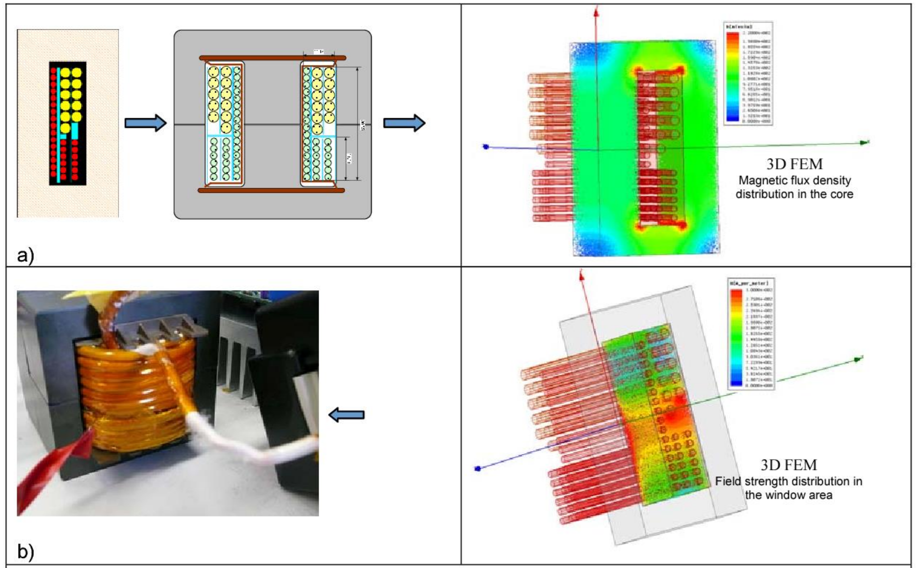


Figure 8 Simulation results and first prototype of the HF Power Transformer, (1/4 of the transformer model)

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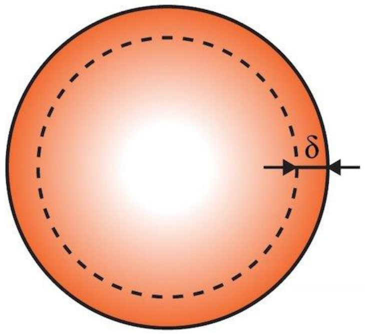


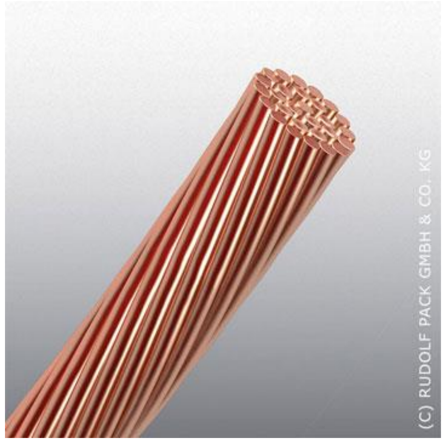
Skin Depth is:

$$\delta = \sqrt{\frac{1}{\pi f \mu_0 \mu_r \sigma_0 \sigma_r}}$$

FLYBACK TRANSFORMER

Design Requirements

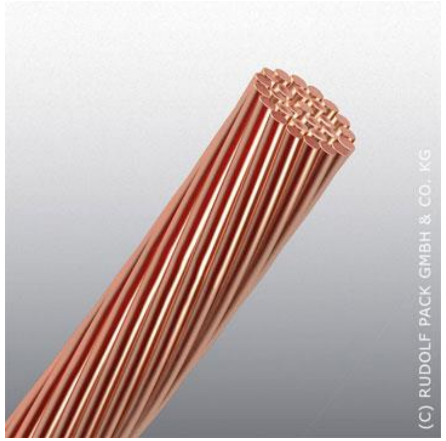
- AC Resistance:
  - Litz wire to optimize AC resistance



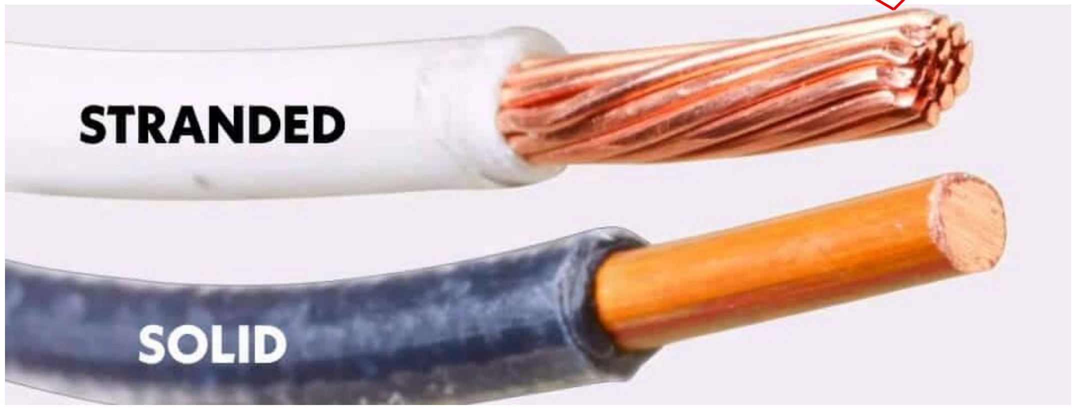
FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Litz wire to optimize AC resistance



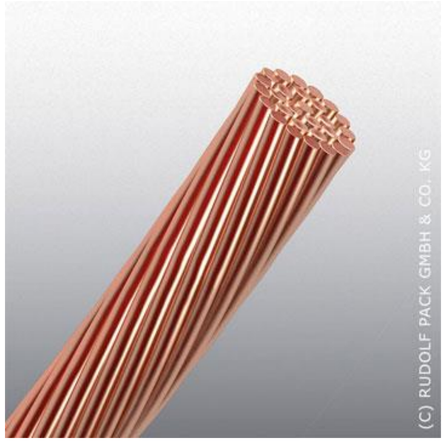
Multi-strands wire **Twisted**



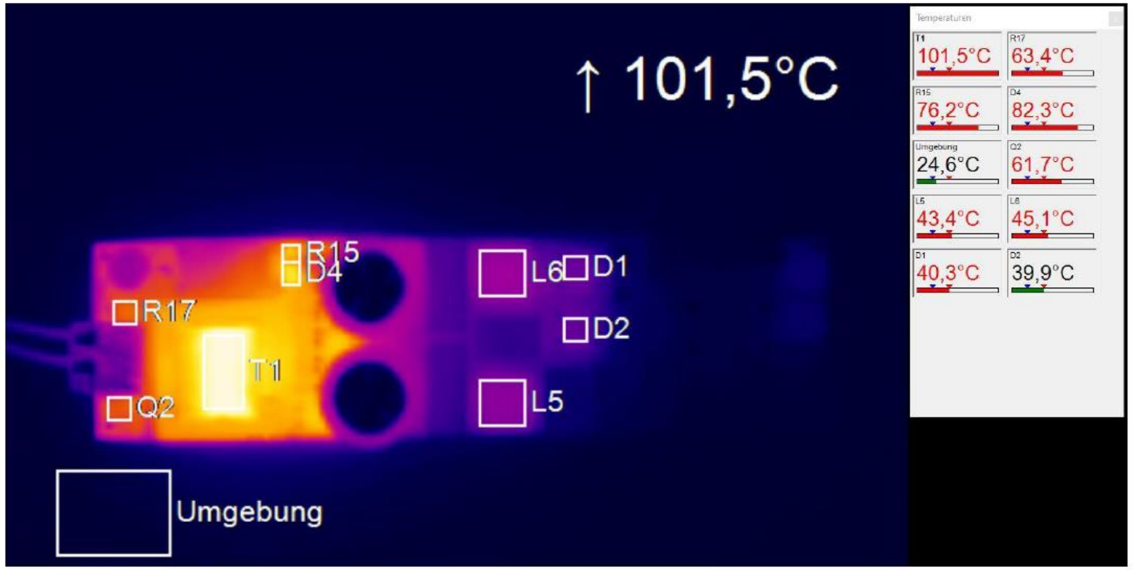
FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Litz wire to optimize AC resistance
  - Example:
    - **Transformer for Offline flyback DCM topology at 100kHz operating freq.**



Line: 230V / Load: 30W

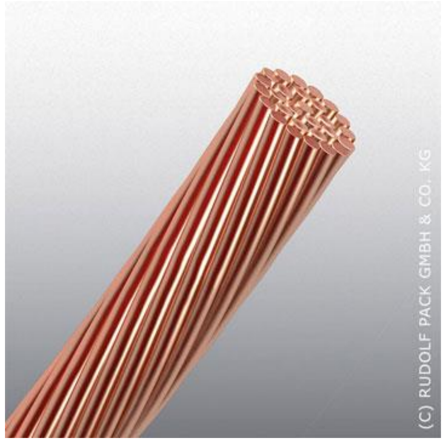


Transformer with solid wire

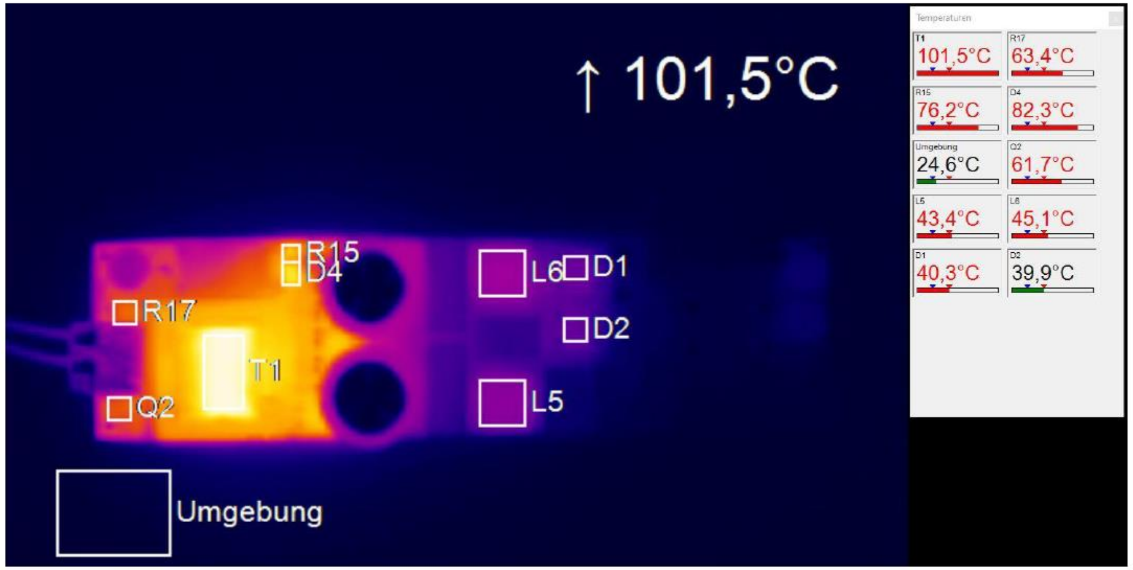
FLYBACK TRANSFORMER

Design Requirements

- AC Resistance:
  - Litz wire to optimize AC resistance
  - Example:
    - **Transformer for Offline flyback DCM topology at 100kHz operating freq.**

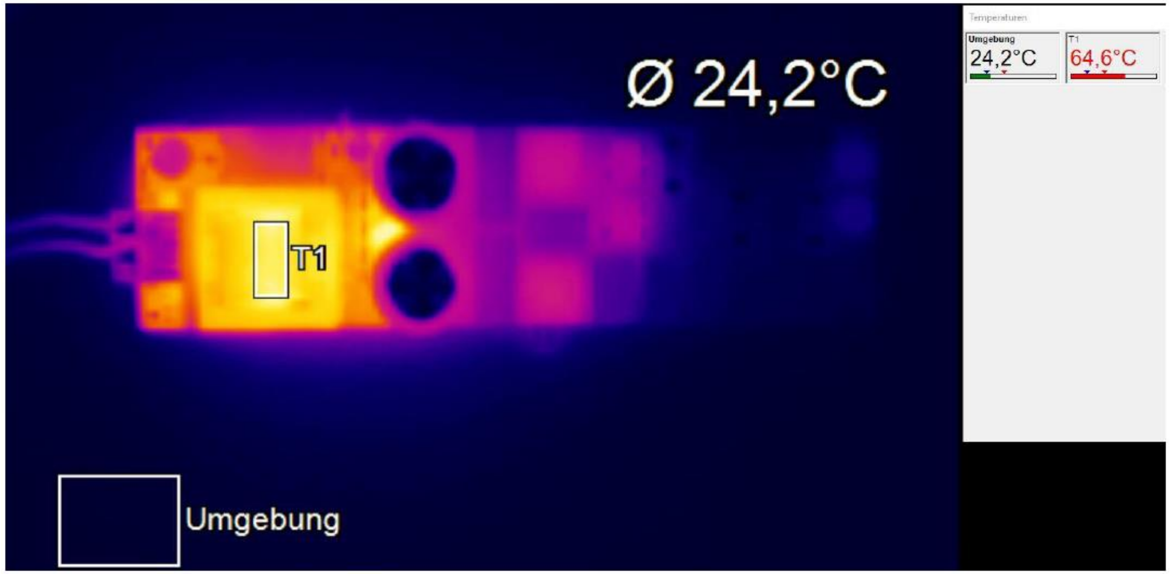


Line: 230V / Load: 30W



Transformer with solid wire

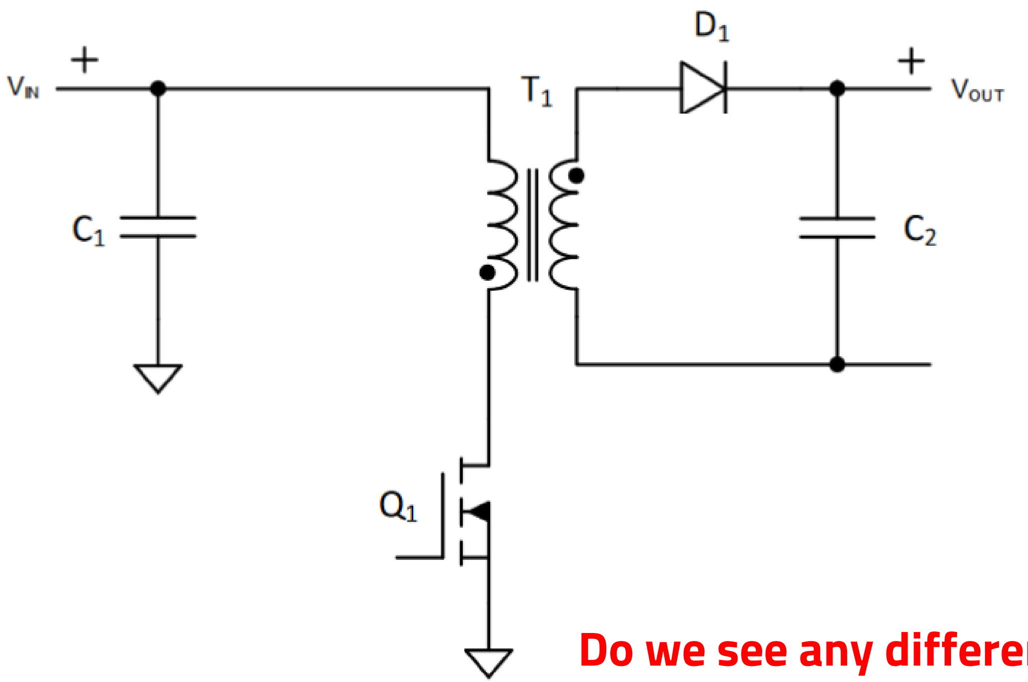
Line: 230V / Load: 30W

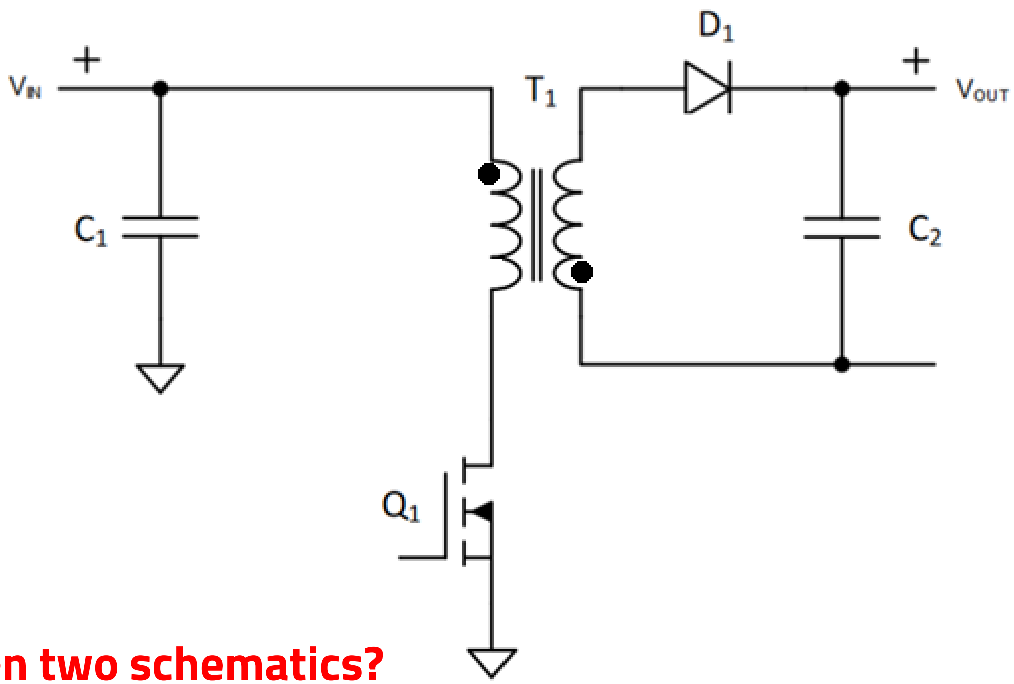


Optimized transformer using litz wire

TIPS TO IMPROVE EMI

- EMI:

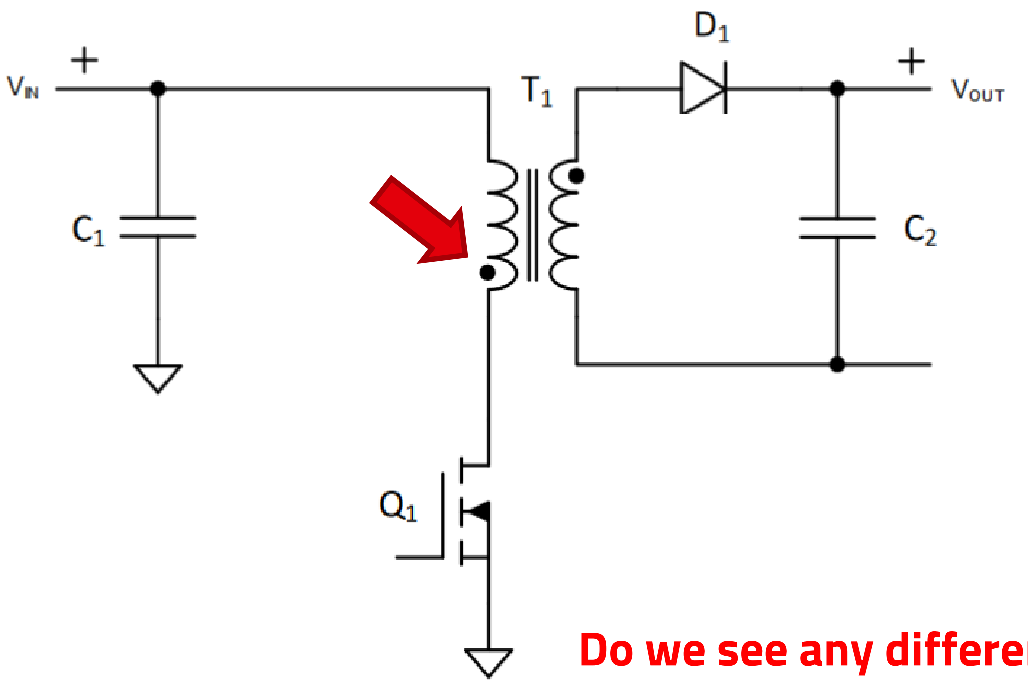


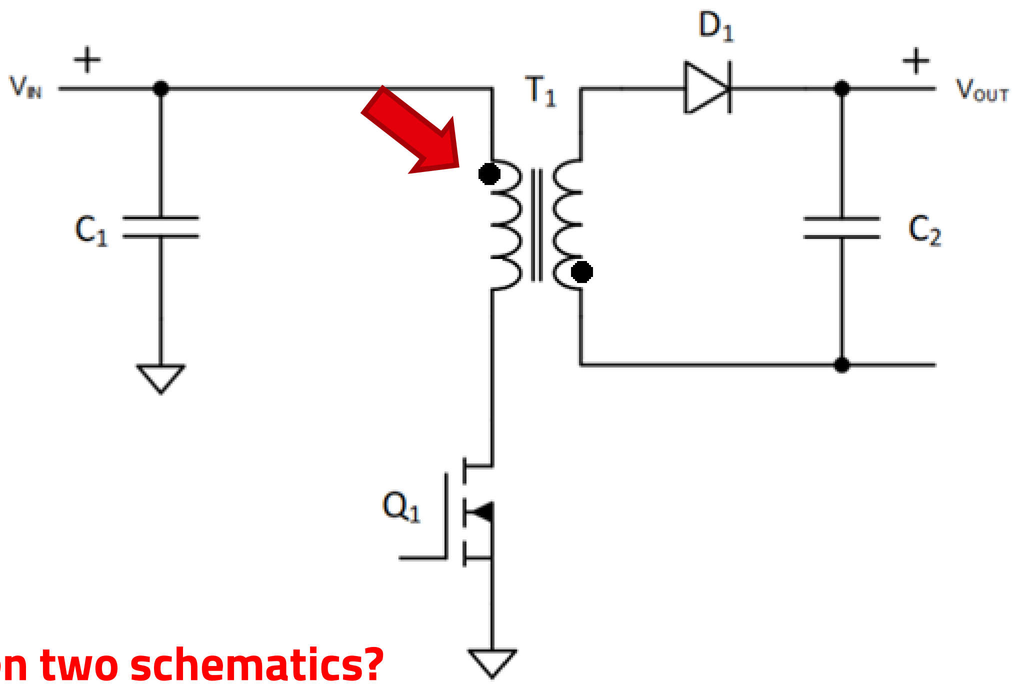


Do we see any difference between two schematics?

TIPS TO IMPROVE EMI

- EMI:

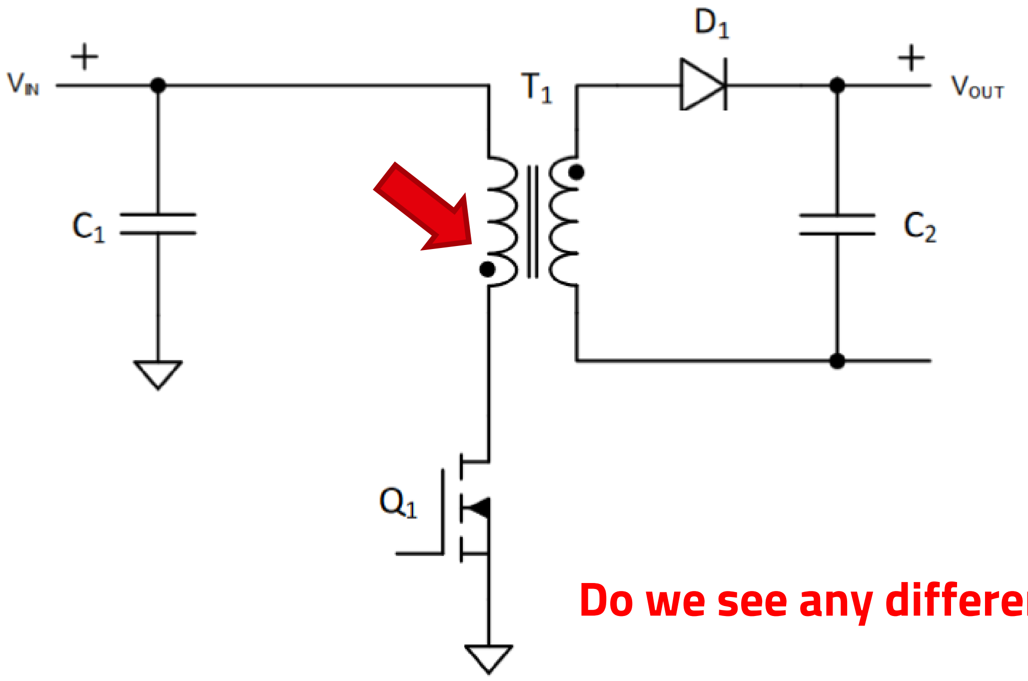


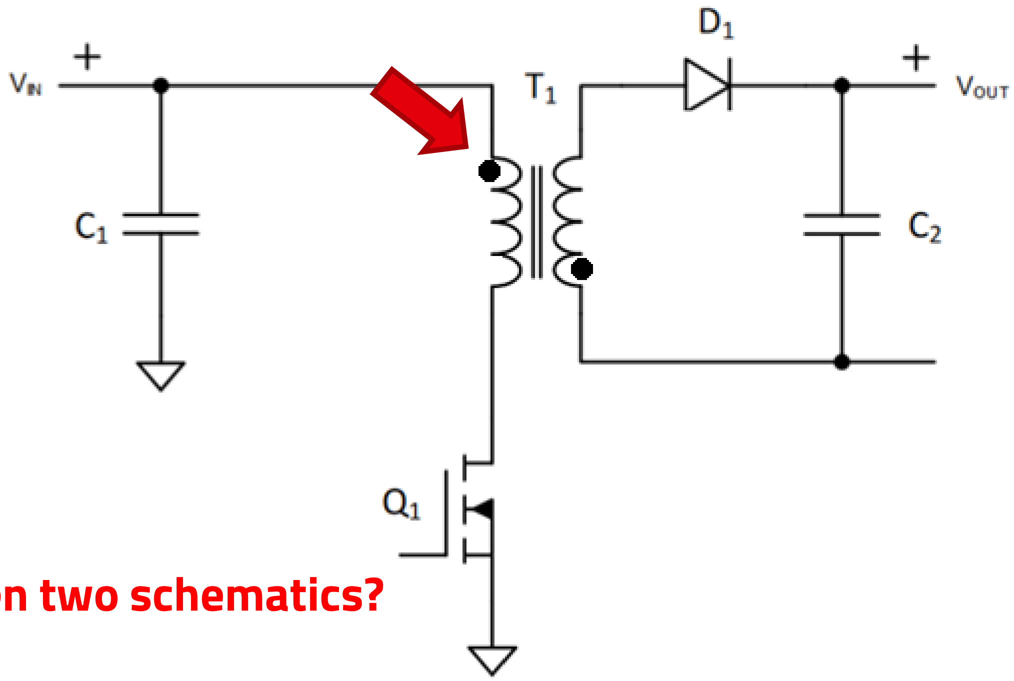


Do we see any difference between two schematics?

TIPS TO IMPROVE EMI

- EMI:
  - No difference on functionality of topology or circuit operation
  - **But** it has impact on EMI performance





Do we see any difference between two schematics?

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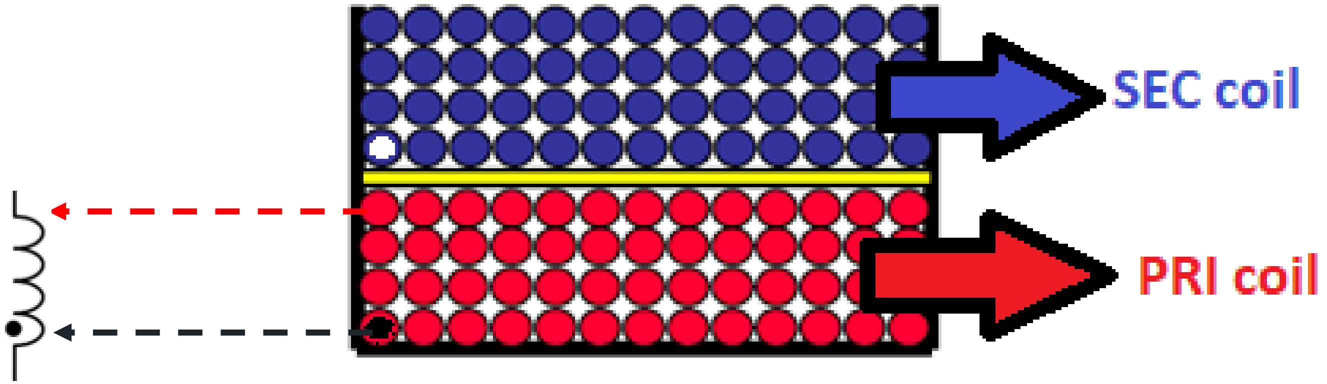

TIPS TO IMPROVE EMI

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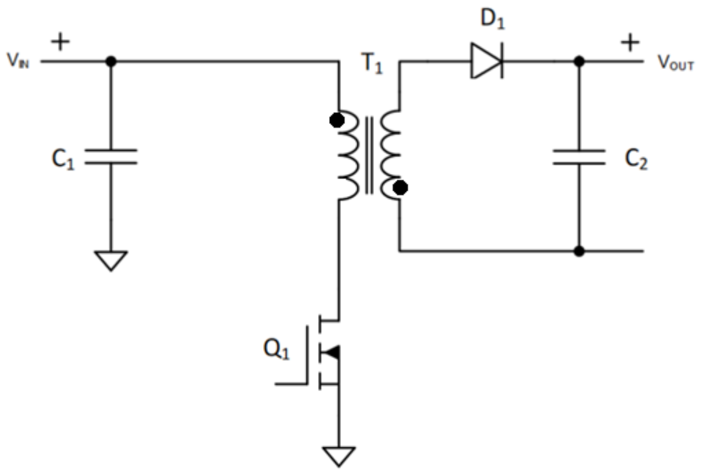
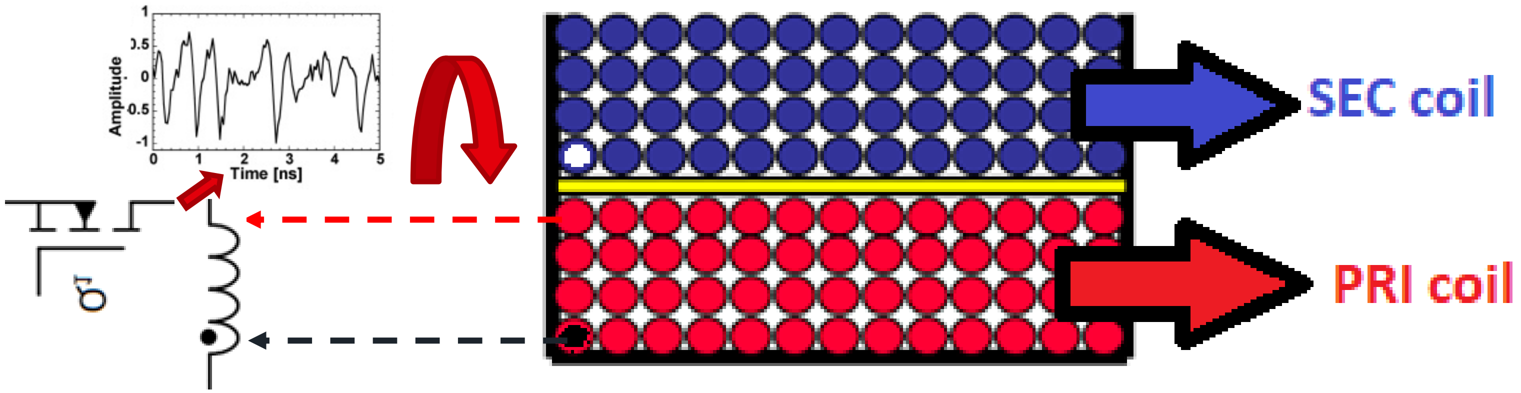
  - No difference on functionality of topology or circuit operation
  - **But** it has impact on EMI performance

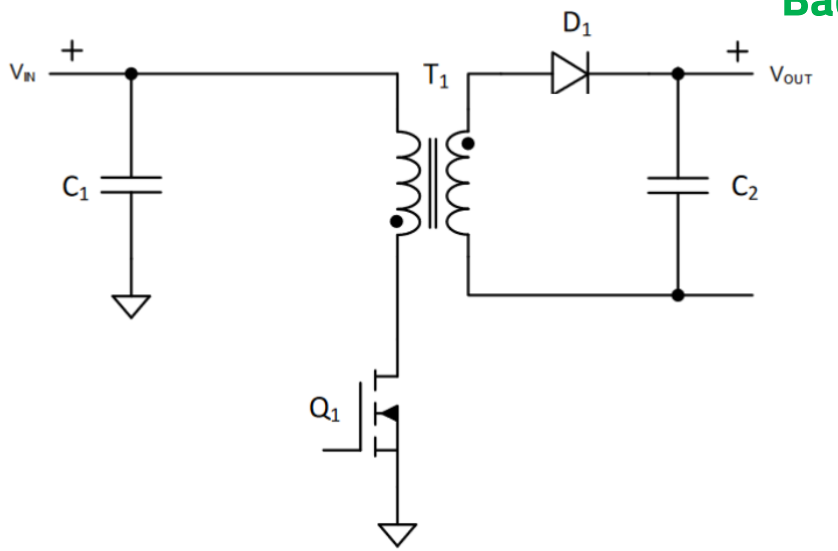


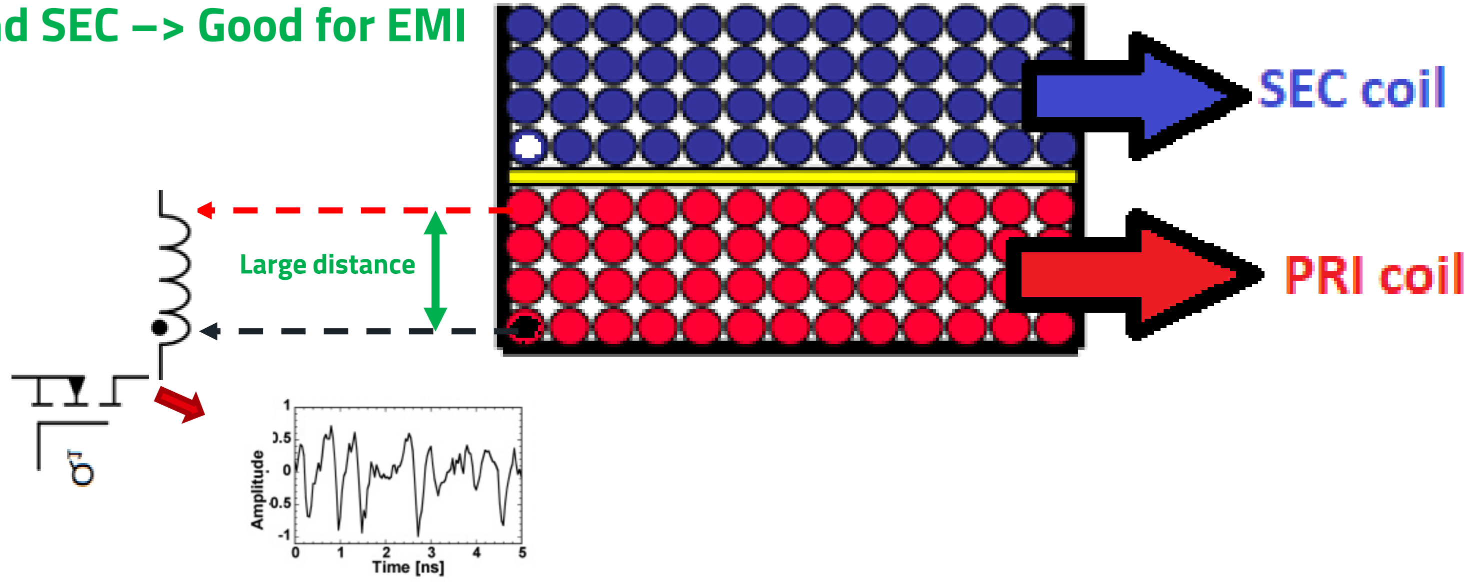


Good coupling between noise node and SEC –> Bad for EMI

TIPS TO IMPROVE EMI

- EMI:
  - No difference on functionality of topology or circuit operation
  - **But** it has impact on EMI performance





TIPS TO IMPROVE EMI

- EMI:
  - Würth Elektronik article for Buck inductor:
    - EM Radiation due to the Influence of the Start of the Winding in an Inductor

https://www.we-online.com/web/en/electronic_components/news_pbs/blog_pbcm/blog_detail-worldofelectronics_109450.php

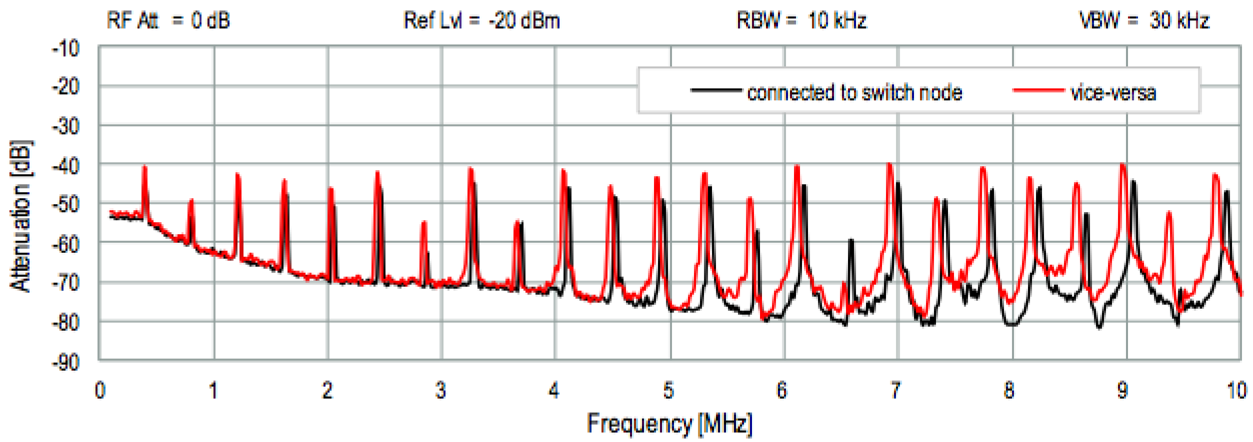


Figure 7: E-field of the inductor's start of winding connected to the switch node and vice-versa

Questions

& Answers

We are here for you now!
Ask us directly via our chat or via E-Mail.

digital-we-days@we-online.com
Khaled.Elshafey@we-online.de