An Optimization Method For Planar Transformer Winding Losses In GaN Based Multi-output Flyback Converter

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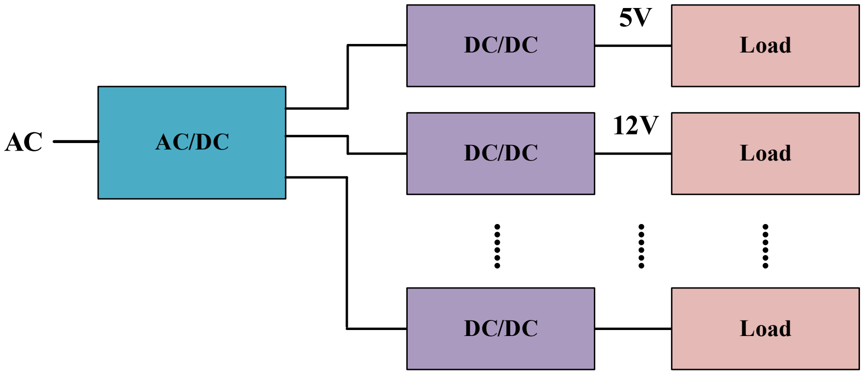
Outlines

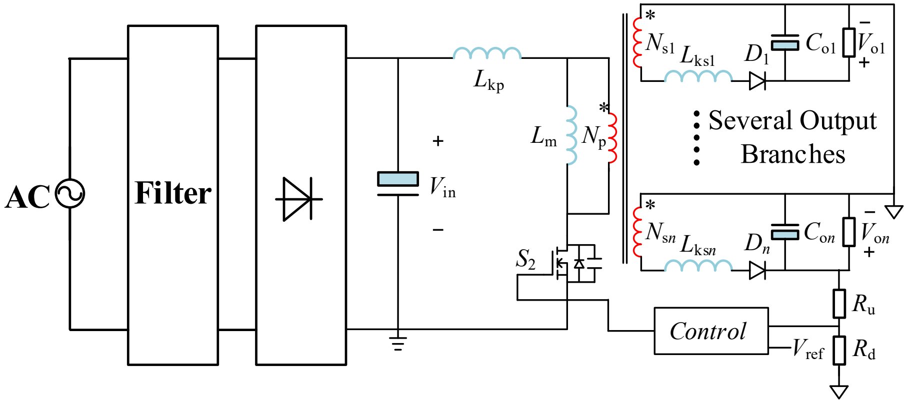
- Background
- The Analysis Method of Winding Losses for Multi-Output Flyback Converter (MOFC) Planar Transformers
  - The analysis method for MOFC Planar Transformer's winding loss
- Winding Design and Optimization of MOFC Planar Transformers
  - Winding design of dual-output Flyback planar transformers
  - A novel design of winding structure for MOFC planar transformers
- Experimental Results
- Summary

Benefit of Multi-Output Flyback

Multi-Output Power System



Multi-Output Flyback Converter

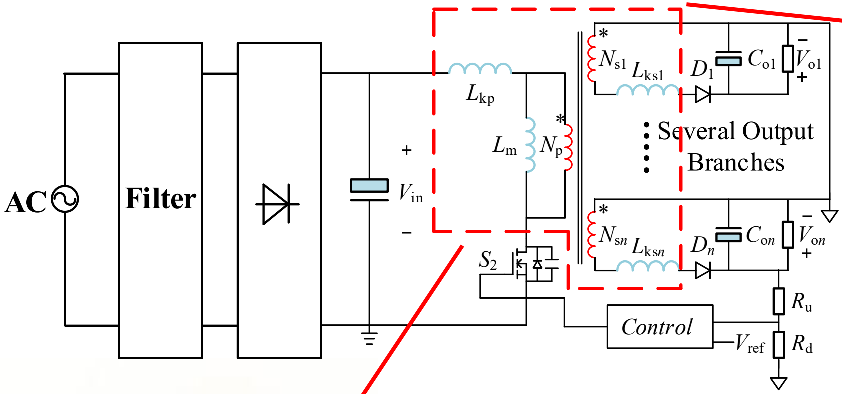


Requirements:

- ☐ Multi-Outputs with Different Voltage Levels
- ☐ Smaller Size and Weight
- ☐ Higher Efficiency

- ✔ **Low Cost, Simple Structure**
- ✔ **Few Components Count**
- ✔ **Small Size**

Benefit of Planar Transformers



Planar Transformer

- Small Leakage
- Better Consistency
- Flexible Winding Structure

Better Cross-Regulation ⇨ System Cost ↓, Efficiency ↑

Wound Transformer

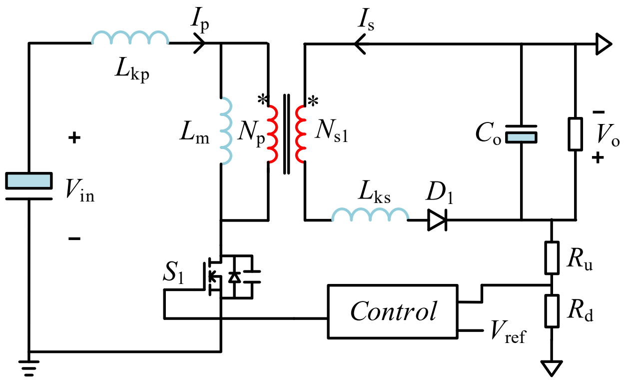
- Big Leakage (L_k)
- Poor Consistency
- Inflexible Winding Structure

Poor Cross-Regulation

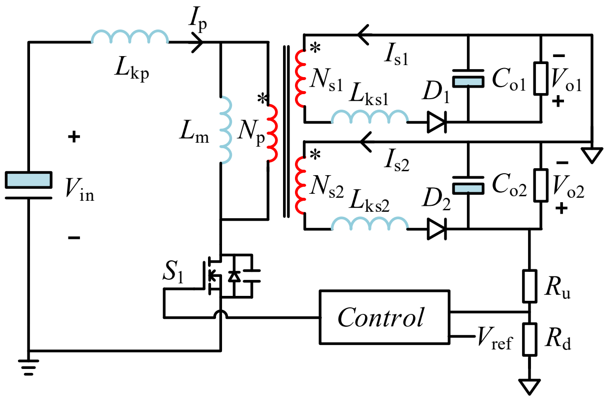
- **The wide bandgap devices (GaN) can help the system operate at the most suitable frequency for planar transformers.**

The Analysis Method of FB Planar Transformer`s Winding Loss

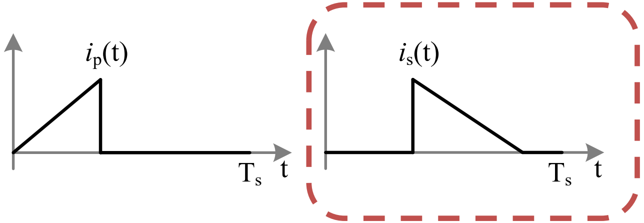
Single-output FB



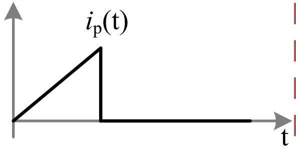
Dual-output FB

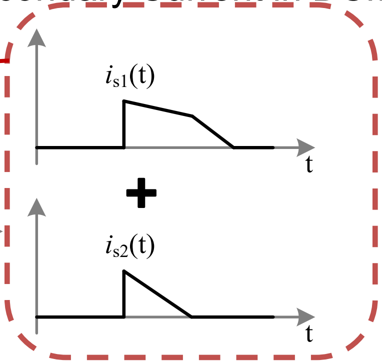


The Primary and the Secondary Current in DCM



The Primary and the Secondary Current in DCM

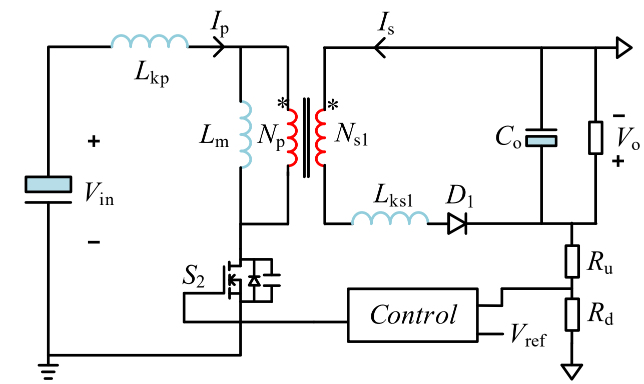




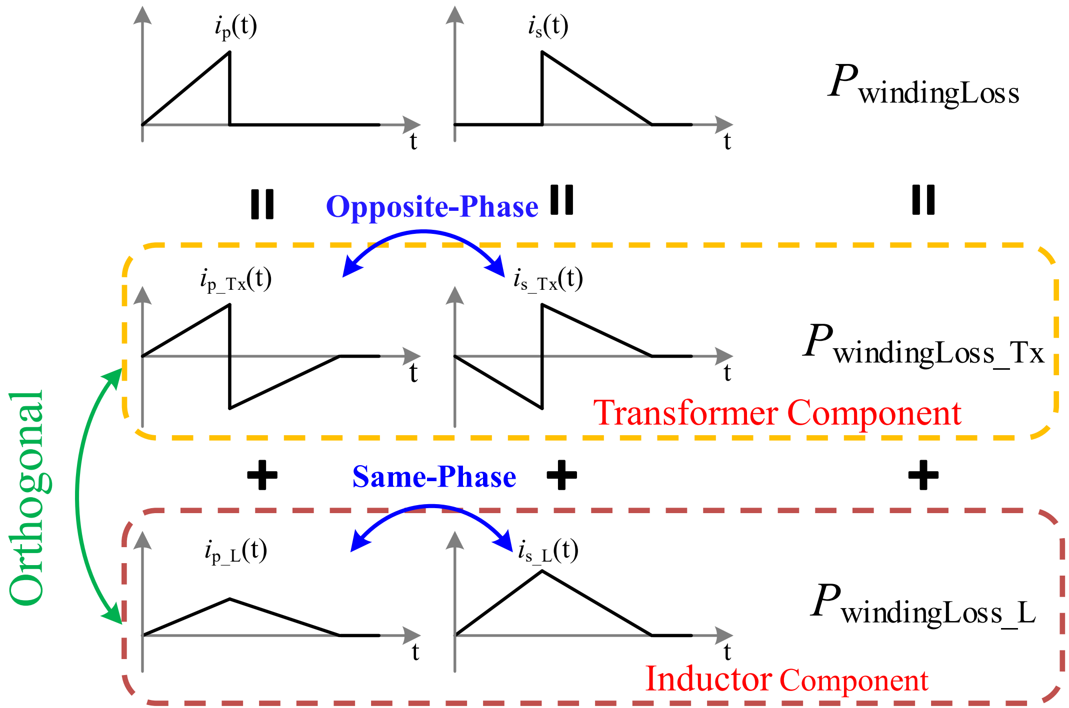
- ❑ **Therefore, the winding loss mechanisms in single-output and dual-output are consistent.**

The Analysis Method of FB Planar Transformer`s Winding Loss

Traditional Single-output FB



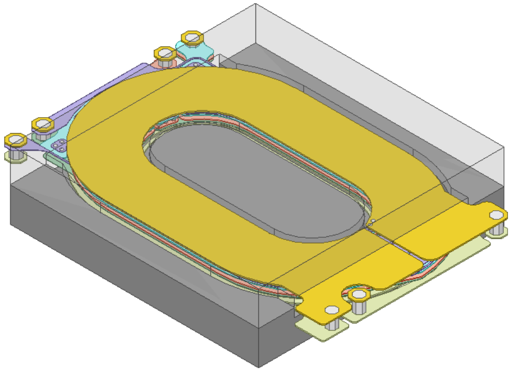
The Primary and the Secondary Current in DCM

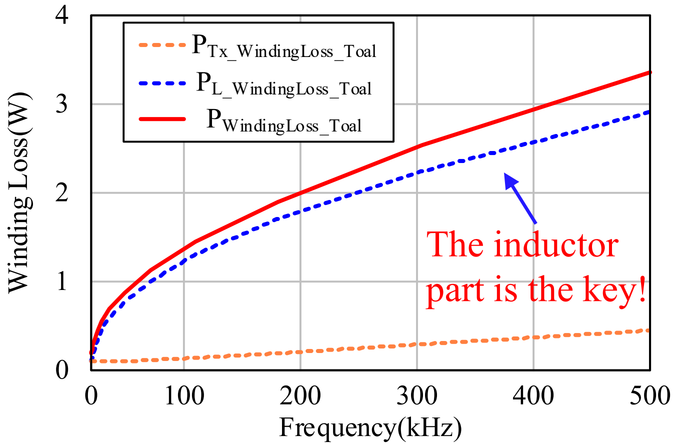


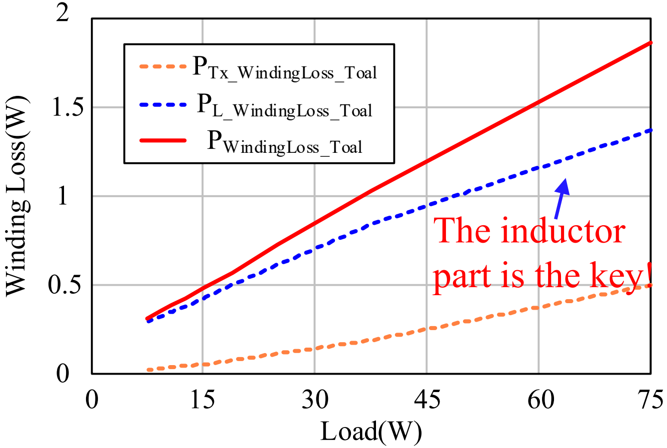
- **The total winding loss is the sum of the transformer part and the inductance part.**

The Analysis Method of MOFB Planar Transformer`s Winding Loss

78W Single-output FB Planar Transformer



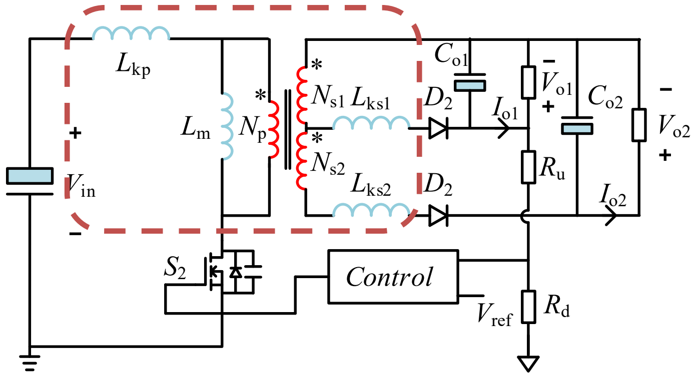




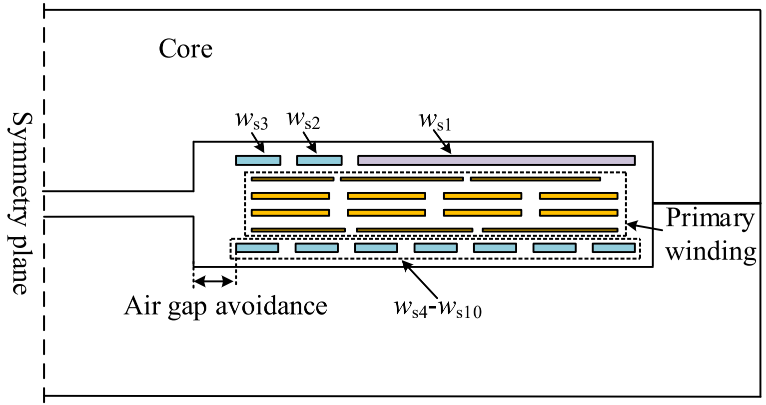
- ❑ **The chief contributor to total winding losses is the inductor component.**
- ❑ **The key to optimizing winding losses is the inductance part.**

Winding Design of A Dual-Output FB Planar Transformers

78W Dual-output FB



Cross-Section of the Planar Transformer



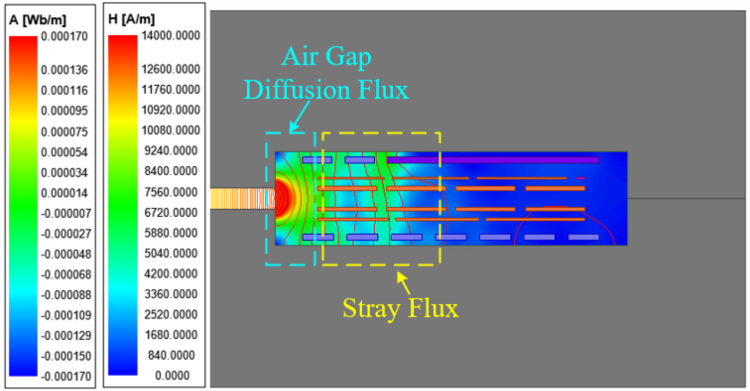
- Main circuit: Dual-output QR Flyback
- Input voltage: 90-264Vac
- V_{o1}=12V, I_{o1}=2.4A, V_{o2}=120V, I_{o2}=0.4A
- $N_p : N_{s1} : N_{s2}$ =14:1:9

Based on minimizes DC winding loss :

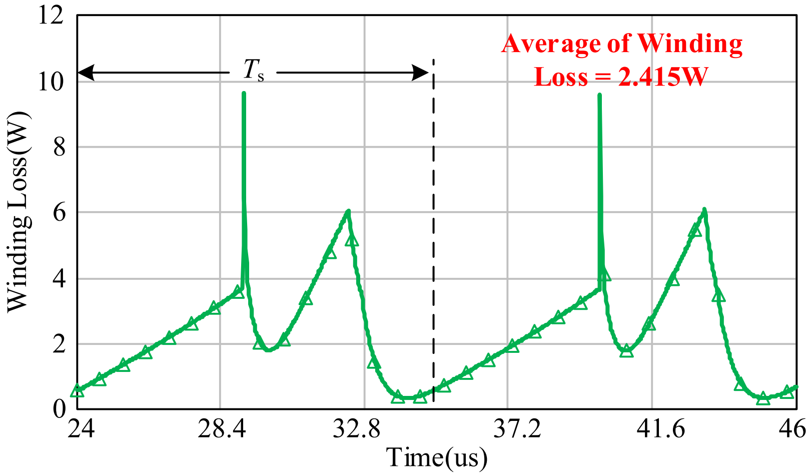
$$\frac{I_{o1}+I_{o2}}{S_{ws1}} = \frac{I_{o2}}{S_{ws2}} = \cdots = \frac{I_{o2}}{S_{ws10}}$$

Winding Design of A Dual-Output FB Planar Transformers

Magnetic Field Distribution of the Winding Structure



Time-Domain Graph of Winding Loss

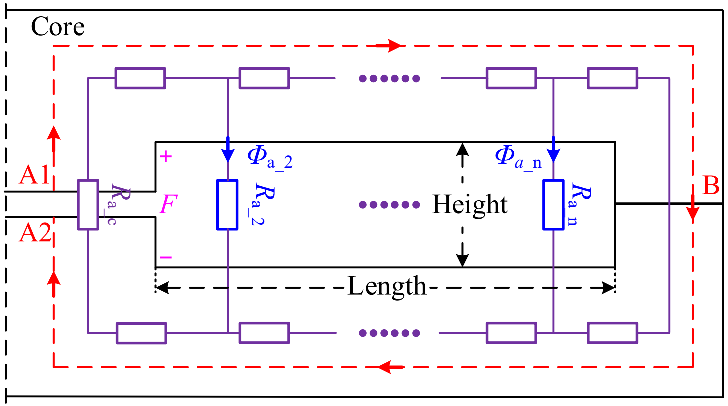


- ⊗ **High Stray Flux**
- ⊗ **High Eddy Current Loss**

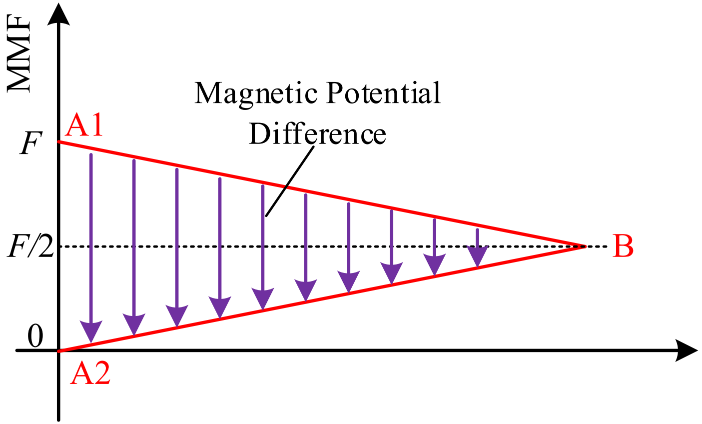
- **The total winding loss is high.**

A Novel Design of Winding Structure

The Equivalent Magnetic Circuit of Transformer Core



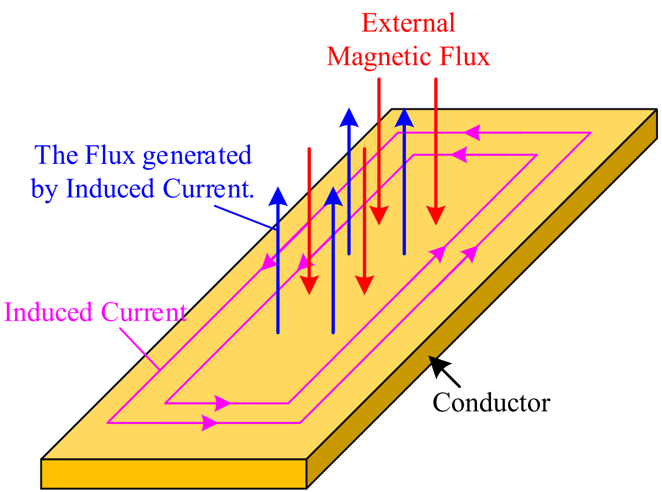
Variation of MMF along the Core Structure



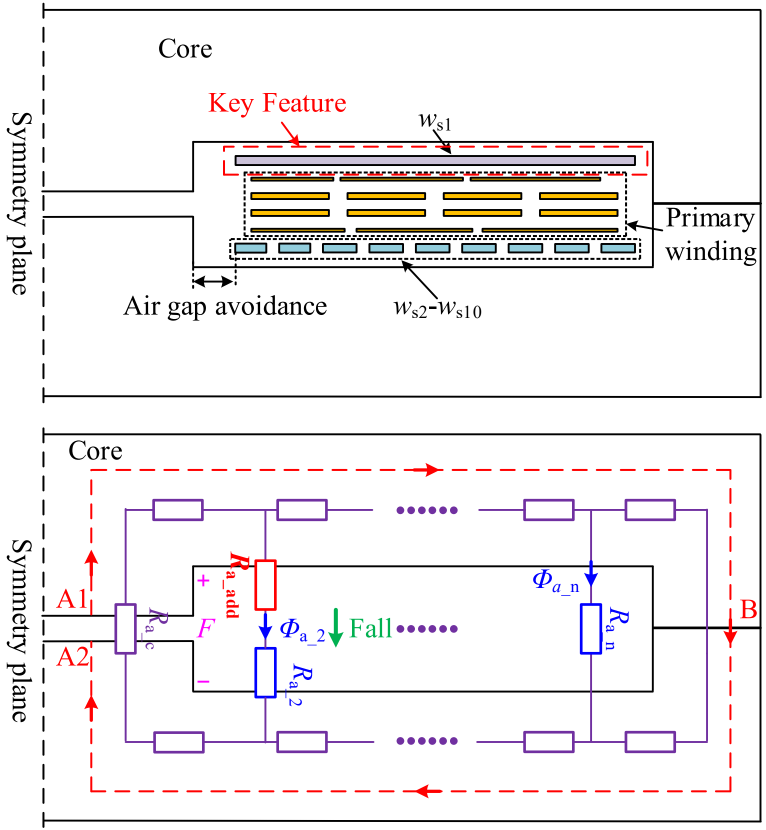
- R_{a_2}~R_{a_n} : Reluctances between the Magnetic Core Window
- Φ_{a_2}~Φ_{a_n}: Stray Flux

Length ↑ **Height** ↓ ⇒ **R_{a_2}~R_{a_n}** ↓ ⇒ **Φ_{a_2}~ Φ_{a_n}** ↑ ⇒ ↑ **Eddy Current Loss**

A Novel Design of Winding Structure



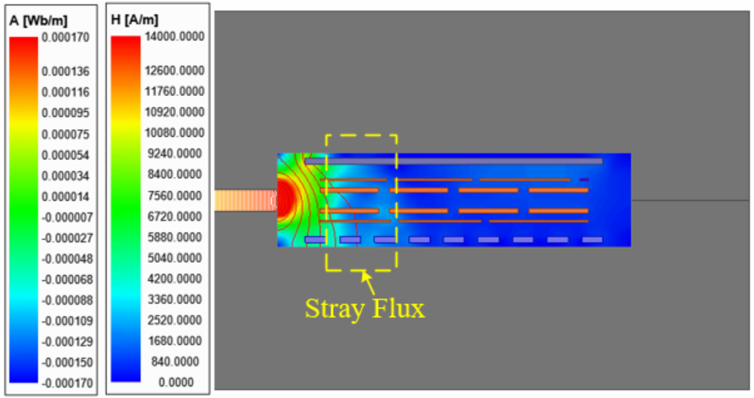
Cross-Section of the Improved Winding Structure



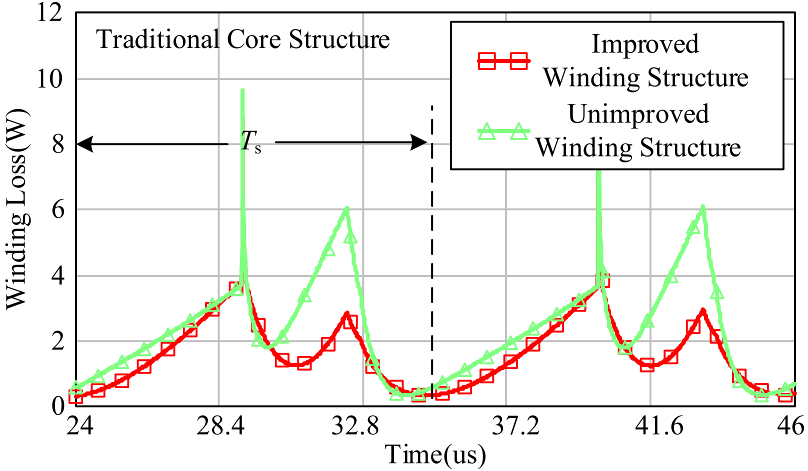
- Conductors can impede alternating magnetic fields.

A Novel Design of Winding Structure

Magnetic Field Distribution of the Improved Winding Structure



Time-Domain Graph of Winding Loss

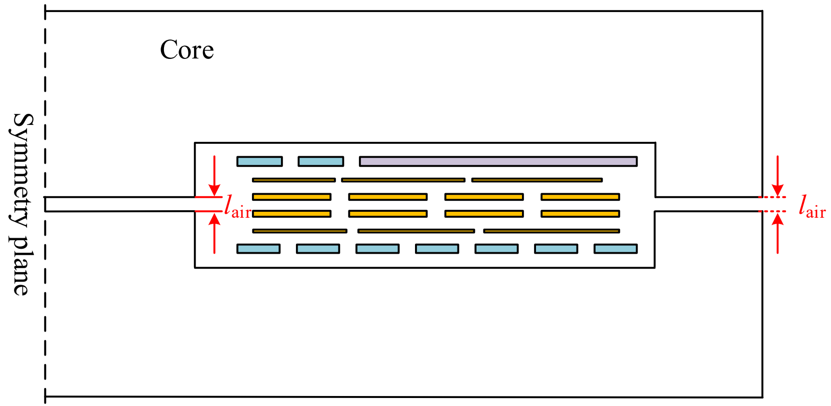


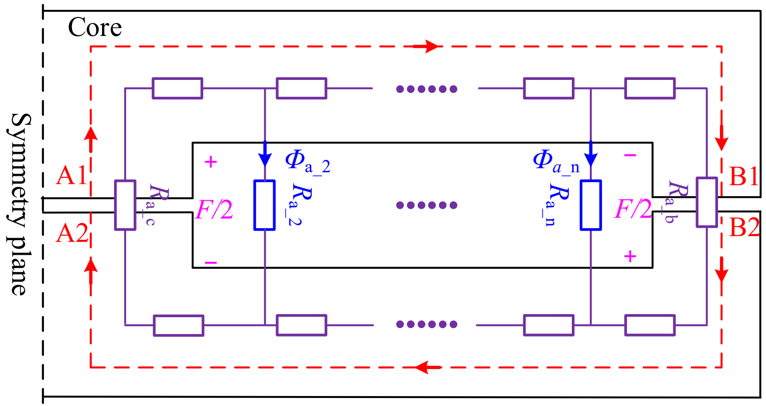
- **Low Stray Flux**
- **Low Eddy Current Loss**

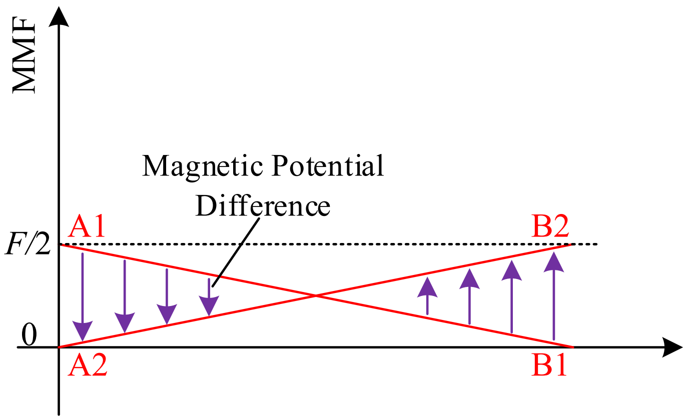
Winding Structure	Unimproved	Improved
Average	2.415W	1.588W

A Novel Design of Winding Structure

The Distributed Air-Gap Transformer Core



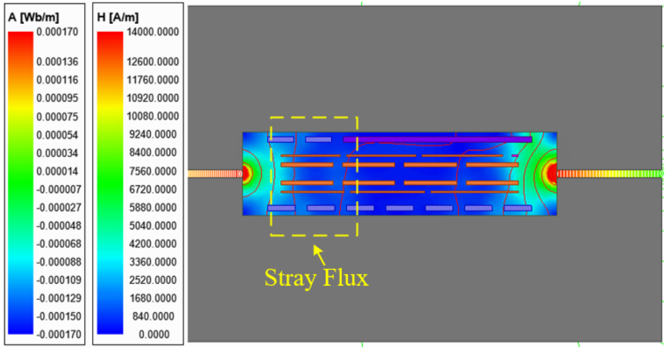




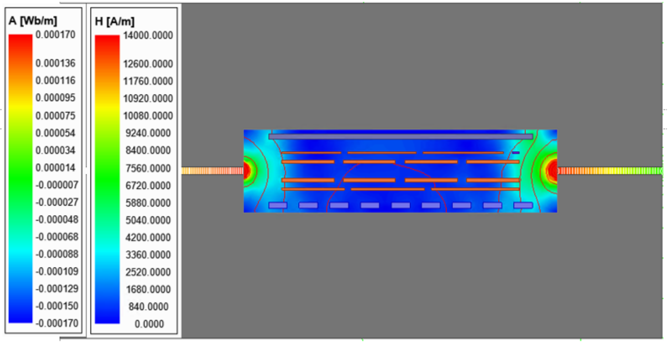
- **Low Magnetic Potential Difference**
- **Low Φ_{a_2}~ Φ_{a_n}**

A Novel Design of Winding Structure

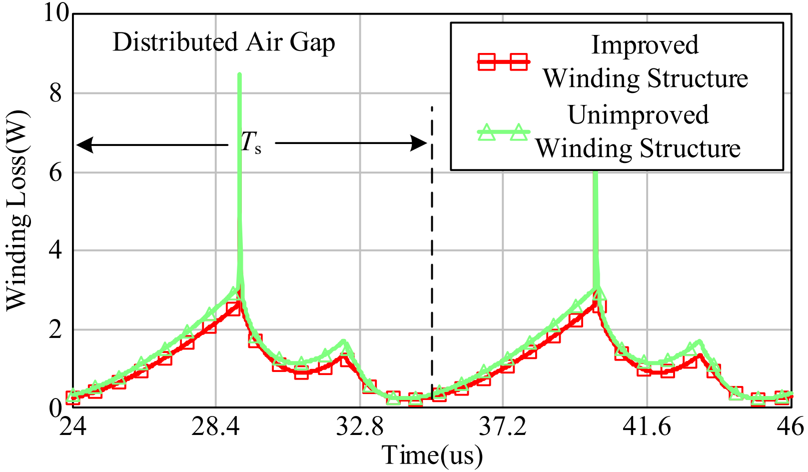
Unimproved Winding Structure



Improved Winding Structure

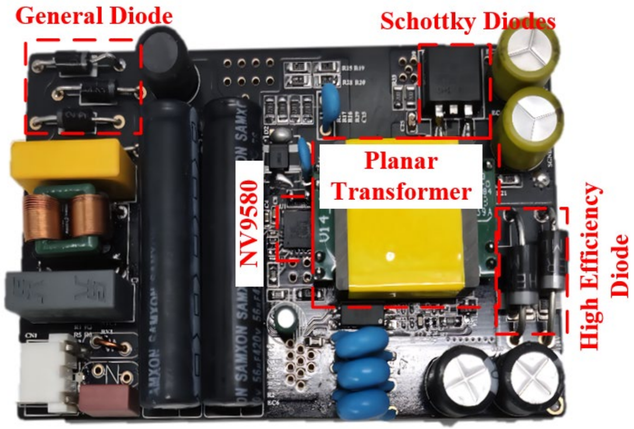


Time-Domain Graph of Winding Loss



Winding Structure	Core Structure	
	Traditional	Distributed Air-gap
Unimproved	2.415W	1.25W
Improved	1.588W	1.07W

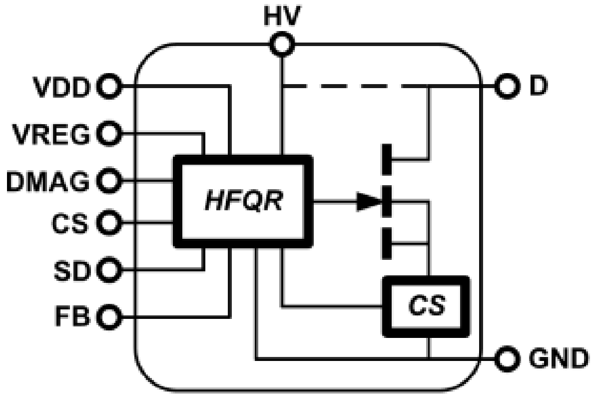
78W Dual-Output TV Power Supply

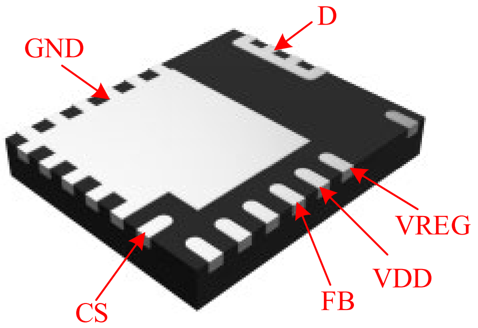


Size: 60.5×93.6×14.5 mm3

High Stability and Low Cost

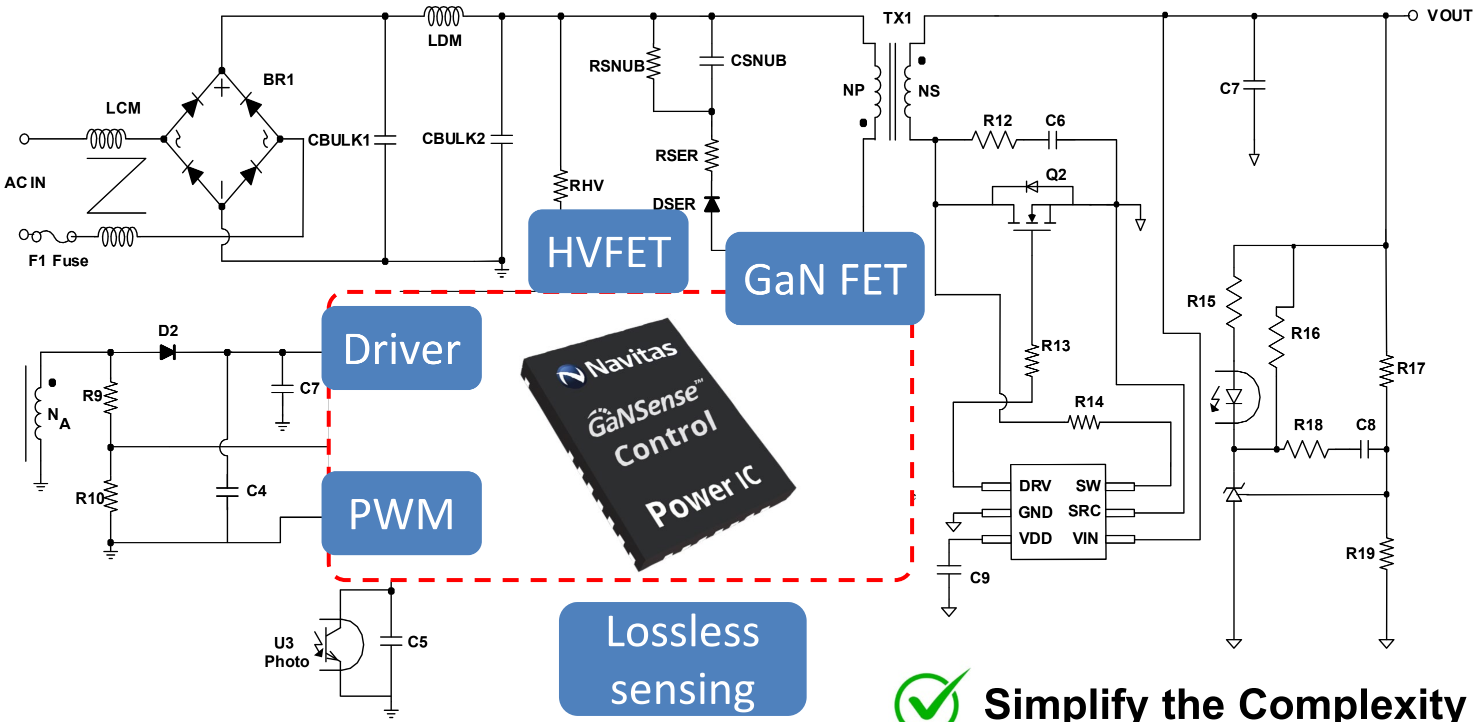
NV9580:





QFN5x6 Super

Benefit of GaNSense Control: NV958X



- Simplify the Complexity of Control
- Working in High Frequency

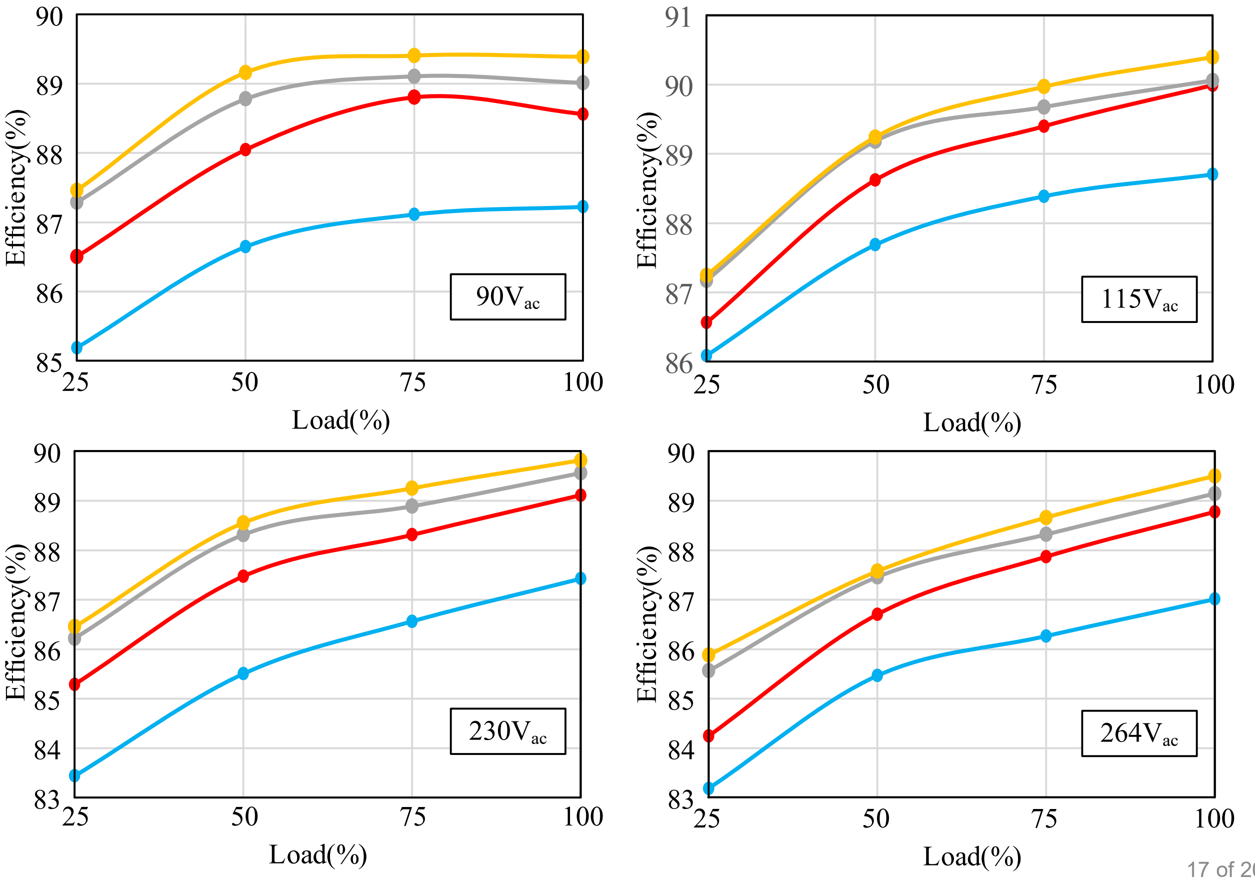
The Efficiency of Different Transformers

Traditional Core Structure:

- Unimproved Winding Structure
- Improved Winding Structure

Distributed Air Gap:

- Unimproved Winding Structure
- Improved Winding Structure

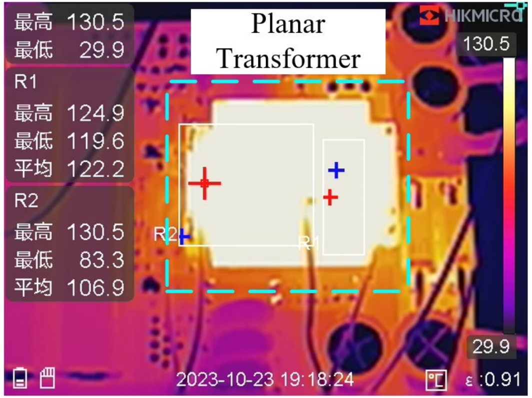


- **In traditional Core, the improved winding structure get a 1.2% increase.**
- **In distributed air gap, the improved winding structure get a 0.3% increase.**

Temperature of Different Planar Transformers

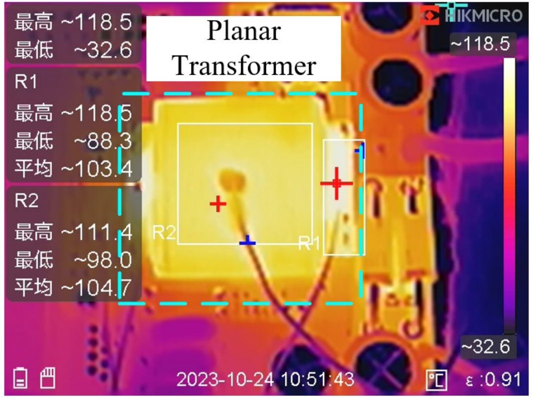
Traditional Core
+
Unimproved Winding

Max Temp 130.5



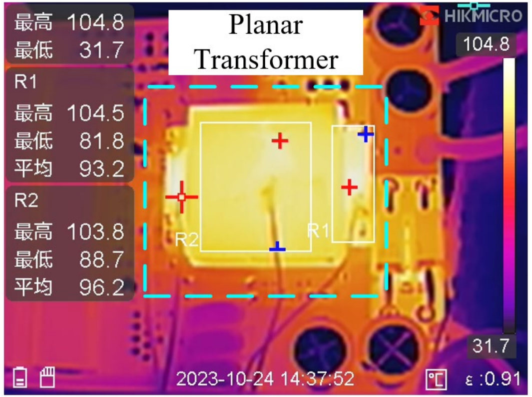
Traditional Core
+
Improved Winding

Max Temp 118.5



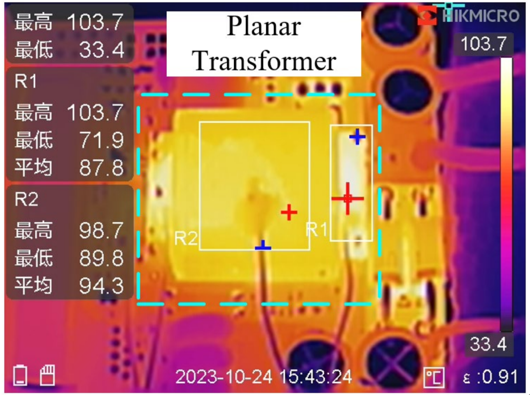
Distributed Air Gap
+
Unimproved Winding

Max Temp 104.8



Distributed Air Gap
+
Improved Winding

Max Temp 103.7



Summary

- In the MOFC, the proposed winding optimization method significantly reduces winding losses in planar transformers without increasing additional costs.
- Utilizing the flat magnetic core structure with distributed air gaps not only reduces air gap leakage flux, but also significantly decreases stray flux, resulting in a substantial reduction in winding losses.