

磁集成开关变换器--正激和倍流整流

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台达电子企业管理（上海）有限公司

世纪电源网—2014（北京）高性能电源技术分享与实战技术研讨会
2014年4月26日





简历介绍



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2001年 福州大学电气工程与自动化学院 学士学位
2004年 福州大学电气工程与自动化学院 硕士学位
2004年^~2008年就职台达能源技术（上海）有限公司
2011年 福州大学电气工程与自动化学院 博士学位
2011年^~至今 就职台达电子企业管理（上海）有限公司，
担任副理，从事博士后研究工作，负责磁性元件设计部。

研究领域：

高频功率磁元件设计技术、电力电子磁集成技术、开关电源电磁兼容技术。



Contents

- **Overview of Magnetic Integrated Technology**
- **Magnetic Integrated Forward Converter**
- **Magnetic Integrated Current Double Rectifier**



开关电源的性能要求

高效率

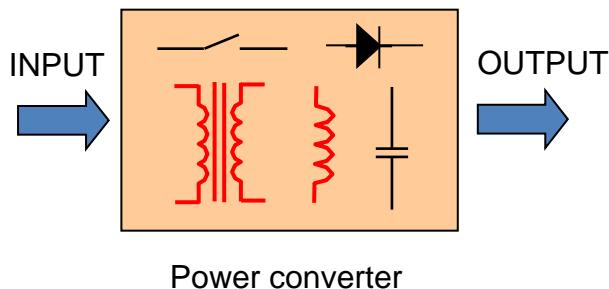


高功率密度





开关电源中的磁性元件

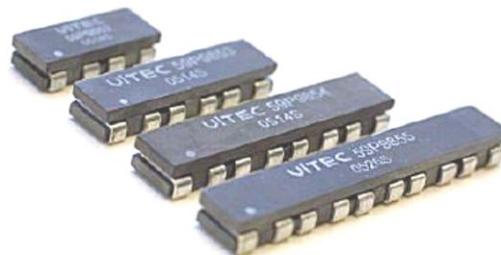
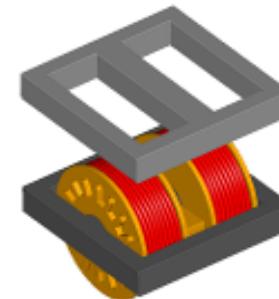
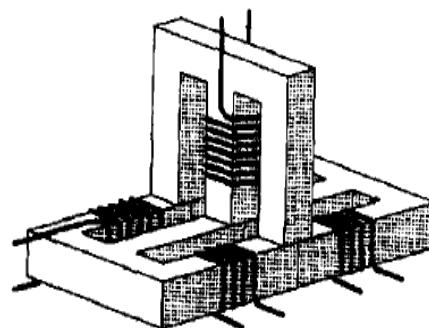
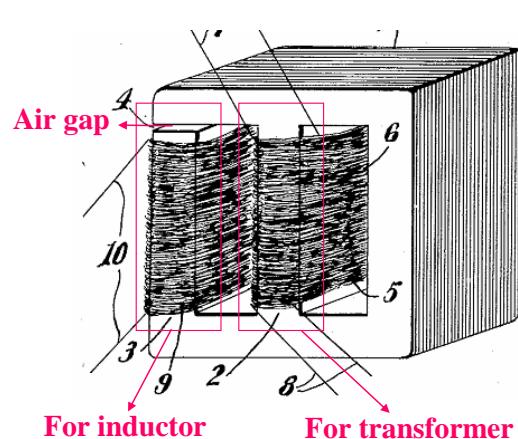


- Volume: 20-30%
- Weight : 30-40%
- Loss : 20-30%
- Cost : 20-40%
- 外观尺寸, 电气参数, 电路拓扑

高频化和集成化是磁性元件小型化的重要手段和发展趋势

磁集成技术的应用

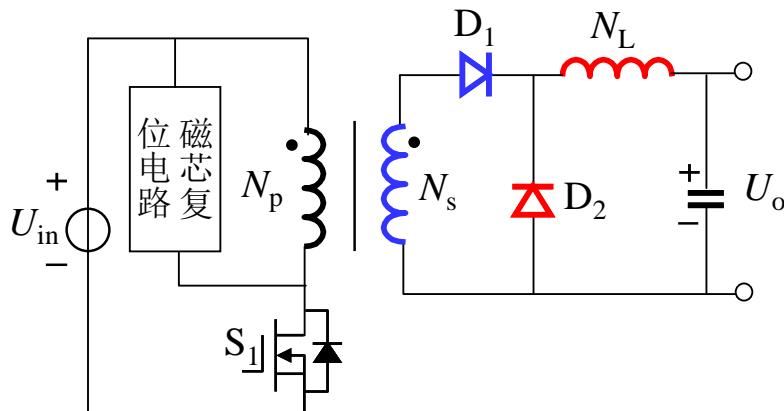
■ 磁集成技术是利用功率变换器中各个磁性元件的绕组电流以及磁路磁通的关系，将这些磁性元件从功能上或结构上有机地集合在一起，以改善变换器的体积、重量、成本、数量、损耗、电气性能、效率、功率密度等。



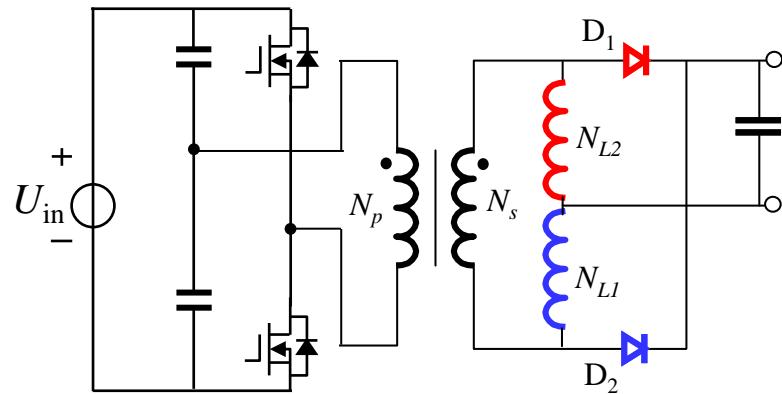


两类磁集成开关变换器

磁集成正激变换器



磁集成倍流整流变换器

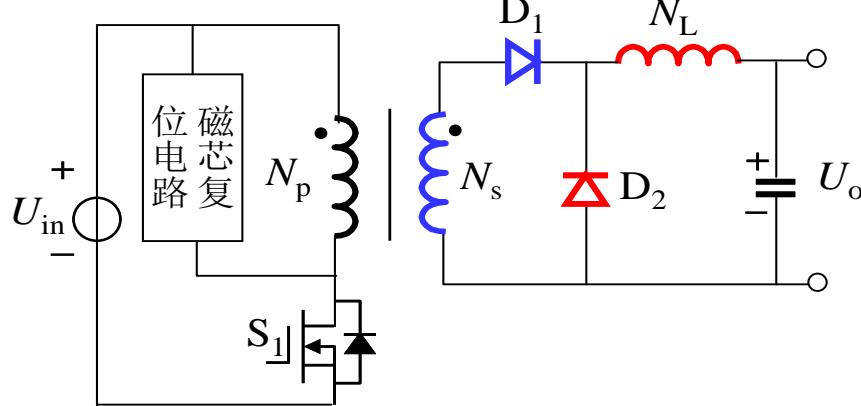




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- Magnetic Integrated Current Double Rectifier

正激变换器的两种磁集成

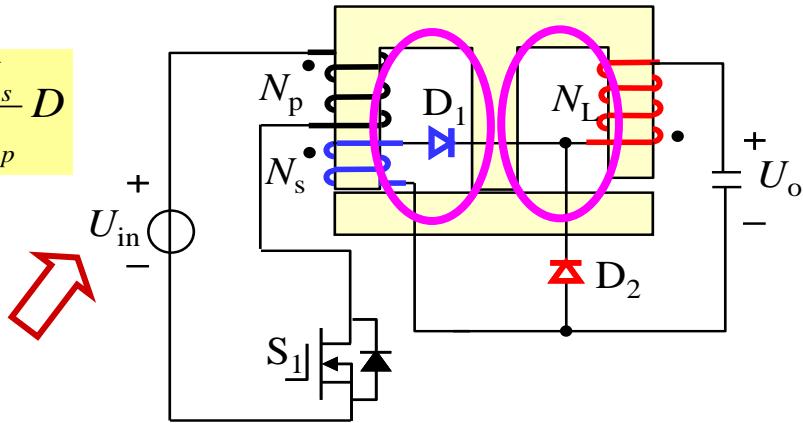


$$\frac{U_o}{U_{in}} = \frac{N_s}{N_p} D$$

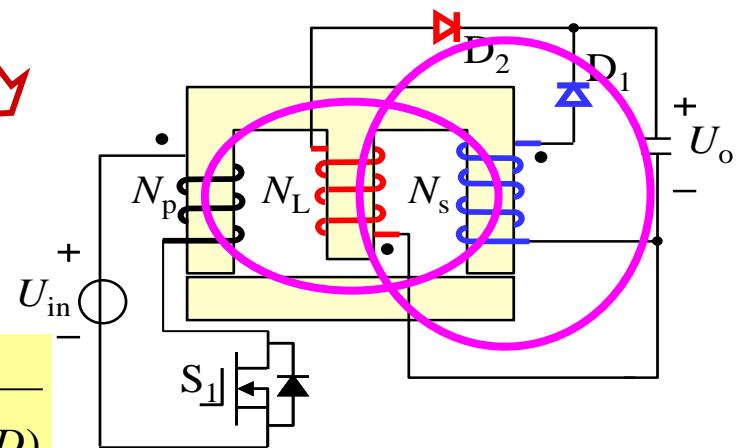
$$N_s = N_L$$

$$\frac{U_o}{U_{in}} = \frac{D}{\frac{N_p}{N_s} D + \frac{N_p}{N_L} (1 - D)}$$

$$\frac{U_o}{U_{in}} = \frac{N_s}{N_p} D$$



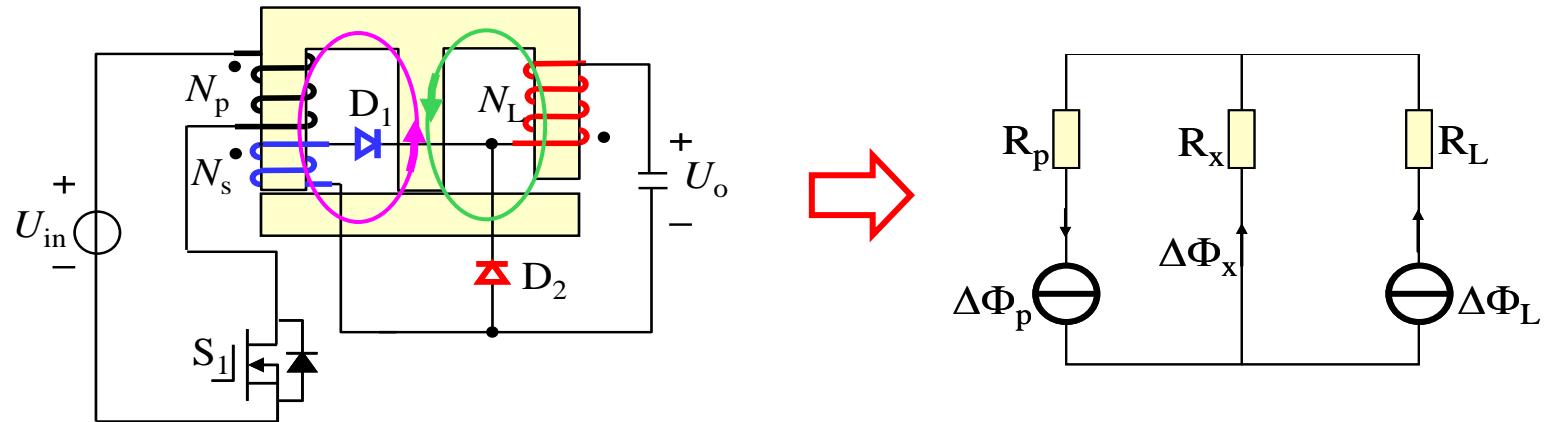
磁集成正激变换器-1



磁集成正激变换器-2



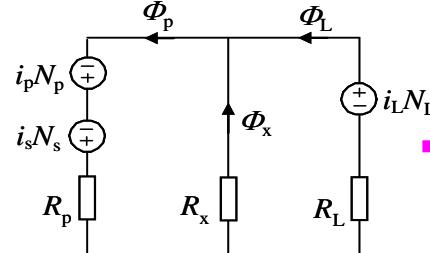
磁集成正激变换器-1



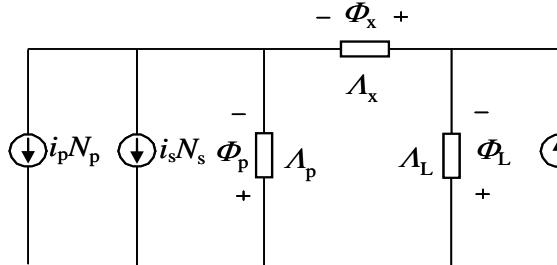
如何考虑磁路对电路的影响？



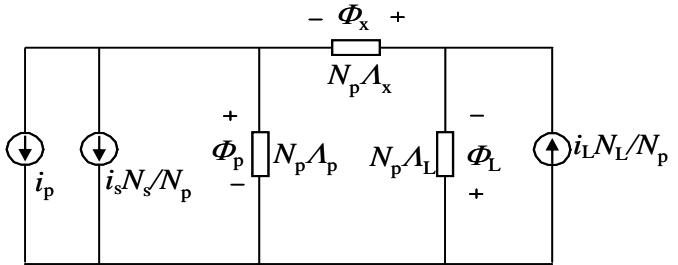
等效电路模型变换



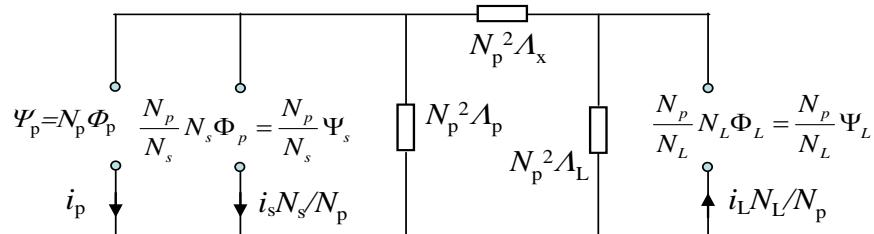
(a) 等效磁路



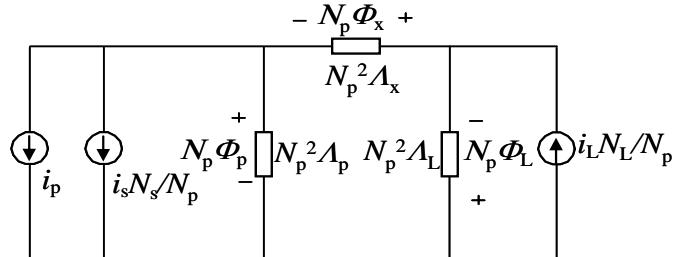
(b) 对偶图



(c) 对 i 尺度变换

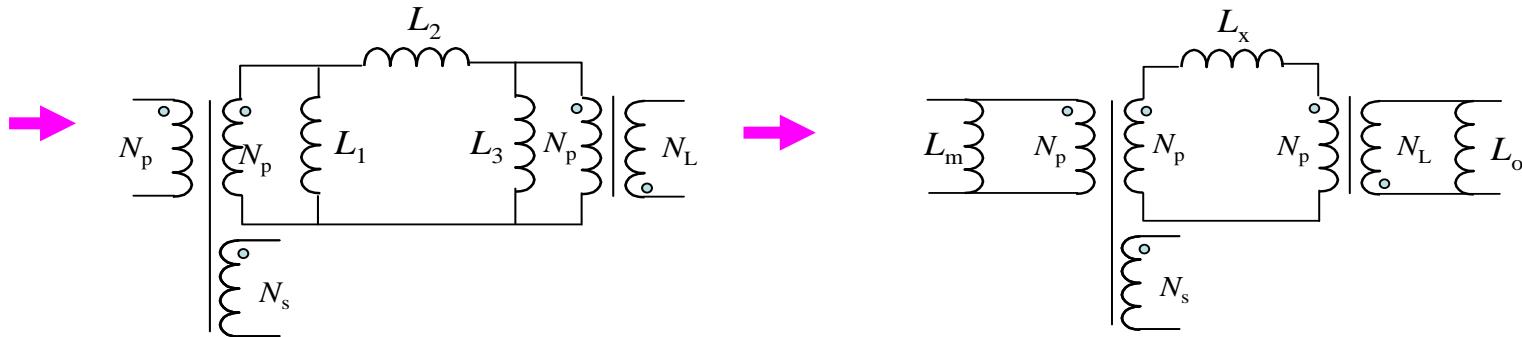


(e) 端口磁链表示



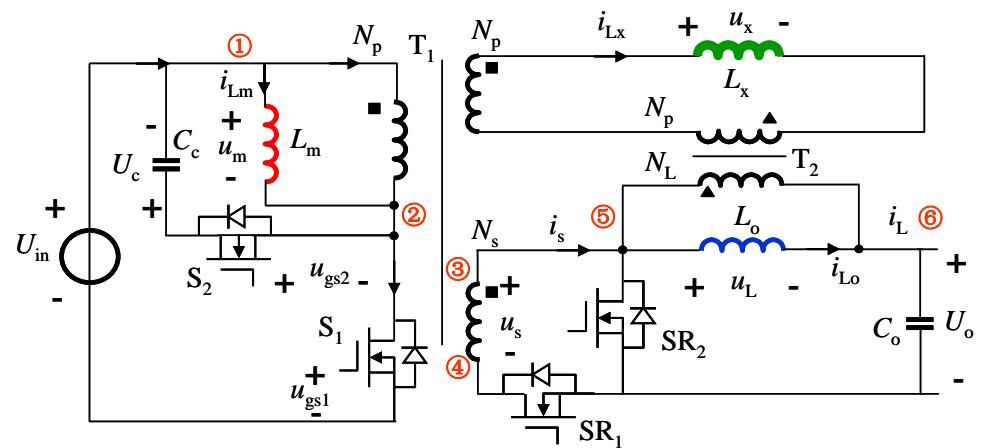
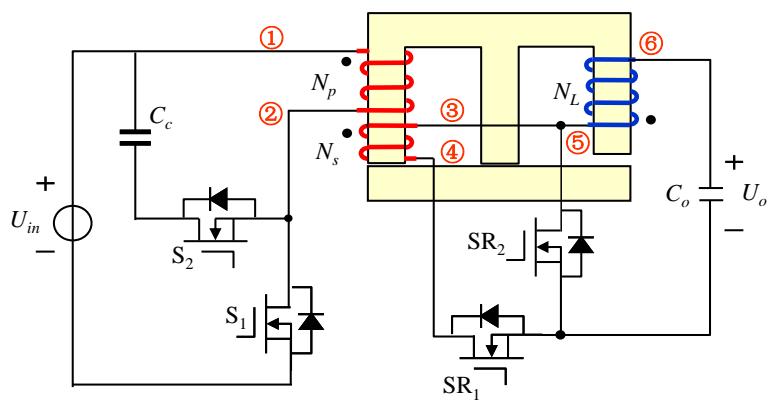
(d) 对 Φ 尺度变换

等效电路模型变换



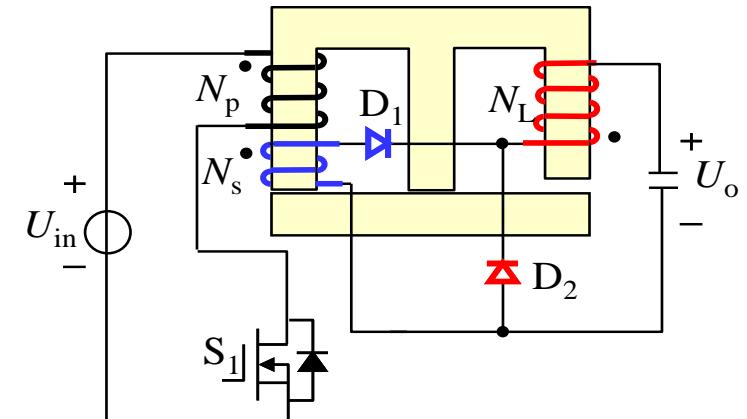
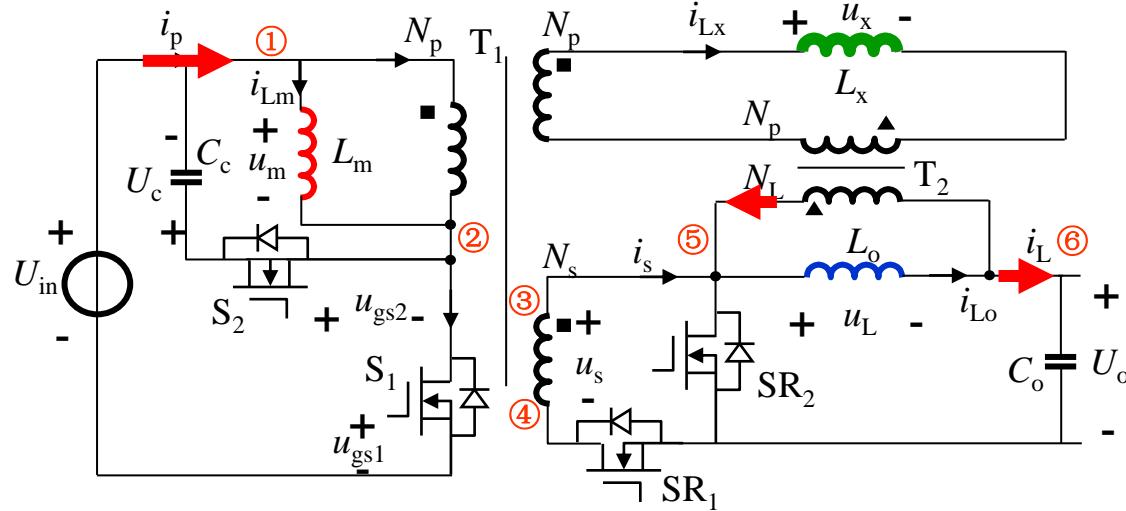
(f) 等效电路一

(g) 等效电路二



磁集成正激变换器的完整等效电路

磁集成正激变换器-1的等效电路

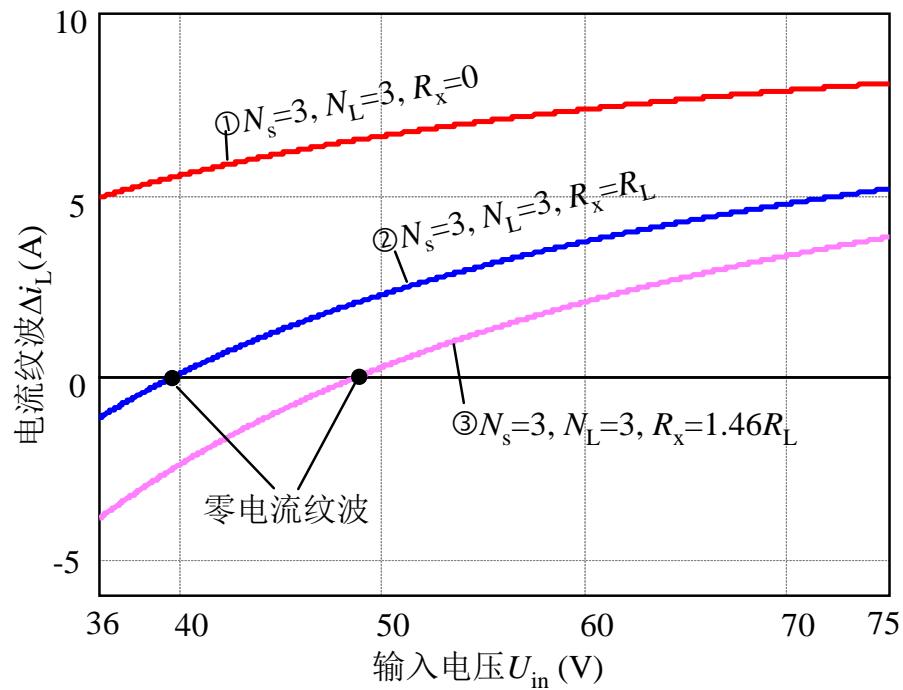
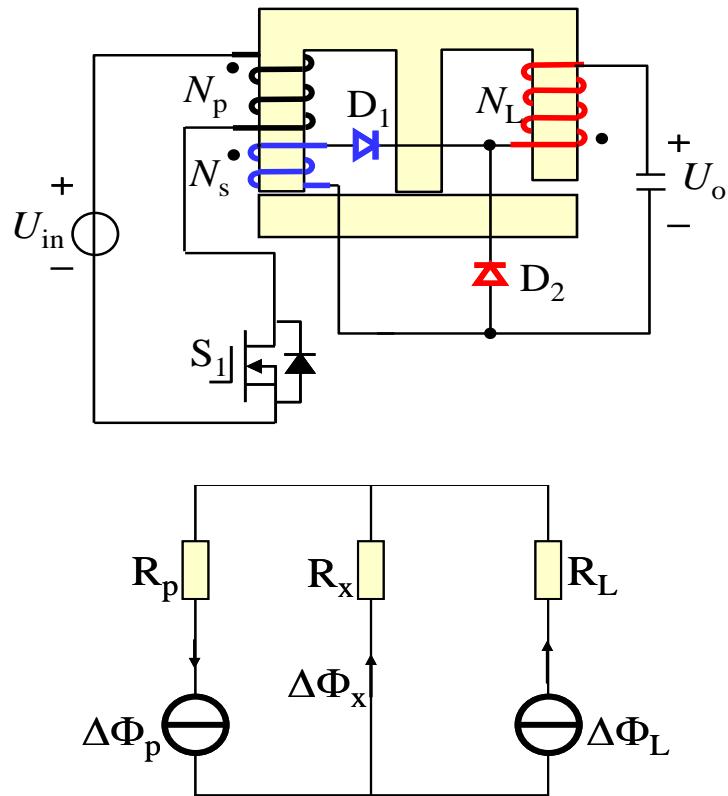


$$[0-DT] \quad \begin{cases} i_p = i_{Lm} + i_s \frac{N_s}{N_p} + i_{Lx} \\ i_s = i_L = i_{Lo} - i_{Lx} \frac{N_p}{N_L} \end{cases}$$

输出电流*i_L*的纹波通过电流*i_{Lx}*耦合
转移到变压器原边绕组上。

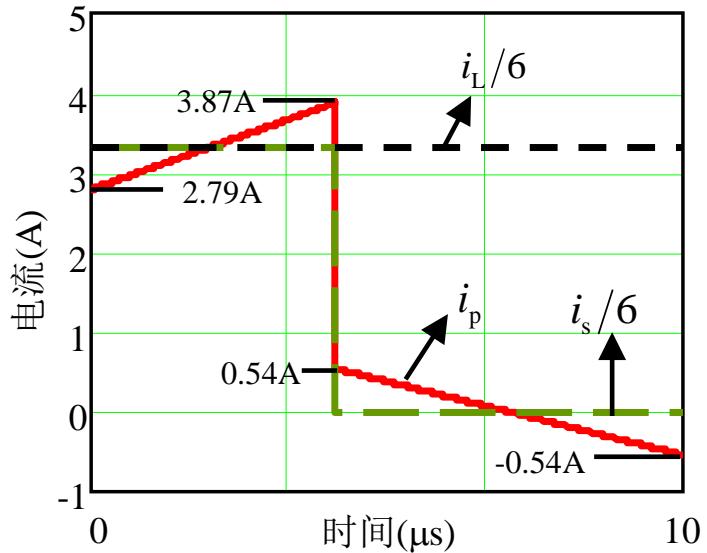
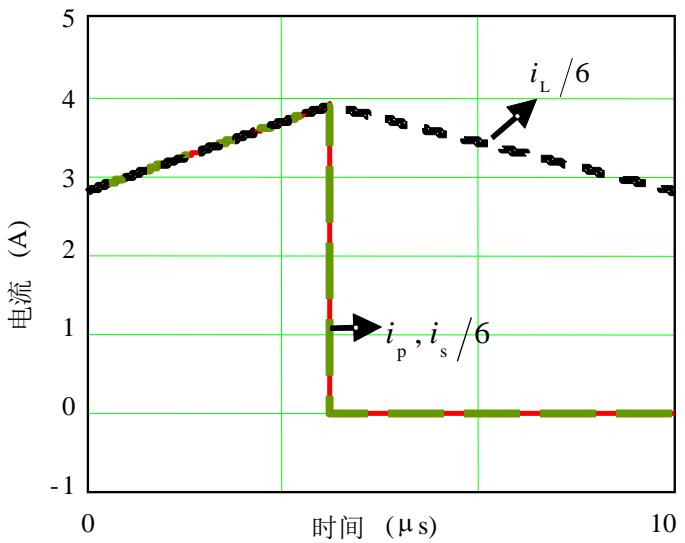
输出电流纹波减小的参数设计

$$\Delta i_L = \frac{U_o T_s (1 - D)}{L_o} \left\{ 1 - \left[\frac{N_L}{N_s (1 - D)} - 1 \right] \frac{R_x}{R_L} \right\}$$



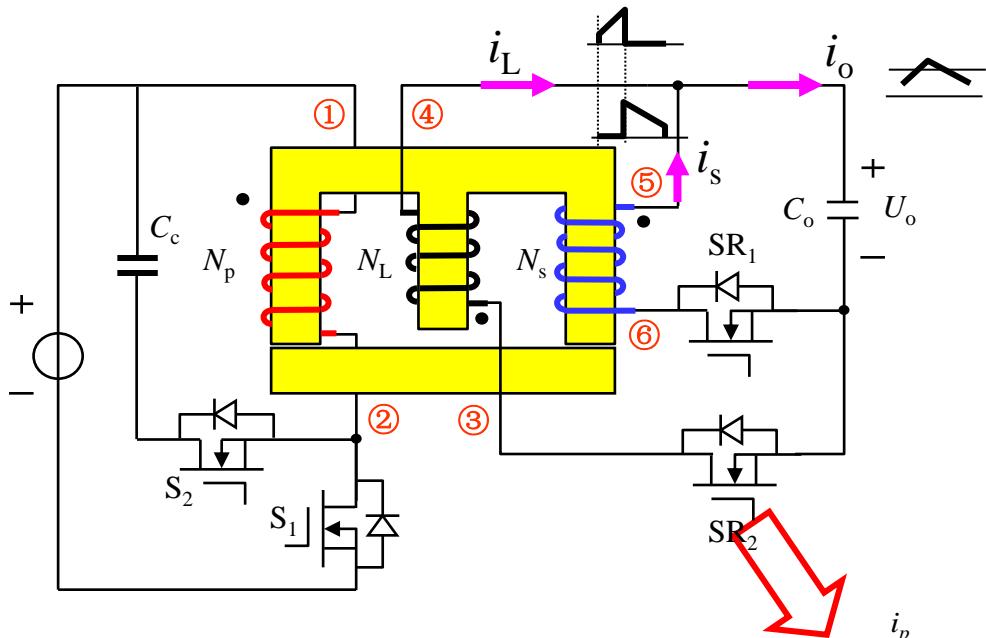


输出电流零纹波



@ $V_{in}=48V$, $V_o=3.3V$,
 $f_s=100kHz$, $I_o=20A$

磁集成正激变换器-2及其等效电路



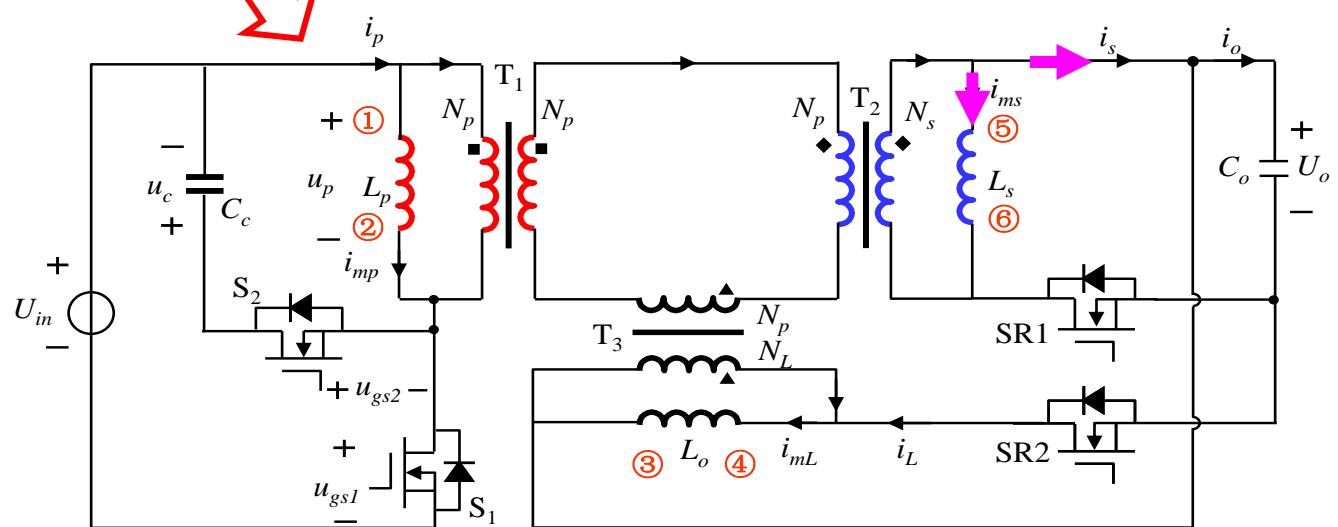
$$\frac{U_o}{U_{in}} = \frac{D}{\frac{N_p}{N_s}D + \frac{N_p}{N_L}(1-D)}$$

$$N_s = N_L$$

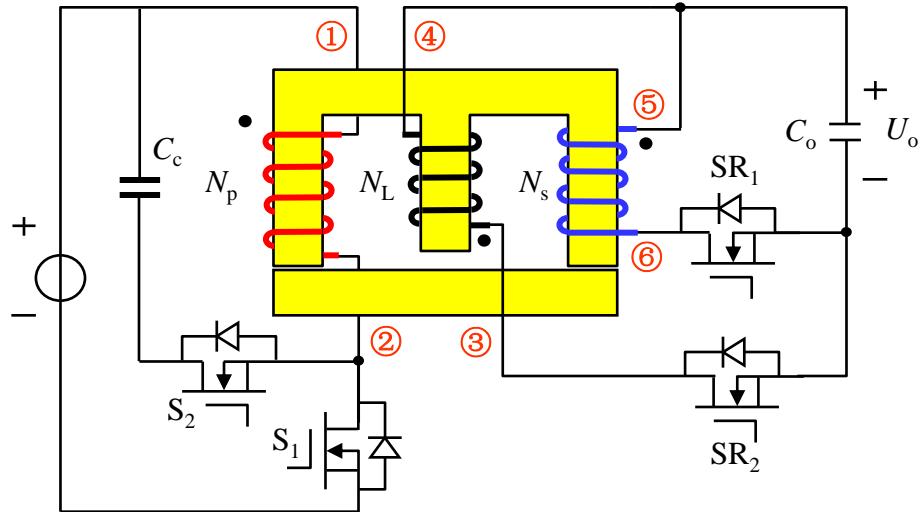
$$\frac{U_o}{U_{in}} = \frac{N_s}{N_p} D$$

[0-DT]

$$\Delta i_o = \Delta i_s = \Delta i_{mL} - \Delta i_{ms}$$



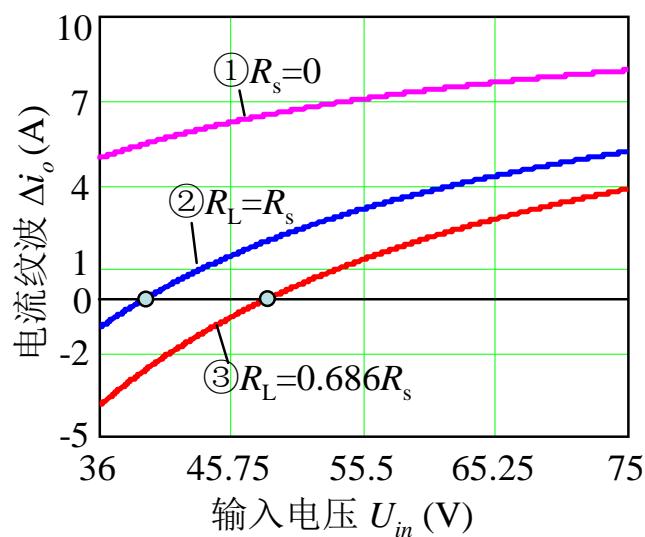
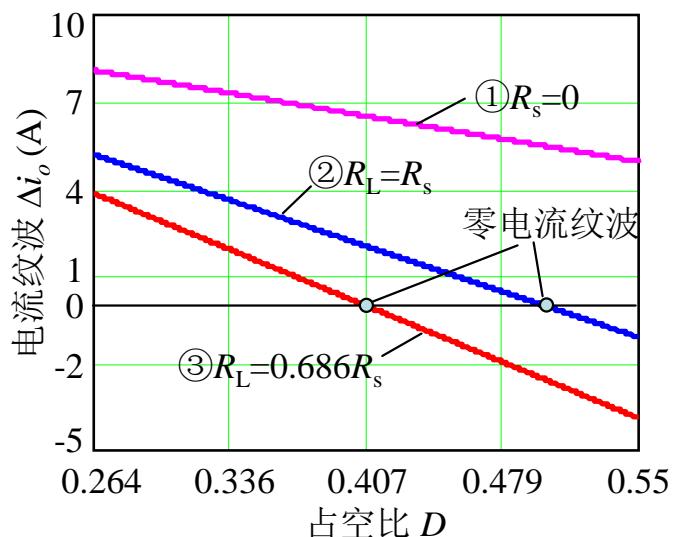
电流纹波分析



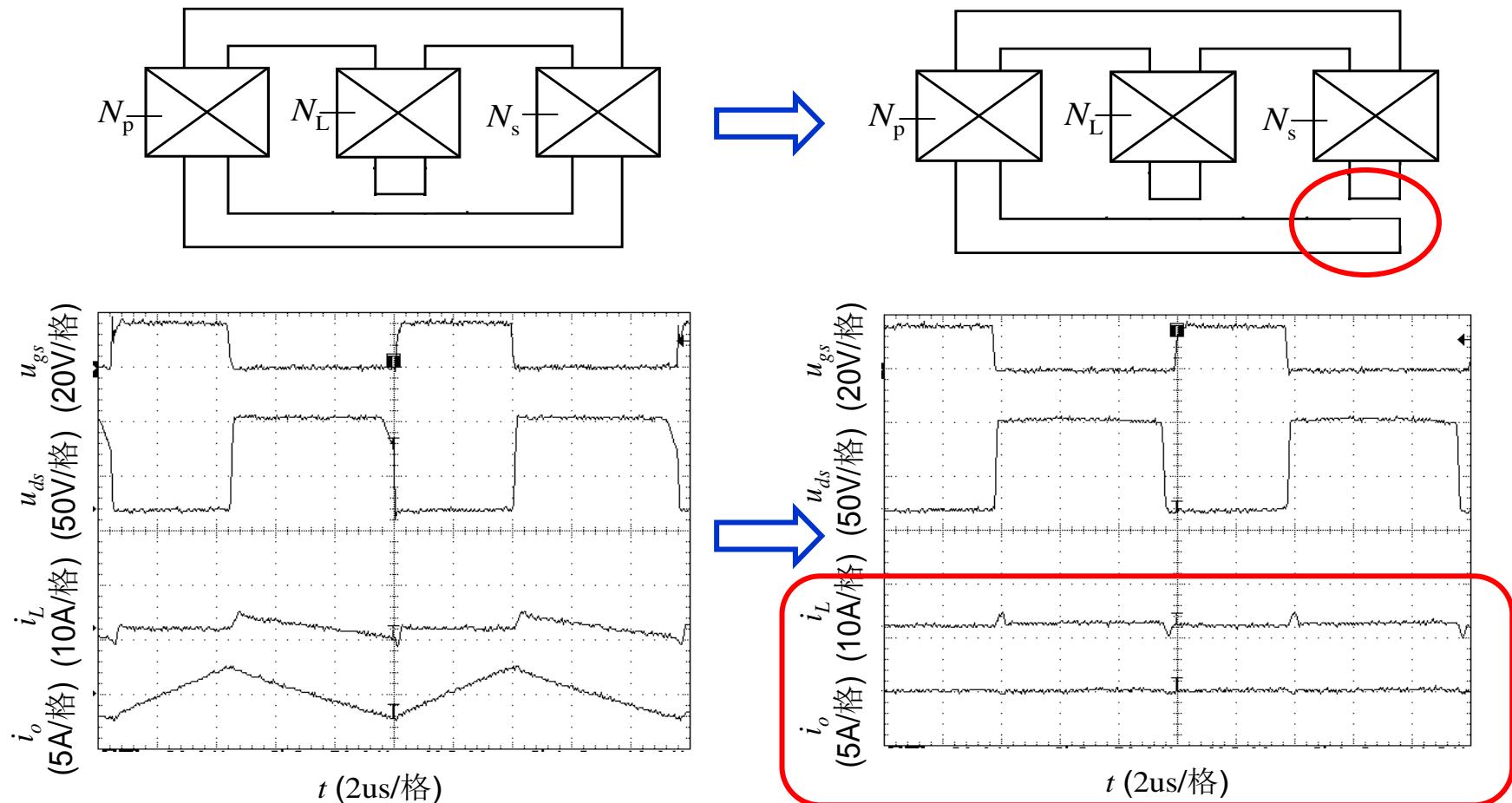
$$\Delta i_o = U_o T_s \left(\frac{N_L}{N_s} \frac{1-D}{L_o} - \frac{D}{L_s} \right)$$

↓

$$\frac{L_o}{L_s} = \frac{R_s}{R_L} = \frac{1-D_z}{D_z}$$



实验验证



■ 基于集成磁件的等效电路模型，揭示了两种磁集成正激变换器输出电流纹波减小的内在机理，可以用纹波转移概念来理解，表现在原来输出电感绕组上的电流纹波通过磁耦合转移到集成磁件的其他等效电感支路上。

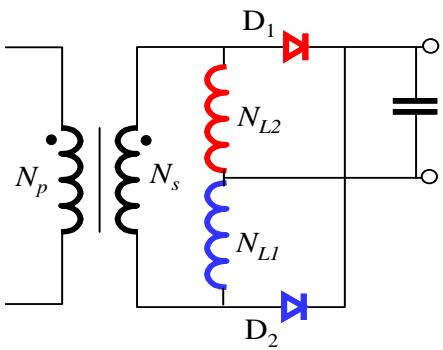


Contents

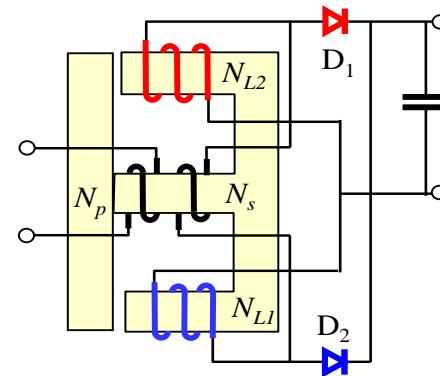
- Overview of Magnetic Integrated Technology
- Magnetic Integrated Forward converter
- **Magnetic Integrated Current Double Rectifier**



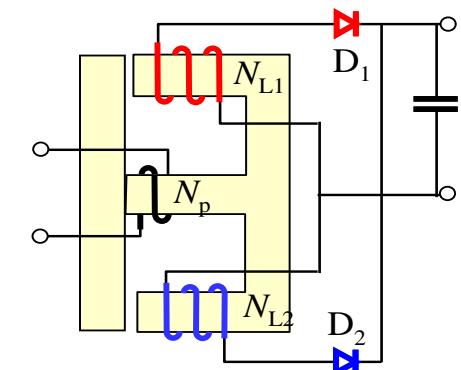
现有磁集成CDR变换器



倍流整流器(CDR)
Peng C, HFPC1991,
(US 4,899,271, 1990-2-6.)
Kevan O'Meara, HFPC1991

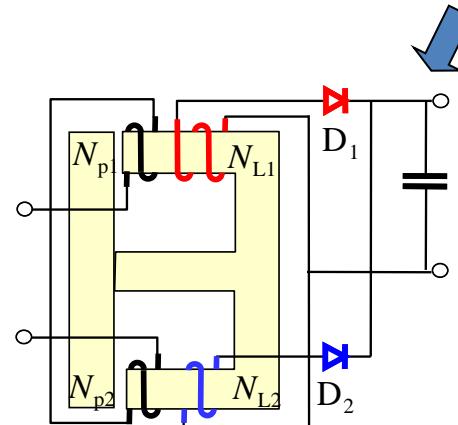


Peng C, HFPC1991,
(US 5,335,163, 1994-8-2)

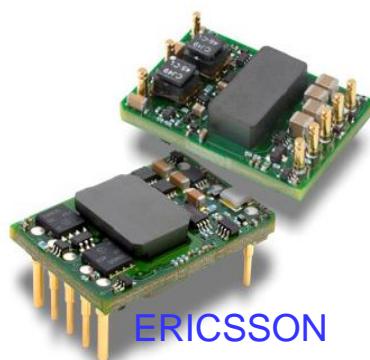


US 5,555,494, 1996-9-10

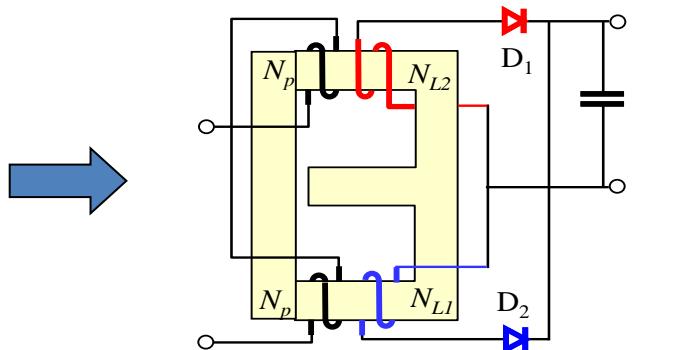
Wei Chen, APEC1997



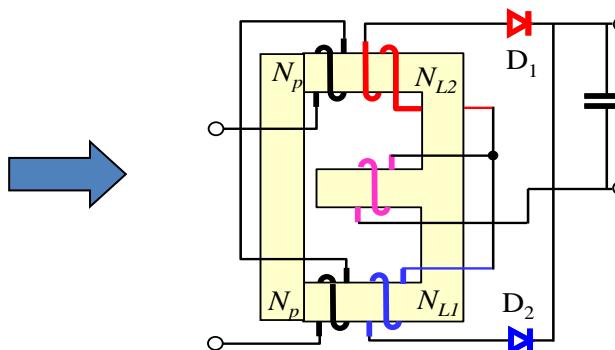
Peng Xu, PESC2000
US 5,555,494, 1996-9-10



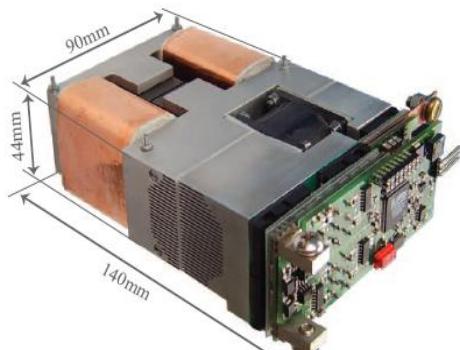
现有磁集成CDR变换器（续）



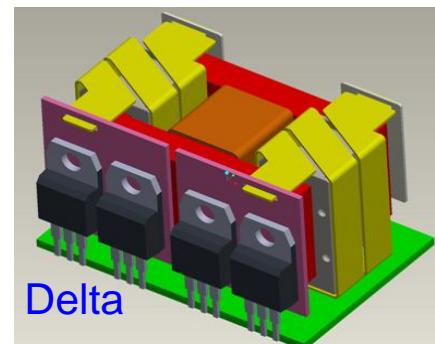
Peng Xu, PESC2000
US 5,555,494, 1996-9-10
US 6,400,249, 2002-6-4



US 6400249, 2002-6-4.
Jian Sun, Trans. on PE, 2004 (US 6,549,436, 2003-4-15)
Liang Yan, Trans. on PE, 2003(US7,034,647, 2006-04-25)



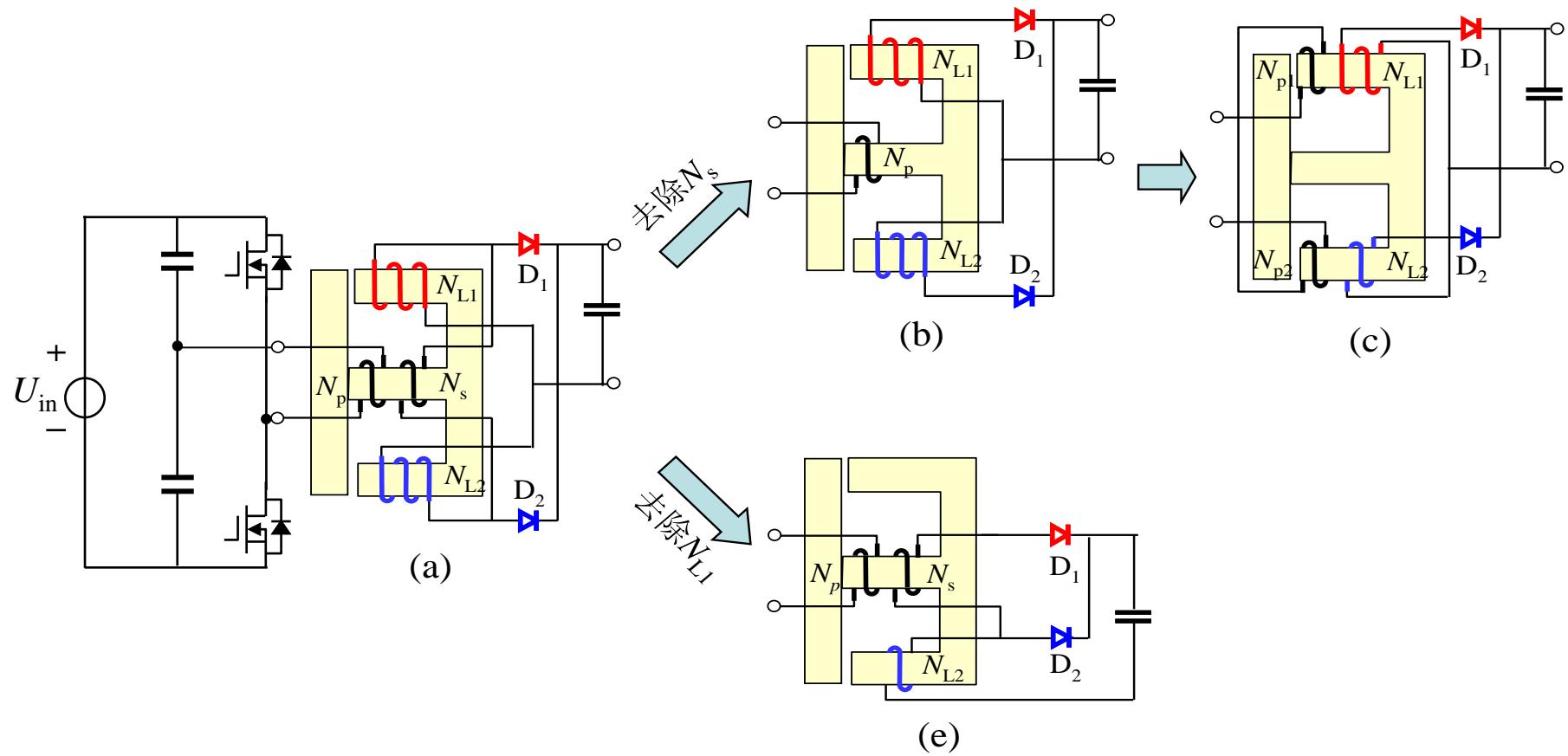
ETH-Zurich(瑞士苏黎世理工学院)
-APEC2009



Delta

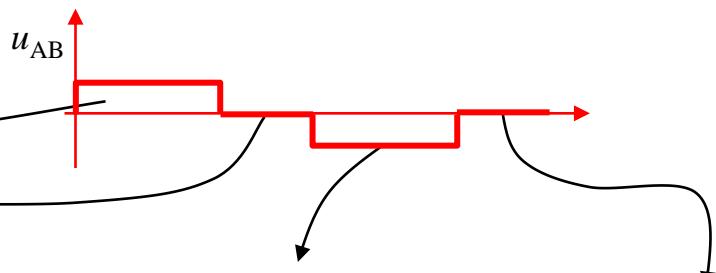
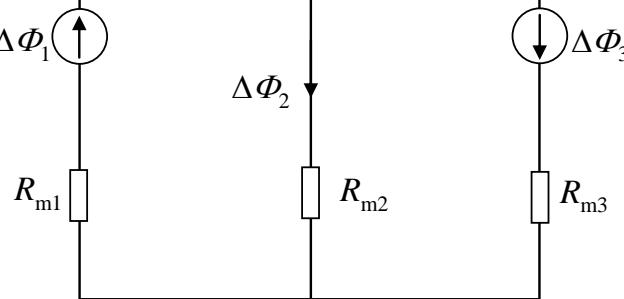
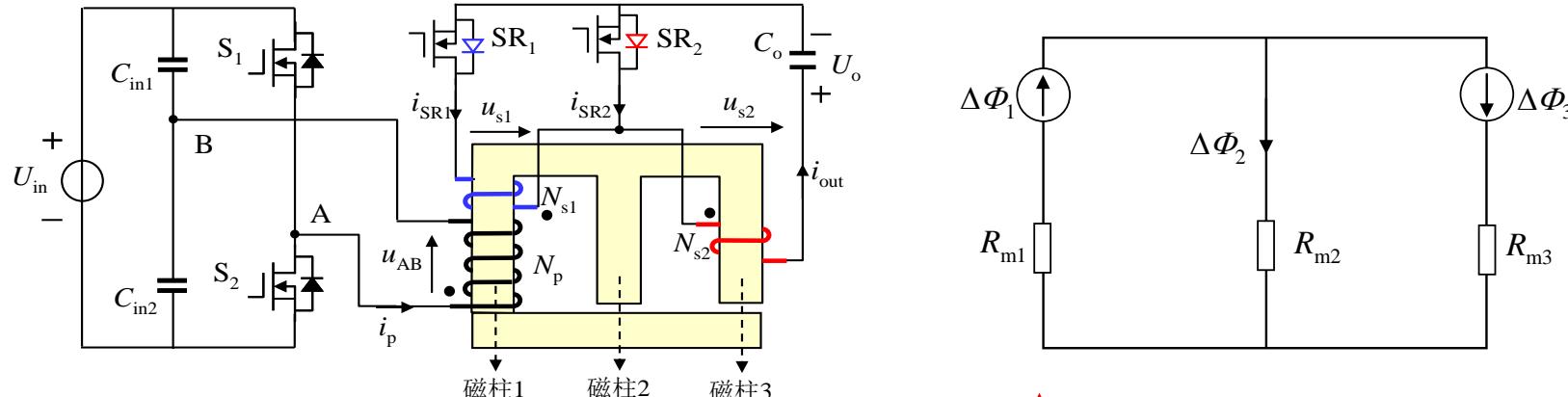


CDR集成磁技术发展及新思路





新CDR集成磁件的磁通分析



$$\begin{cases} \Delta\Phi_1 = \frac{U_{in}DT}{2N_p} \\ \Delta\Phi_3 = \frac{(U_{in}N_{s1} - 2N_pU_o)DT}{2N_pN_{s2}} \\ \Delta\Phi_2 = \Delta\Phi_3 - \Delta\Phi_1 \end{cases}$$

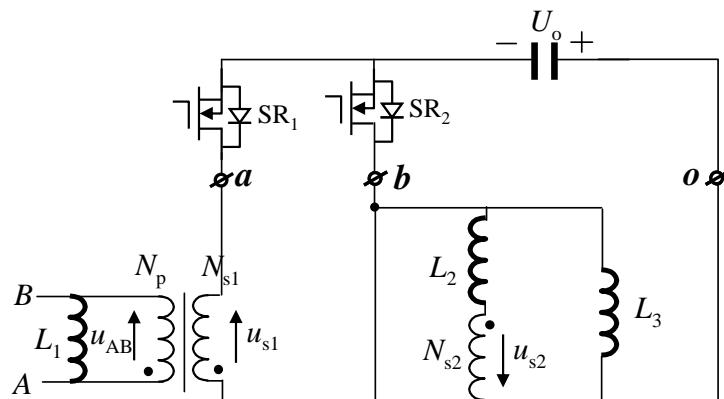
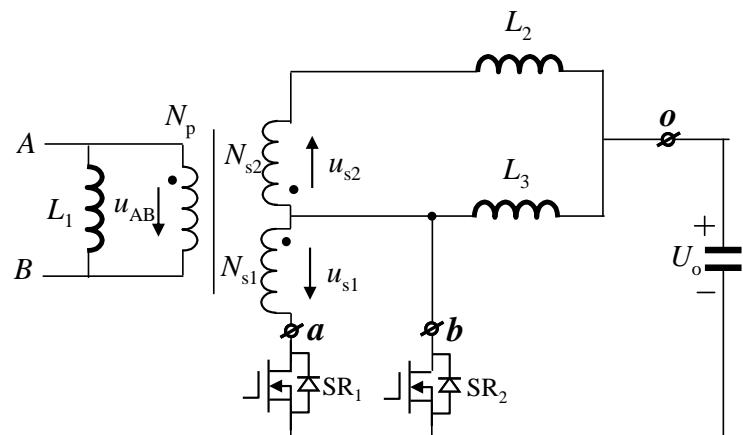
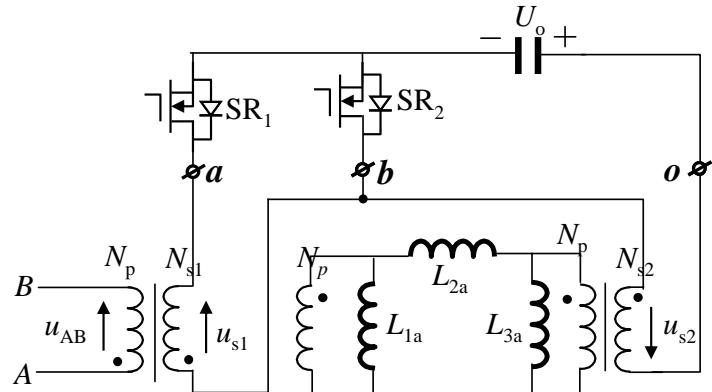
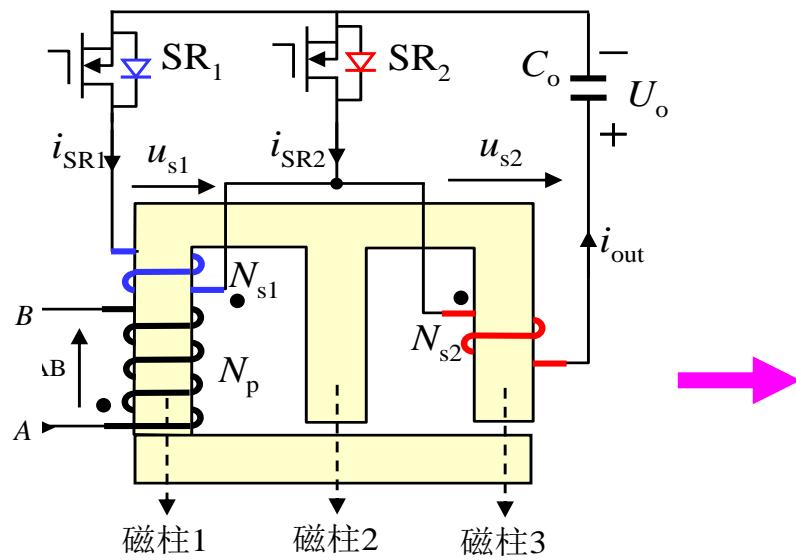
$$\begin{cases} \Delta\Phi_1 = 0 \\ \Delta\Phi_3 = \frac{-U_o(0.5 - D)T}{N_{s2}} \\ \Delta\Phi_2 = -\Delta\Phi_3 \end{cases}$$

$$\begin{cases} \Delta\Phi_1 = -\frac{U_{in}DT}{2N_p} \\ \Delta\Phi_3 = \frac{-U_oDT}{N_{s2}} \\ \Delta\Phi_2 = \Delta\Phi_1 - \Delta\Phi_3 \end{cases}$$

$$\begin{cases} \Delta\Phi_1 = 0 \\ \Delta\Phi_3 = \frac{-U_o(0.5 - D)T}{N_{s2}} \\ \Delta\Phi_2 = -\Delta\Phi_3 \end{cases}$$

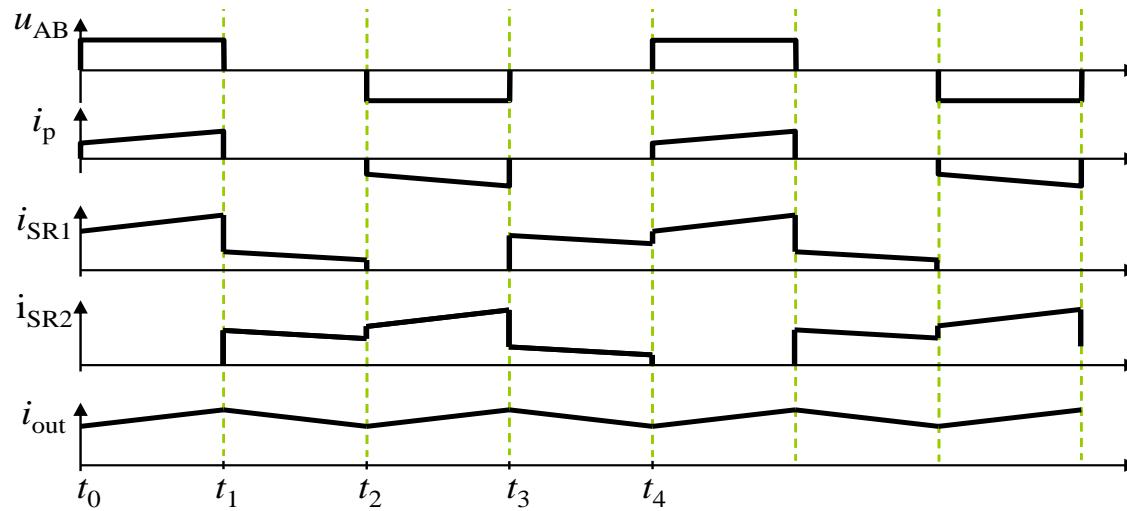
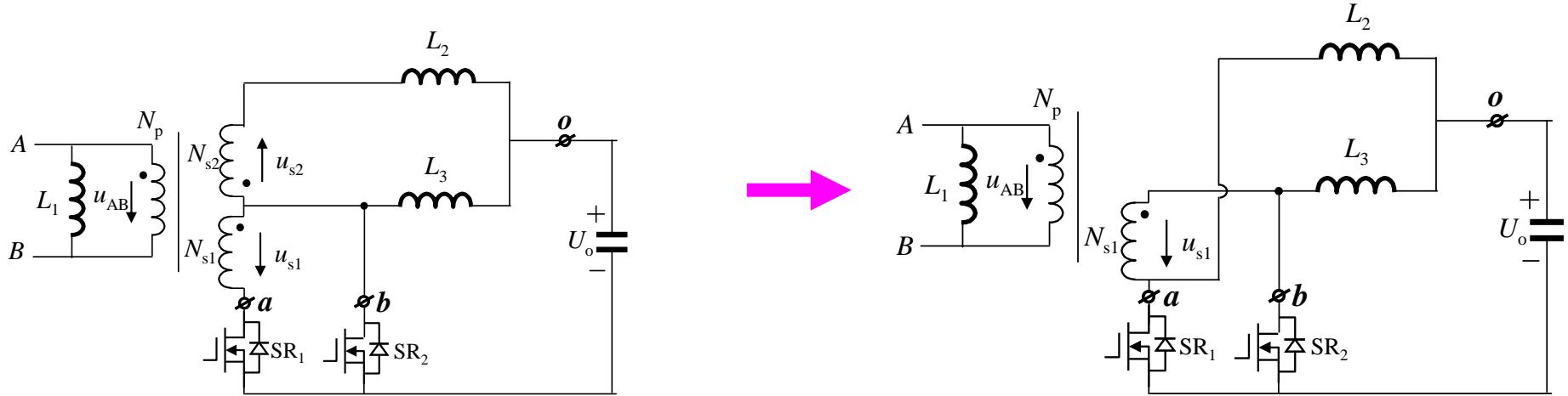
$$\frac{U_o}{U_{in}} = \frac{N_{s1}}{N_p} \frac{D}{2}$$

集成磁件的等效电路



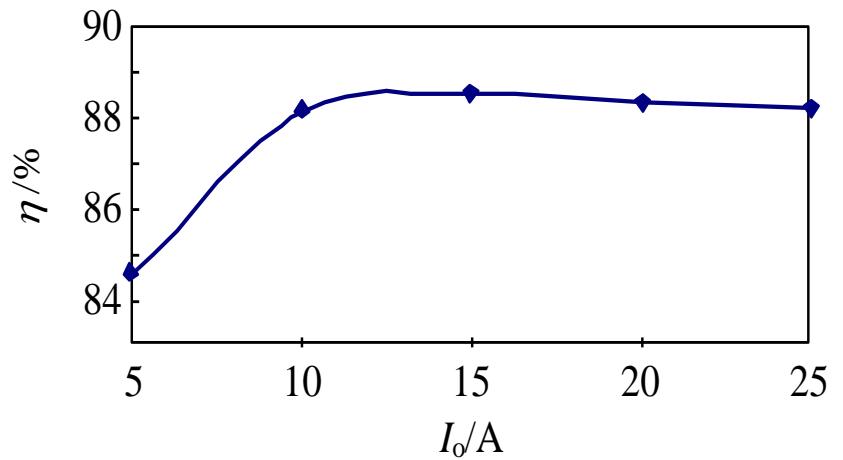
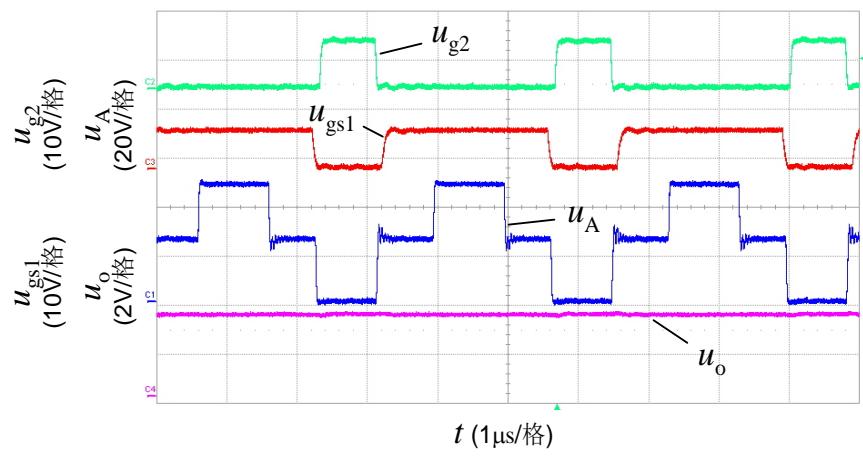
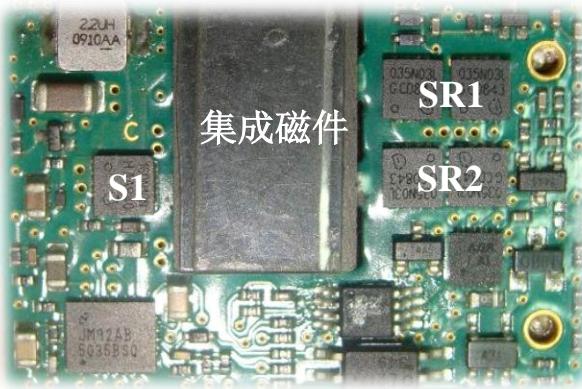
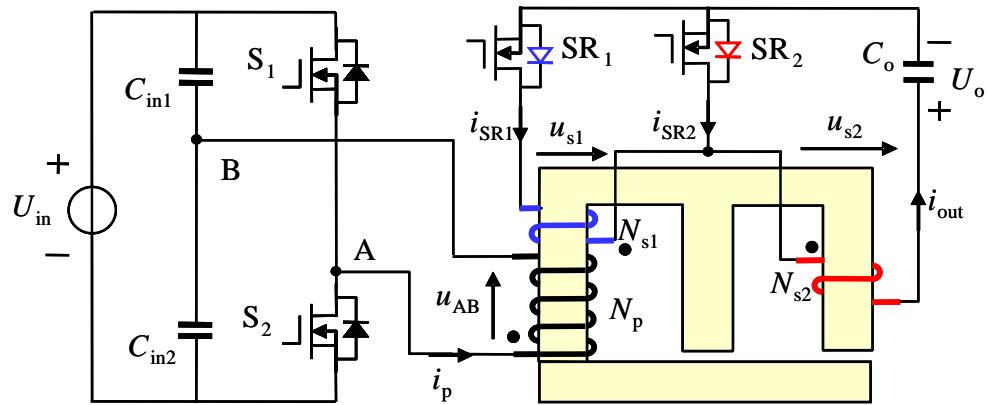


集成磁件的等效电路





实验验证

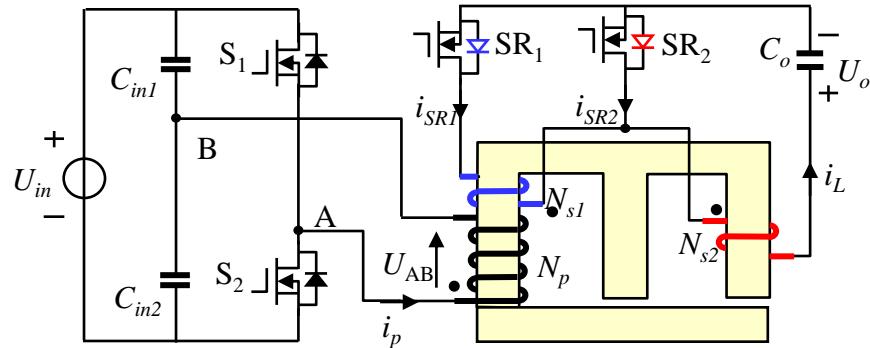


卢增艺, 直流-直流开关功率变换器磁集成关键技术研究, 福州大学博士论文, 2011年

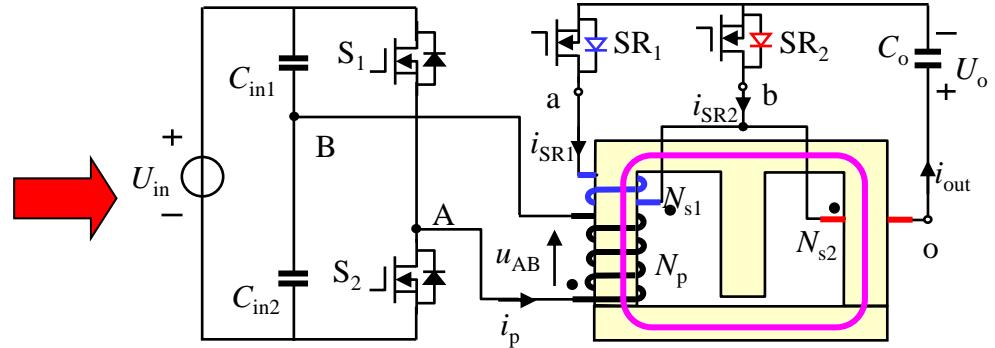


集成磁件气隙位置改进

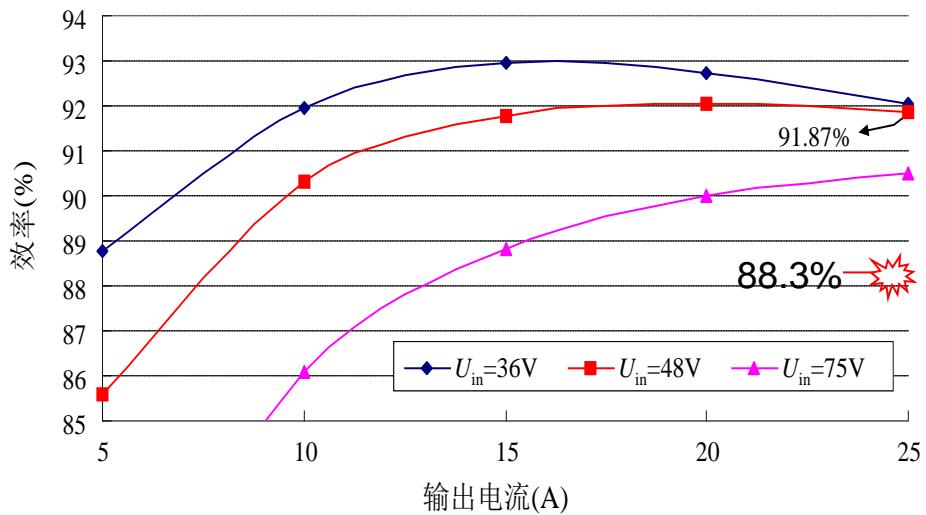
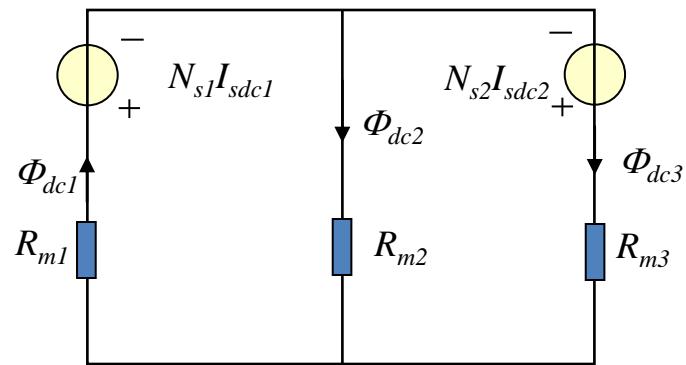
$$N_{s1}:N_{s2}=2:2$$



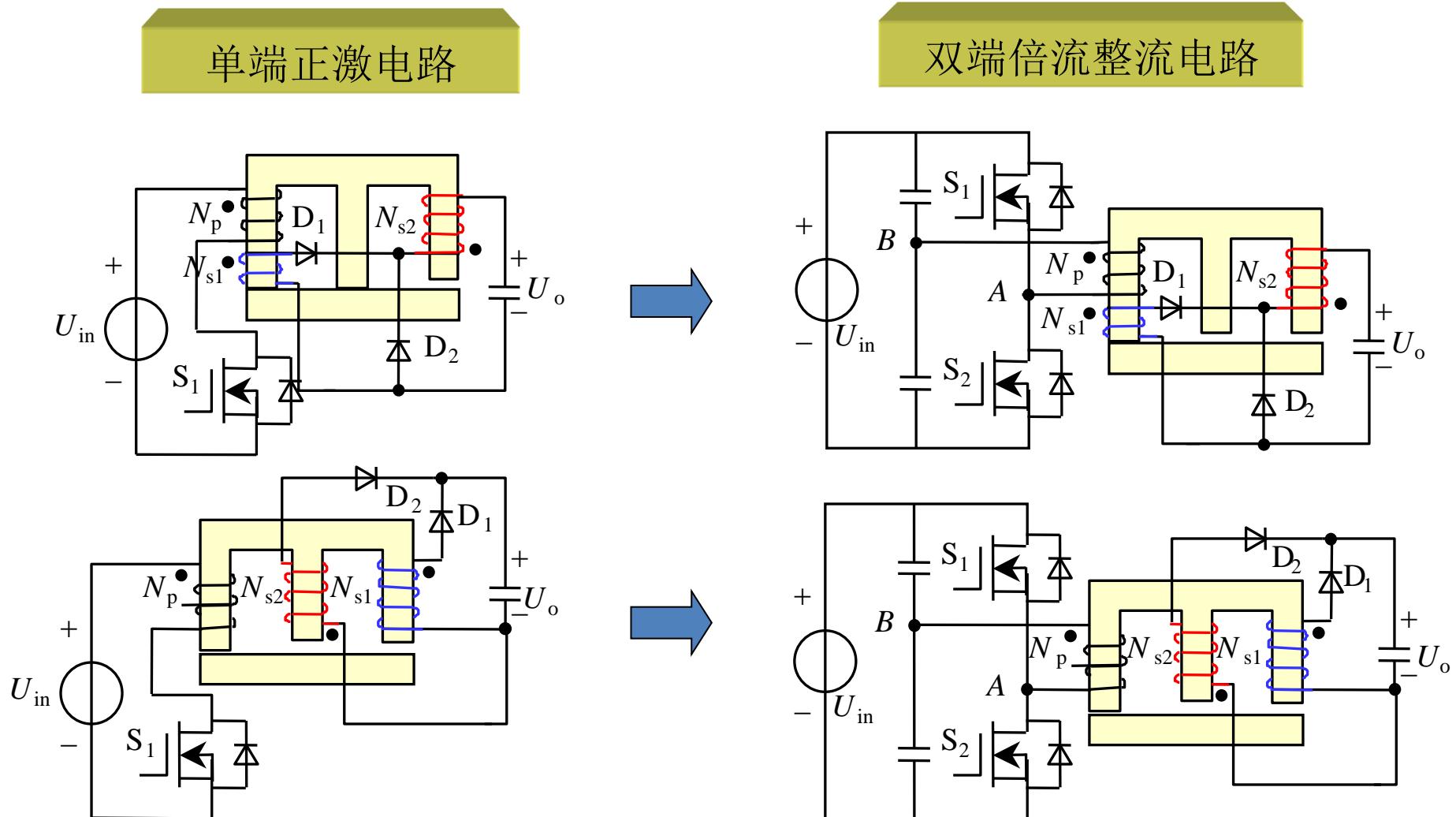
$$N_{s1}:N_{s2}=2:1$$



$$\frac{U_o}{U_{in}} = \frac{N_{s1}}{N_p} \frac{D}{2}$$



不同电路的磁集成结构比较



- 倍流整流变换器的集成磁件是磁集成正激变换器中集成磁件在双端变换器的应用。



谢谢！