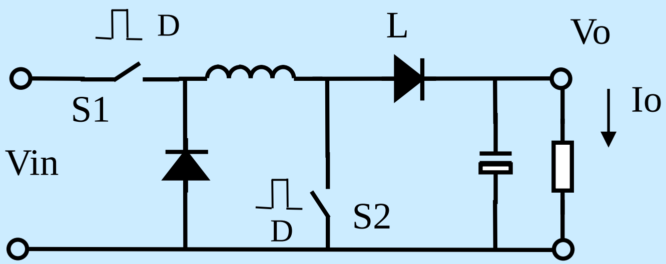
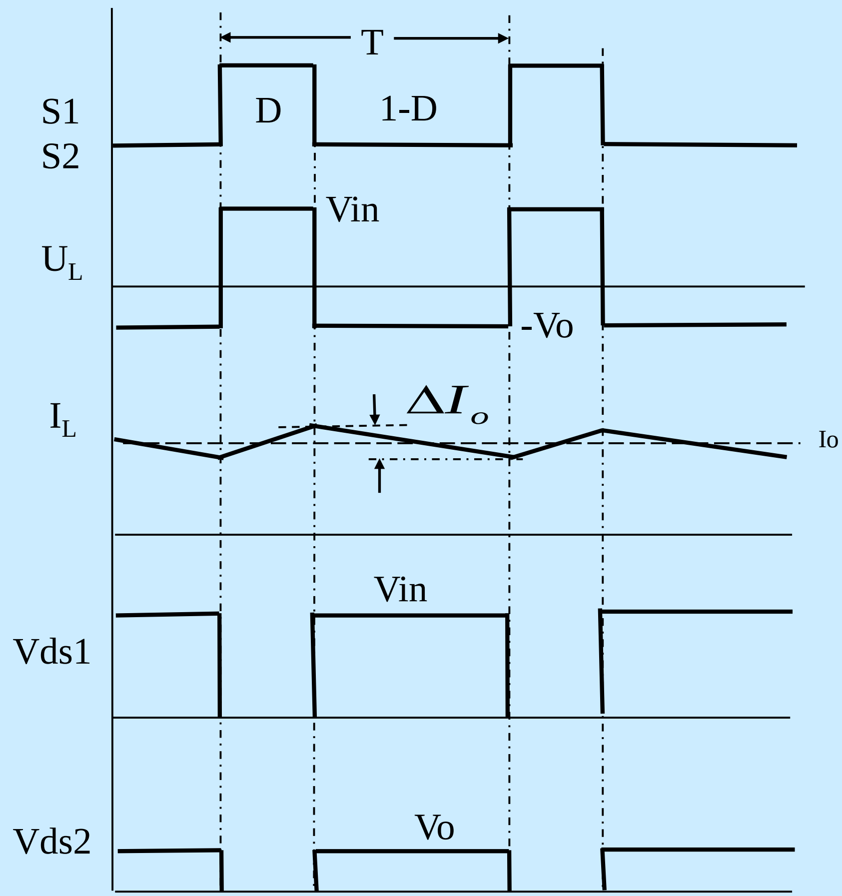
DC/DC模块电源常用的电路形式

开关电源功率电路分析要点

1. 电容的电压不能突变, 电感的电流不能突变
2. 流经电容的电流平均值为零, 电感两端电压的平均值为零
3. 理想变压器电压与匝数成比且同名同极性, 电流与匝数成反比且点进点出
4. 电容恒流充电的公式为 $C*\Delta U = I*T$, 电感恒压储能的公式为 $L*\Delta I = U*T$
5. 变压器与电感的伏秒积必须平衡

Buck-Boost电路工作原理：





根据L的伏秒平衡原则：

Vin*DT=(Vo+2Vd)*(1-D)T

Vo=Vin *D/(1-D)-2Vd

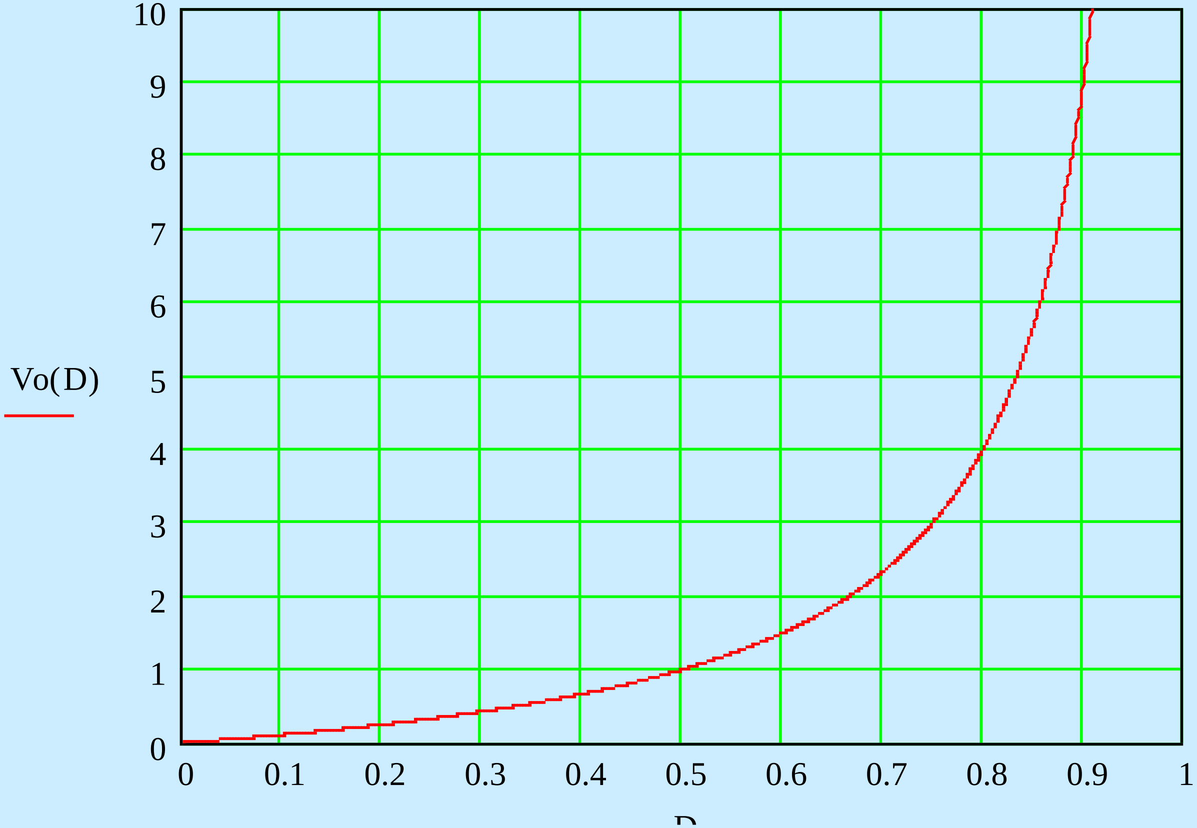
根据L在(1-D)T时间的基本方程：

L*ΔIo=(Vo-2Vd)(1- D)T

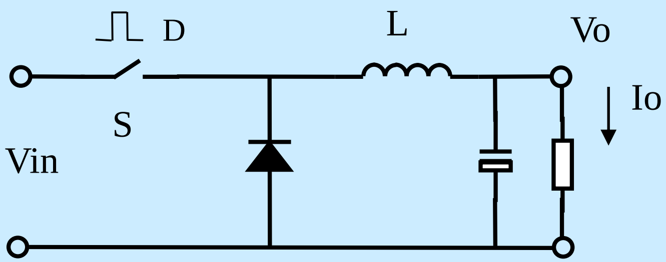
ΔIo=(Vo-2Vd)(1-D)T/L

Buck-Boost电路的输入输出关系：

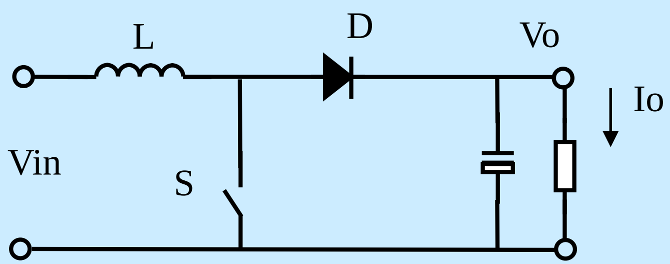
$$V_o/V_{in} = D/(1-D)$$



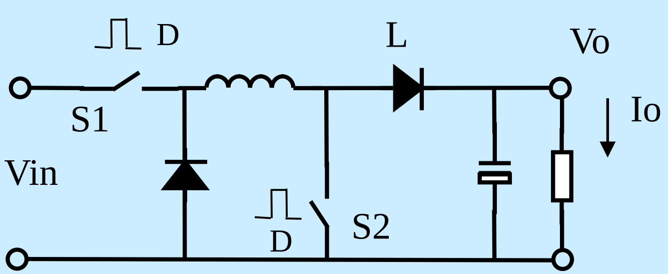
三种基本的非隔离开关电源：



$Vo=Vin *D$　　Vo<Vin, 降压型电路



$Vo=Vin /(1-D)$　　Vo>Vin, 升压型电路



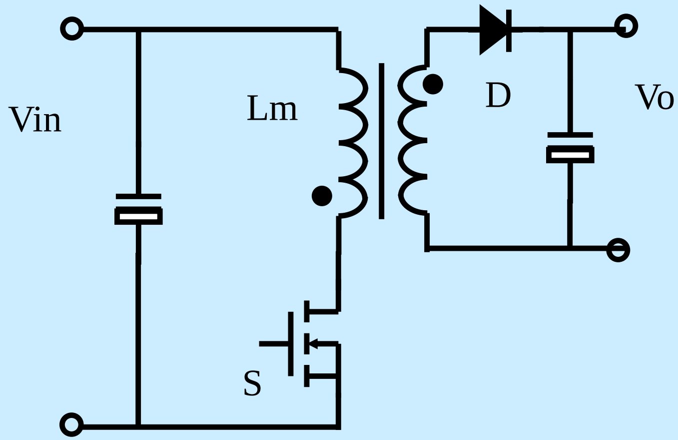
$Vo=Vin *D/(1-D)$

Vo<Vin, 当D<0.5

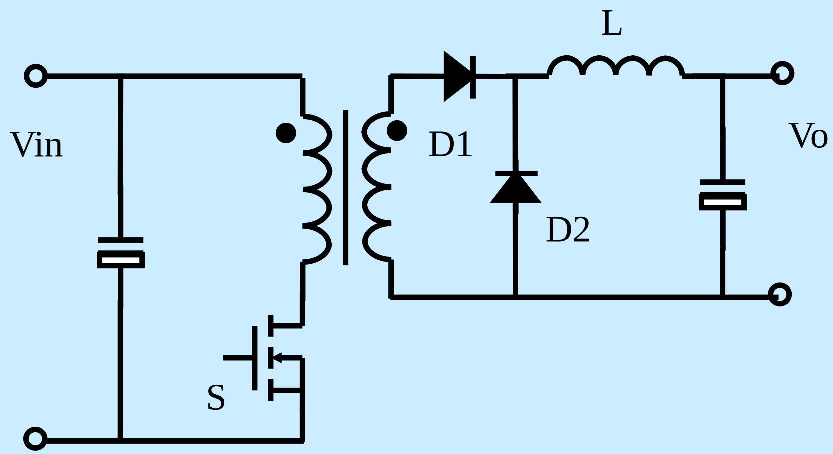
Vo>Vin 当D>0.5

升降压型电路

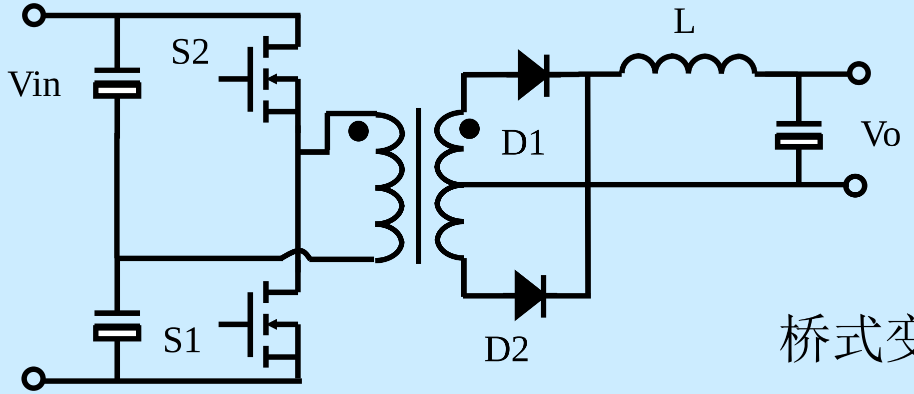
三种基本的隔离开关电源：



反激型变换器

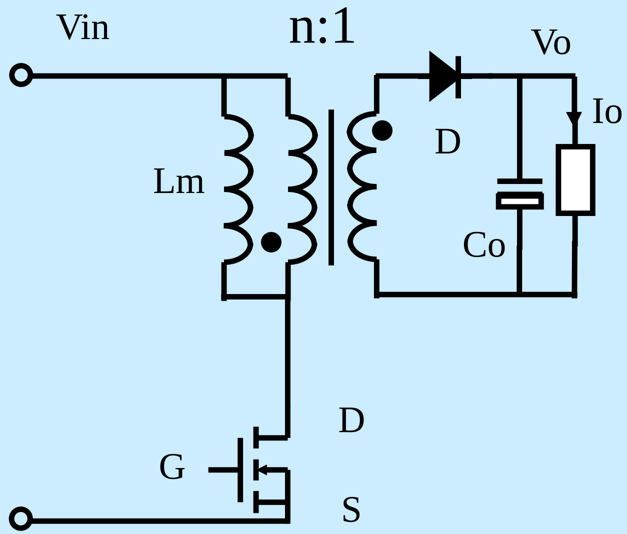


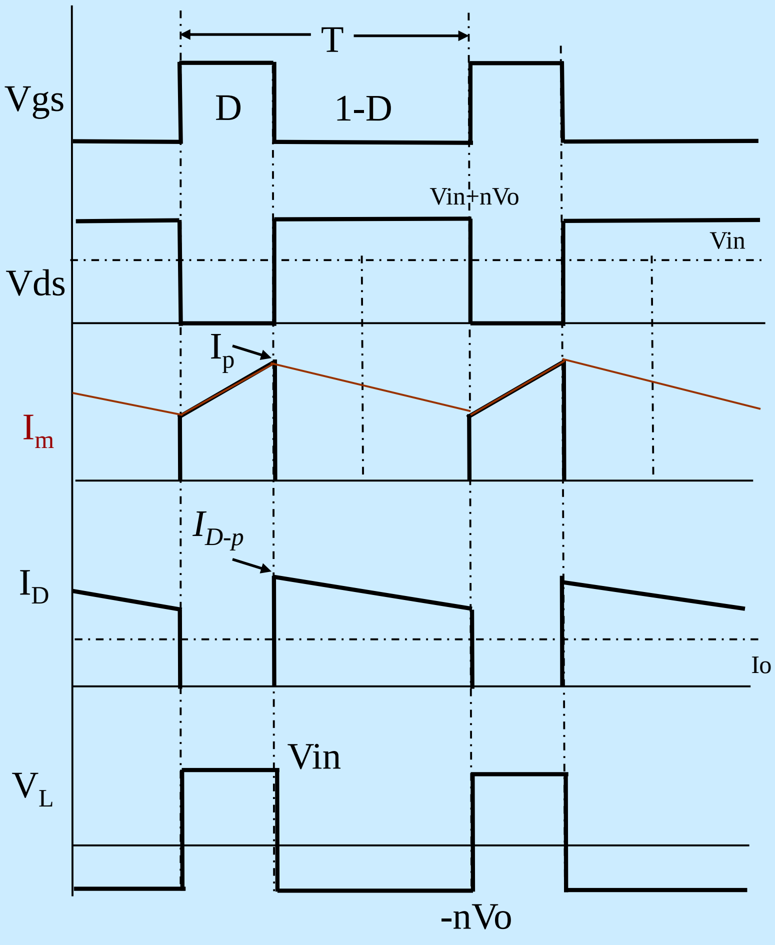
正激型变换器



桥式变换器

反激变换器（Flyback）工作原理（电流连续模式）：



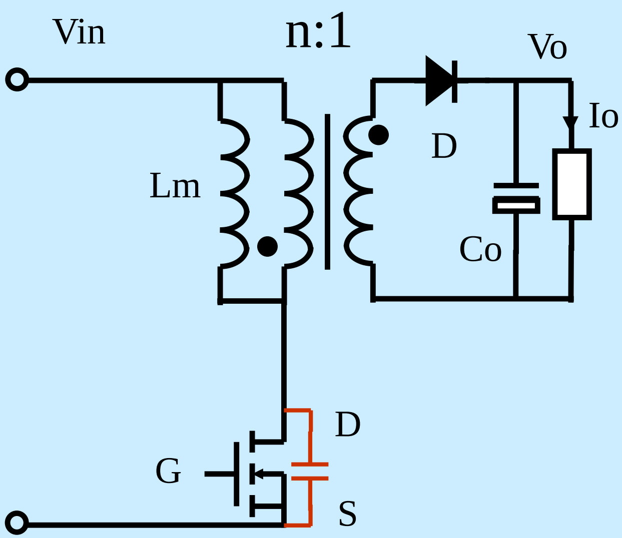


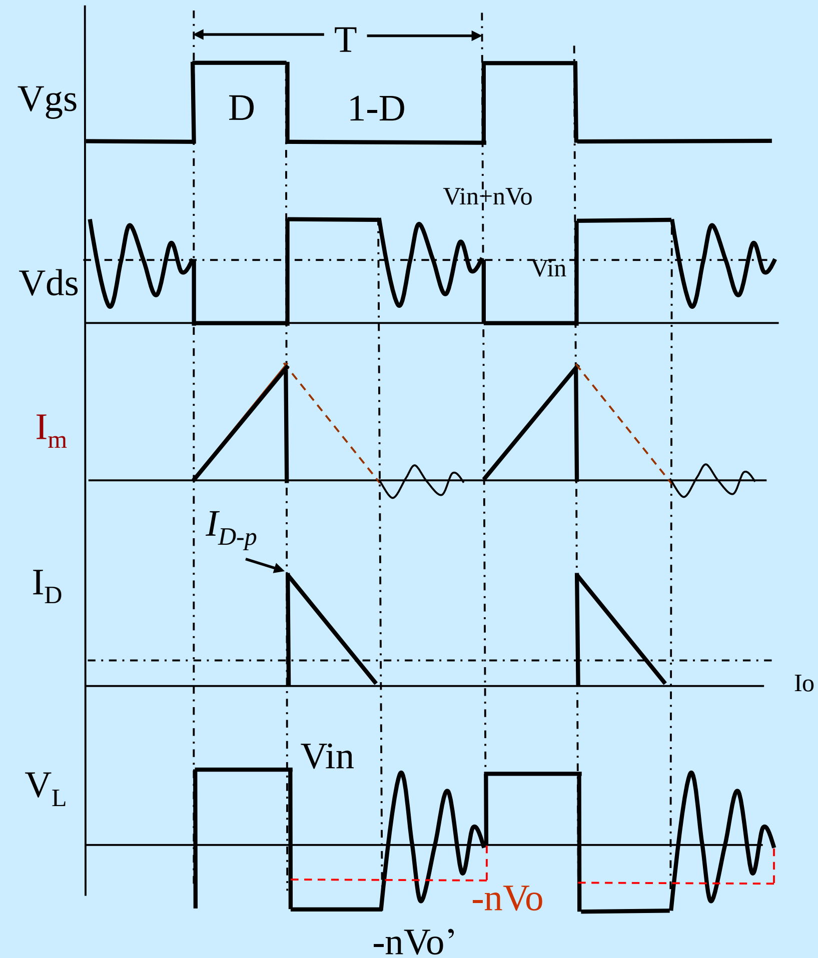
根据变压器的伏秒平衡：

$$Vin*DT = nVo*(1-D)T \Rightarrow Vo = \frac{Vin*D}{n*(1-D)}$$

$$Vds = Vin + nVo \Rightarrow Vds = \frac{Vin}{(1-D)}$$

反激变换器（Flyback）工作原理（电流断续模式）：





根据变压器的伏秒平衡：

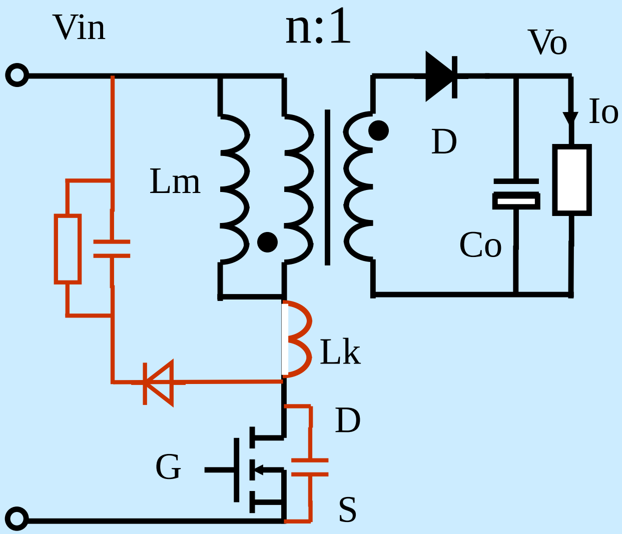
$$Vo = \frac{Vin * D}{n * (1 - D)} \qquad Vo' > Vo$$

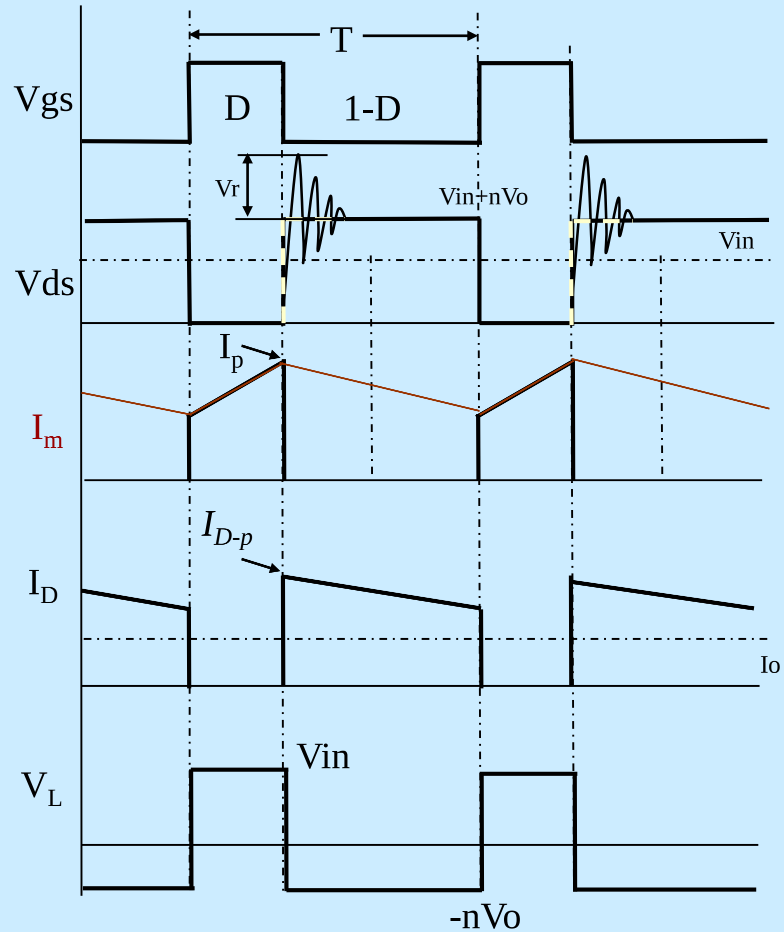
根据能量守恒：

$$\frac{1}{2} Lm I_p^2 = \frac{Vo^2}{R} T$$

$$I_p = \frac{VinDT}{Lm} \quad \Rightarrow \quad Vo = \sqrt{\frac{RT}{2Lm}} VinD$$

反激变换器（Flyback）工作原理：





$Vr = ?$

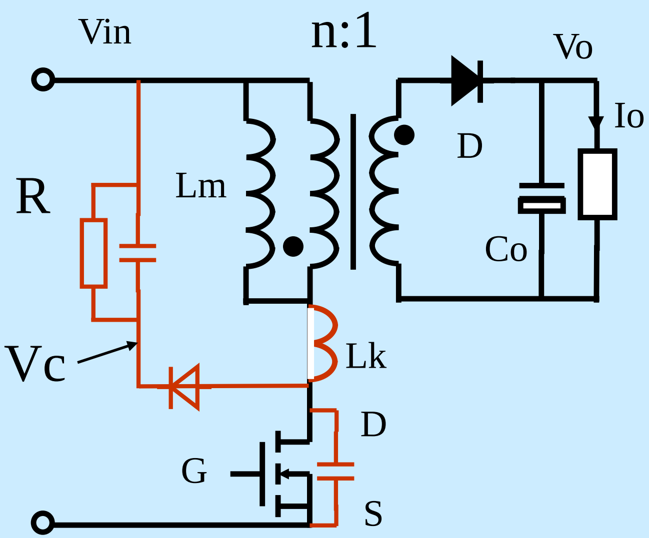
$$\Delta I_D = Vo(1-D)T/Lm$$

$$I_{D-p} = \frac{I_o}{1-D} + \frac{\Delta I_D}{2}$$

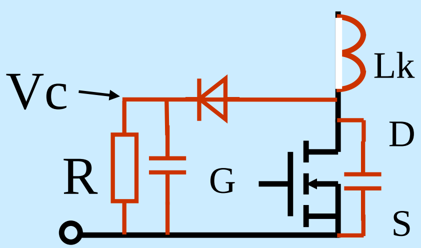
$$Ip = \frac{I_{D-p}}{n}$$

$$\tfrac{1}{2} CdsVr^2 = \tfrac{1}{2} LkIp^2 \quad \Rightarrow \quad Vr = \sqrt{\frac{Lk}{Cds}} * Ip$$

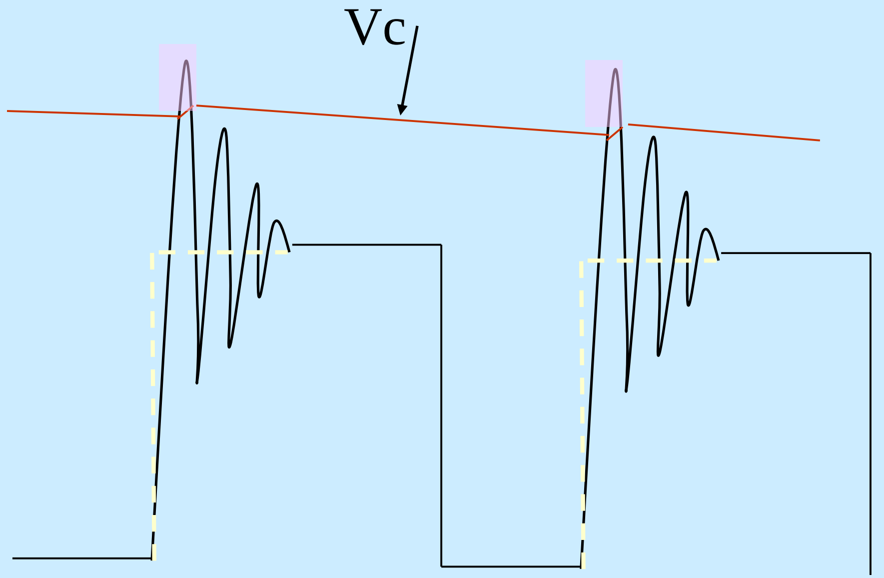
反激变换器（Flyback）工作原理：



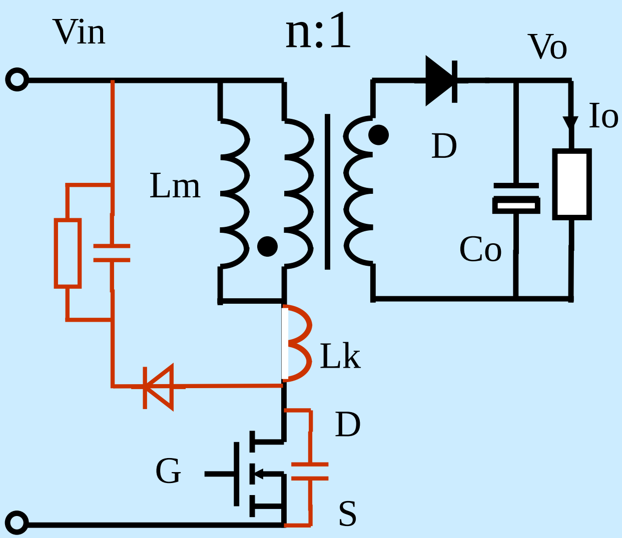
$$P_{loss}=(V_c-V_{in})^2/R$$

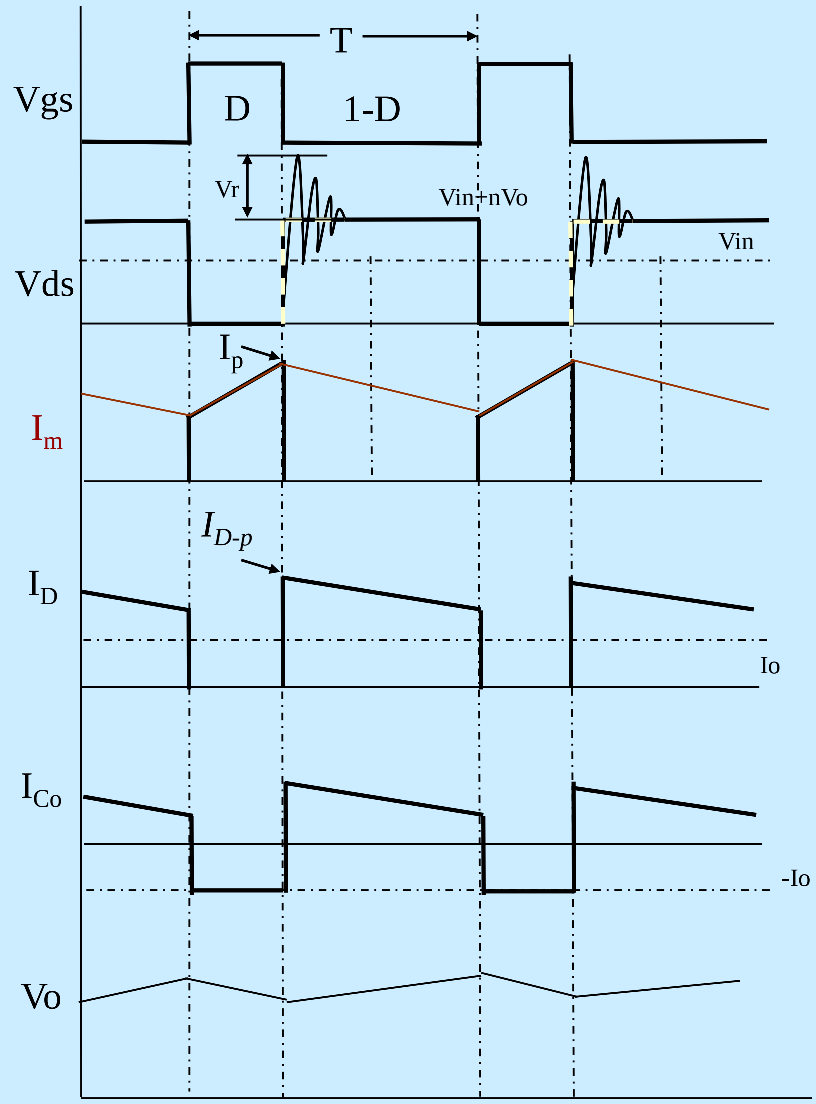


$$P_{loss}=(V_c)^2/R$$



反激变换器（Flyback）工作原理：





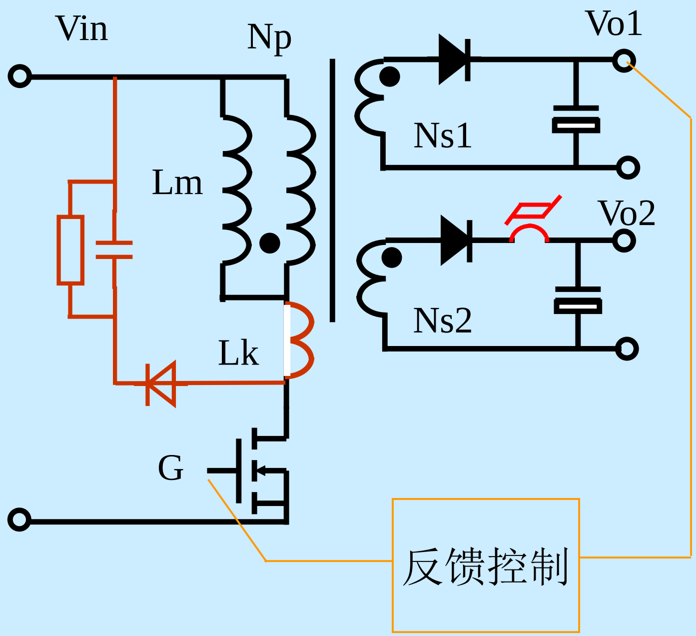
$$\Delta I_{Co} = I_{D-p} \approx I_o /(1-D)$$

$\Delta Vo=?$

根据Co在DT时间的基本方程：

$$C\Delta V_O = I_O DT \quad \Rightarrow \quad \Delta V_O = I_O DT / C$$

反激变换器（Flyback）工作原理：



多路输出的反激变换器：

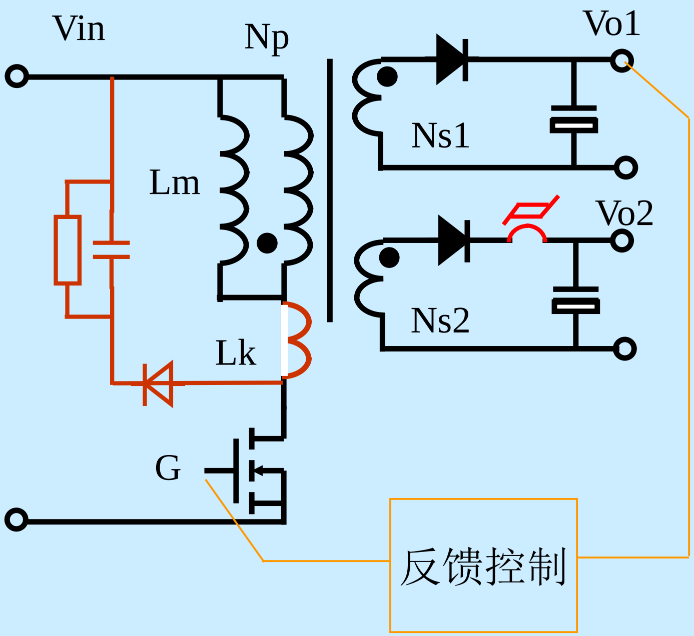
$$Vo1 = \frac{Ns1 * Vin * D}{Np * (1 - D)}$$

$$Vo2 = \frac{Ns2 * Vin * D}{Np * (1 - D)}$$

减小交叉调整率的措施：

1. 尽量减少两个绕组之间的漏感。
2. 在辅助输出一路中加入尖峰抑制器（饱和电感）
3. 主路输出工作于电流连续模式。
4. 采用双路加权反馈的控制方式

反激变换器（Flyback）特征总结：



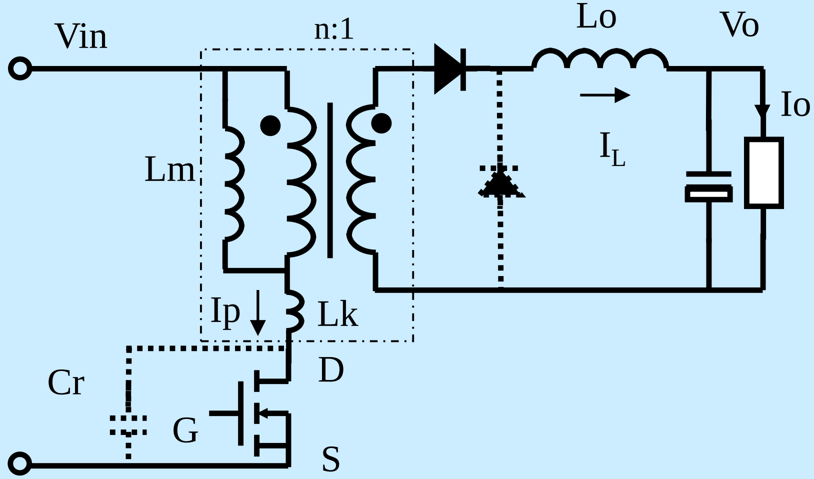
优点：

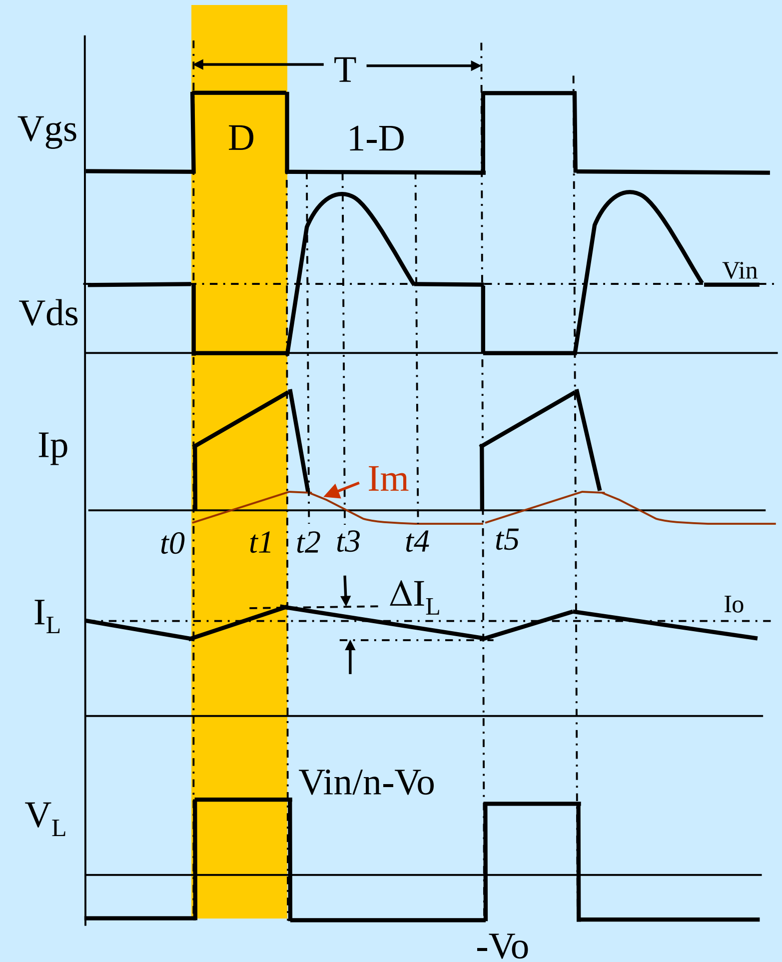
1. 电路简单。
2. 输入电压范围广。
3. 容易实现多路输出。

缺点：

1. 输出纹波电流大。
2. 输出控制特性非线性。
3. 通常需要辅助的吸收回路。
4. 转换效率较低。

谐振复位正激变换器（Resonant Reset Forward):





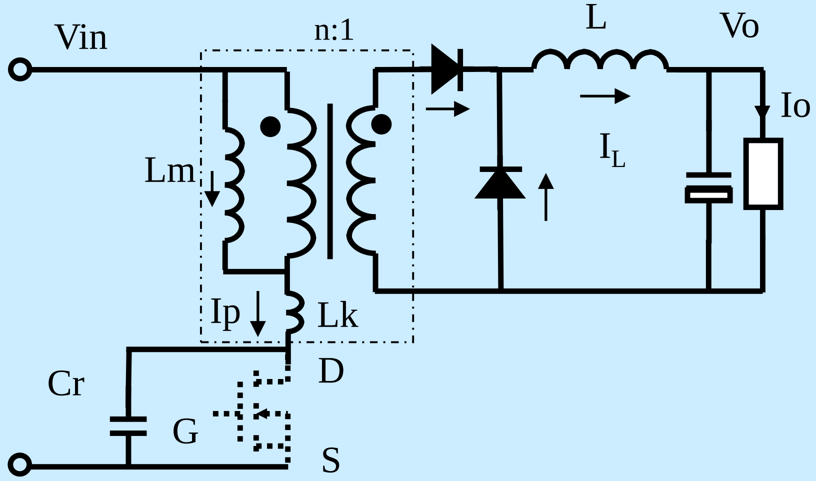
[$t0$, $t1$]

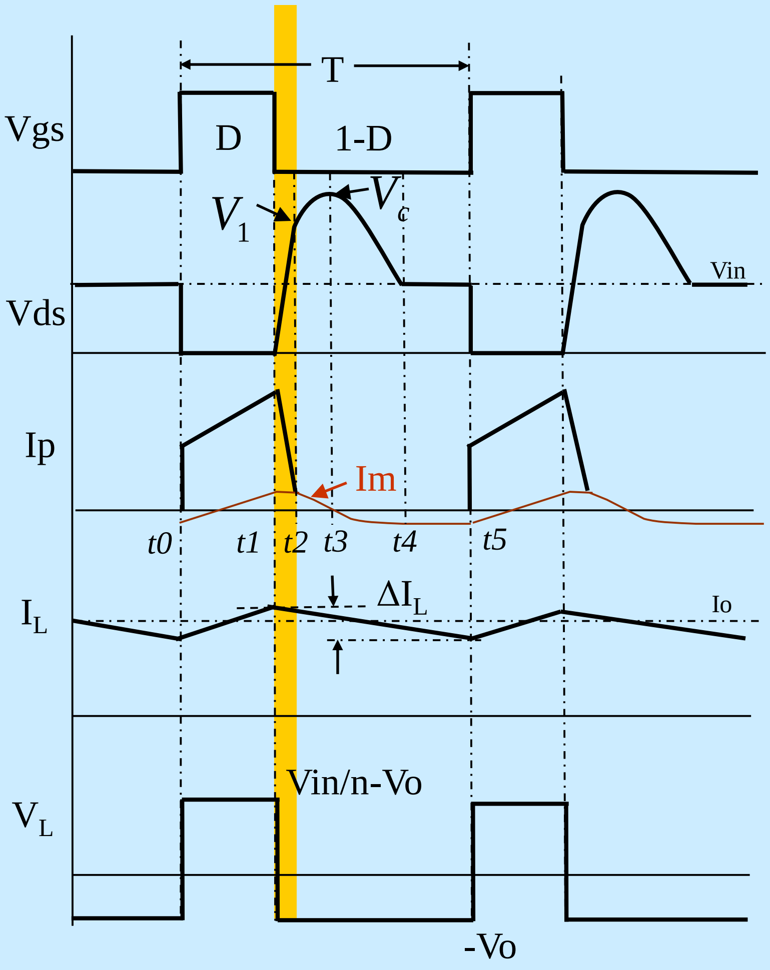
$$\Delta I_m = VinDT / Lm$$

$$\Delta I_L = (Vin / n - Vo)DT / Lo$$

$$\Delta I_P = \Delta I_m + n\Delta I_L$$

谐振复位正激变换器（Resonant Reset Forward):

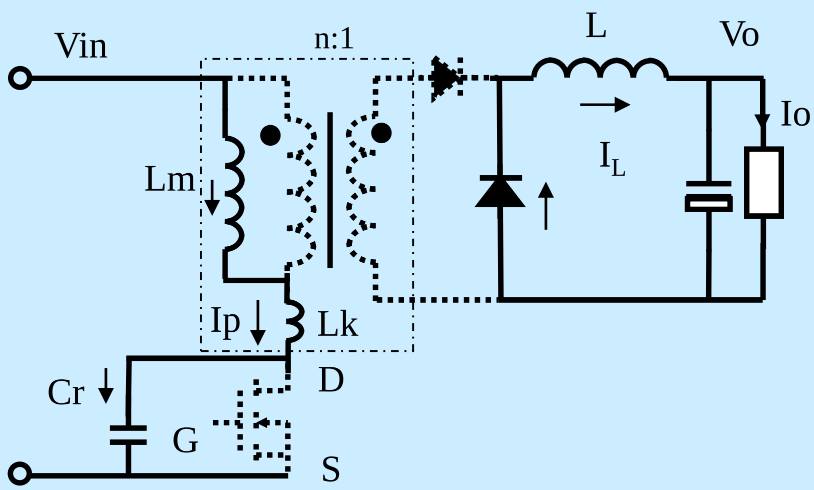


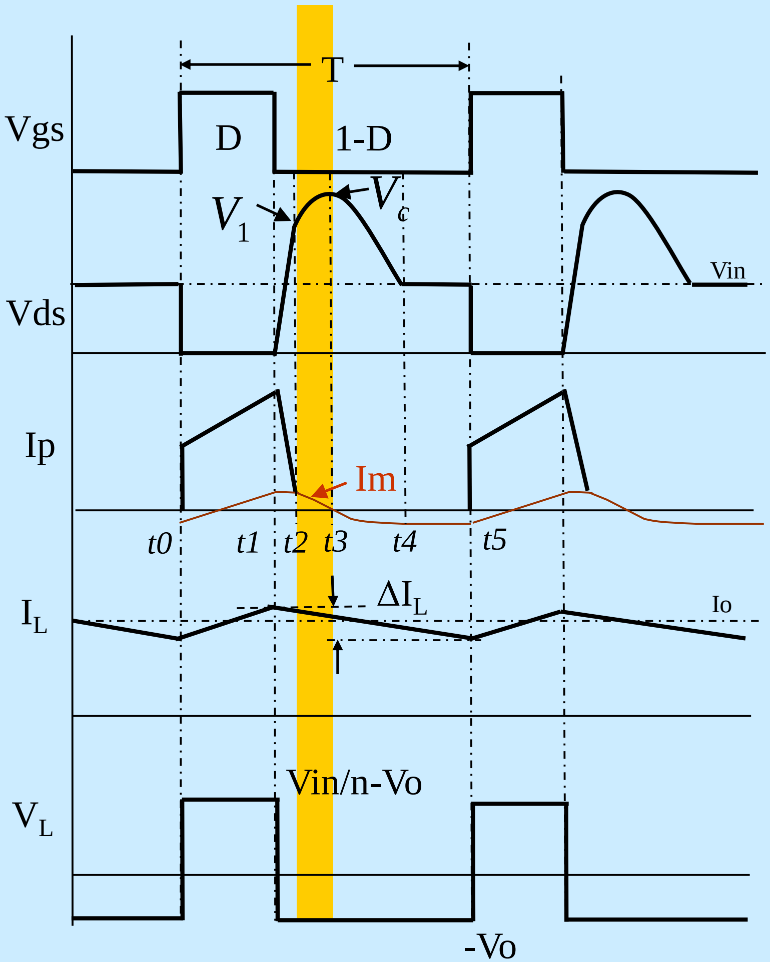


[*t1*, *t2*]

$$V_1 = V_c\left(\frac{2I_p}{\Delta I_m}\sqrt{\frac{Lk}{Lm}}\right)$$

谐振复位正激变换器（Resonant Reset Forward):

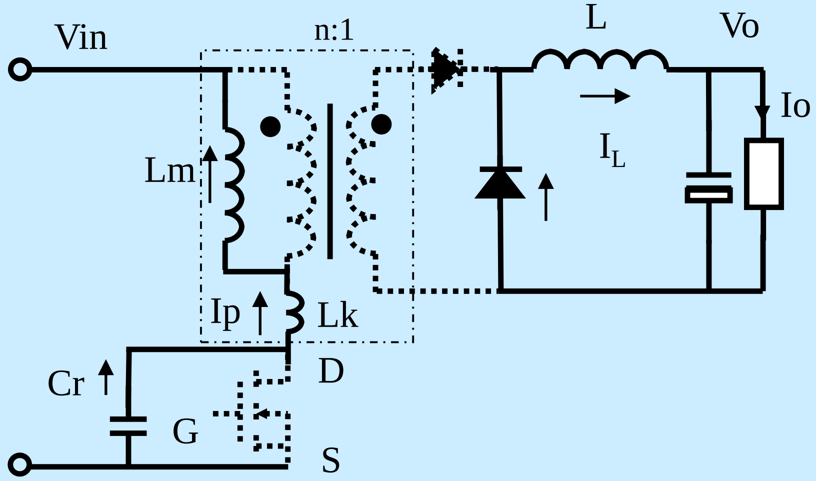


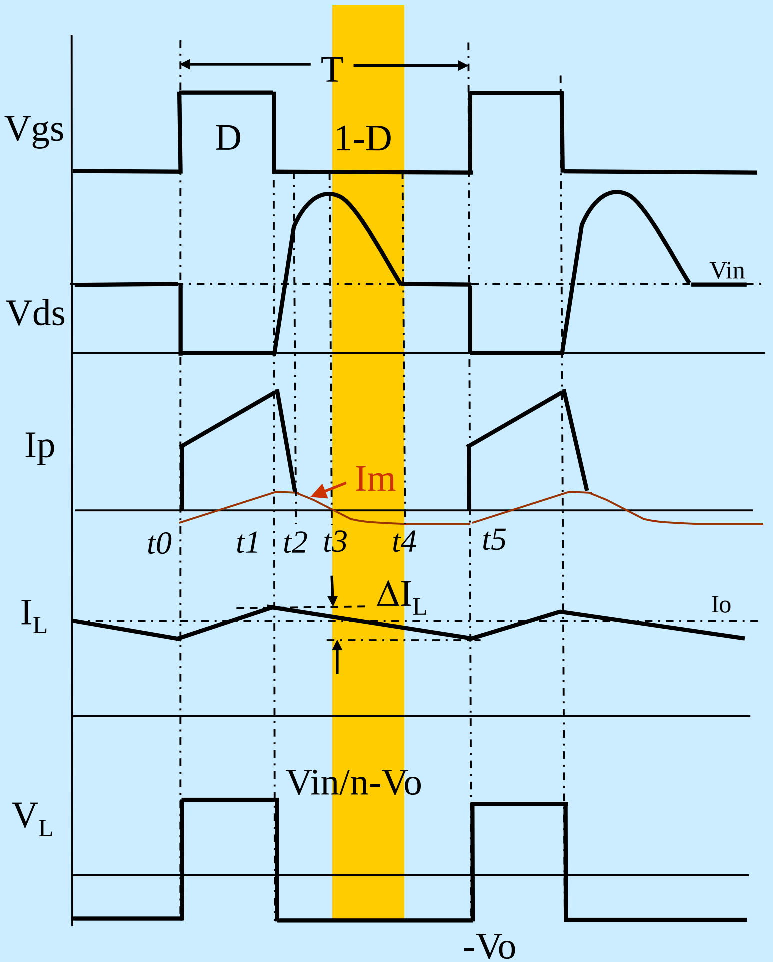


$[t2, t3]$

$$V_c = \frac{V_{in} DT}{2\sqrt{L_m \cdot C_r}}$$

谐振复位正激变换器（Resonant Reset Forward):





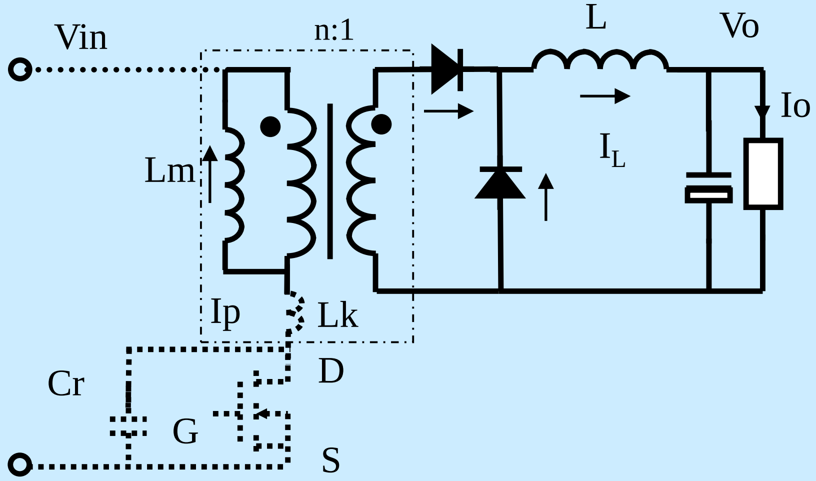
[*t3*, *t4*]

$$t4 - t1 \approx \pi\sqrt{LmCr}$$

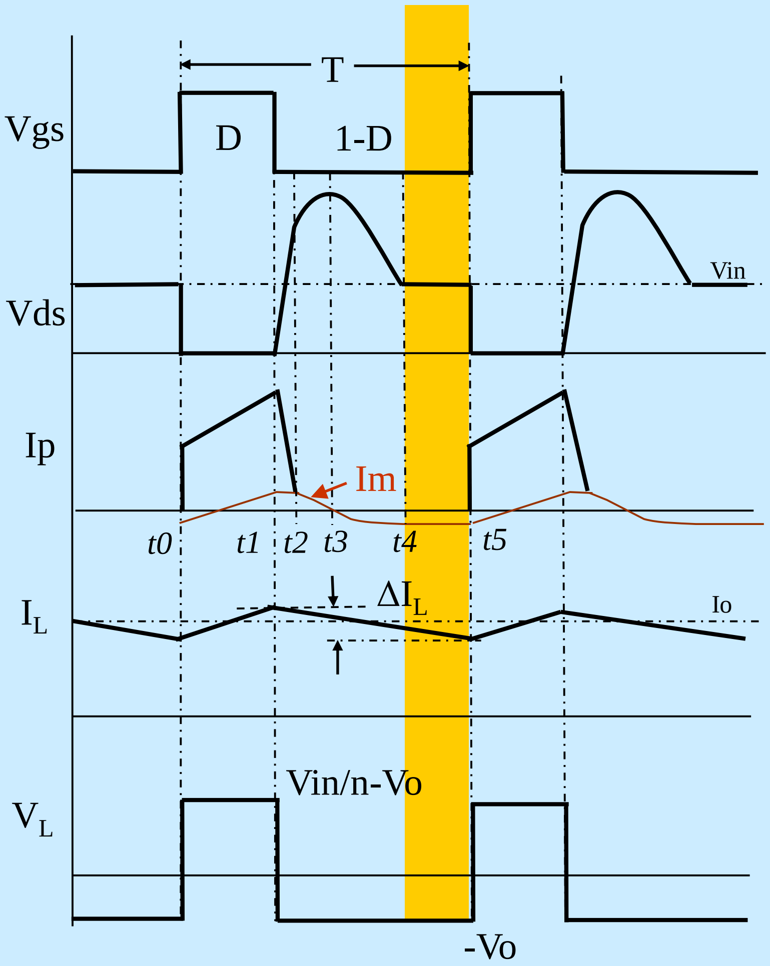
Lm,Cr的选取原则：

$$Lm * Cr = \frac{1}{\pi^2}(1 - D_{max})^2 T^2$$

谐振复位正激变换器（Resonant Reset Forward)：



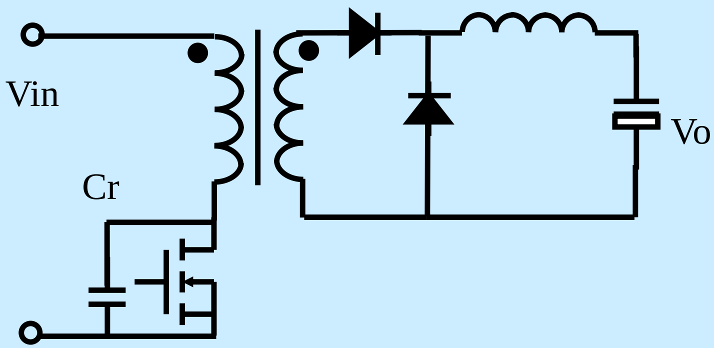
[$t4$, $t5$]

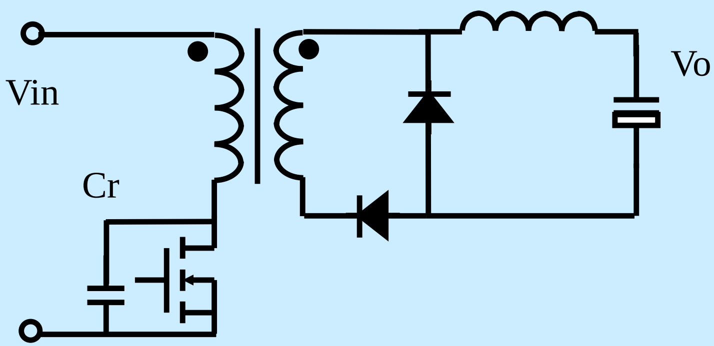


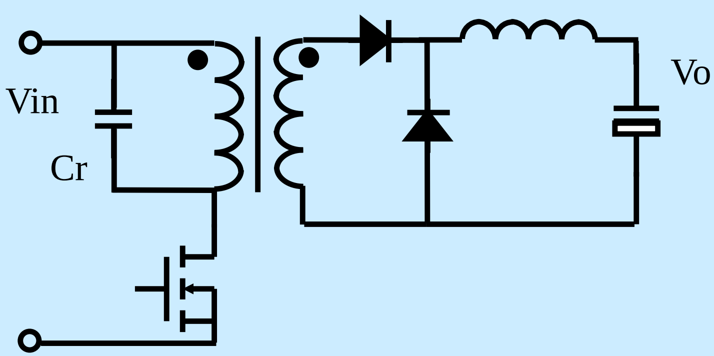
根据电感的伏秒平衡：

(Vin/n-Vo)DT=Vo(1-D)T ⇨ Vo=VinD/n

谐振复位正激变换器（Resonant Reset Forward)特征：







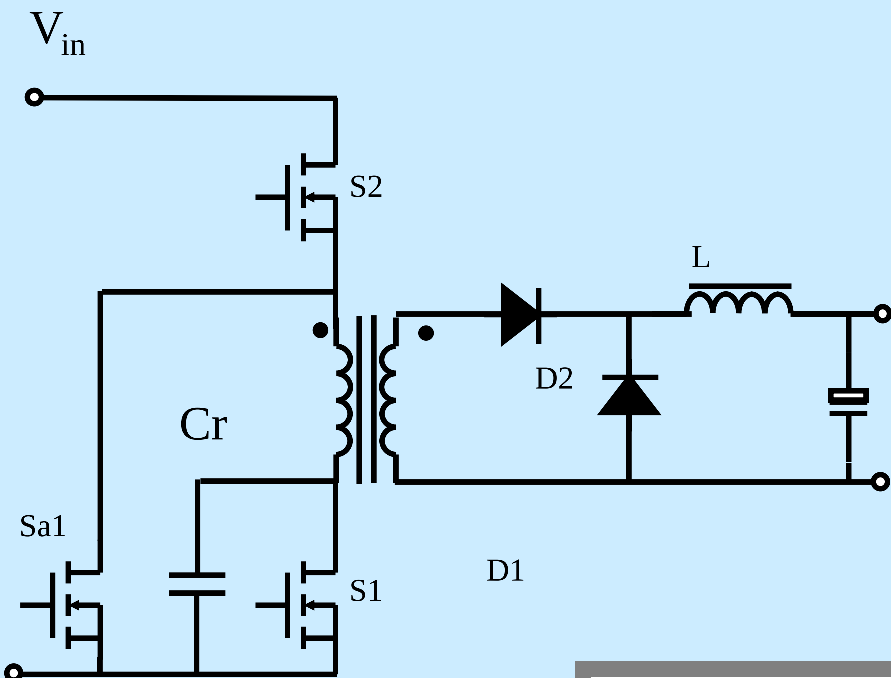
优点：

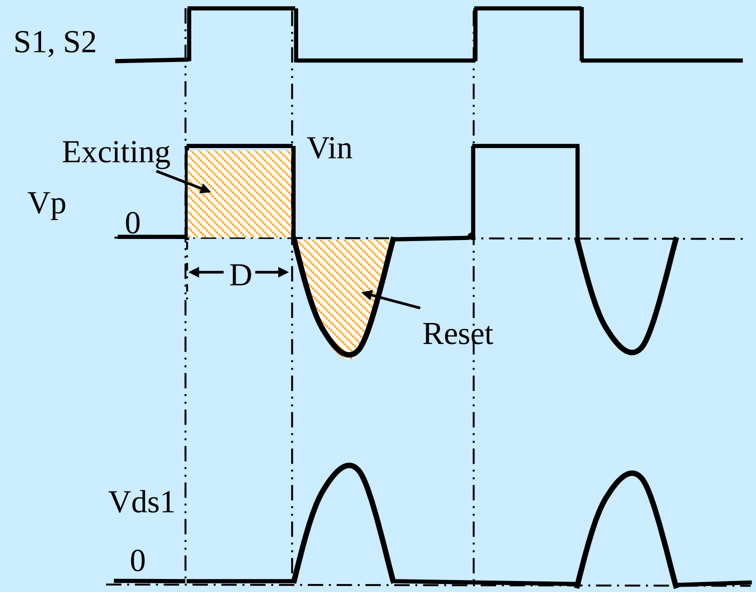
1. 电路简单。
2. 线性输出控制特性。
3. 不需要辅助的吸收回路。

缺点：

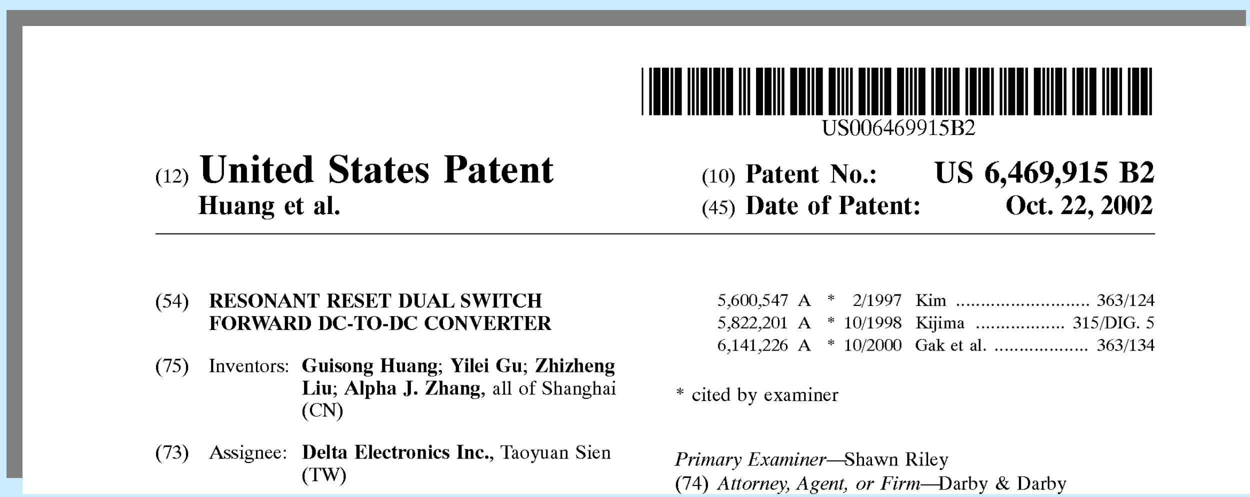
1. 原边开管电压应力较高。
2. 谐振电容的损耗大。
3. 宽范围输入效率很难兼顾。

Resonant Reset Dual Switch Forward





- **>50% Duty Cycle**
- **ZVS for Low side switch**



US006469915B2

(12) **United States Patent**
Huang et al.

(10) **Patent No.: US 6,469,915 B2**
(45) **Date of Patent: Oct. 22, 2002**

(54) **RESONANT RESET DUAL SWITCH FORWARD DC-TO-DC CONVERTER**

(75) Inventors: **Guisong Huang**; **Yilei Gu**; **Zhizheng Liu**; **Alpha J. Zhang**, all of Shanghai (CN)

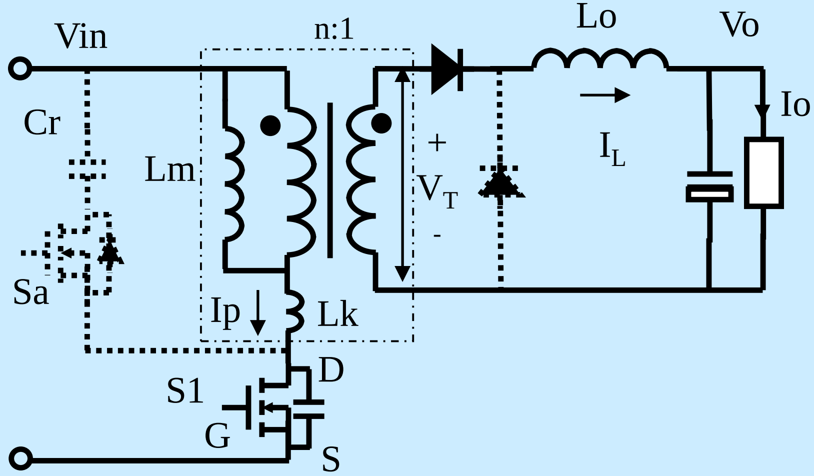
(73) Assignee: **Delta Electronics Inc.**, Taoyuan Sien (TW)

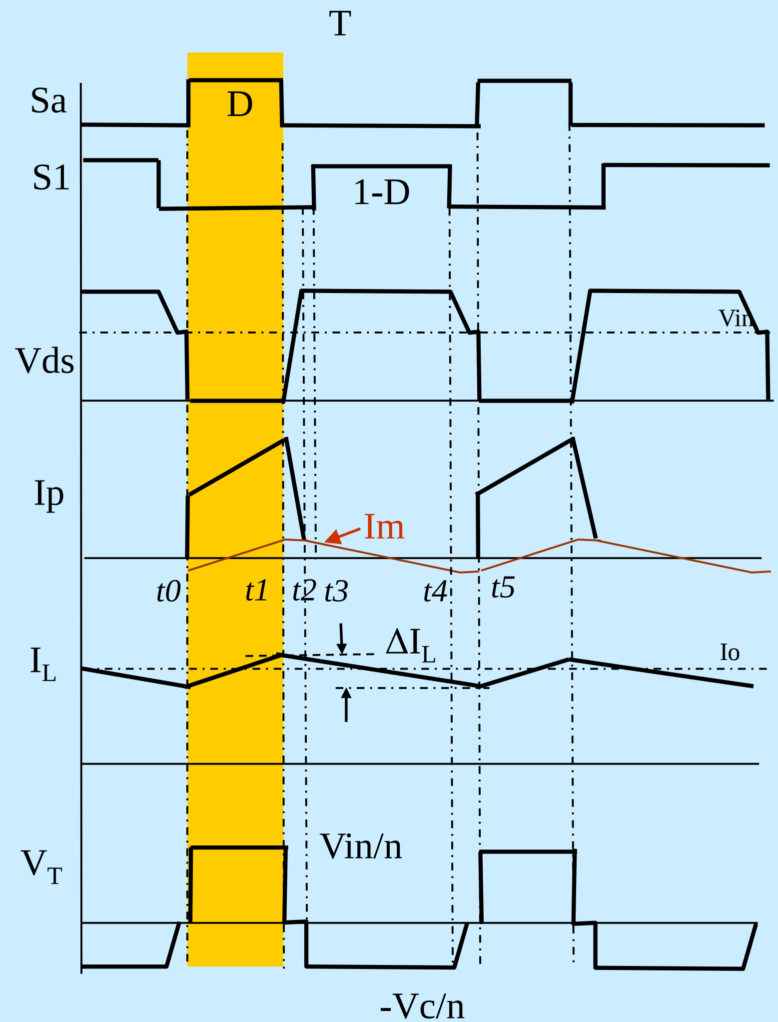
5,600,547 A * 2/1997 Kim 363/124
5,822,201 A * 10/1998 Kijima 315/DIG. 5
6,141,226 A * 10/2000 Gak et al. 363/134

* cited by examiner

Primary Examiner—Shawn Riley
(74) *Attorney, Agent, or Firm*—Darby & Darby

有源钳位正激变换器（Active Clamped Forward):





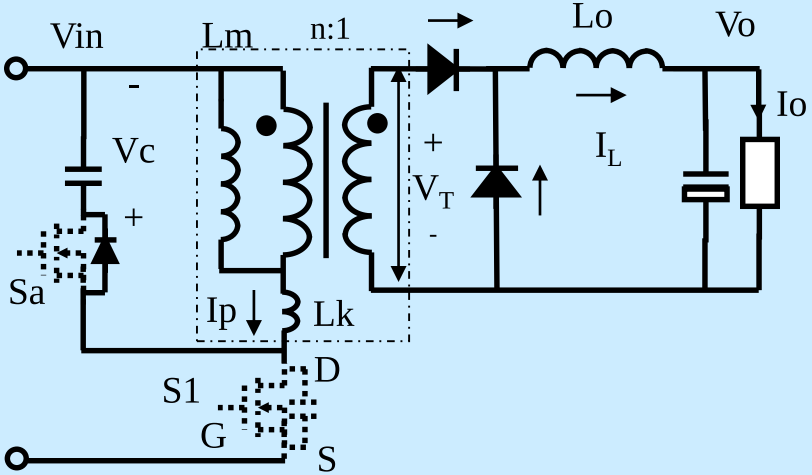
[*t0*, *t1*]

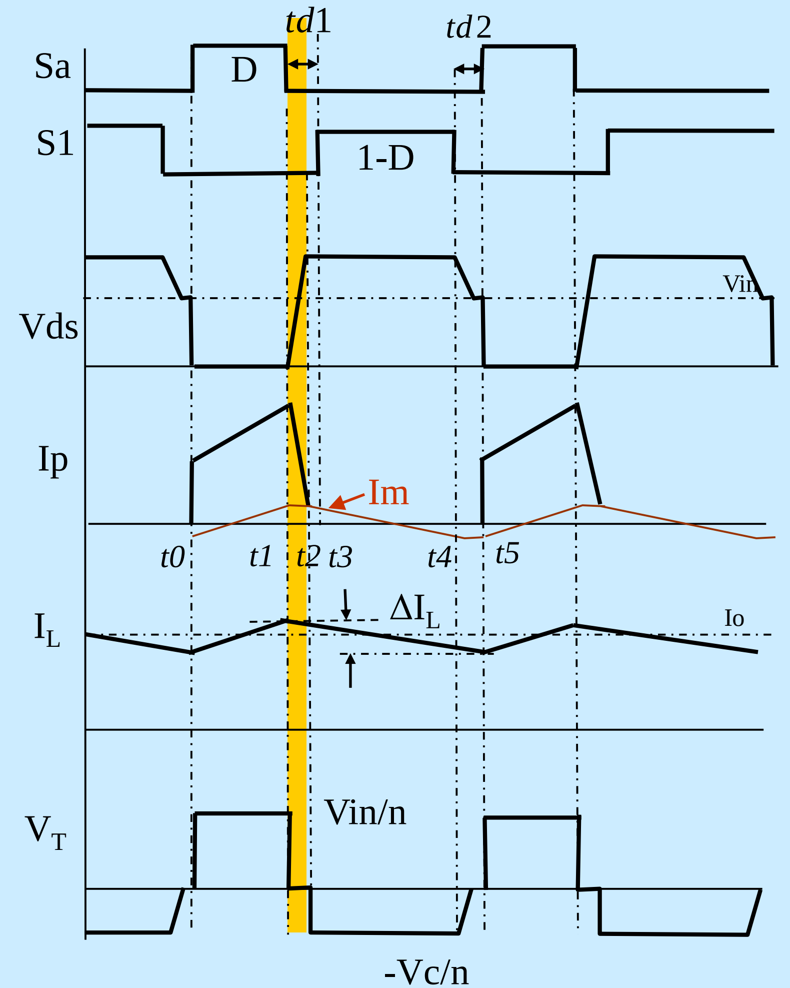
$$\Delta I_m = VinDT / Lm$$

$$\Delta I_L = (Vin / n - Vo)DT / Lo$$

$$\Delta I_P = \Delta I_m + n\Delta I_L$$

有源钳位正激变换器（Active Clamped Forward)：





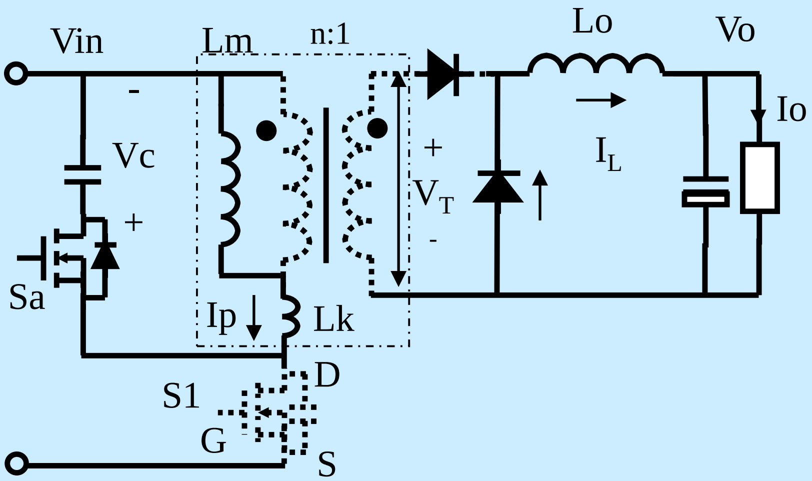
$[t1, t2]$

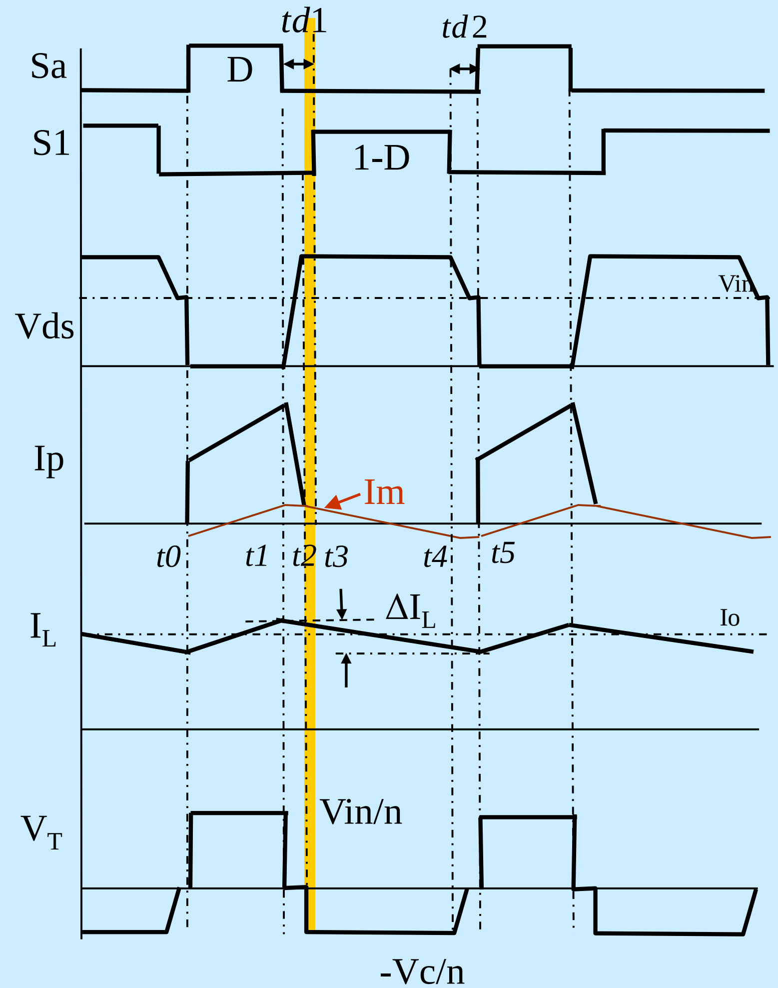
$$Vc(t2-t1)=(Ip-\mathrm{Im})Lk$$

$$(t2-t1)=(Io/n)*Lk/Vc$$

* 副边电压的死区跟Lk和Io有关，跟原边开管的死区无关

有源钳位正激变换器（Active Clamped Forward):





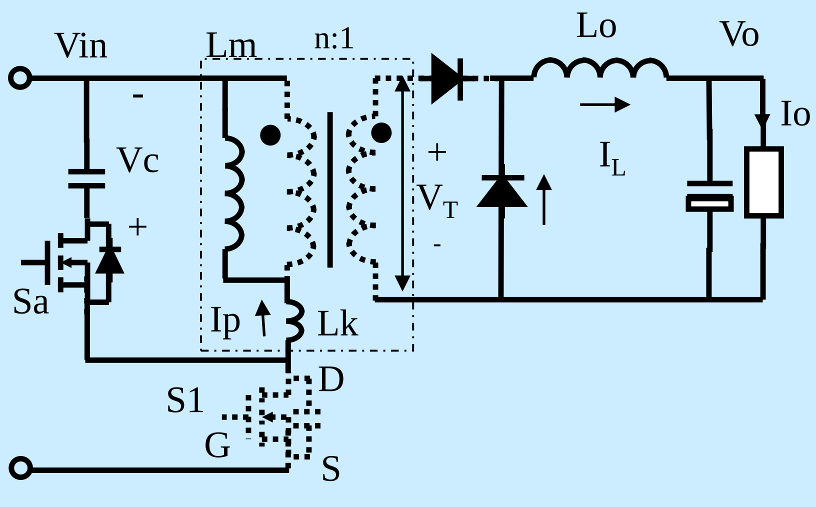
[$t2$, $t3$]

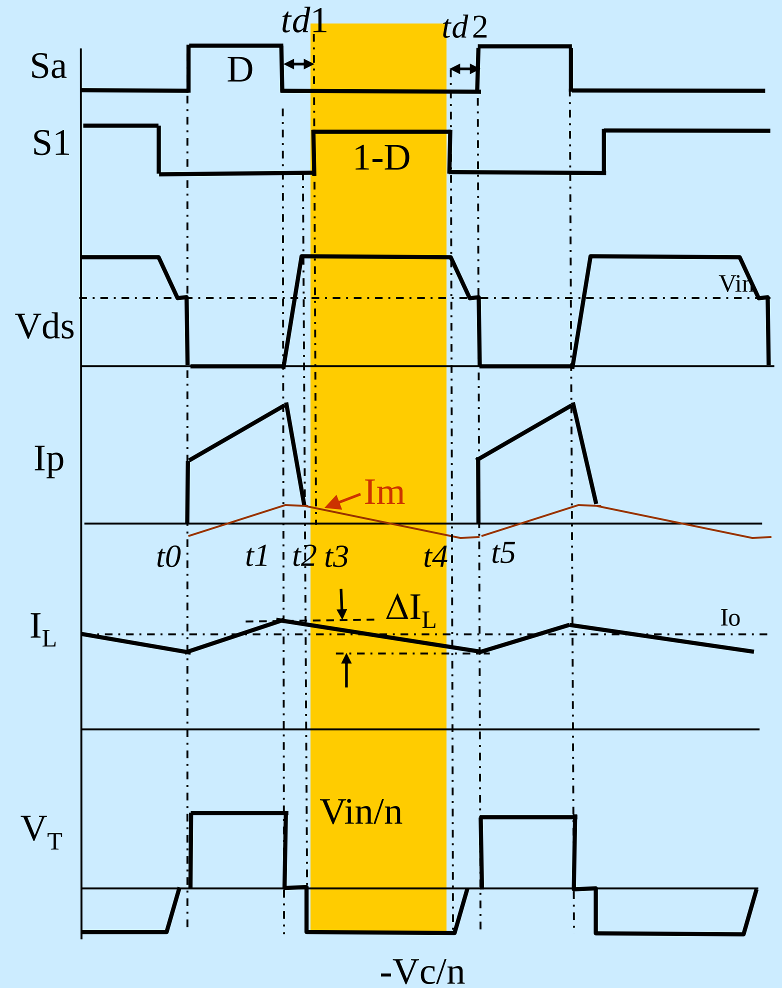
Sa在零电压条件下开通

* 原边开管的死区时间需满足：

$$td1 > (t2 - t1)$$

有源钳位正激变换器（Active Clamped Forward):



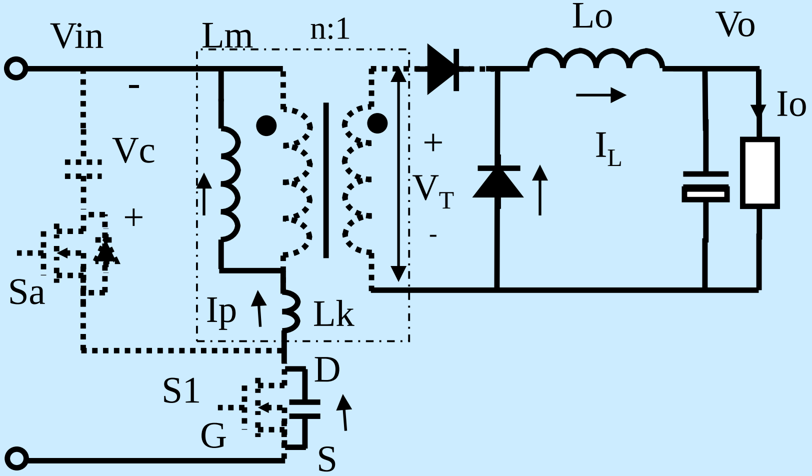


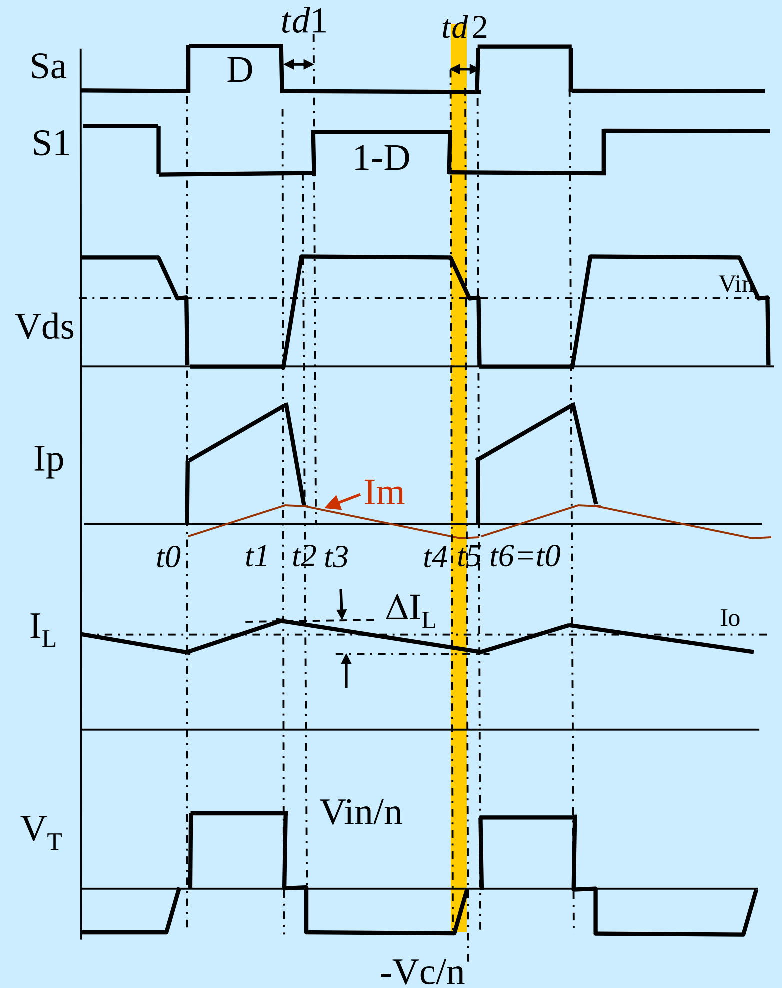
[*t3*, *t4*]

激磁电流反向，变压器被复位

$$\Delta I_m = Vc(1-D)T/Lm$$

有源钳位正激变换器（Active Clamped Forward):

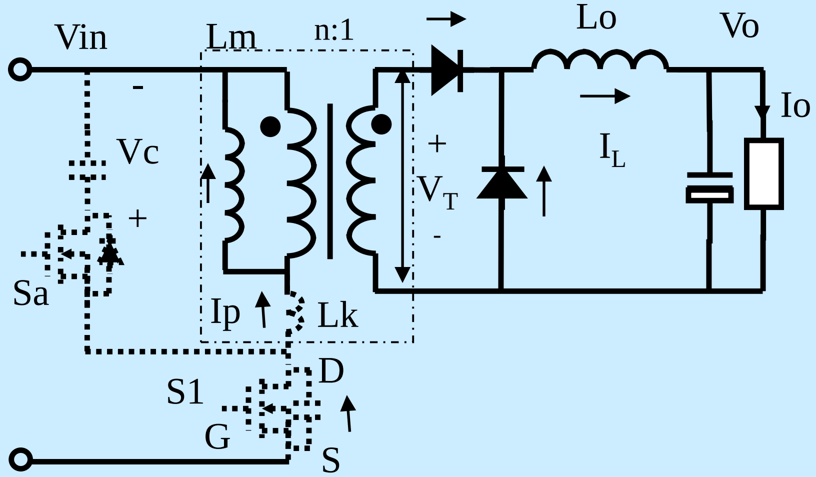


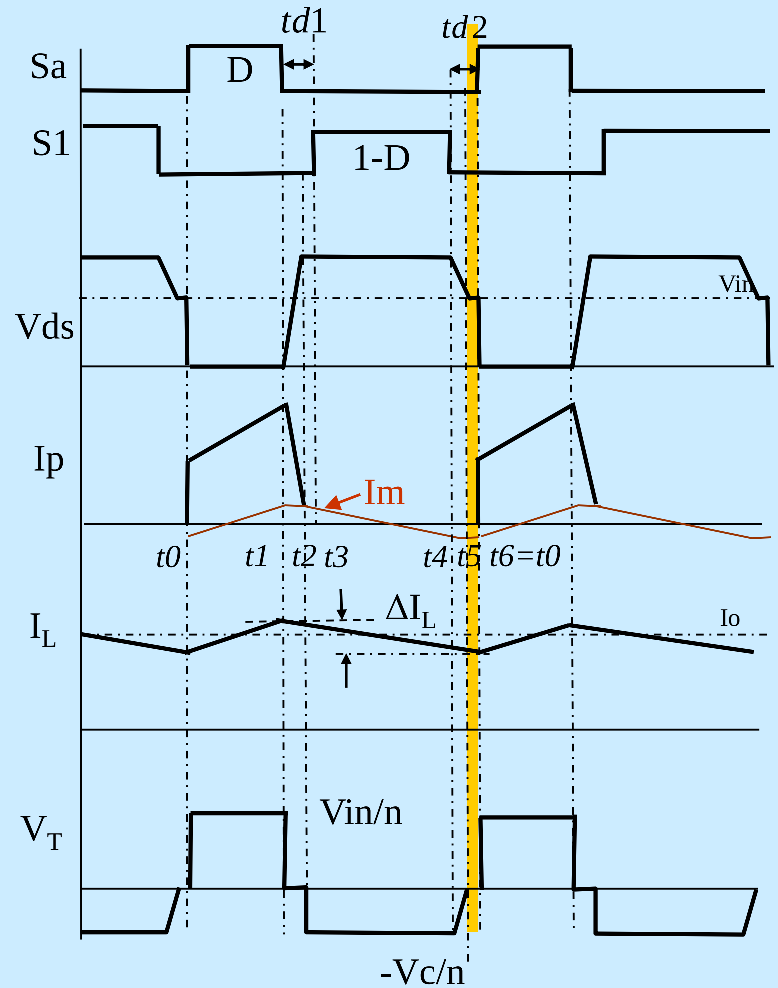


[$t4$, $t5$]

激磁电流对主开关的输出电容放电。

有源钳位正激变换器（Active Clamped Forward):



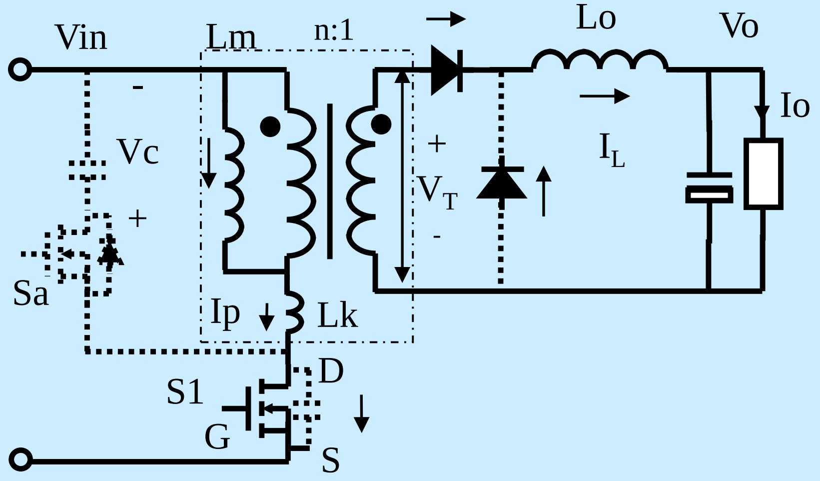


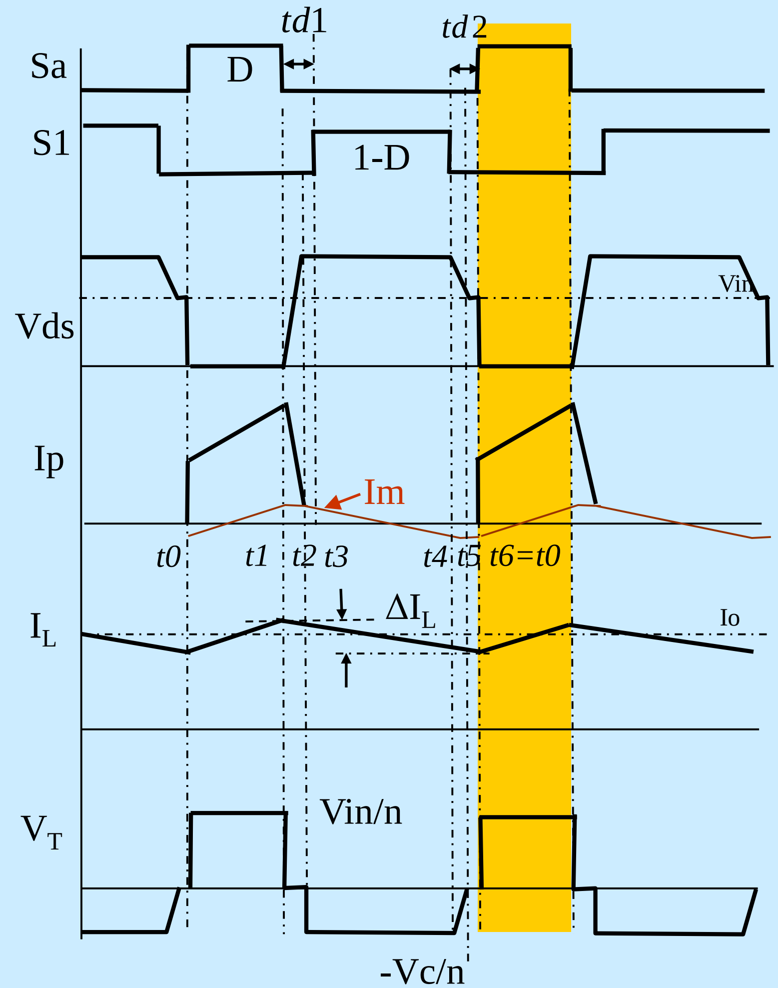
[*t5*, *t6*]

t5时刻副边二极管钳位主开关的输出电容放电结束。

t6时刻新的周期开始

有源钳位正激变换器（Active Clamped Forward):





根据变压器的伏秒平衡：

VinDT=Vc(1-D)T ⇨ Vc=VinD/(1-D)

Vds=Vc+Vin ⇨ Vds=Vin/(1-D)

根据电感的伏秒平衡：

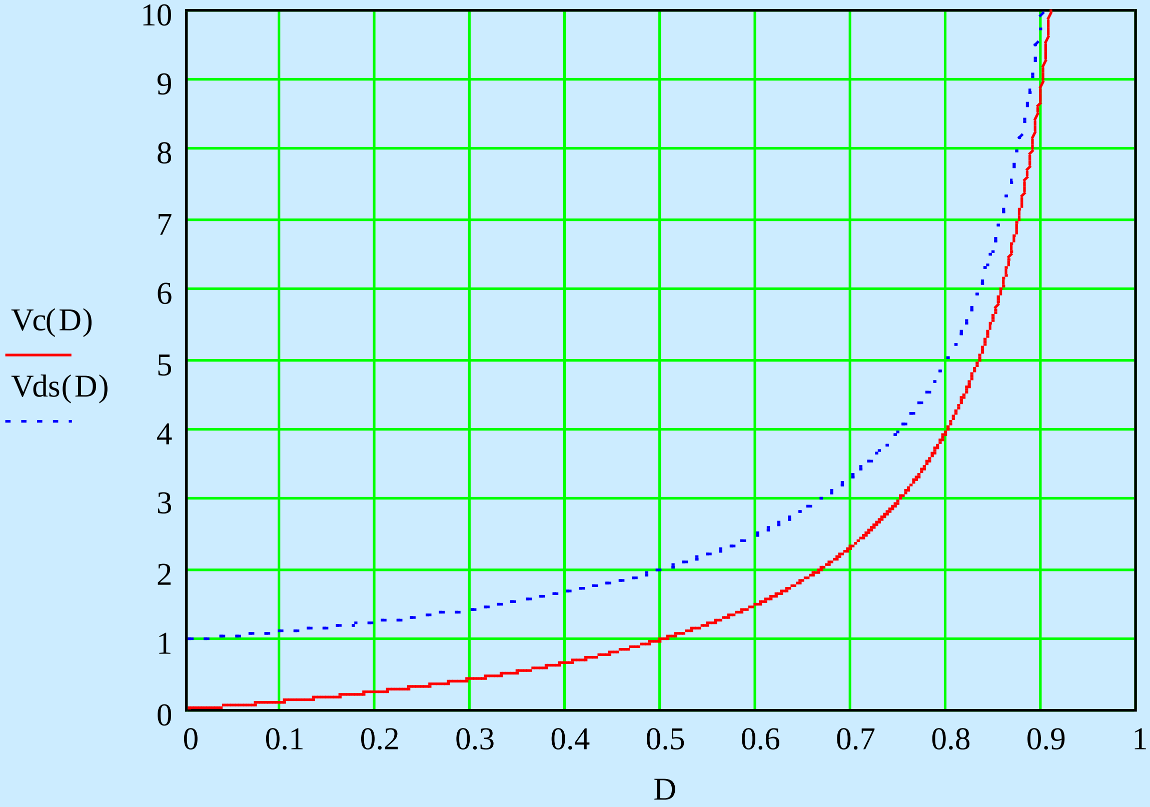
(Vin/n-Vo)DT=Vo(1-D)T ⇨ Vo=VinD/n

有源钳位正激变换器（Active Clamped Forward)：

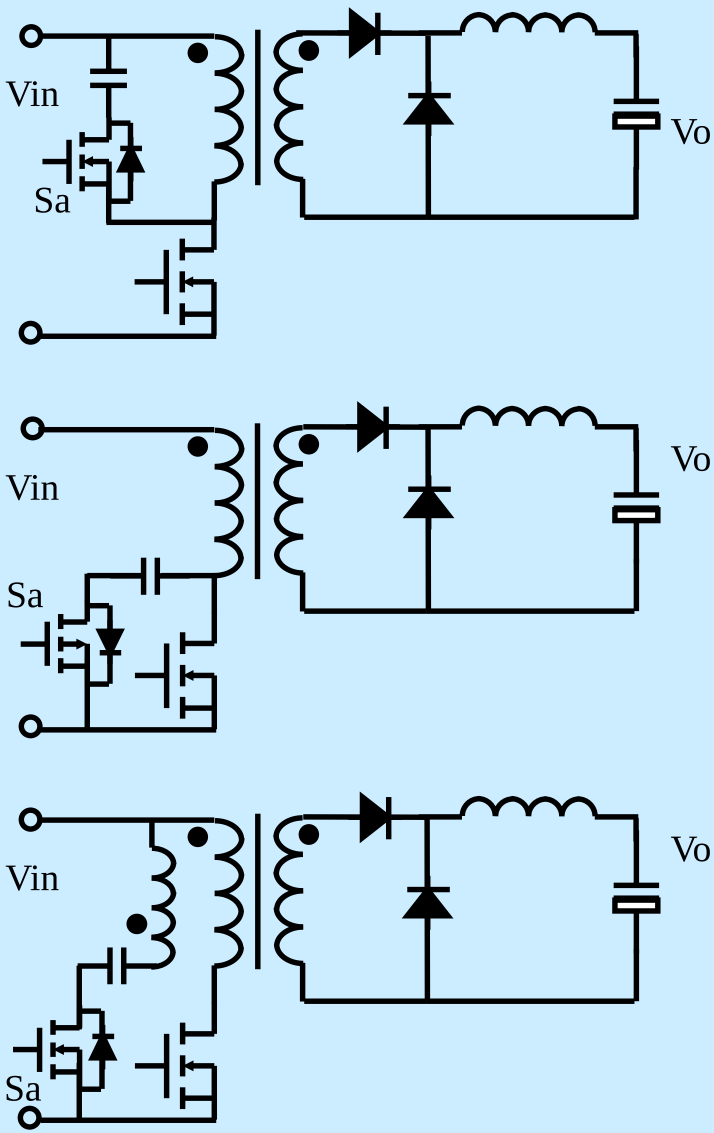
Vin

Vc=VinD/(1-D)

Vds=Vin/(1-D)



有源钳位正激变换器（Active Clamped Forward)特征：



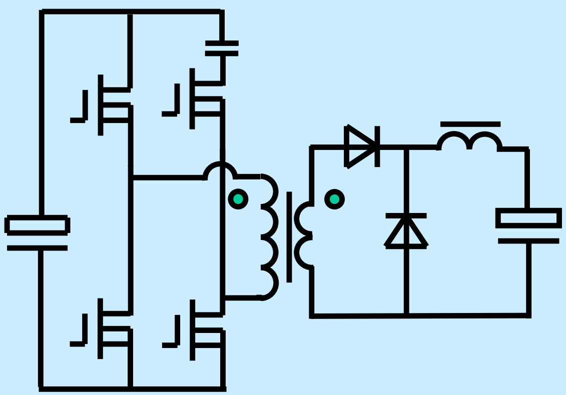
优点：

1. 变压器最优化复位（电压应力低）。
2. 输入电压范围宽。
3. 线性输出控制特性。
4. 不需要辅助的吸收回路。

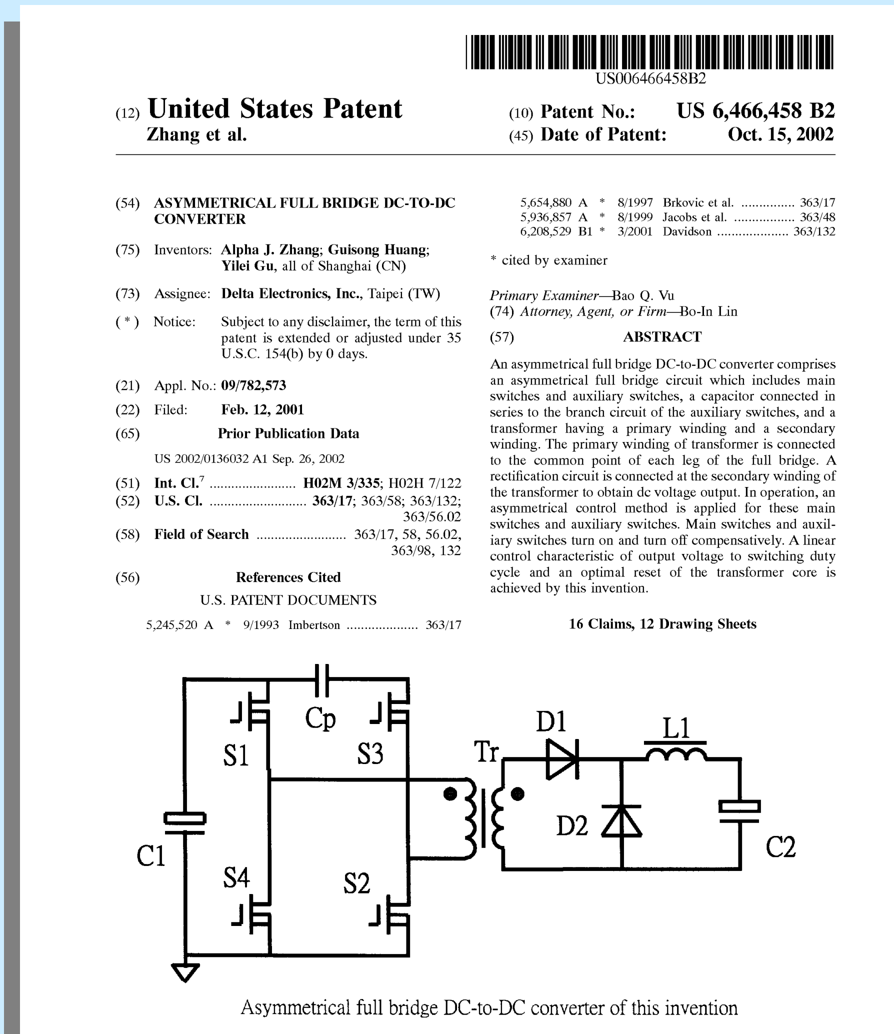
缺点：

1. 钳位电压建立较慢，启动过程变压器易偏磁。
2. 对输入电压的动态响应慢。

有源钳位正激变换器（Active Clamped Forward):



Asymmetrical Full
Bridge DC/DC Converter



US006466458B2

(12) **United States Patent**
Zhang et al.

(10) **Patent No.:** **US 6,466,458 B2**
(45) **Date of Patent:** **Oct. 15, 2002**

(54) **ASYMMETRICAL FULL BRIDGE DC-TO-DC CONVERTER**

(75) Inventors: **Alpha J. Zhang**; **Guisong Huang**; **Yilei Gu**, all of Shanghai (CN)

(73) Assignee: **Delta Electronics, Inc.**, Taipei (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/782,573**

(22) Filed: **Feb. 12, 2001**

(65) **Prior Publication Data**

US 2002/0136032 A1 Sep. 26, 2002

(51) **Int. Cl.**[7] **H02M 3/335**; H02H 7/122

(52) **U.S. Cl.** **363/17**; 363/58; 363/132; 363/56.02

(58) **Field of Search** 363/17, 58, 56.02, 363/98, 132

(56) **References Cited**

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Primary Examiner—Bao Q. Vu
(74) *Attorney, Agent, or Firm*—Bo-In Lin

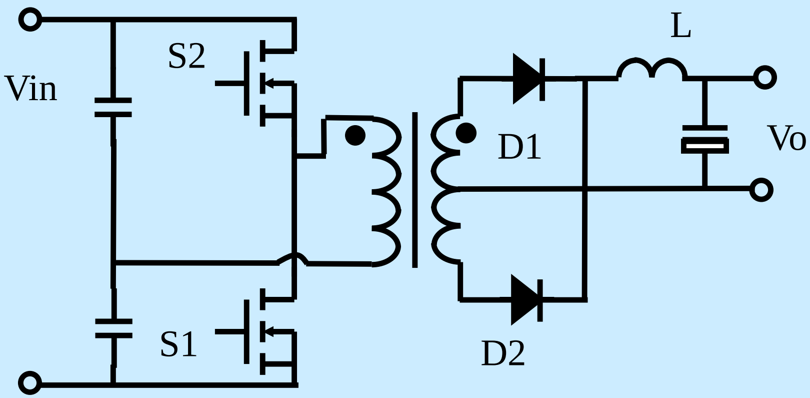
(57) **ABSTRACT**

An asymmetrical full bridge DC-to-DC converter comprises an asymmetrical full bridge circuit which includes main switches and auxiliary switches, a capacitor connected in series to the branch circuit of the auxiliary switches, and a transformer having a primary winding and a secondary winding. The primary winding of transformer is connected to the common point of each leg of the full bridge. A rectification circuit is connected at the secondary winding of the transformer to obtain dc voltage output. In operation, an asymmetrical control method is applied for these main switches and auxiliary switches. Main switches and auxiliary switches turn on and turn off compensatively. A linear control characteristic of output voltage to switching duty cycle and an optimal reset of the transformer core is achieved by this invention.

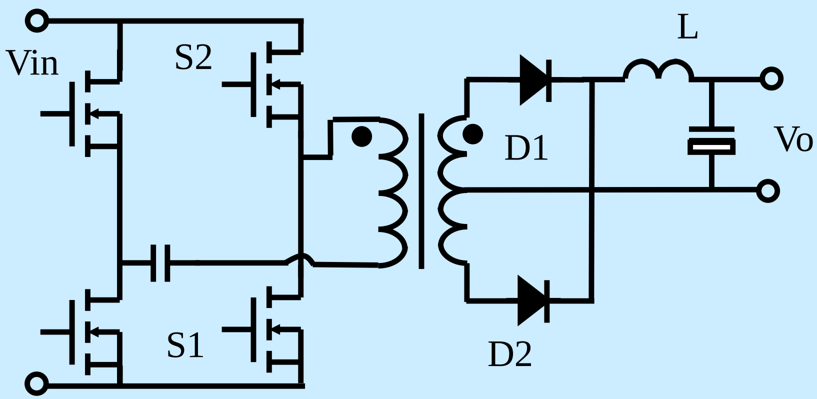
16 Claims, 12 Drawing Sheets

Asymmetrical full bridge DC-to-DC converter of this invention

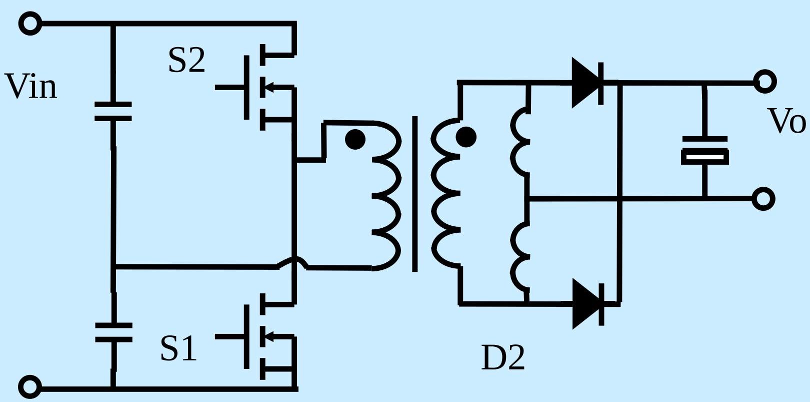
桥式变换器（Bridge Type Converter):



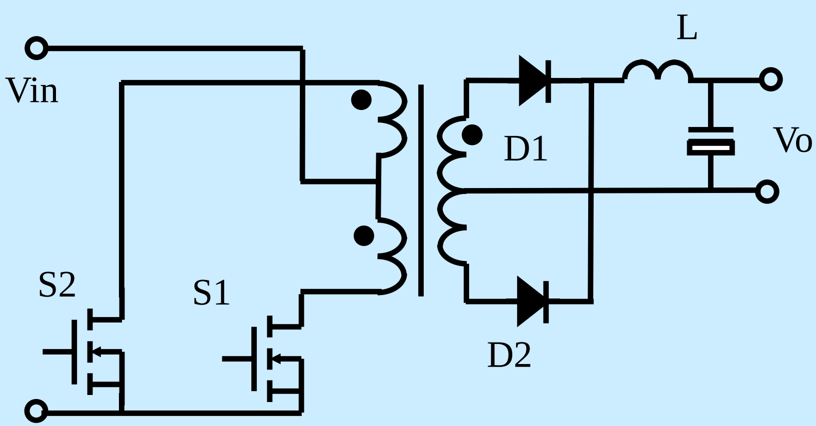
半桥变换器



全桥变换器

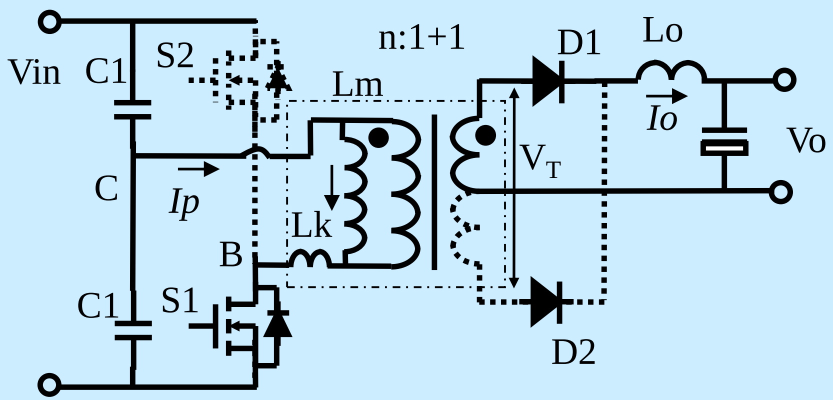


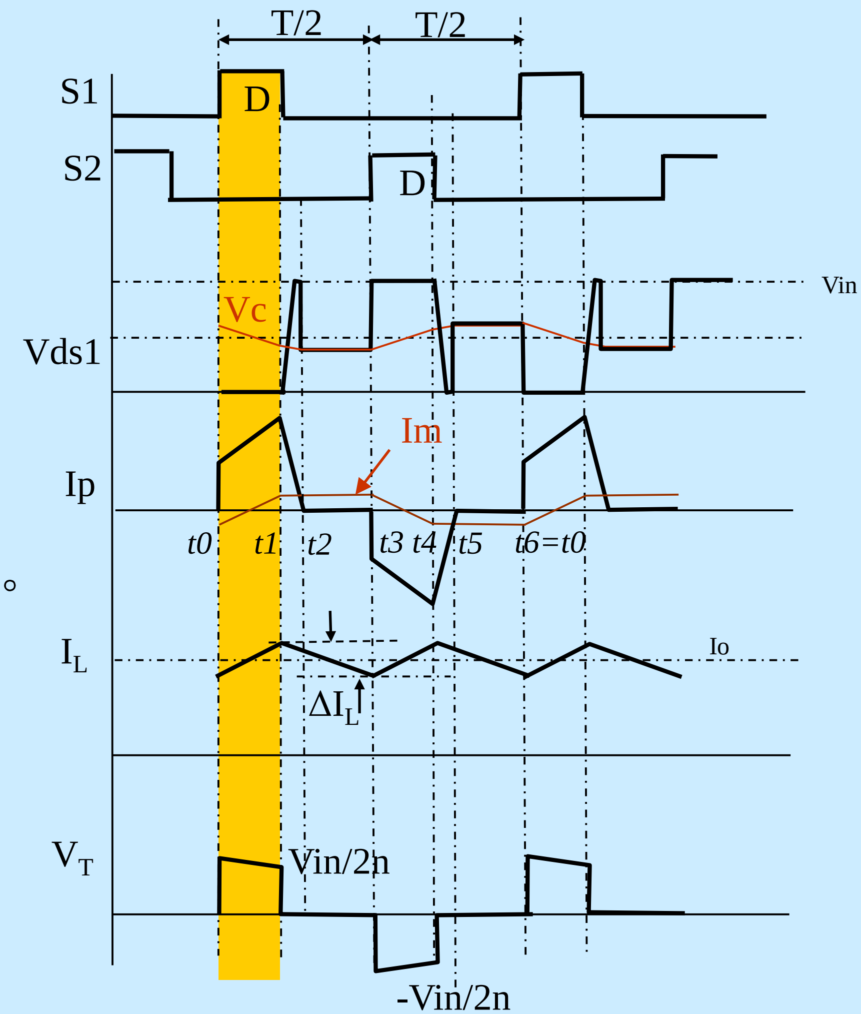
半桥变换器（倍流整流）



推挽变换器

桥式变换器（Bridge Type Converter):





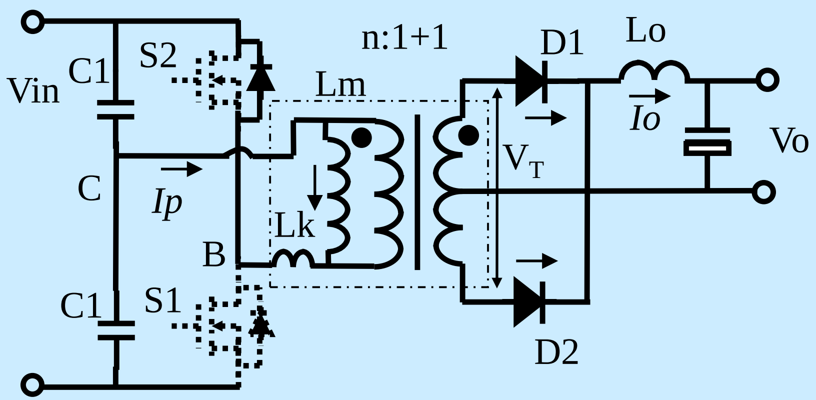
[t0, t1]

变换器正半周工作，Ip, Im增加；Vc减少。

$$\Delta I_m = \frac{Vin}{2} DT / Lm$$

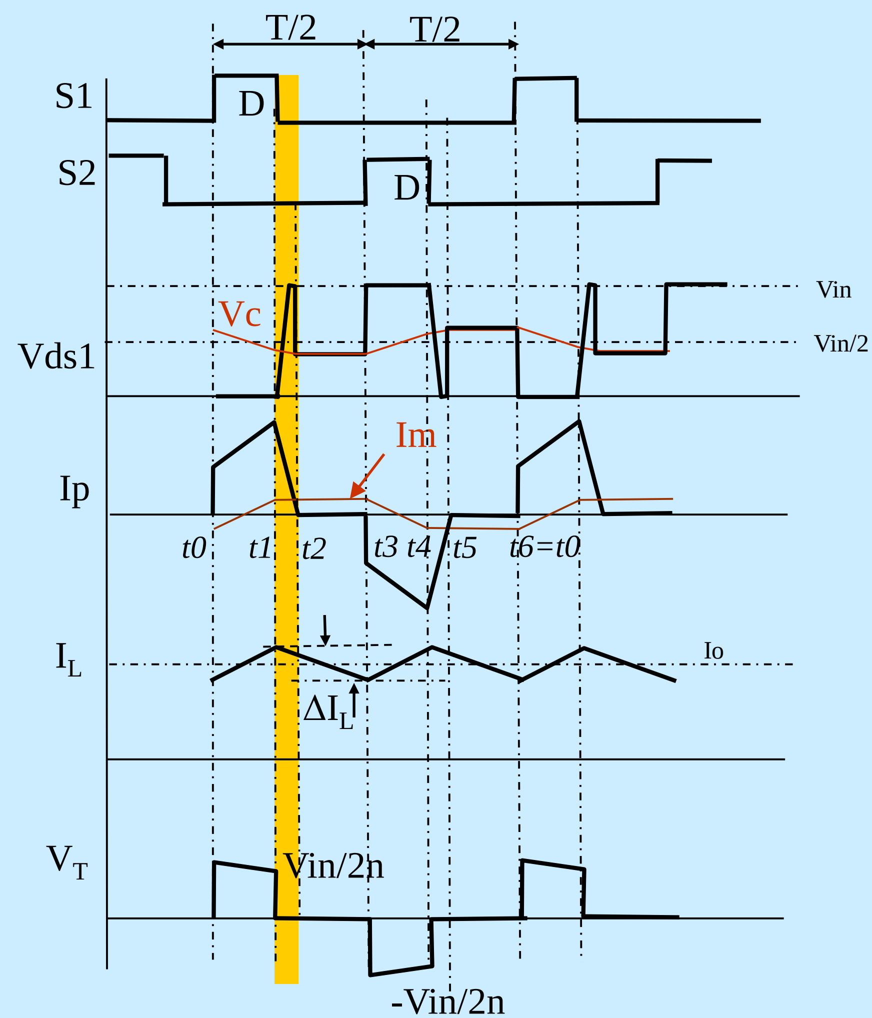
$$\Delta Vc = -(Io / n) DT / (2C1)$$

桥式变换器（Bridge Type Converter):

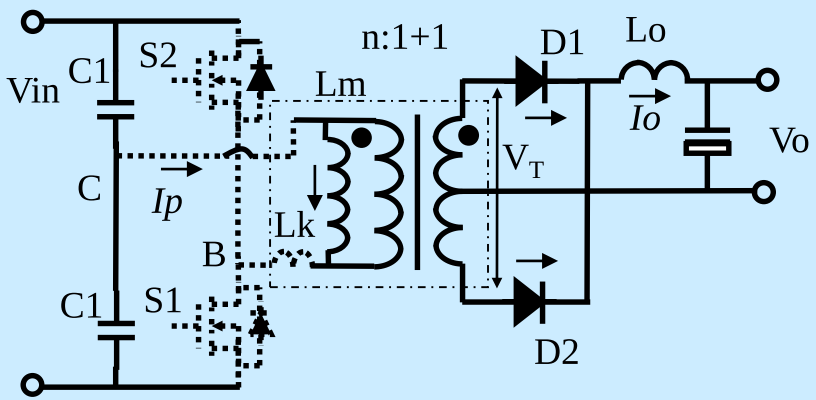


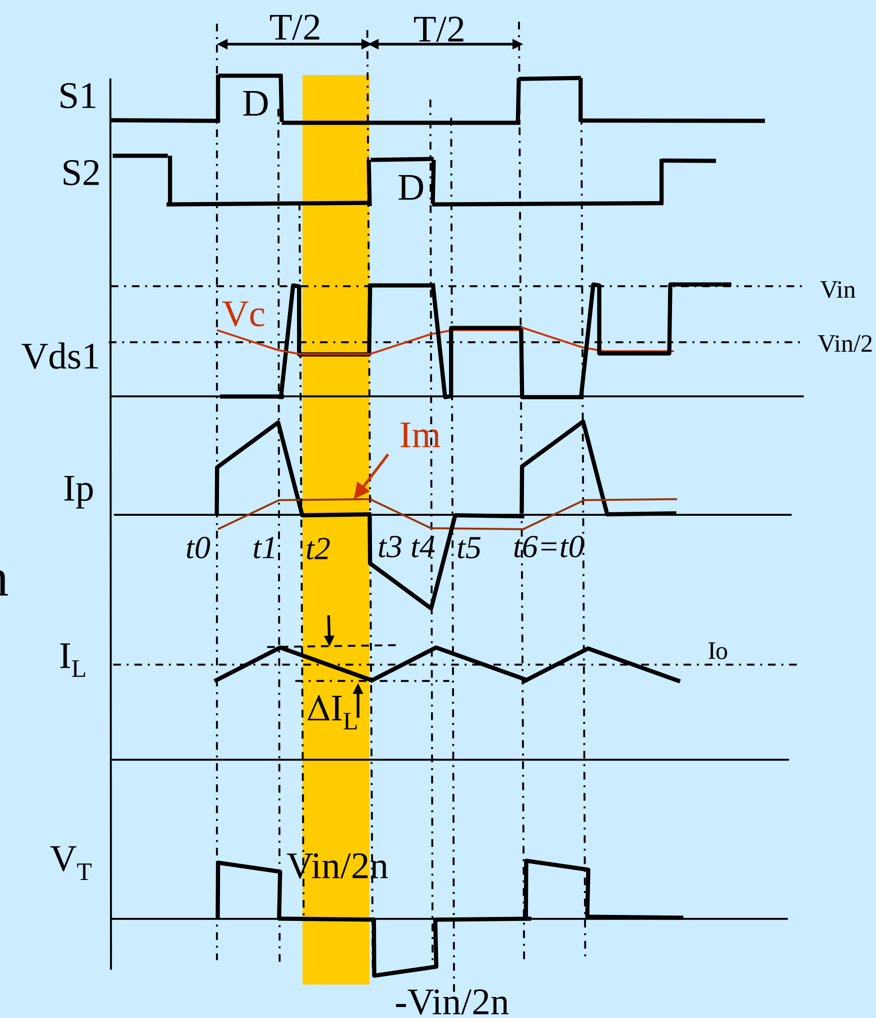
[t1, t2]

S1关断，变压器副边续流，原边漏感能量被S2体二极管钳位。



桥式变换器（Bridge Type Converter):

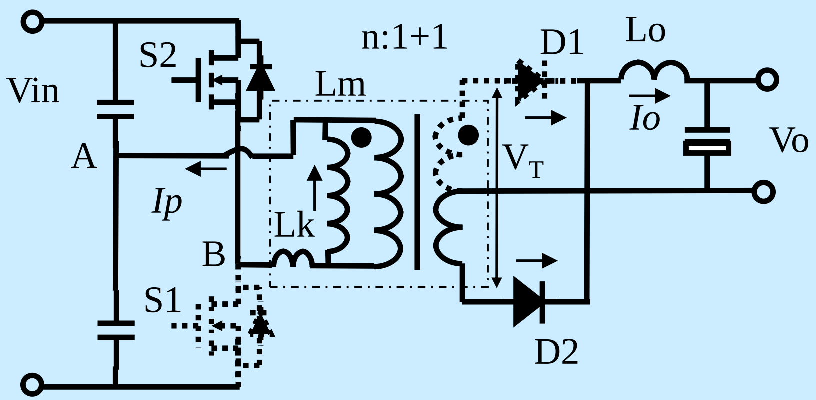


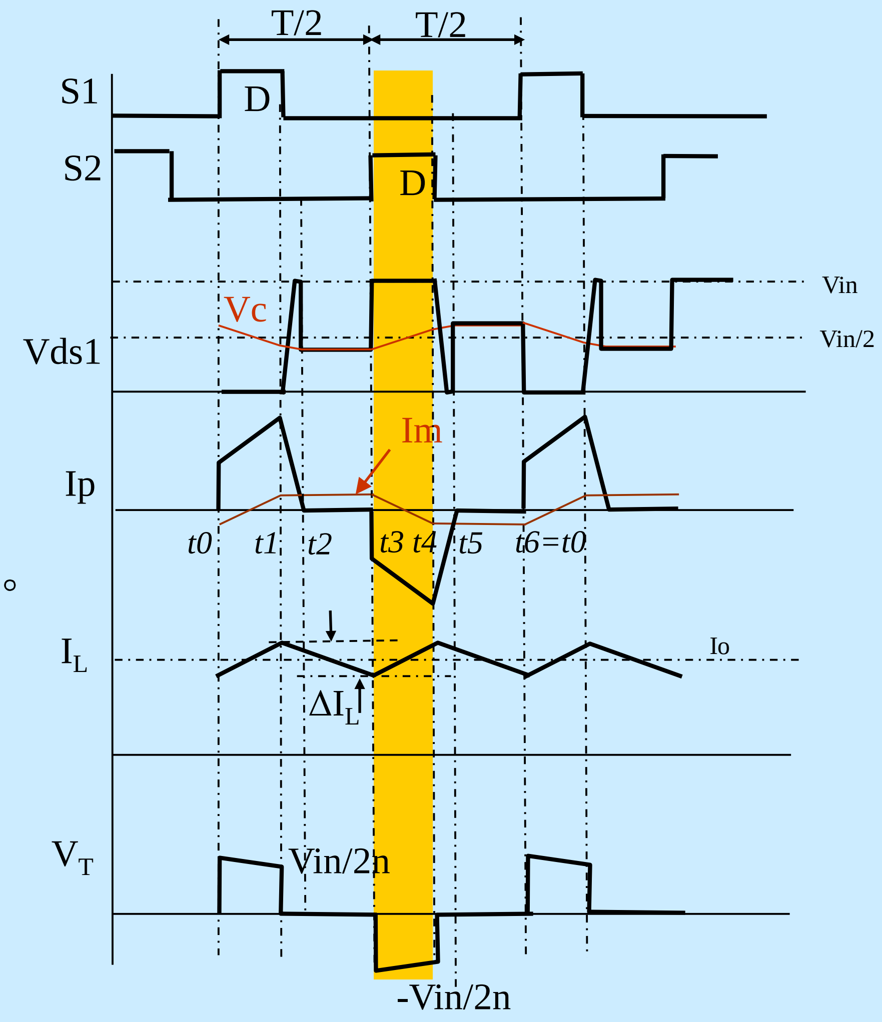


[t2, t3]

S1，S2全部关断，变压器副边续流，Lm保持不变，D1,D2电流之差为Lm。

桥式变换器（Bridge Type Converter):





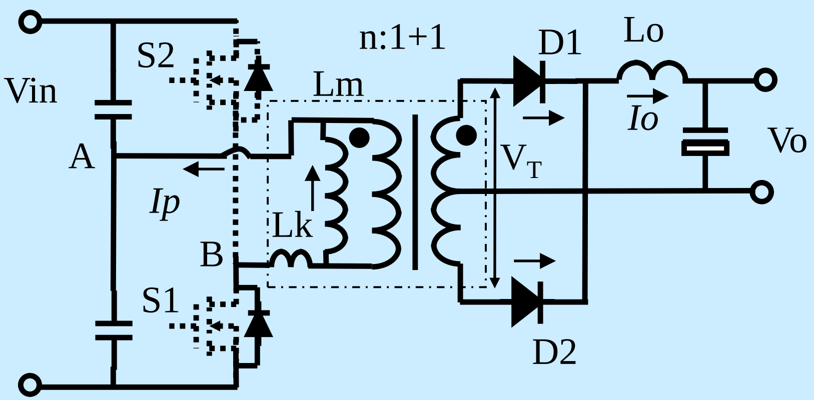
[t3, t4]

变换器负半周工作，Ip, Im减少；Vc增加。

$$\Delta I_m = -\frac{Vin}{2} DT / Lm$$

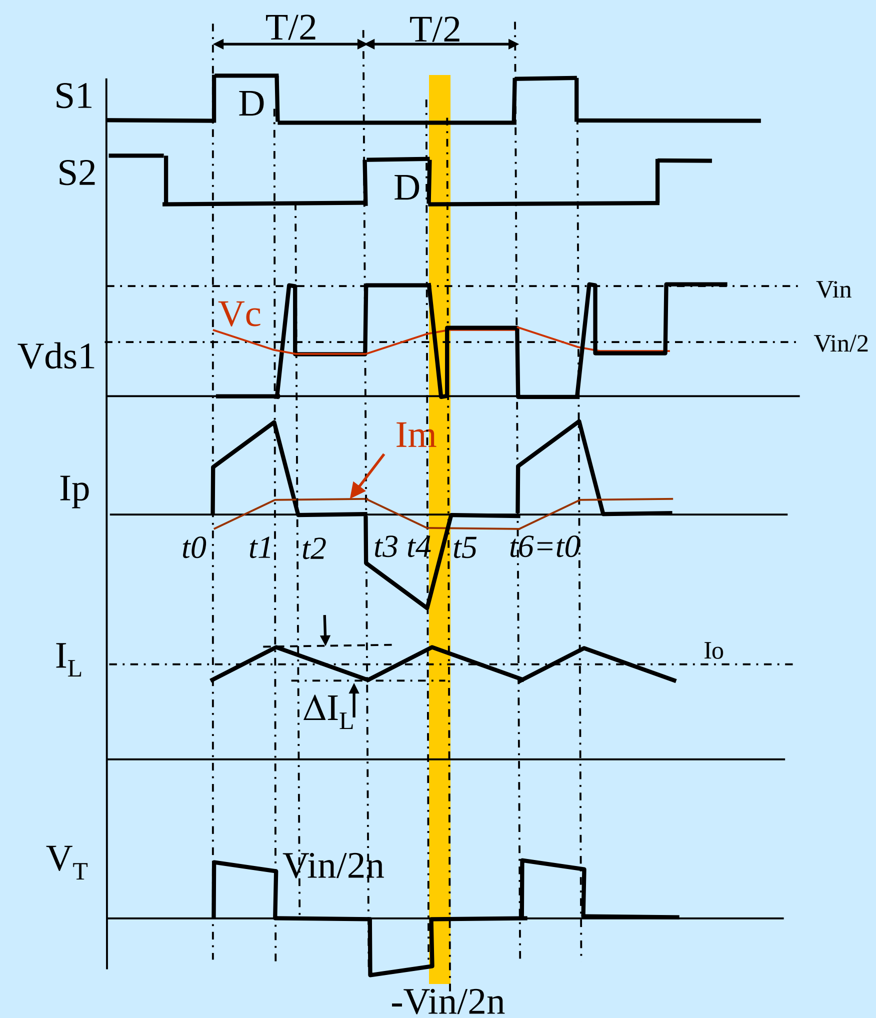
$$\Delta Vc = (Io / n) DT / (2C1)$$

桥式变换器（Bridge Type Converter):

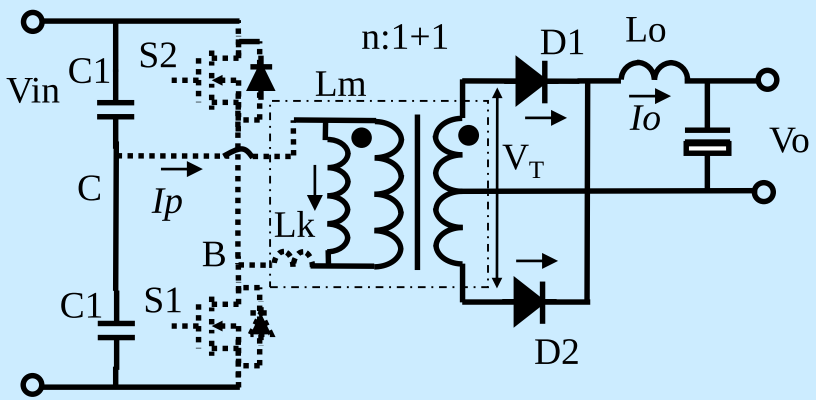


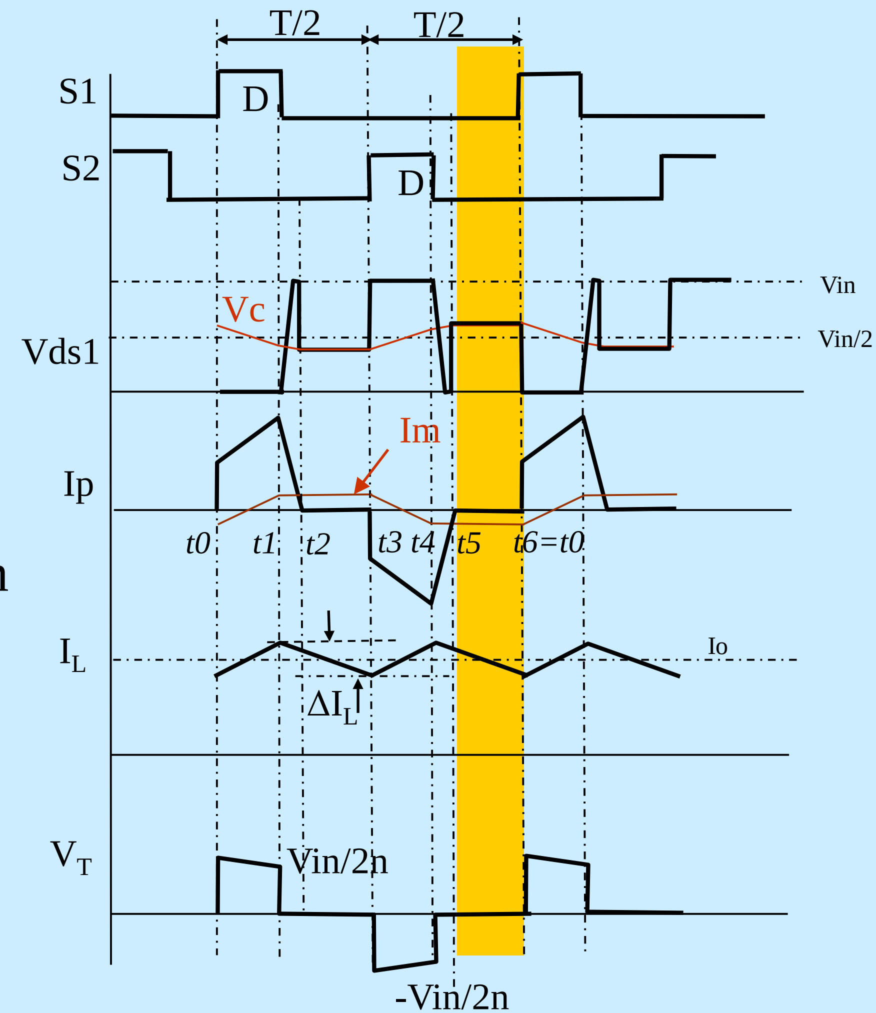
[t4, t5]

S2关断，变压器副边续流，原边漏感能量被S1体二极管钳位。



桥式变换器（Bridge Type Converter):





[t5, t6]

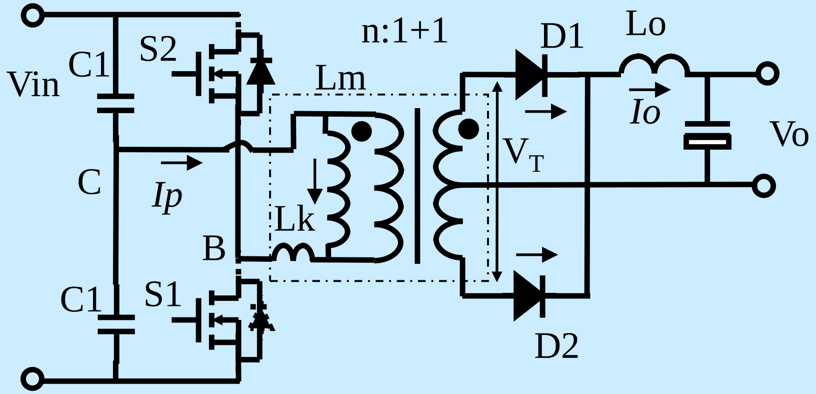
S1，S2全部关断，变压器副边续流，Lm保持不变，D1,D2电流之差为Lm。

[t0, t1] $$\Delta I_L = (\frac{Vin}{2n} - Vo)DT / Lo$$

[t1, t3] $$\Delta I_L = Vo(1/2 - D)T / Lo$$

$$Vo = \frac{Vin}{n} D \qquad D < 0.5$$

桥式变换器（Bridge Type Converter)特征：



$$Vo = \frac{Vin}{n} D \qquad D < 0.5$$

$$\Delta I_L = Vo(1/2 - D)T / Lo$$

$$\Delta Vc = (Io / n)DT / (2C1)$$

优点：

1. 变压器正负工作，不需要辅助的复位电路。
2. 输出纹波频率是开关频率的两倍，所需电感量小。
3. 线性输出控制特性。
4. 电路平衡对称。

缺点：

1. 变压器结构复杂。
2. 输入电压范围较小。

几种隔离式变换器之比较：

	变压器复位方式	原边开管电压应力	输出特性	占空比范围	输出纹波频率	输出纹波电流	适用范围
反激	输出电压复位	Vds=Vin/(1-D)	$Vo=\frac{VinD}{n(1-D)}$	0<D<1	f	$\Delta I_o=\frac{I_o}{1-D}$	小功率，宽范围输入，多路输出
谐振复位正激	谐振电容电压复位	Vds=Vin+Vc	$Vo=\frac{VinD}{n}$	0<D<1	f	$\Delta I_o=\frac{V_o(1-D)T}{Lo}$	小功率，低电压输入
有源钳位正激	钳位电容电压复位	Vds=Vin/(1-D)	$Vo=\frac{VinD}{n}$	0<D<1	f	$\Delta I_o=\frac{V_o(1-D)T}{Lo}$	中小功率，宽范围输入，高效率
半桥	正负半周工作，自动复位	Vin	$Vo=\frac{VinD}{n}$	0<D<0.5	2f	$\Delta I_o=\frac{V_o(1-2D)T}{2Lo}$	较大功率，较小输入范围，快速响应