采用氮化镓设计高功率密度180W PD Adapter

Orson Chen
技术应用处
友尚集团

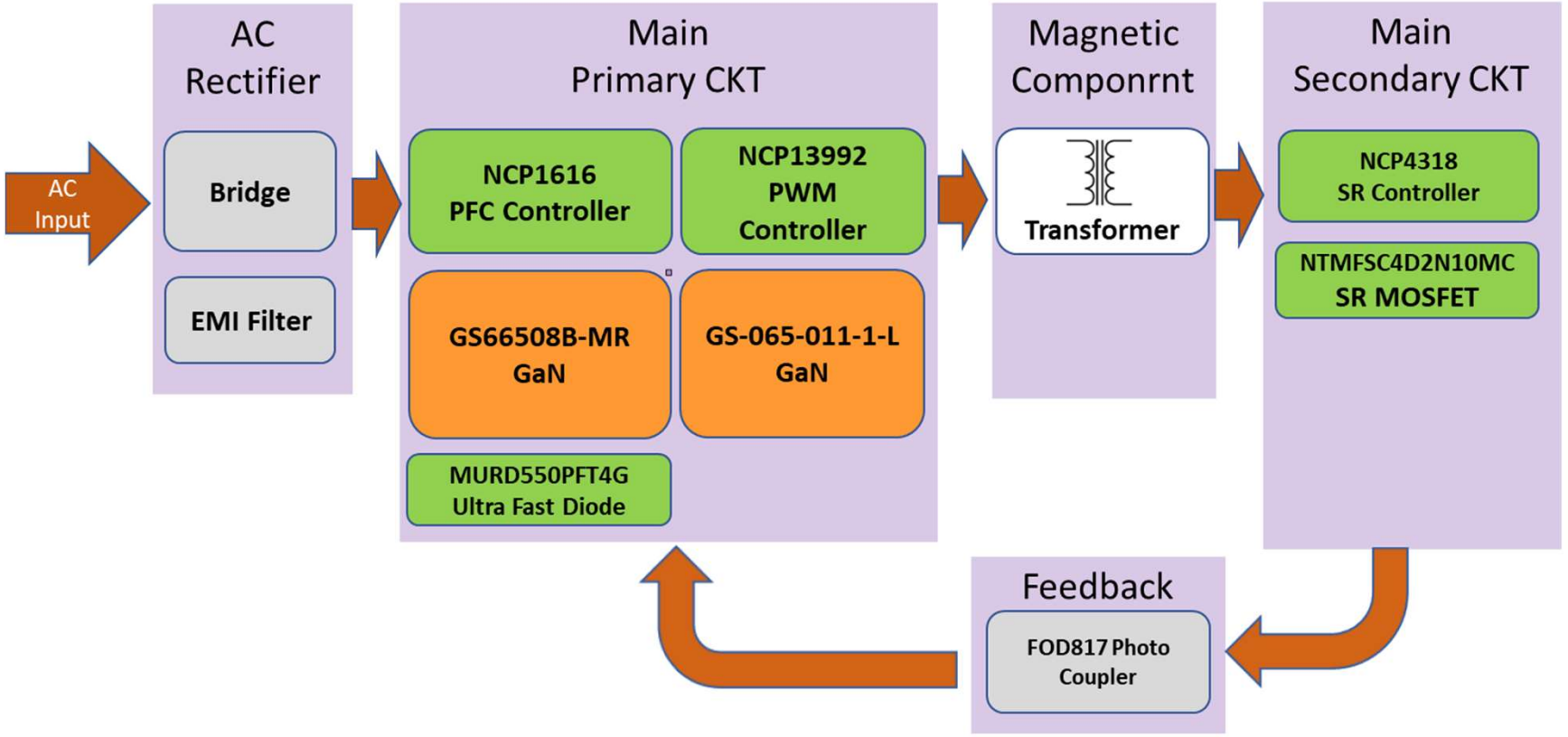
大纲

1. 简介
2. 谐振式转换器
3. LLC谐振式转换器动作原理
4. 设计步骤
5. 测试报告

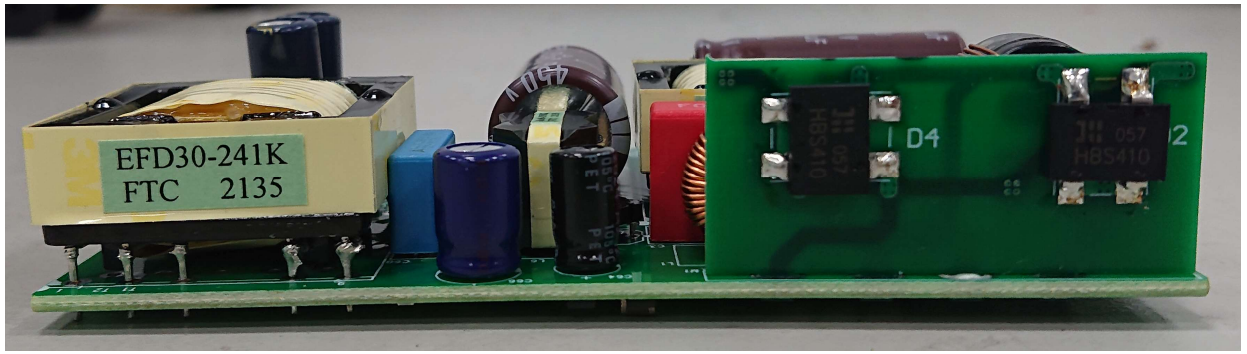
1. 简介

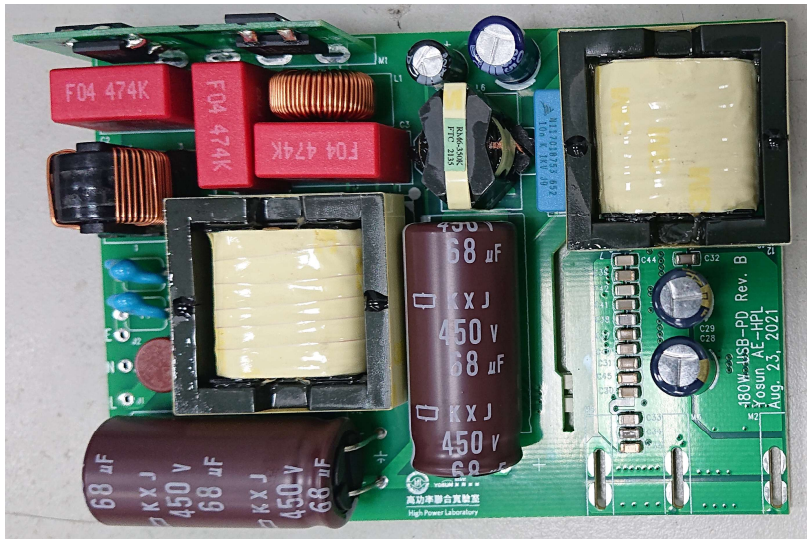
Items	Parameters
Input Voltage	90Vac to 264Vac
Output Power	180W
Topology	PFC + LLC + SR (NCP1616 + NCP13992 + NCP4318)
Power Device	GS66508B-MR, GS-065-011-1-L, NTMFSC4D2N10MC
Output Voltage	22V
Max. Output Current	9A
Dimension	106mm * 75mm * 30mm

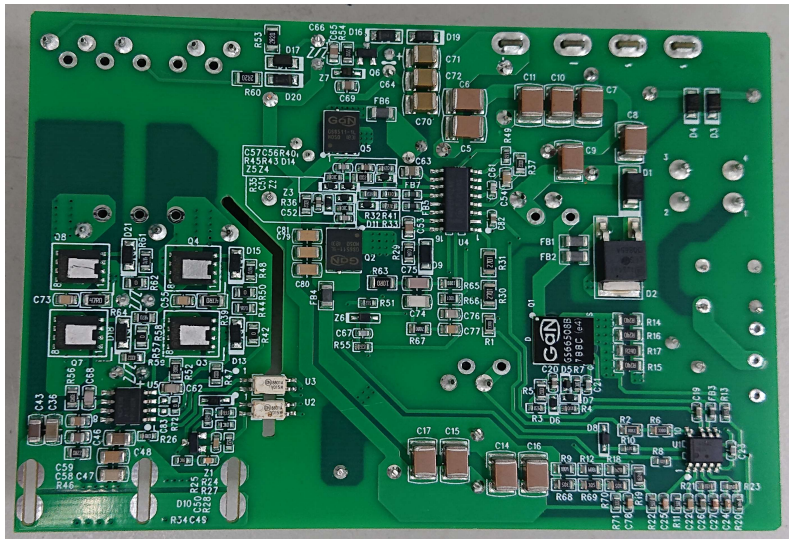
1. 简介


AC Input
AC Rectifier
Bridge
EMI Filter
Main Primary CKT
NCP1616 PFC Controller
NCP13992 PWM Controller
GS66508B-MR GaN
GS-065-011-1-L GaN
MURD550PFT4G Ultra Fast Diode
Magnetic Componrnt
Transformer
Main Secondary CKT
NCP4318 SR Controller
NTMFSC4D2N10MC SR MOSFET
Feedback
FOD817 Photo Coupler

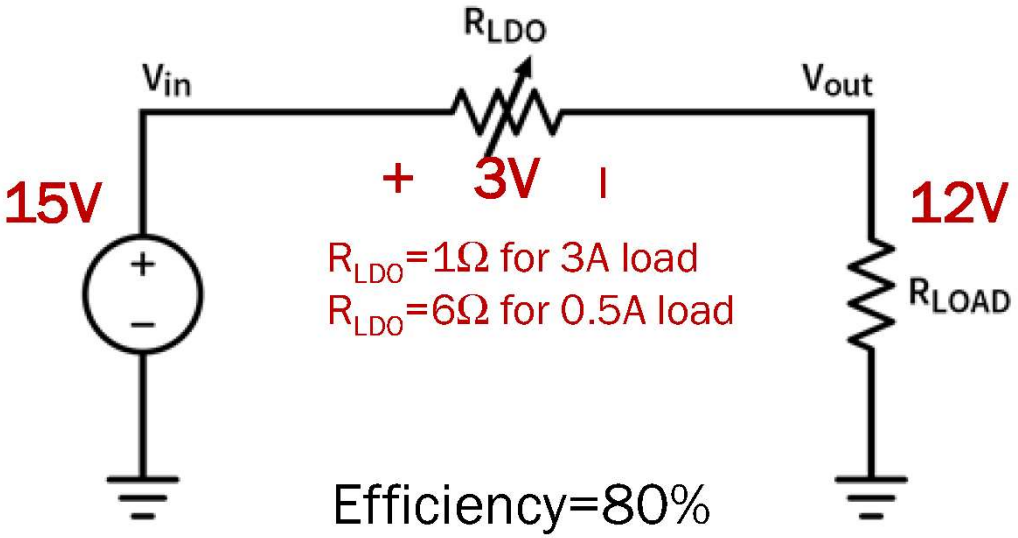
1. 简介

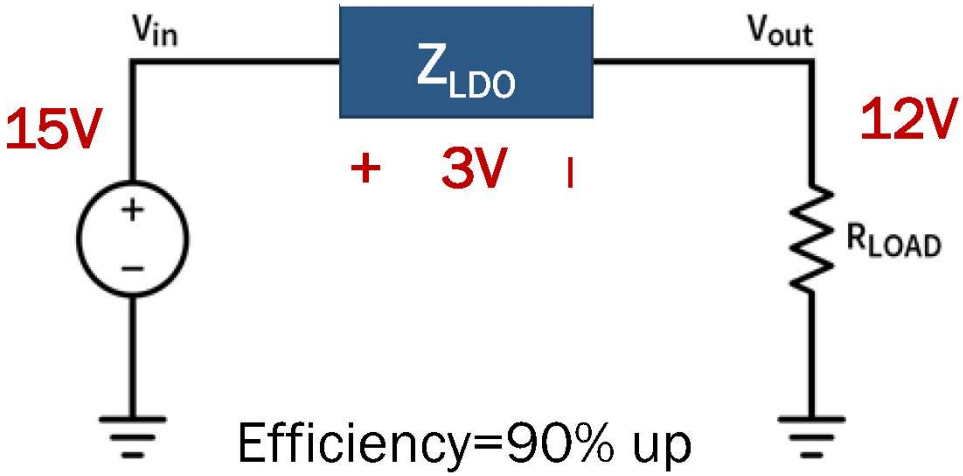

EFD30-241K
FTC 2135
D4


F04 474K
68 μF
450 V
KXJ
180W USB-PD Rev. B
Yosun AE-HPL
Aug. 23, 2021



电压转换器

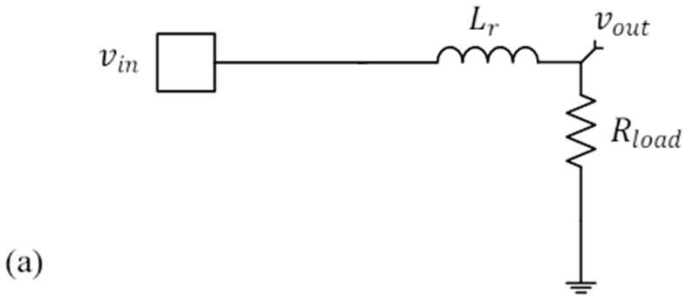




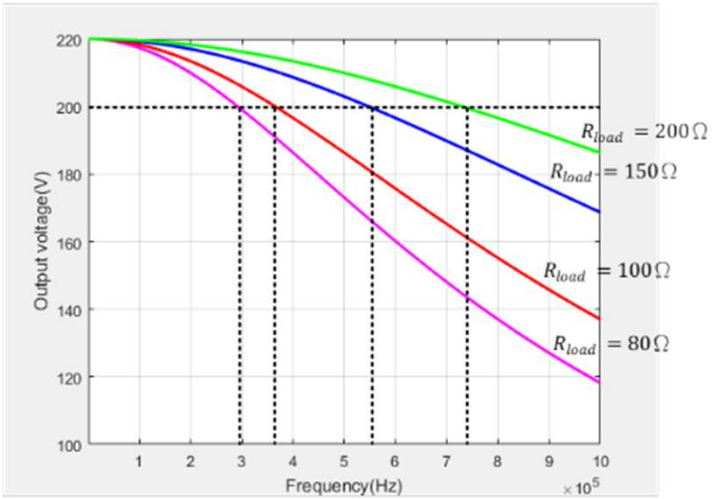
当输出电压由 R_{LDO} 调节时，这会消耗实际功率。 使用电感/电容进行调节可以显著提高效率 。

纯L与纯C转换器

操作频率易受到负载变化的影响

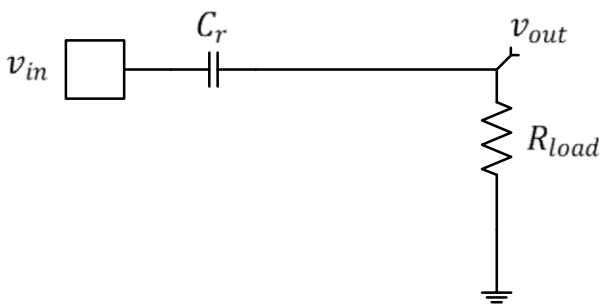


(a)

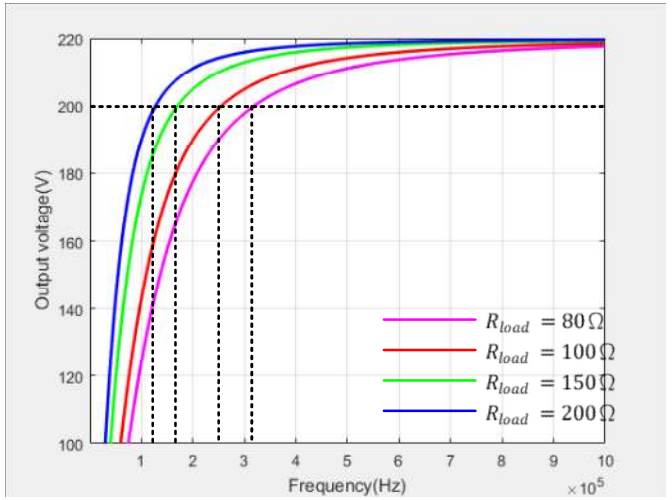


(b)

增益易受到负载变化的影响



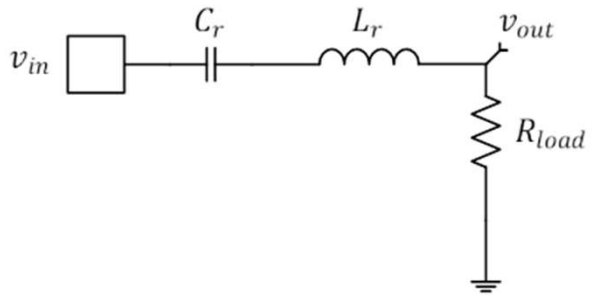
(a)



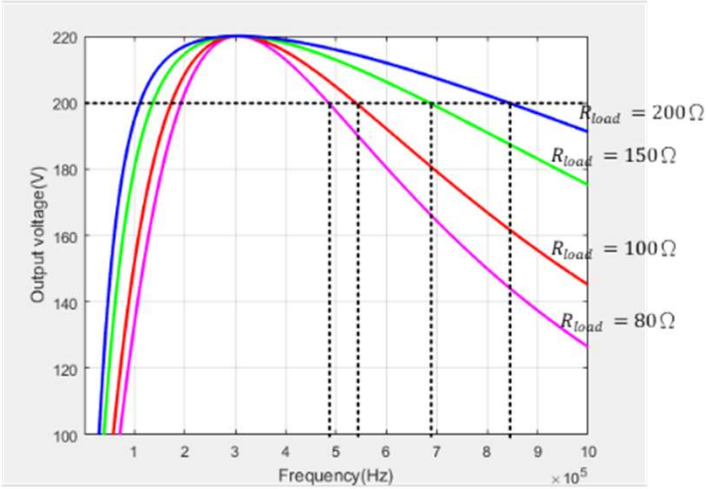
(b)

2. 谐振式轉換器

LC谐振式转换器具有上述两种转换器的优缺点



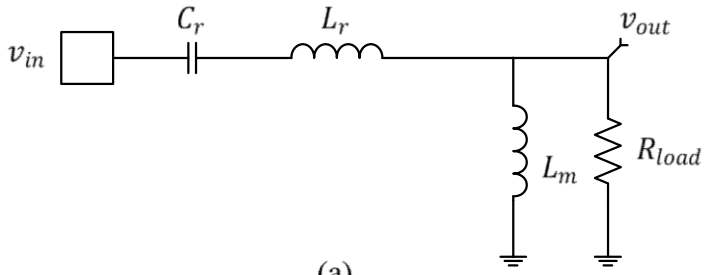
(a)



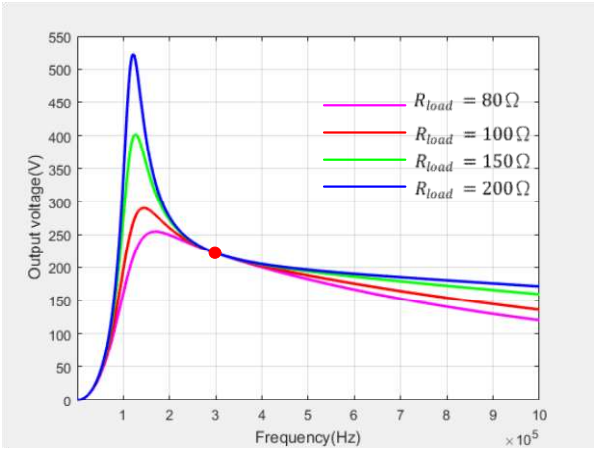
(b)

LLC谐振式转换器

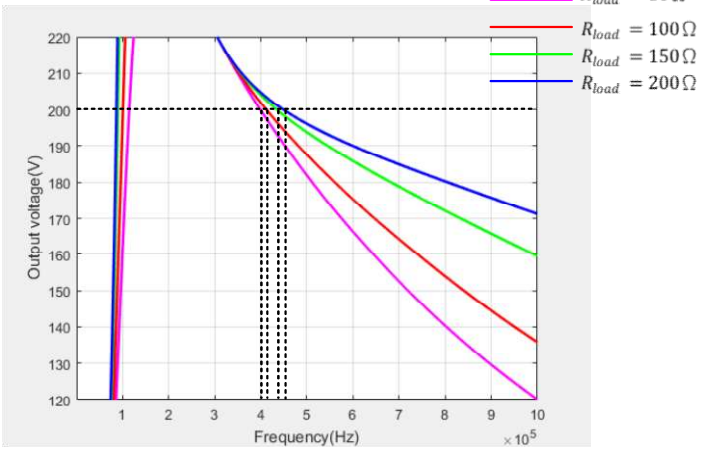
1. 负载变化下操作频率较不会出现剧烈的变化；
2. 转换器增益增加在设计上有更多弹性。



(a)



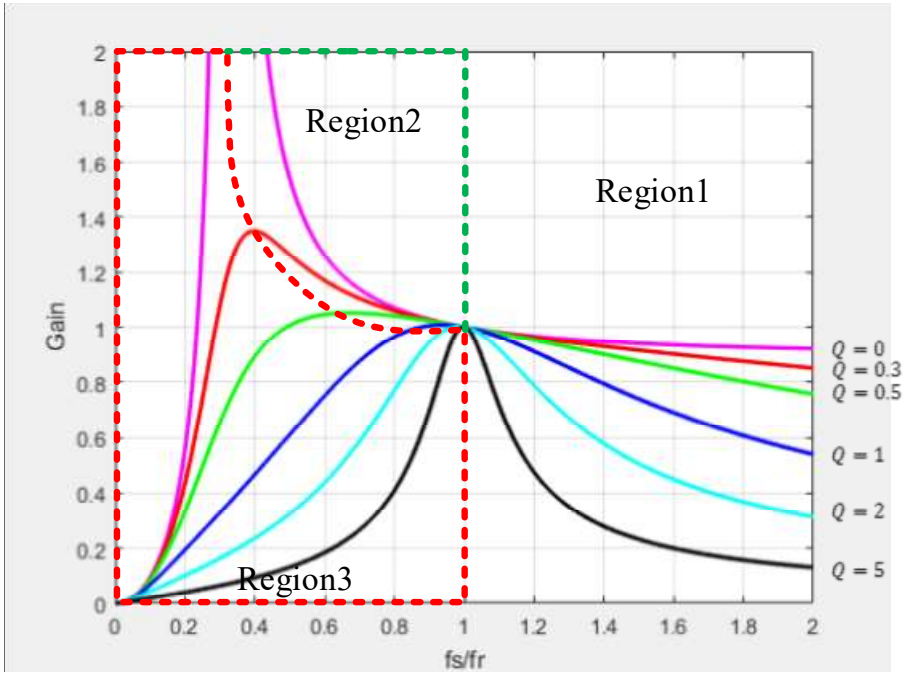
(b)



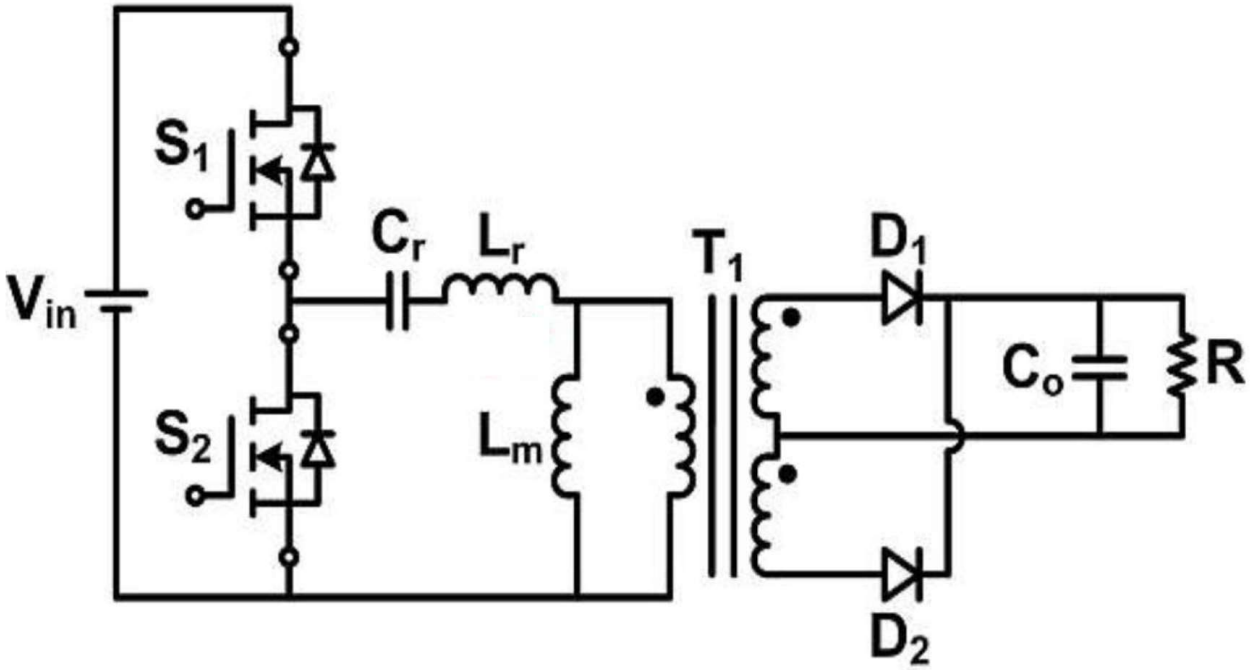
(c)

LLC谐振式转换器

- Region 1：转换器位于电感性区，功率晶体管皆工作于ZVS状态。
- Region 2：转换器处于电阻性，功率晶体管维持工作于ZVS状态。
- Region 3：转换器位于电容性区，二极管工作于ZCS状态。



LLC谐振式转换器

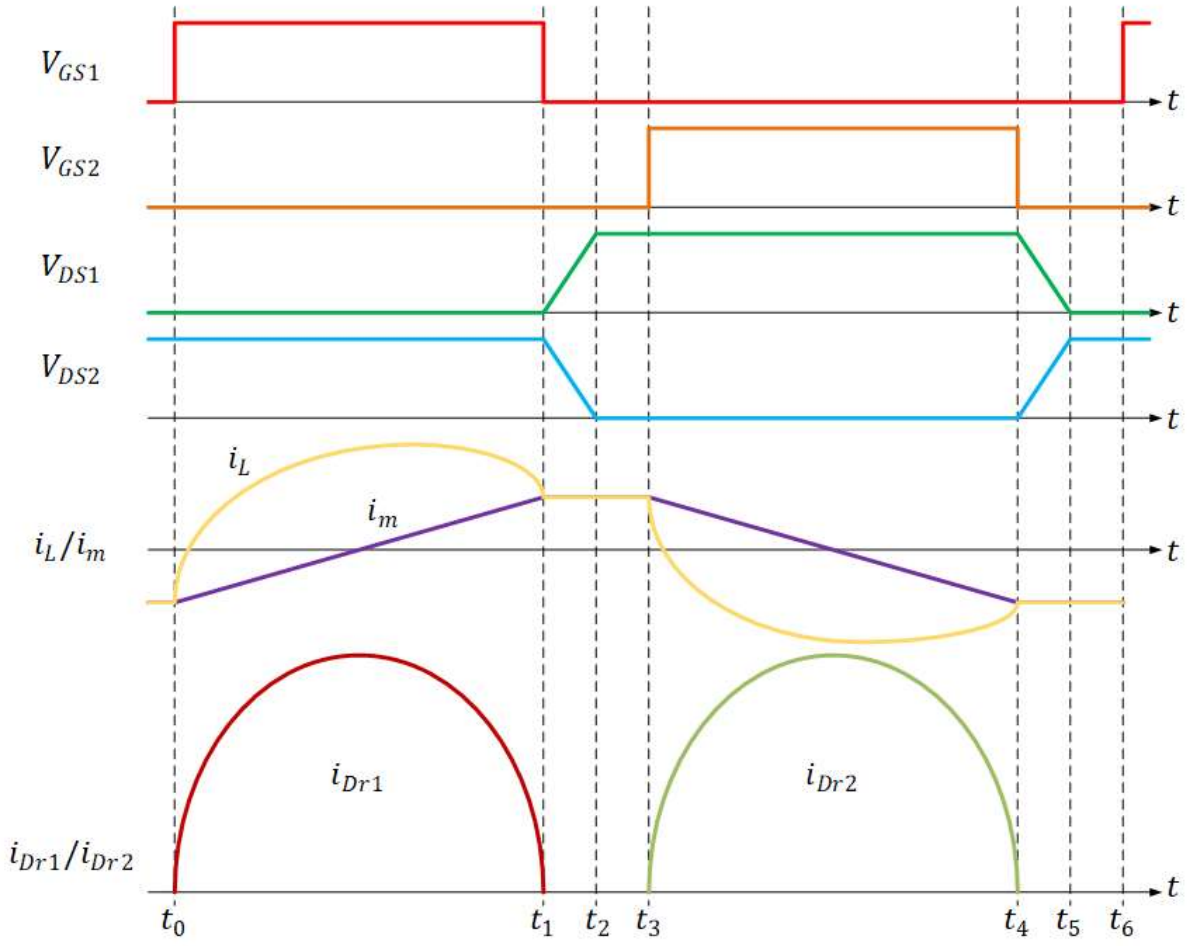


此架构包含两个晶体管、一个谐振电容、两个谐电感。工作频率随负载条件变化，S1、S2晶体管操作于零电压切换。

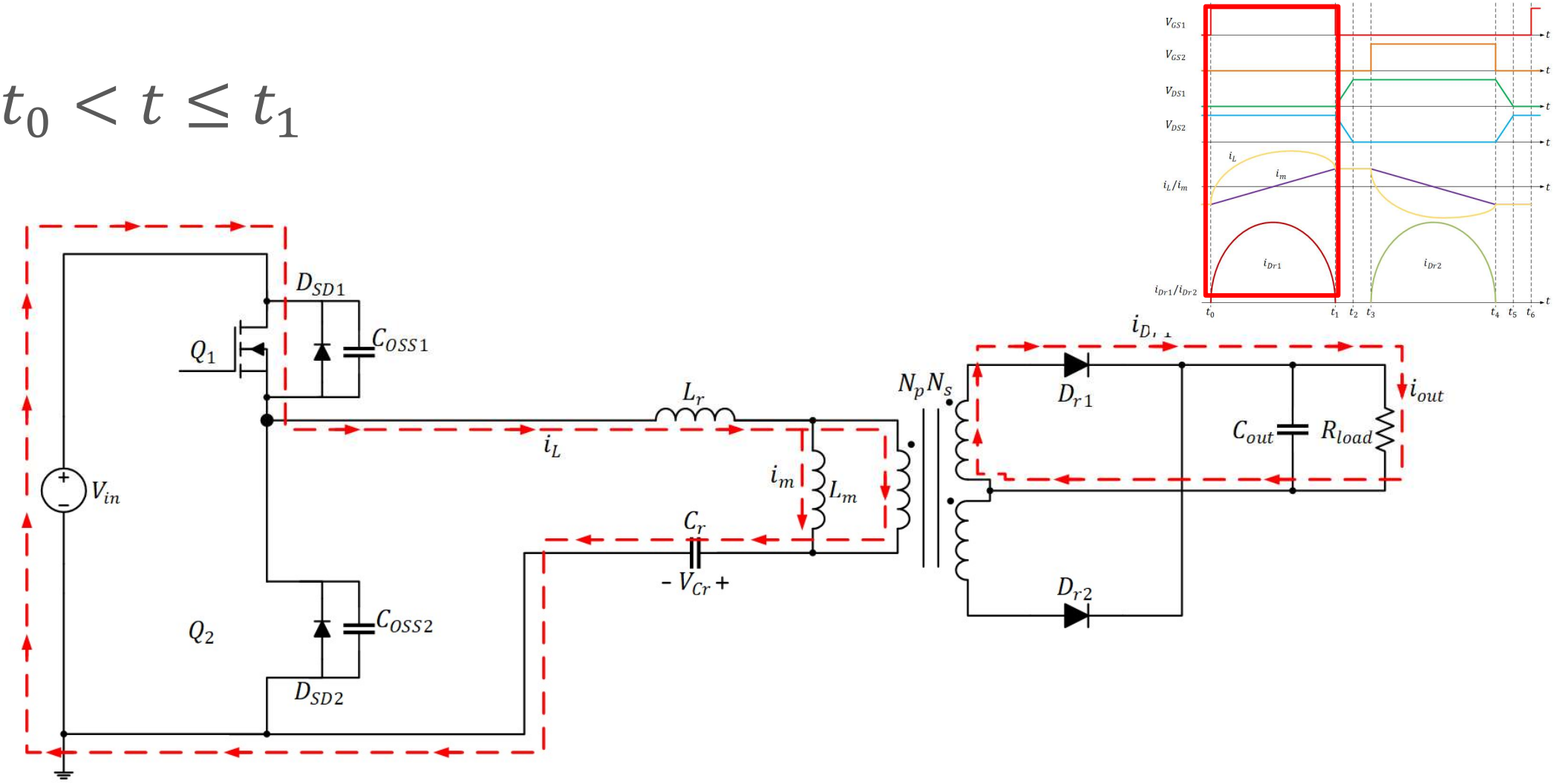
零电压切换(ZVS)

- LLC谐振式转换器最大的一项特性就是在全负载范围下都可以达到ZVS状态；
- 使用ZVS可降低切换损失；
- LLC谐振式转换器是利用死区时间(dead-time)，加上转换器处于电感性操作下达到ZVS状态。

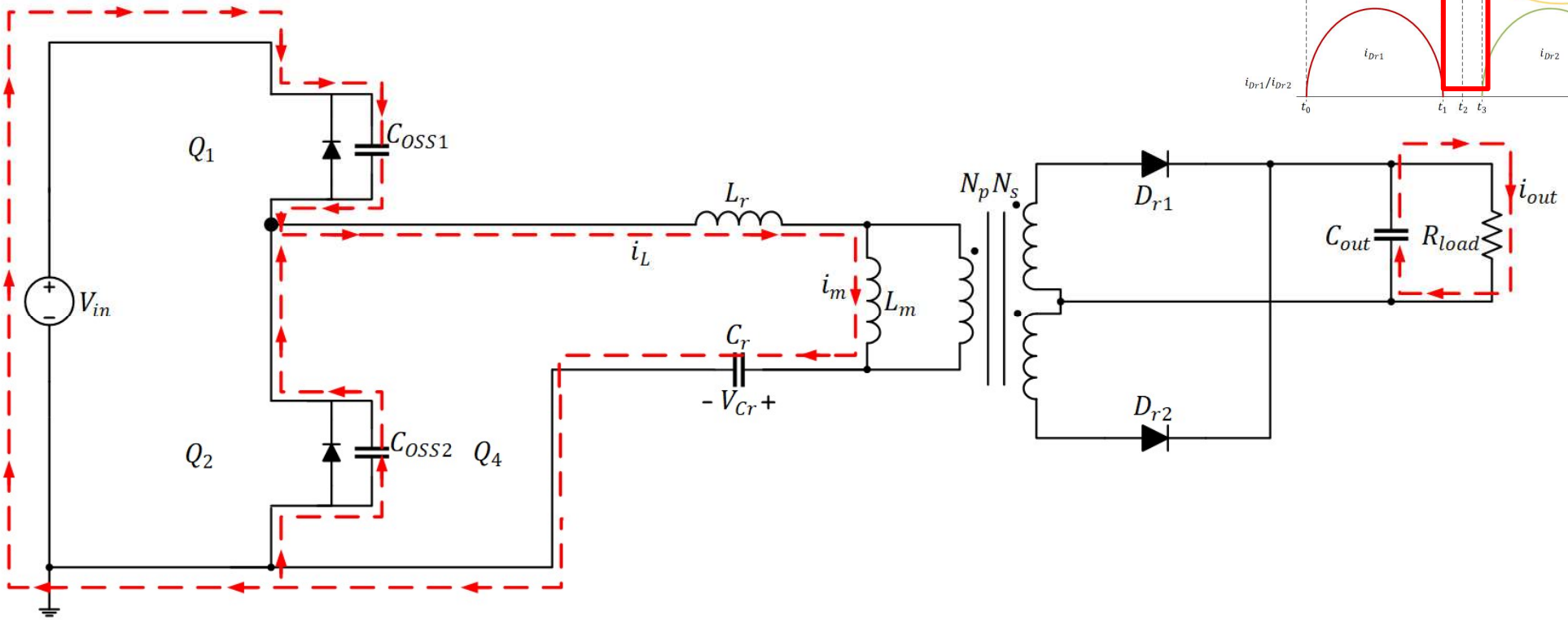
3. LLC谐振式转换器动作原理

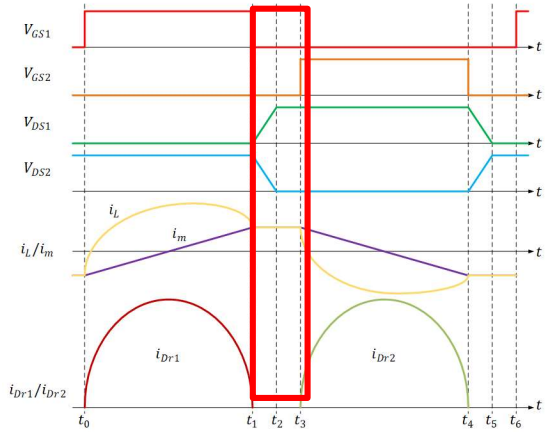


$$t_0 < t \leq t_1$$

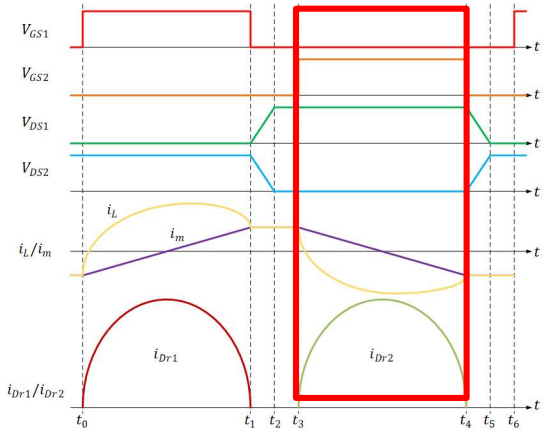

V_{GS1}
V_{GS2}
V_{DS1}
V_{DS2}
i_L
i_m
i_L/i_m
i_{Dr1}
i_{Dr2}
i_{Dr1}/i_{Dr2}
t_0 t_1 t_2 t_3 t_4 t_5 t_6
D_{SD1}
Q_1
C_{OSS1}
L_r
$N_p N_s$
D_{r1}
i_{out}
C_{out}
R_{load}
i_L
i_m
L_m
V_{in}
C_r
$- V_{Cr} +$
Q_2
C_{OSS2}
D_{r2}
D_{SD2}

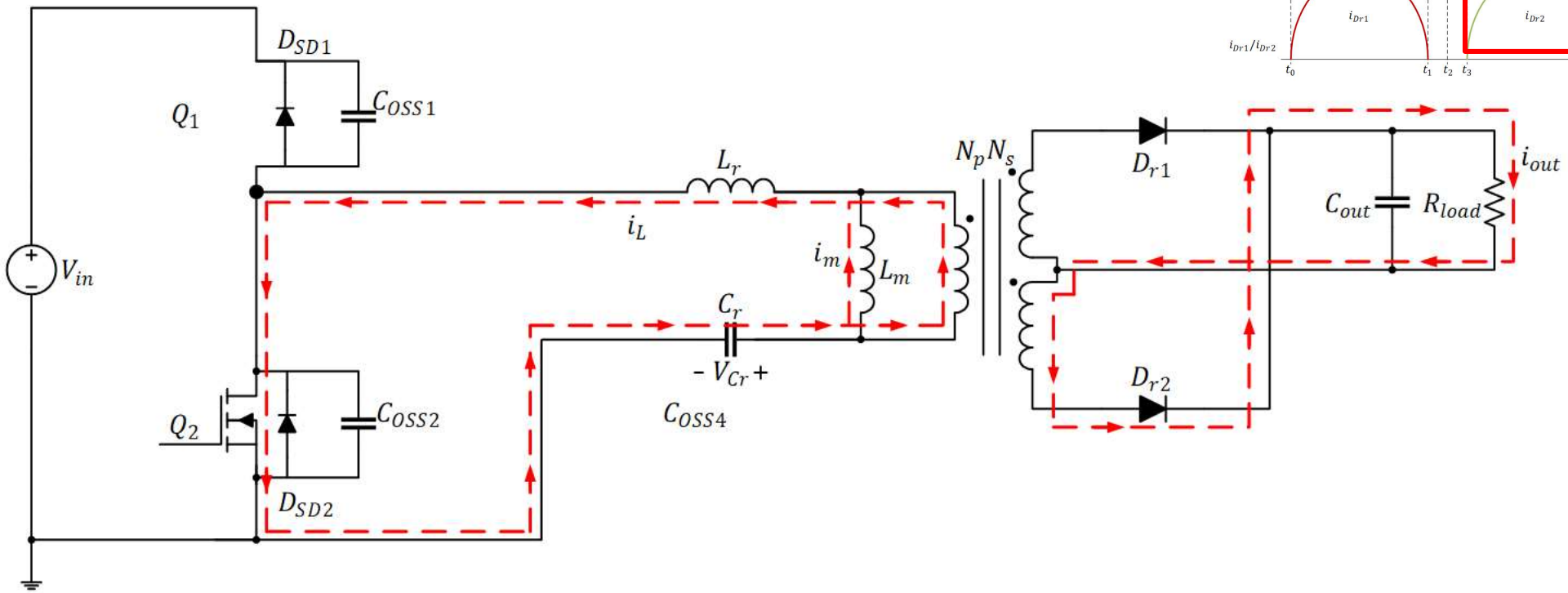
$t_1 < t \leq t_3$


Q_1
C_{OSS1}
L_r
i_L
$N_p N_s$
D_{r1}
C_{out}
R_{load}
i_{out}
V_{in}
i_m
L_m
C_r
$-V_{Cr}+$
Q_2
C_{OSS2}
Q_4
D_{r2}

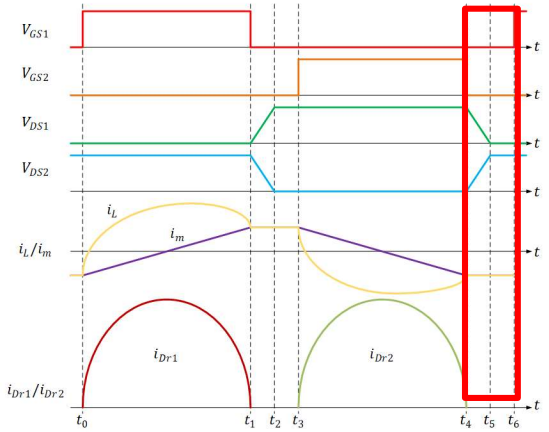

V_{GS1}
V_{GS2}
V_{DS1}
V_{DS2}
i_L
i_m
i_L/i_m
i_{Dr1}
i_{Dr2}
i_{Dr1}/i_{Dr2}
t_0 t_1 t_2 t_3 t_4 t_5 t_6

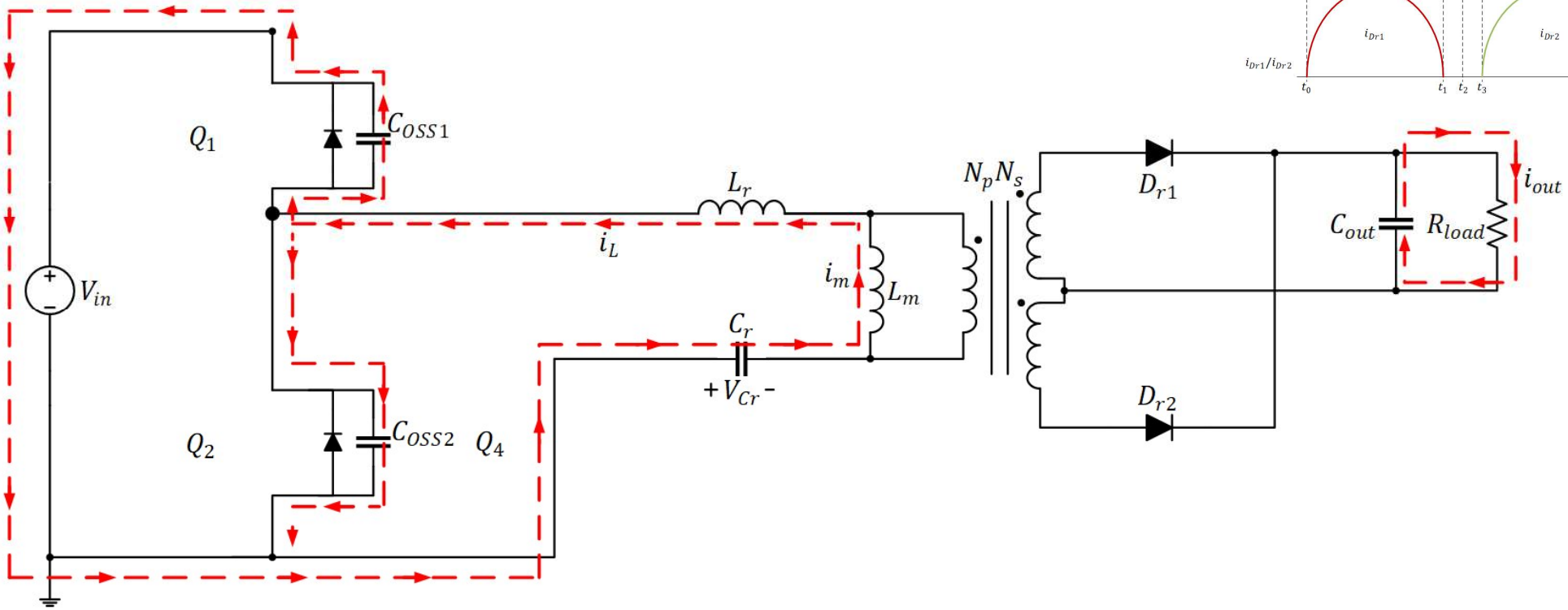
$t_3 < t \leq t_4$


V_{GS1}
V_{GS2}
V_{DS1}
V_{DS2}
i_L
i_m
i_L/i_m
i_{Dr1}
i_{Dr2}
i_{Dr1}/i_{Dr2}
t_0 t_1 t_2 t_3 t_4 t_5 t_6


D_{SD1}
Q_1
C_{OSS1}
L_r
$N_p N_s$
D_{r1}
i_{out}
C_{out}
R_{load}
i_L
i_m
L_m
V_{in}
C_r
$- V_{Cr} +$
Q_2
C_{OSS2}
C_{OSS4}
D_{r2}
D_{SD2}

$t_4 < t \leq t_6$

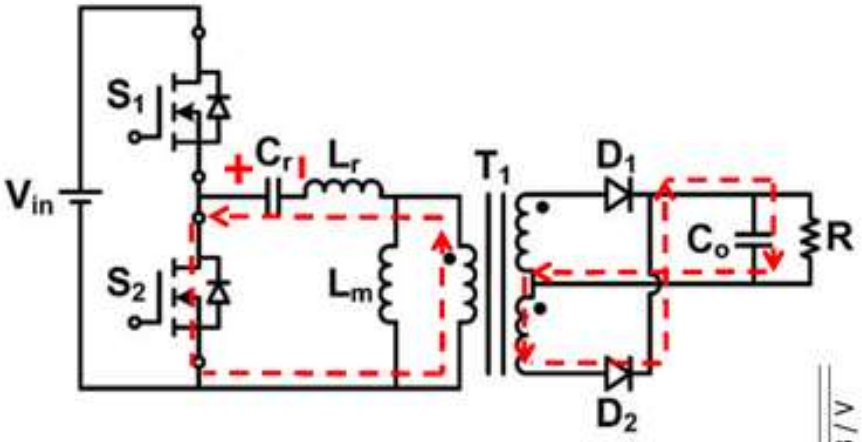

V_{GS1}
V_{GS2}
V_{DS1}
V_{DS2}
i_L
i_m
i_L/i_m
i_{Dr1}
i_{Dr2}
i_{Dr1}/i_{Dr2}
t
t_0
t_1
t_2
t_3
t_4
t_5
t_6

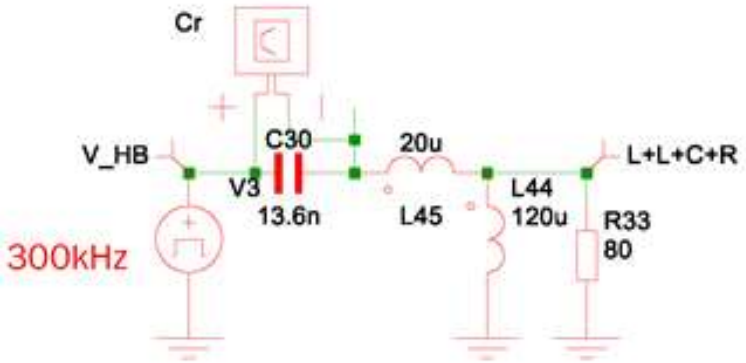

Q_1
C_{OSS1}
L_r
$N_p N_s$
D_{r1}
i_{out}
C_{out}
R_{load}
i_L
i_m
L_m
V_{in}
C_r
$+V_{Cr}-$
Q_2
C_{OSS2}
Q_4
D_{r2}

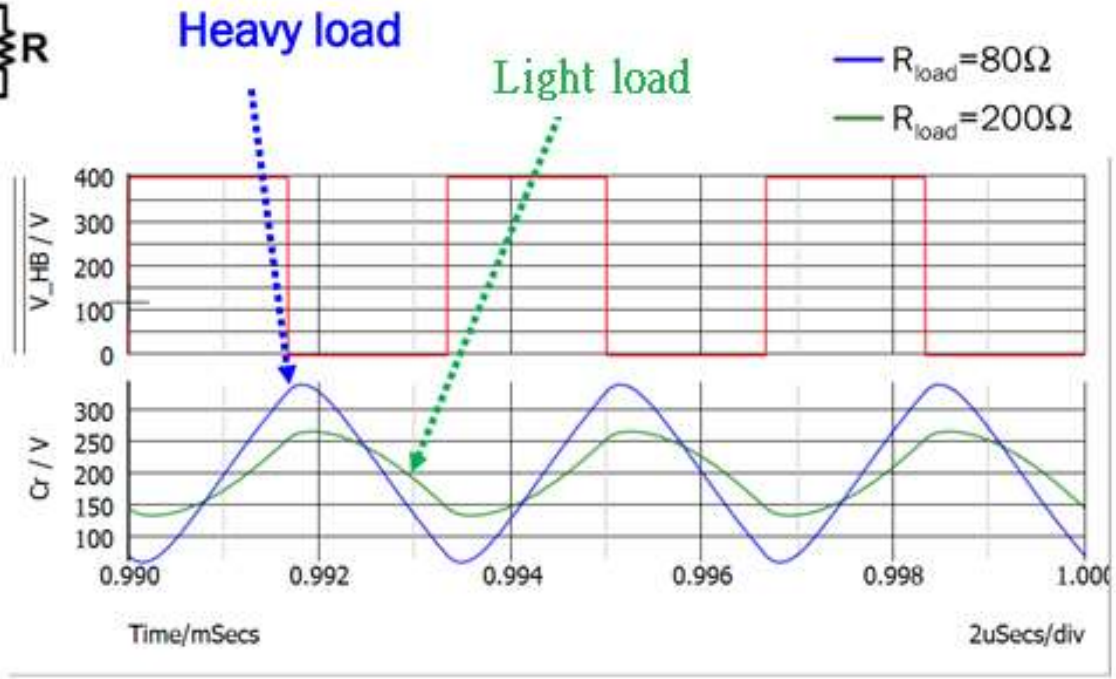
4. 设计步骤

1. **决定重载运行频率 -** 基于开关和磁性组件的选择
2. **决定谐振电容 -** 检查它是否可以输出最大功率并节省保持时间(hold-up time)的余量
3. **决定谐振电感 -** 基于重载运行频率
4. **决定激磁电感 -** 检查保持时间是否足够
5. **决定变压器的匝数比 -** 检查是否有余量输出最大功率

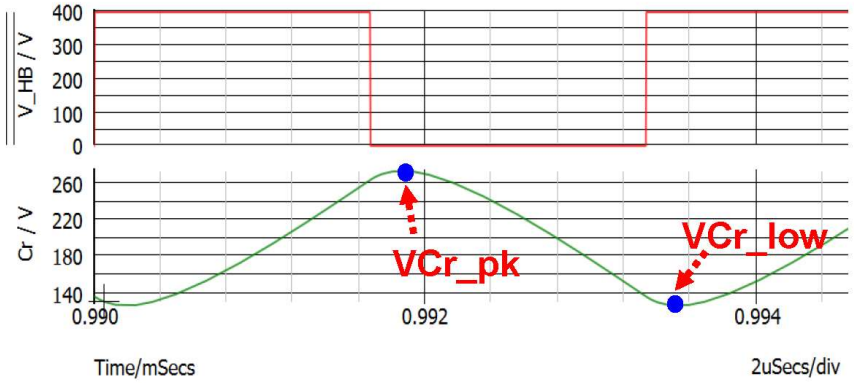
决定谐振电容(1)


S1
S2
Vin
Cr
Lr
Lm
T1
D1
D2
Co
R


Cr
V_HB
C30
V3
13.6n
20u
L45
L44
120u
L+L+C+R
R33
80
300kHz


Heavy load
Light load
Rload=80Ω
Rload=200Ω
V_HB / V
400
300
200
100
0
Cr / V
300
250
200
150
100
0.990
0.992
0.994
0.996
0.998
1.000
Time/mSecs
2uSecs/div

决定谐振电容(2)



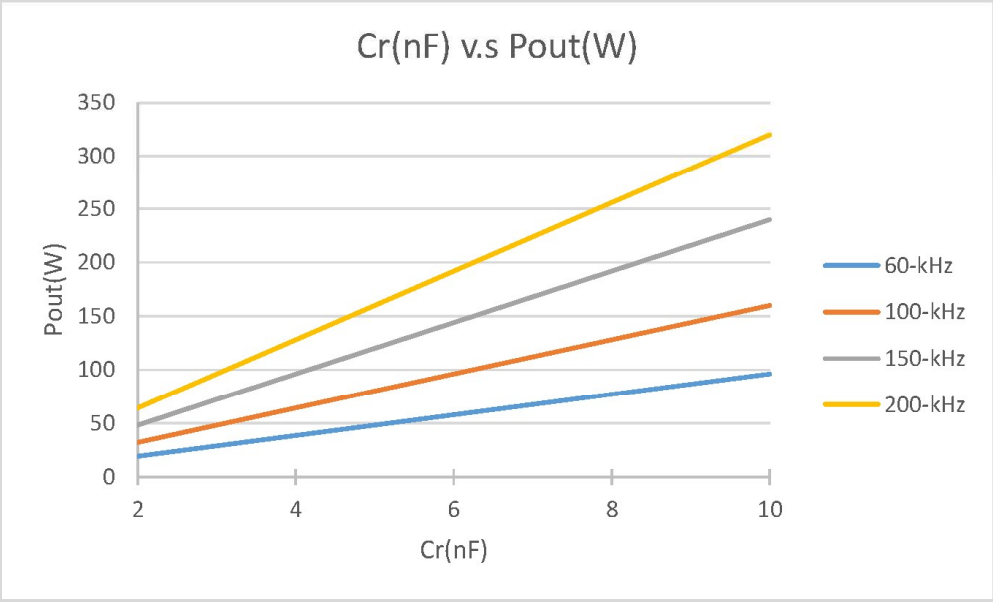
$$\frac{1}{2} \cdot Cr \cdot \left[{V_{Cr\_pk}}^2 - {V_{Cr\_low}}^2 \right] \cdot f_{SW} = \frac{P_{out}}{2}$$

$$Cr \cdot \left[2 \cdot V_{Cr\_avg} \cdot \Delta V_{Cr} \right] \cdot f_{SW} = P_{out}$$

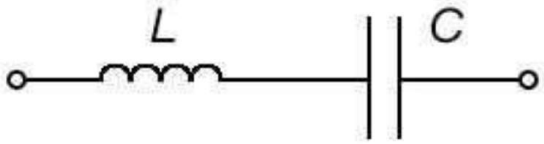
Let V_{Cr_avg} $is\ 200V, max.\Delta V_{Cr}$ $is\ 400V$

$$\rightarrow \boxed{min.Cr = \frac{P_{out}}{400^2 \cdot f_{SW}}}$$

諧振電容和工作頻率決定了最大輸出功率



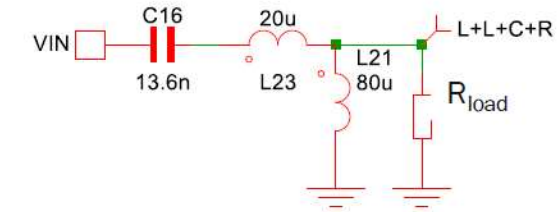
决定谐振电感

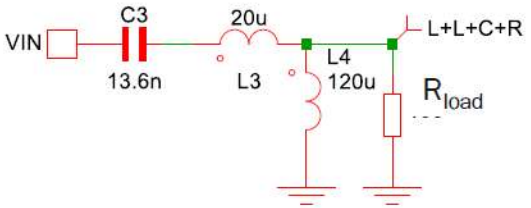


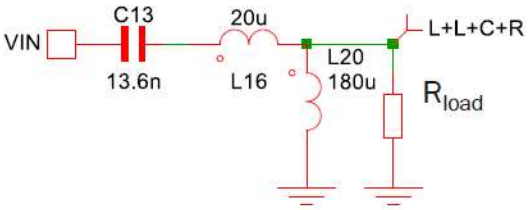
$$f = \frac{1}{2\pi\sqrt{LC}}$$

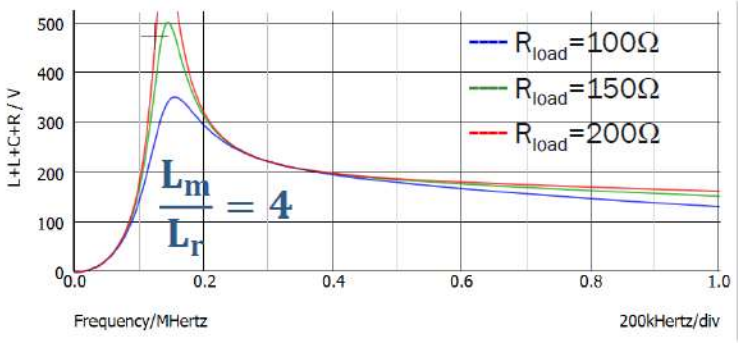
決定諧振電容後，諧振電感可決定諧振頻率。諧振頻率通常接近重載的工作頻率。

L_m/L_r

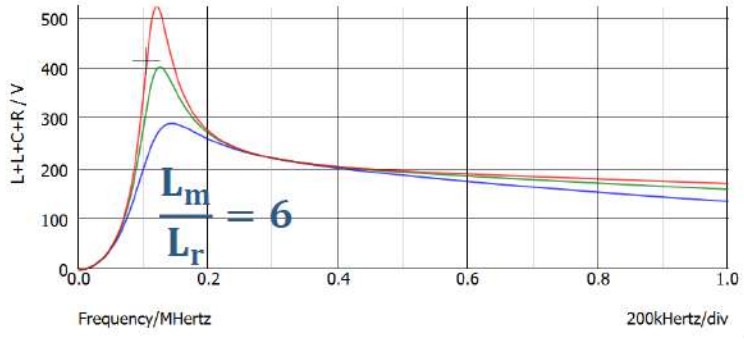


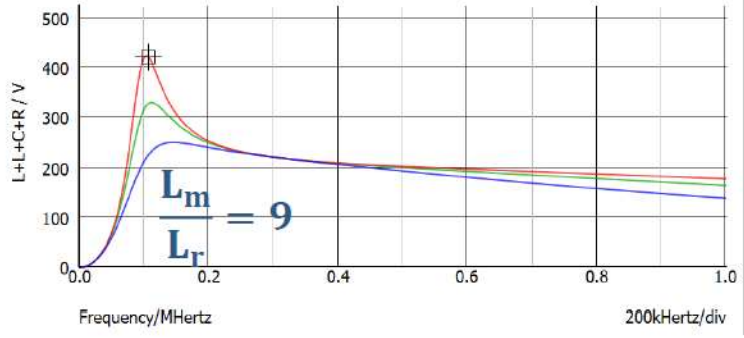






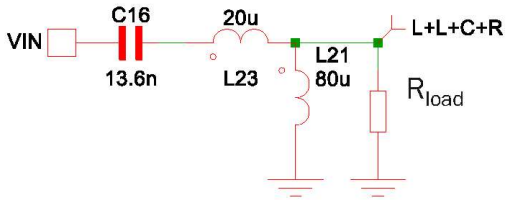
Higher maximum gain

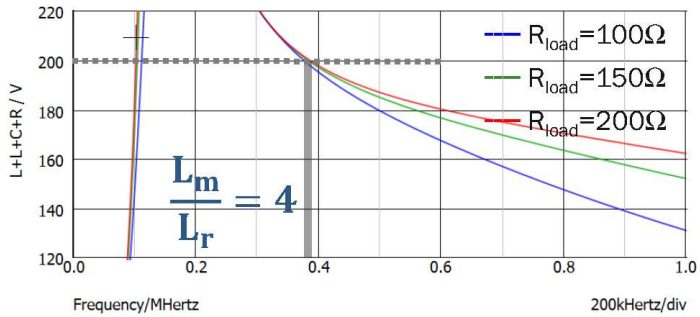




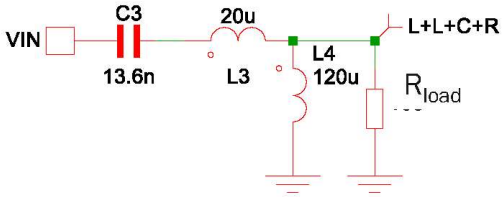
Higher efficiency

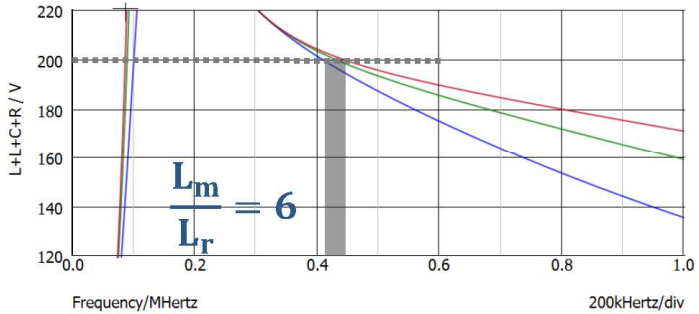
L_m/L_r

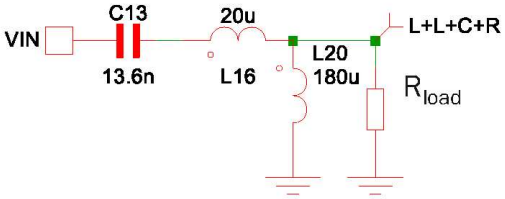


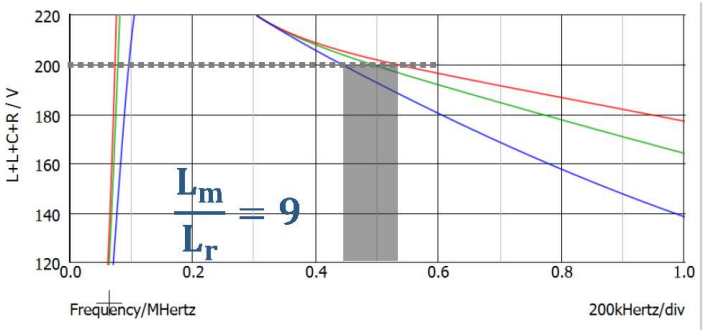


Narrower frequency range



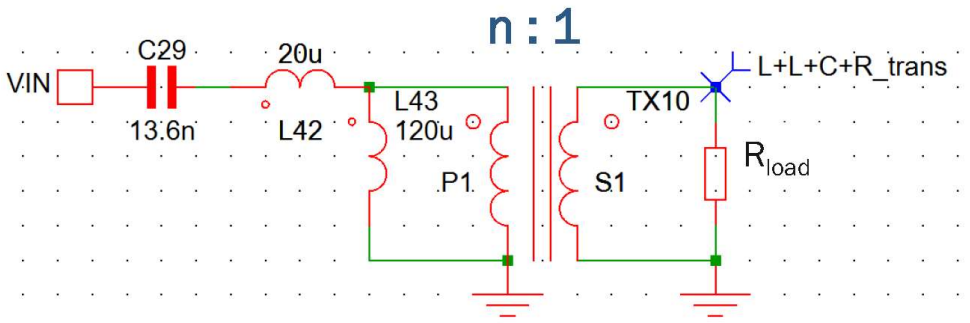


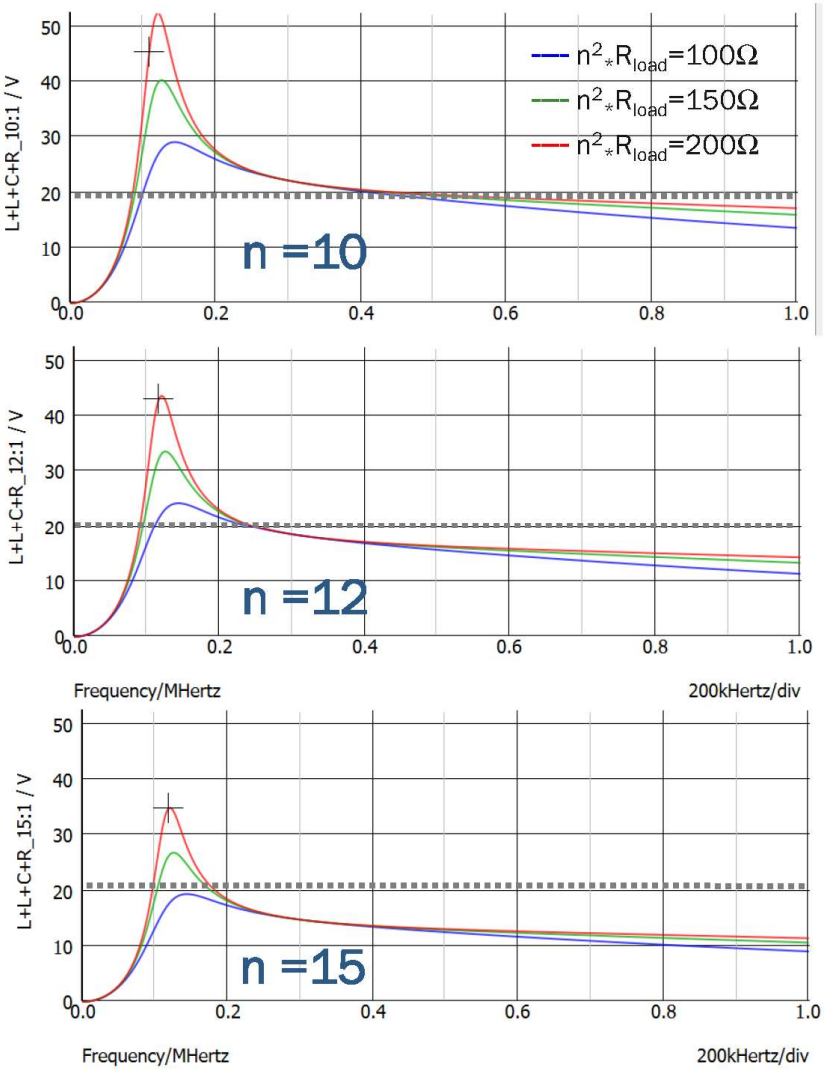




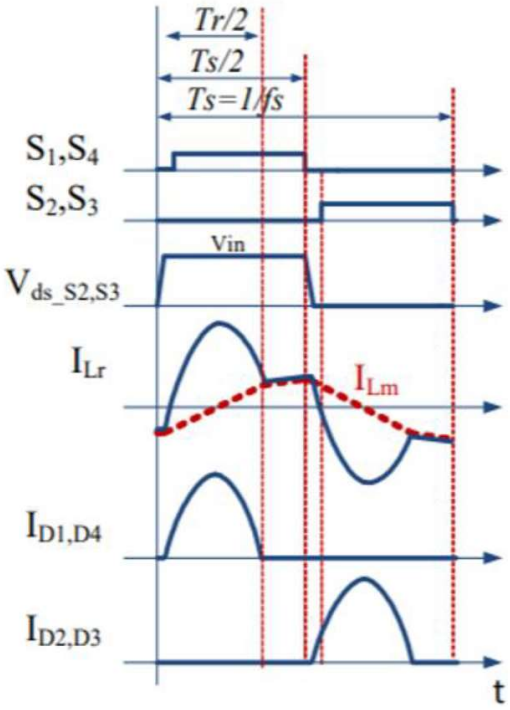
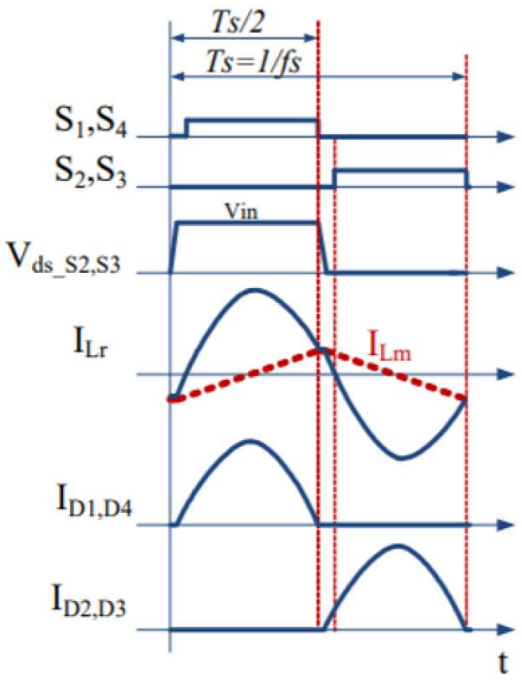
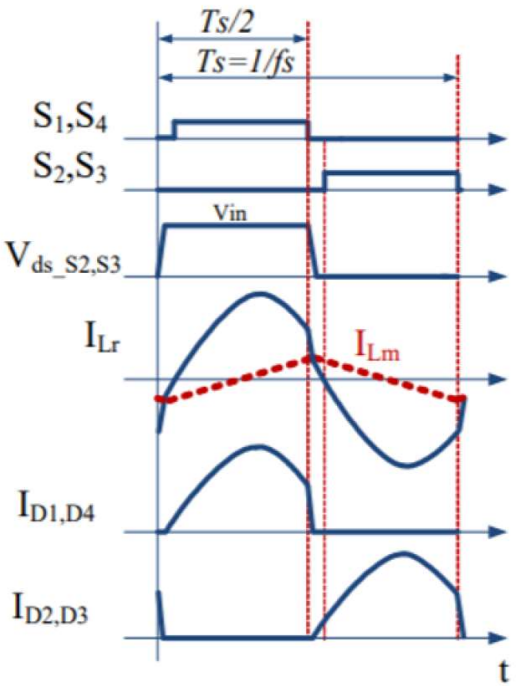
Higher efficiency

Turn Ratio


n : 1
VIN
C29
13.6n
20u
L42
L43
120u
P1
S1
TX10
L+L+C+R_trans
R_{load}

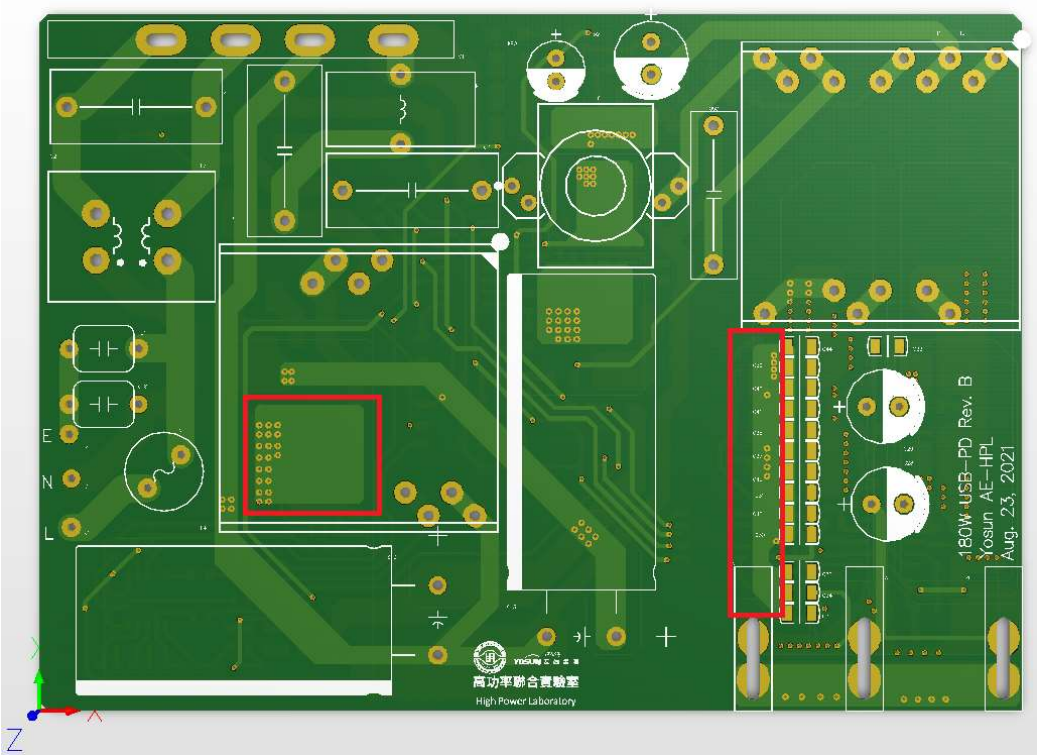

L+L+C+R_10:1 / V
n^2*R_{load}=100Ω
n^2*R_{load}=150Ω
n^2*R_{load}=200Ω
n =10
L+L+C+R_12:1 / V
n =12
Frequency/MHertz
200kHertz/div
L+L+C+R_15:1 / V
n =15
Frequency/MHertz
200kHertz/div

操作特性

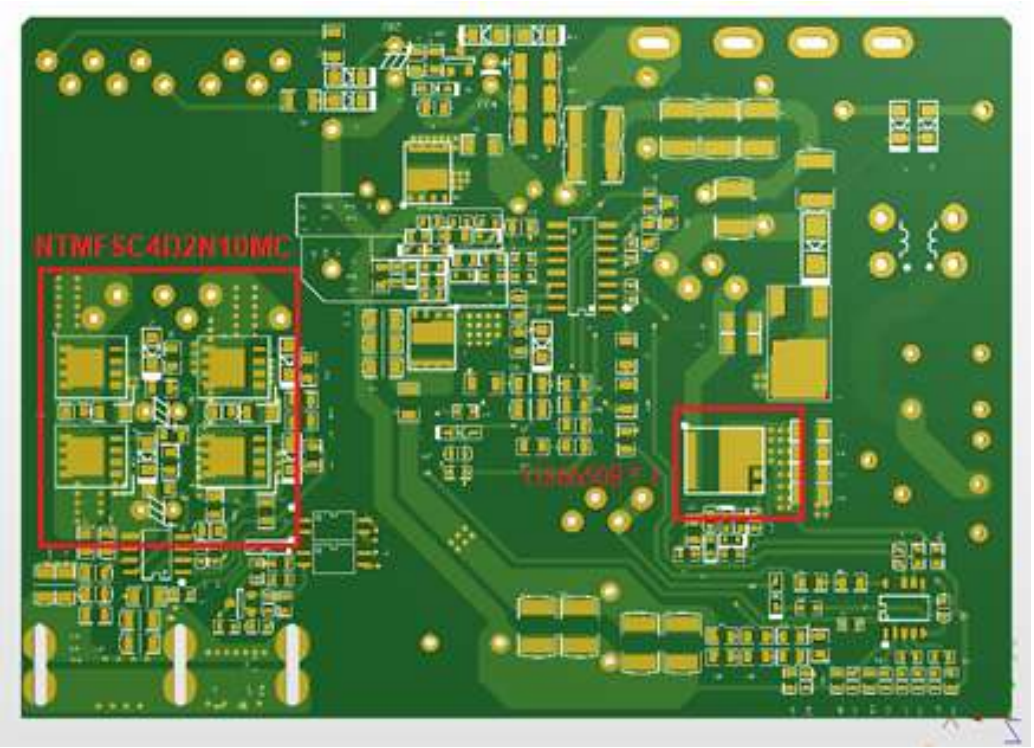
Below resonant frequency operation fs<fr	At Resonant frequency operation fs=fr.	Above resonant frequency operation fs>fr.
		

散热设计

GS66508B及NTMFSC4D2N10MC散热铜箔面积



Top



Bottom

散热设计

Assume

$$\eta_{PFC} = 0.98 ; \eta_{LLC} = 0.93 \Rightarrow \eta_{sys} = \eta_{PFC} \times \eta_{LLC} = 0.91$$

Power Loss from PFC

$$P_{Loss} = 180 \times (1 - 0.98) = 3.6W$$

Power Loss from LLC

$$P_{Loss} = 180 \times (1 - 0.93) = 12.6W$$

Assume the most loss from PFC and LLC are on GS66508B and NTMFSC4D2N10MC.

$$P_{D(GS66508B)} = 3.6 \times 0.9 = 3.24W$$

$$P_{D(\mathrm{NTMFSC2}N10MC)} = 12.6 \times 0.8 = 10.08W$$

散热设计

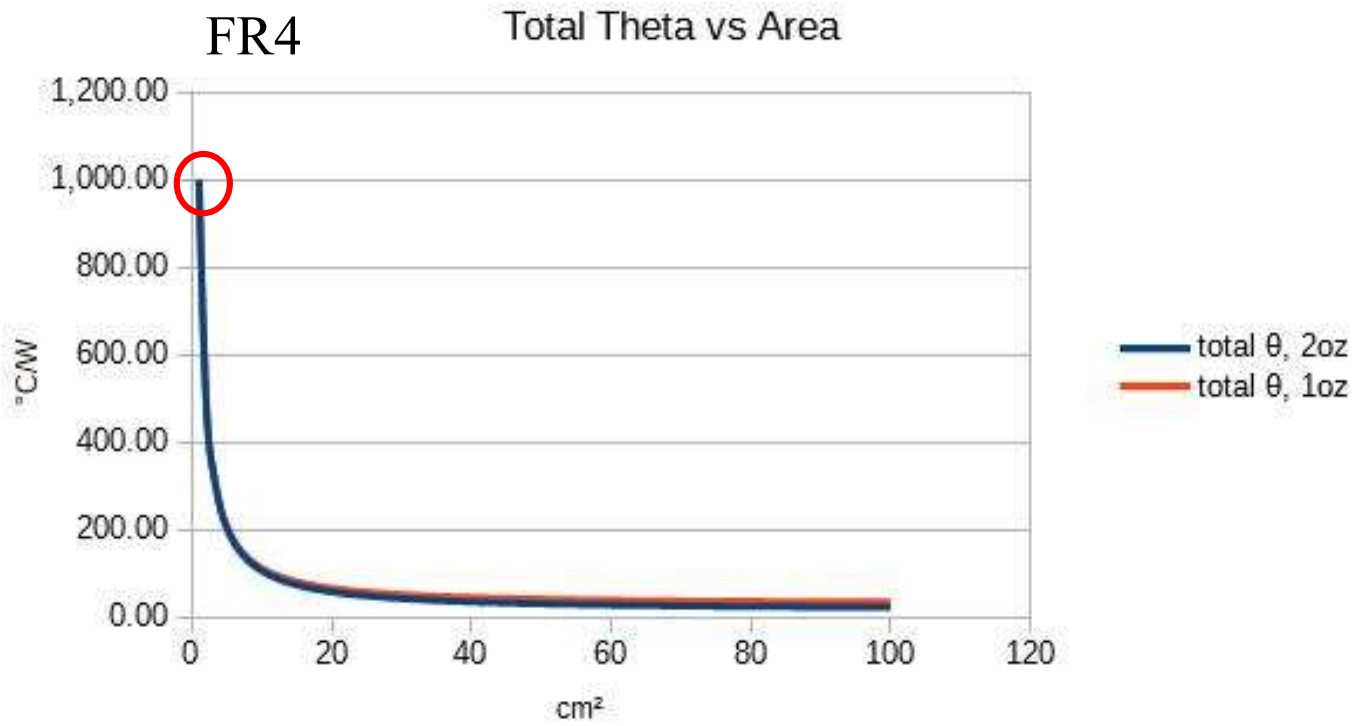
GS66508B Thermal Characteristics (Typical values unless otherwise noted)

Parameter	Symbol	Value	Units
Thermal Resistance (junction-to-case) – bottom side	$R_{\Theta JC}$	0.5	°C /W
Thermal Resistance (junction-to-ambient) (Note 3)	$R_{\Theta JA}$	24	°C /W
Maximum Soldering Temperature (MSL3 rated)	T_{SOLD}	260	°C

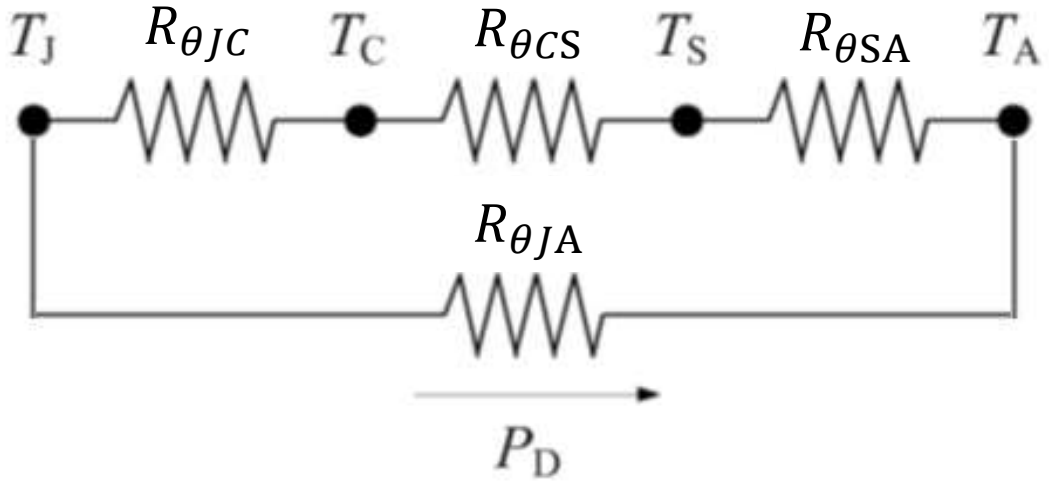
NTMFSC4D2N10MC THERMAL CHARACTERISTICS

Symbol	Parameter	Max	Unit
$R_{\theta JC}$	Junction–to–Case – Steady State (Note 1)	1.23	°C/W
$R_{\theta JA}$	Junction–to–Ambient – Steady State (Note 1)	19	

散热设计


FR4
Total Theta vs Area
1,200.00
1,000.00
800.00
600.00
400.00
200.00
0.00
°C/W
0
20
40
60
80
100
120
cm²
total θ, 2oz
total θ, 1oz

散热设计



The front side is in parallel with the backside and also the FR4:

Total R_θ *= 1/((1/(*R_θ *front side)) + (1/(*R_θ *back side +*$R_{\theta FR4}$*)))*

$R_{\theta FR4}$ *vs*$R_{\theta SA}$*, for 1 cm²:*

(λ_{FR4}*) = 0.0023 W / (cm °C);*

$R_{\theta FR4}$ *= (1/0.0023) * (0.16 cm thick PCB) / 1 cm² = 70 °C/W*

$R_{\theta FR4}$*(one side) = 1000 °C/W*

$R_{\theta FR4}$*(four sides) = 1000 // 1000 // 1000 // (1000 + 70) = 254.17 °C/W*

散热设计

Temperature on GS66508B

$$\mathrm{R}_{\theta\mathrm{FR4}} = \frac{1}{0.0023} \times 0.16cm\ thick\ PCB \times \frac{1}{1.6\times1.0} = 43.48\ ℃/W$$

$$\mathrm{R}_{\theta S}\ (one\ side) = 1000\ ℃/W$$

$$\mathrm{R}_{\theta S}\ (four\ side) = 1000//1000//1000//(1000 + 43.48) = 252.63\ ℃/W$$

$$T_{J(GS66508\mathrm{B})} = P_{D(GS66508\mathrm{B})}\left[\left(R_{\theta JC} + R_{\theta C}\ + \mathrm{R}_{\theta S}\ \right)//R_{\theta JA}\right] + 30$$

$$= 3.24 \times [(0.5 + 0.5 + 252.63)//24] + 30$$

$$= 101.04℃$$

散热设计

Temperature on NTMFSC4D2N10MC

$$\mathrm{R}_{\theta\mathrm{FR}} = \frac{1}{0.0023} \times 0.16cm\ thick\ PCB \times \frac{1}{2.5\times2.5} = 11.13\ ℃/W$$

$$\mathrm{R}_{\theta SA}(one\ side) = 1000\ ℃/W$$

$$\mathrm{R}_{\theta SA}(four\ side) = 1000//1000//1000//(1000 + 11.13) = 250.69\ ℃/W$$

$$T_{J(\mathrm{NTMFSC2}N10MC)} = P_{D(\mathrm{NTMFSC2}N10MC)}\left[\left(R_{\theta JC} + R_{\theta CS} + \mathrm{R}_{\theta SA}\right)//R_{\theta JA}\right] + 30$$

$$= 10.08 \times \left[\left(\frac{1.23}{4} + 0.5 + 250.69\right)//\frac{19}{4}\right] + 30$$

$$\approx 77℃$$

5. 测试报告(1)

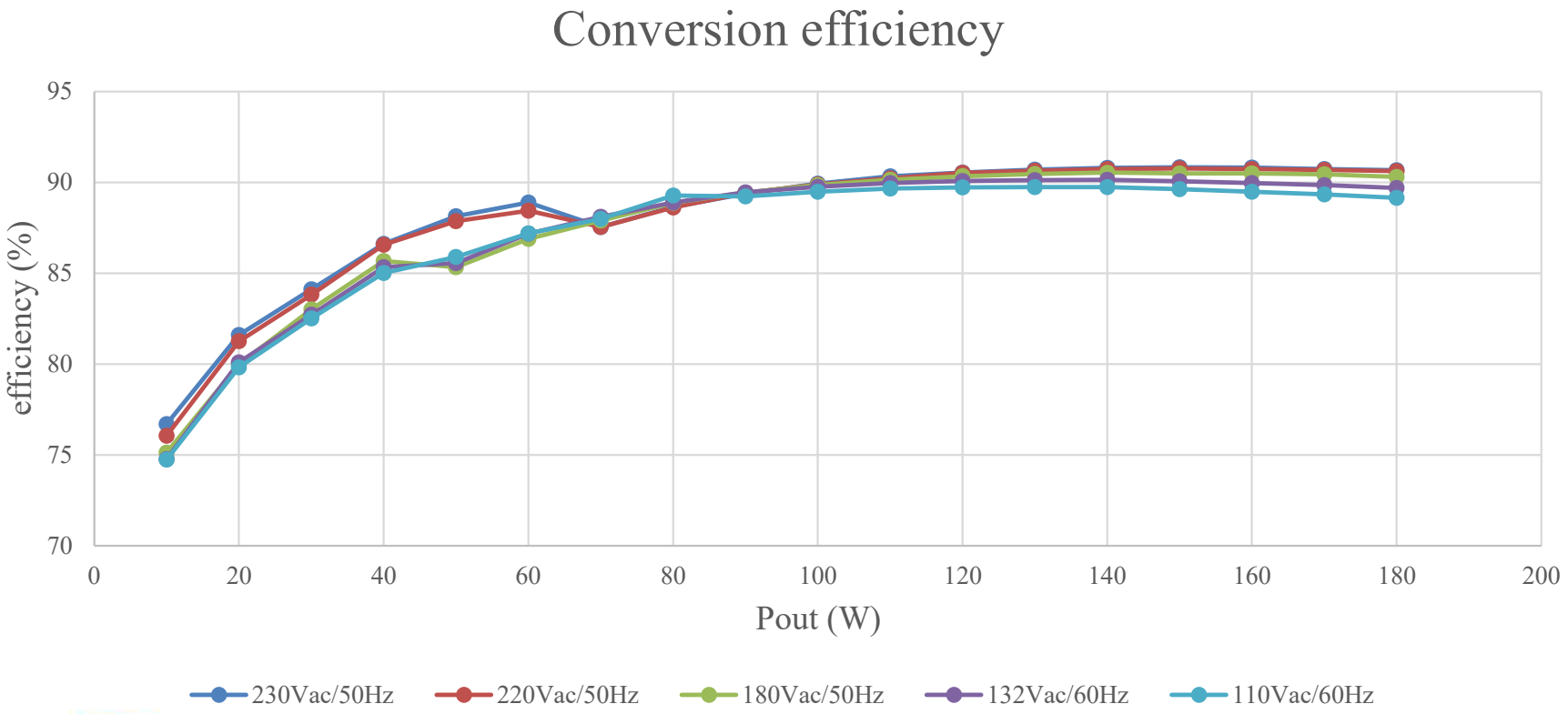
0.05%　　3%

Line/Load Regulation

Input voltage	No load	Half load	Full load
90Vac / 63Hz	21.98	21.68	21.37
110Vac / 60Hz	21.97	21.68	21.37
132Vac / 60Hz	21.98	21.67	21.37
180Vac / 50Hz	21.98	21.67	21.37
220Vac / 50Hz	21.97	21.67	21.37
230Vac / 50Hz	21.97	21.67	21.37

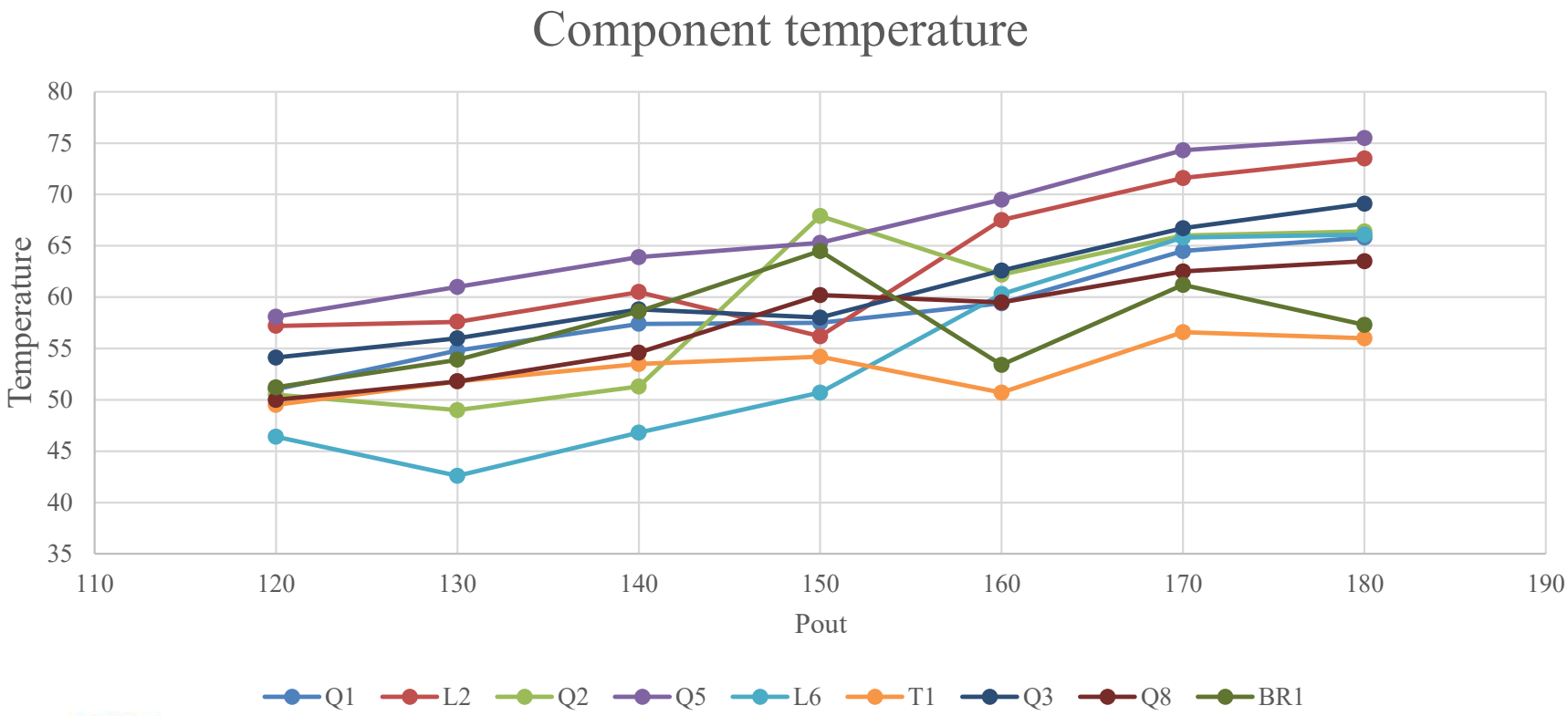
5. 测试报告(2)

Input voltage: 110Vac ~ 230Vac and 50Hz ~ 63Hz



5. 测试报告(3)

Input voltage: 110Vac / 60Hz, Burn-in time: 15min



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设计	支持	购买	合作
1,000+款系统级解决方案参考设计,1,200+博客文章 覆盖物联网、车联网、电源等热门应用领域	700+位工程师 在线工程答疑与 提供技术支持服务	系统级方案部份链接 电商 wpgdadago.com 贩卖开发板, 套件, 模块, PCBA 板卡	外部方案商与原厂共同参与, 取得曝光与媒合之机会

大大通注册二维码

微信公众号二维码

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人联人・志通路 大大通

Thank you

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