安森美半导体
ON Semiconductor®

改进型双开关正激转换器应用
An Improved 2-Switch Forward Converter Application

议程 Agenda

1. 正激转换器概论 Generalities on forward converters
2. 磁芯复位：三次绕组、RCD钳位、双开关正激 Core reset: tertiary winding, RCD clamp, 2-switch forward
3. NCP1252演示板规格概览 Specs review of the NCP1252’s demo board
4. 率功元件计算Power components calculation
5. NCP1252元件计算 NCP1252 components calculation
6. 闭环反馈：仿真及补偿 Closed-loop feedback: simulations and compensation
7. 演示板电路图及图片 Demo board schematics & picture
8. 演示板性能概览 Board performance review
9. 总结 Summary

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单开关正激转换器概论

Generalities About the 1-Switch Forward Converter

优点

- 变压器隔离型降压拓扑结构 It is a transformer-isolated buck-derived topology
- 只需单颗晶体管，对地参考 It requires a single transistor, ground referenced
- 非脉冲输出电流减小电容中的均方根值 Non-pulsating output current reduces rms content in the caps

缺点

- 功率能力小于半桥或全桥拓扑结构 Smaller power capability than a full or half-bridge topology
- 由于磁芯复位，占空比漂移有限 Limited in duty-cycle (duty ratio) excursion because of core reset
- MOSFET 漏电压变化达到输入电压的两倍或更多 The MOSFET drain voltage swings to twice the input voltage or more

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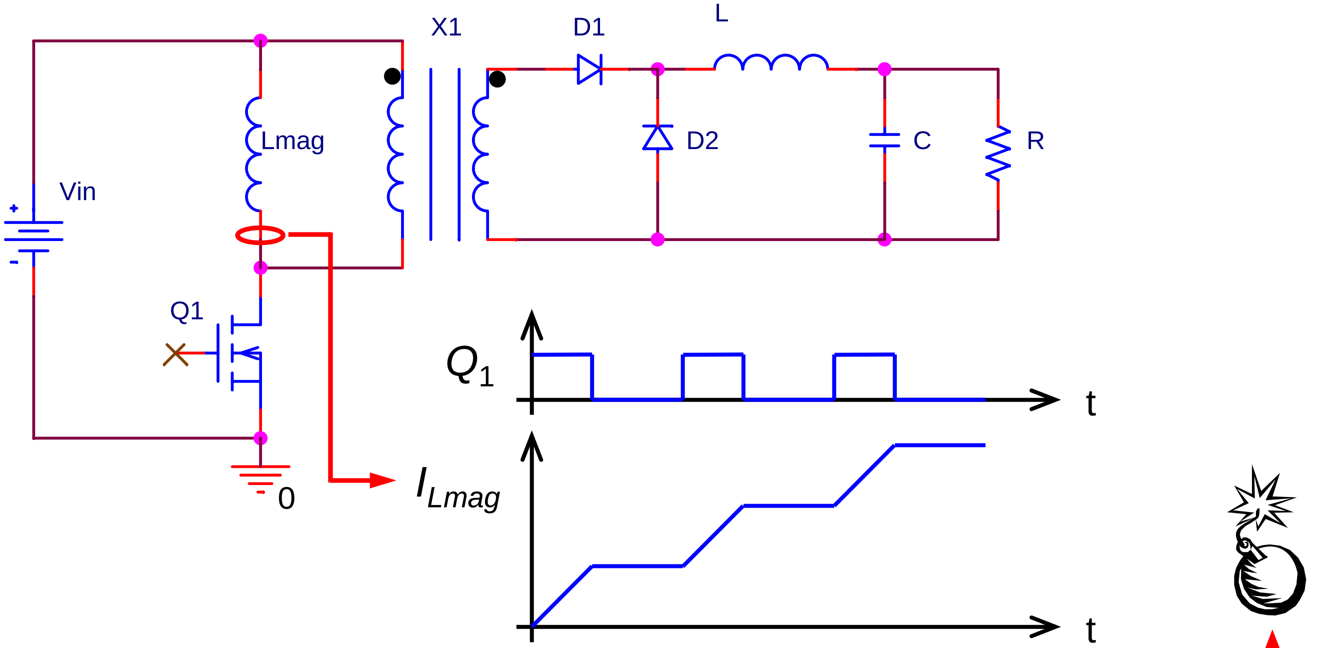
变压器磁芯复位：为什么？
Transformer Core Reset: Why?

❑ 没有变压器磁芯复位时： Without transformer core reset:

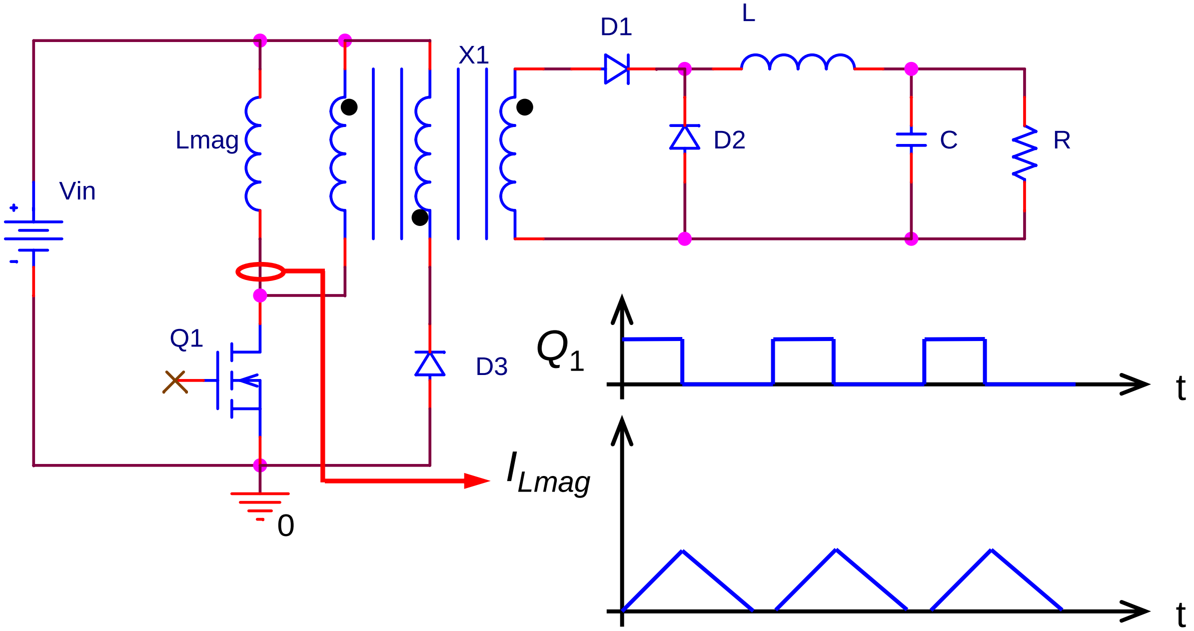


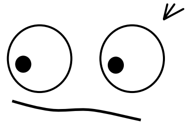
- 电流在每个开关周期增大 The current builds up at each switching cycle
- 将磁芯带入饱和状态 It brings the core into saturation

变压器磁芯复位：为什么？

Transformer Core Reset: Why?

❑有变压器磁芯复位时： With transformer core reset:





- 电流不会在每个开关周期增大 The current does not build up at each switching cycle
  - 每个周期伏秒数平均为零 Volt-seconds average to zero during each cycle
- 电压基于磁化电感反相并使磁芯复位 The voltage reverses over L_{mag} and resets it

磁芯复位技术：怎样实现？
Core Reset Techniques: How ?

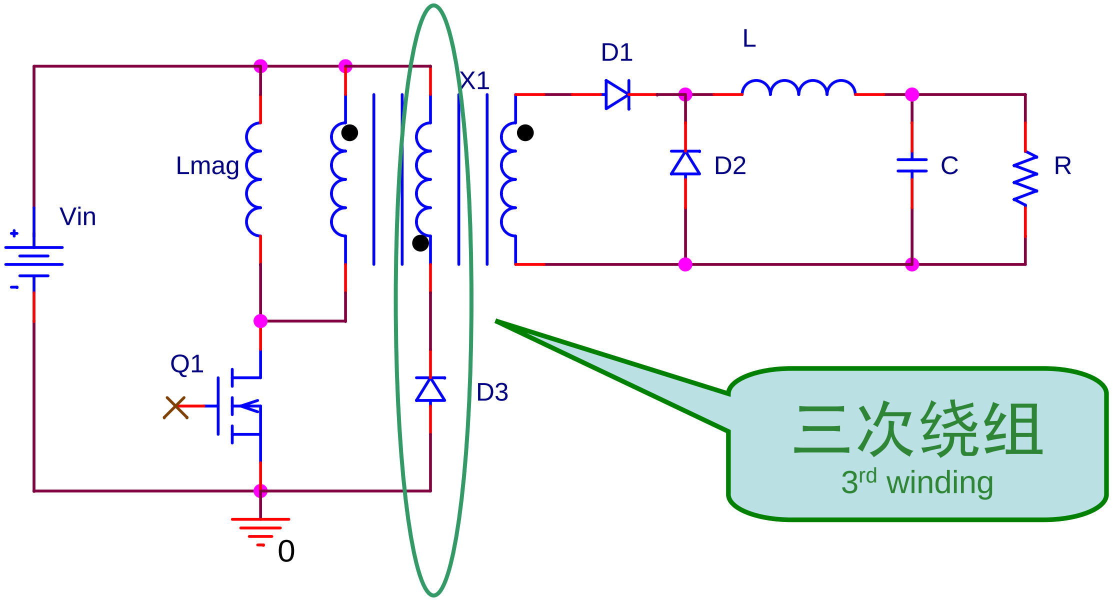
- □ 能量存储在磁化电感(L_{mag})中 Energy is stored in the magnetizing inductor
- □ 这能量不参与电源转换 This energy does not participate to the power transfer
  - ➢ 需要释放这能量，避免磁通量流失 It needs to be released to avoid flux walk away
- □ 3种常见的标准磁芯复位技术： 3 common standard techniques for the core reset:
  - ✓ 三次绕组 Tertiary winding
  - ✓ 电阻-电容-二极管钳位 RCD clamp
  - ✓ 双开关正激 2-switch forward

磁芯复位技术：三次绕组
Core Reset Techniques: Tertiary Winding

- 三次绕组复位 Reset with the 3rd winding
  - ☺ 占空比能够大于50% Duty ratio can be > 50%

  但是 But

  - ☹ Q_1峰值电压可能大于$2 \bullet V_{in}$ Q_1 peak voltage can be > $2 \bullet V_{in}$
  - ☹ 变压器有三次绕组 3rd winding for the transformer



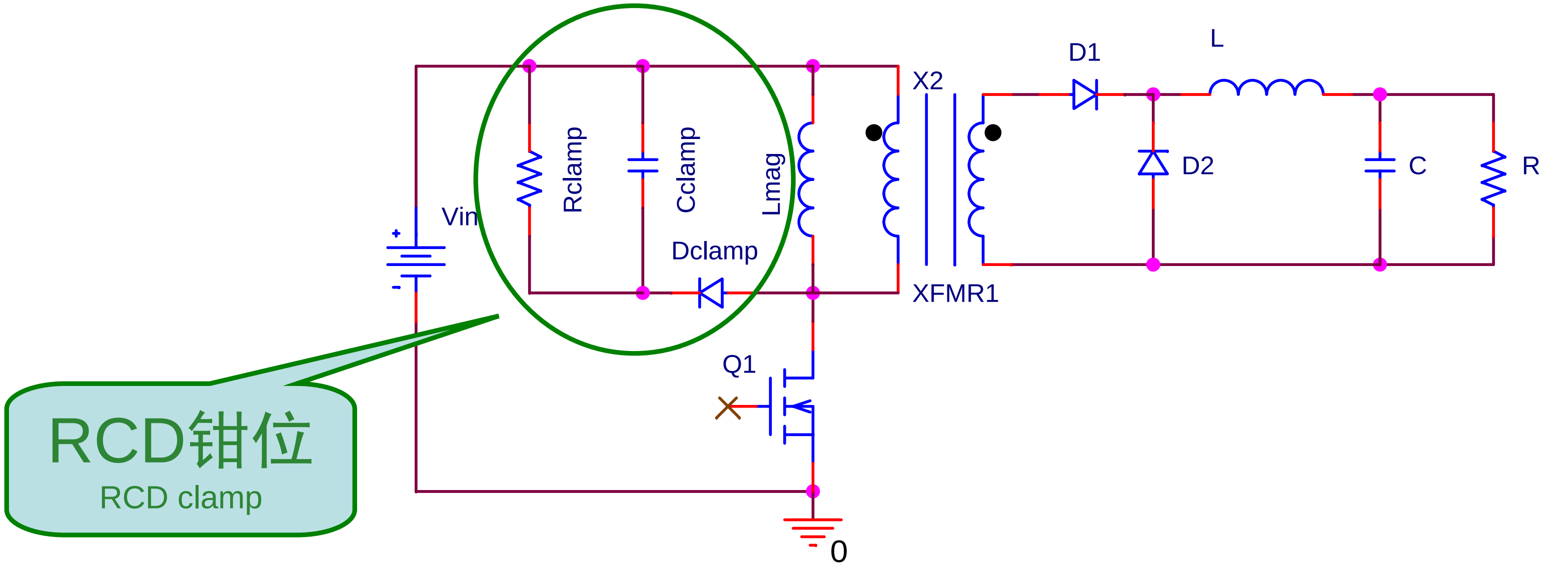
三次绕组
3rd winding

磁芯复位技术：RCD钳位

Core Reset Techniques: RCD Clamp

- RCD钳位复位 Reset with RCD clamp
  - ☺ 占空比能够大于50% Duty ratio can be > 50%

  但是 But
  - ☹ 需要写等式和仿真以检验复位的正确性 Writing equation and simulation are required for checking the correct reset
  - ☹ 成本比三次绕组技术低 Lower cost than 3rd winding technique

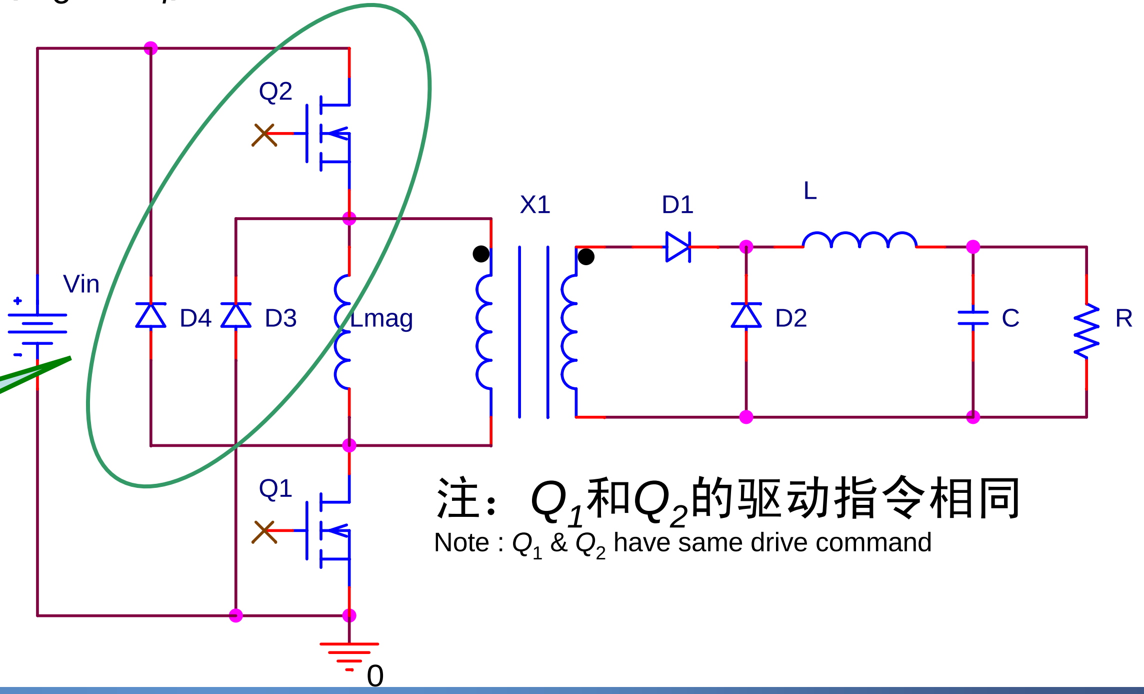


RCD钳位
RCD clamp

磁芯复位技术：双开关正激
Core Reset Techniques: 2-switch Forward

- 双开关正激复位 Reset with a 2-switch forward
  - ☺ 容易实现 Easy to implement
  - ☺ Q_1峰值电压等于V_{in} Q_1 peak voltage is equal to V_{in}

  但是 But
  - ☹ 需要额外的功率MOSFET(Q_2)和高端驱动器 Additional power MOSFET (Q_2) + high side driver
  - ☹ 2个高压低功率二极管(D_3和D_4) 2 High voltage, low power diodes (D_3 & D_4)

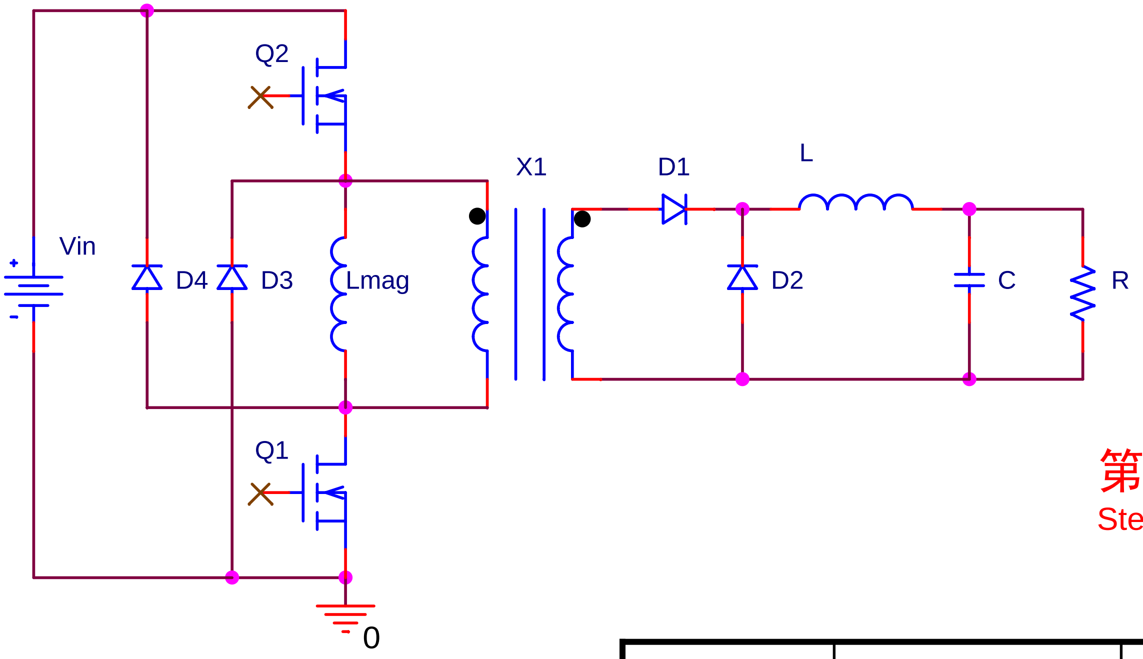


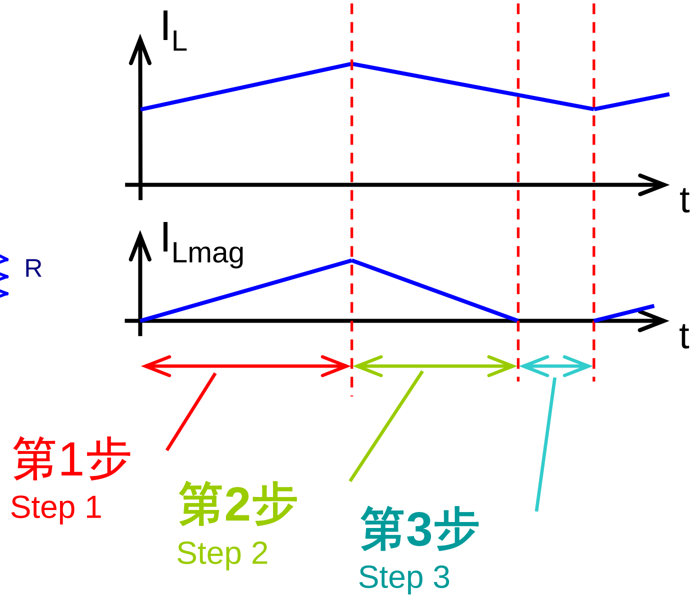
双开关正激复位
2-switch forward reset

注：Q_1和Q_2的驱动指令相同
Note : Q_1 & Q_2 have same drive command

双开关正激：工作原理

2-Switch Forward: How Does It Works?





注：初级控制器状态

Note : Primary controller status

- **"导通时间"：第1步**

  "on time" : Step1

- **"关闭时间"：第2步+第3步**

  "off time": Step 2 + Step 3

	Q_1 & Q_2	D_1	D_2	D_3 & D_4
第1步 Step 1	导通 ON	导通 ON	关闭 OFF	关闭 OFF
第2步 Step 2	关闭 OFF	关闭 OFF	导通 ON	导通 ON
第3步 Step 3	关闭 OFF	关闭 OFF	导通 ON	关闭 OFF

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NCP1252-带跳周期和闩锁过流保护的固定频率控制器

NCP1252 – Fixed Frequency Controller Featuring Skip Cycle and Latch OCP

价值主张 Value Proposition

The NCP1252 offers everything needed to build a cost-effective and reliable ac-dc switching power supply.

独特特性 Unique Features

- Adjustable switching freq.
- Delayed operation upon startup
- Latched Short circuit protection timer based.
- skip cycle mode

优势 Benefits

- Design flexibility
- independent of the aux. winding
- Allow temporary over load and latch permanent fault
- Achieve real no load operation

其它特性 Others Features

- Adjustable soft start duration
- Internal ramp compensation
- Auto-recovery brown-out detection
- Vcc up to 28 V with auto-recovery UVLO
- Frequency jittering ±5% of the switching frequency
- Duty cycle 50% with A Version, 80% with B version

市场及应用 Market & Applications

- ATX Power supply
- AC adapters

与UC384X系列主要区别 Main differences with the UC384X series

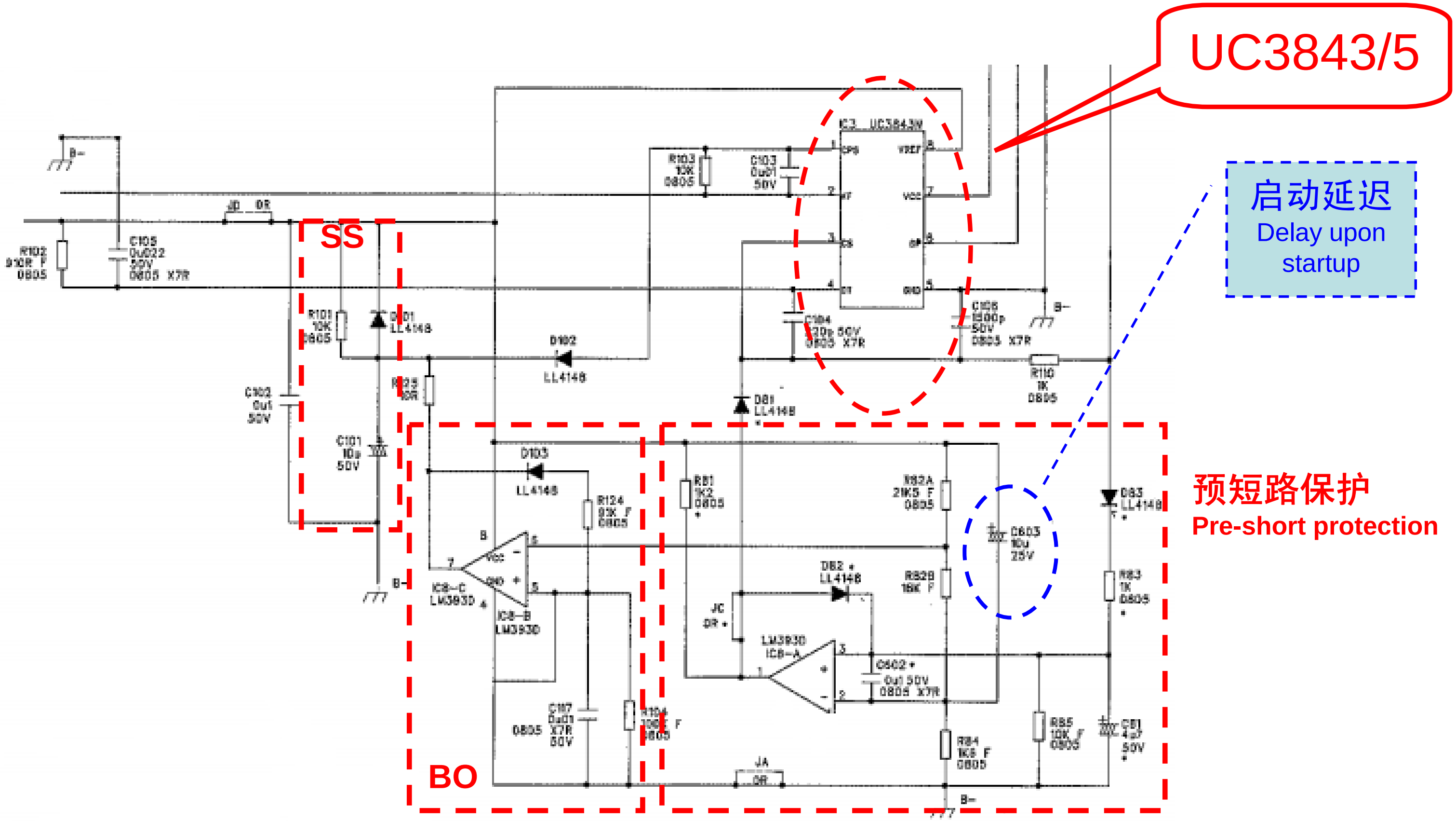
	NCP1252	UC3843/5
Startup current	< 100 µA	500 µA
Leading Edge Blanking (LEB)	Yes	No
Internal Ramp Compensation	Adj.	No
Frequency jittering	300 Hz, ±5%	No
Skip Cycle (light load behavior)	Yes	No
Brown-Out with shutdown feature	Yes	No
Pre-short protection	Latch-off, 15 ms delay	No
Delay on startup	120 ms	No
Soft start	Adj.	No
5 V voltage reference	No	Yes

订购及封装信息 Ordering & Package Information

- NCP1252ADR2G: 50% Duty Cycle SOIC8
- NCP1252BDR2G: 80% Duty Cycle SOIC8

UC3843/5应用示例

UC3843/5 Application Example



UC3843/5

SS

启动延迟
Delay upon startup

预短路保护
Pre-short protection

BO

❑ UC384X不含输入欠压、软启动及过载检测 UC384X does not include brown-out, soft-start and overload detection

➢ 这些功能的外部实现成本为0.07美元 the external implementation cost of these functions is $0.07

❖ NCP1252包含所有这些功能，降低成本及提升可靠性 NCP1252 includes them all, reducing cost and improving reliability

NCP1252演示板规格概览

Spec Review: NCP1252’s Demo Board

- 输入电压范围 Input voltage range: 340-410 V dc
- 输出电压 Output voltage: 12 V dc, ± 5%
- 额定输出功率 Nominal output power: 96 W (8 A)
- 最大输出功率 Maximal output power: 120 W (每分钟持续5秒 5 seconds per minute)
- 最小输出功率 Minimal output power: 真正空载(无假负载!) real no load (no dummy load!)
- 输出纹波 Output ripple : 50 mV峰值至峰值 peak to peak
- 最大瞬态负载分步 Maximum transient load step: 最大负载的50% 50% of the max load
- 最大输出压降 Maximum output drop voltage: 250 mV (5 µs内从输出电流=50%到满载(5 A ➔ 10 A)) from Iout = 50% to Full load (5 A ➔ 10 A) in 5 µs)

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功率元件计算：变压器(1/3)

Power Components Calculation: Transformer (1/3)

- 步骤1：连续导电模式(CCM)匝数比计算 Step 1: Turns ratio calculation in CCM:

$$V_{out} = \eta \cdot V_{bulk\,min} \cdot DC_{max} \cdot N$$

$$\Leftrightarrow \quad N = \frac{V_{out}}{\eta \cdot V_{bulk\,min} \cdot DC_{max}}$$

$$N = \frac{12}{0.9 \times 350 \times 0.45}$$

$$\boxed{N = 0.085}$$

其中 Where:

- V_{out}是输出电压 V_{out} is the output voltage
- η是目标能效 η is the targeted efficiency
- $V_{bulkmin}$是最小输入电压 $V_{bulkmin}$ is the min. input voltage
- DC_{max}是NCP1252的最大占空比 DC_{max} is the max duty cycle of the NCP1252
- N是变压器匝数比 N is the transformer turn ratio

功率元件计算：变压器(2/3)

Power Components Calculation: Transformer (2/3)

- 步骤2：验证：高输入线路最小占空比(DC_{min})时的最大占空比(基于前面等式) Step 2: Verification: Maximum duty cycle at high input line DC_{min} (Based on the previous equation)

$$V_{out} = \eta \cdot V_{bulk\,max} \cdot DC_{min} \cdot N$$

$$\Leftrightarrow \quad DC_{min} = \frac{V_{out}}{\eta \cdot V_{bulk\,max} \cdot N}$$

$$DC_{min} = \frac{12}{0.9 \times 410 \times 0.085}$$

$$\boxed{DC_{min} = 38.2\%}$$

其中 Where:

- $Vout$是输出电压 V_{out} is the output voltage
- η 是目标能效 η is the targeted efficiency
- $V_{bulkmax}$是最大输入电压 $V_{bulkmax}$ is the max. input voltage
- N是变压器匝数比 N is the transformer turn ratio

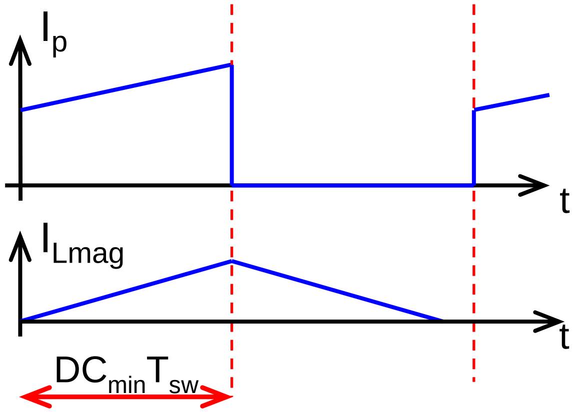
功率元件计算：变压器(3/3)

Power Components Calculation: Transformer (3/3)

- 步骤3：磁化电感值 Step 3: Magnetizing inductor value.
  - – 为了恰当地复位磁芯，需要极小磁化电流来对绕组电压反相 For resetting properly the core, a minimal magnetizing current is needed to reverse the voltage across the winding.
    - (必须存储足够能量来给电容充电 Enough energy must be stored so to charge the capacitance)
  - – 经验法则：磁化电流=初级峰值电流的10% Rule of thumb: Magnetizing current = 10% primary peak current

    (➔ $I_{Lmag\_pk} = 10\%\ I_{p\_pk}$)

$$L_{mag} = \frac{V_{bulk\_min}}{\dfrac{10\% I_{p\_pk}}{T_{ON}}} = \frac{350}{\dfrac{0.1 \times 0.94}{\dfrac{0.45}{125k}}} = \boxed{13.4\ \mathrm{mH}}$$



功率元件计算：LC输出滤波器(1/4)

Power Components Calculation: LC Output Filter (1/4)

- 步骤1：交越频率(f_c)选择 Step 1: Crossover frequency (f_c) selection
  - 直接选定为10 kHz arbitrarily selected to 10 kHz.
  - 因开关噪声缘故，$f_c > 10$ kHz要求无噪声布线(较难)。不推荐在较高的频率交越 $f_c > 10$ kHz requires noiseless layout due to switching noise (difficult). Crossover at higher frequency is not recommended
- 步骤2： C_{out}及R_{ESR} 估计 Step 2: C_{out} & R_{ESR} estimation
  - 如果我们假定由f_c、C_{out}及ΔI_{out}确定ΔV_{out} = 250 mV，我们就能够写出下述等式： If we consider a ΔV_{out} = 250 mV dictated by f_c, C_{out} & ΔI_{out}, we can write the following equation:

$$C_{out} \ge \frac{\Delta I_{out}}{2\pi f_c \Delta V_{out}} \ge \frac{5}{2\pi \times 10k \times 0.25} \Rightarrow \boxed{C_{out} \ge 318\mu F}$$

$$R_{ESR} \le \frac{1}{2\pi f_c C_{out}} \le \frac{1}{2\pi \times 10k \times 318\mu} \Rightarrow \boxed{R_{ESR} \le 50m\Omega}$$

其中 Where:

- f_c为交越频率 f_c crossover frequency
- ΔI_{out}是最大分步负载电流 ΔI_{out} is the max. step load current
- ΔV_{out} 是ΔI_{out} 时的最大压降 ΔV_{out} is the max. drop voltage @ ΔI_{out}

功率元件计算：LC输出滤波器(2/4)

Power Components Calculation: LC Output Filter (2/4)

- 步骤3：由等效串联电阻(ESR)而非电容值决定电容选择 Step 3: Capacitor selection dictated by ESR rather than capacitor value:
  - 选择2颗松下FM系列的1,000 µF@16 V电容 Selection of 2x1000 µF, FM capacitor type @ 16 V from Panasonic.
  - 从电容规范中解析出 Extracted from the capacitor spec:
    - $I_{c,rms}$ = 5.36 A (2*2.38 A) @ T_A = +105 ° C
    - $R_{ESR,low}$ = 8.5 mΩ (19 mΩ/2) @ T_A = +20 ° C
    - $R_{ESR,high}$ = 28.5 mΩ (57 mΩ/2) @ T_A = -10 ° C
  - 计算ΔV_{out} @ ΔI_{out} = 5 A ΔV_{out} calculation @ ΔI_{out} = 5 A
    - $\Delta V_{out} = \Delta I_{out} R_{ESR,max} = 5 \times 28.5m = \boxed{142\ \mathrm{mV}}$

决窍：经验法则：

Tips: Rule of thumb:

$$R_{ESR,high} \square \frac{ESR(\,step\ 2\,)}{2}$$

假定规范为250 mV时可接受

Is acceptable given a specification at 250 mV

功率元件计算：LC输出滤波器(3/4)

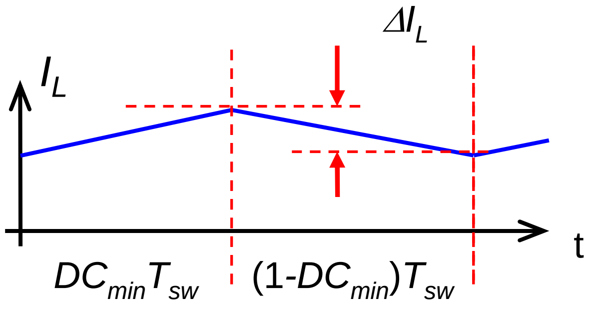
Power Components Calculation: LC Output Filter (3/4)

- 步骤4：最大峰值到峰值输出电流 Step 4: Maximum peak to peak output current

$$\Delta I_L \le \frac{V_{ripple}}{R_{ESR,max}} \le \frac{50m}{22m} \boxed{\le 2.27\ \text{A}}$$

$R_{ESR,max}$ = 22 mΩ @ 0 ° C

- 步骤5：电感值计算 Step 5: Inductor value calculation



$$\Delta I_L \ge \frac{V_{out}}{L}\left(1 - DC_{min}\right)T_{sw}$$

$$\Leftrightarrow \quad L \ge \frac{V_{out}}{\Delta I_L}\left(1 - DC_{min}\right)T_{sw} = \frac{12}{2.27}\left(1 - 0.38\right)\frac{1}{125k}$$

$$L \ge 26\mu H$$

- 选择27 µH的标准值 Let select a standardized value of 27 µH

功率元件计算：LC输出滤波器(4/4)

Power Components Calculation: LC Output Filter (4/4)

- 步骤6：输出电容的均方根电流 Step 6: rms current in the output capacitor

$$I_{C_{out},rms} = I_{out}\frac{1-DC_{min}}{\sqrt{12\tau_L}} = 10\times\frac{1-0.38}{\sqrt{12\times 2.813}} \boxed{= 1.06\text{ A}}$$

$$\text{where}\quad \tau_L = \frac{L_{out}}{\frac{V_{out}}{I_{out}}\frac{1}{F_{sw}}} = \frac{27\mu}{\frac{12}{10}\frac{1}{125k}} = 2.813$$

注： τ_L是额定电感时间常数

Note: τ_L is the normalized inductor time constant

$\boxed{I_{Cout,rms}\ (1.06\text{ A}) < I_{C,rms}\ (5.36\text{ A})}$ ➔ 无需调整或改变输出电容

No need to adjust or change the output capacitors

功率元件计算：变压器电流

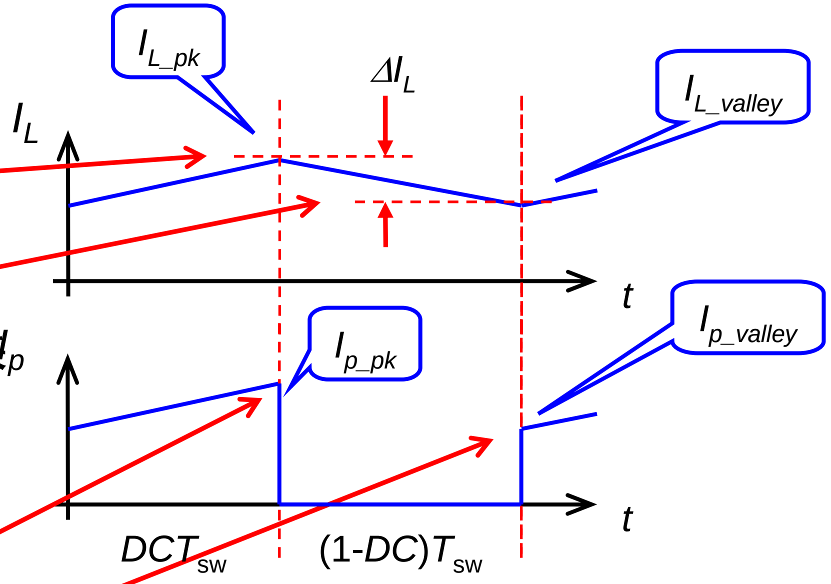
Power Components Calculation: Transformer Current

- 初级和次级端的均方根电流 RMS current on primary and secondary side
  - 次级电流 secondary currents:

$$I_{L\_pk} = I_{out} + \frac{\Delta I_L}{2} = 10 + \frac{2.27}{2} = \boxed{11.13\ \text{A}}$$

$$I_{L\_valley} = I_{L\_pk} - \Delta I_L = 11.13 - 2.27 = \boxed{8.86\ \text{A}}$$

  - 初级电流能以次级电流乘以匝数比来p计算 Primary current can calculated by multiplying the secondary current with the turns ratio:



$$I_{p\_pk} = I_{L\_pk} N = 11.13 \times 0.085 = \boxed{0.95\ \text{A}}$$

$$I_{p\_valley} = I_{L\_valley} N = 8.86 \times 0.085 = \boxed{0.75\ \text{A}}$$

$$\Rightarrow I_{p,rms} = \sqrt{DC_{max}\left(\left(I_{p\_pk}+10\%\right)^2 - \left(I_{p\_pk}+10\%\right)\Delta I_L N + \frac{\left(\Delta I_L N\right)^2}{3}\right)} = \boxed{0.63\ \text{A}}$$

注：已考虑磁化电流(I_{p_pk}的10%)计算出$I_{p,rms}$ Note: $I_{p,rms}$ has been calculated by taking into account the magnetizing current (10% of I_{p_pk}).

功率元件计算：MOSFET(1/3)

Power Components Calculation: MOSFET (1/3)

- 采用双开关正激转换器➔功率MOSFET最大电压限制为输入电压 With a 2-switch forward converter ➔ max voltage on power MOSFET is limited to the input voltage
- 通常漏极至源极击穿电压(BV_{DSS})施加了等于15%的降额因数 Usually a derating factor is applied on drain to source breakdown voltage (BV_{DSS}) equal to 15%.
- 如果我们选择500 V功率MOSFET,降额后的最大电压应该是425 V(即500 V x 0.85) If we select a 500-V power MOSFET type, the derated max voltage should be 425 V (500 V x 0.85).
- 已选择FDP16N50 FDP16N50 has been selected:
  - TO220封装 Package TO220
  - BV_{DSS} = 500 V
  - $R_{DS(on)}$ = 0.434 Ω @ T_j = 110 ° C
  - 总门电荷 Total Gate charge: Q_G = 45 nC
  - 门极至漏极电荷 Gate drain charge: Q_{GD} = 14 nC

功率元件计算：MOSFET(2/3)

Power Components Calculation: MOSFET (2/3)

- 损耗计算 Losses calculation:
  - 导电损耗 Conduction losses:

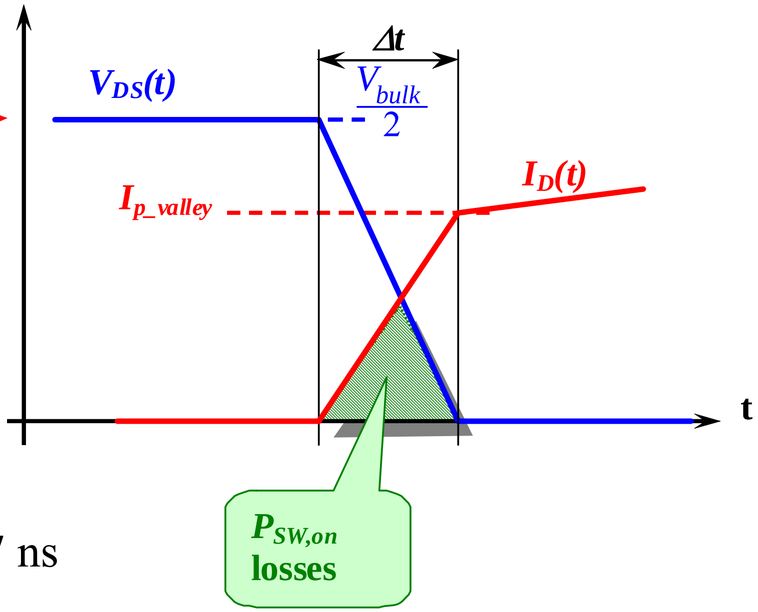
$$P_{cond} = I_{p,rms,10\%}{}^{2} R_{DS(on)} @T_j = 110°C = 0.632^2 \times 0.434 = \boxed{173\ \text{mW}}$$

  - 开关导通损耗 Switch ON losses:

$$P_{SW,on} = F_{sw}\int_0^{\Delta t} I_D(t)V_{DS}(t)\,dt$$

$$= \frac{I_{p\_valley}\frac{V_{bulk}}{2}\Delta t}{6}F_{sw} = \frac{I_{p\_valley}V_{bulk}\Delta t}{12}F_{sw}$$

$$P_{SW,on} = \frac{0.75\times 410\times 46.7n}{12}\times 125k = \boxed{149\ \text{mW}}$$



从下面等式解析出交迭时间(Δ_t)

Overlap (Δ_t) is extracted from

$$\Delta_t = \frac{Q_{GD}}{I_{DRV\_pk}} = \frac{14n}{0.3} = 46.7\ \text{ns}$$

功率元件计算：MOSFET(3/3)

Power Components Calculation: MOSFET (3/3)

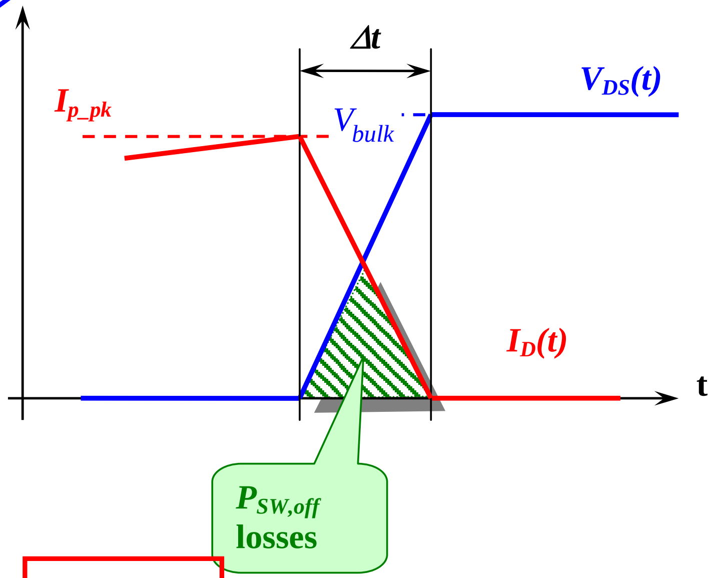
- 开关关闭损耗：基于与开关导通损耗相同的等式计算 Switch OFF losses: based on the same equation of switch ON

$$P_{SW,off} = \frac{I_{p\_valley} V_{bulk,\max} \Delta t}{6} F_{sw} = \frac{1.04 \times 410 \times 40n}{6} \times 125k = \boxed{355\ mW}$$

从下面等式中解析出交迭时间(Δt)

Overlap (Δ_t) is extracted from

$$\Delta_t = \frac{Q_{GD}}{I_{DRV\_pk}} = \frac{14n}{0.35} = 40\ \text{ns}$$



- 总损耗 Total losses:

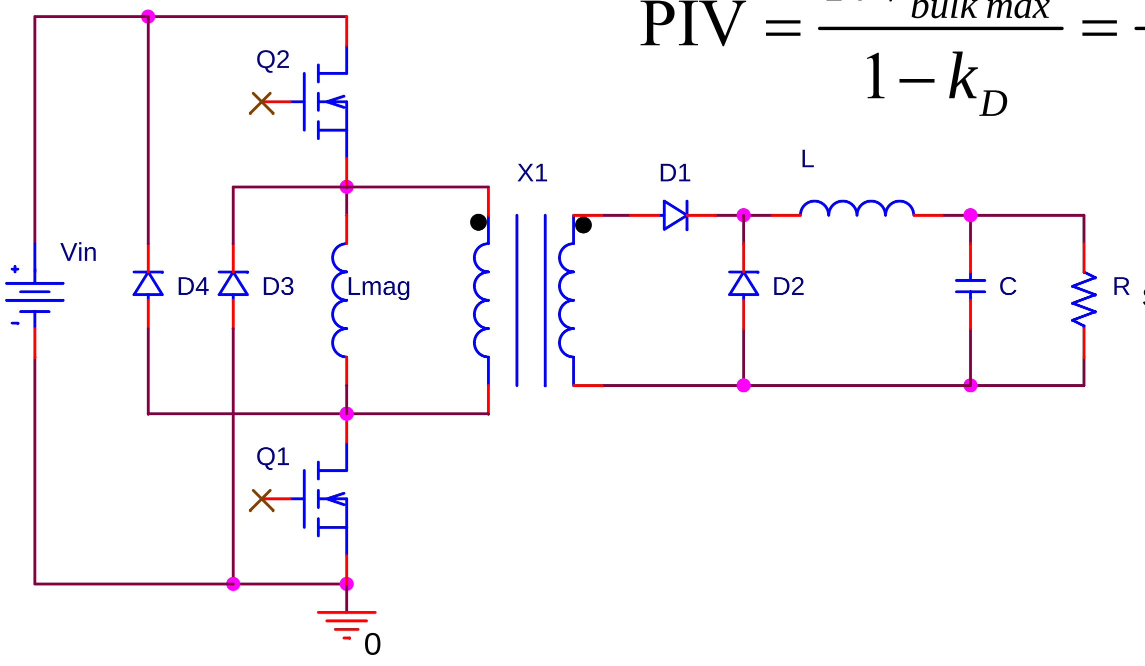
$$P_{losses} = P_{cond} + P_{SW,on} + P_{SW,off} = 173 + 149 + 355 = \boxed{677\ \text{mW}}$$

功率元件计算：二极管(1/2)

Power Components Calculation: Diode (1/2)

- 次级二极管：D_1和D_2维持相同的峰值反相电压(PIC) Secondary diodes: D_1 and D_2 sustain same Peak Inverse Voltage (PIV):
  - 其中k_D是二极管降额因数(40%) Where k_D is derating factor of the diodes (40%)

$$\mathrm{PIV} = \frac{NV_{bulk\,max}}{1-k_D} = \frac{0.085\times 410}{0.6} = \boxed{58\ \mathrm{V}}$$



PIV < 100 V ➔ 能够选择如下肖特基二极管 Schottky diode can be selected:

MBRB30H60CT

(30 A, 60 V，TO-220封装)

功率元件计算：二极管(2/2)

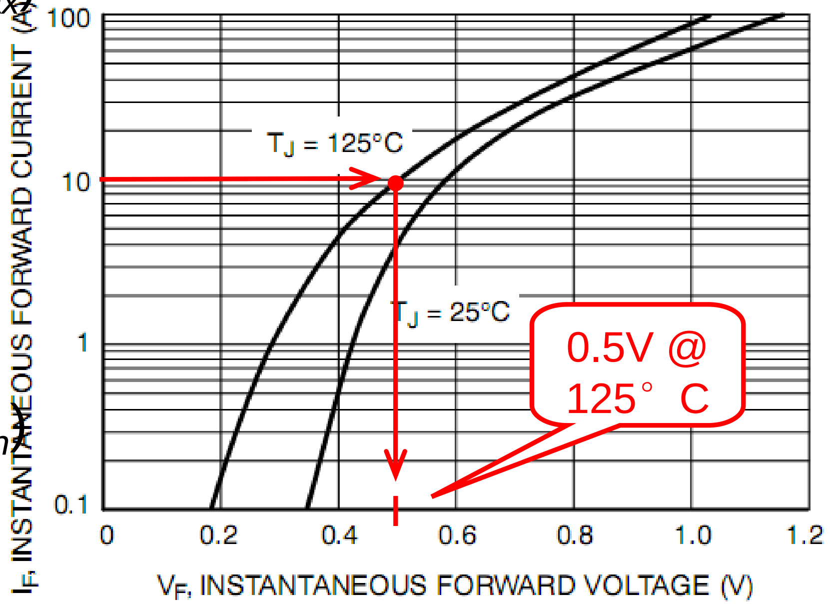
Power Components Calculation: Diode (2/2)

- 二极管选择 Diode selection: MBRB30H60CT (30 A, 60 V in TO-220)
- 损耗计算 Losses calculation:
  - 导通时间期间：低线路输入(DC_{max})时的最坏情况 During ON time : Worst case @ low line (DC_{max})

$$P_{cond,forward} = I_{out} V_f DC_{max} = 10 \times 0.5 \times 0.45 = \boxed{2.25\ \text{W}}$$

  - 关闭时间期间：高线路输入(DC_{min})时的最坏情况 During OFF time : Worst case @ High line (DC_{min})

$$P_{cond,freewheel} = I_{out} V_f \left(1 - DC_{min}\right) = 10 \times 0.5 \times \left(1 - 0.39\right) = \boxed{3.05\ \text{W}}$$



0.5V @ 125° C

Figure 2. Maximum Forward Voltage

议程 Agenda

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NCP1252元件计算：R_t

NCP1252 Components Calculation: R_t

- 开关频率选择：采用一颗简单电阻即可在50至500 kHz之间选择开关频率 Switching frequency selection: a simple resistor allows to select the switching frequency from 50 to 500 kHz:

$$R_t = \frac{1.95\times10^9 V_{R_t}}{F_{sw}}$$

假定 If we assume $F_{sw} = 125$ kHz

$$R_t = \frac{1.95\times10^9\times2.2}{125k} = \boxed{34.3\ k\Omega}$$

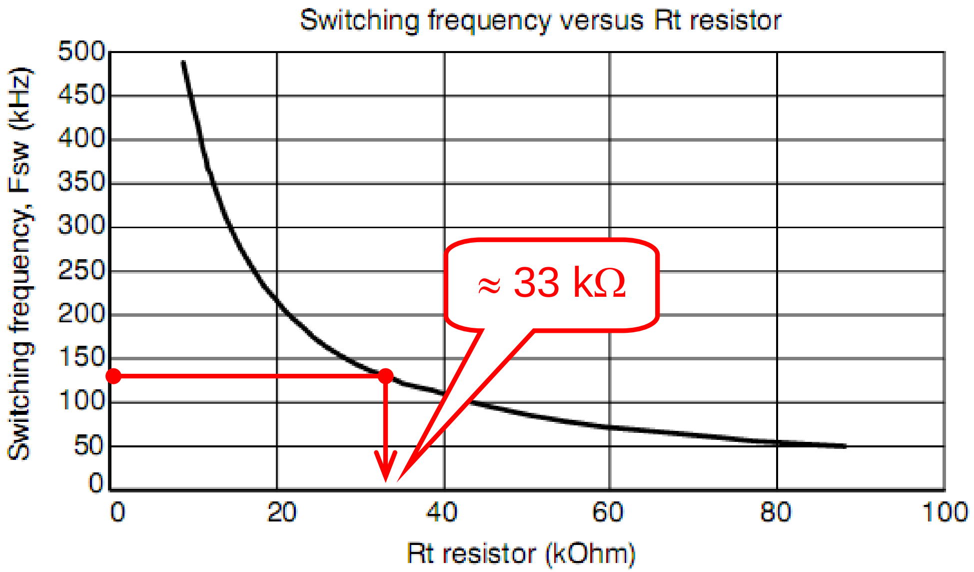


Figure 10. Switching Frequency Selection

其中 Where:

- V_{Rt} 是R_t引脚上呈现的内部电压参考(2.2 V)
  V_{Rt} is the internal voltage reference (2.2 V) present on R_t pin

NCP1252元件计算：感测电阻

NCP1252 Components Calculation: Sense Resistor

- NCP1252最大峰值电流感测电压达1 V NCP1252 features a max peak current sensing voltage to 1 V.
- 感测电阻以初级峰值电流的20%余量（$I_{p,\ rms,\ 20\%}$）来计算：10%为磁化电流+10%为总公差The sense resistor is computed with 20% margin of the primary peak current ($I_{p,rms,20\%}$): 10% for the magnetizing current + 10% for overall tolerances.

$$R_{sense} = \frac{F_{CS}}{I_{p\_pk} + 20\%} = \frac{1}{0.946 \times 1.2} = 884\ \text{m}\Omega$$

$$P_{R_{sense}} = R_{sense} I_{p,rms+20\%}{}^{2} = 0.884 \times 0.695^{2} = 427\ \text{mW}$$

如果我们选择1206表面贴装(SMD)类型的电阻，我们需要并联放置2颗电阻以维持功率：2 x 1.5 Ω If we select 1206 SMD type of resistor, we need to place 2 resistors in parallel to sustain the power: 2 x 1.5 Ω.

其中 Where:

- I_{p_pk}是初级峰值电流 I_{p_pk} is the primary peak current
- $I_{p,rms,20\%}$是带有20%峰值电流余量的初级均方根电流 $I_{p,rms,20\%}$ is the primary rms current with a 20% margin on the peak current

NCP1252元件计算：斜坡补偿(1/5)

NCP1252 Components Calculation: Ramp Compensation (1/5)

- 斜坡补偿防止一半开关频率时出现次斜坡振荡，这时转换器工作在连续导电模式(CCM)，占空比接近或高于50% Ramp compensation prevents sub-harmonic oscillation at half of the switching frequency, when the converter works in CCM and duty ratio close or above 50%.
- 在正激拓扑结构下，重要的是考虑由磁化电感所致自然补偿 With a forward it is important to take into account the natural compensation due to magnetizing inductor.
- 根据所要求的斜坡补偿(通常50%至100%)，仅能够外部增加斜坡补偿与自然补偿之间的差值 Based on the requested ramp compensation (usually 50% to 100%), only the difference between the ramp compensation and the natural ramp could be added externally
  - 否则系统将过补偿及失去电流模式工作，转换器将更象电压模式而非电流模式工作 Otherwise the system will be over compensated and the current mode of operation can be lost, the converter will work more like a voltage mode than current mode of operation.

NCP1252元件计算：斜坡补偿(2/5)

NCP1252 Components Calculation: Ramp Compensation (2/5)

- 如何构建斜坡补偿？ How to build it?

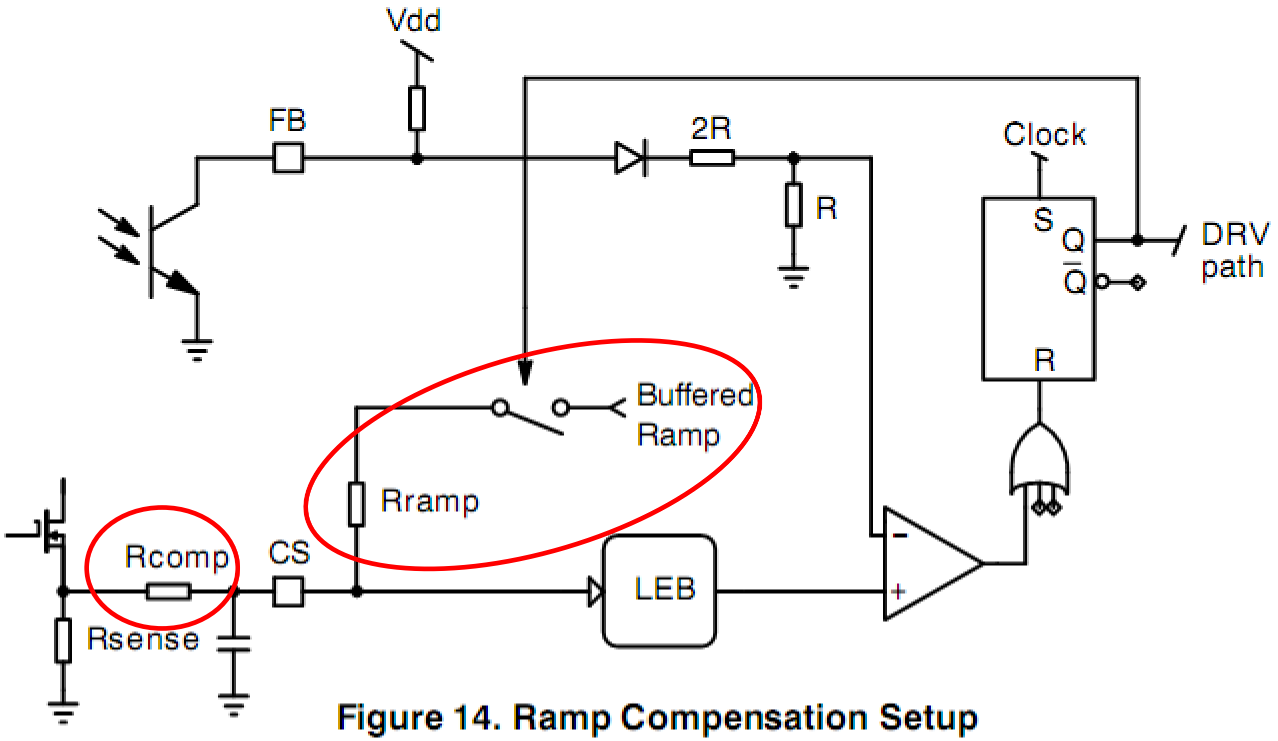


Figure 14. Ramp Compensation Setup

其中 Where:

- V_{ramp} = 3.5 V, 内部斜坡电平 Internal ramp level.
- R_{ramp} = 26.5 kΩ, 内部上拉电阻 Internal pull-up resistance

NCP1252元件计算：斜坡补偿(3/5)

NCP1252 Components Calculation: Ramp Compensation (3/5)

- 计算：目标斜坡补偿等级：100% Calculation: Targeted ramp compensation level: 100%
  - 内部斜坡 Internal Ramp:

$$S_{\text{int}} = \frac{V_{ramp}}{DC_{\max}} F_{sw} = \frac{3.5}{0.50} 125k = \boxed{875 mV / \mu s}$$

  - 自然初级斜坡 Natural primary ramp

$$S_{natural} = \frac{V_{bulk}}{L_{mag}} R_{sense} = \frac{350}{13 \cdot 10^{-3}} 0.75 = \boxed{20.19 mV / \mu s}$$

  - 次级向下斜坡 Secondary down slope

$$S_{sense} = \frac{(V_{out} + V_f)}{L_{out}} \frac{N_s}{N_p} R_{sense} = \frac{(12 + 0.5)}{27 \cdot 10^{-6}} 0.087 \times 0.75 = \boxed{30.21 mV / \mu s}$$

  - 自然斜坡补偿 Natural ramp compensation

$$\delta_{natural\_comp} = \frac{S_{natural}}{S_{sense}} = \frac{20.19}{30.21} = \boxed{66.8\%}$$

其中 Where:

- V_{out} = 12 V
- L_{out} = 27 µH
- V_f = 0.5 V(二极管压降 Diode drop)
- R_{sense} : 0.75 Ω
- F_{sw} : 125 kHz
- $V_{bulk,min}$ = 350 V
- DC_{max} = 50%
- L_{mag} = 13 mH
- N = 0.087

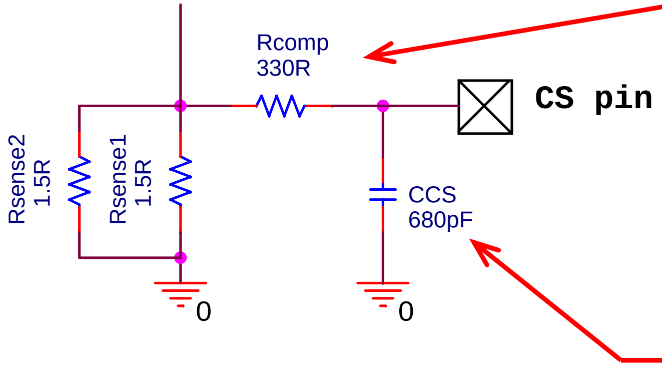
NCP1252元件计算：斜坡补偿(4/5)

NCP1252 Components Calculation: Ramp Compensation (4/5)

- 由于自然斜坡补偿(67%)低于100%的目标斜坡补偿，我们需要计算33%(100-67)的补偿 As the natural ramp comp. (67%) is lower than the targeted 100% ramp compensation, we need to calculate a compensation of 33% (100-67).

$$Ratio = \frac{S_{sense}\left(\delta_{comp} - \delta_{natural\_comp}\right)}{S_{\text{int}}} = \frac{30.21\left(1.00-0.67\right)}{875} = \boxed{0.0114}$$

$$R_{comp} = R_{ramp}\frac{Ratio}{1-Ratio} = 26.5\cdot 10^{3}\,\frac{0.0114}{1-0.0114} = \boxed{305\ \Omega}$$



- $R_{comp}C_{CS}$网络滤波需要约220 ns的时间常数 $R_{comp}C_{CS}$ network filtering need time constant around 220 ns:

$$C_{CS} = \frac{\tau_{RC}}{R_{Comp}} = \frac{220n}{330} = \boxed{666\ pF}$$

NCP1252元件计算：斜坡补偿(5/5)

NCP1252 Components Calculation: Ramp Compensation (5/5)

- CS引脚正确滤波示意图 Illustration of correct filtering on CS pin

✓ 滤除开关噪声

switching noise is filtered

✓ CS引脚电流信号未失真

CS pin current information is not distorted

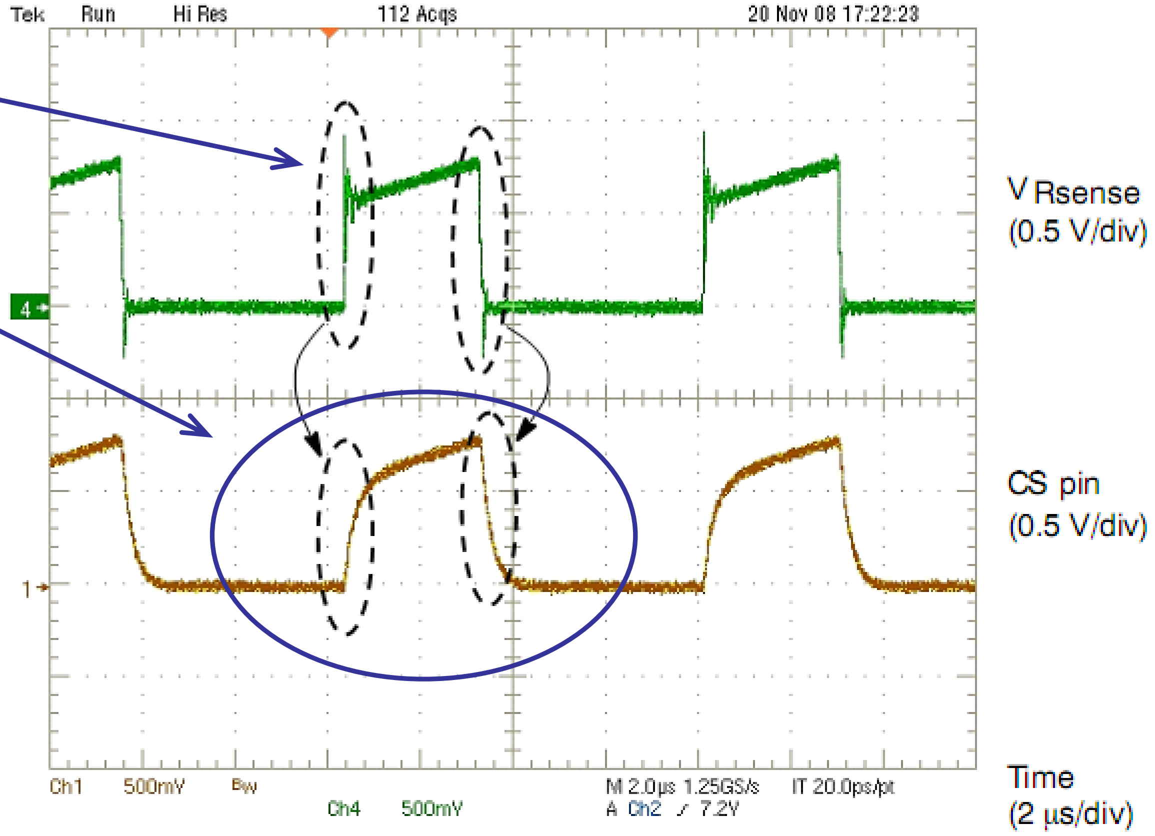


Figure 15. Comparison of the Voltage on the Current Sense Resistor and After the RC Filter

NCP1252元件计算：输入欠压

NCP1252 Components Calculation: Brown-Out

- 专门引脚用于监测大电压，保护转换器免受低输入电压条件
  Dedicated pin for monitoring the bulk voltage to protects the converter against low input voltage.

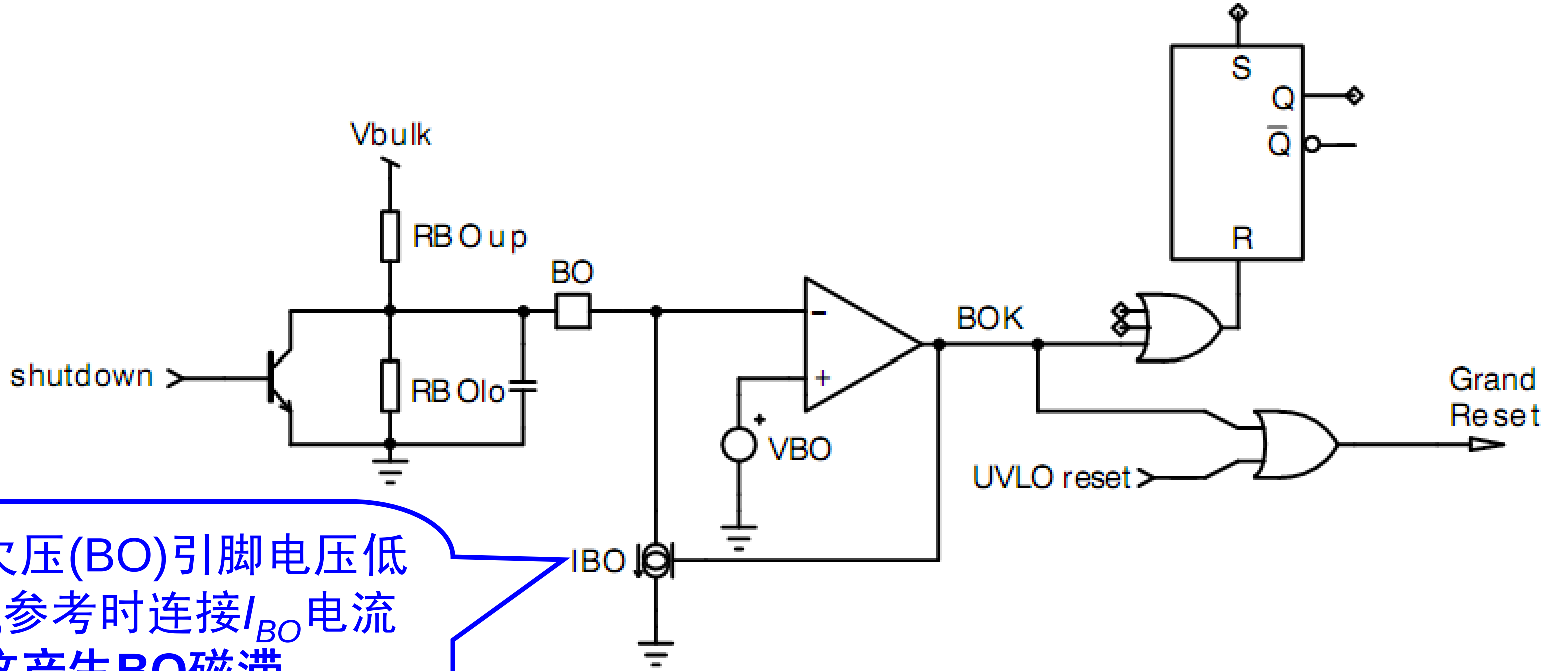


Figure 11. BO Pin Setup

软入欠压(BO)引脚电压低于V_{BO}参考时连接I_{BO}电流源：这产生BO磁滞

I_{BO} current source is connected when BO pin voltage is below V_{BO} reference: ***its creates the BO hysteresis***

NCP1252元件计算：输入欠压

NCP1252 Components Calculation: Brown-Out

- 从前面的原理图，我们能够解析出输入欠压电阻 From the previous schematic, we can extract the brown-out resistors

$$R_{BOlo} = \frac{V_{BO}}{I_{BO}}\left(\frac{V_{bulkon}-V_{BO}}{V_{bulkoff}-V_{BO}}-1\right) = \frac{1}{10\mu}\left(\frac{370-1}{350-1}-1\right) = 5731\,\Omega$$

$$\boxed{R_{BOlo} = 5.1\,\text{k}\Omega + 680\,\Omega}$$

$$R_{BOup} = \frac{V_{bulkon}-V_{bulkoff}}{I_{BO}} = \frac{370-350}{10\mu} = 2.0\,\text{M}\Omega$$

$$\boxed{R_{BOup} = 2\times 1\,\text{M}\Omega}$$

其中 Where :

- V_{bulkon} = 370 V, 启动点电平 starting point level
- $V_{bulkoff}$ = 350 V, 停止点电平 stopping point level
- V_{BO} = 1 V (固定内部电压参考 fixed internal voltage reference)
- I_{BO} = 10 µA (固定内部电流源 fixed internal current source)

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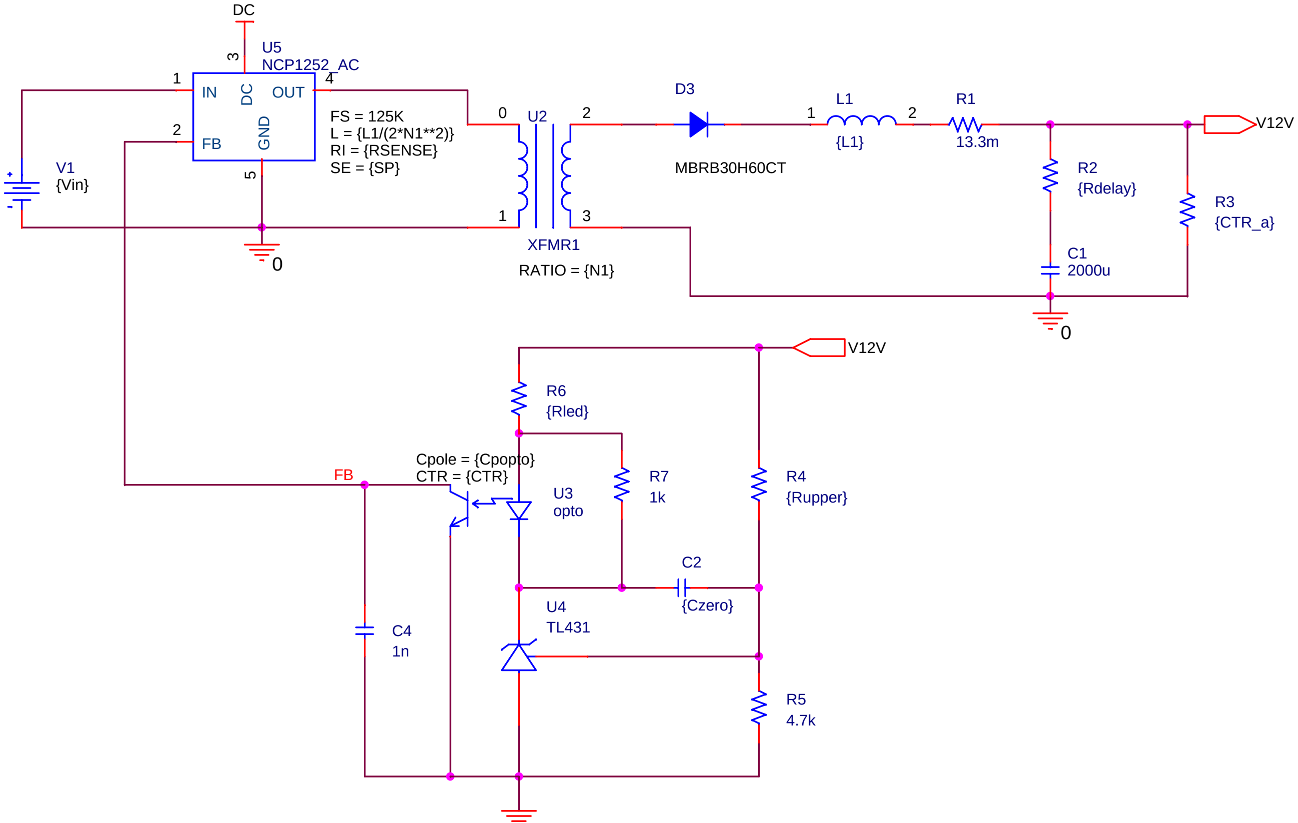
小信号分析：模型

Small Signal Analysis: Model

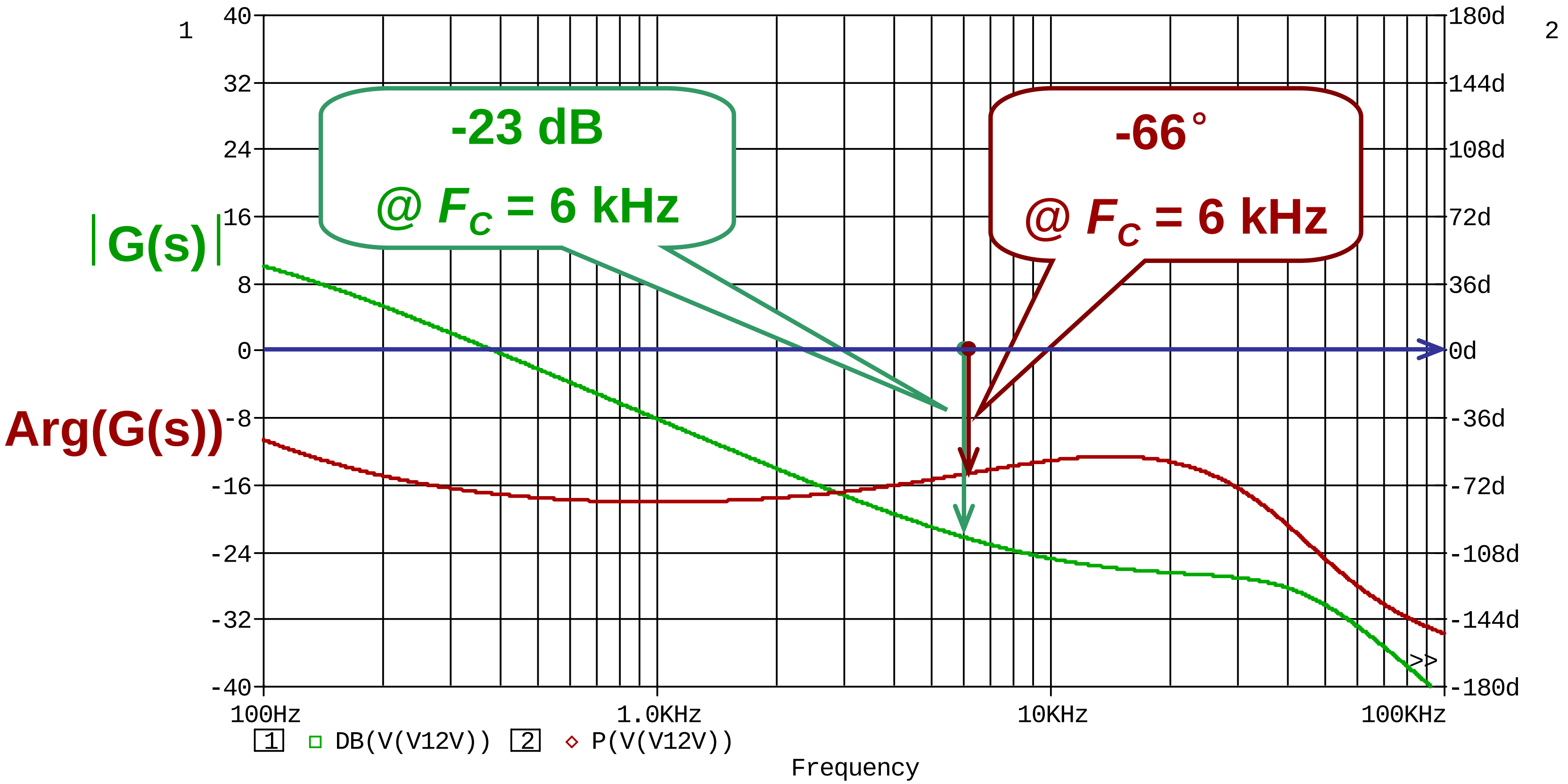
- 提供NCP1252的小信号模型，用于运行及验证闭环稳压及电源的分步负载响应，仿真速度极快 NCP1252’s small signal model is available for running and validating the closed loop regulation, as well as the step load response of the power supply with very fast simulation time.



研究闭环稳压原理图示例 Example of schematic for studying closed loop regulation

小信号分析：电源段

Small Signal Analysis: Power Stage



-23 dB @ F_C = 6 kHz

-66° @ F_C = 6 kHz

如果我们期望在*Fc* = 6 kHz时交越，我们需要测量 If we want a crossover @ F_c = 6 kHz, we need to measure:

- ➔ **|G(6 kHz)| = -23 dB**
- ➔ **Arg(G(6 kHz)) = -66°**

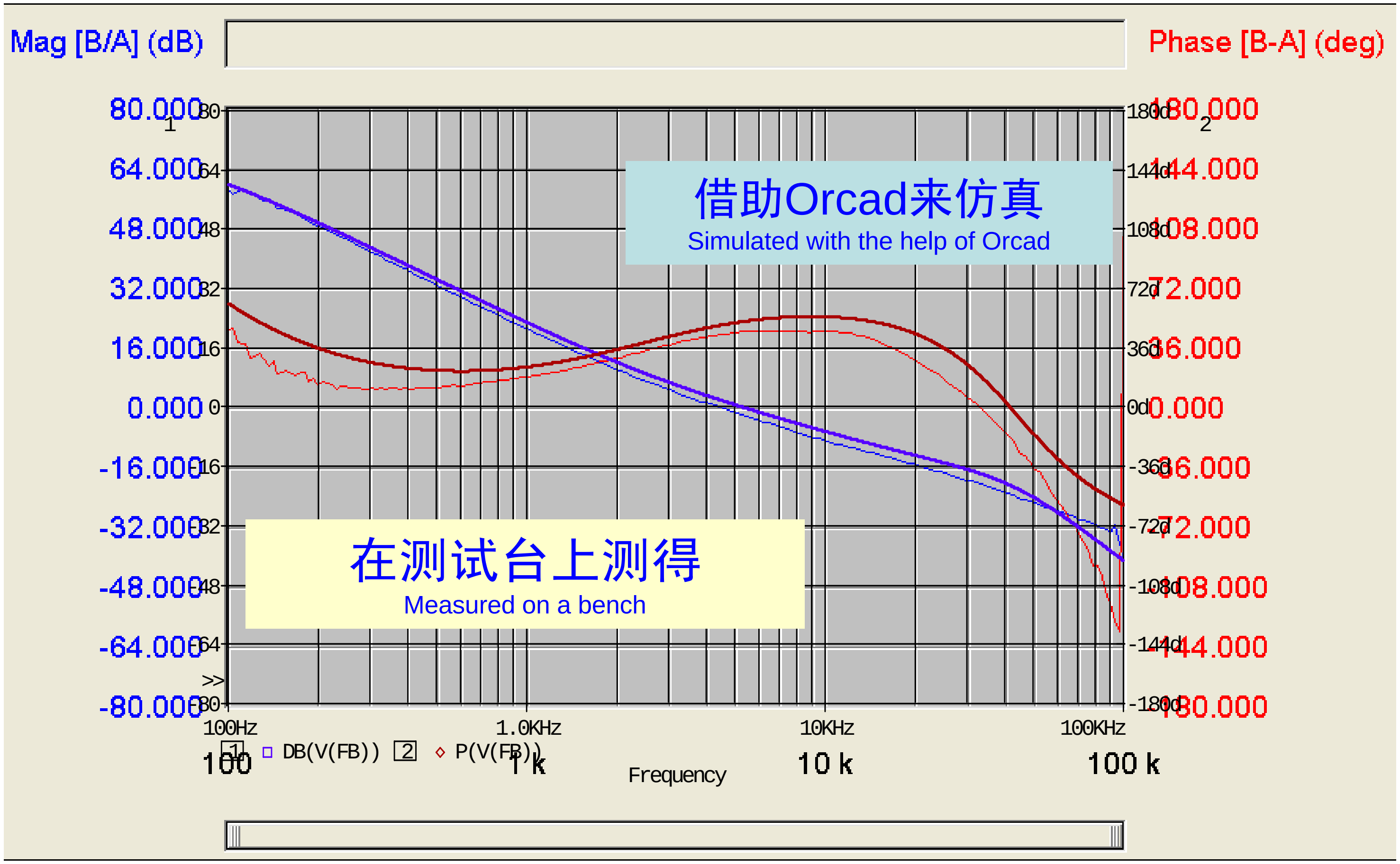
小信号分析：开环 Small Signal Analysis: Open Loop

在F_c = 6 kHz及相位裕量= 70° 时运用K因数方法后，在Orcad自动化仿真工具的帮助下，我们能够获得 After applying the K factor method @ F_c = 6 kHz and phase margin = 70° , with the help of an automated Orcad simulation, we obtain:

PARAMETERS:

Vout = 12V
L1 = 27u
L2 = {L1*(N2/N1)**2}
N1 = 0.0870
N2 = 0.0498
Rsense = 0.75
Rupper = {(Vout-2.5)/532u}
Fc = 6k
PM = 70
GFc = -25
PFc = -66
G = {10**(-GFc/20)}
boost = {PM-PFc-90}

K = {tan((boost/2+45)*pi/180)}
C2 = {1/(2*pi*Fc*G*K*Rupper)}
C1 = {C2*(PWR(K,2)-1)}
R2 = {K/(2*pi*Fc*C1)}
Fzero = {Fc/K}
Fpole = {K*Fc}
Rpullup = 4k
RLED = {CTR*Rpullup/G}
Czero = {1/(2*pi*Fzero*Rupper)}
Cpole = {1/(2*pi*Fpole*Rpullup)}
CTR = 0.7
Lmag = 12.3mH
Sp = {(Vin/Lmag)*Rsense}
Vin = 390V
Cfb = {Cpole-Cpopto}
Cpopto = 3nF



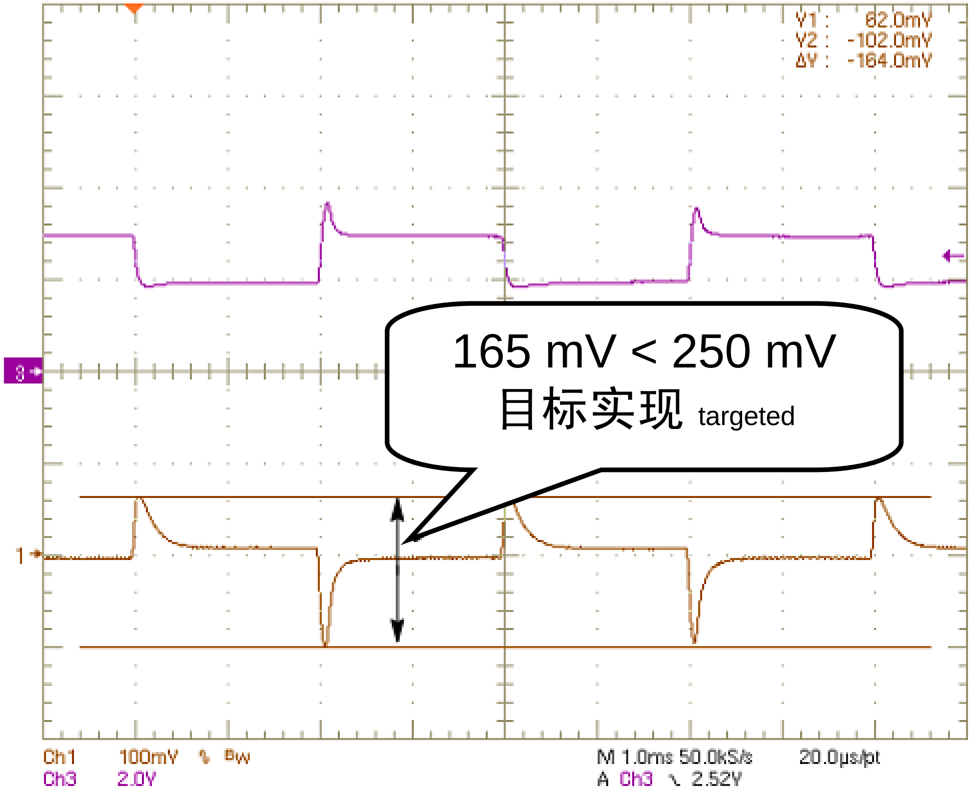
借助Orcad来仿真
Simulated with the help of Orcad

在测试台上测得
Measured on a bench

分步负载稳定性

Step Load Stability

采用分步负载测试来验证闭环稳定性 Validation of the closed loop stability with a step load test



165 mV < 250 mV
目标实现 targeted

FB pin
(2 V/div)

Ac coupling on
12-V output
(0.1 V/div)

Time
(1 ms/div)

Figure 26. Step Load Response from 5 A to 10 A

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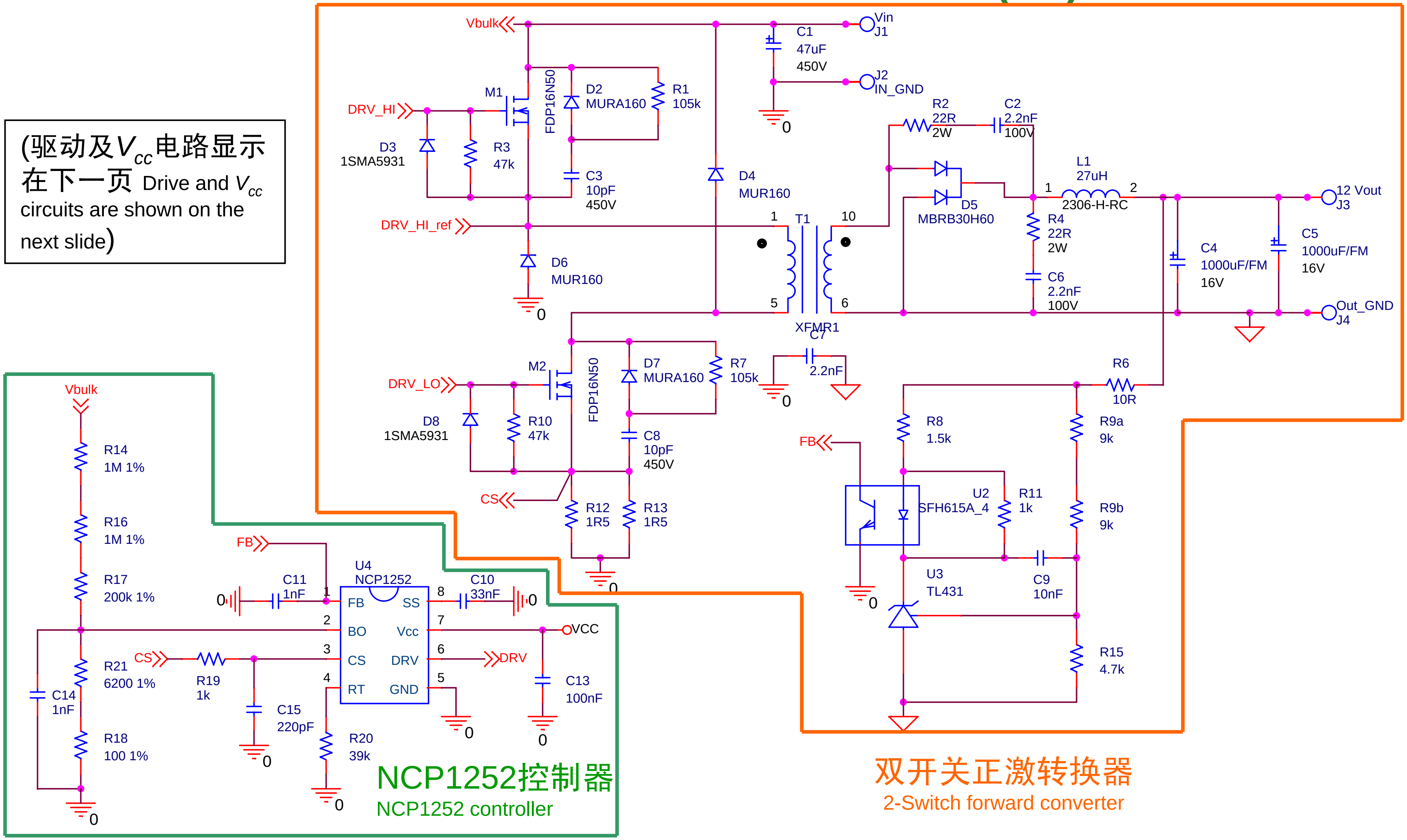
NCP1252演示板电路图(1/2)

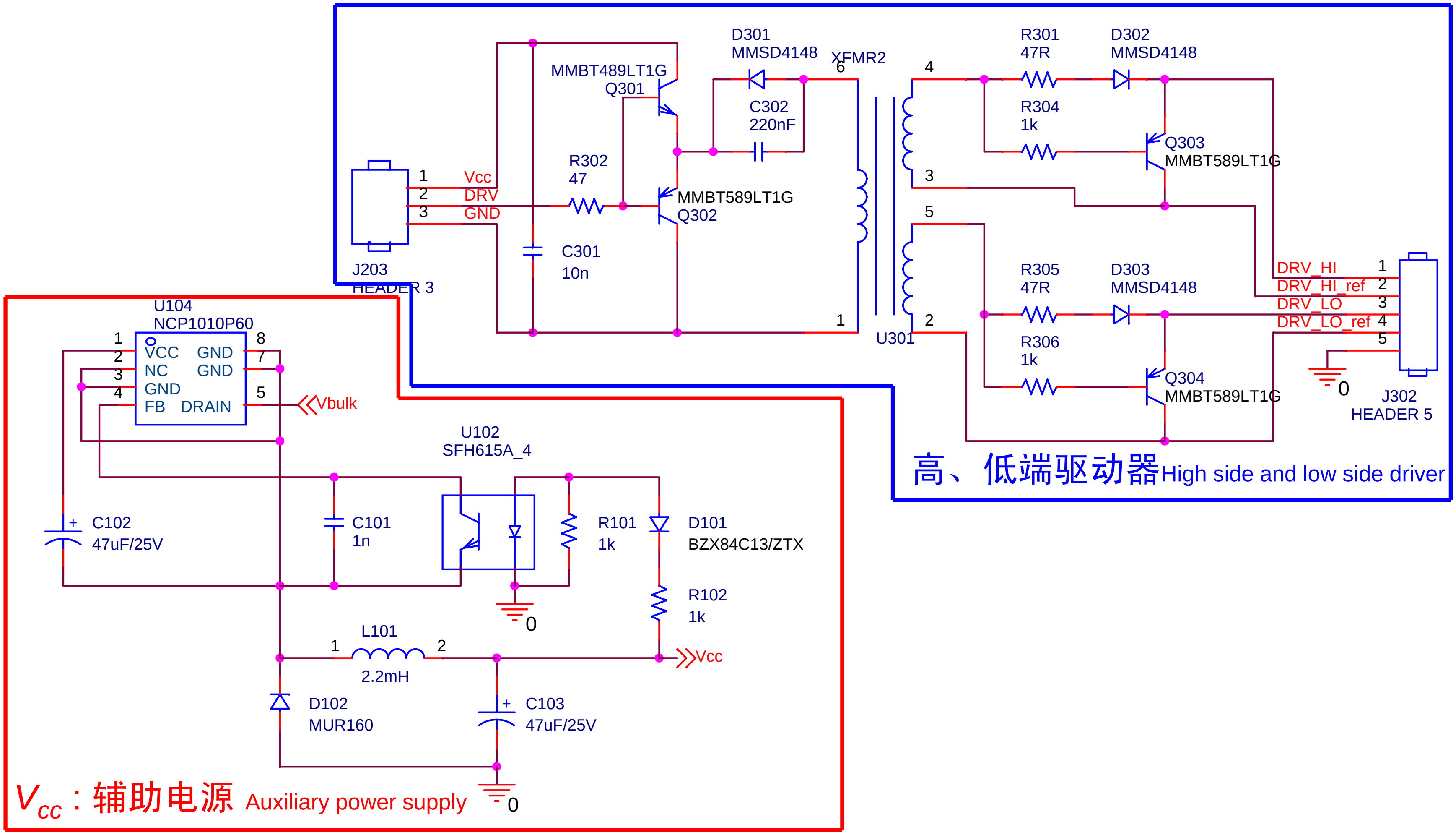
NCP1252 Demo Board Schematic (1/2)

(驱动及V_{cc}电路显示在下一页 Drive and V_{cc} circuits are shown on the next slide)



NCP1252演示板电路图(2/2)

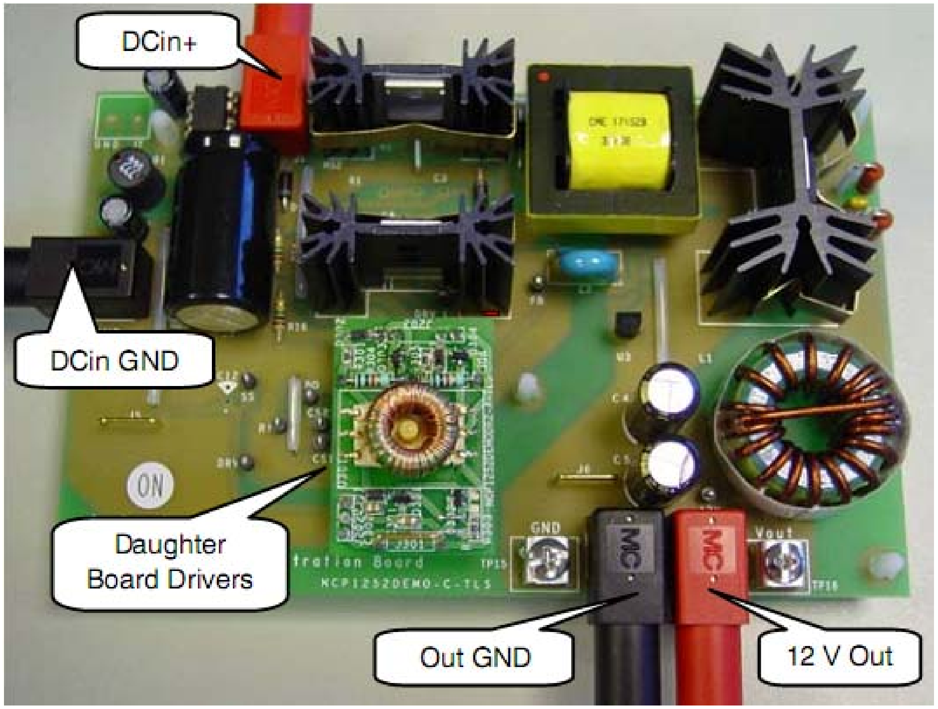
NCP1252 Demo Board Schematic (2/2)



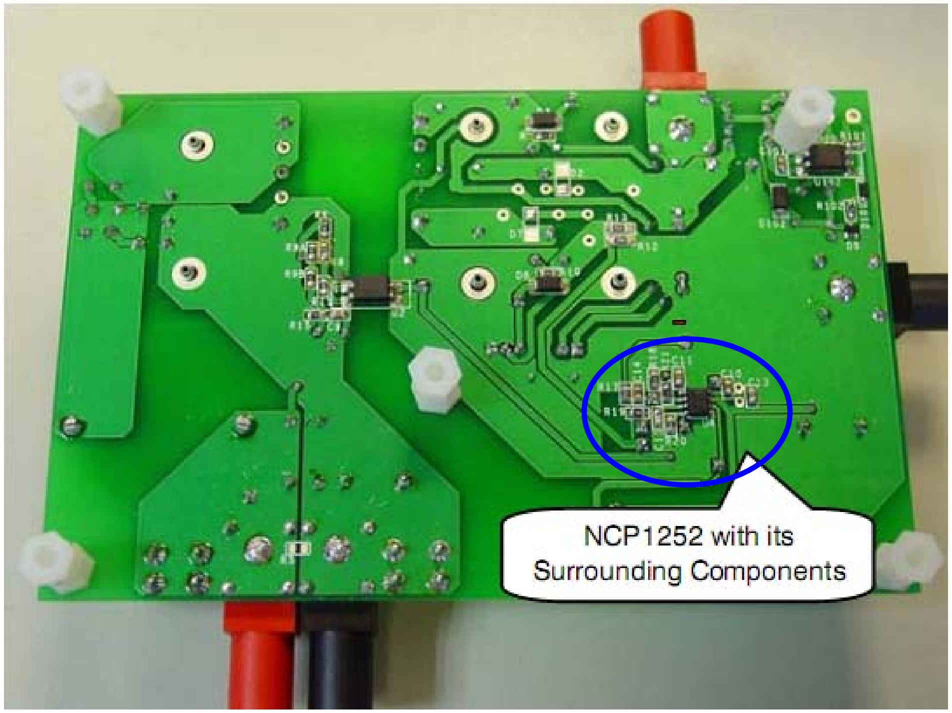
高、低端驱动器High side and low side driver

V_{cc}：辅助电源 Auxiliary power supply

NCP1252演示板：图片
NCP1252 Demo Board: Pictures



顶视图 Top view



底视图 Bottom view

演示板网页链接 Link to demoboard web page:
http://www.onsemi.cn/PowerSolutions/evalBoard.do?id=NCP1252TSFWDGEVB

或者访问有关NCP1252的网页 Or from the page of the NCP1252:

http://www.onsemi.cn/PowerSolutions/product.do?id=NCP1252

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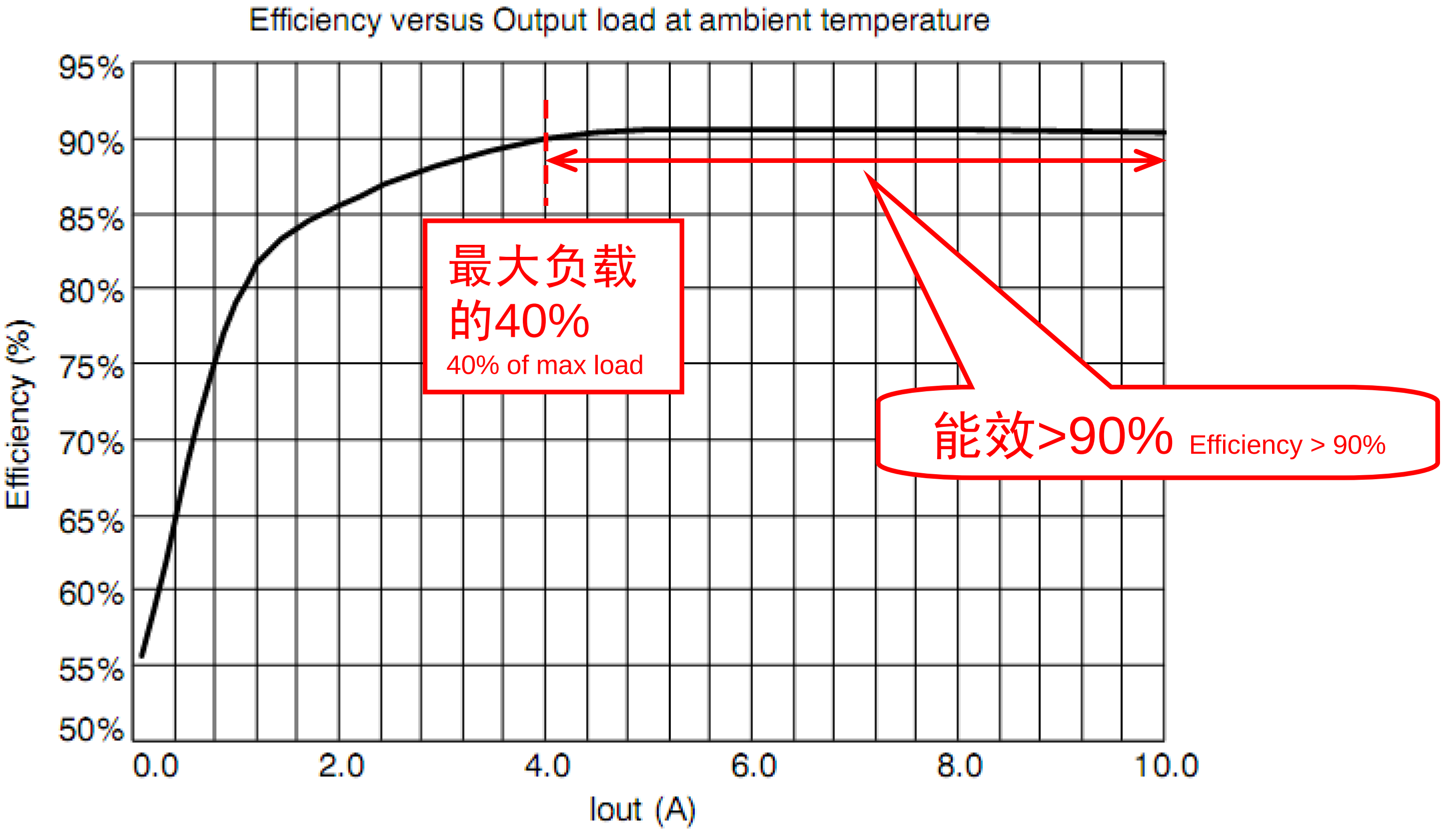
6. 闭环反馈：仿真及补偿 Closed-loop feedback: simulations and compensation
7. 演示板电路图及图片 Demo board schematics & picture
8. **演示板性能概览 Board performance review**
9. 总结 Summary

NCP1252演示板：能效

NCP1252 Demo Board: Efficiency

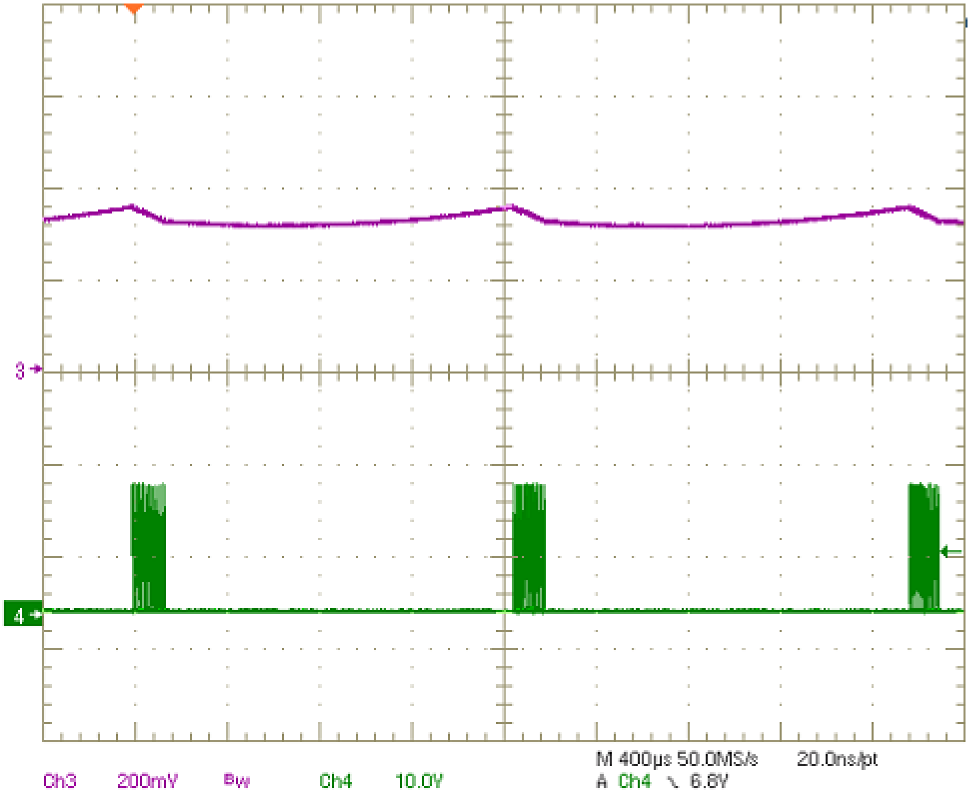


最大负载的40%
40% of max load

能效>90% Efficiency > 90%

Figure 28. Efficiency Measurement at Room Temperature and Nominal Input Voltage (390 V dc) versus Output Load Variation

NCP1252演示板：空载工作
NCP1252 Demo Board: No Load Operation



FB pin
(200 mV/div)

DRV pin
(10 V/div)

Time

(400 µs/div)

Figure 25. No Load Regulation (Real No Load to the Output) Vout = 12.096 V

- 由于NCP1252应用了跳周期特性，有可能实现真正的空载稳压而不会触发任何过压保护。这演示板不含任何假负载，确保恰当的空载稳压。这稳压藉跳过某些驱动周期及迫使NCP1252进入突发工作模式来实现。
Thanks to the skip cycle feature implemented on the NCP1252, it is possible to achieve a real no load regulation without triggering any overvoltage protection. The demonstration board does not have any dummy load and ensure a correct no load regulation. This regulation is achieved by skipping some driving cycles and by forcing the NCP1252 in burst mode of operation.

NCP1252演示板：软启动

NCP1252 Demo Board: Soft Start

一个专用引脚支持调节软启动持续时间及控制启动期间的峰值电流 One dedicated pin allows to adjust the soft start duration and control the peak current during the startup

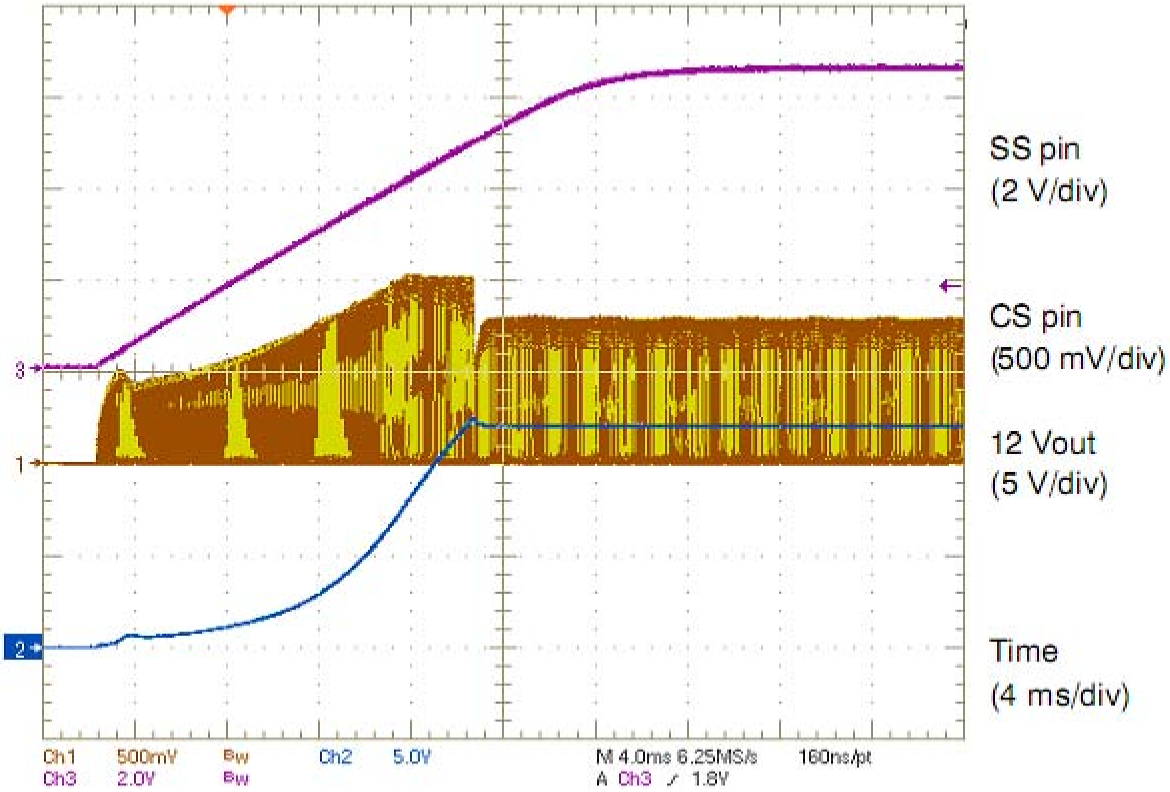


Figure 23. Soft Start at Full Load (10 A)

NCP1252演示板：性能改进

NCP1252 Demo Board: Performance Improvements

- 转换器次级端同步整流➔在中等到大负载时将节省几个百比的能效

  Synchronous rectification on the secondary side of the converter ➔ will save few percent of the efficiency from middle to high load.

- 待机能耗：NCP1252能藉将输入欠压(BO)引脚接地来关闭 ➔ NCP1252关闭时V_{cc}输入端汲入的电流小于100 µA

  Stand-by power: The NCP1252 can be shut down by grounding the BO pin ➔ less than 100 µA is sunk on V_{cc} rail when NCP1252 is shutdown.

议程 Agenda

1. 正激转换器概论 Generalities on forward converters
2. 磁芯复位：三次绕组、RCD钳位、双开关正激 Core reset: tertiary winding, RCD clamp, 2-switch forward
3. NCP1252演示板规格概览 Specs review of the NCP1252’s demo board
4. 功率元件计算Power components calculation
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总结
Summary

- NCP1252以8引脚小型封装提供高端特性 NCP1252 features high-end characteristics in a small 8-pin package
- 增加及改进的功能使其功能强大，易于应用 Added or improved functions make it powerful & easy to use
- 元件数量少 Low part-count
- 非常适合正激转换器应用，特别是适配器、ATX电源，UC38xx替代及其它任何要求低待机能耗的应用 Ideal candidate for forward applications, particularly adapters, ATX power supplies and any others UC38xx replacement applications where a low standby power is requested.

For More Information

- View the extensive portfolio of power management products from ON Semiconductor at www.onsemi.com
- View reference designs, design notes, and other material supporting the design of highly efficient power supplies at www.onsemi.com/powersupplies