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2. AX-CAP®技术

AX-CAP®放电功能是飞兆半导体mWSaver™技术之一，在空载和轻载条件下可实现同类最佳的最小功耗，符合最新的能源之星规范

开关电源(SMPS)前端的EMI滤波器通常包含跨接在交流线路连接器的电容，如图2所示。UL 1950和IEC61010-1等大多数安全法规要求电容在电源插头从电源插座拔下后的给定时间内放电至安全电平。

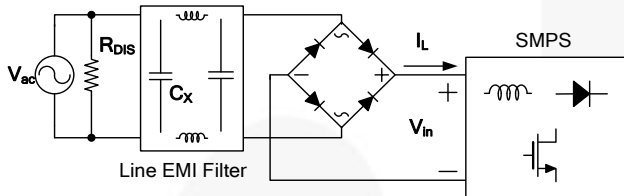


图2. EMI滤波器的典型电路

- UL1950: 对于A类设备，高于0.1 μF 的电容电压必须在1秒内衰减至交流输入峰值电压的37%，而对于B类设备，则必须在10秒内。
- IEC61010-1: 电源断开5秒后，引脚不得处于危险状态（通电）。

放电电阻必须符合等式(1)，以满足放电时间不超过一秒的要求。与X电容并联的放电电阻的功率损耗如等式(2)所示：

$$\tau_{DIS} = C_X \times R_{DIS} \leq 1s \quad (1)$$

$$P_{Loss} = \frac{V_{AC(RMS)}^2}{R_{DIS}} \quad (2)$$

表1显示的是额定输出功率、典型的有效X电容值和放电电阻功耗之间的关系。随着功率的上升，EMI滤波器的电容也会增加，因此，需要更小的放电电阻以保持相同的放电时间。这通常会导致高功率应用中更多的功率消耗。放电电阻功耗是高功率应用中待机功耗的主要原因之一。

表1. 不同额定功率系统的放电电阻功率损耗

有效X电容	典型的额定输出功率	放电电阻	$t_{DIS}=1s$ 、 $240V_{AC}$ 时的放电电阻功耗
250 nF	20~50 W	4 M Ω	14.4 mW
500 nF	50~100 W	2 M Ω	28.8 mW
1 μF	100~200 W	1 M Ω	57.6 mW
2 μF	200~400 W	500 k Ω	115.2 mW
4 μF	400~800 W	250 k Ω	230.4 mW
8 μF	800~1,600 W	125 k Ω	460.8 mW

创新的AX-CAP®放电法是飞兆半导体的一项专有mWSaver™技术，旨在摒弃X电容放电电阻的使用，同时满足安全要求。

2.1 提议解决方案

图3显示的是针对AX-CAP®技术的典型应用电路和内部框图。它仅在电源插头从电源插座上拔下时才对滤波器电容智能放电。由于AX-CAP放电电路在正常工作时被禁用，因此EMI滤波器的功耗几乎可完全消除。正常工作时，通过由外部高压电阻(R_{HV})和内部电阻(R_{LS})组成的开关式分压器对X电容电压进行感测，即可测得线路电压。开关式分压器由极窄的脉冲驱动，因此可实现最少功耗。

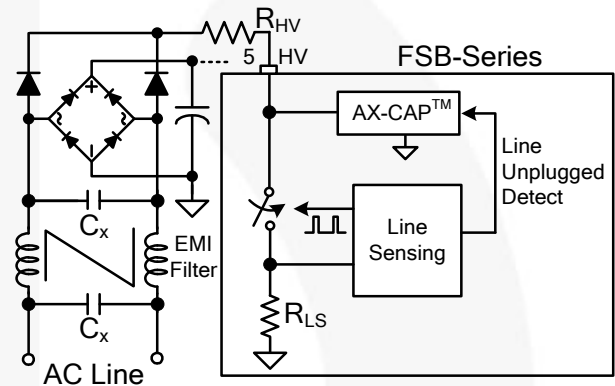


图3. FSB系列的AX-CAP®电路连接

AX-CAP®通过检查X电容电压的零交叉可检测线路连接中断。正常工作时，只要X电容与线路之间有连接，其电压就会重复下降至零。从电源插座拔下电源插头后，桥式整流器被反向偏置，X电容只能通过开关式分压器放电。随后，X电容会缓慢放电，如图4所示。若X电容电压达到线路峰值电压的一半以上，并持续超过防反跳时间，FSB系列会进入放电模式，在该模式下开关式分压器保持为导通，以便提供放电路径。

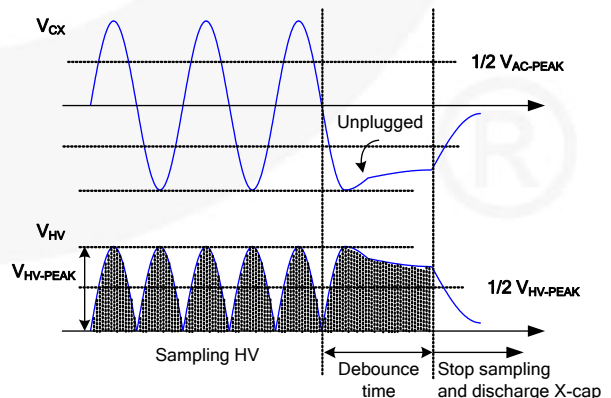


图4. 从电源插座上拔出电源插头时的HV引脚特性

2.2 最差情况分析

拔出电源插头后的放电时间，可由等式 (3) 和 (4) 计算得出：

$$V_{DIS-ST} = V_{CX} \cdot e^{-\frac{t_{AC-OFF} \cdot t_{S-TIME}}{R_{HV} \cdot C_X \cdot t_{S-CYCLE}}} \quad (3)$$

$$t_{DIS} = t_{AC-OFF} + R_{HV} \cdot C_X \cdot \ln \frac{V_{DIS-ST}}{V_{DIS-EN}} \quad (4)$$

其中：

- V_{DIS-ST} X 电容进入放电模式的电压电平；
- V_{DIS-EN} X 电容满足安全要求的电压电平
(交流峰值电压的 37%)；
- t_{AC-OFF} AX-CAP[®] 检测线路电压的去抖时间；
- t_{S-TIME} HV 引脚采样周期；以及
- $t_{S-CYCLE}$ HV 引脚采样速率。

针对最差情况 $V_{CX}=373$ V 的 FSB 系列放电时间如表 2 所示计算得出，因此 $V_{DIS-EN}=138$ V。此处， t_{AC-OFF} 为 160 ms， t_{S-TIME} 为 20 μ s， $t_{S-CYCLE}$ 为 960 μ s。 R_{HV} 由不同的交流输入范围确定；因此，最糟情况可如图 5 所示进行分析。

表 2. 不同 AX-CAP[®] 在 264 V_{AC} 下的最差情况放电时间

X 电容 (μ F)	0.10	0.22	0.47	0.68	1.00	2.20	3.30	4.70
全范围 (85 V _{AC} ~ 264 V _{AC}) - $R_{HV}=200$ k Ω								
t_{DIS} (s)	0.18	0.20	0.25	0.29	0.36	0.59	0.81	1.09
高压单一范围 (170 V _{AC} ~ 264 V _{AC}) - $R_{HV}=400$ k Ω								
t_{DIS} (s)	0.20	0.24	0.34	0.43	0.55	1.03	1.47	2.03

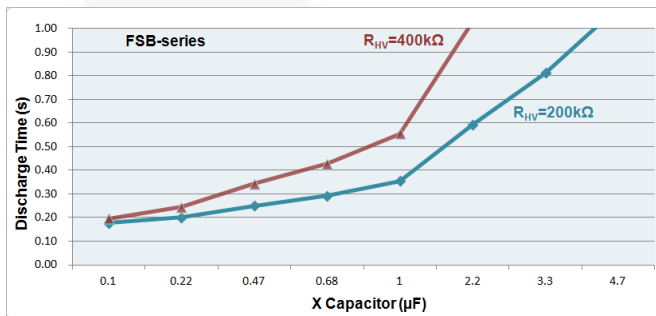


图 5. FSB 系列放电时间的最差情况分析

3. 可调峰值限流

3.1 恒定功率限制

要在任何线路电压条件下都保持恒定的有限输出功率，需采用具有采样-保持的特殊限流配置。限流电平通过限流轮廓采样并保持在栅极驱动信号的下降沿，如图 6 所示。随后，采样限流电平用于下一个开关周期。采样-保持功能用于防止电流模式控制中的次谐波振荡。

限流电平会随占空比增大而上升，随占空比减小而下降。这样，高压输入条件下的限流电平就较低，因为高压输入时的占空比要比低压输入的小。因此，即使是在宽输入电压范围内，有限最大输出功率也能保持恒定。

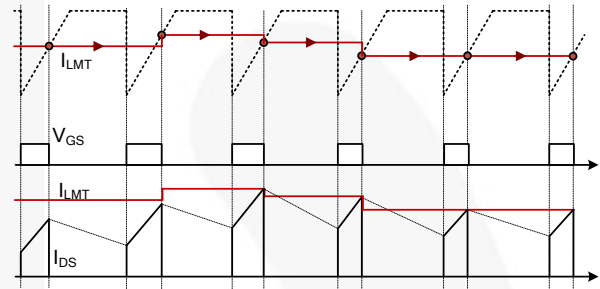


图 6. 限流值随占空比而变化

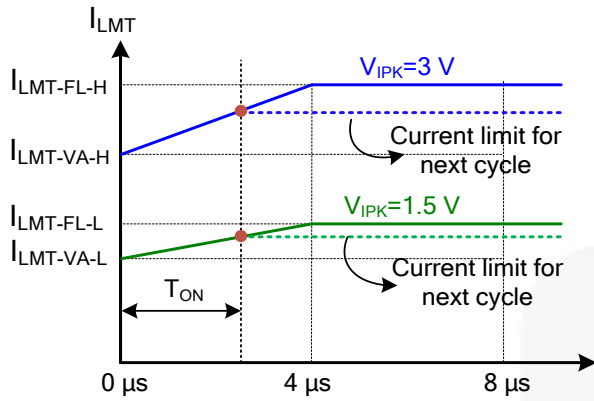
3.2 可调限流值

使用 IPK 引脚电阻可对峰值限流进行编程。IPK 引脚具有 50 μ A 内部电流源，可在电阻上产生压降。IPK 引脚电压可确定限流电平。由于 IPK 引脚的箝位电压上限与下限分别为 3 V 和 1.5 V，建议 IPK 引脚电阻值范围为 30 k Ω 至 60 k Ω 。

图 7 显示的是峰值限流 I_{LMT} 与 PWM 导通时间之间的关系。峰值电流阈值电平参见表 3 中的总结。限流平稳段 I_{LMT-FL} 和 I_{LMT-VA} 可由下列各式确定：

$$I_{LMT-FL} = \frac{1}{1.5} [(V_{IPK} - 1.5) \cdot I_{LMT-FL-H} + (3 - V_{IPK}) \cdot I_{LMT-FL-L}] \quad (5)$$

$$I_{LMT-VA} = \frac{1}{1.5} [(V_{IPK} - 1.5) \cdot I_{LMT-VA-H} + (3 - V_{IPK}) \cdot I_{LMT-VA-L}] \quad (6)$$

图7. I_{LMT} 与 PWM导通时间表3. I_{LMT} 阈值电平

$I_{LMT-FL-H}$	FSB117H	0.80 A
	FSB127H	1.00 A
	FSB147H	1.50 A
$I_{LMT-VA-H}$	FSB117H	0.60 A
	FSB127H	0.75 A
	FSB147H	1.13 A
$I_{LMT-FL-L}$	FSB117H	0.40 A
	FSB127H	0.50 A
	FSB147H	0.75 A
$I_{LMT-VA-L}$	FSB117H	0.30 A
	FSB127H	0.38 A
	FSB147H	0.57 A

3.3 过功率保护电平

要确定IPK引脚电平，首先应由下式给出输出过功率保护电平 P_o ：

$$P_o = \left(I_{LMT} \cdot V_{bulk} \cdot t_{on} - \frac{1}{2} \frac{(V_{bulk} \cdot t_{on})^2}{L_m} \right) \cdot F_s \cdot \eta \quad (7)$$

其中， V_{bulk} 是输入降压型电压， t_{on} 是PWM开通时间， L_m 是变压器初级端电感， f_s 是开关频率， η 针对OPP电平的估算效率。

因此，峰值限流 I_{LMT} 可由下式获得：

$$I_{LMT} = \frac{P_o}{V_{Bulk} \cdot t_{on} \cdot F_s \cdot \eta} + \frac{V_{Bulk} \cdot t_{on}}{2L_m} \quad (8)$$

若变压器规格给定，则PWM开通时间可由确定（参见AN-8024）：

$$t_{on} = \left(\frac{V_o \cdot N_p}{V_o \cdot N_p + V_{Bulk} \cdot N_s} \right) \cdot \frac{1}{F_s} \quad (9)$$

其中， N_p 和 N_s 分别是初级端和次级端的匝数， V_o 是输出电压。

那么， I_{LMT} 可由下式表达：

$$I_{LMT} = \frac{I_{LMT-FL} \cdot t_{on} + I_{LMT-VA} \cdot (4\mu - t_{on})}{4\mu} \quad (10)$$

注意， t_{on} 应当小于4 μ s才能满足等式(10)。 V_{IPK} 可由下式获得：

$$V_{IPK} = \frac{6\mu \cdot I_{LMT}}{t_{on} \cdot (A - C) + (4\mu - t_{on}) \cdot (B - D)} \quad (11)$$

其中，A表示 $I_{LMT-FL-H}$ ，B表示 $I_{LMT-VA-H}$ ，C表示 $I_{LMT-FL-L}$ ，D表示 $I_{LMT-VA-L}$ ，可在表3中找到。

因此，IPK引脚电阻可由下式确定：

$$R_{IPK} = \frac{V_{IPK}}{50\mu} \quad (12)$$

尽管IPK引脚的上限和下限箝位电压分别为3 V和1.5 V，但是建议 R_{IPK} 范围为30 k Ω 至60 k Ω 。

附录： FSB系列峰值限流设计示例

应用	器件	输出功率	输入电压	输出电压	过功率保护 (OPP)
ATX待机	FSB127H	10 W	85 ~ 265 V _{AC}	5 V	15 W

1. 系统指标

输出电压 (V _o)	5	V
过功率保护 (OPP)	15	W
开关频率 (F _s)	100	kHz
估算效率 (η)	75	%

2. 变压器规格

初级匝数 (N _p)	106	T
次级匝数 (N _s)	8	T
初级电感 (L _m)	1.2	mH
85 V _{AC} 时的PWM导通时间 (t _{on})	3.55	μs
峰值限流 (I _{LMT})	0.646	A

3. 限流阈值电平

V _{IPK} =3 V时的平坦电平 (I _{LMT-FL-H})	1.00	A
V _{IPK} =3 V时的谷底电平 (I _{LMT-VA-H})	0.75	A
V _{IPK} =1.5 V时的平坦电平 (I _{LMT-FL-L})	0.50	A
V _{IPK} =1.5 V时的谷底电平 (I _{LMT-VA-L})	0.38	A
IPK引脚电平 (V _{IPK})	1.997	V
限流平坦电平 (I _{LMT-FL})	0.666	A
限流谷底电平 (I _{LMT-VA})	0.503	A

4. FSB127H的过功率保护

交流输入 (V _{AC})	90	115	132	180	230	264	V
过功率保护 (P _o)	15.1	15.0	14.9	14.5	14.1	13.9	W

参考文献

[AN-4137 — 采用FPS™的离线反激式转换器设计指南](#)

[AN-8024 — FSBH系列飞兆电源开关 \(FPS™\) 在备用辅助电源中的应用](#)

[FSB127H / FSB147H — mWSaver™飞兆电源开关 \(FPS™\) 数据手册, 飞兆半导体](#)

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