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应用指南 AN4148

适用于 FPS 应用的声音降噪技术

1. 引言

通常，开关电源在稳定超过频率 (>20kHz) 下工作时不会产生音频噪声。但是，某些开关模式电源在特定负载条件下可能产生音频噪声。大多数飞兆电源开关设计为在轻负载条件下进入间歇工作模式以减少待机功耗，当间歇模式的基频处于图 1 所示的人耳听力范围内时，会导致音频噪声。

本应用指南说明音频噪声的主要来源，并为工程师提供有用提示以解决其飞兆电源开关 (FPS) 应用中的音频噪声问题。

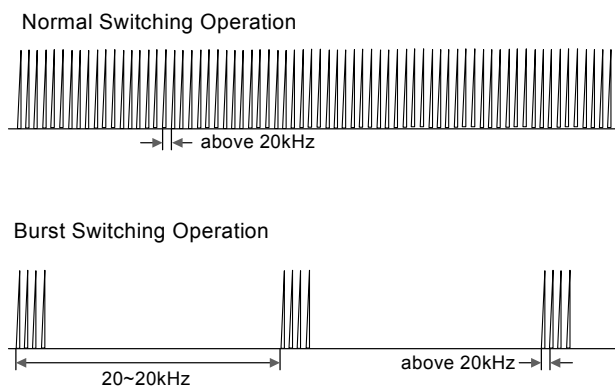


图 1. 间歇模式操作

2. 音频噪声来源

即使 FPS 的开关频率高于人耳听力范围，瞬态或间歇模式操作期间也可能产生音频噪声。在大多数反激式转换器中，主要噪声源是变压器和电容。

- 变压器音频噪声

变压器可产生音频噪声，因为它们包含许多实体可移动的元件，如线圈、隔离卷带和线筒。线圈中的电流产生电磁场，从而在线圈之间产生排斥力和 / 或吸引力。这可能会在线圈、铁氧体磁心或隔离卷带中产生机械振动。

- 电容音频噪声

陶瓷电容也可能产生音频噪声，因为它们具有压电特性。如果对变压器正确进行点胶和涵浸后间歇模式操作中仍有太多音频噪声，则应检查缓冲器网络中的电容。

3. 减少音频噪声的技巧

- 对变压器涵浸

减少变压器中音频噪声的最有效方式是通过使用粘性材料或通过涵浸消除变压器元件实体移动的可能性。这也可以减幅变压器元件的机械共振。

- 更改变压器设计

变压器机械振动的幅度与通量摆幅密切相关。因此，音频噪声可通过降低间歇模式中的通量摆幅来减少，如下式给出

$$\Delta B = \frac{L_m I_{bp}}{N_p A_e} \times 10^6 \quad (T) \quad (1)$$

其中 L_m 是变压器初级端电感， I_{bp} 是突发开关中的电流峰值， A_e 是磁芯的横截面积（单位：mm²）， N_p 是变压器初级端绕组匝数。

从等式 (1) 中可以看出，通过增大 N_p 和 / 或 A_e 同时保持 L_m 稳定（从而减少音频噪声）可减小通量摆幅。

- 减小间歇模式中的电流峰值

等式 (1) 还显示，通量摆幅可通过降低间歇模式中的电流峰值 (I_{bp}) 来减小。通过使用斜率补偿，可降低间歇模式中的电流峰值。遗憾的是，此技巧仅可应用于下面的 FPS，其间歇模式电平由反馈电压电平确定。

- FSDM0465R、FSDM0565R、FSDM07652R、FSDM1265R

- FSCM0565R、FSCM0765R、FSD200、FSD210

斜率补偿电路可使用一个电容和一个电阻轻松实施，如图 2 所示。此斜率补偿电路使反馈电压产生电压突降，从而降低突发开关中的电流峰值（如图 3 和图 4 所示），以 FSDM0565R 为例。在 FSDM0565R 的例子中，当反馈电压降低到低于 0.5V 时开关停止，而当反馈电压达到 0.7V 时开关会恢复。因此，间歇模式电流由反馈电压确定，并可通过引入反馈电压跌落来降低。

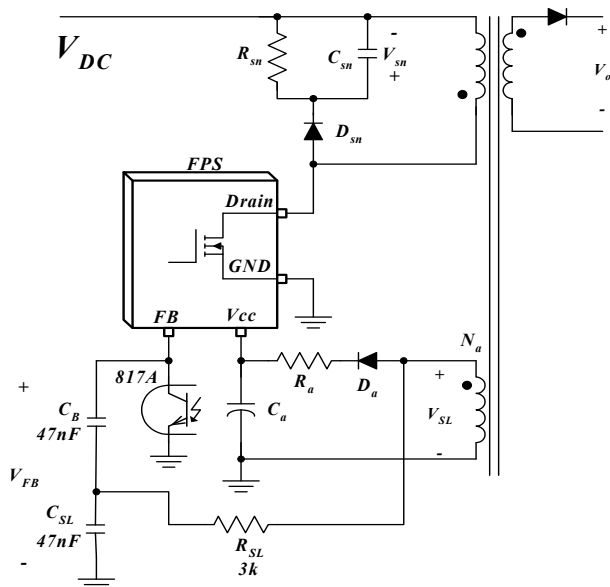


图 2. 斜率补偿电路

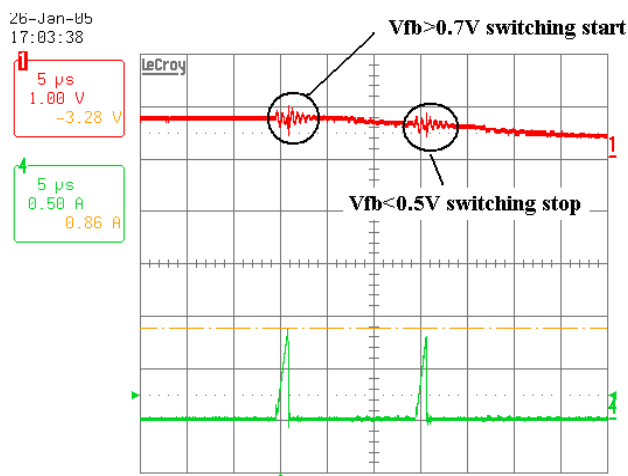


图 3. 无斜率补偿的间歇模式波形 (FSDM0565R)

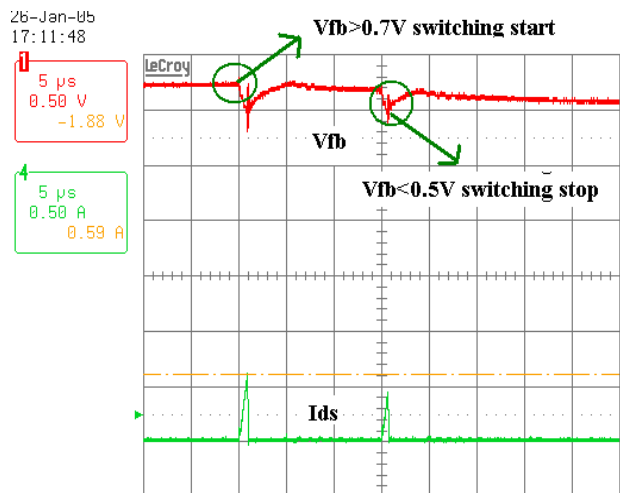


图 4. 有斜率补偿的间歇模式波形 (FSDM0565R)

- 更改 RCD 缓冲器网络

如前所述，陶瓷电容也可能因其压电特性而产生音频噪声。如图 5 所示，将陶瓷电容替换为薄膜电容，可减少音频噪声。

Film capacitor

Ceramic capacitor

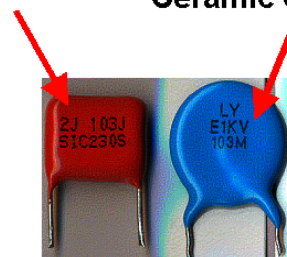


图 5. 薄膜电容和陶瓷电容

降低音频噪声的另一种方式是减小缓冲器电容值，这会减小 FPS 每次在间歇模式下恢复开关操作时对电容进行充电的脉冲电流，如图 6 所示。使用 TVS（瞬态电压抑制二极管）的齐纳箝位电路（如图 7 所示）也可降低由缓冲器电容导致的音频噪声。

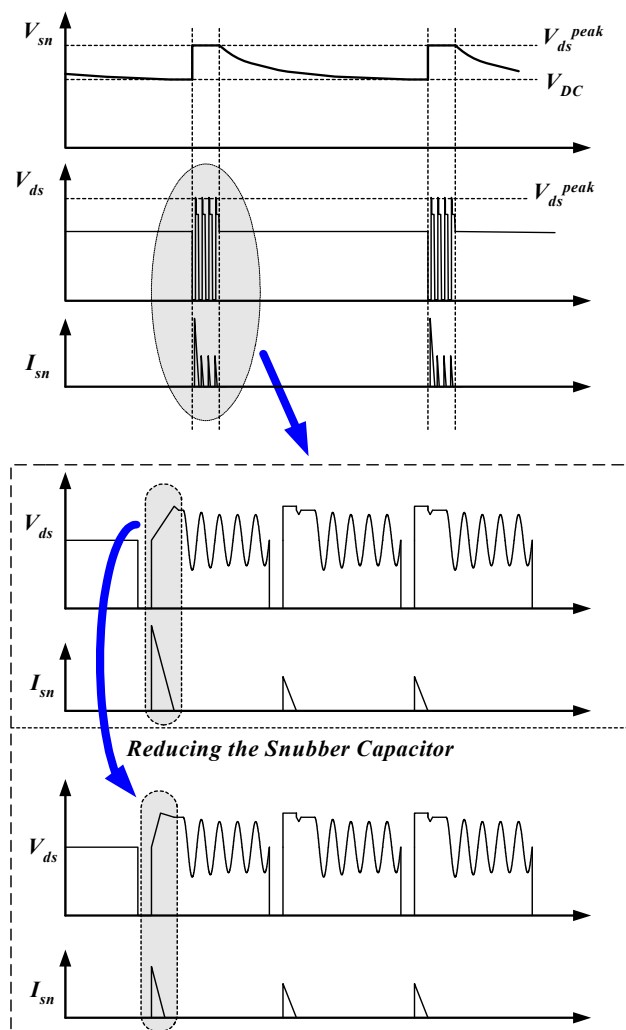


图 6. 减小缓冲器电容的效果

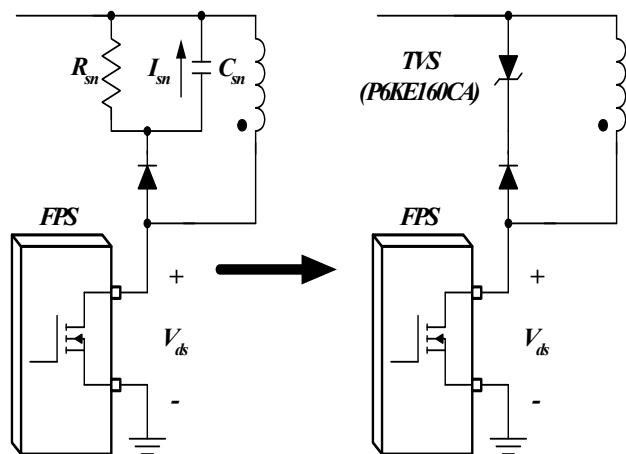


图 7. 使用 TVS 的齐纳箝位电路

- 更改间歇模式的基频

通常，人耳对 2~4kHz 的频率最敏感，对高于或低于图 8 中等响度曲线的频率不太敏感。这些曲线表示人耳对超出各个响度级别人耳听力范围的频率的敏感度。各行显示频率范围的强度等级，描述对参考 1kHz 起始等级的类似响度的主观感受。

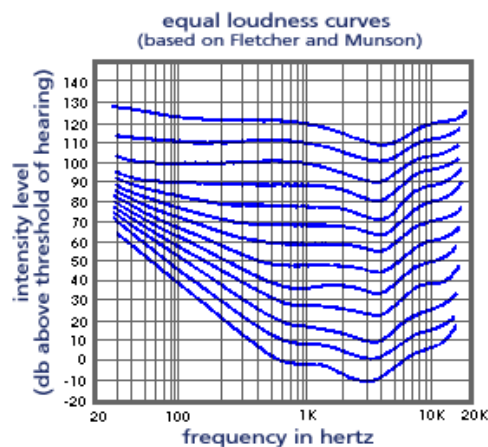


图 8. 等响曲线

因此，可通过将噪音的基频移出 2~4kHz 范围来降低响度的主观感受。间歇模式的基频可通过修改反馈网络来更改。图 9 显示典型反馈网络。基频可通过以下一种或多种方式来降低

- 增大 C_F
- 增大 R_D
- 增大 C_B
- 减小 R_F

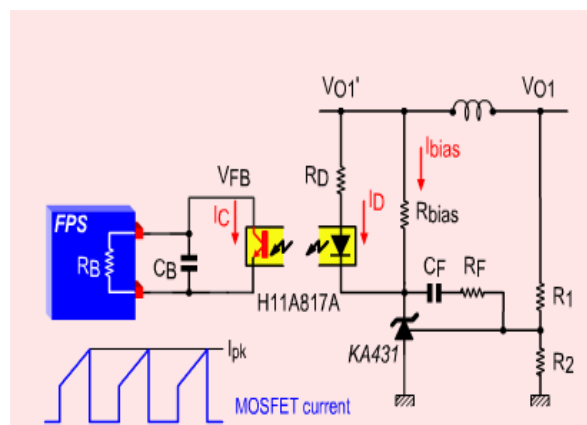


图 9. FPS 的典型反馈网络

图 10 显示使用反馈网络参数的间歇模式波形

- $R_F=1.2k$, $C_F=100nF$, $R_D=100$, $C_B=22nF$

在这种情况下，间歇模式的基频为 1.2kHz。当 R_D 从 100W 增大到 1kW 时，基频减小到 142Hz，如图 11 所示。经过此电路修改，基频和响度的主观感受一起得以降低。但是，降低基频时要谨慎，因为输出电压纹波和间歇模式中的开关次数都会随基频的降低而增加。

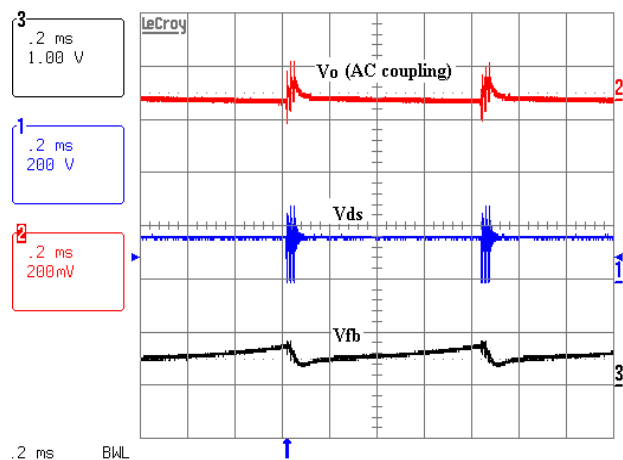


图 10. 间歇模式波形
(基频为 1.2kHz)

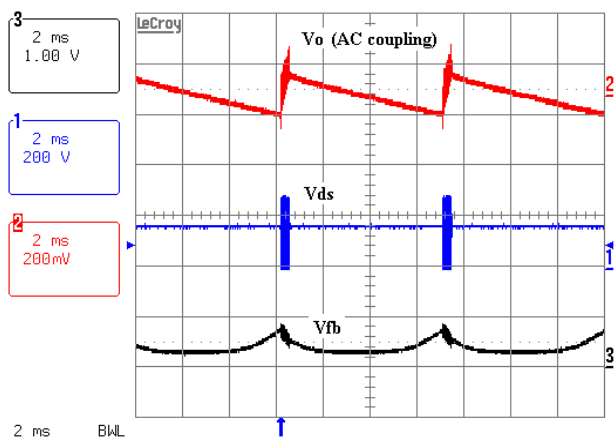


图 11. 突发开关波形
(基频为 142Hz)

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