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2013年11月

# FLS-XS 系列 — 照明用半桥 LLC 谐振控制 IC

## 特性

- 为半桥谐振转换器拓扑提供了 50% 占空比的变频控制
- 通过零电压开关 (ZVS) 实现高效率
- 带快速恢复体二极管的内部 UniFET™
- 针对 MOSFET 优化的固定死区时间 (350 ns)
- 工作频率最高可达 300 kHz
- 通过外部 $LV_{CC}$为所有保护功能提供自动重启操作
- 保护功能: 过压保护(OVP)、过流保护(OCP)、异常过流保护(AOCP)、内部热关断(TSD)

## 应用

- 通用 LED 照明电源
- 工业、商业及住宅 LED 照明装置
- 户外照明: 街道、车道、停车场、建筑及装饰品 LED 照明装置

## 说明

FLS-XS系列通用照明功率控制器包含高度集成的功率开关，适合中到高功率流明应用。FLS-XS系列具有构建可靠而鲁棒的半桥谐振转换器所需的一切特性，可以简化设计、提高生产力、改进性能。FLS-XS 系列将功率 MOSFET 与快速恢复型体二极管、高侧栅极驱动电路、精确电流控制振荡器、频率限制电路、软启动和内置保护功能结合在一起。高侧栅极驱动电路具有共模噪声消除功能，通过卓越的抗噪能力确保运行稳定。MOSFET的快速恢复体二极管可提高可靠性，防止异常操作情况的发生，同时又能将反向恢复的影响降至最低。使用零电压开关(ZVS)可大幅减少开关损耗，显著提高效率。ZVS 还可显著降低开关噪声，允许使用小尺寸的电磁干扰 (EMI) 滤波器。

FLS-XS系列可应用于谐振转换器拓扑，如串联谐振、并联谐振和LLC谐振转换器。

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## 订购信息

| 器件编号 | 封装 | 工作结温 | $R_{DS(ON\_MAX)}$ | 不带散热器时的最大输出功率 ($V_{IN}$= 350~400 V)$^{(1,2)}$ | 带散热器时的最大输出功率 ($V_{IN}$= 350~400 V)$^{(1,2)}$ |
|---|---|---|---|---|---|
| FLS2100XS | 9-SIP | -40 至 +130° C | 0.51Ω | 180W | 400W |
| FLS1800XS | | | 0.95Ω | 120W | 260W |
| FLS1700XS | | | 1.25Ω | 100W | 200W |
| FLS1600XS | | | 1.55Ω | 80W | 160W |

**注意：**

1. 结温可以限制最大输出功率。
2. 环境温度为 50°C 时开放框架应用中的最大实际持续功率。

## 应用电路图

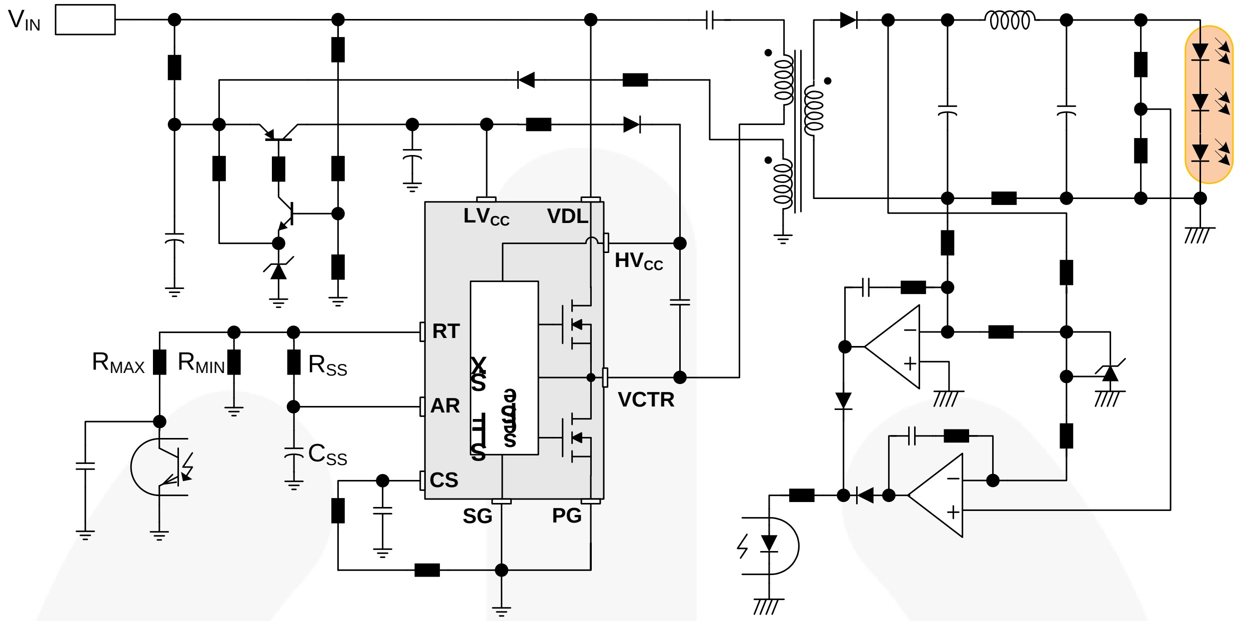


图1. LLC 谐振半桥转换器的典型应用电路

## 框图

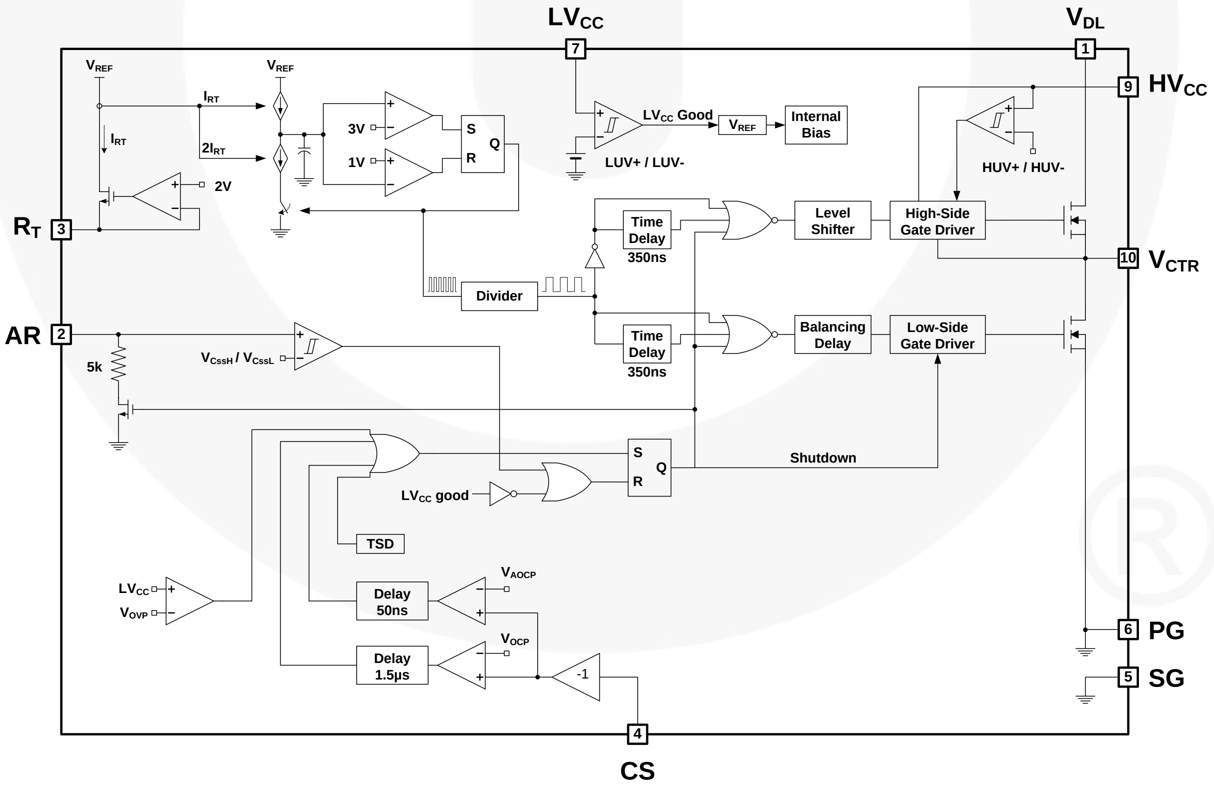


图2. 内部框图

## 引脚布局

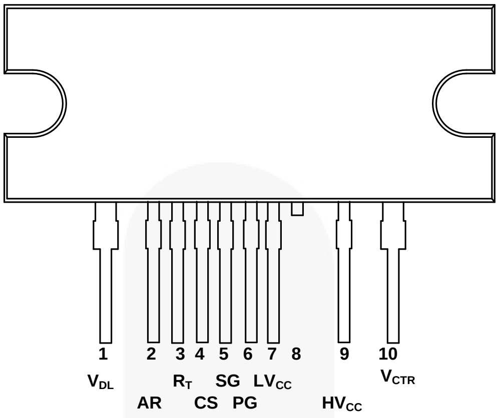


图3. 封装图

## 引脚定义

| 引脚号 | 名称 | 说明 |
|---|---|---|
| 1 | $V_{DL}$ | 该引脚为高侧MOSFET 的漏极，通常连接到直流高压。 |
| 2 | AR | 此引脚用于在任何保护机制被触发时对外部软启动电容放电。如果该引脚电压降至 0.2 V，所有保护机制重新启动并且控制器重新开始工作。 |
| 3 | $R_T$ | 该引脚用于编程开关频率。一般地，需要光耦连接到该引脚，用来调节输出电压的开关频率。 |
| 4 | CS | 该引脚用于检测流过低侧 MOSFET 的电流。典型地，负电压被施加到该引脚。 |
| 5 | SG | 该引脚为 控制地。 |
| 6 | PG | 该引脚为电源地。该引脚连接到低侧MOSFET的源极。 |
| 7 | $LV_{CC}$ | 该引脚为控制IC的供电电压。 |
| 8 | NC | 无连接 |
| 9 | $HV_{CC}$ | 该引脚为高侧栅极驱动电路 IC 的供电电压。 |
| 10 | $V_{CTR}$ | 该引脚为低侧 MOSFET 的漏极。典型地，变压器连接到该引脚。 |

## 绝对最大额定值

应力超过绝对最大额定值，可能会损坏器件。在超出推荐的工作条件的情况下，该器件可能无法正常工作，所以不建议让器件在这些条件下长期工作。此外，过度暴露在高于推荐的工作条件下，会影响器件的可靠性。绝对最大额定值仅是应力规格值。除非另有说明，$T_A$= 25°C。

| 符号 | 参数 | | | 最小值 | 最大值 | 单位 |
|---|---|---|---|---|---|---|
| $V_{DS}$ | 最大漏源极电压（$V_{DL}$-$V_{CTR}$和 $V_{CTR}$-PG） | | | 500 | | V |
| $LV_{CC}$ | 低侧电源电压 | | | -0.3 | 25.0 | V |
| $HV_{CC}$至 $V_{CTR}$ | 高侧 $V_{CC}$引脚至低侧漏极电压 | | | -0.3 | 25.0 | V |
| $HV_{CC}$ | 高侧浮动电源电压 | | | -0.3 | 525.0 | V |
| $V_{AR}$ | 自动重启引脚输入电压 | | | -0.3 | $LV_{CC}$ | V |
| $V_{CS}$ | 电流检测（CS）引脚输入电压 | | | -5.0 | 1.0 | V |
| $V_{RT}$ | $R_T$引脚输入电压 | | | -0.3 | 5.0 | V |
| $dV_{CTR}/dt$ | 允许的低侧 MOSFET 漏极电压变化速率 | | | | 50 | V/ns |
| $P_D$ | 总功耗[3] | FLS2100XS | | | 12.0 | W |
| | | FLS1800XS | | | 11.7 | |
| | | FLS1700XS | | | 11.6 | |
| | | FLS1600XS | | | 11.5 | |
| $T_J$ | 最大结温[4] | | | | +150 | °C |
| | 推荐的工作结温[4] | | | -40 | +130 | |
| $T_{STG}$ | 存储温度范围 | | | -55 | +150 | °C |
| **MOSFET 部分** | | | | | | |
| $V_{DGR}$ | 漏栅极电压（$R_{GS}$= 1 MΩ） | | | 500 | | V |
| $V_{GS}$ | 栅源极（GND）电压 | | | | ±30 | V |
| $I_{DM}$ | 漏极脉冲电流[5] | FLS2100XS | | | 32 | A |
| | | FLS1800XS | | | 23 | |
| | | FLS 1700XS | | | 20 | |
| | | FLS 1600XS | | | 18 | |
| $I_D$ | 连续漏极电流 | FLS2100XS | $T_C$=25°C | | 10.5 | A |
| | | | $T_C$=100°C | | 6.5 | |
| | | FLS1800XS | $T_C$=25°C | | 7.0 | |
| | | | $T_C$=100°C | | 4.5 | |
| | | FLS 1700XS | $T_C$=25°C | | 6.0 | |
| | | | $T_C$=100°C | | 3.9 | |
| | | FLS 1600XS | $T_C$=25°C | | 4.5 | |
| | | | $T_C$=100°C | | 2.7 | |
| **封装部分** | | | | | | |
| 扭矩 | 推荐螺杆扭矩 | | | 5~7 | | kgf·cm |

**注意：**

3. 当两个 MOSFET 同时导通时，是指每个 MOSFET 的总功耗。
4. 所推荐的工作结温最大值受限于热保护功能。
5. 脉冲宽度受限于最大结温。

## 热阻

除非另有说明，$T_A$= 25°C。

| 符号 | 参数 | | 数值 | 单位 |
|---|---|---|---|---|
| $\theta_{JC}$ | 结壳中心热阻<br>（两个 MOSFET 同时导通） | FLS2100XS | 10.44 | °C/W |
| | | FLS1800XS | 10.68 | |
| | | FLS 1700XS | 10.79 | |
| | | FLS 1600XS | 10.89 | |

## 电气特性

除非另有说明，$T_A$= 25°C。

| 符号 | 参数 | | 测试条件 | 最小值 | 典型值 | 最大值 | 单位 |
|---|---|---|---|---|---|---|---|
| **MOSFET 部分** | | | | | | | |
| $BV_{DSS}$ | 漏源极击穿电压 | | $I_D$=200μA, $T_A$=25°C | 500 | | | V |
| | | | $I_D$=200μA, $T_A$=125°C | | 540 | | |
| $R_{DS(ON)}$ | 导通电阻 | FLS2100XS | $V_{GS}$=10V, $I_D$=6.0A | | 0.41 | 0.51 | Ω |
| | | FLS1800XS | $V_{GS}$=10V, $I_D$=3.0A | | 0.77 | 0.95 | |
| | | FLS 1700XS | $V_{GS}$=10V, $I_D$=2.0A | | 1.00 | 1.25 | |
| | | FLS 1600XS | $V_{GS}$=10V, $I_D$=2.25A | | 1.25 | 1.55 | |
| $t_{rr}$ | 体二极管反向恢复时间(6) | FLS2100XS | $V_{GS}$=0V, $I_{Diode}$=10.5A,<br>$dI_{Diode}/dt$=100A/μs | | 120 | | ns |
| | | FLS1800XS | $V_{GS}$=0V, $I_{Diode}$=7.0A,<br>$dI_{Diode}/dt$=100A/μs | | 160 | | |
| | | FLS 1700XS | $V_{GS}$=0V, $I_{Diode}$=6.0A,<br>$dI_{Diode}/dt$=100A/μs | | 160 | | |
| | | FLS 1600XS | $V_{GS}$=0V, $I_{Diode}$=5.0A,<br>$dI_{Diode}/dt$=100A/μs | | 65 | | |
| **电源部分** | | | | | | | |
| $I_{LK}$ | 偏置漏电流 | | $HV_{CC}$=$V_{CTR}$=500V | | | 50 | μA |
| $I_QHV_{CC}$ | $HV_{CC}$静态电源电流 | | ($HV_{CC}$UV+) – 0.1 V | | 50 | 120 | μA |
| $I_QLV_{CC}$ | $LV_{CC}$静态电源电流 | | ($LV_{CC}$UV+) – 0.1V | | 100 | 200 | μA |
| $I_OHV_{CC}$ | $HV_{CC}$工作电源电流<br>（RMS值） | | $f_{OSC}$=100KHz | | 6 | 9 | mA |
| | | | 无开关 | | 100 | 200 | μA |
| $I_OLV_{CC}$ | $LV_{CC}$工作电源电流<br>（RMS值） | | $f_{OSC}$=100KHz | | 7 | 11 | mA |
| | | | 无开关 | | 2 | 4 | mA |

*接下页*

## 电气特性

除非另有说明，$T_A$= 25°C。

| | | | | | | |
|---|---|---|---|---|---|---|
| **UVLO 部分** | | | | | | |
| $LV_{CC}UV+$ | $LV_{CC}$电源欠压正向阀值（$LV_{CC}$开始） | | 11.2 | 12.5 | 13.8 | V |
| $LV_{CC}UV-$ | $LV_{CC}$电源欠压负向阀值（$LV_{CC}$停止） | | 8.9 | 10.0 | 11.1 | V |
| $LV_{CC}UVH$ | $LV_{CC}$电源欠压滞回电压 | | | 2.50 | | V |
| $HV_{CC}UV+$ | $HV_{CC}$电源欠压正向阀值（$HV_{CC}$开始） | | 8.2 | 9.2 | 10.2 | V |
| $HV_{CC}UV-$ | $HV_{CC}$ 电源欠压负向阀值（$HV_{CC}$停止） | | 7.8 | 8.7 | 9.6 | V |
| $HV_{CC}UVH$ | $HV_{CC}$电源欠压滞回电压 | | | 0.5 | | V |
| **振荡器与反馈部分** | | | | | | |
| $V_{RT}$ | V-I 转换器阀值电压 | $R_T$=5.2KΩ | 1.5 | 2.0 | 2.5 | V |
| $f_{OSC}$ | 输出振荡频率 | | 94 | 100 | 106 | KHz |
| DC | 输出占空比 | | 48 | 50 | 52 | % |
| $f_{SS}$ | 内部软启动初始频率 | $f_{SS}=f_{OSC}$+40kHz, $R_T$=5.2KΩ | | 140 | | KHz |
| $t_{SS}$ | 内部软启动时间 | | 2 | 3 | 4 | ms |
| **保护部分** | | | | | | |
| $V_{CssH}$ | 初始电压至放电 $C_{SS}$ | | 0.9 | 1.0 | 1.1 | V |
| $V_{CssL}$ | 初始电压至充电 $C_{SS}$和重启 | | 0.16 | 0.20 | 0.24 | V |
| $V_{OVP}$ | $LV_{CC}$过压保护 | $LV_{CC}$ > 21V | 21 | 23 | 25 | V |
| $V_{AOCP}$ | AOCP 阈值电压 | | -1.0 | -0.9 | -0.8 | V |
| $t_{BAO}$ | AOCP 消隐时间⑹ | $V_{CS} < V_{AOCP}$ | | 50 | | ns |
| $V_{OCP}$ | OCP 阈值电压 | | -0.64 | -0.58 | -0.52 | V |
| $t_{BO}$ | OCP 消隐时间⑹ | $V_{CS} < V_{OCP}$ | 1.0 | 1.5 | 2.0 | μs |
| $t_{DA}$ | 延时时间（低侧）从 $V_{AOCP}$检测至关断⑹ | | | 250 | 400 | ns |
| $T_{SD}$ | 热关断温度⑹ | | +120 | +135 | +150 | °C |
| **死区时间控制部分** | | | | | | |
| $D_T$ | 死区时间⑺ | | | 350 | | ns |

**注意：**

6. 该参数由设计保证；生产过程中不做测试。
7. 尽管这些参数已得到保证，仍仅在 EDS（晶圆测试）过程中检测。

## 典型性能特征

这些在$T_A$=25°C下测得的特性图都被归一化。

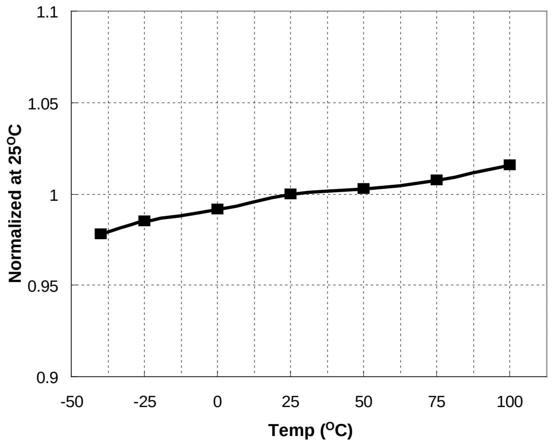


图4. 低侧 MOSFET 占空比与温度的关系

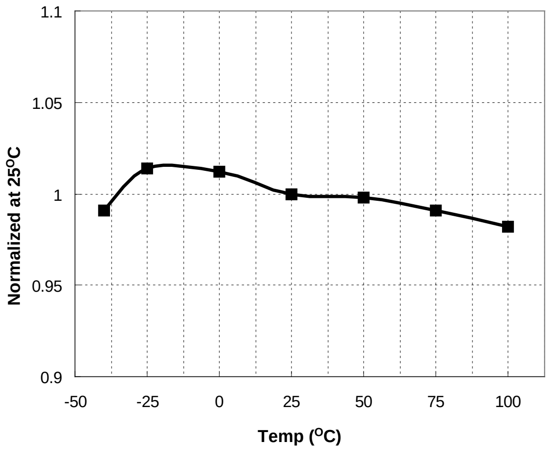


图5. 开关频率与温度的关系

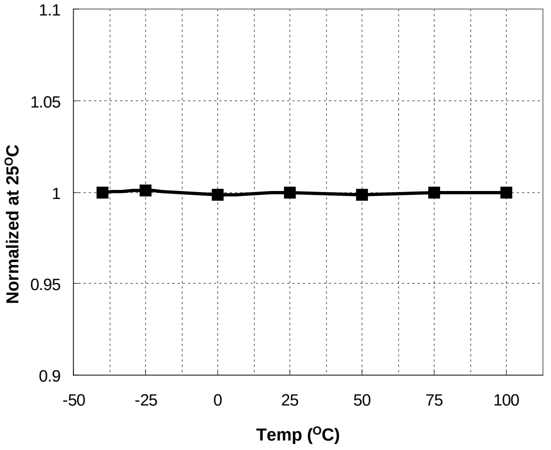


图6. 高侧 $V_{CC}$（$HV_{CC}$）开始与温度的关系

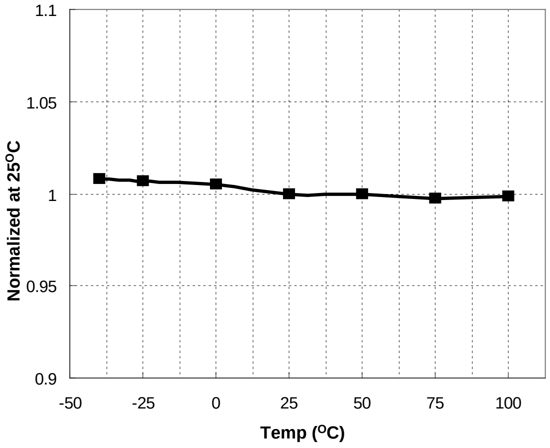


图7. 高侧 $V_{CC}$（$HV_{CC}$）停止与温度的关系

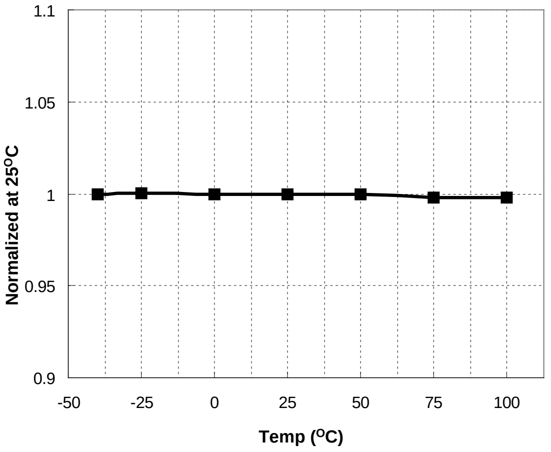


图8. 低侧 $V_{CC}$（$LV_{CC}$）开始与温度的关系

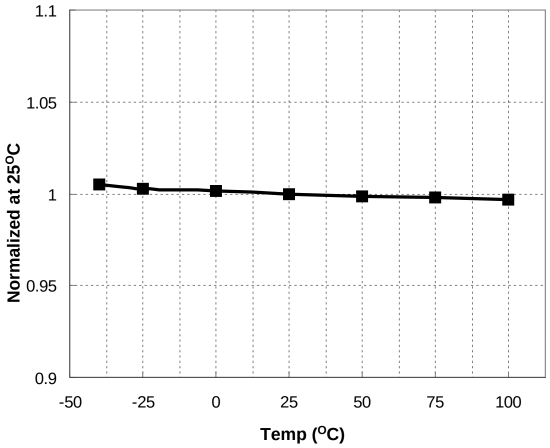


图9. 低侧 $V_{CC}$（$LV_{CC}$）停止与温度的关系

## 典型性能特征（续）

这些在T$_A$=25°C下测得的特性图都被归一化。

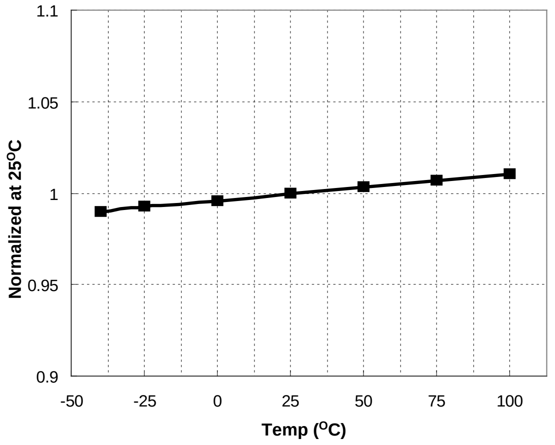


**图10.** LV$_{CC}$ OVP 电压与温度的关系

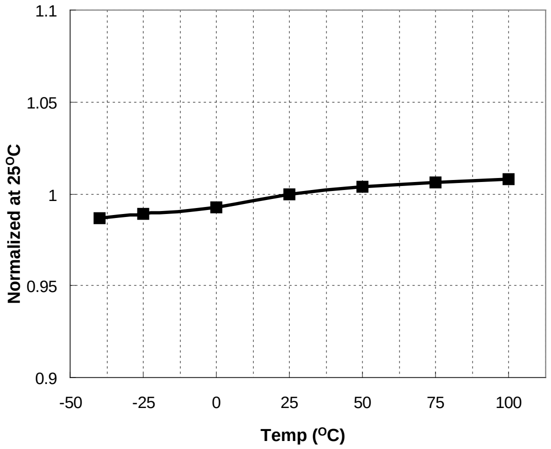


**图11.** R$_T$电压与温度的关系

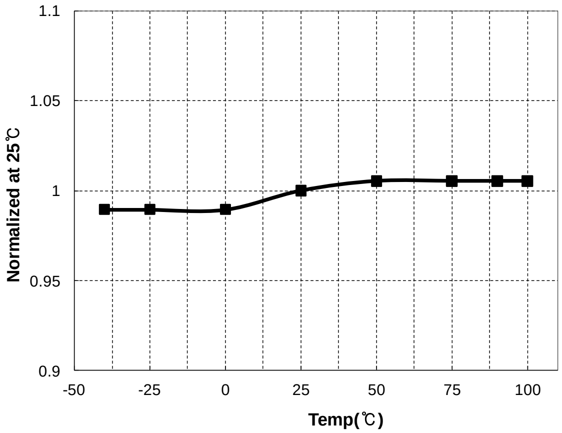


**图12.** V$_{CssL}$与温度的关系

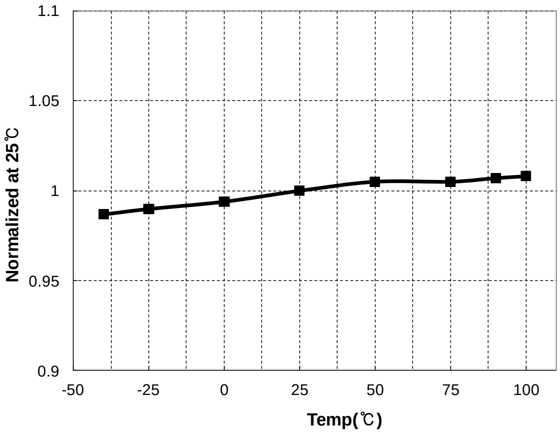


**图13.** V$_{CssH}$与温度的关系

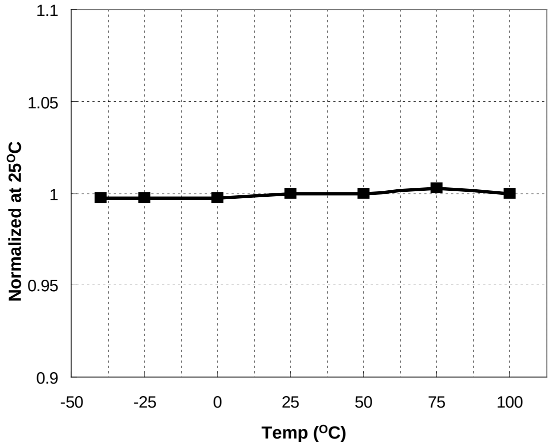


**图14.** OCP 电压与温度的关系

## 功能说明

**1. 基本运行。**FLS-XS 系列设计用于驱动高低侧 MOSFET，并且提供 50% 的占空比。在连续过渡之间引入了 350 ns 的固定死区时间，如图15所示。

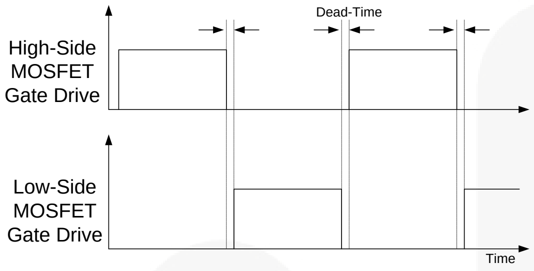


**图15. MOSFET 栅极驱动信号**

**2. 内部振荡器：** FLS-XS 系列采用电流控制振荡器，如图图16所示。在内部，$R_T$引脚电压控制在 2 V，振荡器电容 $C_T$的充放电电流通过使用电流反射镜像 $R_T$引脚流出的电流（$I_{CTC}$）复制获得。因此，开关频率随着 $I_{CTC}$的增加而增加。

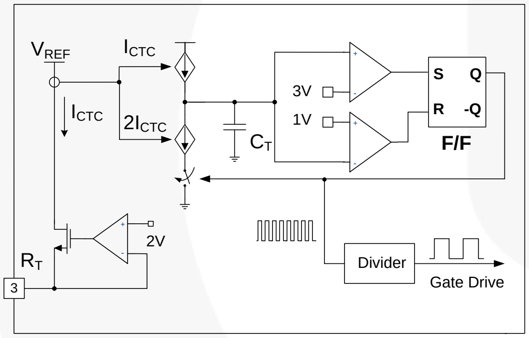


**图16. 电流控制的振荡器**

**3. 频率设置：** 图17显示谐振转换器的典型电压增益曲线，其中增益与 ZVS 区域的开关频率成反比。输出电压通过调节开关频率进行控制。图18显示 $R_T$引脚的典型电路配置，其中光耦合器晶体管连接至 $R_T$引脚，用于调节开关频率。

最小开关频率计算如下：

$$f^{\min} = \frac{5.2k\Omega}{R_{\min}} \times 100(kHz) \tag{1}$$

假定光耦晶体管的饱和电压为0.2V，则最大开关频率决定于：

$$f^{\max} = \left(\frac{5.2k\Omega}{R_{\min}} + \frac{4.68k\Omega}{R_{\max}}\right) \times 100(kHz) \tag{2}$$

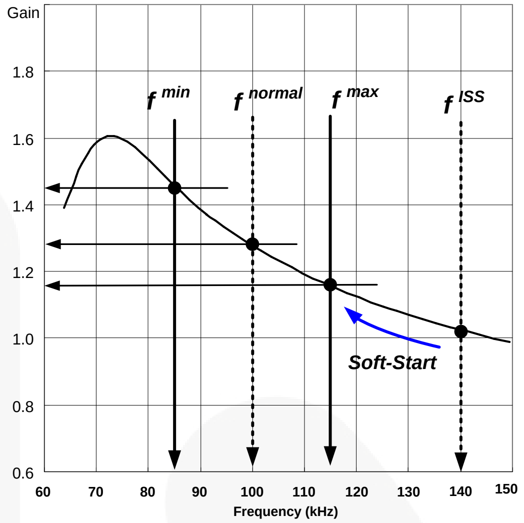


**图17. 谐振转换器典型增益曲线**

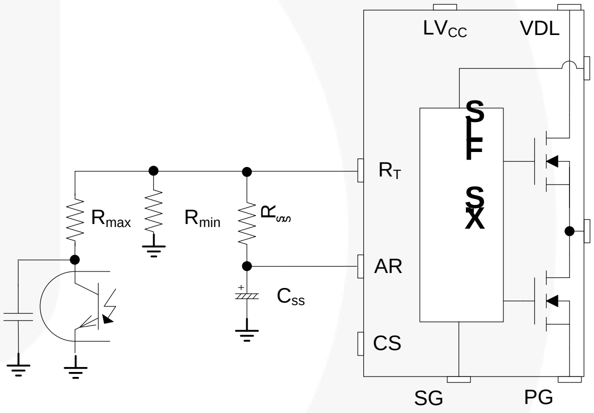


**图18. 频率控制电路**

为了防止在启动阶段，冲击电流过大，输出电压过冲，需要逐渐增加该谐振转换器的电压增益。鉴于谐振转换器的电压增益与开关频率成反比，为实现软启动，应从初始高频（$f^{ISS}$）向下扫描开关频率，直至输出电压建立为止。在 $R_T$引脚上连接 RC 串联电路，即可建立软启动电路，如图18所示。FLS-XS 系列产品还设有 3 ms 的内部软启动，能够再给外部软启动电路的初始频率增加 40 kHz，在启动之初的几个开关周期中，可以降低电流过冲，如图19所示。这样软启动的初始频率计算如下：

$$f^{ISS} = \left(\frac{5.2k\Omega}{R_{\min}} + \frac{5.2k\Omega}{R_{SS}}\right) \times 100 + 40\ (kHz) \tag{3}$$

通常来说，将软启动的初始频率设置为谐振电路谐振频率（$f_0$）的二至三倍。软启动时间为 RC 时间常数的三到四倍。RC 时间常数为：

$$\tau = R_{SS} \bullet C_{SS} \tag{4}$$

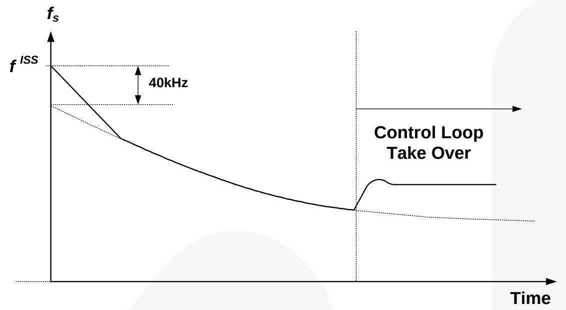


图19.　　软启动中频率扫描

**4. 自动重启：** FLS-XS 系列甚至可以在外部电源电压触发任何内置保护功能时实现自动重启。如图20和图21所示，一旦触发保护功能，M1 开关导通并且 V-I 转换器被禁用。$C_{SS}$开始放电，直至 $C_{SS}$ 两端的 $V_{Css}$降至 $V_{CssL}$。然后，所有保护功能被重置，M1 关断，且 V-I 转换器恢复。FLS-XS 通过软启动再次开始开关过程。如果保护功能出现在 $V_{Css}$低于 $V_{CssL}$和 $V_{CssH}$ 电平情况下，开关过程立即终止，$V_{Css}$继续增加，直至达到 $V_{CssH}$，然后 $C_{SS}$由 M1 放电。

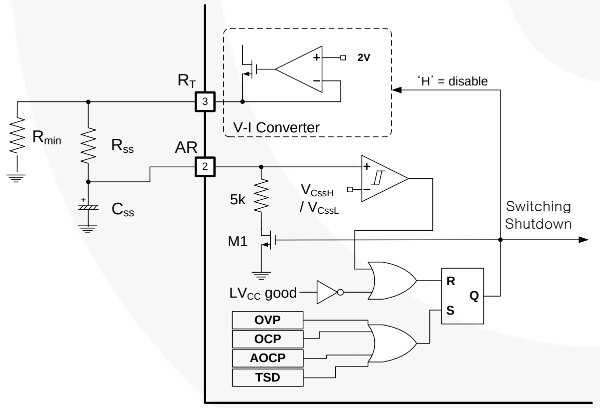
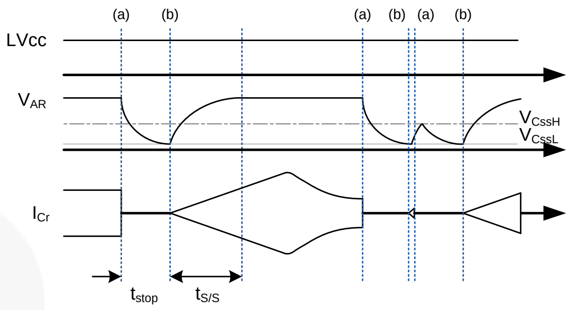


图20.　　AR 引脚的内部框图

触发保护功能后，FLS-XS 在停止时间 $t_{stop}$内被禁用，而 $V_{Css}$降低并达到 $V_{CssL}$。FLS-XS 的停止时间估算如下：

$$t_{STOP} = C_{SS} \bullet \{(R_{SS} + R_{MIN}) \| 5k\Omega\} \tag{5}$$

软启动时间 $t_{s/s}$可根据方程式（4）设置。



(a) Protections are triggered, (b) FLS-XS restarts

图21.　　自动重启运行

**5. 保护电路：** FLS-XS 系列有几个自我保护功能，如过流保护 (OCP)、异常过流保护 (AOCP)、过压保护 (OVP) 和热关断 (TSD)。这些保护功能为自动重启模式保护功能，如图22 所示。

如果出现故障情况，开关过程将终止，且 MOSFET 保持关断。当 $LV_{cc}$降至 $LV_{cc}$停止电压 10 V 或 AR 信号为高电平时，保护功能被重置。FLS-XS 在 $LV_{cc}$达到开始电压 12.5 V 时恢复正常运行。

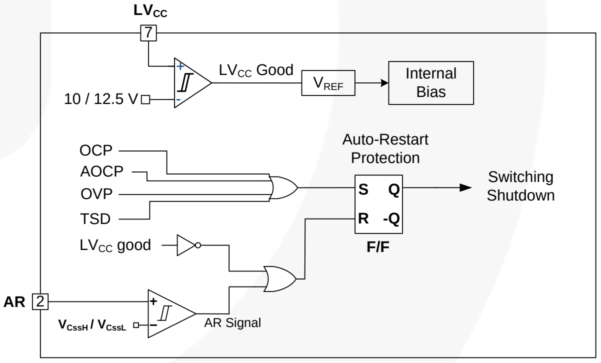


图22.　　保护框图

**5.1 过流保护 (OCP)：** 当检测到引脚电压跌至低于 -0.58 V 时，过流保护功能被触发并且 MOSFET 保持关断。该保护功能有一个 1.5 µs 的关断延时，用于阻止启动期间的过早关断。

**5.2 异常过流保护 (AOCP)：** 如果次级整流器二极管短路，di/dt 非常高的大电流会在触发过流保护前流过 MOSFET。如果检测引脚电压跌至低于 -0.9 V，触发异常过流保护，且没有关断延时。

**5.3 过压保护（OVP）：** 当 $LV_{CC}$达到 23 V 时，触发 OVP。当变压器的辅助绕组提供 $V_{CC}$至 FPS™ 时，使用该保护功能。

**5.4 热关断（TSD）：** 将 MOSFET 和控制 IC 置于单个封装中，有助于控制 IC 检测 MOSFET 的异常过温。如果温度超过大约 130°C，触发热关断。

**6. 通过电阻进行电流感测：** FLS-XS 系列产品检测漏极电流，并以此产生一个负电压，如图23和图24所示。半波检测方式允许检测电阻产生低功耗，但是全波检测方式的检测信号具有较低开关噪声。

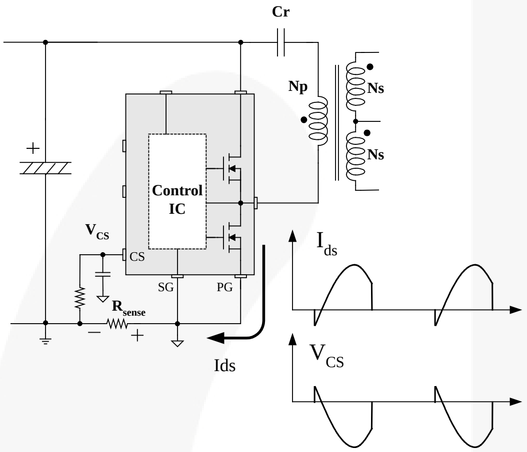


图23. 半波检测

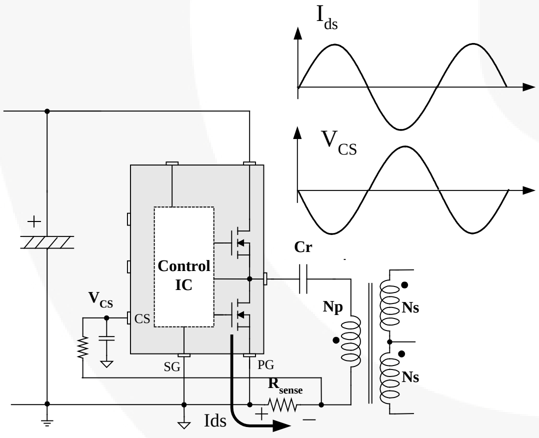


图24. 全波检测

**7. PCB 布局指南：**
出现占空比不平衡问题的原因可能是主变压器产生的辐射噪声、主变压器次级端漏电感的不均等，等等。这是 PCB 布局中 $R_T$引脚附近的控制元件需要与初级电流路径隔离的一个原因。当高低侧 MOSFET 轮流导通时，初级电流产生的磁场方向发生改变。具有不同方向的磁场会导致电流流入或流出 $R_T$引脚，从而改变每个 MOSFET 的导通时段。强烈建议在 PCB 布局中将 $R_T$引脚附近的控制元件与初级电流环路分开。图25显示占空平衡情况下的实例。

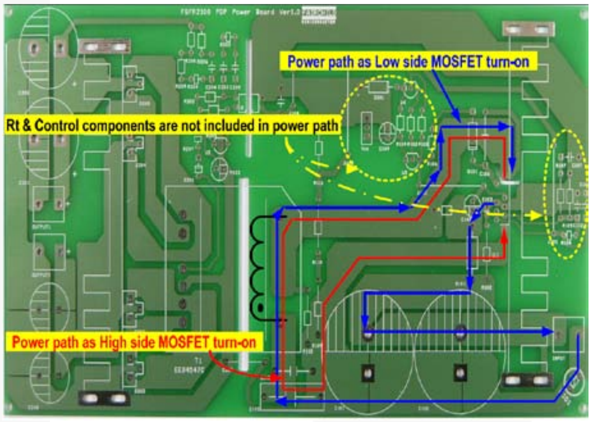


图25. 占空比平衡实例

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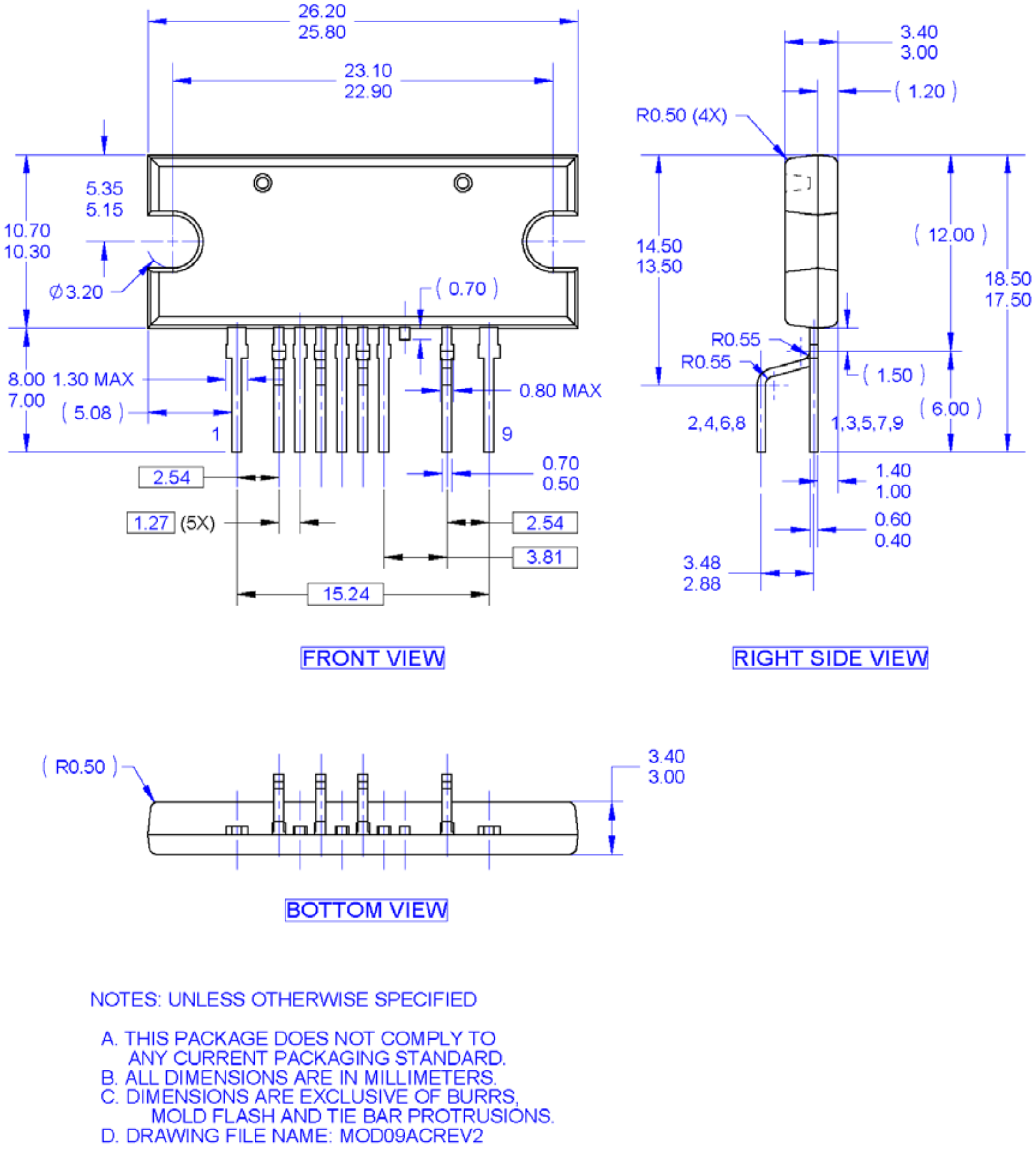

**图26.　9 引脚单列直插式封装 (SIP)**

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