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FSFR-HS 系列 — 适用于半桥谐振转换器的先进的飞兆功率开关 (FPS™)

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
- 内置高侧栅极驱动器 IC
- 具有快速恢复类型体二极管 ($t_{rr}=160$ ns 典型值) 的内部 UniFET™
- 为 MOSFET 优化的固定死区时间 (350 ns)
- 用于软启动高达 600 kHz 的工作频率
- 为所有保护提供自重启操作, 尽管具有外部 LV_{CC} 偏置
- 具有可编程滞回的线电压 UVLO
- 通过线电压 UVLO 引脚实现简单的导通/关断
- 无需外部元件便可提供线电压 UVLO 和 FAULT 指示
- 保护功能 过压保护 (OVP)、过流保护 (OCP)、异常过流保护 (AOCP)、内部关断 (TSD)

应用

- 等离子 (PDP) 与液晶 (LCD) 电视
- 台式计算机 服务器
- 适配器
- 通用电源

说明

FSFR-HS 是高度集成的电源开关, 专为高效率半桥谐振转换器而设计。它提供了构建可靠、强健的谐振转换器所需的一切, FSFR-HS 不仅简化了设计, 同时提高了生产力和性能。FSFR-HS 将功率 MOSFET 与高侧栅极驱动电路、精确的电气控制、振荡器以及内置保护功能完美地整合在了一起。

高侧栅极驱动电路具有共模噪声消除功能, 它为稳定操作提供了出色的抗噪能力。使用零电压开关 (ZVS) 技术可显著降低开关损耗并提高效率。ZVS 还可以显著降低开关噪声, 即使工作频率增加也如此。除了高工作频率外, 它还提供少量的电磁干扰 (EMI) 滤波, 从而可缩小谐振腔, 并提高功率密度。

FSFR-HS 可用于谐振转换器拓扑, 如串联谐振、并联谐振以及 LLC 谐振转换器。

相关资源

[AN4151 — 使用 FSFR 系列飞兆电源开关 \(FPS™\) 的半桥 LLC 谐振转换器设计](#)

订购信息

器件编号	封装	工作结温	$R_{DS(ON_MAX)}$	不带散热片的最大输出功率 ($V_{IN}=350\sim400$ V) ^(1,2)	带散热片的最大输出功率 ($V_{IN}=350\sim400$ V) ^(1,2)
FSFR1800HS	9-SIP	-40 至 +130°C	0.95 Ω	120 W	260 W
FSFR1800HSL	9-SIP L-成型				
FSFR1700HS	9-SIP	-40 至 +130°C	1.25 Ω	100 W	200 W
FSFR1700HSL	9-SIP L-成型				

注意:

1. 结温可限制最大输出功率。
2. 50°C 环境温度时开架式设计中的最大实际持续功率。

应用电路图

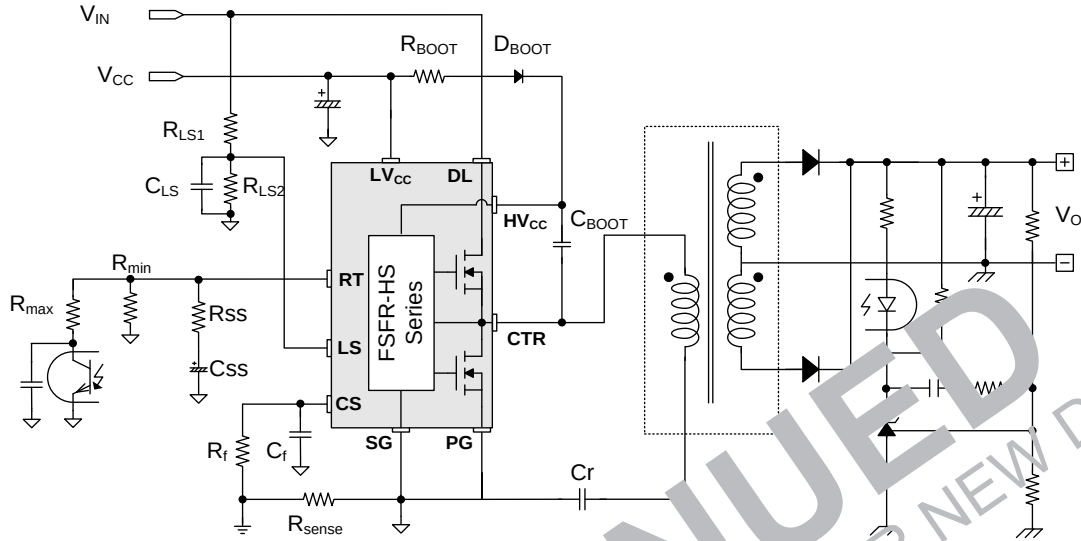


图 1. 典型应用电路 (C 类谐振转换器)

框图

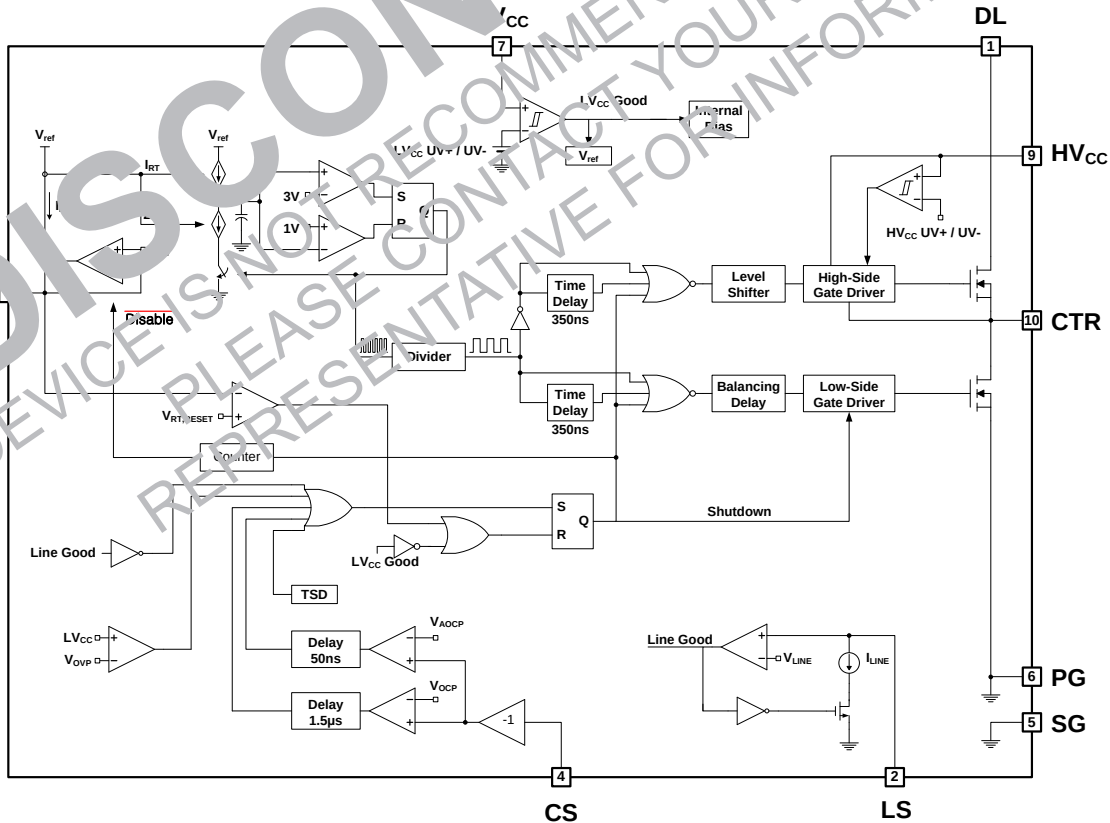


图 2. 内部框图

引脚布局

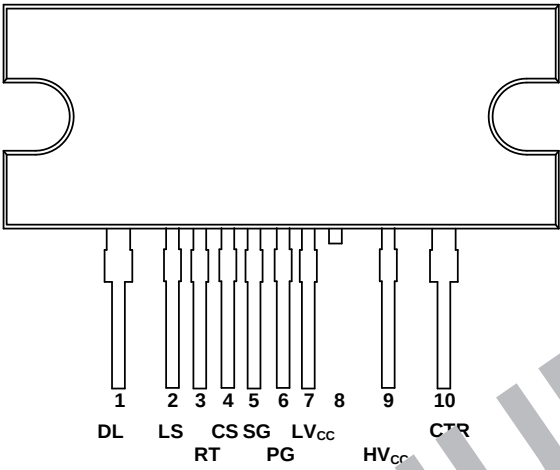


图 3. 封装图

引脚定义

引脚号	名称	说明
1	DL	这是高侧 MOSFET 的漏极，通常连接至高压直流输入。
2	LS	这是输入电压欠压锁定 (UVLO) 的线路感测引脚。
3	CS	此引脚用于控制正常操作下的开关频率。触发任何保护时，内部自动/重启 (A/R) 电路开始感测引脚上的电压，该引脚通过外部电阻自然放电。当电压减小 0.1 V 时，可通过 A/R 操作 IC。通常，连接光电耦合器控制用于输出电压调节的开关频率和用于设置最小/最大工作频率的电阻。
4	SG	此引脚检测流经低侧 MOSFET 的电流。通常，此引脚为负压。
5	PG	该引脚为控制部分的地。
6	PG	该引脚为电源地。该引脚连接到低侧 MOSFET 的源极。
7	LVcc	该引脚为控制 IC 的供电电压。
8	NC	无连接。
9	HVcc	这是高侧栅极驱动电路的电源电压。
10	CTR	这是低侧 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。

符号	参数		最小值	最大值	单位
V _{DS}	最大漏极至源极电压 (DL-CTR 和 CTR-PG)		500		V
LV _{CC}	低侧电源电压		-0.3	25.0	V
HV _{CC} 至 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 _{RT}	定时电阻连接和自动重启引脚电压		-0.3	5.0	V
V _{LS}	线电压感测输入电压		-0.3	LV _{CC}	V
V _{CS}	电流感测 (CS) 引脚输入电压		-5	1	V
f _{sw}	建议开关频率		10	50	kHz
dV _{CTR} /dt	允许的低侧 MOSFET 漏极电压压摆率			50	V/ns
P _D	总功耗 ⁽⁴⁾	FSFR1800HS/L		11.7	W
		FSFR1700HS/L		11.6	
T _J	最大结温 ⁽⁵⁾			+150	°C
	推荐的工作结温 ⁽⁵⁾		-40	+130	
T _{STG}	存储温度范围		-55	+150	°C
MOSFET 部分					
V _{DGR}	漏极栅极电压 (R _{GS} =1 MΩ)		500		V
V _{GS}	栅极源极 (GND) 电压			±30	V
I _{DM}	脉冲漏电流 ⁽⁶⁾	FSFR1800HS/L		23	A
		FSFR1700HS/L		20	
I _D	连续漏极电流	FSFR1800HS/L	T _C =25°C	7.0	A
			T _C =100°C	4.5	
		FSFR1700HS/L	T _C =25°C	6.0	
			T _C =100°C	3.9	
封装部分					
扭矩	建议螺栓扭矩		5~7		kgf·cm

注意：

- 这些参数尽管经过保证，也仅在 EDS（硅片测试）过程中测试。
- 每个 MOSFET（两个 MOSFET 都导通）。
- 所推荐的工作结温最大值受限于热保护功能。
- 脉冲宽度受限于最大结温。

热阻测试

除非另有规定，否则 $T_A=25^\circ\text{C}$ 。

符号	参数		数值	单位
θ_{JC}	结壳中心热阻（两个 MOSFET 传导）	FSFR1800HS/L	10.7	°C/W
		FSFR1700HS/L	10.8	
θ_{JA}	节-环境之间热阻		80	°C/W

电气特性

除非另有规定, 否则 $T_A=25^{\circ}\text{C}$ 、 LV_{CC} 、 $\text{HV}_{\text{CC}}=17\text{ V}_{\text{DC}}$ 和 $R_T=26\text{ k}\Omega$ 。

符号	参数	工作条件	最小值	典型值	最大值	单位
MOSFET 部分						
BV_{DSS}	漏极至源极击穿电压	$\text{I}_\text{D}=200\text{ }\mu\text{A}$, $T_A=25^{\circ}\text{C}$ $\text{I}_\text{D}=200\text{ }\mu\text{A}$, $T_A=125^{\circ}\text{C}$	500			V
$\text{R}_{\text{DS(ON)}}$	导通电阻	FSFR1800HS/L $\text{V}_{\text{GS}}=10\text{ V}$, $\text{I}_\text{D}=3.0\text{ A}$ FSFR1700HS/L $\text{V}_{\text{GS}}=10\text{ V}$, $\text{I}_\text{D}=2.0\text{ A}$		0.77 1.00	0.95 1.25	Ω
t_{rr}	体二极管反向恢复时间 ⁽⁷⁾	FSFR1800HS/L $\text{V}_{\text{GS}}=0\text{ V}$, $\text{I}_{\text{DIODE}}=7.0\text{ A}$, $\text{dI}_{\text{DIODE}}/\text{dt}=100\text{ A}/\mu\text{s}$ FSFR1700HS/L $\text{V}_{\text{GS}}=0\text{ V}$, $\text{I}_{\text{DIODE}}=6.0\text{ A}$, $\text{dI}_{\text{DIODE}}/\text{dt}=100\text{ A}/\mu\text{s}$		160 160		ns
C_{ISS}	输入电容 ⁽⁷⁾	FSFR1800HS/L FSFR1700HS/L		63.5 51.2		pF
C_{OSS}	输出电容 ⁽⁷⁾	FSFR1800HS/L FSFR1700HS/L	$\text{V}_{\text{DS}}=25\text{ V}$, $\text{V}_{\text{GS}}=0\text{ V}$, $f=1.0\text{ MHz}$	82.1 66.5		pF
电源部分						
I_{LK}	偏置漏电流	$\text{V}_{\text{DS}}=\text{V}_{\text{TR}}=500\text{ V}$			50	μA
I_{QHVCc}	HV_{CC} 静态电源电流	$(\text{HV}_{\text{CC}}\text{UV+}) - 0.1\text{ V}$		50	120	μA
I_{QLVCC}	LV_{CC} 静态电源电流	$(\text{LV}_{\text{CC}}\text{UV+}) - 0.1\text{ V}$		100	200	μA
I_{OHVCc}	工作 HV_{CC} 电源电流 (FET 导通)	$f_{\text{OSC}}=50\text{ KHz}$ 无开关		6 100	9 200	mA μA
I_{OLVCC}	工作 LV_{CC} 电源电流 (RT 值)	$f_{\text{OSC}}=50\text{ KHz}$ 无开关		7 2	11 4	mA mA
UVLO 部分						
$\text{LV}_{\text{CC}}\text{UV+}$	LV_{CC} 电源欠压正向阈值 ($\text{LV}_{\text{CC,START}}$)		11.2	12.5	13.8	V
$\text{LV}_{\text{CC}}\text{UV-}$	LV_{CC} 电源欠压负向阈值 ($\text{LV}_{\text{CC,STOP}}$)		8.9	10.0	11.1	V
$\text{LV}_{\text{CC}}\text{UVH}$	LV_{CC} 电源欠压滞回			2.5		V
$\text{HV}_{\text{CC}}\text{UV+}$	HV_{CC} 电源欠压正向阈值 ($\text{HV}_{\text{CC,START}}$)		8.2	9.2	10.2	V
$\text{HV}_{\text{CC}}\text{UV-}$	HV_{CC} 电源欠压负向阈值 ($\text{HV}_{\text{CC,STOP}}$)		7.8	8.7	9.6	V
$\text{HV}_{\text{CC}}\text{UVH}$	HV_{CC} 电源欠压滞回			0.5		V
振荡器与反馈部分						
V_{RT}	RT 引脚上的输出电压	$R_T=26\text{ k}\Omega$	1.5	2.0	2.5	V
f_{OSC}	输出振荡频率		47	50	53	kHz
DC	输出占空比		48	50	52	%

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电气特性(续)

除非另有规定, 否则 $T_A=25^{\circ}\text{C}$ 、 LV_{CC} 、 $HV_{CC}=17\text{ V}_{DC}$ 和 $R_T=26\text{ k}\Omega$ 。

符号	参数	工作条件	最小值	典型值	最大值	单位
保护部分						
$V_{RT,RESET}$	开始重启的阈值电压		0.07	0.12	0.17	V
$t_{DELAY,RESET}$	保护后禁用 OSC 电路的延迟	$f_{OSC}=50\text{ kHz}$		20		ms
V_{LINE}	输入电压的导通阈值		2.38	2.50	2.62	V
I_{LINE}	线电压 UVLO 的滞回电流		7.5	9.5	11.5	μA
V_{OVP}	LV_{CC} 过压保护		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 ⁽⁷⁾	$V_{CS} < V_{AOCP}$		50		ns
V_{OCP}	OCP 阈值电压		-0.64	-0.58	-0.52	V
t_{BO}	OCP 消隐时间 ⁽⁷⁾	$V_{CS} < V_{OCP}$	2.0	3.0	2.0	μs
t_{DA}	延迟时间 (低侧) 从 V_{AOCP} 检测到关断 ⁽⁷⁾			250	400	ns
T_{SD}	热关闭温度 ⁽⁷⁾		120	135	150	$^{\circ}\text{C}$
死区时间控制部分						
D_T	死区时间 ⁽⁸⁾			500		ns

注意:

- 该参数由设计保证; 未经产品测试。
- 这些参数尽管经过保证, 也仅在 EDS (碎片测试) 过程中测试。

典型性能特征

这些特性图在 $T_A=25^\circ\text{C}$ 标准化。

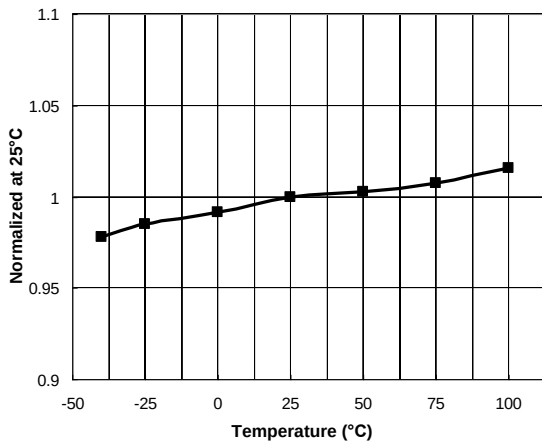


图 4. 低侧 MOSFET 占空比与温度的关系

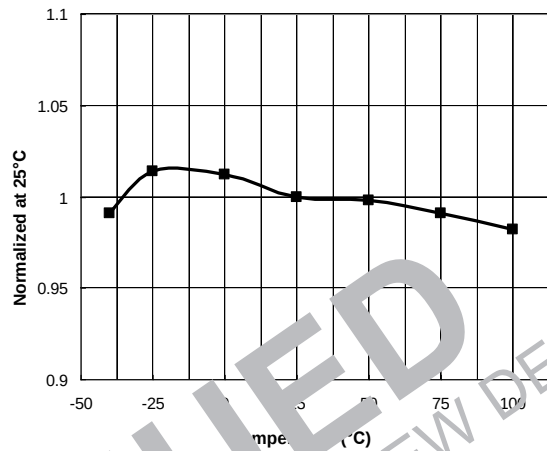


图 5. 开关频率与温度的关系

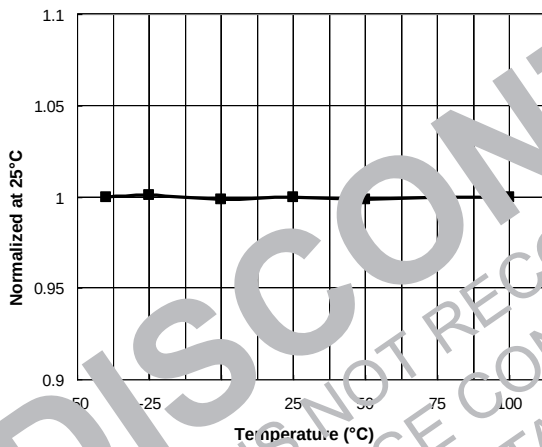


图 6. 高侧 V_{CC} (HV_{CC}) 启动与温度的关系

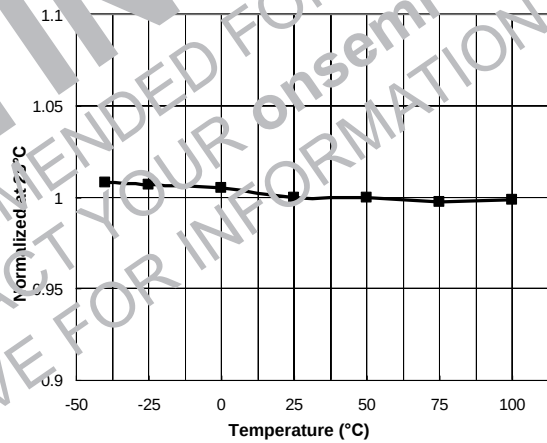


图 7. 高侧 V_{CC} (HV_{CC}) 停止与温度的关系

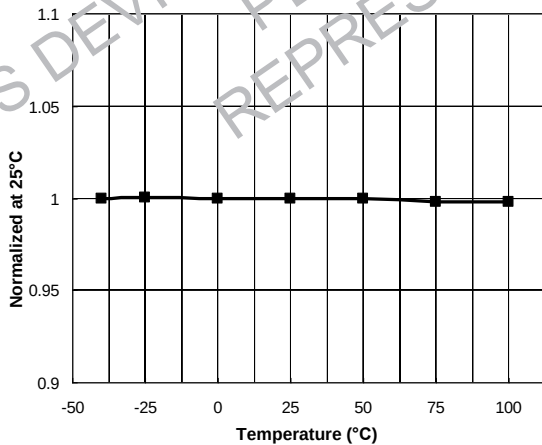


图 8. 低侧 V_{CC} (LV_{CC}) 启动与温度的关系

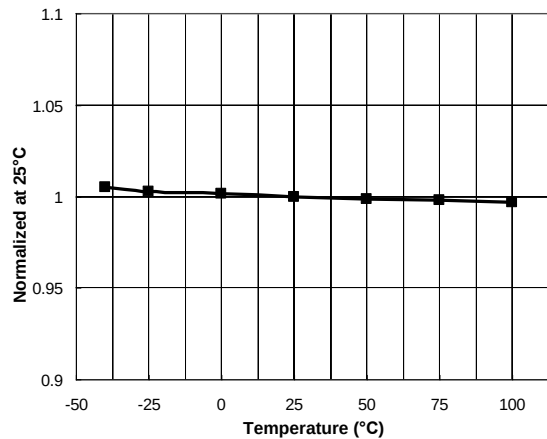


图 9. 低侧 V_{CC} (LV_{CC}) 停止与温度的关系

典型性能特征 (接上页)

这些特性图在 $T_A=25^\circ\text{C}$ 下标准化。

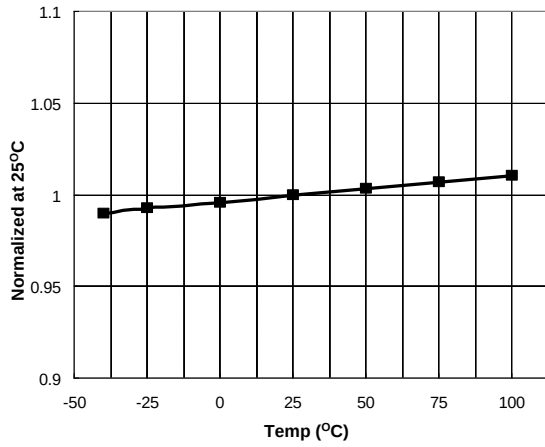


图 10. LVCC OVP 电压与温度的关系

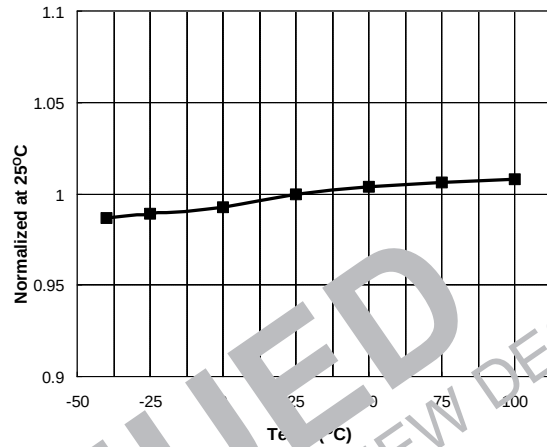


图 11. VRT 电压与温度的关系

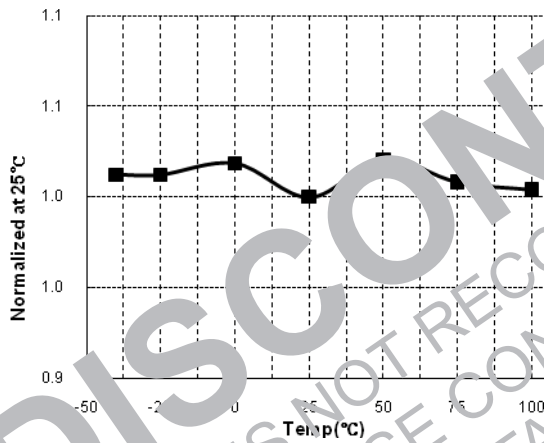


图 12. VRT, RESET 与温度的关系

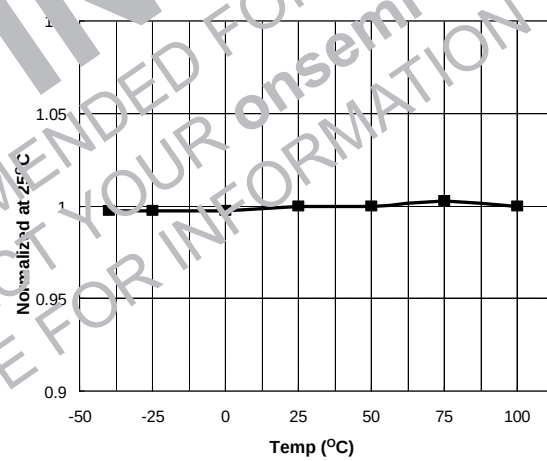


图 13. OCP 电压与温度的关系

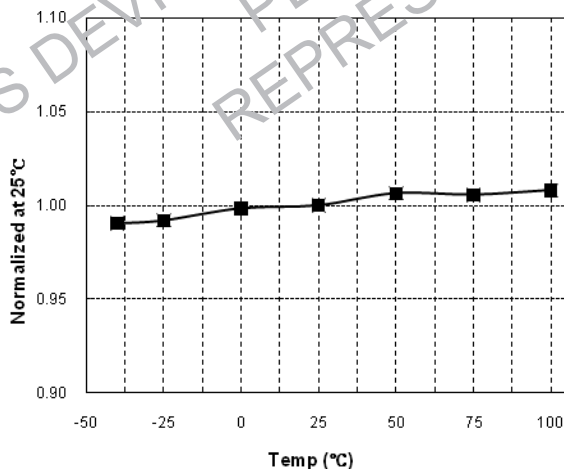


图 14. VLINE 与温度的关系

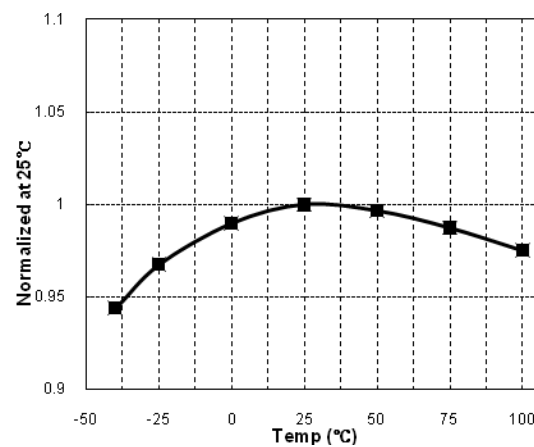


图 15. ILINE 与温度的关系

典型性能特征 (接上页)

这些特性图在 $T_A=25^\circ\text{C}$ 下标准化。

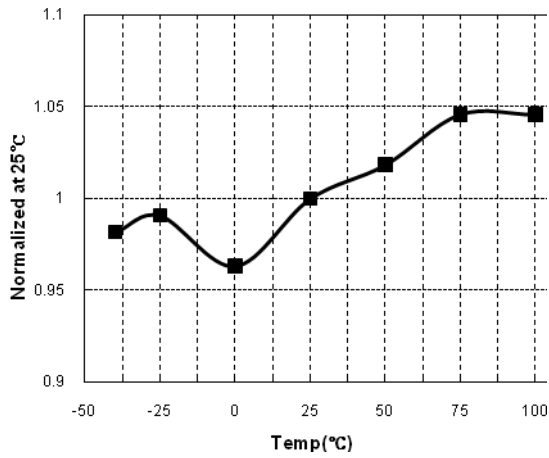


图 16. $t_{\text{DELAY,RESET}}$ 与温度的关系

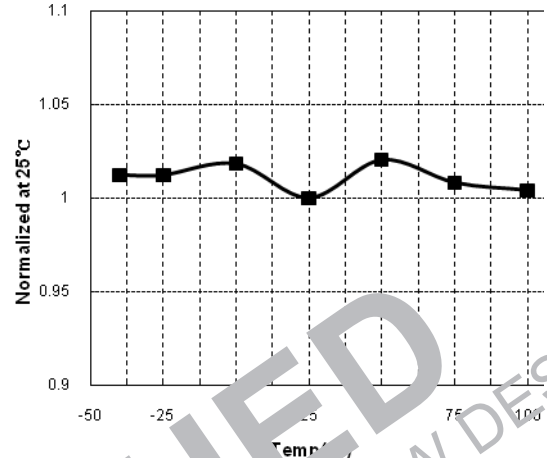


图 17. $t_{\text{T,RESET}}$ 与温度的关系

功能说明

1. 基本操作: FSFR-HS 系列设计为驱动高侧和低侧 MOSFET，分别占 50% 占空比。在连续转换期间引入了固定死区时间 350 ns，如图 18 所示。

一旦 V_{CC} 高于 $V_{CC,START} = 12.5\text{ V}$ ，IC 即开始操作，生成低侧栅极信号并驱动低侧 MOSFET。自举二极管和电容由低侧 MOSFET 的工作期间得到电荷充电。在 V_{CC} 上的电压增至达 $V_{CC,START}$ （通常为 9.2 V ）后，为 MOSFET 生成高侧栅极信号。

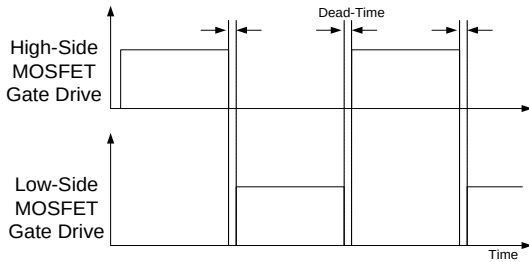


图 18. MOSFET 栅极驱动信号

2. 内部振荡器: FSFR-HS 系列采用电流控制振荡器，如图 19 所示。在内部，RT 引脚的电压调节在 2 V ，并振荡器电容 C_T 的充电/放电电流通过使用电流镜像复制从 RT 引脚 (I_{CTC}) 流出的电流来获得。因此，开关频率随着 I_{CTC} 的增加而增加。

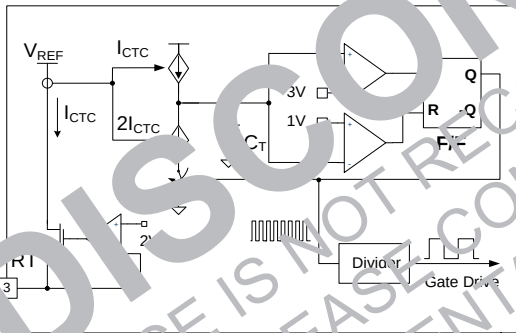


图 19. 电流控制的振荡器

3. 频率设置: 图 20 显示谐振转换器的典型电压增益曲线。其中增益与 ZVS 区中的开关频率成反比。输出电压可通过调制开关频率来调节。图 21 显示 RT 引脚的典型电路配置，其中光电耦合器电阻连接至 RT 引脚以调制开关频率。开关频率可从 20 kHz 控制到 500 kHz 。

最小开关频率由下式确定：

$$f_{min} = \frac{1}{792p \times R_{min} + 0.54\mu} \text{ [Hz]} \quad (1)$$

假定光电耦合器的饱和电压为 0.2 V ，则最大开关频率由下式确定：

$$f_{max} = \frac{1}{792p \times R_{min} \parallel R_{max} + 0.54\mu} \text{ [Hz]} \quad (2)$$

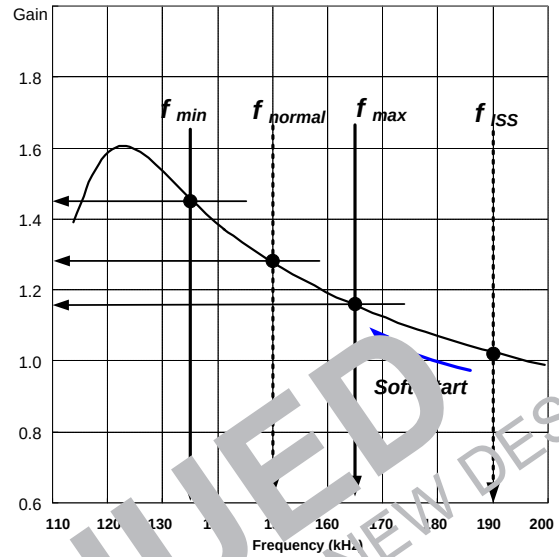


图 20. 谐振转换器典型增益曲线

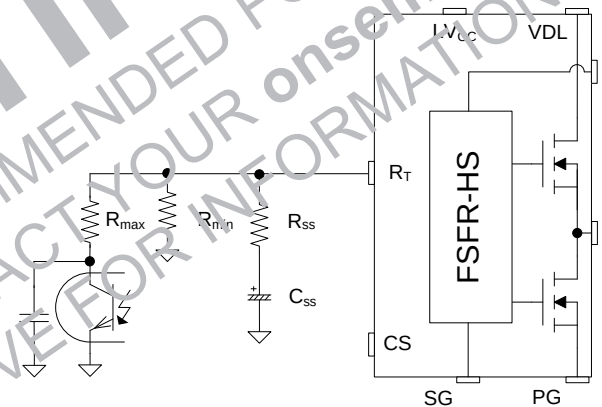


图 21. 频率控制电路

为避免过大的浪涌电流和启动时输出电压过冲，IC 需要逐渐增加谐振转换器的电压增益。由于谐振转换器的电压增益与开关频率成反比，因此实施软启动是通过从初始高频率 (f_{SS}) 向下扫描开关频率，直至建立输出电压。

通过将 R-C 系列网络连接至 RT 引脚来建立软启动电路，如图 21 中所示。起初，工作频率由 R_{SS} 和 R_{min} 的并联阻抗设置。

初始最大频率可设置为高达 600 kHz，由下式确定：

$$f_{ss} = \frac{1}{792p \times R_{min} \parallel R_{SS} + 0.54\mu} [Hz] \quad (3)$$

软启动时间 t_{SS} ，可由下式计算得出：

$$t_{SS} = 3 \times R_{SS} \cdot C_{SS} [s] \quad (4)$$

4. 自动重启：即使在有外部电源电压的情况下触发任何内置保护，FSFR-HS 系列也可自动重启。如图 22 和图 23 所示；一旦触发保护，功率 MOSFET 即停止。计数器开始操作并且对 1008 时钟进行计数，然后禁用 V-I 转换器。 C_{SS} 在通过电阻 R_{SS} 和 R_{min} 自然放电，直至 V_{RT} 下降至 $V_{RT,RESET}$ ，通常为 0.1 V。然后，复位所有保护并且 V-I 转换器恢复。FSFR-HS 再次通过软启动开始开关操作。

激活保护后的 1008 时钟的计数器工作时间由 R_T 引脚流出的电流设定，直至 V_{RT} 下降至 $V_{RT,RESET}$ 。最后，可估算 FSFR-HS 的停止时间，不需考虑计数器工作时间，如：

$$t_{STOP} = 3C_{SS} \cdot (R_{SS} + R_{min}) [s] \quad (5)$$

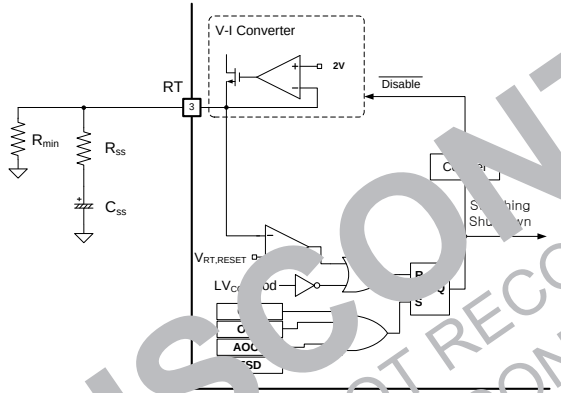
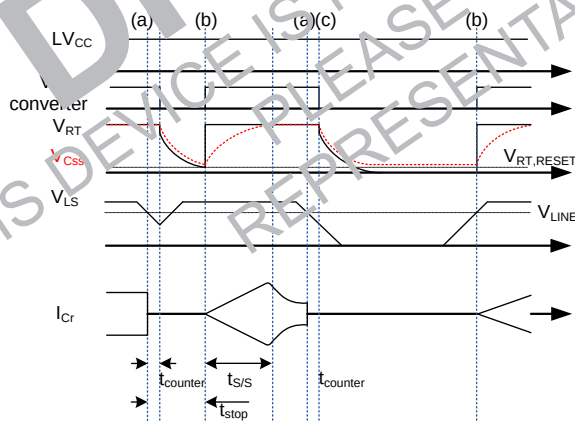


图 22 自重启的内部框图



(a) Protection Trigger, (b) FSFR-HS Restart, (c) Counter Stop

图 23. 自动重启操作

5. 保护电路：FSFR-HS 系列具有多个自我保护功能；如过流保护 (OLP)、异常过流保护 (OCP)、过压保护 (OVP)、热关断 (TSD) 和线电压欠压锁定 (LUVLO 或欠压)。这些保护为自动重启模式保护，如图 24 所示。

一旦检测到故障情况，开关操作即终止并且 MOSFET 保持关断。当 LV_{CC} 下降至 10 V 的 LV_{CC} 停止电压并且 V_{RT} 低于 0.1 V 的 $V_{RT,RESET}$ ，将复位保护。当 LV_{CC} 达到 12.5 V 的启动电压时，FSFR-HS 恢复正常操作。

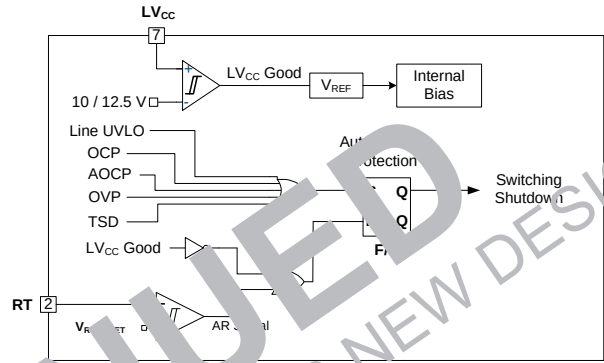


图 24. 保护框图

5.1 过流保护 (OCP)：当感测引脚电压降低至 -0.58 V 并且其持续时间超过 $1.5 \mu s$ 的 OCP 消除时间时，将触发 OCP 并且 MOSFET 保持关断。

5.2 异常过流保护 (AOCP)：如果次级整流器二极管短路，具有极高 dI/dt 的大电流可在触发 OCP 之前流经 MOSFET。如果感测引脚电压降低至 -0.9 V，将触发 AOCP 且没有关断延迟。

5.3 过压保护 (OVP)：当 LV_{CC} 达到 23 V 时，将触发 OVP。当变压器的辅助绕组向 FPS™ 供应 V_{CC} 时，使用此保护。

5.4 热关断 (TSD)：MOSFET 和控制 IC 在一个封装中使控制 IC 检测 MOSFET 的异常过温变得更简单。如果温度超过约 $130^{\circ}C$ ，将触发热关断。

6. 线电压欠压锁定 (UVLO)：FSFR-HS 包括具有可编程滞回电压的精密线电压 UVLO（或欠压）。当感测电阻 R_1 和 R_2 感测到的当直流母线电压变高时依直流母线电压成比例缩小的电压 V_{LS} 高于 2.5 V 的 V_{LINE} 时（反之亦然），此功能可启动或重启 IC。IC 启动和停止电压之间的滞回电压可由 I_{LINE} 编程。在正常工作条件下，比较器的输出为高电平并且禁用 I_{LINE} ，因此 L_S 引脚 V_{LS} 上的电压可由 R_1 和 R_2 的分压获得。相反，当比较器的输出为低电平时，激活 I_{LINE} 。 V_{LS} 由流经 R_1 的电流和 I_{LINE} 的差异生成。

C_{Filter} 可用于减少变压器或开关转换引起的一些噪声。通常，几百 pF 至几十 nF 就够了，具体取决于噪声量。

启动与停止输入电压可以通过下式计算：

$$V_{dc-link, STOP} = V_{LINE} \times \frac{R1 + R2}{R2} [V] \quad (6)$$

$$V_{dc-link, START} = V_{dc-link, STOP} + I_{LINE} \times R1 [V] \quad (7)$$

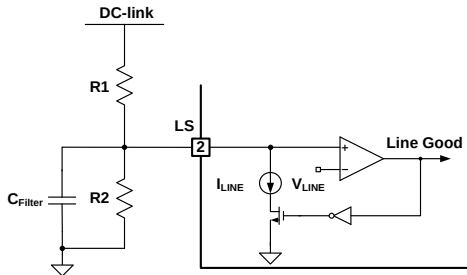


图 25. 半波检测

7. 简单远程开/关：可使用可选自动重启模式关断功率级，如图 26 所示。

在自动重启模式下，为配置外部保护电路，需要采用了一个光电耦合器与 LS 引脚。当 LS 引脚上的电压下拉至低于 V_{LINE} (2.5 V) 时，IC 在保持停止状态。但是，光电耦合器停止下拉时 IC 可自动执行自动重启操作。

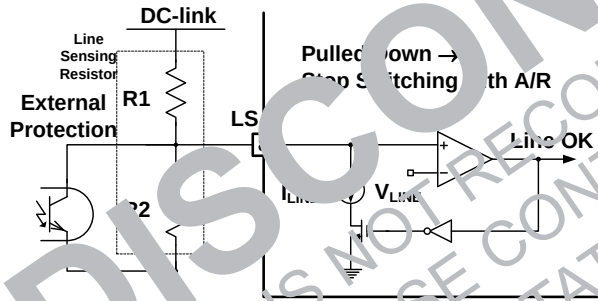


图 26. 外部保护电路

8. 电流感测方法：FSFR-HS 系列采用负压感测来检测 MOSFET 的漏极电流，这允许使用带小时间常数的滤波器的低噪声电阻感测和电容感测。

8.1 电阻感测方法：IC 可感测漏电流为负压，如图 27 和图 28 所示。半波感测允许感测电阻中较低的功耗，而全波感测在感测信号中具有较少的开关噪声。对于滤波器的时间常量范围，3/100~1/10 的工作频率是合理的。

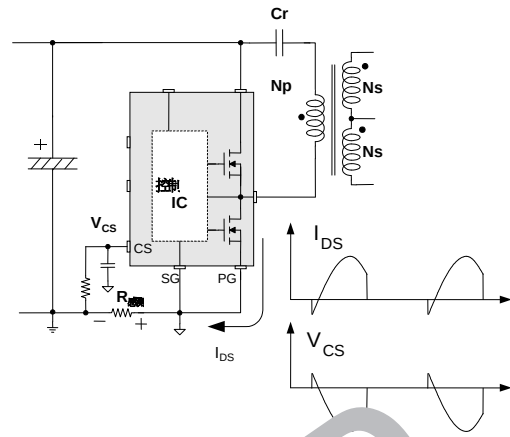


图 27. 半波检测

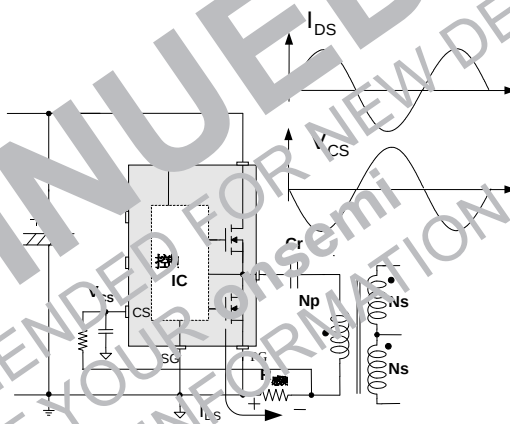


图 28. 全波检测

8.2 电容感测方法：漏极电流可以采用一个额外的与谐振电容并联的电容检测，如所示图 29。在低侧开关导通期间，通过 C_B 的电流 i_{CB} 使 V_{SENSE} 加在 R_{SENSE} 上。 i_{CB} 是 i_p 按阻抗比 C_r 和 C_B 的分流。一般地， C_B 与 C_r 比较合适的比值为 1/100~1/1000。 R_D 用作减少开关转换产生的噪声的阻尼。通常可使用数百欧姆至几千欧姆。

V_{SENSE} 可由下式估算得出；

$$V_{sense} = I_{Cr}^{pk} \frac{C_B}{C_r} \cdot R_{sense} [V] \quad (8)$$

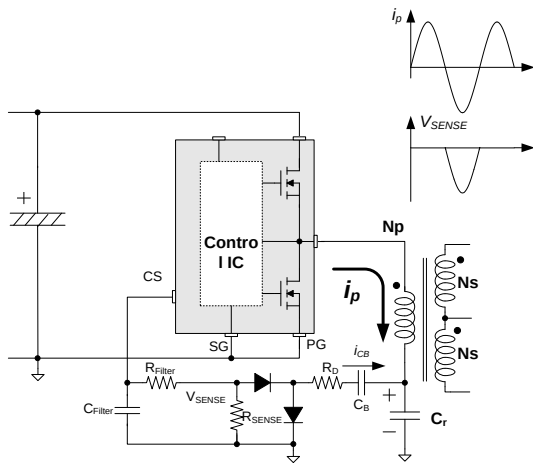


图 29. 电容检测

9. PCB 布局指南: 由于主变压器的辐射噪音、主变压器的次级端漏感不相等等原因可能发生占空比不平衡问题。RT 引脚附近的控制元件在 PCB 布局上被主初级端电流环路包围是造成占空比不平衡的主要原因。当高低侧 MOSFET 交替导通时, 由初级端电流流向导致的元件上磁场的方向发生变化。方向相反的磁场产生通过、进入或从 RT 引脚流出的电流, 这使得每个 MOSFET 的导通持续时间各不相同。强烈建议将 RT 引脚附近的控制元件与 PCB 布局上的初级端电流路径分开。图 30 显示占空比平衡情况的示例。

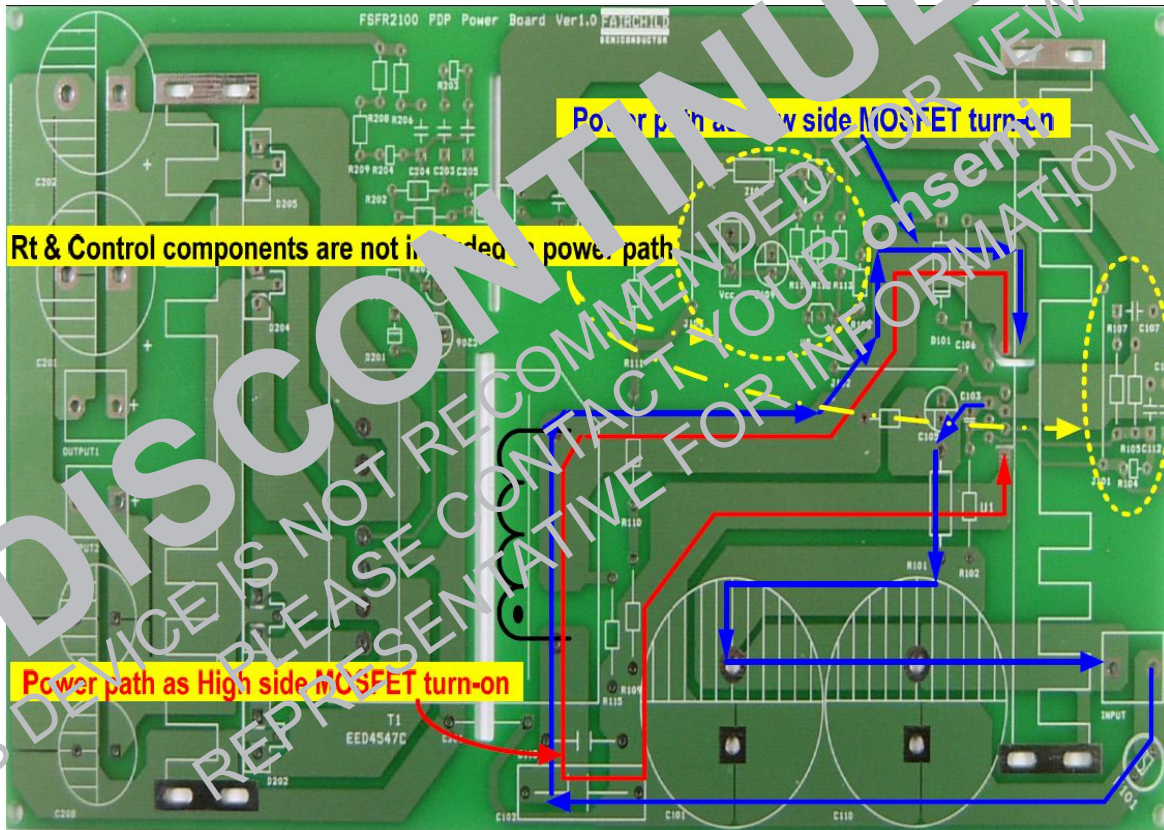
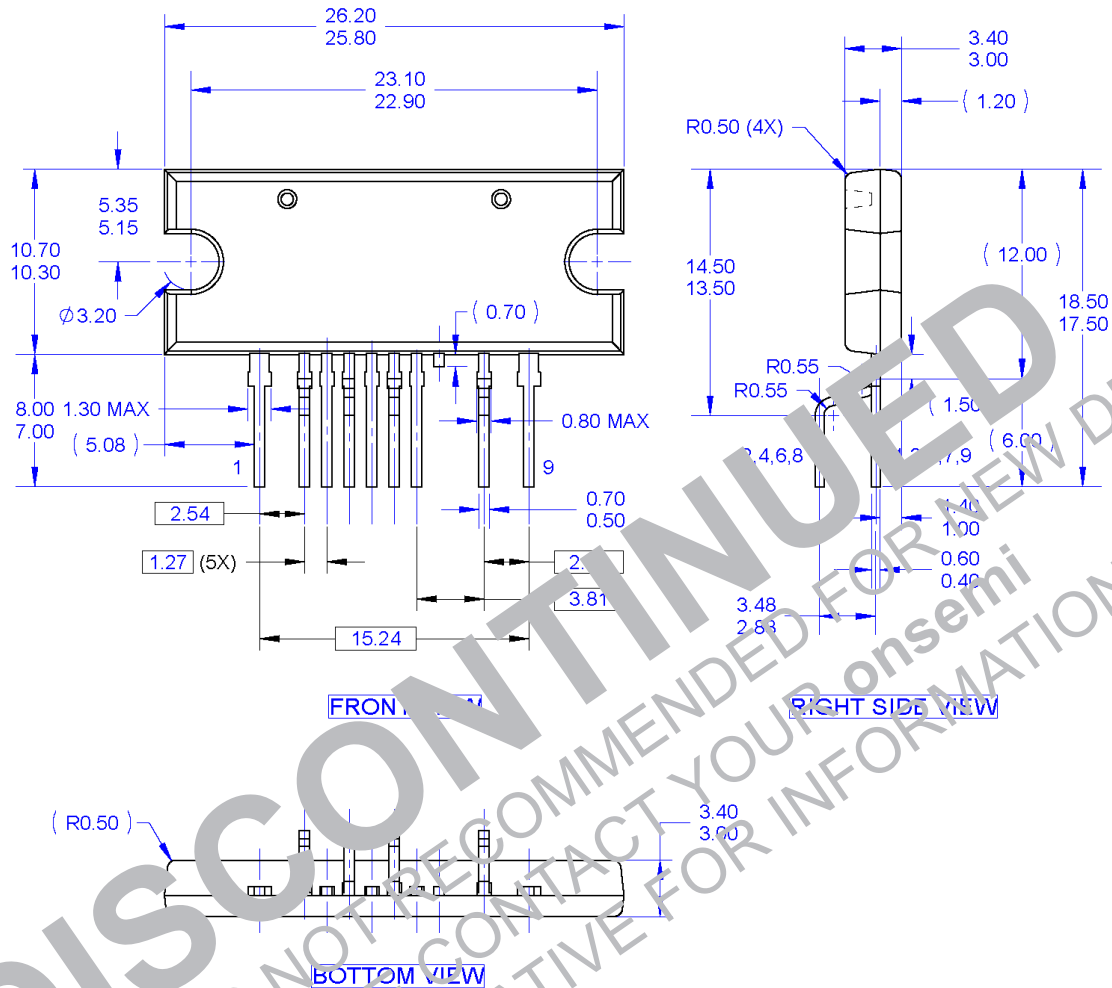


图 30. 占空比平衡的示例

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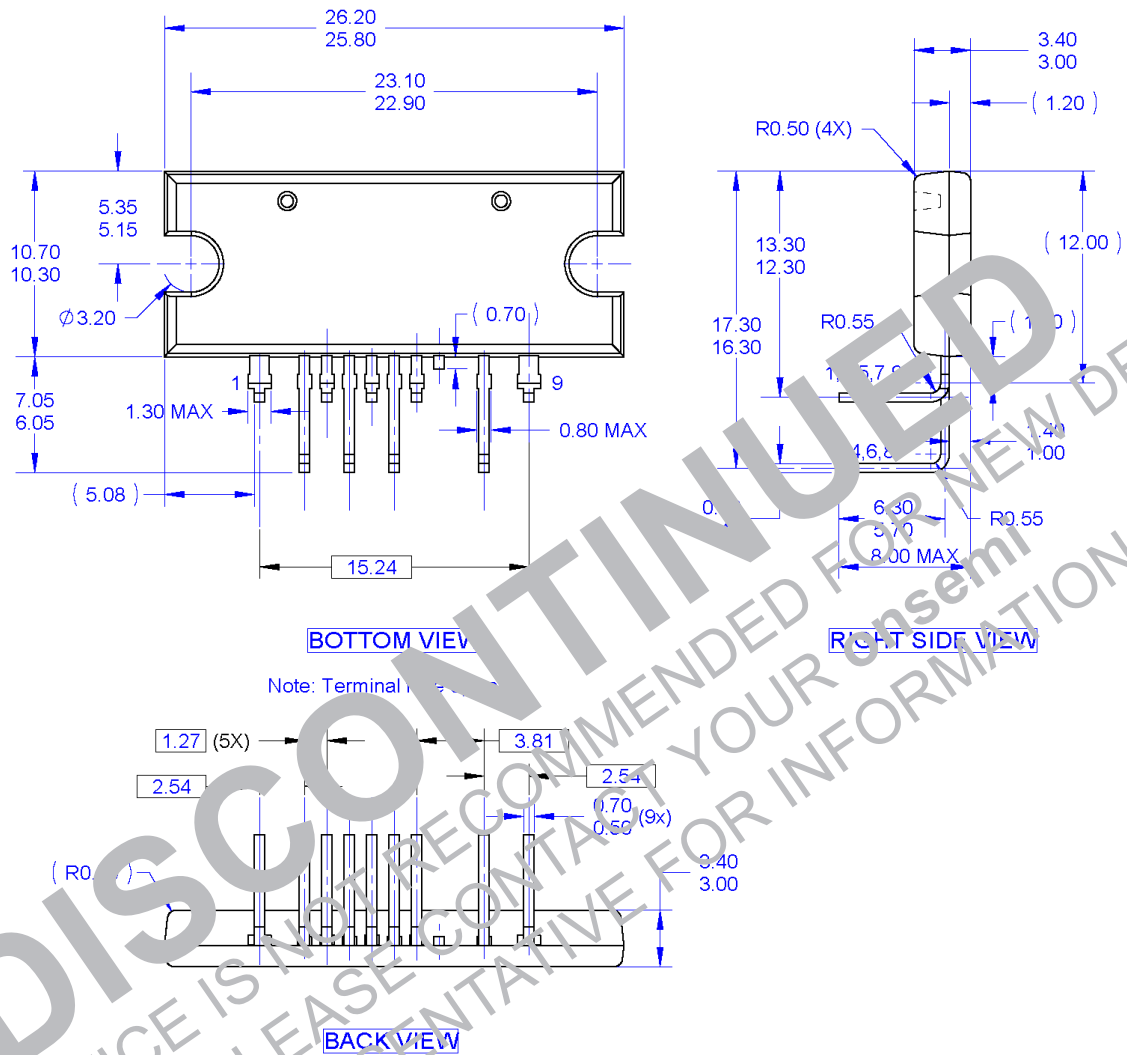
图 31. 9 引脚、单线路内封装 (SIP)

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图 32. 9 引脚单线路内封装 (SIP) L 成型

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