

EVM User's Guide: UCG28846DREVM-151

UCG28846DREVM-151 评估模块



说明

UCG28846DREVM-151 是一款 65W USB-C PD 评估模块 (EVM)，可评估适用于交流/直流适配器、充电器、USB 墙壁插座和其他应用的离线 GaN 集成式准谐振反激式适配器。该 EVM 符合 CoC 第 2 级和 DoE 第 6 级标准的能效要求。EVM 仅用于评估目的，并非产品。UCG28846DREVM-151 将 $90V_{RMS}$ 至 $264V_{RMS}$ 的输入电压向下转换为可选的 USB-C PD 输出电压 $5V_{DC}$ 、 $9V_{DC}$ 、 $15V_{DC}$ 或 $20V_{DC}$ 。该 EVM 还可以配置来产生 $5V_{DC}$ 至 $24V_{DC}$ 范围内的固定输出电压。该 EVM 设计用于提供最高 3.00A 的输出电流 (最高至 $15V_{DC}$)，当输出电压在 $15V_{DC}$ 至 $24V_{DC}$ 范围内时，可提供 65W 的最大输出功率。该设计中使用的主要器件是具有集成式 750V GaN FET 和控制器且采用 $3.9mm \times 9.9mm$ 封装的 UCG28846。

开始使用

1. 在评估之前，请先完整阅读和学习本用户指南。
2. 完成第一步后，订购 [UCG28846DREVM-151](#) 进行评估。
3. 根据用户指南说明设置和测试 [UCG28846DREVM-151](#)。



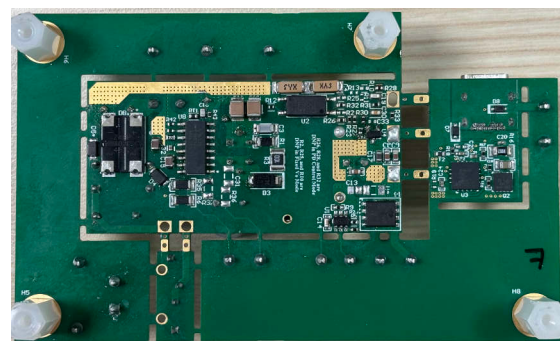
UCG28846DREVM-151 (顶视图)

特性

- 在整个输入电压范围内，满载运行时效率为 93% 至 95%
- **高功率密度配置下**，盒子体积为 $6.06cm \times 2.87cm \times 1.8cm$
- 通过 140kHz 最大开关频率实现 $2.1W/cm^3$ 功率密度
- 通过集成自偏置和无辅助检测、集成电流检测、集成高压启动和集成 X 电容器放电，实现最低 BOM 成本
- 全面的保护特性，包括 OVP、OTP、短路和过流保护以及欠压/掉电保护
- USB-C 输出可用于对适配器、笔记本电脑充电器、USB 墙壁插座等终端设备进行全面的系统级评估

应用

- USB-C PD 电源适配器
- 交流/直流或直流/直流辅助电源
- 用于笔记本电脑、平板电脑、电视和机顶盒的高密度交流/直流转换器、适配器
- USB-C PPS 电源适配器



UCG28846DREVM-151 (底视图)

1 评估模块概述

1.1 简介

UCG28846DREVM-151 评估模块用于在交流-直流准谐振 (QR) 反激式电源转换器中对集成 GaN FET 与控制器的 UCG28846 进行评估。该 EVM 适用于 90VAC 至 264VAC 的通用交流输入范围，并支持 USB PD 3.0 20V/15V/9V/5V 输出协议。该 EVM 还可以配置来产生 5V 至 24V 范围内的固定输出电压。本用户指南提供了高压安全概述、推荐的测试设置、效率结果、波形和热性能。

1.2 套件内容

- 65W USB-C QR 反激式评估模块
- 快速入门指南
- 高压声明

1.3 规格

输入	控制器配置	输出	最大输出功率
90VAC-264VAC 47Hz 至 63Hz	USB-C PD	20V/3.25A、15V/3.00A、9V/3.00A 和 5V/3.00A	65W
	固定输出电压	5V 至 15V/3A 和 >15V 至 24V/65W	

1.4 器件信息

UCG28846 是一款高频率准谐振 (QR) 交流/直流反激式转换器，具有集成式 750V 初级侧 GaN FET，专为高达 65W 的电源设计。该器件通过 GaN 集成带来优势，能够实现开关频率高达 500kHz 的高功率密度设计。

UCG28846 采用具有自偏置功能的无辅助反激式架构，无需在变压器中使用辅助绕组，即可实现紧凑且成本较低的电源设计。由于无需使用低压降稳压器 (LDO) 并消除了生成器件偏置所产生的相关损耗，因此自偏置功能降低了损耗，从而提高了宽输出电压应用（如 USB-PD 充电器）的效率。

UCG28846 支持在低压线路输入条件以及高达 130W（65W 标称输出功率的两倍）的瞬态输出功率条件下，以连续导通模式 (CCM) 运行长达 10ms，而无需使用专为此类瞬态负载条件设计的变压器，从而节省空间和成本。该器件还包含频率折返和突发模式，可分别在轻负载和空载条件下实现更高的运行效率。X 电容器放电电路会在不到 1sec 的时间内将输入 EMI 滤波器中的 X 电容器放电至 0V，以防止用户在从壁式插座拔电源时触电。

UCG28846 提供可通过电阻器编程的选项，这样用户就能够极其灵活地在所需的工作点优化性能，从而克服集成转换器的系统设计限制。该器件还内置多种保护功能，能够应对输出过压、过流、过载、短路和过热情况，并具有自动重启和锁存响应功能，从而实现稳健的电源设计，防止在此类故障情况下造成任何损坏。

1.5 通用德州仪器 (TI) 高压评估模块 (TI HV EVM) 用户安全指南



务必遵循 TI 的设置和应用说明，包括在建议的电气额定电压和功率限制范围内使用所有接口元件。务必采取电气安全防护措施，这样有助于确保自身和周围人员的人身安全。如需更多信息，请联系 TI 的产品信息中心，网址为 <http://support.ti.com>。

保存所有警告和说明以供将来参考。

警告

务必遵循警告和说明，否则可能引发电击和灼伤危险，进而造成财产损失或人员伤亡。

TI HV EVM 一词是指通常以开放式框架、敞开式印刷电路板装配形式提供的电子器件。该器件严格用于开发实验室环境，仅供了解开发和应用高压电路相关电气安全风险且接受过专门培训、具有专业知识背景的合格专业用户使用。德州仪器 (TI) 严禁任何其他不合规的使用和/或应用。如果不满足合格要求，则应立即停止进一步使用 HV EVM。

1. 工作区安全

- a. 保持工作区整洁有序。
- b. 每次电路通电时，都必须由具有资质的观察员在场监督。
- c. TI HV EVM 及接口电子元件通电区域必须设有有效的防护栏和标识；指示可能存在高压操作，以避免意外接触。
- d. 开发环境中使用的所有接口电路、电源、评估模块、仪器、仪表、示波器和其他相关装置如果超过 50Vrms/75VDC，则必须置于紧急断电 EPO 保护电源板内。
- e. 使用稳定且不导电的工作台。
- f. 使用充分绝缘的夹钳和导线来连接测量探针和仪器。尽量不要徒手进行测试。

2. 电气安全：作为一项预防措施，假定整个 EVM 可能存在用户可完全接触到的高电压是一种好的工程做法。

- a. 在进行任何电气或其他诊断测量之前，请断开 TI HV EVM 所有输入、输出和电气负载的电源。再次确认 TI HV EVM 已安全断电。
- b. 确认 EVM 断电后，根据所需的电路配置、接线、测量设备连接和其他应用需求执行进一步操作，同时仍假定 EVM 电路和测量仪器均带电。
- c. EVM 准备就绪后，根据需要 EVM 通电。

警告

EVM 通电后，请勿触摸 EVM 或电路，因为 EVM 或电路可能存在高压，会造成电击危险。

3. 人身安全

- a. 穿戴人员防护装备（例如乳胶手套或具有侧护板的安全眼镜）或将 EVM 放置于带有联锁装置的透明塑料箱中，避免意外接触。

安全使用限制条件：

勿将 EVM 作为整体或部分生产单元使用。

2 硬件

2.1 其他图像

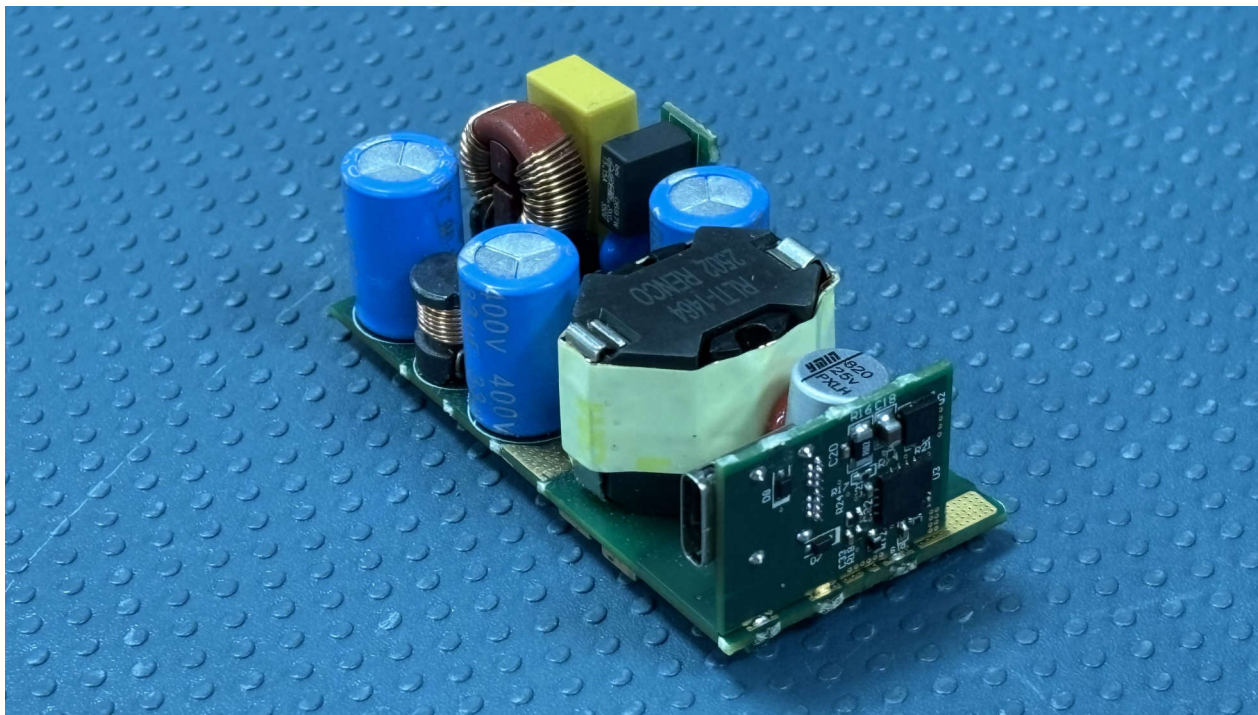


图 2-1. 高功率密度配置 (6.06cm× 2.87cm× 1.8cm)

2.1.1 在具有 USB-C PD 通信功能的负载上使用该 EVM

UCG28846DREVM-151 配备了 USB-C PD 控制器和板载 USB-C 连接器，可通过 USB-C 线缆连接 USB-C PD 负载进行评估。节 3.2.2 展示了相应的测试设置图。USB-C PD 控制器可以调整电路板输出以获得 5V、9V、15V 或 20V 电压。为了进行此 EVM 评估，需要 USB-C PD 通信负载。一个此类负载的示例是 USB-C-PD-DUO-EVM。如果没有此类通信负载，电路板输出 USB-C 连接器 (J2) 将不提供可变输出电压。使用标准 USB-C 电缆从 5V、9V 和 15V 获取满负载电流 3.00A。使用电子标度 USB-C® 电缆在 20V 输出下获得 3.25A

2.1.2 在不具有 USB-C PD 通信功能的负载上使用该 EVM

在使用非 USB-C PD 负载进行评估时，UCG28846DREVM-151 可重新配置为输出 5V 至 24V 范围内的固定电压。节 3.2.2 展示了相应的测试设置图。UCG28846DREVM-151 默认配置为 USB-C PD 控制模式，以便配合 USB-C PD 负载使用。在使用非 USB-C PD 负载进行测试时，必须重新配置控制器电路以启用固定输出电压模式。控制器重新配置指南可在节 4.1 中找到。在固定输出电压控制模式下，转换器可以在 5V 至 15V 的输出下提供 3A 的额定电流，在 15V 至 24V 的输出上提供 65W 的额定功率。

3 实现结果

3.1 电气性能规格

表 3-1. UCC28824EVM-124 电气性能规格

参数		测试条件	最小值	标称值	最大值	单位
输入特性						
V_{IN}	输入线路电压 (RMS)		90	115/230	264	V
f_{LINE}	输入线路频率		47	50/60	63	Hz
P_{STBY}	空载时的输入功率	$V_{IN} = 115V/230V_{RMS}$, $V_{OUT} = 5V$ 且 $I_{OUT} = 0A$, 已启用 USB-C PD 控制器		17/34		mW
P_{180mW}	180mW 负载下的输入功率	$V_{IN} = 230V_{RMS}$, $V_{OUT} = 5V$, $P_{OUT} = 180mW$, 已启用 USB-C PD 控制器		244		mW
P_{300mW}	300mW 负载下的输入功率	$V_{IN} = 230V_{RMS}$, $V_{OUT} = 5V$, $P_{OUT} = 300mW$, 已启用 USB-C PD 控制器		380		mW
输出特性						
V_{OUT}	输出电压	$I_{OUT} = 0A$ 至 $2.71A$, 已启用固定 V_{OUT} 控制器		24		V
		$I_{OUT} = 0A$ 至 $3.25A$, 已启用 USB-C PD 控制器		20		V
		$I_{OUT} = 0A$ 至 $3A$, 已启用 USB-C PD 控制器		15		V
		$I_{OUT} = 0A$ 至 $3A$, 已启用固定 V_{OUT} 控制器		12		V
		$I_{OUT} = 0A$ 至 $3A$, 已启用 USB-C PD 控制器		9		V
		$I_{OUT} = 0A$ 至 $3A$, 已启用 USB-C PD 控制器		5		V
I_{OUT}	满负载额定输出电流	$V_{OUT} = 24V$		2.71		A
		$V_{OUT} = 20V$		3.25		A
		$V_{OUT} = 5V/9V/12V/15V$		3.00		A
V_{OUT_pp}	$V_{IN} = 115V/230V$ 下的输出电压纹波	$V_{OUT} = 24V$, $I_{OUT} = 0A$ 至 $2.71A$		50		mVpp
		$V_{OUT} = 20V$, $I_{OUT} = 0A$ 至 $3.25A$		86		mVpp
		$V_{OUT} = 15V$, $I_{OUT} = 0A$ 至 $3A$		98		mVpp
		$V_{OUT} = 12V$, $I_{OUT} = 0A$ 至 $3A$		117		mVpp
		$V_{OUT} = 9V$, $I_{OUT} = 0A$ 至 $3A$		100		mVpp
		$V_{OUT} = 5V$, $I_{OUT} = 0A$ 至 $3A$		91		mVpp
$V_{OUT_Δ}$	由于负载升压/降压而产生的 V_{OUT} 偏差 (在 25Hz 速率下, I_{OUT} 阶跃在 2% 至 100% 负载之间变化)	$V_{OUT} = 24V$		-472/205		mV
		$V_{OUT} = 20V$		-504/289		mV
		$V_{OUT} = 15V$		-477/294		mV
		$V_{OUT} = 12V$		-454/221		mV
		$V_{OUT} = 9V$		-449/299		mV
		$V_{OUT} = 5V$		-395/307		mV
P_{OPP}	过功率保护阈值	$V_{IN} = 90V$ 至 $264V_{RMS}$		100		W

表 3-1. UCC28824EVM-124 电气性能规格 (续)

参数		测试条件	最小值	标称值	最大值	单位
系统特性						
η	$V_{IN} = 115V/230V$ 下的满负载效率	$V_{OUT} = 24V, I_{OUT} = 2.71A$		94.06/94.59		%
		$V_{OUT} = 20V, I_{OUT} = 3.25A$		94.01/94.70		%
		$V_{OUT} = 15V, I_{OUT} = 3A$		94.10/94.40		%
		$V_{OUT} = 12V, I_{OUT} = 3A$		94.15/94.03		%
		$V_{OUT} = 9V, I_{OUT} = 3A$		93.96/93.54		%
		$V_{OUT} = 5V, I_{OUT} = 3A$		93.19/91.93		%
η	$V_{IN} = 115V/230V^{(1)}$ 下的 4 点平均效率	$V_{OUT} = 24V$ (CoC 2 级, 89.0%)		94.20/94.14		%
		$V_{OUT} = 20V$ (CoC 2 级, 89.0%)		94.19/94.35		%
		$V_{OUT} = 15V$ (CoC 2 级, 88.9%)		94.24/94.03		%
		$V_{OUT} = 12V$ (CoC 2 级, 88.3%)		94.20/93.67		%
		$V_{OUT} = 9V$ (CoC 2 级, 87.3%)		93.85/93.07		%
		$V_{OUT} = 5V$ (CoC 2 级, 81.8%)		92.92/90.90		%
η	$V_{IN} = 115V/230V$ 、10% 负载下的效率	$V_{OUT} = 24V$ (CoC 2 级, 79.0%)		92.41/92.13		%
		$V_{OUT} = 20V$ (CoC 2 级, 79.0%)		93.09/92.36		%
		$V_{OUT} = 15V$ (CoC 2 级, 78.9%)		93.24/91.38		%
		$V_{OUT} = 12V$ (CoC 2 级, 78.3%)		93.27/90.21		%
		$V_{OUT} = 9V$ (CoC 2 级, 77.3%)		92.72/88.48		%
		$V_{OUT} = 5V$ (CoC 2 级, 72.5%)		91.96/86.40		
T_{AMB}	工作环境温度	$V_{IN} = 90V$ 至 $264V_{RMS}$, $I_{OUT} = 0A$ 至 $3.00A$ (5V/9V/15V), $3.25A$ (20V) 或 $2.71A$ (24V)		25		°C

(1) 四个负载点的平均效率, I_{OUT} = 每个相应输出电压的额定满载电流的 100%、75%、50% 和 25%。

3.2 测试设置

3.2.1 测试设置要求

安全性：此评估模块并未进行封装，电路板中存在超过 50V_{DC} 的可接触电压。

隔离输入变压器：此 EVM 的输入端上应连接额定值合适的 1:1 隔离变压器，该变压器构造为通过增强型绝缘、双重绝缘或连接到保护导体端子的屏蔽将初级绕组与次级绕组隔离开来。



警告

- 如果用户没有接受过安全处理和测试功率电子产品方面的培训，请不要测试此评估模块。
- EVM 通电后，请勿触摸 EVM 或电路，因为 EVM 或电路可能存在高压，会造成电击危险。
- 注意：表面高温。接触会导致烫伤。请勿触摸！
- 在进行测试之前，请仔细阅读本用户指南。

电压源：隔离式交流电源或可变交流变压器，额定电压至少为 264V_{RMS}，并能承受 100W 的功率级别。

电压表：数字电压表

功率分析仪：能够测量 1mW 至 100W 输入功率并能够处理 264V_{RMS} 输入电压。一些功率分析仪可能需要使用精密分流电阻器来测量输入电流，以便测量 5W 或更低的输入功率。请阅读功率分析仪的用户手册，以了解正确测量全功率和待机功率的设置。

示波器：

- 4 通道、500MHz 带宽。
- 能够处理 600V 电压的探针。

输出负载：能够在 20V 条件下处理 130W 的电阻负载或电子负载。

建议线规：绝缘 22AWG 至 18AWG。



警告

注意：在无人看管的情况下，请勿让 EVM 处于通电状态。

3.2.2 UCG28846DREVM-151 的测试设置图

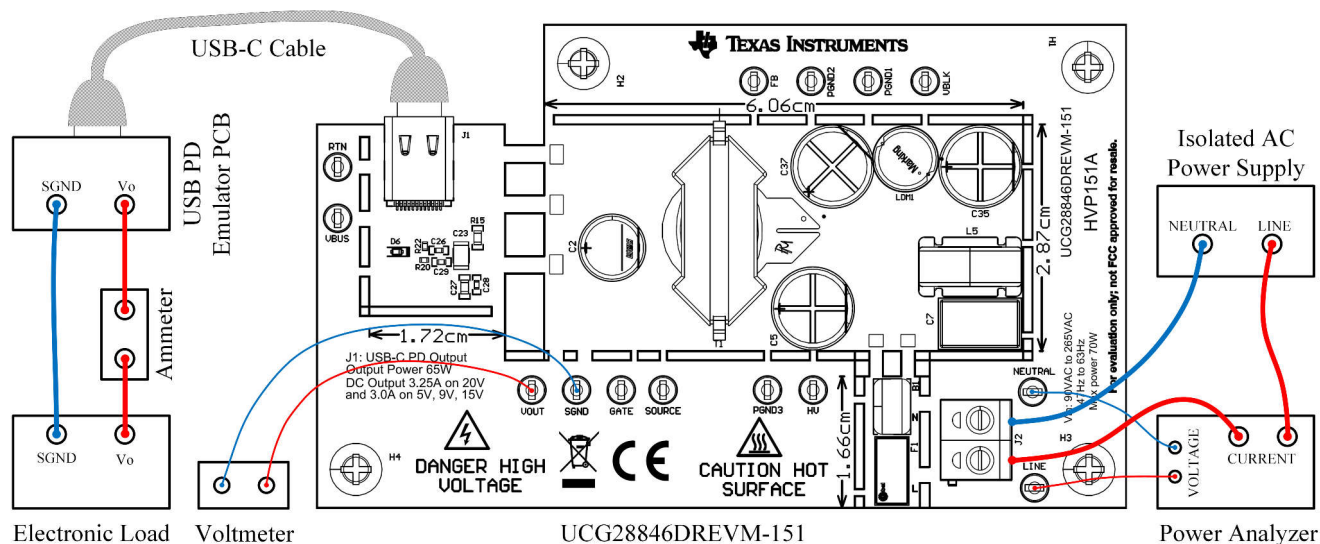


图 3-1. 使用 USB-C PD 负载的 UCG28846DREVM-151 测试设置图

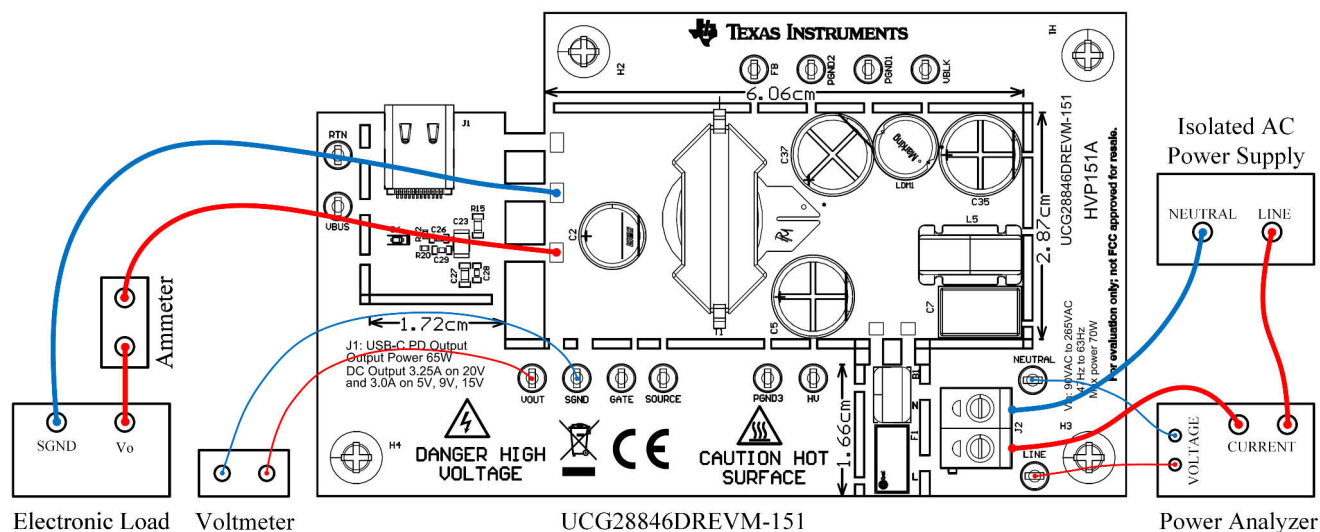
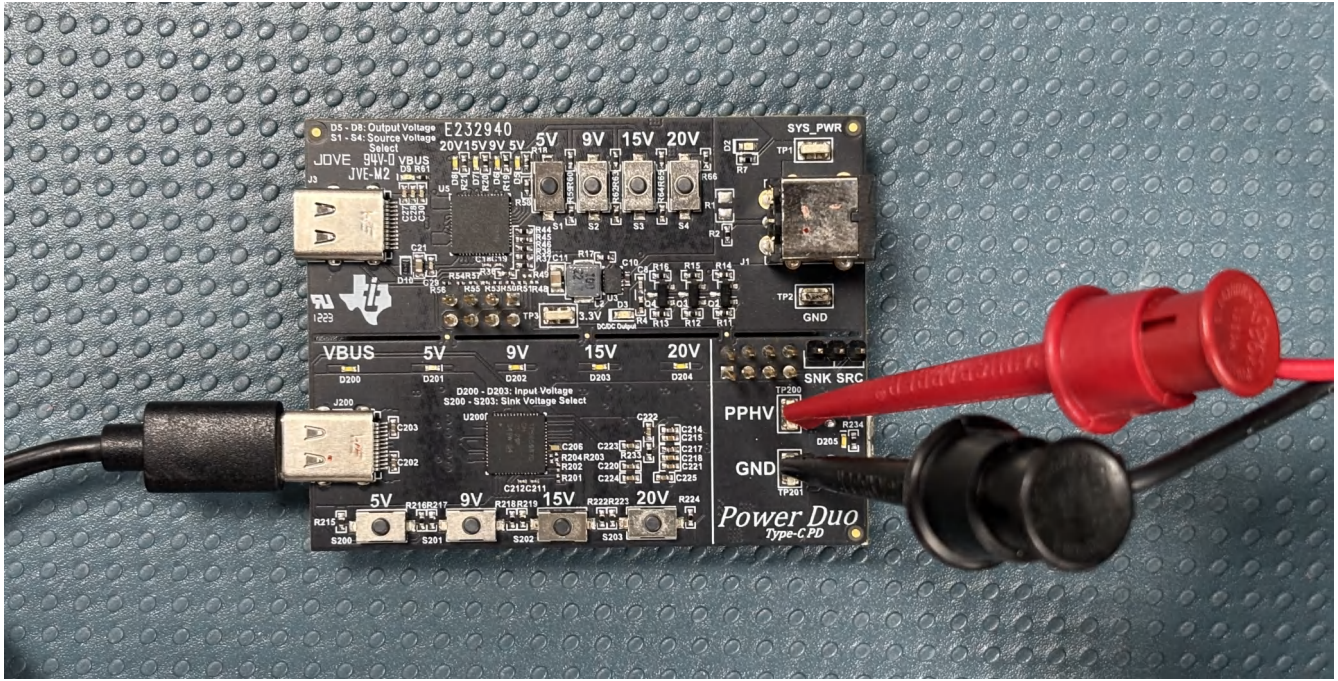


图 3-2. 使用非 USB-C PD 负载的 UCG28846DREVM-151 测试设置图

25%-100% 负载下的效率结果是使用上述配置得出的。在待机和 10% 负载条件下，电压测量在电源端/负载端进行，以记录效率数值。



- A. 下面的 USB 仿真器 “USB-C-DUO EVM” 用于此评估。其他符合 PD3.0 标准的任何 USB-C PD 仿真器也可用于评估此 EVM。请注意，USB-C PD 仿真器消耗的电流为几 mA，在效率计算时需要考虑这一点。

图 3-3. USB-C 仿真器

3.2.3 测试点

表 3-2. 输入/输出端子和测试点功能

端子和测试点	说明
J1	USB-C 终端
J2	交流电压输入终端
LINE	交流输入的测试点 - 线路
NEUTRAL	交流输入的测试点 - 中性
PGND1、PGND2 和 PGND3	初级接地测试点
VBLK	大容量电容器电压的测试点
FB	FB 引脚的测试点
HV	HV 引脚的测试点
SOURCE	SR FET 源极测试点
GATE	SR FET 栅极测试点
SGND	次级接地测试点
VOUT	转换器输出电压测试点
VBUS	输出侧总线电压测试点
RTN	输出侧返回线路的测试点

3.3 性能数据和典型特性曲线

3.3.1 24V_{out} 时的 4 点平均效率结果

V _{IN} (VRMS)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{OUT} (%)	效率	4 点平均效率
90	7.14	23.98	0.275	6.59	10	92.37%	93.46%
90	17.42	23.97	0.680	16.30	25	93.58%	
90	34.64	23.97	1.355	32.48	50	93.75%	
90	52.03	23.97	2.032	48.71	75	93.62%	
90	69.85	23.96	2.708	64.88	100	92.89%	
115	7.18	23.97	0.277	6.64	10	92.41%	94.20%
115	17.39	23.97	0.683	16.37	25	94.17%	
115	34.44	23.96	1.356	32.49	50	94.35%	
115	51.70	23.96	2.033	48.71	75	94.22%	
115	68.98	23.95	2.709	64.88	100	94.06%	
230	7.23	23.96	0.278	6.66	10	92.13%	94.14%
230	17.50	23.96	0.682	16.34	25	93.35%	
230	34.50	23.96	1.356	32.49	50	94.17%	
230	51.53	23.95	2.032	48.67	75	94.44%	
230	68.62	23.95	2.710	64.90	100	94.59%	
264	7.31	23.96	0.277	6.64	10	90.77%	93.78%
264	17.65	23.96	0.683	16.36	25	92.72%	
264	34.67	23.96	1.358	32.54	50	93.85%	
264	51.71	23.95	2.033	48.69	75	94.16%	
264	68.75	23.95	2.709	64.88	100	94.38%	
CoC 2 级, 4 点平均							89.00%
CoC 2 级, 10% 负载							79.00%

3.3.2 20V_{out} 时的 4 点平均效率结果

V _{IN} (VRMS)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{OUT} (%)	效率	4 点平均效率
90	7.29	20.00	0.331	6.79	10	93.07%	93.46%
90	17.59	20.00	0.818	16.53	25	93.99%	
90	34.96	20.00	1.628	32.73	50	93.63%	
90	52.33	20.00	2.440	48.96	75	93.56%	
90	70.34	19.99	3.253	65.19	100	92.68%	
115	7.31	19.99	0.332	6.81	10	93.09%	94.19%
115	17.53	20.00	0.818	16.52	25	94.28%	
115	34.66	19.99	1.628	32.72	50	94.39%	
115	52.05	19.99	2.441	48.97	75	94.08%	
115	69.36	19.99	3.253	65.20	100	94.01%	
230	7.33	20.01	0.330	6.77	10	92.36%	94.35%
230	17.62	20.01	0.817	16.51	25	93.71%	
230	34.67	20.01	1.627	32.72	50	94.37%	
230	51.75	20.00	2.439	48.96	75	94.61%	
230	68.83	20.00	3.251	65.18	100	94.70%	
264	7.43	19.99	0.331	6.79	10	91.33%	93.92%
264	17.78	20.00	0.819	16.54	25	93.05%	
264	34.86	20.00	1.628	32.72	50	93.85%	
264	51.94	20.00	2.441	48.98	75	94.30%	
264	69.01	20.00	3.252	65.20	100	94.47%	
CoC 2 级, 4 点平均							89.00%
CoC 2 级, 10% 负载							79.00%

3.3.3 15V_{out} 时的 4 点平均效率结果

V _{IN} (VRMS)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{OUT} (%)	效率	4 点平均效率
90	5.02	15.02	0.305	4.69	10	93.42%	93.70%
90	12.17	15.02	0.755	11.45	25	94.09%	
90	24.17	15.02	1.503	22.68	50	93.85%	
90	36.26	15.02	2.252	33.93	75	93.57%	
90	48.46	15.02	3.003	45.21	100	93.31%	
115	5.04	15.01	0.306	4.70	10	93.24%	94.24%
115	12.15	15.01	0.755	11.44	25	94.16%	
115	24.02	15.01	1.504	22.69	50	94.45%	
115	36.00	15.01	2.253	33.93	75	94.24%	
115	48.03	15.01	3.003	45.19	100	94.09%	
230	5.13	15.02	0.305	4.69	10	91.38%	94.03%
230	12.25	15.02	0.755	11.45	25	93.43%	
230	24.14	15.02	1.503	22.69	50	93.97%	
230	36.00	15.02	2.253	33.95	75	94.31%	
230	47.88	15.02	3.002	45.20	100	94.40%	
264	5.19	15.02	0.305	4.69	10	90.23%	93.48%
264	12.37	15.02	0.755	11.45	25	92.53%	
264	24.29	15.02	1.504	22.69	50	93.44%	
264	36.17	15.02	2.253	33.95	75	93.86%	
264	48.05	15.02	3.003	45.21	100	94.09%	
CoC 2 级, 4 点平均							88.85%
CoC 2 级, 10% 负载							78.85%

3.3.4 12V_{out} 时的 4 点平均效率结果

V _{IN} (VRMS)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{OUT} (%)	效率	4 点平均效率
90	3.89	11.98	0.305	3.65	10	93.91%	93.74%
90	9.60	11.98	0.754	9.03	25	94.09%	
90	19.15	11.98	1.503	18.00	50	94.01%	
90	28.85	11.98	2.252	26.97	75	93.48%	
90	38.49	11.97	3.002	35.94	100	93.38%	
115	3.92	11.98	0.305	3.65	10	93.27%	94.20%
115	9.62	11.98	0.755	9.04	25	94.01%	
115	19.09	11.97	1.504	18.01	50	94.36%	
115	28.62	11.97	2.253	26.98	75	94.26%	
115	38.18	11.97	3.003	35.95	100	94.15%	
230	4.05	11.98	0.305	3.65	10	90.21%	93.67%
230	9.73	11.98	0.756	9.05	25	93.07%	
230	19.23	11.97	1.504	18.01	50	93.66%	
230	28.73	11.97	2.254	26.98	75	93.93%	
230	38.23	11.97	3.003	35.94	100	94.03%	
264	4.12	11.98	0.305	3.65	10	88.72%	93.09%
264	9.82	11.97	0.756	9.05	25	92.23%	
264	19.35	11.97	1.504	18.01	50	93.05%	
264	28.87	11.97	2.254	26.98	75	93.44%	
264	38.38	11.97	3.003	35.94	100	93.63%	
CoC 2 级, 4 点平均							88.30%
CoC 2 级, 10% 负载							78.30%

3.3.5 9V_{out} 时的 4 点平均效率结果

V _{IN} (VRMS)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{OUT} (%)	效率	4 点平均效率
90	3.00	9.02	0.305	2.80	10	93.33%	93.52%
90	7.32	9.02	0.754	6.85	25	93.62%	
90	14.52	9.02	1.504	13.62	50	93.79%	
90	21.80	9.02	2.253	20.38	75	93.50%	
90	29.13	9.03	3.002	27.14	100	93.18%	
115	3.03	9.02	0.306	2.81	10	92.72%	93.85%
115	7.35	9.02	0.755	6.86	25	93.33%	
115	14.48	9.02	1.504	13.61	50	94.02%	
115	21.66	9.02	2.254	20.38	75	94.08%	
115	28.90	9.02	3.004	27.15	100	93.96%	
230	3.16	9.02	0.304	2.79	10	88.48%	93.07%
230	7.42	9.02	0.754	6.85	25	92.41%	
230	14.63	9.02	1.503	13.61	50	93.03%	
230	21.83	9.02	2.252	20.37	75	93.31%	
230	29.02	9.03	3.002	27.15	100	93.54%	
264	3.22	9.02	0.304	2.79	10	86.84%	92.36%
264	7.50	9.03	0.754	6.86	25	91.43%	
264	14.76	9.03	1.503	13.62	50	92.28%	
264	21.97	9.03	2.252	20.37	75	92.74%	
264	29.19	9.02	3.003	27.15	100	93.01%	
CoC 2 级, 4 点平均							87.30%
CoC 2 级, 10% 负载							77.30%

3.3.6 $5V_{out}$ 时的 4 点平均效率结果

V_{IN} (VRMS)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{OUT} (%)	效率	4 点平均效率
90	1.64	4.99	0.304	1.52	10	92.34%	92.96%
90	4.05	4.99	0.754	3.76	25	92.87%	
90	8.04	4.99	1.503	7.49	50	93.16%	
90	12.08	4.99	2.253	11.23	75	93.01%	
90	16.14	4.99	3.003	14.98	100	92.77%	
115	1.65	4.98	0.305	1.52	10	91.96%	92.92%
115	4.08	4.98	0.755	3.76	25	92.31%	
115	8.07	4.99	1.504	7.50	50	92.93%	
115	12.05	4.99	2.253	11.24	75	93.24%	
115	16.07	4.99	3.003	14.98	100	93.19%	
230	1.76	4.98	0.305	1.52	10	86.40%	90.90%
230	4.24	4.98	0.755	3.76	25	88.85%	
230	8.22	4.99	1.504	7.50	50	91.18%	
230	12.26	4.99	2.254	11.24	75	91.64%	
230	16.29	4.99	3.003	14.98	100	91.93%	
264	1.80	4.98	0.305	1.52	10	84.58%	89.82%
264	4.31	4.98	0.755	3.76	25	87.27%	
264	8.32	4.99	1.504	7.50	50	90.10%	
264	12.38	4.99	2.254	11.24	75	90.77%	
264	16.43	4.99	3.003	14.97	100	91.15%	
CoC 2 级, 4 点平均							81.84%
CoC 2 级, 10% 负载							72.48%

3.3.7 效率典型结果

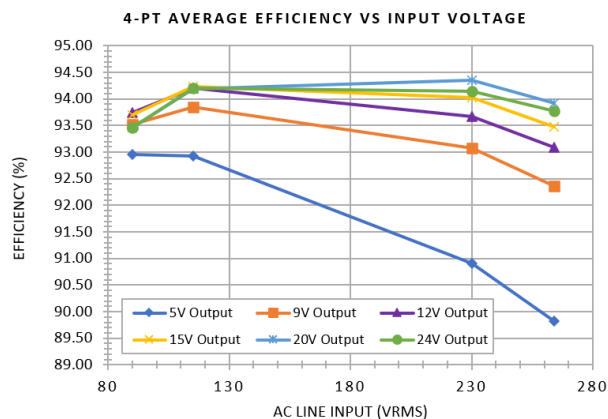


图 3-4. 4 点平均效率与输入电压间的关系

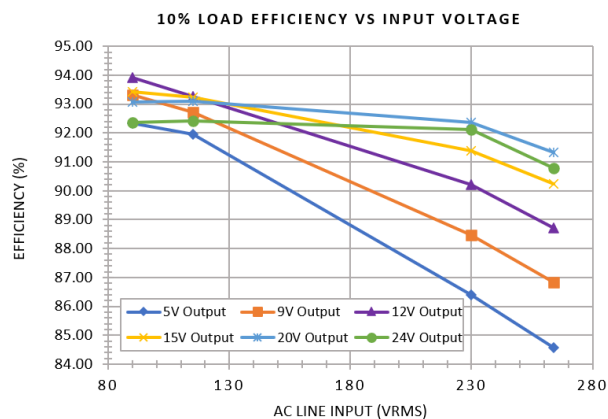


图 3-5. 10% 负载效率与输入电压间的关系

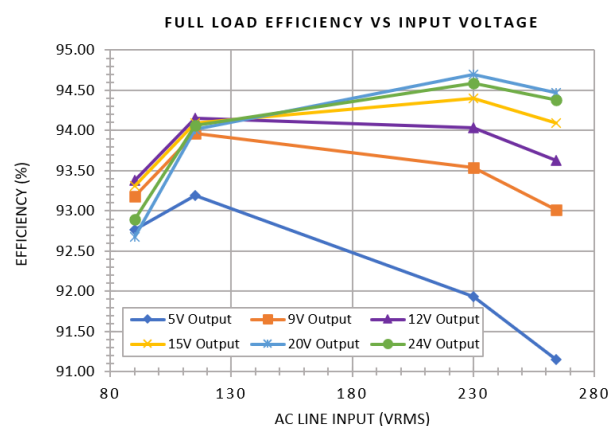


图 3-6. 满负载效率与输入电压

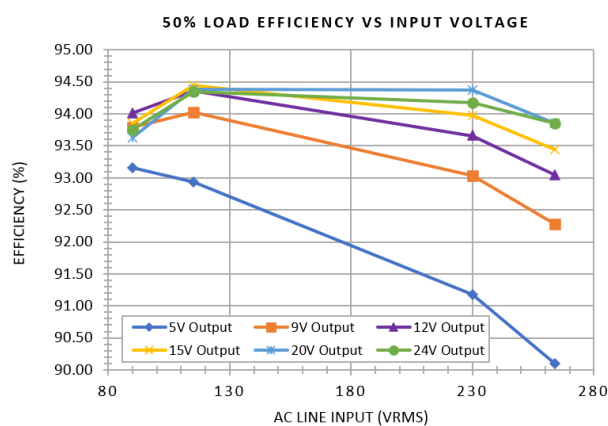


图 3-7. 50% 负载效率与输入电压间的关系

3.3.8 输出特性

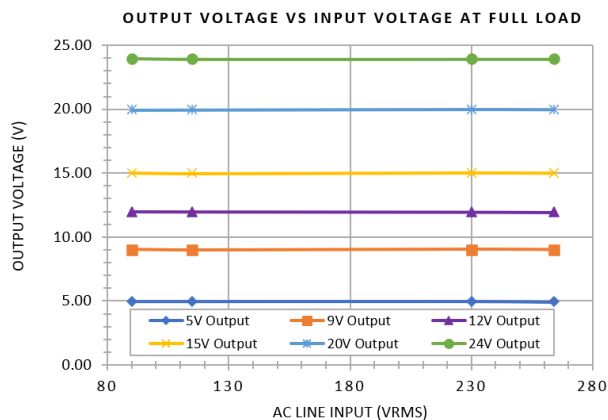


图 3-8. 满负载下 V_{OUT} 与输入电压间的关系

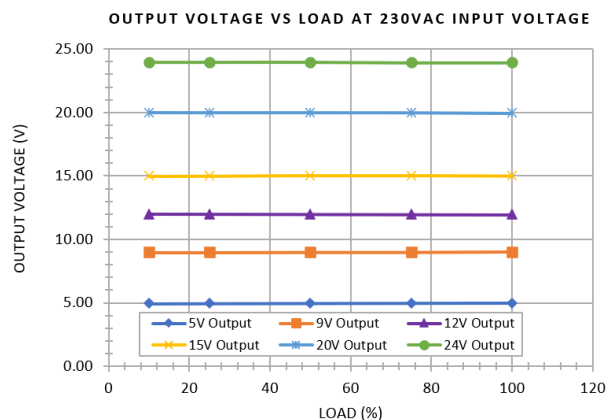


图 3-9. 230Vac 输入电压下 V_{OUT} 与负载间的关系

3.3.9 重要开关波形

本节展示了满载时的典型开关波形。Ch1 - 输出电压，Ch2 - SR 栅极电压，Ch3 - 开关节点电压和 Ch4 - FB 引脚电压。



图 3-10. $V_{in} = 90\text{Vac}$, $V_{out} = 24\text{V}$



图 3-11. $V_{in} = 115\text{Vac}$, $V_{out} = 24\text{V}$

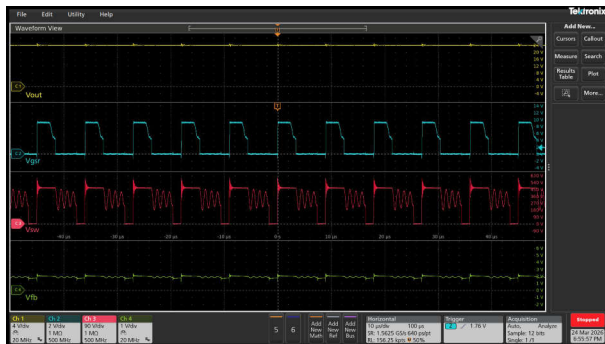


图 3-12. $V_{in} = 230\text{Vac}$, $V_{out} = 24\text{V}$

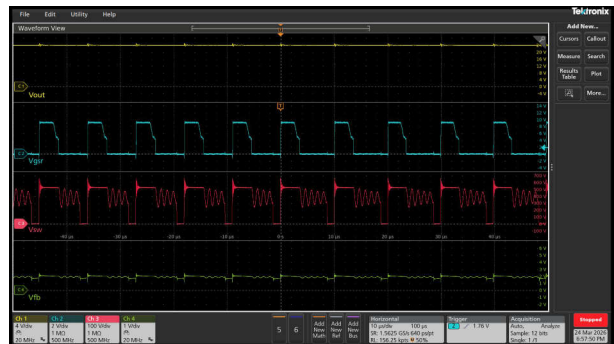


图 3-13. $V_{in} = 264\text{Vac}$, $V_{out} = 24\text{V}$



图 3-14. $V_{in} = 90\text{Vac}$, $V_{out} = 20\text{V}$



图 3-15. $V_{in} = 115\text{Vac}$, $V_{out} = 20\text{V}$



图 3-16. $V_{in} = 230\text{Vac}$, $V_{out} = 20\text{V}$



图 3-17. $V_{in} = 264\text{Vac}$, $V_{out} = 20\text{V}$



图 3-18. $V_{in} = 90\text{Vac}$, $V_{out} = 15\text{V}$



图 3-19. $V_{in} = 115\text{Vac}$, $V_{out} = 15\text{V}$



图 3-20. $V_{in} = 230\text{Vac}$, $V_{out} = 15\text{V}$



图 3-21. $V_{in} = 264\text{Vac}$, $V_{out} = 15\text{V}$



图 3-22. $V_{in} = 90\text{Vac}$, $V_{out} = 12\text{V}$



图 3-23. $V_{in} = 115\text{Vac}$, $V_{out} = 12\text{V}$



图 3-24. $V_{in} = 230\text{Vac}$, $V_{out} = 12\text{V}$



图 3-25. $V_{in} = 264\text{Vac}$, $V_{out} = 12\text{V}$



图 3-26. $V_{in} = 90\text{Vac}$, $V_{out} = 9\text{V}$



图 3-27. $V_{in} = 115\text{Vac}$, $V_{out} = 9\text{V}$



图 3-28. $V_{in} = 230\text{Vac}$, $V_{out} = 9\text{V}$



图 3-29. $V_{in} = 264\text{Vac}$, $V_{out} = 9\text{V}$



图 3-30. $V_{in} = 90\text{Vac}$, $V_{out} = 5\text{V}$



图 3-31. $V_{in} = 115\text{Vac}$, $V_{out} = 5\text{V}$

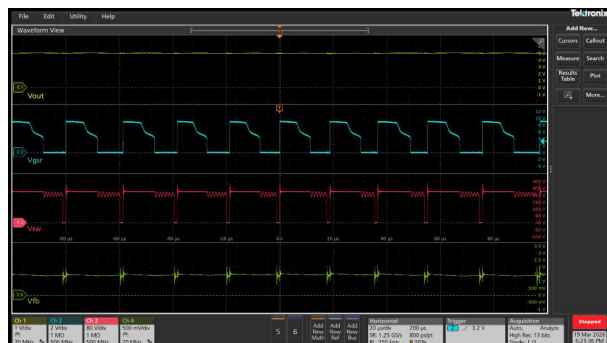


图 3-32. $V_{in} = 230\text{Vac}$, $V_{out} = 5\text{V}$



图 3-33. $V_{in} = 264\text{Vac}$, $V_{out} = 5\text{V}$

3.3.10 开关频率与负载

此部分显示了 230Vac 输入和 20V 输出下不同负载条件下的典型开关波形。Ch1 - 输出电压，Ch2 - 大容量电容器电压，Ch3 - 开关节点电压，Ch4 - FB 引脚电压



图 3-34. 230Vac/0.4W (25kHz 突发频率/Vfb - 0.27V)

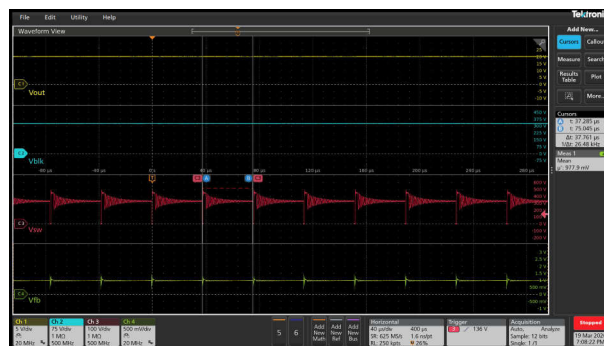


图 3-35. 230Vac/3W (25kHz 频率-折返/Vfb - 0.98V)

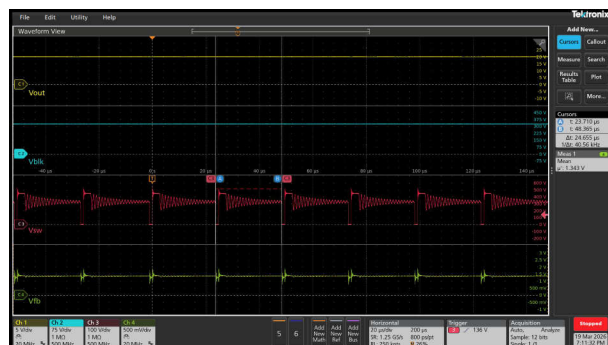


图 3-36. 230Vac/10W (40kHz 频率-折返/Vfb - 1.34V)



图 3-37. 230Vac/16W (53kHz 频率-折返/Vfb - 1.45V)



图 3-38. 230Vac/40W (91kHz 第 6 谷底开关/ Vfb - 1.71V)



图 3-39. 230Vac/65W (115kHz 第 3 谷底开关/Vfb - 1.93V)

3.3.11 输出纹波电压

此节展示了输出电压纹波波形。Ch1 - 输出电压纹波，示波器通道带宽 = 20MHz。

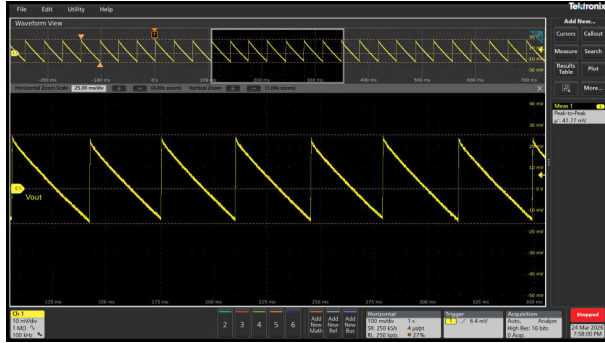


图 3-40. $V_{OUT} = 24V$ 且无负载时的典型纹波电压 (42mVpp)



图 3-41. $V_{OUT} = 24V$ 且满负载时的典型纹波电压 (50mVpp)

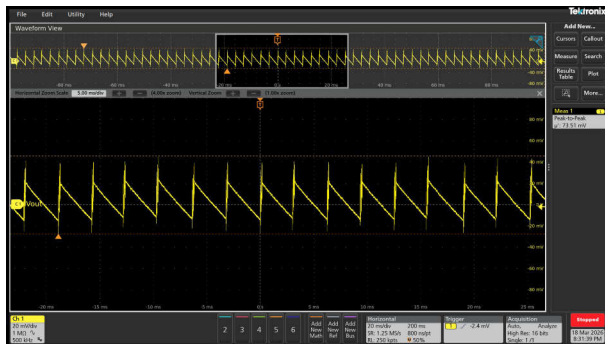


图 3-42. $V_{OUT} = 20V$ 且无负载时的典型纹波电压 (74mVpp)

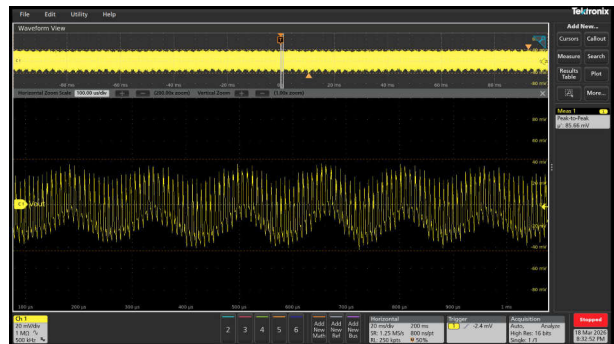


图 3-43. $V_{OUT} = 20V$ 且满负载时的典型纹波电压 (86mVpp)

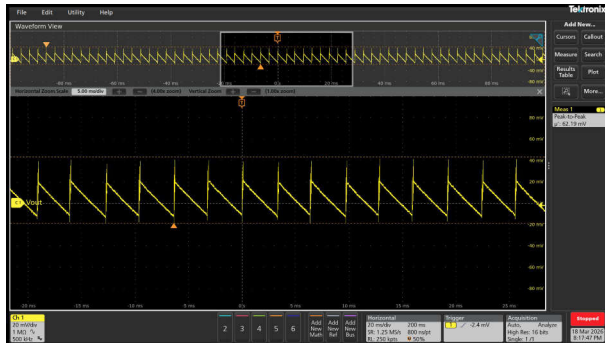


图 3-44. $V_{OUT} = 15V$ 且无负载时的典型纹波电压 (62mVpp)



图 3-45. $V_{OUT} = 15V$ 且满负载时的典型纹波电压 (98mVpp)



图 3-46. $V_{OUT} = 12V$ 且无负载时的典型纹波电压 (63mVpp)



图 3-47. $V_{OUT} = 12V$ 且满负载时的典型纹波电压 (117mVpp)

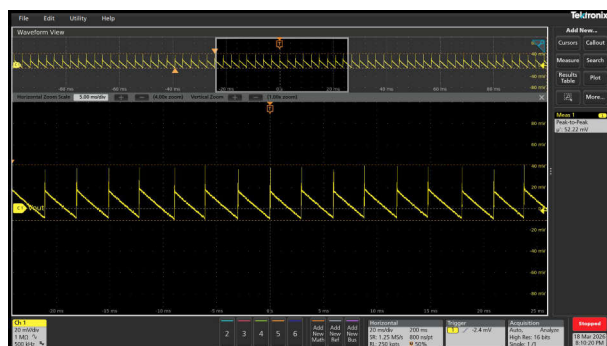


图 3-48. $V_{OUT} = 9V$ 且无负载时的典型纹波电压 (52mVpp)



图 3-49. $V_{OUT} = 9V$ 且满负载时的典型纹波电压 (100mVpp)

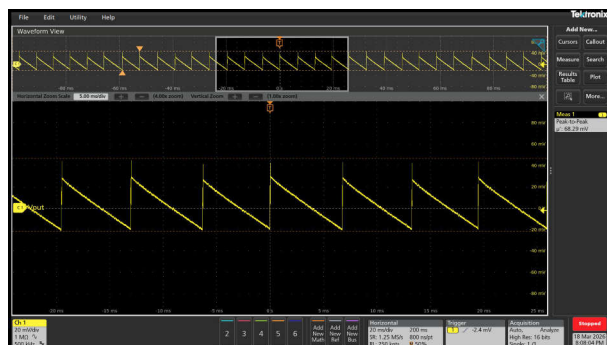


图 3-50. $V_{OUT} = 5V$ 且无负载时的典型纹波电压 (68mVpp)



图 3-51. $V_{OUT} = 5V$ 且满负载时的典型纹波电压 (91mVpp)

3.3.12 负载瞬态响应

本节介绍了负载瞬态条件下的开关波形。此处，负载电流阶跃变化在 2% 到 100% 之间，频率为 25Hz，变化速率为 2.5A/ μ s。

Ch1 - 输出电压 (交流耦合)，Ch2 - 输出电流。

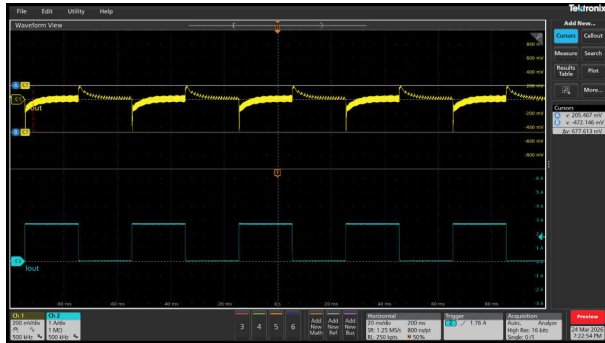


图 3-52. $V_{OUT} = 24V$ 过冲/下冲= 205mV/-472mV 条件下的负载瞬态响应

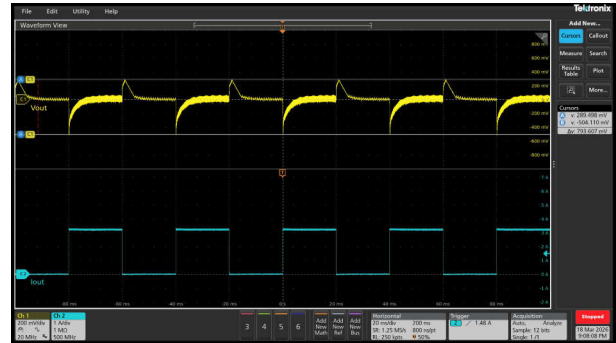


图 3-53. $V_{OUT} = 20V$ 过冲/下冲= 289mV/-504mV 条件下的瞬态响应

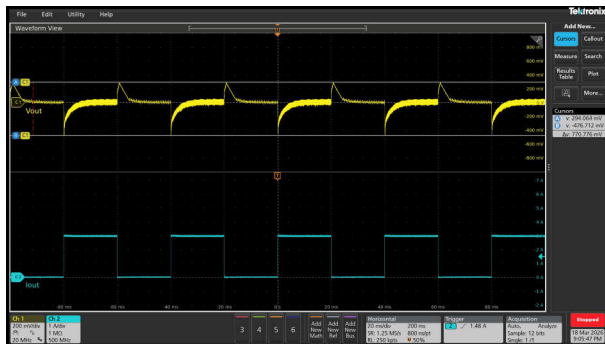


图 3-54. $V_{OUT} = 15V$ 过冲/下冲= 294mV/-477mV 条件下的瞬态响应

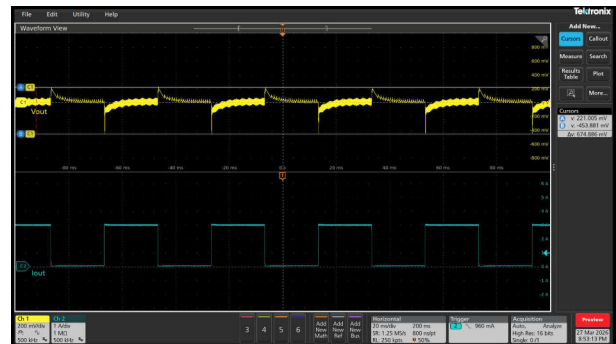


图 3-55. $V_{OUT} = 12V$ 过冲/下冲= 221mV/-454mV 条件下的瞬态响应

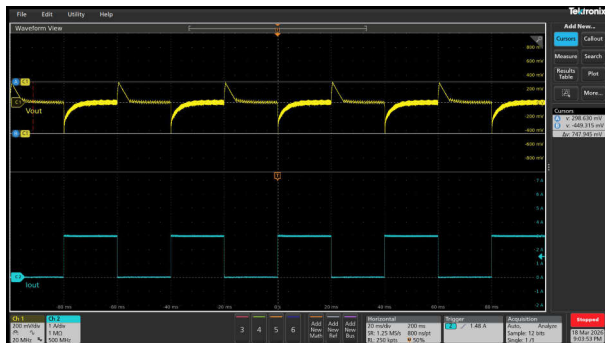


图 3-56. $V_{OUT} = 9V$ 过冲/下冲= 299mV/-449mV 条件下的瞬态响应

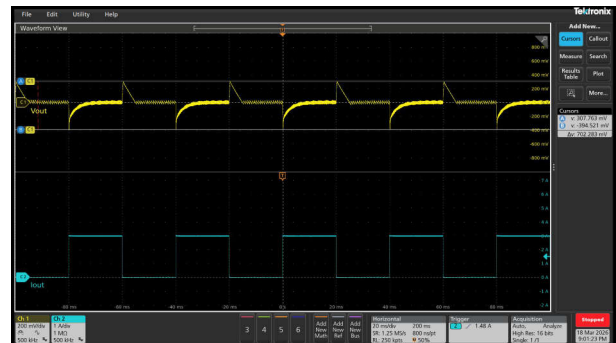


图 3-57. $V_{OUT} = 5V$ 过冲/下冲= 307mV/-395mV 条件下的瞬态响应

3.3.13 线路瞬态响应

本节介绍了空载和满载条件下，线路电压从 90Vac 瞬变至 264Vac 时的开关波形。Ch1 - 输出电压，Ch2 - 交流输入电压，Ch3 - 开关节点电压，Ch4 - FB 引脚电压



图 3-58. 20V 空载条件下从 90Vac 到 264Vac 的线路瞬态

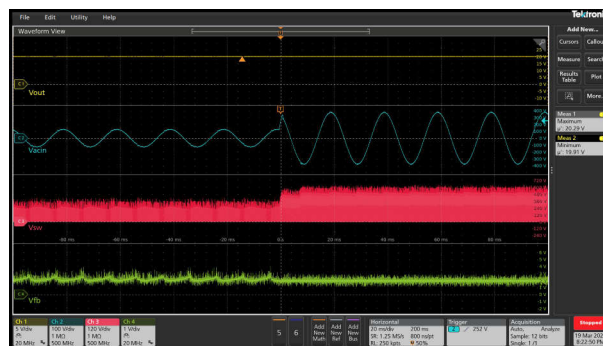


图 3-59. 20V 满负载条件下从 90Vac 到 264Vac 的线路瞬态

3.3.14 短期过载运行

该 EVM 能够支持短期过载运行，而不会造成损坏、安全问题或触发保护功能。当施加 7.3A 的峰值短期过载持续 1ms 时，输出电压降至 17.9V。当施加 6.5A 的峰值短期过载持续 2ms 时，输出电压降至 18.1V。这些结果已在 90Vac 条件下进行检查。Ch1 - 输出电压，Ch2 - 输出电流，Ch3 - 开关节点电压，Ch4 - 反馈引脚电压。

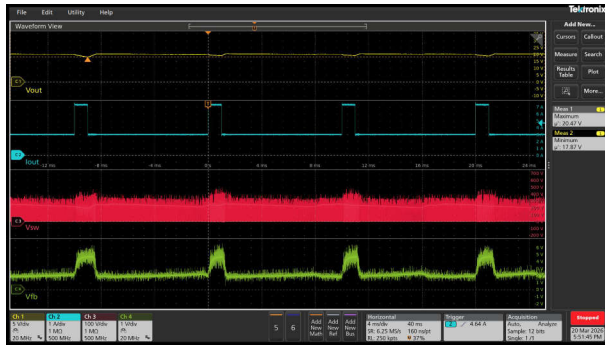


图 3-60. VIN = 90Vac (2.25 倍额定电流并持续 1ms , 0.9 倍额定电流并持续 9ms)

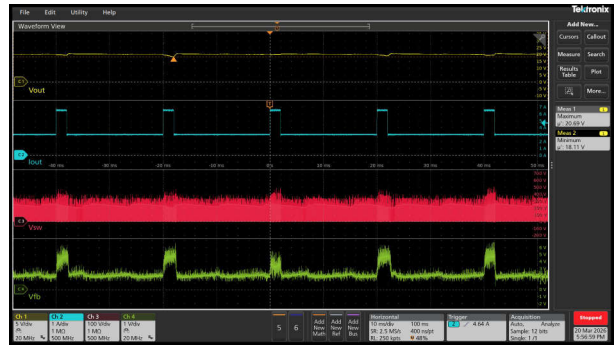


图 3-61. VIN = 90Vac (2 倍额定电流持续 2ms , 0.9 倍额定电流持续 18ms)

3.3.15 CCM 运行

本节介绍了在 90Vac、6.5A 负载条件下以 CCM 模式运行时的开关波形。此处还显示了波形的放大版本。Ch1 - 输出电压，Ch2 - 输出电流，Ch3 - 开关节点电压，Ch4 - 反馈引脚电压。

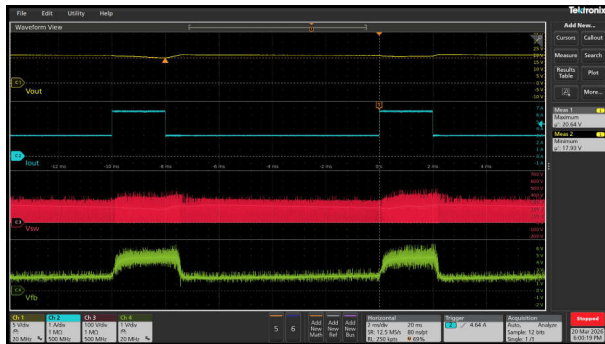


图 3-62. VIN = 90Vac (2 倍额定电流持续 2ms , 0.9 倍额定电流持续 18ms)



图 3-63. VIN = 90Vac (2 倍额定电流并持续 2ms , 0.9 倍额定电流并持续 18ms) - 缩放版本

3.3.16 启动性能

本节介绍转换器在 230Vac 输入下的启动性能。在固定 V_{OUT} 控制模式下捕获 24V 及 12V 下的启动响应。使用 PD 控制模式捕获 5V 时的启动响应。Ch1 - 输出电压，Ch2 - 输出电压，Ch3 - 输出电流，Ch4 - 反馈引脚电压。



图 3-64. 24V 和 0A 下的启动响应 (过冲 = 230mV)



图 3-65. 24V 和 2.71A 下的启动响应 (过冲 = 270mV)

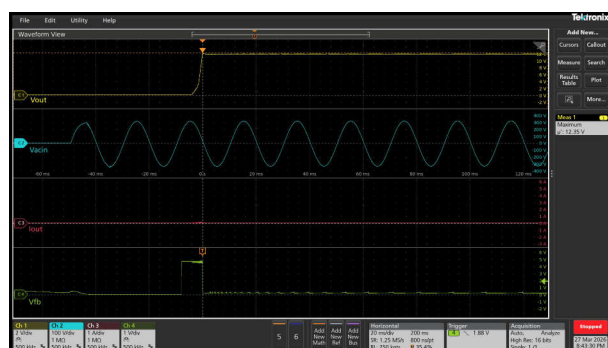


图 3-66. 12V 和 0A 下的启动响应 (过冲 = 350mV)



图 3-67. 12V 和 3A 下的启动响应 (过冲 = 250mV)

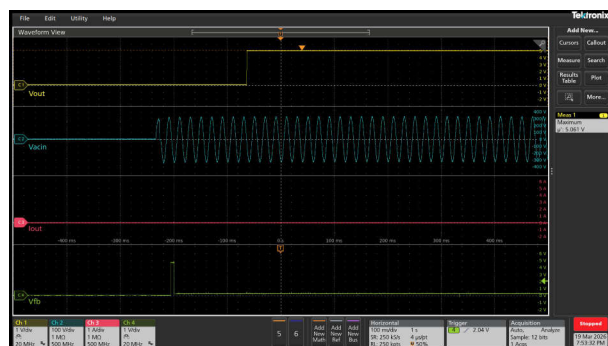


图 3-68. 5V 和 0A 下的启动响应 (过冲 = 61mV)

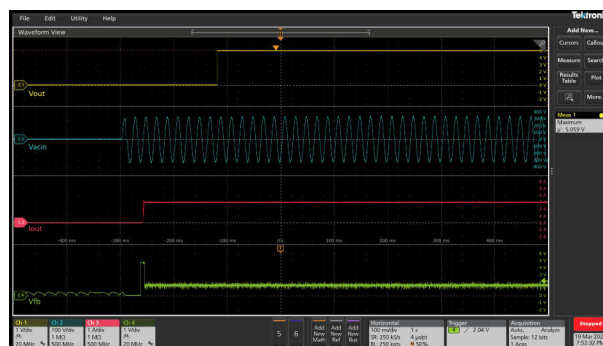


图 3-69. 5V 和 3A 下的启动响应 (过冲 = 59mV)

3.3.17 满负载条件下的热图像 (20V/3.25A 和 24V/2.71A)

此部分介绍了 EVM 在 20V 和 24V 输出电压和不同线路电压下以满载运行时的热图像。数据是在热浸 30 分钟后测量而得。



图 3-70. 顶面为 90Vac 至 24V/2.71A

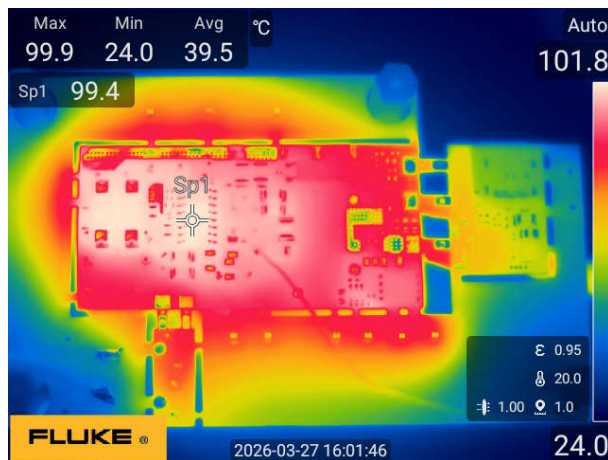


图 3-71. 底面为 90Vac 至 24V/2.71A

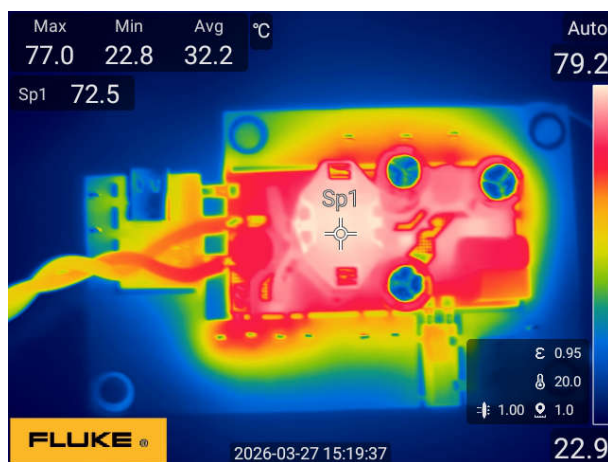


图 3-72. 顶面为 115Vac 至 24V/2.71A



图 3-73. 底面为 115Vac 至 24V/2.71A

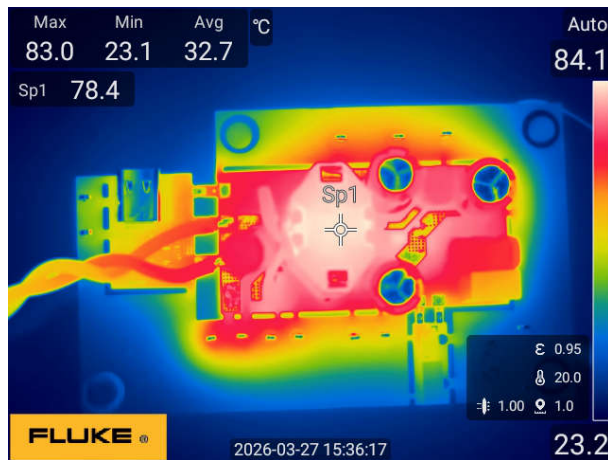


图 3-74. 顶面为 230Vac 至 24V/2.71A

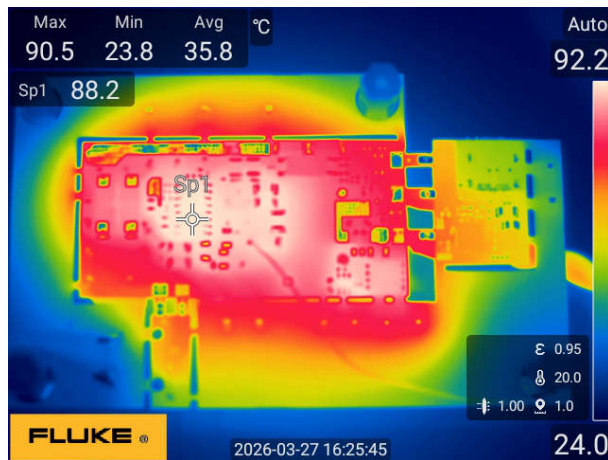


图 3-75. 底面为 230Vac 至 24V/2.71A



图 3-76. 顶面为 264Vac 至 24V/2.71A

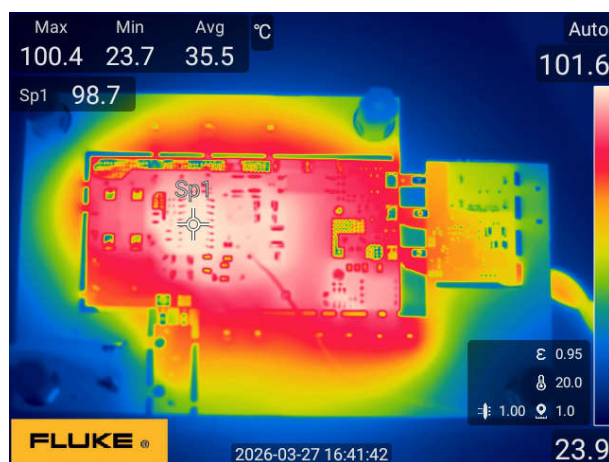


图 3-77. 底面为 264Vac 至 24V/2.71A



图 3-78. 顶面为 90Vac 至 20V/3.25A

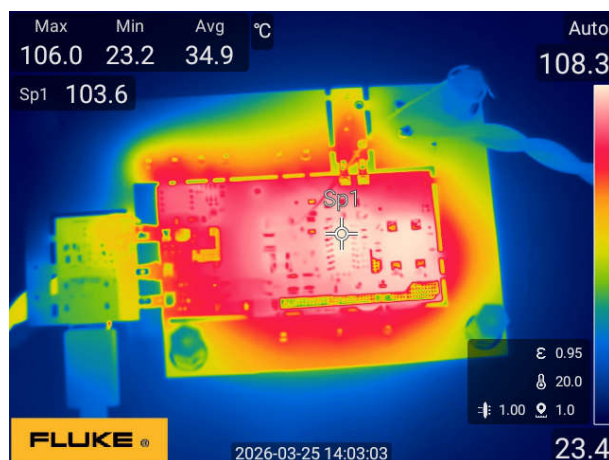


图 3-79. 底面为 90Vac 至 20V/3.25A



图 3-80. 顶面为 115Vac 至 20V/3.25A

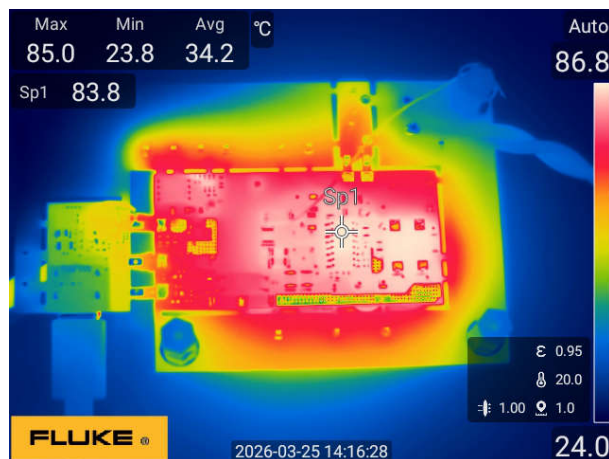


图 3-81. 底面为 115Vac 至 20V/3.25A



图 3-82. 顶面为 230Vac 至 20V/3.25A

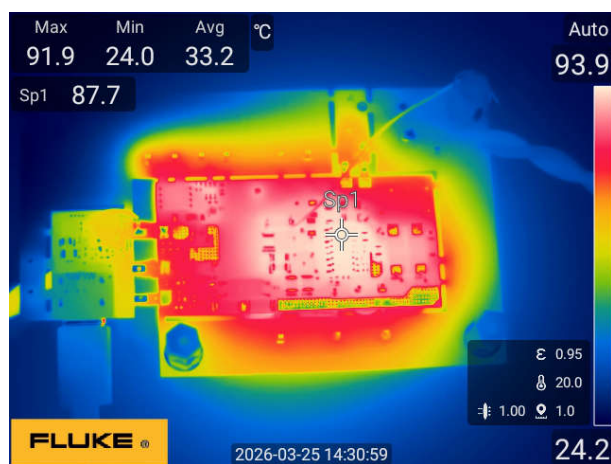


图 3-83. 底面为 230Vac 至 20V/3.25A



图 3-84. 顶面为 264Vac 至 20V/3.25A

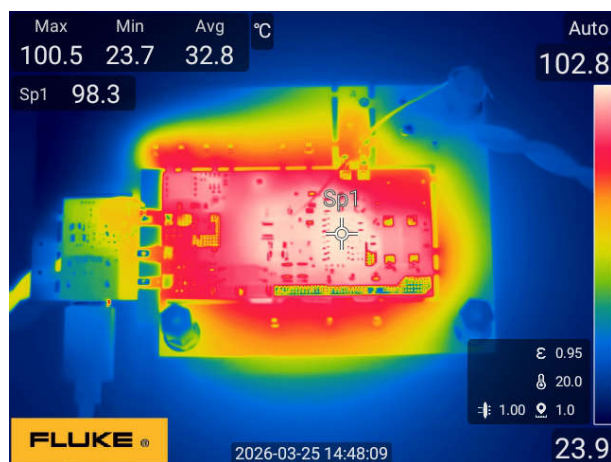


图 3-85. 底面为 264Vac 至 20V/3.25A

3.3.18 CISPR32 B 类传导 EMI 测试结果

请注意，这是在 EMI 工作站上评估的，仅用于预认证目的。TI 建议由具有资质的 EMI 测试机构来验证所有最终设计。以下 EMI 结果是在 SGND 未连接到 LISN 接地端的情况下捕获的。

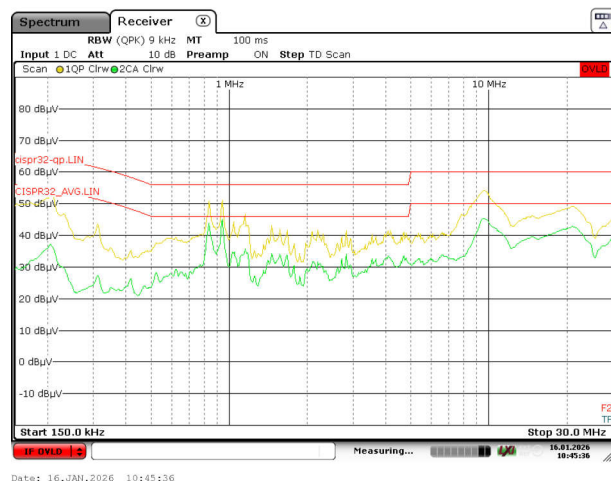


图 3-86. $V_{IN} = 230V_{RMS}$ 、 $V_{OUT} = 20V$ 且 $I_{OUT} = 3.25A$ 时为火线

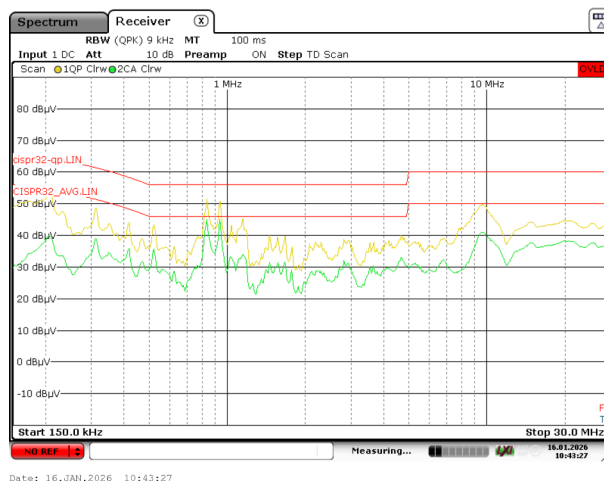


图 3-87. $V_{IN} = 230V_{RMS}$ 、 $V_{OUT} = 20V$ 、 $I_{OUT} = 3.25A$ 时为零线

4 硬件设计文件

4.1 原理图

UCG28846DREVM-151 的原理图如下所示。该 EVM 已配置为启用 USB-PD 控制器，以便使用 USB-PD 负载进行评估。此 EVM 还可以重新配置以产生固定输出电压，用于使用非 USB-EVM PD 负载进行测试。为启用固定输出电压控制器，需先通过移除 0Ω 电阻 R2、R25、R10 和 R19 来禁用 USB-C PD 控制器。然后通过安装零欧姆电阻 R26、R32 和 R28 来启用固定输出电压控制器。随后可通过调整 R34 并使用以下公式来设置输出电压：

$$R34 = R30 \times 2.5V / (V_{out} - 2.5V) \quad (1)$$

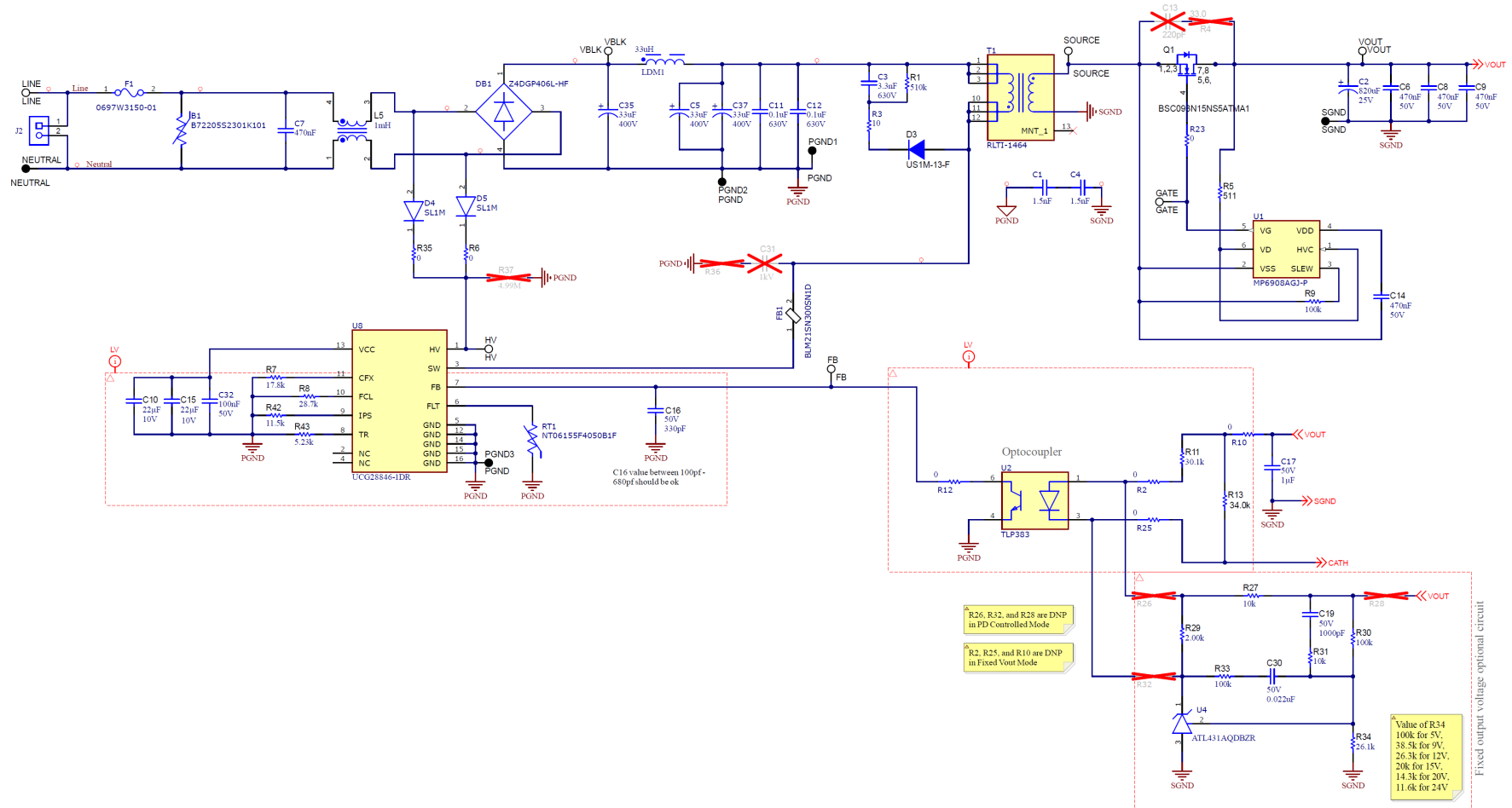


图 4-1. UCG28846DREVM-151 电源电路原理图

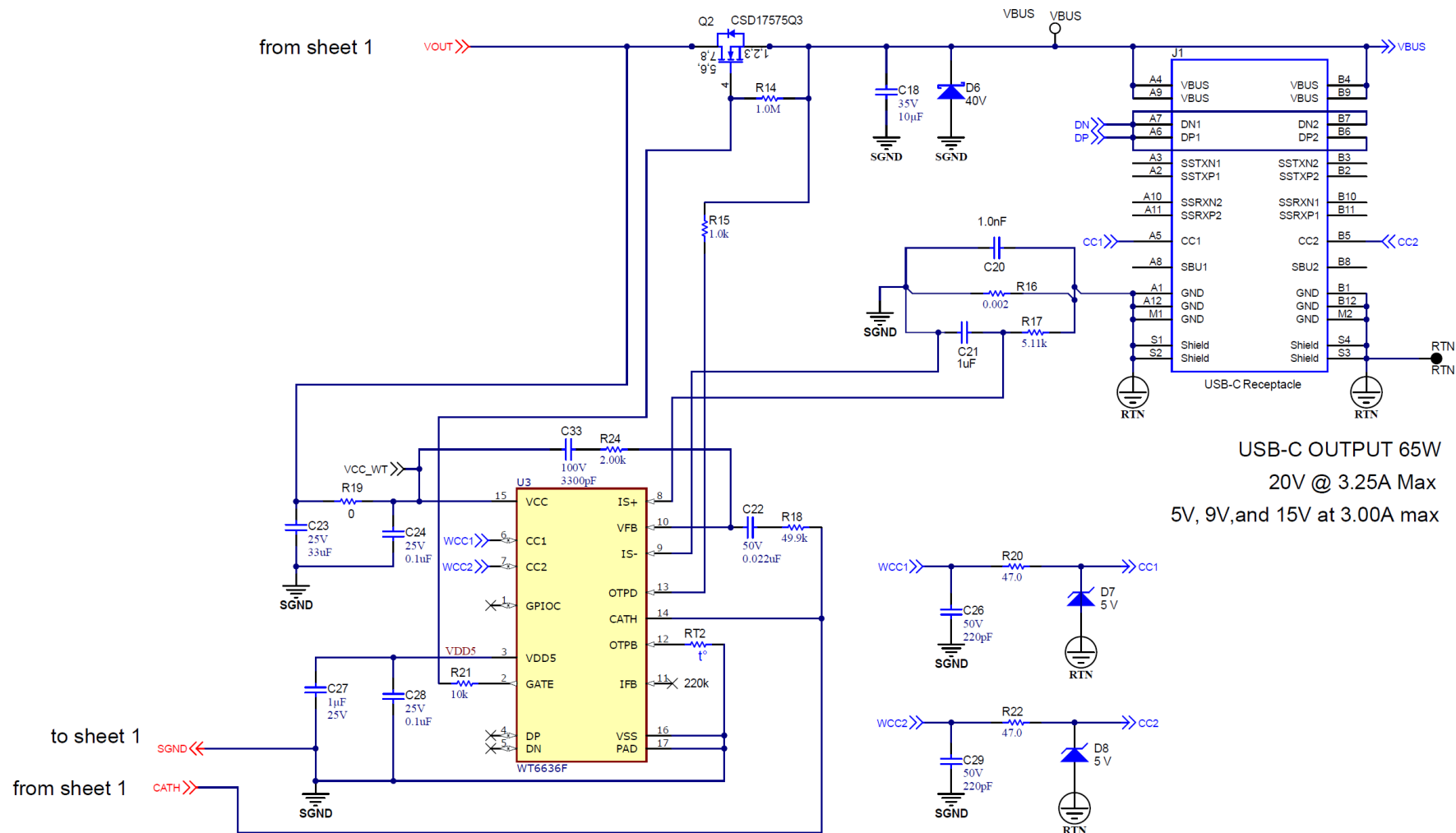


图 4-2. UCG28846DREVM-151 PD 控制器电路原理图

4.2 PCB 布局

UCG28846DREVM-151 使用双层 PCB。每层布局的屏幕截图如下所示。

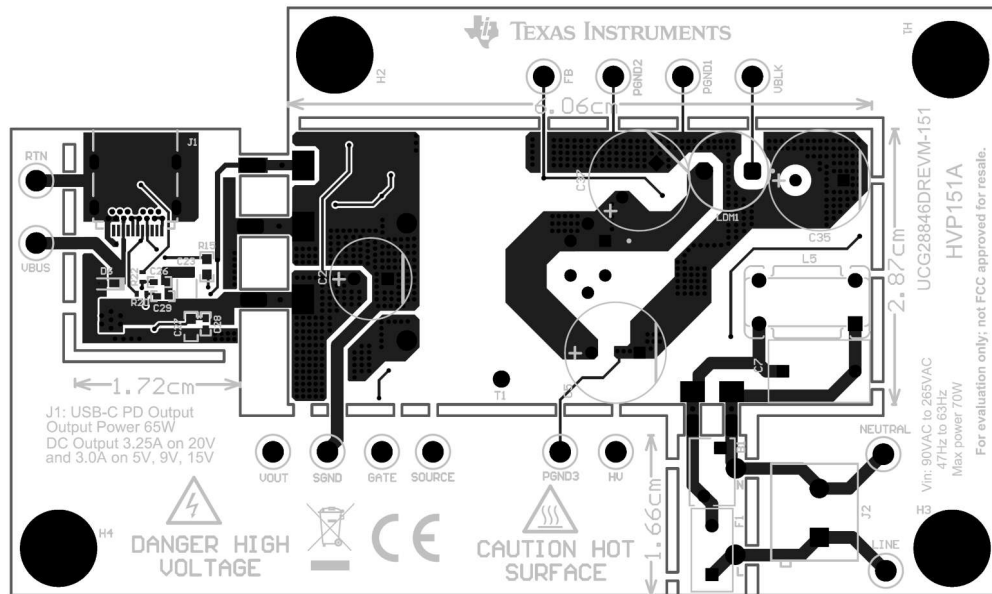


图 4-3. 顶层

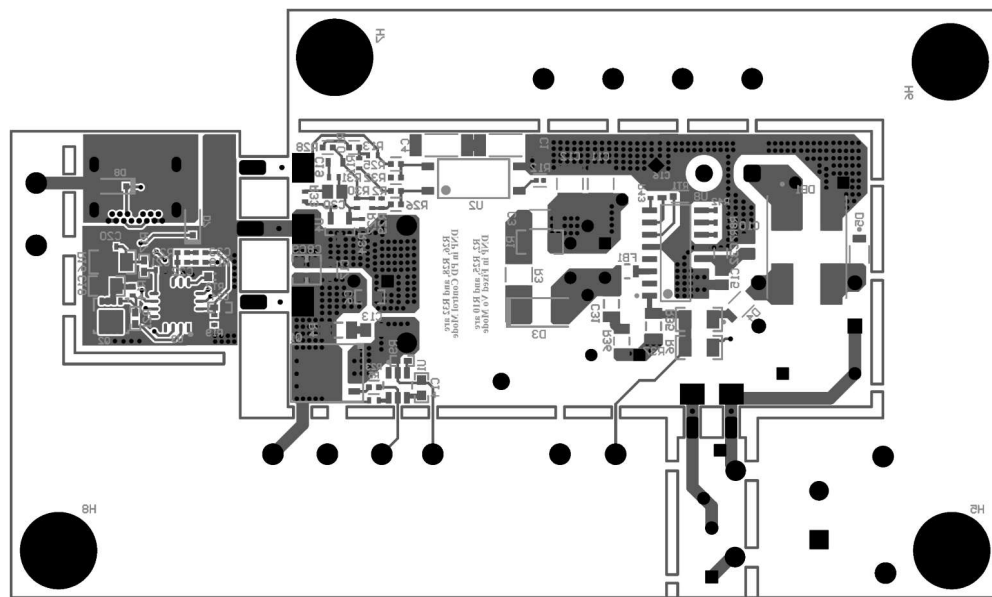


图 4-4. 底层

4.3 变压器详细信息

此设计使用 Renco Electronics 的 RLTI-1464 变压器。该变压器在漏电感和匝间电容之间实现了良好的平衡。下面提供了 RLTI-1464 变压器的详细信息。

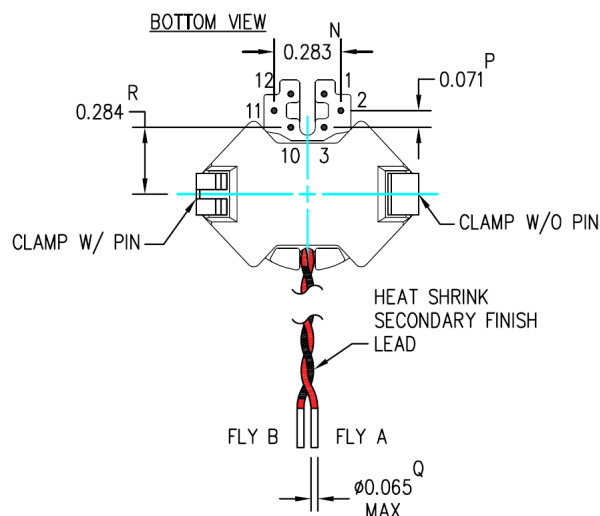


图 4-5. RLTI-1464 引脚配置

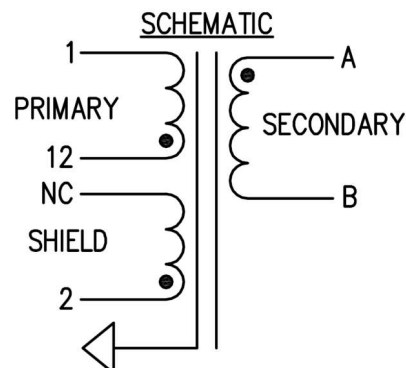


图 4-6. RLTI-1464 原理图

表 4-1. 25°C 时的变压器规格

参数	典型值	引脚/引线	测试条件
电感 (μH)	325, ±5%	1 - 12	所有其他引脚均为开路, 100kHz/0.1Vac
漏电感 (μH)	3.5 (最大值)	1 - 12	短接 A - B, 100kHz/0.1Vac
直流电阻 (Ω)	0.220, ±15%	1 - 12	
直流电阻 (Ω)	0.007 (最大值)	A - B	
电介质 (VAC, 60Hz)	3000Vac	1 - A	1mA, 60Hz, 1s
匝数比	6:1	(1-12):(A-B)	施加: 1.0V/10kHz 至 (12 - 1) Vout: (A-B) 0.167V

4.4 物料清单

本部分展示 UCG28846DREVM-151 的物料清单。

表 4-2. 物料清单

位号	数量	说明	器件型号	制造商
B1	1	470V 800A 压敏电阻 1 电路穿孔圆盘 5mm	B72205S2301K101	EPCOS
C1, C4	2	1500pF $\pm 10\%$ 250VAC 陶瓷电容器 X7R 1808 (公制 4520)	1808YA250152KJTSYX	Knowles Syfer
C2	1	820uF 25V $\pm 20\%$ 插件、D8xL14mm 铝制电解电容器 - 引脚型, 符合 ROHS	NPXD1401E821MF	Ymin
C3	1	电容, 陶瓷, 3.3nF, 630V, C0G, 5%, 焊盘 SMD, 1206 +125°C, 汽车 T/R	CGA5L4C0G2J332J160AA	TDK
C5、C35、C37	3	33uF 400V 500m Ω @100kHz 370mA@100kHz $\pm 20\%$ 插件式 D10xL15mm 铝电解电容器 - 引脚型, 符合 ROHS	87EC0493	KNSCHA
C6、C8、C9、C14	4	电容, 陶瓷, 0.47 μ F, 50V, +/-10%, X7R, 0603	C1608X7R1H474K080AC	TDK
C7	1	470nF $\pm 10\%$ X2 插件式, P = 7.5mm 抑制电容器, 符合 ROHS	MPX474K31B9KN20600	KNSCHA
C10、C15	2	电容, 陶瓷, 22 μ F, 10V, +/-20%, X7R, 0805	GRM21BZ71A226ME15L	Murata
C11、C12	2	电容, 陶瓷, 0.1 μ F, 630V, X7R 10%, 焊盘 SMD 1210 125C 低 ESR 医用 T/R	C1210C104KBRACU	KEMET
C16	1	电容, 陶瓷, 330pF, 50V, +/-5%, C0G/NP0, 0603	885012006060	Wurth Elektronik
C17	1	1 μ F $\pm 10\%$ 50V 陶瓷电容器 X7R 0603 (公制 1608)	CC0603KRX7R9BB105	Yageo Group
C18	1	电容器, 陶瓷, 10 μ F, 35V, +/- 10%, X5R, 0805	GMK212BBJ106KG-T	TAIYO YUDEN (太阳诱电)
C19	1	电容, 陶瓷, 1000pF, 50V, +/-5%, C0G/NP0, 0603	C0603C102J5GAC	Kemet
C20	1	电容, 陶瓷, 1000pF, 50V, +/-10%, X7R, 0402	885012205061	Wurth Elektronik
C21	1	电容, 陶瓷, 1 μ F, 6.3V, +/-20%, X7R, 0402	GRM155R70J105MA12D	Murata
C22	1	电容, 陶瓷, 0.022 μ F, 50V, +/-10%, X7R, AEC-Q200 1 级, 0402	CGA2B3X7R1H223K050BB	TDK
C23	1	电容, 陶瓷, 33 μ F, 25V, +/-20%, X5R, 1206	C3216X5R1E336M160AC	TDK
C24、C28	2	电容, 陶瓷, 0.1 μ F, 25V, +/-10%, X7R, 0402	GRM155R71E104KE14D	Murata
C26、C29	2	电容, 陶瓷, 220pF, 50V, +/-10%, X7R, 0402	GRM155R71H221KA01D	Murata
C27	1	电容, 陶瓷, 1 μ F, 25V, +/-10%, X7R, AEC-Q200 1 级, 0603	GCM188R71E105KA64D	Murata
C30	1	电容, 陶瓷, 0.022 μ F, 50V, +/-1%, C0G/NP0, 0805	C0805C223F5GACU	KEMET
C32	1	多层陶瓷电容器, 100nF, 50V, X7R $\pm 10\%$, 0402, 纸质 T/R	GRT155R71H104KE01D	Murata
C33	1	电容, 陶瓷, 3300pF, 100V, +/-10%, X7R, 0402	GRM155R72A332KA01D	Murata
D3	1	二极管, 超快速, 1000V, 1A, SMA	US1M-13-F	Diodes Inc.
D4、D5	2	二极管 800V 1A 表面贴装 SOD-123FL	SL1K	Diotec

表 4-2. 物料清单 (续)

位号	数量	说明	器件型号	制造商
D6	1	二极管, 肖特基, 40V, 0.2A, SOD-523	RB521SM-40T2R	ROHM
D7、D8	2	二极管, 齐纳, 5.1V, 400mW, SOD-323F	D3Z5V1BF-7	Diodes Inc.
DB1	1	桥接整流器、单相标准、600V 表面贴装 Z4-D	Z4DGP406L-HF	Comchip
F1	1	微型慢断保险丝, 3.15A, 350V, 径向引脚, 8.35 × 4 × 7.8mm, 热塑性盒装	0697W3150-01	百富电子 (Bel Fuse)
FB1	1	铁氧体磁珠, 100MHz 下为 30 Ω, 单功率线, 0805 (2012 公制), 8.5A, 4m Ω	BLM21SN300SN1D	Murata
FB, GATE, HV, LINE, SOURCE, VBLK, VBUS, VOUT	8	测试点, 通用, 白色, TH	5012	Keystone
H1、H2、H3、H4	4	#4-40 平头机用螺钉十字螺丝刀, 尼龙	NY PMS 440 0038 PH	结构紧固件
H5、H6、H7、H8	4	六角螺柱, 0.5"L #4-40, 尼龙	1902C	Keystone
J1	1	连接器, 插口, USB Type C, R/A	632723300011	Würth Elektronik
J2	1	端子块, 5.08mm, 2x1, 黄铜, TH	ED120/2DS	On Shore Technology Inc.
L5	1	耦合电感器, 1mH, 2A, 0.045 Ω, TH	744821201	Würth Elektronik
LDM1	1	WE-TI 径向引脚绕线电感, 尺寸 8095, 33uH, 2.5A, 0.066 Ω	7447720330	Würth Elektronik
NEUTRAL、PGND1、PGND2、PGND3、RTN、SGND	6	测试点, 多用途, 黑色, TH	5011	Keystone
Q1	1	MOSFET, N 沟道, 150V, 87A, PG-TDSON-8	BSC093N15NS5ATMA1	Infineon Technologies
Q2	1	MOSFET, N 沟道, 30V, 60A, DQG0008A (VSON-CLIP-8)	CSD17575Q3	德州仪器 (TI)
R1	1	电阻, 510k, 5%, 0.25W, AEC-Q200 0 级, 1206	CRCW1206510KJNEA	Vishay/Dale
R2、R10、R12、R23、R25	5	电阻厚膜, 0 Ω, 0.2W, 0402	CRCW04020000Z0EDHP	Vishay
R3	1	10 Ω ±5% 0.5W 1210 厚膜片上电阻, 符合 AEC-Q200 标准	RMCF1210JT10R0	Stackpole Electronics
R5	1	电阻, 511, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW0402511RFKED	Vishay/Dale
R6、R35	2	电阻, 0, 5%, 0.25W, AEC-Q200 0 级, 1206	CRCW12060000Z0EA	Vishay/Dale
R7	1	电阻, 17.8k Ω, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040217K8FKED	Vishay / Dale
R8	1	电阻, 28.7k Ω, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040228K7FKED	Vishay/Dale
R9、R30、R33	3	电阻, 100k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW0402100KFKED	Vishay / Dale
R11	1	电阻, 30.1k, 1%, 0.063W, 0402	CRCW040230K1FKED	Vishay / Dale
R13	1	电阻, 34.0k Ω, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040234K0FKED	Vishay / Dale

表 4-2. 物料清单 (续)

位号	数量	说明	器件型号	制造商
R14	1	电阻, 1.0M Ω , 5%, 0.063W, AEC-Q200 0 级, 0402	CRCW04021M00JNED	Vishay / Dale
R15	1	电阻, 1.0k, 5%, 0.25W, AEC-Q200 0 级, 0603	ESR03EZPJ102	ROHM
R16	1	电阻, 0.002, 1%, 1W, 1206	CSNL1206FT2L00	Stackpole Electronics Inc
R17	1	电阻, 5.11k, 1%, 0.063W, 0402	CRCW04025K11FKED	Vishay / Dale
R18	1	电阻, 49.9k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040249K9FKED	Vishay / Dale
R19	1	电阻, 0, 5%, 0.063W, AEC-Q200 0 级, 0402	CRCW04020000Z0ED	Vishay / Dale
R20、R22	2	电阻, 47.0, 1%, 0.063W, 0402	RK73H1ETTP47R0F	KOA Speer
R21、R27、R31	3	电阻, 10k, 5%, 0.063W, 0402	CRCW040210K0JNED	Vishay / Dale
R24	1	电阻, 2.00k, 0.1%, 0.063W, 0402	RG1005P-202-B-T5	Susumu
R29	1	电阻, 2.00k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW04022K00FKED	Vishay / Dale
R34	1	电阻, 26.1k Ω , 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040226K1FKED	Vishay / Dale
R42	1	电阻, 11.5k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040211K5FKED	Vishay / Dale
R43	1	电阻, 5.23k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW04025K23FKED	Vishay / Dale
RT1	1	NTC 热敏电阻 150k 0603 (公制 1608)	NT06155F4050B1F	Eaton
RT2	1	热敏电阻 NTC, 220k Ω , 5%, 0603	NCP18WM224J03RB	Murata
T1	1	反激式变压器	RLTI-1464	RENCO
U1	1	快速关断智能整流器	MP6908GJ-Z	Monolithic Power Systems
U2	1	光耦合器晶体管输出 5000Vrms 1 通道 6-SO	TLP383(GR-TPL,E	Toshiba Semiconductor and Storage
U3	1	USB PD/QC4/QC4+ 控制器	WT6636F	Weltrend
U4	1	电压基准, 可调/精密型, 2.5V 至 36V, 100mA, 3 引脚, SOT-23, T/R	ATL431AQDBZR	德州仪器 (TI)
U8	1	具有集成式 GaN 的自偏置高频 QR 反激式转换器	UCG28846-1DR	德州仪器 (TI)

5 其他信息

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 - 1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software
 - 1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.
2. *Limited Warranty and Related Remedies/Disclaimers:*
 - 2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.
 - 2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.
 - 2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGRADATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 Regulatory Notices:

3.1 United States

3.1.1 Notice applicable to EVMs not FCC-Approved:

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

3.2 Canada

3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/sds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html>

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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3.4 European Union

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive):*

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 EVM Use Restrictions and Warnings:

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 Safety-Related Warnings and Restrictions:

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. Disclaimers:

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8. *Limitations on Damages and Liability:*

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9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.
10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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最后更新日期：2025 年 10 月