

EVM User's Guide: UCG28824EVM-124

使用 **UCG28824EVM-124 45W 高密度 GaN 集成式准谐振反激式转换器**

说明

UCG28824EVM-124 是一款 45W 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。该 EVM 的用途是进行评估, 不是最终产品。UCG28824EVM-124 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 $45W$ 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 $5mm \times 5mm$ 封装的 UCG28824。

开始使用

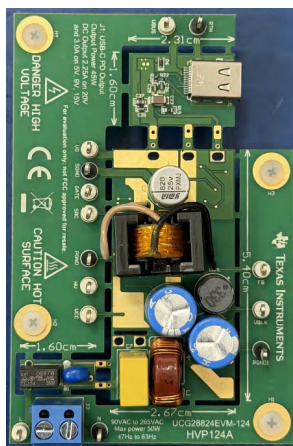
1. 在评估之前, 请先完整阅读和学习本用户指南。
2. 订购 [UCG28824EVM-124](#) 以进行评估 (如果符合步骤 1 的要求)。
3. 根据用户指南说明设置和测试 [UCG28824EVM-124](#)。

特性

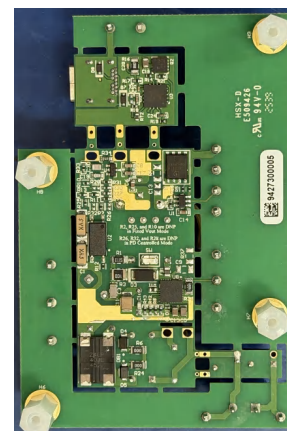
- 整个输入电压范围内满载运行时的效率为 93-95%
- 通过 $140kHz$ 最大开关频率, 实现 $2W/cm^3$ ($5.4cm \times 2.67cm \times 1.6cm$) 功率密度
- 通过集成自偏置和无辅助检测、集成电流检测、集成高压启动和集成 X 电容器放电, 实现最低 BOM 成本
- 全面的保护特性, 包括 OVP、OTP、短路和过流保护以及欠压/掉电保护
- USB-C 输出可用于对适配器、笔记本电脑充电器、USB 墙壁插座等终端设备进行全面系统级评估

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



UCG28824EVM-124 (顶视图)



UCG28824EVM-124 (底视图)

1 评估模块概述

1.1 简介

UCG28824EVM-124 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 UCG28824 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、波形和传导 EMI 性能。

1.2 套件内容

- 45W 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/2.25A、15V/3.00A、9V/3.00A 和 5V/3.00A	45W
	固定输出电压	5V - 15V/3A 和 15V-24V/45W	

1.4 器件信息

UCG28824 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 45W 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。UCG28824 采用业内较早推出的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。UCG28824 支持在低压线路输入条件以及高达 90W（45W 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。UCG28824 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

- 保持工作区整洁有序。
- 每次电路通电时，都必须由具有资质的观察员在场监督。
- 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。
- 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。
- 使用稳定且不导电的工作台。
- 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。

- 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。
- 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。
- 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

- 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

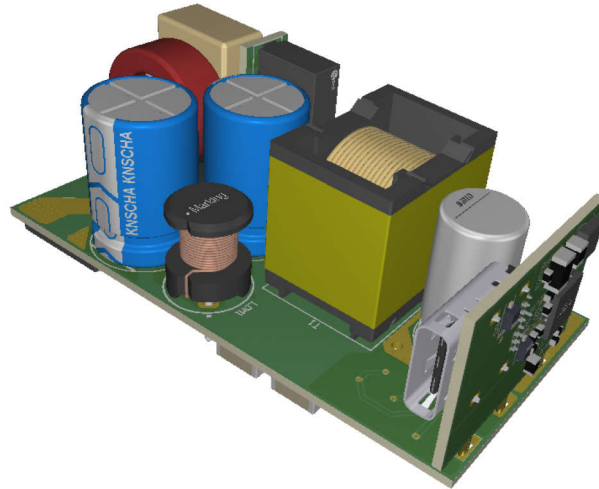


图 2-1. 高功率密度配置

2.1.1 在具有 USB-C PD 通信功能的负载上使用该 EVM

UCG28824EVM-124 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。要从 5V、9V 和 15V 获取满载电流 3.00A，可以使用标准 USB-C 电缆。要在 20V 输出下获得 3.25A 电流，必须使用“电子标度”USB-C® 电缆。

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，UCG28824EVM-124 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。UCG28824EVM-124 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”一节中找到。在固定输出电压控制模式下，该转换器可在 5V 至 15V 输出时提供额定 3A 电流，在 15V 至 24V 输出时提供额定 45W 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		8/32		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		260		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		390		
输出特性						
V_{OUT}	输出电压	$I_{OUT} = 0A$ 至 $1.875A$, 已启用固定 V_{OUT} 控制器		24		V
		$I_{OUT} = 0A$ 至 $2.25A$, 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	$V_{OUT} = 24V$		1.875		A
		$V_{OUT} = 20V$		2.250		A
		$V_{OUT} = 5V/9V/12V/15V$		3.000		A
V_{OUT_pp}	$V_{IN} = 115V/230V$ 下的输出电压纹波	$V_{OUT} = 24V$, $I_{OUT} = 0A$ 至 $1.875A$		45		mVpp
		$V_{OUT} = 20V$, $I_{OUT} = 0A$ 至 $2.25A$		98		mVpp
		$V_{OUT} = 15V$, $I_{OUT} = 0A$ 至 $3A$		89		mVpp
		$V_{OUT} = 12V$, $I_{OUT} = 0A$ 至 $3A$		108		mVpp
		$V_{OUT} = 9V$, $I_{OUT} = 0A$ 至 $3A$		136		mVpp
		$V_{OUT} = 5V$, $I_{OUT} = 0A$ 至 $3A$		115		mVpp
$V_{OUT_Δ}$	由于负载升压/降压而产生的 V_{OUT} 偏差 (在 100Hz 速率下, I_{OUT} 阶跃在 0 至 100% 负载之间变化)	$V_{OUT} = 24V$		-260/120		mV
		$V_{OUT} = 20V$		-440/330		mV
		$V_{OUT} = 15V$		-510/360		mV
		$V_{OUT} = 12V$		-410/120		mV
		$V_{OUT} = 9V$		-450/380		mV
		$V_{OUT} = 5V$		-440/460		mV
P_{OPP}	过功率保护阈值	$V_{IN} = 90V$ 至 $264V_{RMS}$		100		W
系统特性						

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
η	$V_{IN} = 115V/230V$ 下的满载效率	$V_{OUT} = 24V, I_{OUT} = 1.875A$		94.50/95.17		%
		$V_{OUT} = 20V, I_{OUT} = 2.25A$		94.44/94.96		%
		$V_{OUT} = 15V, I_{OUT} = 3A$		94.16/94.56		%
		$V_{OUT} = 12V, I_{OUT} = 3A$		93.81/94.31		%
		$V_{OUT} = 9V, I_{OUT} = 3A$		93.66/93.56		%
		$V_{OUT} = 5V, I_{OUT} = 3A$		92.36/91.62		%
η	$V_{IN} = 115V/230V^{(1)}$ 下的 4 点平均效率	$V_{OUT} = 24V$ (CoC 2 级, 87.7%)		94.41/94.01		%
		$V_{OUT} = 20V$ (CoC 2 级, 87.7%)		94.49/94.29		%
		$V_{OUT} = 15V$ (CoC 2 级, 87.7%)		94.33/94.06		%
		$V_{OUT} = 12V$ (CoC 2 级, 86.8%)		94.12/93.19		%
		$V_{OUT} = 9V$ (CoC 2 级, 85.4%)		93.86/92.86		%
		$V_{OUT} = 5V$ (CoC 2 级, 81.8%)		92.57/91.03		%
η	$V_{IN} = 115V/230V$ 、10% 负载下的效率	$V_{OUT} = 24V$ (CoC 2 级, 77.8%)		92.24/90.10		%
		$V_{OUT} = 20V$ (CoC 2 级, 77.8%)		93.64/92.48		%
		$V_{OUT} = 15V$ (CoC 2 级, 77.8%)		94.15/92.88		%
		$V_{OUT} = 12V$ (CoC 2 级, 77.1%)		92.97/90.10		%
		$V_{OUT} = 9V$ (CoC 2 级, 75.9%)		93.67/91.30		%
		$V_{OUT} = 5V$ (CoC 2 级, 72.5%)		92.25/88.73		
T_{AMB}	工作环境温度	$V_{IN} = 90V$ 至 $264V_{RMS}$, $I_{OUT} = 0A$ 至 $3.00A$ (5V/9V/15V), 2.25A (20V) 或 1.875A (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 UCG28824EVM-124 的测试设置图

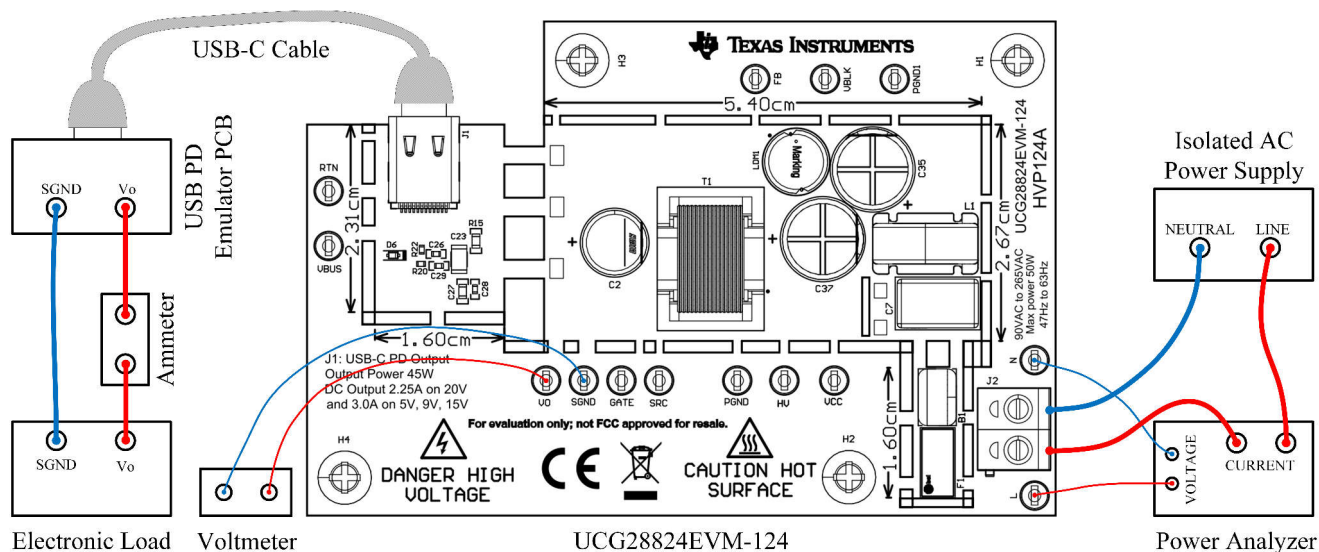


图 3-1. 使用 USB-C PD 负载的 UCG28824EVM-124 测试设置图

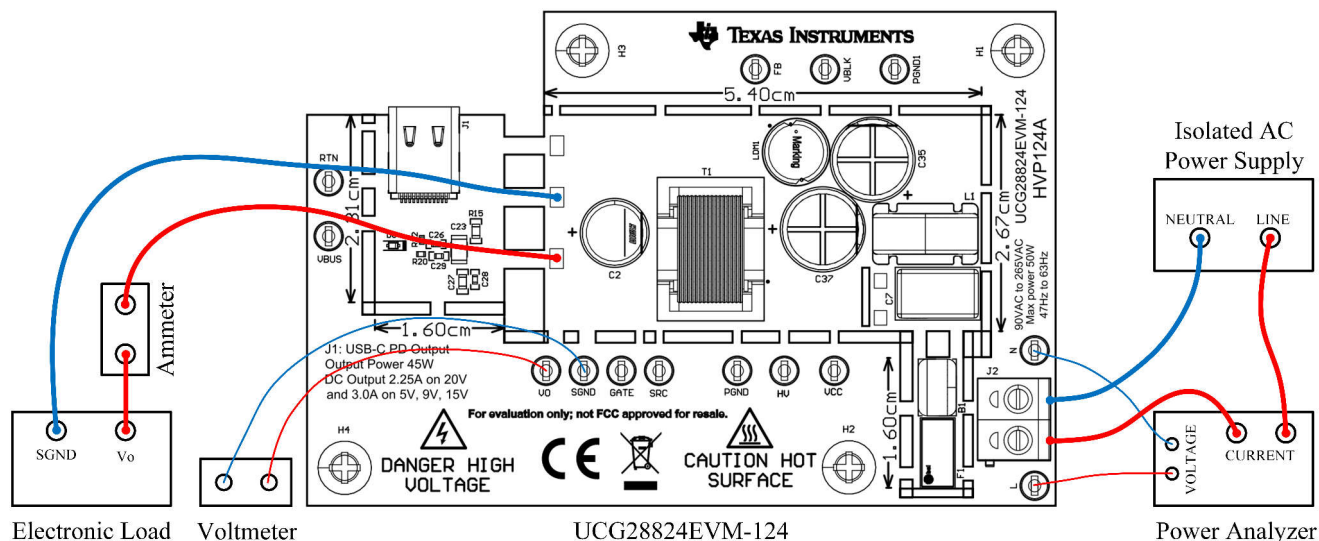
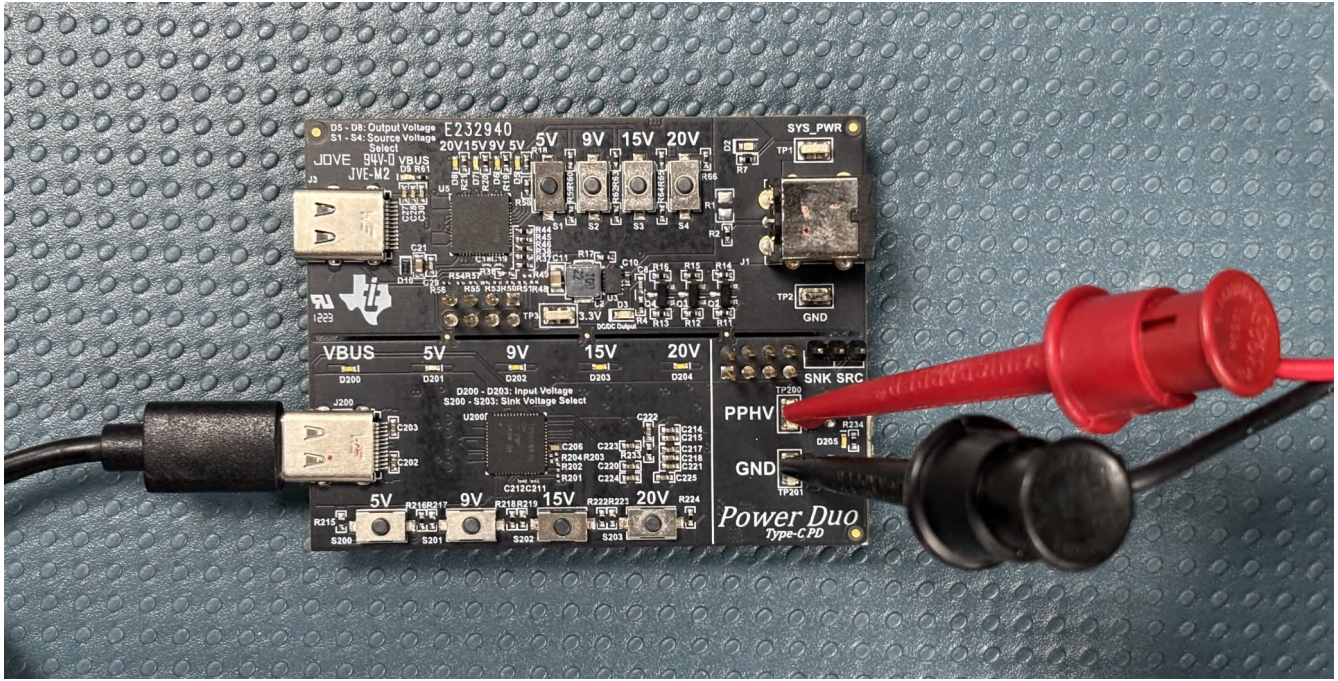


图 3-2. 使用非 USB-C PD 负载的 UCG28824EVM-124 测试设置图

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
L	交流输入的测试点 - 线路
N	交流输入的测试点 - 中性
PGND、PGND1	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
VCC	VCC 引脚的测试点
HV	HV 引脚的测试点
SRC	SR FET 源极测试点
GATE	SR FET 栅极测试点
SGND	次级接地测试点
VO	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	4.94	23.99	0.188	4.50	10	90.99%	93.85%
90	12.04	23.99	0.470	11.28	25	93.65%	
90	23.93	23.99	0.939	22.53	50	94.15%	
90	35.90	23.99	1.406	33.73	75	93.96%	
90	48.03	23.99	1.875	44.98	100	93.65%	
115	5.08	24.05	0.195	4.69	10	92.24%	94.41%
115	12.16	24.05	0.475	11.42	25	93.95%	
115	23.97	24.05	0.943	22.68	50	94.63%	
115	35.84	24.05	1.409	33.89	75	94.54%	
115	47.79	24.05	1.878	45.17	100	94.50%	
230	5.23	24.06	0.196	4.72	10	90.10%	94.01%
230	12.44	24.05	0.475	11.42	25	91.82%	
230	24.08	24.05	0.943	22.68	50	94.17%	
230	35.72	24.04	1.410	33.90	75	94.89%	
230	47.44	24.04	1.878	45.15	100	95.17%	
264	5.14	23.99	0.188	4.51	10	87.70%	93.46%
264	12.41	23.99	0.470	11.28	25	90.86%	
264	24.07	23.99	0.938	22.50	50	93.48%	
264	35.68	23.99	1.406	33.70	75	94.47%	
264	47.32	23.99	1.875	44.96	100	95.02%	
CoC 2 级、4 点平均值							87.70%
CoC 2 级，10% 负载							77.83%

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	4.98	19.94	0.225	4.65	10	93.50%	94.00%
90	12.12	19.94	0.564	11.41	25	94.15%	
90	24.02	19.93	1.126	22.61	50	94.14%	
90	35.98	19.94	1.688	33.83	75	94.02%	
90	48.06	19.94	2.250	45.03	100	93.71%	
115	4.97	19.95	0.225	4.66	10	93.64%	94.49%
115	12.11	19.95	0.564	11.42	25	94.27%	
115	23.90	19.94	1.126	22.62	50	94.63%	
115	35.76	19.94	1.688	33.83	75	94.60%	
115	47.68	19.94	2.250	45.03	100	94.44%	
230	5.04	19.95	0.225	4.66	10	92.48%	94.29%
230	12.27	19.95	0.564	11.42	25	93.09%	
230	24.00	19.95	1.127	22.65	50	94.36%	
230	35.71	19.95	1.688	33.84	75	94.76%	
230	47.42	19.94	2.250	45.03	100	94.96%	
264	5.08	19.95	0.225	4.66	10	91.71%	93.83%
264	12.35	19.95	0.564	11.42	25	92.47%	
264	24.16	19.95	1.126	22.63	50	93.69%	
264	35.86	19.95	1.688	33.84	75	94.38%	
264	47.55	19.95	2.250	45.06	100	94.76%	
CoC 2 级、4 点平均值							87.70%
CoC 2 级, 10% 负载							77.83%

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	4.98	15.00	0.300	4.61	10	93.78%	93.71%
90	12.12	15.00	0.750	11.36	25	94.17%	
90	24.02	15.00	1.501	22.62	50	94.03%	
90	35.98	15.00	2.250	33.86	75	93.58%	
90	48.06	15.00	3.000	45.11	100	93.06%	
115	4.91	15.00	0.301	4.62	10	94.15%	94.33%
115	12.05	15.00	0.750	11.36	25	94.29%	
115	23.93	15.00	1.500	22.61	50	94.47%	
115	35.86	15.00	2.250	33.86	75	94.40%	
115	47.90	15.00	3.000	45.11	100	94.16%	
230	4.98	15.01	0.301	4.63	10	92.88%	94.06%
230	12.21	15.01	0.751	11.38	25	93.20%	
230	24.05	15.00	1.501	22.62	50	94.06%	
230	35.86	15.00	2.250	33.86	75	94.42%	
230	47.70	15.00	3.000	45.11	100	94.56%	
264	5.02	15.01	0.301	4.63	10	92.06%	93.66%
264	12.30	15.01	0.750	11.37	25	92.40%	
264	24.14	15.00	1.501	22.62	50	93.70%	
264	36.01	15.00	2.250	33.86	75	94.02%	
264	47.73	15.00	3.001	45.12	100	94.53%	
CoC 2 级、4 点平均值							87.70%
CoC 2 级, 10% 负载							77.83%

3.3.4 12Vout 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	3.96	12.10	0.305	3.69	10	93.25%	93.41%
90	9.72	12.10	0.755	9.13	25	94.00%	
90	19.41	12.10	1.504	18.19	50	93.76%	
90	29.17	12.10	2.252	27.25	75	93.40%	
90	39.25	12.10	3.001	36.31	100	92.50%	
115	3.97	12.10	0.305	3.69	10	92.97%	94.12%
115	9.71	12.10	0.755	9.13	25	94.08%	
115	19.30	12.10	1.504	18.20	50	94.31%	
115	28.92	12.10	2.253	27.26	75	94.28%	
115	38.72	12.10	3.002	36.33	100	93.81%	
230	4.10	12.10	0.305	3.69	10	90.10%	93.19%
230	10.00	12.10	0.755	9.13	25	91.36%	
230	19.53	12.10	1.504	18.19	50	93.12%	
230	29.00	12.10	2.253	27.26	75	93.98%	
230	38.51	12.10	3.002	36.32	100	94.31%	
264	4.14	12.10	0.306	3.70	10	89.32%	92.53%
264	10.12	12.10	0.755	9.13	25	90.26%	
264	19.70	12.09	1.504	18.19	50	92.34%	
264	29.14	12.10	2.252	27.24	75	93.46%	
264	8.62	12.10	3.002	36.32	100	94.05%	
CoC 2 级、4 点平均值							86.83%
CoC 2 级, 10% 负载							77.11%

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	2.95	9.01	0.301	2.76	10	93.68%	93.37%
90	7.27	9.01	0.750	6.81	25	93.68%	
90	14.49	9.01	1.500	13.57	50	93.61%	
90	21.76	9.01	2.250	20.32	75	93.39%	
90	29.15	9.00	3.000	27.05	100	92.81%	
115	2.95	9.01	0.301	2.76	10	93.67%	93.86%
115	7.25	9.01	0.751	6.82	25	93.97%	
115	14.44	9.01	1.501	13.57	50	93.99%	
115	21.66	9.01	2.250	20.32	75	93.82%	
115	28.92	9.01	3.001	27.09	100	93.66%	
230	3.03	9.01	0.301	2.76	10	91.30%	92.86%
230	7.40	9.01	0.750	6.81	25	92.04%	
230	14.66	9.01	1.501	13.57	50	92.59%	
230	21.77	9.00	2.250	20.30	75	93.24%	
230	28.92	9.00	3.001	27.06	100	93.56%	
264	3.07	9.01	0.301	2.76	10	90.10%	92.25%
264	7.47	9.01	0.751	6.82	25	91.28%	
264	14.78	9.01	1.500	13.57	50	91.77%	
264	21.89	9.01	2.250	20.32	75	92.83%	
264	29.06	9.00	3.001	27.06	100	93.11%	
CoC 2 级、4 点平均值							85.42%
CoC 2 级, 10% 负载							75.86%

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	1.65	4.98	0.301	1.52	10	92.43%	92.30%
90	4.05	4.98	0.750	3.75	25	92.60%	
90	8.08	4.97	1.500	7.48	50	92.56%	
90	12.15	4.97	2.250	11.20	75	92.21%	
90	16.24	4.97	3.000	14.92	100	91.84%	
115	1.65	4.98	0.301	1.52	10	92.25%	92.57%
115	4.05	4.97	0.750	3.75	25	92.62%	
115	8.07	4.97	1.501	7.49	50	92.73%	
115	12.10	4.97	2.250	11.20	75	92.56%	
115	16.16	4.97	3.000	14.92	100	92.36%	
230	1.71	4.98	0.301	1.52	10	88.73%	91.03%
230	4.16	4.97	0.751	3.76	25	90.45%	
230	8.24	4.97	1.500	7.48	50	90.72%	
230	12.27	4.97	2.251	11.21	75	91.34%	
230	16.28	4.97	3.000	14.92	100	91.62%	
264	1.75	4.98	0.301	1.52	10	87.07%	90.11%
264	4.21	4.98	0.751	3.76	25	89.31%	
264	8.34	4.97	1.501	7.49	50	89.78%	
264	12.42	4.97	2.250	11.21	75	90.25%	
264	16.39	4.97	3.000	14.93	100	91.10%	
CoC 2 级、4 点平均值							81.84%
CoC 2 级, 10% 负载							72.48%

3.3.7 效率典型结果

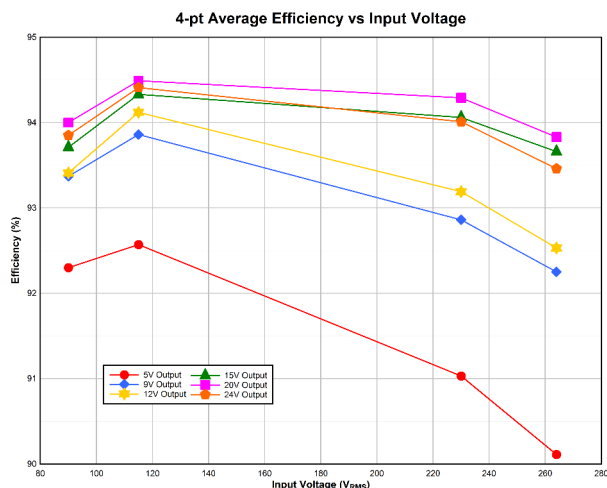


图 3-4. 4 点平均效率与输入电压间的关系

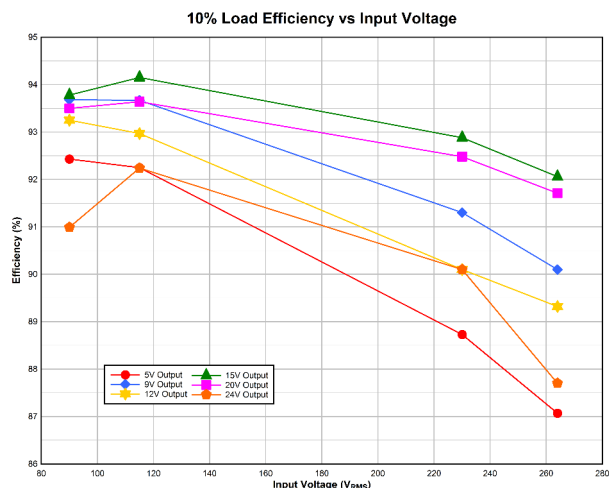


图 3-5. 10% 负载效率与输入电压间的关系

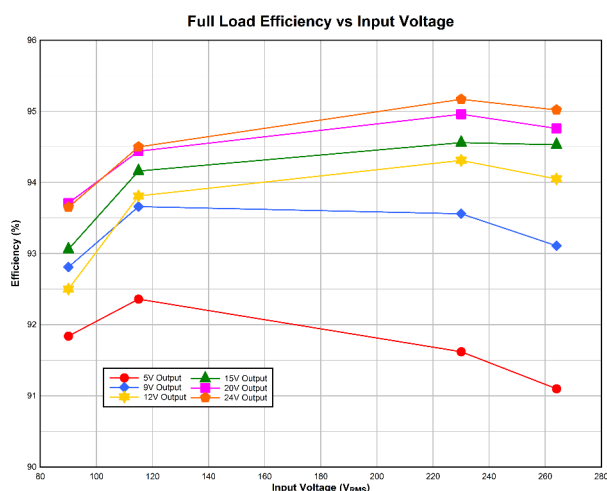


图 3-6. 满负载效率与输入电压间的关系

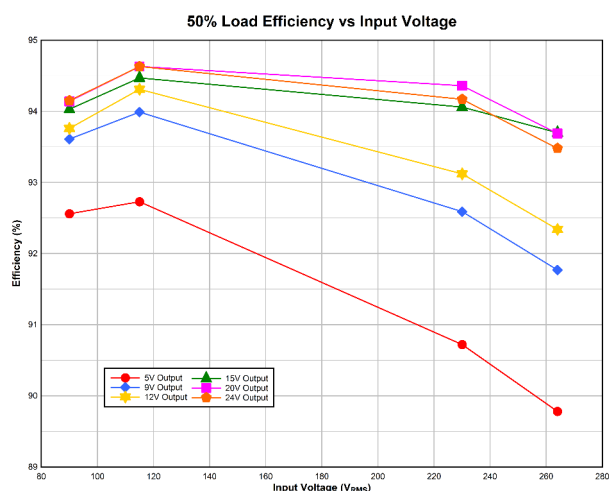


图 3-7. 50% 负载效率与输入电压

3.3.8 输出特性

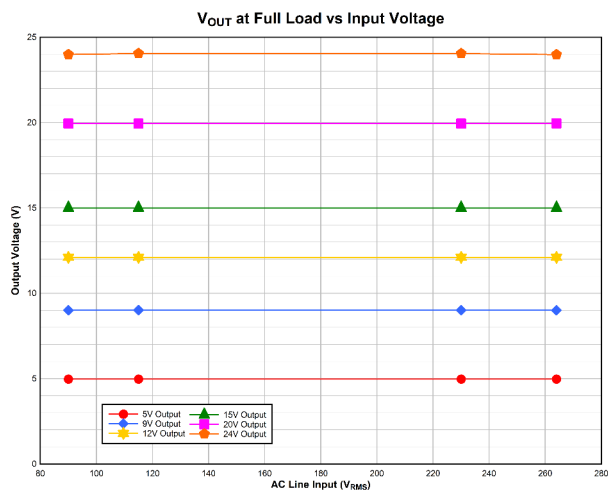


图 3-8. 满负载条件下的 V_{OUT} 与输入电压间的关系

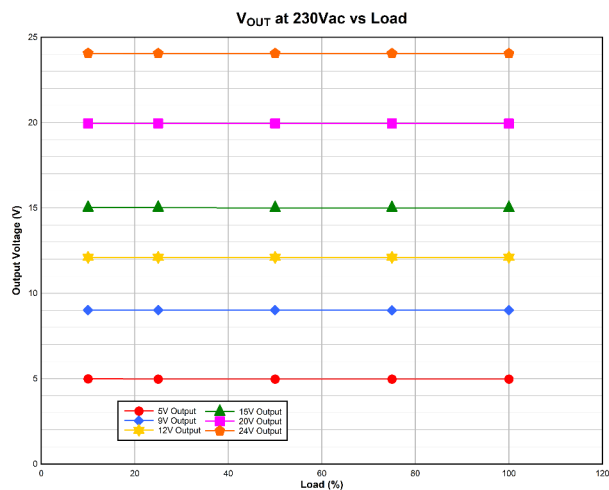


图 3-9. V_{OUT} 与输出电流间的关系

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。

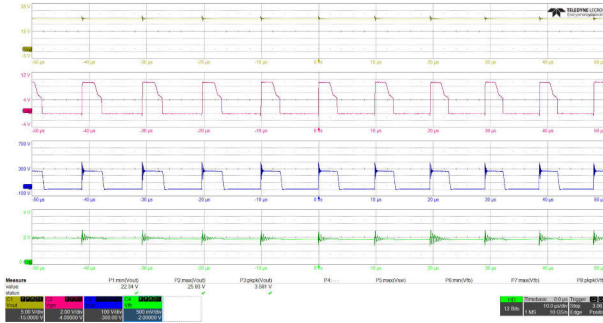


图 3-10. Vin = 90Vac , Vout = 24V

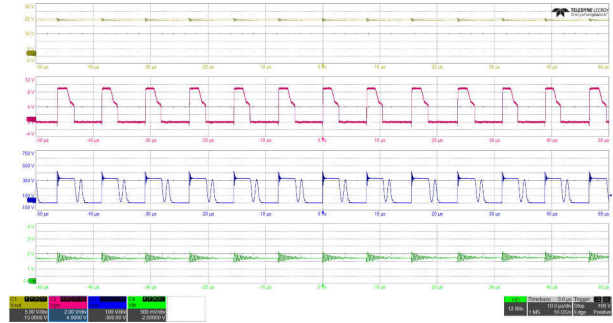


图 3-11. Vin = 115Vac , Vout = 24V

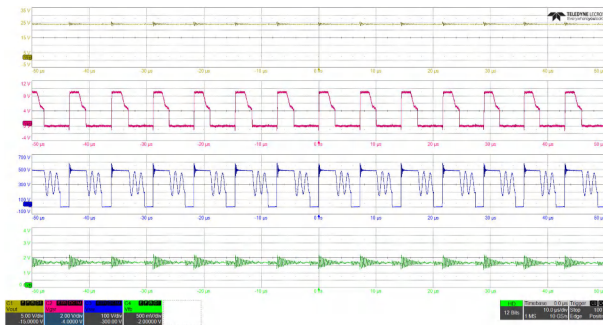


图 3-12. Vin = 230Vac , Vout = 24V

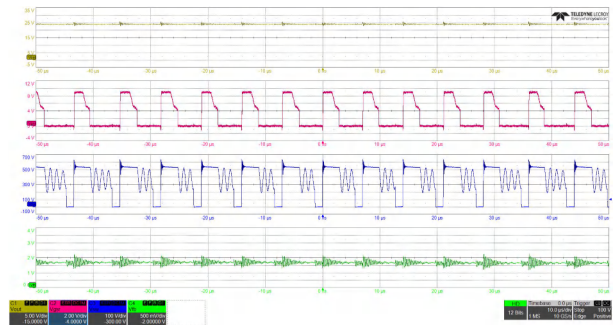


图 3-13. Vin = 264Vac , Vout = 24V



图 3-14. Vin = 90Vac , Vout = 20V



图 3-15. Vin = 115Vac , Vout = 20V



图 3-16. Vin = 230Vac , Vout = 20V



图 3-17. Vin = 264Vac , Vout = 20V

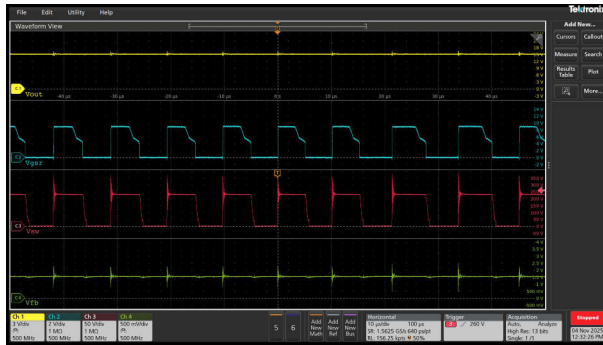


图 3-18. $V_{in} = 90\text{Vac}$, $V_{out} = 15\text{V}$



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. $V_{in} = 90V_{ac}$, $V_{out} = 9V$

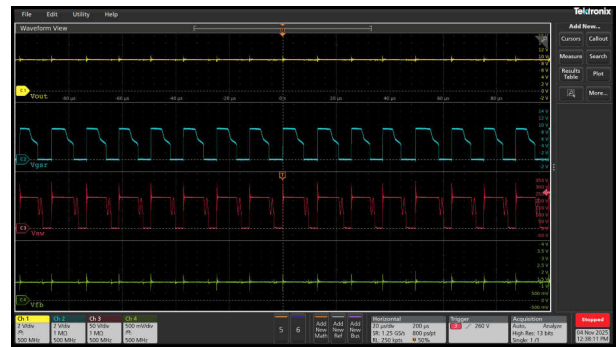


图 3-27. $V_{in} = 115V_{ac}$, $V_{out} = 9V$



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



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

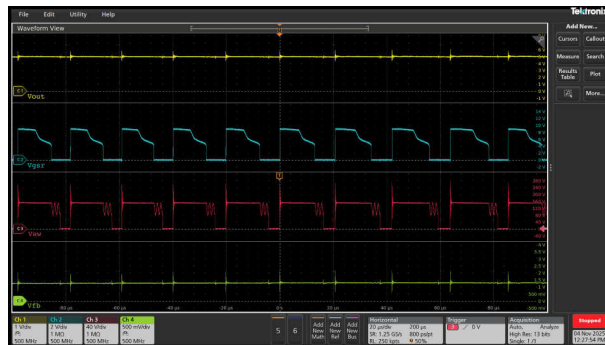


图 3-30. $V_{in} = 90V_{ac}$, $V_{out} = 5V$

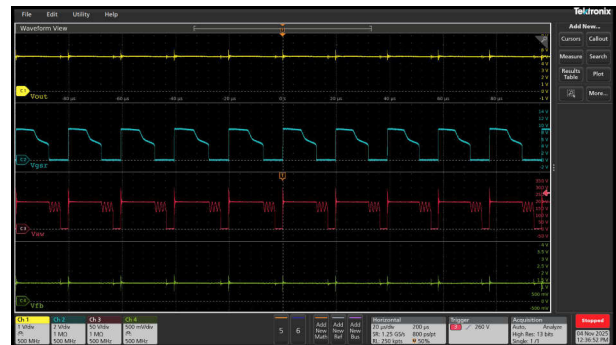


图 3-31. $V_{in} = 115V_{ac}$, $V_{out} = 5V$

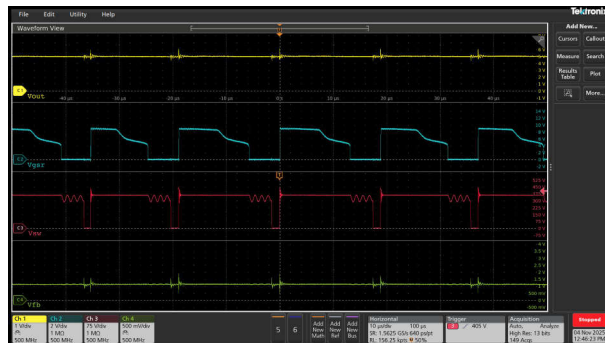


图 3-32. $V_{in} = 230V_{ac}$, $V_{out} = 5V$



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

3.3.10 开关频率与负载

本节展示了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/1W (250kHz 突发频率/Vfb - 0.29V)

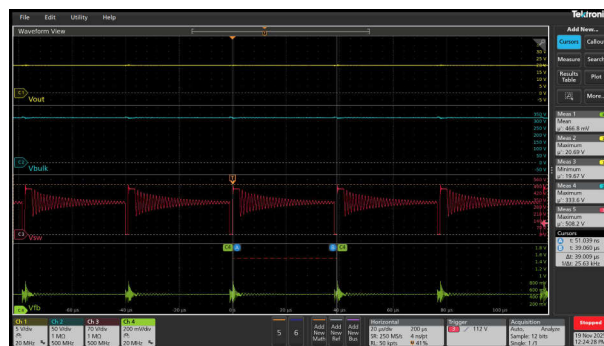


图 3-35. 230Vac/4.3W (25kHz 开关频率/频率 - 折返模式/Vfb - 0.47V)



图 3-36. 230Vac/12W (68kHz 频率/Vfb - 0.76V)

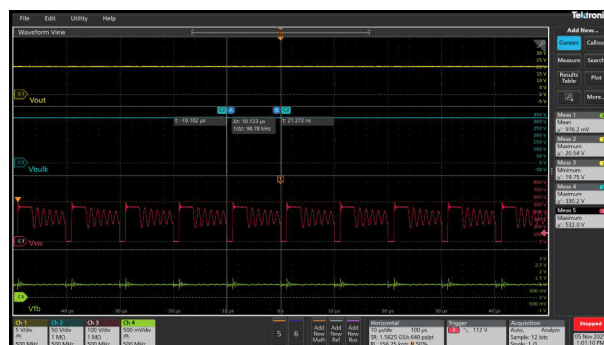


图 3-37. 230Vac/18W (99kHz 频率/Vfb - 0.98V)

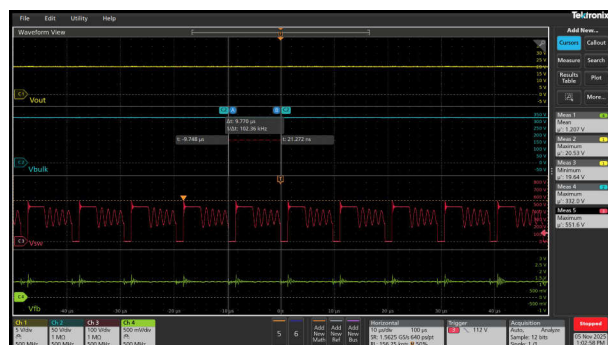


图 3-38. 230Vac/30W (102kHz 频率/Vfb - 1.21V)



图 3-39. 230Vac/45W (128kHz 频率/Vfb - 1.26V)

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。

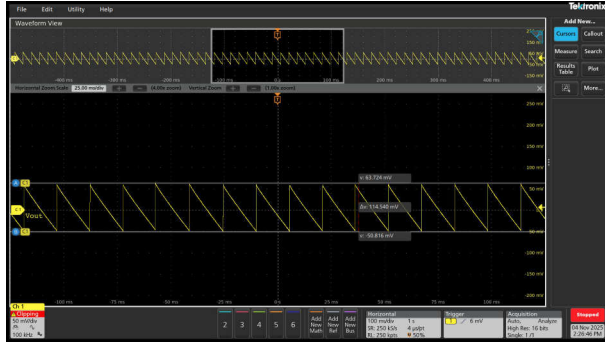


图 3-40. $V_{OUT} = 5V$ 且无负载时的典型纹波电压 (115mVpp)

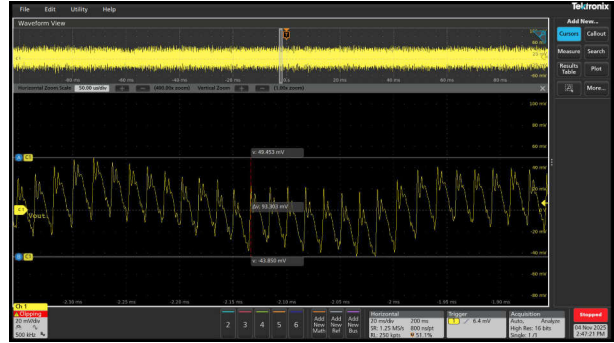


图 3-41. $V_{OUT} = 5V$ 且满负载时的典型纹波电压 (93mVpp)

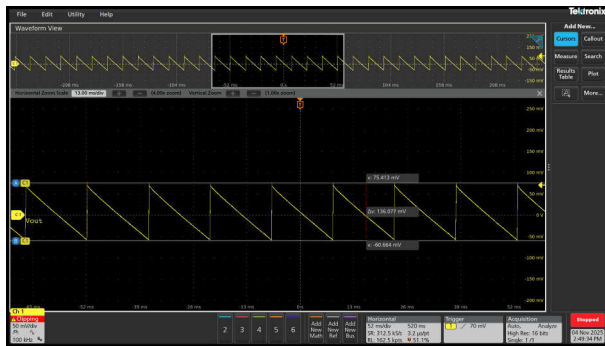


图 3-42. $V_{OUT} = 9V$ 且无负载时的典型纹波电压 (136mVpp)

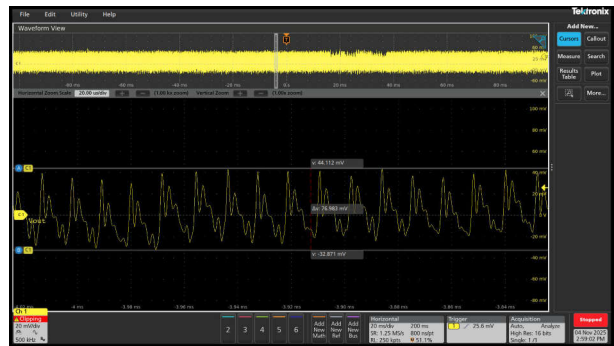


图 3-43. $V_{OUT} = 9V$ 且满负载时的典型纹波电压 (77mVpp)

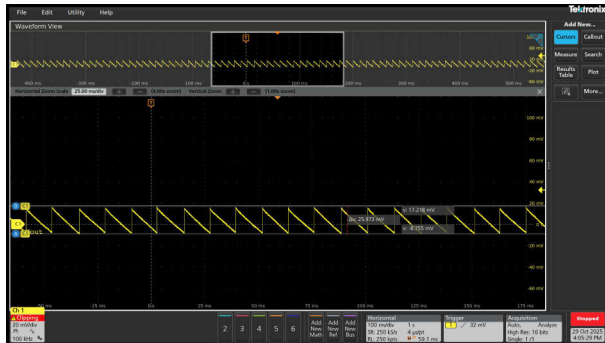


图 3-44. $V_{OUT} = 12V$ 且无负载时的典型纹波电压 (26mVpp)

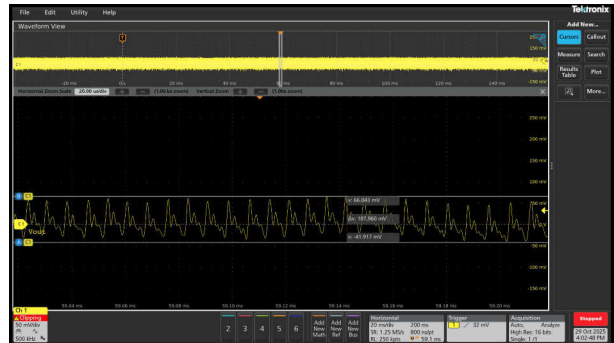


图 3-45. $V_{OUT} = 12V$ 且满负载时的典型纹波电压 (108mVpp)

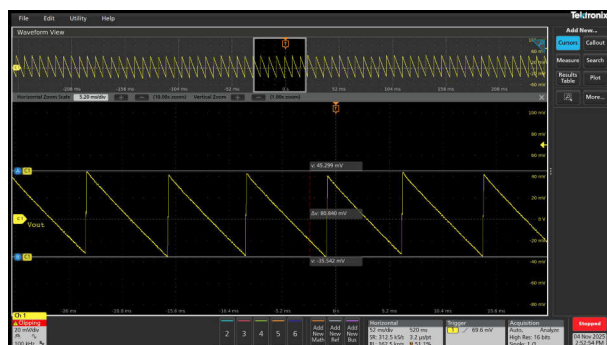


图 3-46. $V_{OUT} = 15V$ 且无负载时的典型纹波电压 (89mVpp)

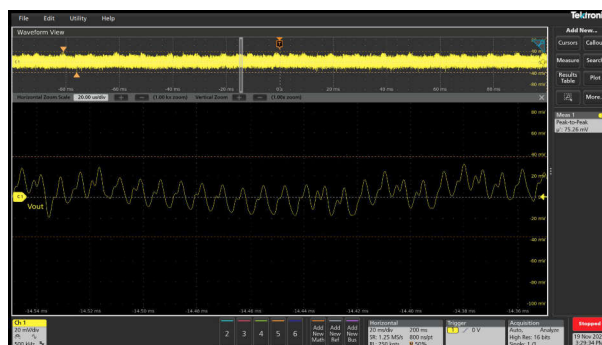


图 3-47. $V_{OUT} = 15V$ 且满负载时的典型纹波电压 (75mVpp)

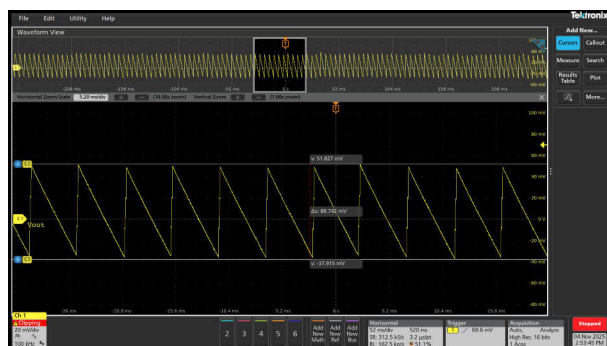


图 3-48. $V_{OUT} = 20V$ 且无负载时的典型纹波电压 (90mVpp)

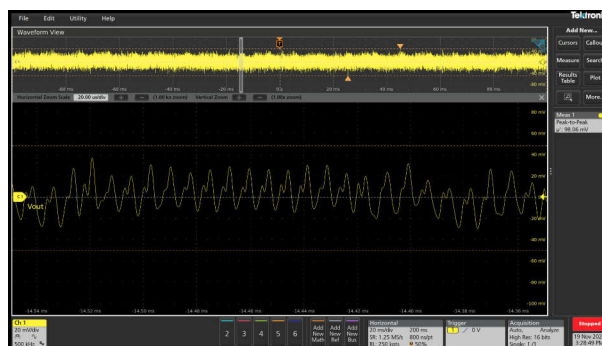


图 3-49. $V_{OUT} = 20V$ 且满负载时的典型纹波电压 (98mVpp)

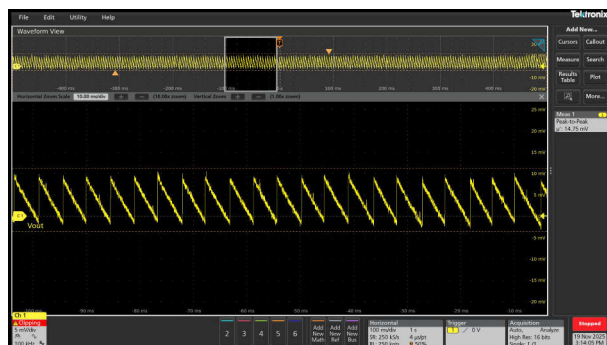


图 3-50. $V_{OUT} = 24V$ 且无负载时的典型纹波电压 (15mVpp)

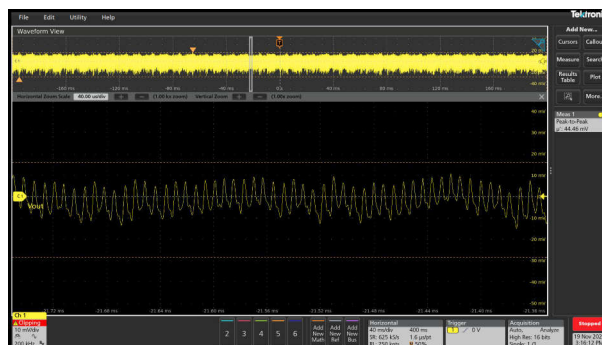


图 3-51. $V_{OUT} = 24V$ 且满负载时的典型纹波电压 (45mVpp)

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 0% 到 100% 之间，频率为 100Hz，变化速率为 $2.5\text{A}/\mu\text{s}$ 。

Ch1 - 输出电压 (交流耦合)，Ch2 - 输出电流。

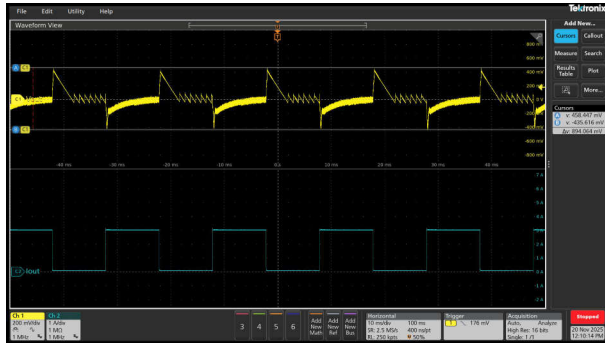


图 3-52. $V_{\text{OUT}} = 5\text{V}$ 过冲/下冲= $460\text{mV}/-440\text{mV}$ 条件下的负载瞬态响应

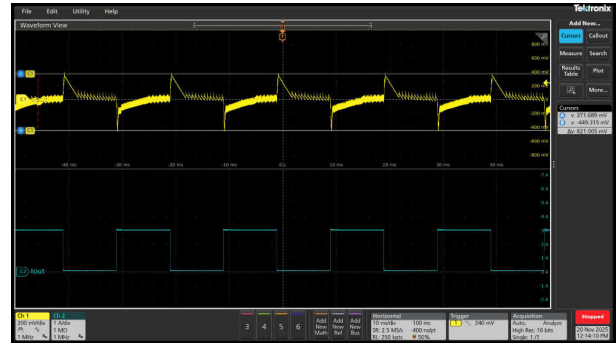


图 3-53. $V_{\text{OUT}} = 9\text{V}$ 过冲/下冲= $380\text{mV}/-450\text{mV}$ 条件下的瞬态响应

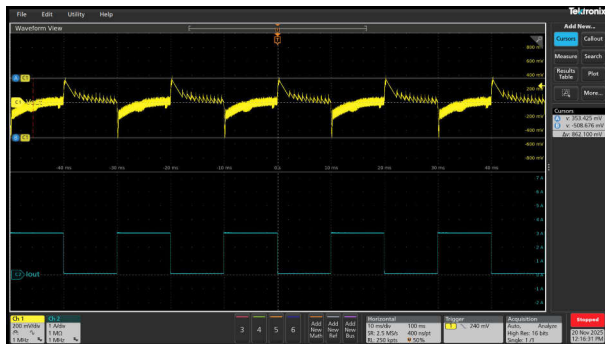


图 3-54. $V_{\text{OUT}} = 15\text{V}$ 过冲/下冲= $360\text{mV}/-510\text{mV}$ 条件下的瞬态响应

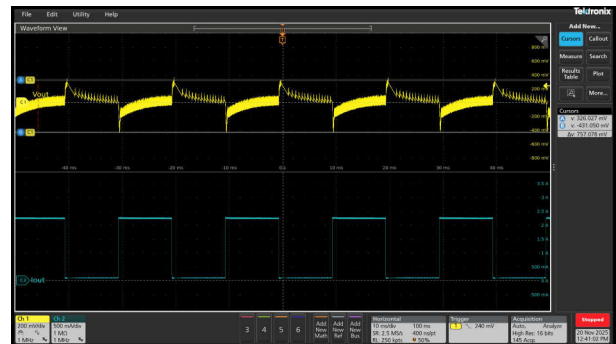


图 3-55. $V_{\text{OUT}} = 20\text{V}$ 过冲/下冲= $330\text{mV}/-440\text{mV}$ 条件下的瞬态响应

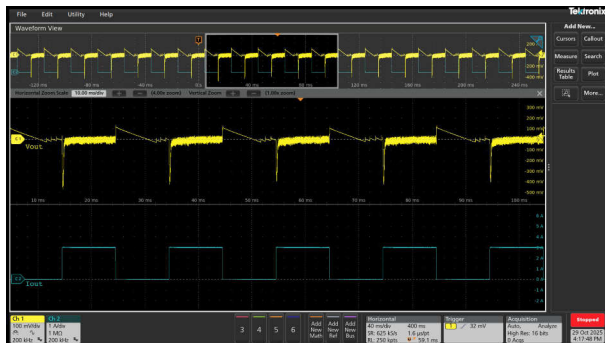


图 3-56. $V_{\text{OUT}} = 12\text{V}$ 过冲/下冲= $120\text{mV}/-410\text{mV}$ 条件下的瞬态响应

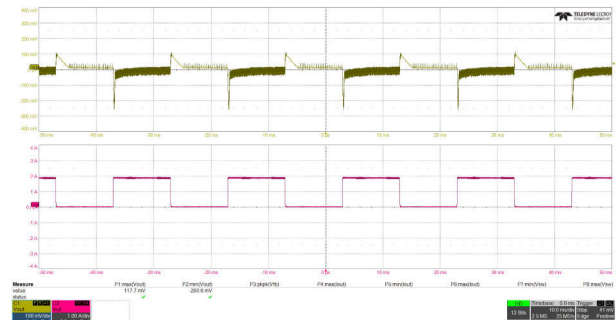


图 3-57. $V_{\text{OUT}} = 24\text{V}$ 过冲/下冲= $120\text{mV}/-260\text{mV}$ 条件下的瞬态响应

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

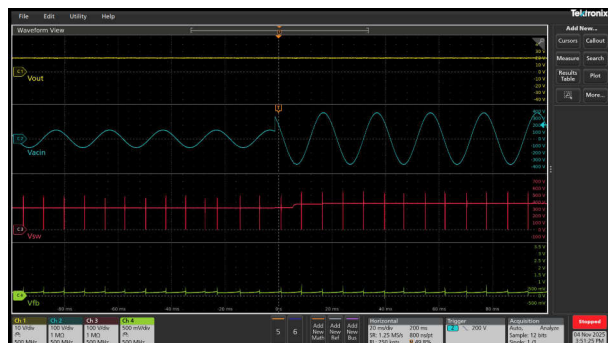


图 3-58. 20V 空载条件下从 90Vac 到 264Vac 的线路瞬态

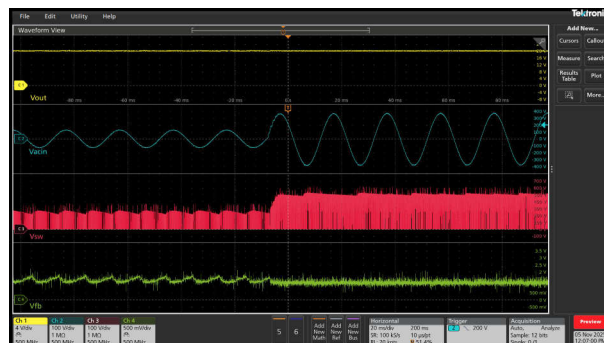


图 3-59. 20V 满负载条件下从 90Vac 到 264Vac 的线路瞬态

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 5.1A 的峰值短期过载持续 1ms 时，输出电压降至 19.2V。当施加 4.5A 的峰值短期过载持续 2ms 时，输出电压降至 19.3V。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。

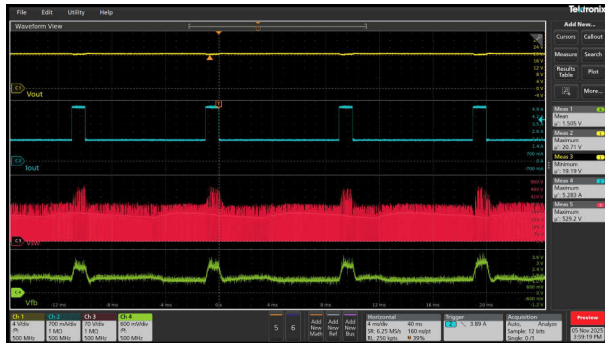


图 3-60. VIN = 90Vac (2.25 倍额定电流并持续 1ms , 0.9 倍额定电流并持续 9ms)

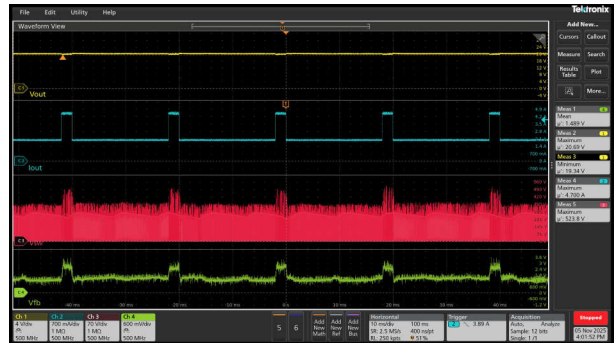


图 3-61. VIN = 90Vac (2 倍额定电流持续 2ms , 0.9 倍额定电流持续 18ms)

3.3.15 CCM 运行

本节介绍了在 90Vac、4.5A 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。

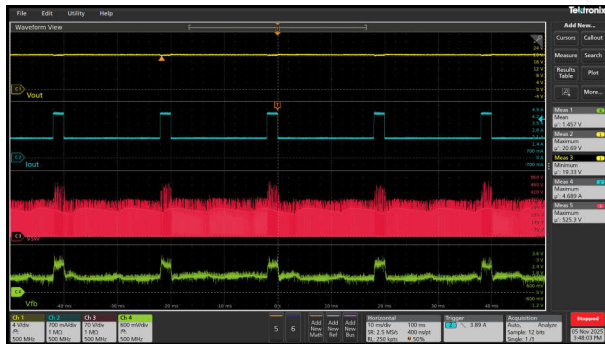


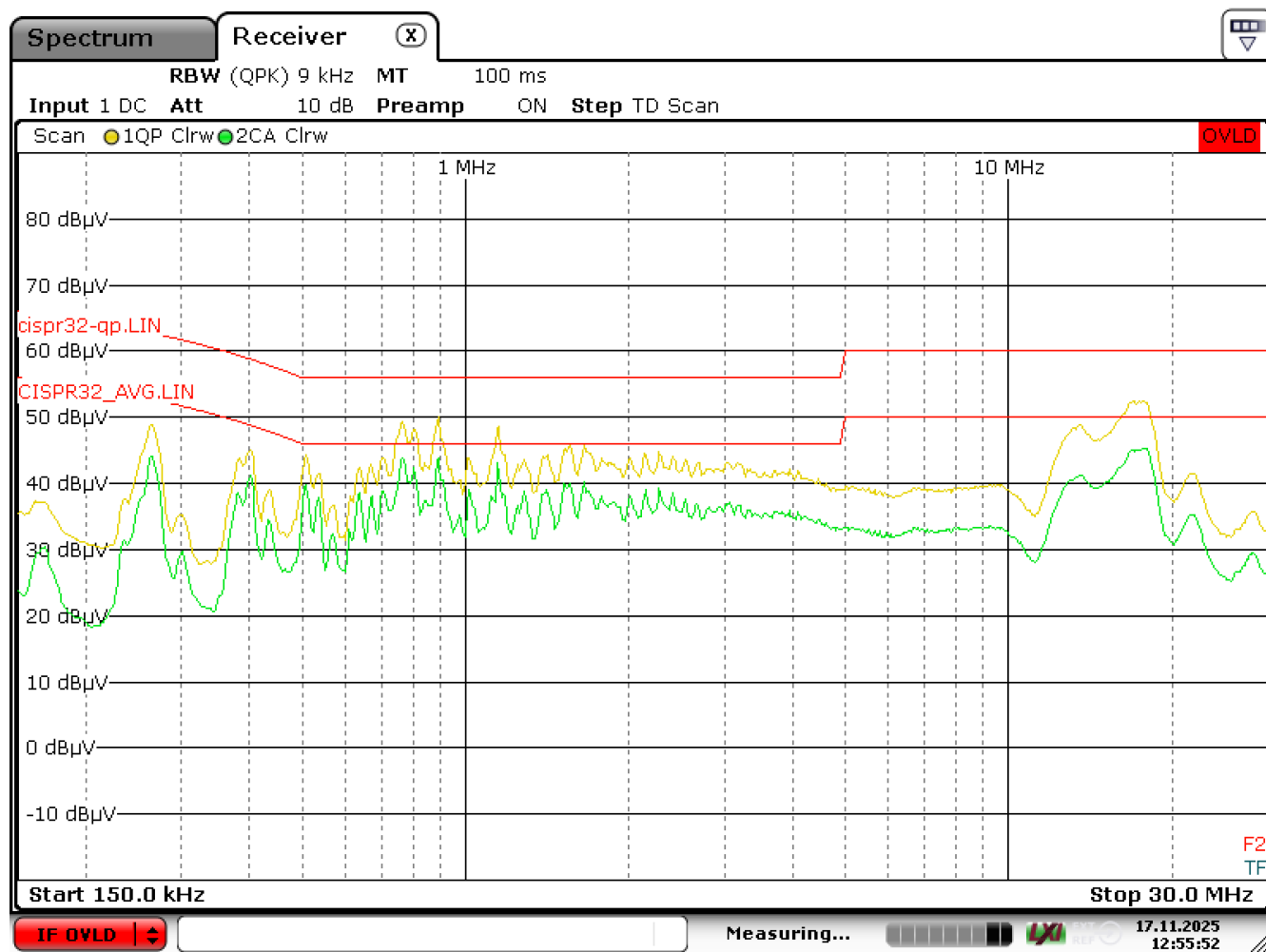
图 3-62. VIN = 90Vac (2 倍额定电流持续 2ms , 0.9 倍额定电流持续 18ms)



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 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。



Date: 17.NOV.2025 12:55:52

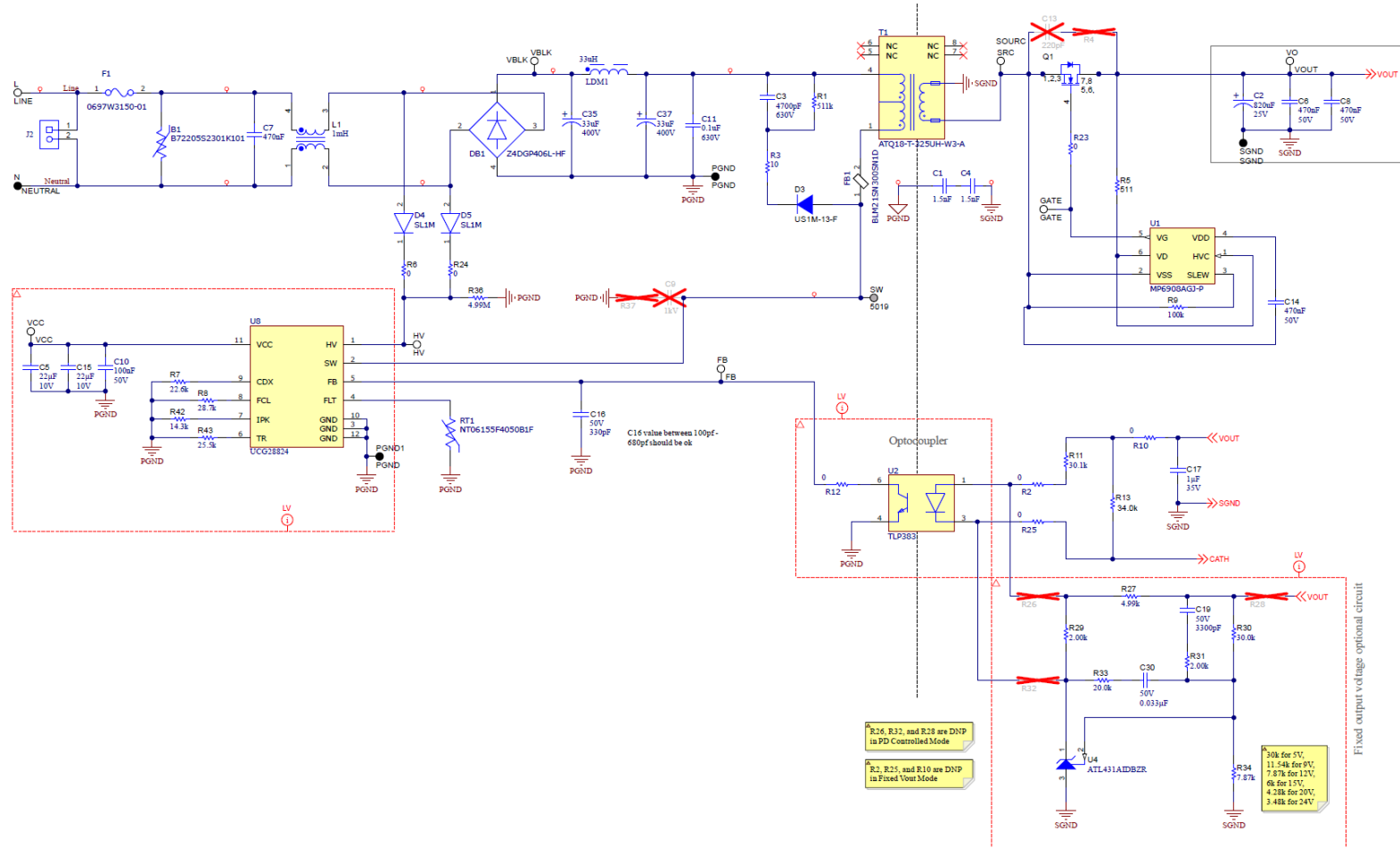
图 3-64. $V_{IN} = 230V_{RMS}$, $V_{OUT} = 20V$, 负载 = 3.25A (SGND 未连接至 LISN 接地端)

4 硬件设计文件

4.1 原理图

UCG28824EVM-124 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，需先通过移除零欧姆电阻 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...

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



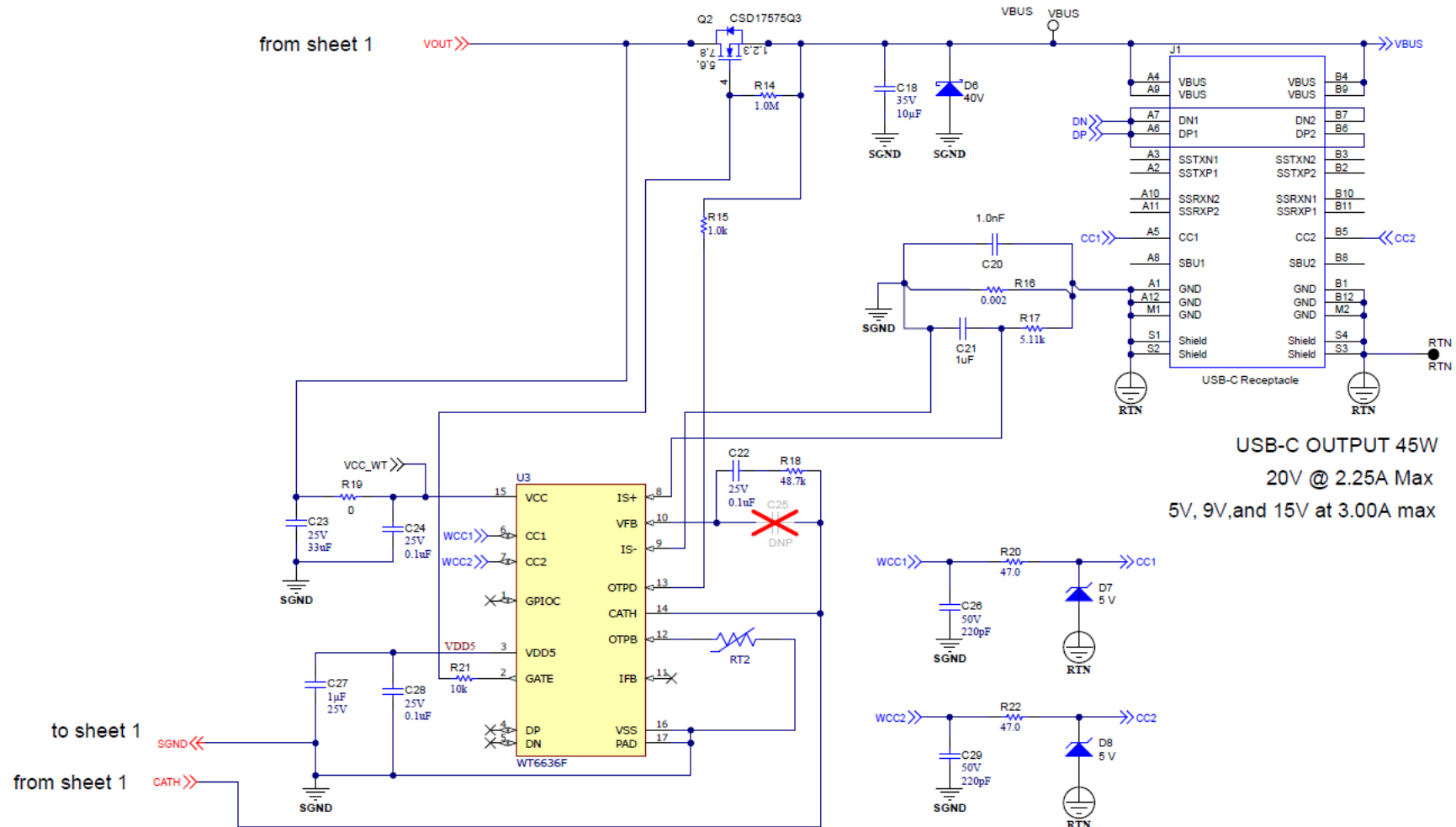


图 4-1. UCG28824EVM-124 电路原理图

4.2 PCB 布局

UCG28824EVM-124 使用双层 PCB。每层布局的屏幕截图如下所示。

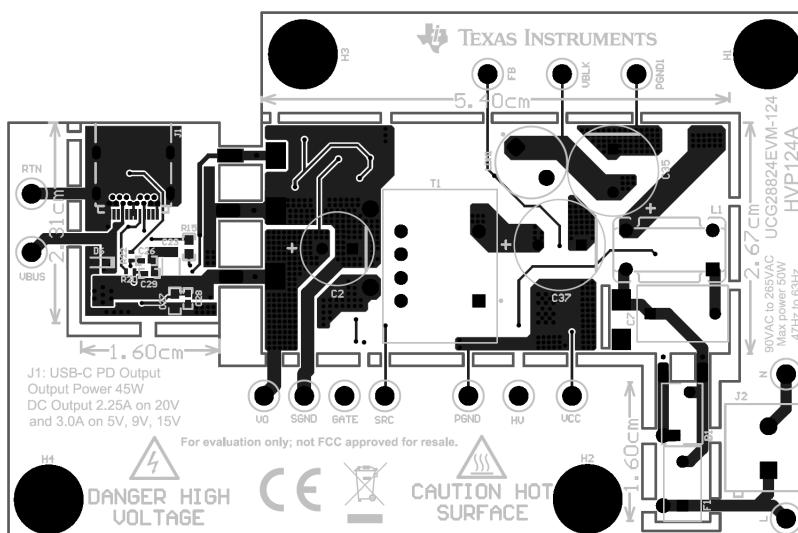


图 4-2. 顶层

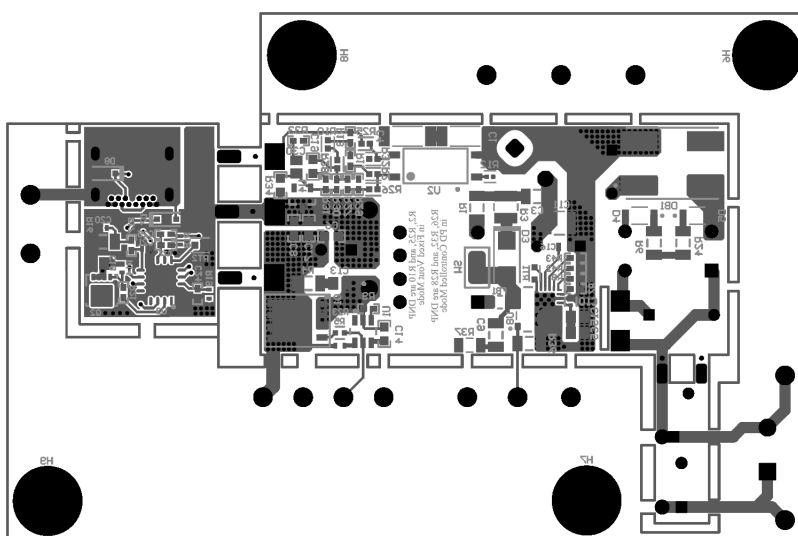


图 4-3. 底层

4.3 变压器详细信息

本设计采用 3L Coils 公司的 ATQ18-T-325UH-W3-A 变压器，其规格如下所述。

4.3.1 ATQ18-T-325UH-W3-A

下面提供了 ATQ18-T-325UH-W3-A 的详细信息。

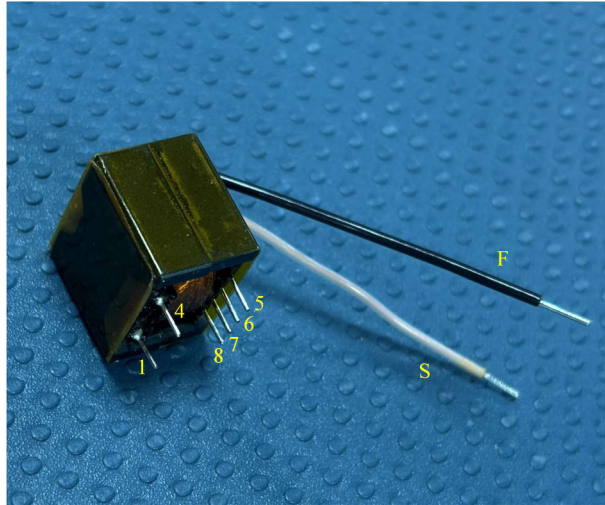


图 4-4. 变压器图片

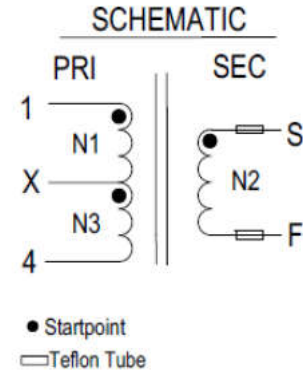


图 4-5. 变压器的原理图

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 , ±10%	1 - 4	所有其他引脚均为开路, 100kHz/ 0.25Vac
漏电感 (μH)	6.73	1 - 4	短接 S - F , 100kHz/0.25Vac
直流电阻 (Ω)	0.255	1 - 4	
直流电阻 (Ω)	0.017 (最大值)	S - F	
电介质 (VAC , 60Hz)	3000Vac	1 - S	3mA , 50Hz , 3s
匝数比	7:1	(1-4):(S-F)	

4.4 物料清单

本部分展示 UCG28824EVM-124 的物料清单。

表 4-2. 物料清单

位号	值	数量	说明	器件型号	制造商
B1	470V	1	470V 800A 压敏电阻穿孔圆盘 5mm	B72205S2301K101	EPCOS
C1, C4	1.5nF	2	1500pF ±10% 250VAC 陶瓷电容器 X7R 1808 (公制 4520)	1808YA250152KJTSYX	Knowles
C2	820uF	1	820uF 25V±20% 插件、D8xL14mm 铝制电解电容器	NPXD1401E821MF	Ymin
C3	4.7nF	1	电容, 陶瓷, 4700pF, 630V, +/-5%, C0G/NP0, 1206	CGA5F4C0G2J472J085AA	TDK
C5、C15	22uF	2	电容, 陶瓷, 22uF, 10V, +/-20%, X7R, 0805	GRM21BZ71A226ME15L	Murata
C6、C8、C14	470nF	3	电容, 陶瓷, 0.47μF, 50V, +/-10%, X7R, 0603	C1608X7R1H474K080AC	TDK
C7	470nF	1	470nF ± 10% 310Vac X2 插件, P=7.5mm 安全电容器	MPX474K31B9KN20600	KNSCHA
C10	100nF	1	电容, 陶瓷, 100nF, 50V X7R ±10% 0402	GRT155R71H104KE01D	Murata
C11	100nF	1	电容, 陶瓷, 0.1uF, 630V, +/-10%, X7R, 1210	C1210C104KBRACU	KEMET
C16	330pF	1	电容, 陶瓷, 330pF, 50V, +/-5%, C0G/NP0, 0603	885012006060	Wurth Elektronik
C17	1uF	1	电容, 陶瓷, 1μF, 35V, +/-10%, X7R, 0603	CGA3E1X7R1V105K080A C	TDK
C18	10uF	1	电容, 陶瓷, 10μF, 35V, +/- 10%, X5R, 0805	GMK212BBJ106KG-T	Taiyo Yuden
C19	3.3nF	1	电容, 陶瓷, 3300pF, 50V, +/-5%, C0G/NP0, 0603	GRM1885C1H332JA01D	Murata
C20	1nF	1	电容, 陶瓷, 1000pF, 50V, +/-10%, X7R, 0402	885012205061	Wurth Elektronik
C21	1uF	1	电容, 陶瓷, 1μF, 6.3V, +/-20%, X7R, 0402	GRM155R70J105MA12D	Murata
C22	100nF	1	电容, 陶瓷, 0.1μF, 25V, +/-10%, X7R, 0402	GRM155R71E104KE14D	Murata
C23	33uF	1	电容, 陶瓷, 33μF, 25V, +/-20%, X5R, 1206	C3216X5R1E336M160AC	TDK
C24、C28	100nF	2	电容, 陶瓷, 0.1μF, 25V, +/-10%, X7R, 0402	GRM155R71E104KE14D	Murata
C26、C29	220pF	2	电容, 陶瓷, 220pF, 50V, +/-10%, X7R, 0402	GRM155R71H221KA01D	Murata
C27	1uF	1	电容, 陶瓷, 1μF, 25V, +/-10%, X7R, 0603	GCM188R71E105KA64D	Murata
C30	33nF	1	电容, 陶瓷, 0.033μF, 50V, +/- 5%, C0G/NP0, 0805	CGA4J2C0G1H333J125AA	TDK

表 4-2. 物料清单 (续)

位号	值	数量	说明	器件型号	制造商
C35、C37	33uF	2	33uF 400V 500mΩ @100kHz 370mA@100kHz ±20% 插件、 D10xL15mm 铝制电解电容器	87EC0493	KNSCHA
D3	1000V	1	二极管, 超快速, 1000V, 1A, SMA	US1M-13-F	Diodes Inc.
D4、D5	800V	2	二极管 800V 1A 表面贴装 SOD-123FL	SL1K	Diotec
D6	40V	1	二极管, 肖特基, 40V, 0.2A, SOD-523	RB521SM-40T2R	ROHM
D7、D8	5.1V	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	Z4DGP406L-HF	Comchip
F1	3.15A	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 30Ω, 单功率 线, 0805 (2012 公制), 8.5A, 4mΩ	BLM21SN300SN1D	Murata
FB、GATE、HV、 L、SRC、VBLK、 VBUS、VCC、VO		9	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
H6、H7、H8、H9		4	螺柱, 六角, 0.5	1902C	Keystone
J1	USB-C 插座	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.
L1	1mH	1	耦合电感器, 1mH, 2A, 0.045Ω, TH	744821201	Würth Elektronik
LDM1	33uH	1	WE-TI 径向引脚绕线电感, 尺寸 8095, 33uH, 2.5A, 0.066Ω	7447720330	Würth Elektronik
N、PGND、 PGND1、RTN、 SGND		5	测试点, 多用途, 黑色, TH	5011	Keystone
Q1	150V	1	MOSFET, N 沟道, 150V, 87A, PG- TDSON-8	BSC093N15NS5ATMA1	Infineon Technologies
Q2	30V	1	MOSFET, N 沟道, 30V, 60A, DQG0008A (VSON-CLIP-8)	CSD17575Q3	德州仪器 (TI)
R1	511k	1	电阻, 511k, 1%, 0.25W, AEC-Q200 0 级, 1206	CRCW1206511KFKEA	Vishay/Dale
R2、R10、R12、 R23、R25	0	5	电阻厚膜, 0, 0.2W, 0402	CRCW04020000Z0EDHP	Vishay
R3	10	1	10 ±5% 0.5W 1210 厚膜片上电阻, 符合 AEC-Q200 标准	RMCF1210JT10R0	Stackpole Electronics
R5	511	1	电阻, 511, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW0402511RFKED	Vishay Dale
R6、R24	0	2	电阻, 0, 5%, 0.25W, AEC-Q200 0 级, 1206	CRCW12060000Z0EA	Vishay/Dale

表 4-2. 物料清单 (续)

位号	值	数量	说明	器件型号	制造商
R7	22.6	1	电阻, 22.6k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040222K6FKED	Vishay Dale
R8	28.7	1	电阻, 28.7k Ω , 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040228K7FKED	Vishay Dale
R9	100k	1	电阻, 100k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW0402100KFKED	Vishay / Dale
R11	30.1k	1	电阻, 30.1k, 1%, 0.063W, 0402	CRCW040230K1FKED	Vishay Dale
R13	34k	1	电阻, 34.0k Ω , 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040234K0FKED	Vishay Dale
R14	1Meg	1	电阻, 1.0M Ω , 5%, 0.063W, AEC-Q200 0 级, 0402	CRCW04021M00JNED	Vishay Dale
R15	1k	1	电阻, 1.0k, 5%, 0.25W, AEC-Q200 0 级, 0603	ESR03EZPJ102	ROHM
R16	0.002	1	电阻, 0.002, 1%, 1W, 1206	CSNL1206FT2L00	Stackpole Electronics Inc
R17	5.11k	1	电阻, 5.11k, 1%, 0.063W, 0402	CRCW04025K11FKED	Vishay Dale
R18	48.7k	1	电阻, 48.7k Ω , 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040248K7FKED	Vishay Dale
R19	0	1	电阻, 0, 5%, 0.063W, AEC-Q200 0 级, 0402	CRCW04020000Z0ED	Vishay / Dale
R20、R22	47	2	电阻, 47.0, 1%, 0.063W, 0402	RK73H1ETTP47R0F	KOA Speer
R21	10k	1	电阻, 10k, 5%, 0.063W, 0402	CRCW040210K0JNED	Vishay / Dale
R27	4.99k	1	电阻, 4.99k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW04024K99FKED	Vishay Dale
R29、R31	2.00k	2	电阻, 2.00k, 0.1%, 0.063W, 0402	RG1005P-202-B-T5	Susumu
R30	30k	1	电阻, 30.0k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040230K0FKED	Vishay
R33	20.0k	1	电阻, 20.0k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040220K0FKED	Vishay / Dale
R34	7.87k	1	电阻, 7.87k, 1%, 0.1W, AEC-Q200 0 级, 0603	CRCW06037K87FKEA	Vishay / Dale
R36	4.99k	1	电阻, 4.99M, 1%, 0.25W, AEC-Q200 0 级, 1206	CRCW12064M99FKEA	Vishay/Dale
R42	14.3k	1	电阻, 14.3k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040214K3FKED	Vishay / Dale
R43	25.5k	1	电阻, 25.5k, 1%, 0.063W, AEC-Q200 0 级, 0402	CRCW040225K5FKED	Vishay / Dale
RT1	150k	1	NTC 热敏电阻 150k 0603 (公制 1608)	NT06155F4050B1F	Eaton
RT2	220k	1	热敏电阻 NTC, 220k Ω , 5%, 0603	ERT-J1VT224J	Panasonic
SW		1	测试点, 微型, SMT	5019	Keystone
T1		1	反激式变压器	ATQ18-T-325UH-W3-A	3L Coil

表 4-2. 物料清单 (续)

位号	值	数量	说明	器件型号	制造商
U1		1	快速关断智能整流器	MP6908GJ-Z	Monolithic Power Systems Inc.
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	2.5V 低 Iq 可调精密并联稳压器, DBZ0003A (SOT-23-3)	ATL431AIDBZR	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	UCG28824-1REZR	德州仪器 (TI)

5 其他信息

商标

USB-C® is a registered trademark of USB Implementers Forum.

所有商标均为其各自所有者的财产。

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.
 - 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.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社
東京都新宿区西新宿 6 丁目 2 4 番 1 号
西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/sds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html>

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:

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

8.1 *General Limitations.* IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMNITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2023, Texas Instruments Incorporated

重要通知和免责声明

TI“按原样”提供技术和可靠性数据（包括数据表）、设计资源（包括参考设计）、应用或其他设计建议、网络工具、安全信息和其他资源，不保证没有瑕疵且不做任何明示或暗示的担保，包括但不限于对适销性、与某特定用途的适用性或不侵犯任何第三方知识产权的暗示担保。

这些资源可供使用 TI 产品进行设计的熟练开发人员使用。您将自行承担以下全部责任：(1) 针对您的应用选择合适的 TI 产品，(2) 设计、验证并测试您的应用，(3) 确保您的应用满足相应标准以及任何其他安全、安保法规或其他要求。

这些资源如有变更，恕不另行通知。TI 授权您仅可将这些资源用于研发本资源所述的 TI 产品的相关应用。严禁以其他方式对这些资源进行复制或展示。您无权使用任何其他 TI 知识产权或任何第三方知识产权。对于因您对这些资源的使用而对 TI 及其代表造成的任何索赔、损害、成本、损失和债务，您将全额赔偿，TI 对此概不负责。

TI 提供的产品受 [TI 销售条款](#)、[TI 通用质量指南](#) 或 [ti.com](#) 上其他适用条款或 TI 产品随附的其他适用条款的约束。TI 提供这些资源并不会扩展或以其他方式更改 TI 针对 TI 产品发布的适用的担保或担保免责声明。除非德州仪器 (TI) 明确将某产品指定为定制产品或客户特定产品，否则其产品均为按确定价格收入目录的标准通用器件。

TI 反对并拒绝您可能提出的任何其他或不同的条款。

版权所有 © 2026，德州仪器 (TI) 公司

最后更新日期：2025 年 10 月