EVM User's Guide: UCG28828EVM-094

UCG28828 具有集成 GaN 的 120W QR 反激式转换器评估模块

说明

UCG28828 评估模块 (EVM) 支持设计人员评估 UCG28828 无辅助 QR 反激式控制器的操作和性能。此评估模块演示了 UCG28828 如何驱动准谐振反激式转换器，以在整个负载和通用线路输入中实现高效率。

开始使用

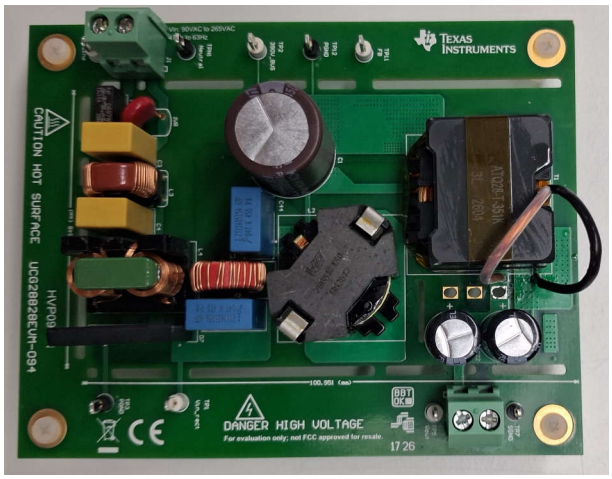
1. 在评估之前，请先完整阅读和学习本用户指南。
2. 订购 UCG28828EVM-094 以进行评估（如果符合步骤 1 的要求）。
3. 根据用户指南说明设置和测试 UCG28828EVM-094。

特性

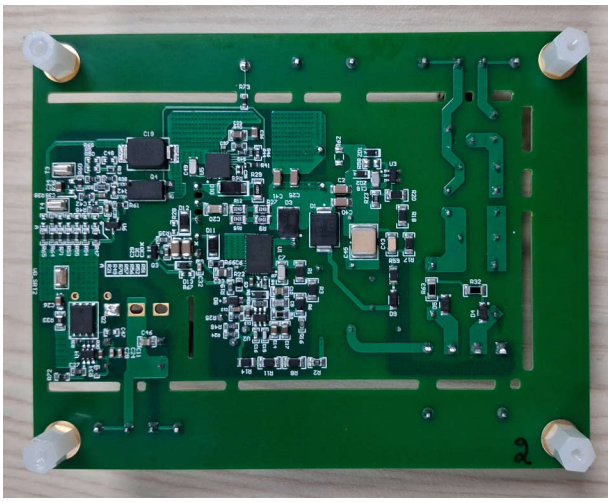
- 具有 170mΩ Rds(on)，动态 QR/DCM/CCM 运行模式和峰值电流模式受控 QR 反激式转换器的集成式 750V GaN
- 支持 90VAC 至 264VAC 交流输入电压，线路频率为 43Hz - 63Hz，输出功率为 20V/5A、24V/5A 和 28V/4.3A。此外，可以将此 EVM 配置为 5V/3A、9V/3A、12V/3A 和 15V/3A，并针对所有此输出电压禁用 PFC。
- 高效率和低待机功耗以及两级（PFC + 反激式）峰值效率：输入电压为 115VAC 时效率大于 93%，输入电压为 230VAC 时效率约为 95%
- PFC 需要在 20V 输出设置下最小具有 20mA，以在输入电压范围内启用 PFC 电路
- 自偏置和无辅助检测，集成电流检测，集成 HV 启动和集成 X 电容器放电均可通过集成实现最低 BOM 成本
- 全套保护特性，包括 OVP，OTP，短路，过电流保护和棕色输入和输出保护。
- UCC28056 PFC 转换模式控制器实现了分立式欠压电路。
- 该 EVM 包含 TI 器件，其中包括 UCG28828、UCC28056、LMG3622、LM8364 和 ATL431。

应用

- USB 墙壁电源适配器
- USB 交流/直流适配器
- 电池充电器
- 集线站



UCG28828EVM-094 顶视图



UCG28828EVM-094 底视图

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1 评估模块概述

1.1 简介

本用户指南介绍了 120W 两级交流/直流电源评估模块 (EVM) 的设计、运行和性能。EVM 展示了一种适用于交流-直流适配器、消费类电子产品、工业和医疗电源应用的高效，高密度隔离式电源设计。

此 EVM 可实现两级电源转换拓扑。第一级使用 UCC28056 转换模式 PFC 控制器和 LMG3622 GaN FET 开关，在 90VAC 至 264VAC 的通用交流输入范围内，实现接近单位功率因数和低总谐波失真 (THD)。第二级使用集成了 750V GaN HEMT 的 UCG28828 无辅助准谐振 (QR) 反激式控制器，可提供 20V、24V 或 28V 的稳压直流输出，以及 120W 的输出功率。UCG28828 无辅助架构省去了反激偏置电源所需的变压器辅助绕组，从而降低了变压器复杂性和总体物料清单 (BOM) 成本。谷值开关工作模式可将开关损耗降至最低，在全负载范围内保持 92% 以上效率的同时，实现高功率密度。该 EVM 的设计符合以下行业标准：

- 效率：DoE 级 VI 平均效率
- 待机功耗：CoC 2 级（空载时 <210mW）
- EMC：CISPR 32 B 类传导发射
- 输入：通用交流，90VAC 至 264VAC，47Hz 至 63Hz
- 输出：20V，24V 或 28V 和 120W 最大功率。

本用户指南介绍了 EVM 原理图、物料清单、测试设置和测得的性能数据，包括效率、负载调节、启动、负载范围内的开关频率、线路瞬态、负载瞬态、输出电压纹波、热性能、传导 EMI 和 PFC 级测试数据。本用户指南从 QR 反激式转换器的系统运行角度，提供了基本评估说明。在为此电路板加电之前，请仔细阅读本用户指南。

1.2 套件内容

条目	说明	数量
UCG28828EVM-094	PCB（评估模块）	1

1.3 规格

输入	输出	最大输出功率
90VAC-264VAC47-63Hz	28V/4.3A、24V/5A 和 20V/5A [可将输出设置为 15V/3A、12V/3A、9V/3A、5V/3A（将禁用 PFC）]	120W

1.4 器件信息

UCG28828 是一款高频、准谐振 (QR) 交流/直流反激式转换器，集成了 750V 初级侧 GaN 高电子迁移率晶体管 (HEMT)，低至 170mΩ RDS(on)，专为 120W 的交流至直流功率转换而设计，在高功率密度设计中开关频率高达 500kHz。该器件采用业界最早推出的、具有自偏置功能的无辅助反激式架构，无需使用变压器辅助绕组，即可实现紧凑、成本更低且效率更高的电源设计 — 尤其是在 USB PD 充电器等宽输出电压应用中。集成了输入电压检测、输出电压检测、电流检测、HV 启动和 X 电容器放电功能，可显著减少外部元件数量并降低 BoM 成本。UCG28828 支持在 CCM、QR 和 DCM 工作模式之间进行动态模式转换，可在整个功率范围内实现高效率，待机功耗低于 30mW，并通过频率抖动、谷锁定、频率折返、突发模式和开关斜率控制等技术内置了 EMI 抑制功能。一套全面的保护功能 — OVP、SCP、带 LPS 的两级过功率保护、OTP、上电欠压保护与掉电欠压保护、开路反馈保护以及逐周期电流限制 — 结合紧凑型 5mm × 5mm QFN 封装中灵活的电阻可编程配置引脚，使 UCG28828 成为一款面向 USB-PD 适配器、USB 墙式插座、工业 DIN 导轨电源和服务器辅助电源的完全集成、支持平台设计的解决方案。

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



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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良好的工程实践。
   a. 执行任何电气测量或其他诊断测量之前，需切断 TI HV EVM 及其全部输入、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，根据需要将 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。

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2 硬件

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：能够提供 $264V_{RMS}$ 且能够处理 100W 功率级别的隔离式交流电源或可变交流变压器。

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。

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2.2 建议的测试设置

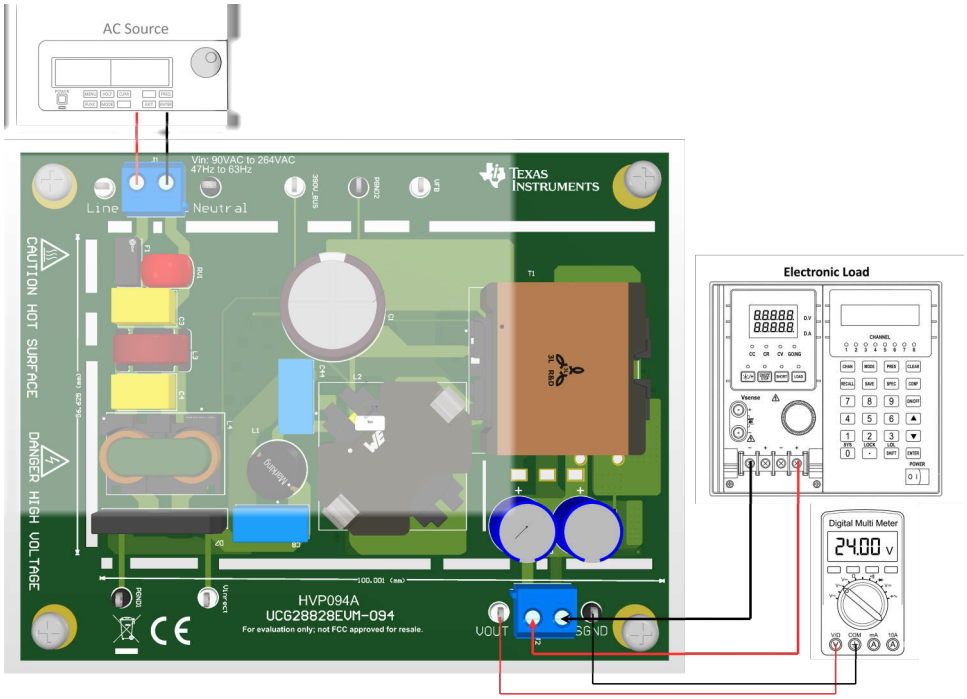


图 2-1. UCG28828EVM-094 测试设置图

2.3 测试点

表 2-1. 测试点

测试点	说明
线路	交流输入线路终端
中性	交流输入中性端子
Vinrect	整流输入电压
390V_BUS	PFC 输出电压
PGND1、PGND2	初级侧接地
VFB	UCG28828 反馈引脚电压
VD_SR	SR FET 漏极引脚电压
VOUT	反激式输出电压
SGND	次级侧接地
T2、T3	用于稳定性分析的 50Ω 电阻器上的测试引脚 (R36)

2.4 端子

表 2-2. 表格中列出了 EVM 终端

端子	说明
J1	交流输入终端
J2	反激式输出终端

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3 性能数据和典型特性曲线

120W 两级交流/直流电源整合了一个 UCC28056 控制的 PFC 前端级，采用 LMG3622 700V GaN FET 作为功率开关，后跟 UCG28828（750V 集成式 GaN 无辅助 FET 反激式转换级）。此电源在所有三种可编程输出电压 — 28V，24V 和 20V 下及 90VAC 至 264VAC 的全通用输入范围内，始终提供高效率。

LMG3622 基于 GaN 的 PFC 开关可在 PFC 级实现高频，低损耗开关操作，从而直接提升了在所有线路和负载条件下能观察到的整体系统效率。在 28V 输出下，264VAC 满载时峰值效率达到 95.23%，4 点平均效率在 90VAC 时为 92.13%，在 264VAC 时为 94.05%。在 24V 输出下，264VAC 满载时峰值效率达到 95.00%，4 点平均效率在 90VAC 时为 91.92%，在 264VAC 时为 94.00%。在 20V 输出下，264VAC 满载时峰值效率达到 94.82%，4 点平均效率在 90VAC 时为 91.82%，在 264VAC 时为 93.71%。在所有输出电压设置下，在所有线路条件下，当负载达到 50% 及以上时，系统效率始终超过 92%，且所有结果均符合针对 120W 外部电源的 DoE 级 VI 和 CoC 2 级要求。

这些测量证实，UCC28056、LMG3622 和 UCG28828 的组合可在整个输出电压范围、负载范围和通用输入电压范围内保持高转换效率 — 从而验证了高功率密度适配器应用的设计。

3.1 28V 输出电压下的效率测试数据

V_{IN} 和 Fline	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	效率	4 点平均效率
90VAC 和 60Hz	0.22733	27.89	0.00489	0.13624	0.11%	59.93%	
90VAC 和 60Hz	0.32208	27.89	0.0070	0.1963	0.16%	60.94%	
90VAC 和 60Hz	0.44436	27.89	0.0108	0.3023	0.25%	68.02%	
90VAC 和 60Hz	0.5901	27.89	0.0153	0.4264	0.35%	72.26%	
90VAC 和 60Hz	0.6722	27.89	0.0178	0.4951	0.41%	73.66%	
90VAC 和 60Hz	1.2286	27.89	0.0350	0.9756	0.81%	79.41%	
90VAC 和 60Hz	5.6506	27.89	0.1769	4.9340	4.11%	87.32%	
90VAC 和 60Hz	13.5907	27.88	0.4290	11.9605	10%	88.01%	
90VAC 和 60Hz	33.38	27.87	1.084	30.2111	25%	90.51%	
90VAC 和 60Hz	64.75	27.86	2.147	59.8154	50%	92.38%	92.13%
90VAC 和 60Hz	96.41	27.84	3.216	89.5334	75%	92.87%	
90VAC 和 60Hz	128.68	27.84	4.288	119.3779	100%	92.46%	
115VAC 和 60Hz	0.355	27.89	0.00654	0.182	0.15%	51.39%	
115VAC 和 60Hz	0.349	27.89	0.007	0.202	0.17%	57.93%	
115VAC 和 60Hz	0.465	27.89	0.011	0.317	0.26%	68.26%	
115VAC 和 60Hz	0.604	27.89	0.016	0.437	0.36%	72.32%	
115VAC 和 60Hz	0.677	27.89	0.018	0.502	0.42%	74.10%	
115VAC 和 60Hz	1.278	27.89	0.037	1.026	0.86%	80.23%	
115VAC 和 60Hz	5.726	27.89	0.18	5.014	4.17%	87.56%	
115VAC 和 60Hz	13.704	27.87	0.434	12.096	10%	88.26%	
115VAC 和 60Hz	33.26	27.87	1.086	30.267	25%	91.00%	
115VAC 和 60Hz	64.436	27.86	2.146	59.788	50%	92.79%	92.81%
115VAC 和 60Hz	95.767	27.85	3.220	89.677	75%	93.64%	
115VAC 和 60Hz	127.332	27.84	4.291	119.461	100%	93.82%	
230VAC 和 50Hz	0.303	27.88	0.006	0.156	0.13%	51.41%	
230VAC 和 50Hz	0.365	27.88	0.008	0.215	0.18%	58.76%	
230VAC 和 50Hz	0.478	27.88	0.012	0.325	0.27%	68.12%	
230VAC 和 50Hz	0.620	27.88	0.016	0.444	0.37%	71.65%	
230VAC 和 50Hz	0.703	27.88	0.018	0.509	0.42%	72.37%	
230VAC 和 50Hz	1.275	27.88	0.037	1.029	0.86%	80.71%	

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V_{IN} 和 Fline	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	效率	4 点平均效率
230VAC 和 50Hz	5.607	27.88	0.179	4.982	4.15%	88.85%	
230VAC 和 50Hz	13.519	27.88	0.430	11.988	10%	88.68%	
230VAC 和 50Hz	32.796	27.87	1.081	30.138	25%	91.90%	93.83%
230VAC 和 50Hz	63.898	27.86	2.149	59.871	50%	93.70%	
230VAC 和 50Hz	95.026	27.85	3.230	89.956	75%	94.66%	
230VAC 和 50Hz	125.914	27.84	4.3	119.712	100%	95.07%	
264VAC 和 50Hz	0.285	27.89	0.005	0.145	0.12%	50.99%	
264VAC 和 50Hz	0.366	27.89	0.007	0.208	0.17%	56.81%	
264VAC 和 50Hz	0.479	27.89	0.011	0.317	0.26%	66.26%	
264VAC 和 50Hz	0.619	27.89	0.016	0.437	0.36%	70.54%	
264VAC 和 50Hz	0.695	27.88	0.018	0.504	0.42%	72.56%	
264VAC 和 50Hz	1.234	27.88	0.035	0.982	0.82%	79.61%	
264VAC 和 50Hz	5.611	27.88	0.179	4.980	4.15%	88.76%	
264VAC 和 50Hz	13.75	27.86	0.439	12.231	10%	88.95%	
264VAC 和 50Hz	32.591	27.85	1.078	30.022	25%	92.12%	94.049%
264VAC 和 50Hz	63.611	27.85	2.146	59.766	50%	93.96%	
264VAC 和 50Hz	94.356	27.84	3.216	89.533	75%	94.89%	
264VAC 和 50Hz	125.533	27.83	4.2990.145	119.641	100%	95.23%	

3.2 24V 输出电压下的效率测试数据

V_{IN} 和 Fline	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	效率	4 个点的平均效率
90VAC 和 60Hz	0.199	24.02	0.005	0.116	0.09%	58.08%	
90VAC 和 60Hz	0.317	24.02	0.008	0.196	0.16%	61.83%	
90VAC 和 60Hz	0.426	24.02	0.012	0.293	0.24%	68.84%	
90VAC 和 60Hz	0.542	24.02	0.016	0.392	0.33%	72.27%	
90VAC 和 60Hz	0.646	24.02	0.020	0.485	0.40%	75.10%	
90VAC 和 60Hz	1.267	24.02	0.043	1.028	0.86%	81.09%	
90VAC 和 60Hz	5.714	24.02	0.208	4.992	4.15%	87.37%	
90VAC 和 60Hz	13.874	24.02	0.508	12.202	10%	87.95%	
90VAC 和 60Hz	33.330	24.01	1.253	30.085	25%	90.26%	91.92%
90VAC 和 60Hz	65.040	24.00	2.500	60.000	50%	92.25%	
90VAC 和 60Hz	97.060	24.00	3.750	90.000	75%	92.73%	
90VAC 和 60Hz	129.700	23.99	4.997	119.878	100%	92.43%	
115VAC 和 60Hz	0.246	24.02	0.006	0.113	0.09%	54.10%	
115VAC 和 60Hz	0.336	24.02	0.009	0.218	0.18%	65.05%	
115VAC 和 60Hz	0.442	24.02	0.013	0.304	0.25%	68.77%	
115VAC 和 60Hz	0.550	24.02	0.017	0.403	0.34%	73.34%	
115VAC 和 60Hz	0.642	24.02	0.020	0.480	0.40%	74.76%	
115VAC 和 60Hz	1.252	24.02	0.042	1.019	0.85%	81.39%	
115VAC 和 60Hz	5.518	24.02	0.201	4.838	4.03%	87.68%	
115VAC 和 60Hz	13.710	24.01	0.505	12.125	10%	88.44%	

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V_{IN} 和 Fline	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	效率	4 个点的平均效率
115VAC 和 60Hz	33.176	24.01	1.253	30.085	25%	90.68%	92.64%
115VAC 和 60Hz	64.662	24.00	2.500	60.000	50%	92.79%	
115VAC 和 60Hz	96.178	24.00	3.750	90.000	75%	93.58%	
115VAC 和 60Hz	128.203	23.99	4.998	119.902	100%	93.52%	
230VAC 和 50Hz	0.265	24.02	0.006	0.132	0.11%	49.94%	
230VAC 和 50Hz	0.354	24.02	0.009	0.212	0.17%	59.87%	
230VAC 和 50Hz	0.453	24.02	0.013	0.303	0.25%	67.02%	
230VAC 和 50Hz	0.558	24.02	0.017	0.402	0.33%	72.01%	
230VAC 和 50Hz	0.665	24.02	0.021	0.493	0.41%	74.14%	
230VAC 和 50Hz	1.230	24.02	0.042	1.003	0.84%	81.52%	
230VAC 和 50Hz	5.515	24.02	0.204	4.897	4.08%	88.81%	
230VAC 和 50Hz	13.514	24.02	0.505	12.130	10%	89.76%	
230VAC 和 50Hz	32.732	24.02	1.253	30.097	25%	91.95%	93.79%
230VAC 和 50Hz	63.984	24.01	2.500	60.025	50%	93.81%	
230VAC 和 50Hz	95.105	24.00	3.749	89.976	75%	94.61%	
230VAC 和 50Hz	126.432	23.98	4.998	119.852	100%	94.80%	
264VAC 和 50Hz	0.261	24.02	0.005	0.117	0.10%	44.83%	
264VAC 和 50Hz	0.350	24.02	0.008	0.198	0.17%	56.56%	
264VAC 和 50Hz	0.451	24.02	0.012	0.296	0.25%	65.60%	
264VAC 和 50Hz	0.564	24.02	0.016	0.395	0.33%	70.01%	
264VAC 和 50Hz	0.680	24.02	0.020	0.489	0.41%	71.87%	
264VAC 和 50Hz	1.203	24.02	0.040	0.967	0.81%	80.38%	
264VAC 和 50Hz	5.513	24.02	0.205	4.924	4.10%	89.31%	
264VAC 和 50Hz	13.521	24.02	0.505	12.130	10%	89.71%	
264VAC 和 50Hz	32.687	24.01	1.254	30.109	25%	92.11%	94.00%
264VAC 和 50Hz	63.840	24.01	2.501	60.049	50%	94.06%	
264VAC 和 50Hz	94.860	24.00	3.749	89.976	75%	94.85%	
264VAC 和 50Hz	126.166	23.98	4.998	119.852	100%	95.00%	

3.3 20V 输出电压下的效率测试数据

V_{IN} 和 Fline	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	效率	4 点平均效率
90VAC 和 60Hz	0.309	20.034	0.010	0.199	0.20%	64.26%	
90VAC 和 60Hz	0.440	20.034	0.015	0.310	0.31%	70.54%	
90VAC 和 60Hz	0.551	20.034	0.021	0.412	0.41%	74.88%	
90VAC 和 60Hz	0.677	20.033	0.026	0.517	0.52%	76.35%	
90VAC 和 60Hz	1.251	20.033	0.051	1.019	1.02%	81.47%	
90VAC 和 60Hz	5.796	20.029	0.255	5.017	5.02%	88.12%	
90VAC 和 60Hz	11.501	20.028	0.505	10.114	10.11%	87.94%	
90VAC 和 60Hz	27.889	20.023	1.254	25.109	25.00%	90.03%	91.82%
90VAC 和 60Hz	54.447	20.017	2.502	50.083	50.00%	91.98%	
90VAC 和 60Hz	81.000	20.009	3.751	75.054	75.00%	92.66%	
90VAC 和 60Hz	108.014	20.001	5.001	100.025	100.00%	92.60%	
115VAC 和 60Hz	0.312	20.034	0.010	0.199	0.20%	63.91%	
115VAC 和 60Hz	0.437	20.033	0.016	0.311	0.31%	71.25%	

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V_{IN} 和 Fline	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{out} %	效率	4 点平均效率
115VAC 和 60Hz	0.544	20.033	0.021	0.412	0.41%	75.76%	
115VAC 和 60Hz	0.677	20.033	0.026	0.517	0.52%	76.36%	
115VAC 和 60Hz	1.247	20.033	0.051	1.020	1.02%	81.77%	
115VAC 和 60Hz	5.790	20.020	0.257	5.145	5.14%	88.86%	
115VAC 和 60Hz	11.510	20.021	0.508	10.171	10.17%	88.36%	
115VAC 和 60Hz	27.770	20.018	1.257	25.163	25.00%	90.61%	92.47%
115VAC 和 60Hz	54.196	20.013	2.504	50.113	50.00%	92.47%	
115VAC 和 60Hz	80.417	20.006	3.752	75.063	75.00%	93.34%	
115VAC 和 60Hz	107.014	19.997	5.001	100.005	100.00%	93.45%	
230VAC 和 50Hz	0.315	20.034	0.010	0.200	0.20%	63.53%	
230VAC 和 50Hz	0.446	20.033	0.016	0.313	0.31%	70.20%	
230VAC 和 50Hz	0.555	20.033	0.021	0.414	0.41%	74.59%	
230VAC 和 50Hz	0.674	20.033	0.026	0.517	0.52%	76.78%	
230VAC 和 50Hz	1.224	20.033	0.050	0.994	1.00%	81.23%	
230VAC 和 50Hz	5.705	20.025	0.257	5.146	5.15%	90.21%	
230VAC 和 50Hz	11.336	20.025	0.506	10.133	10.13%	89.38%	
230VAC 和 50Hz	27.336	20.022	1.256	25.148	25.00%	92.00%	93.62%
230VAC 和 50Hz	53.584	20.016	2.503	50.100	50.00%	93.50%	
230VAC 和 50Hz	79.567	20.012	3.752	75.085	75.00%	94.37%	
230VAC 和 50Hz	105.710	20.001	5.001	100.025	100.00%	94.62%	
264VAC 和 50Hz	0.341	20.034	0.010	0.200	0.20%	58.69%	
264VAC 和 50Hz	0.448	20.034	0.016	0.314	0.31%	69.93%	
264VAC 和 50Hz	0.561	20.033	0.021	0.415	0.42%	74.03%	
264VAC 和 50Hz	0.651	20.033	0.024	0.490	0.50%	75.37%	
264VAC 和 50Hz	1.266	20.033	0.051	1.022	1.00%	80.71%	
264VAC 和 50Hz	5.611	20.032	0.251	5.028	5.00%	89.61%	
264VAC 和 50Hz	11.231	20.030	0.502	10.055	10.00%	89.53%	
264VAC 和 50Hz	27.302	20.026	1.253	25.093	25.00%	91.91%	93.71%
264VAC 和 50Hz	53.514	20.024	2.502	50.100	50.00%	93.62%	
264VAC 和 50Hz	79.438	20.015	3.751	75.076	75.00%	94.51%	
264VAC 和 50Hz	105.516	20.005	5.001	100.045	100.00%	94.82%	

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3.4 效率曲线：效率与输出功率间的关系

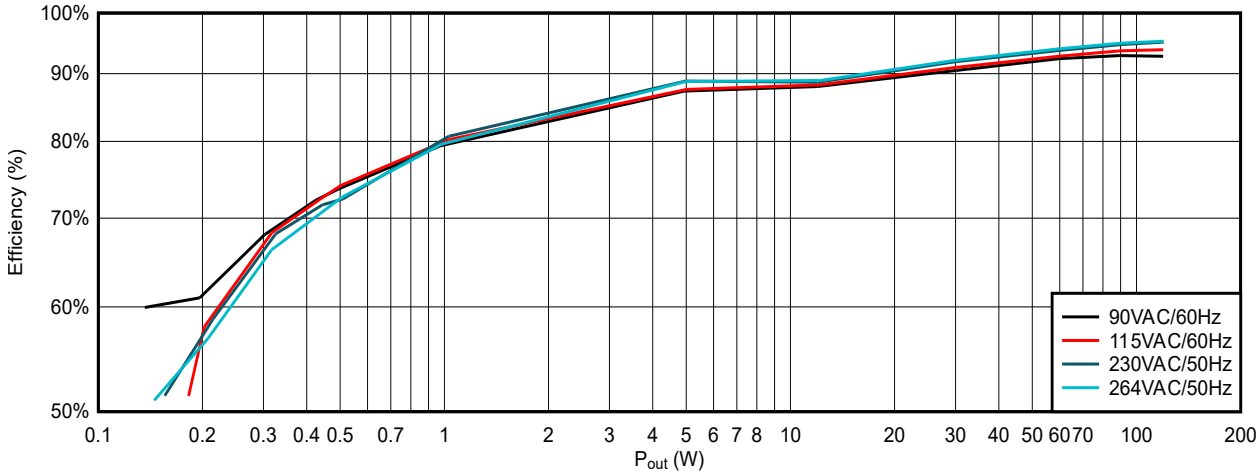


图 3-1. 效率与 P_{out} 间的关系 (28V V_{out})

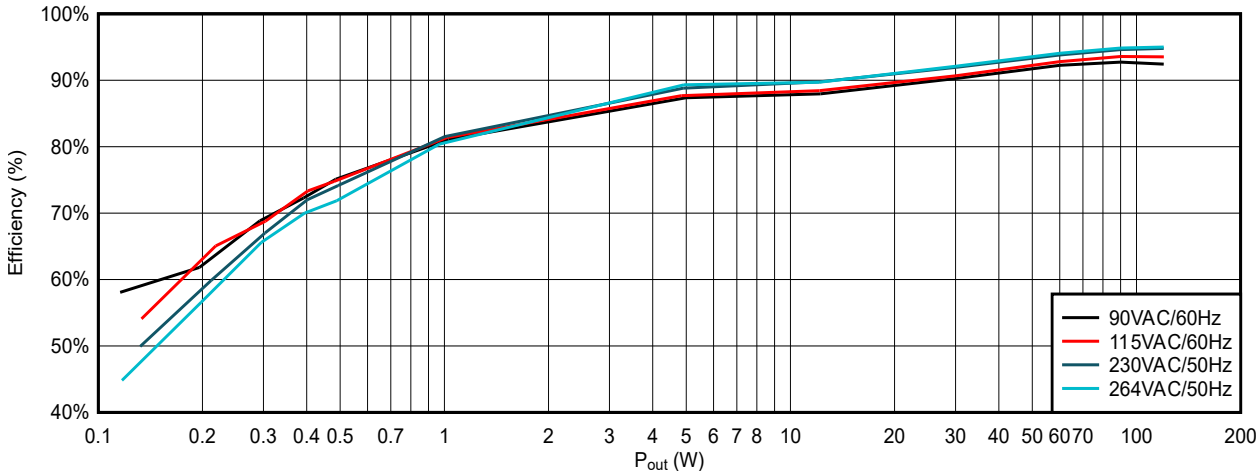


图 3-2. 效率与 P_{out} 间的关系 (24V V_{out})

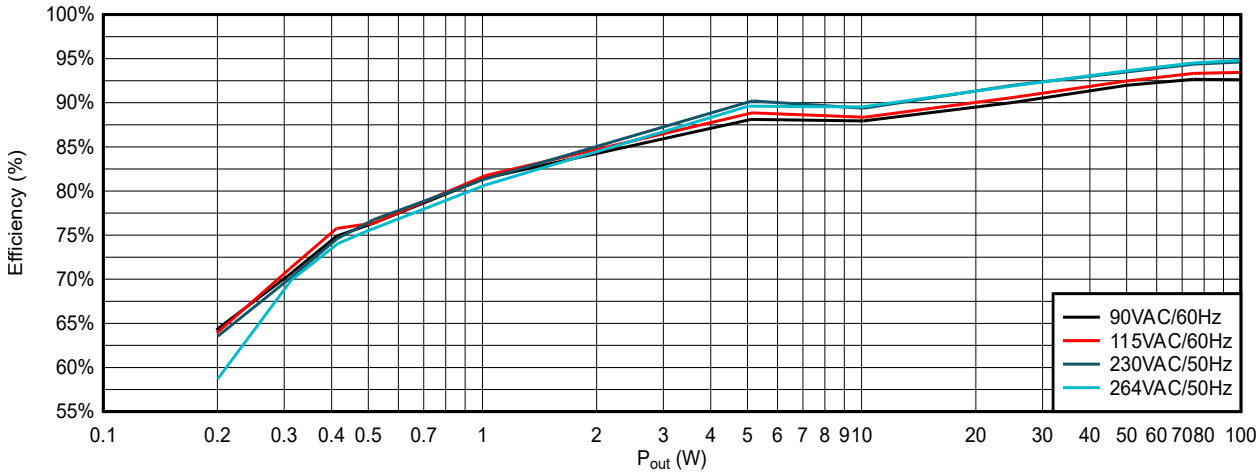


图 3-3. 效率与 P_{out} 间的关系 (20V V_{out})

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3.5 负载调整率

本部分显示了交流输入电压为 90VAC/60Hz、115VAC/60Hz、230VAC/50Hz 和 264VAC/50Hz 时负载上的输出电压调节情况。

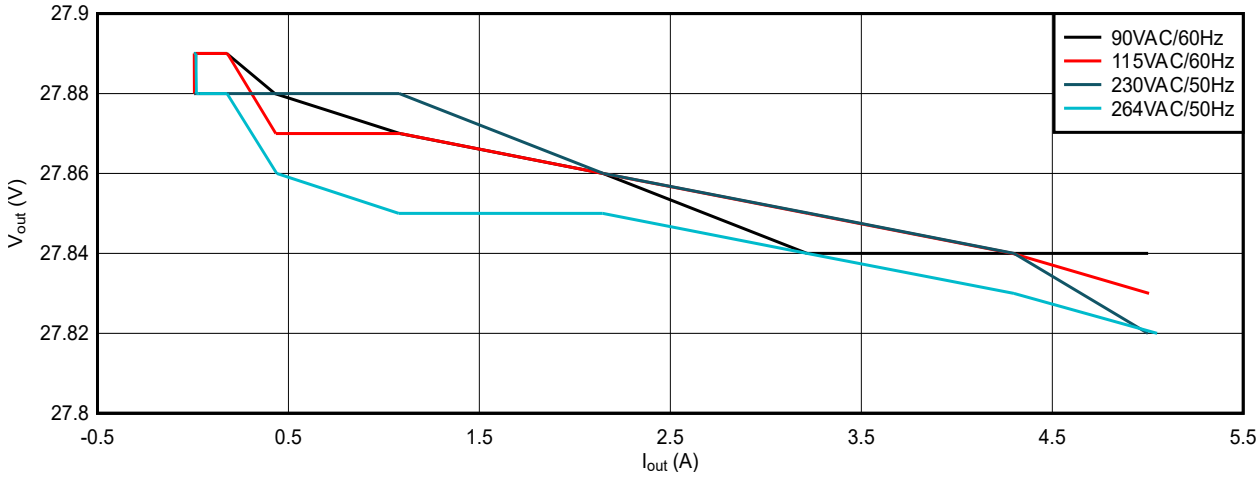


图 3-4. 负载调节：28V 输出电压时

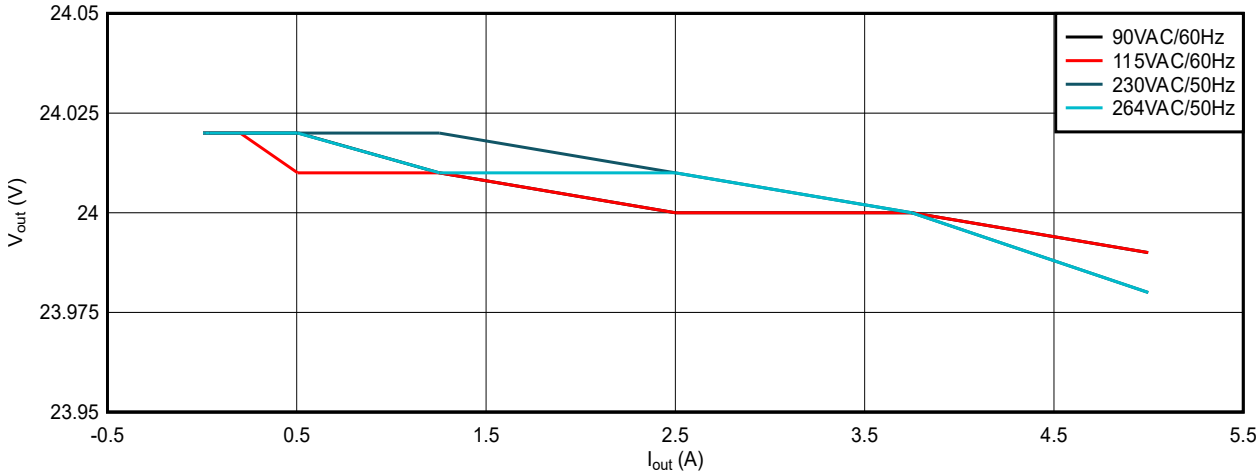


图 3-5. 负载调节：24V 输出电压时

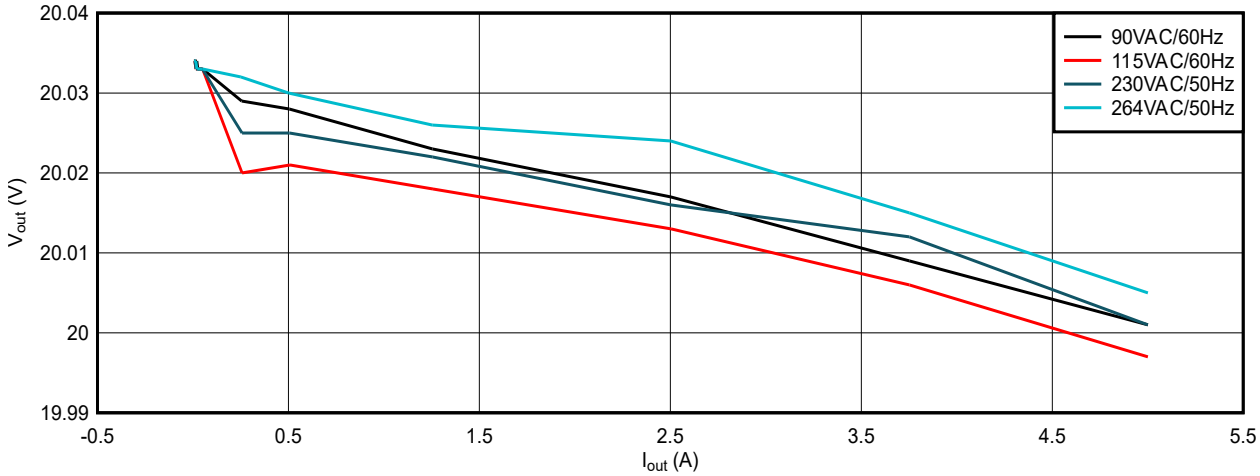


图 3-6. 负载调节：20V 输出电压时

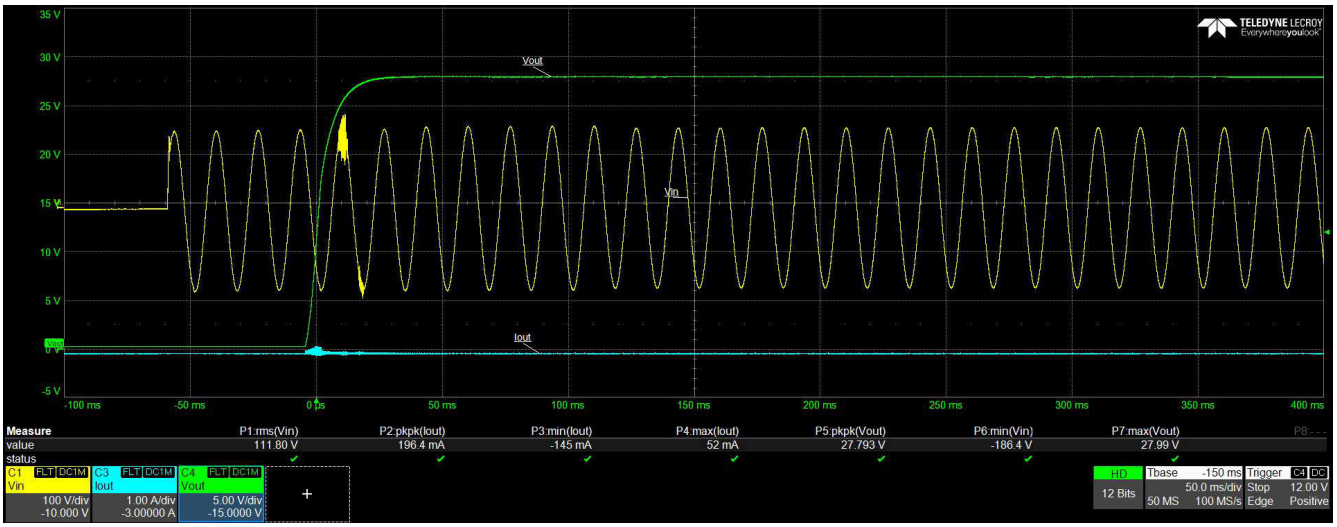
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3.6 启动波形

以下波形显示了启动期间空载和满载条件下的交流输入电压、输出电压和负载电流。测试条件列于图注中。

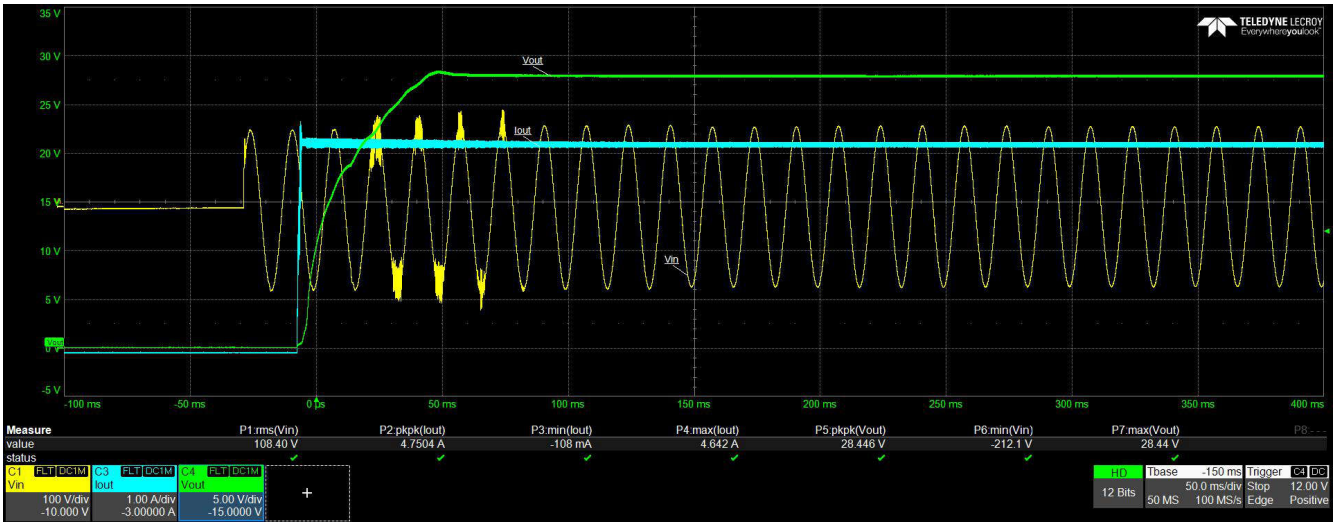
备注

由于 PFC 偏置电源依赖于反激，因此该 EVM 不支持在低于 115VAC 的任何输出电压设置 (20V/24V/28V) 下实现全电源启动。



C1 = Vin（交流）　　C3 = Iout　　C4 = Vout

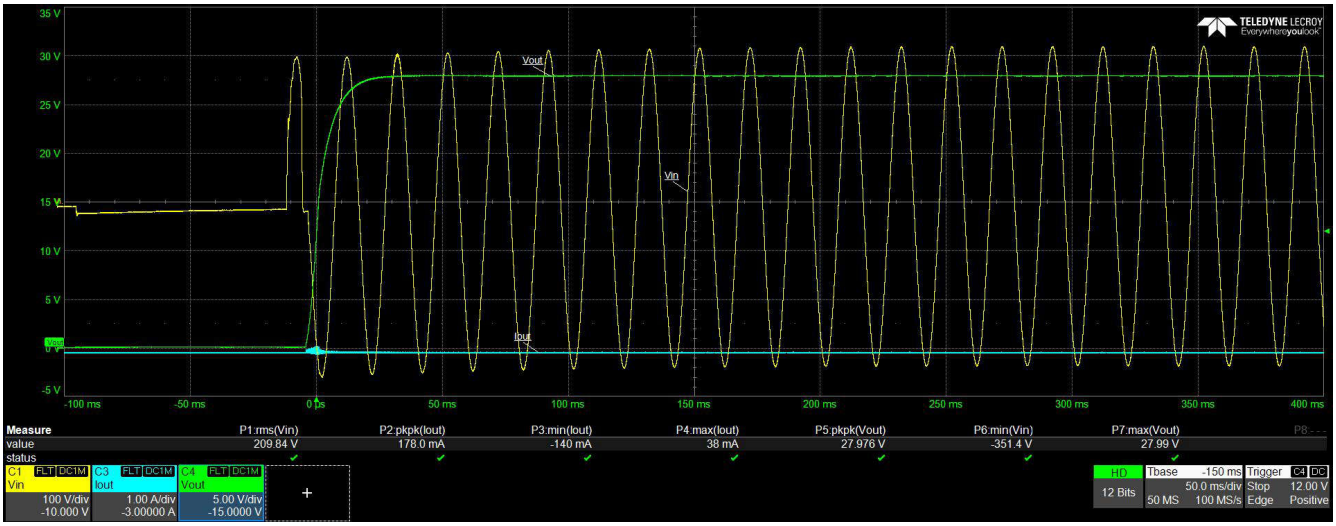
图 3-7. 115VAC/60Hz，28V/0A 条件下的启动波形



C1 = Vin（交流）　　C3 = Iout　　C4 = Vout

图 3-8. 115VAC/60Hz，28V/4.3A 条件下的启动波形

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C1 = Vin（交流） C3 = Iout C4 = Vout

图 3-9. 230VAC/50Hz，28V/0A 条件下的启动波形

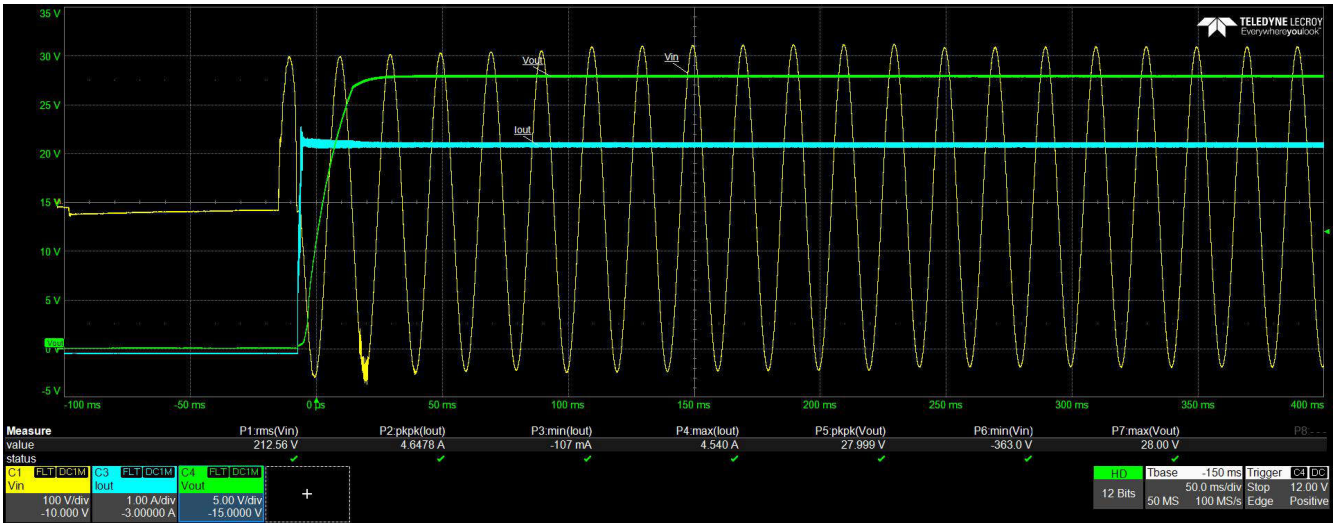
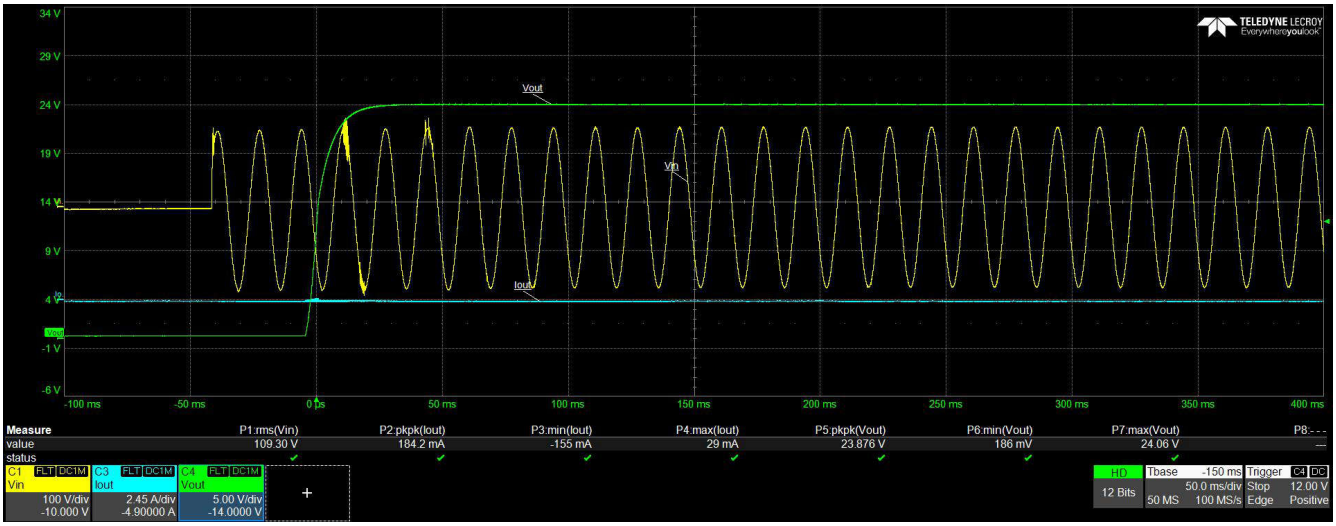


图 3-10. 230VAC/50Hz，28V/4.3A 条件下的启动波形

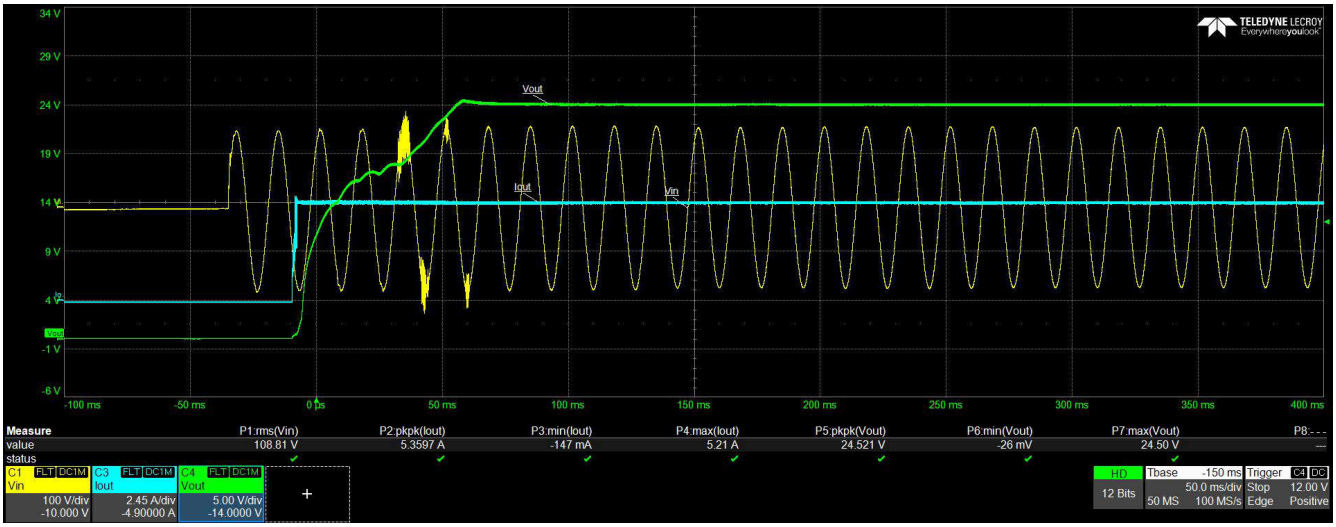
C1 = Vin（交流） C3 = Iout C4 = Vout

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C1 = Vin（交流）　　C3 = Iout　　C4 = Vout

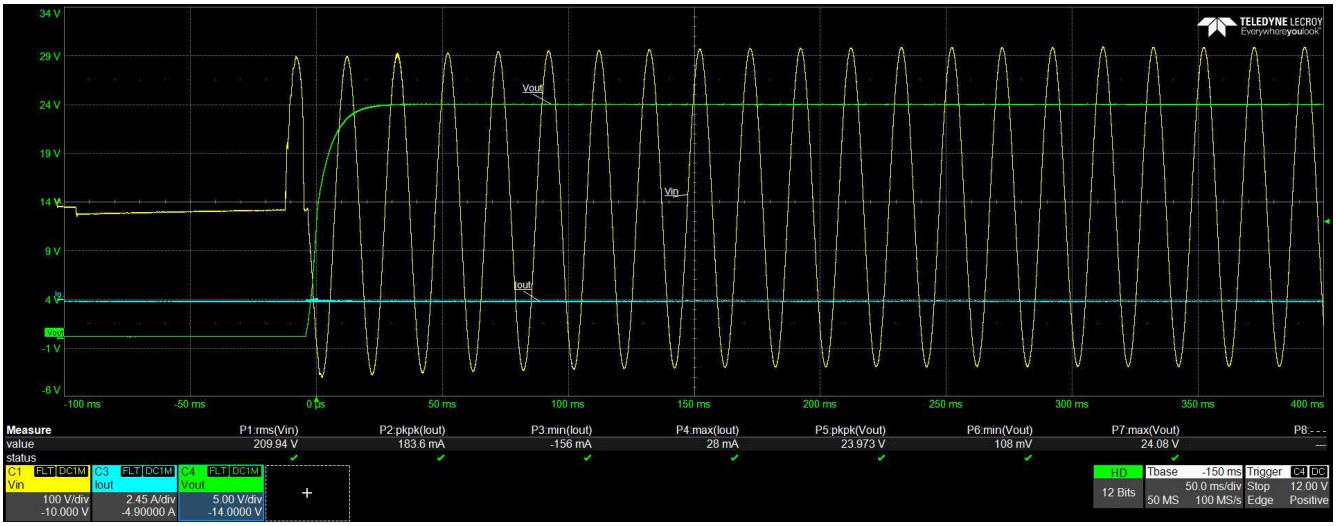
图 3-11. 115VAC/60Hz，24V/0A 条件下的启动波形



C1 = Vin（交流）　　C3 = Iout　　C4 = Vout

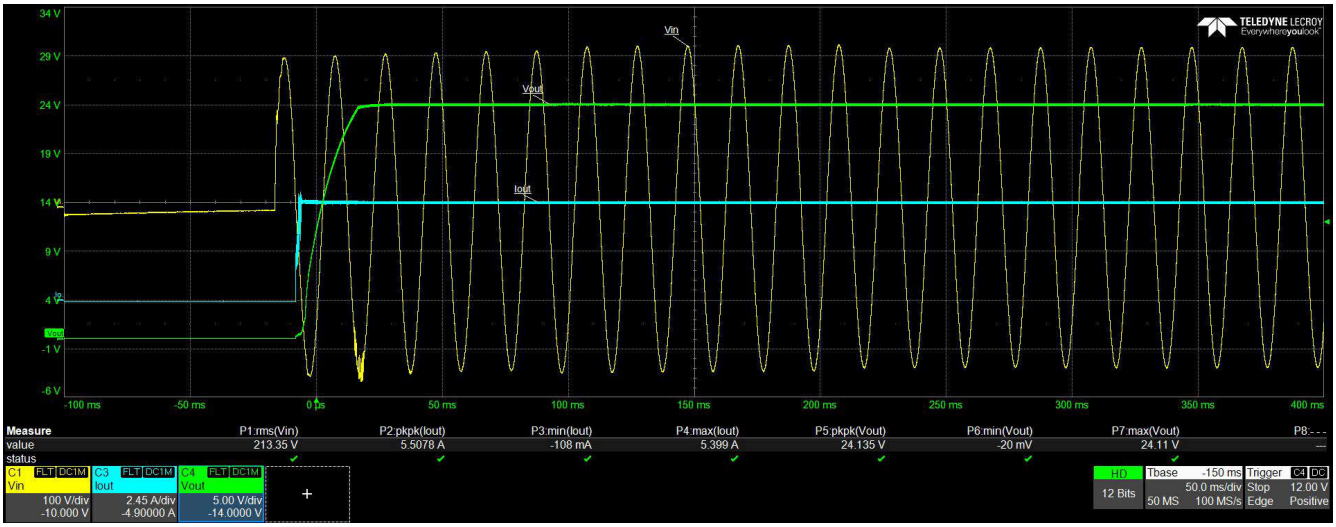
图 3-12. 115VAC/60Hz，24V/5A 条件下的启动波形

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C1 = Vin（交流） C3 = Iout C4 = Vout

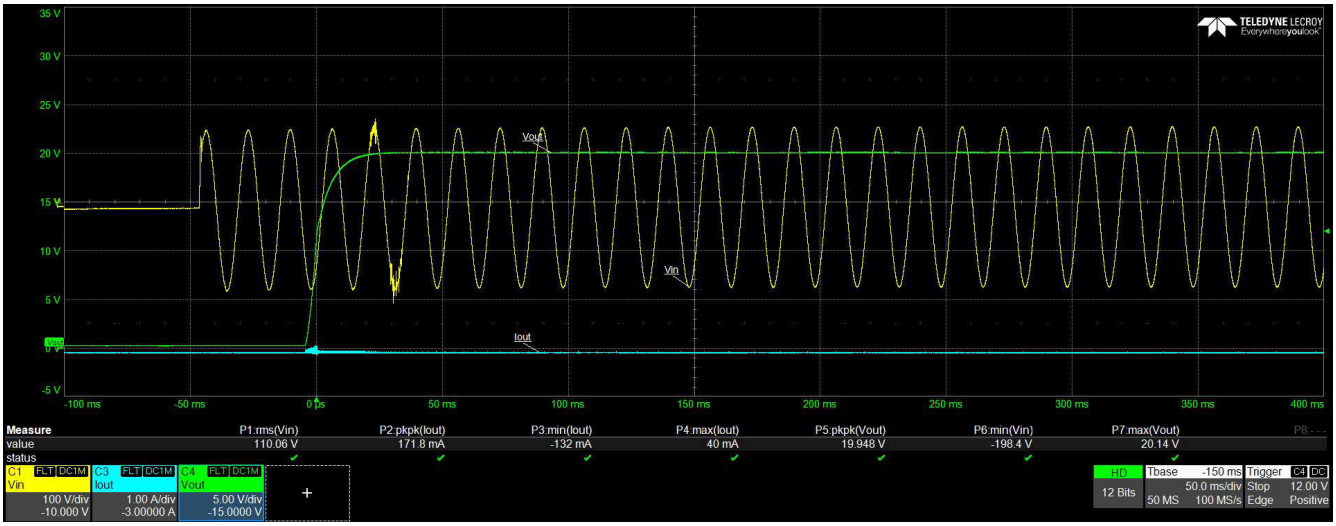
图 3-13. 230VAC/50Hz，24V/0A 条件下的启动波形



C1 = Vin（交流） C3 = Iout C4 = Vout

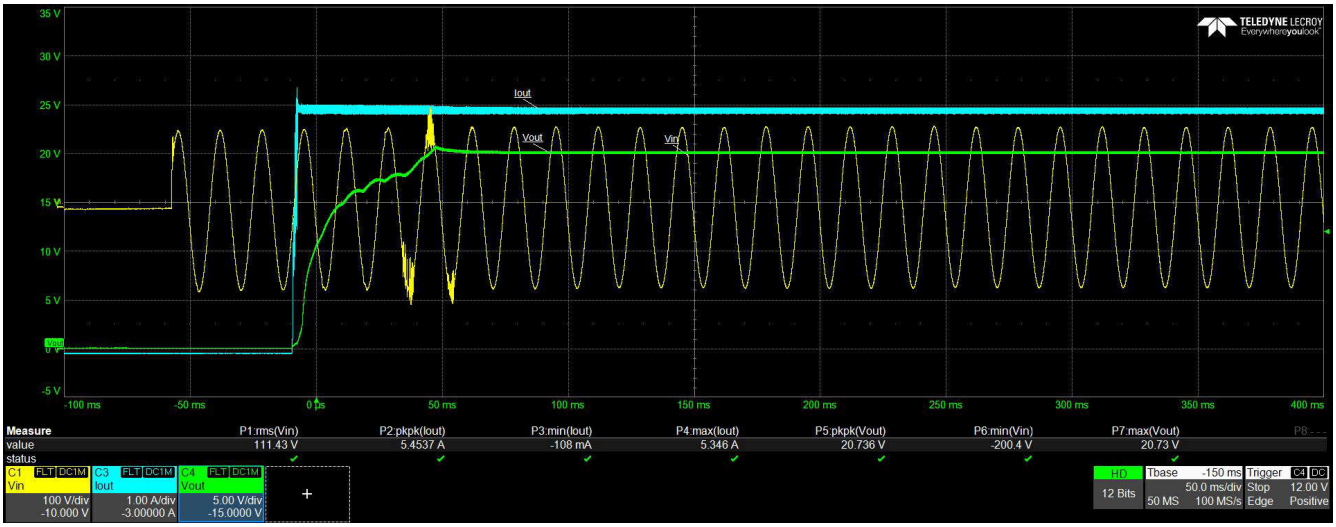
图 3-14. 230VAC/50Hz，24V/5A 条件下的启动波形

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C1 = Vin（交流） C3 = Iout C4 = Vout

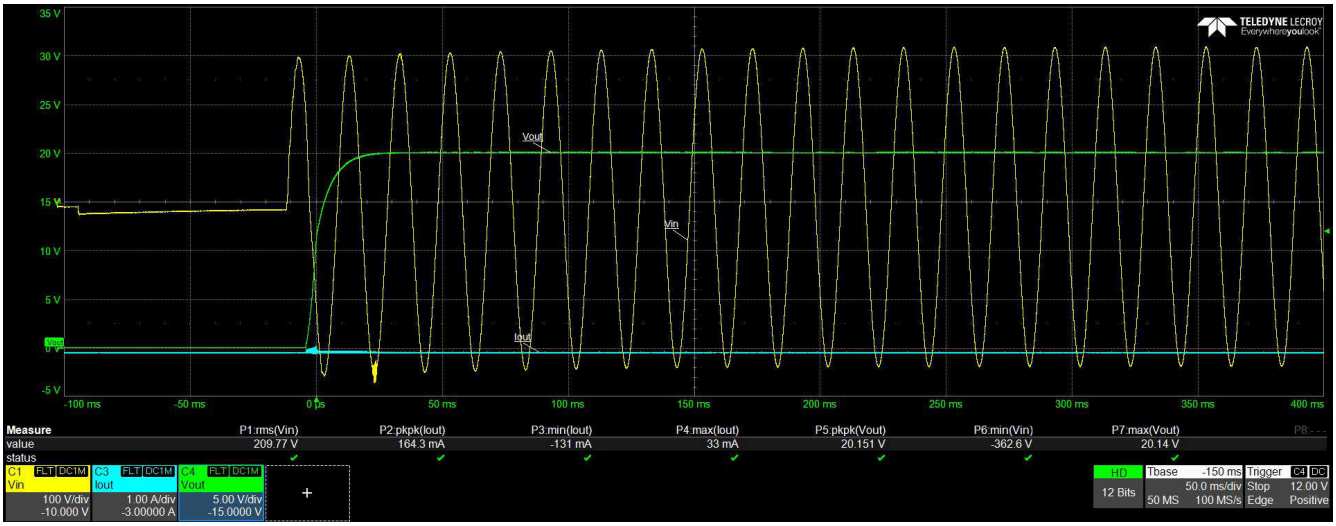
图 3-15. 115VAC/60Hz，20V/0A 条件下的启动波形



C1 = Vin（交流） C3 = Iout C4 = Vout

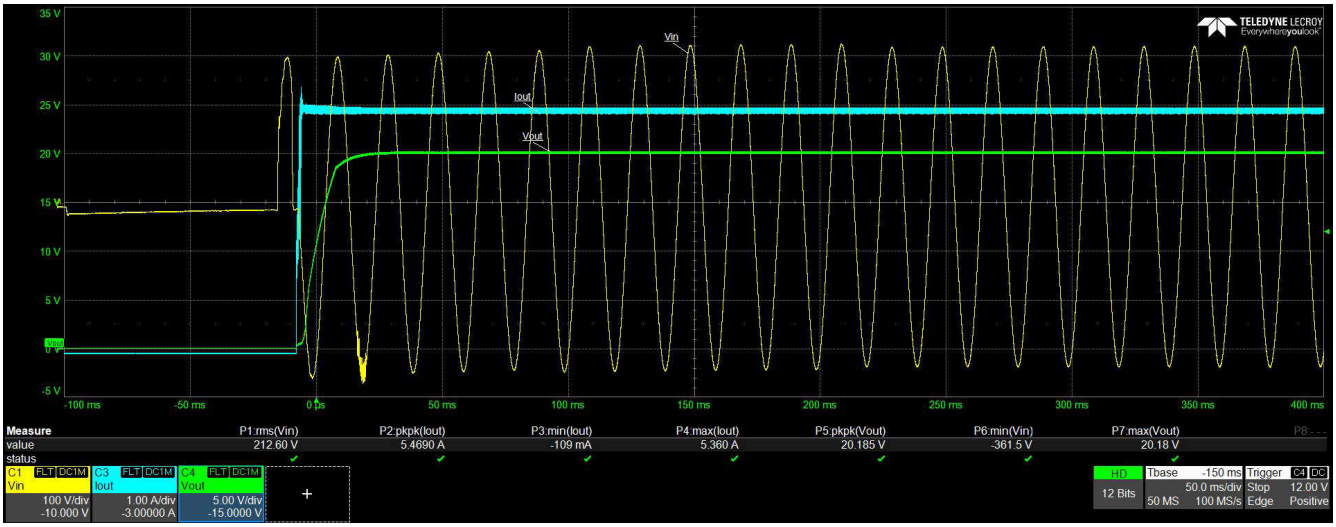
图 3-16. 115VAC/60Hz，20V/5A 条件下的启动波形

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C1 = Vin（交流） C3 = Iout C4 = Vout

图 3-17. 230VAC/50Hz，20V/0A 条件下的启动波形



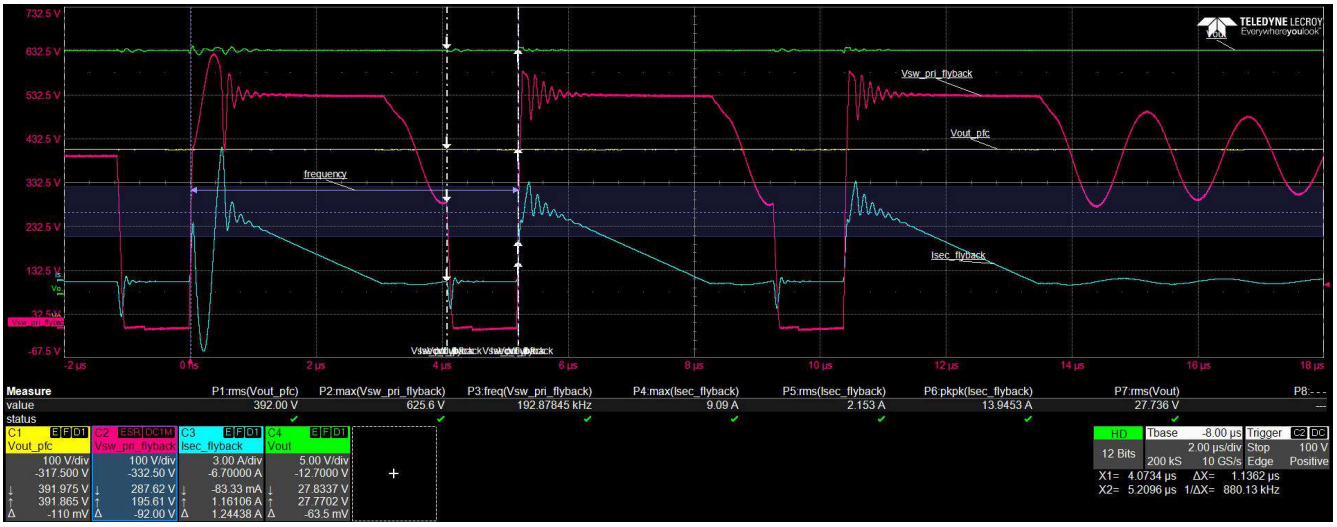
C1 = Vin（交流） C3 = Iout C4 = Vout

图 3-18. 230VAC/50Hz，20V/5A 条件下的启动波形

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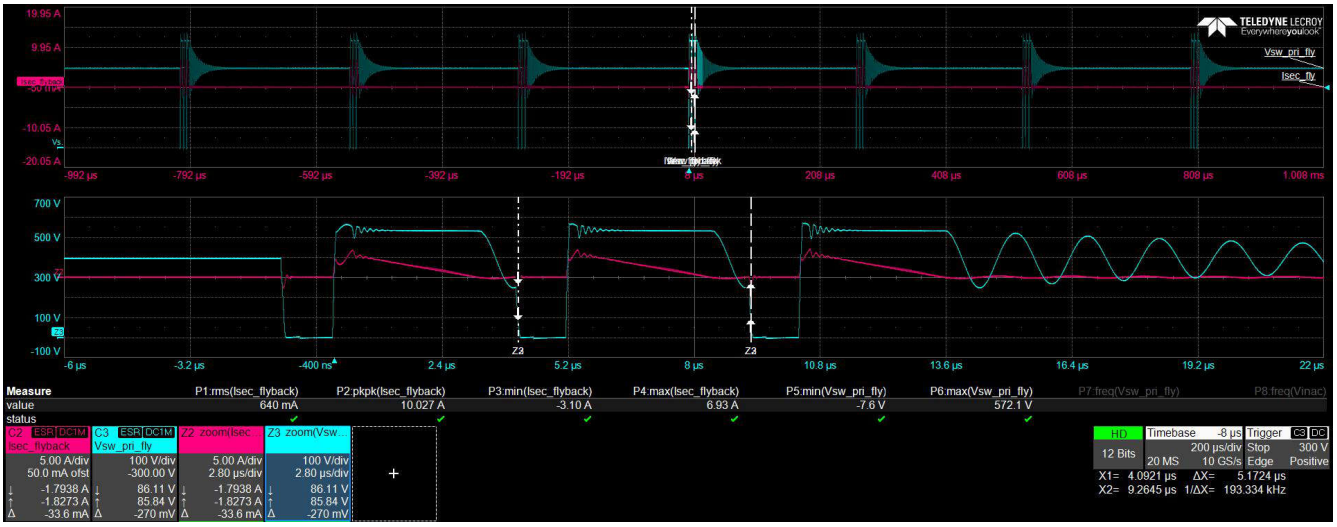
3.7 负载范围内的开关频率

以下波形显示了在 20V、24V 和 28V 输出设置下，UCG28828-1REZR 在负载范围内 115VAC/60Hz 和 230VAC/50Hz 工作点的开关行为。



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

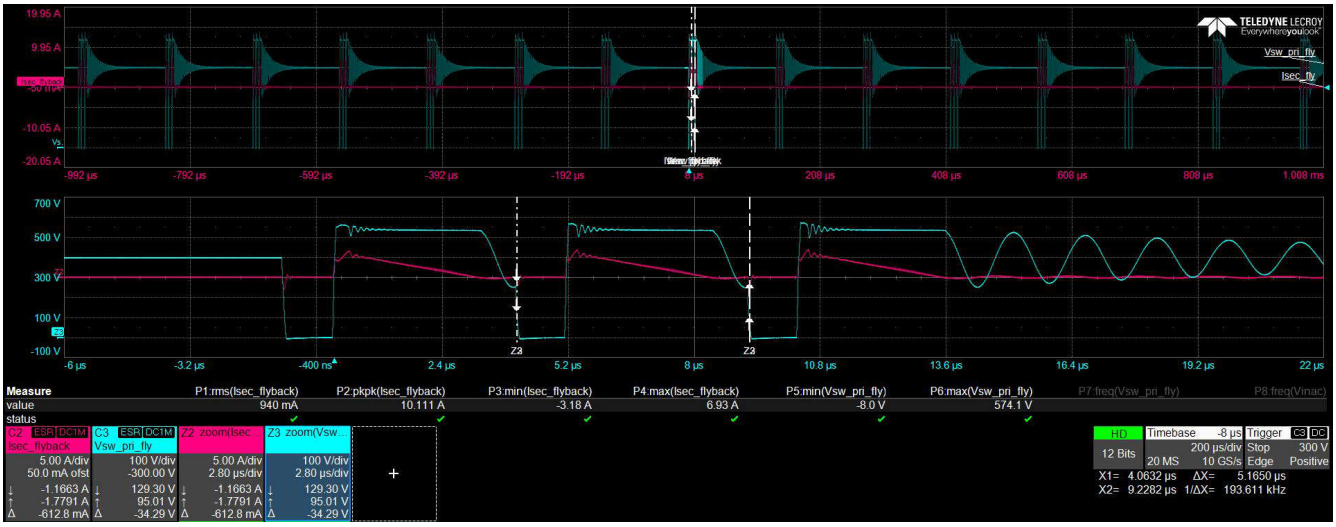
图 3-19. 在 V_{out} = 28V 和 I_{out} = 0A 条件下的开关行为



C2 = 反激式次级侧电流　　C3 = 反激式初级侧开关节点电压

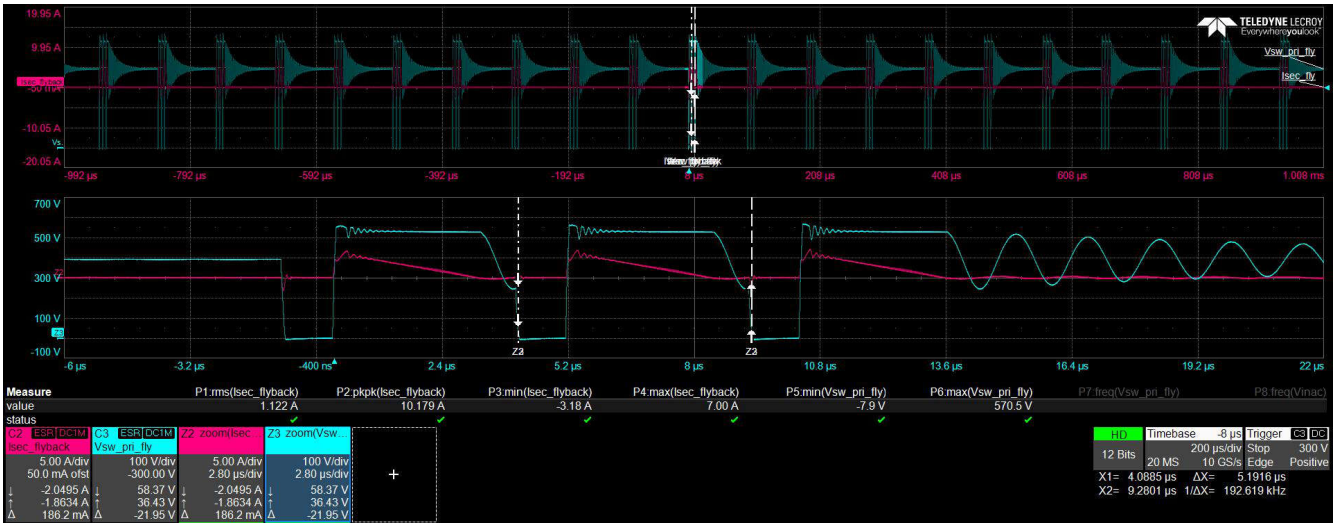
图 3-20. 在 V_{out} = 28V 和 I_{out} = 0.1A 条件下的开关行为

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C2 = 反激式次级侧电流　　C3 = 反激式初级侧开关节点电压

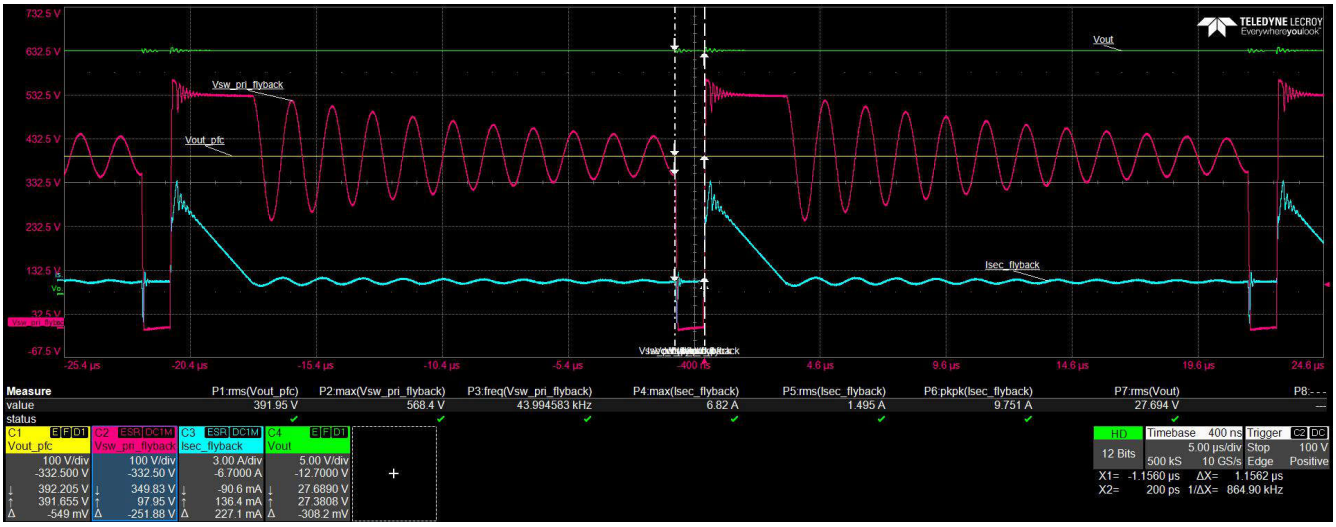
图 3-21. 在 V_{out} = 28V 和 I_{out} = 0.2A 条件下的开关行为



C2 = 反激式次级侧电流　　C3 = 反激式初级侧开关节点电压

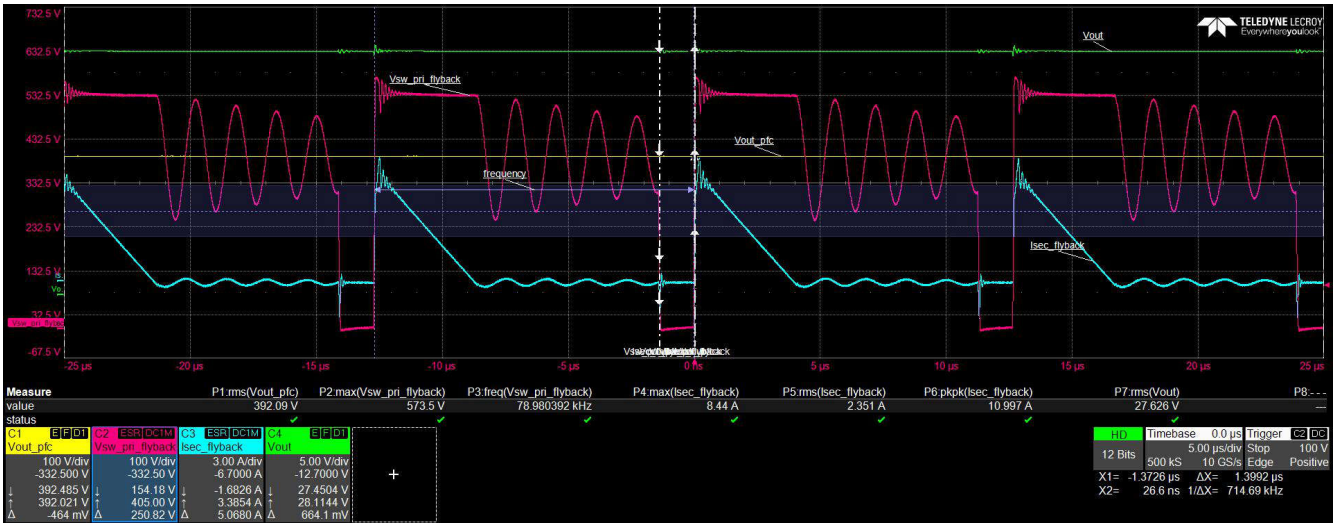
图 3-22. 在 V_{out} = 28V 和 I_{out} = 0.3A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

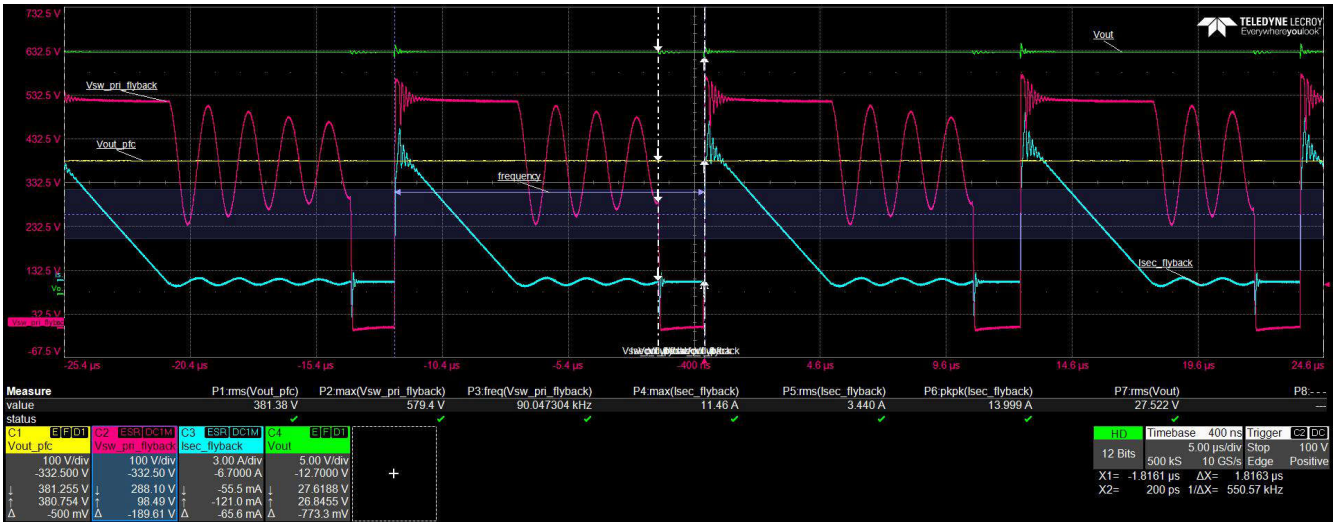
图 3-23. 在 V_{out} = 28V 和 I_{out} = 0.43A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

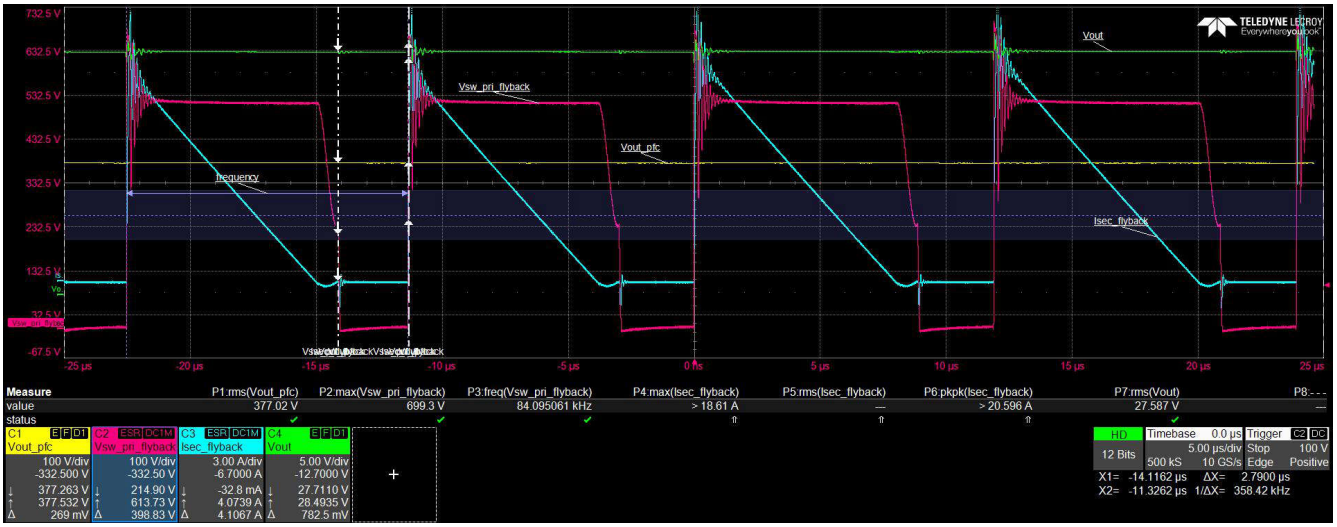
图 3-24. 在 V_{out} = 28V 和 I_{out} = 1.075A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

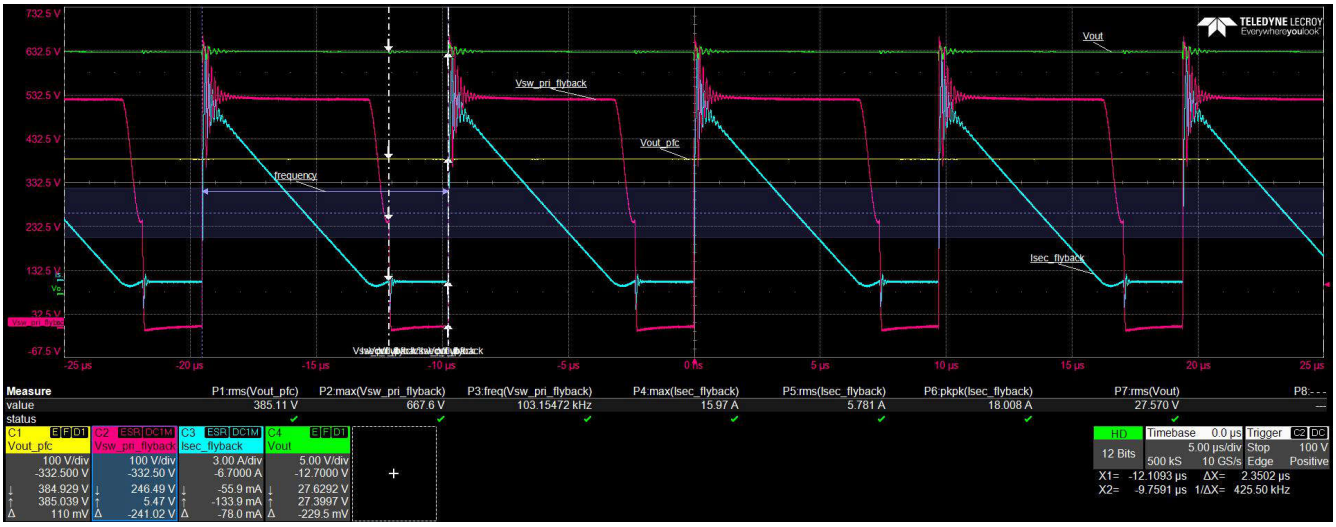
图 3-25. 在 V_{out} = 28V 和 I_{out} = 2.15A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

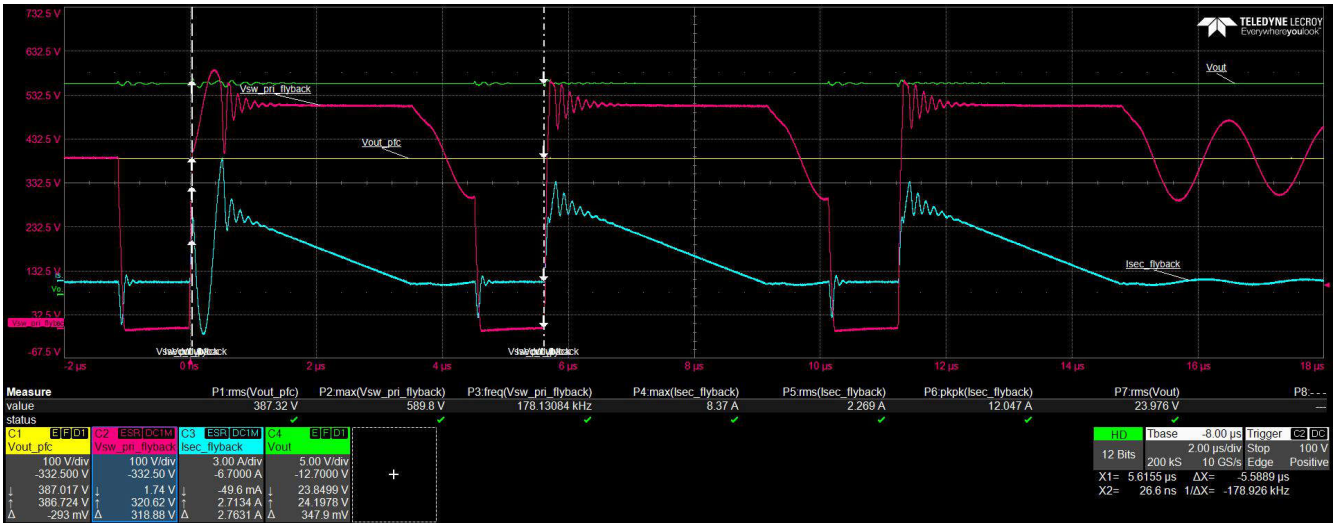
图 3-26. 在 V_{out} = 28V 和 I_{out} = 3.225A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

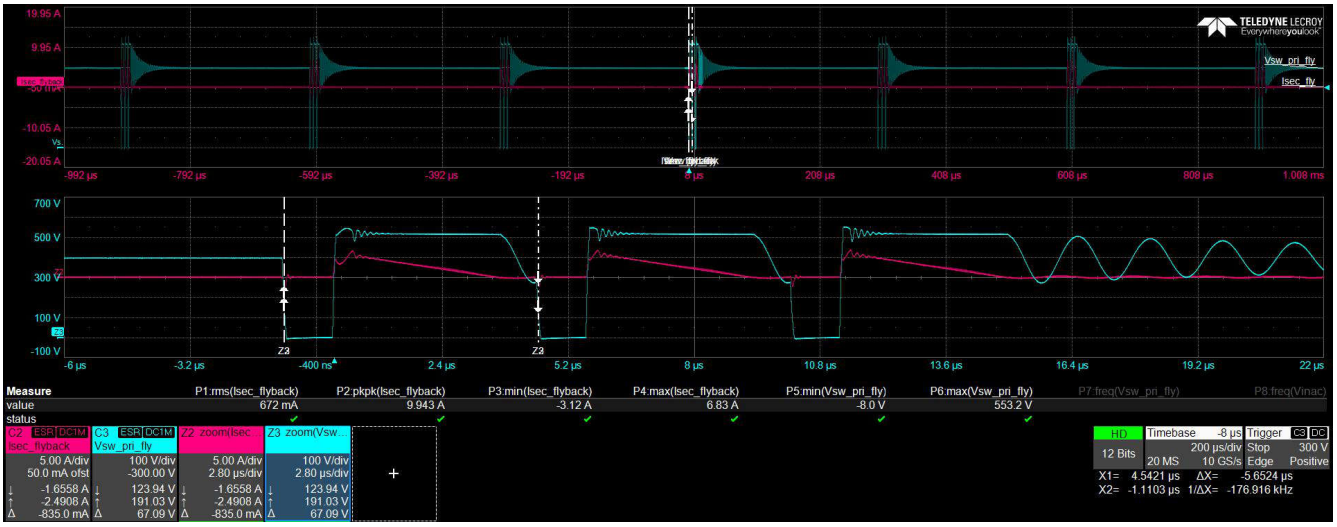
图 3-27. 在 V_{out} = 28V 和 I_{out} = 4.3A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

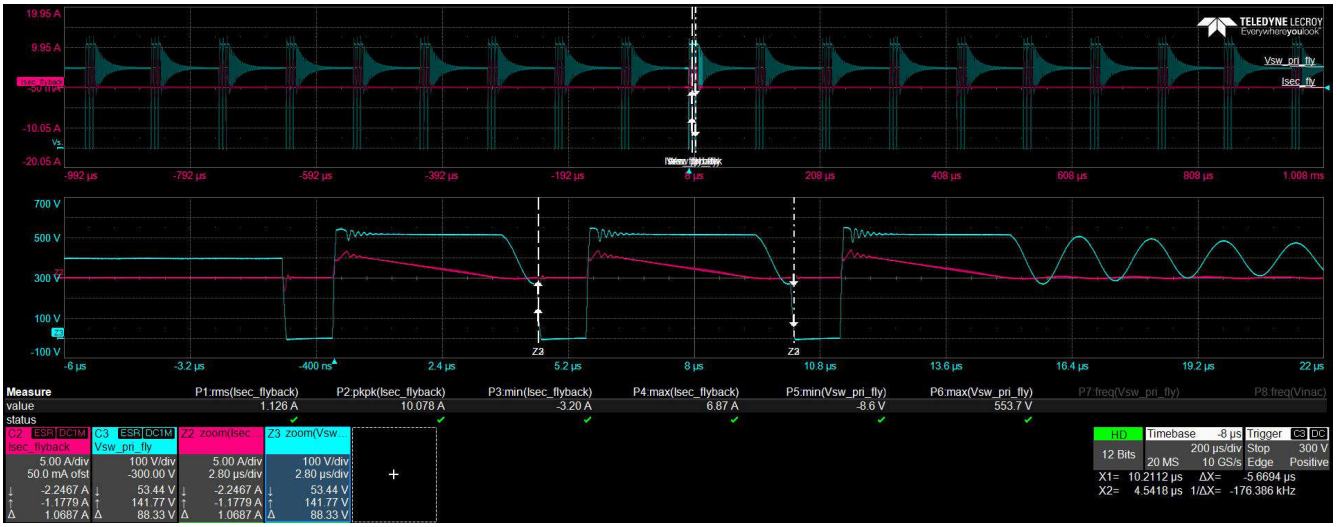
图 3-28. 在 V_{out} = 24V 和 I_{out} = 0A 条件下的开关行为

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C2 = 反激式次级侧电流　　C3 = 反激式初级侧开关节点电压

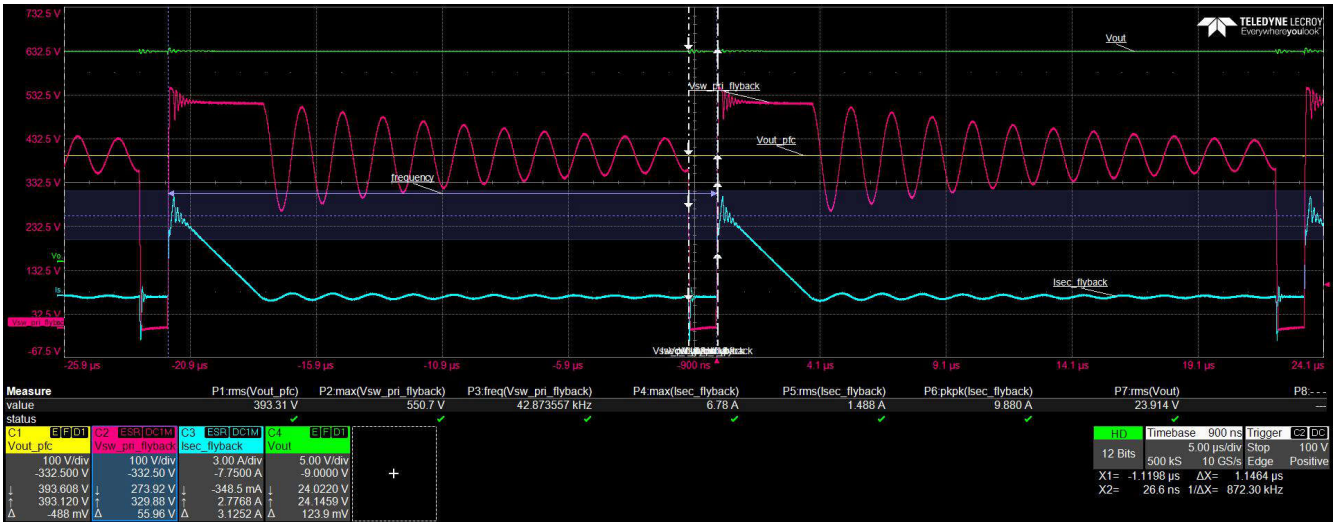
图 3-29. 在 V_{out} = 24V 和 I_{out} = 0.1A 条件下的开关行为



C2 = 反激式次级侧电流　　C3 = 反激式初级侧开关节点电压

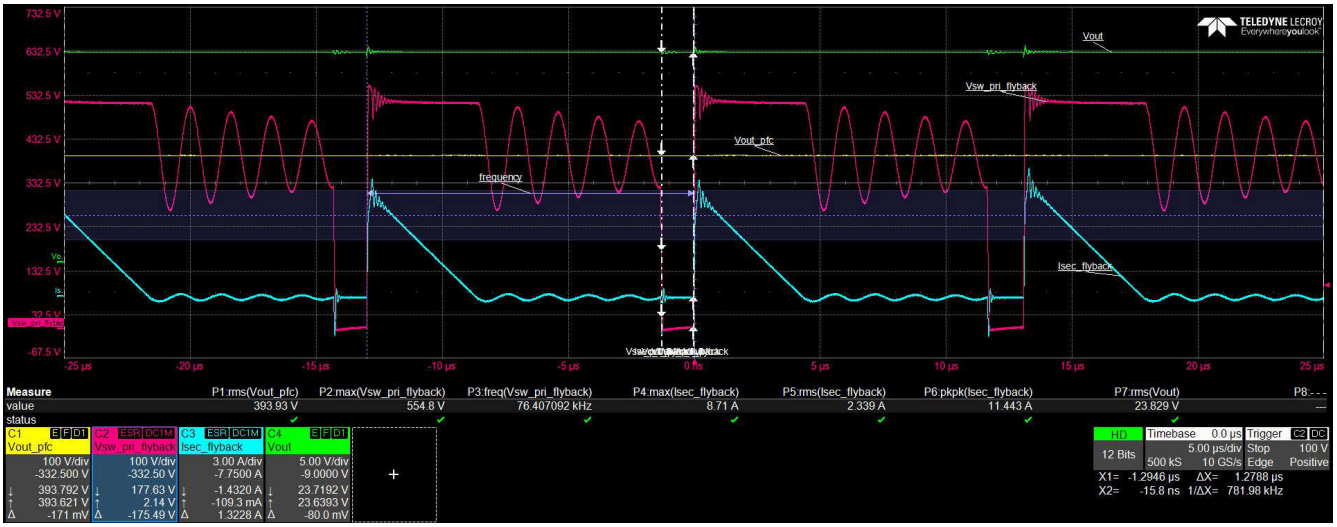
图 3-30. 在 V_{out} = 24V 和 I_{out} = 0.3A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

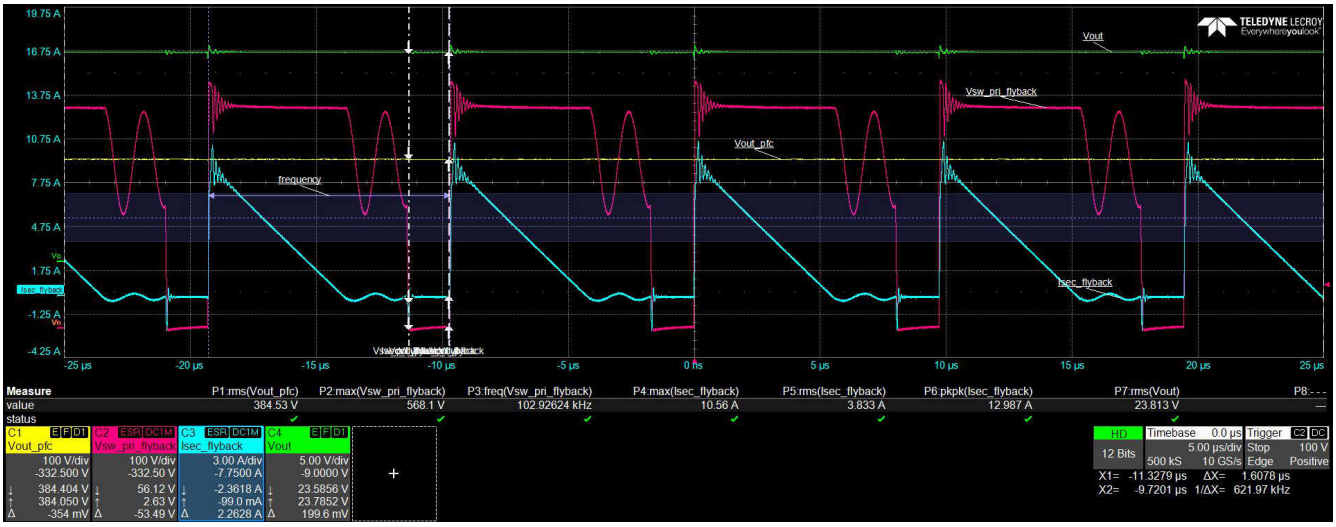
图 3-31. 在 V_{out} = 24V 和 I_{out} = 0.5A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

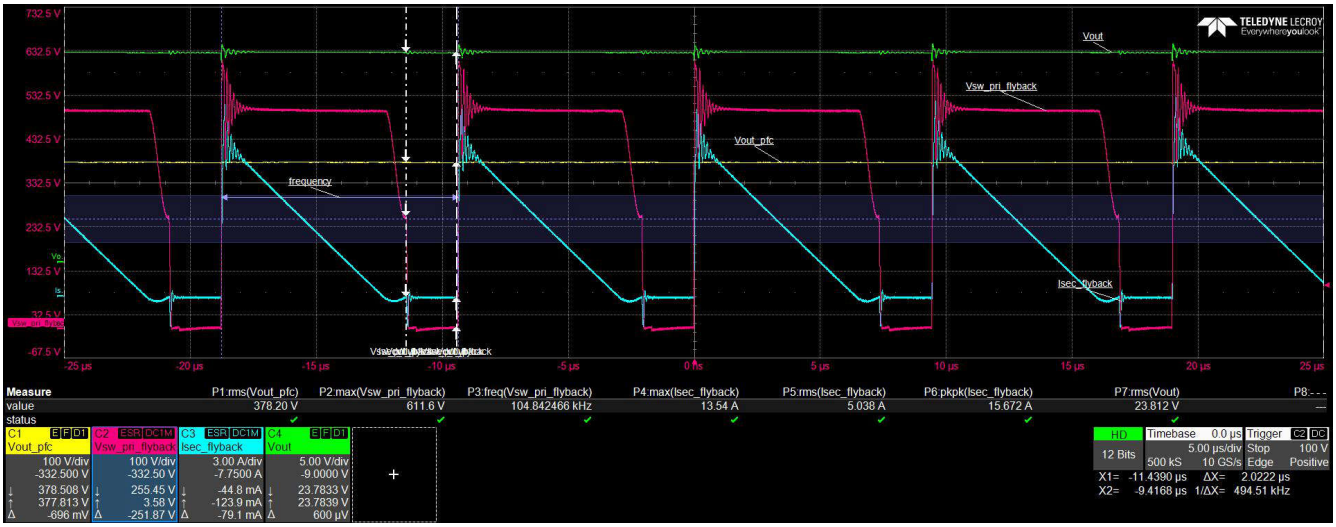
图 3-32. 在 V_{out} = 24V 和 I_{out} = 1.25A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

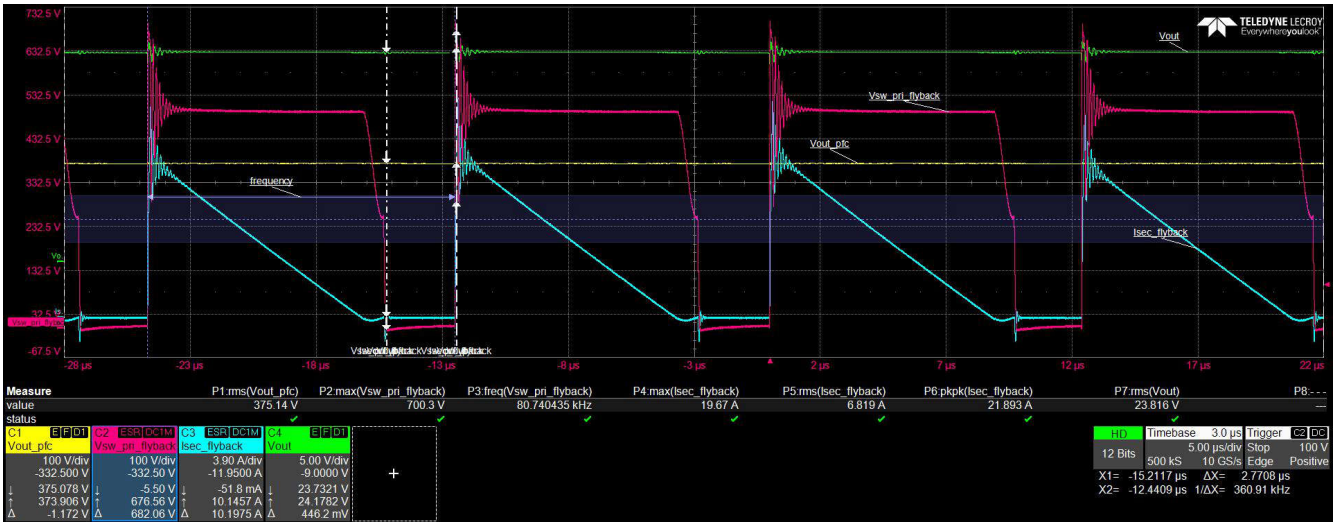
图 3-33. 在 V_{out} = 24V 和 I_{out} = 2.5A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

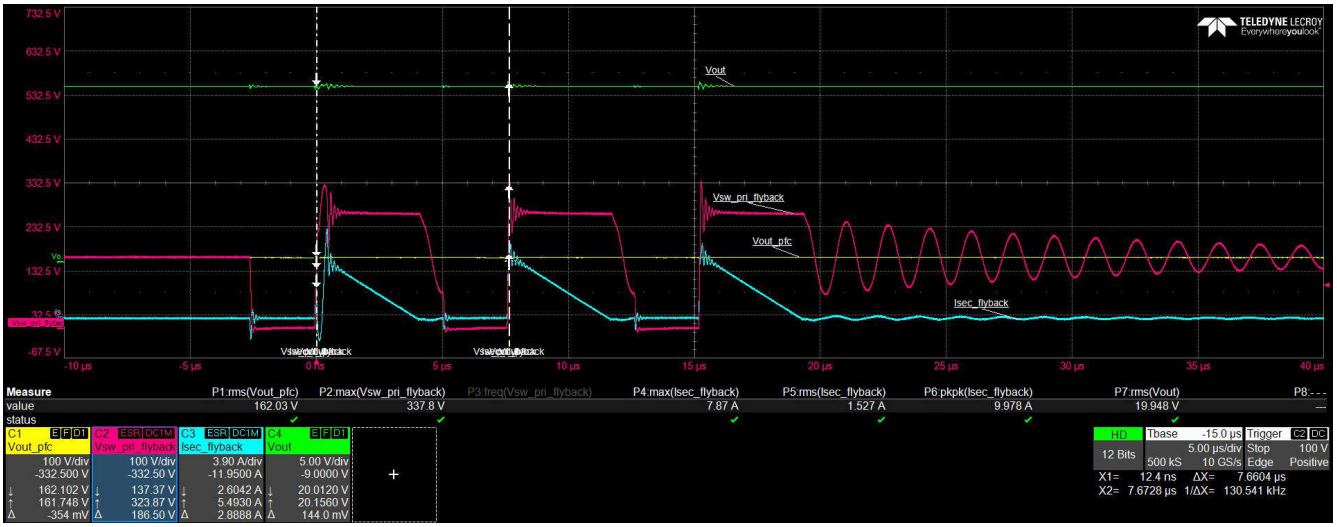
图 3-34. 在 V_{out} = 24V 和 I_{out} = 3.75A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

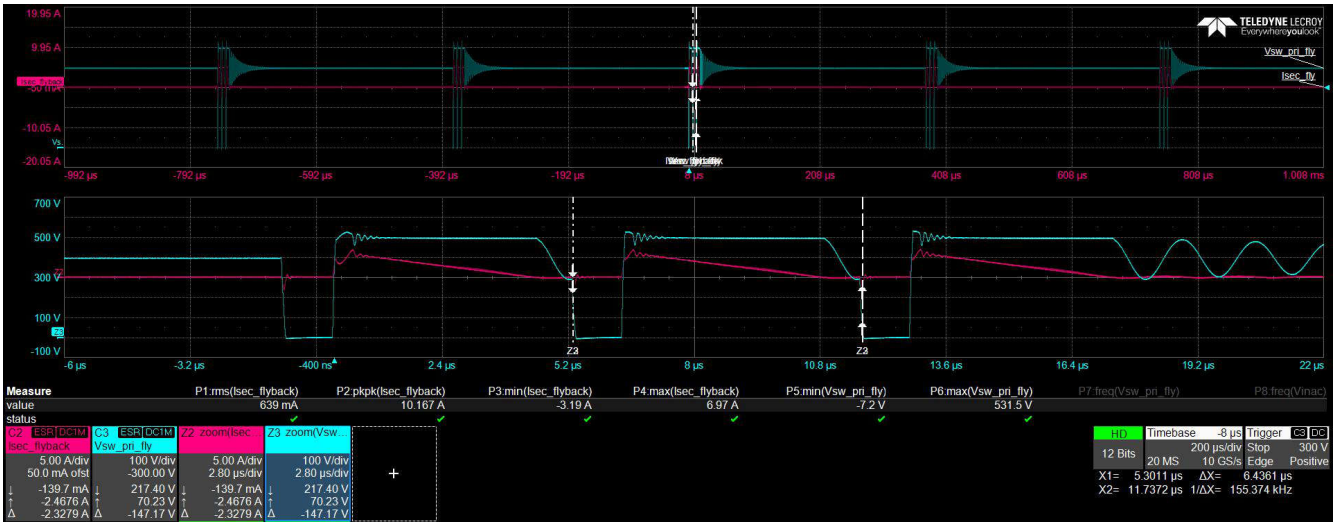
图 3-35. 在 V_{out} = 24V 和 I_{out} = 5A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

图 3-36. 在 V_{out} = 20V 和 I_{out} = 0A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

图 3-37. 在 V_{out} = 20V 和 I_{out} = 0.1A 条件下的开关行为

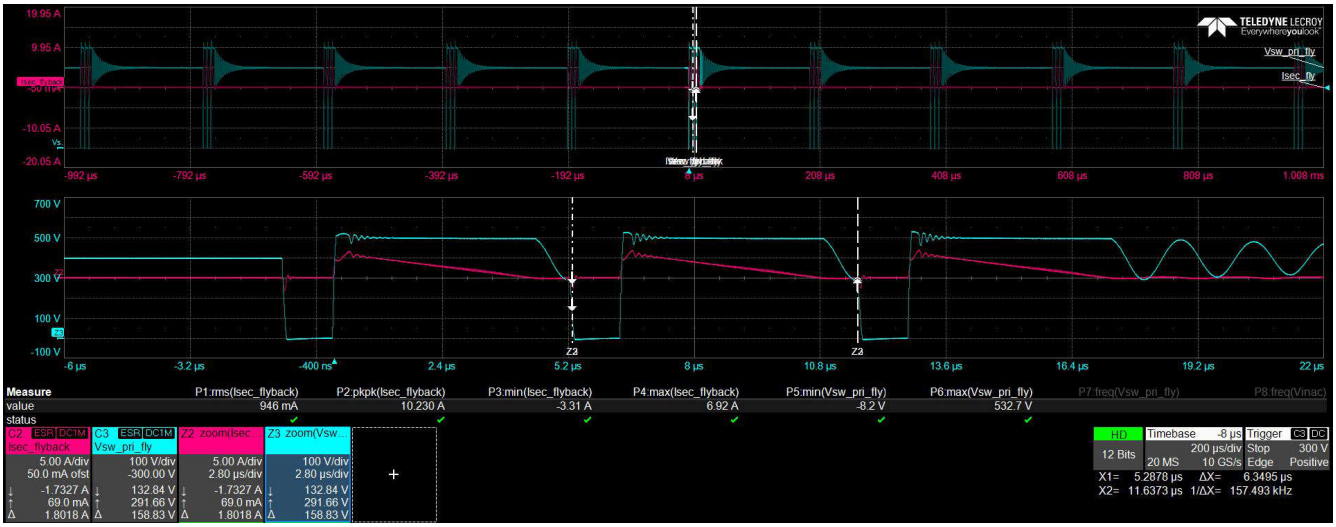


图 3-38. 在 V_{out} = 20V 和 I_{out} = 0.2A 条件下的开关行为

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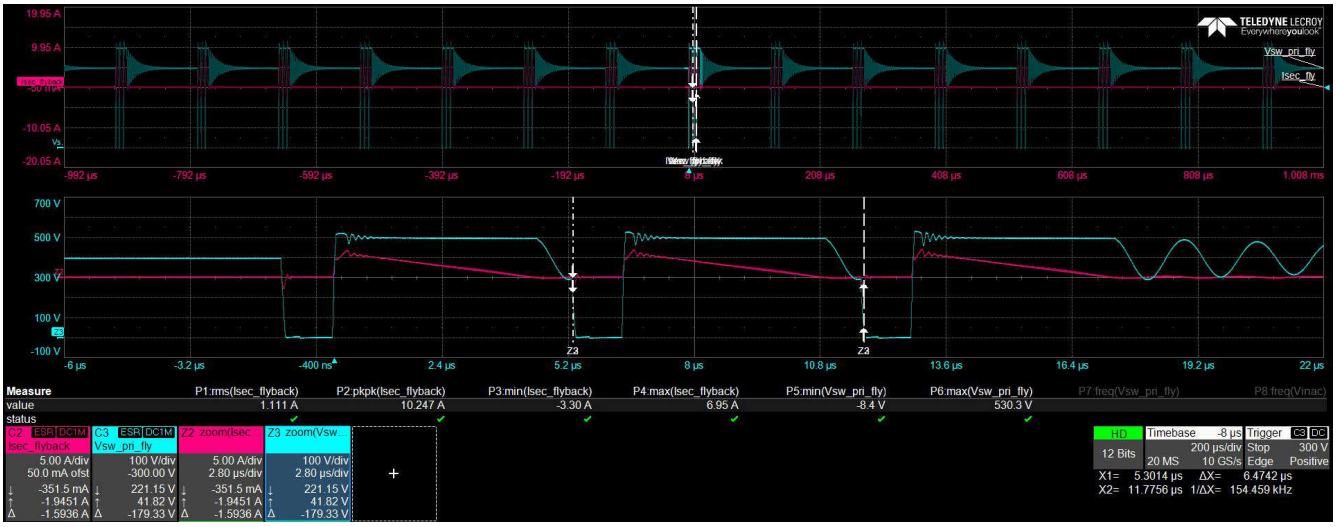
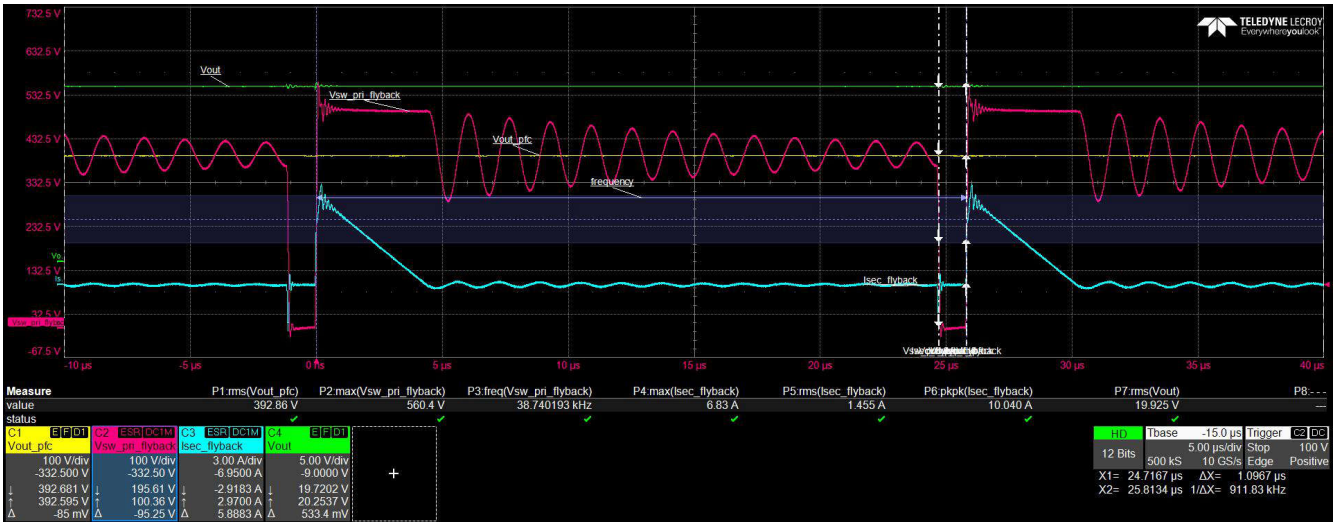


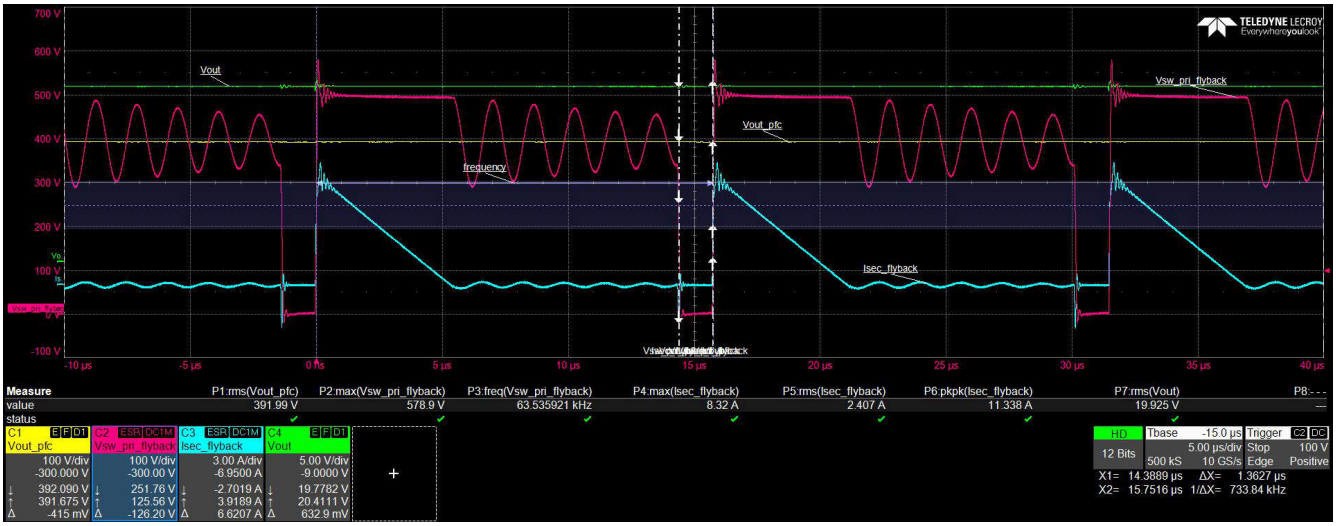
图 3-39. 在 V_{out} = 20V 和 I_{out} = 0.3A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

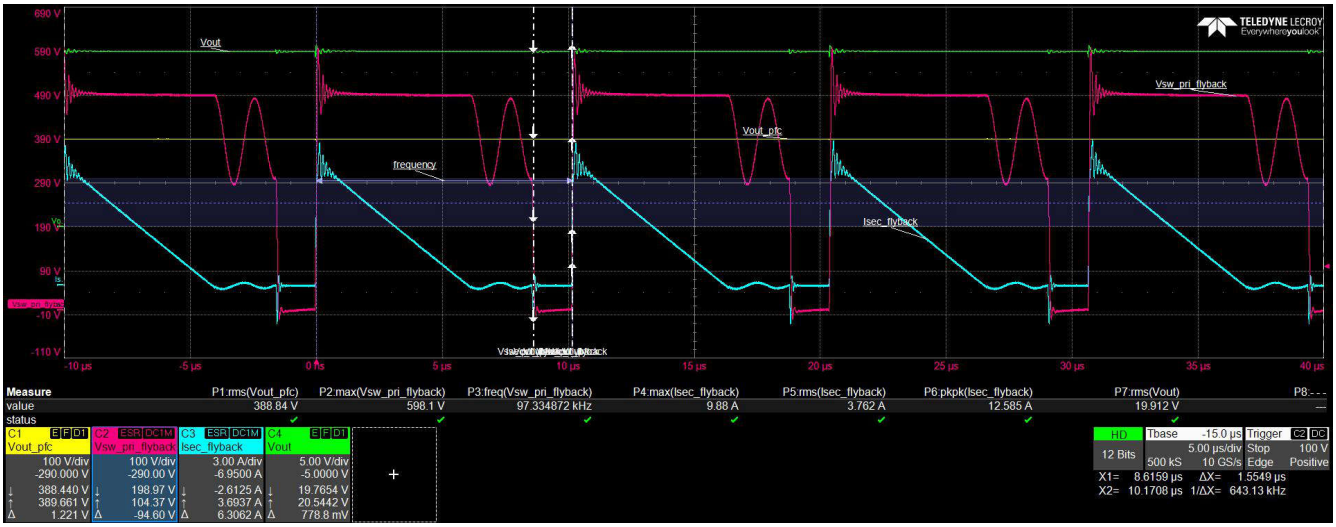
图 3-40. 在 V_{out} = 20V 和 I_{out} = 0.5A 条件下的开关行为

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C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

图 3-41. 在 V_{out} = 20V 和 I_{out} = 1.25A 条件下的开关行为



C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

图 3-42. 在 V_{out} = 20V 和 I_{out} = 2.5A 条件下的开关行为

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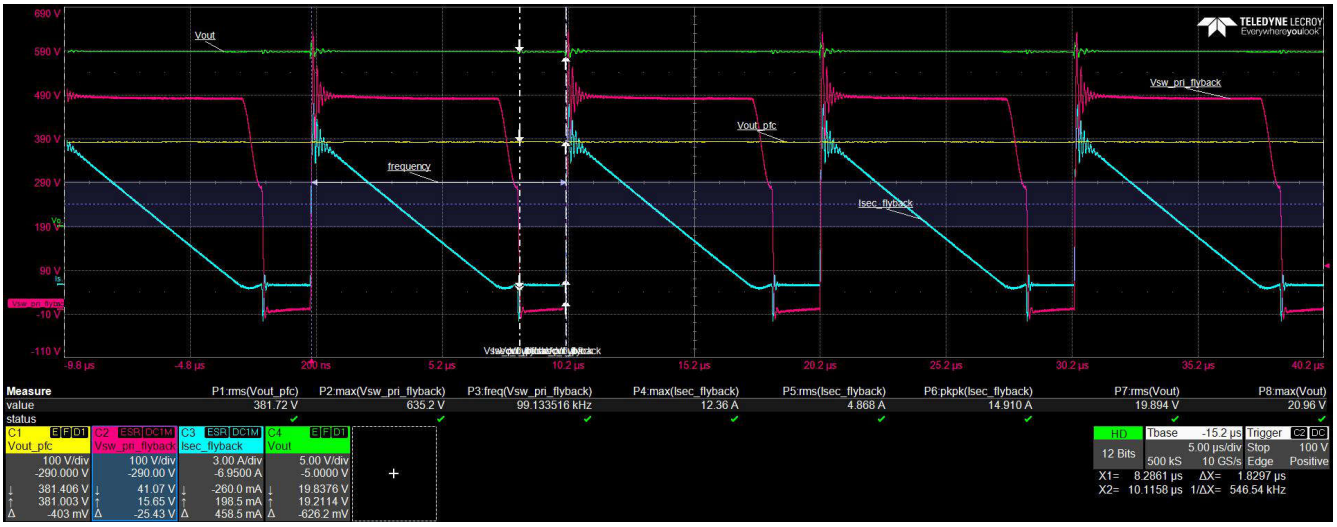
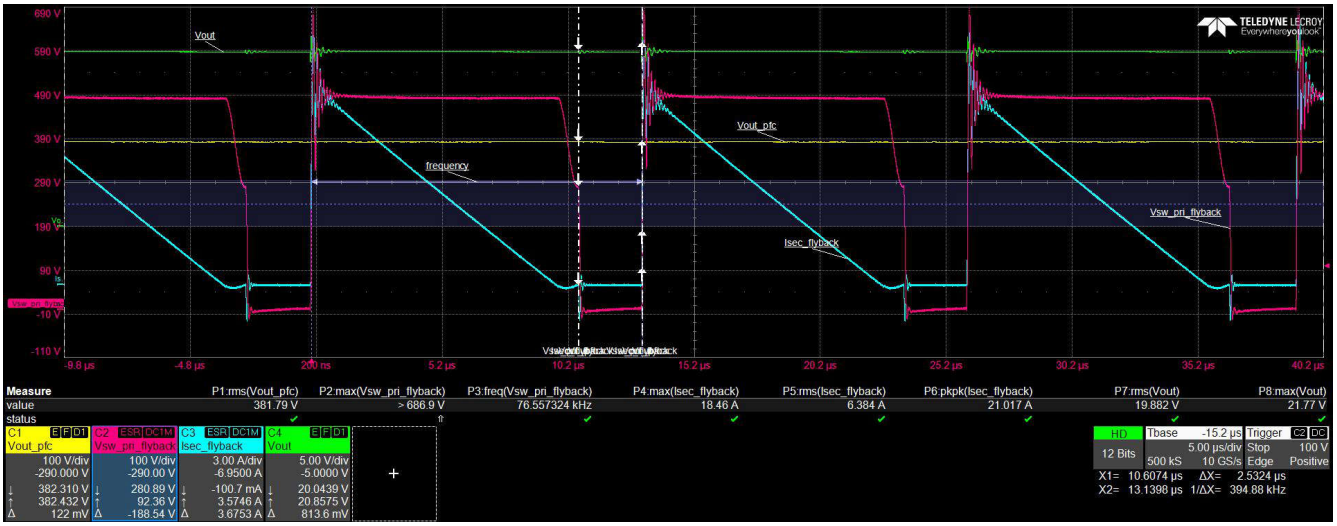


图 3-43. 在 V_{out} = 20V 和 I_{out} = 3.75A 条件下的开关行为



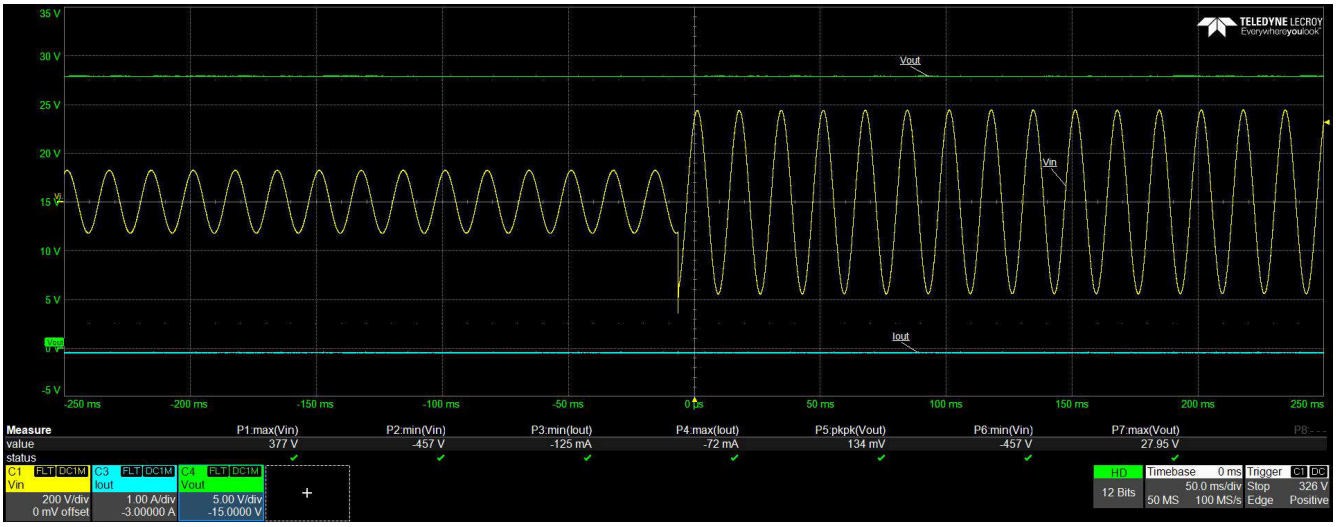
C1 = PFC 输出电压　　C2 = 反激式初级侧开关节点电压　　C3 = 反激式次级侧电流　　C4 = 输出电压

图 3-44. 在 V_{out} = 20V 和 I_{out} = 5A 条件下的开关行为

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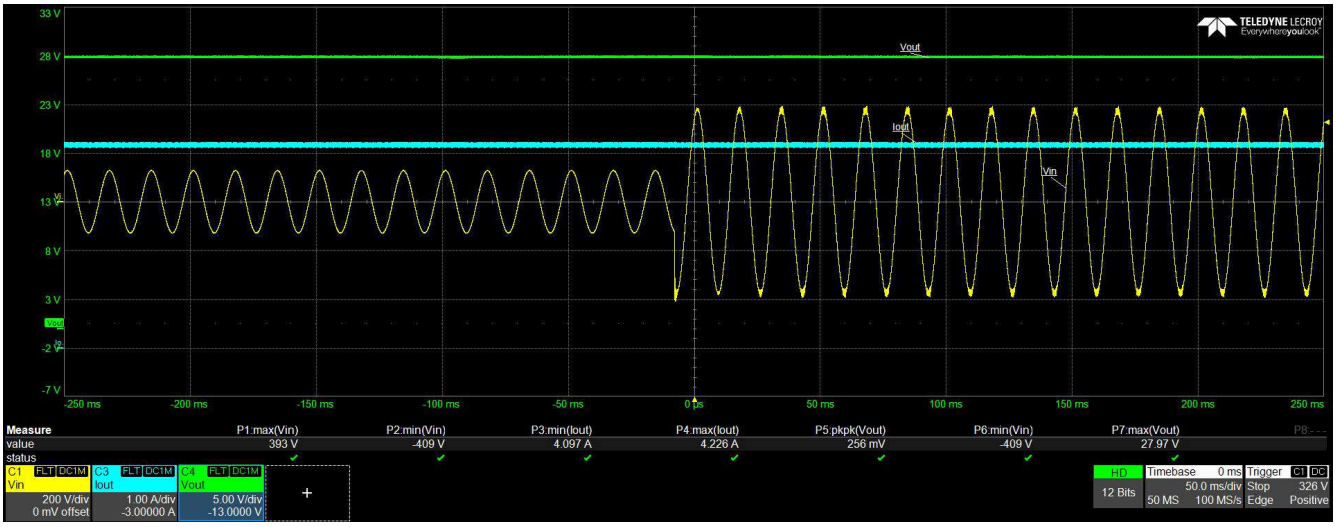
3.8 线路瞬态响应

本部分演示了 EVM 能够在交流输入电压发生较大变化时，保持稳定的直流输出电压。波形显示了当输入电压在 60Hz 频率下从最低 90VAC 阶跃至最高 264VAC 时，系统的响应情况。



C1 = 交流输入电压　　C3 = 反激式输出电流　　C4 = 反激式输出电压

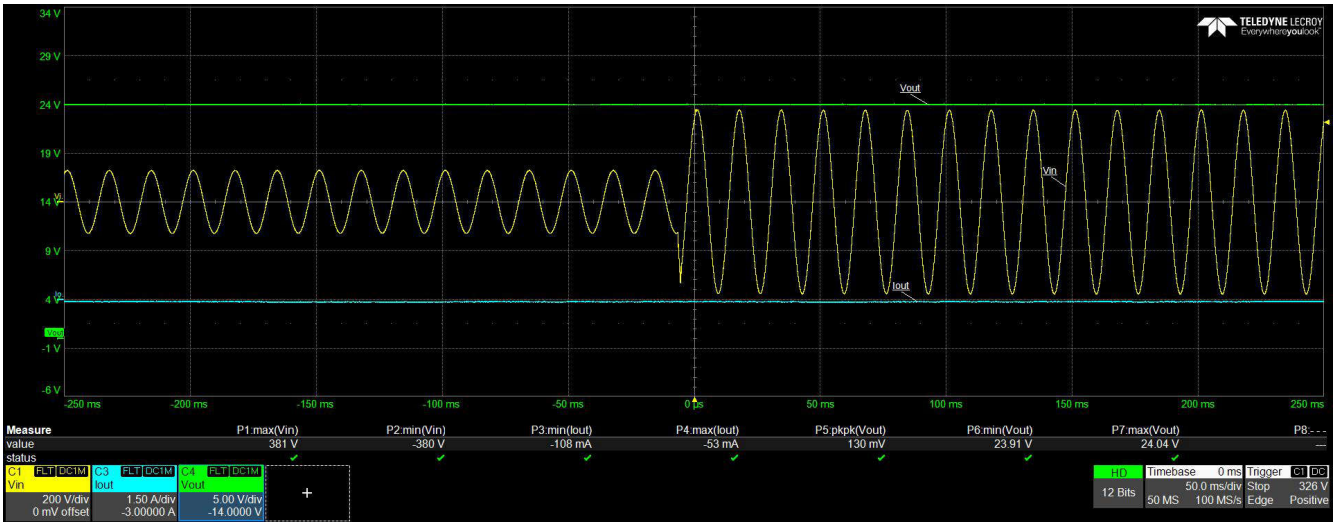
图 3-45. 线路瞬态波形：V_{in} = 90VAC 至 264VAC/60Hz、V_{out} = 28V 和 I_{out} = 0A



C1 = 交流输入电压　　C3 = 反激式输出电流　　C4 = 反激式输出电压

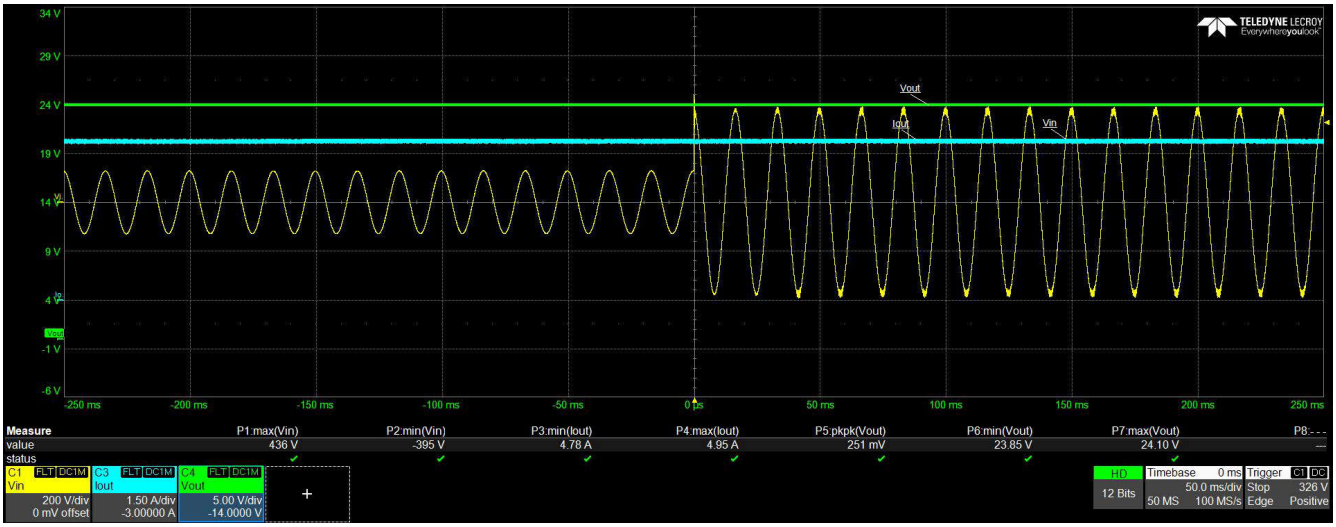
图 3-46. 线路瞬态波形：V_{in} = 90VAC 至 264VAC/60Hz、V_{out} = 28V 和 I_{out} = 4.3A

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C1 = 交流输入电压　　C3 = 反激式输出电流　　C4 = 反激式输出电压

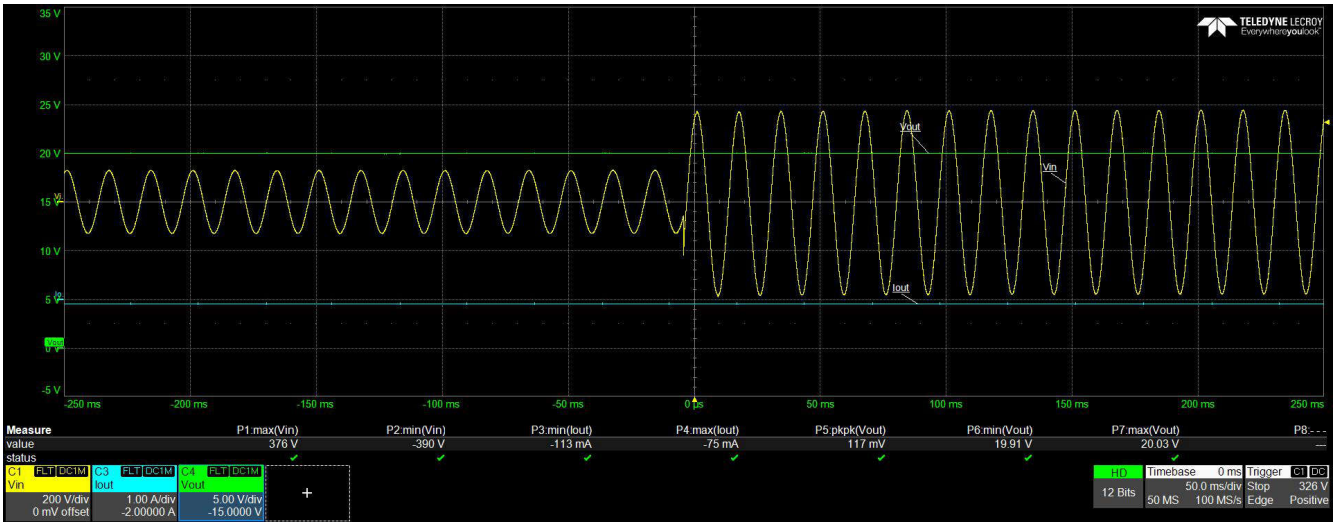
图 3-47. 线路瞬态波形：V_{in} = 90VAC 至 264VAC/60Hz、V_{out} = 24V 和 I_{out} = 0A



C1 = 交流输入电压　　C3 = 反激式输出电流　　C4 = 反激式输出电压

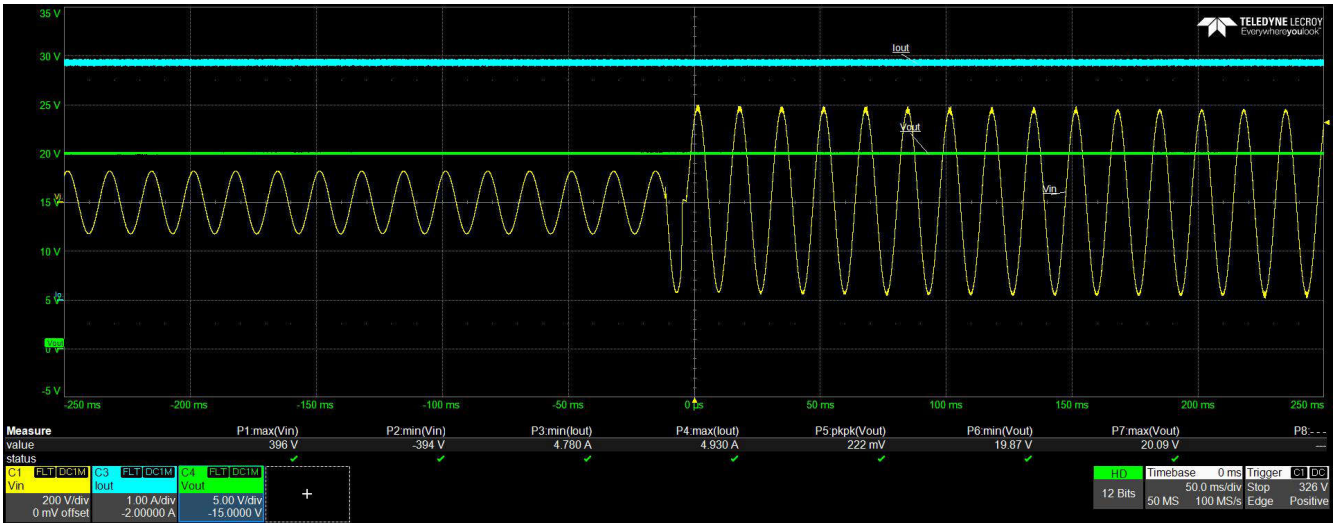
图 3-48. 线路瞬态波形：V_{in} = 90VAC 至 264VAC/60Hz、V_{out} = 24V 和 I_{out} = 5A

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C1 = 交流输入电压　　C3 = 反激式输出电流　　C4 = 反激式输出电压

图 3-49. 线路瞬态波形：V_{in} = 90VAC 至 264VAC/60Hz、V_{out} = 20V 和 I_{out} = 0A



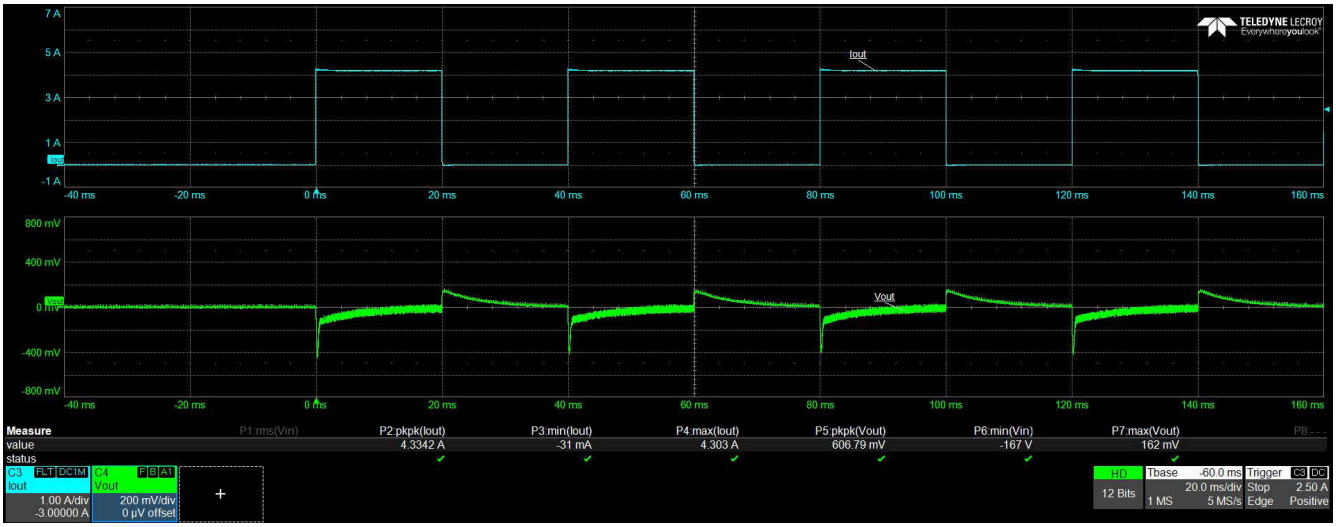
C1 = 交流输入电压　　C3 = 反激式输出电流　　C4 = 反激式输出电压

图 3-50. 线路瞬态波形：V_{in} = 90VAC 至 264VAC/60Hz、V_{out} = 20V 和 I_{out} = 5A

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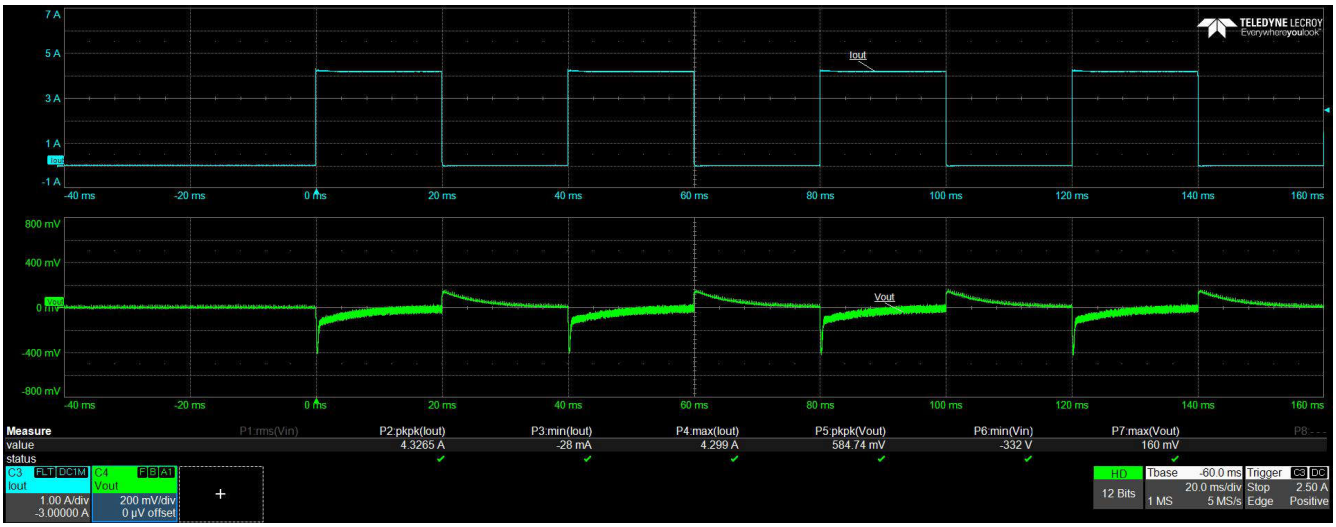
3.9 负载瞬态波形

本部分演示了 EVM 在 25Hz 频率下，在 2% 至 100% 负载的阶跃负载瞬态期间，以 2.5A/μs 的压摆率（上升沿和下降沿）保持稳定的直流输出电压的能力。以下波形适用于 115VAC/60Hz 输入和 230VAC/50Hz 输入以及 28V/24V/20V 输出。



C3 = 反激式输出电流　　C4 = 反激式输出电压

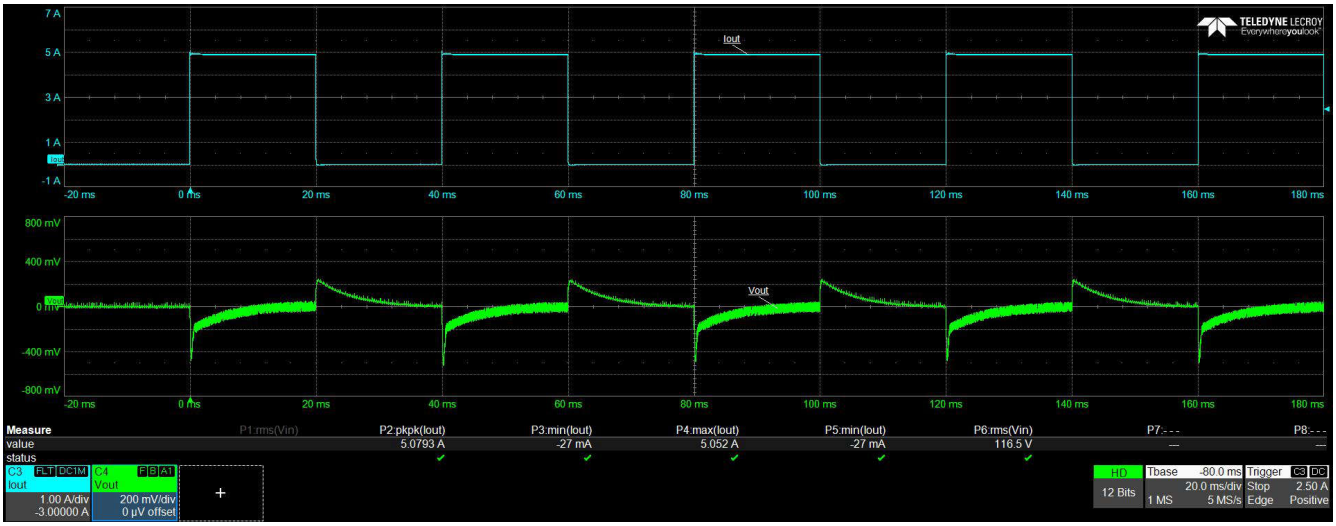
图 3-51. 115VAC/60Hz 且输出 28V/0.1A 至 4.3A 时的瞬态波形



C3 = 反激式输出电流　　C4 = 反激式输出电压

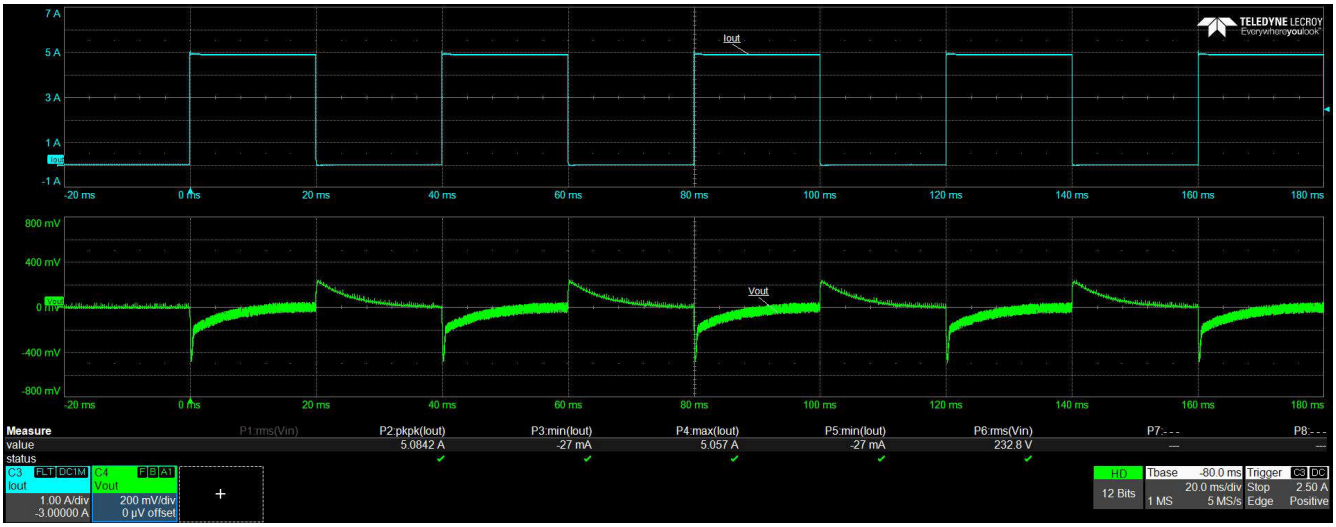
图 3-52. 230VAC/50Hz 且输出 28V/0.1A 至 4.3A 时的瞬态波形

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C3 = 反激式输出电流　　C4 = 反激式输出电压

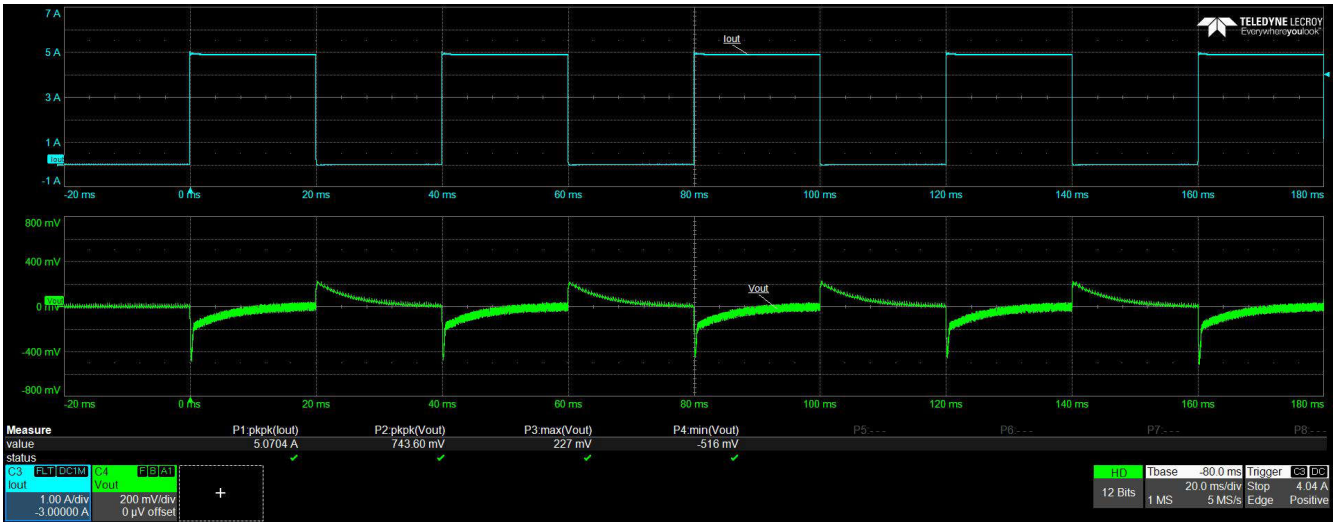
图 3-53. 115VAC/60Hz 且输出 24V/0.1A 至 5A 时的瞬态波形



C3 = 反激式输出电流　　C4 = 反激式输出电压

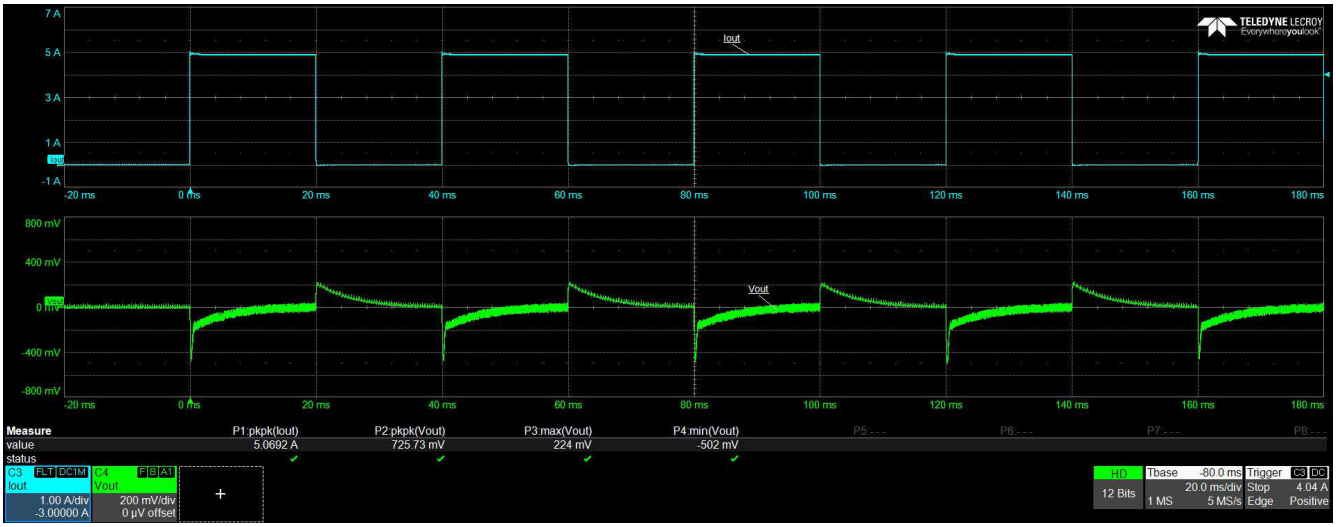
图 3-54. 230VAC/50Hz 且输出 24V/0.1A 至 5A 时的瞬态波形

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C3 = 反激式输出电流　　C4 = 反激式输出电压

图 3-55. 115VAC/60Hz 且输出 20V/0.1A 至 5A 时的瞬态波形



C3 = 反激式输出电流　　C4 = 反激式输出电压

图 3-56. 230VAC/50Hz 且输出 20V/0.1A 至 5A 时的瞬态波形

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3.10 输出纹波电压

以下波形显示了在 20V，24V 和 28V 输出设置下，空载和满载条件下 115VAC/60Hz 和 230VAC/50Hz 的输出电压纹波。在此，C4 — 输出电压纹波，示波器通道带宽 = 20MHz 和示波器探头采用交流耦合方式。

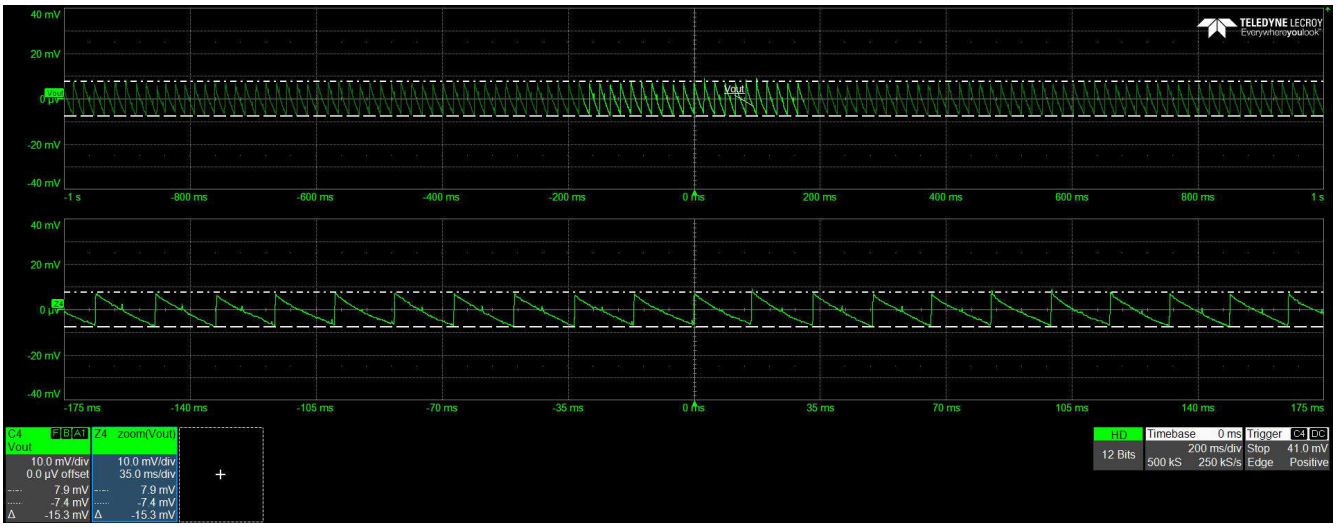


图 3-57. 输入 = 115VAC/60Hz 且输出 = 28V/0A 时的输出电压纹波

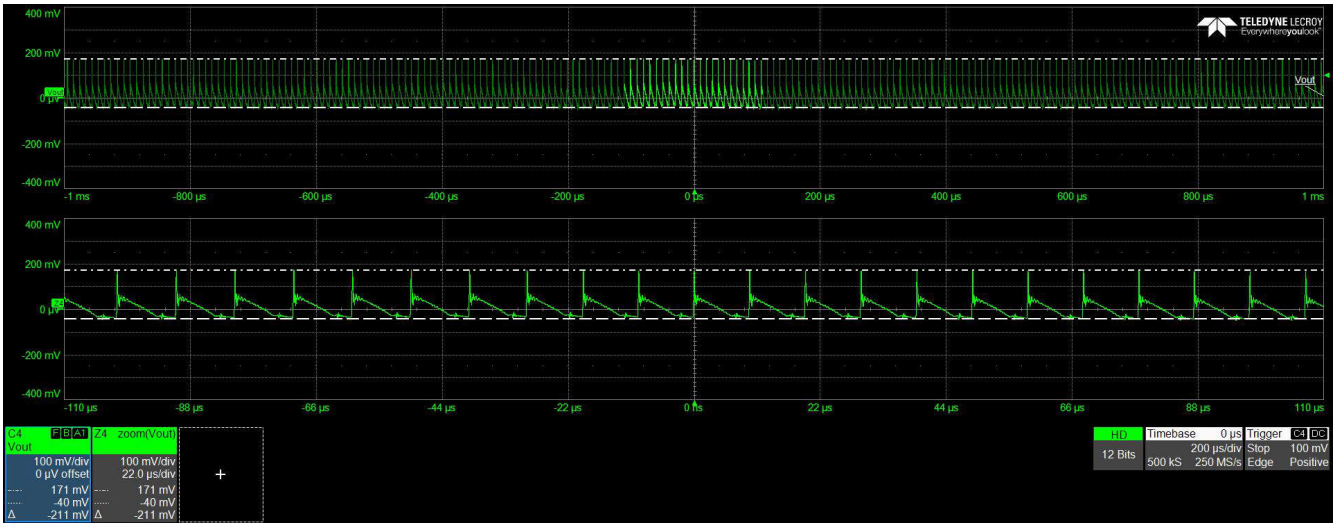


图 3-58. 输入 = 115VAC/60Hz 且输出 = 28V/4.3A 时的输出电压纹波

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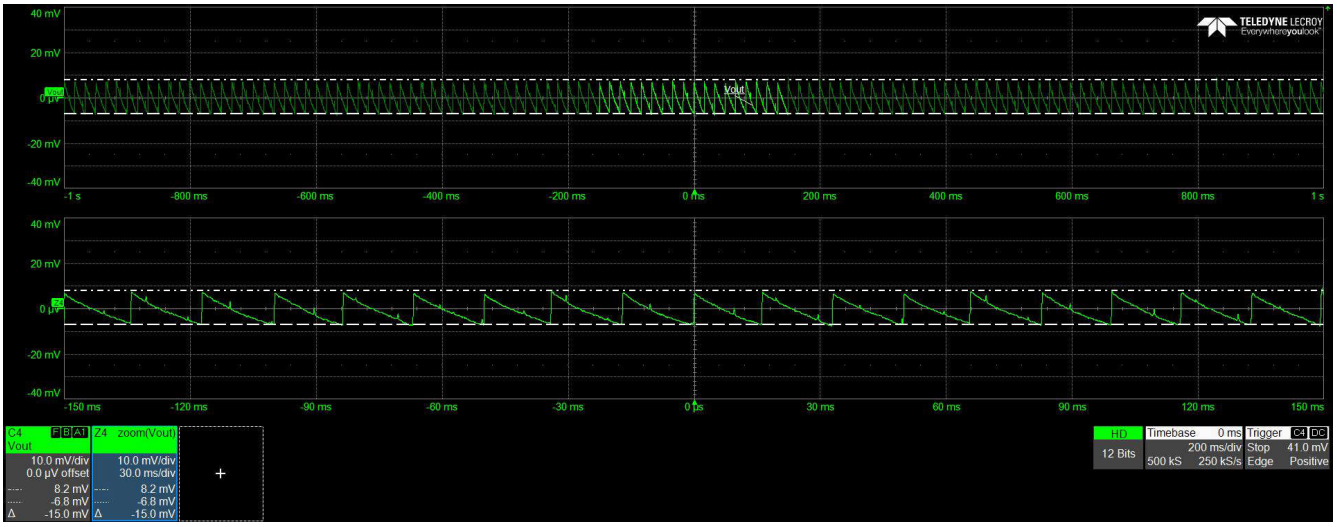


图 3-59. 输入 = 230VAC/50Hz 且输出 = 28V/0A 时的输出电压纹波

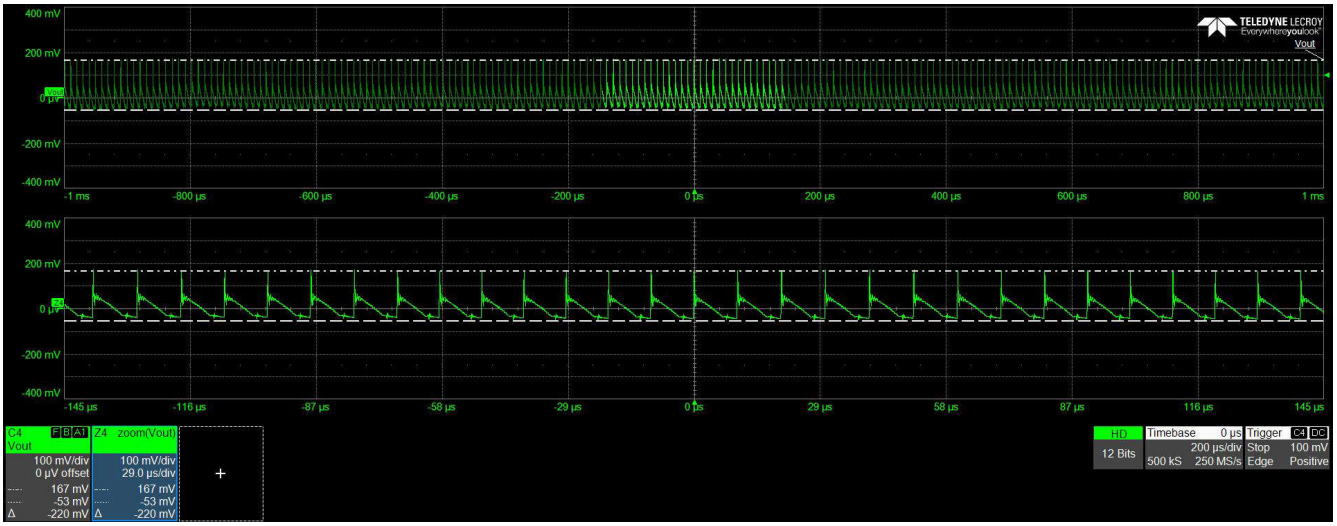


图 3-60. 输入 = 230VAC/50Hz 且输出 = 28V/4.3A 时的输出电压纹波

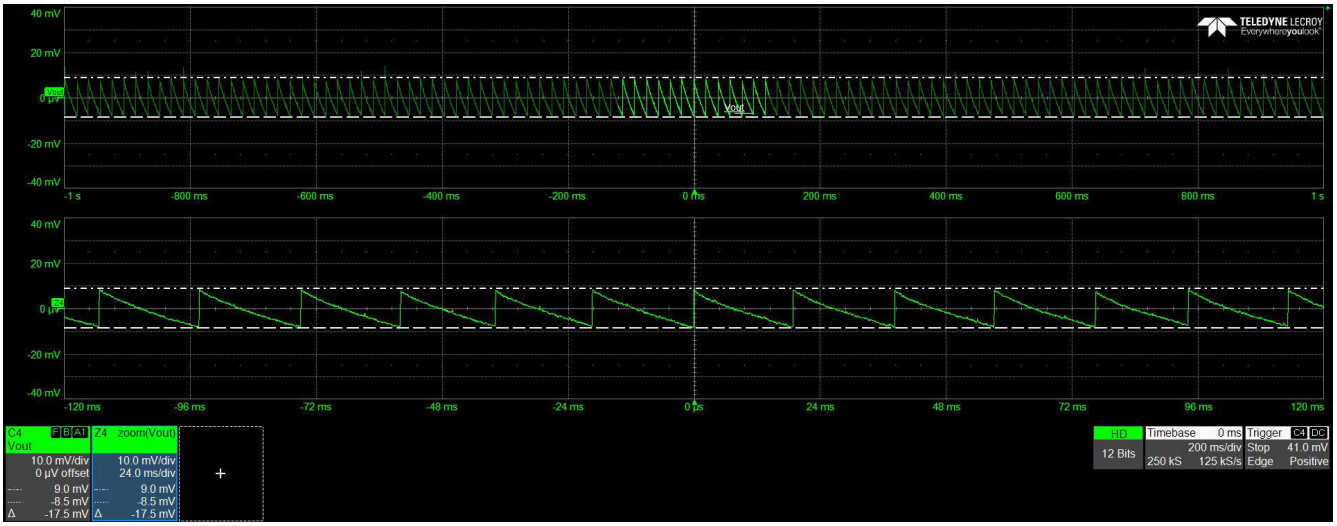


图 3-61. 输入 = 115VAC/60Hz 且输出 = 24V/0A 时的输出电压纹波

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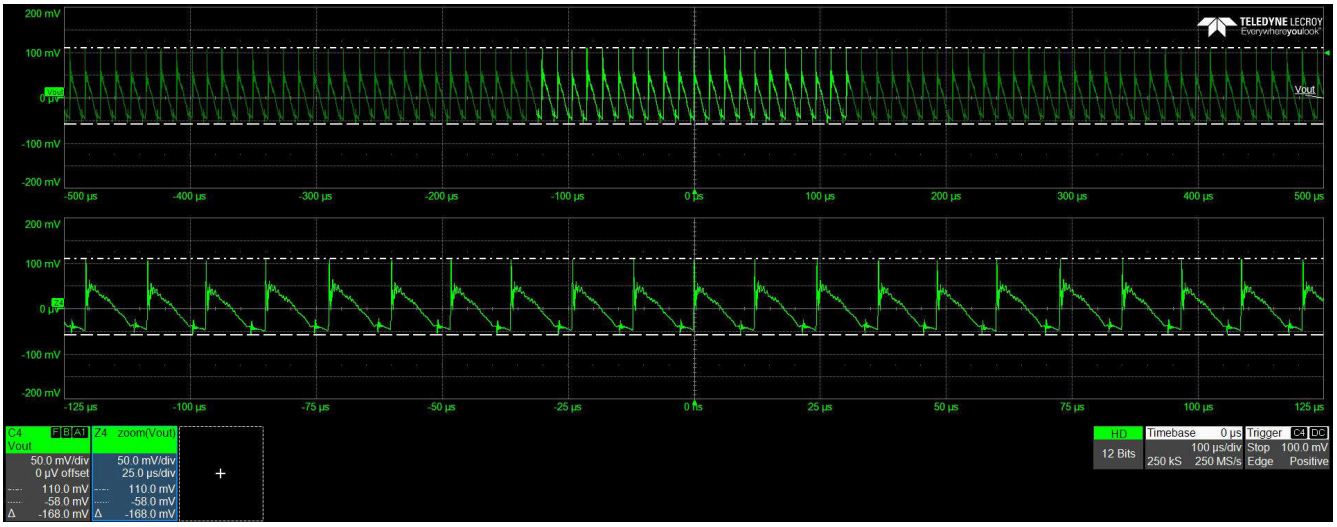


图 3-62. 输入 = 1150VAC/60Hz 且输出 = 24V/5A 时的输出电压纹波

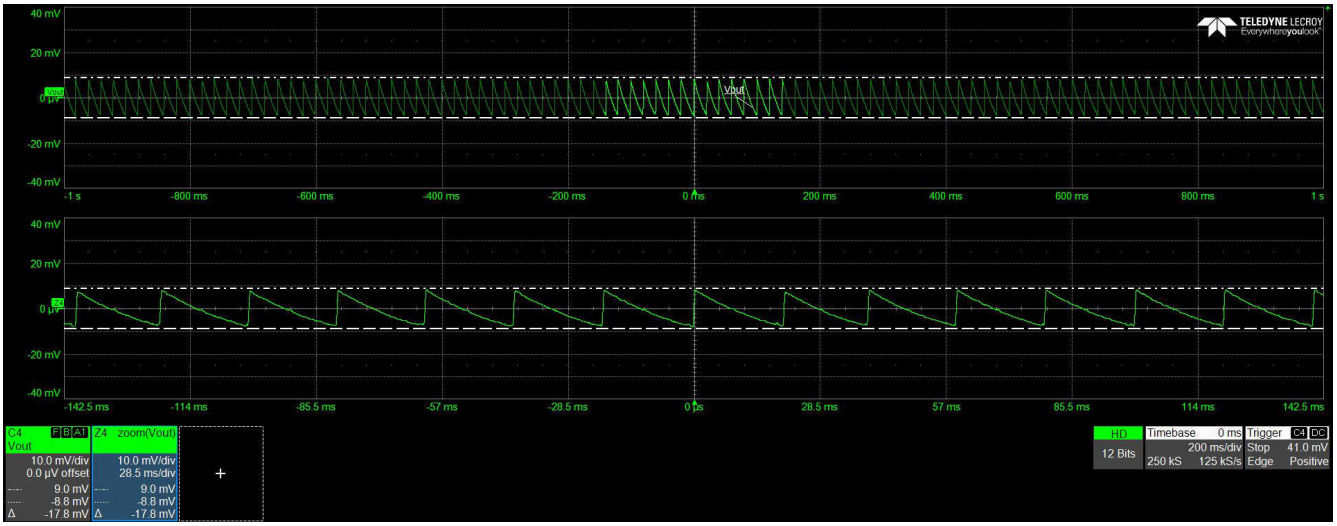


图 3-63. 输入 = 230VAC/50Hz 且输出 = 24V/0A 时的输出电压纹波

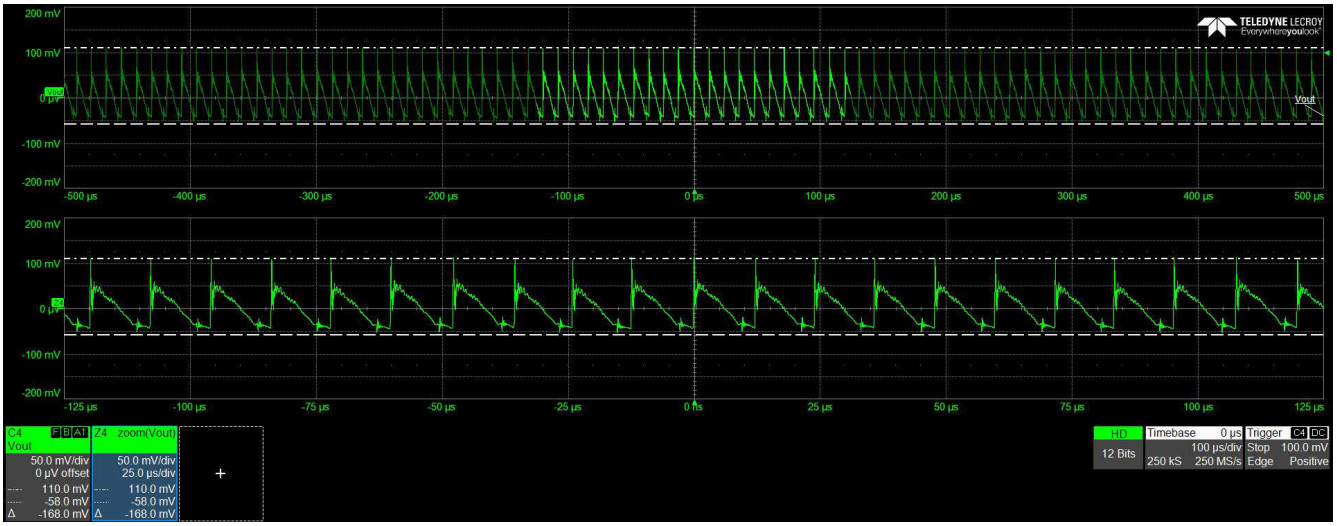


图 3-64. 输入 = 230VAC/50Hz 且输出 = 24V/5A 时的输出电压纹波

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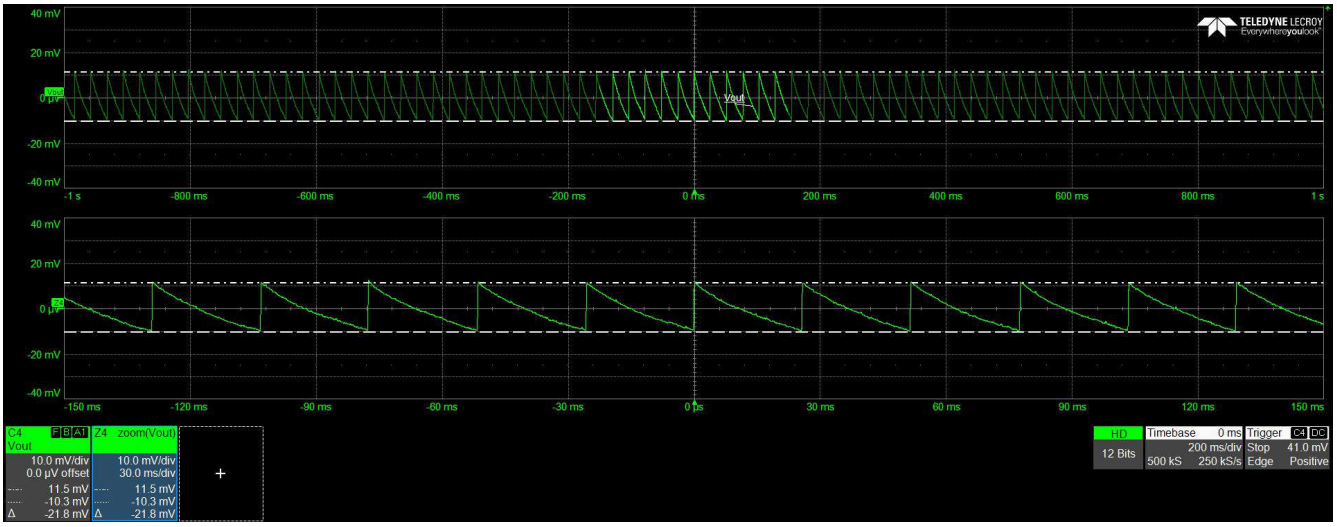


图 3-65. 输入 = 115VAC/60Hz 且输出 = 20V/0A 时的输出电压纹波

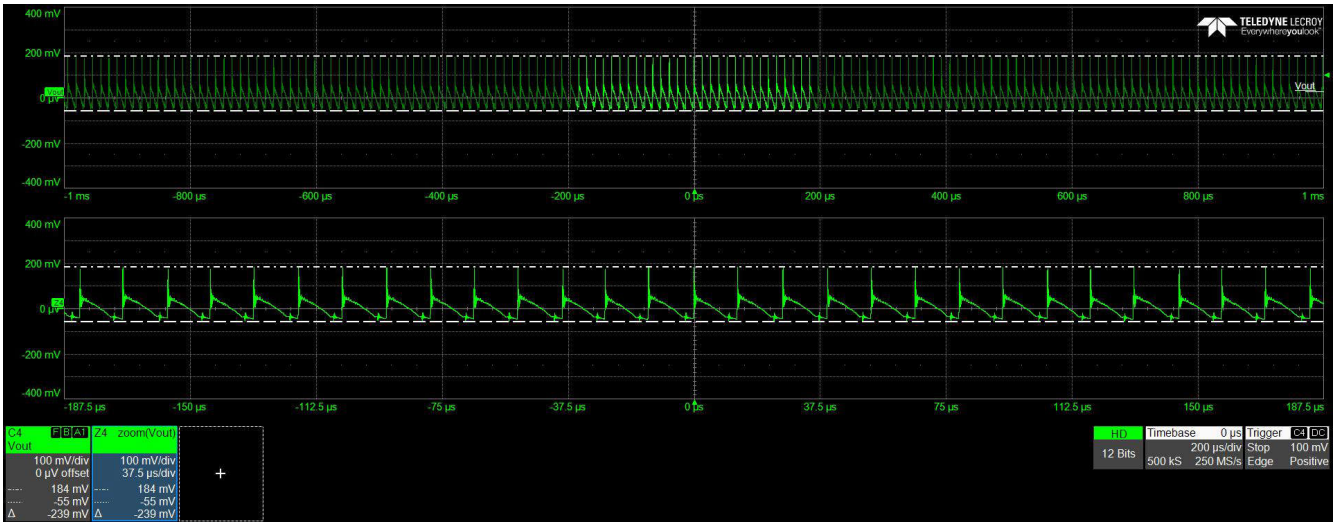


图 3-66. 输入 = 115VAC/60Hz 且输出 = 20V/5A 时的输出电压纹波

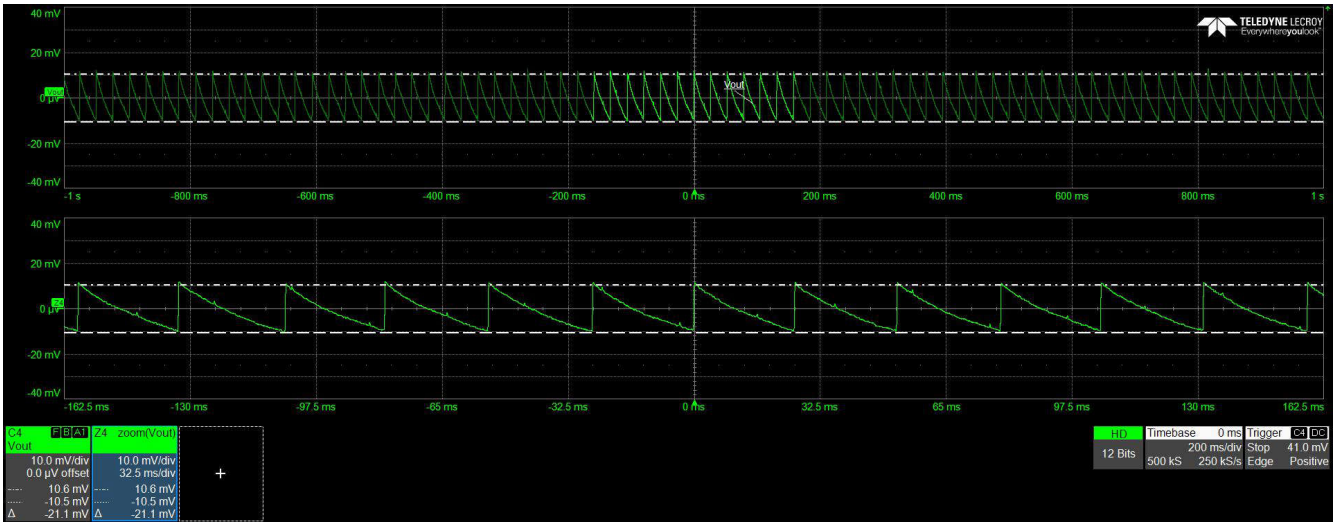


图 3-67. 输入 = 230VAC/50Hz 且输出 = 20V/0A 时的输出电压纹波

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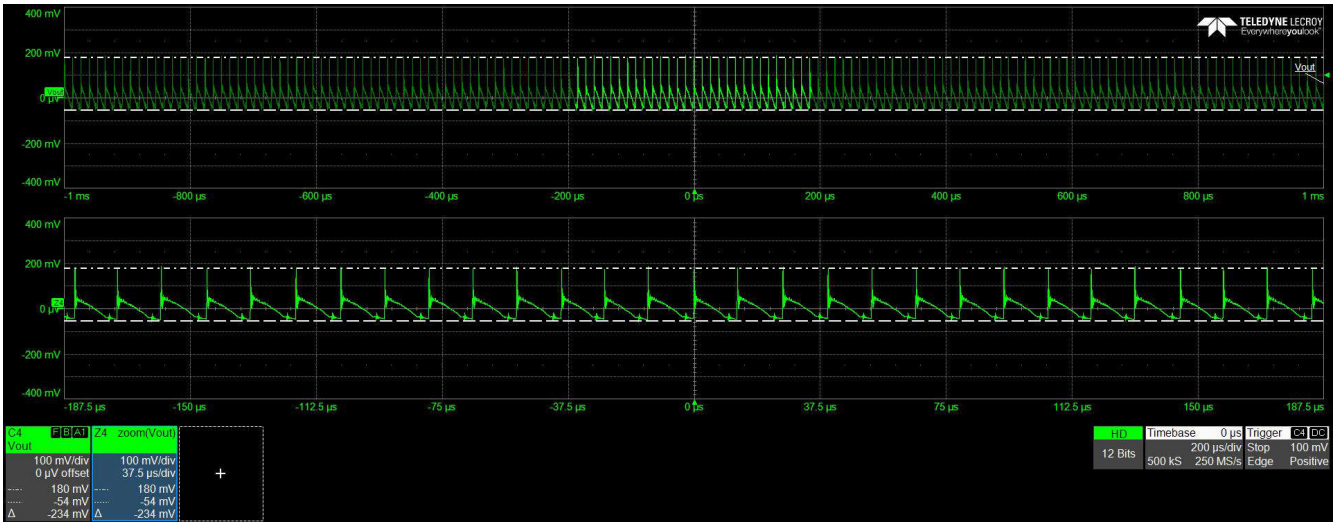


图 3-68. 输入 = 230VAC/50Hz 且输出 = 20V/5A 时的输出电压纹波

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3.11 EN55022 B 类传导 EMI 测试结果

请注意，本器件在预合规性 EMI 实验中进行了评估。TI 建议需要由具有资质的 EMI 测试机构来验证所有最终设计。图注中列出了测试条件。

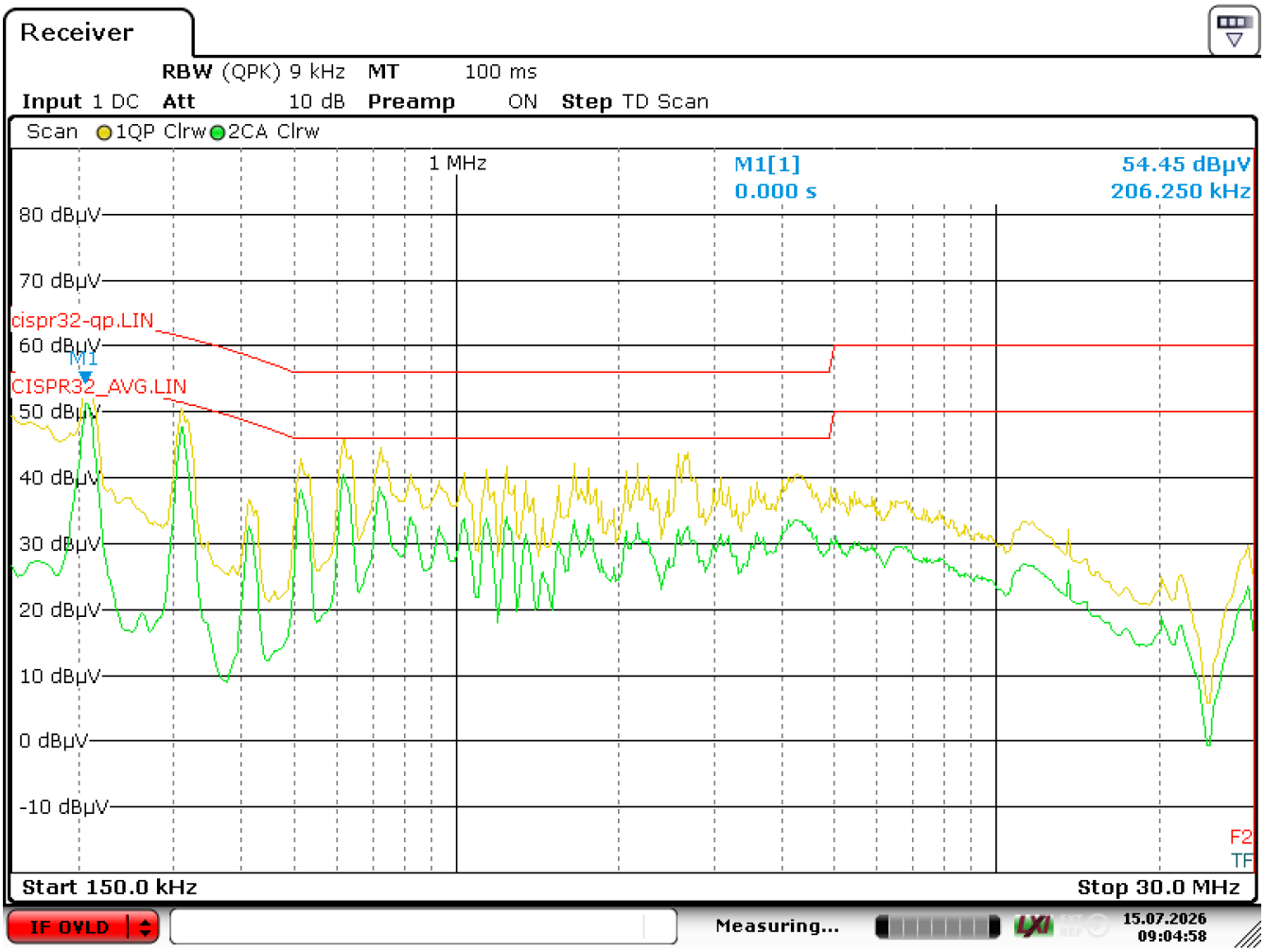
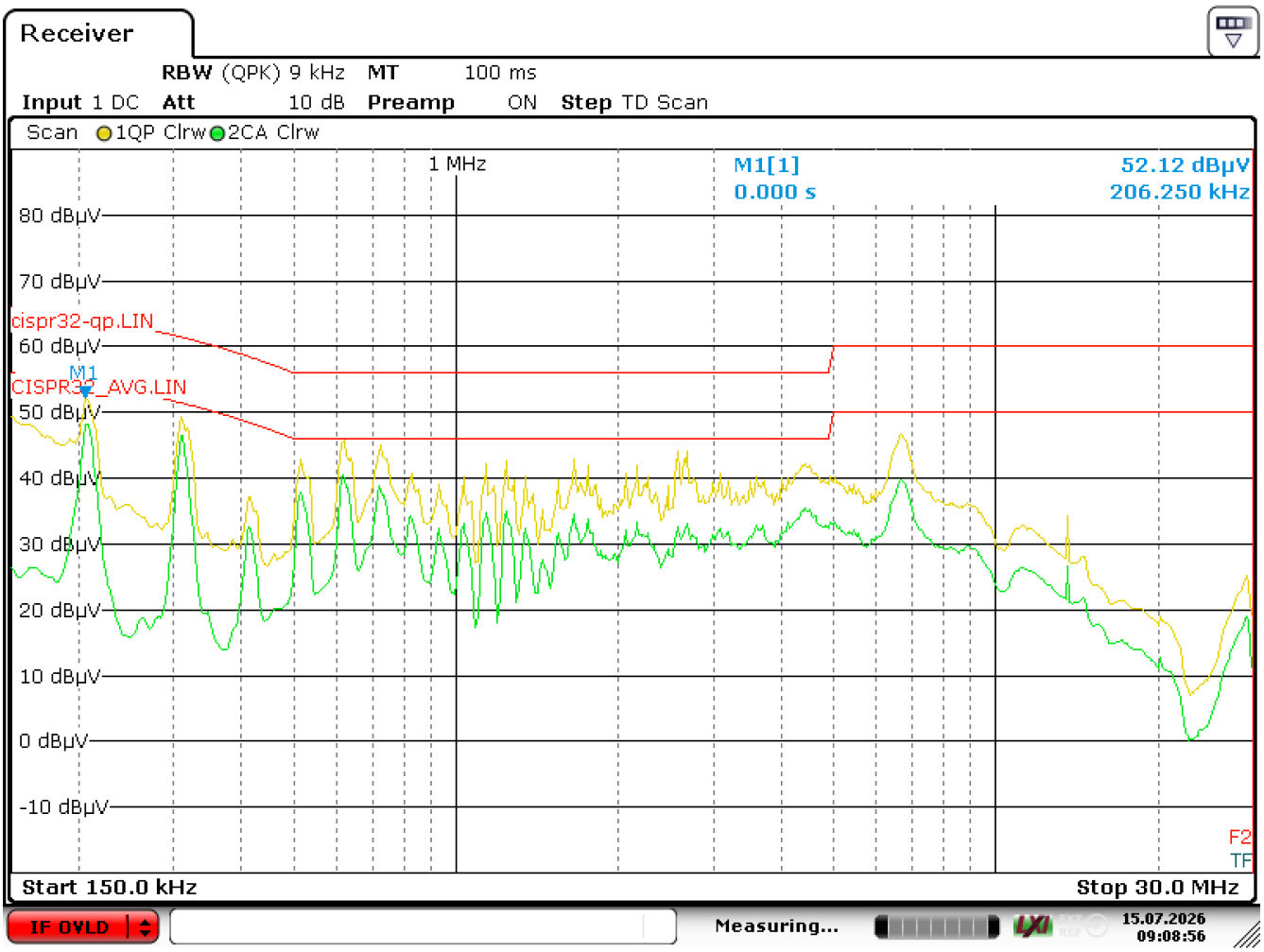


图 3-69. 输入 = 230VAC/50Hz，输出 = 28V/4.3A，线路扫描和中性端接

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Date: 15.JUL.2026 09:08:57

图 3-70. 输入 = 230VAC/50Hz，输出 = 28V/4.3A，中性扫描和线路端接

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Date: 7.JUL.2026 13:04:35

图 3-71. 输入 = 230VAC/50Hz，输出 = 24V/5A，线路扫描和中性端接

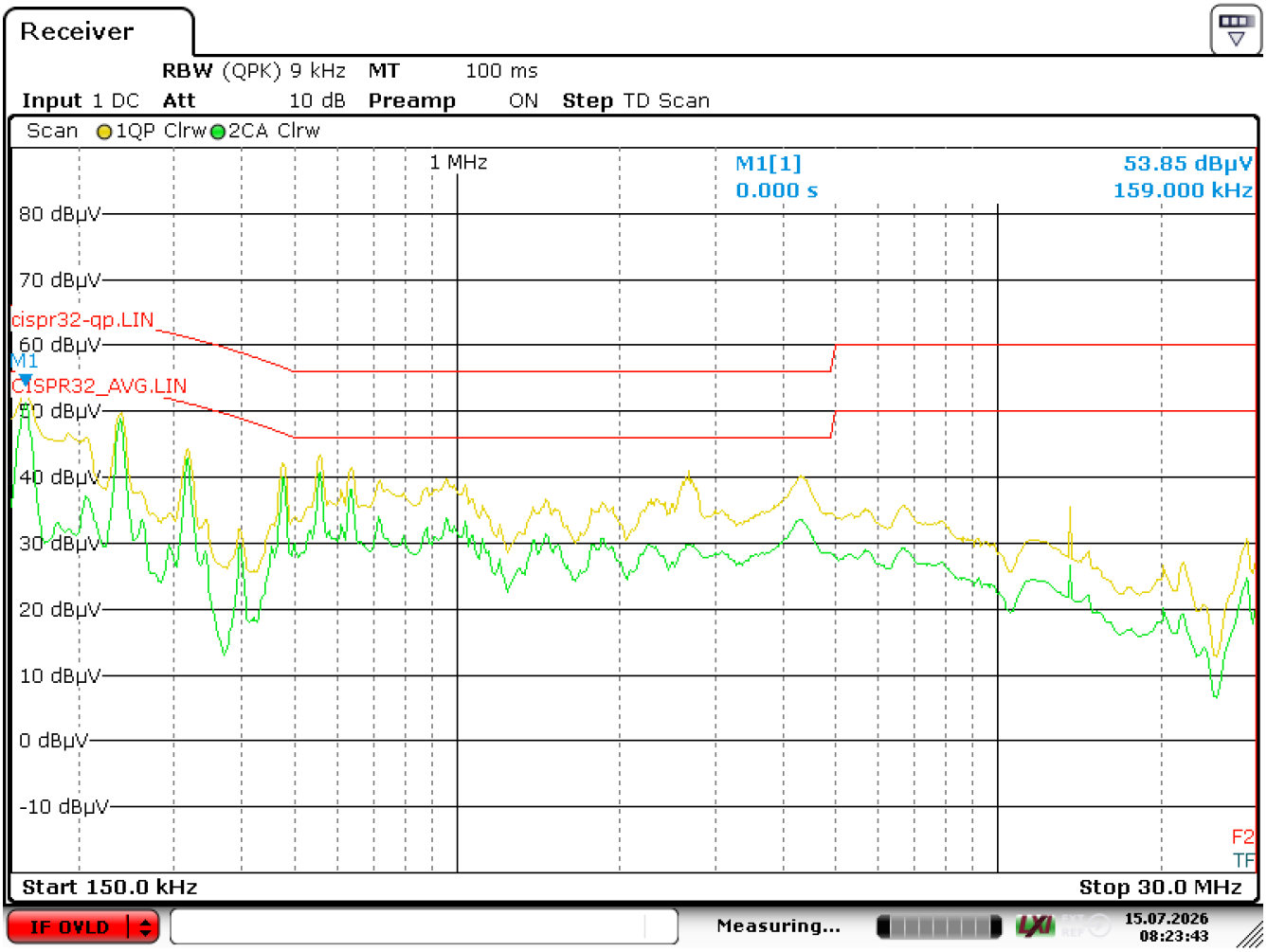
English Document: SLVUDN4
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Date: 7.JUL.2026 13:19:40

图 3-72. 输入 = 230VAC/50Hz，输出 = 24V/5A，中性扫描和线路端接

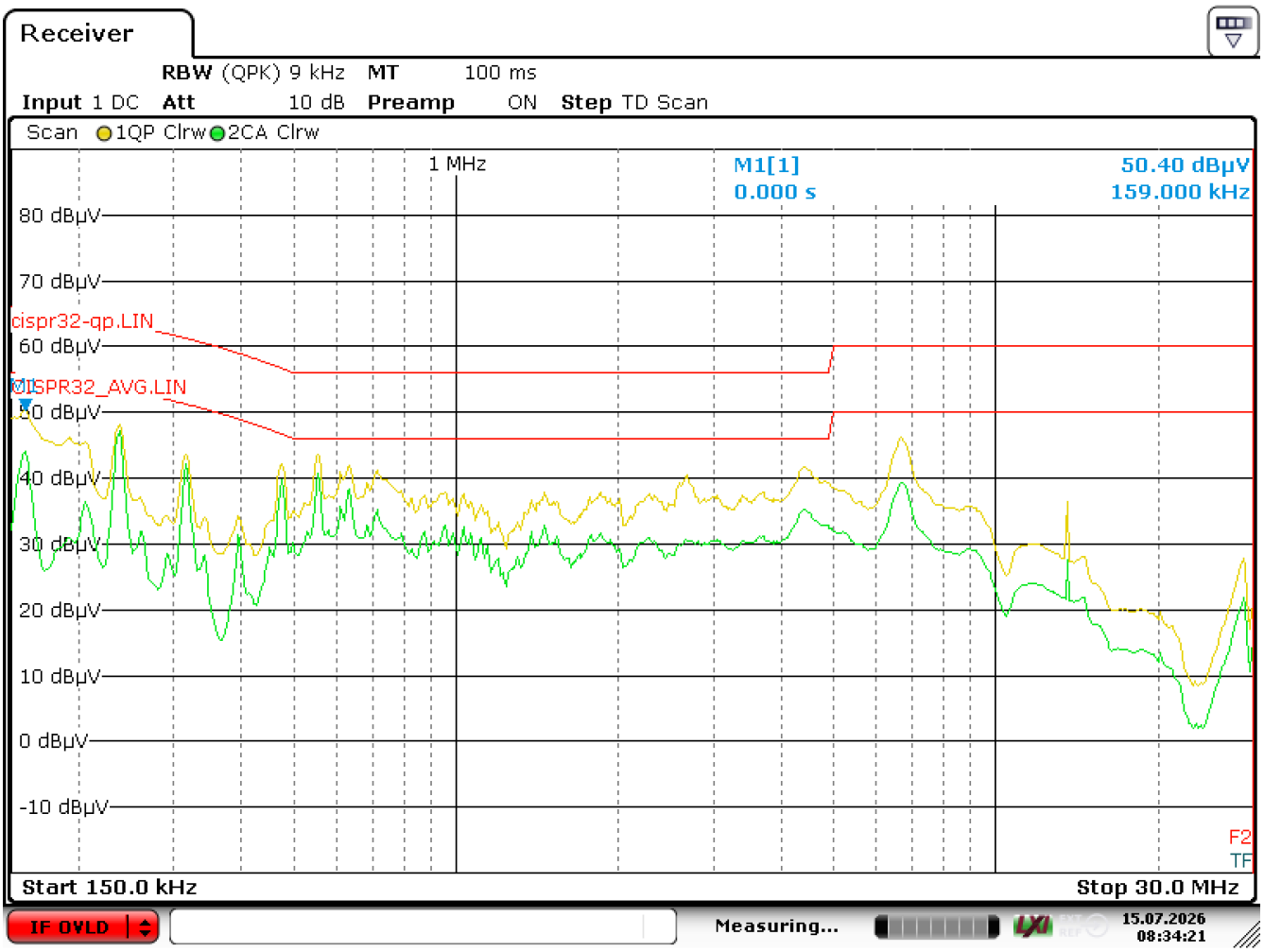
English Document: SLVUDN4
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Date: 15.JUL.2026 08:23:44

图 3-73. 输入 = 230VAC/50Hz，输出 = 20V/5A，线路扫描和中性端接

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Date: 15.JUL.2026 08:34:22

图 3-74. 输入 = 230VAC/50Hz，输出 = 20V/5A，中性扫描和线路端接

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3.12 最大负载时的热性能

以下各图展示了在 90VAC/60Hz 条件下浸泡 1 小时，2 小时和 3 小时，输出设置为 24V，满载且无强制空气后的 EVM 温度。

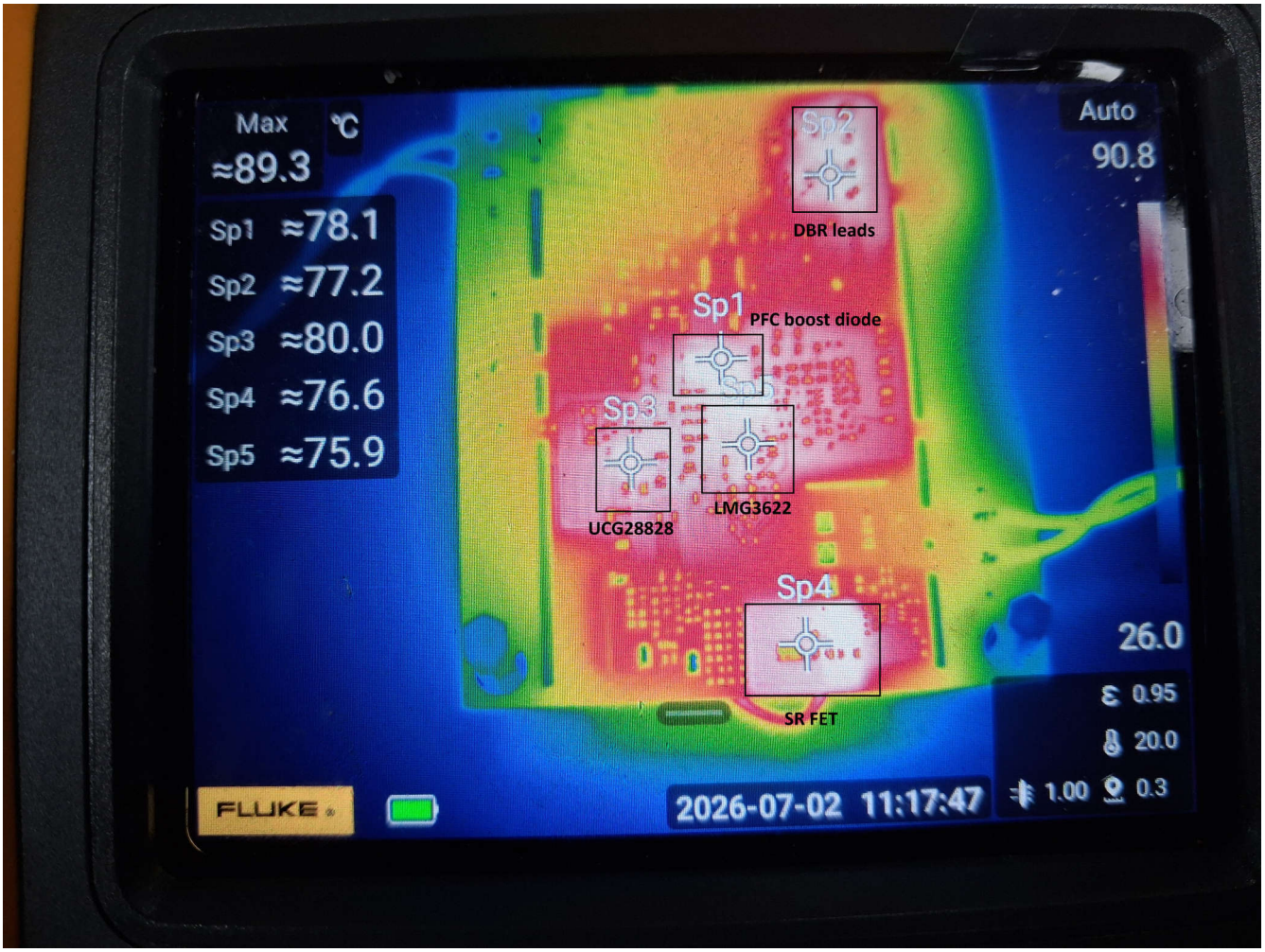


图 3-75. 输入 = 90VAC/60Hz，输出 = 24V/5A，运行 1 小时后进行扫描（底部）

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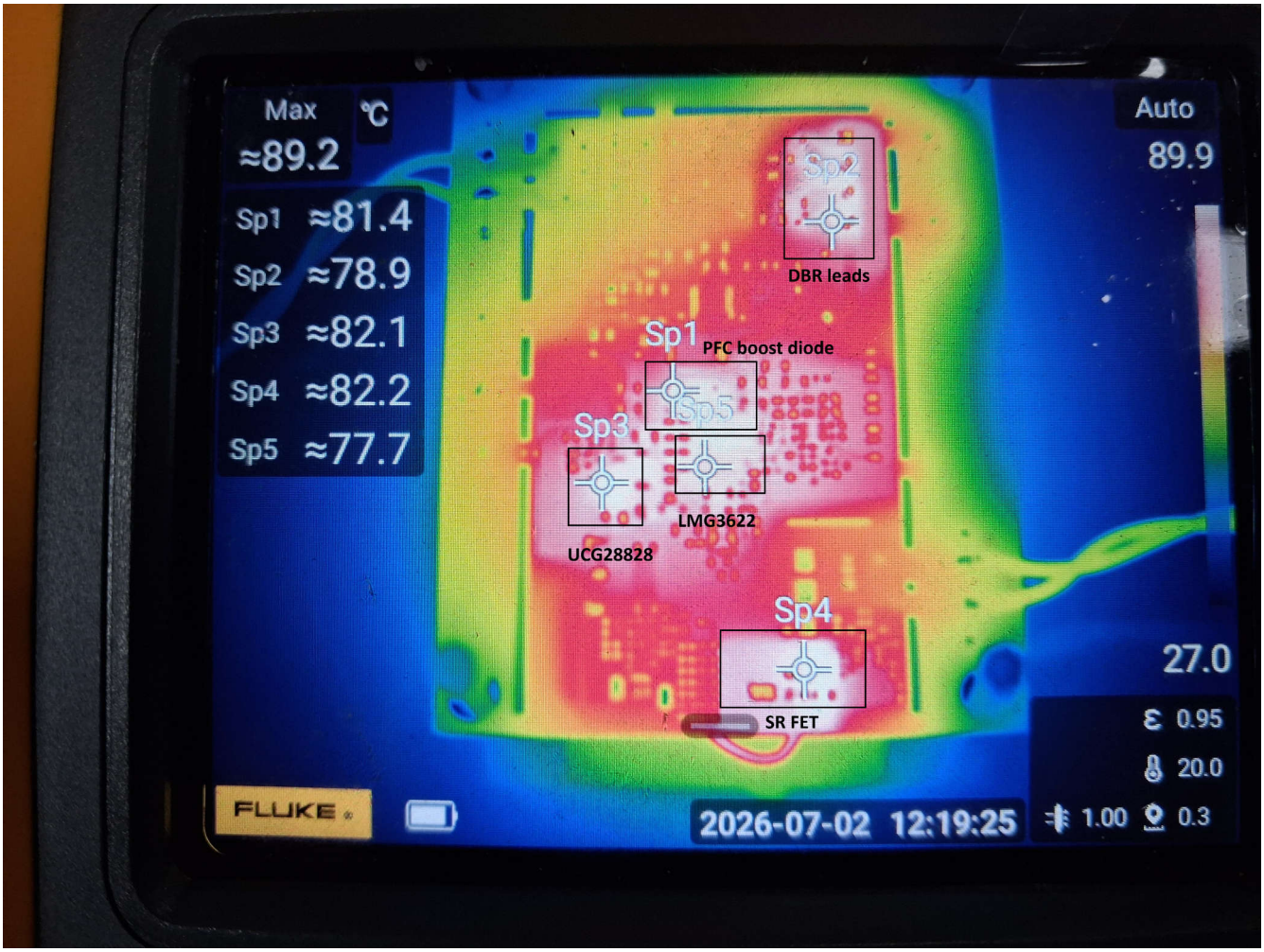


图 3-76. 输入 = 90VAC/60Hz，输出 = 24V/5A，运行 2 小时后进行扫描（底部）

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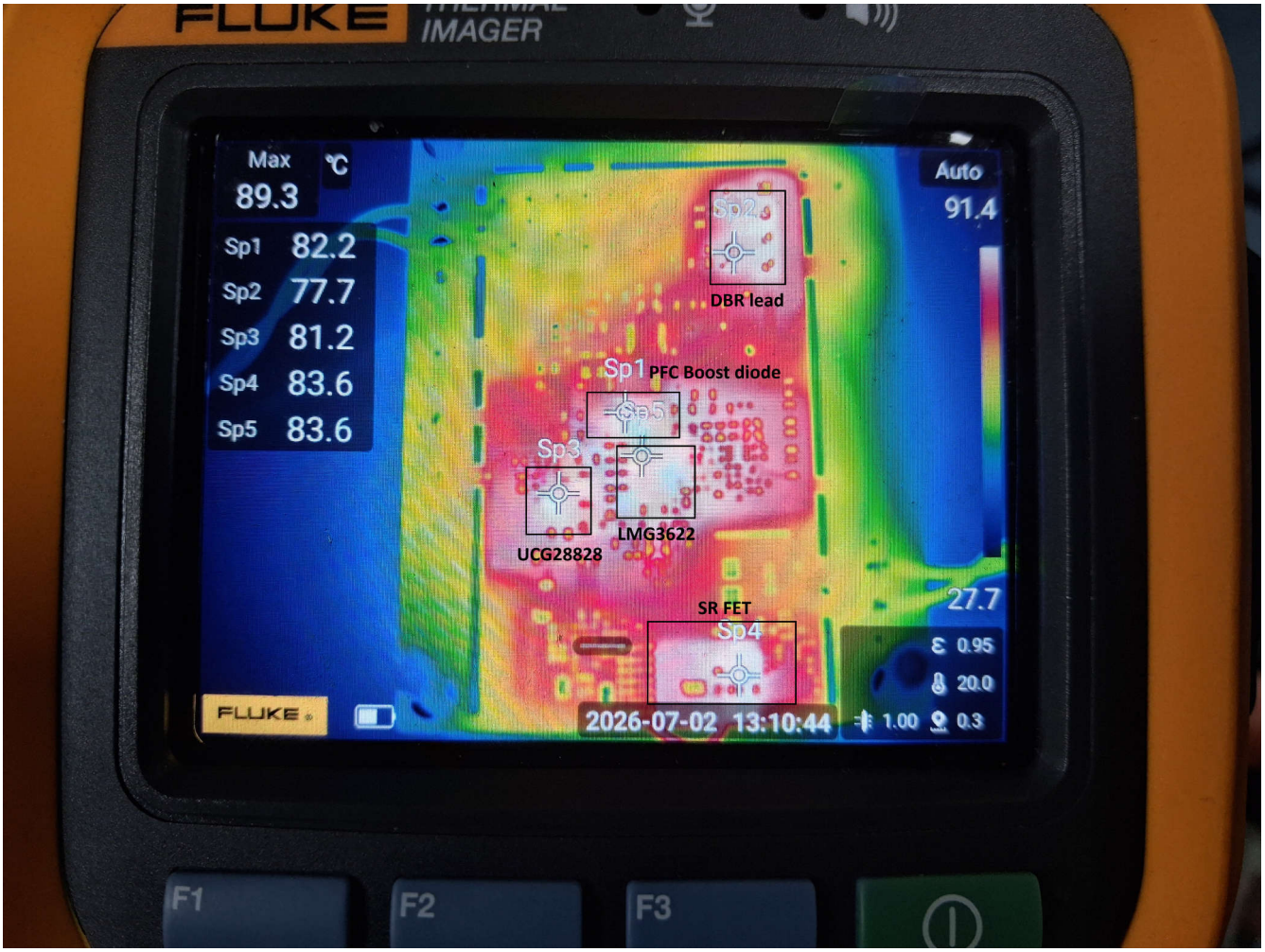


图 3-77. 输入 = 90VAC/60Hz，输出 = 24V/5A，运行 3 小时后进行扫描（底部）

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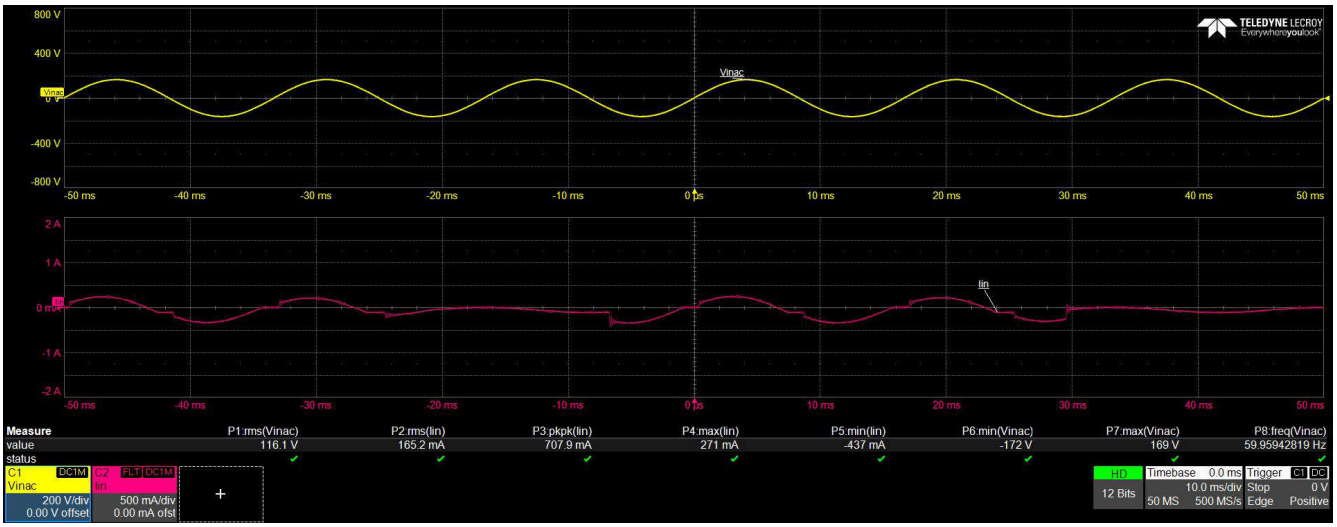


图 3-78. 输入 = 90VAC/60Hz，输出 = 24V/5A，运行 3 小时后进行扫描（顶部）

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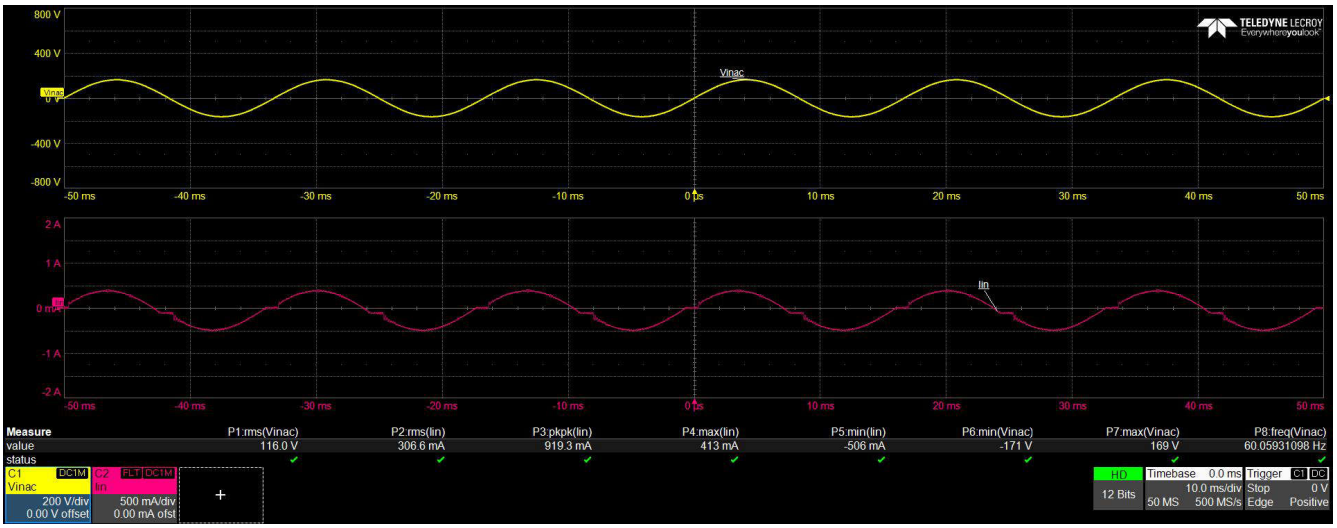
3.13 PFC 测试结果：V_{in} 与 Iin 间的关系

以下波形显示了在 115VAC/60Hz 和 230VAC/50Hz 输入电压下 24V 输出设置的不同负载条件下的输入电流行为。



C1 = 交流输入电压　　C2 = 输入电流

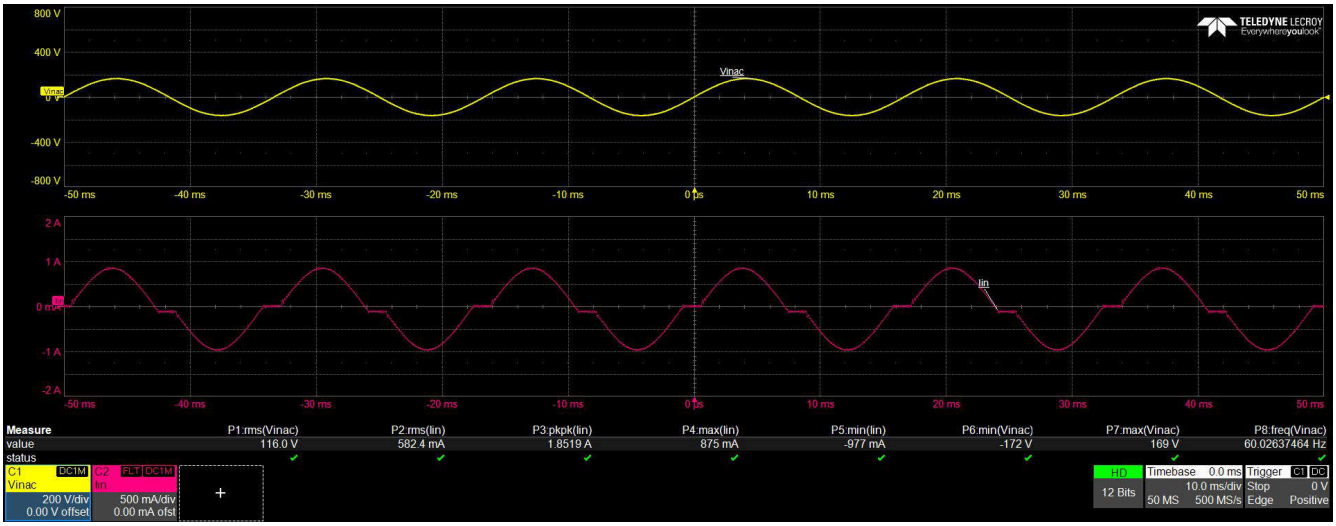
图 3-79. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 0.5A



C1 = 交流输入电压　　C2 = 输入电流

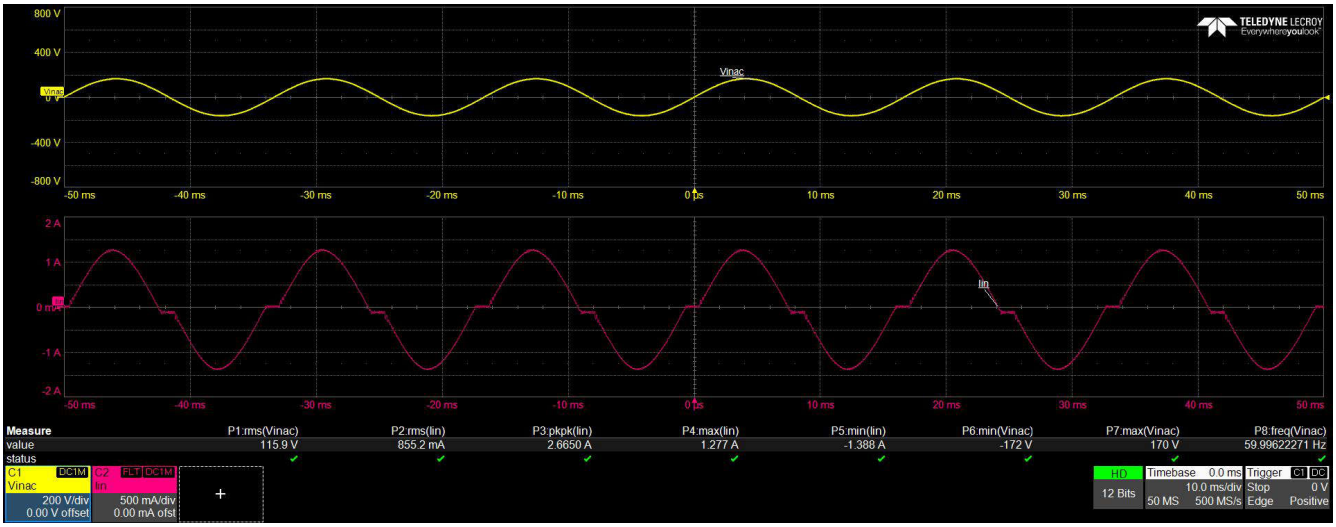
图 3-80. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 1.25A

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C1 = 交流输入电压　　C2 = 输入电流

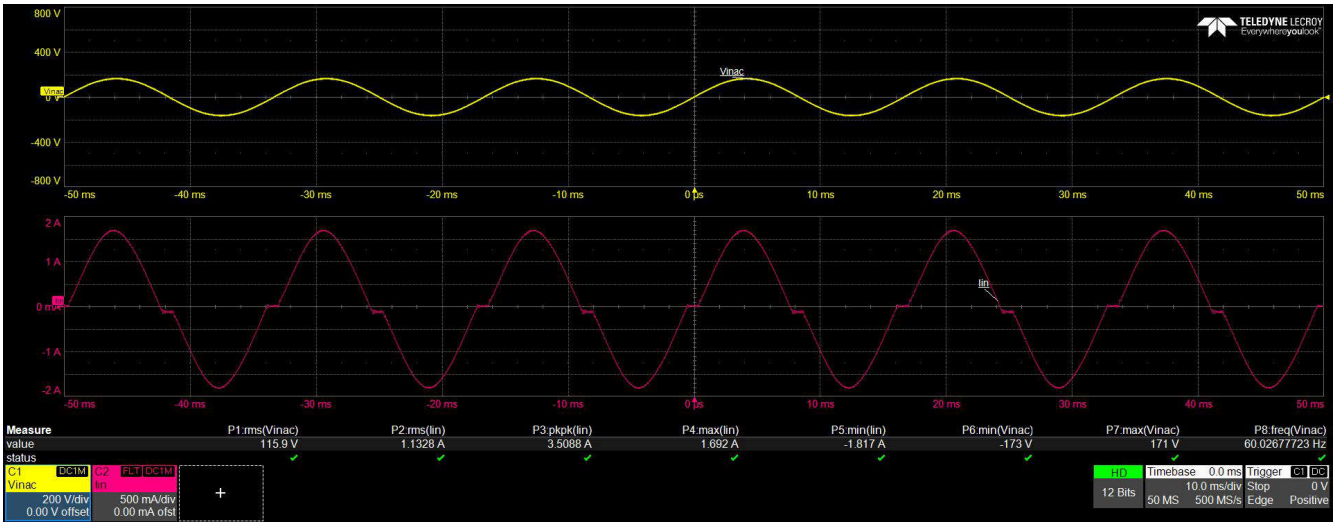
图 3-81. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 2.5A



C1 = 交流输入电压　　C2 = 输入电流

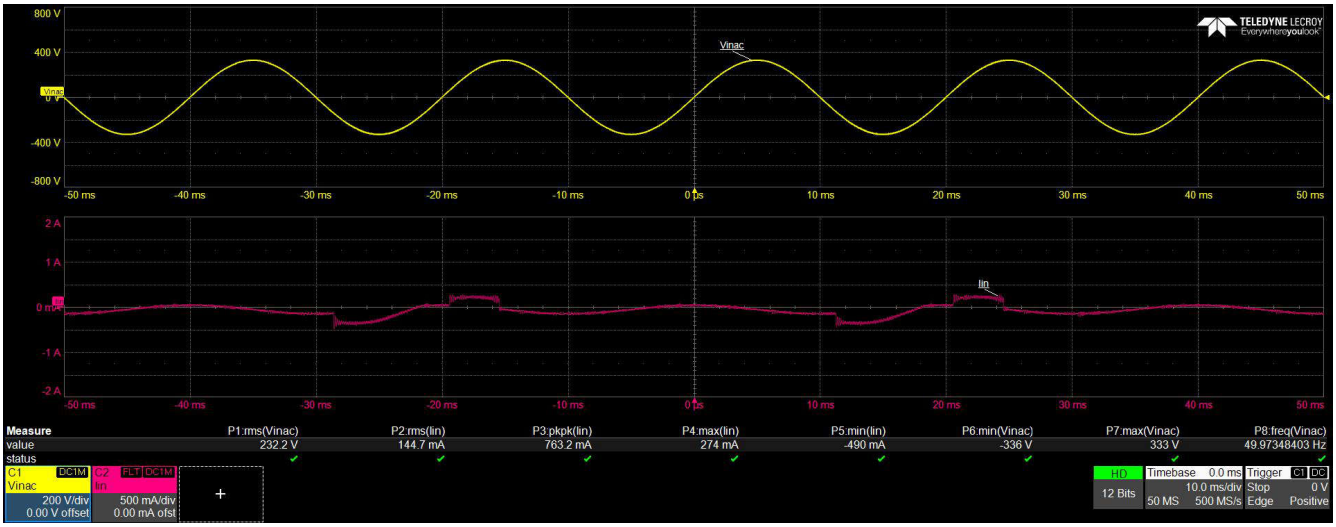
图 3-82. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 3.75A

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C1 = 交流输入电压　　C2 = 输入电流

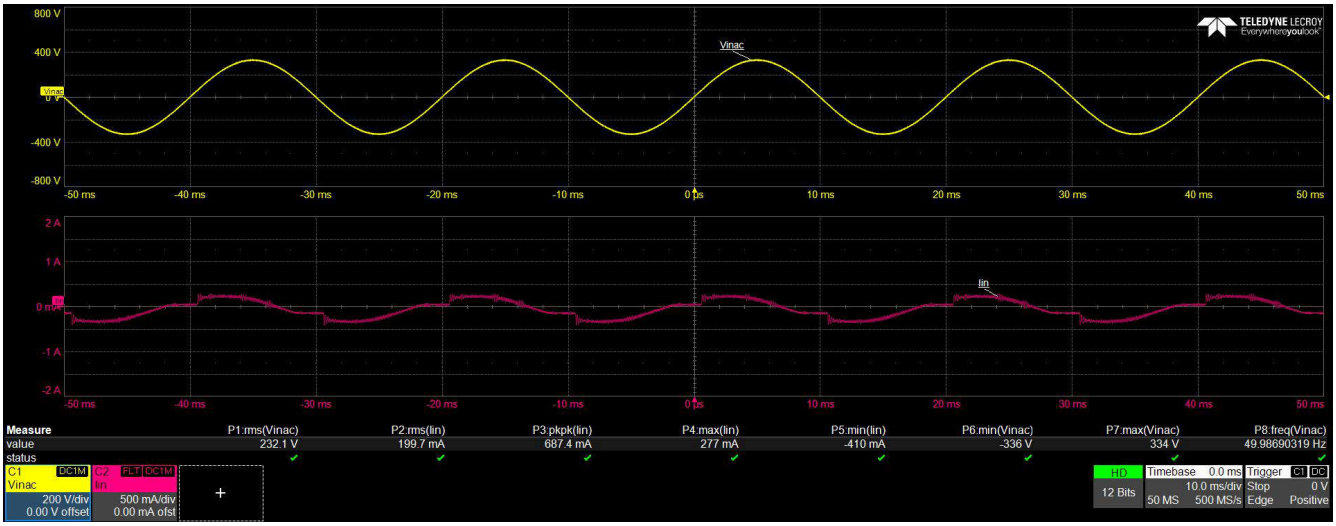
图 3-83. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 5A



C1 = 交流输入电压　　C2 = 输入电流

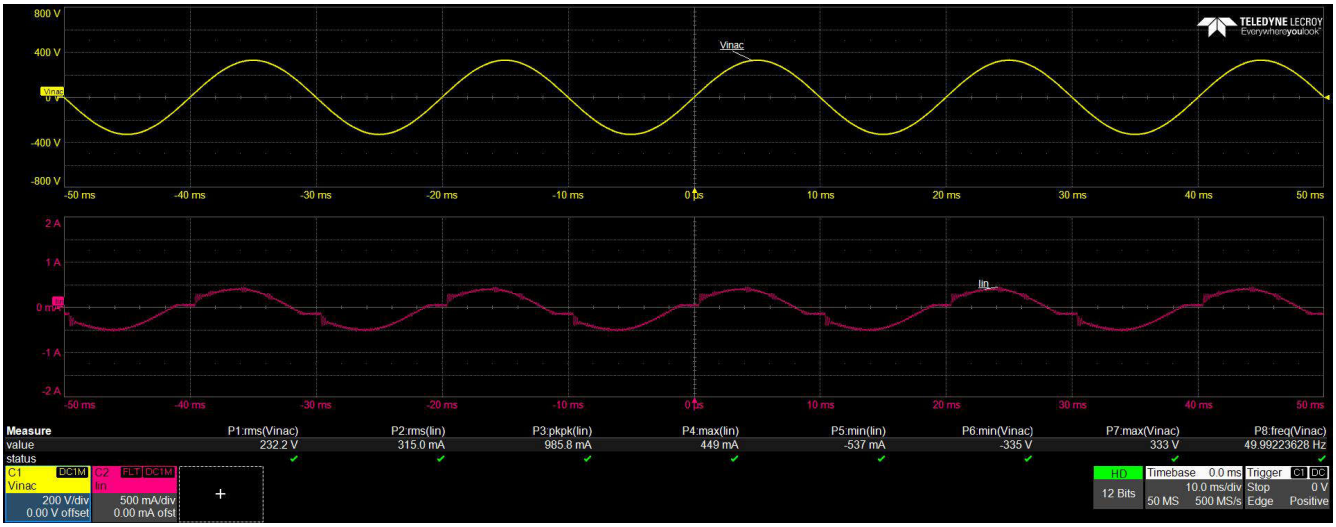
图 3-84. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 0.5A

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C1 = 交流输入电压　　C2 = 输入电流

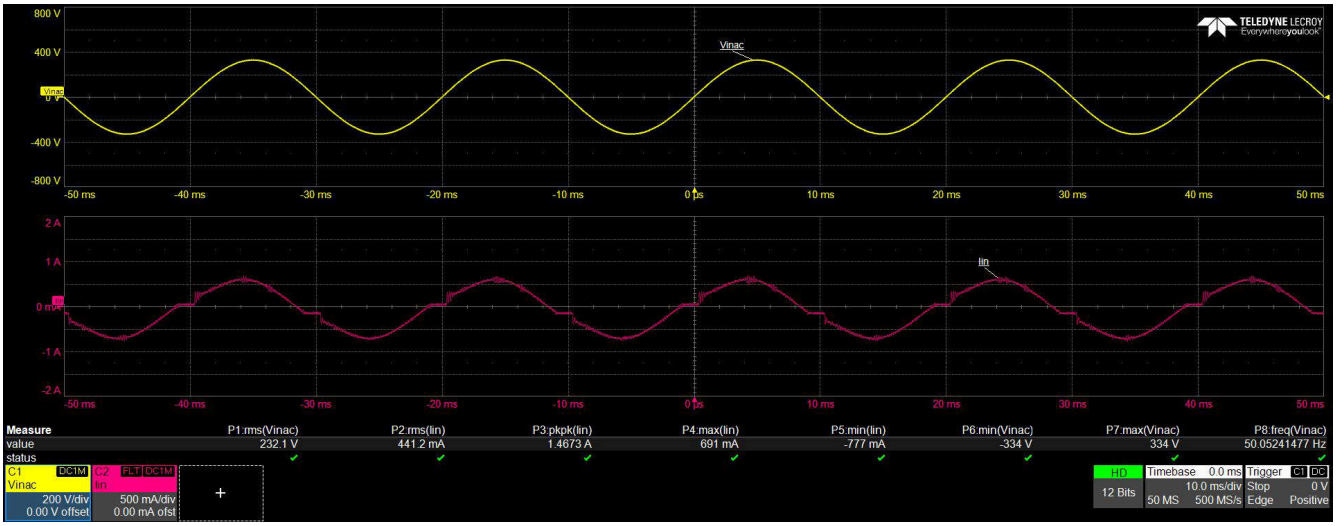
图 3-85. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 1.25A



C1 = 交流输入电压　　C2 = 输入电流

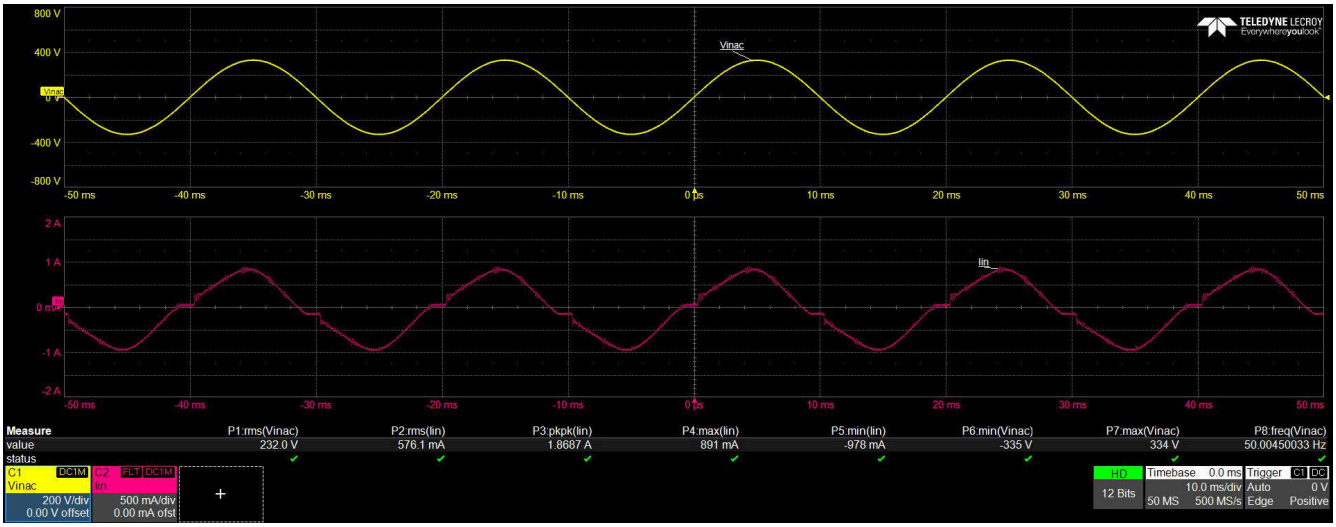
图 3-86. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 2.5A

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C1 = 交流输入电压　　C2 = 输入电流

图 3-87. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 3.75A



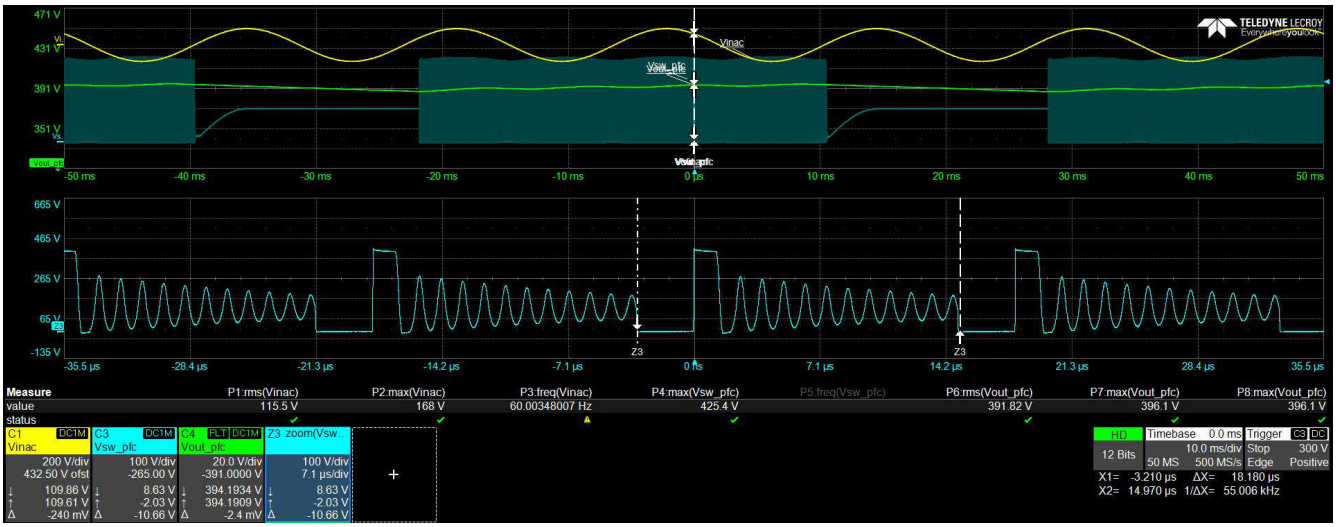
C1 = 交流输入电压　　C2 = 输入电流

图 3-88. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 5A

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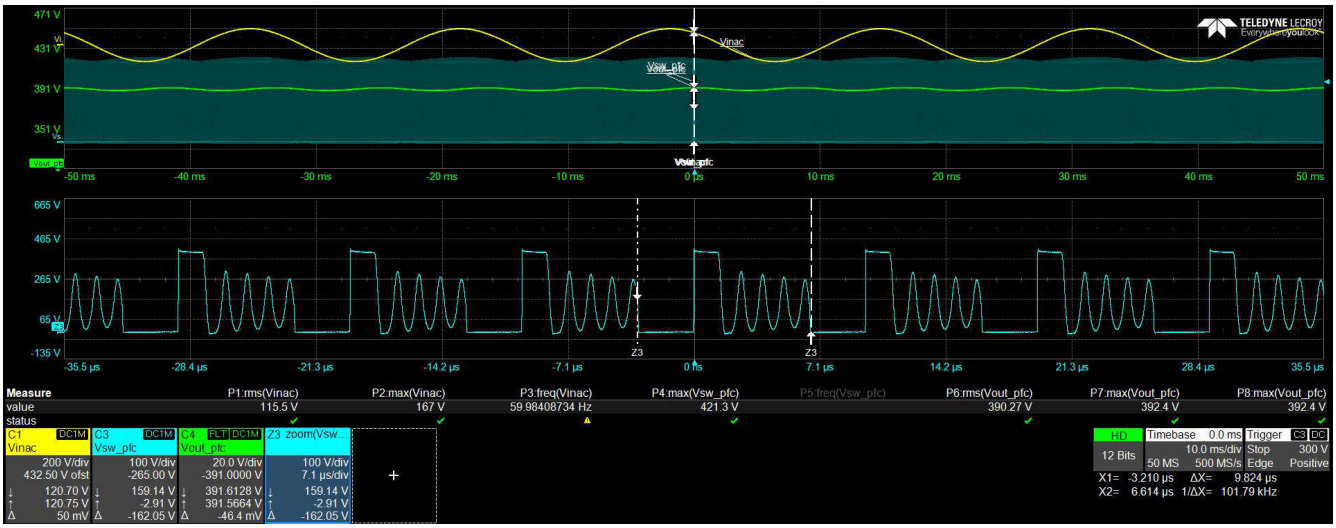
3.14 PFC 测试结果：负载上的开关节点波形

以下波形显示了在 115VAC/60Hz 和 230VAC/50Hz 输入电压下，24V 输出设置在不同负载条件下的开关节点行为。



C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

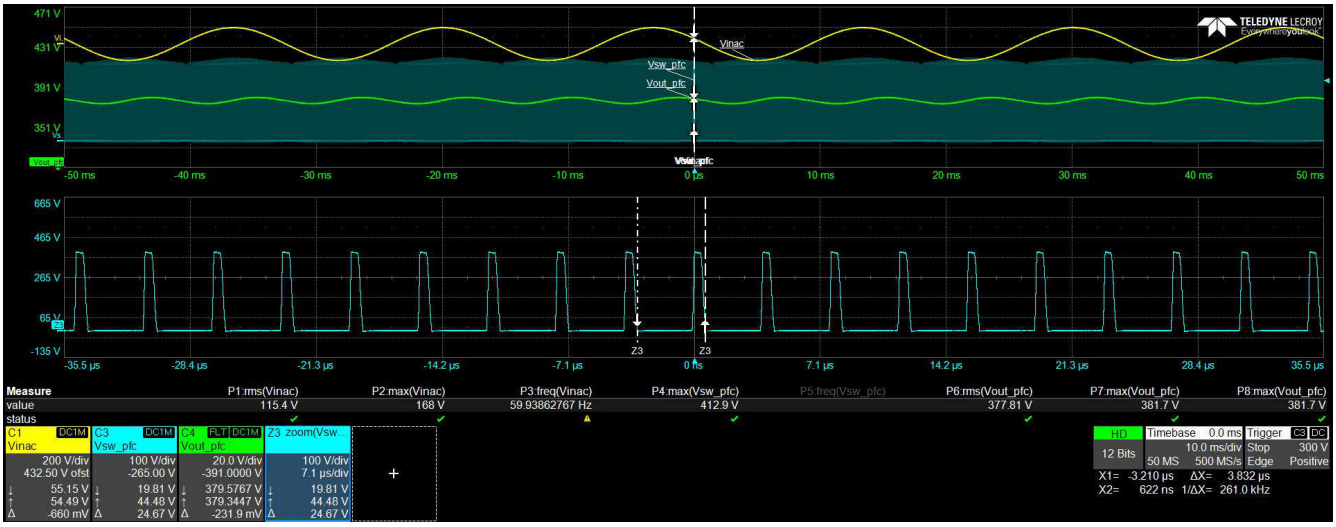
图 3-89. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 0.5A



C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

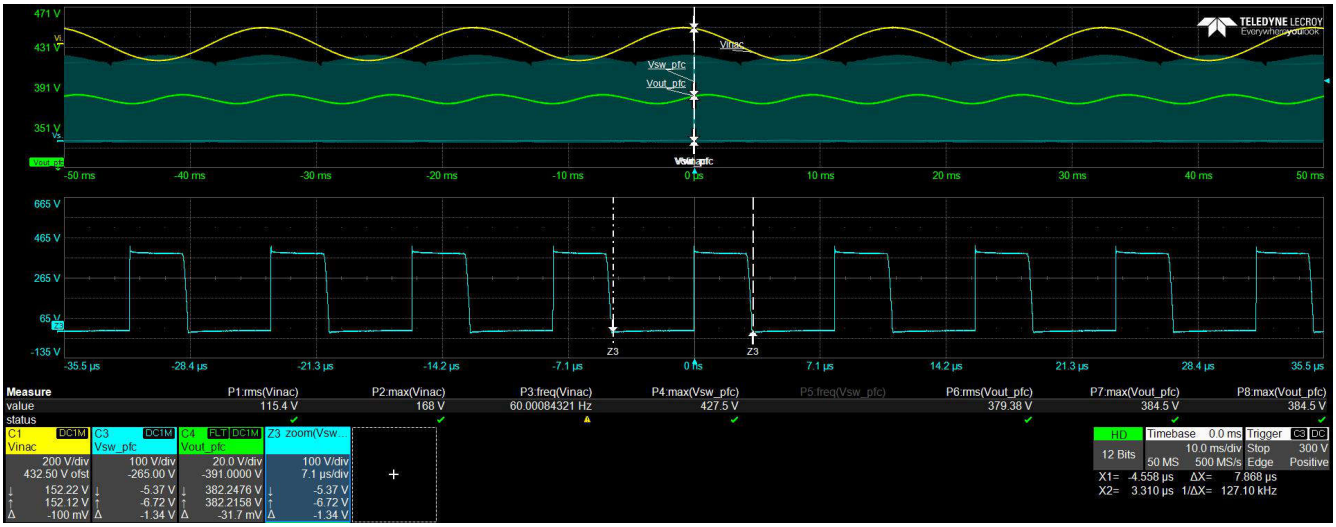
图 3-90. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 1.25A

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C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

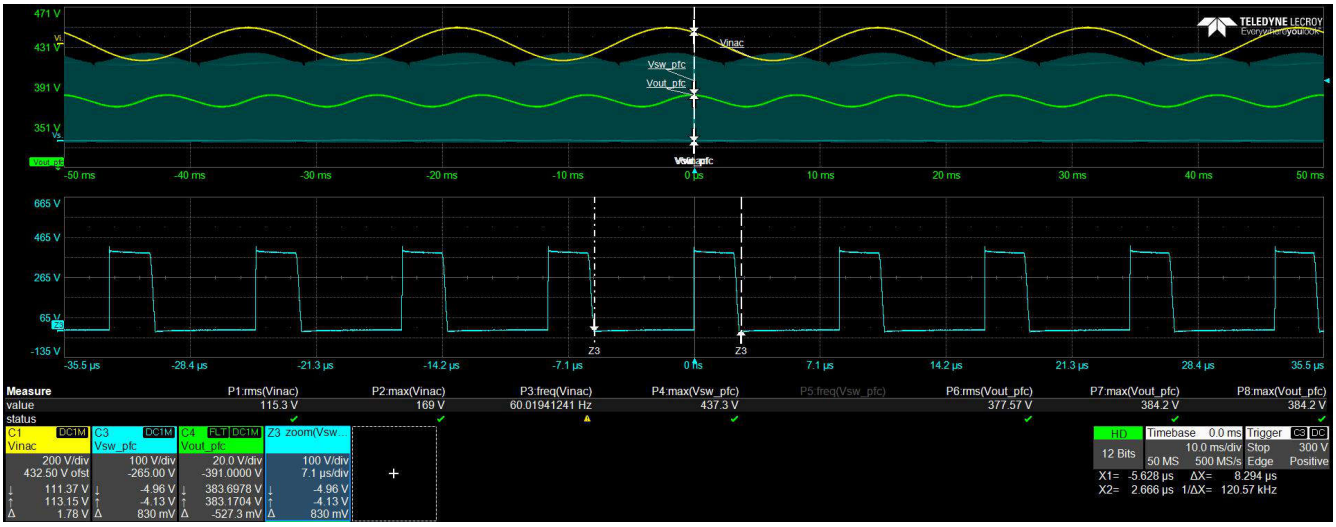
图 3-91. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 2.5A



C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

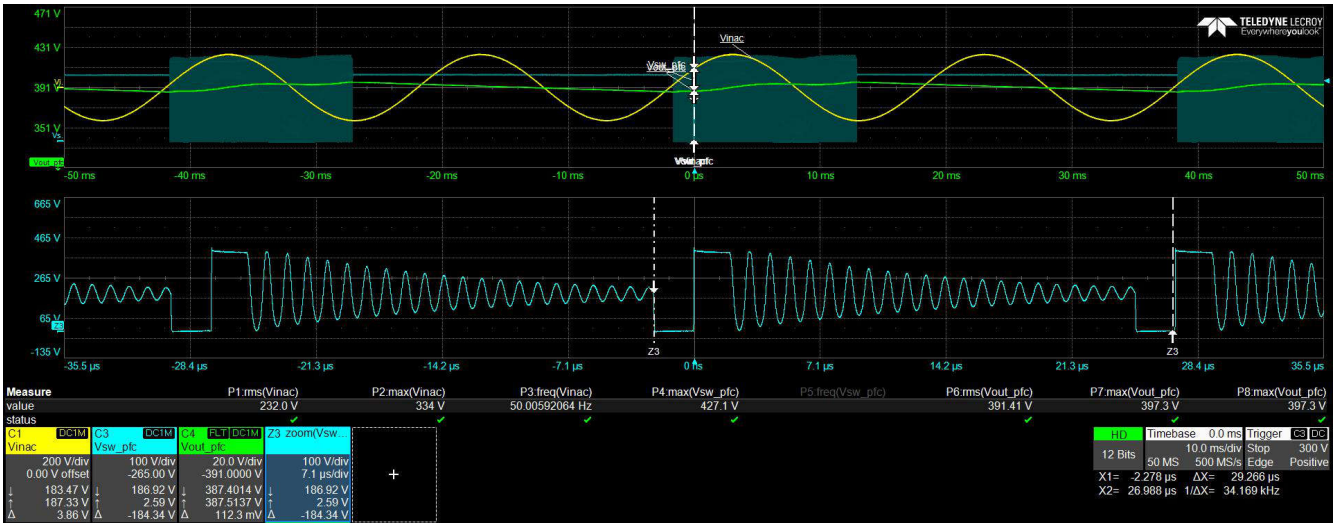
图 3-92. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 3.75A

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C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

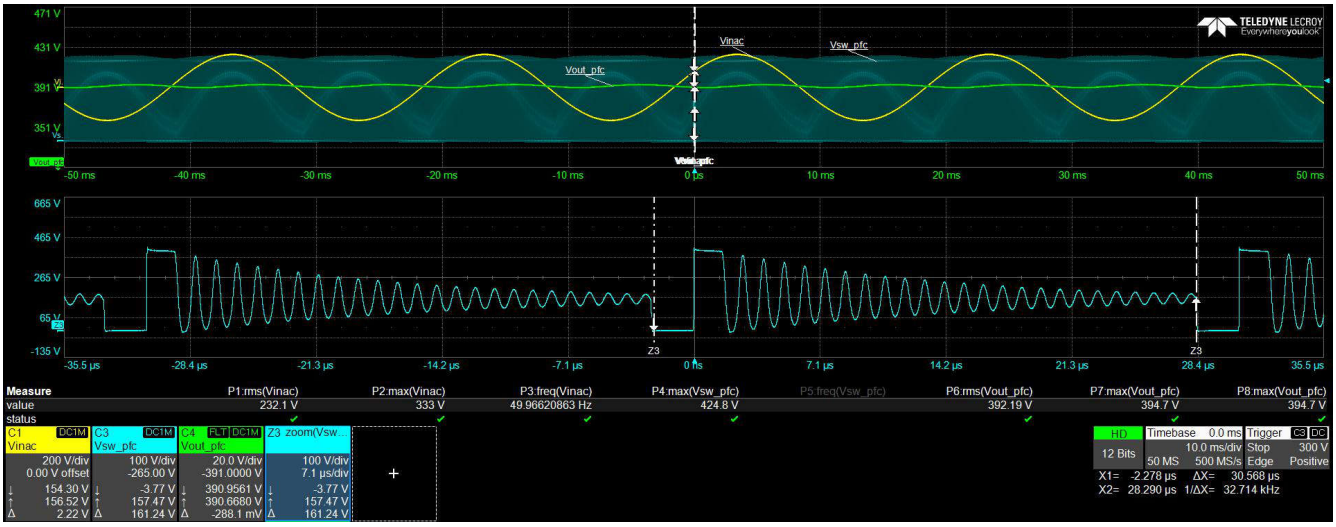
图 3-93. V_{in} = 115VAC/60Hz、V_{out_fly} = 24V 和 I_{out} = 5A



C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

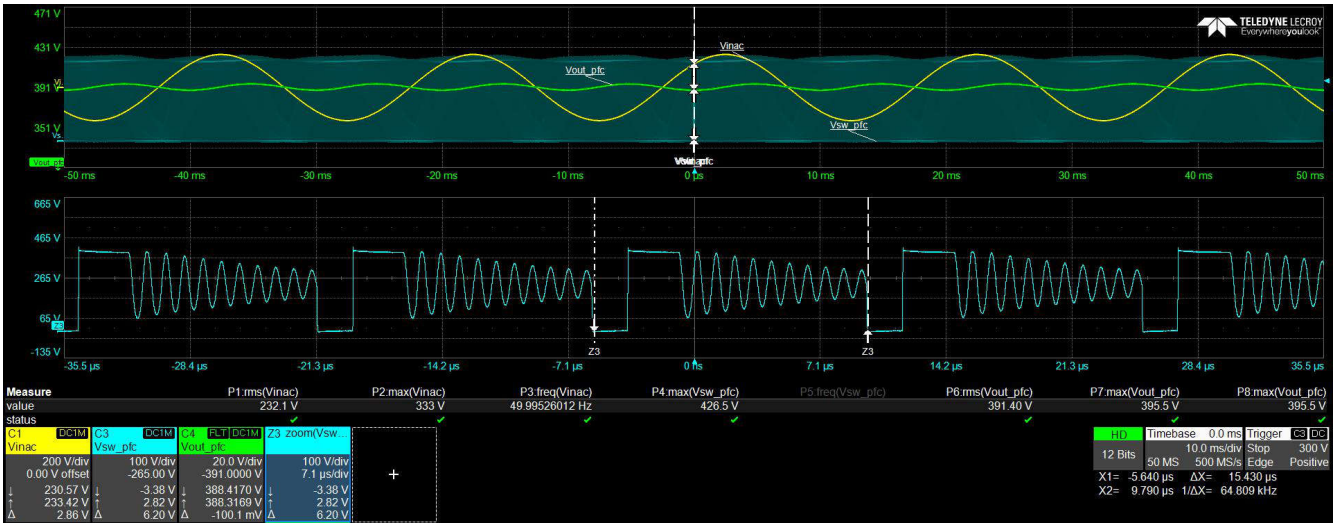
图 3-94. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 0.5A

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C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

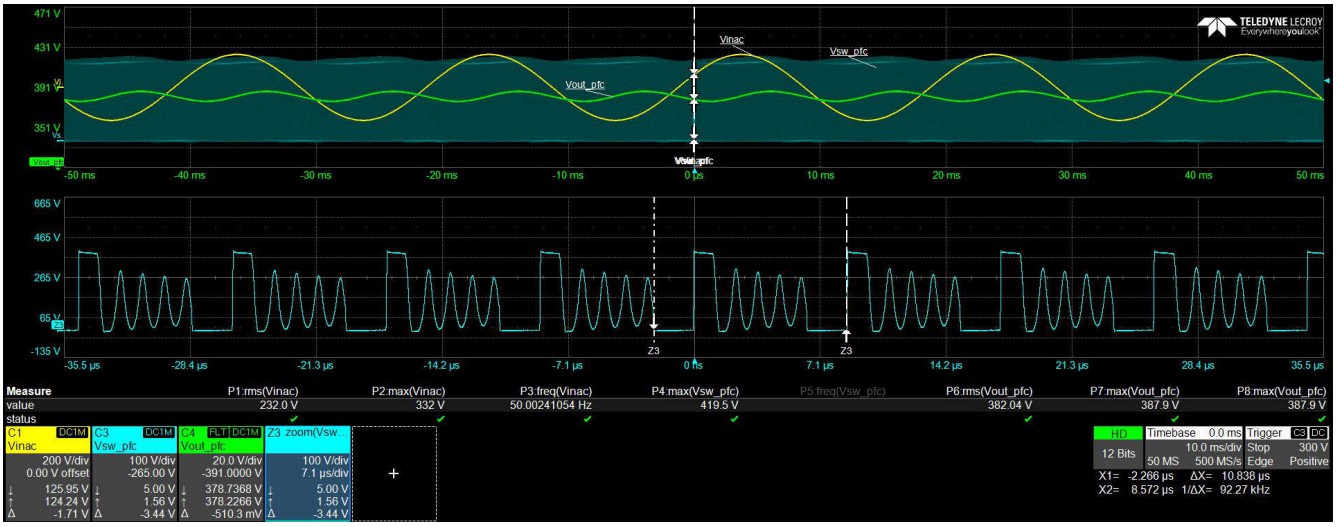
图 3-95. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 1.25A



C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

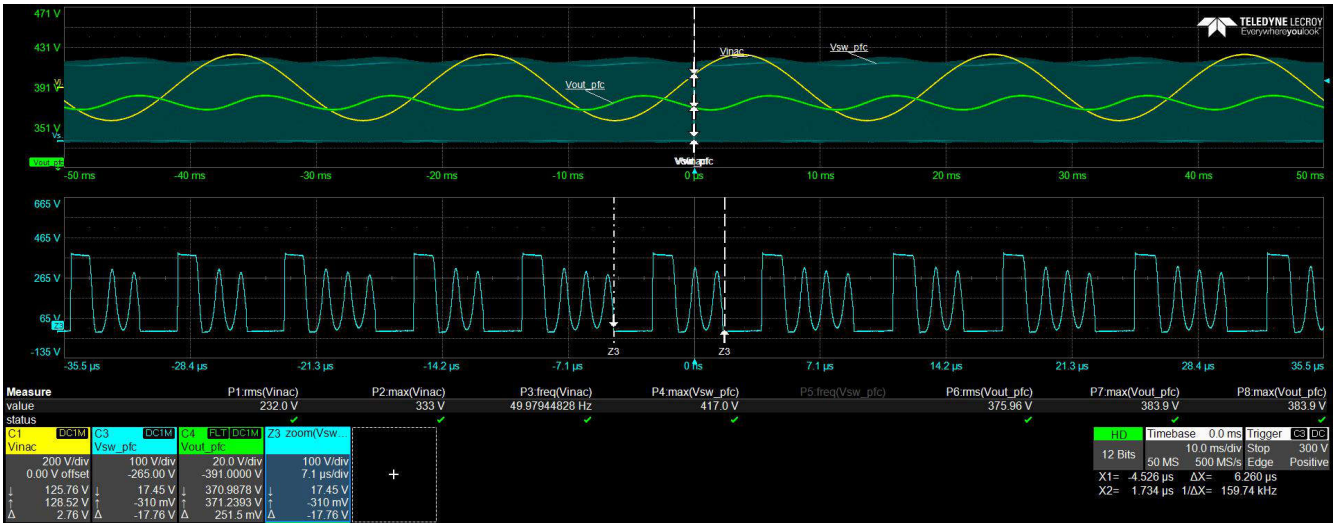
图 3-96. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 2.5A

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C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

图 3-97. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 3.75A



C1 = 交流输入电压　　C3 = PFC 开关节点电压　　C4 = PFC 输出电压

图 3-98. V_{in} = 230VAC/50Hz、V_{out_fly} = 24V 和 I_{out} = 5A

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3.15 PFC 测试结果：效率（仅限具有外部 Vcc 的 PFC）

本节展示了在向 PFC 提供 15V 外部偏置电压时的 PFC 级效率，且在计算各工作点的效率时已将功耗（例如，Vcc × I_Vcc）考虑在内。下表显示了 115VAC 和 60Hz 以及 230VAC 和 50Hz 条件下的前端 PFC 效率。

V_{IN} 和 Fline	P_{IN} (W)	Vout(V)	I_{out} (A)	P_{OUT} (W)	效率
115VAC 和 60Hz	3.273	390.3	0.008	3.111	94.19%
115VAC 和 60Hz	10.483	390.4	0.026	9.963	95.04%
115VAC 和 60Hz	21.075	391.1	0.051	20.126	95.50%
115VAC 和 60Hz	31.406	390	0.077	29.956	95.38%
115VAC 和 60Hz	41.315	385.8	0.103	39.626	95.91%
115VAC 和 60Hz	51.992	387.1	0.129	49.948	96.07%
115VAC 和 60Hz	61.257	380.6	0.155	58.909	96.17%
115VAC 和 60Hz	71.763	382.5	0.181	69.076	96.26%
115VAC 和 60Hz	81.864	380.4	0.207	78.815	96.28%
115VAC 和 60Hz	94.327	379.2	0.239	90.629	96.08%
115VAC 和 60Hz	104.839	378.4	0.266	100.654	96.01%
115VAC 和 60Hz	114.869	377.6	0.292	110.259	95.99%
115VAC 和 60Hz	125.244	376.9	0.318	119.854	95.70%
115VAC 和 60Hz	135.382	376.4	0.347	130.611	95.77%
230VAC 和 50Hz	3.238	390	0.008	3.026	93.01%
230VAC 和 50Hz	10.761	390.2	0.027	10.352	96.06%
230VAC 和 50Hz	20.675	390.2	0.051	19.916	96.19%
230VAC 和 50Hz	30.980	390.5	0.077	29.971	96.65%
230VAC 和 50Hz	41.318	391.3	0.102	40.093	96.93%
230VAC 和 50Hz	51.273	391.3	0.127	49.781	97.01%
230VAC 和 50Hz	61.579	391.1	0.153	59.827	97.08%
230VAC 和 50Hz	72.130	390.1	0.180	70.124	97.16%
230VAC 和 50Hz	83.268	386.9	0.209	80.986	97.19%
230VAC 和 50Hz	93.290	382.4	0.238	91.011	97.49%
230VAC 和 50Hz	103.479	380.4	0.265	100.806	97.28%
230VAC 和 50Hz	113.479	378.7	0.292	110.580	97.39%
230VAC 和 50Hz	123.912	376.5	0.321	120.857	97.49%
230VAC 和 50Hz	133.826	374.3	0.348	130.256	97.29%

效率曲线：

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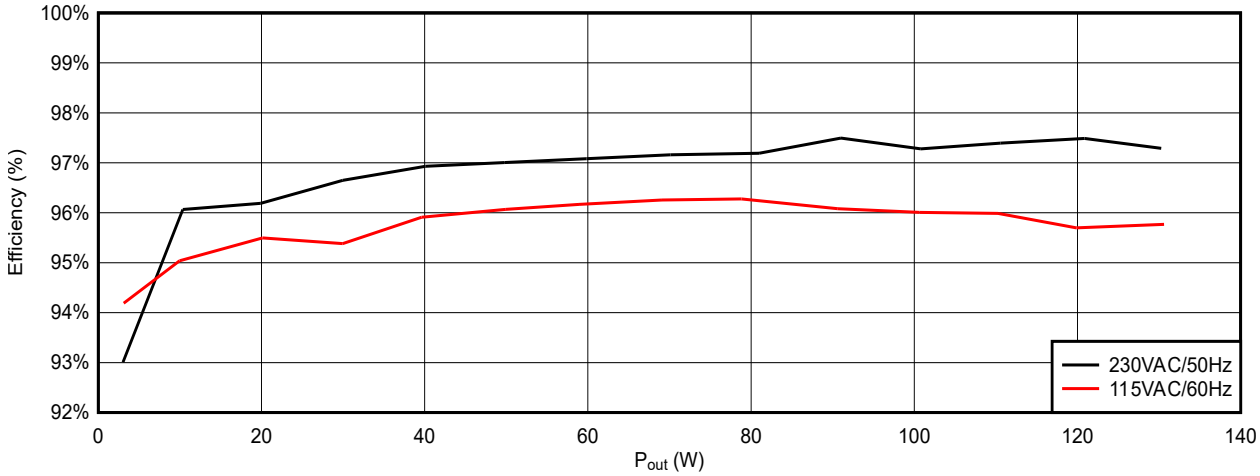


图 3-99. 外部 Vcc = 15V 时前端 PFC 的效率曲线

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4 硬件设计文件

4.1 原理图

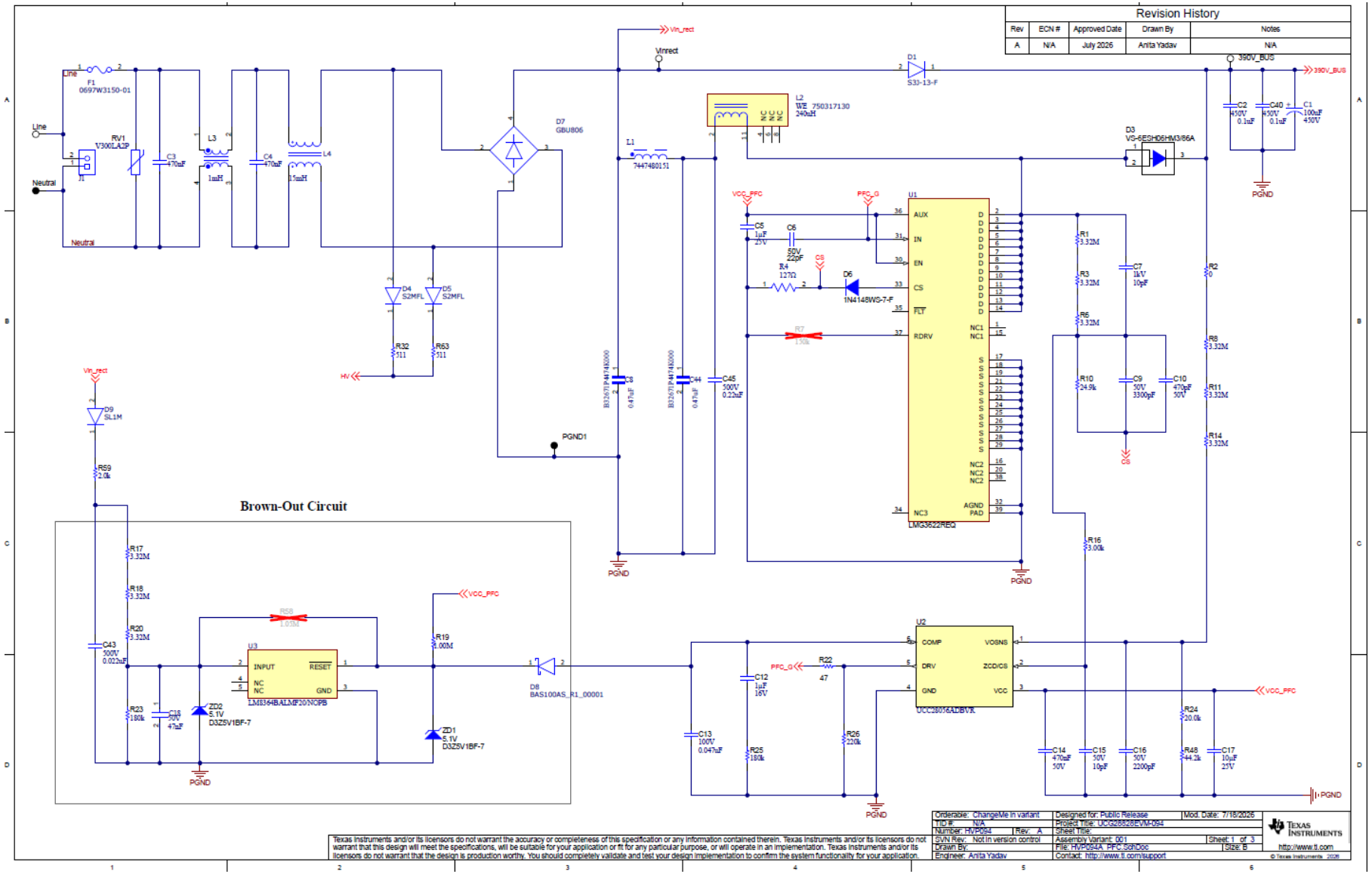


图 4-1. UCG28828EVM-094：PFC 原理图

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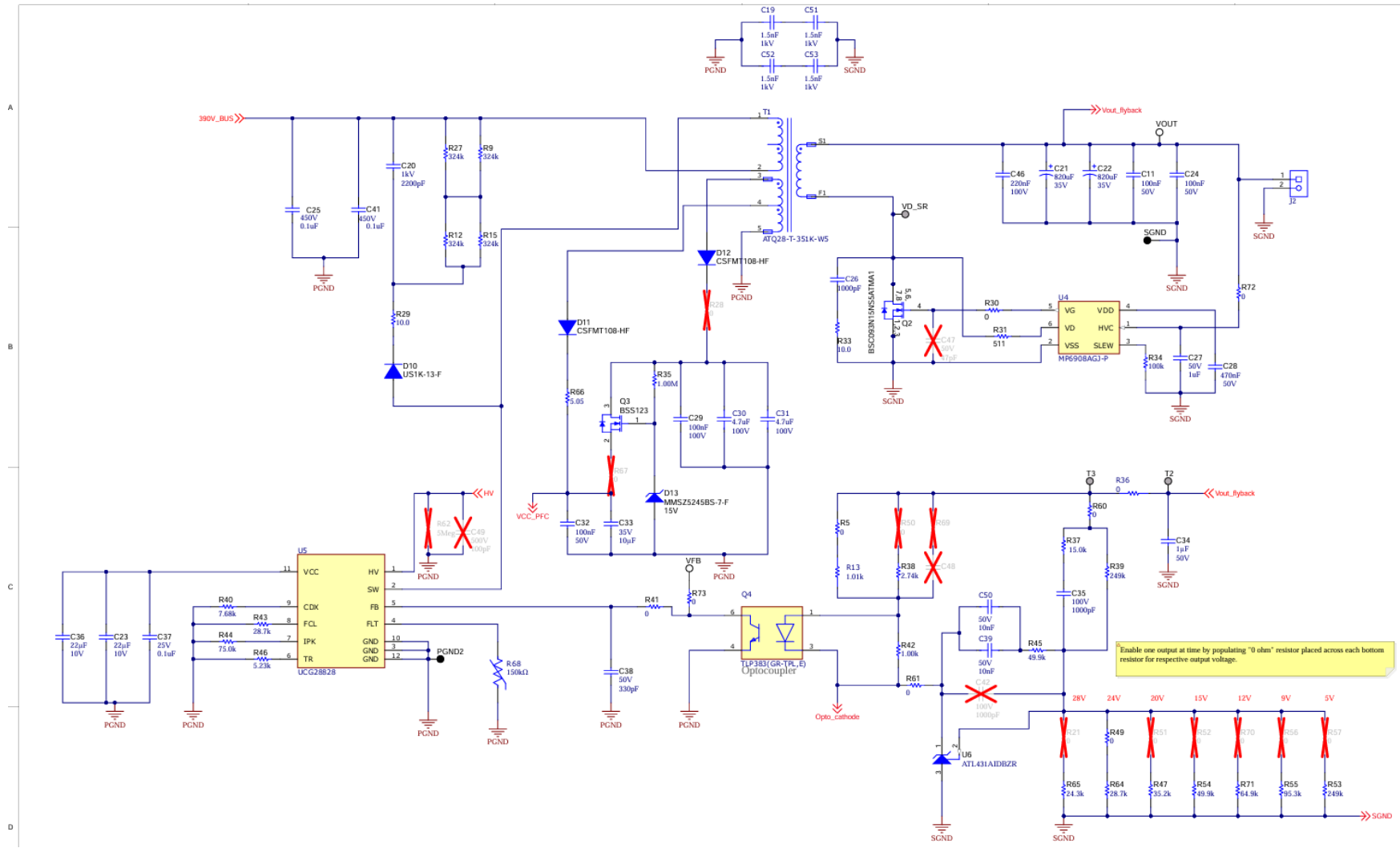


图 4-2. UCG28828EVM-094：反激式原理图

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4.2 PCB 布局

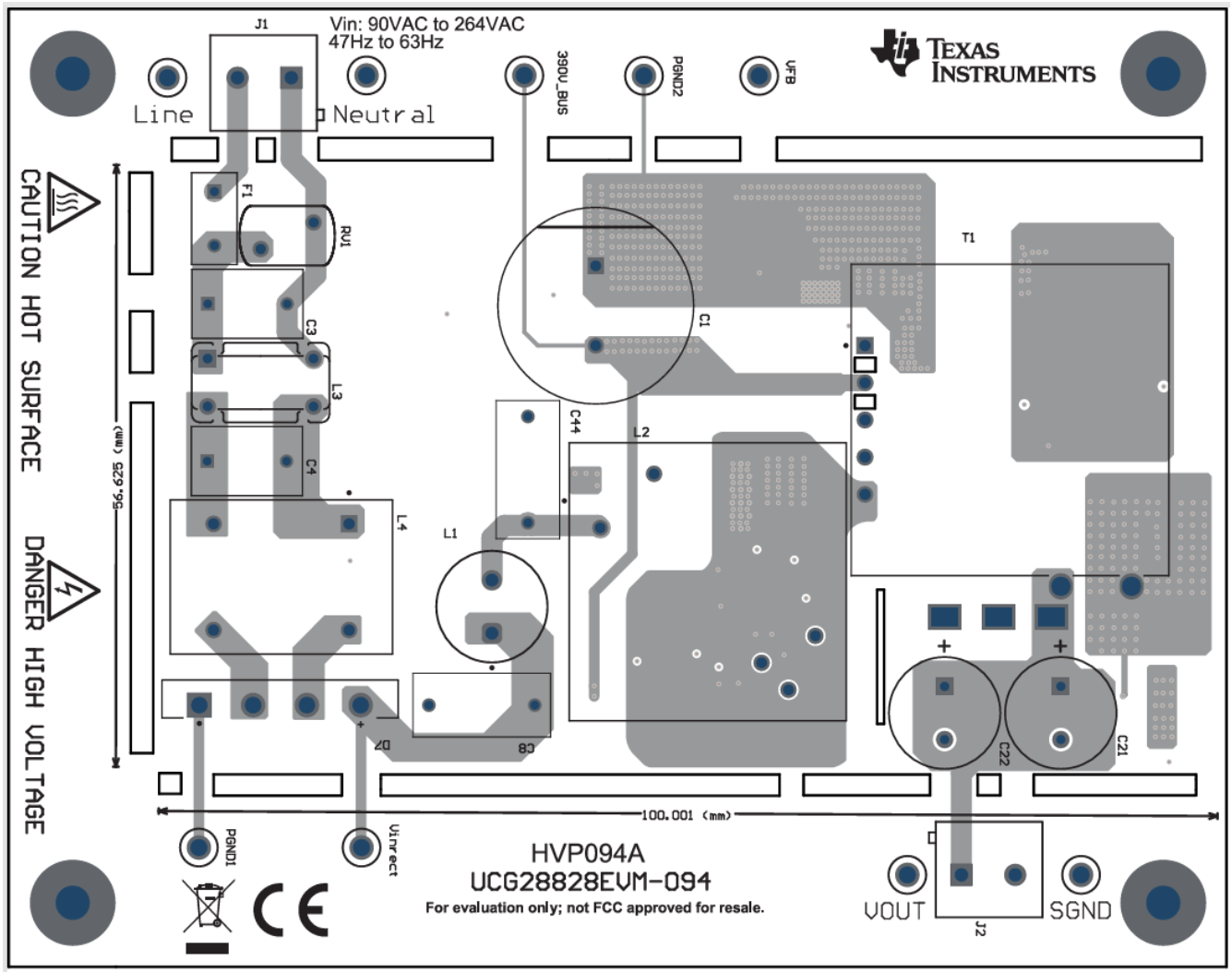


图 4-3. EVM 装配图（顶视图）

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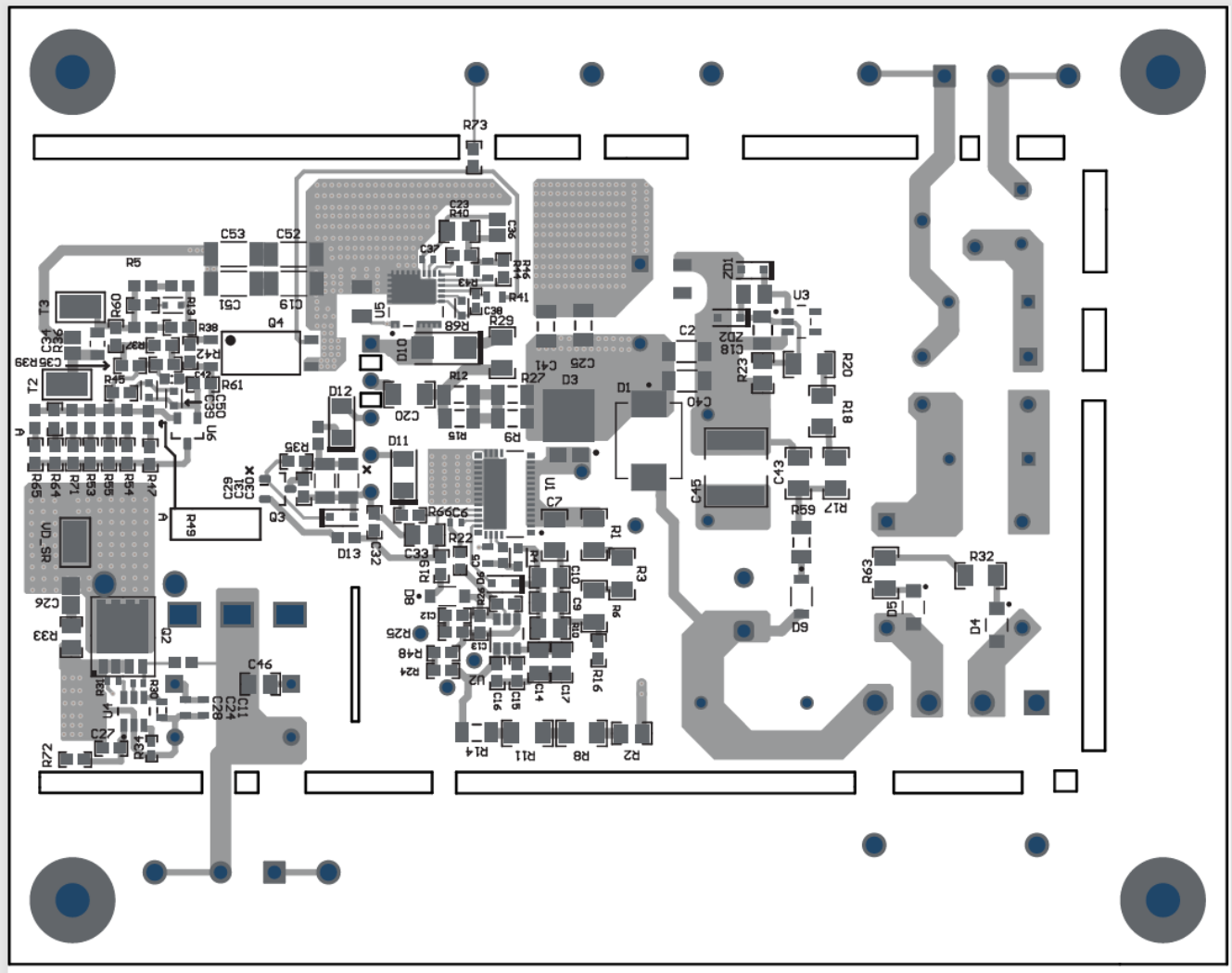


图 4-4. EVM 装配图（底视图）

4.3 变压器详细信息

本设计采用 3L Coils 公司的变压器，其规格如下所述。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 ATQ28-T-351K-W5 变压器的详细信息。

参数	典型值	引脚/引线
电感 (μH)	350 ± 10%	1 - 2
漏电感 (μH)	3.76	1 - 2
直流电阻 (mΩ)	97.17	1 - 2
直流电阻 (mΩ)	9.57	S - F
寄生电容 (pF)	47.8	1 - S
匝数比	25T:5T:3T:10T± 0.5TS	(1-2):(S-F):(4-5):(3-4)

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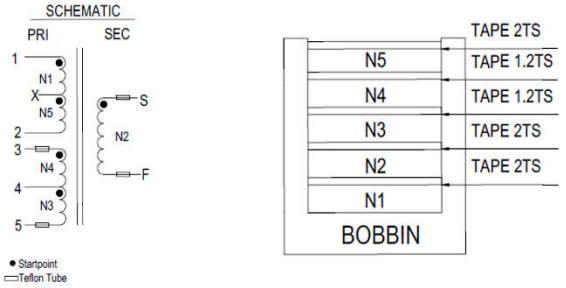
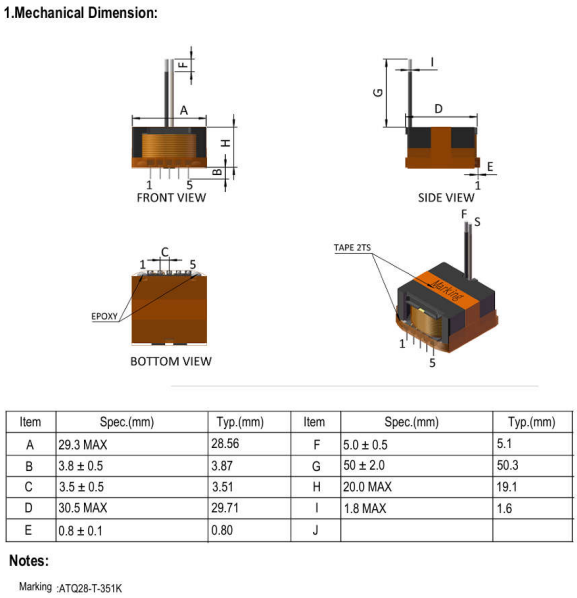


图 4-5. ATQ28-T-351K-W5：原理图



Item	Spec.(mm)	Typ.(mm)	Item	Spec.(mm)	Typ.(mm)
A	29.3 MAX	28.56	F	5.0 ± 0.5	5.1
B	3.8 ± 0.5	3.87	G	50 ± 2.0	50.3
C	3.5 ± 0.5	3.51	H	20.0 MAX	19.1
D	30.5 MAX	29.71	I	1.8 MAX	1.6
E	0.8 ± 0.1	0.80	J		

Notes:
Marking :ATQ28-T-351K

图 4-6. ATQ28-T-351K-W5：机械尺寸

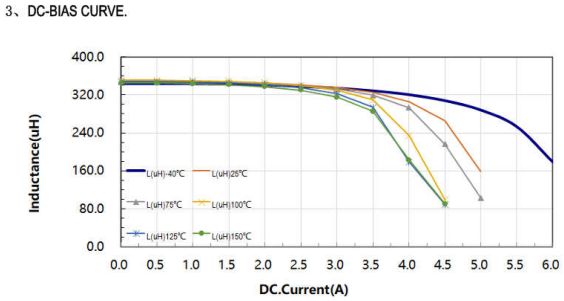


图 4-7. ATQ28-T-351K-W5：直流偏置曲线

4.4 物料清单

下表列出了 UCG28828EVM-098 的物料清单。

表 4-1. 物料清单

位号	数量	说明	器件型号
390V_BUS、线路、VFB、Vinrect 和 Vout	5	测试点，通用，白色，TH	5012
C1	1	100µF 450V 铝制电解电容器，径向，Can 3000 小时，105°C	KCMJ2002W101MF
C2、C25、C40、C41	4	电容，陶瓷，0.1 µ F，450V，±10%，X7T，AEC-Q200 1 级，1206_190	CGA5L4X7T2W104K160AE
C3、C4	2	470nF ±10% X2 插件式，P = 7.5mm 抑制电容器，符合 ROHS	MPX474K31B9KN20600
C5	1	电容，陶瓷，1µF，25V，± 10%，X7R，AEC-Q200 1 级，0603	CGA3E1X7R1E105K080AC
C6	1	电容，陶瓷，22pF，50V，±5%，C0G/NP0，0402	CC0402JRNPO9BN220
C7	1	电容，陶瓷，10pF，1000V，±5%，C0G/NP0，1206	VJ1206A100JXGAT5Z
C8、C44	2	0.47ÂµF 薄膜电容器，160V 450V，聚丙烯 (PP)，金属化径向	B32671P4474K000
C9	1	电容，陶瓷，3300pF，50V，±5%，C0G/NP0，0805	GRM2165C1H332JA01D
C10	1	电容，陶瓷，470pF，50V，±10%，X7R，0805	C0805C471K5RACTU

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表 4-1. 物料清单（续）

位号	数量	说明	器件型号
C11、C24	2	电容，陶瓷，0.1μF，50V，± 10%，X7R，AEC-Q200 1 级，0603	06035C104KAZ2A
C12	1	电容，陶瓷，1μF，16V，± 10%，X7R，AEC-Q200 1 级，0603	GCM188R71C105KA64J
C13	1	电容，陶瓷，0.047 µ F，100V，±10%，X7S，0603	C1608X7S2A473K080AB
C14	1	电容，陶瓷，0.47 µ F，50V，±10%，X7R，0805	GRM21BR71H474KA88L
C15	1	电容，陶瓷，10pF，50V，±5%，C0G/NP0，0603	C0603C100J5GACTU
C16	1	电容，陶瓷，2200pF，50V，±5%，C0G/NP0，0603	GRM1885C1H222JA01D
C17	1	电容，陶瓷，10 µ F，25V，±10%，X7R，0805	GRM21BZ71E106KE15L
C18	1	通用片状多层陶瓷电容器，1206，47000pF，C0G，30ppm/°C，5%，50V	GRM31M5C1H473JA01K
C19、C51、C52、C53	4	1500pF ±10% 250VAC 陶瓷电容器 X7R 1808（公制 4520）	1808YA250152KJTSYX
C20	1	电容，陶瓷，2200pF，1000V，±10%，X7R，1206	GRM31BR73A222KW01L
C21、C23	2	铝电解电容器（径向引线型）820 µ F±20% 35V	EEUFS1V821
C23、C36	2	电容，陶瓷，22 µ F，10V，±20%，X7R，0805	GRM21BZ71A226ME15L
C26	1	电容，陶瓷，1000PF，1KV，X7R，0805	C0805X102KDRACTU
C27	1	电容，陶瓷，1 µ F，50V，±10%，X5R，0603	C1608X5R1H105K080AB
C28	1	电容，陶瓷，0.47 µ F，50V，±10%，X7R，0603	C1608X7R1H474K080AC
C29	1	电容，陶瓷，0.1μF，100V，± 10%，X7R，AEC-Q200 1 级，0603	HMK107B7104KAHT
C30、C31	2	通用片状多层陶瓷电容器，1206，4.7 µ F，X7R，15%，10%，100V	GRM31CZ72A475KE11L
C32	1	电容，陶瓷，0.1 µ F，50V，±10%，X7R，0603	C1608X7R1H104K080AA
C33	1	电容，陶瓷，10μF，35V，±10%，X5R，0805	GMK212BBJ106KG-T
C34	1	电容，陶瓷，1μF，50V，± 10%，X7R，AEC-Q200 1 级，0805	08055C105K4Z2A
C35	1	电容，陶瓷，1000pF，100V，±5%，C0G/NP0，0603	C1608C0G2A102J080AA
C37	1	电容，陶瓷，0.1 µ F，25V，±10%，X7R，0402	GRM155R71E104KE14D
C38	1	电容，陶瓷，330pF，50V，±1%，C0G/NP0，0402	GRM1555C1H331FA01J
C39、C50	2	多层陶瓷电容器，10nF，50V，C0G ±5%，0603，纸质 T/R	GRT1885C1H103JA02D
C43	1	电容，陶瓷，0.022 µ F，500V，±10%，X7R，1206	VJ1206Y223KXEAT5Z
C45	1	电容，陶瓷，0.22 µ F，500V，±10%，X7R，2220	VJ2220Y224KBEAT4X
C46	1	电容，陶瓷，0.22 µ F，100V，±10%，X7R，0805	CL21B224KCFSNWE
D1	1	整流器，单路，600V，3A，Smc 符合 Rohs 标准：是	S3J-13F
D3	1	超快速二极管，600V，6A，AEC-Q101，TO-277A	VS-6ESH06HM3/86A
D4、D5	2	二极管 1000V 2A 表面贴装 SOD-123F	S2MFL
D6	1	二极管，开关，75V，0.15A，AEC-Q101，SOD-323	1N4148WS-7F
D7	1	二极管整流桥单路 600V 8A 4 引脚封装 GBU 管	GBU806
D8	1	肖特基二极管小信号 100V 0.5A 2 引脚 SOD-123T/R	BAS100AS_R1_00001
D9	1	二极管 1000V 1A 表面贴装 SOD-123FL	SL1M
D10	1	二极管，快速整流器，800V，1A，SMA	US1K-13F
D11、D12	2	二极管，超快速整流器，600V，1A，3.5x1.6mm	CSFMT108-HF
D13	1	二极管，齐纳，15V，200mW，SOD-323	MMSZ5245BS-7F
F1	1	微型慢断保险丝，3.15A，350V，径向，8.35 × 4 × 7.8mm，热塑性盒装	0697W3150-01

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表 4-1. 物料清单（续）

位号	数量	说明	器件型号
H1、H2、H3、H4	4	六角螺柱，0.5"L #4-40，尼龙	NY PMS 440 0025 PH
H5、H6、H7、H8	4	六角螺柱，0.5"L #4-40，尼龙	1902C
J1、J2	2	端子块，5.08mm，2x1，黄铜，TH	ED120/2DS
L1	1	‘功率扼流圈无屏蔽绕线式 150uH 10% 10KHz 铁氧体 2A 180mΩ DCR RDL 托盘	7447480151
L2	1	电感器 240uH 10% 100kHz 0.223Ω 9.8A 26.16x26.16x19.05mm TH	750317130
L3	1	耦合电感器，1mH，2A，0.045Ω，TH	744821201
L4	1	耦合电感器 15mH	DC-SQ1515-02010-03L
中性，PGND1，PGND2，SGND	4	测试点，多用途，黑色，TH	中性，PGND，SGND
Q2	1	MOSFET，N 沟道，150V，87A，PG-TDSON-8	BSC093N15NS5ATMA1
Q3	1	MOSFET，N 沟道，100V，0.17A，SOT-23	BSS123
Q4	1	光耦合器晶体管输出 5000Vrms 1 通道 6-SO	TLP383(GR-TPL,E)
R1、R3、R6、R8、R11、R14、R17、R18、R20	9	电阻，3.32M，1%，0.25W，AEC-Q200 0 级，1206	CRCW12063M32FKEA
R2	1	电阻，0，5%，0.125W，AEC-Q200 0 级，0805	ERJ-6GEY0R00V
R4	1	RES SMD 127Ω 0.5% 1/10W 0603	RT0603DRD07127RL
R5、R49	2	电阻，0，5%，0.125W，AEC-Q200 0 级，0805	RC0603JR-070RL
R9、R12、R15、R27	4	电阻，324k，1%，0.25W，AEC-Q200 0 级，1206	ERJ-8ENF3243V
R10	1	电阻，24.9k，1%，0.125W，AEC-Q200 0 级，0805	CRCW080524K9FKEA
R13	1	1.01kΩ ±0.1% 0.1W，1/10W 片上电阻 0603（公制 1608），防潮薄膜	RN73R1JTTD1011B25
R16	1	电阻，3.00k，0.1%，0.1W，0603	RG1608P-302B-T5
R19、R35	2	电阻，1.00M，1%，0.125W，0603	MCT06030C1004FP500
R22	1	电阻，47，5%，0.1W，AEC-Q200 0 级，0603	CRCW060347R0JNEA
R23	1	电阻，180k，0.1%，0.125W，0805	RT0805BRD07180KL
R24	1	电阻，20.0k，0.1%，0.1W，0603	RT0603BRD0720KL
R25	1	电阻，180k，0.1%，0.1W，0603	RT0603BRD07180KL
R26	1	电阻，220k，0.1%，0.1W，0603	RG1608P-224B-T5
R29	1	电阻，10.0，0.5%，1W，AEC-Q200 0 级，1206	HRG3216Q-10R0D-T1
R30	1	电阻，0，5%，0.063W，AEC-Q200 0 级，0402	CRCW04020000Z0ED
R31	1	电阻，511，1%，0.063W，AEC-Q200 0 级，0402	CRCW0402511RFKED
R32、R63	2	电阻，511，1%，0.25W，AEC-Q200 0 级，1206	CRCW1206511RFKEA
R33	1	电阻，10.0，0.05%，0.1W，0805	RNCF0805AKT10R0
R34	1	电阻，100k，1%，0.1W，0402	ERJ-2RKF1003X
R36	1	0Ωs 跳线 0.125W，1/8W 片上电阻 0805（公制 2012），汽车类 AEC-Q200 厚膜	RMCF0805ZT0R00
R37	1	电阻，15.0k，0.05%，0.1W，AEC-Q200 0 级，0603	ERA-3ARW153V
R38	1	电阻，2.74k，0.1%，0.1W，0603	RT0603BRD072K74L
R39、R53	2	电阻，249k，0.1%，0.1W，0603	RT0603BRD07249KL
R40	1	电阻，7.68k，0.5%，0.1W，0603	RT0603DRE077K68L
R41、R60、R61、R72、R73	5	电阻，0，0%，0.25W，AEC-Q200 0 级，0603	RCS06030000Z0EA
R42	1	电阻，1.00k，0.01%，0.063W，0603	RNCF0603TKY1K00
R43	1	电阻，28.7k，0.5%，0.1W，0603	RT0603DRE0728K7L
R44	1	电阻，75.0k，0.5%，0.1W，0603	RT0603DRE0775KL

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表 4-1. 物料清单（续）

位号	数量	说明	器件型号
R45	1	电阻，49.9k，0.5%，0.1W，0603	RT0603DRE0749K9L
R46	1	电阻，5.23k，0.1%，0.1W，0603	RT0603BRD075K23L
R47	1	电阻，35.2k，0.1%，0.1W，0603	RT0603BRD0735K2L
R48	1	电阻，44.2k，0.5%，0.1W，0603	RT0603DRE0744K2L
R54	1	电阻，49.9k，0.1%，0.1W，0603	RT0603BRD0749K9L
R55	1	电阻，95.3k，0.1%，0.1W，0603	RT0603BRD0795K3L
R59	1	电阻，2.0k，5%，0.25W，AEC-Q200 0 级，1206	CRCW12062K00JNEA
R64	1	电阻，28.7k，0.1%，0.1W，0603	RT0603BRD0728K7L
R65	1	电阻，24.3k，0.1%，0.1W，0603	RT0603BRD0724K3L
R66	1	电阻，5.05，0.5%，0.1W，0603	RT0603DRE075R05L
R68	1	NTC 热敏电阻 150k 0603（公制 1608）	NT06155F4050B1F
R71	1	电阻，64.9k，0.5%，0.1W，0603	RT0603DRE0764K9L
RV1	1	压敏电阻 490V 1.2KA 圆盘 7MM	V300LA2P
T1	1	变压器	ATQ28T-351K-W5
T2，T3，VD_SR	3	测试点，微型，SMT	5019
U1	1	具有集成驱动器和电流检测仿真功能的 650V GaN FET	LMG3622REQ
U2	1	6 引脚单相转换模式 PFC 控制器，DBV0006A (SOT-23-6)	UCC28056ADBVR
U3	1	具有低静态电流和 2.5% 阈值精度的低电平有效电压监控器，5-SOT-23，–40 至 85	LM8364BALMF20/NOPB
U4	1	快速关断智能整流器	MP6908AGJ-P
U5	1	具有 750V 集成式 GaN HEMT 的自偏置高频 QR 反激式转换器	UCG28828-1REZR
U6	1	分流电压基准 IC 可调节 2.5V 36W±1% 15mA SOT-23-3	ATL431LIAIDBZR
ZD1、ZD2	2	二极管，齐纳，5.1V，400mW，SOD-323F	D3Z5V1BF-7

5 其他信息

商标

所有商标均为其各自所有者的财产。

6 修订历史记录

注：以前版本的页码可能与当前版本的页码不同

Changes from Revision * (July 2026) to Revision A (August 2026)	Page
• 更新了 图 3-4 至 图 3-6 的轴标签	11

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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 DEGREDATION 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 instruction manual, 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/lsds/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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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。

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

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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:*

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.

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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, INDEMITY 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.

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