Design Example Report

Title	***Two-Wire (No Neutral), Wide Range Input, Bluetooth Wall Switch with Relay Zero-Voltage Switching and Automatic Set/Reset Time Calibration using LinkSwitch™-TNZ LNK3302D***
Specification	90 VAC – 277 VAC Input
Application	Lighting Control, Home Automation
Author	Applications Engineering Department
Document Number	DER-867
Date	October 13, 2022
Revision	1.0

Summary and Features

- Compatible with 2-wire (no neutral), home / building wiring
- Relay zero-voltage switching with automatic set time calibration at start-up
- Non-isolated LNK3302D power supply with half-wave rectifier
- Low-component count with integrated 725 V MOSFET, current-sensing, and protection
- Wide-range AC input
- 3 W to 500 W resistive load, 5 to 150 W LED load
- <150 μA standby current (including BLE) at 230 VAC

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Important Note:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

A typical smart wall switch requires LINE and NEUTRAL to properly work. This is true especially on many WIFI-based switches that consume higher power. However, a majority of homes around the world do not have a neutral wire on the wall switch. A two-wire (no Neutral) smart wall switch addresses this market.

One of the challenges in making a two-wire switch is the need to minimize leakage current that might cause 'ghosting' or light flutter even when the switch is OFF. Many bulbs, especially the non-dimmable types, do not have a bleeder circuit that prevents 'ghosting' due to high leakage current. Minimizing the leakage current ensures wider compatibility across many types of load.

Another challenge is the need to switch the relay exactly at the zero crossing to eliminate high in-rush current. However, when considering different set and reset times for relays and their respective tolerances, it is difficult to design a smart switch that dynamically knows the set time and reset time of the actual relay used. Without knowing these delays, the relay can't be switched at zero crossing of input line.

This report addresses both challenges using the LinkSwitch-TNZ, paired with a proprietary current-shaping circuit for ultra-low current consumption. With the ZCD signal coming from the LinkSwitch-TNZ IC, relay set time and reset time can be known during one-time start-up calibration. The relay can now be switched at zero crossing even if the user requests for an asynchronous turn-on via the app or physical switch. With this solution, alternate relays with varying set and reset times can be used interchangeably and still switch at zero-crossing. Specifically, this report can calibrate up to one-line period of set time variation.

This document is an engineering report describing a two-wire (no Neutral) Bluetooth low-energy (BLE) smart wall switch using LinkSwitch-TNZ LNK3302D. This demo board is intended as a general purpose evaluation platform for LinkSwitch-TNZ.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit board layout, and performance data.

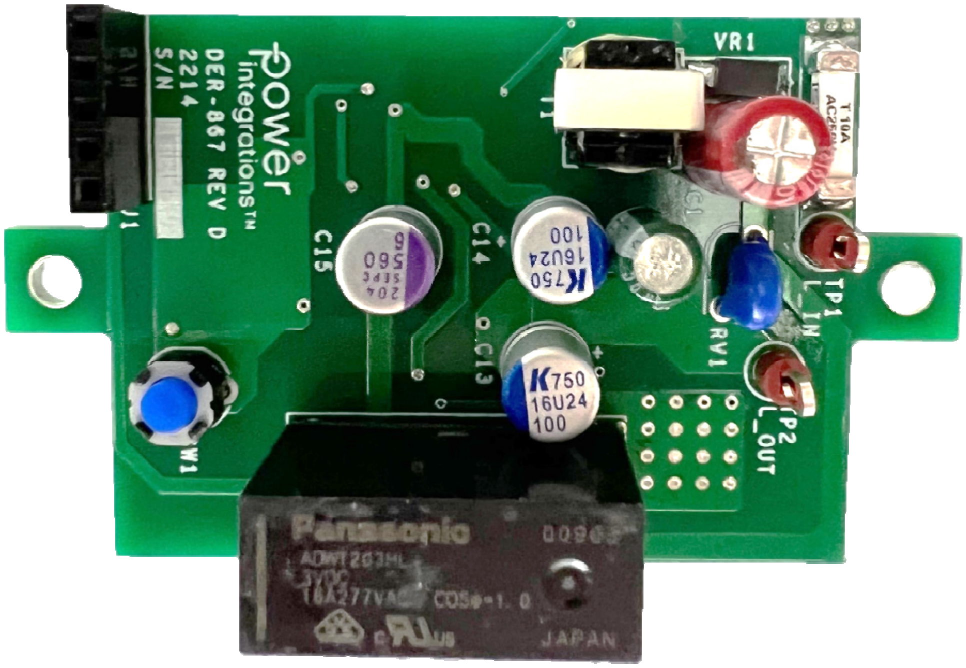


Figure 1 – Populated Circuit Board Photograph, Top.

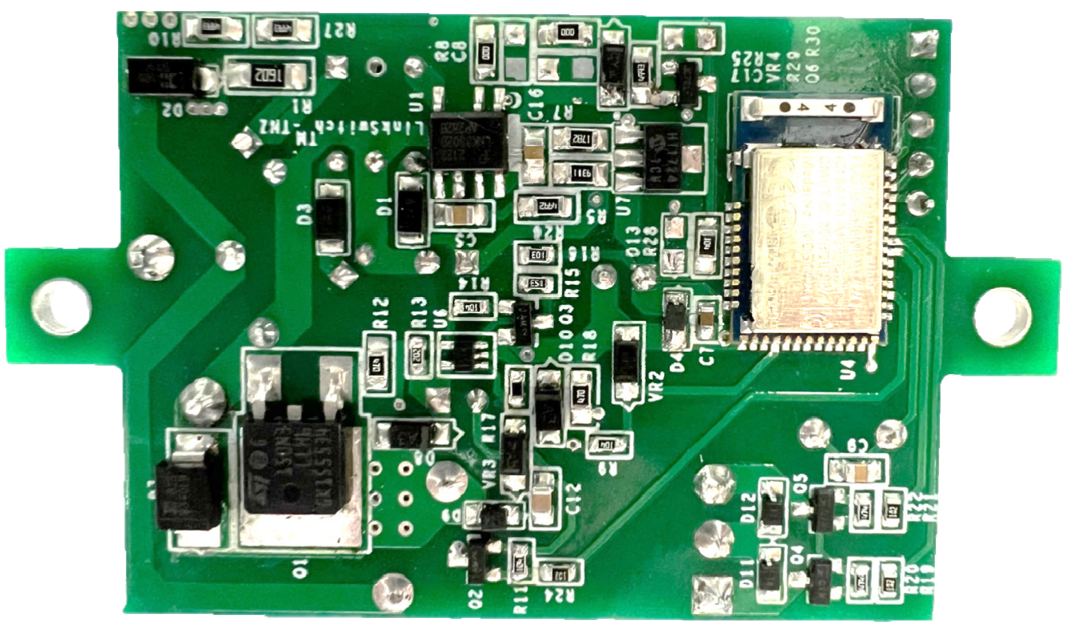


Figure 2 – Populated Circuit Board Photograph, Bottom.

2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		277	VAC	
Frequency	f_{LINE}	47	50/60	63	Hz	
Rated Load						
Resistive Load or High PF Load		3		500	W	
Low PF Load		5		150	W	
System Standby Input Current			125	160	µA	At 120 VAC, After 5 Minutes.
			110	140	µA	At 230 VAC, After 5 Minutes.
LinkSwitch-TNZ + LDO Block						
LinkSwitch-TNZ Output Voltage	V_{TNZ}		3.5		V	
3 V Regulator Output Voltage	V_{OUT}		3		V	
3 V Regulator Output Current	I_{OUT}		60		mA	
No-Load Input Current			110		µA	At 120 VAC, After 5 Minutes.
			100		µA	At 230 VAC, After 5 Minutes.
BLE Module						
Power Consumption			5		mW	
Ambient Temperature	T_{AMB}		40		ºC	Free Convection, Sea Level.
Relay Set Time	T_{SET}	0	4	16	ms	Range of Relay Set Times that can be Dynamically Calibrated by the Algorithm.

3 Schematic

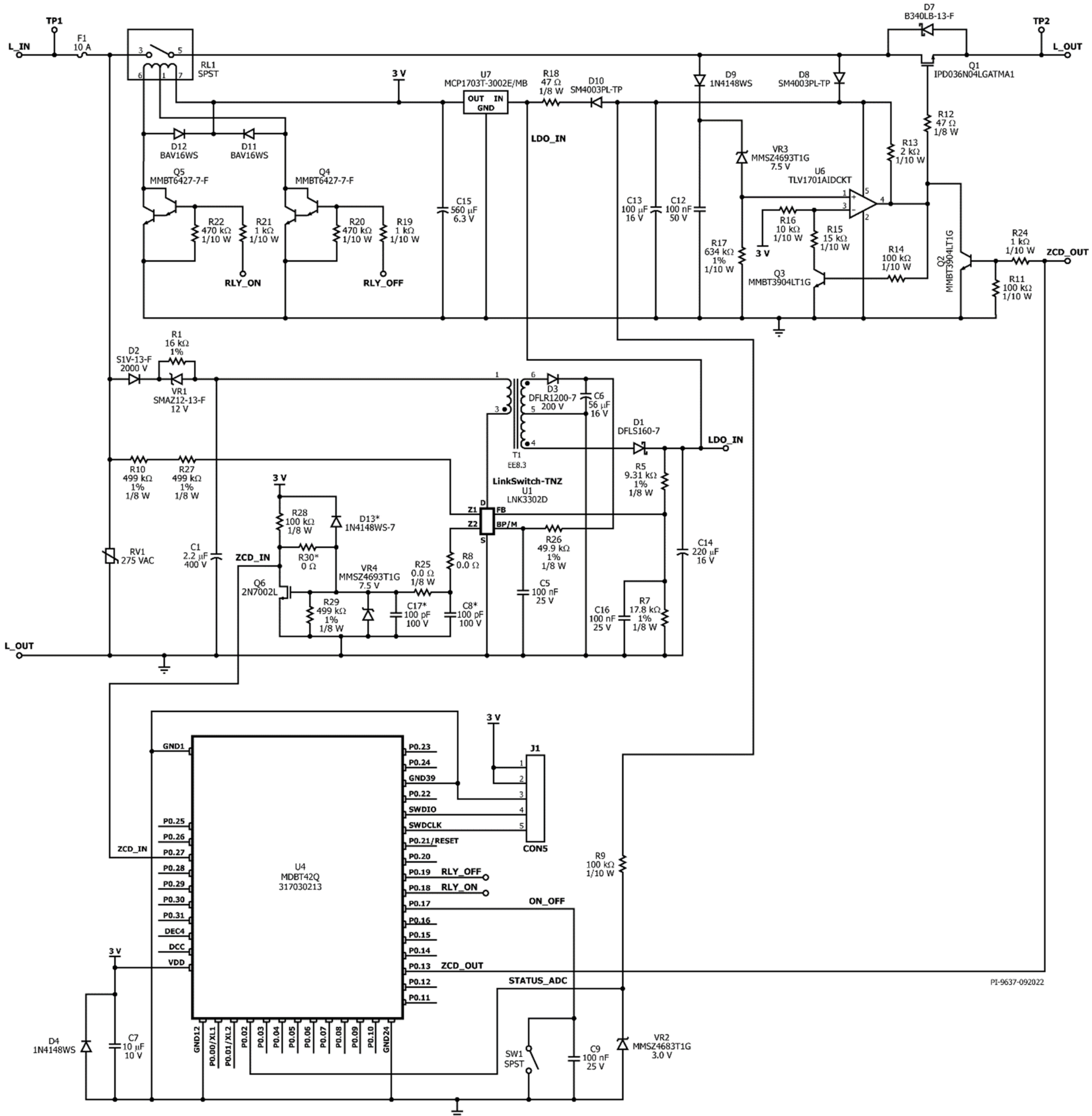


Figure 3 – Schematic.

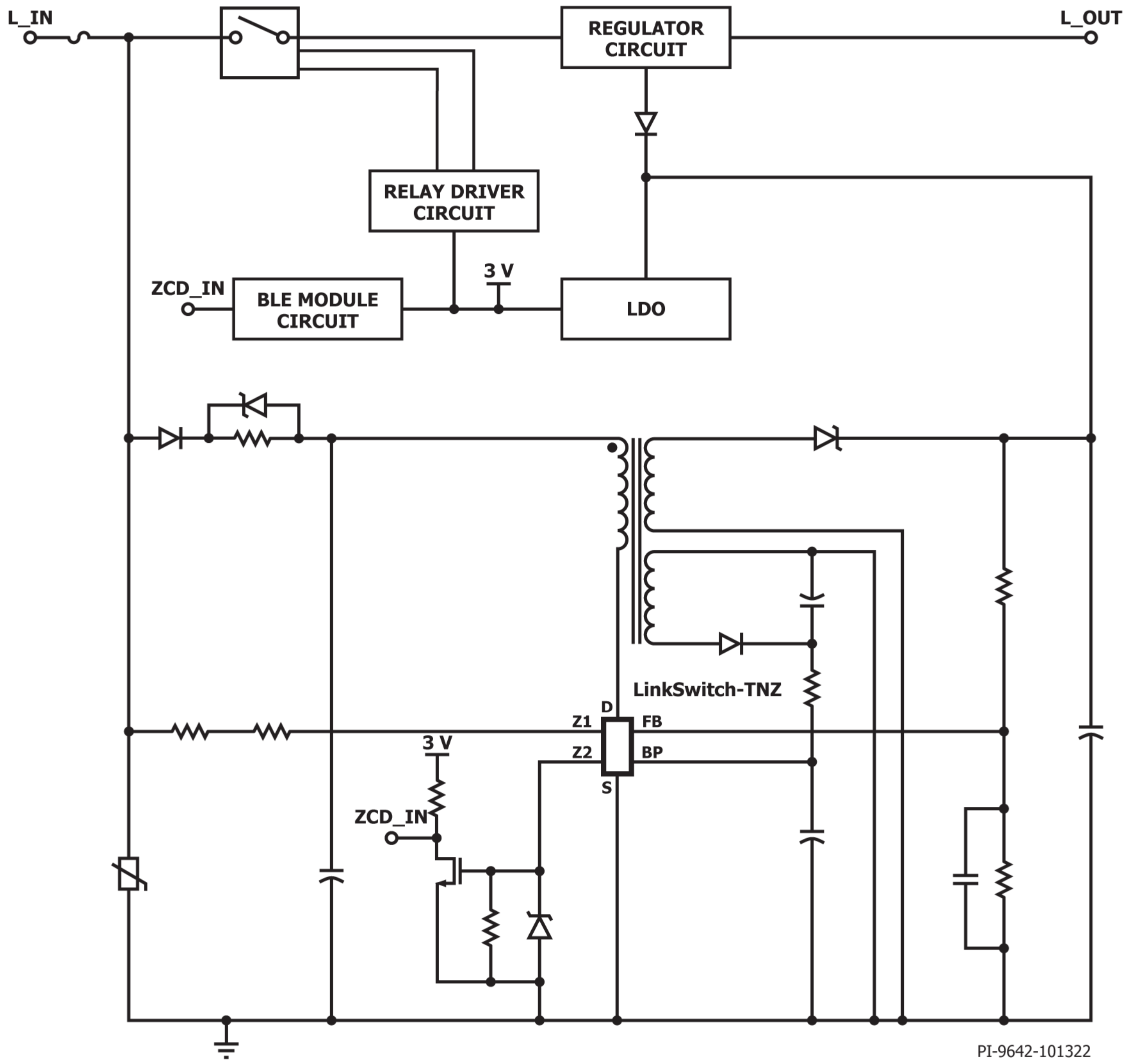


Figure 4 – Block Diagram Schematic.

4 Circuit Description

4.1 *LinkSwitch-TNZ Block*

4.1.1 Input Stage

The input stage is comprised of fuse F1 for safety protection, varistor RV1 for up to 500 V differential line surge protection, half-wave bridge rectifier diode D2, and bulk capacitor C1.

4.1.2 Current-Shaping Circuit

The proprietary R-Z circuit R1 and VR1 form a simple, yet effective means to improve the power factor of the circuit. A higher PF will result to the lowest standby input current. Resistor R1 reduces the peak input current which effectively reduces the input RMS current and increases the power factor. Zener diode VR1 connected in parallel with R1 provides the charging path for the bulk capacitor C1 during start-up to be able to operate the circuit properly. Please see appendix A for tips on how to choose the optimum values for R1 and VR1.

4.1.3 LinkSwitch-TNZ Circuit Operation

LinkSwitch-TNZ LNK3302D was configured in a non-isolated flyback topology to be able to have a fixed reference ground for both the converter and the microcontroller. This configuration allows relay to be turned on and turned off at zero crossing through processing the ZCD signal from LNK3302D IC. The flyback circuit is formed by the main controller LNK3302D U1, transformer T1, bulk capacitor C1, secondary diode D1 and capacitor C14. The BP pin capacitor C5, with a value of 100 nF, sets the current limit to standard mode.

4.1.4 Primary Bias Supply

A 12 V auxiliary supply was taken from the bias winding of T1, rectified by D3 and C6. It provides external biasing of the BP pin through R26. The value of R26 was tuned to provide the lowest no-load input current by setting the BP current slightly higher than I_{S1}. Since the auxiliary winding is just a "slave" winding, there could be some part-to-part variation on the auxiliary voltage that may cause the BP current to deviate from its ideal supply current. If tighter control of BP current is desired, then a simple constant current circuit using a transistor and a Zener may be added.

4.1.5 Feedback

Output regulation is achieved through resistor divider formed by R5 and R7 to set the output voltage. Capacitor C16 provides decoupling and stability compensation to prevent overshoot during start-up or load step.

4.2 *Low Drop-Out Regulator Block*

The LDO regulator U7 provides a stable 3 V supply for the BLE module and relay RL1. Capacitor C15 is the output capacitor of U7. A 560 μF was used to sustain the power drawn by the relay during its transition period of 10-20 ms. When the relay is OFF, the input to the LDO comes from LinkSwitch-TNZ. When the relay is ON, the supply comes from Q1 regulator via D10 and R18.

4.3 *Relay Circuit Block*

A 3 V, 2-coil, latching relay RL1 from Panasonic (ADW1203HL) was used. Unlike conventional relay, latching type retains its last state even when the power is gone, similar to that of a regular wall switch. Moreover, it only requires a 3 V pulse of about 10 ms to set and reset the relay unlike conventional relay that needs steady supply.

Transistor Q4, R19, R20 drive the relay OFF while Q5, R21, R22 drive the relay ON. Diodes D11 and D12 protect the transistors Q4 and Q5 from 'inductive kick' by clamping the voltage to 3 V plus 1 diode drop.

4.4 *Q1 Regulator Circuit Block (Power Supply when the Relay is ON)*

This DER uses low voltage MOSFET Q1 and gate driver circuit using a comparator U6.

When the relay is ON, the FET Q1 gate is initially OFF. Depending on the phase of the input line, current may flow from the Source to Drain through Q1 body diode or D7 if the AC line phase is more positive than neutral. In the negative-going phase, since Q1 is OFF, then current will flow through D8 and D9 and will charge the capacitors C12, C13 and C14. The output of comparator U6 is kept low until the voltage on its (+) input equals the reference (-) input which was set to 3 V. The 7.5 V Zener VR3 provides the voltage threshold that determines when the comparator will change state. The threshold is given by Vz (7.5 V) + Vref (3 V) = 10.5V. Resistor R17 provides the bias for the Zener and is also responsible for the R-C timer formed by R17 and C12. A 1% tolerance resistor is recommended for R17 and C12 should be of NPO/COG type.

Once the threshold has been reached, the comparator will change from LOW to HIGH state, driving Q1 ON. The circuit comprised of R14, R15, R16 and Q3 provide hysteresis (from 3 V to 1.8 V reference) to prevent Q1 from rapidly turning ON and OFF and is also part of the R-C timer circuit.

The time constant formed by R17 and C12 was selected such that once Q1 turns ON, it will remain ON for about 32.4 ms. This time could be computed using the equation below:

$$t_{Q1\_on} = -RC * \ln\left(\frac{V_{ref\_1.8V}}{V_{ref\_3V}}\right)$$

$$t_{Q1\_on} = -(634\ k)(100\ n) * \ln\left(\frac{1.8}{3}\right) = 32.4\ ms$$

The choice of 32.4 ms is chosen to ensure that the regulator will work properly for both 50 Hz and 60 Hz system. The ON-time may be adjusted on a single input system (voltage, frequency). In selecting the ON time, the goal is to maximize the time that Q1 is ON, and make sure that it turns OFF when the current is flowing in the direction from the Source to Drain (LINE IN more positive than LINE OUT). Diode D7 is connected in parallel with Q1 so that the current will not flow through Q1 body diode after the FET turns OFF. To minimize the dissipation on D7, the ON-time can be set as close as possible to the input voltage zero-crossing. However, enough margin must be maintained due to component tolerances that affects the timing.

The ON time of Q1 was optimized at 60 Hz system and not on 50 Hz system. Due to this, the dissipation on D7 is higher on 50 Hz system since Q1 ON time was not maximized. To minimize the dissipation on D7 for both 50 Hz and 60 Hz system, circuit comprising R24, R11, and Q2, provides a bypass turn off function to the output of the comparator U6 to control when to turn off Q1. Hence, ON time of Q1 can now be maximized since delay to turn off Q1 can be controlled by the microcontroller using the ZCD signal from the LinkSwitch-TNZ. The ZCD_OUT signal from the microcontroller is configured to turn off Q1 every 14 ms delay for a 60 Hz system and 18 ms delay for a 50 Hz system.

Resistor R13 is the pull-up resistor for the output of the comparator U6.

The regulator circuit used in this DER has some restrictions:

a. There is a minimum load required to operate the switch properly. Unlike conventional wall switch with line and neutral, the bulb load is required to close the power loop. If the load is too small, it presents a high impedance or open-circuit; hence, the BLE switch will not work.

b. It is not advisable to use smart bulbs with the wall switch. When the smart bulb is remotely turned OFF, for example, it usually goes into low-power mode and the BLE switch might stop working because the load drops below the minimum load requirement.

4.5 ***Bluetooth Low Energy (BLE) Module Circuit Block***

This DER uses a Bluetooth 5-certified Bluetooth Low Energy (BLE) module U4, MDBT42Q, based on Nordic NRF52832 SoC. Its ultra-low current consumption, together with LinkSwitch-TNZ power supply, enables a < 150 µA standby input current at 230 VAC.

4.5.1 Pin Functions

Pin Number	Description
4 (P0.27)	Configured as Digital Input. This pin detects low-to-high transition interrupt or toggle interrupt from the ZCD_IN signal.
15 (P0.02)	Configured as ADC Input. The pin detects the relay state by sensing the voltage across VR2. Resistor R9 provides the bias current for the Zener.
31 (P0.17)	Configured as Digital Input. Senses the push-button switch SW1 to trigger relay ON/OFF. C9 provides passive de-bouncing to ensure clean input signal when the switch SW1 is pressed.
32 (P0.18)	Configured as Digital Output. Provides a 20 ms pulse to turn OFF the latching relay.
33 (P0.19)	Configured as Digital Output. Provides a 10 ms pulse to turn ON the latching relay.
27 (P0.13)	Configured as Digital Output. Provides a 100 µs pulse (ZCD_OUT signal) to turn OFF the output of comparator U6.
36 (SWDCLK)	Programming pin.
37 (SWDIO)	Programming pin.
11 (VDD)	The VDD comes from the 3V LDO regulator. C7 is the VDD filter capacitor while D4 protects the BLE module from negative voltage.

Table 1 – Bluetooth Module Pin Description.

4.5.2 Using the App

This DER uses a Nordic based application, nRF Blinky, for its BLE functionality.

Step 1: Power-up the BLE wall switch.

Step 2: Install nRF Blinky App on Android or IOS devices that support Bluetooth 4.0 or higher.

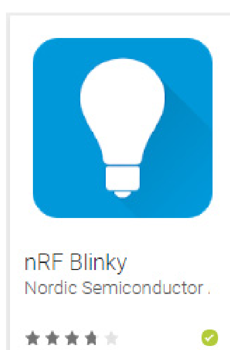


Figure 5 – nRF Blinky Application.

Step 3: Switch-ON Bluetooth on the mobile device.

Step 4: Open the nRF Blinky App, the app should detect "DER 867"

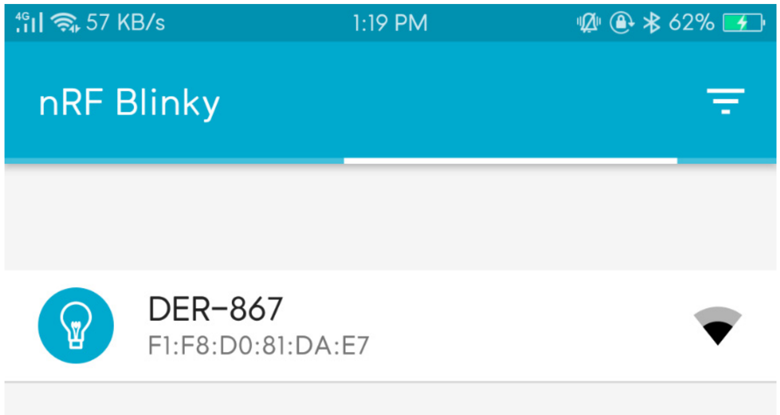


Figure 6 – DER-867 on nRF Blinky App.

Step 5: Select DER-867 to connect to unit. Once connected, LED and Button interface can be seen.

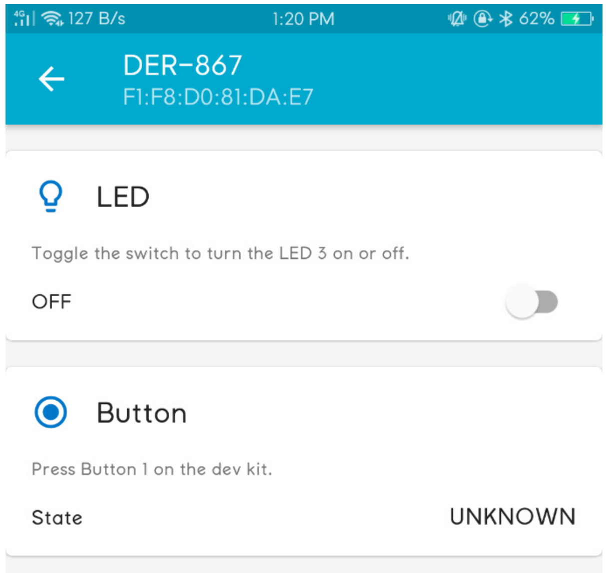


Figure 7 – "Connected" Status Interface.

Step 6: Press the LED button to toggle the wall switch.

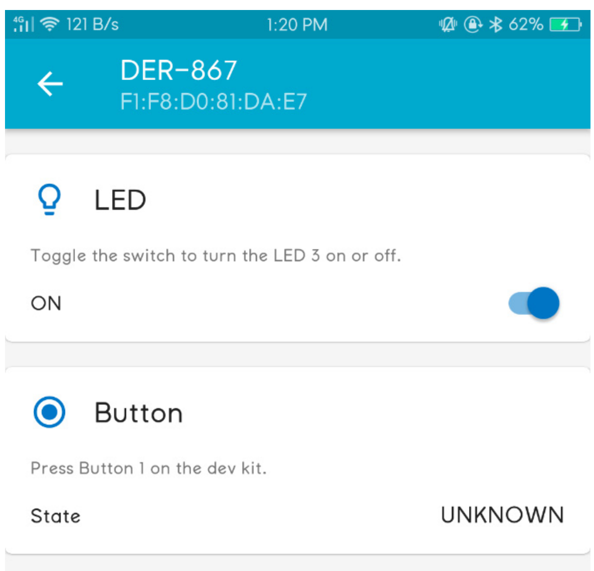


Figure 8 – Switched-ON Status.

5 Firmware Block Diagram

This DER uses the following algorithm to detect the inherent relay set time and relay reset time of the relay through the zero crossing signal from the LinkSwitch-TNZ LNK3302D.

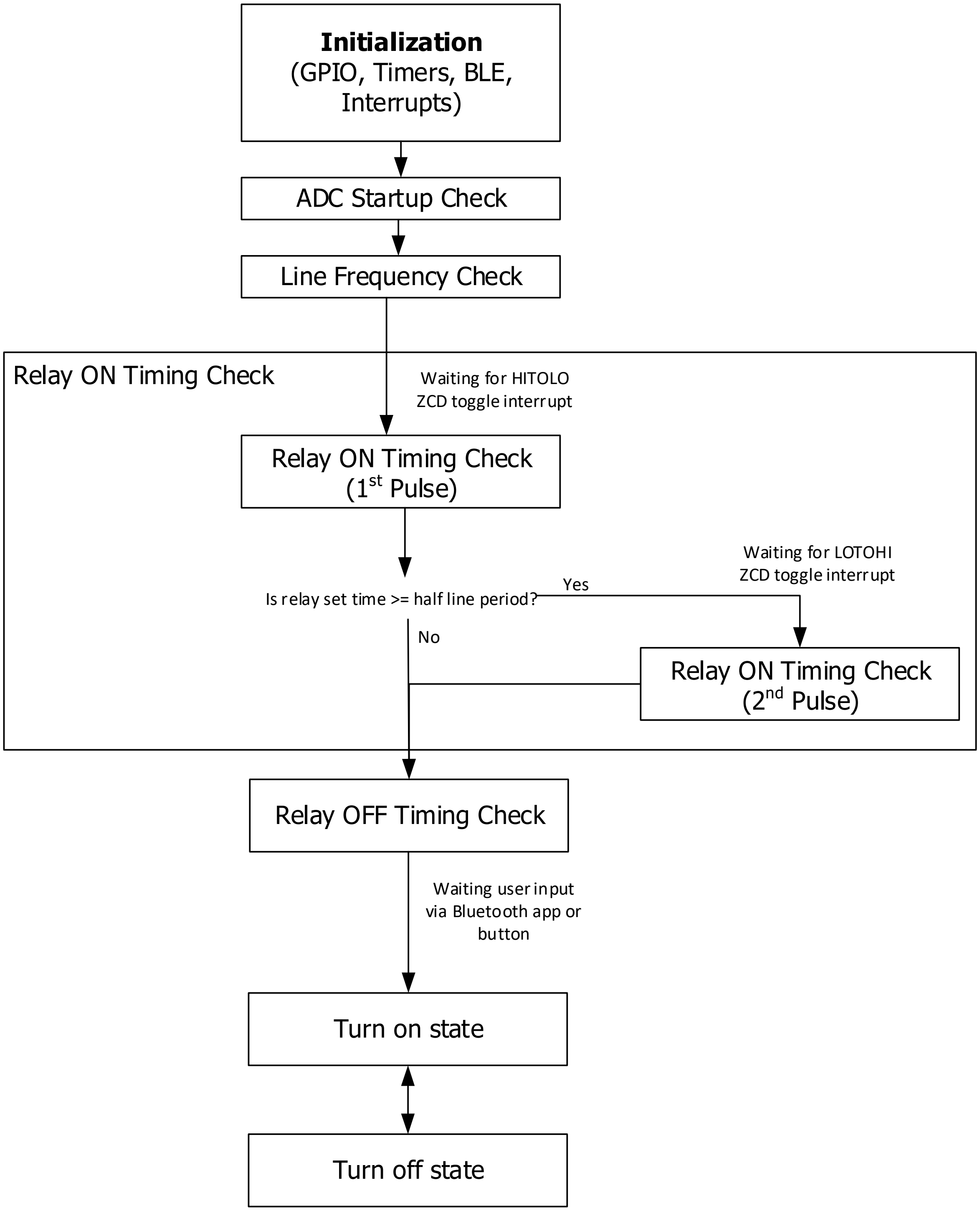


Figure 9 – Firmware Block Diagram.

5.1 *Initialization*

Initialization starts on the onset of unit power-up through the line. During power-up the following peripherals needs to be initialized for algorithm to properly work: GPIO, Timers, Bluetooth communication, Interrupts.

5.2 *ADC Start-up Check*

After initialization, power must be stable before beginning any operation at the microcontroller. This code block ensures that the relay is turned off by throwing a relay off signal then implementing a 500 ms delay before enabling ZCD interrupt for Line Frequency Check state.

5.3 *Line Frequency Check*

After ZCD interrupt has been enabled, this state identifies the line frequency based on the ZCD signal. This correctly identifies whether input voltage is operating at 60 Hz or 50 Hz frequency. Once line frequency has been identified, ZCD interrupt will be disabled for 100 ms before proceeding to the Relay ON Timing Check state.

5.4 *Relay ON Timing Check*

After ZCD interrupt has been enabled again, the algorithm will wait for a high-to-low (HITOLO) transition from the ZCD signal. Once transition has been determined, a timer will immediately start and a switch on signal will be sent to the relay driver circuit to turn on the relay. Due to the inherent set time of the relay, the relay will not switch on immediately. Consequently, ZCD signal remains low during this delay. Once the relay is on, ZCD signal will toggle to high. This will signal the microcontroller to stop the timer and store the relay set time delay determined from the timer.

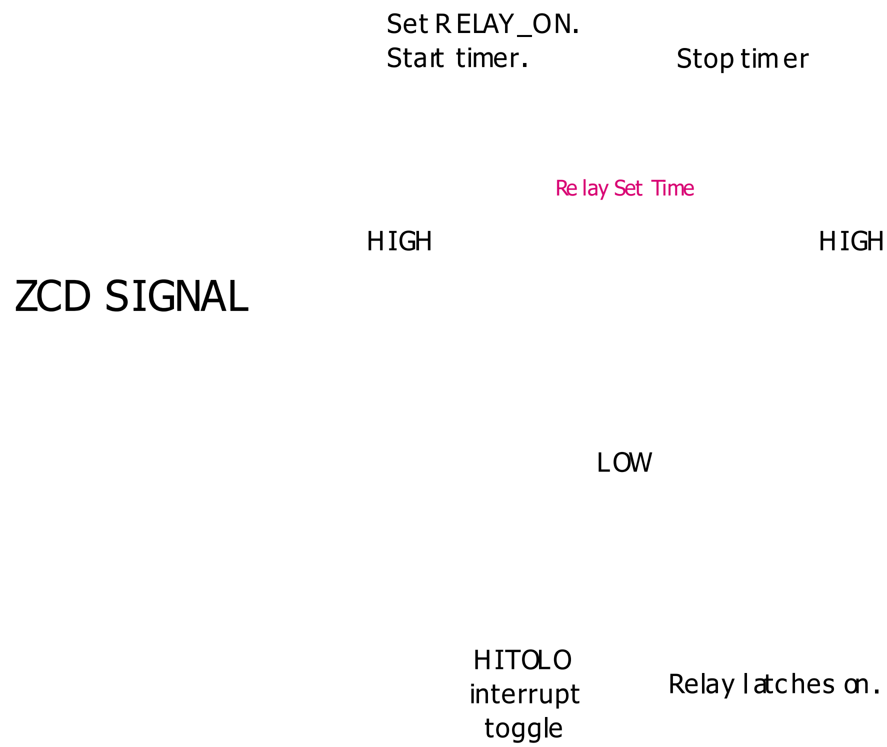


Figure 10 – Determining Relay Set Time During the 1st Pulse Calibration.

The relay set time will then be check if it is below half line period. If it is below the half line period, it will proceed to the Relay Off Timing Check state. Otherwise, the relay has not turned on yet since relay set time might be greater than half line period or relay turned on at exactly at half line period.

To address this, a 2nd pulse start-up calibration will be fired but this time instead of waiting for a HITOLO transition from the ZCD signal, LOTOHI transition will be the interrupt. Similar from the 1st pulse start-up calibration, timer will start when there is a LOTOHI transition and will stop when there is a 2nd LOTOHI transition toggle in the ZCD signal because it is the indication that the relay successfully latches.

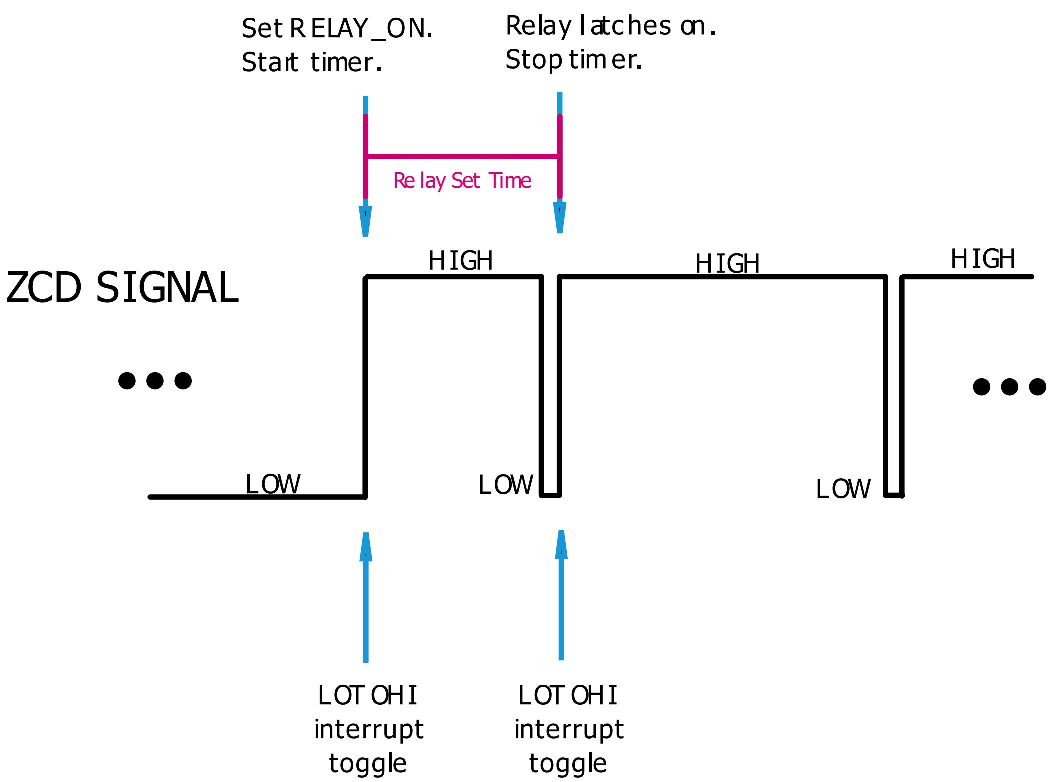


Figure 11 – Determining Relay Set Time During the 2nd Pulse Calibration.

Once relay set time has been determined from either the 1st pulse start-up calibration or 2nd pulse start-up calibration, it will proceed to the Relay OFF Timing Check state.

5.5 *Relay OFF Timing Check*

Once relay set time has been stored, relay off time will be determined in this code block. The ZCD state handler from the microcontroller will now only detect LOTOHI transitions. Once a LOTOHI transition has been determined, there will be a one period delay before sending signal to set relay off. The timer will start after the relay off signal was sent and will stop when a LOTOHI interrupt has been registered. After relay off delay has been stored, ZCD interrupt handler will be disabled and the relay set time and reset time has been configured.

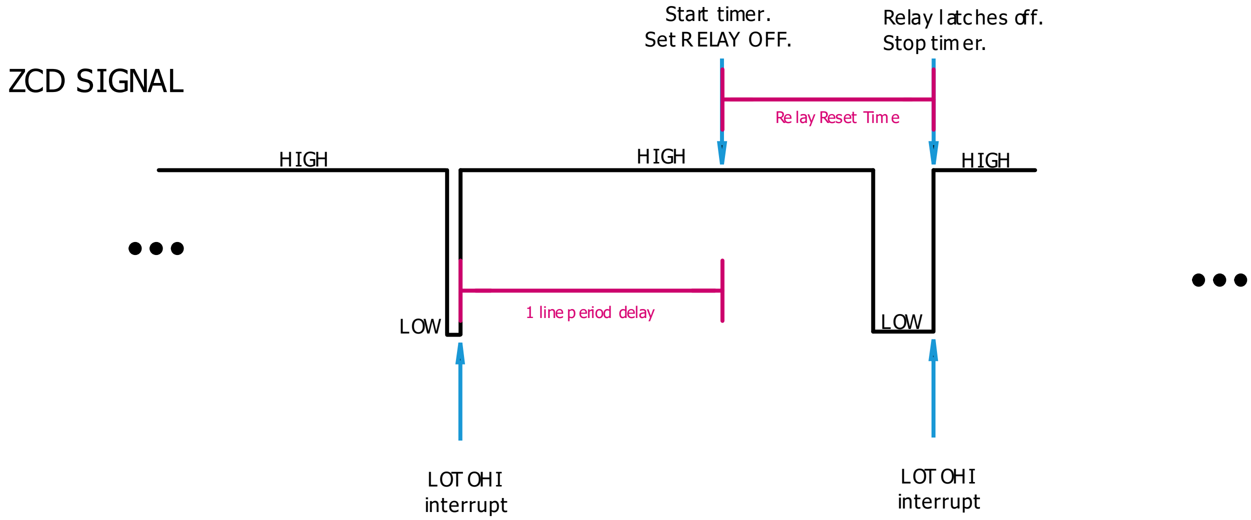


Figure 12 – Determining Relay Reset Time.

5.6 *Turn-On State and Turn-Off State*

Once turn on delay and turn off delay has been configured to switch the relay at zero crossing. The microcontroller waits for user input either through Bluetooth app (NRF Blinky) or through on-board button. Depending on the relay status, the code switches between Turn on state and Turn off state.

For switching on the relay, the following equation will be the delay to include the turn on delay/set time to switch at zero crossing:

$$turn\_on\_delay = linePeriod - relaySetTime$$

For switching off the relay, the following equation will be the delay to include the turn off delay/reset time to switch at zero crossing:

$$turn\_off\_delay = 2 * linePeriod - relayOFF\_delay$$

6 PCB Layout

PCB specifications:

- Layer count: 2 layers
- Solder mask: Green
- Silkscreen: White
- Finish: LF HASL
- Board Thickness: 1.6 mm
- Copper Thickness: 2 oz. (2.8 mils)
- Material: FR4

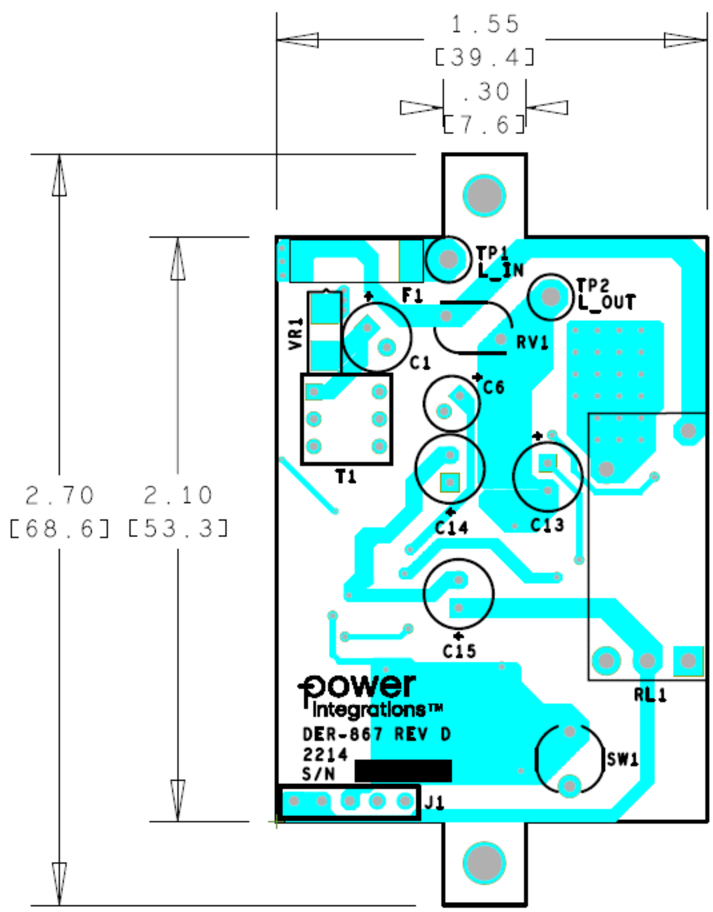


Figure 13 – Printed Circuit Board Layout, Top.

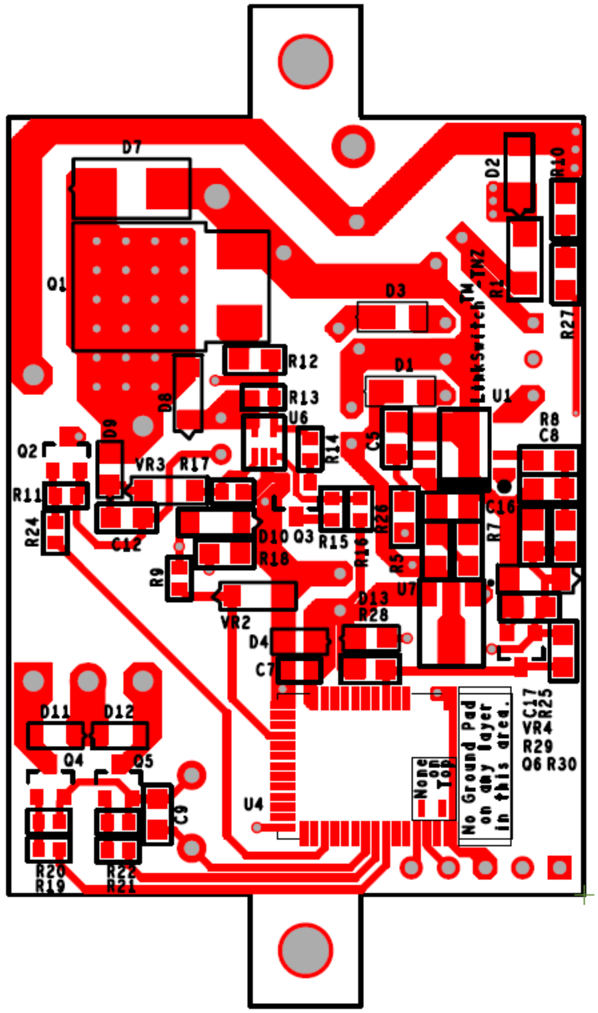


Figure 14 – Printed Circuit Board Layout, Bottom.

7 Bill of Materials

7.1 *Electrical Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C1	2.2 µF 400 V Aluminum Electrolytic Radial, Can - 2000 Hrs @ 105 °C, (6.3 x 16.5)	860021373003	Würth
2	1	C5	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
3	1	C6	56 µF, 16 V, Electrolytic, Very Low ESR, 22 mΩ, (10 x 25)	EKZE160ELL560ME11N	Nippon Chemi-Con
4	1	C7	10 µF, 10 V, Ceramic, X5R, 0603	C1608X5R1A106M	TDK
5	1	C9	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
6	1	C12	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
7	1	C13	100 µF, ±20%, 16V, Electrolytic, Gen. Purpose, 2000 Hrs @ 105 °C, (6.3 x 9)	A750EK107M1CAAE018	Nichicon
8	1	C14	220 µF, ±20%, 16V, Electrolytic, Gen. Purpose, 2000 Hrs @ 105 °C, (6.3 x 9)	A750EK227M1CAAE016	Nichicon
9	1	C15	560 µF, 6.3 V, Electrolytic, Low ESR, 7 mΩ, (6.3 x 9)	6SEPC560MW	Sanyo
10	1	C16	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
11	1	D1	60 V, 1 A, Diode SCHOTTKY, PWRDI 123	DFLS160-7	Diodes, Inc.
12	1	D2	Diode, Standard, 2000 V, 1 A, SMT, SMA, DO-214AC (SMA)	S1V-13-F	Diodes, Inc.
13	1	D3	200 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1200-7	Diodes, Inc.
14	1	D4	Diode, GEN PURP, 75 V 150 mA, SOD323	1N4148WS-7-F	Diodes, Inc.
15	1	D7	40 V, 3 A, Schottky, SMD, DO-214AA	B340LB-13-F	Diodes, Inc.
16	1	D8	200 V, 1 A, Standard Recovery, SOD-123FL	SM4003PL-TP	Micro Commercial
17	1	D9	Diode, GEN PURP, 75 V 150 mA, SOD323	1N4148WS-7-F	Diodes, Inc.
18	1	D10	200 V, 1 A, Standard Recovery, SOD-123FL	SM4003PL-TP	Micro Commercial
19	1	D11	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
20	1	D12	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
21	1	F1	FUSE, BOARD MNT, 10 A, 250 VAC, 125 VDC, SMT, 2-SMD, Square End Block	3403.0176.11	Schurter
22	1	Q1	N-Channel, 40 V, 90A (Tc), 94W (Tc), Surface Mount PG-TO252-3-11 PG-TO252-3, DPAK,TO-252-3, DPak (2 Leads + Tab), SC-63	IPD036N04LGATMA1	Infineon Technologies
23	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	ON Semi
24	1	Q3	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	ON Semi
25	1	Q4	NPN, DARL NPN 40 V SMD SOT23-3	MMBT6427-7-F	Diodes, Inc.
26	1	Q5	NPN, DARL NPN 40 V SMD SOT23-3	MMBT6427-7-F	Diodes, Inc.
27	1	Q6	N-Channel 60 V 115 mA (Ta) 200 mW (Ta) Surface Mount SOT-23-3, TO-236-3, SC-59	2N7002L	On Semi
28	1	R1	RES, 16 kΩ, ±1%, ¼ W, 1206, Moisture Resistant, Thick Film	RC1206FR-0716KL	Yageo
29	1	R5	RES, 9.31 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9311V	Panasonic
30	1	R7	RES, 17.8 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1782V	Panasonic
31	1	R8	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	RMCF0805ZT0R00	Stackpole
32	1	R9	RES, 100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
33	1	R10	RES, 499 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4993V	Panasonic
34	1	R11	RES, 100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
35	1	R12	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
36	1	R13	RES, 2 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ202V	Panasonic
37	1	R14	RES, 100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
38	1	R15	RES, 15 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ153V	Panasonic
39	1	R16	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
40	1	R17	RES, 634 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF6343V	Panasonic
41	1	R18	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
42	1	R19	RES, 1 k, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
43	1	R20	RES, 470 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ474V	Panasonic
44	1	R21	RES, 1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic

45	1	R22	RES, 470 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ474V	Panasonic
46	1	R24	RES, 1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
47	1	R25	RES, 0 Ω, 5%, 1/8 W, Thick Film, 0805	RMCF0805ZT0R00	Stackpole
48	1	R26	RES, 49.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4992V	Panasonic
49	1	R27	RES, 499 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4993V	Panasonic
50	1	R28	RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
51	1	R29	RES, 499 k, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4993V	Panasonic
52	1	RL1	RELAY, GP, Dual coil, SPST, 16 A, 3 VDC coils, 277 VAC, PCPin	ADW1203HLW	Panasonic
53	1	RV1	275 VAC 8.6 J, 5 mm, RADIAL	S05K275	Epcos
54	1	SW1	Tactile Switch, 0.05A, 12V, SPST-NO, Top Actuated, Through Hole	TL59AF100Q	E-Switch
55	1	T1	Bobbin, EE8.3, Vertical, 6 pins (8.2 mm W x 8.2 mm L x 6.9 mm H)	EE-0802	Zhenhui
56	1	U1	LinkSwitch-TNZ, SO8	LNK3302D	Power Integrations
57	1	U4	MDBT42Q, (Nordic nRF52832 BASED BLE MODULE), (Serial interfaces: I²C, I²S, SPI, UART)	317030213	Seeed Technology
58	1	U6	IC, Comparator General Purpose Open Collector SC-70-5,5-TSSOP, SC-70-5, SOT-353 SC-70	TLV1701AIDCKT	Texas Instruments
59	1	U7	IC, Linear Voltage Regulator, Positive, Fixed, 1 Output, 3 V, 0.25 A, SOT-89-3, TO-243AA	MCP1703T-3002E/MB	Microchip
60	1	VR1	Zener Diode 12 V 1 W ±5% Surface Mount SMA	SMAZ12-13-F	Diodes, Inc.
61	1	VR2	Diode, ZENER, 3.0 V, ±5%, 500 mW, SOD123, 150 °C	MMSZ4683T1G	ON Semi
62	1	VR3	Diode, ZENER, 7.5 V, ±5%, 500 mW, SOD123, 150 °C	MMSZ4693T1G	ON Semi
63	1	VR4	Diode, ZENER, 7.5 V, ±5%, 500 mW, SOD123, 150 °C	MMSZ4693T1G	ON Semi

7.2 *Mechanical Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
64	1	J1	5 Position (1 x 5) Female header, 0.1 pitch, 00.126" (3.20 mm), Vertical, Au	PPPC051LFBN-RC	Sullins Connector
65	1	TP1	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
66	1	TP2	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone

7.3 *Do Not Populate / Optional Parts*

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
67	1	C8	100 pF, 100 V, Ceramic, COG, 0805	C0805C101J1GACTU	Kemet
68	1	C17	100 pF, 100 V, Ceramic, COG, 0805	C0805C101J1GACTU	Kemet
69	1	D13	Diode, GEN PURP, 75 V 150 mA, SOD323	1N4148WS-7-F	Diodes, Inc.
70	1	R30	RES, 0 Ω, Jumper, ¼ W Chip Resistor, 0805, Anti-Sulfur, Moisture Resistant Thick Film	RK73Z2ARTTD	KOA Speer

8 Transformer Specification

8.1 *Electrical Diagram*

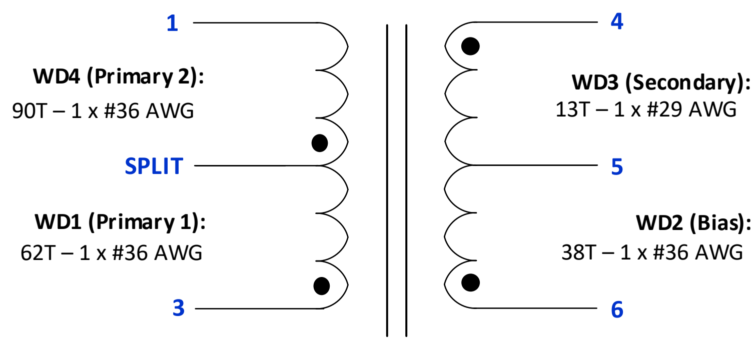


Figure 15 – Transformer Electrical Diagram.

8.2 *Electrical Specifications*

Primary Inductance	Pins 1-3, all other windings open, measured at 100 kHz.	1725 μH ±10%
Resonant Frequency	Pins 1-3, all other windings open.	100 kHz (Min.)
Primary Leakage Inductance	Pins 1-3, with pins 4-6 shorted, measured at 100 kHz.	40 μH (Max.)

8.3 *Material List*

Item	Description
[1]	Core: EE8.3-V-6PINS. 25-01086-00.
[2]	Bobbin: EE8.3, Vertical, 6 pins (8.2 mm W x 8.2 mm L x 6.9 mm H).
[3]	Magnet Wire: #36 AWG.
[4]	Magnet Wire: #29 AWG.
[5]	Polyester Tape: 5 mm.
[6]	Polyester Tape: 4.5 mm.
[7]	Varnish: Dolph BC-359.

8.4 *Build Diagram*

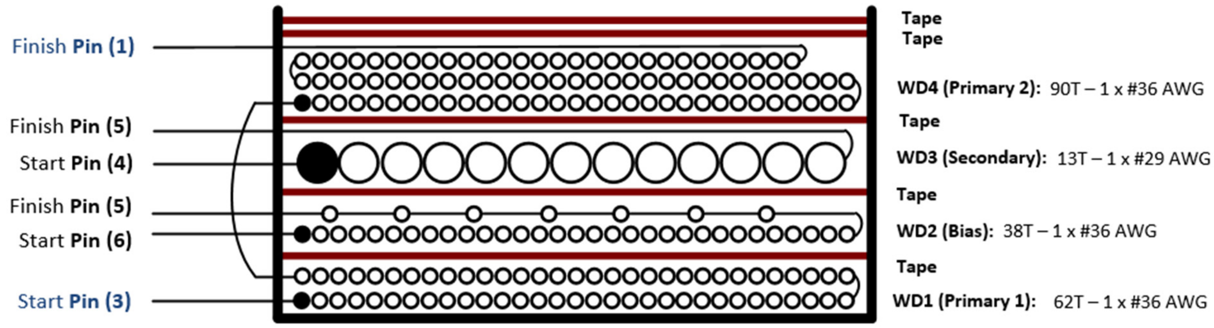
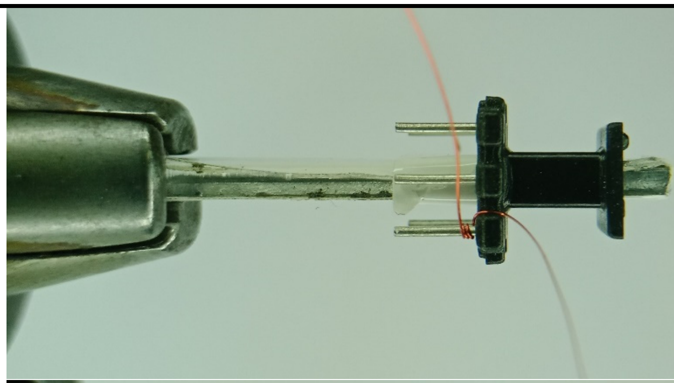
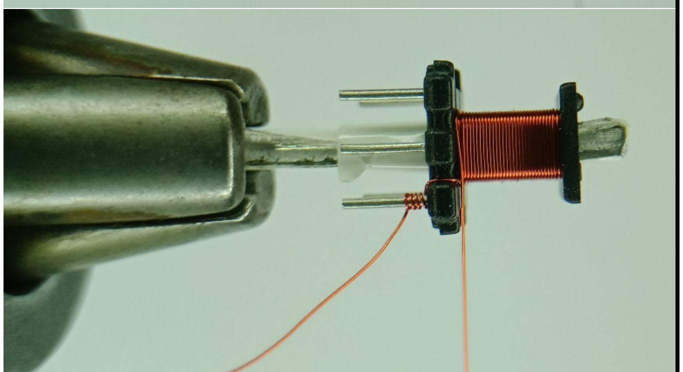
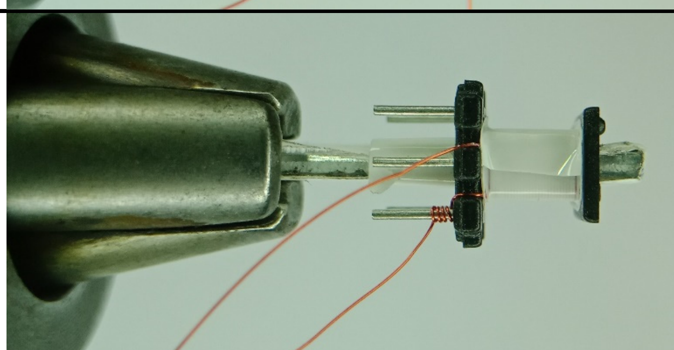
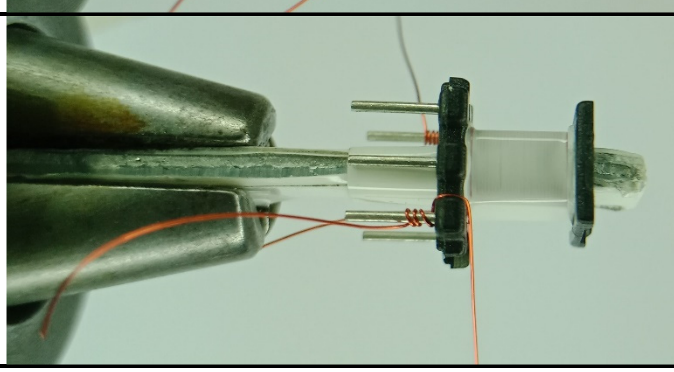


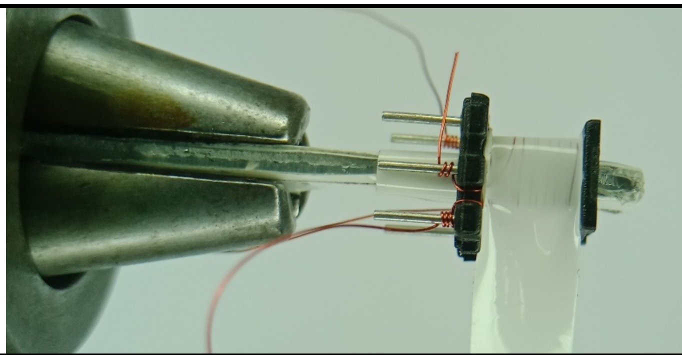
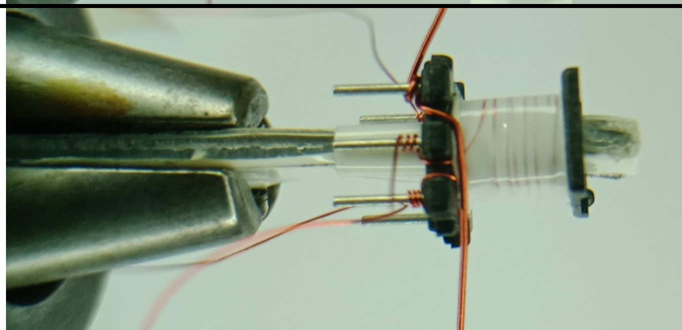
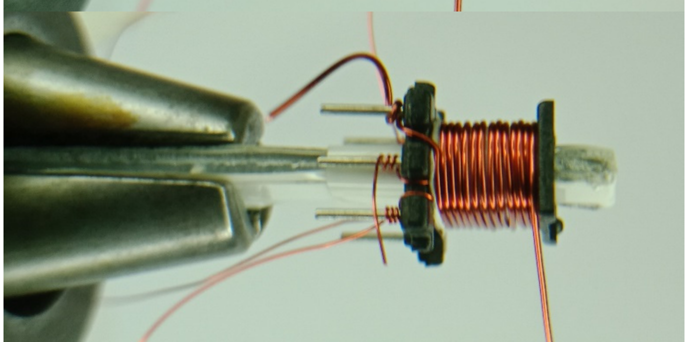
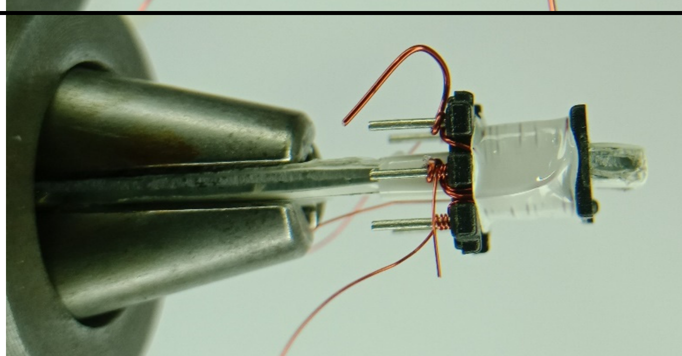
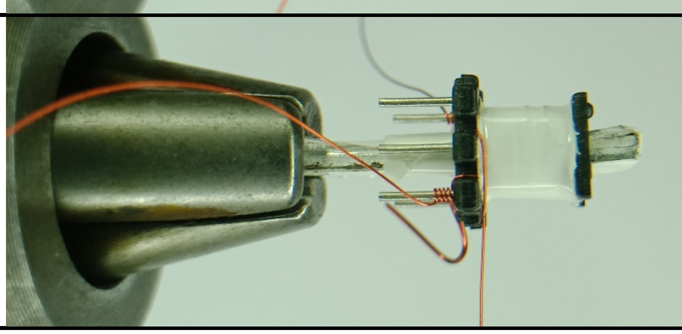
Figure 16 – Transformer Build Diagram.

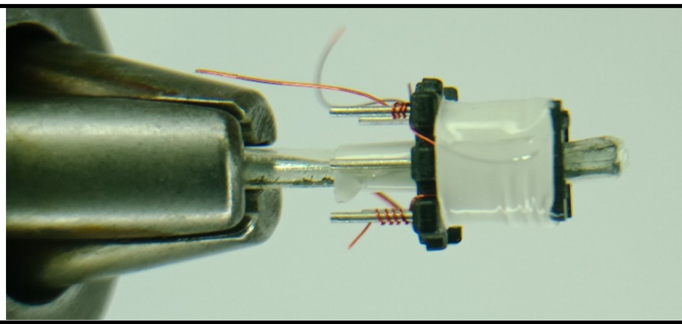
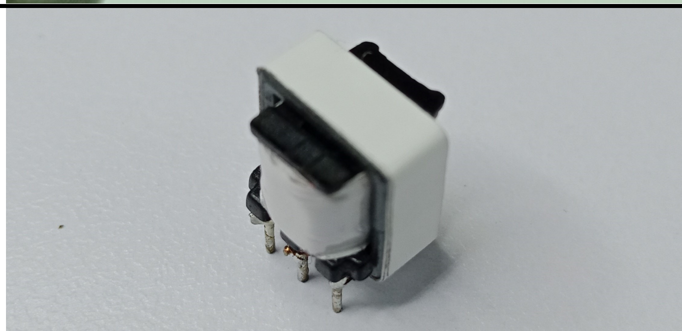
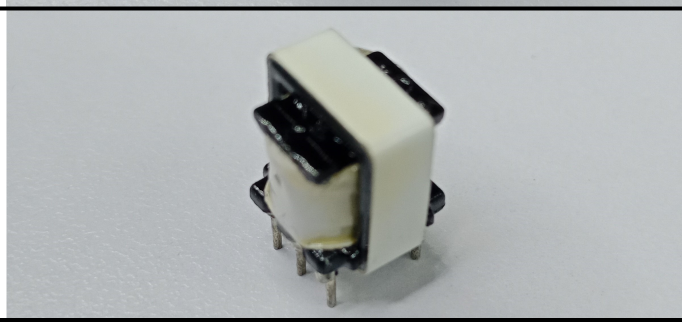
8.5 *Construction*

WD1 (Primary 1)	Start at pin 3. Wind 62 turns of Item [3] in approximately 2 layers. Split primary winding by reserving Item [3] for WD4.
Basic Insulation	Use 1 layer of Item [5] for basic insulation.
WD2 (Bias)	Start at pin 6. Wind 38 turns of Item [3].
Basic Insulation	Use 1 layer of Item [5] for basic insulation.
WD3 (Secondary)	Start at pin 4. Wind 13 turns of Item [4] (1 layer). Finish on pin 5.
Basic Insulation	Use 1 layer of Item [5] for basic insulation.
WD4 (Primary 2)	From the reserved Item [3] earlier, wind 90 turns of Item [3]. Finish on pin 1.
Final Insulation	Use 2 layers of Item [5] for basic insulation.
Final Assembly	Assemble and secure core halves so that the tape Item [6] wrapped E core is at the bottom of the transformer.
Varnish	Dip varnish uniformly in Item [7]. Do not vacuum impregnate.

8.6 *Winding Illustrations*

WD1 (Primary 1)	 	Start at pin 3. Wind 62 turns of Item [3] in approximately 2 layers. Split primary winding by reserving Item [3] for WD4.
Basic Insulation		Use 1 layer of Item [5] for basic insulation.
WD2 (Bias)		Start at pin 6. Wind 38 turns of Item [3].

Basic Insulation		Use 1 layer of Item [5] for basic insulation.
WD3 (Secondary)	 	Start at pin 4. Wind 13 turns of Item [4] (1 layer). Finish on pin 5.
Basic Insulation		Use 1 layer of Item [5] for basic insulation.
WD4 (Primary 2)		From the reserved Item [3] earlier, wind 90 turns of Item [3]. Finish on pin 1.

Final Insulation		Use 2 layers of Item [5] for basic insulation.
Final Assembly		Assemble and secure core halves so that the tape Item [6] wrapped E core is at the bottom of the transformer.
Varnish		Dip varnish uniformly in Item [7]. Do not vacuum impregnate.

9 Transformer Design Spreadsheet

1	ACDC_LinkSwitchTNZ_ Flyback_091321; Rev.2.0; Copyright Power Integrations 2021	INPUT	INFO	OUTPUT	UNIT	ACDC LinkSwitch-TNZ Flyback Design Spreadsheet
2	**ENTER APPLICATION VARIABLES**					
3	LINE VOLTAGE RANGE			CUSTOM		AC line voltage range
4	VACMIN	90.00		90.00	V	Minimum AC line voltage
5	VACMAX	277.00		277.00	V	Maximum AC line voltage
6	fL			60.00	Hz	AC mains frequency
7	LINE RECTIFICATION TYPE	H		H		Line rectification type: select "F" if full wave rectification or "H" if half wave rectification
8	VOUT	3.50		3.50	V	Output voltage
9	IOUT	0.060		0.060	A	Average output current
10	CC THRESHOLD VOLTAGE	0.100		0.100	V	Voltage drop across sense resistor
11	OUTPUT CABLE RESISTANCE			0.000	Ohms	Resistance of output cable (if used)
12	EFFICIENCY (User Estimate)			0.80		Overall efficiency estimate
13	LOSS ALLOCATION FACTOR			0.75		The ratio of power losses during the primary switch off-state to the total system losses
14	POUT			0.22	W	Continuous output power
15	CIN	2.20		2.20	uF	Input capacitor
16	VMIN			112.06	V	Valley voltage of the rectified minimum AC line voltage
17	VMAX			391.74	V	Peak voltage of the maximum AC line voltage
18	FEEDBACK	BIAS		BIAS		Type of feedback required. Choose "BIAS" for bias winding feedback and "OPTO" for an optocoupler feedback
19	BIAS WINDING	YES		YES		Select whether a bias winding is required or not
20	INPUT STAGE RESISTANCE			10.0	Ohms	Input stage resistance (includes thermistor, filtering components, etc)
21	PLOSS_INPUTSTAGE			0.000	W	Maximum input stage power loss
25	**LINKSWITCH-TNZ VARIABLES**					
26	CURRENT LIMIT MODE	STD		STD		Choose "STD" for Standard current limit or "RED" for reduced current limit
27	XCAP REQUIRED	NO		NO		Select whether an X-capacitor is required or not
28	PACKAGE			SO-8C		Device package
29	DEVICE SERIES	AUTO		LNK3302		Generic LinkSwitch-TNZ device
30	DEVICE CODE			LNK3302D		Required LinkSwitch-TNZ device
31	ILIMITMIN			0.126	A	Minimum current limit of the device
32	ILIMITTYP			0.136	A	Typical current limit of the device
33	ILIMITMAX			0.146	A	Maximum current limit of the device
34	RDSON			88.4	Ohms	Switch on-state drain-to-source resistance at 100 degC
35	FSMIN			62000	Hz	Minimum switching frequency
36	FSTYP			66000	Hz	Typical switching frequency
37	FSMAX			70000	Hz	Maximum switching frequency
38	BVDSS			725	V	Device breakdown voltage
42	**PRIMARY WAVEFORM PARAMETERS**					
43	OPERATION MODE			DCM		Discontinuous mode of operation
44	VOR	50.0		50.0	V	Voltage reflected across the primary winding when the primary switch is off
45	VDSON			2.00	V	Primary switch on-time drain-to-source voltage

46	VDSOFF			511.7	V	Primary switch off-time drain-to-source voltage stress
47	KRP/KDP			11.245		Degree on how much the operation tend to be continuous or discontinuous
48	KP_TRANSIENT			0.708		KP value under transient conditions
49	DUTY			0.039		Maximum duty cycle
50	TIME_ON_MIN			0.594	us	Primary switch minimum on-time is less than the device minimum on-time specification (0.687 us). Pick a larger device
51	IPEAK_PRIMARY			0.191	A	Maximum primary peak current
52	IPED_PRIMARY			0.000	A	Maximum primary pedestal current
53	IAVG_PRIMARY			0.002	A	Maximum primary average current
54	IRMS_PRIMARY			0.016	A	Maximum root-mean-squared value of the primary current
55	PLOSS_SWITCH			0.052	W	Maximum primary switch power loss
56	THERMAL RESISTANCE OF SWITCH			95	degC/W	Net thermal resistance of primary switch
57	T_RISE_SWITCH			5.0	degC	Maximum temperature rise of the switch in degrees Celsius
58	LPRIMARY_MIN			1552	uH	Minimum primary inductance
59	LPRIMARY_TYP			1725	uH	Typical primary inductance
60	LPRIMARY_MAX			1897	uH	Maximum primary inductance
61	LPRIMARY_TOL			10	%	Primary inductance tolerance
65	**SECONDARY WAVEFORM PARAMETERS**					
66	IPEAK_SECONDARY			2.236	A	Peak secondary current
67	IRMS_SECONDARY			0.307	A	Maximum root-mean-squared value of the secondary current
68	IRIPPLE_SECONDARY			2.236	A	Maximum ripple value of the secondary current
69	PIV_SECONDARY			36.8	V	Peak inverse voltage of the secondary diode
70	VF_SECONDARY			0.70	V	Forward voltage drop of the secondary diode
74	**TRANSFORMER CONSTRUCTION PARAMETERS**					
75	**Core Selection**					
76	CORE	EE8		EE8		Select the transformer core
77	BOBBIN			B-EE8-H		Select the bobbin
78	AE			7.00	mm^2	Cross-sectional area of the core
79	LE			19.20	mm	Effective magnetic path length of the core
80	AL			610.0	nH/(T^2)	Ungapped effective inductance of the core
81	VE			134.0	mm^3	Effective volume of the core
82	AW			0.00	mm^2	Window area of the bobbin
83	BW			4.78	mm	Width of the bobbin
84	MLT			17.00	mm	Mean length per turn of the bobbin
85	MARGIN			0.00	mm	Safety margin
87	**Primary Winding**					
88	NPRIMARY			152	turns	Primary winding number of turns
89	BMAX		Info	3222	Gauss	The target magnetic flux density of 1500 Gauss has been exceeded. Increase the number of turns in secondary
90	BAC			1611	Gauss	AC flux density
91	ALG			75	nH/(T^2)	Gapped core effective inductance
92	LG			0.103	mm	Core gap length
93	LAYERS_PRIMARY			2	layers	Number of primary winding layers
94	AWG_PRIMARY	36		36		Primary winding wire size in AWG
95	OD_PRIMARY_INSULATED			0.157	mm	Primary winding wire outer diameter with insulation

96	OD_PRIMARY_BARE			0.127	mm	Primary winding wire outer diameter without insulation
97	CMA_PRIMARY		Info	1598	mil^2/A	The primary winding wire CMA is higher than 500 mil^2/Amperes and may result into oversized wire for a given current flowing through it. Decrease the primary layers or wire thickness
99	**Secondary Winding**					
100	NSECONDARY	13		13	turns	Secondary winding number of turns
101	AWG_SECONDARY	29		29		Secondary winding wire size in AWG
102	OD_SECONDARY_INSULATED			0.592	mm	Secondary winding wire outer diameter with insulation
103	OD_SECONDARY_BARE			0.286	mm	Secondary winding wire outer diameter without insulation
104	CMA_SECONDARY			413	mil^2/A	Secondary winding wire CMA
106	**Bias Winding**					
107	DIODE_BIAS			1N4003-4007		Recommended bias diode is 1N400X
108	NBIAS			38	turns	Bias winding number of turns
109	VF_BIAS			0.70	V	Forward voltage drop of bias diode
110	VBIAS	12.00		12.00	V	Voltage across the bias winding
111	PIV_BIAS			110.45	V	Peak inverse voltage on the bias diode
112	RBP			84500	Ohms	BP pin resistor
113	CBP			0.1	uF	BP pin capacitor
115	**Primary Winding Losses**					
116	PLOSS_PRIMARYWINDING			0.001	W	Maximum power loss dissipated in the primary winding
120	**FEEDBACK PARAMETERS**					
121	RUPPER			9310	Ohms	
122	RLOWER			17800	Ohms	

10 Performance Data

All measurements performed at room temperature. Unless otherwise stated, the test data refers to system-level performance.

10.1 *Standby Input Leakage Current*

Standby current was measured when the relay is OFF. A 500 W incandescent bulb was connected between Line Out and Neutral to complete the circuit loop. The leakage current, even with BLE connected, was kept below 200 μA at worst-case input voltage. At 230 VAC, the leakage current was below 150 μA.

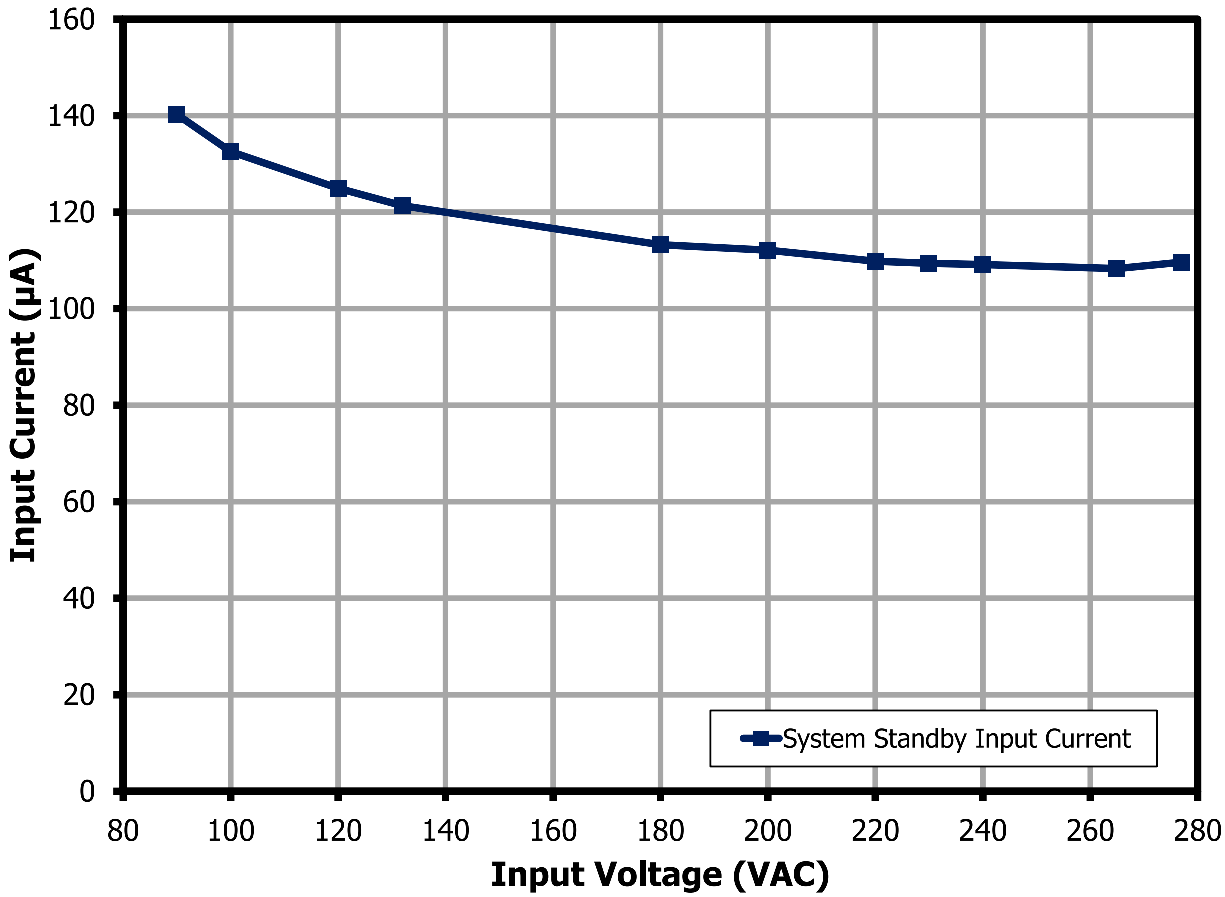


Figure 17 – Standby Input Current.

10.2 *LinkSwitch-TNZ Leakage Current vs. System-Level Leakage Current*

The leakage current contribution of the LinkSwitch-TNZ power supply was taken by disconnecting the LDO regulator from the circuit. System input current measurements were taken after adding the 3 V regulator and the BLE module.

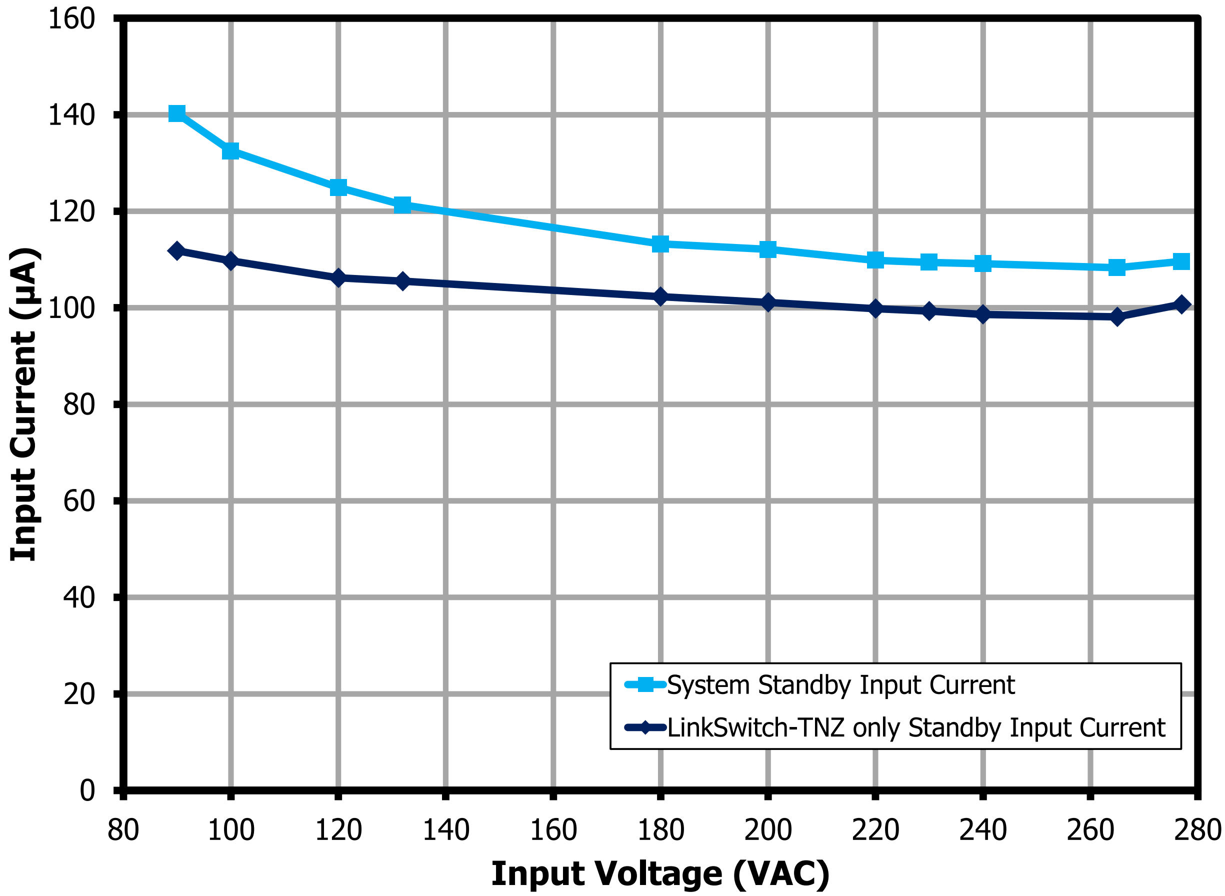


Figure 18 – LinkSwitch-TNZ Leakage Current vs. System Leakage.

10.3 *LinkSwitch-TNZ Regulation vs. Load on 3 V Output, Relay OFF*

The non-isolated flyback design using LinkSwitch-TNZ LNK3302D is rated for 3.5 V, 60 mA output. Actual current capability increases as the input voltage increases as shown in the graph below.

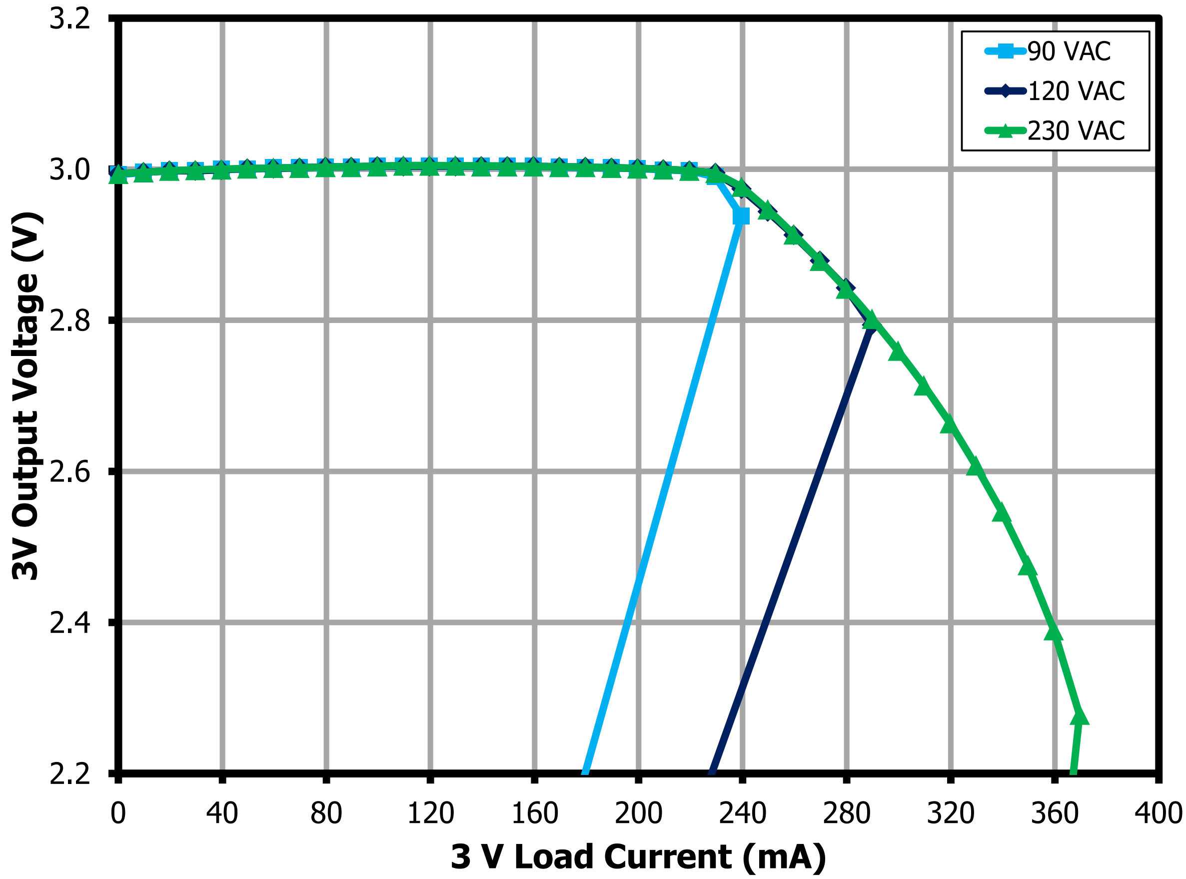


Figure 19 – LinkSwitch-TNZ Regulation vs. Load on 3 V Output.

10.4 *Maximum Continuous Load on 3 V Regulator Output, Relay ON*

Supply comes from the Q1 FET regulator.

The MOSFET Q1 regulator current capability is dependent on the characteristic of the load connected to the AC line. This is because the charging current needed to charge the capacitor that supplies power to the 3 V LDO regulator is limited by the current being drawn by the bulb load.

If this reference design is used on other wireless module, then the maximum load that the FET regulator can supply is shown on Figure 20. Also, as the 3 V load goes up, it is necessary to reduce or even short R18, increase C13, C14, and C15, as well as use a higher current-rated 3 V linear regulator.

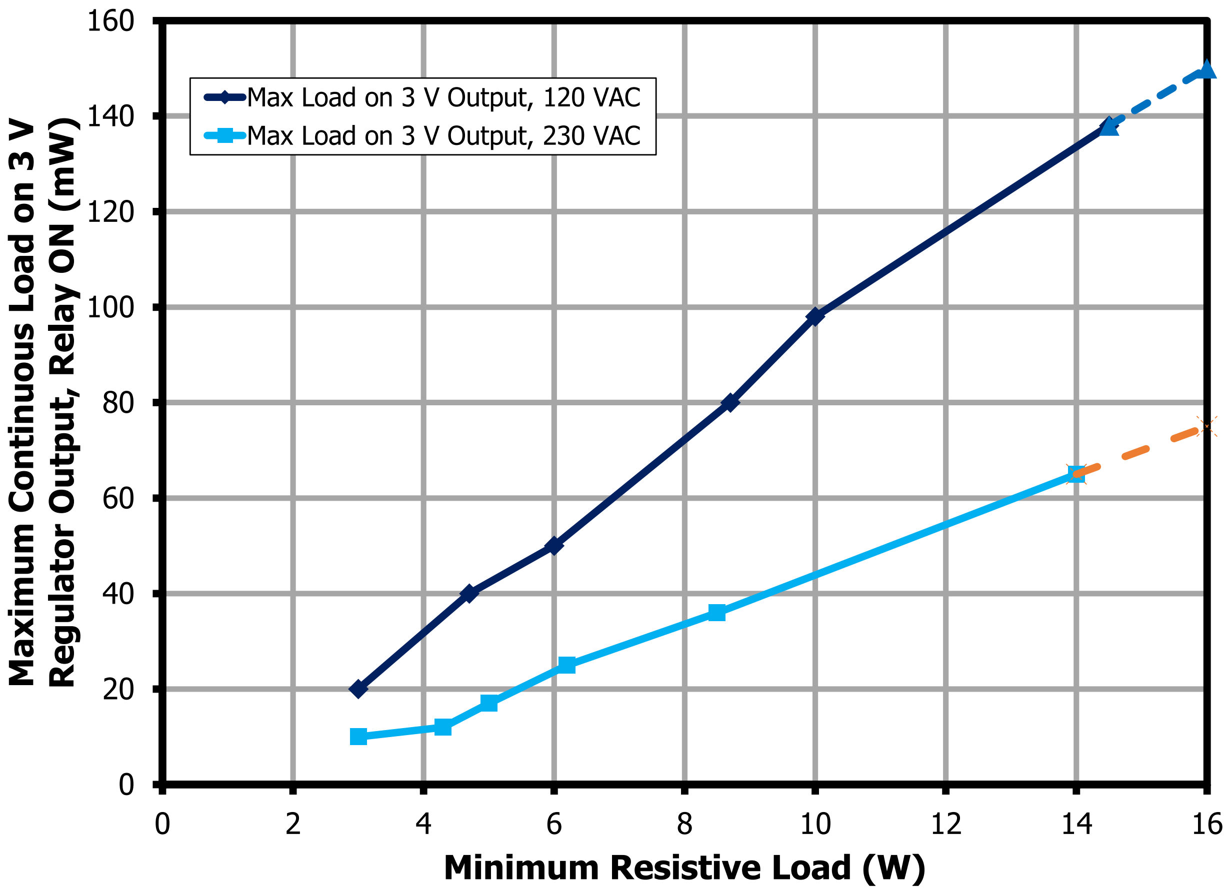


Figure 20 – Maximum Continuous Load on 3 V Regulator Output vs. Resistive Load (Connected to AC Line).

11 Waveforms

11.1 *Inrush Current Comparison with and without Zero Crossing Detection*

11.1.1 50 W Synthetic Low Power Factor Load (PF = 0.5)

Tested at 120 VAC, 60 Hz. The synthetic low power factor load used is based on NEMA SSL 7A-2013.
Inrush current reduced by about 45 A on subsequent power-up.

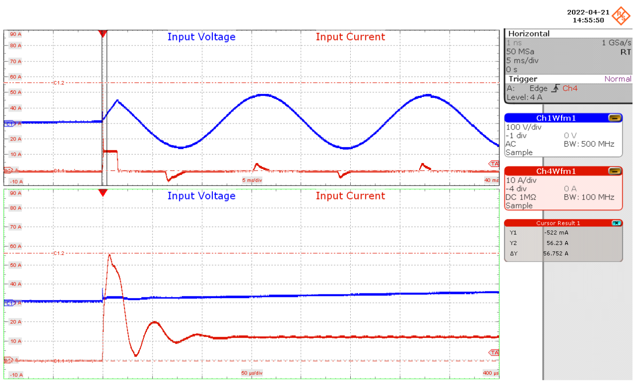


Figure 21 – Without using ZCD, 1st Power-up, 120 VAC, 60 Hz, 50 W 0.5 PF Synthetic Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 10 A / div.
I_{PEAK} = 56.23 A.

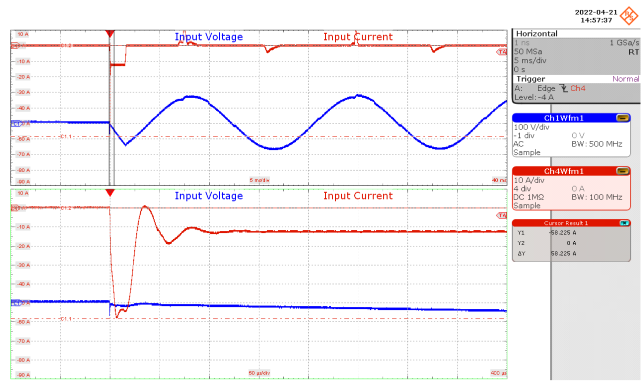


Figure 22 – Without using ZCD, Subsequent Power-up, 120 VAC, 60 Hz, 50 W 0.5 PF Synthetic Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 10 A / div.
I_{PEAK} = 58.23 A.

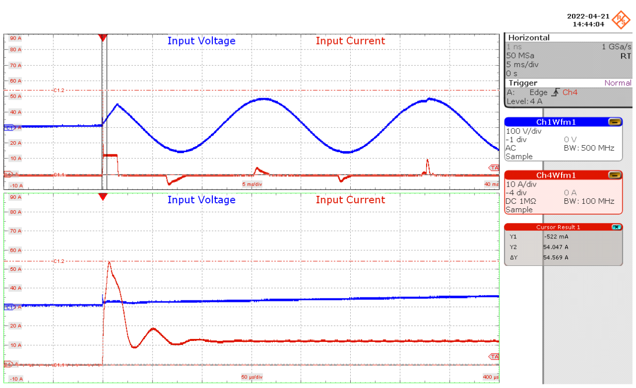


Figure 23 – Using ZCD, 1st Power-up, 120 VAC, 60 Hz, 50 W 0.5 PF Synthetic Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 10 A / div.
I_{PEAK} = 54.05 A.

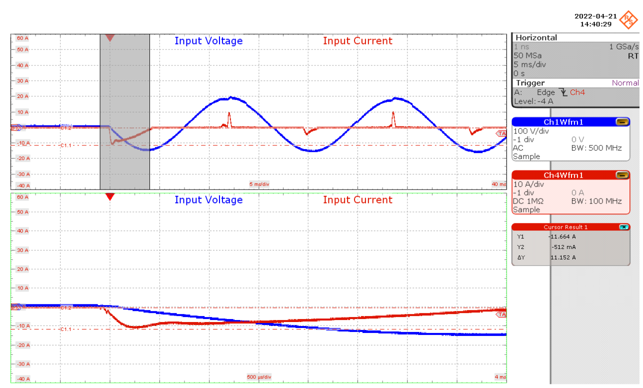


Figure 24 – Using ZCD, Subsequent Power-up, 120 VAC, 60 Hz, 50 W 0.5 PF Synthetic Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 10 A / div.
I_{PEAK} = 11.66 A.

11.1.2 23 W LED Load

Tested at 230 VAC, 50 Hz. Inrush current reduced by about 24 A on subsequent power-up.

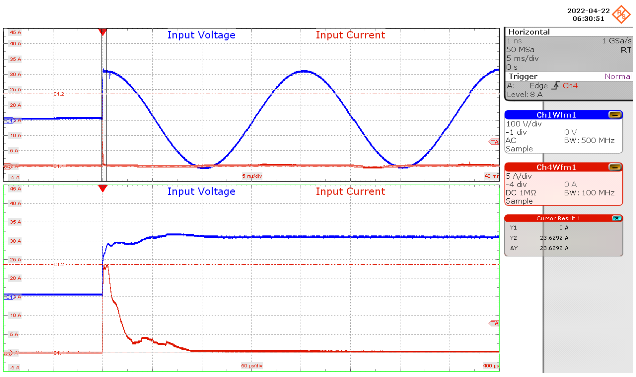


Figure 25 – Without using ZCD, 1st Power-up, 230 VAC, 50 Hz, 23 W LED Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 5 A / div.
I_{PEAK} = 23.63 A.

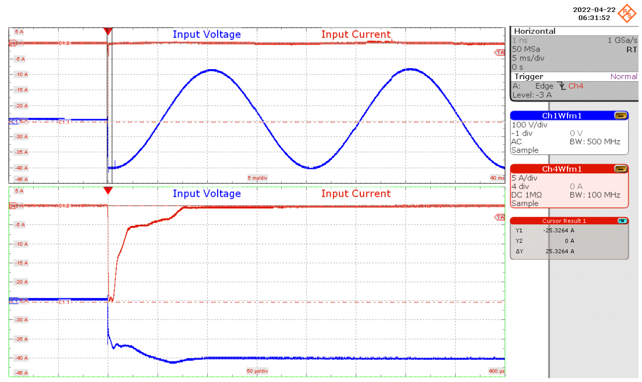


Figure 26 – Without using ZCD, Subsequent Power-up, 230 VAC, 50 Hz, 23 W LED Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 5 A / div.
I_{PEAK} = 25.33 A.

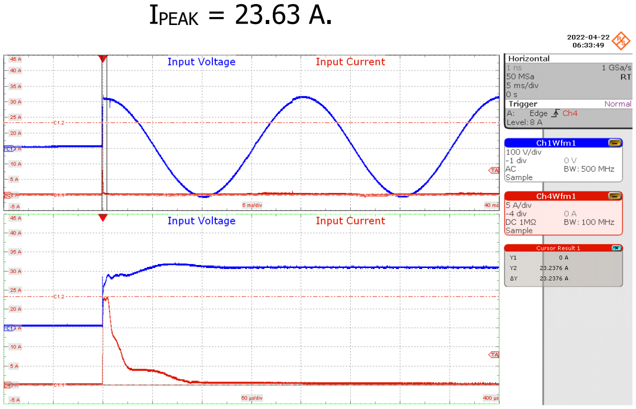


Figure 27 – Using ZCD, 1st Power-up, 230 VAC, 50 Hz, 23 W LED Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 5 A / div.
I_{PEAK} = 23.24 A.

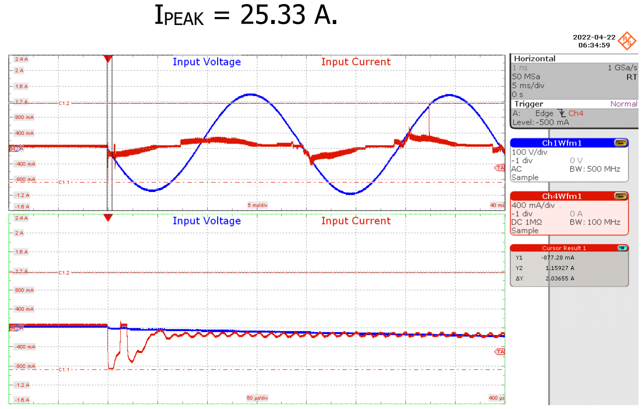


Figure 28 – Using ZCD, Subsequent Power-up, 230 VAC, 50 Hz, 23 W LED Load.

CH1: Input Voltage, 100 V / div.
CH4: Input Current, 400 mA / div.
I_{PEAK} = 877.28 mA.

11.1.3 100 W Incandescent Load

Tested at 230 VAC, 50 Hz. Inrush current reduced by about 4 A on subsequent power-up.

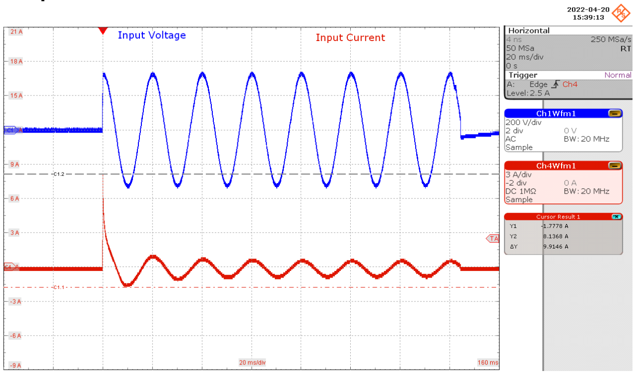


Figure 29 – Without using ZCD, 1st Power-up, 230 VAC, 50 Hz, 100 W Incandescent Load.

CH1: Input Voltage, 200 V / div.
CH4: Input Current, 3 A / div.
I_{PEAK} = 8.14 A.

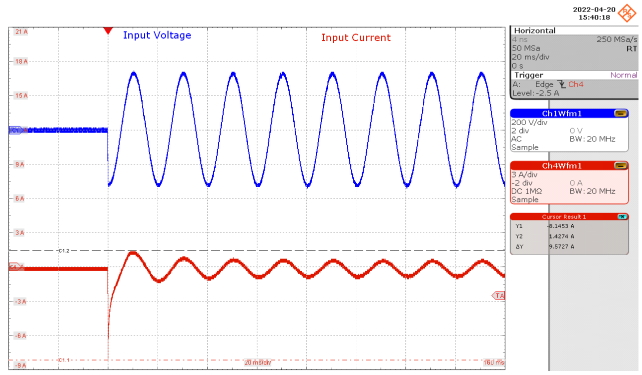


Figure 30 – Without using ZCD, Subsequent Power-up, 230 VAC, 50 Hz, 100 W Incandescent Load.

CH1: Input Voltage, 200 V / div.
CH4: Input Current, 3 A / div.
I_{PEAK} = 8.15 A.

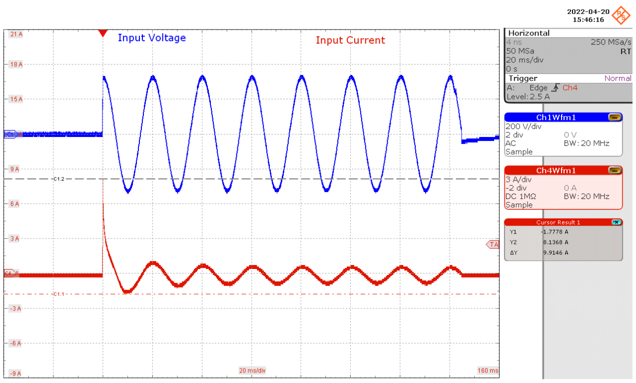


Figure 31 – Using ZCD, 1st Power-up, 230 VAC, 50 Hz, 100 W Incandescent Load.

CH1: Input Voltage, 200 V / div.
CH4: Input Current, 3 A / div.
I_{PEAK} = 8.14 A.

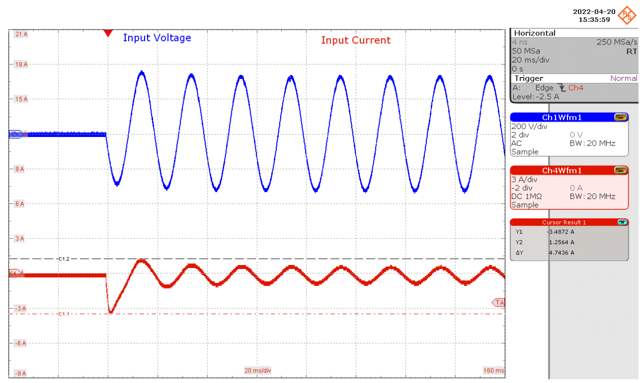


Figure 32 – Using ZCD, Subsequent Power-up, 230 VAC, 50 Hz, 100 W Incandescent Load.

CH1: Input Voltage, 200 V / div.
CH4: Input Current, 3 A / div.
I_{PEAK} = 3.49 A.

11.2 *Zero Crossing Switching Waveforms using Incandescent Load*

To demonstrate the automatic set time calibration at start-up, the unit must be able to calibrate with no hardware and no firmware modification if the relay is changed to a different relay. Table 2 describes the specification of the three different relays used for this test.

Specification	ADW1203HLW (DER default relay)	ST1-L2-DC3V-F	DSP1A-L2-DC3V
Contact arrangement	1 Form A	1 Form A 1 Form B	1 Form A
Operating function	2 coil latching	2 coil latching	2 coil latching
Rated coil voltage (DC)	3 V	3 V	3 V
Contact Rating (resistive)	Inrush type (16A, Inrush current 100A)	8 A 250 V AC, 5 A 30 V DC	8 A 250 V AC, 5 A 30 V DC
Max. switching voltage	277 VAC	250 V AC, 30 V DC	250 V AC, 125 V DC (0.2A)
Max. switching current	16 A (AC)	8 A (AC), 5 A (DC)	8 A (AC), 5 A (DC)
Operate (Set) time	Max. 15 ms at rated coil voltage (without bounce)	Max. 15 ms (Max. 15 ms) at rated coil voltage (at 20°C, without bounce)	Max. 10 ms (Max. 10 ms) at rated coil voltage (at 20 °C, without bounce)
	Measured set time = 4 ms	Measured set time = 8.2 ms	Measured set time = 5 ms
Release (Reset) time	Max. 15 ms at rated coil voltage (without bounce)	Max. 10 ms (Max. 15 ms) at rated coil voltage (at 20°C, without bounce, without diode)	Max. 5 ms (Max. 10 ms) at rated coil voltage (at 20 °C, without bounce, without diode)
	Measured reset time, max = 9 ms	Measured reset time, max = 9 ms	Measured reset time, max = 8.7 ms
Contact material	AgSnO2 type	Au-flashed $AgSnO_2$ type	Au-flashed $AgSnO_2$ type

Table 2 – Specification of the Two Relay Used.

11.2.1 Using ADW1203HLW – Switching ON Relay (Measured Relay Set Time = 4 ms)

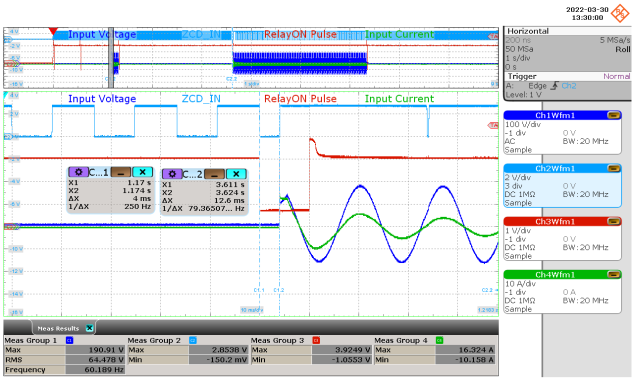


Figure 33 – Set Time Calibration (1 pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

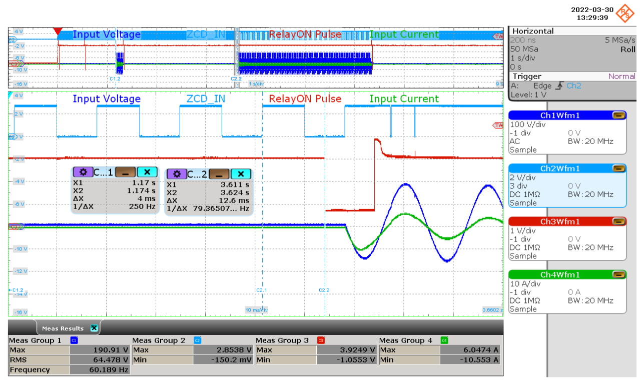


Figure 34 – Subsequent Switch ON, 120 VAC, 60 Hz, 190 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

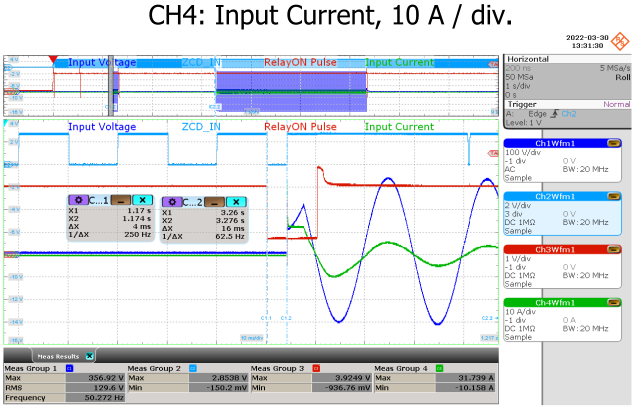


Figure 35 – Set Time Calibration (1 pulse), 230 VAC, 50 Hz, 500 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

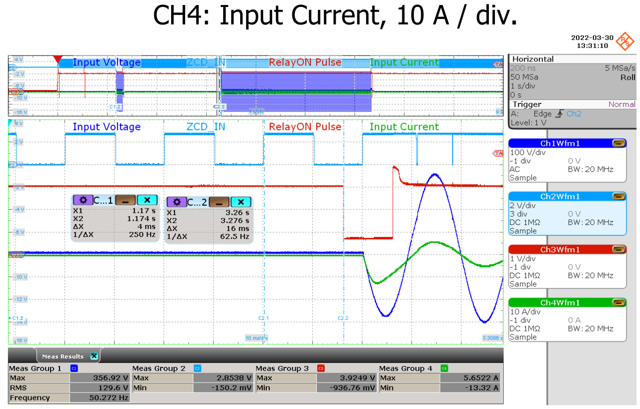


Figure 36 – Subsequent Switch ON, 230 VAC, 50 Hz, 500 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

11.2.2 Using ADW1203HLW – Switching OFF Relay

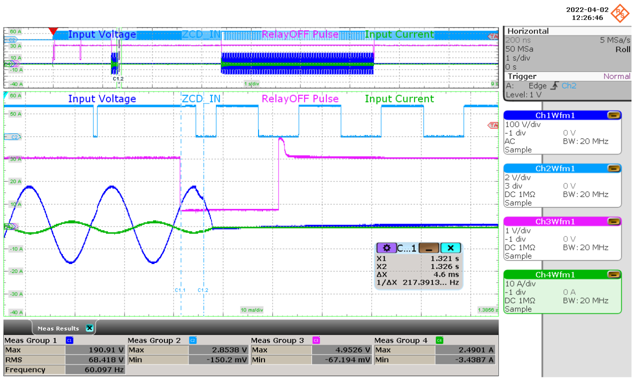


Figure 37 – Reset Time Calibration (1 Pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

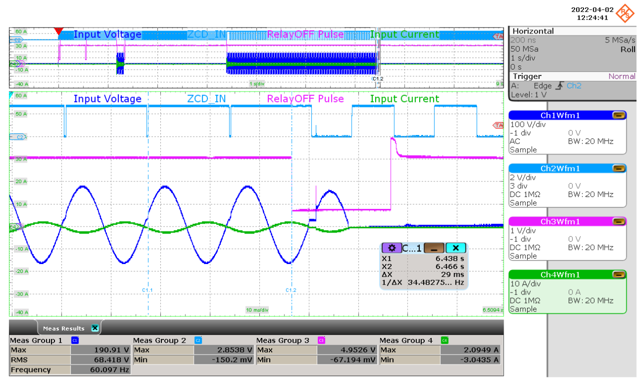


Figure 38 – Subsequent Switched OFF, 120 VAC, 60 Hz, 190 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

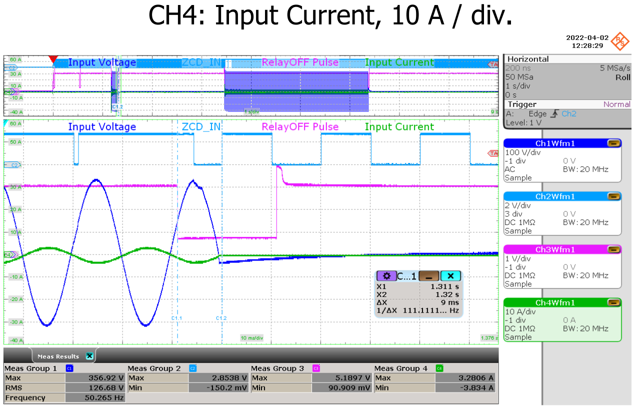


Figure 39 – Reset Time Calibration (1 Pulse), 230 VAC, 50 Hz, 500 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

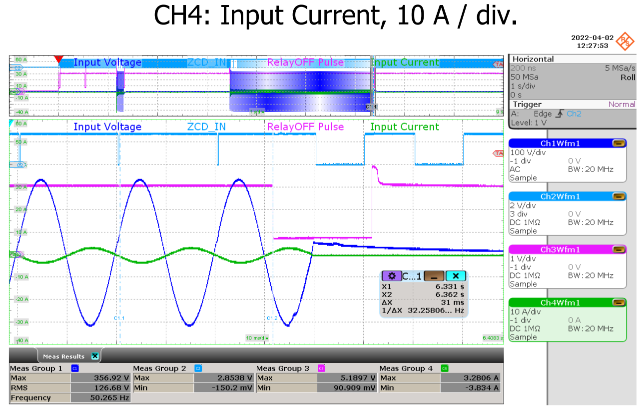


Figure 40 – Subsequent Switched OFF, 230 VAC, 50 Hz, 500 W Incandescent Load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

11.2.3 Using ST1-L2-DC3V-F – Switching ON Relay (Measured Relay Set Time = 8.2 ms)

Unit still switches on at zero crossing even when default relay (ADW1203HLW) replaced with ST1-L2-DC3V-F.

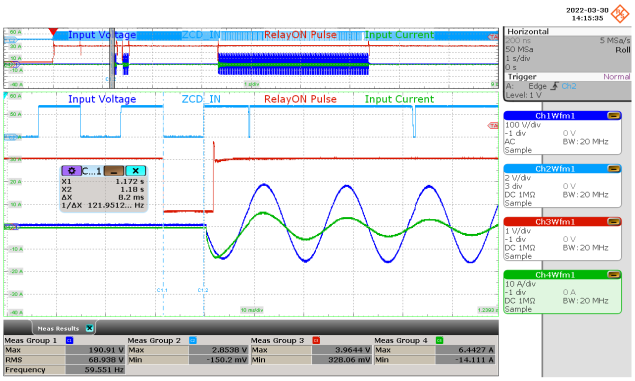


Figure 41 – Set Time Calibration (1st pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

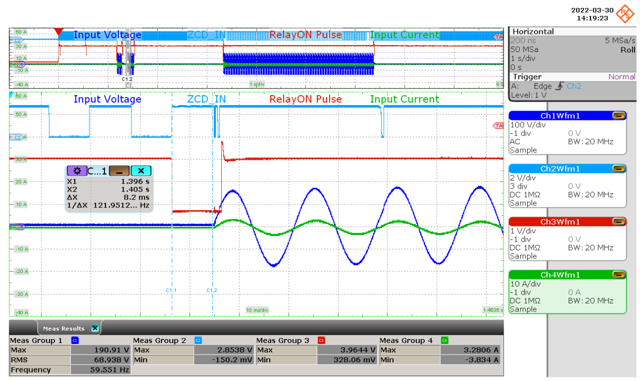


Figure 42 – Set Time Calibration (2nd pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

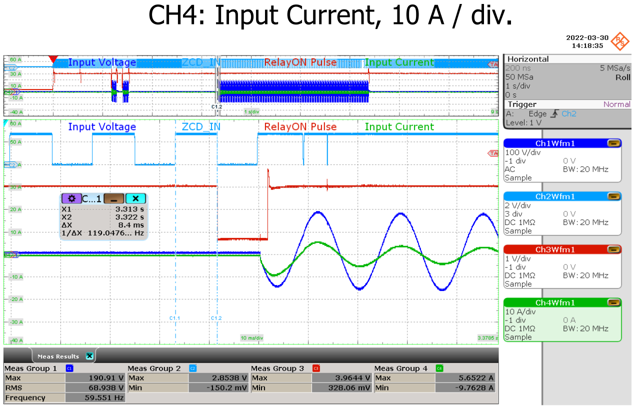


Figure 43 – Subsequent Switch ON, 120 VAC, 60 Hz, 190 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

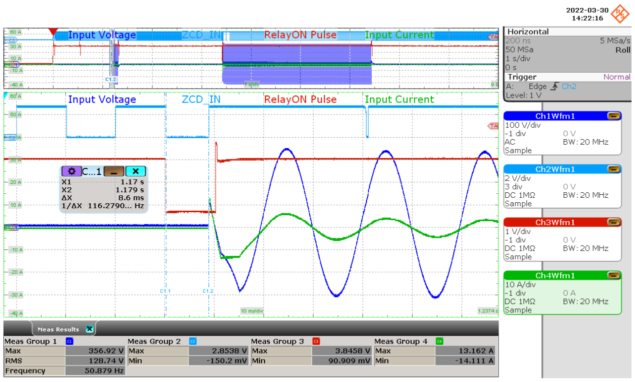


Figure 44 – Set Time Calibration (1 pulse), 230 VAC, 50 Hz, 500 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

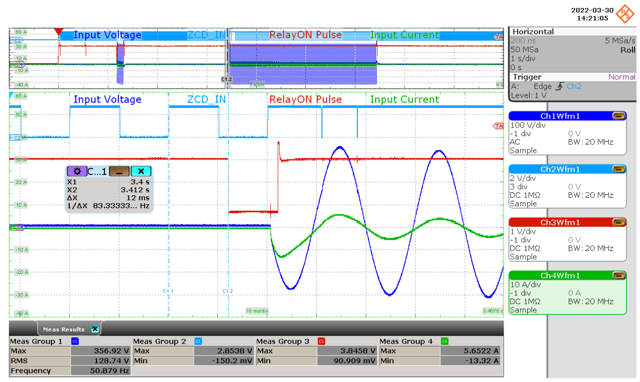


Figure 45 – Subsequent Switch ON, 230 VAC, 50 Hz, 500 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

11.2.4 Using ST1-L2-DC3V-F – Switching OFF Relay

Unit still switches off at zero crossing even when default relay (ADW1203WL) replaced with ST1-L2-DC3V-F.

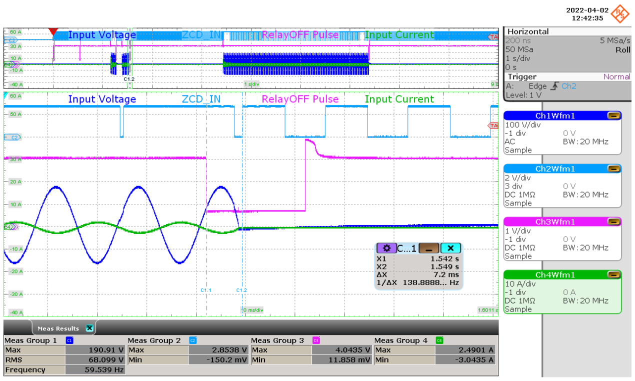


Figure 46 – Reset Time Calibration (2nd Pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

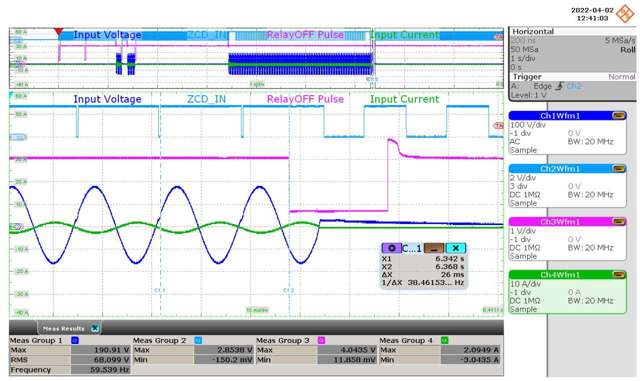


Figure 47 – Subsequent Switched OFF, 120 VAC, 60 Hz, 190 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

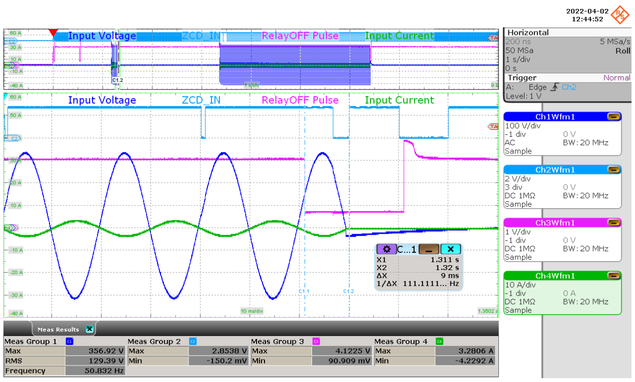


Figure 48 – Reset Time Calibration (1 Pulse), 230 VAC, 50 Hz, 500 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

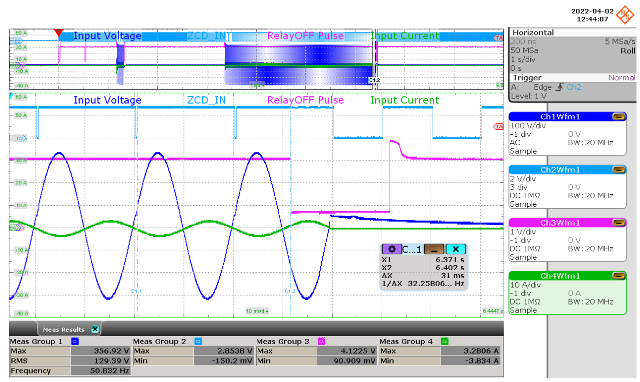


Figure 49 – Subsequent Switched OFF, 230 VAC, 50 Hz, 500 W Incandescent Load, Using ST1-L2-DC3V-F.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

11.2.5 Using DSP1A-L2-DC3V – Switching ON Relay (Measured Relay Set Time = 5 ms)

Unit still switches off at zero crossing even when default relay (ADW1203WL) replaced with DSP1A-L2-DC3V.

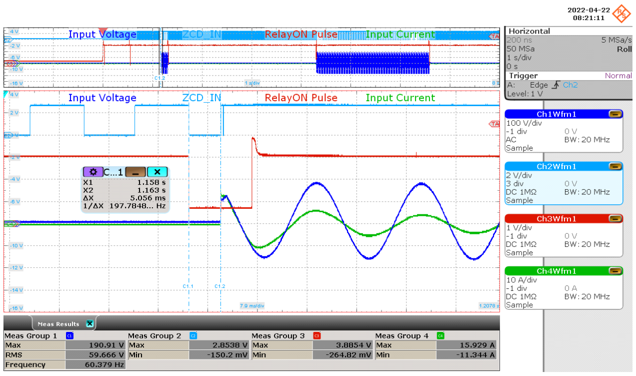


Figure 50 – Set Time Calibration (1 pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

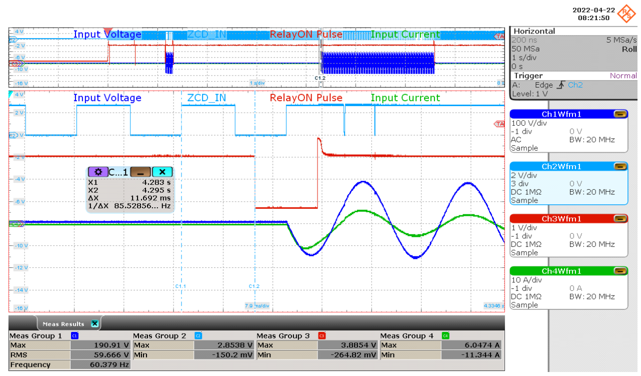


Figure 51 – Subsequent Switch ON, 120 VAC, 60 Hz, 190 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

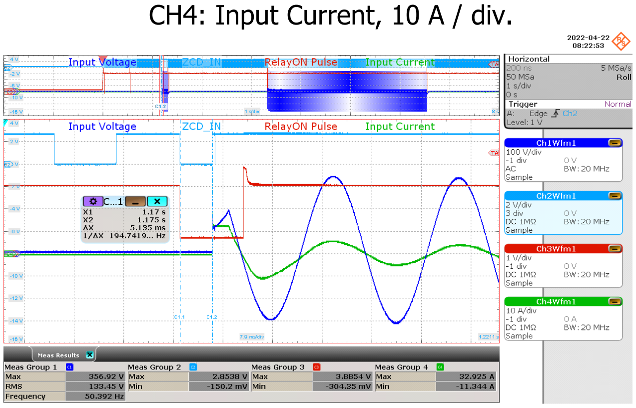


Figure 52 – Set Time Calibration (1 pulse), 230 VAC, 50 Hz, 500 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

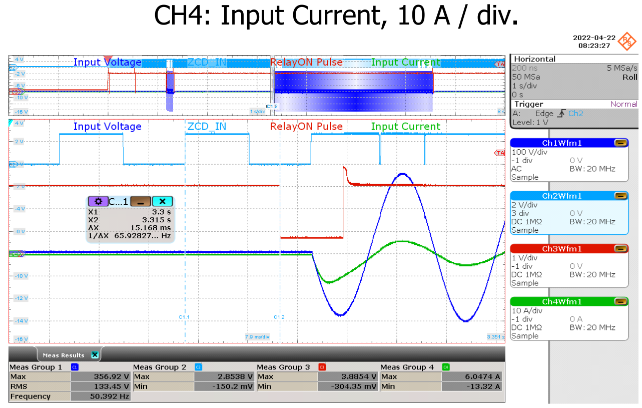


Figure 53 – Subsequent Switch ON, 230 VAC, 50 Hz, 500 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

11.2.6 Using DSP1A-L2-DC3V – Switching OFF Relay

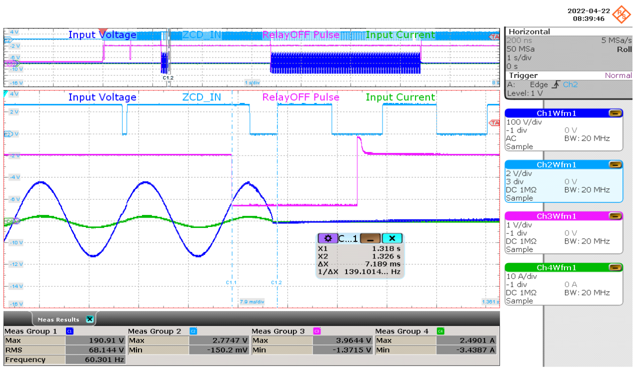


Figure 54 – Reset Time Calibration (1 Pulse), 120 VAC, 60 Hz, 190 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

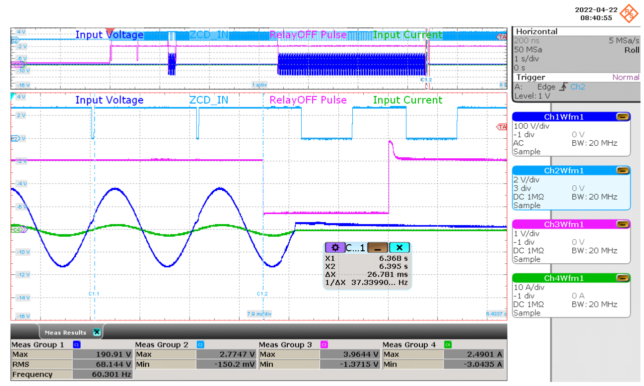


Figure 55 – Subsequent Switched OFF, 120 VAC, 60 Hz, 190 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

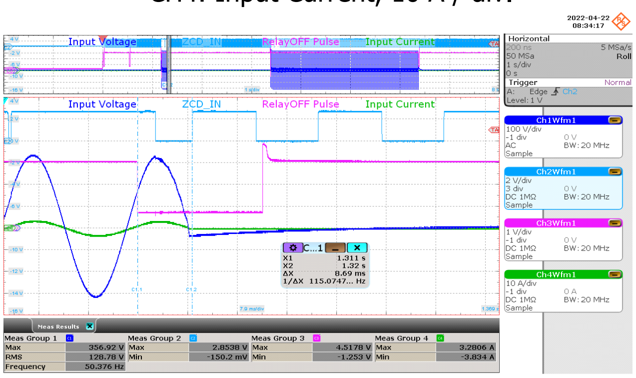


Figure 56 – Reset Time Calibration (1 Pulse), 230 VAC, 50 Hz, 500 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

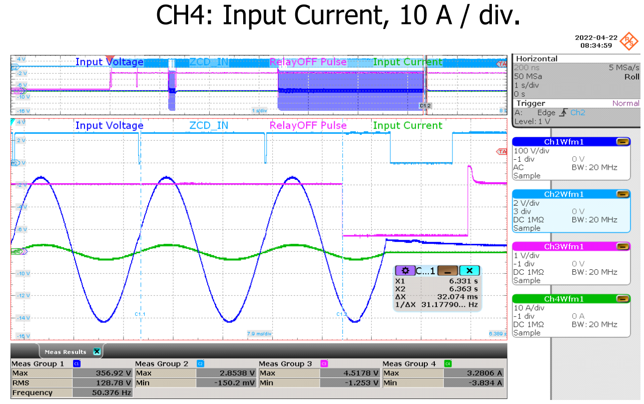


Figure 57 – Subsequent Switched OFF, 230 VAC, 50 Hz, 500 W Incandescent Load, Using DSP1A-L2-DC3V.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 10 A / div.

11.3 *Zero Crossing Switching Waveforms using LED load*

11.3.1 Using ADW1203HLW – Switching ON Relay (Measured Relay Set Time = 4 ms)

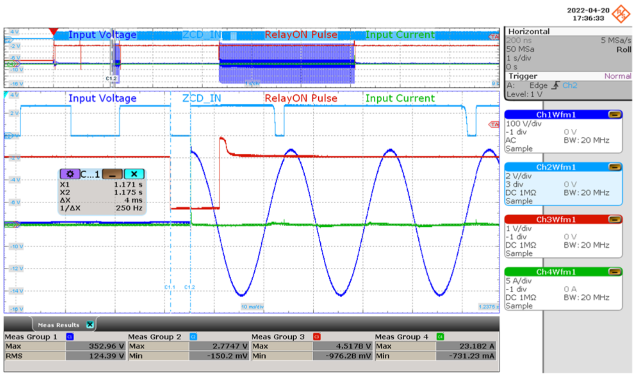


Figure 58 – Set Time Calibration (1 pulse), 230 VAC, 50 Hz, 23 W LED load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 5 A / div.

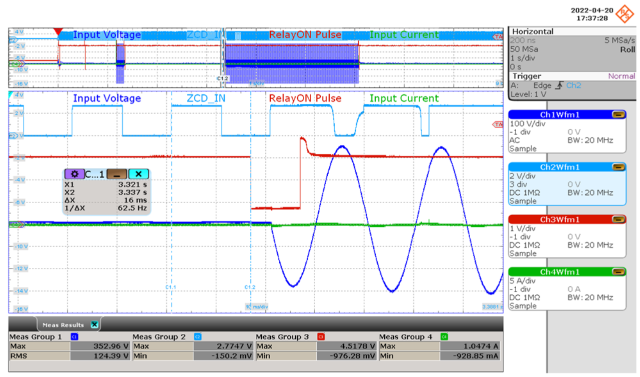


Figure 59 – Subsequent Switch ON, 230 VAC, 50 Hz, 23 W LED load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayON Pulse, 1 V / div.
CH4: Input Current, 5 A / div.

11.3.2 Using ADW1203HLW – Switching OFF Relay

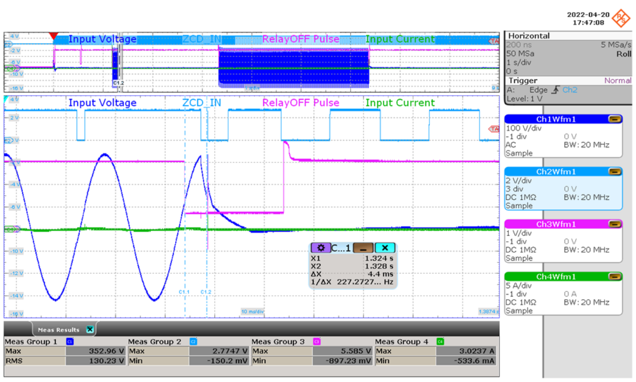


Figure 60 – Reset Time Calibration (1 Pulse), 230 VAC, 50 Hz, 23 W LED load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 5 A / div.

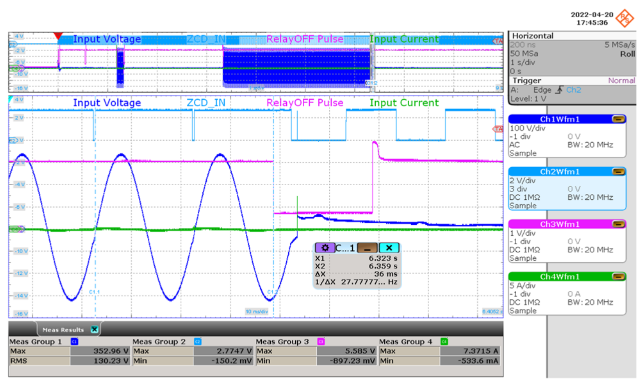


Figure 61 – Subsequent Switched OFF, 230 VAC, 50 Hz, 23 W LED load, Using ADW1203HLW.

CH1: Input Voltage, 100 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: RelayOFF Pulse, 1 V / div.
CH4: Input Current, 5 A / div.

11.4 *LinkSwitch-TNZ Drain Voltage, Start-up Operation, Relay OFF*

The VDS stress on LinkSwitch-TNZ IC kept below 80% of rated BV_{DSS} = 725 V at nominal input (230 VAC). No primary snubber was used. For designs that require higher power, an R-C-D snubber may be added.

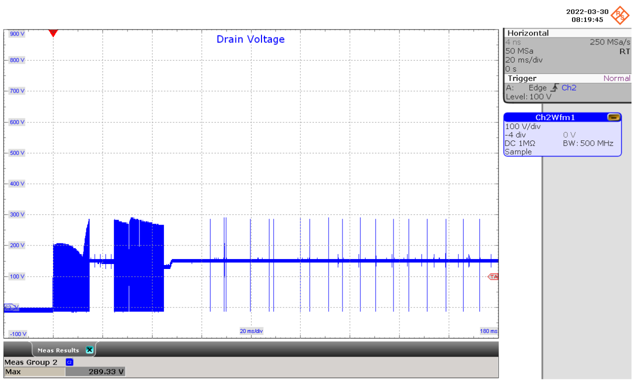


Figure 62 – Drain Voltage, 120 VAC, 60 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 289.33 V Peak.

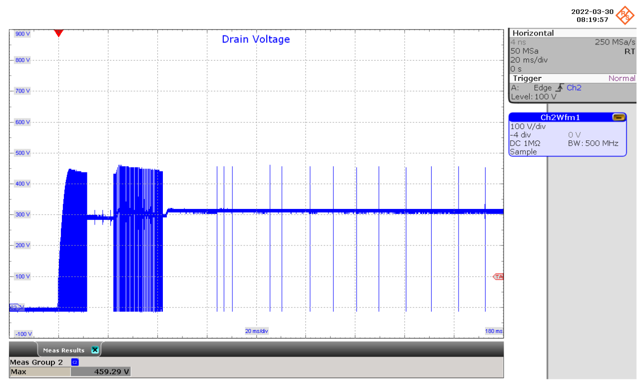


Figure 63 – Drain Voltage, 230 VAC, 50 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 459.29 V Peak.

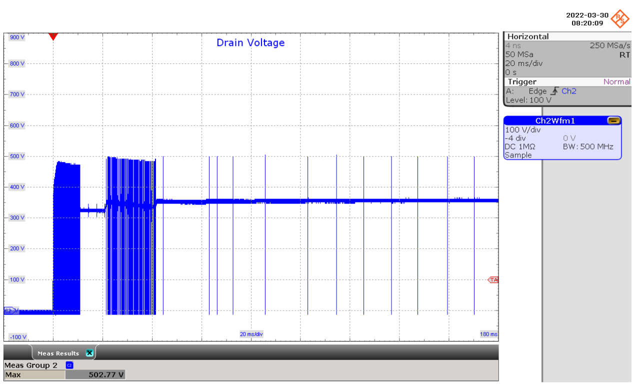


Figure 64 – Drain Voltage, 265 VAC, 50 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 502.77 V Peak.

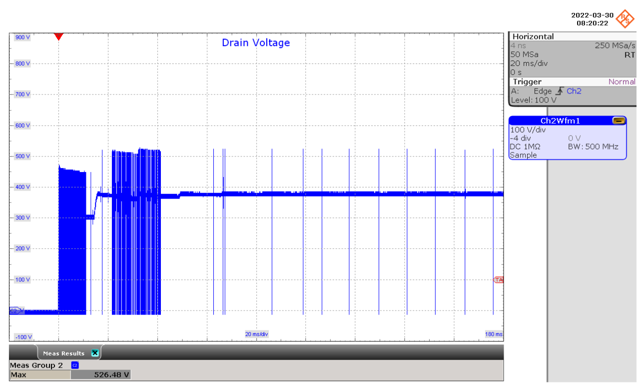


Figure 65 – Drain Voltage, 277 VAC, 60 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 526.48 V Peak.

11.5 *LinkSwitch-TNZ Drain Voltage, Normal Operation, Relay OFF*

The VDS stress on LinkSwitch-TNZ IC kept below 80% of rated BV_{DSS} = 725 V at nominal input (230 VAC). No primary snubber was used. For designs that require higher power, an R-C-D snubber may be added.

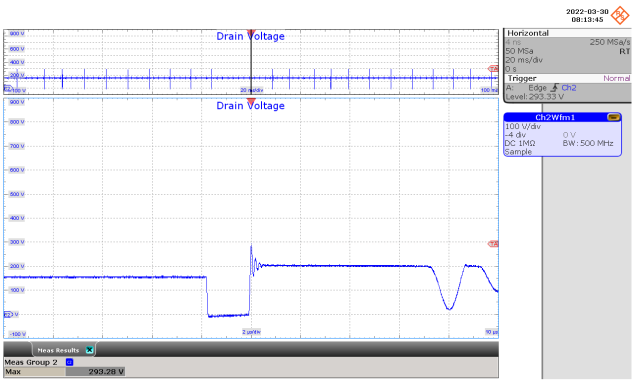


Figure 66 – Drain Voltage, 120 VAC, 60 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 293.28 V Peak.

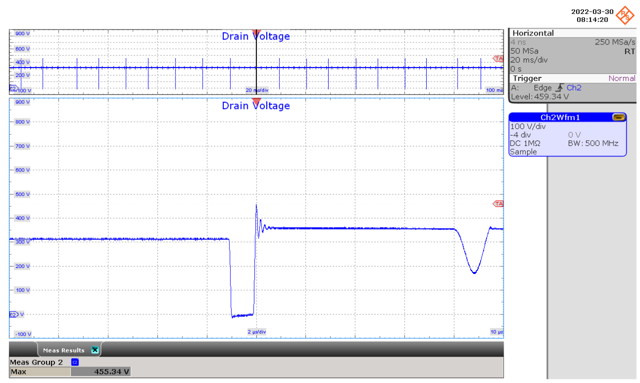


Figure 67 – Drain Voltage, 230 VAC, 50 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 455.34 V Peak.

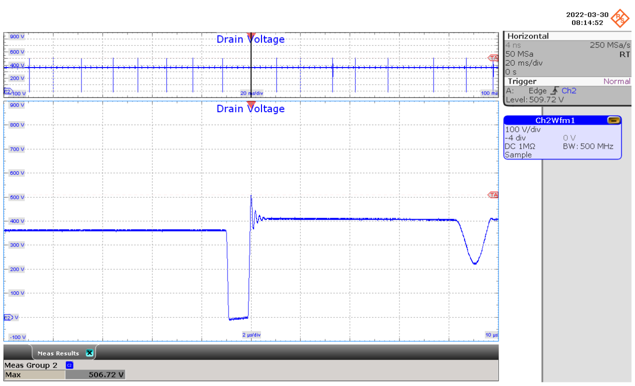


Figure 68 – Drain Voltage, 265 VAC, 50 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 506.72 V Peak.

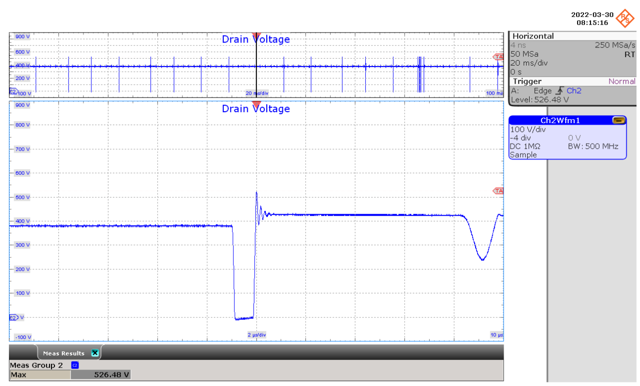


Figure 69 – Drain Voltage, 277 VAC, 60 Hz.

CH2: Drain Voltage, 100 V / div.
VDS Max: 526.48 V Peak.

11.6 *Output Waveforms, Start-up, Relay OFF*

No huge overshoot/undershoot on the 3 V LDO output.

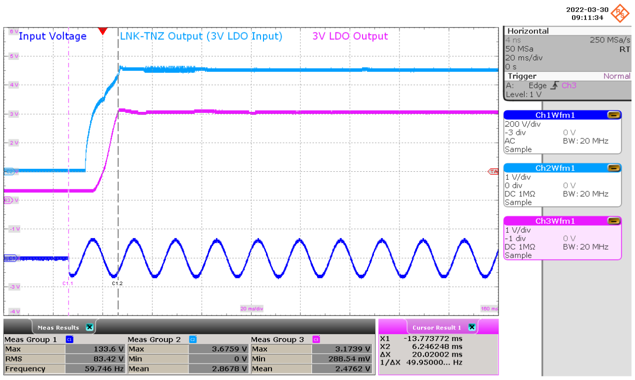


Figure 70 – Output Waveforms, Start-up, Relay OFF, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 20.02 ms.

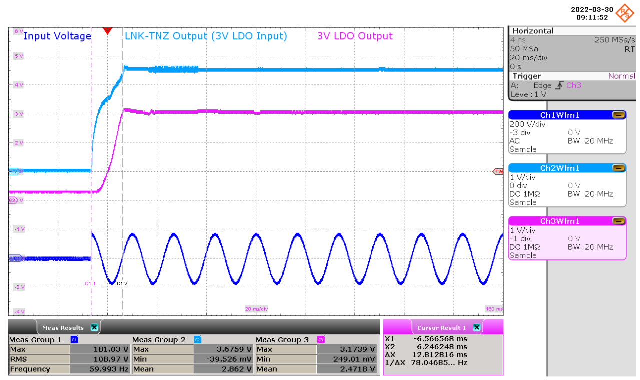


Figure 71 – Output Waveforms, Start-up, Relay OFF, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 12.82 ms

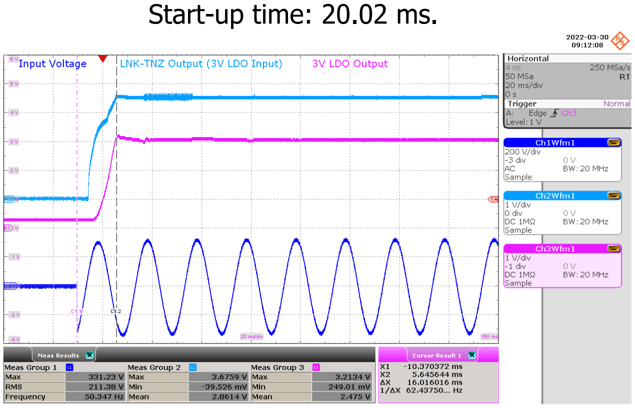


Figure 72 – Output Waveforms, Start-up, Relay OFF, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 16.02 ms.

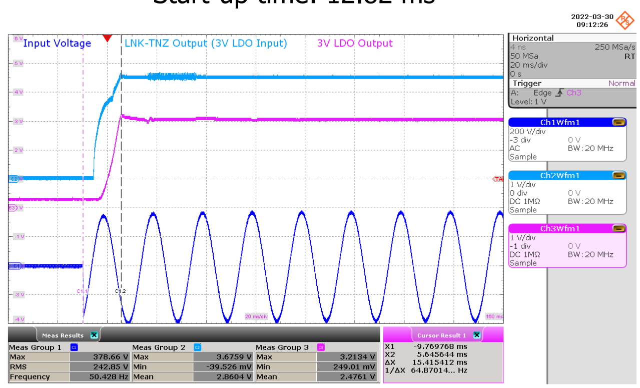


Figure 73 – Output Waveforms, Start-up, Relay OFF, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 15.42 ms.

11.7 *Output Waveforms, Start-up, Relay ON*

With the relay already ON, the supply comes from the output of the Q1 regulator circuit.

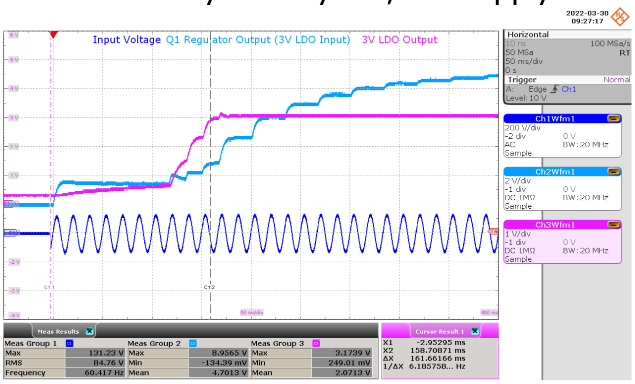


Figure 74 – Output Waveforms, Start-up, Relay ON, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 161.66 ms.

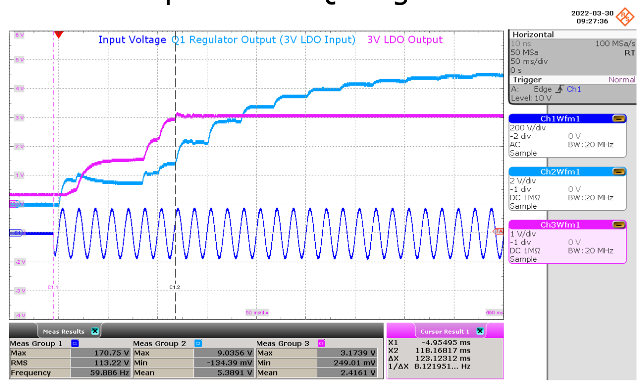


Figure 75 – Output Waveforms, Start-up, Relay ON, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 123.12 ms.

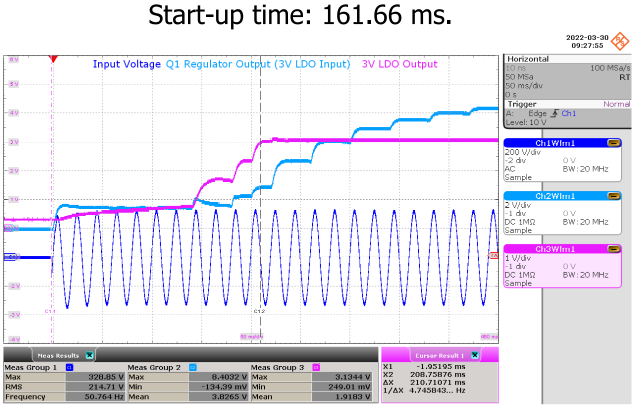


Figure 76 – Output Waveforms, Start-up, Relay ON, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 210.71 ms.

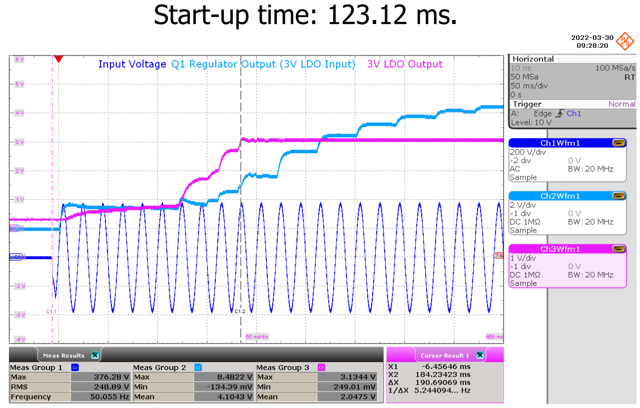


Figure 77 – Output Waveforms, Start-up, Relay ON, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
Start-up time: 190.69 ms.

11.8 ***Output Waveforms, Steady-State, Relay OFF***

When the relay is OFF, the supply comes from LinkSwitch-TNZ output voltage.

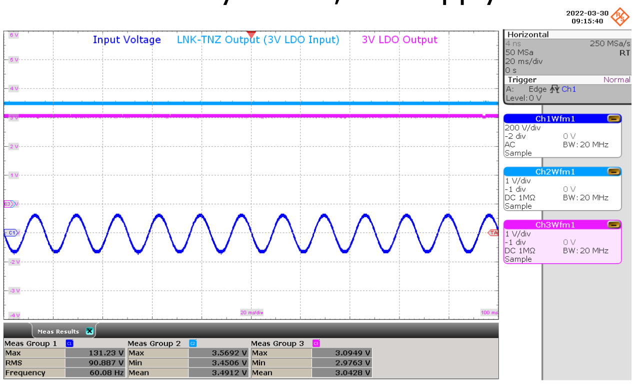


Figure 78 – Output Waveforms, Steady-State, Relay OFF, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.

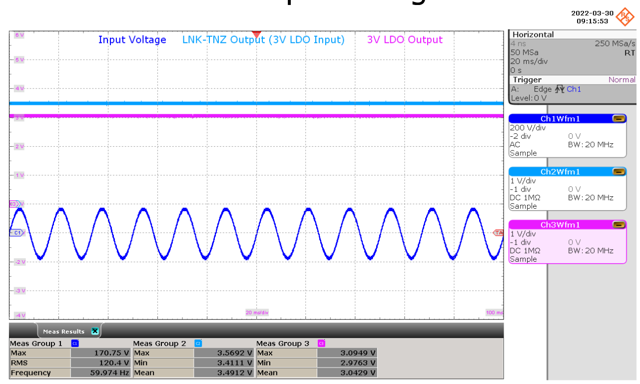


Figure 79 – Output Waveforms, Steady-State, Relay OFF, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.

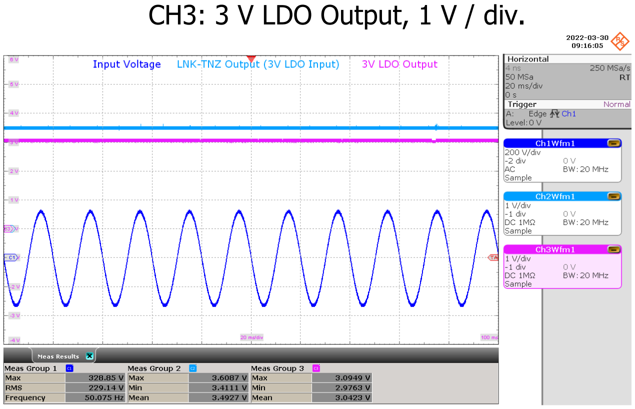


Figure 80 – Output Waveforms, Steady-State, Relay OFF, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.

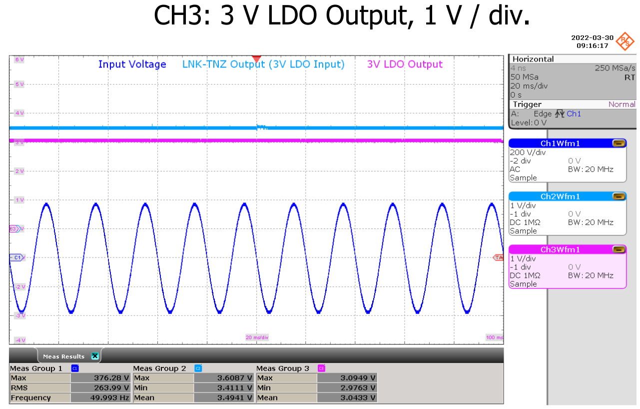


Figure 81 – Output Waveforms, Steady-State, Relay OFF, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: LinkSwitch-TNZ Output (3 V LDO Input), 1 V / div.
CH3: 3 V LDO Output, 1 V / div.

11.9 *Output Waveforms, Steady-State, Relay ON*

When the relay is ON, the supply comes from the output of the Q1 regulator circuit.

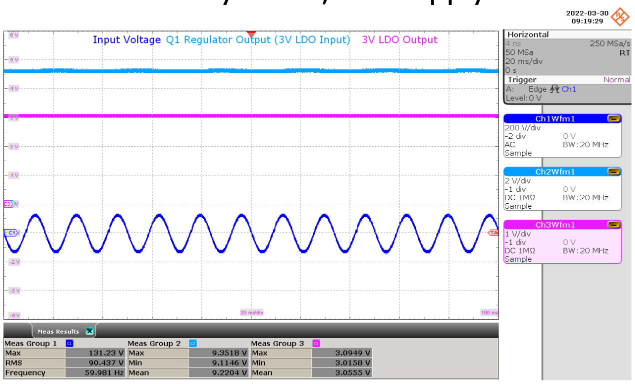


Figure 82 – Output Waveforms, Steady-State, Relay OFF, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.

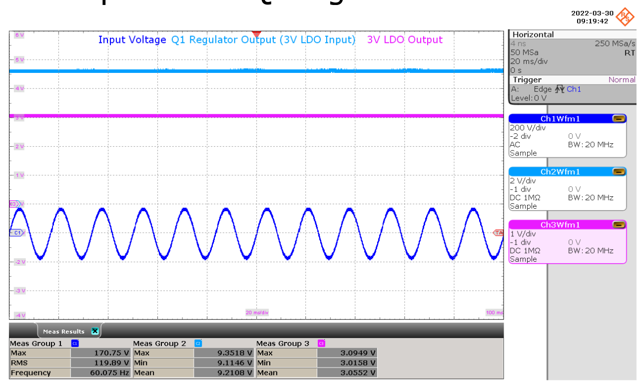


Figure 83 – Output Waveforms, Steady-State, Relay OFF, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.

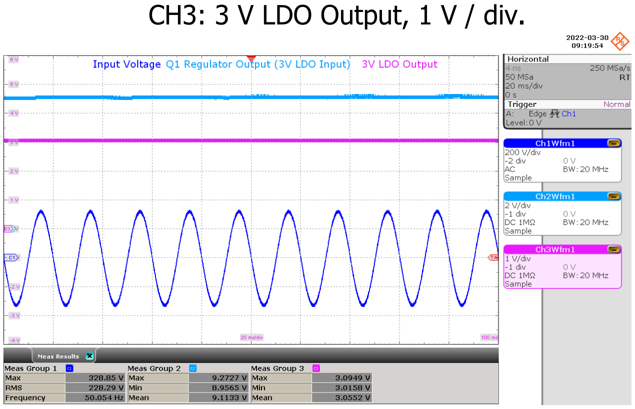


Figure 84 – Output Waveforms, Steady-State, Relay OFF, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.

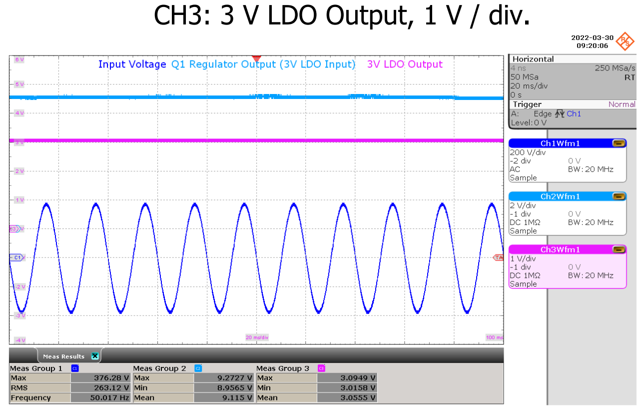


Figure 85 – Output Waveforms, Steady-State, Relay OFF, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: Q1 Regulator Output (3 V LDO Input), 2 V / div.
CH3: 3 V LDO Output, 1 V / div.

11.10 *Output Waveforms, Relay OFF to ON Transition*

No huge overshoot/undershoot on the 3 V LDO output during the transition.

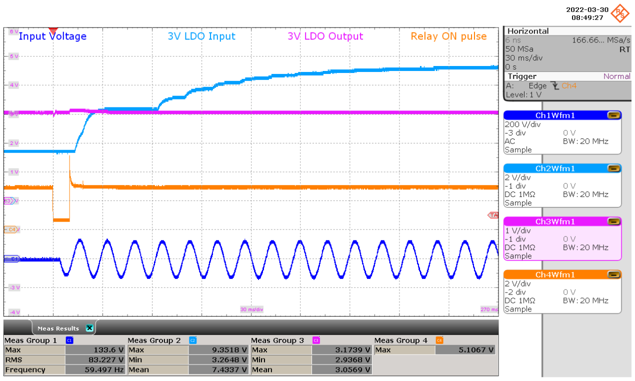


Figure 86 – Output Waveforms, Relay OFF to ON Transition, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay ON pulse, 2 V / div.

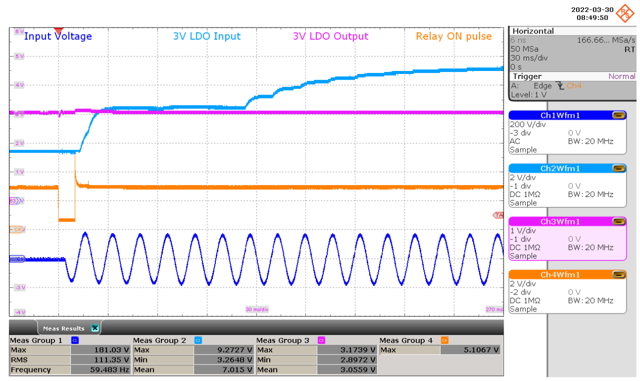


Figure 87 – Output Waveforms, Relay OFF to ON Transition, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay ON pulse, 2 V / div.

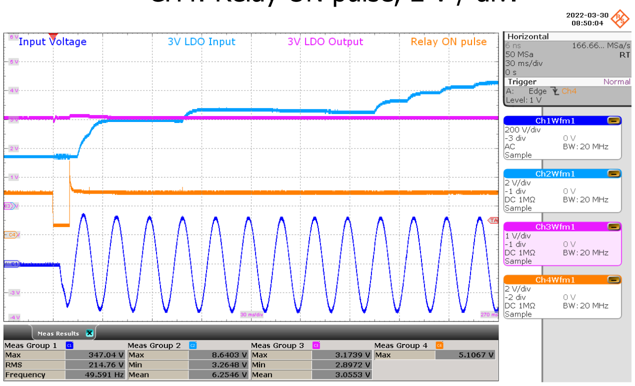


Figure 88 – Output Waveforms, Relay OFF to ON Transition, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay ON pulse, 2 V / div.

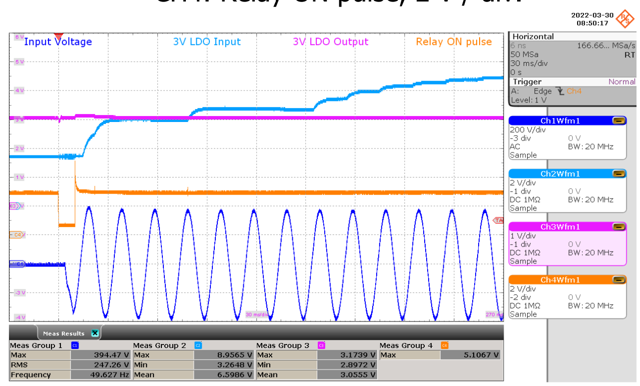


Figure 89 – Output Waveforms, Relay OFF to ON Transition, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay ON pulse, 2 V / div.

11.11 *Output Waveforms, Relay ON to OFF Transition*

No huge overshoot/undershoot on the 3 V LDO output during the transition.

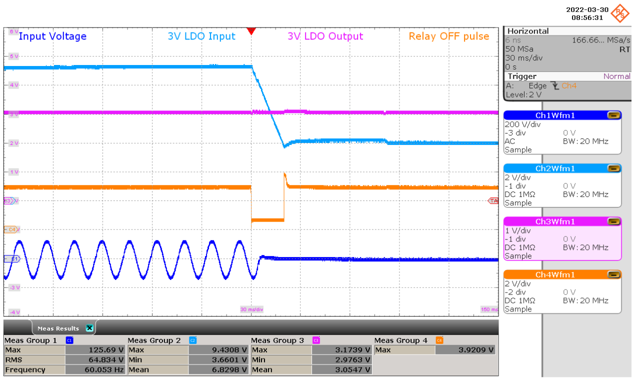


Figure 90 – Output Waveforms, Relay ON to OFF Transition, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay OFF pulse, 2 V / div.

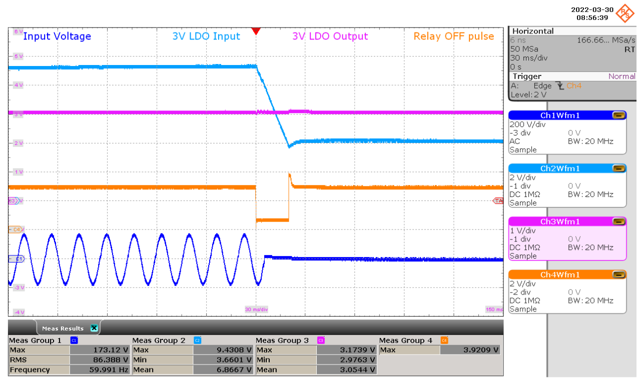


Figure 91 – Output Waveforms, Relay ON to OFF Transition, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay OFF pulse, 2 V / div.

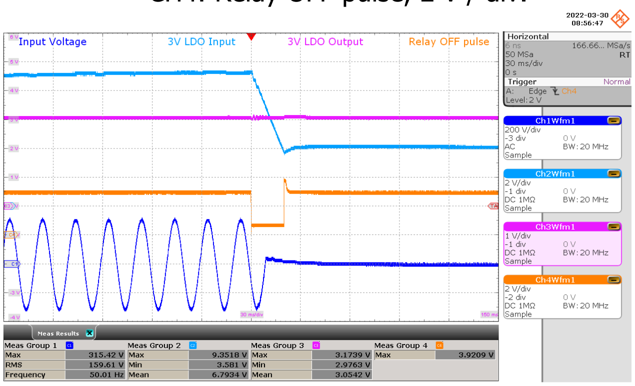


Figure 92 – Output Waveforms, Relay ON to OFF Transition, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay OFF pulse, 2 V / div.

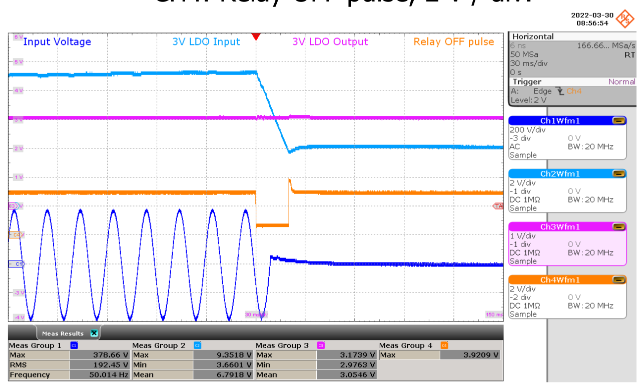


Figure 93 – Output Waveforms, Relay ON to OFF Transition, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: 3 V LDO Input, 2 V / div.
CH3: 3 V LDO Output, 1 V / div.
CH4: Relay OFF pulse, 2 V / div.

11.12 *Q1 Regulator Waveforms*

The regulator circuit works on either 50 Hz or 60 Hz system.

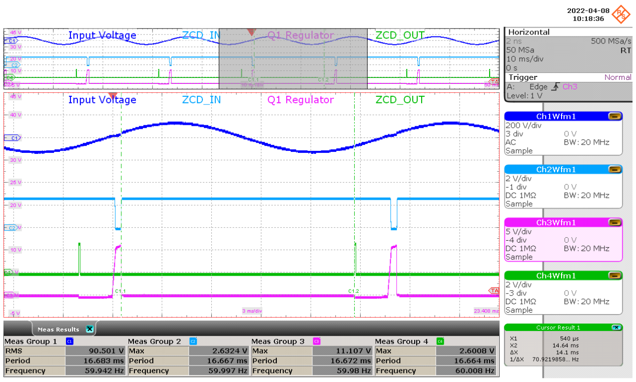


Figure 94 – Q1 Regulator Waveforms, 90 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: Q1 Regulator, 5 V / div.
CH4: ZCD_OUT, 2 V / div.

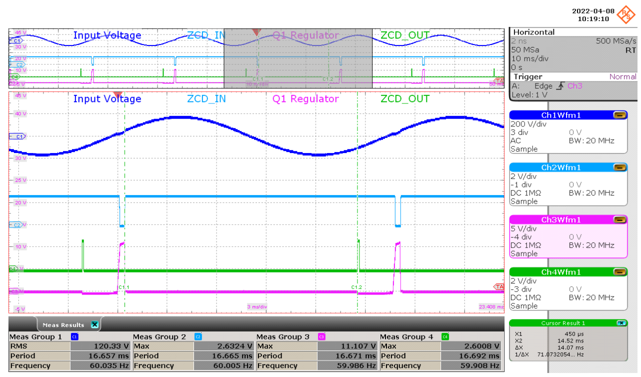


Figure 95 – Q1 Regulator Waveforms, 120 VAC, 60 Hz.

CH1: Input Voltage, 200 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: Q1 Regulator, 5 V / div.
CH4: ZCD_OUT, 2 V / div.

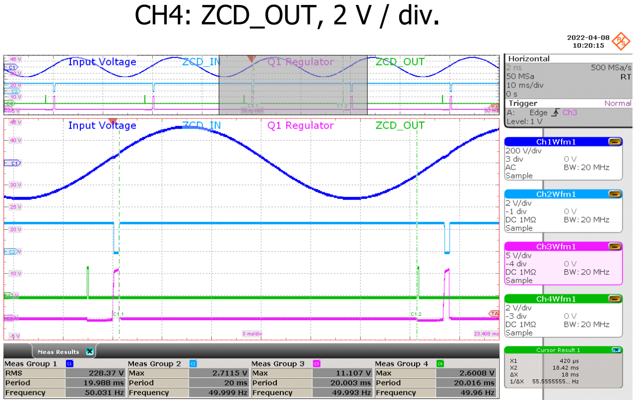


Figure 96 – Q1 Regulator Waveforms, 230 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: Q1 Regulator, 5 V / div.
CH4: ZCD_OUT, 2 V / div.

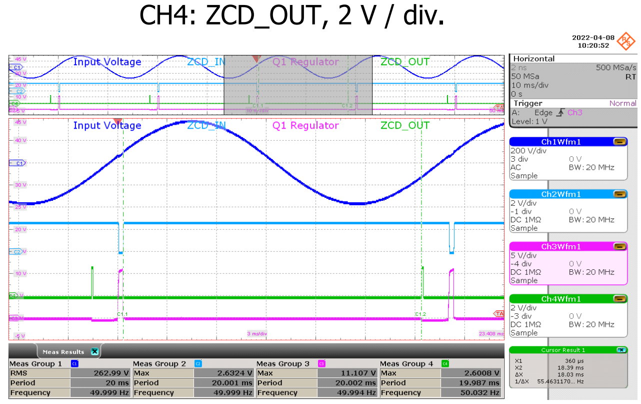


Figure 97 – Q1 Regulator Waveforms, 265 VAC, 50 Hz.

CH1: Input Voltage, 200 V / div.
CH2: ZCD_IN, 2 V / div.
CH3: Q1 Regulator, 5 V / div.
CH4: ZCD_OUT, 2 V / div.

12 Thermals

12.1 *Thermals, Relay ON*

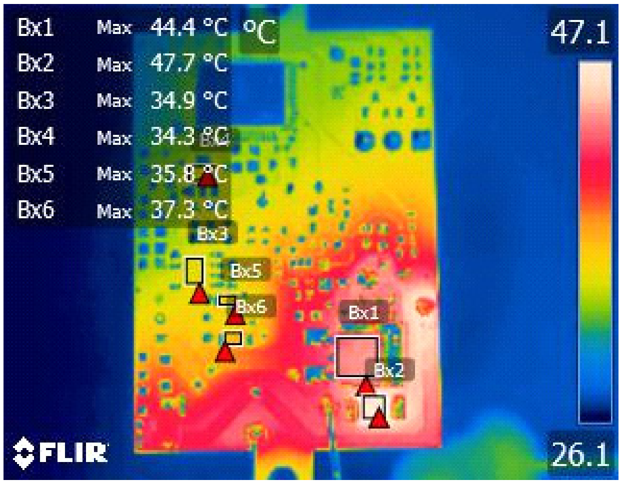


Figure 98 – Bottom, 120 VAC, 60 Hz, 500 W Incandescent Bulb Load, 1-hour Soak.

Bx1: Q1 Regulator – 44.4 °C.
Bx2: D7 – 47.7 °C.
Bx3: U1 (LNK3302D) – 34.9 °C
Bx4: U7 (LDO) – 34.3 °C.
Bx5: D1 – 35.8 °C.
Bx6: D3 – 37.3 °C.

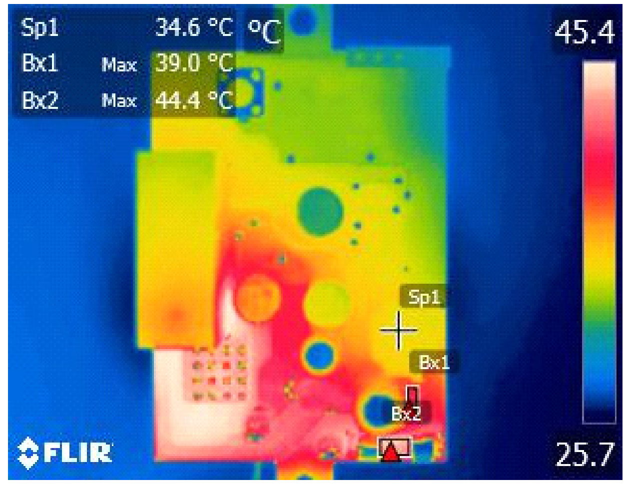


Figure 99 – Top, 120 VAC, 60 Hz, 500 W Incandescent Bulb Load, 1-hour Soak.

Bx1: F1 – 39.0 °C.
Bx2: VR1 – 44.4 °C.
Sp1: T1 – 34.6 °C.

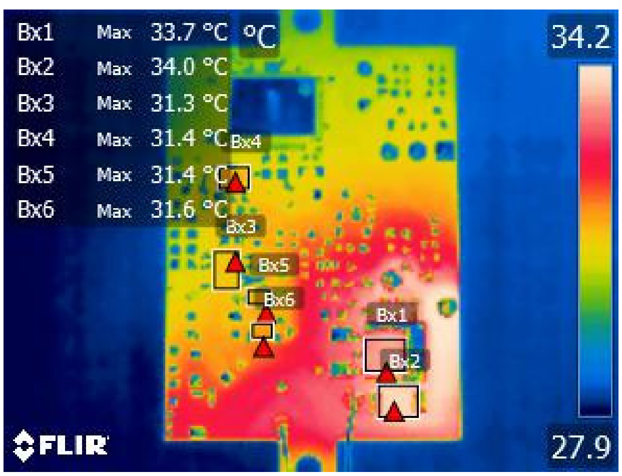


Figure 100 – Bottom, 230 VAC, 50 Hz, 500 W Incandescent Bulb Load, 1-hour Soak.

Bx1: Q1 Regulator – 33.7 °C.
Bx2: D7 – 34.0 °C.
Bx3: U1 (LNK3302D) – 31.3 °C.
Bx4: U7 (LDO) – 31.4 °C.
Bx5: D1 – 31.4 °C.
Bx6: D3 – 31.6 °C.

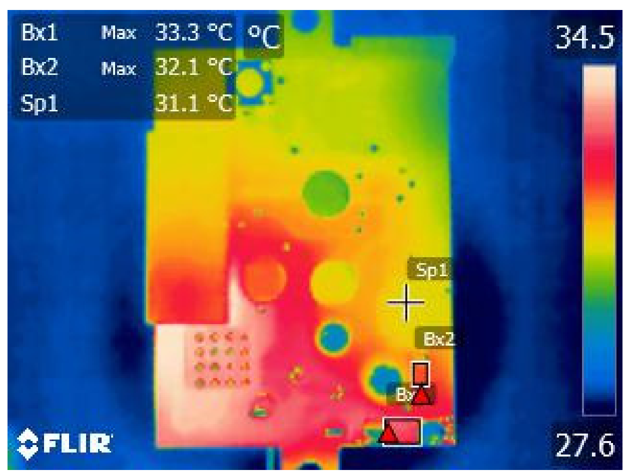


Figure 101 – Top, 230 VAC, 50 Hz, 500 W Incandescent Bulb Load, 1-hour Soak.

Bx1: F1 – 33.3 °C.
Bx2: VR1 – 32.1 °C.
Sp1: T1 – 31.1 °C.

12.2 *Thermals, Relay OFF*

When the relay is OFF, the power supply comes from the LinkSwitch-TNZ circuit. The thermal data, however, was taken using simulated load on the 3 V output to verify the performance if the same design will be used on higher power design up to its rated limit.

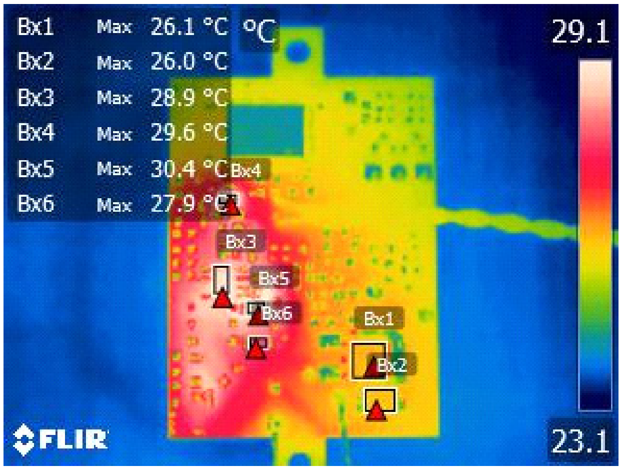


Figure 102 – Bottom, 90 VAC, 60 Hz. Load: 3 V, 60 mA.

Bx1: Q1 Regulator – 26.1 °C.
Bx2: D7 – 26.0 °C.
Bx3: U1 (LNK3302D) – 28.9 °C.
Bx4: U7 (LDO) – 29.6 °C.
Bx5: D1 – 30.4 °C.
Bx6: D3 – 27.9 °C.

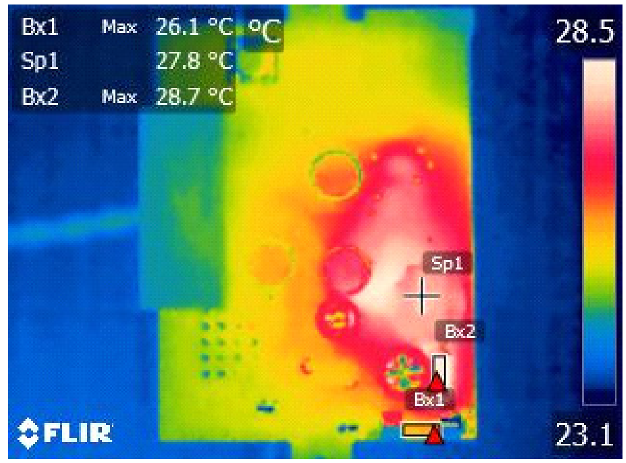


Figure 103 – Top, 90 VAC, 60 Hz. Load: 3 V, 60 mA.

Bx1: F1 – 26.1 °C.
Bx2: VR1 – 28.7 °C.
Sp1: T1 – 27.8 °C.

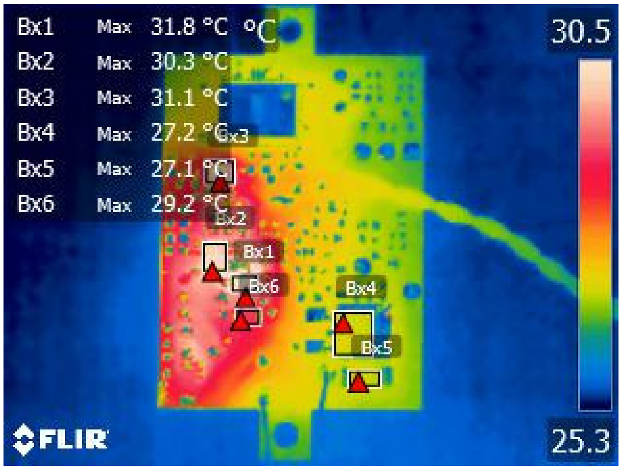


Figure 104 – Bottom, 230 VAC, 50 Hz. Load: 3 V, 60 mA.

Bx1: D1 – 31.8 °C.
Bx2: U1 (LNK3302D) – 30.3 °C.
Bx3: U7 (LDO) – 31.1 °C.
Bx4: Q1 Regulator – 27.2 °C.
Bx5: D7 – 27.1 °C.
Bx6: D3 – 29.2 °C.

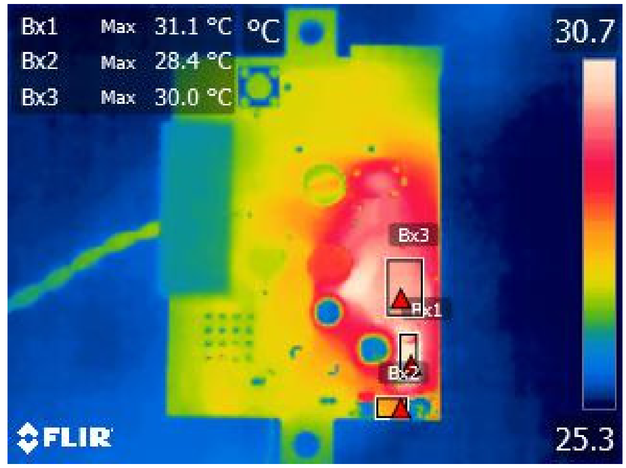
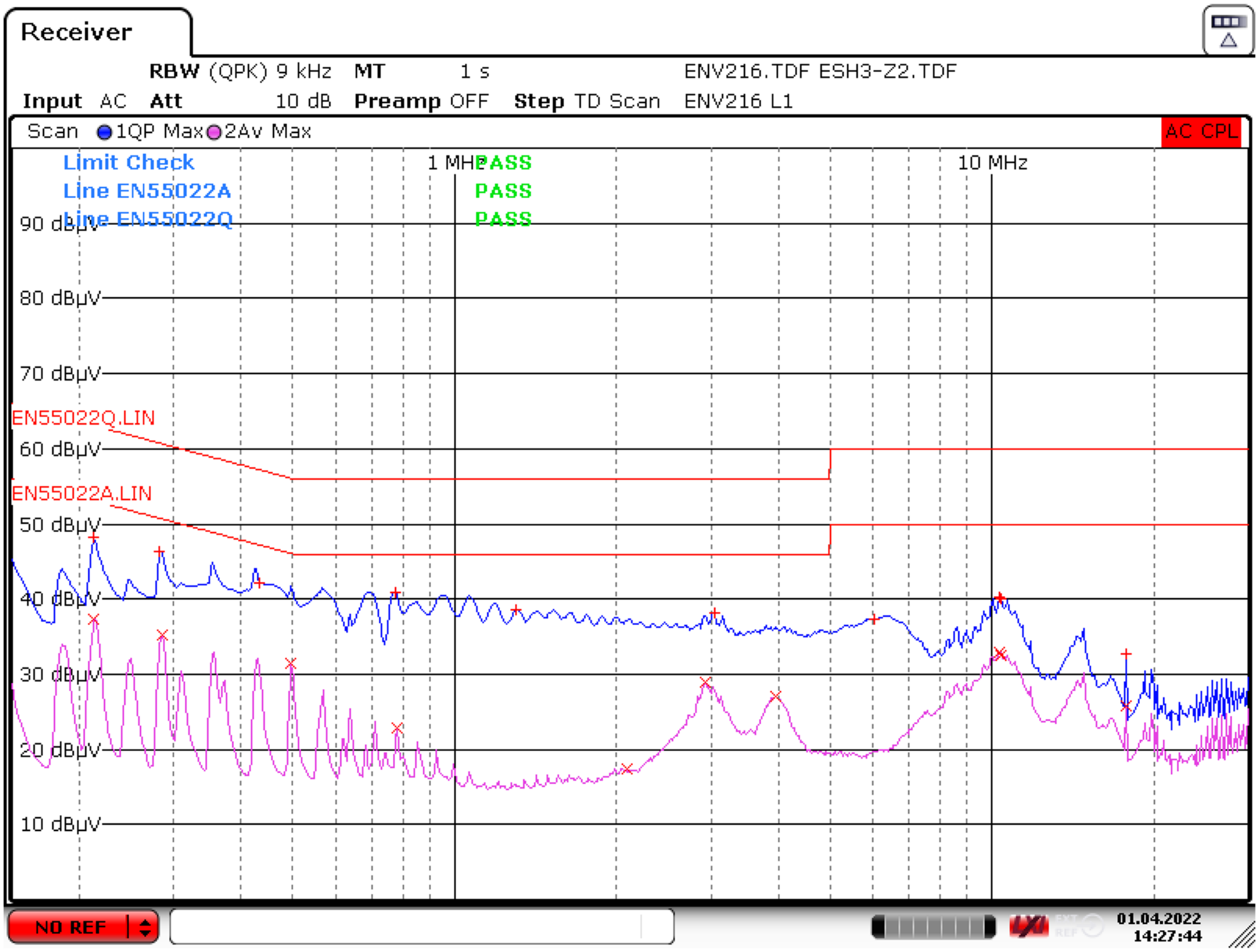


Figure 105 – Top, 230 VAC, 50 Hz. Load: 3 V, 60 mA.

Bx1: VR1 – 31.1 °C.
Bx2: F1 – 28.4 °C.
Bx3: T1 – 30.0 °C.

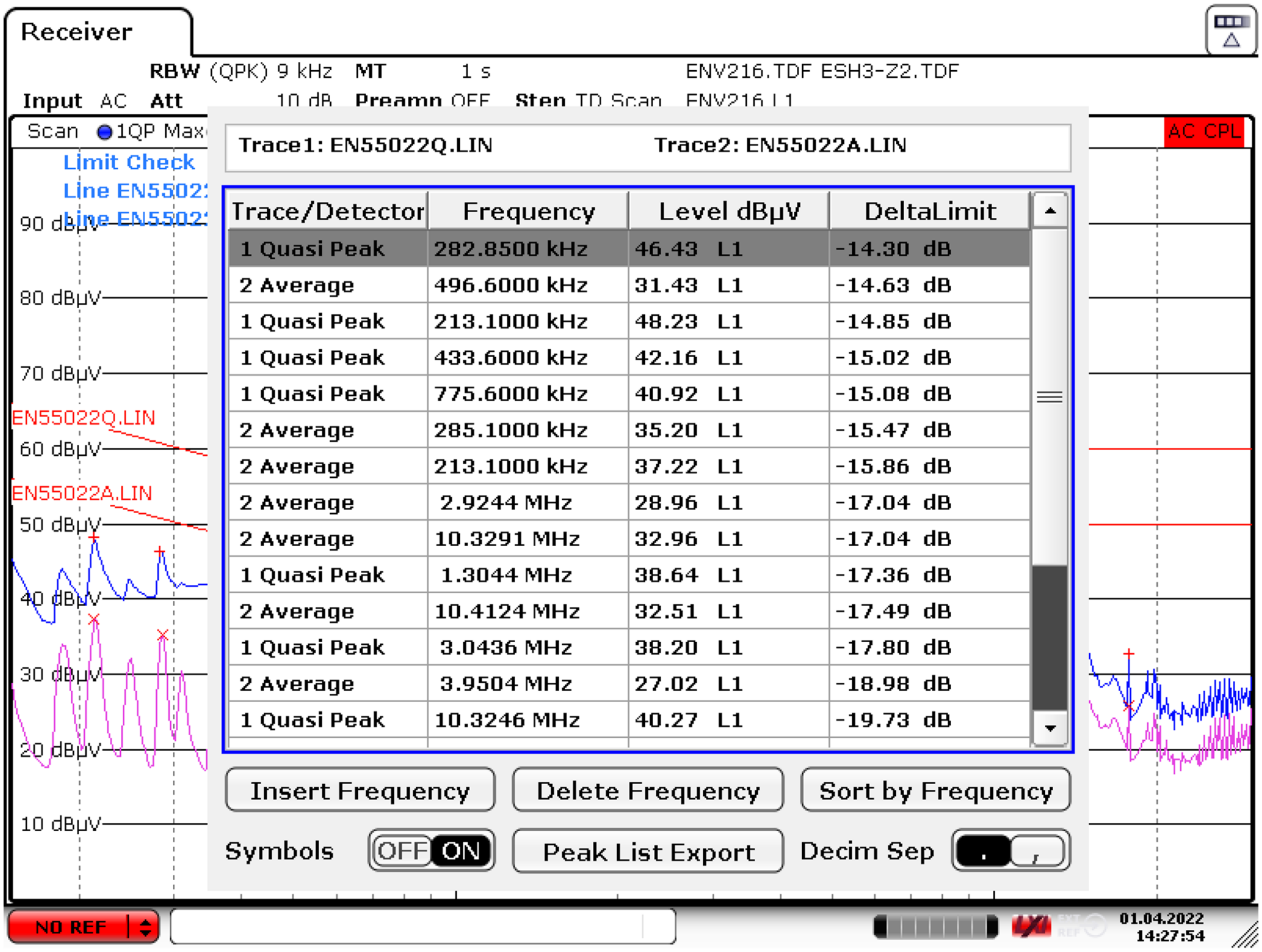
13 Conducted EMI

Conducted EMI was tested when the relay is OFF. This was to check the emission of LinkSwitch-TNZ IC only. When the relay is ON, LinkSwitch-TNZ IC does not switch anymore and only the Q1 regulator is operational. Since the regulator switches every AC line cycle, it is possibly to get worse EMI than when a bulb is directly connected to the line. However, this response is analogous to a typical TRIAC dimmer that 'chops' the line voltage and causes incident emission which is acceptable as per FCC part 15 standard. Hence, this DER does not address EMI issue that may arise due to the Q1 regulator.



Date: 1.APR.2022 14:27:45

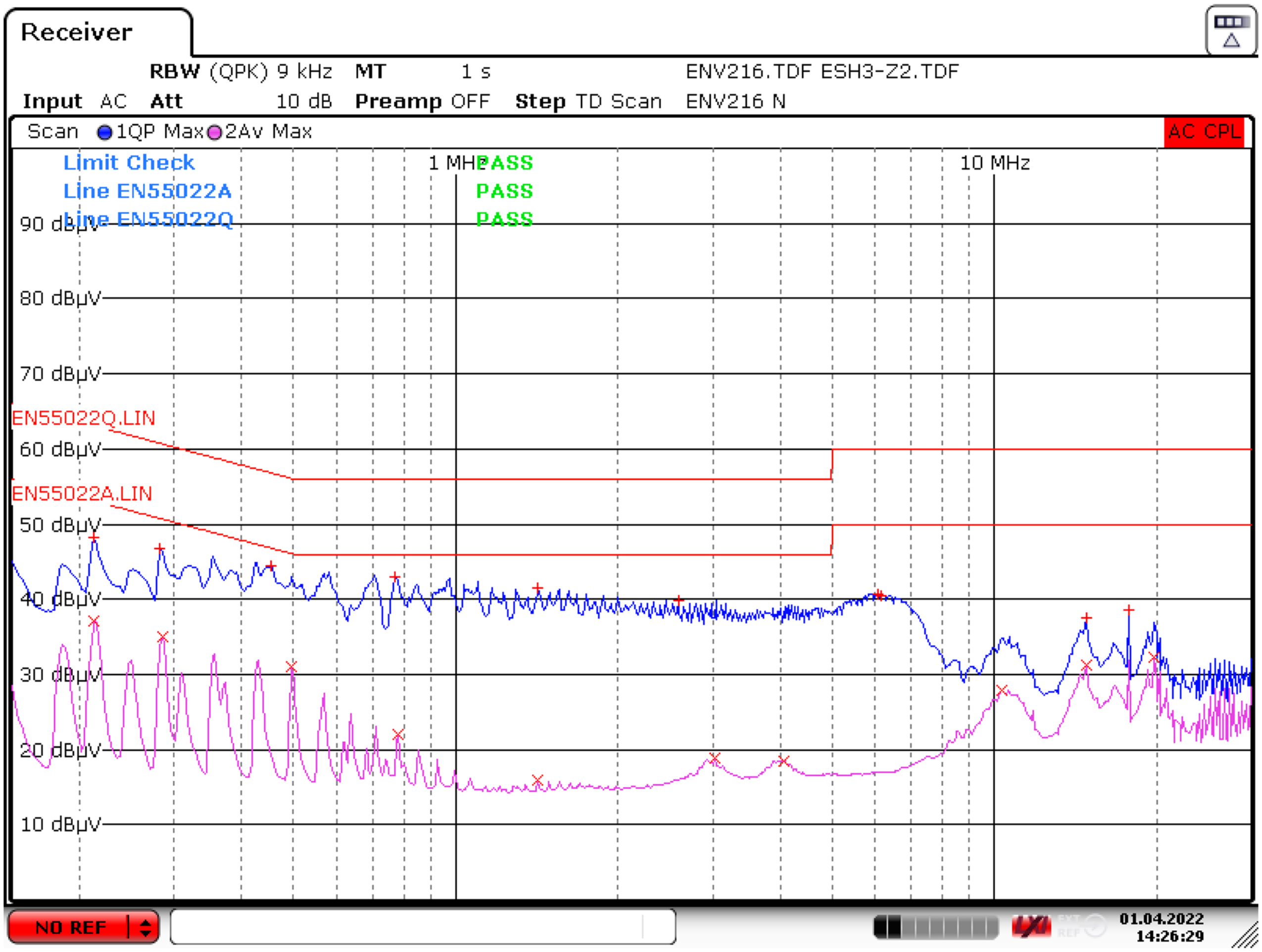
Figure 106 – Conducted EMI (LINE) at 120 VAC, 60 Hz, Floating Output.



Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	282.8500 kHz	46.43 L1	-14.30 dB
2 Average	496.6000 kHz	31.43 L1	-14.63 dB
1 Quasi Peak	213.1000 kHz	48.23 L1	-14.85 dB
1 Quasi Peak	433.6000 kHz	42.16 L1	-15.02 dB
1 Quasi Peak	775.6000 kHz	40.92 L1	-15.08 dB
2 Average	285.1000 kHz	35.20 L1	-15.47 dB
2 Average	213.1000 kHz	37.22 L1	-15.86 dB
2 Average	2.9244 MHz	28.96 L1	-17.04 dB
2 Average	10.3291 MHz	32.96 L1	-17.04 dB
1 Quasi Peak	1.3044 MHz	38.64 L1	-17.36 dB
2 Average	10.4124 MHz	32.51 L1	-17.49 dB
1 Quasi Peak	3.0436 MHz	38.20 L1	-17.80 dB
2 Average	3.9504 MHz	27.02 L1	-18.98 dB
1 Quasi Peak	10.3246 MHz	40.27 L1	-19.73 dB

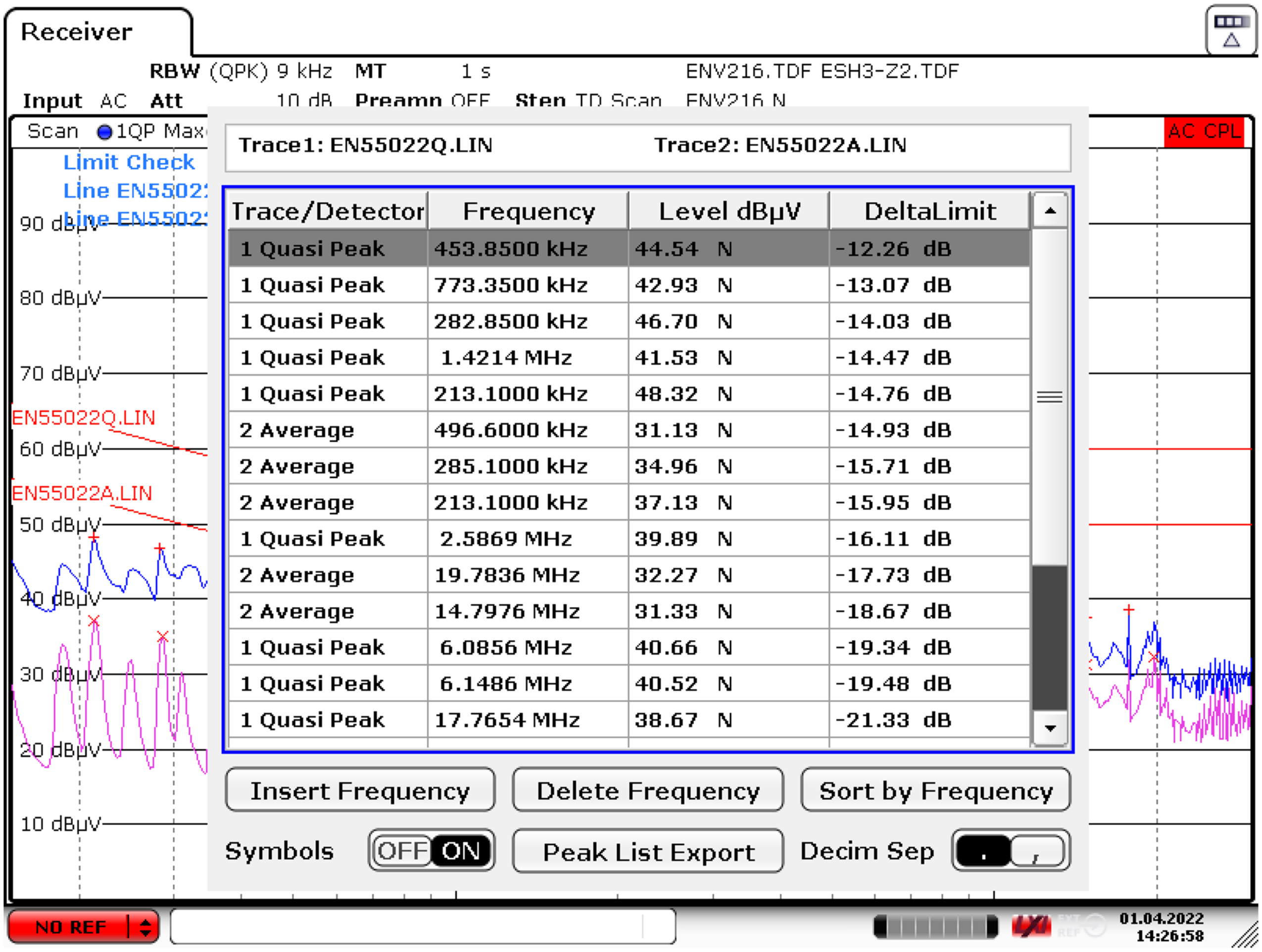
Date: 1.APR.2022 14:27:54

Figure 107 – Conducted EMI (LINE) at 120 VAC, 60 Hz, Floating Output, Peak List.



Date: 1.APR.2022 14:26:29

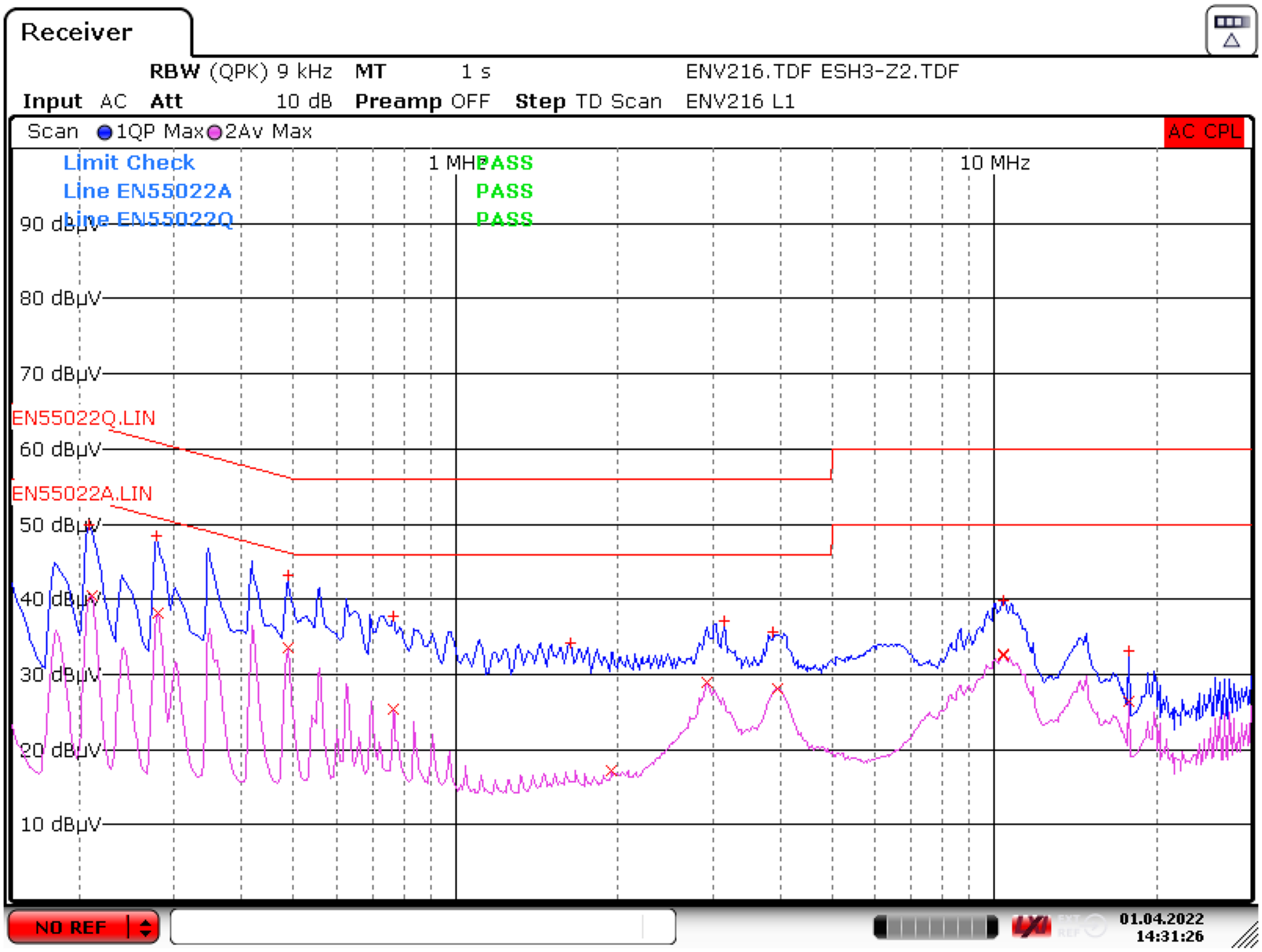
Figure 108 – Conducted EMI (NEUTRAL) at 120 VAC, 60 Hz, Floating Output.



Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	453.8500 kHz	44.54 N	-12.26 dB
1 Quasi Peak	773.3500 kHz	42.93 N	-13.07 dB
1 Quasi Peak	282.8500 kHz	46.70 N	-14.03 dB
1 Quasi Peak	1.4214 MHz	41.53 N	-14.47 dB
1 Quasi Peak	213.1000 kHz	48.32 N	-14.76 dB
2 Average	496.6000 kHz	31.13 N	-14.93 dB
2 Average	285.1000 kHz	34.96 N	-15.71 dB
2 Average	213.1000 kHz	37.13 N	-15.95 dB
1 Quasi Peak	2.5869 MHz	39.89 N	-16.11 dB
2 Average	19.7836 MHz	32.27 N	-17.73 dB
2 Average	14.7976 MHz	31.33 N	-18.67 dB
1 Quasi Peak	6.0856 MHz	40.66 N	-19.34 dB
1 Quasi Peak	6.1486 MHz	40.52 N	-19.48 dB
1 Quasi Peak	17.7654 MHz	38.67 N	-21.33 dB

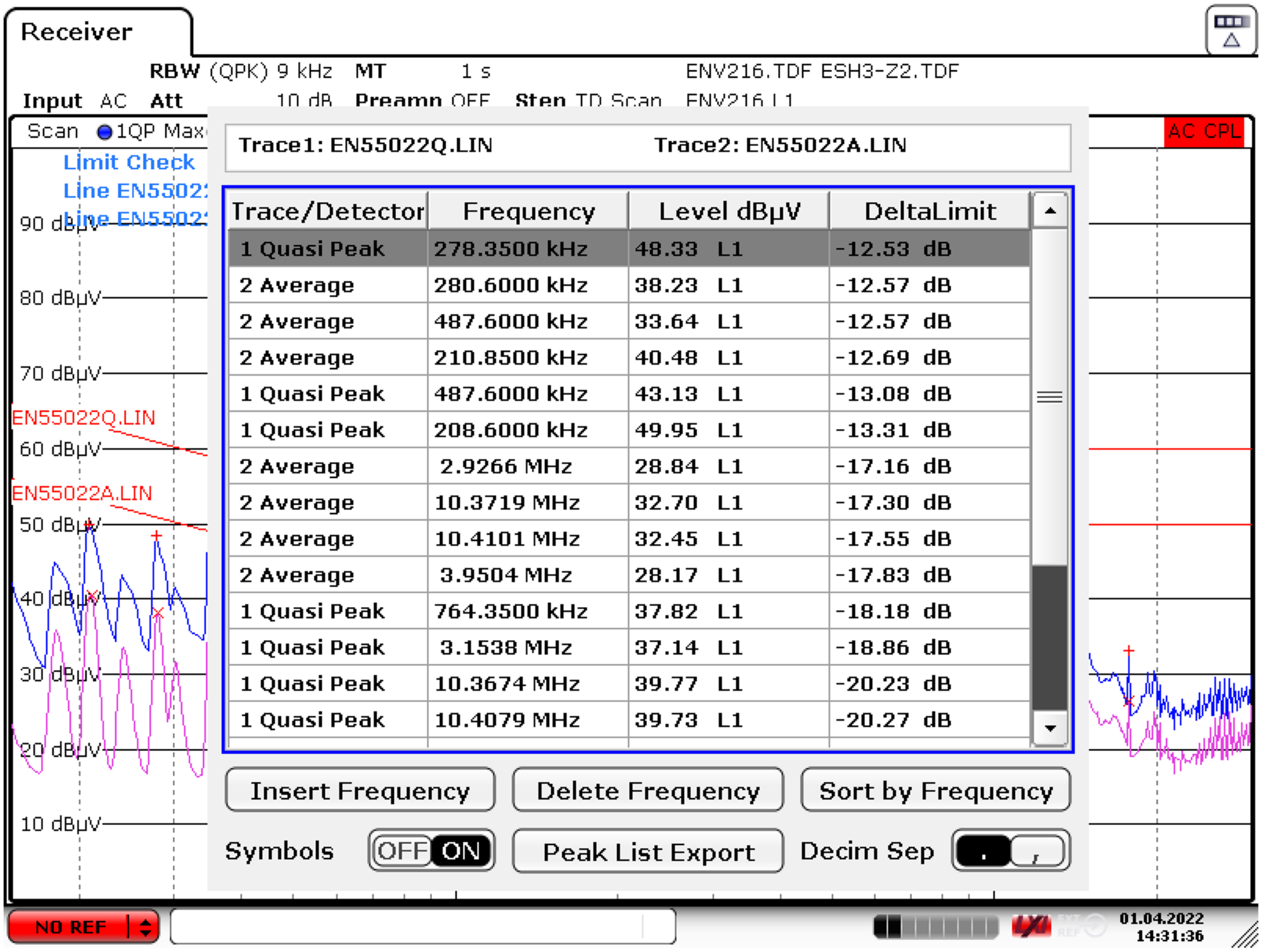
Date: 1.APR.2022 14:26:57

Figure 109 – Conducted EMI (NEUTRAL) at 120 VAC, 60 Hz, Floating Output, Peak List.



Date: 1.APR.2022 14:31:27

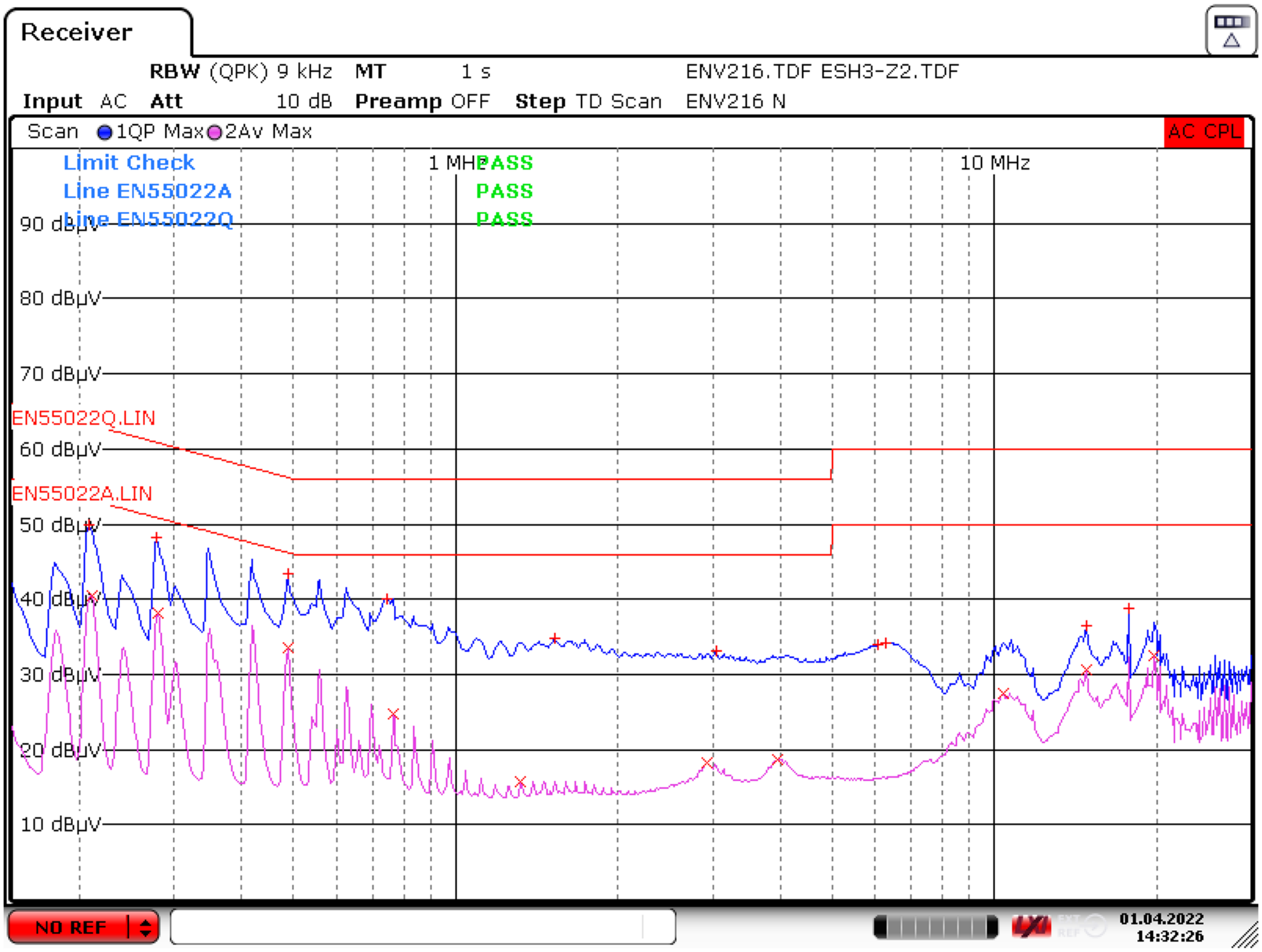
Figure 110 – Conducted EMI (LINE) at 230 VAC, 50 Hz, Floating Output.



Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	278.3500 kHz	48.33 L1	-12.53 dB
2 Average	280.6000 kHz	38.23 L1	-12.57 dB
2 Average	487.6000 kHz	33.64 L1	-12.57 dB
2 Average	210.8500 kHz	40.48 L1	-12.69 dB
1 Quasi Peak	487.6000 kHz	43.13 L1	-13.08 dB
1 Quasi Peak	208.6000 kHz	49.95 L1	-13.31 dB
2 Average	2.9266 MHz	28.84 L1	-17.16 dB
2 Average	10.3719 MHz	32.70 L1	-17.30 dB
2 Average	10.4101 MHz	32.45 L1	-17.55 dB
2 Average	3.9504 MHz	28.17 L1	-17.83 dB
1 Quasi Peak	764.3500 kHz	37.82 L1	-18.18 dB
1 Quasi Peak	3.1538 MHz	37.14 L1	-18.86 dB
1 Quasi Peak	10.3674 MHz	39.77 L1	-20.23 dB
1 Quasi Peak	10.4079 MHz	39.73 L1	-20.27 dB

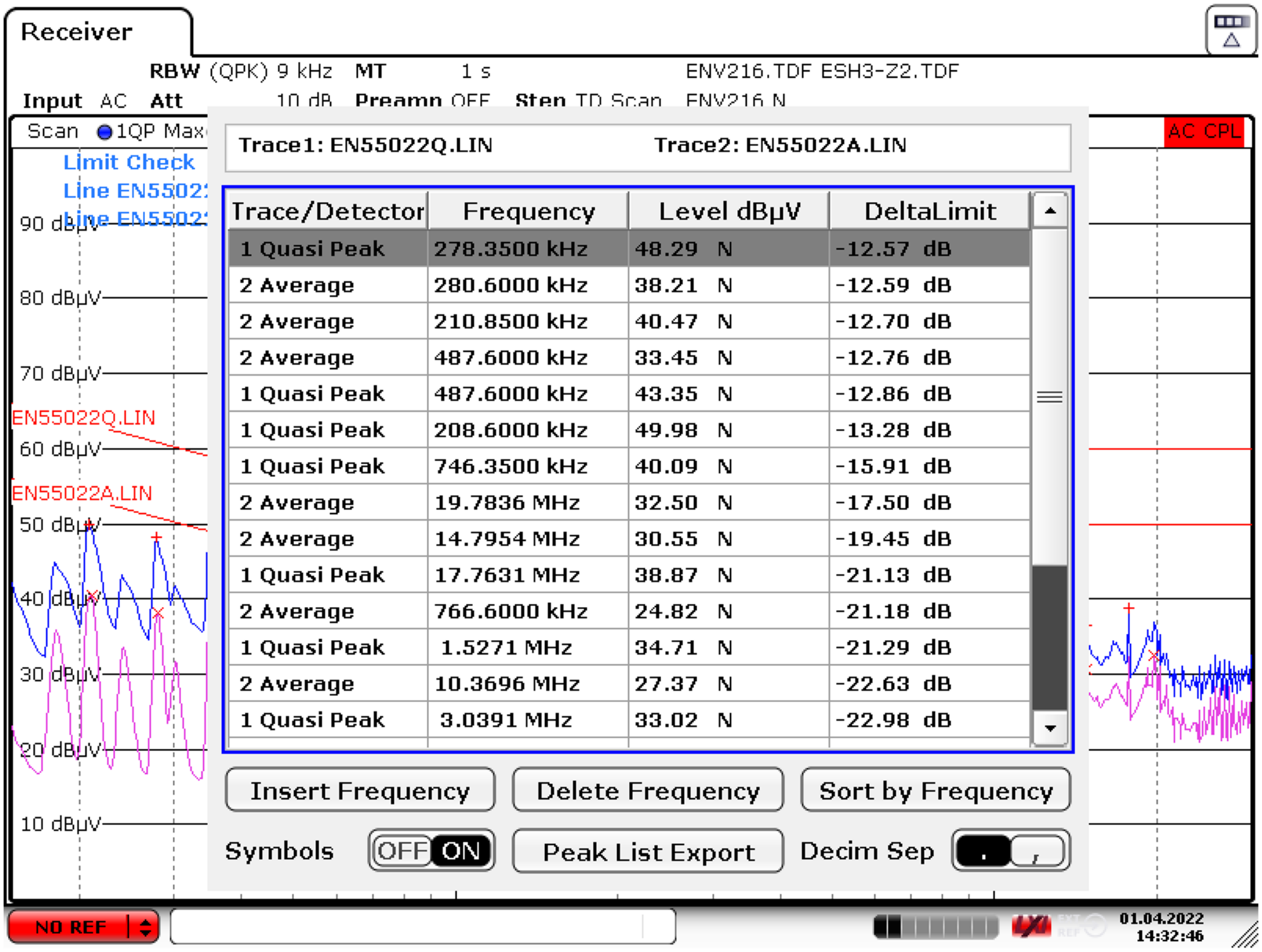
Date: 1.APR.2022 14:31:37

Figure 111 – Conducted EMI (LINE) at 230 VAC, 50 Hz, Floating Output, Peak List.



Date: 1.APR.2022 14:32:26

Figure 112 – Conducted EMI (NEUTRAL) at 230 VAC, 50 Hz, Floating Output.



Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	278.3500 kHz	48.29 N	-12.57 dB
2 Average	280.6000 kHz	38.21 N	-12.59 dB
2 Average	210.8500 kHz	40.47 N	-12.70 dB
2 Average	487.6000 kHz	33.45 N	-12.76 dB
1 Quasi Peak	487.6000 kHz	43.35 N	-12.86 dB
1 Quasi Peak	208.6000 kHz	49.98 N	-13.28 dB
1 Quasi Peak	746.3500 kHz	40.09 N	-15.91 dB
2 Average	19.7836 MHz	32.50 N	-17.50 dB
2 Average	14.7954 MHz	30.55 N	-19.45 dB
1 Quasi Peak	17.7631 MHz	38.87 N	-21.13 dB
2 Average	766.6000 kHz	24.82 N	-21.18 dB
1 Quasi Peak	1.5271 MHz	34.71 N	-21.29 dB
2 Average	10.3696 MHz	27.37 N	-22.63 dB
1 Quasi Peak	3.0391 MHz	33.02 N	-22.98 dB

Date: 1.APR.2022 14:32:47

Figure 113 – Conducted EMI (NEUTRAL) at 230 VAC, 50 Hz, Floating Output, Peak List.

14 Line Surge Testing

The unit was subjected to ±2500 V, 100 kHz ring wave and ±500 V differential surge with 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage. The test was done with the relay in OFF position, and with an incandescent bulb to close the circuit loop.

14.1 *Differential Line Surge Test Results*

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Line Impedance (Ω)	Test Result (Pass/Fail)
+500	230	L to N	0	2	Pass
-500	230	L to N	0	2	Pass
+500	230	L to N	90	2	Pass
-500	230	L to N	90	2	Pass
+500	230	L to N	270	2	Pass
-500	230	L to N	270	2	Pass

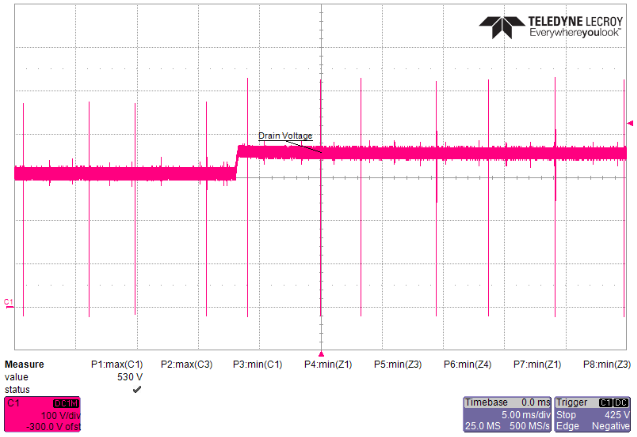


Figure 114 – (+500 V, 0°) Differential Line Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 530 V Peak.

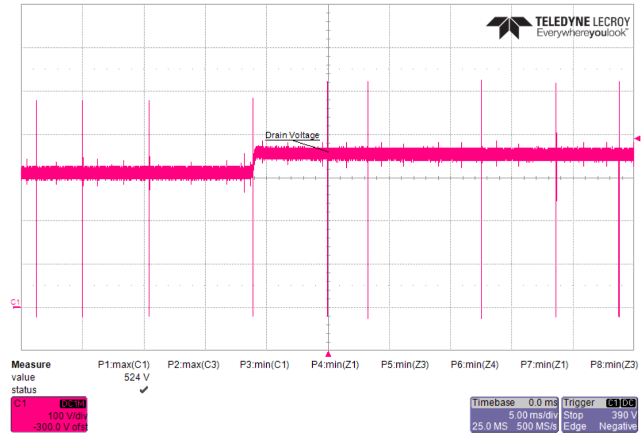


Figure 115 – (-500 V, 0°) Differential Line Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 524 V Peak.

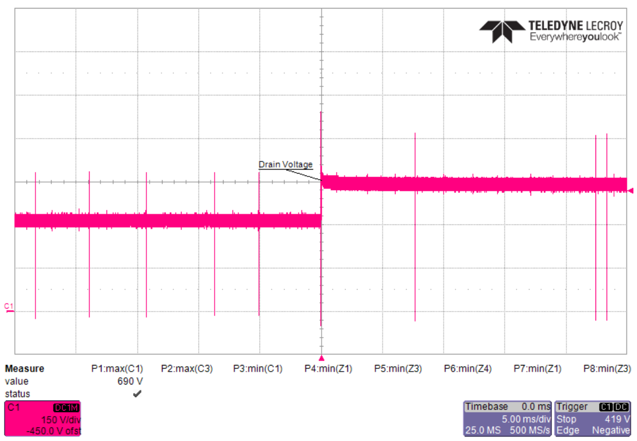


Figure 116 – (+500 V, 90°) Differential Line Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 690 V Peak.

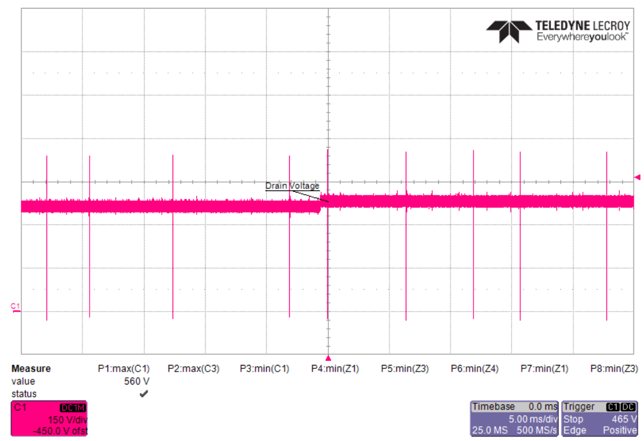


Figure 117 – (-500 V, 90°) Differential Line Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 560 V Peak.

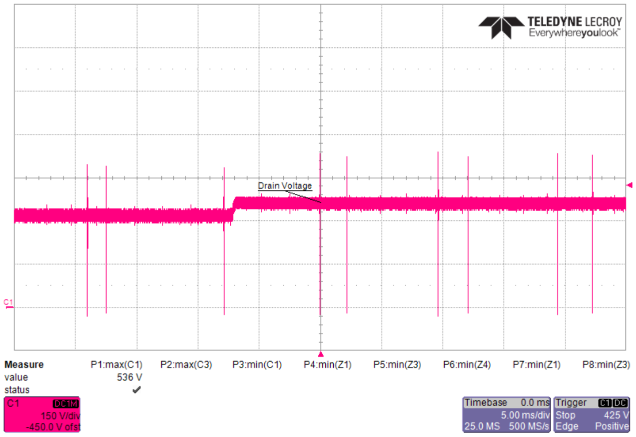


Figure 118 – (+500 V, 270°) Differential Line Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 536 V Peak.

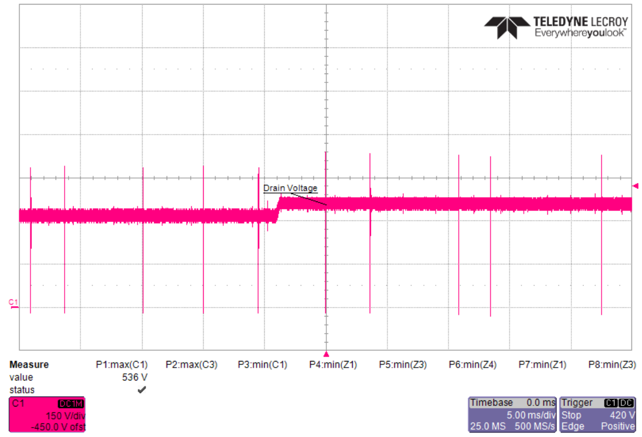


Figure 119 – (-500 V, 270°) Differential Line Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 536 V Peak.

14.2 ***Ring Wave Test Results***

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Line Impedance (Ω)	Test Result (Pass/Fail)
+2500	230	L to N	0	12	Pass
-2500	230	L to N	0	12	Pass
+2500	230	L to N	90	12	Pass
-2500	230	L to N	90	12	Pass
+2500	230	L to N	270	12	Pass
-2500	230	L to N	270	12	Pass

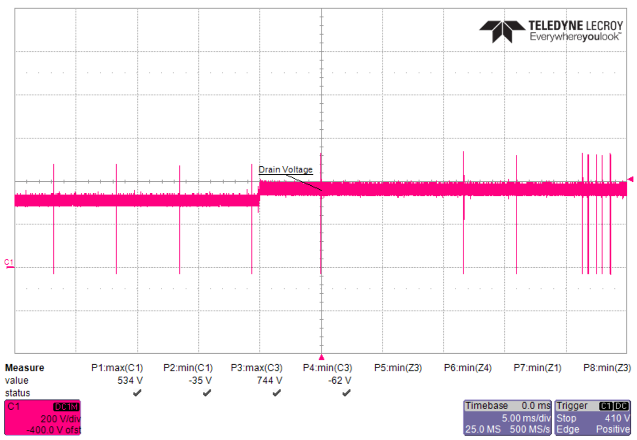


Figure 120 – (+2500 V, 90°) Ring Wave Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 534 V Peak.

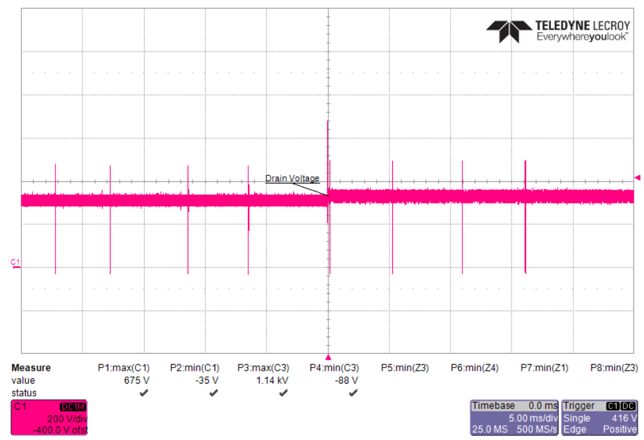


Figure 121 – (-2500 V, 270°) Ring Wave Surge, 230 VAC, 50 Hz. $V_{DS(MAX)}$: 675 V Peak.

14.3 *Electrical Fast Transients (EFT) Test Results*

Tested at 5 kHz and 100 kHz EFT burst frequency. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage. The load used for this test is a 500 W incandescent bulb.

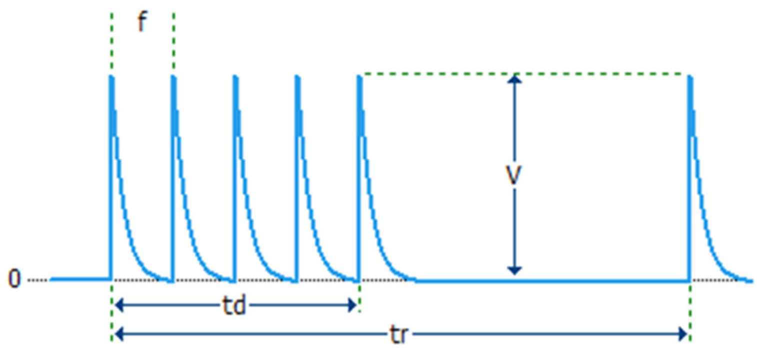


Figure 122 – Electrical Fast Transient Waveform.

14.3.1 5 kHz EFT

Test Voltage (V)	Input Voltage (VAC)	Test Time	Frequency (f)	Burst Duration (td)	Time Repetition (tr)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
2000	230	60 s	5 kHz	15 ms	300 ms	L	0	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	L	0	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	N	0	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	N	0	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	L, N	0	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	L, N	0	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	L	90	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	L	90	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	N	90	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	N	90	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	L, N	90	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	L, N	90	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	L	270	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	L	270	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	N	270	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	N	270	Pass
2000	230	60 s	5 kHz	15 ms	300 ms	L, N	270	Pass
-2000	230	60 s	5 kHz	15 ms	300 ms	L, N	270	Pass

14.3.2 100 kHz EFT

Test Voltage (V)	Input Voltage (VAC)	Test Time	Frequency (f)	Burst Duration (td)	Time Repetition (tr)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
2000	230	60 s	100 kHz	0.75 ms	300 ms	L	0	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	L	0	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	N	0	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	N	0	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	L, N	0	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	L, N	0	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	L	90	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	L	90	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	N	90	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	N	90	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	L, N	90	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	L, N	90	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	L	270	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	L	270	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	N	270	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	N	270	Pass
2000	230	60 s	100 kHz	0.75 ms	300 ms	L, N	270	Pass
-2000	230	60 s	100 kHz	0.75 ms	300 ms	L, N	270	Pass

15 Appendix A – Current-Shaping Circuit Optimization

The proprietary current-shaping circuit using R1 and VR1 improves the power factor of the circuit, which results to lower standby input current. The optimized value to maximize PF depends on the amount of load that is being drawn by the circuit. In this DER, since the overall system consumption is very low, then a value of 100 kΩ can be used. The Zener voltage was set to 12 V so that LinkSwitch-TNZ IC would still operate properly even if the available bulk voltage on C1 is reduced by 12 V.

If the system current consumption is higher, such as when using different wireless module with higher standby current, then the value of R1 needs to be re-tuned accordingly. Maximum PF can be achieved by setting the resistor value such that the voltage across the resistor is slightly below the Zener voltage. Figure 123 shows the graph of recommended R1 value for various 3 V load current.

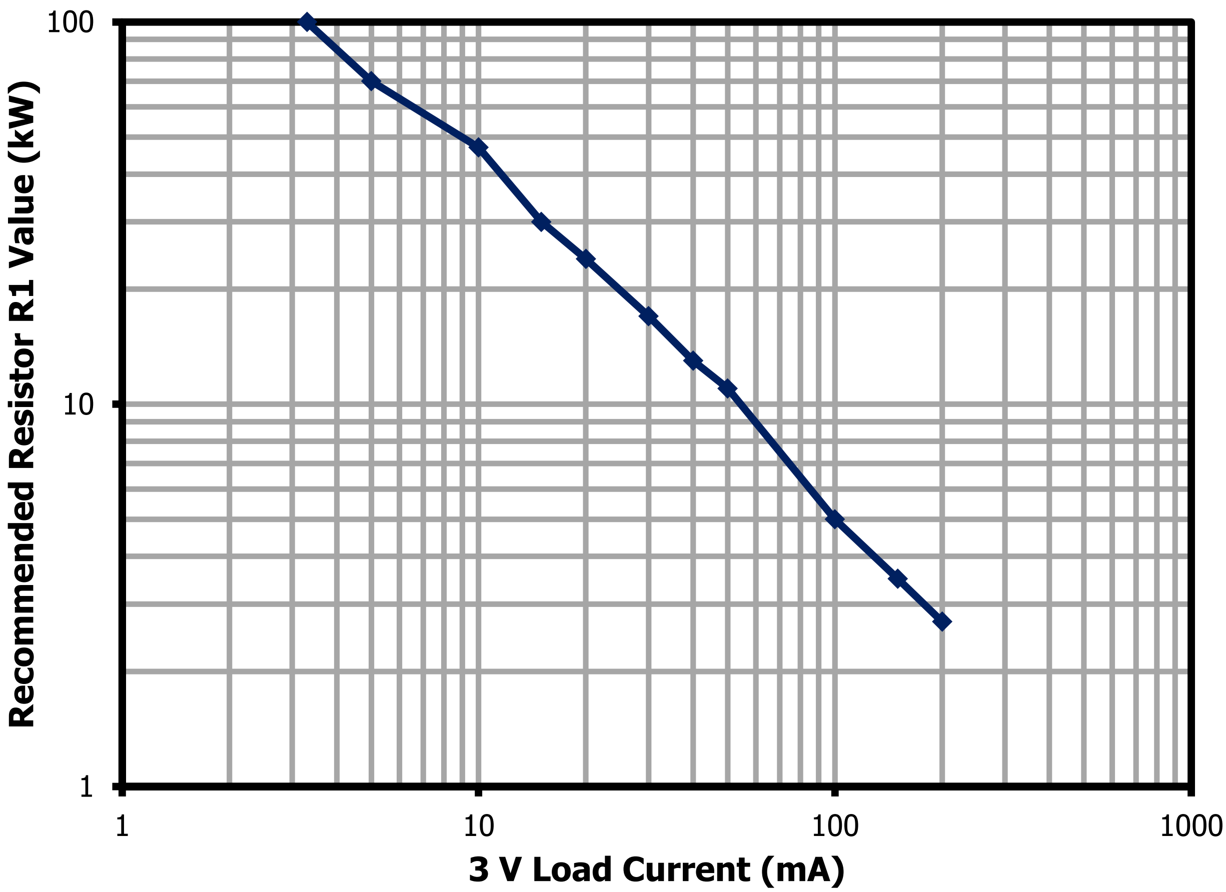


Figure 123 – Recommended R1 Value for Various Load on the 3 V Regulator.

16 Revision History

Date	Author	Revision	Description & changes	Reviewed
13-Oct-22	CMC	1.0	Initial Release.	Apps & Mktg

For the latest updates, visit our website: www.power.com

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