HV9901
Universal Relay Driver Reference Design User's Guide

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ISBN: 978-1-5224-2795-7

HV9901 UNIVERSAL RELAY DRIVER REFERENCE DESIGN USER'S GUIDE

Table of Contents

Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our website (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXXXXA", where "XXXXXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the HV9901 Universal Relay Driver. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Web Site
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes how to use the HV9901 Universal Relay Driver Reference Design as a development tool. The manual layout is as follows:

- **Chapter 1. "Product Overview"** – Important information about the HV9901 Universal Relay Driver.
- **Chapter 2. "Installation and Operation"** – Includes description and instructions on how to use the HV9901 Universal Relay Driver.
- **Appendix A. "Schematics and Layouts"** – Shows the schematic and layout diagrams for the HV9901 Universal Relay Driver.
- **Appendix B. "Bill of Materials (BOM)"** – Lists the parts used to build the HV9901 Universal Relay Driver.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

Description	Represents	Examples
Arial font:		
Italic characters	Referenced books	*MPLAB® IDE User's Guide*
	Emphasized text	...is the *only* compiler...
Initial caps	A window	the Output window
	A dialog	the Settings dialog
	A menu selection	select Enable Programmer
Quotes	A field name in a window or dialog	"Save project before build"
Underlined, italic text with right angle bracket	A menu path	*File>Save*
Bold characters	A dialog button	Click **OK**
	A tab	Click the **Power** tab
N'Rnnnn	A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.	4'b0010, 2'hF1
Text in angle brackets < >	A key on the keyboard	Press <Enter>, <F1>
Courier New font:		
Plain Courier New	Sample source code	`#define START`
	Filenames	`autoexec.bat`
	File paths	`c:\mcc18\h`
	Keywords	`_asm, _endasm, static`
	Command-line options	`-Opa+, -Opa-`
	Bit values	`0, 1`
	Constants	`0xFF, 'A'`
Italic Courier New	A variable argument	*`file`*`.o`, where *`file`* can be any valid filename
Square brackets [ ]	Optional arguments	`mcc18 [options]` *`file`* `[options]`
Curly brackets and pipe character: { | }	Choice of mutually exclusive arguments; an OR selection	`errorlevel {0|1}`
Ellipses...	Replaces repeated text	`var_name [, var_name...]`
	Represents code supplied by user	`void main (void) { ... }`

RECOMMENDED READING

This user's guide describes how to use the HV9901 Universal Relay Driver Reference Design. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources:

- **HV9901 Data Sheet –** ***"Universal Relay Driver" (DS20005550).***
- **MCP2221 Data Sheet –** ***"USB 2.0 to I^{2}C/UART Protocol Converter with GPIO" (DS20005292).***
- **MCP39F511A Data Sheet –** ***"AC/DC Dual-Mode Power-Monitoring IC with Calculation and Energy Accumulation" (DS20006044).***

THE MICROCHIP WEB SITE

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- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

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Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at:
http://www.microchip.com/support

DOCUMENT REVISION HISTORY

Revision A (March 2018)

- Initial Release of this Document.

NOTES:

Chapter 1. Product Overview

1.1 INTRODUCTION

This chapter provides an overview of the HV9901 Universal Relay Driver and covers the following topics:

- Core Components Short Overview
- The HV9901 Universal Relay Driver
- What the HV9901 Universal Relay Driver Kit Contains

1.2 CORE COMPONENTS SHORT OVERVIEW

1.2.1 HV9901 Device Overview

The HV9901 universal relay driver provides high-efficiency driving for low-voltage relays with supply voltages as high as 450V. For example, a relay with a 5V coil can be driven directly from the rectified 120 VAC or 230 VAC line.

The IC includes two high-voltage linear regulators. The first one is for providing power to internal control circuitry. The second one has an adjustable output voltage and a 1 mA output current capability to support external circuitry, such as a microcontroller control circuit.

The pull-in current, pull-in time and hold current for the relay are individually programmable through two resistors and a capacitor. PWM switching can be synchronized with an external clock or with another HV9901 operating at a higher frequency.

The relay is operated through the enable input ENI. Logic polarity is under control of the polarity input POL. Audible noise coming from the relay can be suppressed by operating at a PWM frequency exceeding 20 kHz.

1.2.1.1 DEVICE FEATURES:

- 10V to 450V Input Voltage Range
- Energy-saving Hold Current Mode
- Output Voltage Range: up to 32V
- Adjustable Microcontroller Supply
- Low Supply Current <1 mA

- Constant-current Coil Drive
- Programmable Pull-in Current, Pull-in Time and Hold Current

1.2.2 MCP2221 Device Overview

The MCP2221 is a USB-to-UART/I2C serial converter that enables USB connectivity between applications that have a UART and I^2C interfaces. The device reduces external components by integrating the USB termination resistors and the oscillator needed for USB operation. The MCP2221 also has four GP pins providing miscellaneous functions (GPIO, USBCFG, SSPND, Clock Output, ADC, DAC, interrupt detector).

1.2.2.1 DEVICE FEATURES:

- Supports full-speed USB (12 Mb/s)
- Implements USB protocol composite device
- 128-byte Buffer to handle data throughput at any UART baud rate
- Human Interface Device (HID) for both I^2C communication and control
- 64 byte buffer to handle data throughput at any I^2C baud rate
- Fully configurable VID and PID assignments, and string descriptors
- Bus-powered or self-powered
- USB 2.0 Compliant
- USB Driver and Software Support
- CDC and Universal Asynchronous Receiver/Transmitter (UART) Options
- I^2C/SMBus
- SMBus Master

1.2.3 MCP39F511A Device Overview

The MCP39F511A device is a highly-integrated, complete single-phase power-monitoring IC designed for real-time measurement of input power for AC or DC power supplies, making it suitable for a wide range of consumer and industrial applications. It is capable of detecting the input voltage in order to work as DC or AC mode. It includes dual-channel Delta-Sigma ADCs, a 16-bit calculation engine, EEPROM and a flexible 2-wire interface. Separate AC and DC calibration registers are provided, to ensure high-accuracy measurements in both modes. An integrated low-drift voltage reference with 7 ppm/°C in addition to 94.5 dB of SINAD performance on each measurement channel allows for better than 0.1% accurate designs across a 4000:1 dynamic range.

1.2.3.1 DEVICE FEATURES:

- Real Time Measurement of Input Power for AC or DC Supplies
- AC/DC Dual-Mode Power Monitoring Accuracy Capable of 0.1% Error Across 4000:1 Dynamic Range
- Automatic Sensing and Switching Between AC and DC Modes
- Built-In Calculations on Fast 16-Bit Processing Core
  - Active and Reactive Energy Accumulation
  - Active, Reactive, Apparent Power
  - True RMS Current, RMS Voltage
  - Line Frequency, Power Factor
- 64-bit Wide Import and Export Active Energy Accumulation Registers
- 64-bit Four Quadrant Reactive Energy Accumulation Registers
- Automatic Saving the Energy Accumulation Registers into EEPROM at Power Off
- Automatic Loading the Energy Accumulation Registers from EEPROM at Power On
- Signed Active and Reactive Power Outputs
- Dedicated Zero Crossing Detection (ZCD) Pin Output with Less than 200 µs Latency
- Dedicated PWM Output Pin with Programmable Frequency and Duty Cycle
- Automatic Event Pin Control through Fast Voltage Sag/Surge Detection
- Two Wire Serial Protocol with Selectable Baud Rate Up to 115.2 kbps using Universal Asynchronous Receiver/Transmitter (UART)
- Four Independent Registers for Minimum and Maximum Output Quantity Tracking
- Fast Calibration Routines and Simplified Command Protocol
- 512 Bytes User-Accessible EEPROM through Page Read/Write Commands
- Low-Drift Internal Voltage Reference, 7 ppm/°C Typical
- 28-lead 5x5 QFN Package
- Extended Temperature Range -40°C to +125°C

1.2.4 MCP9701 Device Overview

The MCP9701 analog temperature sensor with Linear Active Thermistor Integrated Circuit (IC) converts temperature to analog voltage.

The low-cost, low-power sensor features an accuracy of ±4°C from 0°C to +70°C while consuming 6 µA (typical) of operating current.

Unlike resistive sensors, e.g., thermistors, the Linear Active Thermistor IC does not require an additional signal-conditioning circuit. Therefore, the biasing circuit development overhead for thermistor solutions can be avoided by implementing a sensor from this low-cost device. The Voltage Output pin (VOUT) can be directly connected to the ADC input of a microcontroller. The MCP9701 temperature coefficient is scaled to provide a 1°C/bit resolution for an 8-bit ADC with a reference voltage of 5V.

The MCP9701 provides a low-cost solution for applications that require measurement of a relative change of temperature. When measuring relative change in temperature from +25°C, an accuracy of ±1°C (typical) can be realized from 0°C to +70°C. This accuracy can also be achieved by applying system calibration at +25°C.

In addition, this device is immune to the effects of parasitic capacitance and can drive large capacitive loads. This provides printed circuit board (PCB) layout design flexibility by enabling the device to be remotely located from the microcontroller. Adding some capacitance at the output also helps the output transient response by reducing overshoots or undershoots. However, capacitive load is not required for the stability of sensor output.

1.2.4.1 DEVICE FEATURES

- Tiny Analog Temperature Sensor
- Available Packages:
  - SC70-5, SOT-23-3, TO-92-3
- Wide Temperature Measurement Range:
  - -40°C to +125°C (Extended Temperature)
- Accuracy:
  - ±4°C (max.), 0°C to +70°C
- Optimized for Analog-to-Digital Converters (ADCs):
  - 19.5 mV/°C (typical)
- Wide Operating Voltage Range:
  - V_{DD} = 3.1V to 5.5V
- Low Operating Current: 6 µA (typical)
- Optimized to Drive Large Capacitive Loads

1.2.5 MCP1754ST-3302E Device Overview

The MCP1754S is a family of CMOS low-dropout (LDO) voltage regulators that can deliver up to 150 mA of current while consuming only 56 µA of quiescent current (typical). The input operating range is specified from 3.6V to 16.0V, making it an ideal choice for four to six primary cell battery-powered applications, 12V mobile applications and one to three-cell Li-ion-powered applications.

The MCP1754S is capable of delivering 150 mA of current with only 300 mV (typical) of input to output voltage differential. The output voltage tolerance of the MCP1754S is typically ±0.2% at +25°C and ±2.0% maximum over the operating junction temperature range of -40°C to 125°C. Line regulation is ±0.01% typical at +25°C.

Output voltages available for MCP1754S range from 1.8V to 5.5V. The LDO output is stable when using only 1 µF of output capacitance. Ceramic, tantalum or aluminum electrolytic capacitors may all be used for input and output. Overcurrent limit and overtemperature shutdown provide a robust solution for any application.

The MCP1754S family introduces a true current foldback feature. When the load impedance decreases beyond the MCP1754S load rating, the output current and voltage will gracefully foldback towards 30 mA at about 0V output. When the load impedance decreases and returns to the rated load, the MCP1754S follows the same foldback curve as the device comes out of current foldback.

Package options for the MCP1754S include the SOT-23A, SOT-89-3, SOT-223-3 and 2x3 DFN-8.

1.2.5.1 DEVICE FEATURES:

- High PSRR: >70 dB @ 1 kHz, Typical
- 56.0 µA Typical Quiescent Current
- Input Operating Voltage Range: 3.6V to 16.0V
- 150 mA Output Current for All Output Voltages
- Low-Dropout Voltage, 300 mV Typical @ 150 mA
- 0.4% Typical Output Voltage Tolerance
- Standard Output Voltage Options (1.8V, 2.5V, 2.8V, 3.0V, 3.3V, 4.0V, 5.0V)
- Output Voltage Range 1.8V to 5.5V in 0.1V Increments (tighter increments also possible per design)
- Output Voltage Tolerances of ±2.0% Over Entire Temperature Range

- Stable with Minimum 1.0 µF Output Capacitance
- Power Good Output
- Shutdown Input
- True Current Foldback Protection
- Short-Circuit Protection
- Overtemperature Protection

1.3 THE HV9901 UNIVERSAL RELAY DRIVER

The HV9901 Universal Relay Driver is used to demonstrate inter-functionality between a broad range of analog and digital Microchip devices, by means of a real industrial application: a solar breaker.

The compact packaging and high integration of the Microchip ICs fitted on the board allows the entire solution to be very size effective.

The HV9901 is configured as a constant current buck converter as shown in Figure 1-1, which regulates the sufficient coil current to hold the relay in on-state by using a PWM signal to ensure stable operation while reducing power consumption and increasing efficiency. This topology allows low voltage relays to be driven by stepping down the rectified input voltage to any target low coil voltages.

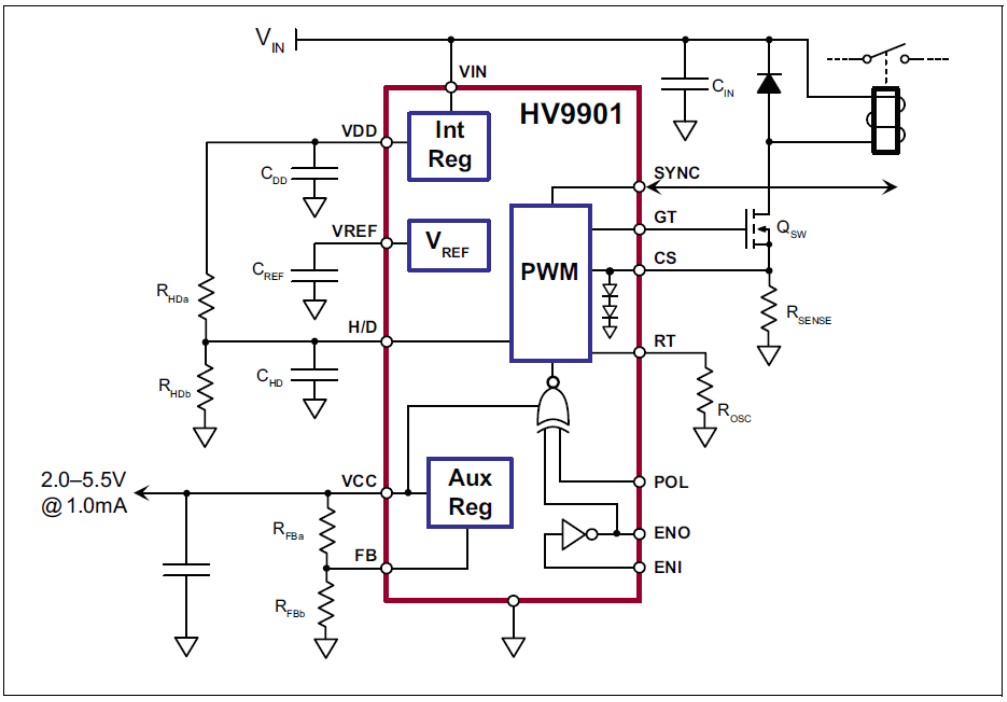


FIGURE 1-1: *HV9901 Universal Relay Driver Application Circuit*

Power stage input:

$V_{in,min}$ = 270V

$V_{in,max}$ = 374V

Load (coil resistance of relay) = 2.6kΩ

$$I_{pull-in} = 17.5mA$$

$$I_{hold} = 10mA$$

$$V_{o,max} = 17.5m \times 2.6k = 45.5V$$

$$V_{o,min} = 10m \times 2.6k = 26V$$

$$\boxed{D_{max} = \frac{V_{o,max}}{V_{in,min} \times \eta} = \frac{45.5}{270 \times 0.9} = 18.7\%}$$

$$\boxed{D_{min} = \frac{V_{o,min}}{V_{in,max} \times \eta} = \frac{26}{374 \times 0.9} = 7.7\%}$$

T_{on}@D_{min}: 1.5µs

$\Rightarrow \boxed{D_{min}T_s = 1.5\mu s} \rightarrow \boxed{T_s = 19.48\mu s}$

$$\boxed{f_s = 50kHz}$$

$$\boxed{\Delta i = 0.4 \times 17.5m = 7mA}$$

$$\boxed{V = L\frac{di}{dt}} \Rightarrow \boxed{L = \frac{(V_{in,min} - V_{o,max})D_{max}T_s}{\Delta i} = \frac{(270 - 45.5) \times 0.187 \times 20\mu}{7m} = 120mH}$$

@Hold current

$$\boxed{\Delta i = \frac{(V_{in,max} - V_{o,min})D_{min}T_s}{L} = \frac{(374 - 26) \times 0.077 \times 20\mu}{120m} = 4.46mA} (= 44\%\ of\ I_o)$$

∴ Insert a 100mH inductor with saturated current of 20~25mA along the relay acting as a controlled current source

For the IC setup, we have

$$\boxed{I_{pull-in} = 17.5m \times 1.2 = \frac{0.833}{R_{SENSE}}} \Rightarrow \boxed{R_{SENSE} = 40\Omega}$$

$$\boxed{I_{hold} = \frac{V_{CS(LL)}}{R_{SENSE}}} \Rightarrow \boxed{V_{CS(LL)} = 10m \times 1.2 \times 40 = 0.48V}$$

$$\boxed{V_{CS(HL)} = 0.833V}$$

$$\boxed{1 + \frac{R_{HDa}}{R_{HDb}} = \frac{V_{DD}}{V_{CS(LL)}} = \frac{9}{0.48} = 18.75} \Rightarrow \boxed{\begin{matrix} R_{HDa} = 177.5k\Omega \\ R_{HDb} = 10k\Omega \end{matrix}}$$

$$\boxed{1 + \frac{R_{FBa}}{R_{FBb}} = \frac{V_{CC}}{1.25} = \frac{5}{1.25} = 4} \Rightarrow \boxed{\begin{matrix} R_{FBa} = 30k\Omega \\ R_{FBb} = 10k\Omega \end{matrix}}$$

$$\boxed{f_{PWM} \approx 3.23k + \frac{21.8G}{R_{OSC}} = 50k} \Rightarrow \boxed{R_{OSC} = 466k\Omega}$$

$$\boxed{t_{pull-in} = -R_{HDa}//R_{HDb} \times C_{HD} \times \ln\left(1 - \frac{V_{CS(HL)} - V_{DD}}{V_{CS(LL)} - V_{DD}}\right)}$$

∴ Choose C_{HD} = 22nF to give $t_{pull-in}$ = 663µs. In general, C_{DD} = 1µF, C_{REF} = 0.1µF, and C_{CC} = 0.1µF.

1.4 WHAT THE HV9901 RELAY DRIVER KIT CONTAINS

The HV9901 Relay Driver kit includes:

- HV9901 Relay Driver (ARD00xxx)
- Important Information Sheet

Chapter 2. Installation and Operation

2.1 INTRODUCTION

The HV9901 Relay Driver provides a high-efficiency and easy-to-use relay driver solution for engineers. Whether supplied from a wall plug, it drives low-voltage relays as low as 5V coil with a rectified supply voltage from 10V to 450V.

An application with a simple GUI allows for an instant, full-functional, and single-phase power and energy monitor. The system calculates active power, reactive power, RMS current, RMS voltage, active energy (both import and export), reactive energy and other typical power quantities, as defined in the MCP39F511A datasheet.

The Power Monitoring stage uses the Power Monitor Utility software for measurement through a USB connection to the board. The Power Monitor Utility software is used to calibrate and monitor the system, can be used to create custom calibration setups. For most accuracy requirements, only a single-point calibration is needed. The software offers an automatic step-by-step calibration process that can be used to quickly calibrate power meters.

A download link for this software can be found on the MCP39F511A demonstration board's web page. For instructions on how to use the software, refer to the software's supporting documentation included within the application installation package.

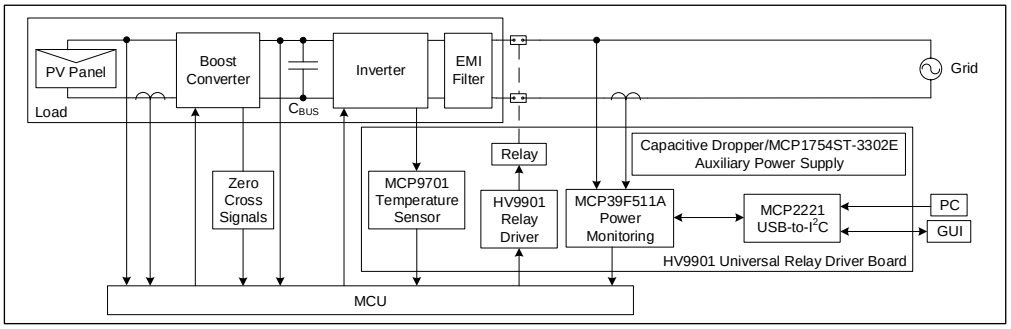


FIGURE 2-1: *HV9901 Universal Relay Driver Functional Blocks*

2.2 HV9901 UNIVERSAL RELAY DRIVER FEATURES

2.2.1 Board Features

- 195.5VAC to 264.5VAC input voltage
- Up to 15A [rms] peak input current
- Manual or signal controlled disconnect in case of fault
- Input power measurement (voltage/current)

2.2.2 Application Features

- Protects solar microinverter from fluctuations in grid voltages by relay disconnect
- Offers high temperature operation with high reliability as mounted under solar panels

2.3 GETTING STARTED

To use both HV9901 Universal Relay Driver and MCP39F511A Power Monitor functions, follow the steps described in this section below. The meter is calibrated at a load current of 5A [rms] and the maximum current I_{MAX} is 15A [rms].

It is not recommended to put more than 15A [rms] through the AC plugs mounted in the Printed Circuit Board (PCB).

2.3.1 Powering the Meter

The meter turns on when the line input voltage is between 190V [rms] and 270V [rms].

2.3.2 Connecting the USB cable to a PC

1. The Power Monitor Utility software needs to be installed to proceed.
2. Select the appropriate COM port. The connection status in the bottom-left corner of the software displays "Meter Connected" when the meter is connected correctly. The status "Meter Disconnected" is displayed when no meter is found. Check that the correct COM port was selected and try again.
3. Click the **Start** button to begin showing output data and UART transmitted/received packets of data exchanged between the PC and the MCP39F511A device.

2.3.3 Activating the Relay Driver

The relay driver is enabled by either putting a jumper to short ENI to ground manually or feeding a logic high controlled signal to EXT-MCU-IN since POL is connected to ground internally.

2.4 OPERATION

The HV9901 Universal Relay Driver overview is depicted in Figure 2-2.

The board is supplied from the AC inlet connector, while the output voltage is accessible on the outlet terminal block once the relay is driven on.

A red LED indicates the Auxiliary Power Status. It switches ON when this house keeping power is working normally to provide an output voltage of 3.3V at a typical current of 30mA from a line supply of 195.5 VAC to 264.5 VAC via a generic implementation of a non-isolated half wave "capacitive dropper" front-end combined with the MCP1754ST-3302E High-Performance LDO, which is an easy and cost effective approach for such low load AC-to-DC conversion.

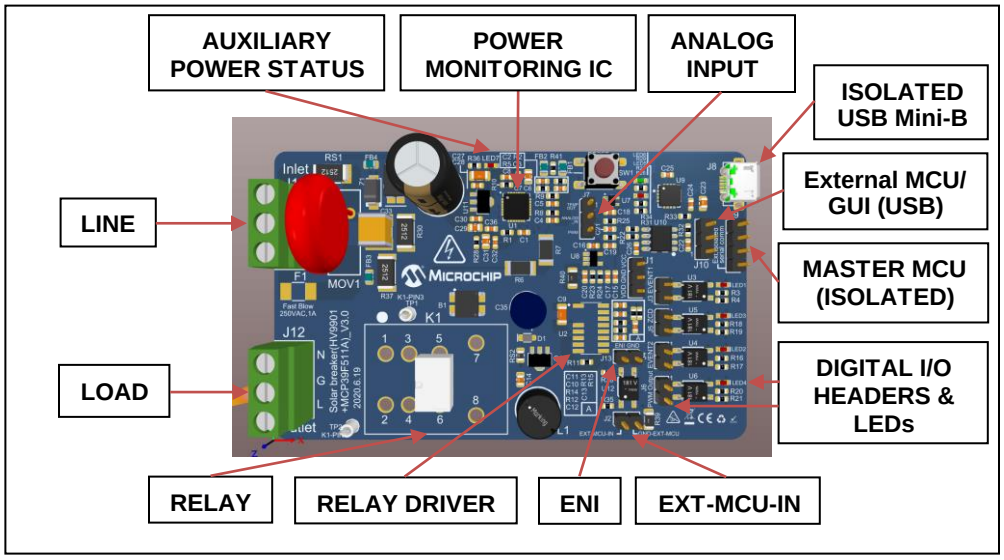


FIGURE 2-2: *The HV9901 Universal Relay Driver Overview*

2.5 TYPICAL WAVEFORMS

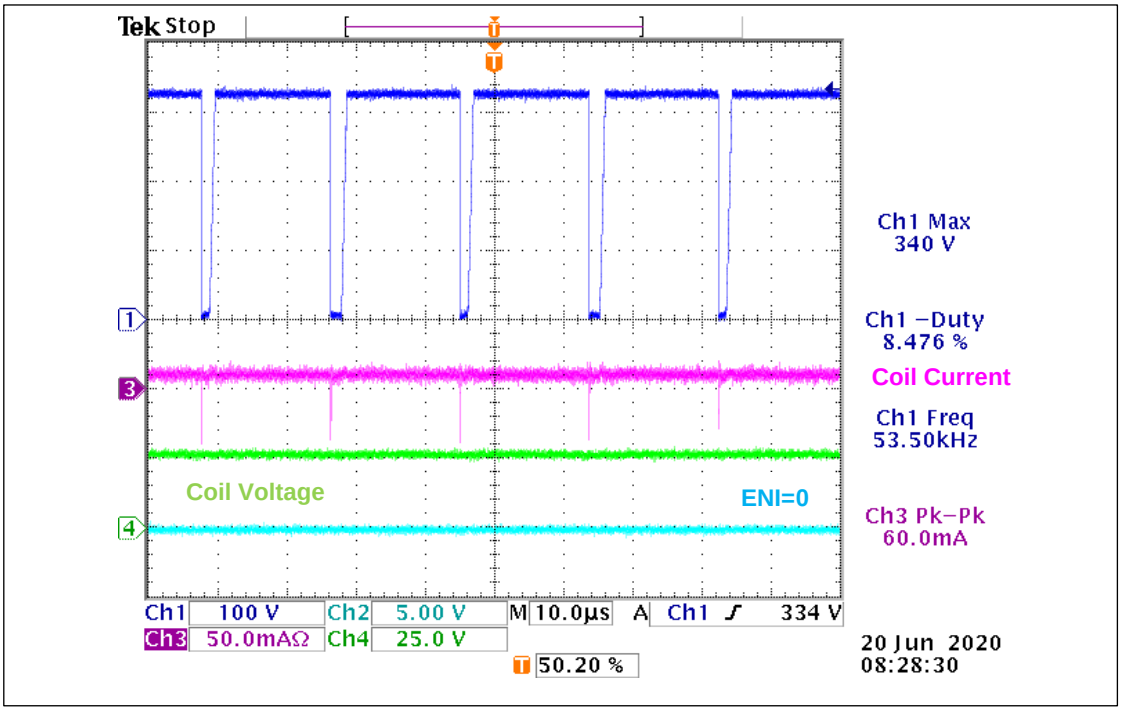


FIGURE 2-3: *Relay Driver Operational Waveforms at 230V_{AC} Input*

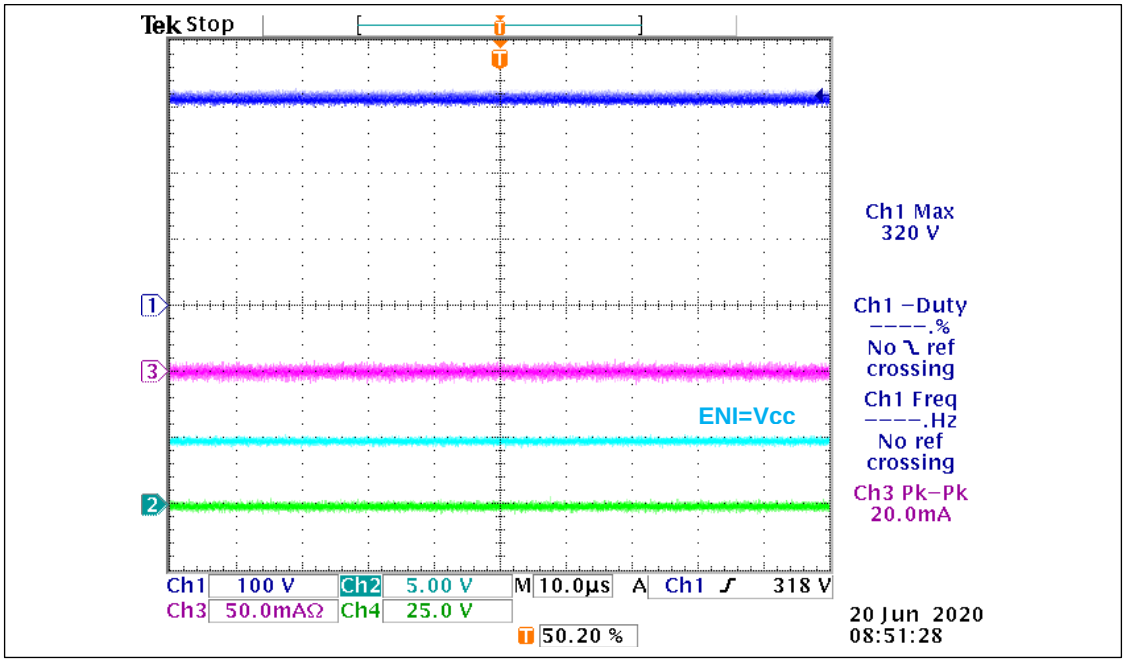


FIGURE 2-4: *Relay Driver Off Waveforms at 230V_{AC} Input*

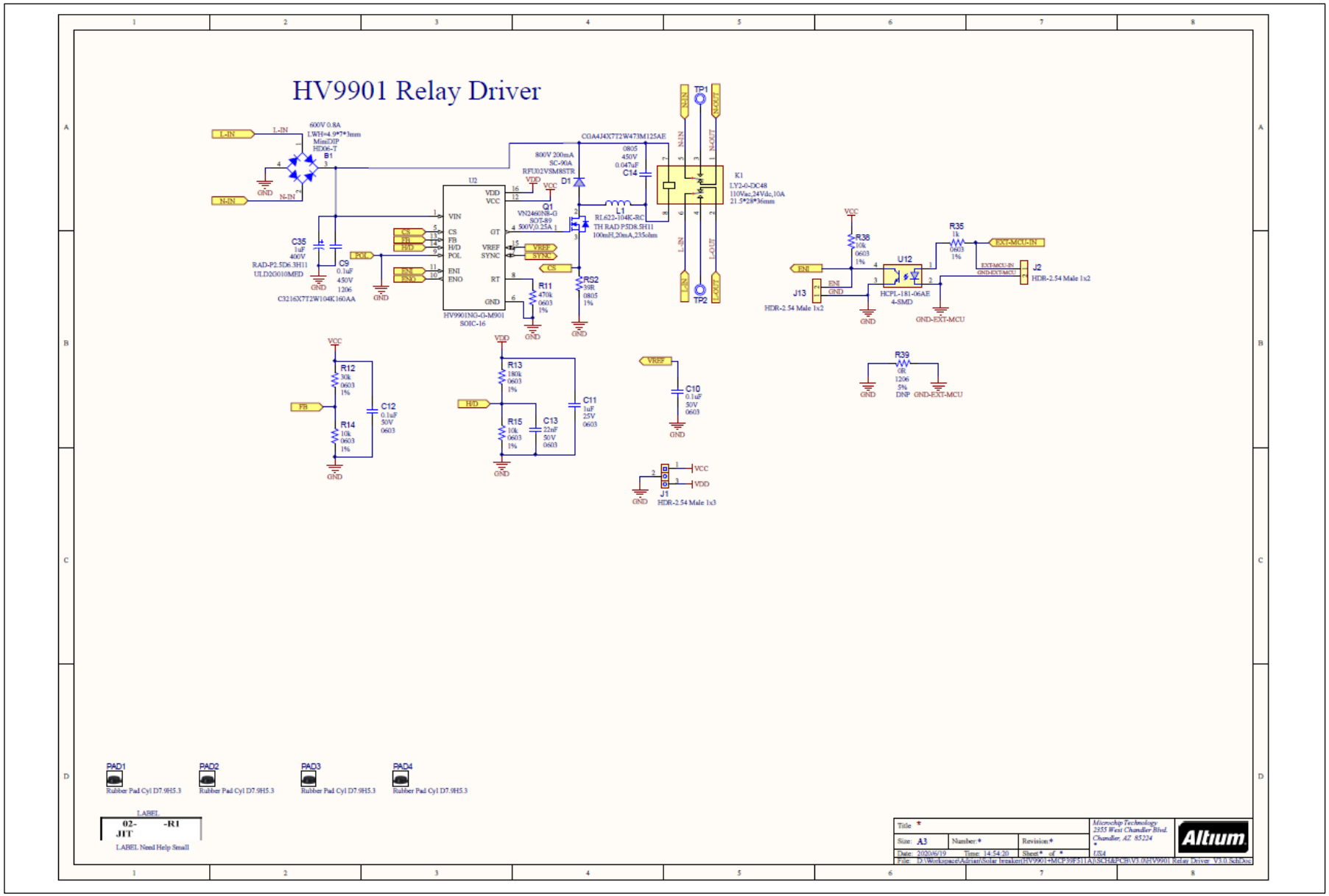
Appendix A. Schematics and Layouts

A.1 INTRODUCTION

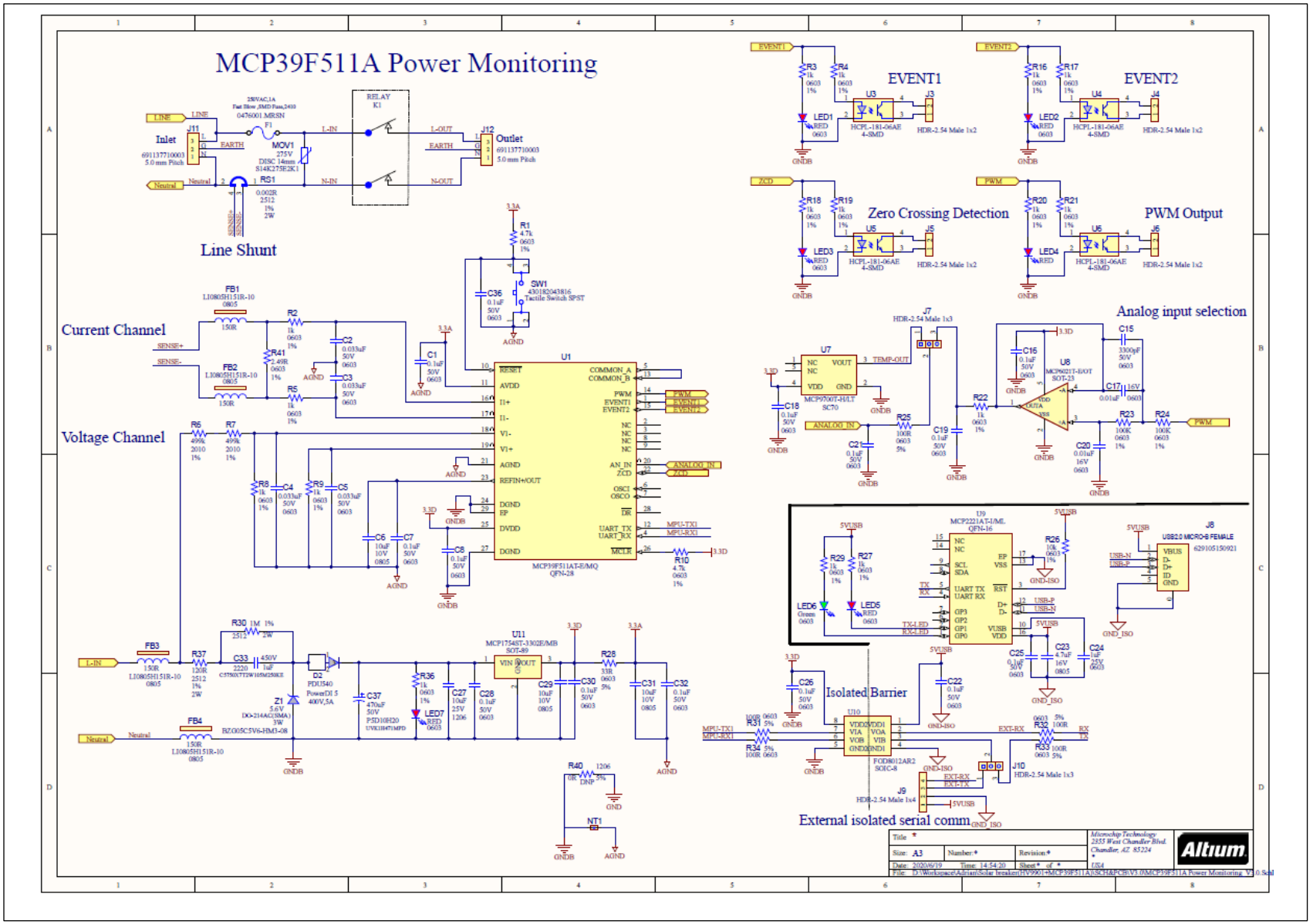
This appendix contains the following schematics and layouts for the HV9901:

- Board – Schematic
- Board – Top Silk and Pads
- Board – Top Copper Layer
- Board – Layer 2
- Board – Layer 3
- Board – Bottom Copper Layer
- Board – Bottom Silk Layer

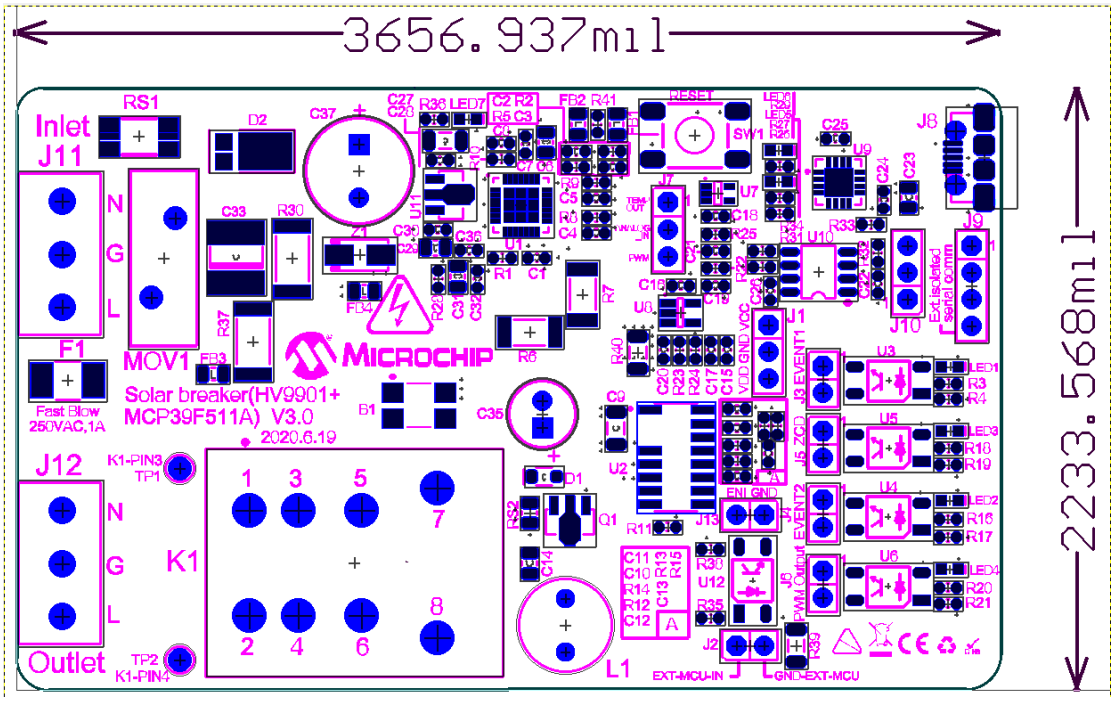
A.2 BOARD – SCHEMATIC



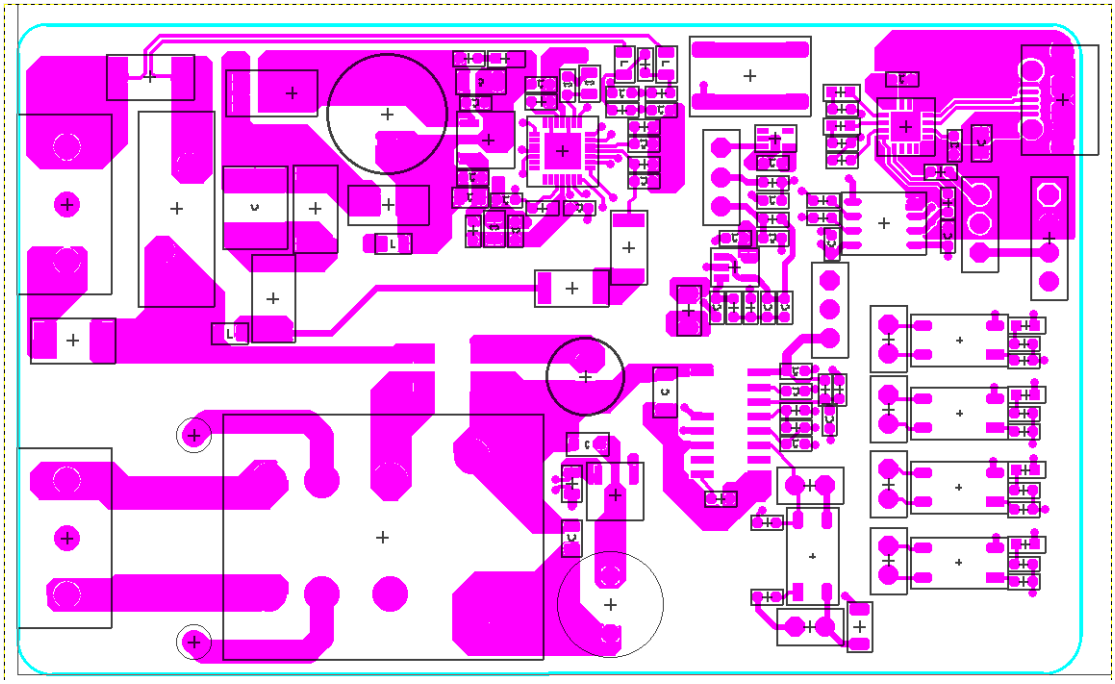
HV9901 UNIVERSAL RELAY DRIVER REFERENCE DESIGN USER'S GUIDE



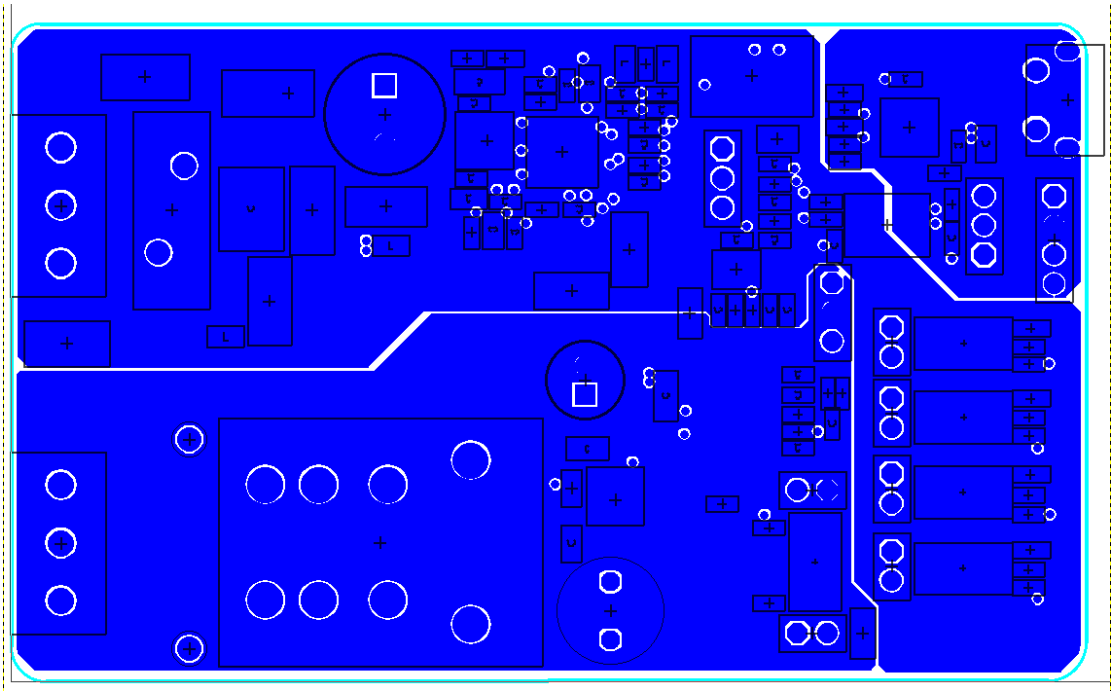
A.3 BOARD – TOP SILK AND PADS



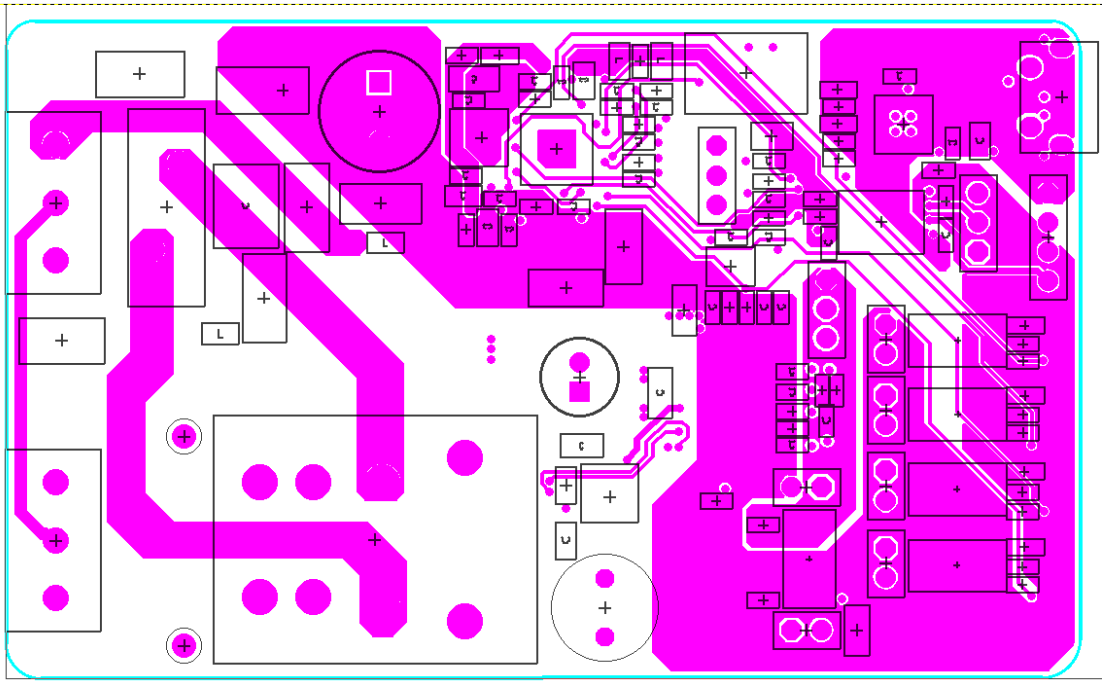
A.4 BOARD – TOP COPPER LAYER



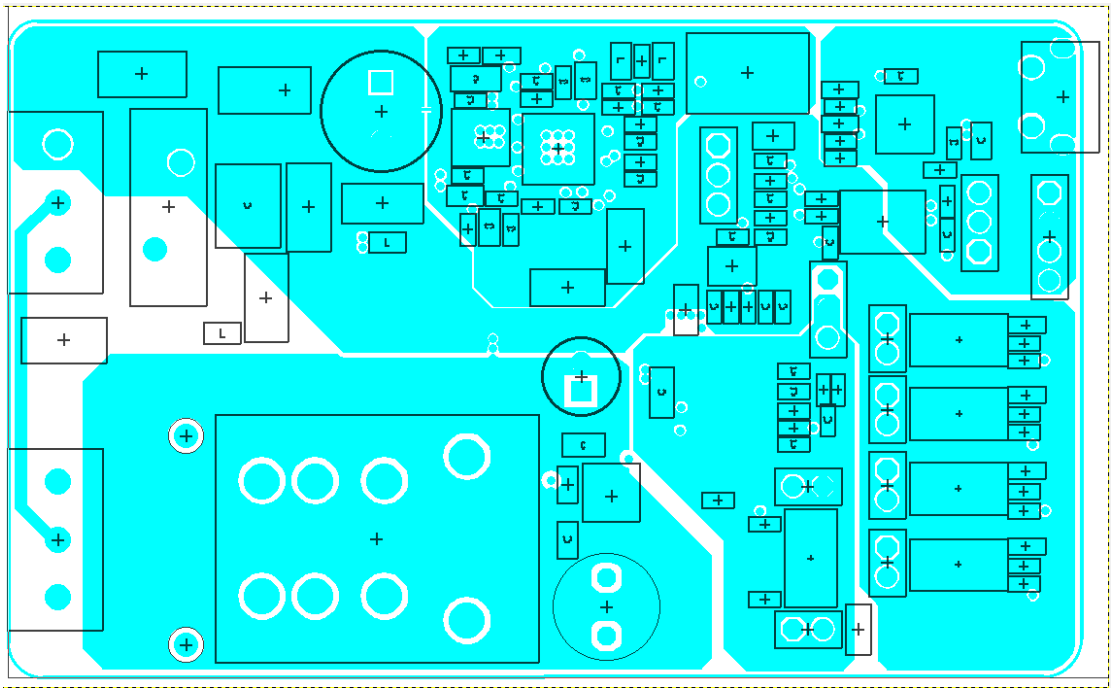
A.5 BOARD – LAYER 2



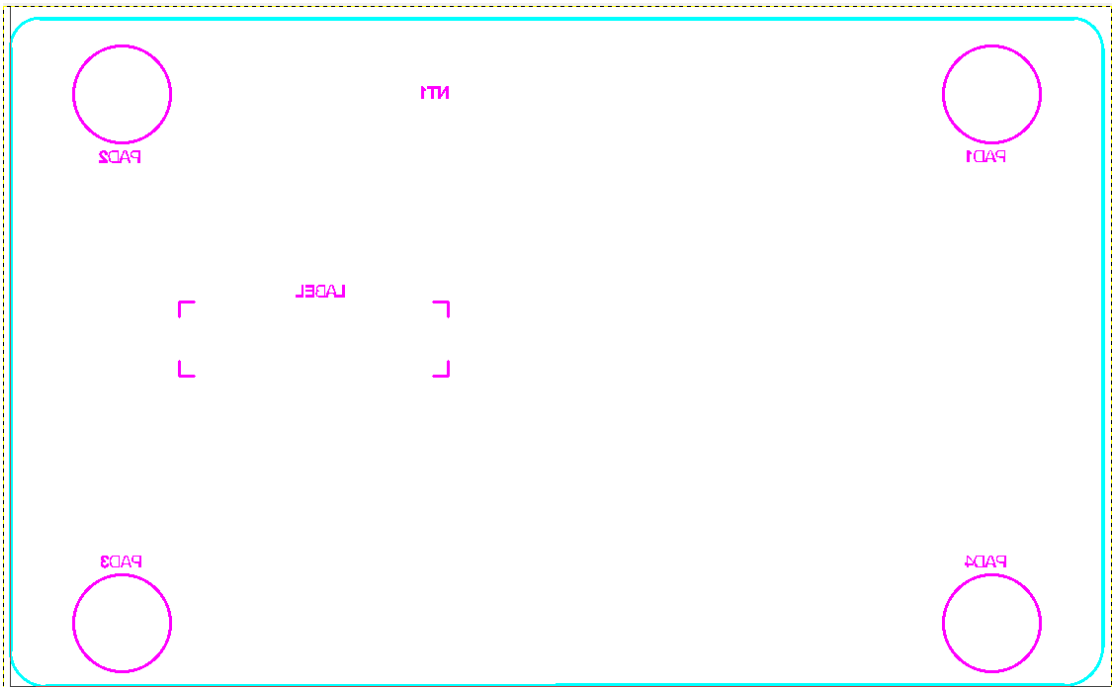
A.6 BOARD – LAYER 3



A.7 BOARD – BOTTOM COPPER LAYER



A.8 BOARD – BOTTOM SILK LAYER



NOTES:

Appendix B. Bill of Materials (BOM)

TABLE B-1: BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
1	B1	Bridge Rectifiers 600V 0.8A MINI-DIP	Diodes Incorporated	HD06-T
16	C1, C7, C8, C10, C12, C16, C18, C19, C21, C22, C25, C26, C28, C30, C32, C36	0.1µF ±10% 50V Ceramic Capacitor X7R 0603 (1608 Metric)	Wurth Electronik	885012206095
4	C2, C3, C4, C5	Multilayer Ceramic Capacitors MLCC - SMD/SMT CGA 0603 50V 0.033uF X7R 10% AEC-Q200	TDK Corporation	CGA3E2X7R1H333K080AA
3	C6, C29, C31	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 10V 10uF X7R 10% T: 1.25mm	TDK Corporation	C2012X7R1A106K125AC
1	C9	Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 450V 0.1uF X7T 10% T: 1.6mm	TDK Corporation	C3216X7T2W104K160AA
2	C11, C24	1µF ±20% 25V Ceramic Capacitor X5S 0603 (1608 Metric)	Wurth Electronik	885012106022
1	C13	Multilayer Ceramic Capacitors MLCC - SMD/SMT SOFT 0603 50V 0.022uF X7R 10% T: 0.8mm	TDK Corporation	C1608X7R1H223K080AE
1	C14	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 450V 0.047uF SOFT 20% AEC-Q200	TDK Corporation	CGA4J4X7T2W473M125AE
1	C15	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0603 50V 3300pF C0G 5% T: 0.8mm	TDK Corporation	C1608C0G1H332J080AA
2	C17, C20	Multilayer Ceramic Capacitors MLCC - SMD/SMT RECOMMENDED ALT 810-CGJ3E2X7R1E103K	TDK Corporation	CGJ3E2X7R1C103K080AA
1	C23	Multilayer Ceramic Capacitors MLCC - SMD/SMT CGA 0805 16V 4.7uF X7R 10% AEC-Q200	TDK Corporation	CGA4J3X7R1C475K125AB
1	C27	Multilayer Ceramic Capacitors MLCC - SMD/SMT CGA 1206 25V 10uF X7R 10% AEC-Q200	TDK Corporation	CGA5L1X7R1E106K160AC
1	C33	MLCC - SMD/SMT SOFT 2220 450V 1uF X7T 20% T:2.5mm	TDK Corporation	C5750X7T2W105M250KE
1	C35	Aluminum Electrolytic Capacitors - Radial Leaded 1uF 400 Volts 20% P2.5D6.3H11	Nichicon	ULD2G010MED

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: BILL OF MATERIALS (BOM) (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
1	C37	Aluminum Electrolytic Capacitors - Radial Leaded 50volts 470uF 10x20 20% 5LS P5D10H20	Nichicon	UVK1H471MPD
1	D1	Diodes - General Purpose, Power, Switching 800V Vrm 0.2A Io Recovery Diode TUMD2SM SC-90A	ROHM Semiconductor	RFU02VSM8STR
1	D2	RECTIFIER ULTRAFAST PWRDI 5 5.0A 400V	Diodes Incorporated	PDU540
1	F1	Surface Mount Fuses 250VAC 1A .1575ohms 476 NANO2 Fast Blow	Littelfuse	0476001.MRSN
4	FB1, FB2, FB3, FB4	Ferrite Beads 150ohms 100MHz .8A Monolithic 0805 SMD	Laird Performance Materials	LI0805H151R-10
2	J1, J7	Connector Header Through Hole 3 position 0.100" (2.54mm)	Wurth Electronik	61300311121
6	J2, J3, J4, J5, J6, J13	Headers & Wire Housings WR-PHD 2.54mm 2Pin THT Header	Wurth Electronik	61300211121
4	J7, J10, J11, J12	Barrier Terminal Blocks WR-TBL Terminal Block - Wire protector - THT 3 Positions 5.0 mm Pitch 16A	Wurth Electronik	691137710003
1	J8	USB Connectors WR-COM USB Micro SMT Type AB Horiztl Jack (Female) USB 2.0	Wurth Electronik	629105150921
1	J9	Headers & Wire Housings WR-PHD 2.54mm Hdr 4P Single Str Gold	Wurth Electronik	61300411121
1	K1	General Purpose Relays GP RELAY 48 VDC 2 Form C (DPDT-NO, NC) 10 A 250 VAC, 125 VDC Through Hole L21.59W27.94H35.56mm	Omron Automation and Safety	LY2-0-DC48
1	L1	Fixed Inductors 100mH 10% 25KHz 20mA L5D8.5H11mm	Bourns	RL622-104K-RC
6	LED1, LED2, LED3, LED4, LED5, LED7	Standard LEDs - SMD WL-SMCW SMDMono TpVw Waterclr 0603 Red	Wurth Electronik	150060RS75000
1	LED6	Standard LEDs - SMD WL-SMCW SMDMono TpVw 0603 BrtGrn	Wurth Electronik	150060VS75000
1	MOV1	Varistors Circuit Protection TVS - Varistors, MOVs - VARISTOR 275V RMS 14MM RADIAL	EPCOS/TDK	S14K275E2K1
4	PAD1, PAD2, PAD3, PAD4	Bumper Cylindrical, Tapered 0.375" Dia (9.53mm) Polyurethane Black	3M	SJ61A4
1	Q1	MOSFET N-Channel 500V 250 mA 13Ohm SOT-89-3	Microchip Technology Inc.®	**VN2450N8-G**
2	R1, R10	4.7 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Anti-Sulfur, Automotive AEC-Q200 Thick Film	Vishay Dale	RCA06034K70FKEA

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: BILL OF MATERIALS (BOM) (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
17	R2, R3, R4, R5, R8, R9, R16, R17, R18, R19, R20, R21, R22, R27, R29, R35, R36	Thick Film Resistors - SMD 1/10W 1K ohm 1% AEC-Q200 0603	Yageo	AC0603FR-101KL
2	R6, R7	Thick Film Resistors - SMD 3/4watt 499Kohms 1% 2010	Vishay Dale	CRCW2010499KFKEF
1	R11	Thick Film Resistors - SMD 1/10W 470K ohm 1% AEC-Q200 0603	Yageo	AC0603FR-07470KL
1	R12	Thick Film Resistors - SMD 30K ohm 1% 1/10W AEC-Q200 0603	Yageo	AC0603FR-1030KL
1	R13	Thick Film Resistors - SMD 180K ohm 1% 75V General Purpose 0603	Yageo	RC0603FR-10180KL
4	R14, R15, R26, R38	10 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Thick Film	Vishay Dale	CRCW060310K0FKEBC
2	R23, R24	Thick Film Resistors - SMD 100K ohm 1% 1/10W AEC-Q200 0603	Yageo	AC0603FR-07100KL
5	R25, R31, R32, R33, R34	Thick Film Resistors - SMD 100ohm 50V +/- 5% 0603	Yageo	AF0603JR-07100RL
1	R28	Thick Film Resistors - SMD 1/10W 33ohm 5% AEC-Q200 0603	Yageo	AC0603JR-0733RL
1	R30	1 MOhms 2512 2W 1%	Yageo	AC2512FK-7W1ML
1	R37	120 Ohms 2512 2W 1%	Yageo	AC2512FK-7W120RL
1	R41	Thick Film Resistors - SMD 2.49 ohm 1% 1/10W AEC-Q200	Yageo	AC0603FR-072R49L
1	RS1	Current Sense Resistors - SMD 2watts .002ohms 1% 2512	Vishay Dale	WSL25122L000FEA18
1	RS2	Thick Film Resistors - SMD 39 OHM 1% 0805	Yageo	RC0805FR-0739RL
1	SW1	Tactile Switches Tact Switch SMT 4.3mm Blk Act.	Wurth Electronik	430182043816
2	TP1, TP2	Black PC Test Point, Miniature Phosphor Bronze, Silver Plating 0.040" (1.02mm) Hole Diameter Mounting Type	Keystone Electronics	5001
1	U1	Current & Power Monitors & Regulators Single-Phase, Dual-Mode (AC/DC) Power-Monitoring IC with Calculation and Energy Accumulation QFN-28	Microchip Technology Inc.®	**MCP39F511AT-E/MQ**
1	U2	Motor / Motion / Ignition Controllers & Drivers LED Buck Driver IC SOIC-16	Microchip Technology Inc.®	**HV9901NG-G-M901**
5	U3, U4, U5, U6, U12	Transistor Output Optocouplers 3750 Vrms 0.2mA SMD-4	Broadcom/Avago	HCPL-181-06AE

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: BILL OF MATERIALS (BOM) (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
1	U7	Board Mount Temperature Sensors Linear Active Thrmst (TM) IC (10mV/oC) SC70-5	Microchip Technology Inc.®	**MCP9700T-H/LT**
1	U8	Operational Amplifiers - Op Amps Single 2.5V 10 MHz OP E temp SOT-23-5	Microchip Technology Inc.®	**MCP6021T-E/OT**
1	U9	USB Interface IC USB 2.0 to I2C Converter with GPIO QFN-16	Microchip Technology Inc.®	**MCP2221AT-I/ML**
1	U10	High Speed Optocouplers Bi-Direct High Speed Logic Gate Optocoupler SO-8	ON Semiconductor/ Fairchild	FOD8012AR2
1	U11	LDO Voltage Regulators LDO 18 I/O 10-BIT ADC SOT-89-3	Microchip Technology Inc.®	**MCP1754ST-3302E/MB**
1	Z1	Zener Diodes Uni-direc 40W Pppm SMA (DO-214AC), 5.6V, 3W	Vishay Semiconductors	BZG05C5V6-HM3-08

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

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