User's Guide
SLRU001A–April 2012–Revised April 2012

ULN2003LV 7-Channel Relay and Inductive Load Sink Driver EVM

1 Overview

The ULN2003LVEVM is a 7-Channel Relay and Inductive Load Sink Driver evaluation module that demonstrates the ULN2003LVDR integrated circuit from Texas Instruments (TI).

The ULN2003LVDR is a high-performance peripheral driver designed to drive loads of many types including: relays, stepper motors, lamps, and light emitting diodes.

The EVM is configured with seven push buttons that supply input to the ULN2003 driver and seven relays are driven by the ULN2003LV outputs. A four terminal block can be connected to external power supplies to provide input and relay power. All of the ULN2003LV input and output pins are accessible for external connection.

1.1 ULN2003EVM Features

- Seven numbered push buttons control input for device testing.
- Seven numbered light emitting diodes indicate relay contact closure.
- Three 0.1” spaced post connector ports that allow access to all input pins, output pins, and relay contacts.
- Three open locations, per channel, on the circuit board for user supplied components.
- Onboard relay loads that can be disconnected by removing surface mounted 0Ω resistors.
- A large device clearance area that allows the use of small profile temperature forcing equipment.

Table 1. ULN2003EVM Specification

Key Parameters	
Input Supply Voltage:	0V – 5.5V
Relay Supply Voltage:	0V – 4.5V (0 V to 8 V with relays disconnected)
Output Current:	0mA to 140mA
Number of Channels:	7
Onboard Load:	Seven AGQ20003 relays

AGQ20003 specs

- Nominal coil resistance is 64.2Ω
- Nominal coil current is 46.7mA
- Nominal coil voltage is 3V
- Pickup voltage < 75% Nominal
- Dropout voltage > 10% Nominal
- Maximum coil voltage 150% Nominal

CAUTION: Applying voltages above the limitations given in Table 1 may cause permanent damage to your hardware.

Gerber (layout) files are available at www.ti.com.

The EVM includes mating connectors for input, output, and contact pins.

1.2 PCB Key Map

Physical structure for the ULN2003EVM is illustrated in Figure 1.

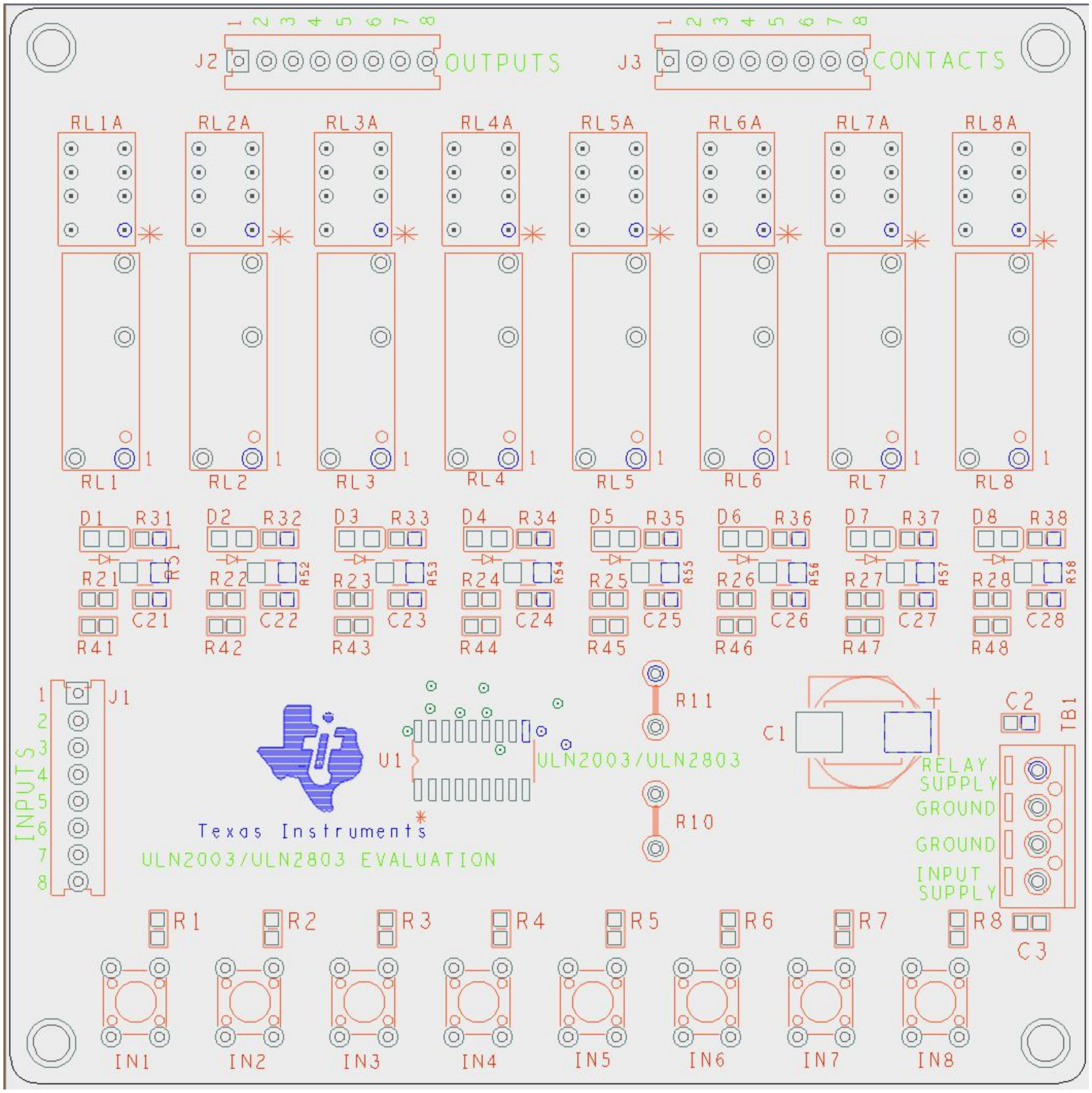

Figure 1. Physical Structure for the ULN2003EVM (Approximate Layout)

2 Quick Setup Guide

This section describes the setup to quickly check the functionality of ULN2003LVEVM.

2.1 Electrostatic Discharge Warning

Many of the components on the ULN2003EVM are susceptible to damage by electrostatic discharge (ESD). Customers are advised to observe proper ESD handling precautions when unpacking and handling the EVM, including the use of a grounded wrist strap at an approved ESD workstation.

CAUTION: Failure to observe ESD handling procedures may result in damage to EVM components.

2.2 Unpacking the EVM

After opening the ULN2003EVM package, check to ensure that the following items are included:

- 1 pc. ULN2003LVEVM board using one ULN2003LVDR
- 3 pc. Eight pin insulation displacement connectors that accept AWG 22 insulated wire.

2.3 Power Supply Setup

A 3.3V power supply capable of 500 mA of current is required.

Connect the positive power supply lead to the “Input Supply” on TB1-1 and also connect it to the “Relay Supply” on TB1-4. Connect the negative power supply lead to either of the two ground connections on TB1-2 or TB1-3.

It is important to connect the power supply correctly because opposite supply polarity will damage the EVM.

Turn the power supply on. At this time, the EVM light emitting diodes (LEDS) should be off and no current should be flowing from the power supply. The ULN2003LV consumes no power when all seven channels are off.

Press the pushbuttons labeled IN1 through IN7 one at a time. When pressed the corresponding relay will click as the contacts engage and the LED will illuminate.

Releasing a pushbutton will disengage the corresponding relay contacts and extinguish the LED.

If all seven buttons operate as previously described, then the ULN2003LVEVM passes functional testing.

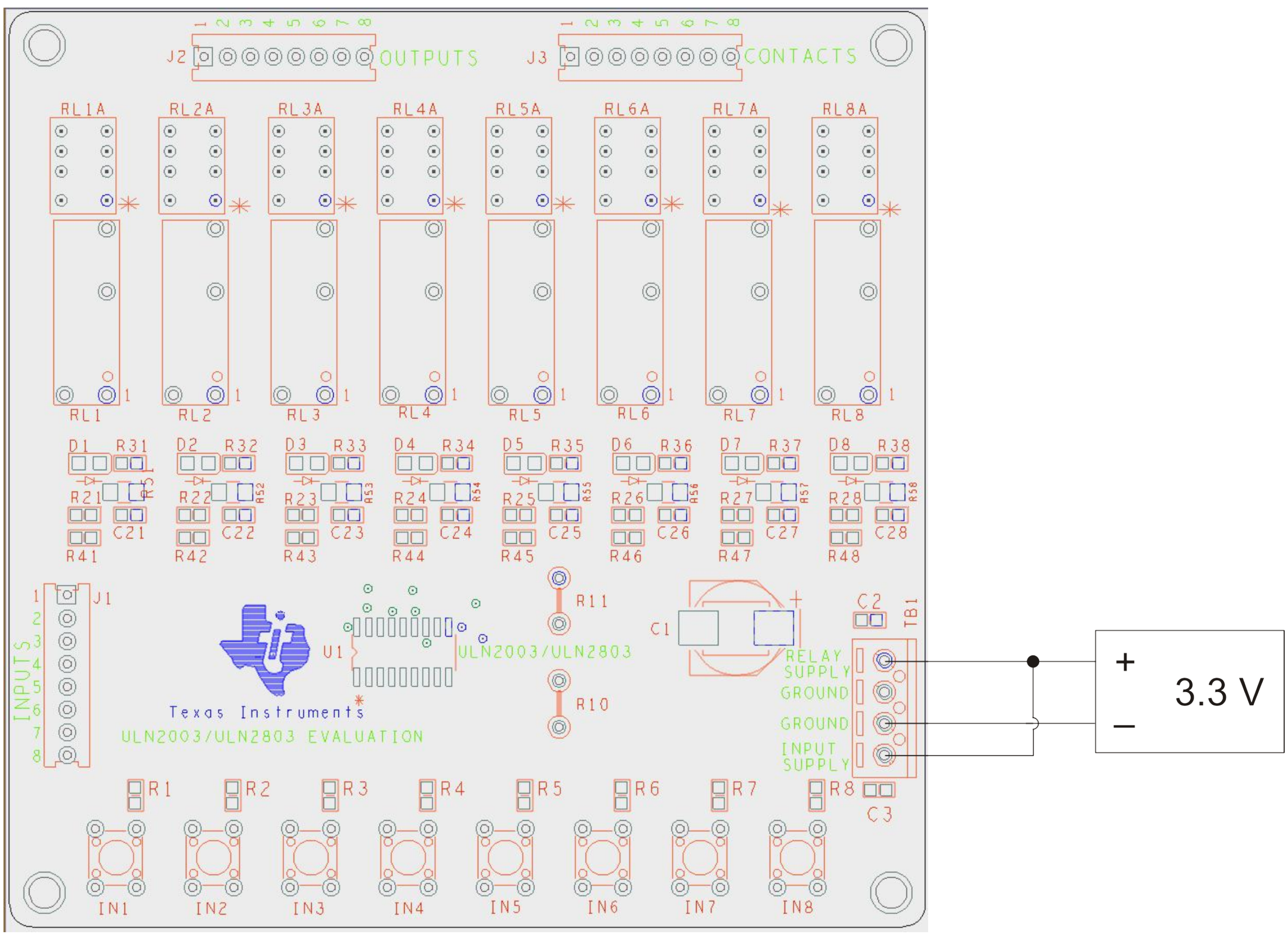

Figure 2. Quick Setup

3 EVM Theory and Operation

The following single channel schematic is representative of the seven identical driver channels.

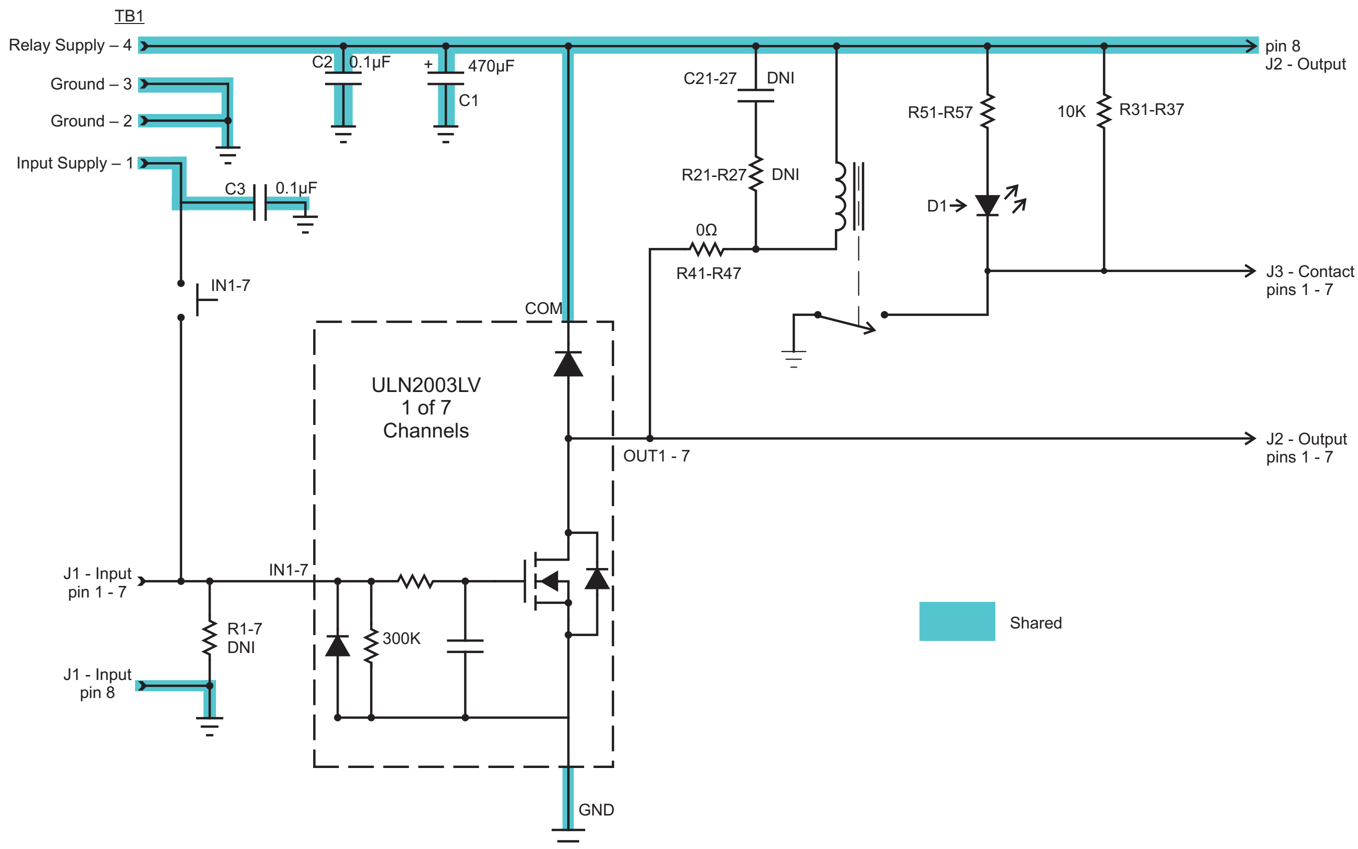

Figure 3. Single Channel Schematic

The ULV2003LVEVM is designed to accept an “Input Supply” on TB1-1 with a voltage range of 1.8V to 5.5V and a “Relay Supply” on TB1-4 with a voltage range ideally set to 3.3V ±10%, but will still operate with a minimum voltage of 2.5V (70% of 3V plus 0.4V) and a maximum voltage of 4.5V (150% of 3V).

When none of the buttons are pressed, the ULN2003LV inputs will be open circuit and the internal resistors in the ULN2003LV will ensure zero volts on the inputs. With the inputs low, the ULN2003LV output pins will set to a high impedance state; therefore, no current will flow through the relay coils. The relay contact will not be engaged and the voltage on the J3-Contact pins 1 to 7 will be pulled up to the relay supply voltage by a 10kΩ resistor on the PCB.

Pressing one of the input buttons, labeled IN1 to IN7, will apply the input voltage supply on TB1-1 to the corresponding input pin on the ULN2003LV. The internal resistor on the ULN2003 input pin will draw a small current proportional to the input voltage. The nominal current is input voltage divided by 300kΩ, it can also be expressed as the ratio, 3.3µA/V. The NMOS switch inside the ULN2003LV turns on providing a low resistance path from output to ground. This completes the circuit and current flows from the relay supply through the AGQ20003 relay coil and through the ULN2003LV output switch to ground and finally back through the relay supply return lead. The relay coil current will engage the relay contacts. The relay contacts will short the corresponding J3 “contact” pin to ground. It will also complete the corresponding LED circuit and the LED will illuminate.

Releasing one of the input buttons, labeled IN1 to IN7, will remove the input voltage from the corresponding input pin on the ULN2003LV. The internal resistor on the ULN2003 input pin will decrease the input voltage to zero. The NMOS switch inside the ULN2003LV turns off breaking the current path for the relay coil. Since the coil is an inductor, the current cannot change in zero time. The coil voltage will change polarity resulting in a ULN2003LV output voltage that is greater than the relay supply voltage. This will forward bias the diode inside the ULN2003LV passing current back to the relay supply voltage. This current will continue until the stored coil energy is depleted. The relay contacts will disengage and the short on the J3-Contact pin will be removed and the pin voltage will increase back to the relay supply voltage. The LED circuit will be open, thus extinguishing the LED.

The voltage on the output pins is always available on the J2-Output connector pins 1-7. Pin 8 is connected to the COM pin on the ULN2003LV and the relay supply voltage on TB1 pin 4. The J2-Output connector can be used measure the output voltage. It can also be used to add additional loads to the ULN2003LV output pins. The series resistance between the J2-output connector and the ULN2002LV is approximately 20 mΩ. The onboard AGQ2003 relay coils can be removed from the ULV2003LV by removing the seven 0Ω resistors at locations R41 to R47.

The voltage on the input pins is always available on the J1-Input connector pins 1-7. Pin 8 is connected to the GND pin on the ULN2003LV and the ground voltage on TB1 pins 2 & 3. The J1-Input connector can be used measure the input voltage. It can also be used to inject external signals onto the ULN2003LV input pins.

Three user supplied components, per channel, can be added if needed. All three circuit board footprints are SMD 0603 sized. The first location, R1 to R7, allows adding a resistor from each input to ground. The second, R21 to R27, and third location, C21 to C27, are in series with each other and parallel with the AGQ20003 relay coils.

The terminal block, TB1, provides power for the input pushbuttons and relay coils. When directly controlling the inputs using the J1-Input connector, the input source on TB1 pin1 may be disconnected.

The ULN2003 EVM board has seven identical channels. The single channel schematic is easier to read then the complete schematic. The ULN2003LV single model functional diagram is enclosed by dotted lines. The input pin has a 300kΩ resistor that keeps the driver off when no input is disconnected or put in to a high impedance state. The NMOS transistor sinks to a shared ground connection when the input voltage is applied. When the load is inductive and the NMOS turns off, the output voltage will increase beyond the relay supply voltage and inductor current will continue to flow though the free wheeling diode to the COM pin until the inductor is discharged.

Resistors R41 through R47 can be removed to isolate the output from the relay coils when external load or automated test equipment is provided through the J2-Output connector.

The relay is an AGQ20003 relay with a 64.2Ω, 3V, 46.7mA nominal coil. The pull-in voltage is less than 2.25V (3V × 75%) and the drop out voltage is greater than 0.3V. The maximum coil voltage is 4.5V (3V × 150%).

The relay contact when open will allow the J3-Contact pin to rise to the Relay supply voltage. The voltage on J3-Contact connector can be measured by any high impedance (>100kΩ) measuring device. When the contacts close the J2-Contact pin will be pulled down to ground potential.

The ULN2003LV output pins 16 to 10 are connected to relays RL1 to RL7 and J2-Output port pins 1 -7 (pin 8 is relay coil power sense).

The ULN2003LV COM, pin 9, is connected to the relay supply on TB1. This pin connects to the cathodes of free wheeling diodes for each output. It provides a discharge path when the inductive load is turned off.

The inputs can be fully controlled by external test equipment using the J1-Input Port. The outputs can be measured by external test equipment using the J2-Output Port. If relay supply voltage, ULN2003LV COM pin, exceeds 4.5V or full external control is required, then the relay coils should be disconnected by removing the zero ohm resistors labeled R41 to R47.

The ULN2003EVM has open 0603 foot prints for input resistors to ground as R11 to R17, coil wave shaping resistor and capacitors as R31 to R37 and C31 to C37. The ULN2003 does not require these components.

Increasing output load using onboard relays: Shorting two or more of the J2 pins 1-7 (output port) will parallel the ULN2003LV outputs and relay coils. By activate just one of the inputs for the shorted output channels will cause a single output to drive multiple relay coil loads. Two coils typically uses 93.4mA and three coils typically use 140mA.

4 ULN2003EVM Performance Testing Using Lab Equipment

Datasheet electrical characterization parameters can be measured using the following test setups. Setups for both standard EVM boards and modified EVM boards that have R41 to R47 removed to disconnect the onboard relay loads. It is acceptable to keep some channels “standard” (R4x installed) and other channels “modified” (R4x removed). The capacitors (470µF & 0.1µF) on the ULN2003LV COM pin are connected regardless of R41 to R47 presence. Therefore the charging, discharging, and leakages of the capacitors must be considered. Each output pin has an internal diode to the COM pin. Testing for channel 1 will be described; test other channels by using a different pin on the J1(input) and J2(output) connectors.

Channel Tested	J1(Input)-pin	J2(Output)-pin
CH 1	J1–1	J2–1
CH 2	J1–2	J2–2
CH 3	J1–3	J2–3
CH 4	J1–4	J2–4
CH 5	J1–5	J2–5
CH 6	J1–6	J2–6
CH 7	J1–7	J2–7

Relay supply is connected to TB1 pin 4; the Relay supply sense line can also be connected to TB1-pin4. Alternatively the sense line can be connected to J2 pin 8. The relay supply is the same node as the ULN2003LV COM (pin 9).

Ground power and ground sense connection can be made to TB1 pins 2 and 3. An alternative ground sense can be made at J1 pin 8.

Warning: All tests that supply current should be limited to the data sheet limit of 140mA. Input pin voltage should be limited to 5.5V and output pin voltage should be limited to 8V.

4.1 Input parameter VI(on) and VI(off) Channel 1 Test Setup and Typical Results

Board setup: Sweep input voltage on J1-1; Set Output J2-1 and Relay Supply to 3.3V, measure output current on J2-1 [current clamp on measurement range of 10mA is recommended].

Note: any difference between voltage on J2-1 and Relay Supply(TB1-4) will affect low current accuracy with Standard board.

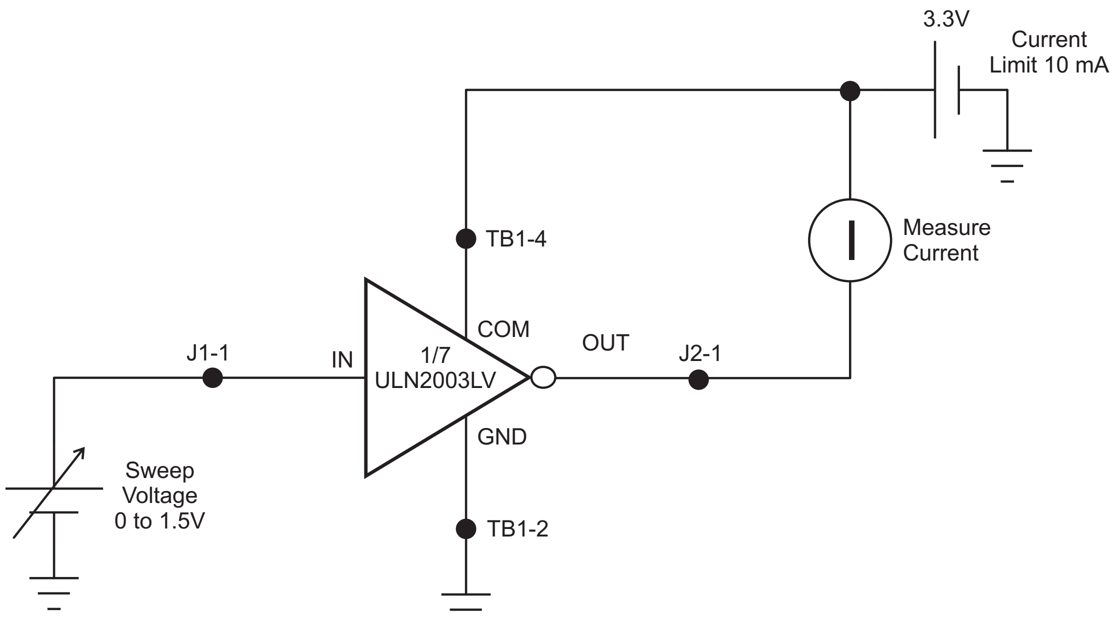

Figure 4. VI(on) and VI(off) Schematic

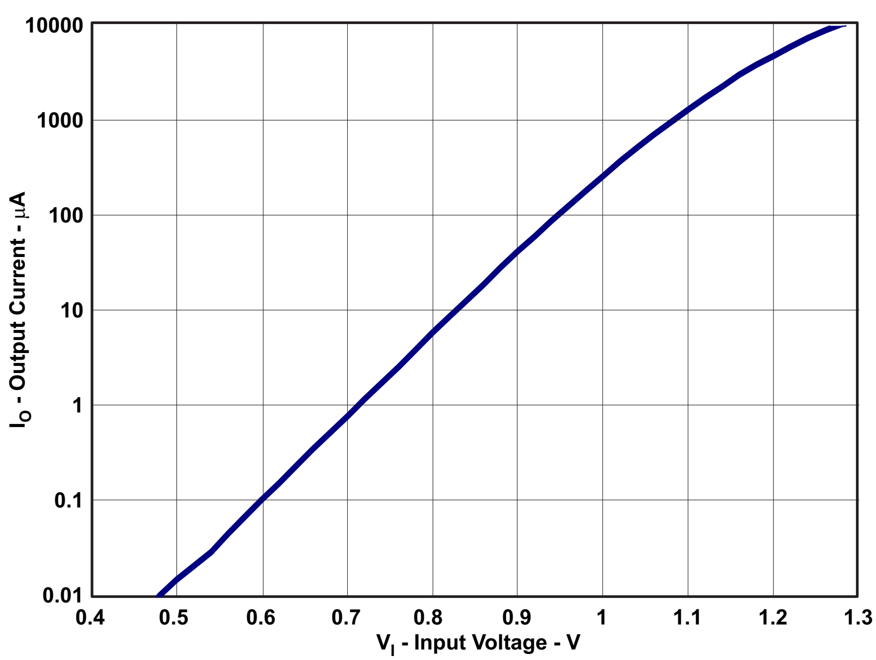

Figure 5. VI(on, off) = IOS(3.3V) vs Vin

4.2 Input Parameter II(on) Channel 1 Test Setup and Typical Results

Input current is a function of input voltage alone. The output load impedance and termination voltage have no impact on the results.

Board setup: Sweep input voltage on J1-1. Measure input current on J1-1. Optionally, Relay supply can be connected to 3.3V.

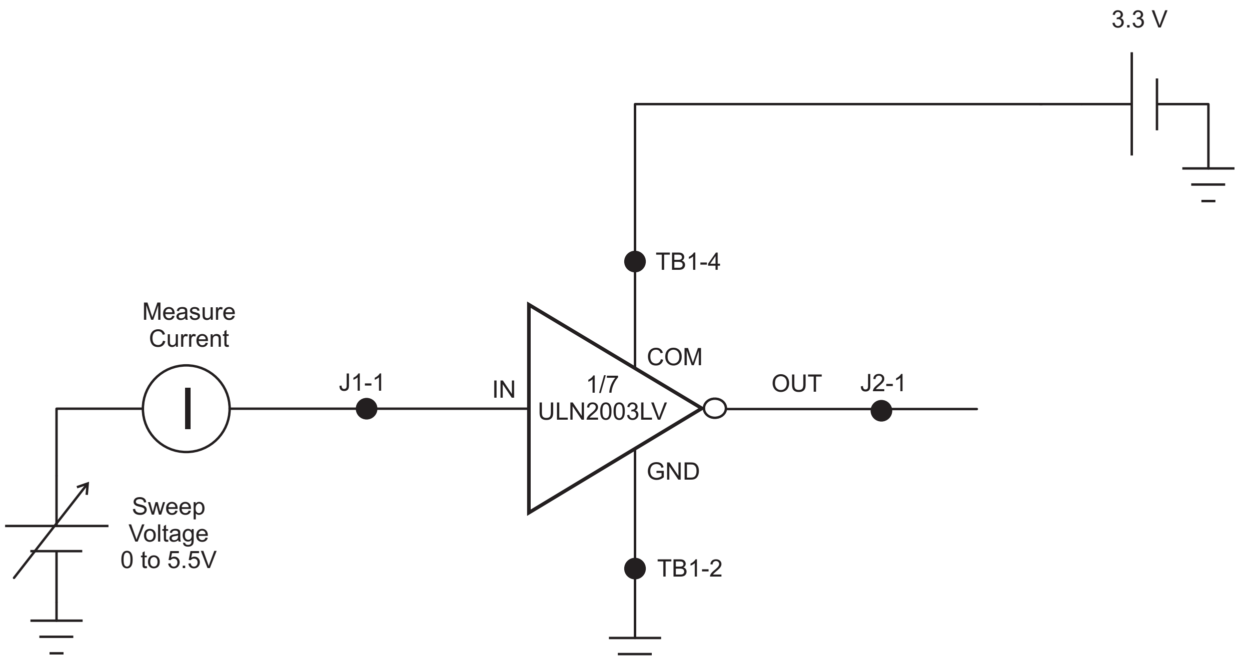

Figure 6. II(on) Schematic

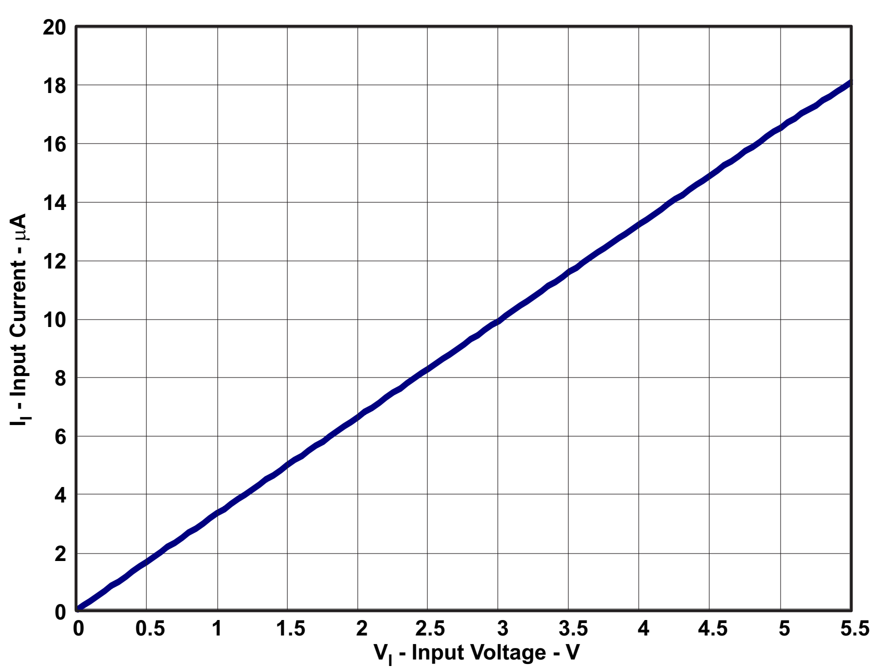

Figure 7. II(on) = IIN vs VIN

4.3 Input Parameter II(off) Channel 1 Test Setup and Typical Results

Input current with zero input voltage will be very low. A pico-amp meter is recommended. This is a signal point test.

Standard board setup: Set input voltage on J1-1 to 0V. Measure input current on J1-1. Optionally, output J2-1 and Relay Supply can be set to 3.3V.

Modified board setup: Sweep CH1 voltage on J1-1; Set Output J2-1 and Relay Supply to 3.3V, measure current on J1-1. The return lead of the pico-amp meter must be at board ground potential.

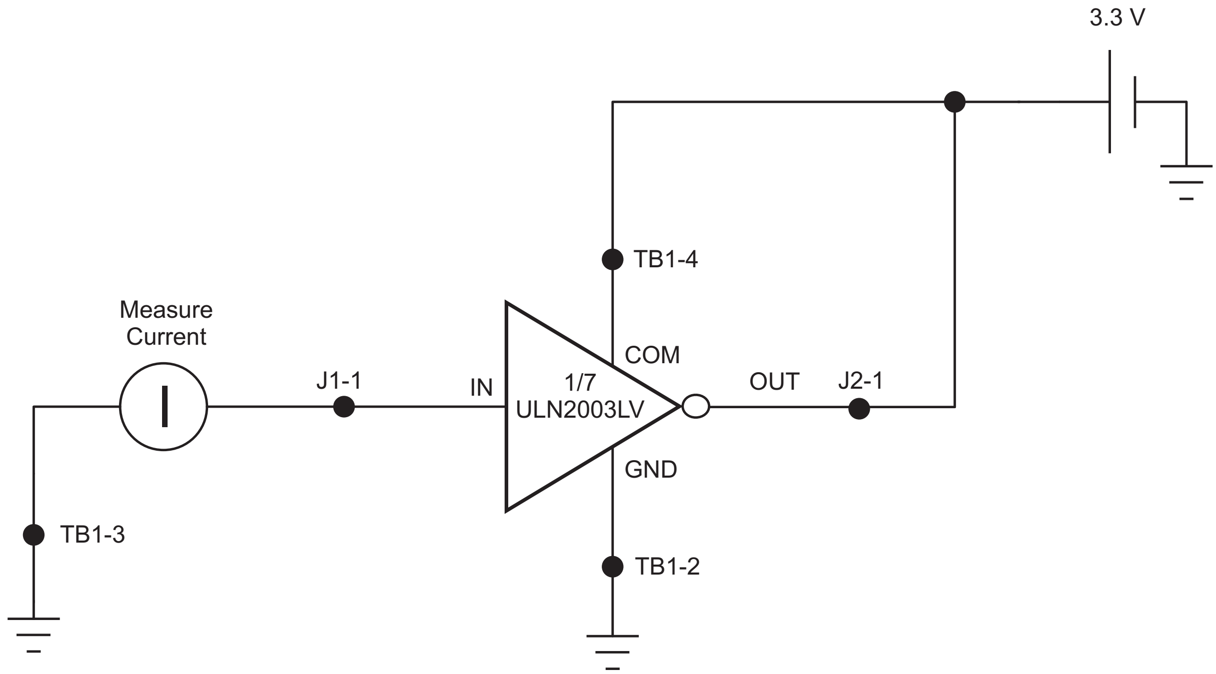

Figure 8. II(off) Schematic

4.4 Output Parameter VOL Channel 1 Test Setup and Typical Results

This parameter was called collector emitter saturation voltage on the original ULN2003 device.

The data sheet has specifications for input voltages of 3.3V and 5V.

Board setup: Sweep output current on J2-1. Set desired input voltage on J1-1 [3.3V, 5V, and other voltages]. Disconnect the relay supply on TB1-4. Measure output voltage on J2-1 (kelvin connections at J2-1 and ground are highly recommended for accurate results).

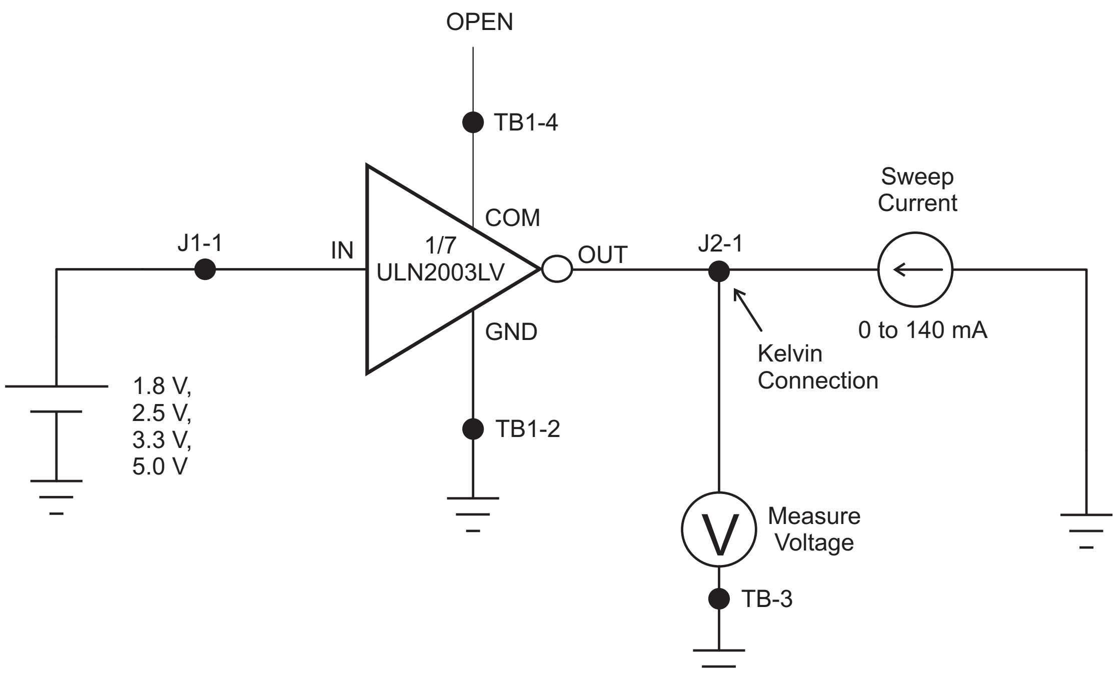

Figure 9. VOL Schematic

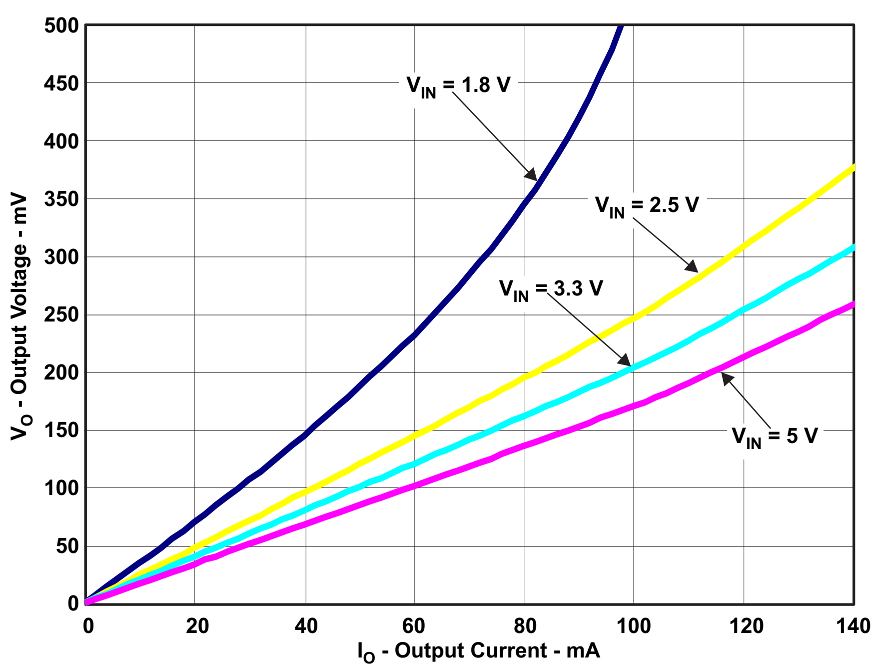

Figure 10. VOL vs IOL

4.5 Output Parameter IOUT(on) Channel 1 Test Setup and Typical Results

Board setup: Sweep input voltage on J1-1. Set output voltage on J2-1 to 0.4V. Disconnect the relay supply on TB1-4. Measure output current on J2-1 (sense connections at J2-1 and ground are highly recommended to keep 0.4V on the EVM regardless of line losses in wires and current meter).

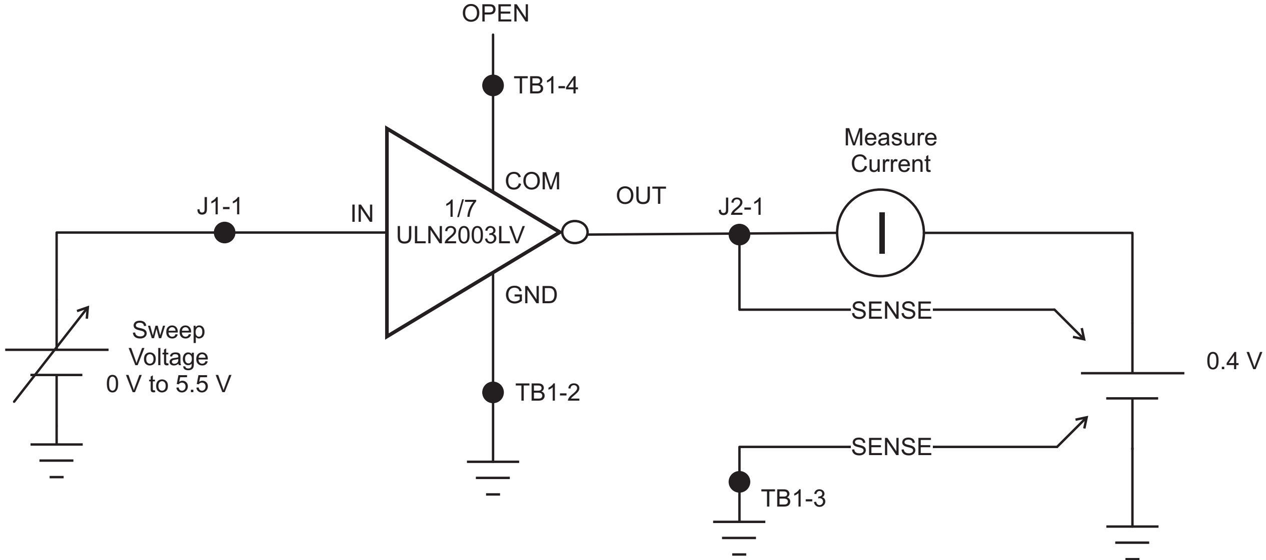

Figure 11. IOUT(on) Schematic

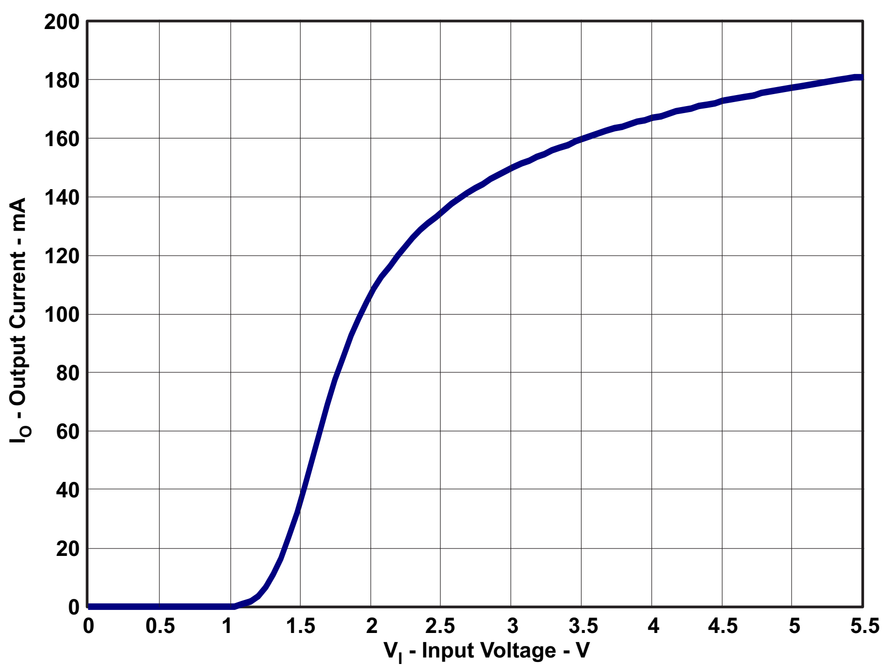

Figure 12. IOUT(on) = IOS(400mV) vs VIN

4.6 Switching Parameter t_{PHL} 3.3V 50Ω Channel 1 Test Setup and Typical Results

Board setup: The ULN2003LV and ULN2003EVM are primarily designed for slow responding loads like relays, stepper motors, and DC lab equipment; however, the ULN2003LV rise/fall times and propagation delays are short. Therefore line termination and short wires are important for signal quality. The waveform below uses a 50 ohm cable “T” tapped within 3 cm of the J1-Input connector and terminated at the oscilloscope set to 50 ohm input impedance. This input is used as the scope trigger. A locally grounded 10X scope probe is used to measure the input signal and the same probe was used to measure the output on J2-1. A pull up resistor of 50Ω is connected between the output (J2-1) and Relay supply (J2-8). Set scope trigger for rising edge. Pulse generator is 10% duty cycle 100kHz 3.3V logic level signal.

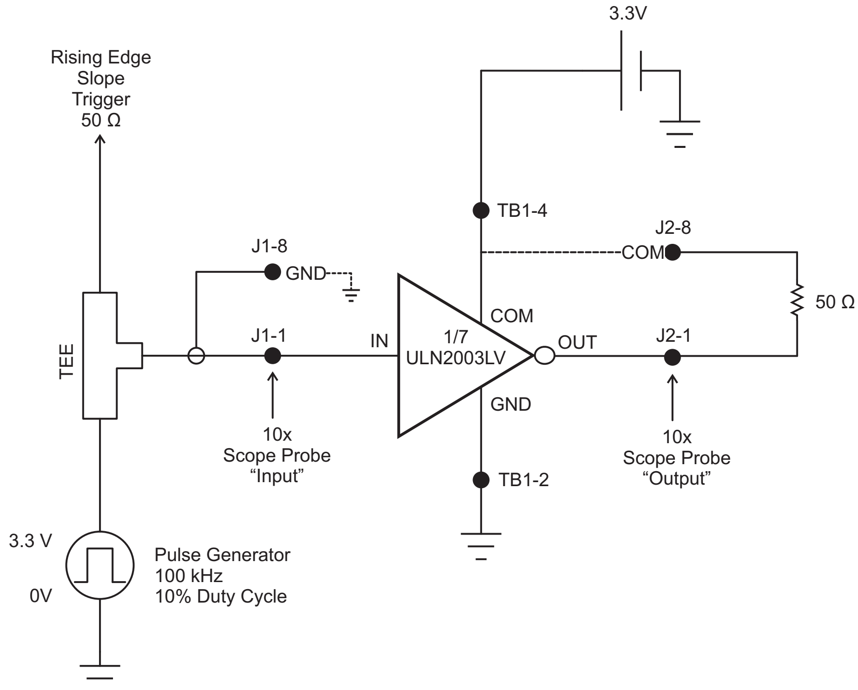

Figure 13. T_{PHL} Schematic

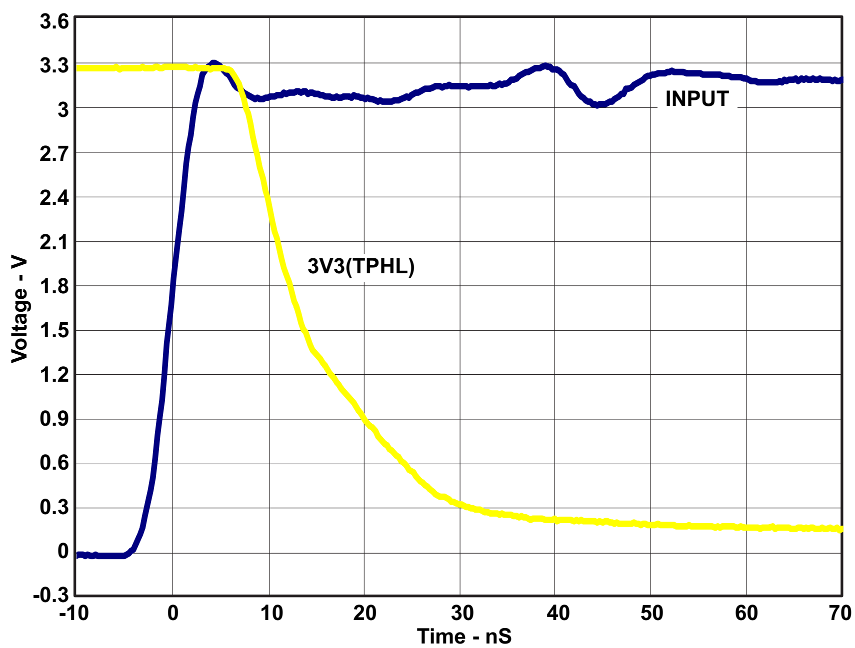

Figure 14. TPHL 3.3V 50Ω pullup = 13nS

4.7 Switching Parameter t_{PLH} 3.3V 50Ω Channel 1 Test Setup and Typical Results

Board setup: The ULN2003LV and ULN2003EVM are primarily designed for slow responding loads like relays, stepper motors, and DC lab equipment; however, the ULN2003LV rise/fall times and propagation delays are quite short. Therefore line termination and short wires are important for signal quality. The waveform below uses a 50 ohm cable “T” tapped within 3 cm of the J1-Input connector and terminated at the oscilloscope set to 50 ohm input impedance. This input is used as the scope trigger. A locally grounded 10X scope probe is used to measure the input signal and the same probe was used to measure the output on J2-1. A pull up resistor of 50Ω is connected between the output (J2-1) and Relay supply (J2-8). Set scope trigger for falling edge. Pulse generator is 10% duty cycle 100kHz 3.3V logic level signal.

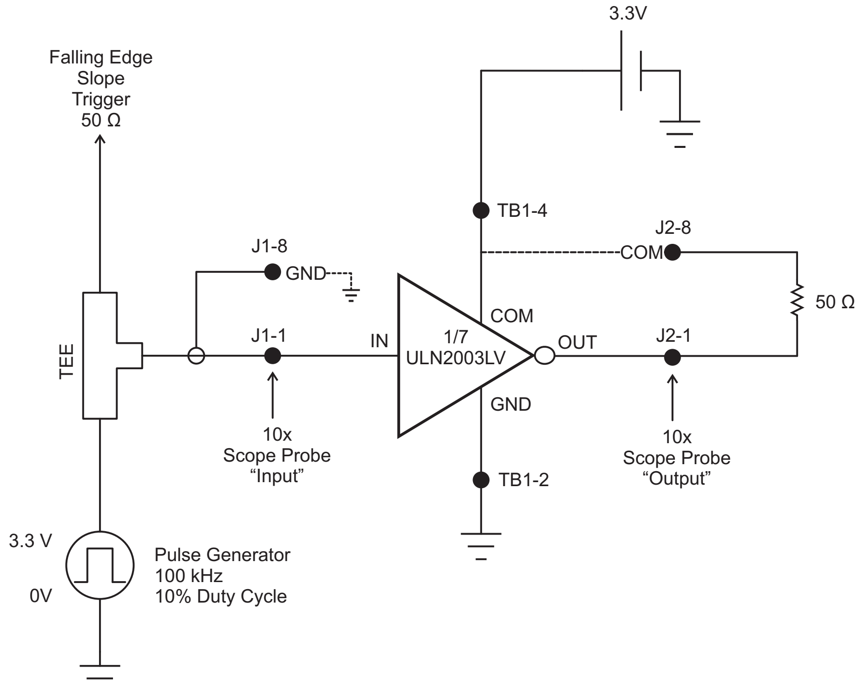

Figure 15. T_{PLH} Schematic

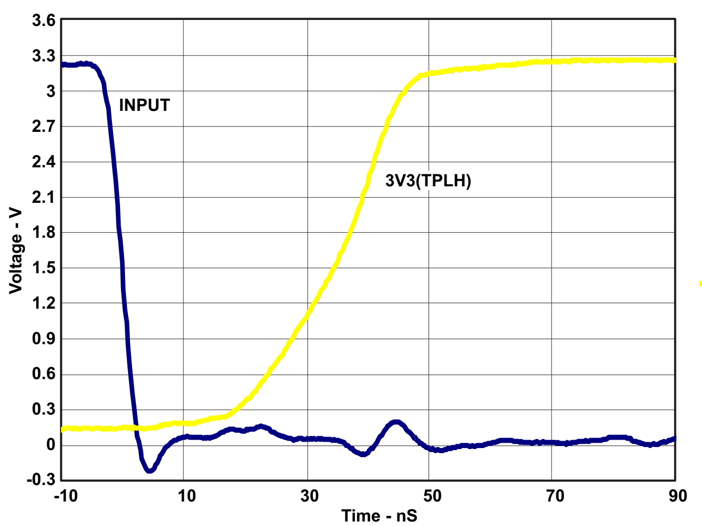

Figure 16. TPHL 3.3V 50Ω pullup = 36nS

4.8 Switching Parameter t_{PHL} 5V 1000Ω Channel 1 Test Setup and Typical Results

Board setup: The ULN2003LV and ULN2003EVM are primarily designed for slow responding loads like relays, stepper motors, and DC lab equipment; however, the ULN2003LV rise/fall times and propagation delays are quite short. Therefore line termination and short wires are important for signal quality. The waveform below uses a 50 ohm cable “T” tapped within 3 cm of the J1-Input connector and terminated at the oscilloscope set to 50 ohm input impedance. This input is used as the scope trigger. A locally grounded 10X scope probe is used to measure the input signal and the same probe was used to measure the output on J2-1. A pull up resistor of 1000Ω is connected between the output (J2-1) and Relay supply (J2-8). Set scope trigger for rising edge. Pulse generator is 10% duty cycle 100kHz 5V logic level signal.

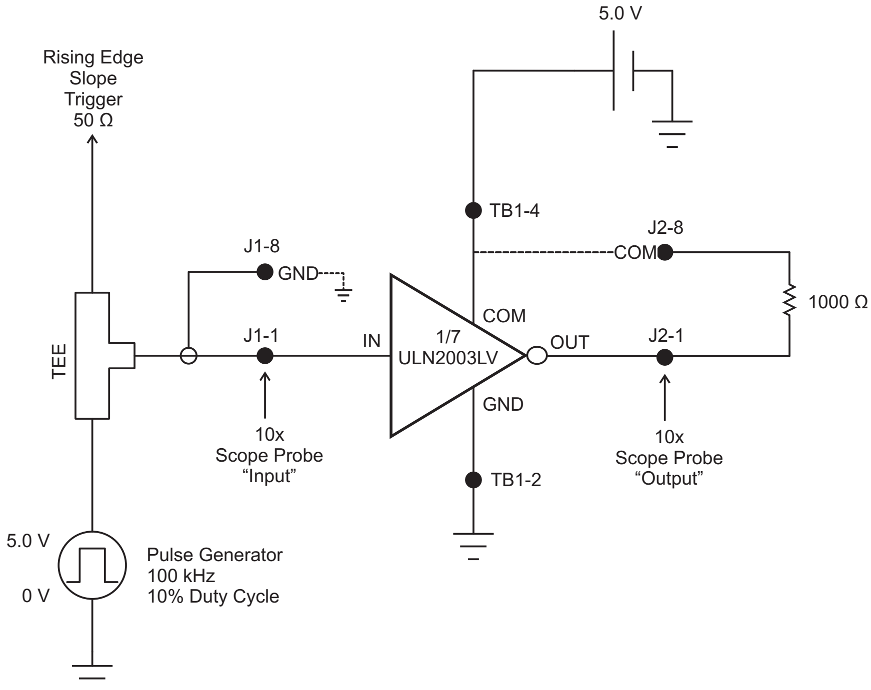

Figure 17. T_{PHL} Schematic

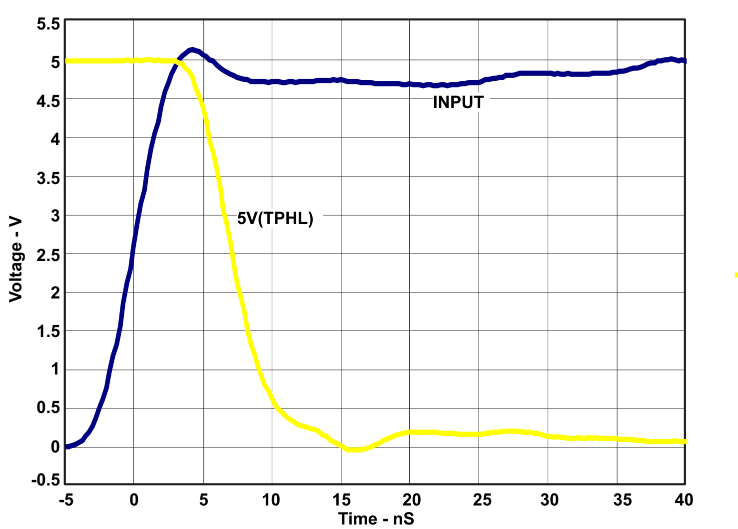

Figure 18. TPHL 5V 1KΩ pullup = 7nS

4.9 Switching Parameter t_{PLH} 5V 1000Ω channel 1 Test Setup and Typical Results

Board setup: The ULN2003LV and ULN2003EVM are primarily designed for slow responding loads like relays, stepper motors, and DC lab equipment; however, the ULN2003LV rise/fall times and propagation delays are quite short. Therefore line termination and short wires are important for signal quality. The waveform below uses a 50 ohm cable "T" tapped within 3 cm of the J1-Input connector and terminated at the oscilloscope set to 50 ohm input impedance. This input is used as the scope trigger. A locally grounded 10X scope probe is used to measure the input signal and the same probe was used to measure the output on J2-1. A pull up resistor of 1000Ω is connected between the output (J2-1) and Relay supply (J2-8). Set scope trigger for falling edge. Pulse generator is 10% duty cycle 100kHz 5V logic level signal.

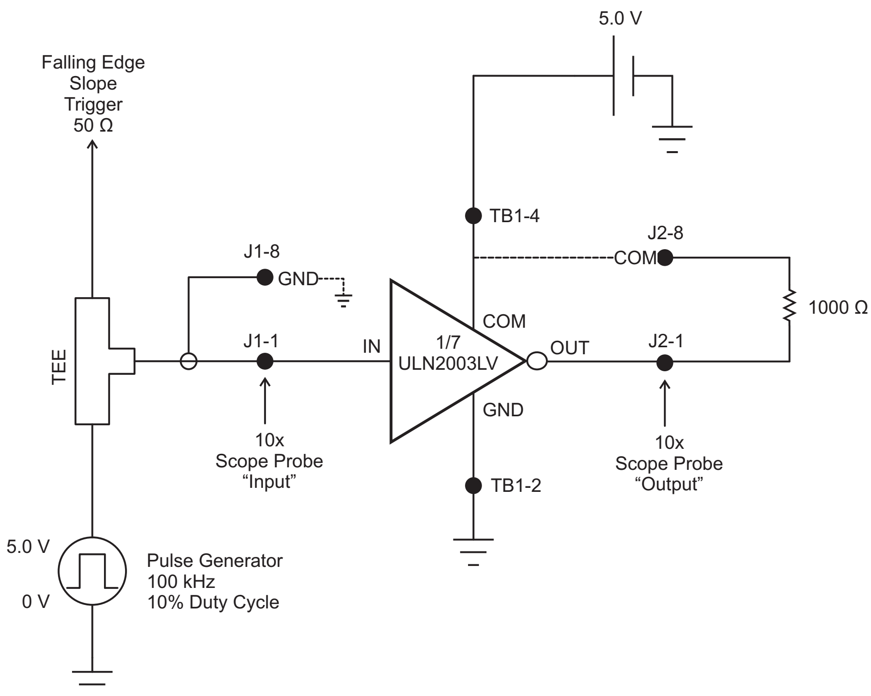

Figure 19. T_{PLH} Schematic

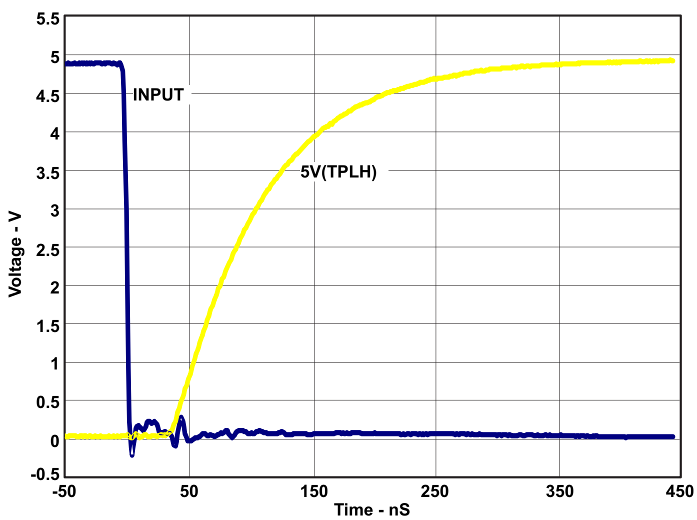

Figure 20. TPLH 5V 1KΩ pullup = 90nS

4.10 Switching Parameter R_{IN} Channel 1 Test Setup and Typical Results.

The data to calculate RIN, the DC input resistance, was recorded during the II(on) test. The input resistance is simply input voltage divided by input current.

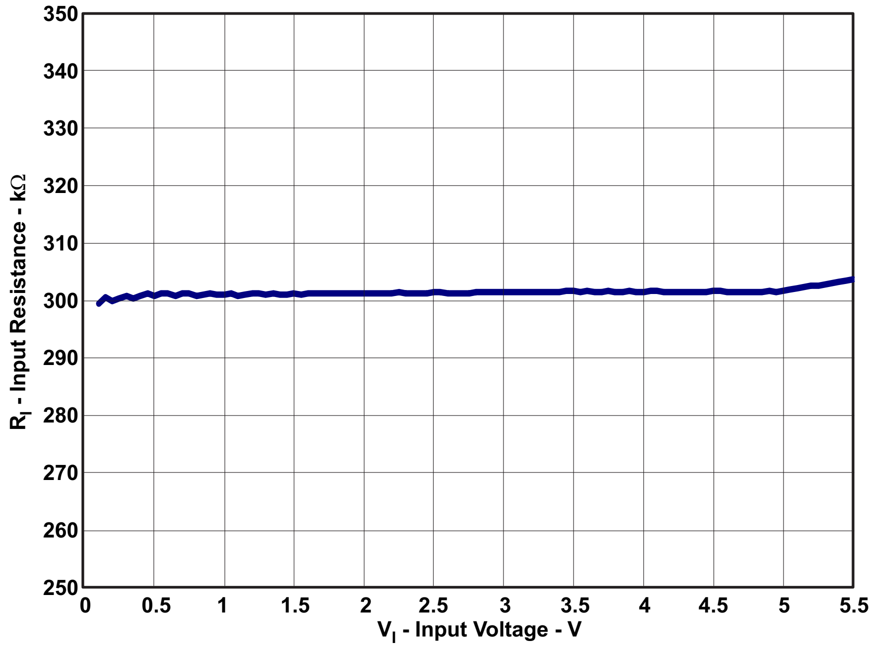

Figure 21. RIN = VIN/IIN vs VIN

4.11 Free-wheeling Diode Parameter VF channel 1 Test Setup and Typical Results

Board setup: Sweep output current on J2-1. Set Relay supply voltage to 0V. On standard boards the X axis (output current) will need to be compensated for coil current flow. The real diode current is approximately X-VF/64.2Ω. Measure output current on J2-1 (Kelvin connections at J2-1 and relay supply are highly recommended for accurate results).

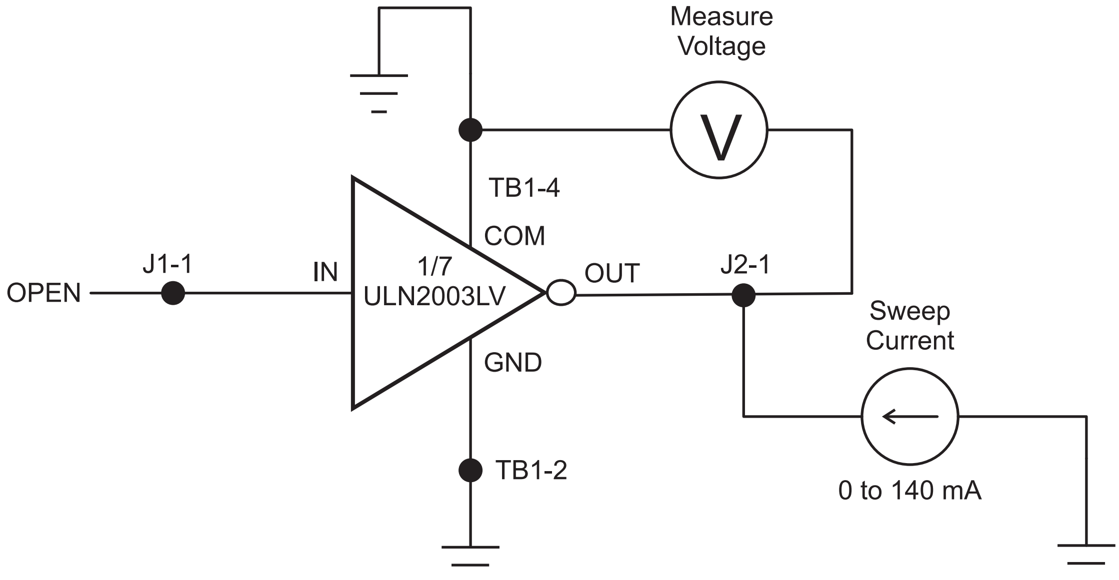

Figure 22. VF Schematic

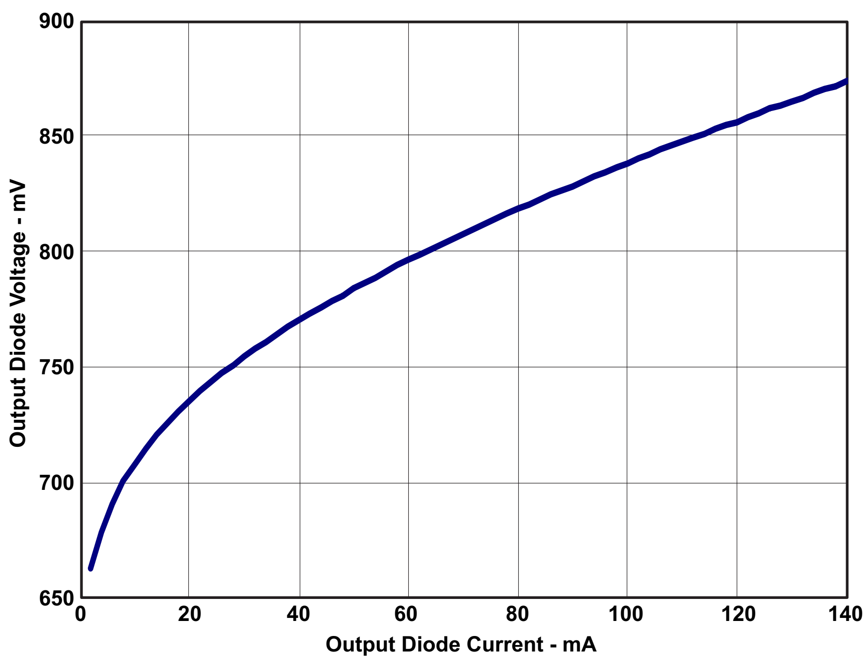

Figure 23. VF = Diode(V) vs Diode(I)

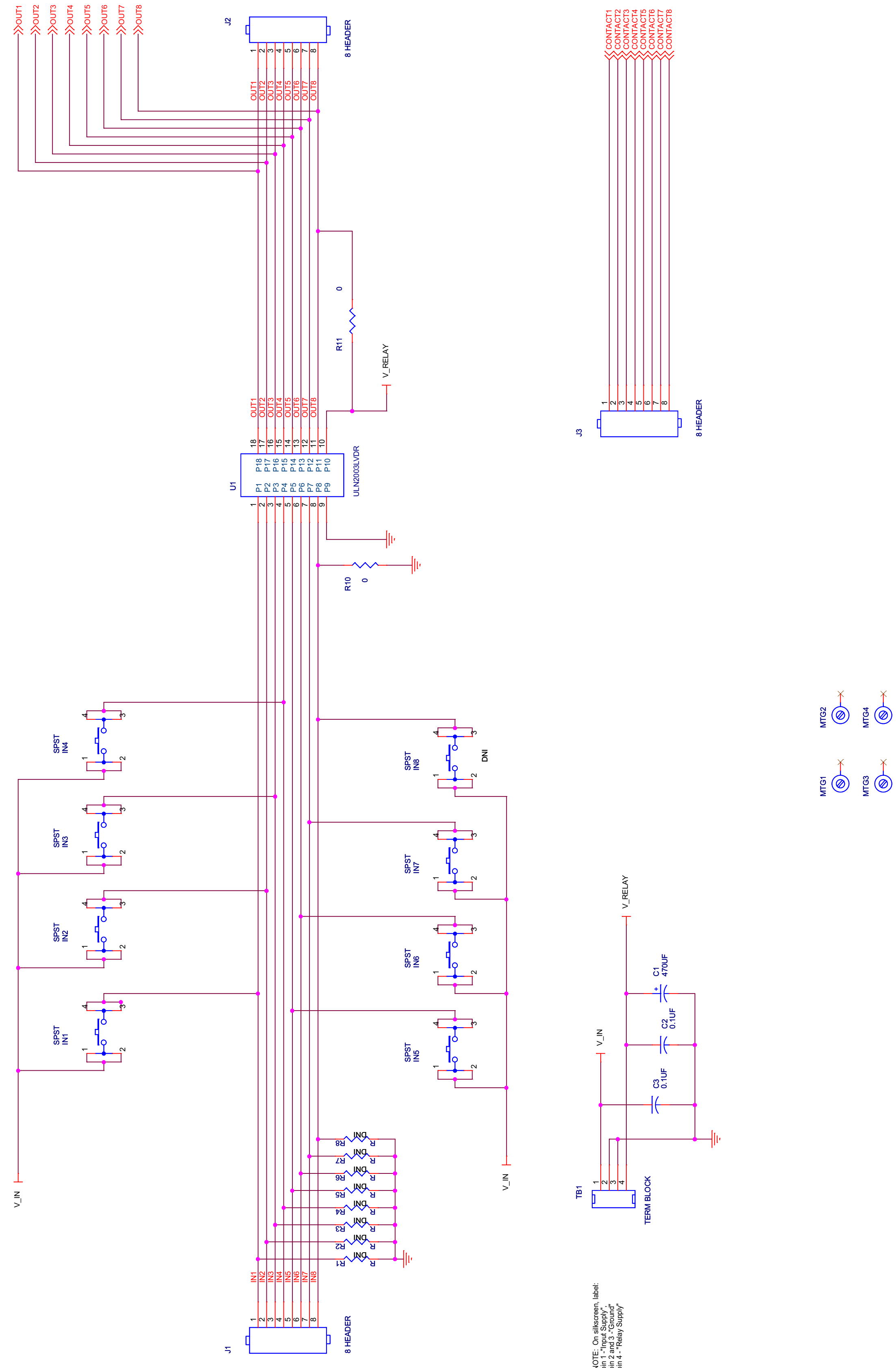

Figure 24. Full Schematic

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FCC Warning

This evaluation board/kit is intended for use for **ENGINEERING DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY** and is not considered by TI to be a finished end-product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC rules, which are designed to provide reasonable protection against radio frequency interference. Operation of this equipment in other environments may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

EVM Warnings and Restrictions

It is important to operate this EVM within the input voltage range of 1.8 V to 5.5 V and the output voltage range of 1.8 V to 5.5 V.

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 85°C. The EVM is designed to operate properly with certain components above 85°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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