User's Guide

SNOU158–August 2018

TLV1805-Q1EVM Evaluation Board Users Manual

The TLV1805-Q1EVM Evaluation Board demonstrates discrete comparator based reverse current protection solutions using both P-Channel and N-Channel MOSFET topologies.

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Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The TLV1805-Q1EVM Evaluation Board demonstrates discrete comparator based reverse current protection solutions using both P-Channel and N-Channel MOSFET topologies utilizing the TLV1805-Q1 comparator.

This EVM circuit does not protect against under and overvoltage or overcurrent.

1.1 Features

- Reverse Current Protection
- Reverse Voltage Protection
- Less than 1µs response time
- TVS Transient protection up to 28V
- Independent P and N Channel MOSFET Circuits
- Internal or External N-Channel Charge Pump Oscillator
- Withstood selected ISO 16750-2 and ISO 6737-2 waveforms

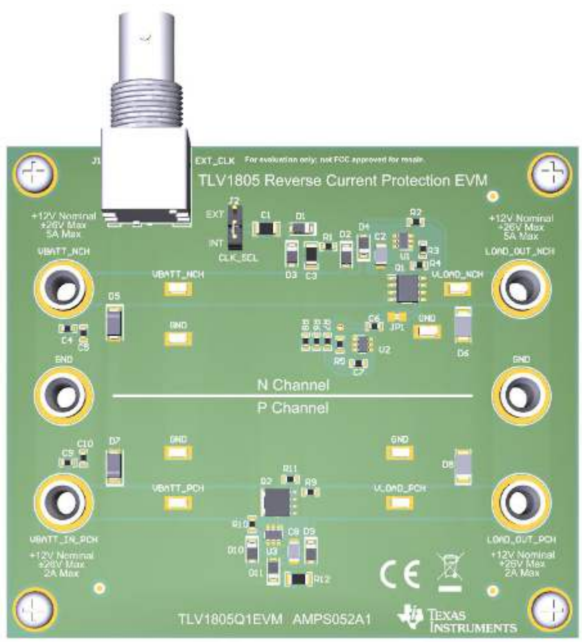

Figure 1. TLV1805-Q1EVM Top View

2 Specifications

Table 1. EVM Specifications

SPECIFICATION	LIMIT
Minimum V_{BATT} Voltage	+3.5 V (Body Diode conduction below 3.5 V)
Maximum V_{BATT} Voltage	±26 V (TVS clamped at ±33 V)
Maximum Load Current, N-Channel	+5 A Max
Maximum Load Current, P-Channel	+2 A Max
Maximum Reverse Trip Current, N-Channel	-750 mA (-480 mA typ)
Maximum Reverse Trip Current, P-Channel	-750 mA (-520 mA typ)
Typical Supply Current, N-Channel	1 mA (+ Osc + CP) at 12 V
Typical Supply Current, P-Channel	170 µA at 12 V

3 Description

3.1 *Basic Operational Theory*

Both the P-Channel and N-Channel circuits work on the same basic principal. A comparator monitors the voltage across the MOSFET Source and Drain terminals (monitors V_{DS}).

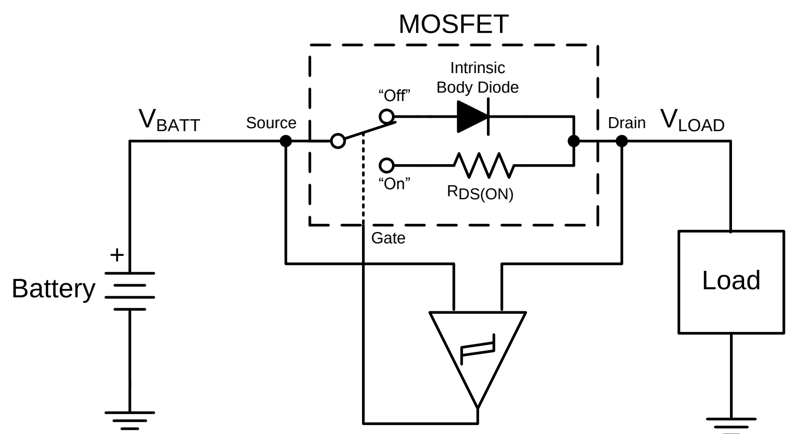

Figure 2. Simplified Operational Theory

When the current is flowing from the battery (V_{BATT}) to the load (V_{LOAD}), the battery voltage will be higher than the load voltage due to voltage loss across the MOSFET due to $R_{DS(ON)}$ or the intrinsic body diode forward voltage drop.

With V_{BATT} higher than the V_{LOAD} voltage, the comparator drives the gate to turn the MOSFET "on" (conducting), and current flows through $R_{DS(ON)}$ to V_{LOAD}.

In a reverse current condition, the V_{LOAD} will be higher than V_{BATT}. The comparator will detect this and drive the gate to set V_{GS} = 0 to turn "off" the MOSFET (non-conducting). The body diode is reverse biased and will block current flow.

For P-Channel MOSFETs, the gate must be driven at least 4V or more *below* the battery voltage to turn "on" the MOSFET.

For N-Channel MOSFETs, the Gate must be driven 4V or more *above* the battery voltage to turn "on" the MOSFET. If a higher voltage is not available in the system, a charge pump is usually required to generate a voltage higher than the battery voltage to provide the necessary positive gate drive voltage.

See the Applications Section of the *TLV1805-Q1 datasheet* for more detailed information.

3.2 P-Channel Circuit

To turn "on" the P-Channel MOSFET, the gate must be brought "Low" towards ground. To accomplish this, the comparator Inverting input is tied to the battery side of the MOSFET to go low during forward current.

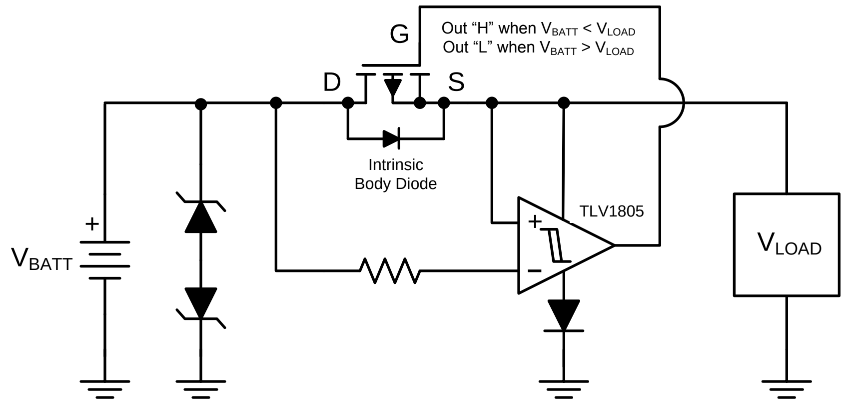

Figure 3. Simplified P-Channel Circuit

The comparator circuit is powered from the load side of the MOSFET to benefit from the reverse voltage protection of the MOSFET body diode. The diode in shown in the negative lead of the comparator is to prevent the load from discharging the comparators large bypass caps (not shown) during V_{LOAD} loss so that the comparator can maintain operation as long as possible.

3.3 N-Channel Circuit

To turn "on" the N-Channel MOSFET, the gate must be brought "High" above V_{BATT}. To accomplish this, a charge pump circuit is required to provide the comparator with a supply voltage above V_{BATT}.

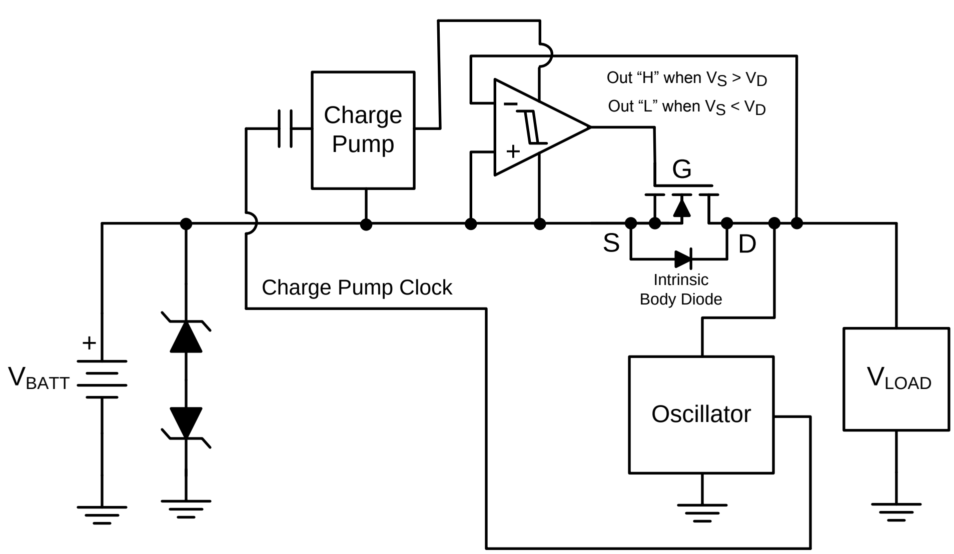

Figure 4. Simplified N-Channel Circuit

The N-Channel section has the option of utilizing the on-board oscillator, based on the TLV1805-Q1, or utilizing an external source through J1.

The charge pump must be fed by a 50% duty cycle square wave source of 5Vpp or more. Because the input capacitor of the charge-pump effectively AC-couples the input, the oscillator can be ground referenced.

3.4 TVS Clamps

Both sections contain bidirectional TVS diodes and series bypass capacitors on the input for transient protection.

While the circuits as shown do not need the TVS to function, the TVS provides the needed clamping protection for high voltage transients for passing ISO transient tests and normal battery line transients. The selected TVS diodes can pass up to 28V DC and will clamp at approximately ±33V.

3.5 Bypass Capacitors

The input bypass capacitors are two capacitors in series mounted at right angles to each other, as is custom in automotive circuits to increase reliability and prevent shorting of the battery bus if one of the ceramic caps fail shorted.

Bypass capacitors were not included on the output as they can interfere with obtaining the fast transient waveform measurements. Normally, large bypass capacitors are part of the load and are recommended.

3.6 Minimum Reverse Current

There is a minimum amount of reverse current that is needed to trip the comparator. To detect this current, a voltage must be dropped across the MOSFET (V_{MEAS}).

When the MOSFET is off, V_{GS} will be in the -600mV to -1V range due to the forward voltage drop (V_F) of the MOSFET body diode. Response to this large voltage will be immediate.

However, with the MOSFET "on" (conducting), the voltage drop required across the MOSFET $R_{DS(ON)}$ will be the comparator offset voltage plus half of the hysteresis.

With a maximum offset of the TLV1805-Q1 is 5mV and typical hysteresis of 15mV, the trip voltage can be calculated from:

$$V_{TRIP} = V_{OS(max)} + (V_{HYST} / 2) = 5 \text{ mV} + 7.5 \text{ mV} = 12.5 \text{ mV} \quad (1)$$

The actual current trip point will depend on the MOSFET $R_{DS(ON)}$ and V_{GS} drive level. Assuming the MOSFET has a 22 mΩ on resistance, the trip current is found from:

$$I_{TRIP} = V_{TRIP} / R_{DS(ON)} = 12.5 \text{ mV} / 22 \text{ m}\Omega = 568\text{mA} \quad (2)$$

As can be seen, the $R_{DS(ON)}$ has a large influence on the trip point!

3.7 N-Channel Oscillator Circuit

The EVM contains a built-in relaxation oscillator using the TLV1805-Q1 to allow stand-alone operation of the EVM.

The oscillation frequency is determined by R7 and C5. The default configuration oscillates around 50kHz (depending on RC component tolerances). For further information on selecting these RC values, please see the Engineers Cookbook Circuit entitled *Oscillator Circuit* (Lit# SNOA990). Do note that R7 does present an AC load to the oscillator output, and must be sized to minimize the peak charging currents of C5 (use large resistors and small capacitors).

The output amplitude is roughly equivalent to the V_{LOAD} voltage minus the TLV1805-Q1 output saturation (approximately 100mV). With a maximum supply voltage of 40V for the TLV1805-Q1, the oscillator circuit is capable of generating up to 39Vpp!

The TLV1805 oscillator typically starts oscillating when V_{LOAD} reaches 2.5V, though full specified operation does not occur until 3.3V.

If the internal oscillator (U2) operation not be desired, the copper link JP1 may be cut to remove power from the oscillator. Oscillator power may be restored by mounting a zero ohm resistor or a solder bridge across the pads.

See section Section 4.2 for more information about the clock requirements.

4 Setup

This section describes the jumpers and connectors on the EVM as well and how to properly connect, set up and use the TLV1805-Q1 EVM. Ensure the power supply is turned off while making connections on the board.

The P-Channel and N-Channel circuits are separate and independent and only share a common ground.

4.1 Input/Output Connector Description

- VBATT_NCH: Battery voltage input to N channel circuit
- GND: Common Ground
- VBATT_PCH: Battery voltage input to P channel circuit
- LOAD_OUT_NCH: Output of N-Channel circuit to positive side of load (5A Max)
- LOAD_OUT_PCH: Output of P-Channel circuit to positive side of load (2A Max)
- EXT_CLK (J1): Input for external N-channel charge pump drive
- CLK_SEL (JP2): Selects internal or external clock for N-channel charge pump
- INT OSC PWR (JP1): Disconnects internal oscillator power when cut

4.2 N-Channel Oscillator Options

The N-Channel charge pump has the option to use the built-in oscillator, or an external oscillator applied through the BNC connector, J1.

The selection is done with the CLK_SEL jumper header, J2. Place the jumper in the lower INT position to select the internal oscillator. Place the jumper in the upper EXT position to use the external oscillator, and apply the oscillator signal to J1.

The applied external waveform should ideally be a symmetrical, 50% duty cycle square wave, capable of peak currents up to 50mA.

The peak-peak amplitude of the square wave will determine the supply voltage of the comparator, minus about 0.6V ($V_{COMPARATOR} = V_{PP}$ - 0.6V). The recommended minimum voltage for the comparator is 4V, or the V_{GS} for the MOSFET required for proper saturation. Maximum voltage must be limited to the maximum $V_{GS(MAX)}$ of the MOSFET. The Zener diode D2 performs the comparator supply clamping function and must be sized for $V_{GS(MAX)}$.

The frequency is not critical, any value between 1kHz and several MHz may be used, but will influence start-up and transient recovery time at the low frequency end, and radiated EMI at the high frequency end (AC current return is through the V_{BATT} bus, so supply bypassing and filtering is crucial on both input and output.

5 Board Setup

Before applying power to the TLV1805-Q1 EVM, all external connections must be verified. External power supplies must be turned off and connected with proper polarity to the VBATT_xCH and GND connectors. An electronic or resistive load must be connected at the output.

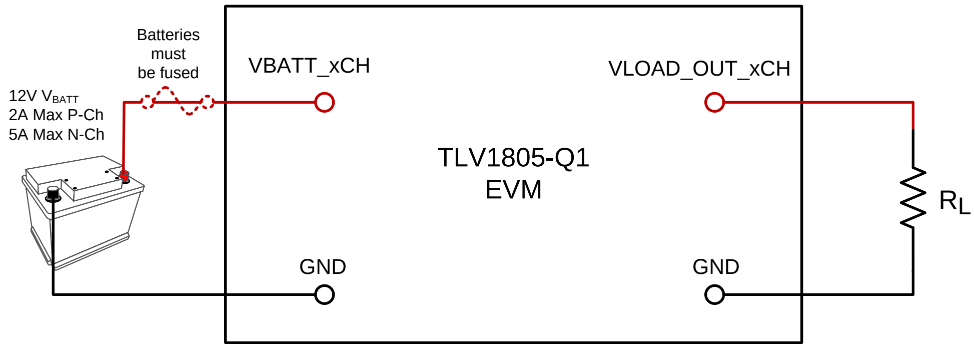

Figure 5. Typical TLV1805-Q1 EVM Connections

The P-Channel and N-Channel sections are Independent and not connected. The user may select which section is used by applying the power and load to the appropriate VBATT and LOAD_OUT terminals. The verification procedure is similar for both sections.

The tests outlined in this document have 1 A constant load current and 12.00V input voltage supply (VBATT_xCH). Make sure that the external power supply source for the input voltage is capable of providing enough current to the output load so that the output voltage can be obtained.

The TLV1805-Q1 EVM does not contain any current limiting. External supplies must have adjustable foldback current limiting to limit the maximum current to below 2A for the P-Channel, and 5A for the N-Channel. Batteries will require external fuses or circuit breakers.

5.1 Recommended Equipment

- Power supply capable of 12 V at 5 A with current limiting and current readback*
- Programmable Electronic Load or suitable resistive load (12 Ω, >30W recommended)
- 5.5 Digit Digital Multi-Meter or better (capable of 1 mV resolution)
- Oscilloscope with test probes

* For best results, the supply must have an output capable of sinking and sourcing current

Note: If testing with negative input voltages, it is recommended to use a resistive load because electronic loads may not be able to handle negative input voltages (cannot source current), or require a minimum voltage for proper operation.

6 Verify N-Channel Operation

Set supply output voltage to 12.00 V with a current limit of 1.1 A. Disable supply output.

Verify that the jumper on J2 (CLK_SEL) is set to the lower INT position.

Figure 6. Verifying J2 Setting

Connect the Negative load lead to the GND jack, and the Positive load lead to the LOAD_OUT_NCH jack, as shown in Figure 7.

Connect the Negative supply lead to the GND jack, and the Positive supply lead to the VBATT_NCH jack, as shown in Figure 7.

Turn on the power supply. Verify that the supply load current is 1 A at 12 V. Using a DMM, adjust the supply if needed to obtain 12.000V at the input terminals.

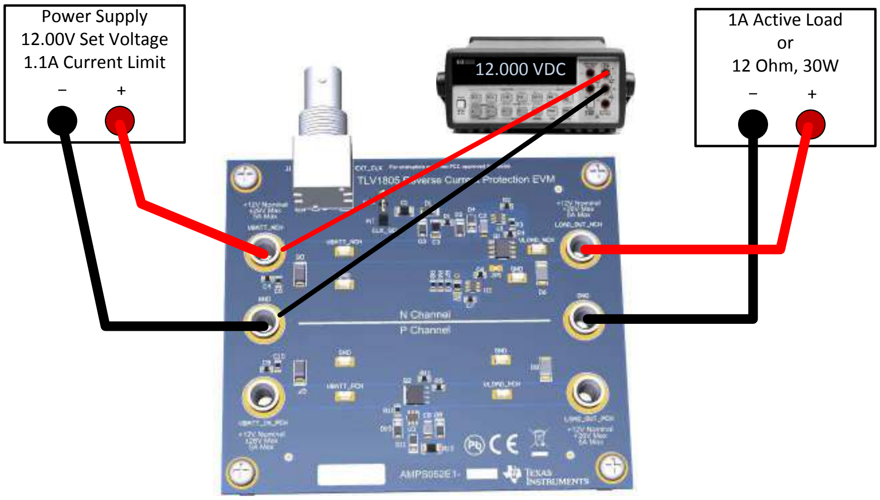

Figure 7. Connecting Supply and Load to N-Channel Section

Using a DMM, measure the voltage between GND and the top (striped end) of C2, as shown in Figure 8. Verify there is 23.4V (±300 mV) present. This verifies the operation of both the charge pump and the oscillator.

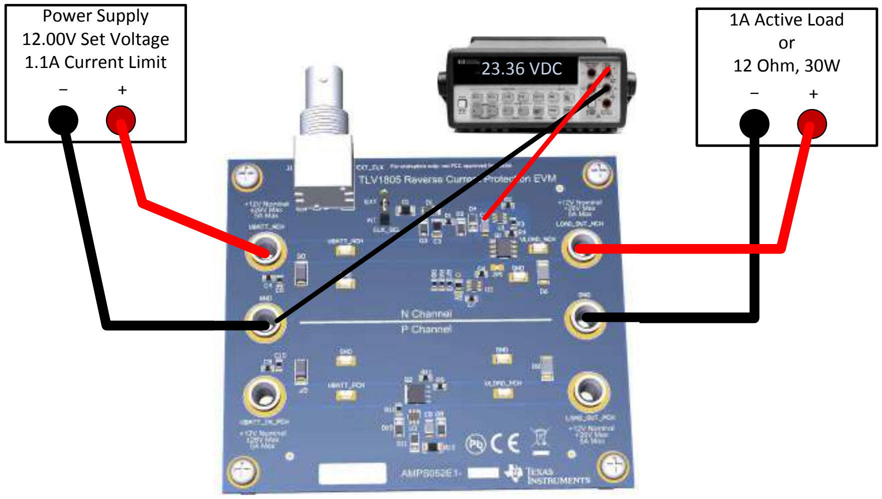

Figure 8. Measuring C2 Voltage to Check Charge Pump and Oscillator Operation

Using a DMM, measure the voltage between the VBATT_NCH and VLOAD_NCH test points, as shown in Figure 9 (note the polarity of the test leads, negative to VBATT_NCH and positive to LOAD_OUT_NCH). This is the voltage drop across the MOSFET and should be a small negative voltage in the -20mV range (typ -22 mV at 1 A load). A measured voltage greater than -100 mV indicates a problem.

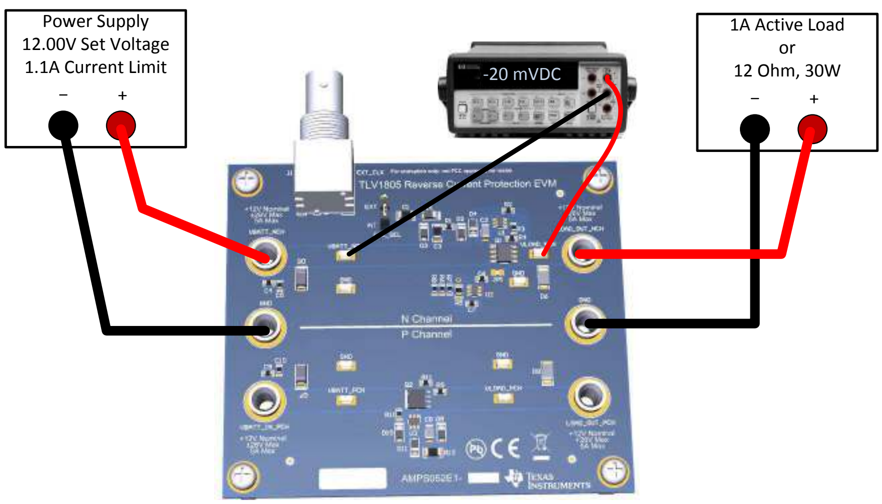

Figure 9. Measuring the N-Channel Voltage Drop

7 Verify P-Channel Operation

Set output voltage to 12.00 V with a current limit of 1.1 A. Disable supply output.

Connect the Negative load lead to the GND jack, and the Positive load lead to the LOAD_OUT_PCH jack, as shown in Figure 10.

Connect the Negative supply lead to the GND jack, and the Positive supply lead to the VBATT_PCH jack, as shown in Figure 10.

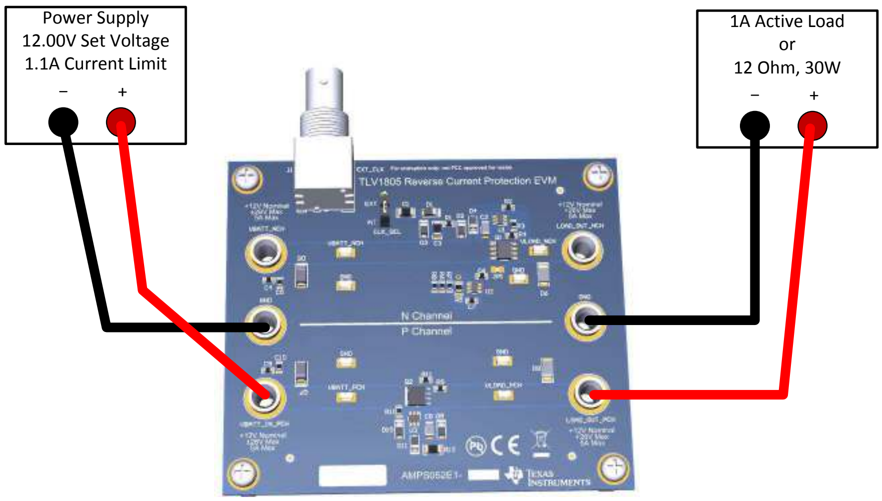

Figure 10. Connecting Supply and Load to P-Channel Section

Turn on the power supply. Verify that the supply load current is 1 A at 12 V.

Using a DMM, measure the voltage between the VBATT_NCH and VLOAD_NCH, as shown inFigure 11. This is the voltage drop across the MOSFET and should be a small negative voltage in the -18 mV range. A measured voltage greater than -100mV at 1A indicates a problem.

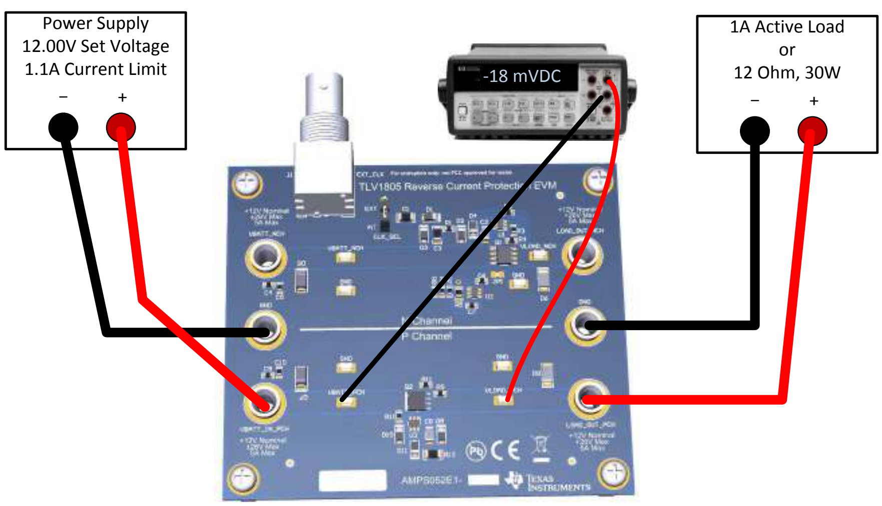

Figure 11. Measuring the P-Channel Voltage Drop

NOTE: The measured millivolt voltages across the MOSFET is dependent on the load current and is directly related to the MOSFET $R_{DS(ON)}$. So variations in the above measured voltage depend on the accuracy of the applied load current, supply voltage and process variations of the MOSFET. The above voltage were measured with 12.000V at the input jacks and 1.00A load current

7.1 Reverse Voltage

The input V_{BATT} may be reversed to test the reverse voltage protection function. The output load current and voltage must be zero, though there may be a few mV due to MOSFET and clamp diode leakage.

7.1.1 N-Channel Reverse Voltage

Turn off the supply output. Reverse the input connections, as shown in Figure 12, and turn the supply output back on. The supply current for the N-Channel should be about 1 mA, due to the input clamping action of D4 and current through R2 (at -12 V).

The load current must be zero and the load voltage must be less than -20mV with load (-100 mV unloaded). The majority of the 15 mV shown below is due to the 1mA from the R2 clamp circuit flowing through the 12 ohm load (12mV) to GND.

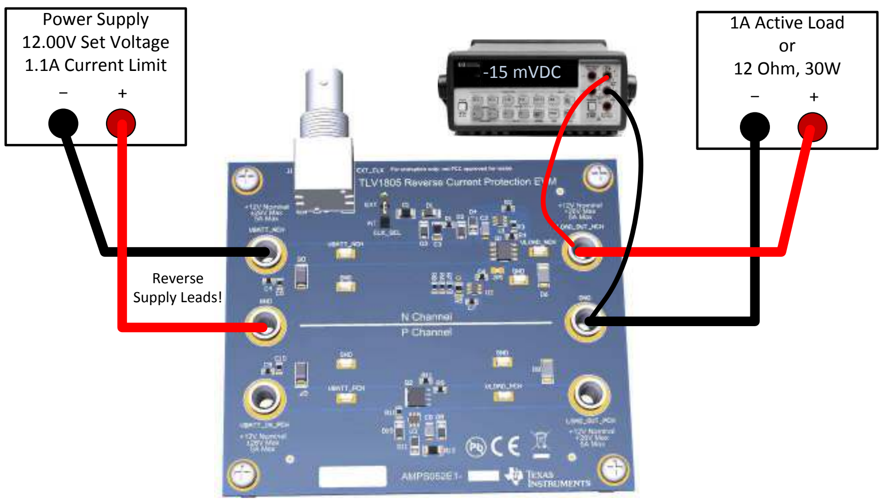

Figure 12. Checking N-Channel Reverse Voltage Operation

7.1.2 P-Channel Reverse Voltage

Turn off the supply output. Reverse the input connections, as shown in Figure 13, and turn the supply output back on. The supply current of the P-Channel must be less than 150uA . Because of the negative "pull-down" path of R10, D8 and D10, the comparator "floating ground" is pulled negative and powers the comparator. The P-Channel comparator circuit is actually functioning during reverse voltage! The load current should be zero and load voltage should be less than -10mV, or -50mV unloaded

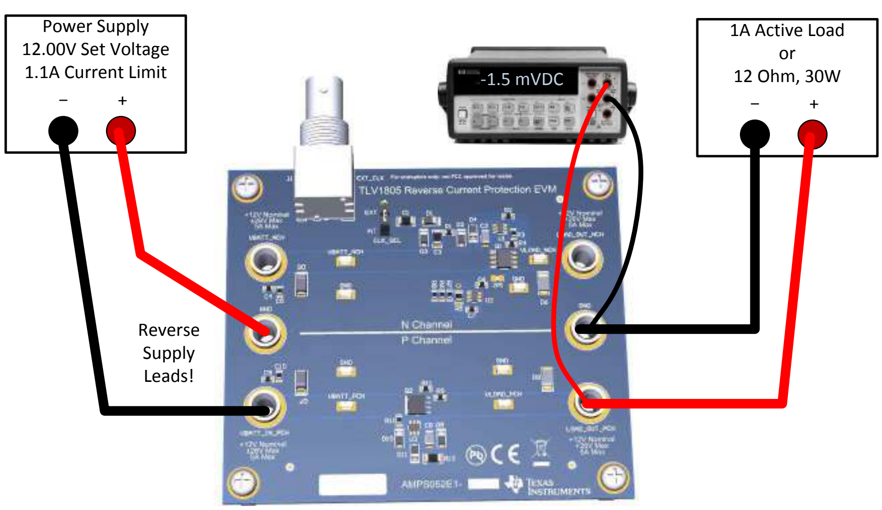

Figure 13. Checking P-Channel Reverse Voltage Operation

8 Verify Reverse Current Operation

The following applies to both the P-Channel and N-Channel sections.

To create the necessary bipolar test currents, a "bridged" load between two supplies can be used, as shown in Figure 14.

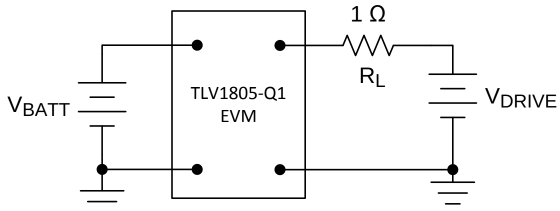

Figure 14. "Bridged" Load to Create Bipolar Current

Both the Battery (V_{BATT}) and Load side (V_{DRIVE}) have a power source, with the load resistor (R_L) between them. The load current and polarity will be determined by the difference in voltage between the supplies and the load resistor value.

$$I_{LOAD} = (V_{BATT} - V_{DRIVE}) / R_L \quad (3)$$

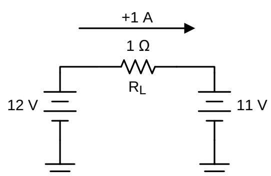

Figure 15. Forward Current

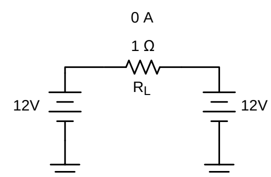

Figure 16. Zero Current

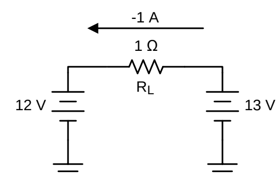

Figure 17. Reverse Current

When both supplies are equal, no current flows as shown in Figure 16.

When the V_{BATT} voltage is higher than V_{LOAD}, as shown in Figure 15 then positive current will flow.

When V_{LOAD} is higher than V_{BATT}, as shown in Figure 17 then negative current is flowing.

Using the 1Ω R_L example, a ±1V difference between the supplies would generate a ±1 A current.

However, this configuration requires that both the source (V_{BATT}) and the load (V_{DRIVE}) are able to sink and source current. This requires the use of so-called "Bipolar" or "4-Quadrant" supply, which is capable of both sinking and sourcing output current.

Most common laboratory bench supplies are based on a series-pass transistor or switching architecture and cannot sink current. Forcing a voltage into the input above the set output voltage will cause the internal control loop to turn off, resulting in the supply output "floating" up to the forced voltage and are not suitable for these tests. For a work-around using common bench supplies, see Section 8.1.

Even when using the bipolar supplies, it is still recommended to use the R_L load resistor to act as a ballast resistor to prevent possible supply output instabilities due to each supply driving into the output of the other.

With V_{BATT} = V_{DRIVE}, no current must be flowing through R_L. The MOSFET can be on or off depending on the comparators internal offset.

When V_{BATT} is greater than V_{DRIVE}, creating a forward current, the MOSFET should turn on. This action can be confirmed by measuring the voltage between the VBATT_xCH and VLOAD_xCH test points. This voltage should only be a few mV when the MOSFET is conducting. A 500 mV to 1 V voltage would indicate body-diode mode with the MOSFET off.

When V_{BATT} is less than V_{DRIVE}, reverse current is flowing and the MOSFET should turn off after the load current passes the reverse current threshold. This action can be confirmed by measuring the voltage between the VBATT_xCH and VLOAD_xCH test points. This voltage must be equal to the difference in the V_{BATT} and V_{DRIVE} voltages.

Keep in mind that the reverse current threshold will be larger if the MOSFET is conducting and thus a larger reverse current must be passed across the lower $R_{DS(ON)}$before the required trip voltage is created.

8.1 Using Non-Bipolar Supplies

If "Bipolar" sink-source output type supplies are not available, common bench supplies can be used if a sinking path is provided. To provide a sinking current path, each supply will need to be pre-loaded with a load resistor, as shown in Figure 18. This is essentially this is creating a Class-A output stage and is by nature, very, very inefficient!

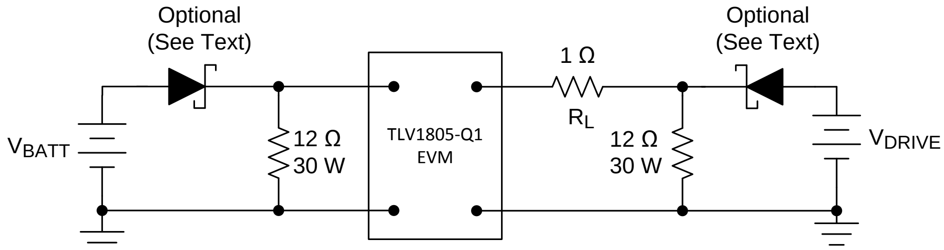

Figure 18. Setup Showing Loading Resistors for Source Only Bench Supplies

NOTE: This scheme works best with older, simple series-pass transistor analog power supplies (not switching). The schematic also shows two optional Schottky diodes, one on each output of the supplies. These diodes must be used if the user is unsure if the supply can accept a voltage forced onto the output. These diodes need to be able to handle the large currents involved. Schottky rectifier diodes in tabbed transistor or stud packages mounted to a large heatsink are recommended. The V_{BATT} and V_{DRIVE} output voltages must now be set and measured at the EVM input connectors due to the forward voltage drop of the diodes.

12 Ohm resistors were chosen to create a 1 A load at 12 V.

If V_{BATT} and V_{DRIVE} are both 12 V, no R_L current is flowing. Because minimal current is flowing, the MOSFET could be on or off. If the MOSFET is on, the more dominant supply will supply all the load current (2A). If the MOSFET is off, then each supply will see 1A due to it's own 12 Ω load.

If V_{BATT} = +12 V and V_{DRIVE} = +11V, creating a positive current flow, then the MOSFET must be conducting and V_{BATT} must see the total load current of the V_{BATT} load resistor and the series combination load of RL and the V_{DRIVE} load resistor (13Ω total), for a total V_{BATT} current of 1.92 A. The voltage across the VBATT_xCH and VLOAD_xCH test points must be in the millivolt range. V_{DRIVE} must be suppling no current (remember it is assumed that a source only supply output will turn-off when the applied voltage is greater than the set voltage).

If V_{BATT} = +12 V and V_{DRIVE} = +13 V, creating a reverse current, the MOSFET must be off and each supply must see it's own load resistor current (1 A). The voltage across the VBATT_xCH and VLOAD_xCH test points should be equal to the difference in the supply voltages (+1V)

The negative current trip points may be found by adjusting the V_{DRIVE} or V_{BATT} voltages. Note that changing the voltages also changes the $V_{DS(ON)}$ of the MOSFET due to changing the V_{DS} drive, particularly below 6V.

9 ISO 16750-2 and ISO 6737-2 Tests

The TLV1805-Q1 EVM board was subjected to selected ISO 16750-2 and ISO 6737-2 waveforms for 12V systems.

The ISO 7637-2 pulses included pulses 1, 2a & 2b, 3a & 3b, 4 and 5 (clamped). The 16750-2 tests included reverse voltage, overvoltage, momentary drop, slow ramp and superimposed AC.

The circuits survived with no performance degradation, and the load voltage did not exceed design limits.

Testing was done in-house and does not imply full ISO certification of the board, or that the use of these circuits implies ISO certification of users end equipment.

10 Board Layout

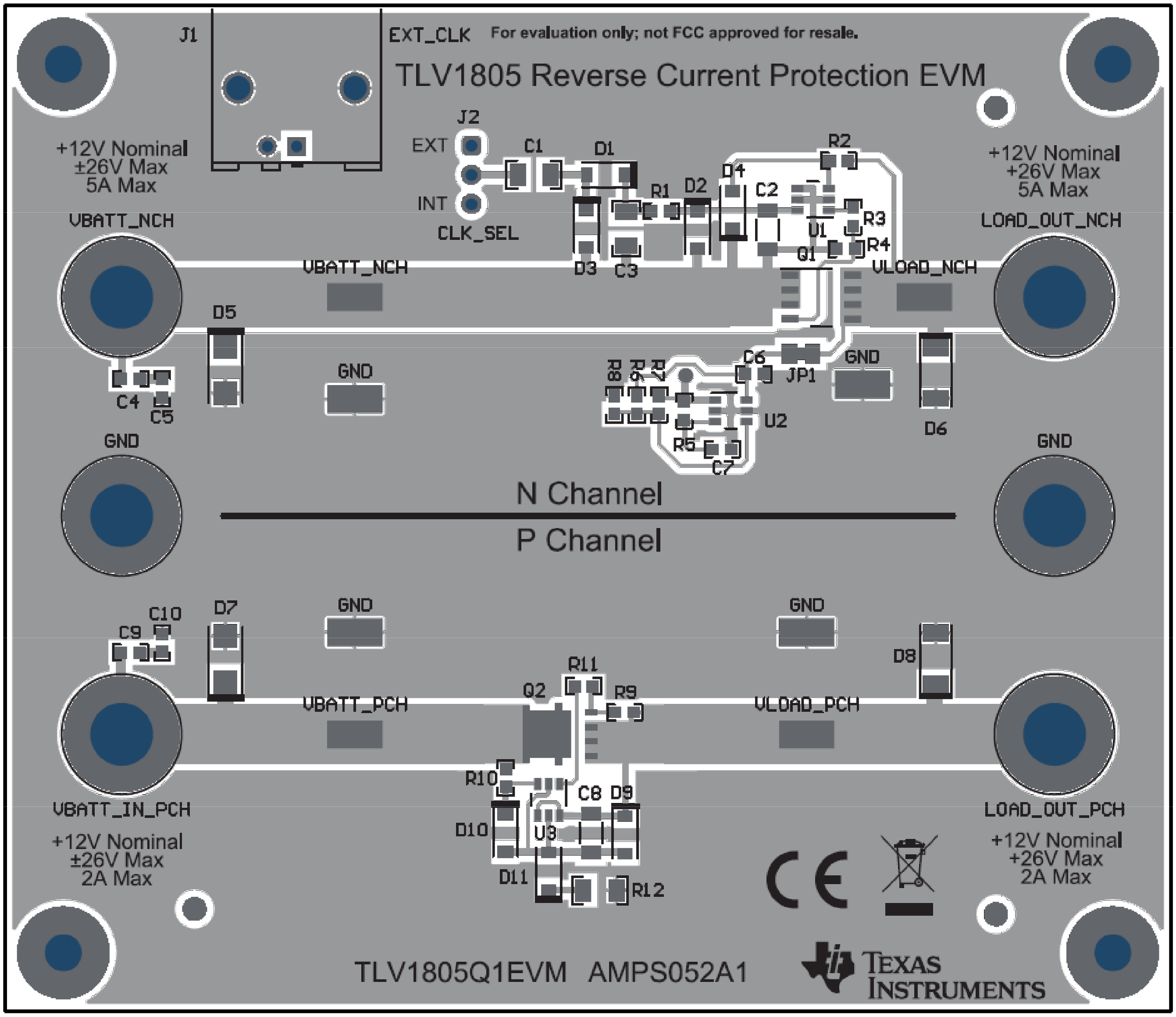

Figure 19. Top View

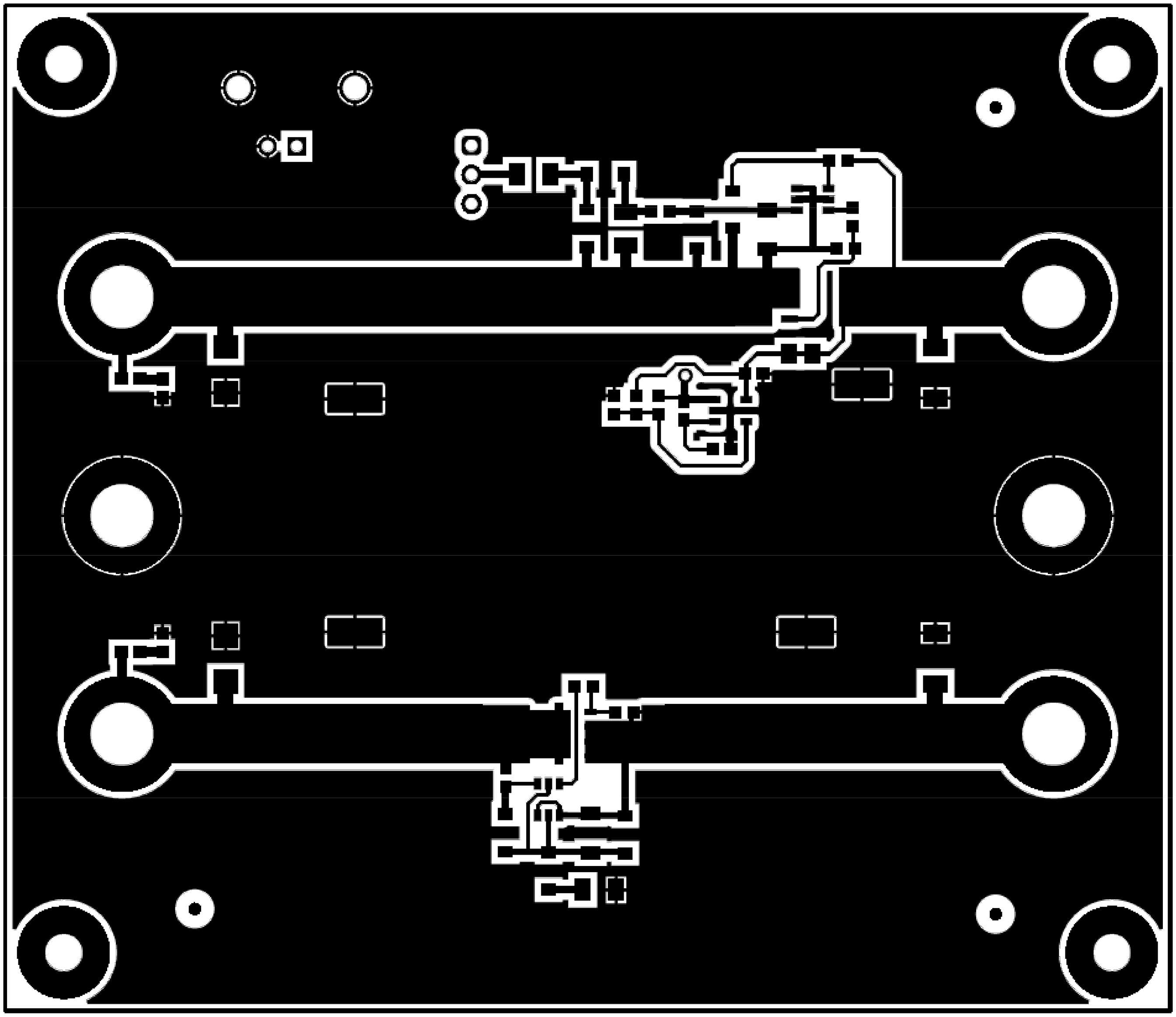

Figure 20. Top Layer

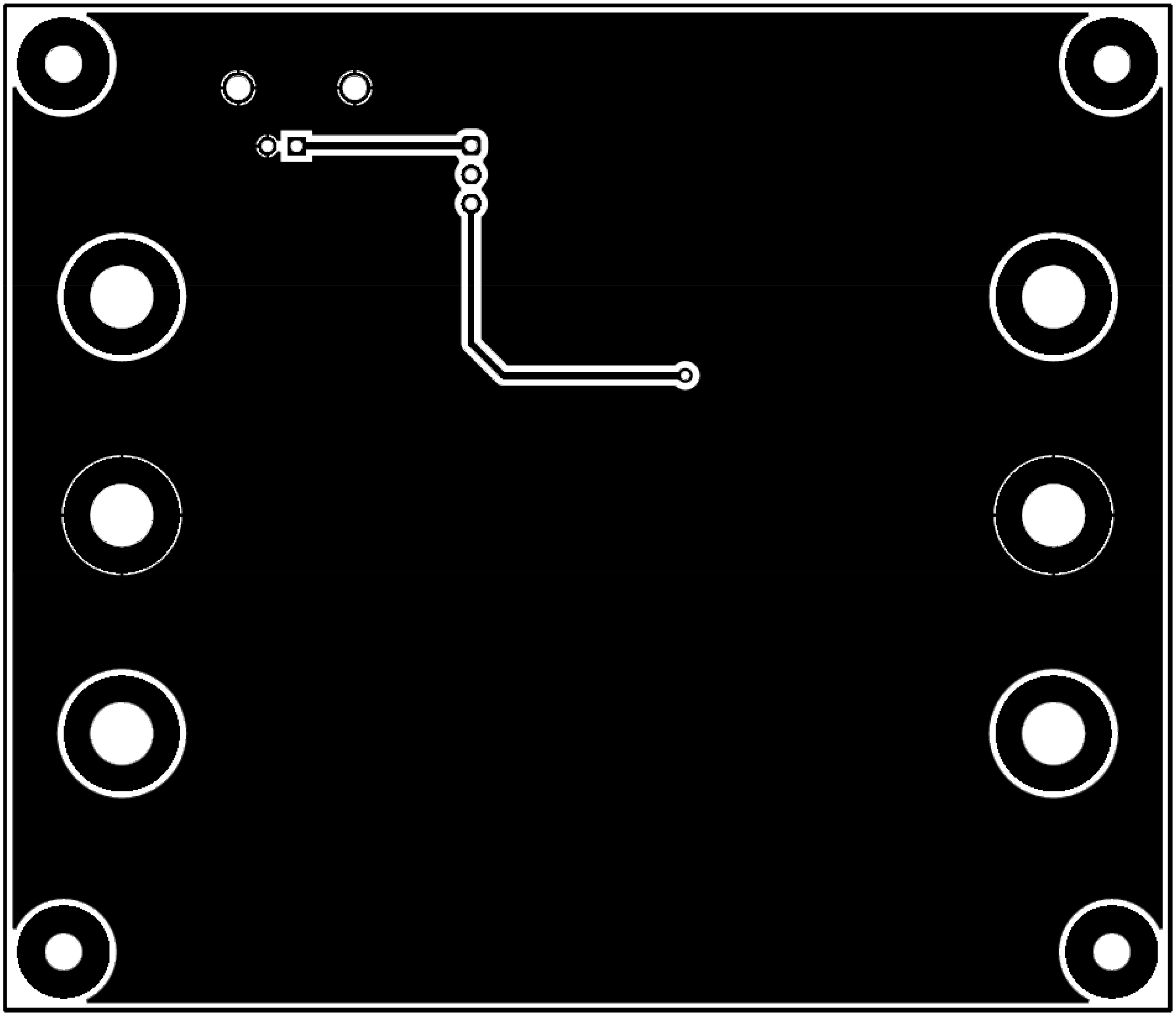

Figure 21. Bottom Layer

11 Schematic and Bill of Materials

11.1 Schematics

11.1.1 N Channel Schematic

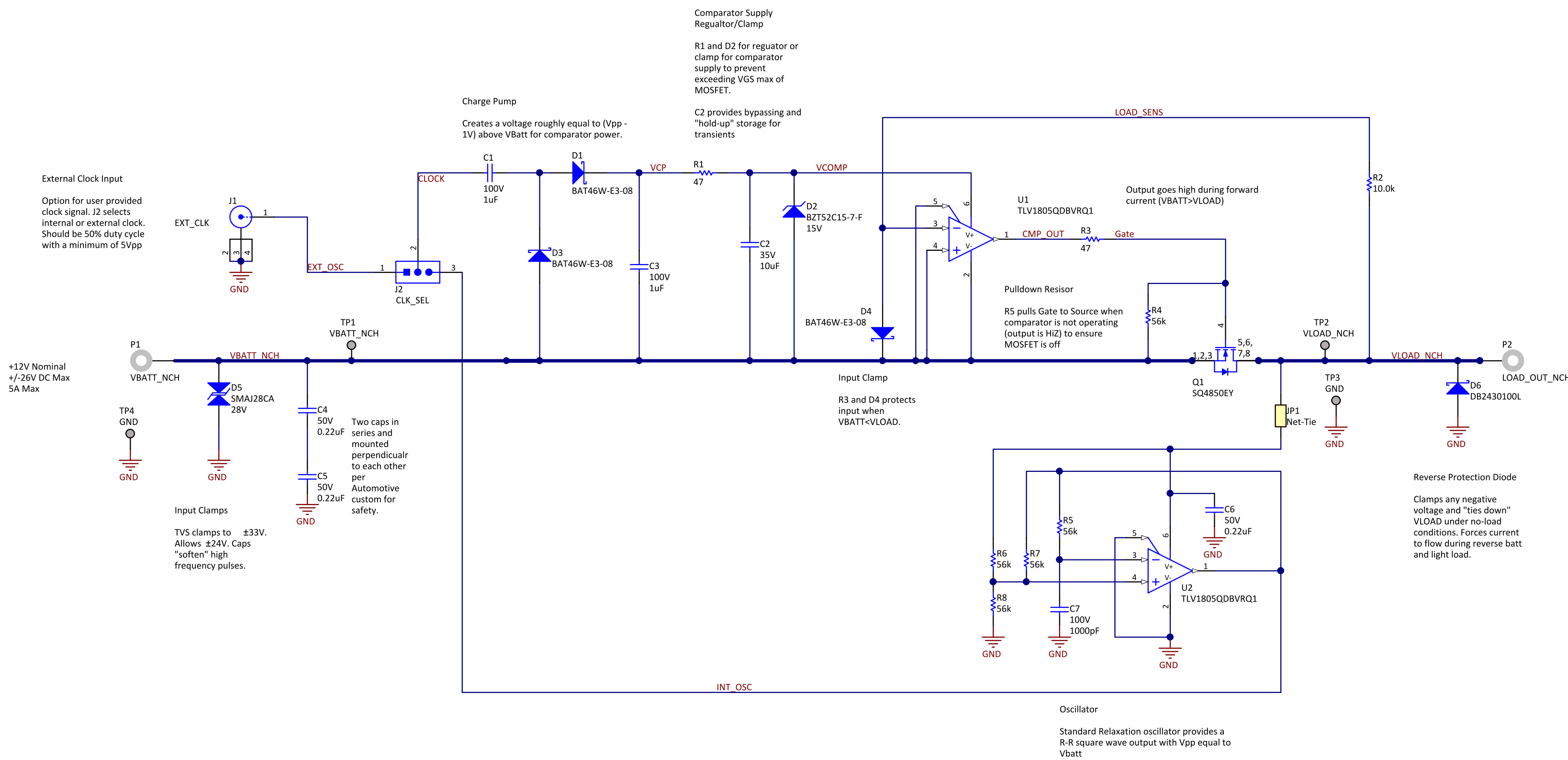

Figure 22. N-Channel Schematic

11.1.2 P Channel Schematic

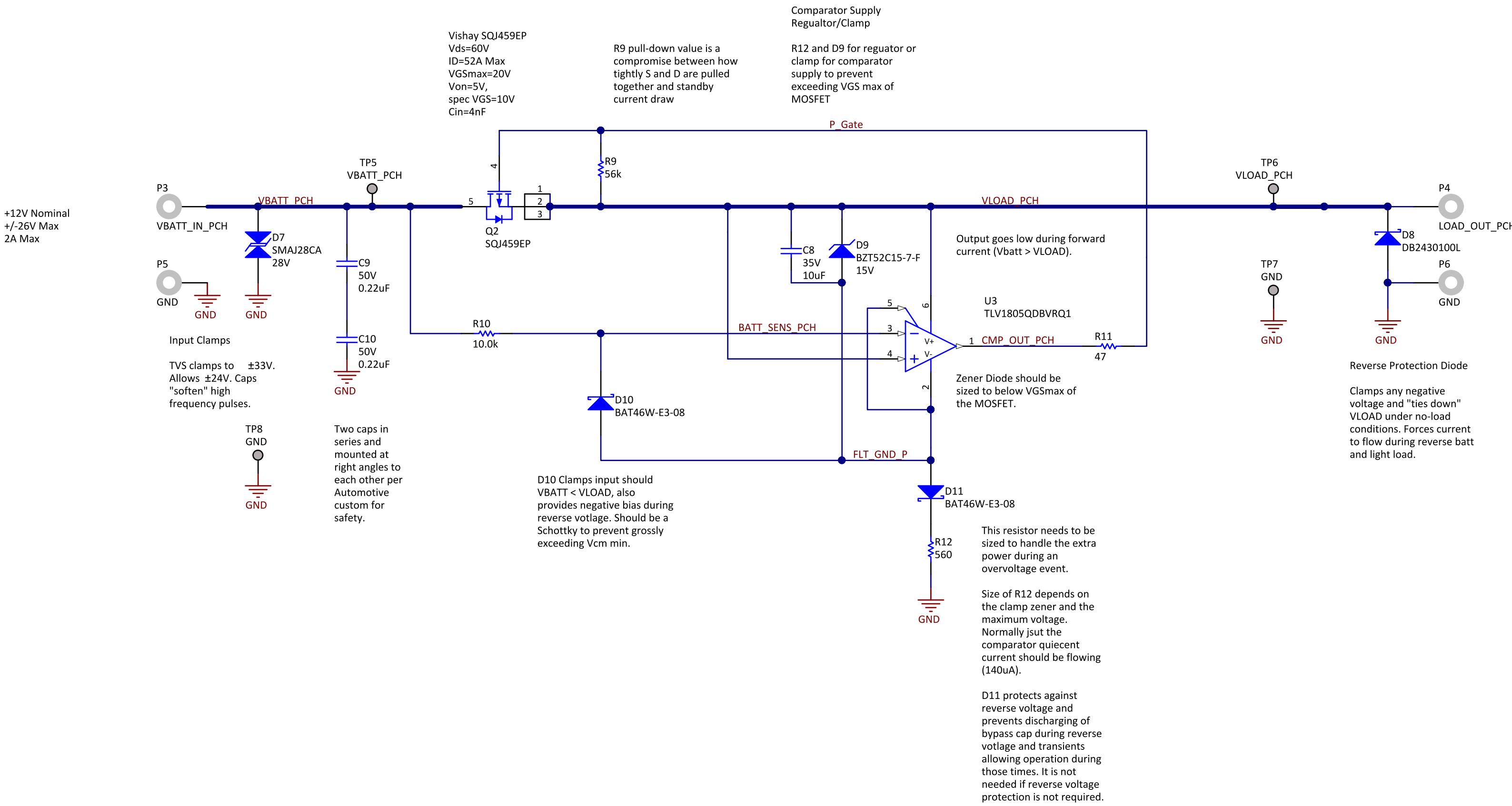

Figure 23. P-Channel Schematic

11.2 Bill of Materials

Table 2. Bill of Materials

Designator	Qty	Description	Manufacturer	Part Number
C1, C3	2	CAP, CERM, 1 uF, 100 V, +/- 20%, X7R, 1206	TDK	C3216X7R2A105M160AA
C2, C8	2	CAP, CERM, 10 uF, 35 V, +/- 20%, X7R, 1206_190	TDK	C3216X7R1V106M160AC
C4, C5, C6, C9, C10	5	CAP, CERM, 0.22 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	TDK	CGA3E3X7R1H224K080AB
C7	1	CAP, CERM, 1000 pF, 100 V, +/- 5%, C0G/NP0, 0603	MuRata	GRM1885C2A102JA01D
D1, D3, D4, D10, D11	5	Diode, Schottky, 100 V, 0.15 A, AEC-Q101, SOD-123	Vishay	BAT46W-E3-08
D2, D9	2	Diode, Zener, 15 V, 370 mW, AEC-Q101, SOD-123	Diodes Inc.	BZT52C15-7-F
D5, D7	2	Diode, TVS, Bi, 28 V, SMA	Littelfuse	SMAJ28CA
D6, D8	2	Diode, Schottky, 30 V, 2 A, SOD-128	Panasonic	DB2430100L
H1, H2, H3, H4	4	Machine Screw, Round, #4-40 x 1/4, Nylon, Philips Panhead	B&F Fastener Supply	NY PMS 440 0025 PH
H5, H6, H7, H8	4	Standoff, Hex, 0.5"L #4-40 Nylon	Keystone	1902C
J1	1	Jack, BNC, PCB, R/A, TH	TE Connectivity	1-1337543-0
J2	1	Header, 100mil, 3x1, Gold, TH	Samtec	TSW-103-07-G-S
P1, P2, P3, P4, P5, P6	6	Standard Banana Jack, Uninsulated, 8.9mm	Keystone	575-8
Q1	1	MOSFET, N-CH, 60 V, 12 A, SOIC-8	Vishay	SQ4850EY
Q2	1	MOSFET, P-CH, -60 V, -52 A, PowerPAK_SO-8L	Vishay	SQJ459EP
R1, R3, R11	3	RES, 47, 5%, 0.1 W, AEC-Q200 Grade 0, 0603	Panasonic	ERJ-3GEYJ470V
R2, R10	2	RES, 10.0 k, 1%, 0.1 W, 0603	Panasonic	ERJ-3EKF1002V
R4, R5, R6, R7, R8, R9	6	RES, 56 k, 5%, 0.1 W, 0603	Yageo	RC0603JR-0756KL
R12	1	RES, 560, 1%, 0.25 W, 1206	Yageo	RC1206FR-07560RL
SH-J1	1	Shunt, 2.54mm, Gold, Black	Wurth Elektronik	60900213421
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8	8	Natural PC Test Point, SMT	TE Connectivity	RCW-0C
U1, U2, U3	3	Automotive 40-V, microPower, Push-Pull Comparator with Shutdown, DBV0006A (SOT-23-6)	Texas Instruments	TLV1805QDBVRQ1

12 Related Documentation

- Texas Instruments, *TLV1805-Q1 Datasheet* (SNOSD52)
- Texas Instruments, *Reverse Current Protection Using MOSFET and Comparator to Minimize Power Dissipation* (SNOA971)

13 Trademarks

All other trademarks are the property of their respective owners.

STANDARD TERMS FOR EVALUATION MODULES

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

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

3 *Regulatory Notices:*

   3.1 *United States*

   3.1.1 *Notice applicable to EVMs not FCC-Approved:*

   FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

   3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

   CAUTION

   This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

   Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

   FCC Interference Statement for Class A EVM devices

   NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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

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

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

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

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

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

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

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

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

8. *Limitations on Damages and Liability:*

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

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

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265