TPS92691 SEPIC LED Driver Evaluation Board

This user's guide describes the characteristics, operation, and use of the TPS92691 SEPIC Evaluation Module (EVM). A complete schematic diagram, printed-circuit board layouts, and bill of materials are included in this document.

Contents

List of Figures

List of Tables

1 Introduction

The TPS92691EVM-001 evaluation module (EVM) helps designers evaluate the operation and performance of the TPS92691-Q1 and TPS92691, a multi-topology controller designed for automotive lighting and general illumination applications. The TPS92691EVM-001 uses the TPS92691-Q1 (AEC Q100) IC; however, for general illumination and other non-automotive applications, the TPS92691 is available in the same package and pin configuration and with identical performance characteristics. The TPS92691-Q1 device implements fixed-frequency peak current mode control technique with programmable switching frequency, slope compensation and startup timing. It incorporates a low offset rail-to-rail current sense amplifier that can directly measure LED current over an output voltage range of 0 V to 65 V. Additional features include wide input voltage range (0 V to 65 V), PWM dimming capability, analog dimming capability, adjustable/syncable switching frequency, input undervoltage protection, output overvoltage protection and switch cycle-by-cycle current limit. The controller can be used to implement a range of LED driver topologies including Boost, Buck-Boost (Boost-to-Battery), SEPIC, Cuk, and Flyback, based on the output LED stack voltage.

2 Description

The TPS92691EVM-001 is a fully assembled and tested SEPIC LED driver designed to power a single string of series-connected LEDs. Accurate closed-loop LED current regulation is achieved using a low-offset current sense amplifier that is compatible with either high- or low-side current-sensing implementations. The DC current set point can be varied over a 15:1 ratio using the high-impedance analog adjust (IADJ) input. An integrated gate-driver circuit and proprietary PWM dimming logic is incorporated to enable external series FET PWM dimming with greater than 100:1 dimming ratio.

LED short-circuit failure and other cable harness fault detection is facilitated by current monitor output (IMON), which reports the instantaneous status of LED current measured by the rail-to-rail current sense amplifier. The current monitor output is used in conjunction with microcontroller or discrete circuitry to implement customized fault protection schemes.

2.1 Typical Applications

This converter design describes an application of the TPS92691-Q1 device as a SEPIC LED driver with the specifications described in Table 1. For applications with a different input voltage range or different output voltage range, refer to the TPS92691-Q1 datasheet.

2.2 Features

- Versatile LED driver capable of driving a string of 1 to 20 series-connected white LEDs
- Wide input voltage range (4.5 V to 40 V): Supports automotive start-stop and load dump transients (65 V_{max})
- Compatible with high- or low-side current sense resistor locations
- Simple microcontroller interface to set LED current reference and PWM duty cycle
- Integrated gate-drive circuit to enable series FET dimming
- Instantaneous current monitor output to facilitate LED fault detection and mitigation
- Supports Boost, Buck-Boost (Boost-to-Battery), SEPIC, Cuk, and Flyback LED driver topologies

3 Connector Description

This section describes the connectors and test points on the EVM and how to properly connect, setup, and use the TPS92691EVM-001.

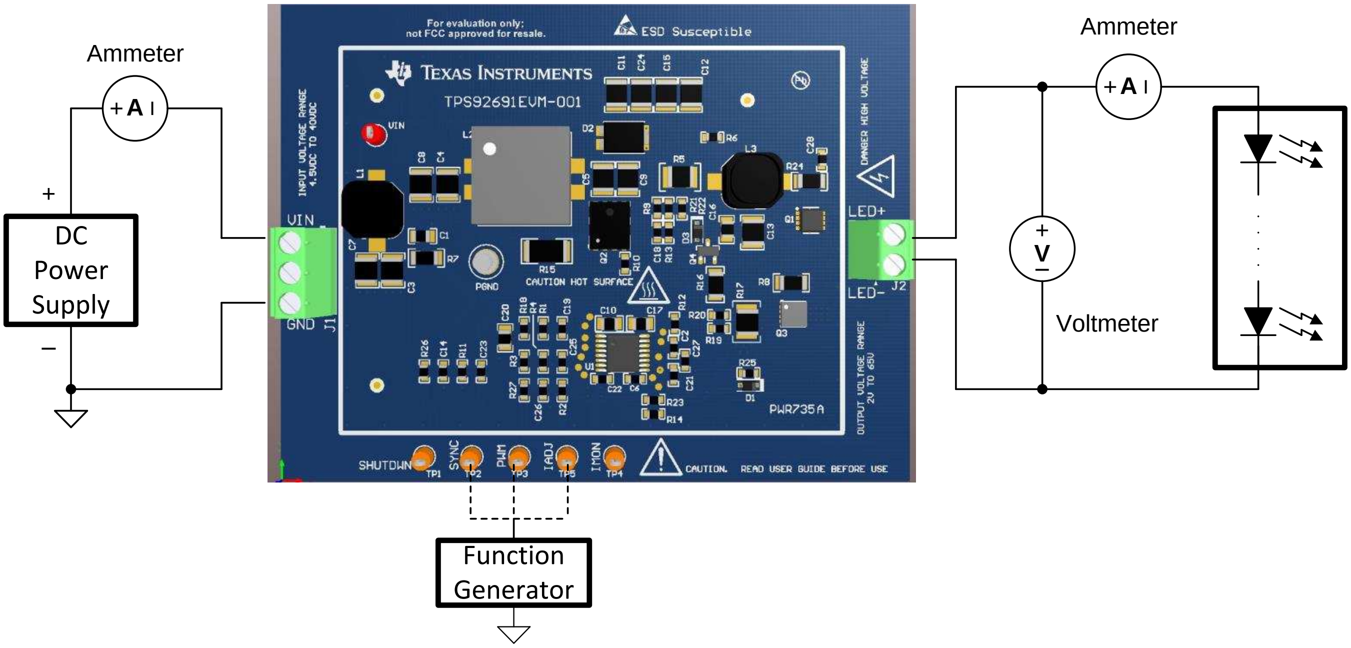


Figure 1. Connection Diagram

3.1 J1, VIN, GND

The screw-down connector, J1, marked VIN and GND is for connecting the EVM to the DC input voltage supply. One other VIN and PGND test point is provided on the board that can also be used for all purposes but input power.

3.2 J2, LED+, LED–

The screw-down connector, J2, marked LED+ and LED– is for connecting the LED load to the board. The leads to the LED load should be twisted and kept as short as possible to minimize voltage drop, inductance, and EMI transmission. This design is for approximately 1 to ≈20 white LEDs.

3.3 TP1, SHUTDOWN

The test point SHUTDOWN connects through a 1-kΩ resistor to the SS pin of the TPS92691-Q1 device. The voltage range is from 0 V to 5 V, if driven externally. The SS voltage can be monitored with this test point. Pulling SHUTDOWN to GND will also serve to disable the part and put it into STANDBY mode.

3.4 TP2, SYNC

The SYNC test point is AC-coupled to the RT/SYNC pin of the TPS92691-Q1 device through a 100-pF capacitor. Apply a square wave with pulse width greater than 200 ns and logic-low level of GND and a high level between 3 V and 5 V to synchronize the switching frequency to the applied frequency. The frequency range of SYNC is from 332 kHz to 449 kHz (±15%) for the nominal set point of 390-kHz switching frequency.

3.5 TP3, PWM

The PWM test point connects through a 1-kΩ resistor to the PWM pin of the TPS92691-Q1 device. Leave open for normal operation. If PWM dimming is used, apply a square wave with a low level of GND and a high level of between 3 V and 5 V. The dimming frequency range is 100 Hz to 1 kHz.

3.6 TP5, IADJ

The IADJ test point connects through a two-pole low-pass filter to the IADJ pin of the TPS92691-Q1 device. The default reference is set to 420 mV through a resistor divider network connected to VCC resulting in output current of 300 mA. The voltage on IADJ can be externally set using either a pulse width modulated signal from function generator or a DC power supply between 140 mV to over 2.4 V. For more details on setting analog adjust voltage refer to Section 6.5.

3.7 TP4, IMON

The IMON test point connects directly to the IMON pin of the TPS92691-Q1 device. The IMON voltage, corresponding to measured LED current by integrated rail-to-rail current sense amplifier, can be monitored with this test point. The pin can be connected to an external comparator or microcontroller to detect LED short-circuit, LED+ to VIN, and LED+ to GND fault conditions.

4 Electrical Performance Specifications

Table 1. TPS92691EVM-001 Electrical Performance Specifications

Parameter	Test Conditions	MIN	TYP	MAX	Unit
Input Characteristics					
Input voltage range		7	14	40	V
Input UVLO setting			4.5		V
Maximum switch node voltage				100	V
Output Characteristics					
Output voltage, VOUT	LED+ to LED–	2	40	65	V
Output current		100	300	1700	mA
Maximum output power				25	W
Analog dimming range	V_{IADJ} = 140 mV to 2.4 V	17:1			
PWM dimming range	240-Hz PWM frequency	100:1			
Systems Characteristics					
Efficiency	Input voltage = 14 V, 13 LEDs, I_{LED} = 300 mA		90%		
Switching frequency			390		kHz

5 Schematic

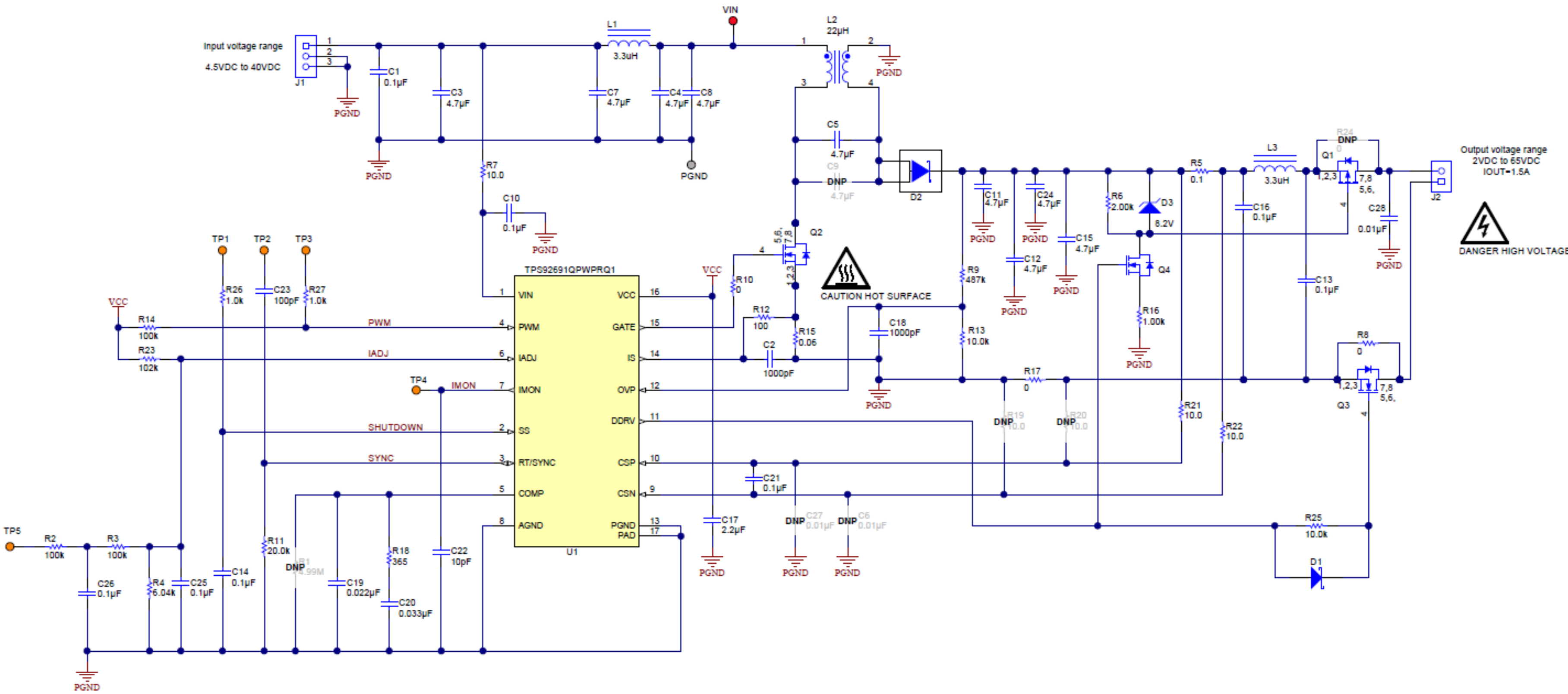


Figure 2. TPS92691EVM-001 Schematic: Configured With a High-Side Current Sense and a High-Side Series PFET Device

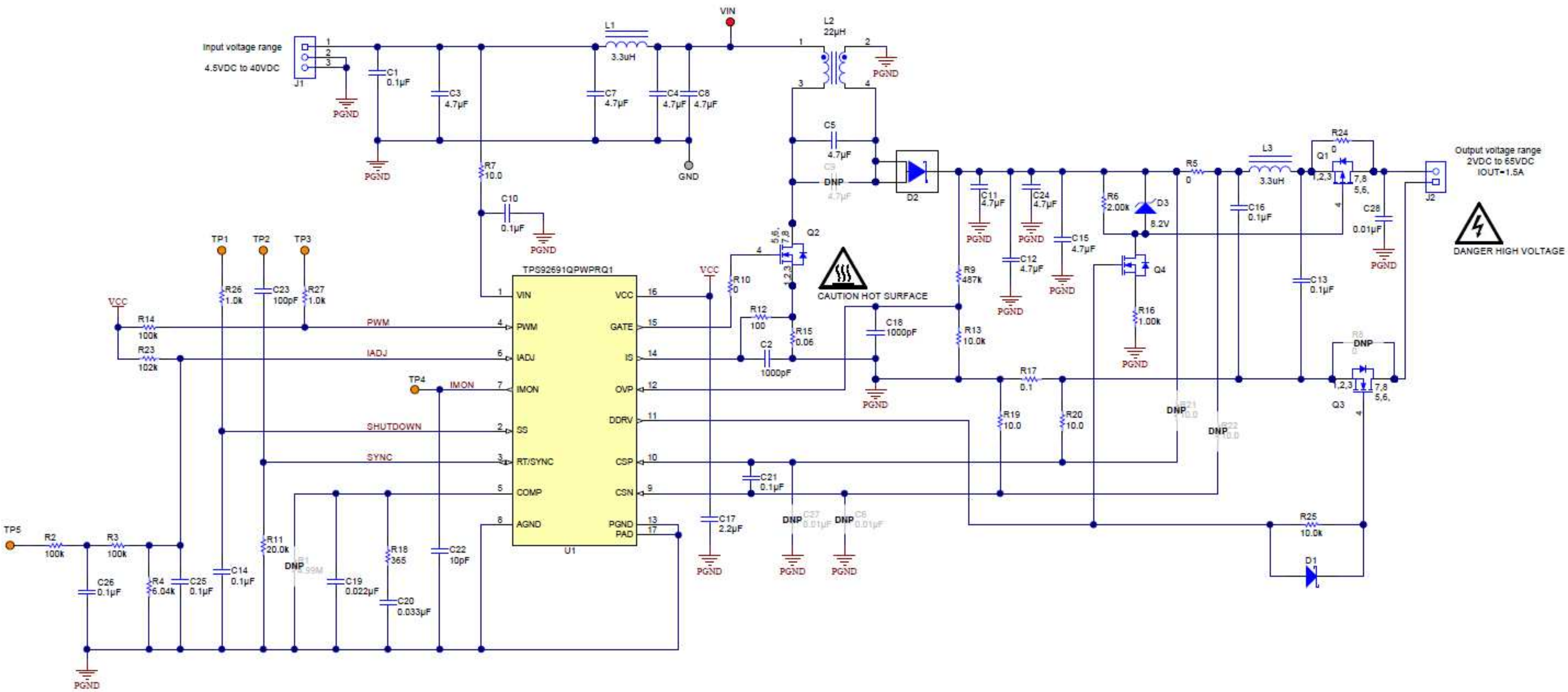


Figure 3. Alternate Configuration With a Low-Side Current Sense and a Low-Side Series NFET Device

6 Performance Data and Typical Characteristic Curves

The following performance curves are presented for the EVM configured with a high-side current sense resistor and a series PFET device (Figure 2). The EVM circuit can be modified to implement low-side current sense and series NFET dimming (Figure 3), with minor differences in performance.

6.1 Efficiency

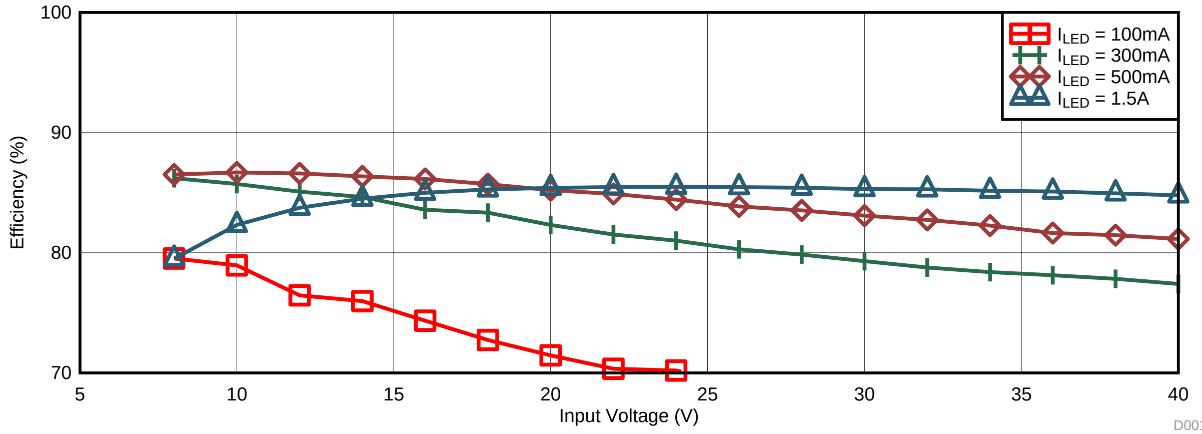


Figure 4. Efficiency vs Input Voltage (Number of series connected LEDs = 3)

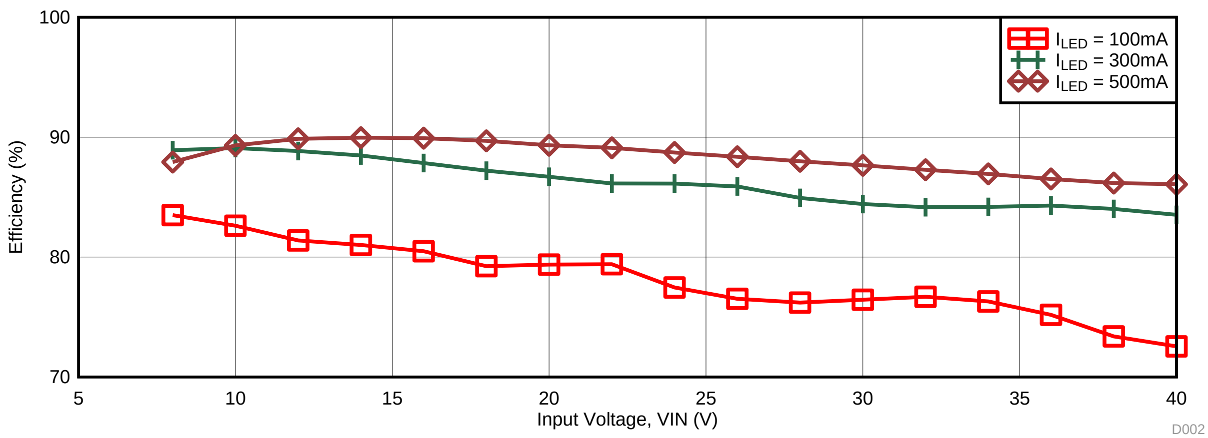


Figure 5. Efficiency vs. Input Voltage (Number of series connected LEDs = 7)

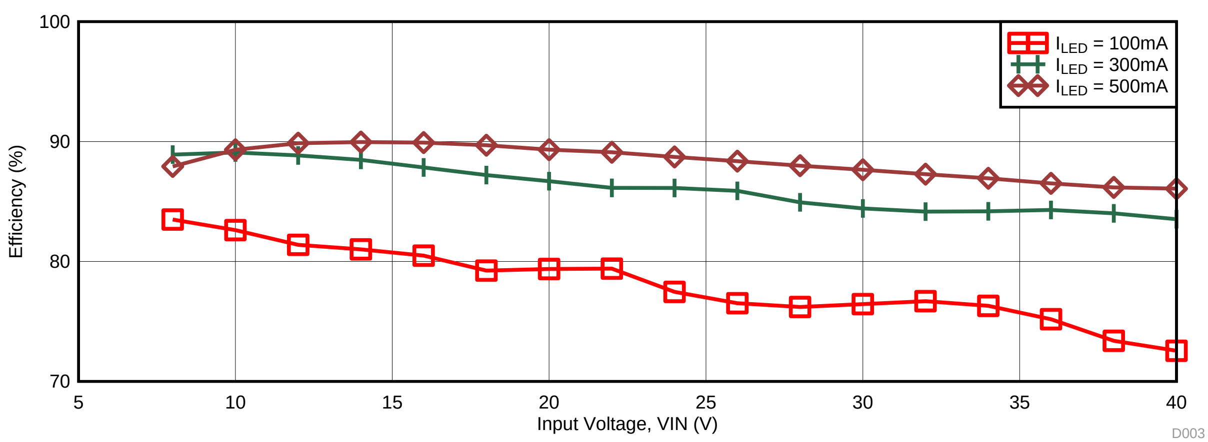


Figure 6. Efficiency vs. Input Voltage (Number of Series-Connected LEDs = 13)

6.2 Line Regulation

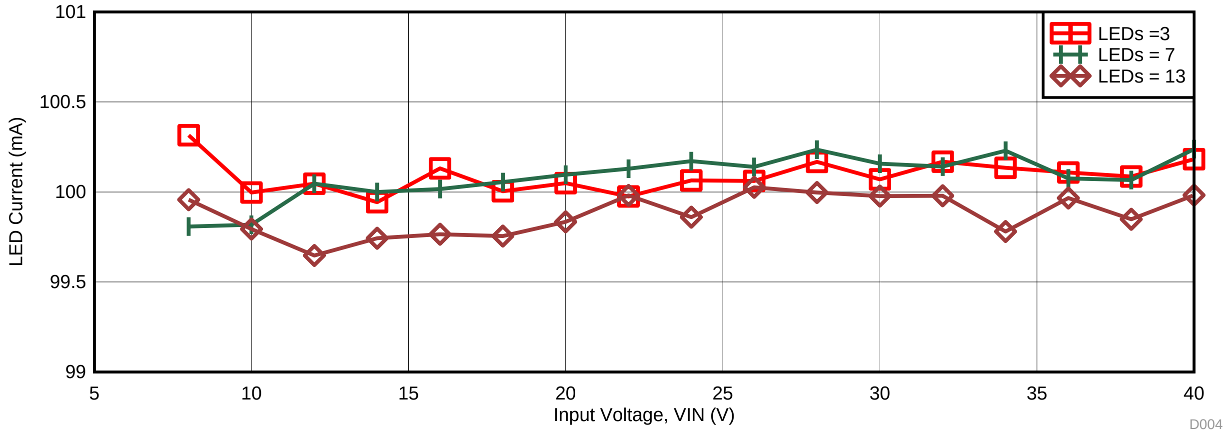


Figure 7. Output LED Current vs Input Voltage (V_{IADJ} = 140 mV)

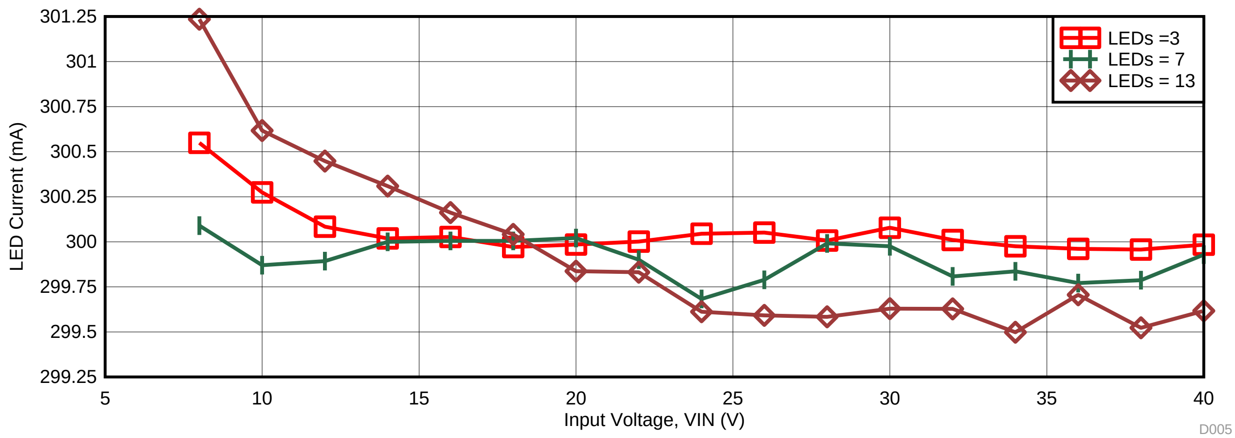


Figure 8. Output LED Current vs Input Voltage (V_{IADJ} = 420 mV)

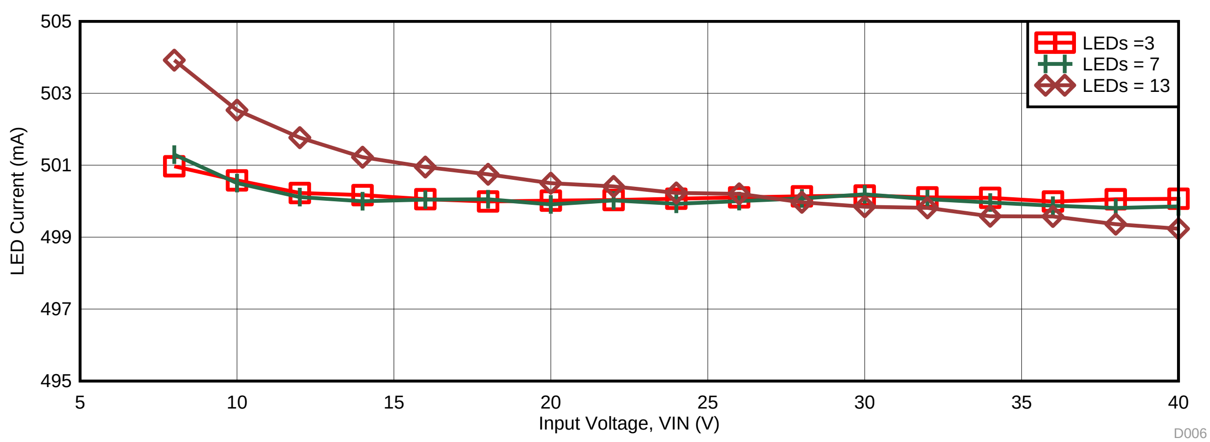


Figure 9. Output LED Current vs Input Voltage (V_{IADJ} = 700 mV)

6.3 Load Regulation

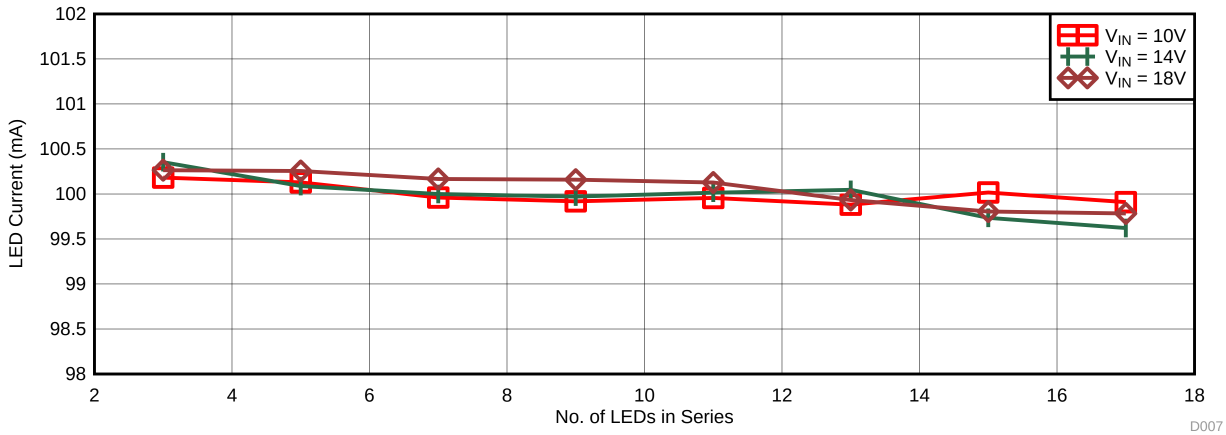


Figure 10. Output LED Current vs. LED String Configuration (V_{IADJ} = 140 mV)

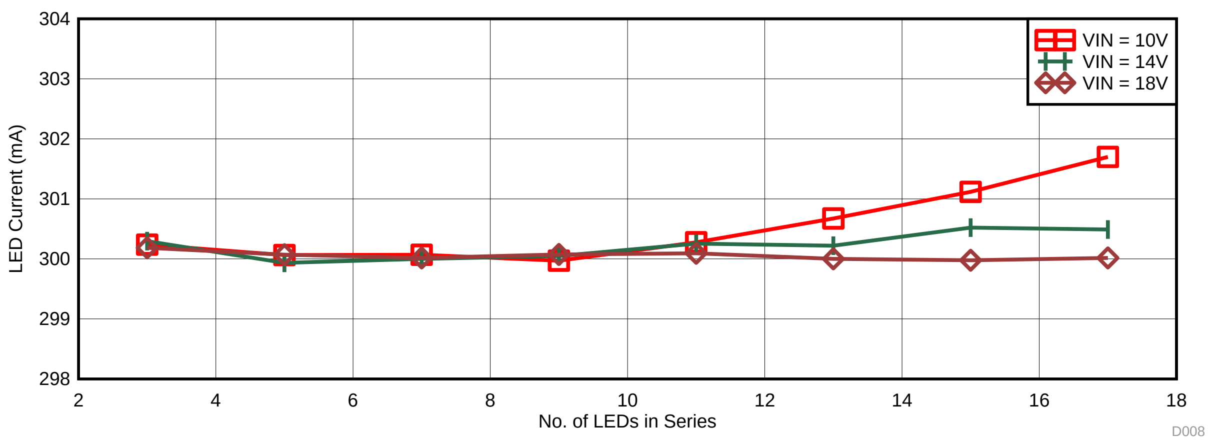


Figure 11. Output LED Current vs. LED String Configuration (V_{IADJ} = 420 mV)

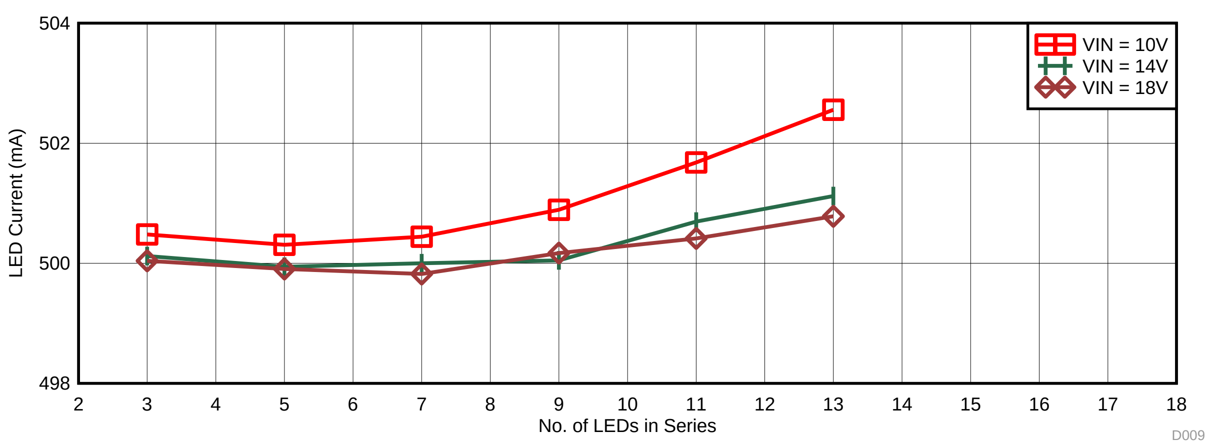


Figure 12. Output LED Current vs. LED String Configuration (V_{IADJ} = 700 mV)

6.4 Temperature Characteristics

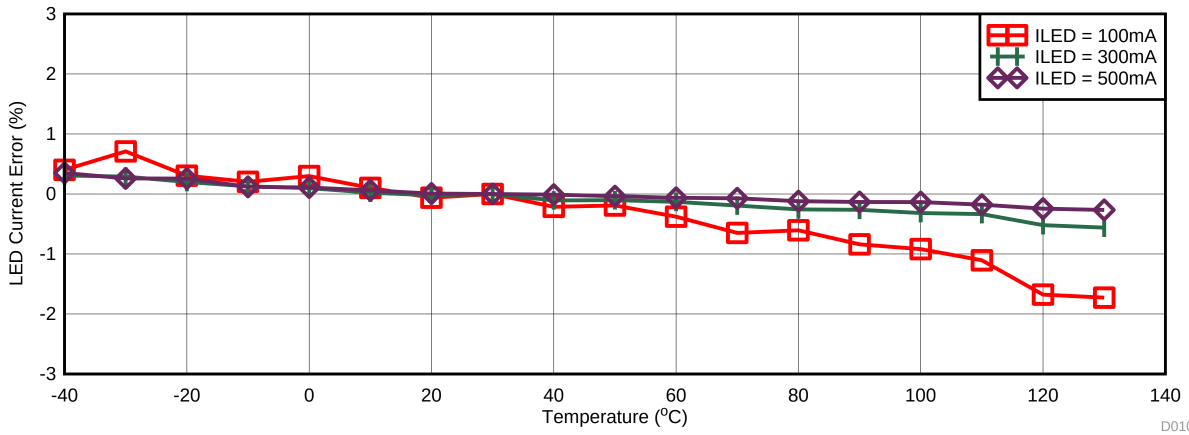


Figure 13. LED Current Error vs. Ambient Temperature (VIN = 14 V, Number of LEDs in series = 3)

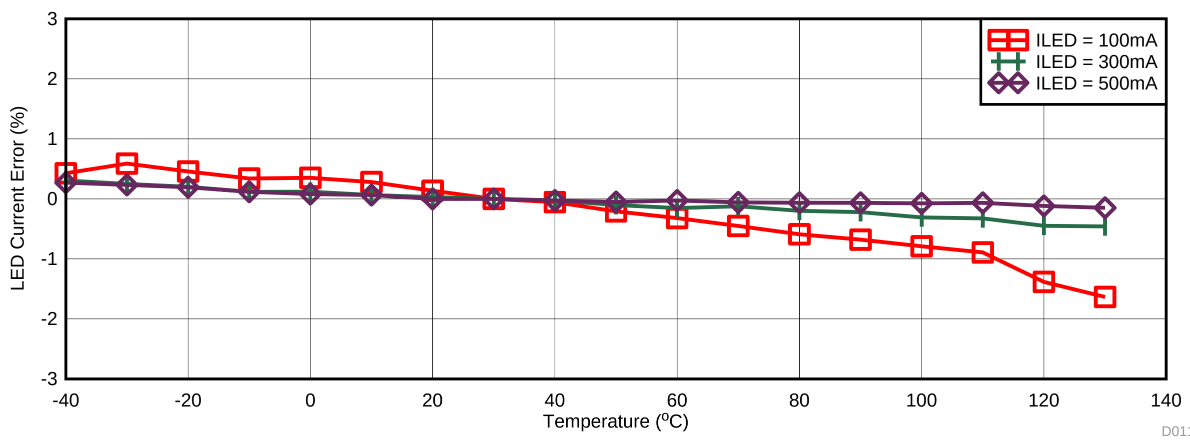


Figure 14. LED Current Error vs. Ambient Temperature (VIN = 14 V, Number of LEDs in series = 7)

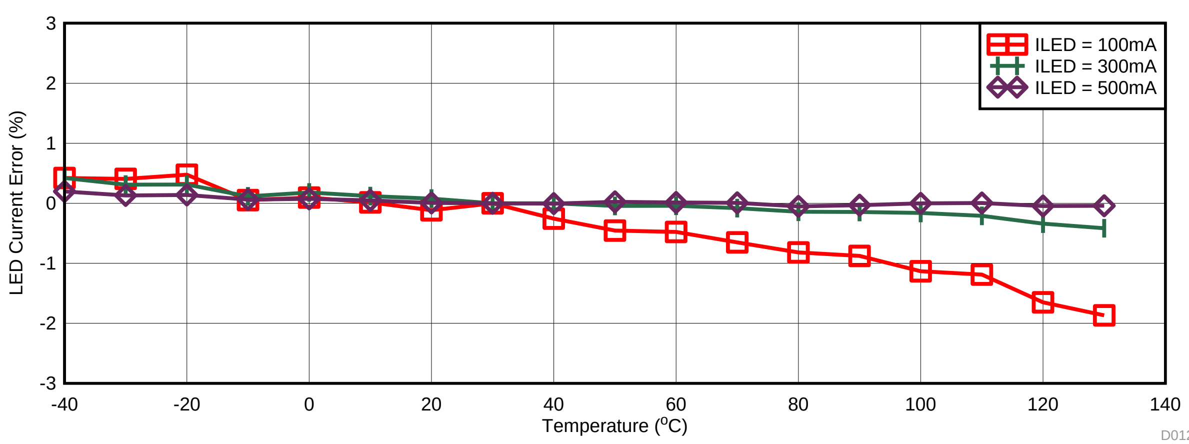


Figure 15. LED Current Error vs. Ambient Temperature (VIN = 14 V, Number of LEDs in series = 13)

6.5 Analog Adjust Settings

LED current can be varied from 100 mA to 1.7 A by varying the voltage at analog adjust, IADJ pin from 140 mV to 2.4 V, respectively. The EVM is configured with the IADJ voltage, V_{IADJ}, set to 420 mV using resistor divider network, R23 and R4 between VCC and GND. The resulting LED current is 300 mA for a current sense resistor, R_{CS} = R5, of 100 mΩ. Calculation is based on:

$$I_{LED} = \frac{V_{IADJ}}{14}\frac{1}{R_{CS}}$$

The desired LED current can be achieved by setting the corresponding voltage, V_{IADJ} and reconfiguring the resistor divider network, R23 and R4. The internal reference clamp of 2.4 V can be activated by depopulating resistor R4 and connecting IADJ to VCC through pull-up resistor R23.

External control via IADJ test point, TP5 can be enabled by **depopulating** resistor R23 and R4. The IADJ voltage and hence the LED current can be modulated over the entire operating range by connecting a DC power supply or a function generator across TP5 to GND. To ensure proper operation and limit temperature rise, the maximum output power should be limited to 25 W for any given LED stack voltage and LED current combination.

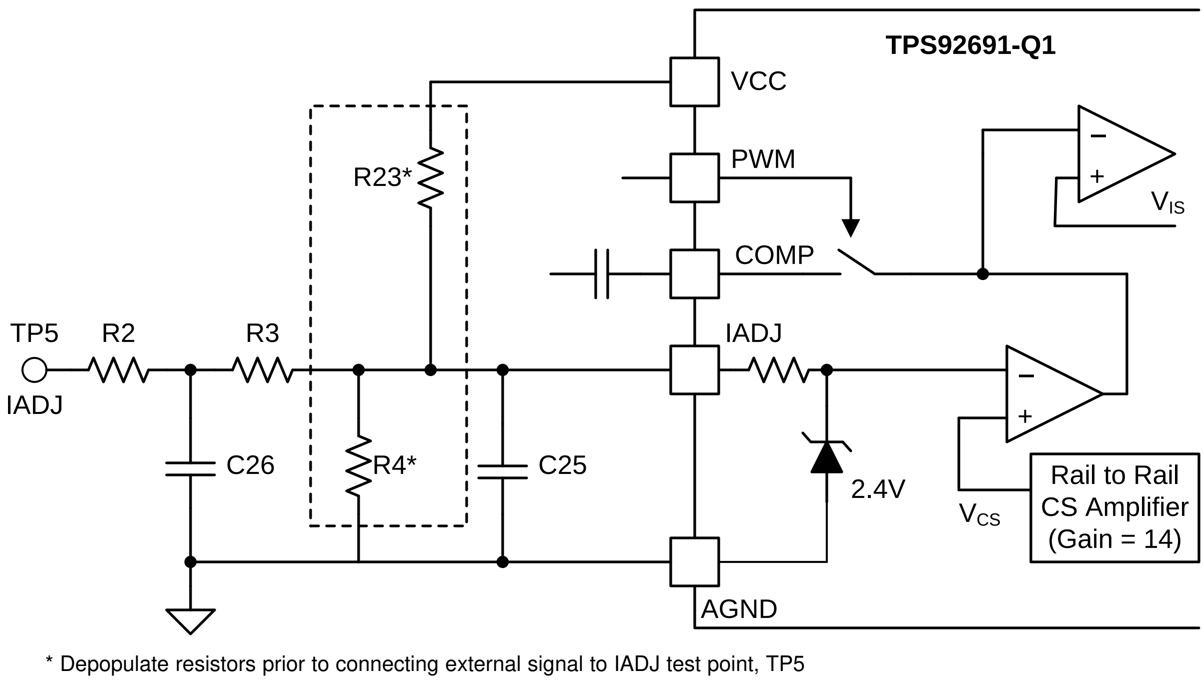


Figure 16. Circuit Configurations to Set Analog Adjust Reference Voltage

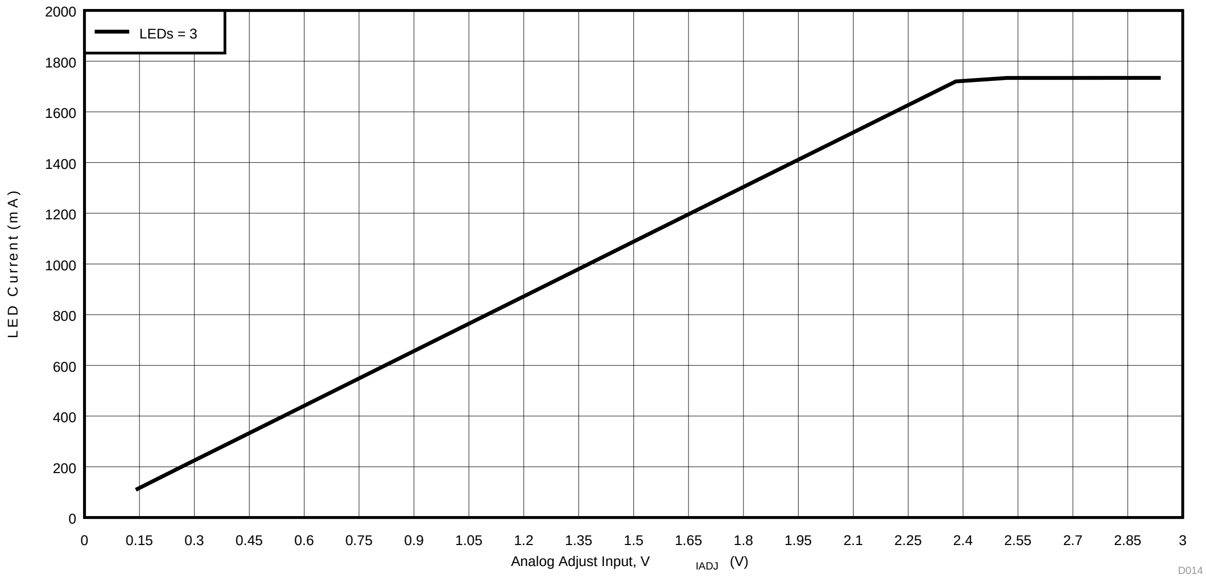


Figure 17. Output LED Current vs. IADJ Voltage, V_{IADJ} (VIN = 14 V, Number of LEDs in Series = 3)

6.6 PWM Dimming

In order to enable EVM at power-up, the PWM pin of TPS92691-Q1 is tied to VCC through a 100-kΩ pullup resistor, R14. The PWM pin can be over-driven by connecting an external digital signal, generated through a microcontroller or function generator, to PWM test point, TP3. PWM pin can be pulled to ground to disable switching under fault conditions.

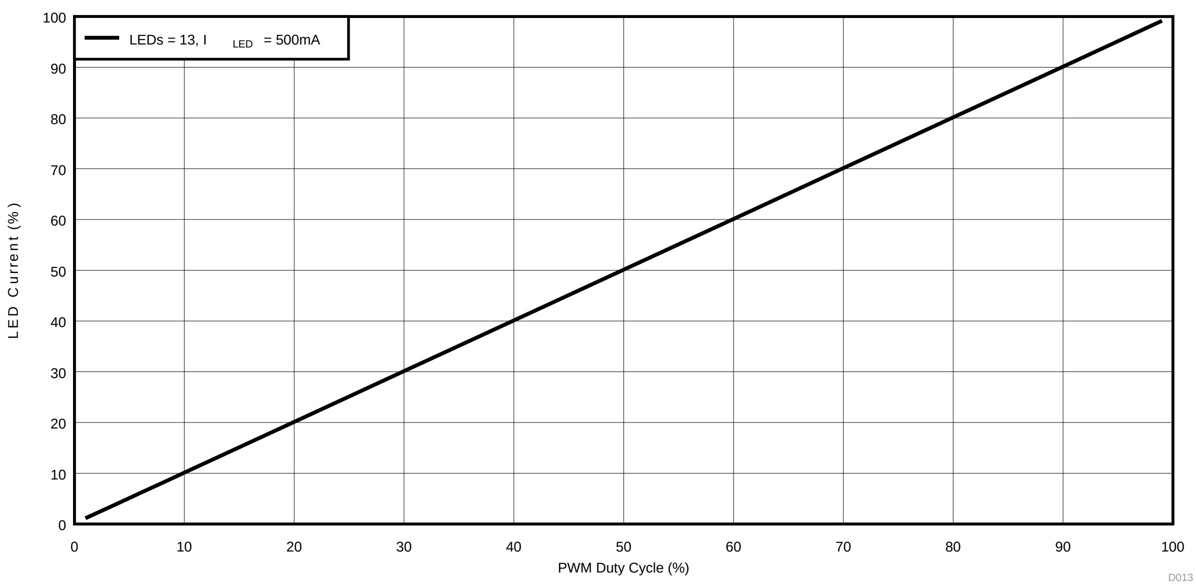


Figure 18. Normalized LED Current vs. PWM Duty Cycle (V_{IADJ} = 700 mV, Number of LEDs in series = 13)

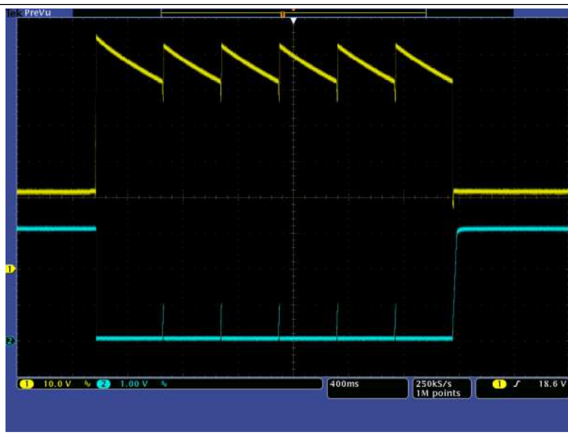
6.7 Typical Waveforms

Ch1: Input voltage; Ch2: SS pin voltage;
Ch3: Input current; Ch4: LED current; Time: 10 ms/div

Figure 19. Soft-Start Sequence

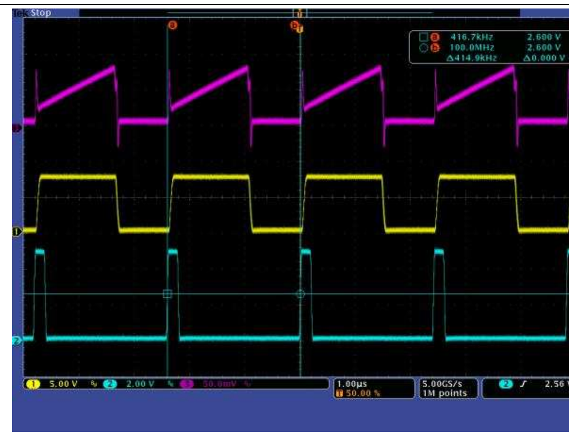
Ch1: Q2 Drain voltage;
Ch2: Switch current sense (R15) voltage;
Ch4: LED current; Time: 1 µs/div

Figure 20. Nominal Operation



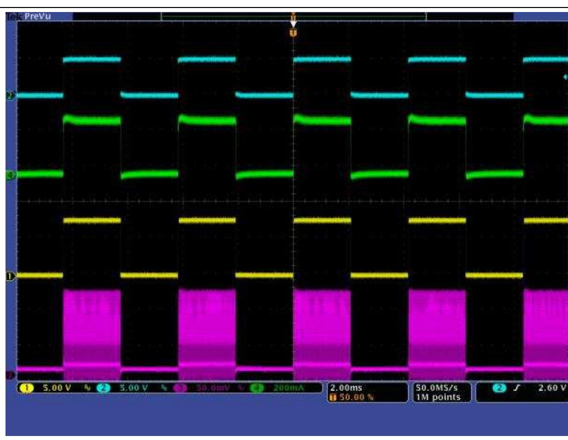
Ch1: C_{OUT} = C24, SEPIC output voltage;
Ch2: SS pin voltage; Time: 400 ms/div

Figure 21. Over-Voltage Protection



Ch1: GATE voltage; Ch2: SYNC input, TP2;
Ch3: Switch sense current resistor (R15) voltage, Time: 1 µs/div

Figure 22. SYNC Operation

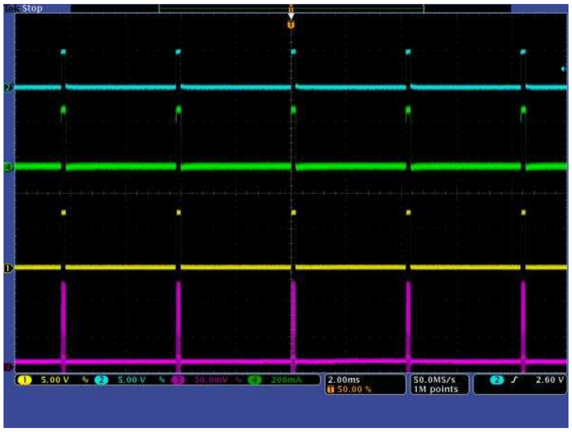


Ch1: DDRV voltage; Ch2: PWM input, TP3;
Ch3: Switch sense current resistor (R15) voltage;
Ch4: LED current; Time: 2 ms/div

Figure 23. PWM Dimming (Duty Cycle = 50 %, Frequency = 240 Hz)

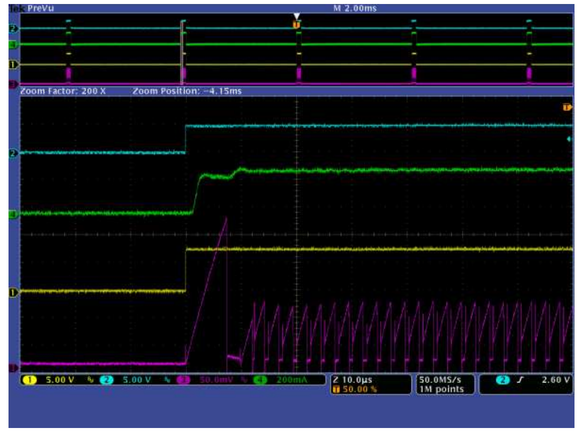
Ch1: DDRV voltage; Ch2: PWM input,
Ch3: Switch sense current resistor (R15) voltage;
Ch4: LED current; Time: 10 µs/div

Figure 24. PWM Dimming (Duty cycle = 50 %, Frequency = 240 Hz)



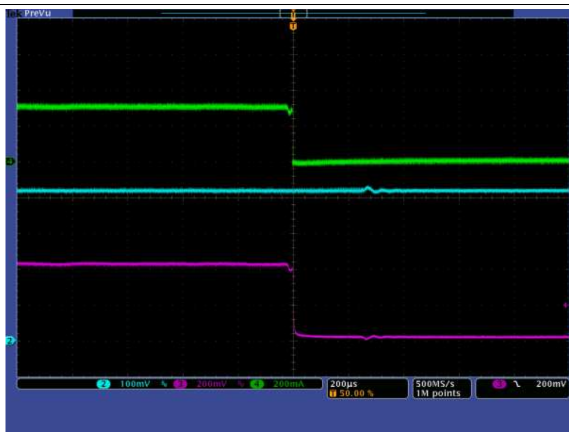
Ch1: DDRV voltage; Ch2: PWM input, TP3;
Ch3: Switch sense current resistor (R15) voltage;
Ch4: LED current; Time: 2 ms/div

Figure 25. PWM Dimming (Duty cycle = 4%, Frequency = 240 Hz)



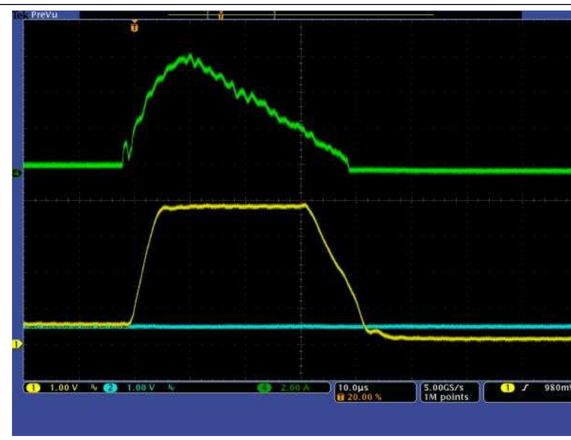
Ch1: DDRV voltage; Ch2: PWM input, TP3;
Ch3: Switch sense current resistor (R15) voltage;
Ch4: LED current; Time: 10 µs/div

Figure 26. PWM Dimming (Duty cycle = 4%, Frequency = 240 Hz)



Ch2: IADJ voltage; Ch3: IMON voltage;
Ch4: LED current; Time: 200 µs/div

Figure 27. IMON Response to LED Open-Circuit Fault

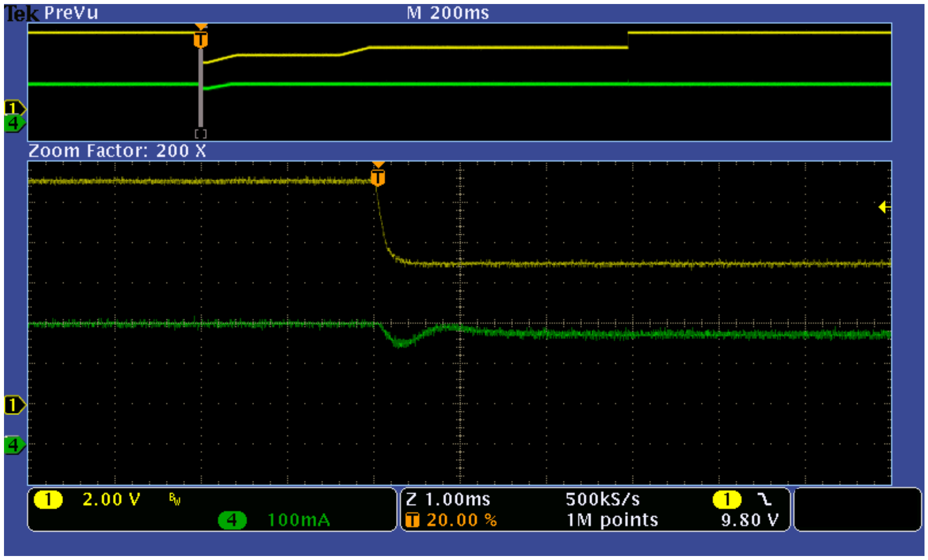


Ch1: IMON voltage; Ch2: IADJ voltage;
Ch4: LED current; Time: 10 µs/div

Figure 28. IMON Response to LED Short-Circuit Fault

Ch1: Input voltage; Ch4: LED current; Time: 200 ms/div

Figure 29. Start-Stop (Warm-Crank) Transient Response



Ch1: Input voltage; Ch4: LED current; Time: 1 ms/div

Figure 30. Start-Stop (Warm-Crank)Transient Response

6.8 EMI

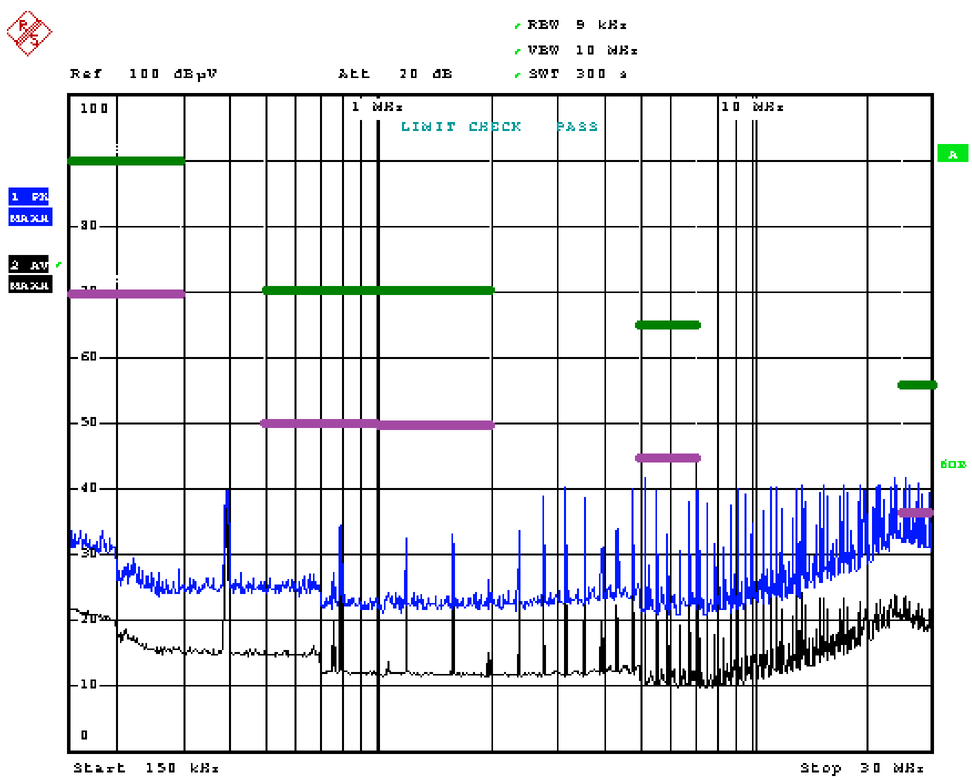


Figure 31. Conducted EMI Based on CISPR 25 Class 3 Limits

7 Optimizing EVM Performance Based on LED String Voltage and Current

The default EVM schematic is configured to operate over a wide range of LED currents (100 mA to 1.7 A) and string configurations (1 to 20 LEDs). The driver operation, efficiency and transient response can be improved by re-configuring the schematic for a given LED current and LED string forward voltage drop. The LED current sense resistor, (R_{CS} = R5 = R17) value can be calculated based on the maximum allowable differential voltage of 172 mV which is achieved by pulling the IADJ pin to VCC through an external resistor. The slope compensation voltage can be adjusted by changing the switch current sense resistor, R_{IS} = R15, based on the maximum expected LED stack voltage. The proportional integral compensation network can be tuned to achieve high bandwidth and desired phase margin for a specified range of input and output voltages. For more details and design procedure refer to the TPS92691-Q1 datasheet.

8 TPS92691EVM-001 Assembly Drawing and PCB layout

Figure 32, Figure 33, and Figure 34 show the design and assembly of the TPS92691EVM-001 printed circuit board.

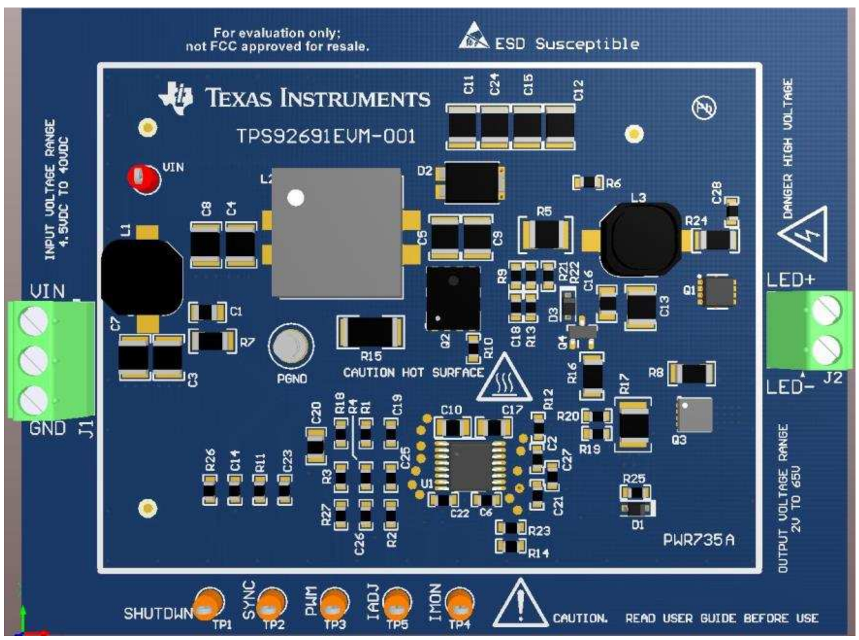


Figure 32. Assembly Drawing

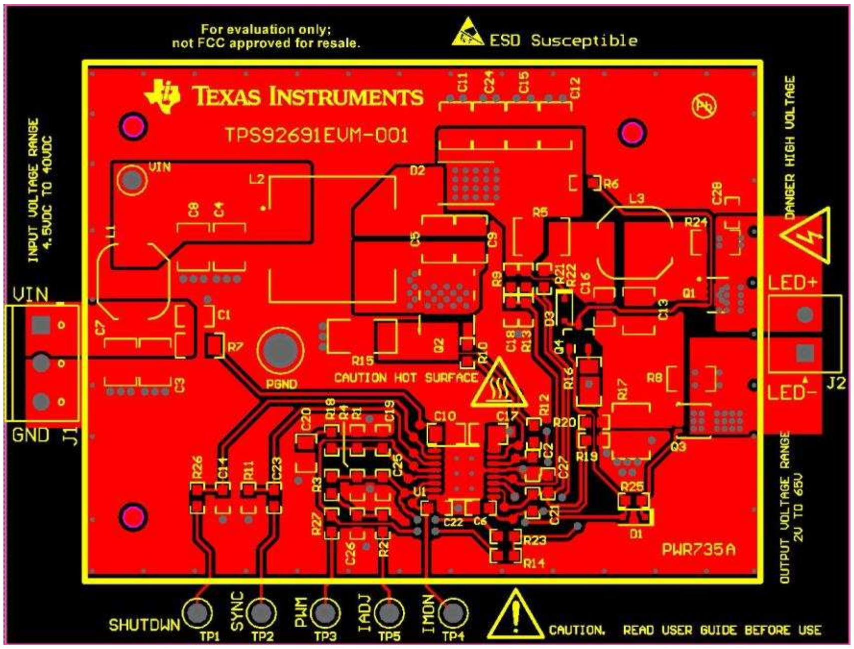


Figure 33. Top Layer and Top Overlay (Top View)

Figure 34. Bottom Layer and Bottom Overlay (Bottom View)

9 Bill of Materials

Table 2 lists the TPS92691EVM-001 components list according to the schematic shown in Figure 2.

Table 2. Bill of Materials

Designator	Qty	Value	Description	Package	PartNumber	Manufacturer
U1	1		Multi-Topology LED Driver with Rail-to-Rail Current Sense Amplifier	PWP0016J	TPS92691QPWPRQ1	Texas Instruments
C1	1	0.1uF	CAP, CERM, 0.1 µF, 100 V, +/- 10%, X7R	0805	C0805C104K1RACTU	Kemet
C2, C18	2	1000pF	CAP, CERM, 1000 pF, 100 V, +/- 5%, C0G/NP0	0603	C1608C0G2A102J	TDK
C3, C4, C5, C7, C8, C11, C12, C15, C24	9	4.7uF	CAP, CERM, 4.7 µF, 100 V, +/- 10%, X7S, 1210	1210	C3225X7S2A475K200AE	TDK
C10, C16	2	0.1uF	CAP, CERM, 0.1 µF, 100 V, +/- 10%, X7R	0805	C2012X7R2A104K	TDK
C13	1	0.1uF	CAP, CERM, 0.1 µF, 100 V, +/- 10%, X7R	1210	GRM32NR72A104KA01L	MuRata
C14, C25, C26	3	0.1uF	CAP, CERM, 0.1 µF, 25 V, +/- 10%, X8R	0603	C1608X8R1E104K	TDK
C17	1	2.2uF	CAP, CERM, 2.2 µF, 16 V, +/- 10%, X7R	0805	C2012X7R1C225K	TDK
C19	1	0.022uF	CAP, CERM, 0.022 µF, 16 V, +/- 10%, X7R	0603	GRM188R71C223KA01D	MuRata
C20	1	0.033uF	CAP, CERM, 0.033 µF, 25 V, +/- 10%, X7R	0805	GRM216R71E333KA01D	MuRata
C21	1	0.1uF	CAP, CERM, 0.1 µF, 100 V, +/- 10%, X7R	0603	GRM188R72A104KA35D	MuRata
C22	1	10pF	CAP, CERM, 10 pF, 50 V, +/- 5%, C0G/NP0	0603	C1608C0G1H100D	TDK
C23	1	100pF	CAP, CERM, 100 pF, 50 V, +/- 5%, C0G/NP0	0603	C1608C0G1H101J	TDK
C28	1	0.01uF	CAP, CERM, 0.01 µF, 100 V, +/- 10%, X8R	0603	C1608X8R2A103K	TDK
D1	1	30V	Diode, Schottky, 30 V, 0.2 A, SOD-323	SOD-323	BAT54HT1G	ON Semiconductor
D2	1	100V	Diode, Schottky, 100 V, 3 A, AEC-Q101	PowerDI5	PDS3100Q-13	Diodes Inc.
D3	1	8.2V	Diode, Zener, 8.2 V, 200 mW	SOD-323	MMSZ5237BS-7-F	Diodes Inc.
L1, L3	2	3.3uH	Inductor, Shielded, Ferrite, 3.3 µH, 5 A	6.2x4.5	CLF7045T-3R3N	TDK
L2	1	22uH	Coupled inductor, 22 µH, 7.26 A	12.3x8.05	MSD1278T-223MLB	Coilcraft
Q1	1	-100V	MOSFET, P-CH, -100 V, -13.2 A	1212	SI7113DN-T1-GE3	Vishay-Siliconix
Q2	1	100V	MOSFET, N-CH, 100 V, 20 A, AEC-Q101	8-PowerVDFN	STL8N10LF3	STMicroelectronics
Q3	1	100V	MOSFET, N-CH, 100 V, 3.8 A	8-PowerVDFN	DMN10H120SFG-13	Diodes Inc.
Q4	1	100V	MOSFET, N-CH, 100 V, 1.4 A, SOT-23	SOT-23	DMN10H220L-7	Diodes Inc.
R2, R3, R14	3	100k	RES, 100 k, 1%, 0.1 W, 0603	0603	CRCW0603100KFKEA	Vishay-Dale
R4	1	6.04k	RES, 6.04 k, 1%, 0.1 W, 0603	0603	CRCW06036K04FKEA	Vishay-Dale
R5	1	0.1	RES, 0.1, 1%, 0.33 W, 1210	1210	ERJ-L14KF10CU	Panasonic
R6	1	2.00k	RES, 2.00 k, 1%, 0.1 W, 0603	0603	CRCW06032K00FKEA	Vishay-Dale
R7	1	10.0	RES, 10.0, 1%, 0.25 W, 1206	1206	CRCW120610R0FKEA	Vishay-Dale
R8	1	0	RES, 0, 5%, 0.25 W, 1206	1206	CRCW12060000Z0EA	Vishay-Dale

Table 2. Bill of Materials (continued)

Designator	Qty	Value	Description	Package	PartNumber	Manufacturer
R9	1	487k	RES, 487 k, 1%, 0.1 W, 0603	0603	CRCW0603487KFKEA	Vishay-Dale
R10	1	0	RES, 0, 5%, 0.1 W, 0603	0603	CRCW06030000Z0EA	Vishay-Dale
R11	1	20.0k	RES, 20.0 k, 1%, 0.1 W, 0603	0603	CRCW060320K0FKEA	Vishay-Dale
R12	1	100	RES, 100, 1%, 0.1 W, 0603	0603	CRCW0603100RFKEA	Vishay-Dale
R13, R25	2	10.0k	RES, 10.0 k, 1%, 0.1 W, 0603	0603	CRCW060310K0FKEA	Vishay-Dale
R15	1	0.06	RES, 0.06, 1%, 1 W, 2010	2010	CSRN2010FK60L0	Stackpole
R16	1	1.00k	RES, 1.00 k, 1%, 0.25 W, 1206	1206	CRCW12061K00FKEA	Vishay-Dale
R17	1	0	RES, 0, 5%, 0.25 W, 1210	1210	MCR25JZHJ000	Rohm
R18	1	365	RES, 365, 1%, 0.1 W, 0603	0603	CRCW0603365RFKEA	Vishay-Dale
R21, R22	2	10.0	RES, 10.0, 1%, 0.1 W, 0603	0603	CRCW060310R0FKEA	Vishay-Dale
R23	1	102k	RES, 102 k, 1%, 0.1 W, 0603	0603	CRCW0603102KFKEA	Vishay-Dale
R26, R27	2	1.0k	RES, 1.0 k, 5%, 0.1 W, 0603	0603	CRCW06031K00JNEA	Vishay-Dale

STANDARD TERMS AND CONDITIONS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, or documentation (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.

   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 and conditions 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 and conditions 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 any defects that are 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. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.

   2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, 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:*

   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*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). 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 by Radio Law of Japan to follow the instructions below with respect to EVMs:

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

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 WRITTEN DESIGN MATERIALS PROVIDED WITH THE EVM (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 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 AND CONDITIONS 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 MADE, CONCEIVED OR ACQUIRED PRIOR TO OR AFTER DELIVERY OF THE EVM.

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 AND CONDITIONS. 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 ANDCONDITIONS OR THE USE OF THE EVMS PROVIDED HEREUNDER, 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 ONE YEAR AFTER THE RELATED CAUSE OF ACTION HAS OCCURRED.

8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY WARRANTY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS AND CONDITIONS, OR ANY USE OF ANY TI EVM PROVIDED HEREUNDER, EXCEED THE TOTAL AMOUNT PAID TO TI FOR THE PARTICULAR UNITS SOLD UNDER THESE TERMS AND CONDITIONS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM AGAINST THE PARTICULAR UNITS SOLD TO USER UNDER THESE TERMS AND CONDITIONS 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