TPS92682-Q1 Dual-Channel Constant-Voltage and Constant-Current Controller with SPI Interface

1 Features

• AEC-Q100 grade 1 qualified
• Wide input voltage range: 4.5 V to 65 V
• ± 4% LED current accuracy over –40°C to 150°C junction temperature Range
• SPI communication interface
• SPI programmable features:
  – Spread spectrum for Improved EMI
  – Soft-start timing
  – ILED current and output voltage settings
  – Current limit, overvoltage, fault-timer
  – Single vs dual phase
  – CV and CC mode configuration
• Dual channel peak-current-mode (PCM) controller
• Low Input offset rail-to-rail current sense amplifier
• Analog dimming
• External series FET PWM dimming with integrated P-channel driver interface
  – Over 1000:1 PWM dimming range
• Open drain fault flag indicator per channel
• Up to 1-MHz Programmable switching frequency with external clock synchronization capability
• Comprehensive programmable fault protection circuitry
• Wettable flank with VQFN package

2 Applications

• Automotive forward lighting
• Emergency vehicles
• General lighting

3 Description

The TPS92682-Q1 is a dual-channel, peak current-mode controller with SPI communication interface. The device is programmable to operate in constant-voltage (CV) or constant-current (CC) modes.

In CV mode, TPS92682-Q1 can be programmed to operate as two independent or dual-phase Boost voltage regulators. The output voltage can be programmed using an external resistor voltage divider, and a SPI-programmable 8-bit DAC.

In CC mode, the device is designed to support dual channel step-up or step-down LED driver topologies. LED current can be independently modulated using analog or PWM dimming techniques. Analog dimming with over 28:1 range is obtained using a programmable 8-bit DAC. PWM dimming of LED current is achieved either by directly modulating the PWM input pins with the desired duty cycle, or using a SPI-programmable 10-bit PWM counter. The optional PDRV gate driver output can be used to drive an external P-Channel series MOSFET.

The TPS92682-Q1 incorporates an advanced SPI-programmable diagnostic and fault protection mechanism including: cycle-by-cycle current limit, output overvoltage and undervoltage protection, ILED overcurrent protection, and thermal warning. The device also includes an open-drain fault indicator output per channel.

The TPS92682-Q1 includes an LH pin, when pulled high, initiates the limp home (LH) condition. In LH mode, the device uses a separate set of SPI-programmed registers.

Device Information\(^{(1)}\)

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS92682-Q1</td>
<td>VQFN (32)</td>
<td>5.0 mm x 5.0 mm</td>
</tr>
</tbody>
</table>

\(^{(1)}\) For all available packages, see the orderable addendum at the end of the data sheet.

![Typical Application](image-url)
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4 Revision History

Changes from Original (March 2019) to Revision A

• Changed from Advance Information to Production Data ................................................................. 1
## 5 Pin Configuration and Functions

**RHM Package**

32-Pin VQFN with PowerPAD

**Top View**

![Diagram of the RHM Package](image)

(Not to scale)

### Pin Functions

<table>
<thead>
<tr>
<th>PIN</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGND</td>
<td>30</td>
<td>P Signal ground</td>
</tr>
<tr>
<td>COMP1</td>
<td>29</td>
<td>I/O Connect to an integral or integral-proportional compensation network to ensure stability for channel-1</td>
</tr>
<tr>
<td>COMP2</td>
<td>12</td>
<td>I/O Connect to an integral or integral-proportional compensation network to ensure stability for channel-2</td>
</tr>
<tr>
<td>CSN1</td>
<td>27</td>
<td>I High-side current sense amplifier input (–) for channel-1</td>
</tr>
<tr>
<td>CSN2</td>
<td>14</td>
<td>I High-side current sense amplifier input (–) for channel-2</td>
</tr>
<tr>
<td>CSP1</td>
<td>26</td>
<td>I High-side current sense amplifier input (+) for channel-1</td>
</tr>
<tr>
<td>CSP2</td>
<td>15</td>
<td>I High-side current sense amplifier input (+) for channel-2</td>
</tr>
<tr>
<td>EN</td>
<td>2</td>
<td>I Hardware enable. Pull this pin low, to enter shutdown</td>
</tr>
<tr>
<td>FB1/OV1</td>
<td>25</td>
<td>I/O Connect using a resistor divider to VOUT1 to set OVP threshold (and VOUT in CV mode) for channel-1</td>
</tr>
<tr>
<td>FB2/OV2</td>
<td>16</td>
<td>I/O Connect using a resistor divider to VOUT2 to set OVP threshold (and VOUT in CV mode) for channel-2</td>
</tr>
<tr>
<td>FLT1</td>
<td>10</td>
<td>O Open drain fault output for channel-1 (or both channels if PIN-11 is programmed to be SYNC)</td>
</tr>
<tr>
<td>FLT2/SYNC</td>
<td>11</td>
<td>I/O Dual function pin (programmable) either open drain fault output for channel-2 or SYNC input</td>
</tr>
<tr>
<td>GATE1</td>
<td>22</td>
<td>I/O Channel-1 gate driver output for external N-channel FET</td>
</tr>
<tr>
<td>GATE2</td>
<td>19</td>
<td>I/O Channel-2 gate driver output for external N-channel FET</td>
</tr>
<tr>
<td>ISN1</td>
<td>24</td>
<td>I Switch current sense input (–) for channel-1. Connect to the GND connection of the external switch current sense resistor.</td>
</tr>
<tr>
<td>ISN2</td>
<td>17</td>
<td>I Switch current sense input (–) for channel-2. Connect to the GND connection of the external switch current sense resistor.</td>
</tr>
<tr>
<td>ISP1</td>
<td>23</td>
<td>I Switch current sense input (+) for channel-1. Connect to external switch current sense resistor between N-channel FET and ground.</td>
</tr>
<tr>
<td>ISP2</td>
<td>18</td>
<td>I Switch current sense input (+) for channel-2. Connect to external switch current sense resistor between N-channel FET and ground.</td>
</tr>
</tbody>
</table>
## Pin Functions (continued)

<table>
<thead>
<tr>
<th>PIN NAME</th>
<th>NO.</th>
<th>I/O</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH</td>
<td>9</td>
<td>I</td>
<td>Digital input, when set high, the device enters the limp home mode</td>
</tr>
<tr>
<td>MISO</td>
<td>7</td>
<td>O</td>
<td>SPI slave data output</td>
</tr>
<tr>
<td>MOSI</td>
<td>8</td>
<td>I</td>
<td>SPI slave data input</td>
</tr>
<tr>
<td>PDRV1</td>
<td>28</td>
<td>I/O</td>
<td>Channel-1 P-channel gate driver. Connect to gate of external series P-channel FET switch.</td>
</tr>
<tr>
<td>PDRV2</td>
<td>13</td>
<td>I/O</td>
<td>Channel-2 P-channel gate driver. Connect to gate of external series P-channel FET switch.</td>
</tr>
<tr>
<td>PWM1</td>
<td>3</td>
<td>I</td>
<td>Connect to external PWM signal to enable PWM dimming for channel-1</td>
</tr>
<tr>
<td>PWM2</td>
<td>4</td>
<td>I</td>
<td>Connect to external PWM signal to enable PWM dimming for channel-2</td>
</tr>
<tr>
<td>PGND</td>
<td>20</td>
<td>P</td>
<td>Power ground</td>
</tr>
<tr>
<td>RT</td>
<td>32</td>
<td>I/O</td>
<td>Set internal clock frequency by connecting a resistor to ground</td>
</tr>
<tr>
<td>SCK</td>
<td>6</td>
<td>I</td>
<td>SPI clock input</td>
</tr>
<tr>
<td>SSN</td>
<td>5</td>
<td>I</td>
<td>SPI chip select input</td>
</tr>
<tr>
<td>VCC</td>
<td>21</td>
<td>P</td>
<td>7.5-V low-dropout regulator output</td>
</tr>
<tr>
<td>VDD</td>
<td>31</td>
<td>P</td>
<td>5-V LDO output</td>
</tr>
<tr>
<td>VIN</td>
<td>1</td>
<td>P</td>
<td>High-voltage input (65 V) to internal LDO</td>
</tr>
</tbody>
</table>

## 6 Specifications

### 6.1 Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>VIN, EN, CSPx, CSNx</td>
<td>–0.3</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>CSPx to CSNx (3)</td>
<td>–0.3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>ISPx, ISNx</td>
<td>–0.3</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>SSN, SCK, MOSI, LH, RT, FLT?x</td>
<td>–0.3</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>FBx/OVx</td>
<td>–0.3</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>PWMx</td>
<td>–0.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Output voltage (4)</td>
<td>VCC, GATEx</td>
<td>–0.3</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>VDD</td>
<td>–0.3</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>PDRV</td>
<td>VCSP</td>
<td>VCSP</td>
</tr>
<tr>
<td></td>
<td>MISO</td>
<td>–0.3</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>COMPx</td>
<td>–0.3</td>
<td>4</td>
</tr>
<tr>
<td>Source current</td>
<td>IGATE, (pulsed &lt; 20 ns)</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>IDDRV, (pulsed &lt; 10 µs)</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Sink current</td>
<td>IGATE (pulse &lt; 20 ns)</td>
<td>500</td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>IDDRV (pulse &lt; 10 µs)</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Operating junction temperature, T_J</td>
<td>–40</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Storage temperature, T_STG</td>
<td>165</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) All voltages are with respect to GND unless otherwise noted.

(3) Continuous sustaining voltage

(4) All output pins are not specified to have an external voltage applied.
6.2 ESD Ratings

<table>
<thead>
<tr>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>±2000</td>
<td>V</td>
</tr>
<tr>
<td>±500</td>
<td>V</td>
</tr>
</tbody>
</table>

(1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

<table>
<thead>
<tr>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN</td>
<td>6.5</td>
<td>14</td>
<td>65 V</td>
</tr>
<tr>
<td>VIN, crank</td>
<td>4.5</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>V_{CSP}, V_{CSN}</td>
<td>0</td>
<td>60</td>
<td>V</td>
</tr>
<tr>
<td>f_{SW}</td>
<td>100</td>
<td>700</td>
<td>kHz</td>
</tr>
<tr>
<td>f_{SYNC}</td>
<td>0.8×f_{CLK}</td>
<td>1.2×f_{CLK}</td>
<td>Hz</td>
</tr>
<tr>
<td>f_{SS}</td>
<td>0.1</td>
<td>10</td>
<td>kHz</td>
</tr>
<tr>
<td>T_{A}</td>
<td>–40</td>
<td>125</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) For current sense common mode voltage below 6.5 V, PFET dimming may not be applied.

6.4 Thermal Information

<table>
<thead>
<tr>
<th>THERMAL METRIC(1)</th>
<th>TPS92682-Q1</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_{JJA} Junction-to-ambient thermal resistance</td>
<td>31.2</td>
<td>°C/W</td>
</tr>
<tr>
<td>R_{JJC(top)} Junction-to-case (top) thermal resistance</td>
<td>21.9</td>
<td>°C/W</td>
</tr>
<tr>
<td>R_{JJB} Junction-to-board thermal resistance</td>
<td>12.1</td>
<td>°C/W</td>
</tr>
<tr>
<td>ψ_{JT} Junction-to-top characterization parameter</td>
<td>0.2</td>
<td>°C/W</td>
</tr>
<tr>
<td>ψ_{JB} Junction-to-board characterization parameter</td>
<td>12.0</td>
<td>°C/W</td>
</tr>
<tr>
<td>R_{JJC(bot)} Junction-to-case (bottom) thermal resistance</td>
<td>2.3</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.
## 6.5 Electrical Characteristics

\(-40^\circ\text{C} < T_J < 150^\circ\text{C}, V_{INH} = 14\text{V}, \text{VIAD}, \text{DACx} = 0\times DF, C_{VCC} = 1\mu F, C_{VDD} = 1\mu F, C_{COMP} = 2.2nF, R_{CS} = 100m\Omega, R_T = 50k\Omega, V_{PWM} = 5\text{V},\) no load on GATE and PDRV, DIV=4 (unless otherwise noted)

### PARAMETER

<table>
<thead>
<tr>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT VOLTAGE (VIN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(I_{IN-SHDN}) Input shutdown current</td>
<td>(V_{EN} = 0\text{ V}, V_{CSP} = V_{CSN} = V_{PDRV} = 0\text{ V})</td>
<td>10</td>
<td></td>
<td>(\mu A)</td>
</tr>
<tr>
<td>(I_{IN-STBY}) Input standby current</td>
<td>Software EN1 and EN2 = 0, (V_{PWM1} = V_{PWM2} = 0\text{ V})</td>
<td>2.3</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>(I_{IN-SW}) Supply switching current</td>
<td>(V_{CC}=7.5\text{V}, \text{C}_{\text{GATEx}} = 1nF, ) Both channels are switching</td>
<td>10</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>VCC BIAS SUPPLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{CCU/LLO}) Supply under-voltage protection</td>
<td>VCC rising threshold, (V_{VIN} = 8\text{ V})</td>
<td>4.5</td>
<td>4.9</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>VCC falling threshold, (V_{VIN} = 8\text{ V})</td>
<td>3.7</td>
<td>4.1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Hysteresis</td>
<td>411</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>(I_{VCC\text{(REG)}}) VCC regulation voltage</td>
<td>No load</td>
<td>7</td>
<td>7.5</td>
<td>8</td>
</tr>
<tr>
<td>(I_{VCC\text{(LIMIT)}}) VCC current limit</td>
<td>(V_{VCC} = 0\text{ V})</td>
<td>40</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>(V_{CCDO}) VCC LDO dropout voltage</td>
<td>(V_{VCC} = 30\text{ mA}, V_{VIN} = 4.5\text{ V})</td>
<td>300</td>
<td>475</td>
<td>mV</td>
</tr>
<tr>
<td>VDD BIAS SUPPLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{DD\text{(REG)}}) VDD regulation voltage</td>
<td>No load</td>
<td>4.85</td>
<td>5</td>
<td>5.25</td>
</tr>
<tr>
<td>(V_{DD\text{(POR-RISE)}}) VDD rising threshold</td>
<td>(V_{VIN} = 5\text{ V})</td>
<td>4.1</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>(V_{DD\text{(POR-FALL)}}) VDD falling threshold</td>
<td>(V_{VIN} = 5\text{ V})</td>
<td>2.58</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>(V_{DDO}) VDD LDO dropout voltage</td>
<td>(I_{VDD} = 15\text{ mA}, V_{VIN} = 4.5\text{ V})</td>
<td>400</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>(I_{VDD\text{(LIMIT)}}) VDD current limit</td>
<td>(V_{VDD} = 0\text{ V})</td>
<td>30</td>
<td>39</td>
<td>50</td>
</tr>
<tr>
<td>ENABLE INPUT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{EN}) EN voltage threshold</td>
<td></td>
<td>1.12</td>
<td>1.21</td>
<td>1.3</td>
</tr>
<tr>
<td>(V_{EN-HYS}) EN pin hysteresis</td>
<td>Difference between rising and falling threshold</td>
<td>100</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>(I_{EN}) EN PIN input bias current</td>
<td>(V_{EN} = 14\text{ V})</td>
<td>5</td>
<td></td>
<td>(\mu A)</td>
</tr>
<tr>
<td>OSCILLATOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(I_{SW}) Switching frequency</td>
<td>(RT = 200k\Omega, \text{DIV}=4)</td>
<td>85</td>
<td>100</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>(RT = 50k\Omega, \text{DIV}=4)</td>
<td>340</td>
<td>400</td>
<td>460</td>
</tr>
<tr>
<td>(V_{RT}) RT PIN voltage</td>
<td></td>
<td>1</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>SPREAD SPECTRUM DAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(DAC_{DT\text{-BITS}}) Internal DAC resolution</td>
<td></td>
<td>8</td>
<td></td>
<td>Bits</td>
</tr>
<tr>
<td>(DAC_{DT\text{-MAX}}) DAC maximum voltage</td>
<td></td>
<td>1.156</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>(DAC_{DT\text{-MIN}}) DAC minimum voltage</td>
<td></td>
<td>855</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>GATE DRIVER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R_{GH}) Driver pull-up resistance</td>
<td>(I_{GATE} = -10\text{ mA})</td>
<td>5.1</td>
<td>11.2</td>
<td></td>
</tr>
<tr>
<td>(R_{GL}) Driver pull-down resistance</td>
<td>(I_{GATE} = 10\text{ mA})</td>
<td>4.1</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>SWITCH CURRENT SENSE and ILIMIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{ILIM\text{(THR)}}) (\text{ILIM threshold PWM = LOW})</td>
<td>(V_{PWM}= 0\text{ V}, \text{CHxILIM} = \text{XX})</td>
<td>649</td>
<td>711</td>
<td>769</td>
</tr>
<tr>
<td></td>
<td>(V_{PWM}= 5\text{ V}, \text{CHxILIM} = 11\text{ X})</td>
<td>228</td>
<td>253</td>
<td>277</td>
</tr>
<tr>
<td></td>
<td>(V_{PWM}= 5\text{ V}, \text{CHxILIM} = 10\text{ X})</td>
<td>132</td>
<td>151</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>(V_{PWM}= 5\text{ V}, \text{CHxILIM} = 01\text{ X})</td>
<td>82</td>
<td>100.6</td>
<td>119</td>
</tr>
<tr>
<td></td>
<td>(V_{PWM}= 5\text{ V}, \text{CHxILIM} = 00\text{ X})</td>
<td>57</td>
<td>75.2</td>
<td>93</td>
</tr>
<tr>
<td>(I_{ILIM\text{(BLANK)}}) Leading edge blanking</td>
<td>(\text{CHxLEB} = 0\text{ X})</td>
<td>75</td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>(\text{CHxLEB} = 1\text{ X})</td>
<td>150</td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>
Electrical Characteristics (continued)

\(-40°C < T_J < 150°C, V_{IN} = 14V, VIADJDACx = 0xDF, C_{VCC} = 1\mu F, C_{VDD} = 1\mu F, C_{COMP} = 2.2nF, R_{CS} = 100\text{m}\Omega, R_T = 50\text{k}\Omega, V_{PWM} = 5V, \text{no load on GATE and PDRV, DIV}=4\) (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I_{\text{ILIMIT(DELAY)}})</td>
<td>IS to GATEx delay</td>
<td>86</td>
<td></td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>PWM COMPARATOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D_{\text{MAX}})</td>
<td>Maximum duty cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(V_{\text{LVx-Delta}})</td>
<td>Difference between CH1 and CH2 PWM comparator offset</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(I_{\text{LVx}})</td>
<td>IS level shift bias current</td>
<td>No slope compensation added</td>
<td>40</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>(T_{\text{PWM-Delta}})</td>
<td>Turn-off propagation delay from input of PWM comp. to gate output</td>
<td></td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>(T_{\text{PWMDEL-Delta}})</td>
<td>Difference between CH1 and CH2 PWM comp. propagation delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CURRENT SENSE AMPLIFIER (CSP, CSN)**

| \(V_{\text{(CSP-CSN)x}}\) | Current Sense REG Voltage | | | | |
| \(V_{\text{CSN(CM)}}\) | \(V_{\text{(CSP-CSN)}} = 14 V, \text{IADJDAC} = 0x9F\) | 165.8 | 172.7 | 179.6 | mV |
| \(V_{\text{CSN(CM)}}\) | \(V_{\text{(CSP-CSN)}} = 14 V, \text{IADJDAC} = 0x95\) | 96.5 | 100.8 | 104.5 | mV |
| \(V_{\text{CSN(CM)}}\) | \(V_{\text{(CSP-CSN)}} = 14 V, \text{IADJDAC} = 0x0F\) | 10.3 | | | mV |

| \(G_{\text{CS}}\) | Current Sense Gain = \(V_{\text{ADJ}}/V_{\text{(CSP-CSN)}}\) | | | | |
| \(K_{\text{(OCP)}}\) | Ratio of over-current detection threshold to \(V_{\text{ADJ}}\) | | | | |
| \(K_{\text{(UC)}}\) | Ratio of under-current detection threshold to \(V_{\text{ADJ}}\) | | | | |
| \(I_{\text{CS(BIAS)}}\) | CSP bias current | | | | |
| \(I_{\text{CSN(BIAS)}}\) | CSN bias current | | | | |

**SSDAC**

| \(\text{DAC}_{\text{BS-BITs}}\) | Internal DAC resolution | 8 | | Bits |
| \(\text{DAC}_{\text{BS-FS}}\) | DAC full scale voltage | 2.8 | | V |

**CALDAC**

| \(\text{DAC}_{\text{CAL-BITs}}\) | Switch current sense calibration DAC | 3 | | Bits |
| \(\text{DAC}_{\text{CAL-RES}}\) | Offset-per-Bit applied to the switch current sense | 2.5 | | mV |

**FAULT FLAG (FLTx)**

| \(R_{\text{FLT}}\) | Open-drain pull down resistance | 36 | | Ω |

**VIADJDAC**

| \(\text{DAC}_{\text{ADJ-BITs}}\) | Internal DAC resolution | 8 | | Bits |
| \(\text{DAC}_{\text{ADJ-FS}}\) | DAC full scale voltage | 2.32 | 2.4 | 2.48 | V |

**ERROR AMPLIFIER (COMP)**

| \(g_{M}\) | Transconductance | | | | |
| \(I_{\text{COMP(SRC)}}\) | COMP source current capacity | | | | |
| \(I_{\text{COMP(SINK)}}\) | COMP sink current capacity | | | | |

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Electrical Characteristics (continued)

\(-40^\circ C < T_J < 150^\circ C, V_{IN} = 14V, \text{VIADJDACx} = 0xDF, C_{VCC} = 1\mu F, C_{VDD} = 1\mu F, C_{COMP} = 2.2nF, R_{CS} = 100m\Omega, R_T = 50k\Omega, V_{PWM} = 5V, \text{no load on GATE and PDRV, DIV=4 (unless otherwise noted)}\)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>EA_{BW}</td>
<td>Error amplifier bandwidth</td>
<td></td>
<td></td>
<td></td>
<td>MHz</td>
</tr>
<tr>
<td></td>
<td>Gain = –3 dB, HG = 0</td>
<td>5</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gain = –3 dB, HG = 1</td>
<td>100</td>
<td></td>
<td>1</td>
<td>mV</td>
</tr>
<tr>
<td>V_{COMP(RST)}</td>
<td>V_{COMP} reset voltage</td>
<td>100</td>
<td></td>
<td>1</td>
<td>mV</td>
</tr>
<tr>
<td>R_{COMP(DCH)}</td>
<td>COMPx discharge FET R_{DSON}</td>
<td>248</td>
<td></td>
<td></td>
<td>\Omega</td>
</tr>
<tr>
<td>R_{COMP(DIFF)}</td>
<td>COMP1 to COMP2 short path resistance</td>
<td>300</td>
<td></td>
<td></td>
<td>\Omega</td>
</tr>
<tr>
<td>SLOPEDAC</td>
<td>DAC_{BLP-FS} DAC full scale voltage</td>
<td>0.36</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>VFB</td>
<td>Regulation voltage error</td>
<td>–4</td>
<td>4</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>VFBBIAS</td>
<td>V_{FB} pin pull up bias current</td>
<td>200</td>
<td></td>
<td></td>
<td>nA</td>
</tr>
<tr>
<td>OVDAC</td>
<td>OV limit threshold, 0%</td>
<td>CHxOVDAC = 000</td>
<td>1.2</td>
<td>1.237</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 2.5%</td>
<td>CHxOVDAC = 001</td>
<td>1.268</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 5%</td>
<td>CHxOVDAC = 010</td>
<td>1.299</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 7.5%</td>
<td>CHxOVDAC = 011</td>
<td>1.329</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 10%</td>
<td>CHxOVDAC = 100</td>
<td>1.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 12.5%</td>
<td>CHxOVDAC = 101</td>
<td>1.391</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 15%</td>
<td>CHxOVDAC = 110</td>
<td>1.422</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OV limit threshold, 20%</td>
<td>CHxOVDAC = 111</td>
<td>1.483</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_{OV-HYS}</td>
<td>OV hysteresis current</td>
<td>11.5</td>
<td>20.5</td>
<td>28.5</td>
<td>\mu A</td>
</tr>
<tr>
<td>UV (Output Under Voltage)</td>
<td>V_{UV(THR)} Under voltage protection threshold</td>
<td>40</td>
<td>53.2</td>
<td>67</td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td>I_{UV(BLANK)} Under voltage blanking period</td>
<td>5</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
<tr>
<td>DIGITAL INPUTs (PWMx, SYNC, FS, SSN, SCK, MOSI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_{BIAS}</td>
<td>Input bias current</td>
<td></td>
<td></td>
<td></td>
<td>1 \mu A</td>
</tr>
<tr>
<td></td>
<td>Except PWM inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT_{INPUT-FALL}</td>
<td>Falling threshold</td>
<td>0.7</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>VT_{INPUT-RISE}</td>
<td>Rising threshold</td>
<td>1.85</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>PWM INPUT (PWM)</td>
<td>R_{PWM(PD)} PWM pull-down resistance</td>
<td>10</td>
<td></td>
<td></td>
<td>\text{M}\Omega</td>
</tr>
<tr>
<td></td>
<td>t_{DLY(RISE)} PWM rising to PDRV delay</td>
<td>235</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>t_{DLY(FALL)} PWM falling to PDRV delay</td>
<td>222</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>PFET GATE DRIVE</td>
<td>V_{PDRV(OFF)} PDRV off-state voltage</td>
<td>V_{CSP} = 14 V</td>
<td>14</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>V_{PDRV(ON)} PDRV on-state voltage</td>
<td>V_{CSP} = 14 V</td>
<td>7.34</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>I_{PDRV(SINK)} PDRV sink current</td>
<td>V_{CSP} – V_{PDRV} = 5 V, pulsed &lt; 100 \mu s</td>
<td>29</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>R_{PDRV} PDRV pull up resistance</td>
<td>V_{CSP} – V_{PDRV} = 0 V, pulsed &lt; 100 \mu s</td>
<td>83.5</td>
<td></td>
<td>\Omega</td>
</tr>
<tr>
<td>SPI INTERFACE</td>
<td>V_{OL-MISO} Output low voltage threshold</td>
<td>I_{MISO} = 10 mA</td>
<td>0.25</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>R_{DS-MISO}</td>
<td>25</td>
<td></td>
<td></td>
<td>\Omega</td>
</tr>
<tr>
<td></td>
<td>C_{MISO}</td>
<td>10</td>
<td></td>
<td></td>
<td>\text{pF}</td>
</tr>
<tr>
<td></td>
<td>I_{SS-SU} SSN setup time</td>
<td>Falling edge of SSN to 1st SCK rising edge</td>
<td>500</td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>
Electrical Characteristics (continued)

$-40°C < T_J < 150°C$, $V_{IN} = 14V$, $V\text{IADJDACx} = 0xDF$, $C_{VCC} = 1\mu F$, $C_{VDD} = 1\mu F$, $C_{COMP} = 2.2nF$, $R_{CS} = 100m\Omega$, $R_T = 50k\Omega$, $V_{PWM} = 5V$, no load on GATE and PDRV, DIV=4 (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{SS-H}$</td>
<td>SSN hold time</td>
<td>250</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$t_{SS-HI}$</td>
<td>SSN high time</td>
<td>1</td>
<td></td>
<td></td>
<td>\mu s</td>
</tr>
<tr>
<td>$t_{SCK}$</td>
<td>SCK period</td>
<td>500</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$D_{SCK}$</td>
<td>SCK duty cycle</td>
<td>40</td>
<td>60</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>$t_{MOSI-SU}$</td>
<td>MOSI setup time</td>
<td>125</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$t_{MOSI-H}$</td>
<td>MOSI hold time</td>
<td>140</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$t_{MISO-HIZ}$</td>
<td>MISO tristate time</td>
<td>110</td>
<td>320</td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$t_{MISO-HL}$</td>
<td>MISO valid high-to-low</td>
<td>320</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$t_{MISO-LH}$</td>
<td>MISO valid low-to-high</td>
<td>320+$t_{RC}$</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>$T_{ZO-HL}$</td>
<td>MISO drive time high-to-low</td>
<td>320</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>
6.6 Typical Characteristics

\( T_A = 25^\circ C \) free air, \( V_{IN} = 14 \) V, \( DIV = 2 \) (CHxDIV = 0x00) unless otherwise specified

![Figure 1. Regulated VCC Voltage vs Junction Temperature](image1.png)

\( I_{VCC} = 20 \) mA

\( V_{IN} = 4.5 \) V, \( I_{VCC} = 30 \) mA

![Figure 3. VCC Dropout Voltage vs Junction Temperature](image3.png)

\( V_{DD} = 20 \) mA

![Figure 2. Regulated VDD Voltage vs Junction Temperature](image2.png)

![Figure 4. VCC Current Limit vs Junction Temperature](image4.png)

![Figure 5. VCC UVLO Threshold vs Junction Temperature](image5.png)

![Figure 6. RT Pin Voltage vs Junction Temperature](image6.png)
Typical Characteristics (continued)

\[ T_A = 25^\circ \text{C} \text{ free air, } \text{VIN} = 14 \text{ V}, \text{ DIV} = 2 (\text{CHxDIV} = 0x00) \] unless otherwise specified.

- **Switching Frequency (kHz)**
  - RT = 50 k\( \Omega \), CHxDIV = 01
  - RT = 100 k\( \Omega \), CHxDIV = 01

- **Maximum Duty Cycle (%)**
  - RT = 50 k\( \Omega \), CHxDIV = 01
  - CHxILIM = 11

- **ILIM Current Limit Threshold (mV)**
  - CHxILIM = 01
  - CHxOV = 000

- **OVP Threshold (V)**
  - CHxOV = 000

---

**Notes:**
- T\( _A \) = 25°C free air, VIN = 14 V, DIV = 2 (CHxDIV = 0x00) unless otherwise specified.
- Switching Frequency (kHz)
- Maximum Duty Cycle (%)
- ILIM Current Limit Threshold (mV)
- OVP Threshold (V)

---

**Images:**
- Switching Frequency vs Junction Temperature
- Maximum Duty Cycle vs Junction Temperature
- ISP Current Limit Threshold vs Junction Temperature
- Over Voltage Protection Threshold vs Junction Temperature
Typical Characteristics (continued)

T_A = 25°C free air, VIN = 14 V, DIV = 2 (CHxDIV = 0x00) unless otherwise specified

CHxOV = 111

Figure 13. Over Voltage Protection Threshold vs Junction Temperature

V_CSP = 14 V

Figure 15. CSP Pin Input Bias Current vs Junction Temperature

V_CSN = 14 V

Figure 16. CSN Pin Input Bias Current vs Junction Temperature

CHxIADJ = FF (hex)

Figure 17. VIADJ Voltage vs Junction Temperature

CHxIADJ = 95 (hex)

Figure 18. VIADJ Voltage vs Junction Temperature
### Typical Characteristics (continued)

$T_A = 25^\circ C$ free air, $VIN = 14$ V, $DIV = 2$ (CHxDIV = 0x00) unless otherwise specified.

#### Figure 19. $V_{(CSP - VCSN)}$ Voltage vs Junction Temperature

![Graph](image)

**CHxIADJ = FF (hex)**

#### Figure 20. $V_{(CSP - VCSN)}$ Voltage vs Junction Temperature

![Graph](image)

**CHxIADJ = 95 (hex)**

#### Figure 21. Over Current Protection Gain vs Junction Temperature

![Graph](image)

**CHxIADJ = 95 (hex)**

#### Figure 22. Channel Switching Frequency $F_{SW}$ vs $R_T$ Resistance

![Graph](image)

**CHxIADJ = 95 (hex)**
7 Detailed Description

7.1 Overview
The TPS92682-Q1 device is an automotive-grade two-channel controller with Serial Peripheral Interface (SPI) interface, ideally suited for exterior lighting applications. The device is optimized to achieve high-performance solutions and features all of the functions necessary to implement LED drivers based on step-up or step-down power converter topologies with a small form-factor at a lower cost.

The two channels of the TPS92682-Q1 device can be configured independently as CC (constant current) or CV (constant voltage) mode. The device implements fixed-frequency peak current mode control to achieve regulation and fast dynamic response. Each channel can be configured as boost, boost-to-battery, SEPIC, or other converter topologies.

In CC mode, the integrated low offset and rail-to-rail current sense amplifier provide the flexibility required to power a single string consisting of 1 to 20 series connected LEDs while maintaining 4% current accuracy over the operating temperature range. The LED current regulation threshold is set by the analog adjust input CHxIADJ register over 28:1 dimming range. The TPS92682-Q1 incorporates an internal 10-bit counter for PWM dimming function for each channel. The PWM width and frequency are programmable via SPI registers. Alternatively, the device can also be configured to implement direct PWM dimming based on the duty cycle of external PWM signal connected to PWM1 or PWM2 pins for channel-1 or channel-2, respectively. The internal PWM signals control the GATEx and PDRVx outputs which control the external N-channel switching FETs and P-channel dimming FETs connected in series with LED strings.

The TPS92682-Q1 device can be configured in CV mode. In this mode, the device regulates the voltage connected to the FBx/OVx pins to an internal programmable reference voltage, set by CHxIADJ register. The TPS92682-Q1 device, in CV mode, can be used as the first stage of a two-stage LED driver in an ECU (electronic control unit) of an exterior lighting application. The device can also be configured to operate in two-phase mode, where the switching frequencies of the two channels are phase-shifted by 180° and the channel-1 compensation loop, including COMP1 and the FB1/OV1, is shared between the two channels.

The TPS92682-Q1 device incorporates an enhanced programmable fault feature. A selected number of faults including ILIMIT (cycle-by-cycle current limit), OV (output Over-Voltage), UV (output Under-Voltage) and OC (LED Over-Current) can be programmed to be latched faults, or automatically re-start the channel when the fault is cleared and after a programmed timer is expired. In addition, the TPS92682-Q1 includes open-pin faults for the FBx, ISNx and RT pins. Other fault and diagnostic features include Thermal Shutdown (TSD), Thermal Warning (TW), LED Under-Current (UC), and POR. Each channel includes an active-low fault pin (FLT) that is pulled low when a fault occurs. For each fault there is an associated fault read-bit in the register map that can be read via SPI communication interface. For a complete list of the fault and diagnostic features refer to the Faults and Diagnostics section.

The TPS92682-Q1 device includes a limp home (LH) function that is initiated when the LH pin is set high. In LH mode, the operation of the device is set by the LH registers. The LH registers are programmed upon initialization of the device. To exit the LH mode, the LH pin must be set low and the LH bit in the CFG1 register must be written to “0”.

The TPS92682-Q1 device has numerous enhanced programmable features that can be accessed via the 4-wire SPI bus. The SPI bus consists of four signals: SSN, SCK, MOSI, and MISO. The SSN, SCK, and MOSI pins are TTL inputs into the device.

7.2 Functional Block Diagram
The block diagram below shows the associated blocks for channel-1. Channel-2 has similar configuration.
Functional Block Diagram (continued)
Functional Block Diagram (continued)
7.3 Feature Description

The TPS92682-Q1 device implements a fixed frequency Peak Current Mode (PCM) control. In a PCM, the switching cycle starts with a rising edge of the clock. The switching cycle ends when the sensed switch current $V_{iSW}$ (added with $V_{SLOPE}$) exceeds the compensator voltage $V_{COMP}$. As shown in Figure 23 and Figure 24, a transconductance $g_M$ error amplifier generates an error signal by comparing the feedback signal and the reference voltage $V_{REF}$. The resulting error current generates the compensator voltage $V_{COMP}$, via a compensator impedance, connected to the COMPx pin.

For stability at high duty cycle, and better noise immunity, a compensation ramp $V_{SLOPE}$ is added to the sensed switch current $V_{iSW}$.

Figure 23. PCM Control in CC Mode

Figure 24. PCM Control in CV Mode
Feature Description (continued)

7.3.1 Device Enable

The TPS92682-Q1 device can be enabled or disabled via EN pin or the software enable bits. When EN pin is pulled low, the device enters the shutdown state, where the quiescent current of the device is decreased to \( I_{\text{IN-SHDN}} \). In shutdown state, the internal regulators are turned off and the registers are reset. When the voltage on the enable pin is increased above the voltage threshold of \( V_{\text{EN}} \), the two channels can be enabled. In addition to the EN pin, there are two enable bits for the two channels of the TPS92682-Q1 as shown in the Table 2. In order for each channel to be turned on, the associated CHxEN bit must be set to "1" in the EN Register.

In addition to the EN pin and the CHxEN bits, the PWMx signals (hardware or software) must be set high and the associated CHxIADJ must be set to a value greater than eight (refer to CH1IADJ Register) in order for the associated channel to be turned on.

7.3.2 Internal Regulator and Under-voltage Lockout (UVLO)

The device incorporates 65-V input voltage rated linear regulators to generate the 7.5-V (typical) VCC bias supply, the 5-V (typical) VDD supply and other internal reference voltages. The device monitors the VCC output to implement UVLO protection. Operation is enabled when VCC exceeds the 4.5-V (typ) threshold and is disabled when VCC drops below the 4.1-V (typical) threshold. The UVLO comparator provides a hysteresis to avoid chatter during transitions. The UVLO thresholds are internally fixed and cannot be adjusted. An internal current limit circuit is implemented to protect the device during VCC pin short-circuit conditions. The VCC supply powers the internal circuitry and the N-channel gate driver outputs, GATEx. Place a bypass capacitor in the range of 2.2 \( \mu \)F to 4.7 \( \mu \)F across the VCC output and GND to ensure proper operation. The regulator operates in dropout when input voltage VIN falls below 7.5 V. The VCC is a regulated output of the internal regulator and is not recommended to be driven with an external power supply.

The internal VDD regulator is used to generate supply voltage for various internal analog and digital circuits. The supply current is internally limited to protect the device from output overload and short-circuit conditions. Place a bypass capacitor in the range of 2.2 \( \mu \)F to 4.7 \( \mu \)F across the VDD output to GND to ensure proper operation. The POR circuit of the device is placed at the output of the VDD regulator. The POR rise and fall thresholds are provided in Electrical Characteristics.

7.3.3 Oscillator

The internal clock frequency of the TPS92682-Q1 device is programmable by a single external resistor, connected between the RT pin and the GND. The relationship between the resistor \( R_T \) and the internal main clock (CLKM) frequency is shown in Equation 1 and Figure 22.

\[
\frac{f_{\text{CLKM}}}{10^{12}} = \frac{1}{12.5 \times R_T}
\]  

(1)

The relationship between channel switching frequency, \( f_{\text{SW}} \), and \( f_{\text{CLKM}} \) is shown in SWDIV Register. TI recommends a switching frequency setting between 100 kHz to 700 kHz for best efficiency and for optimal performance over input and output voltage operating range. Operation at higher switching frequencies requires careful selection of N-channel MOSFET characteristics as well as detailed analysis of switching losses.

To use the synchronization functionality of the TPS92682-Q1 device, the SYNCEN bit shown in Table 3 must be set to "1", and a square wave signal with the desired \( f_{\text{CLKM}} \) frequency must be applied to the SYNC pin.
7.3.4 Spread Spectrum Function

The main clock of the TPS92682-Q1, CLK\(_M\), is generated using an internal ramp generator as shown in Figure 27. The internal ramp, RAMP\(_{CLKM}\), is compared with a reference voltage of VOSC\(_{REF}\) to reset the ramp at the end of the clock period T\(_{CLKM}\). When the reference voltage VOSC\(_{REF}\) is constant (1 V), the main clock frequency is fixed. The frequency modulation of the main clock is achieved using an internal 8-bit digital counter DAC, and by modulating the reference voltage as shown in Figure 28. Both modulation frequency, F\(_M\), and the modulation magnitude \(\Delta F_M\) are programmable in FM Register.

![Figure 26. TPS92682 SYNC Function](image1)

![Figure 27. Internal Ramp for CLK\(_M\) Generation](image2)

![Figure 28. Internal Ramp Waveform](image3)
Feature Description (continued)

To achieve maximum attenuation in average-EMI scan, set a modulation frequency of $F_M$ ranging from 100 Hz to 1.2 kHz. A low modulating frequency has a small impact on the quasi-peak EMI scan. Set the modulation frequency to 10 kHz or higher to achieve attenuation for quasi-peak EMI measurements. A modulation frequency higher than the receiver resolution bandwidth (RBW) of 9 kHz impacts only the quasi-peak EMI scan and has little impact on the average EMI measurement. The TPS92682-Q1 device simplifies EMI compliance by providing the means to tune the modulation frequency, $F_M$, and modulation magnitude, $\Delta F_M$, based on the measured EMI signature.

Equation 2 shows the relation between the channel switching frequency, $f_{SW}$, and the desired modulation frequency $F_M$.

$$F_M = \frac{DIV \times f_{SW}}{FM_{FREQ}}$$  \hspace{1cm} (2)

In Equation 2, DIV is the division factor between CLK$_M$ and the CHx_CLK provided in SWDIV Register, and FM$_{FREQ}$ is the division factor given in FM Register.

The output of the FM 8-bit digital counter always resets and starts from 1 V when a register write is performed to the FM Register.

7.3.5 Gate Driver

The TPS92682-Q1 device contains an N-channel gate driver that switches the output GATEx between $V_{CC}$ and GND. A peak source and sink current of 500 mA allows controlled slew-rate of the MOSFET gate and drain voltages, limiting the conducted and radiated EMI generated by switching.

The gate driver supply current $I_{CC(GATE)}$ depends on the total gate drive charge (QG) of the MOSFET and the operating frequency of the converter, $f_{SW}$, $I_{CC(GATE)} = QG \times f_{SW}$. Select a MOSFET with a low gate charge specification to limit the junction temperature rise and switch transition losses.

It is important to consider a MOSFET threshold voltage when operating in the dropout region (input voltage $V_{IN}$ is below the $V_{CC}$ regulation level). TI recommends a logic level device with a threshold voltage below 5 V when the device is required to operate at an input voltage less than 7 V.

7.3.6 Rail-to-Rail Current Sense Amplifier

The internal rail-to-rail current sense amplifier measures the average LED current based on the differential voltage drop between the CSPx and CSNx inputs over a common mode range of 0 V to 65 V. The differential voltage, $V_{(CSPx-CSN)}$, is amplified by a voltage-gain factor of 14 and is connected to the negative input of the transconductance error amplifier. Accurate LED current feedback is achieved by limiting the cumulative input offset voltage (represented by the sum of the voltage-gain error, the intrinsic current sense offset voltage, and the transconductance error amplifier offset voltage) over the recommended common-mode voltage and temperature range.

An optional common-mode (C$_{FCM}$) or differential mode (C$_{FDM}$) low-pass filter implementation, as shown in Figure 29, can be used to filter the effects of large output current ripple, and switching current spikes caused by diode reverse recovery. TI recommends a filter resistance in the range of 10 $\Omega$ to 100 $\Omega$ to limit the additional offset caused by amplifier bias current mismatch to achieve the best accuracy and line regulation.

---

**Figure 29. Current Sense Amplifier**
Feature Description (continued)

7.3.7 Transconductance Error Amplifier

As shown in Figure 30, the internal transconductance error amplifier generates an error signal proportional to the difference between the internal programmable 8-bit CHxIADJ-DAC (CH1IADJ Register) and the feedback signal. The feedback signal is the sensed current CHxIsense in CC mode, or the sense output voltage CHxVFB in CV mode. The gain $g_M$ of the error amplifier is programmable via the CHx_HG bit in CFG1 Register. The gain values for CHx_HG = 0 or 1 are provided in Electrical Characteristics. Based on the value of CHx_CV bit in Table 4, either CHxIsense or CHxVFB is connected to the input of the error amplifier. Therefore, the TPS92682-Q1 device either operates in CV or CC mode.

The output of the error amplifier is connected to an external compensation network to achieve closed-loop LED current (CC), or output voltage (CV) regulation. In most LED driver applications, a simple integral compensation circuit consisting of a capacitor connected from COMPx output to GND provides a stable response over a wide range of operating conditions. TI recommends a capacitor value between 10 nF and 100 nF as a good starting point. To achieve higher closed-loop bandwidth a proportional-integral compensator, consisting of a series resistor and a capacitor network connected across the COMPx output and GND, is required. The Application and Implementation section includes a summarized detailed design procedure.

![Figure 30. Feedback Connection to the Error Amplifier](image)

7.3.8 Switch Current Sense

Figure 31 shows the simplified block diagram of the switch current sense circuitry. The ISPx input pin monitors the main MOSFET current to implement peak current mode control. The GATEx output duty cycle is derived by comparing the peak switch current, measured by the $R_{IS}$ resistor, to the internal CHx_COMP voltage threshold. An internal slope signal, CHx_ISLOPE, is added to the measured sense voltage to prevent sub-harmonic oscillations for duty cycles greater than 50%.

An internal leading-edge blanking (LEB) is applied to the switch current sense at the beginning of each switching cycle by shunting the ISPx input to the ISNx (GND connection of the $R_{IS}$) for the duration of the LEB time. The LEB circuit prevents unwanted duty cycle termination due to MOSFET switching-current spike at the beginning of the new switching cycle. The LEB time can be set to 150 ns or 75 ns (typical) using the CHxLEB bit set in Table 5. For additional noise suppression, connect an external low-pass RC filter with resistor values ranging from 100 $\Omega$ to 500 $\Omega$ and a 1000 pF capacitor across $R_{IS}$.
Feature Description (continued)

Cycle-by-cycle current limit is accomplished by a separate internal comparator. The current limit threshold is set based on the status of internal PWM signal and the CHxILIM setting. The current limit threshold is set to a value programmed in the CHxILIM in Table 17 when PWM signal is high. The current limit threshold is set to 700 mV (typical) when PWM signal is low. In CC mode, the transition between the two thresholds in conjunction with the slope compensation and the error amplifier circuit allows for higher inductor current immediately after the PWM transition, to improve LED current transient response in PWM dimming.

The device immediately terminates the GATEx and PDRVx outputs when the sensed voltage at the ISPx input exceeds the current limit threshold. For more detail on the cycle by cycle current limit refer to Faults and Diagnostics.

Figure 31. Switch Current Sense and Current Limit

7.3.9 Slope Compensation

Switching converters with peak current mode control are subject to sub-harmonic oscillation for duty cycles greater than 50%. To avoid instability, the control scheme adds an artificial ramp to the sensed switch current (shown in Figure 31). The required slope of the artificial ramp depends on the input voltage, \( V_{IN} \), output voltage, \( V_O \), inductor \( L \), and switch current sense resistor \( R_{IS} \). The TPS92682-Q1 device provides a programmable slope compensation with seven levels of slope magnitude to simplify and enhance the performance of common switching converter topologies, such as boost, boost-to-battery and SEPIC. The slope magnitude can be programmed via CHxISLP in ISLOPE Register. The Application and Implementation section includes calculations for the choice of correct slope magnitude for a given application.

7.3.10 ILED Setting in CC Mode

In CC mode, as shown in Figure 30, the voltage across the LED current sense resistor, \( V_{(CSP-CSN)} \), is regulated to the output of the programmable 8-bit CHxIADJ-DAC, scaled by the current sense amplifier voltage gain of 14. The LED current can be linearly adjusted by writing a different value to the CHxIADJ register. The 8-bit DAC output can be set in the range of 85 mV (CHxIADJ = 9) to 2.4 V (CHxIADJ = 255). The associated channel is turned off for CHxIADJ ≤ 8.

7.3.11 Output Voltage Setting in CV Mode

In CV mode, as shown in Figure 30, the voltage at the FBx pin (output voltage divider) is regulated to the output of the programmable 8-bit CHxIADJ-DAC. The FBx voltage can be adjusted in the range of 85 mV (CHxIADJ = 9) to 2.4 V (CHxIADJ = 255). The associated channel is turned off for CHxIADJ ≤ 8.
Feature Description (continued)

7.3.12 PWM Dimming

As shown in Figure 32, the TPS92682-Q1 device incorporates both internal and external PWM dimming. To select between external or internal PWM dimming, the INTPWM bit in the CFG1 Register must be set to "0" or "1" respectively. If internal PWM dimming operation is selected, the state of the PWMx pins do not have any effect on the operation of the device. For external PWM dimming, apply a square-wave signal to the PWMx pin with the rising and falling thresholds provided in Electrical Characteristics. The LED current modulates based on the duty cycle of the external PWM signal, $D_{PWM(EXT)}$.

To use internal PWM dimming, the INTPWM bit in the CFG1 Register must be set to "1". The TPS92682-Q1 device incorporates a 10-bit PWM counter for each channel. The duty cycle of the internal PWM can be set using a 10-bit value in CHxPWML and CHxPWMH registers. Because CHxPWM is a 10-bit value, a PWM duty cycle update may require two SPI writes, one to the CHxPWMH and another to the CHxPWML register. In order to prevent transferring incoherent values, the contents of the two registers transfer to the CHxPWM counter only upon the write to the CHxPWML register. Therefore, for an update to the PWM duty cycle, it is recommended consecutively writing to CHxPWMH first and CHxPWML second. In addition, in order to avoid corrupting the progress of the current PWM duty cycle, the update from the CHxPWM registers to the CHxPWM counter occurs two PWM_CLK before the end of each PWM period (at the count of 1022).

Due to synchronization of the external PWM with internal clock, when switching from external PWM to internal PWM, a glitch for the total of one PWM period could be observed in the output.

The clock to the 10-bit PWM counter is related to the main clock, CLK_M, by a division factor set by a 3-bit value in PWM_DIV Register. The relation between the PWM_CLK and PWM frequency with CLK_M frequency are shown in Equation 3 and Equation 4.

\[
P_{PWM\_CLK} = \frac{f_{CLK\_M}}{PWM\_DIV} \quad (3)
\]

\[
P_{PWM\_FREQ} = \frac{PWM\_FREQ}{1024} \quad (4)
\]

For example, if the CLK_M frequency is set to $f_{CLK\_M} = 800$ kHz and PWM_DIV = 001 (division value of 2), the PWM frequency is $PWM_{FREQ} \approx 390$ Hz.

The phase between the internal PWM dimming for the two channels can be set to 180° if the PWMPH bit in the CFG1 Register is set to 0. For PWMPH = 1, there is zero phase shift between the internal 10-bit PWM counters of the two channels.

The PWM signal controls the GATEx and PDRVx outputs. If PWM_int is set low, the associated channel is turned off, the COMPx pin is disconnected from the error amplifier, and the PDRVx output is set to $V_{CSP}$ in order to maintain the charge on the compensation network and output capacitors. On the rising edge of the PWM_int, the GATEx and PDRVx outputs are enabled to ramp the inductor current to the previous steady-state value. The COMPx pin connects to the error amplifier only when the switch current sense voltage $V_{ISP}$ exceeds the COMPx voltage, CHx_comp. This connection immediately forces the converter into steady-state operation with minimum LED current overshoot. When dimming is not required, connect the PWMx pins to the VDD pin. An internal pull-down resistor sets the PWM inputs to logic-low and disables the device when the pins are disconnected or left floating, and the INTPWM bit in the CFG1 Register is set to the default value of "0".

---

**Figure 32. PWM Dimming Circuit**

The phase between the internal PWM dimming for the two channels can be set to 180° if the PWMPH bit in the CFG1 Register is set to 0. For PWMPH = 1, there is zero phase shift between the internal 10-bit PWM counters of the two channels.

The PWM signal controls the GATEx and PDRVx outputs. If PWM_int is set low, the associated channel is turned off, the COMPx pin is disconnected from the error amplifier, and the PDRVx output is set to $V_{CSP}$ in order to maintain the charge on the compensation network and output capacitors. On the rising edge of the PWM_int, the GATEx and PDRVx outputs are enabled to ramp the inductor current to the previous steady-state value. The COMPx pin connects to the error amplifier only when the switch current sense voltage $V_{ISP}$ exceeds the COMPx voltage, CHx_comp. This connection immediately forces the converter into steady-state operation with minimum LED current overshoot. When dimming is not required, connect the PWMx pins to the VDD pin. An internal pull-down resistor sets the PWM inputs to logic-low and disables the device when the pins are disconnected or left floating, and the INTPWM bit in the CFG1 Register is set to the default value of "0".
Feature Description (continued)

7.3.13 P-Channel FET Gate Driver Output

The PDRVx output is a function of the internal PWM signal and is capable of sinking and sourcing up to 50 mA of peak current to control a high-side series connected P-channel dimming FET. The PDRV switches between VCSP and (VCSP – 7 V) based on the status of PWM signal to completely turn-off and turn-on the external P-channel dimming FET. In CC mode, a series dimming FET is required to achieve high contrast ratio as it ensures fast rise and fall times of the LED current in response to the PWM input. Without any dimming FET, the rise and fall times are limited by the inductor slew rate and the closed-loop bandwidth of the system. In CC mode leave the PDRVx pin unconnected if not used. In CV mode, the PDRVx together with CSPx and CSNx pins can be connected to GND to limit the shutdown current. The PDRVx can also be disabled by setting the CHxPDRVEN bit in Table 3 to zero.

7.3.14 Soft-Start

The soft-start feature helps the regulator gradually reach the steady-state operating point, thus reducing startup stresses and current surges. The device clamps the COMPx pin to the output of the SSDAC plus the threshold voltage of a P-FET, until the LED current or the output voltage approaches the regulation threshold. The soft-start is controlled with an 8-bit DAC which ramps from 0 V to 2.8 V during startup of an associated channel. The soft-start ramp (or the ramp time) can be controlled by programming the clock of the internal digital ramp counter. The clock of the digital ramp counter is related to the associated channel clock (switching frequency $f_{SW}$) by:

$$SS_{CLK} = \frac{CHx_{CLK}}{SSx_{DIV}}$$

(5)

The SSxDIV is a division factor provided in SOFTSTART Register. For example, if the channel switching frequency is set to 400 kHz, the soft-start ramp time can be programmed between 1.3 ms and 64 ms. It is important to note that the ramp time is the time for the SSDAC output to ramp from 0 V to 2.8 V (digital ramp counter to count from 0 to 255), but the controller may reach the regulation point before the ramp is completed.

![Figure 33. Soft-Start Circuit](image)

When programming the soft-start ramp, it is essential to ensure that the soft-start ramp time is longer than the time required to charge the output capacitor.

To initiate the soft-start ramp, the PWM signal (internal or external) must be set high. If PWM dimming occurs during the soft-start period, the digital ramp counter holds the ramp value when PWM = LOW, and re-starts the ramp from the last ramp value when PWM = HIGH. Figure 34 shows an example of this feature.
7.3.15 Two-Phase Operation

The TPS92682-Q1 device can be programmed in two-phase mode by setting the 2PH bit to "1" in CFG1 Register. In two-phase mode, the CH1_comp is internally connected to the CH2_comp with 500-Ω (max) of resistance. In this case the error amplifier of channel-2 is disabled and only the error amplifier of channel-1 connects to both COMP1 and COMP2 pins. TI recommends that external compensators be connected to both COMP1 and COMP2 pins, and that these two pins be shorted together externally.

Two-phase mode uses only the channel-1 soft-start DAC and controls both phases. To generate the channel clocks, only the division factor for the channel-1, programmed in the SWDIV Register, is used. The two channel clocks (switching frequency \( f_{SW} \)) are the same and are 180° out-of-phase.

In two-phase mode, in the case of internal PWM, only CH1PWM is used for both channels. When external PWM is used, it is recommended to short both PWMx pins together and use only one PWM signal for both channels.

A selected number of the faults, CH2_OV, CH2_UV, CH2_OC and CH2_UC have no effect in the operation of two-phase mode. For more detail about faults and diagnostics in TPS92682-Q1, refer to the Faults and Diagnostics section.

7.3.15.1 Current Sharing In Two-Phase

In two-phase operation, the current sharing between the two phases depends on the mismatch between the current sense circuitry of the two channels. The TPS92682-Q1 incorporates a feature and a register setting to improve the current sharing in two-phase operation. Table 40 includes three bits of calibration settings, CHxCAL2:0, which introduce an offset of 0 to 17.5 mV (with a resolution of 2.5 mV) to the channel switch current sense voltage. The calibration offset can be used to compensate for the mismatch offset between the two channels.

The following procedure is recommended for offset calibration between the two phases in a CV two-phase design:

- In two-phase CV, Comp1 and Comp2 pins are connected together.
- Configure the registers for the application and turn on the two-phase converter.
- Set the load at the output of the two-phase converter to half of the maximum load in the application.
- Set the CH2GOFF = 1 and CH1GOFF = 0 in Table 40. This setting turns off channel-2. Measure the COMP voltage as shown in Figure 35 and record the measurement as \( V_{COMP1} \).
- Set the CH1GOFF = 1 and CH2GOFF = 0 in Table 40. This setting turns off channel-1. Measure the COMP voltage and record the measurement as \( V_{COMP2} \).
- The difference between the two measurements, \( \Delta V_{OFST} = V_{COMP1} - V_{COMP2} \), is the offset mismatch between the two phases.
- By setting a similar offset voltage through CHxCAL bits, the mismatch can be corrected (offset must be set in CH2CAL if \( V_{COMP1} > V_{COMP2} \), and in CH1CAL if \( V_{COMP1} < V_{COMP2} \)).
- At the end of the procedure set both CH1GOFF and CH2GOFF bits to zero.
7.3.16 Faults and Diagnostics

The TPS92682-Q1 device includes a comprehensive configurable faults and diagnostics feature. Table 1 shows the list of the faults and diagnostics. A selected number of the faults, UVLO, RTOPEN, TW, TSD and POR are shared between the two channels.

As shown in Table 1, a selected number of the faults can be enabled or disabled using FLT EN-bits in FEN1 and FEN2 registers. The rest of the faults and diagnostics feature are always enabled and operational.

All the faults and diagnostics features, except FBOPEN, TSD and UVLO, have an associated Fault-Read-bit in the FLT1 and FLT2 registers. Upon occurrence of the fault, the associated Fault-Read-bit is set in the register map. Reading these registers clears the bits that are set if the condition no longer exists. The clearing of the Fault-Read-bits happens at the end of the SPI transfer read response, not at the end of the read command. Although FBOPEN fault does not have a dedicated Fault-Read-bit, this fault sets the OV-fault read bit.

In TPS92682-Q1, the OV, UV, ILIM and OC faults can be configured to be a non-latched fault in FLATEN Register. If a fault is configured as non-latched, upon occurrence of the fault, the associated channel turns off. The channel performs a soft-start after expiration of a configurable fault timer and when the fault is cleared. In latched fault condition, the associated channel is turned off and remains off until the channel enable-bits are re-programmed in the EN Register.

Table 1. TPS92682 Faults and Diagnostics

<table>
<thead>
<tr>
<th>List</th>
<th>Description</th>
<th>Fault or Diagnos.</th>
<th>FLT EN-bit</th>
<th>FLT R-bit</th>
<th>Enable FTPtimer</th>
<th>F-PIN Trigger</th>
<th>Disable Latch</th>
</tr>
</thead>
<tbody>
<tr>
<td>OV</td>
<td>Output over voltage fault</td>
<td>Fault</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UV</td>
<td>Output under voltage fault</td>
<td>Fault</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ILIM</td>
<td>Cycle/Cycle switch current limit</td>
<td>Fault</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UVLO</td>
<td>Input under voltage lockout</td>
<td>Fault</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>OC</td>
<td>ILED over current</td>
<td>Fault</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>UC</td>
<td>ILED under current</td>
<td>Diagnos.</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ISOPEN</td>
<td>ISNx open pin fault</td>
<td>Fault</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>RTOPEN</td>
<td>RT open pin fault</td>
<td>Fault</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Feature Description (continued)

Table 1. TPS92682 Faults and Diagnostics (continued)

<table>
<thead>
<tr>
<th>List</th>
<th>Description</th>
<th>Fault or Diagnos.</th>
<th>FLT EN-bit</th>
<th>FLT R-bit</th>
<th>Enable FTimer</th>
<th>F-PIN Trigger</th>
<th>Disable Latch</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBOPEN</td>
<td>FB pin open pin fault</td>
<td>Fault</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>TW</td>
<td>Thermal warning at 150°C (typ)</td>
<td>Diagnos.</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>TSD</td>
<td>Thermal shutdown</td>
<td>Fault</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>POR</td>
<td>Power On Reset</td>
<td>Fault</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

As shown in Table 1, all faults, except UVLO, UC and TW, set the active low fault pins, FLT1 and FLT2. Figure 36 shows the functionality of the fault pins. SYNC/FLT2 is a dual function pin. When SYNCEN bit in EN Register is set to “1”, SYNC/FLT2 is an input pin and a square wave signal with the desired f_CLKM frequency must be applied to this pin. In this case, faults on both channels are ORed and applied to the FLT1 pin.

![Figure 36. Fault PINs](image)

7.3.16.1 Main Fault Timer (MFT)

For each channel of the TPS92682-Q1, there is a 14-bit counter that implements a main fault timer. The timer can be programmed by a 4-bit value for each channel in MFT Register. The MFT time can be set to a value between 1000 and 16383 times the input clock period. The input clock of the MFT is the channel clock, CHx_CLK (the switching frequency f_SW). For example, for a channel with a switching frequency of f_SW = 400 kHz, the timer can be programmed from 2.5 to 41 ms.

Only UV and OC faults can trigger the MFT. When either of these two faults are enabled as a non-latched fault, the fault event turns off the channel and triggers the MFT. The associated channel is turned back on via a soft-start process when the MFT count is completed and the fault is cleared.

7.3.16.2 OV Fault

If CHxOVEN is set to “1” in the FEN1 Register, the output over voltage fault is enabled. When V_FB exceeds the threshold voltage OV_THR, the CHx_OV fault is set high and turns off the associated channel. The OV_THR voltage is set by OV_DAC; OV_THR = V_FB_REF × OV_%v, where OV_%v is provided in the OV Register. The VFB_REF in CC mode is set to 1.228 V (typical), and in CV mode is set to the output of the CHxIADJ. When CHx_OV is high, OV_THR is set to V_FB_REF and a 20 µA hysteresis current is applied to the feedback resistor divider. For the boost converter with the output voltage sensing according to Figure 37, V_OUT must decrease to a level shown in Equation 6 for the CHx_OV to be cleared.

\[
V_O \leq \frac{R_{FB1} + R_{FB2}}{R_{FB1}} \times V_FB_REF - I_{20\mu} \times R_{FB2}
\]

Equation 6
If the CHxOVFL bit is set to “1” in the FLATEN Register, the OV fault is configured as a latched fault and the associated channel turns off with the rising edge of CHx_OV. The channel can be turned on again only by re-setting the CHxEN bit in the EN Register.

For CHxOVFL = 0, the OV fault is a non-latched fault. In this case, the associated channel turns off when the OV fault occurs, but the channel goes through a restart and soft-start ramp when CHx_OV goes low. Figure 38 shows a non-latched OV situation for a converter in CV mode, where the output voltage \( V_{FBx} \) is regulated to \( V_{FB} \) in normal condition.

The UV fault is disabled during the soft-start ramp if the CHxRFEN bit is set to “0” in the FEN1 Register.

If CHxUVFL bit is set to “1” in the FEN2 Register, the cycle-by-cycle switch current limit is achieved by comparing the sensed switch current with a programmable ILIM threshold and terminating the duty cycle when \( V_{ISPx} \geq V_{ILIM(THR)} \). The ILIM\_THR can be set using a 2-bit value in the ILIM Register. If CHxILIMEN is set to zero in the FEN2 Register, the ILIM fault is disabled. However, the cycle-by-cycle current limit is always active as long as the sensed switch current exceeds the ILIM\_THR.
If CHxILIMEN is set to "1", the ILIM fault is enabled, and it can be set as a latched or non-latched fault. There is an ILIM event counter for each channel that counts the number of ILIM fault events. When the ILIM event counter reaches a programmed value, the associated channel is turned off. The maximum number of ILIM fault events can be set using a 2-bit CHxILIMCNT in the **ILIM Register**. The ILIM event counter is reset every 100-CHxCLK cycles to prevent transients and non-real faults, resulting in an unwanted channel disable.

If CHxILIMFL is set to "1" in the **FLATEN Register**, the ILIM event is set to a latched fault. The associated channel is turned off and remains off when the ILIM event counter reaches the programmed value. The channel can be turned on again only by re-setting the CHxEN bit to "1" in the **EN Register**.

For CHxILIMFL = 0, the ILIM fault is a non-latched fault. When the ILIM event counter reaches the programmed value, the associated channel is turned off and an ILIM fault timer, IFT, is triggered. The associated channel is turned back on via a soft-start ramp, when the ILIM fault timer count is completed and the output of the ILIM event counter is cleared. The ILIM fault timer can be programmed using a 2-bit value CHxIFT in the **IFT Register**. The IFT time can be set to a value between 4 and 32 cycles of the input clock. The input clock of the IFT is the channel clock, CHxCLK (the switching frequency $f_{SW}$). For example, for a channel with a switching frequency of $f_{SW} = 400$ kHz, the timer can be programmed from 10 to 80 µs.

Figure 39 shows the simplified functional block diagram of the ILIM fault. Figure 40 shows the progress of the cycle by cycle current limit, the ILIM event counter (IFEC), the ILIM Fault Timer (IFT), and the re-start of the channel for a non-latched ILIM fault.

![Figure 39. ILIM Fault Diagram](image)

![Figure 40. ILIM Fault](image)

The ILIM fault in CV mode is disabled during the soft-start ramp if the CHxRFEN bit is set to "0" in the **FEN1 Register**.

As stated before, it is important to note that the cycle-by-cycle switch current limit is always active even if the ILIM fault is disabled.
7.3.16.5 UVLO
For details on the UVLO fault, refer to Internal Regulator and Under-voltage Lockout (UVLO).

7.3.16.6 ILED Over Current (OC)
When CHxOCEN is set to “1” in the FEN2 Register, the ILED over current fault is enabled, and the voltage across the current sense inputs (CSPx and CSNx) is monitored. The device sets the OC fault signal when the voltage at the output of the current sense amplifier exceeds the regulation set point $V_{IADJ}$ by 50%. The OC fault threshold is calculated as follows:

$$V_{(CSPx-CSNx)} = 1.5 \times \frac{V_{IADJ}}{14}$$  \hspace{1cm} (7)

If the CHxOCFL bit is set to “1” in the FLATEN Register, the OC fault is configured as a latched fault and the associated channel turns off and remains off with the rising edge of CHx_OC. The channel can be turned on again only by re-setting the CHxEN bit to “1” in the EN Register. For CHxOCFL = 0, the OC fault is a non-latched fault. In this case, the associated channel turns off when an OC fault occurs, but the channel goes through a restart and soft-start ramp when CHx_OC is cleared and the MFT is expired.

7.3.16.7 ILED Under Current (UC)
The ILED Under Current (UC) is a diagnostic feature and not a fault event. Therefore, the UC event sets the fault read bits in the FLT2 register only, and does not have any effect on the operation of the associated channel or trigger the fault pins.

The device sets the UC event when the voltage at the output of the current sense amplifier decreases by 50% from the regulation set point $V_{IADJ}$. The UC threshold is calculated as follows:

$$V_{(CSPx-CSNx)} = 0.5 \times \frac{V_{IADJ}}{14}$$  \hspace{1cm} (8)

When PWM dimming, the UC fault read bit might be set during the time when PWM is low.

7.3.16.8 ISNOPEN, FBOPEN and RTOPEN Faults
The device can detect open pin fault on ISNx, FBx and RT pins. If any of these pins are opened during operation, the device turns off the associated channel (or both channels for RT open pin). The channels can be turned on again only by re-setting the CHxEN bits high and if the faults are removed.

7.3.16.9 TW and TSD
The thermal warning (TW) bit is set in the FLT1 Register when the junction temperature exceeds 150°C (typ). The TW event is a diagnostic feature and not a fault event. As a result, TW does not have any effect on the operation of the device.

Internal thermal shutdown (TSD) circuitry is implemented to protect the controller in the event the junction temperature exceeds a value of 175°C. In the event of TSD, the controller is forced into a shutdown mode, disabling the internal regulator. This feature is designed to prevent overheating and damage to the device.

7.3.16.10 COMPx Pull-Down and Comp-Low signal
As shown in Figure 30, an internal switch pulls down the COMPx pin when there is a fault. The Comp-Pull-Down discharges the compensator capacitors, such that the converter startup always begins from a known state.

The converter does not start unless the COMPx voltage decreases below 100 mV (when CHx_complow goes high).

7.4 Device Functional Modes
The TPS92682-Q1 operates in the functional modes shown in Figure 41.
Device Functional Modes (continued)

7.4.1 POR Mode

Upon POR, all the register settings are reset to their default values and both channels are turned off. The device enters functional modes if the main clock, CLK_M, is active.

7.4.2 Normal Operation

In Normal operation mode, the registers can be programmed and the channels can be turned on. To operate in this mode, the LH pin must be low. The state machine for this mode is shown in Figure 42 and Figure 43.

- State 0: After POR, all the registers are reset to their default values, and the two channels are off
- State 1 (CHx_EN-BIT = 0): In this state, the device registers are ready to be programmed. Read FLT1 and FLT2 registers to clear all the fault read bits and the PC bit. Set the FPINRST bit in the EN register in order for the fault pins to be cleared. All the initializations must be completed before turning on the channels. The device stays in state-1 unless the condition of CHx_IADJ > 8 is met.
- State 2 (CHx_EN-BIT = 1): The device advances to state-2 when the CHx_EN bit is set to "1". In this state all the necessary conditions for initiating the soft-start ramp are checked. The CHx_complow signal and CHx_PWM are high, and the condition of CHx_IADJ > 8 is met. If a latched fault occurs in this state, the CHx_comp pin is pulled low, the CHx_EN bits are set to zero and the device returns to state-1. For a non-latched fault, the device remains in this mode until the fault is removed.
- State 3 (SSDAC_RAMP): The SSDAC_RAMP state begins when all the conditions for the soft-start ramp initialization are met. In this state, the soft-start ramp DAC increments only when CHx_PWM is high. For CHx_PWM = LOW, the ramp is held constant. The DAC ramp re-starts the increment from the previous value at the next PWM dimming cycle, and when CHx_PWM = HIGH. If a latched-fault occurs in this state, the CHx_comp pin is pulled low, the CHx_EN bit is set to zero and the device returns to state-1. For a non-latched fault, the associated channel is turned off, the CHx_comp pin is pulled low and the device returns to state-2. At the end of the soft-start ramp, read FLT1 and FLT2 registers and set the FPINRST bit in the EN register in order for the fault read-bits and the fault pins to be cleared.
Device Functional Modes (continued)

Figure 42. Operational Mode, States 0 and 1
Device Functional Modes (continued)

Figure 43. Operational Mode, States 2 and 3
Device Functional Modes (continued)

7.4.3 Limp Home

The TPS92682-Q1 device enters the limp home (LH) mode, when the LH pin is pulled high (VDD, or logic level voltage). In LH mode the device sets the operation of the device based on the SPI programmable LH-registers (register addresses 0x17 to 0x24). The LH-registers should be programmed during initialization of the device. To exit the LH mode, the LH pin must be pulled low, and the LH bit in the **CFG1 Register** must be written to "0". The LH bit is set to "1" when the LH pin is pulled high. Writing a value of "1" to the LH bit does not have any effect and does not change the operation of the device.

7.5 Programming

The programming of the TPS92682-Q1 registers can be performed via a serial interface communication. The 4-wire control interface in the TPS92682-Q1 device is compatible with the Serial Peripheral Interface (SPI) bus. A Micro-Controller-Unit (MCU) may write to and read from the device registers to configure the channel operation and enable or disable a specific channel.

7.5.1 Serial Interface

The SPI bus consists of four signals: SSN, SCK, MOSI, and MISO. The SSN, SCK, and MOSI pins are TTL inputs into the TPS92682-Q1 while the MISO pin is an open-drain output. The SPI bus can be configured for both star-connect and daisy chain hardware connections.

A bus transaction is initiated by the MCU creating a falling edge on SSN. While SSN is low, the input data present on the MOSI pin is sampled on the rising edge of SCK, with MS-bit first. The output data is asserted on the MISO pin at the falling edge of the SCK. **Figure 44** shows the data transition and sampling edges of SCK.

![Figure 44. SPI DATA Format](image)

A valid transfer requires a non-zero integer multiple of 16 SCK cycles (16, 32, 48, and so forth.). If SSN is pulsed low and no SCK pulses are issued before SSN rises, a SPI error is reported. Similarly, if SSN is raised before the 16th rising edge of SCK, the transfer is aborted and a SPI error is reported. If SSN is held low after the 16th falling edge of SCK and additional SCK edges occur, the data continues to flow through the TPS92682-Q1 shift register and out of the MISO pin. When SSN transitions from low-to-high, the internal digital block decodes the most recent 16 bits that were received prior to the SSN rising edge.

SSN must transition to high after a multiple of 16 SCK cycles for a transaction to be valid and does not set the SPI error bit. In the case of a write transaction, the TPS92682-Q1 logic performs the requested operation when SSN transitions high. In the case of a read transaction, the read data is output during the next frame, regardless of whether a SPI error has occurred.

The data bit on MOSI is shifted into an internal 16-bit shift register (MS-bit first) while data is simultaneously shifted out of the MISO pin. While SSN is high (bus idle), MISO is tri-stated by the open-drain driver. While SSN is low, MISO is driven according to the 16-bit data pattern being shifted out based on the prior received command. At the falling edge of the SSN, to begin a new transaction, MISO is driven with the MS-bit of the outbound data, and is updated on each subsequent falling edge of SCK.
Programming (continued)

7.5.2 Command Frame

The command frames are the only defined frame-format that are sent from master to slave on MOSI. A command frame can be either a read command or a write command. A Command frame consists of a CMD bit, six bits of ADDRESS, a PARITY bit (odd parity), and eight bits of DATA. The format of the Command frame is shown in Figure 45. The bit sequence is as follows:

1. The COMMAND bit (CMD). CMD = 1 means the transfer is a write command; CMD = 0 means it is a read command.
2. Six bits of ADDRESS (A5..A0).
3. The PARITY bit (PAR). This bit is set by the following equation: PARITY = XNOR(CMD, A5..A0, D7..D0).
4. Eight bits of DATA (D7..D0). For read commands, the DATA bits must be set to zero.

Both the Read and the Write Command follow the Command frame format.

7.5.3 Response Frame

There are three possible response frame formats: Read Response, Write Response and Write Error/POR. These formats are further described below.

7.5.3.1 Read Response Frame Format

The Read Response has the following format:

1. The SPI Error bit (SPE).
2. Four reserved bits (always ‘1100’).
3. The RT Open Fault bit (RTO).
4. The Power-Cycled bit (PC).
5. The Thermal Warning bit (TW).
6. Eight bits of DATA (D7..D0).

This is shown in Figure 46. This frame is sent out by the TPS92682-Q1 following a read command.

7.5.3.2 Write Response Frame Format

The Write Response frame has the following format:

1. The SPI Error bit (SPE).
2. The COMMAND bit (CMD).
Programming (continued)

3. Six bits of ADDRESS (A5..A0).
4. Eight bits of DATA (D7..D0).

This is shown in Figure 47. This frame is sent out following a write command if the previously received frame was a write command and no SPI Error occurred during that frame.

The data and address bits in the write response are the data and address that were sent in the previous write command.

![Figure 47. Write Response Frame Format](image)

### 7.5.3.3 Write Error/POR Frame Format

The Write Error/POR frame is simply a ‘1’ in the MSB, followed by all zeroes (see Figure 48). This frame is sent out by the TPS92682-Q1 internal digital block during the first SPI transfer following power-on reset, or following a write command with a SPI Error.

![Figure 48. Write Error/POR](image)

### 7.5.4 SPI Error

The TPS92682-Q1 device records a SPI Error if any of the following conditions occur:

- The SPI command has a non-integer multiple of 16 SCK pulses.
- Any of the DATA bits during a read command are non-zero.
- There is a parity error in the previously received command.

If any of these conditions are true, the TPS92682 sets the SPE bit high in the next response frame. A write command with a SPI Error (not 16-bit aligned or bad parity) does NOT write to the register being addressed. Similarly, a read command to FLT1 or FLT2 does not clear any active fault bits in those registers if the command has a SPI Error.

### 7.6 TPS92682 Registers

The SPI-accessible registers are 8-bits wide and exist in a 6-bit-addressable register array (0x00 through 0x3F). The registers in the TPS92682 device contain programmed information and operating status. Upon power-up the registers are reset to their default values. Writes to unlisted addresses are not permitted and may result in undesired operation. Reads of unlisted addresses return the zero value.

Reserved bits (“RSVD”) must be written with ‘0’ values when writing. Registers are read/write unless indicated in the register’s description. Table 2 lists the TPS92682 register map.
### TPS92682 Registers (continued)

#### Table 2. TPS92682 Register Map

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<th>D4</th>
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<th>D2</th>
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<td>LCH2PWM9:8</td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
<tr>
<td>1 Eh</td>
<td>LHILIM</td>
<td>LHCH2ILIMCNT1:0</td>
<td>LHCH1ILIMCNT1:0</td>
<td>LHCH2ILIM1:0</td>
<td>LHCH1ILIM1:0</td>
<td></td>
<td></td>
<td></td>
<td>00001111</td>
<td></td>
</tr>
<tr>
<td>1Fh</td>
<td>LHIFT</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>LHCH2IFT1:0</td>
<td>LHCH1IFT1:0</td>
<td></td>
<td>00001010</td>
</tr>
<tr>
<td>20h</td>
<td>LHMFT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LCH2MFT3:0</td>
<td>LCH1MFT3:0</td>
<td></td>
<td></td>
<td>10011001</td>
</tr>
<tr>
<td>21h</td>
<td>LHFEN1</td>
<td>LHCH2RF EN</td>
<td>LHCH1RF EN</td>
<td>LHCH2FB OEN</td>
<td>LHCH1FB OEN</td>
<td>LHCH2OV EN</td>
<td>LHCH1OV EN</td>
<td>LHCH2UV EN</td>
<td>LHCH1UV EN</td>
<td>00111100</td>
</tr>
<tr>
<td>22h</td>
<td>LHFEN2</td>
<td>RSVD</td>
<td>RSVD</td>
<td>LHCH2OC EN</td>
<td>LHCH1OC EN</td>
<td>LHCH2ILI MEN</td>
<td>LHCH1ILI MEN</td>
<td>LHCH2IS OEN</td>
<td>LHCH1IS OEN</td>
<td>00001111</td>
</tr>
<tr>
<td>23h</td>
<td>LHFLATEN</td>
<td>LHCH2ILI MFL</td>
<td>LHCH1ILI MFL</td>
<td>LHCH2OCCFL</td>
<td>LHCH1OCCFL</td>
<td>LHCH2OVFL</td>
<td>LHCH1OVFL</td>
<td>LHCH2UFL</td>
<td>LHCH1UFL</td>
<td>00000000</td>
</tr>
<tr>
<td>24h</td>
<td>LHOV</td>
<td>RSVD</td>
<td>LCH2OV2:0</td>
<td></td>
<td></td>
<td>LCH1OV2:0</td>
<td></td>
<td></td>
<td></td>
<td>00100010</td>
</tr>
<tr>
<td>25h</td>
<td>CAL</td>
<td>CH2CAL2:0</td>
<td></td>
<td>CH2G0FF</td>
<td>CH1CAL2:0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>
7.6.1 EN Register

EN is the channel enable register. This register contains bits associated with the enabling of channels and several channel-related functions.

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>00h</td>
<td>EN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00111100</td>
</tr>
</tbody>
</table>

- **FPINRST:**
  Setting this bit to one resets both fault pins, if there are no active faults in the system. Note that this bit is write-only. Any reads of this register return 0 in the FPINRST bit location.

- **SYNCEN:**
  0: SYNC input is disabled.
  1: SYNC input is enabled.

- **CHxMAXDEN:**
  0: Maximum duty cycle for the associated channel is disabled.
  1: Maximum duty cycle for the associated channel is enabled.

- **CHxPDRVEN:**
  0: The associated channel PFET driver is disabled
  1: The associated channel PFET driver is enabled

- **CHxEN:**
  0: The associated channel is disabled.
  1: The associated channel is enabled. SPI writes of ‘1’ to these bits are blocked if the PC bit in FLT1 register is high.

7.6.2 CFG1 Register

Configuration register 1.

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>01h</td>
<td>CFG1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

- **PWMPH:**
  0: Phase shift of 180° between internal PWM signals.
  1: Zero phase shift between internal PWM signals.

- **INTPWM:**
  0: External PWM inputs are used.
  1: Internal PWM inputs are used.

- **2PH:**
  0: Single phase, two-channel configuration.
  1: Dual phase configuration.

- **LH:**
This bit is latched high when the LH pin is set high. The LH bit remains high until this bit is written back to zero via SPI (the LH pin cannot set this bit to zero). If the LH bit is high, the LH registers are used to control the logic instead of the normal registers. The part comes out of LH mode when LH pin is pulled low and the LH bit is written to 0.

It is recommended that the LH bit always be written with a ‘1’ during normal programming. This will ensure that a true limp-home event triggered by LH pin is captured.

- **CHxHG:**
  0: The error-amp of the associated channel is set to low gain.
  1: The error-amp of the associated channel is set to high gain.

- **CHxCV:**
  0: The associated channel is set in CC mode.
  1: The associated channel is set in CV mode.

### 7.6.3 CFG2 Register

Configuration register 2.

```plaintext
<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>02h</td>
<td>CFG2</td>
<td>CH2LEB</td>
<td>CH1LEB</td>
<td>RSVD</td>
<td>RSVD</td>
<td>CH2FILT1</td>
<td>RSVD</td>
<td>RSVD</td>
<td>CH1FILT1</td>
<td>00000000</td>
</tr>
</tbody>
</table>
```

- **CHxLEB:**
  0: Short Leading Edge Blanking.
  1: Long Leading Edge Blanking.

- **CHxFILT1:** ILIM comparator filter.

### 7.6.4 SWDIV Register

SWDIV register holds the divider value associated with dividing down the main clock to generate the channel clocks (switching frequency $f_{SW}$).

```plaintext
<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>03h</td>
<td>SWDIV</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>CH2DIV1:0</td>
<td>CH1DIV1:0</td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>
```

- **CHxDIV:**
  00: Division = 2. CHxCLK = $f_{CLKM}/2$.
  01: Division = 4. CHxCLK = $f_{CLKM}/4$.
  10: Division = 8. CHxCLK = $f_{CLKM}/8$.
  11: Division = 8. CHxCLK = $f_{CLKM}/8$.

### 7.6.5 ISLOPE Register

ISLOPE register programs the slope compensation ramp magnitude.

```plaintext
<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>04h</td>
<td>ISLOPE</td>
<td>RSVD</td>
<td>CH2ISLP2:0</td>
<td>RSVD</td>
<td></td>
<td>CH1ISLP2:0</td>
<td></td>
<td></td>
<td>01010101</td>
<td></td>
</tr>
</tbody>
</table>
```

- **CHxISLP:**
  000: $V_{SLP(PK)} = 0$ mV.
  001: $V_{SLP(PK)} = 50$ mV.
  010: $V_{SLP(PK)} = 100$ mV.
  011: $V_{SLP(PK)} = 150$ mV.
  100: $V_{SLP(PK)} = 200$ mV.
  101: $V_{SLP(PK)} = 250$ mV.
  110: $V_{SLP(PK)} = 300$ mV.
111: \( V_{SLP(PK)} = 350 \text{ mV} \).

### 7.6.6 FM Register

FM contains the Frequency Modulation configuration bits.

#### Table 8. FM Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>05h</td>
<td>FM</td>
<td>RSVD</td>
<td>RSVD</td>
<td>FMMAG1:0</td>
<td>FMFREQ3:0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000101</td>
</tr>
</tbody>
</table>

- The \( \text{CLK}_M \) frequency is varied by a percentage defined by FMMAG:
  - 00: Frequency modulation is disabled.
  - 01: The modulation magnitude is set to \( \pm 3.75\% \).
  - 10: The modulation magnitude is set to \( \pm 7.5\% \).
  - 11: The modulation magnitude is set to \( \pm 15\% \).

- The FMFREQ programs a division factor applied to \( \text{CLK}_M \) that sets the frequency modulation:
  - 0000: FM frequency is \( 1/4096 \) of \( \text{CLK}_M \) frequency.
  - 0001: FM frequency is \( 1/3584 \) of \( \text{CLK}_M \) frequency.
  - 0010: FM frequency is \( 1/3072 \) of \( \text{CLK}_M \) frequency.
  - 0011: FM frequency is \( 1/2560 \) of \( \text{CLK}_M \) frequency.
  - 0100: FM frequency is \( 1/2048 \) of \( \text{CLK}_M \) frequency.
  - 0101: FM frequency is \( 1/1536 \) of \( \text{CLK}_M \) frequency.
  - 0110: FM frequency is \( 1/1024 \) of \( \text{CLK}_M \) frequency.
  - 0111: FM frequency is \( 1/512 \) of \( \text{CLK}_M \) frequency.
  - 1000: FM frequency is \( 1/256 \) of \( \text{CLK}_M \) frequency.
  - 1001: FM frequency is \( 1/128 \) of \( \text{CLK}_M \) frequency.
  - 1010: FM frequency is \( 1/64 \) of \( \text{CLK}_M \) frequency.
  - 1011: FM frequency is \( 1/32 \) of \( \text{CLK}_M \) frequency.
  - 1100: FM frequency is \( 1/16 \) of \( \text{CLK}_M \) frequency.
  - 1101: FM frequency is \( 1/8 \) of \( \text{CLK}_M \) frequency.
  - 1110: Frequency modulation is disabled.
  - 1111: Frequency modulation is disabled.

### 7.6.7 SOFTSTART Register

The SOFTSTART register determines the division factor to be applied to the input clock of the soft-start 8-bit ramp counter.

#### Table 9. SOFTSTART Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>06h</td>
<td>SOFTSTART</td>
<td>CH2SS3:0</td>
<td></td>
<td></td>
<td></td>
<td>CH1SS3:0</td>
<td></td>
<td></td>
<td></td>
<td>01110111</td>
</tr>
</tbody>
</table>

- \( \text{CHxSS} \):
  - 0000: Soft-start is disabled.
  - 0001: Division factor = 2.
  - 0010: Division factor = 4.
  - 0011: Division factor = 6.
  - 0100: Division factor = 8.
  - 0101: Division factor = 12.
  - 0110: Division factor = 16.
  - 0111: Division factor = 20.
  - 1000: Division factor = 26.
  - 1001: Division factor = 32.
  - 1010: Division factor = 38.
1011: Division factor = 46.
1100: Division factor = 54.
1101: Division factor = 64.
1110: Division factor = 80.
1111: Division factor = 100.

If 2PH is set to ‘1’, only CH1 parameter is used.

7.6.8 CH1IADJ Register

CH1IADJ register programs the 8-bit IADJ DAC for the channel 1. If CH1IADJ ≤ 8, channel 1 is turned off. The DAC output can be set from 85 mV (code 9) to 2.4 V (code 255).

Table 10. CH1IADJ Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>07h</td>
<td>CH1IADJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

7.6.9 CH2IADJ Register

CH2IADJ register programs the 8-bit IADJ DAC for the channel 2. If CH2IADJ ≤ 8, channel 2 is turned off. The DAC output can be set from 85 mV (code 9) to 2.4 V (code 255).

Table 11. CH2IADJ Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>08h</td>
<td>CH2IADJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

If 2PH is set to ‘1’, only CH1 parameter is used.

7.6.10 PWMDIV Register

PWMDIV register sets the clock divider for the internal PWM generator block.

Table 12. PWMDIV Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>09h</td>
<td>PWMDIV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000001</td>
</tr>
</tbody>
</table>

PWMDIV:

000: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 1 \).
001: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 2 \).
010: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 3 \).
011: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 4 \).
100: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 5 \).
101: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 6 \).
110: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 7 \).
111: \( \text{PWM}_{\text{CLK}} = \text{CLK}_M \div 8 \).

7.6.11 CH1PWML Register

CH1PWML register sets the 8 LSBs of the PWM-width on a 10-bit counter for channel 1.

Table 13. CH1PWML Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Ah</td>
<td>CH1PWML</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>
7.6.12 CH1PWMH Register
CH1PWMH register sets the 2 MSBs of the PWM-width on a 10-bit counter for channel-1.

Table 14. CH1PWMH Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Bh</td>
<td>CH1PWMH</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>CH1PWM9:8</td>
<td>00000000</td>
<td></td>
</tr>
</tbody>
</table>

7.6.13 CH2PWML Register
CH2PWML register sets the 8 LSBs of the PWM-width on a 10-bit counter for channel-2.

Table 15. CH2PWML Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Ch</td>
<td>CH2PWML</td>
<td>CH2PWM7:0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

7.6.14 CH2PWMH Register
CH2PWMH register sets the 2 MSBs of the PWM-width on a 10-bit counter for channel-2.

Table 16. CH2PWMH Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Dh</td>
<td>CH2PWMH</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>CH2PWM9:8</td>
<td>00000000</td>
<td></td>
</tr>
</tbody>
</table>

7.6.15 ILIM Register
ILIM register configures the ILIM event counter and the $V_{\text{ILIM(THR)}}$ of channel-1 and channel-2.

Table 17. ILIM Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Eh</td>
<td>ILIM</td>
<td>CH2ILIMCNT1:0</td>
<td>CH1ILIMCNT1:0</td>
<td>CH2ILIM1:0</td>
<td>CH1ILIM1:0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00001111</td>
</tr>
</tbody>
</table>

ILIM event counter counts the number of ILIM fault events before disabling the associated channel completely or initiating the ILIM Fault Timer.

- CHxILIMCNT:
  - 00: ILIM event counter threshold = 1.
  - 01: ILIM event counter threshold = 4.
  - 10: ILIM event counter threshold = 16.
  - 11: ILIM event counter threshold = 32.

- The current limit threshold voltage of the associated channel is set by CHxILIM:
  - 00: $V_{\text{ILIM(THR)}}$ = 75 mV.
  - 01: $V_{\text{ILIM(THR)}}$ = 100 mV.
  - 10: $V_{\text{ILIM(THR)}}$ = 150 mV.
  - 11: $V_{\text{ILIM(THR)}}$ = 250 mV.

7.6.16 IFT Register
ILIM Fault Timer register, IFT, determines the maximum count value of a 6-bit counter used for the ILIM Fault Timer. The clock for the ILIM Fault Timer is the CHxCLK.

Table 18. IFT Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Fh</td>
<td>IFT</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>CH2IFT1:0</td>
<td>CH1IFT1:0</td>
<td>00001010</td>
<td></td>
</tr>
</tbody>
</table>
• CHxIFT:
  00: ILIM Fault Timer maximum count = 4.
  01: ILIM Fault Timer maximum count = 8.
  10: ILIM Fault Timer maximum count = 16.
  11: ILIM Fault Timer maximum count = 32.

If 2PH is set to ‘1’, only CH1 parameters are used and only ILIM Fault Timer 1 is active. In this case, ILIM Fault Timer 1 affects both channels.

7.6.17 MFT Register

Main Fault Timer register, MFT, determines the maximum count value of a 14-bit counter, used for the Main Fault Timer. The clock for the MFT is the CHxCLK.

Table 19. MFT Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10h</td>
<td>MFT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1001001</td>
</tr>
</tbody>
</table>

• CHxMFT:
  0000: Main Fault Timer maximum count = 0 (Main Fault Timer is disabled).
  0001: Main Fault Timer maximum count = 1000.
  0010: Main Fault Timer maximum count = 1500.
  0100: Main Fault Timer maximum count = 2500.
  0101: Main Fault Timer maximum count = 3000.
  0110: Main Fault Timer maximum count = 3500.
  0111: Main Fault Timer maximum count = 4000.
  1000: Main Fault Timer maximum count = 5000.
  1001: Main Fault Timer maximum count = 6000.
  1010: Main Fault Timer maximum count = 7000.
  1011: Main Fault Timer maximum count = 8000.
  1100: Main Fault Timer maximum count = 10000.
  1101: Main Fault Timer maximum count = 12000.
  1110: Main Fault Timer maximum count = 14000.
  1111: Main Fault Timer maximum count = 16383.

If 2PH is set to ‘1’, only CH1 parameters are used and only Fault Timer 1 is active. In this case, Fault Timer 1 affects both channels.

7.6.18 FLT1 Register (read only)

FLT1 register bits are set if a selected fault shown in Table 20 occurs. Reading this register clears the bits that are set, if the associated faults no longer exist. Note that the clearing of the bits happens at the end of the read response SPI transfer, not at the end of the read command SPI transfer.

Table 20. FLT1 Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>11h</td>
<td>FLT1</td>
<td>RTO</td>
<td>RSVD</td>
<td>PC</td>
<td>TW</td>
<td>CH2OV</td>
<td>CH1OV</td>
<td>CH2UV</td>
<td>CH1UV</td>
<td>read</td>
</tr>
</tbody>
</table>

• RTO: RT pin is open.
• PC: Power Cycled bit; This bit is set at power-up and is considered a fault. The PC bit must be cleared before the softstart DAC state machine can progress and the channels can be turned on.
• TW: Thermal Warning bit.
• CHxOV: Output over-voltage fault (CH2OV is disabled if 2PH is set to ‘1’).
• CHxUV: Output under-voltage fault (CH2UV is disabled if 2PH is set to ‘1’).
7.6.19 FLT2 Register (read only)

FLT2 register bits are set if a selected fault shown in Table 21 occurs. Reading this register clears the bits that are set, if the associated faults no longer exist. Note that the clearing of the bits happens at the end of the read response SPI transfer, not at the end of the read command SPI transfer.

Table 21. FLT2 Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>12h</td>
<td>FLT2</td>
<td>C2H</td>
<td>C1H</td>
<td>C2O</td>
<td>C1O</td>
<td>C2IL</td>
<td>C1IL</td>
<td>C2ISO</td>
<td>C1ISO</td>
<td>read</td>
</tr>
</tbody>
</table>

- CHxUC: CHx output current less than 0.5 time of the set value (CH2UC is disabled if 2PH is set to ‘1’).
- CHxOC: CHx output current more than 1.5 time of the set value (CH2OC is disabled if 2PH is set to ‘1’).
- CHxILIM: ILIM bit is only set after CHxILIMCNT counter has reached the programmed value.
- CHxISO: Open pin detection on ISN pins.

7.6.20 FEN1 Register

Fault Enable-1 register, FEN1, determines which of the faults shown in Table 22 are enabled. If a fault enable is set to ‘1’, it is enabled and it will affect the operation of the associated channel. The faults that are disabled will not affect the CHx fault pin output.

Table 22. FEN1 Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>13h</td>
<td>FEN1</td>
<td>C2RF</td>
<td>C1RF</td>
<td>C2FB</td>
<td>C1FB</td>
<td>C2OV</td>
<td>C1OV</td>
<td>C2U</td>
<td>C1U</td>
<td>00111100</td>
</tr>
</tbody>
</table>

- Ramp Fault Enable, CHxRFEN:
  0: Disables the CHxUV fault from affecting channel operation before or during the Soft-Start ramp. In CV mode, CHx ILIM neither triggers the IFT, nor turns off the channel before or during the Soft-Start ramp. Note that the cycle-by-cycle current limit is still active.
  1: All the enabled faults are active before or during the Soft-Start ramp.
- CHxFBOEN: if set to ‘1’, FB pin open fault is enabled. There are no associated fault read bits for this fault.
- CHxOVEN: if set to ‘1’, output over-voltage fault is enabled. CH2OV fault is disabled if 2PH bit is set to ‘1’.
- CHxUVEN: if set to ‘1’, output under-voltage fault is enabled. CH2UV fault is disabled if 2PH bit is set to ‘1’.

If 2PH is set to ‘1’, only CH1 parameter is used.

7.6.21 FEN2 Register

Fault Enable-2 register, FEN2, determines which of the faults shown in Table 23 are enabled. If a fault enable is set to ‘1’, it is enabled and it will affect the operation of the associated channel. The faults that are disabled will not affect the CHx fault pin output.

Table 23. FEN2 Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>14h</td>
<td>FEN2</td>
<td>OVO</td>
<td>RSVD</td>
<td>C2OC</td>
<td>C1OC</td>
<td>C2ILIM</td>
<td>C1ILIM</td>
<td>C2ISO</td>
<td>C1ISO</td>
<td>00001111</td>
</tr>
</tbody>
</table>

- OVOPT: if set to ‘1’, the OV fault is only captured by the analog block and the digital state machine is not affected by the over-voltage fault.
- CHxOCEN: if set to ‘1’, output over-current fault is enabled.
- CHxILIMEN: if set to ‘1’, ILIM fault is enabled.
- CHxISOEN: if set to ‘1’, ISN open pin fault is enabled.

If 2PH is set to ‘1’, only CH1 parameter is used.

7.6.22 FLATEN Register

Fault Latch Enable register, FLATEN, determines which of the faults shown in Table 24 are latched faults. A latched fault turns off the channel. In this case, to turn the channel back on, the CHxEN should be set to ‘1’ in Table 3 via a SPI write command.
### Table 24. FLATEN Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>15h</td>
<td>FLATEN</td>
<td>CH2LIMFL</td>
<td>CH1LIMFL</td>
<td>CH2OCFL</td>
<td>CH1OCFL</td>
<td>CH2OVFL</td>
<td>CH1OVFL</td>
<td>CH2UVFL</td>
<td>CH1UVFL</td>
<td>00000000</td>
</tr>
</tbody>
</table>

- CHxLIMFL: if set to ‘1’, ILIM fault is set to a latched fault.
- CHxOCFL: if set to ‘1’, output over-current fault is set to a latched fault.
- CHxOVFL: if set to ‘1’, output over-voltage fault is set to a latched fault.
- CHxUVFL: if set to ‘1’, output under-voltage fault is set to a latched fault.

If 2PH is set to ‘1’, only CH1 parameter is used.

### 7.6.23 OV Register

CHxOV programs a 3-bit DAC to set the OV threshold relative to the VFB_{REF}.

### Table 25. OV Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>16h</td>
<td>OV</td>
<td>RSVD</td>
<td>CH2OV2:0</td>
<td>RSVD</td>
<td>CH1OV2:0</td>
<td>00100010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- CHxOV:
  - 000: OV_{THR} = VFB_{REF}×(1.000).
  - 001: OV_{THR} = VFB_{REF}×(1.025).
  - 010: OV_{THR} = VFB_{REF}×(1.050).
  - 011: OV_{THR} = VFB_{REF}×(1.075).
  - 100: OV_{THR} = VFB_{REF}×(1.100).
  - 101: OV_{THR} = VFB_{REF}×(1.125).
  - 110: OV_{THR} = VFB_{REF}×(1.150).
  - 111: OV_{THR} = VFB_{REF}×(1.200).

If 2PH is set to ‘1’, only CH1 parameter is used.

### 7.6.24 LHCFG Register

LHCFG is the Limp-Home Configuration register. The settings in this register are applied when LH pin is set high.

### Table 26. LHCFG Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>17h</td>
<td>LHCFG</td>
<td>LHPWMPH</td>
<td>LHINTPWM</td>
<td>LHCH2M</td>
<td>AXDEN</td>
<td>LHCH1M</td>
<td>AXDEN</td>
<td>LHCH2PD</td>
<td>RVEN</td>
<td>LHCH1PD</td>
</tr>
</tbody>
</table>

- LHPWMPH:
  - 0: Phase shift of 180° between internal PWM signals.
  - 1: Zero phase shift between internal PWM signals.
- LHINTPWM:
  - 0: External PWM inputs are used.
  - 1: Internal PWM inputs are used.
- LHCHxMAXDEN:
  - 0: Maximum duty cycle for the associated channel is disabled.
  - 1: Maximum duty cycle for the associated channel is enabled.
- LHCHxPDVEN:
  - 0: The associated channel PFET driver is disabled
  - 1: The associated channel PFET driver is enabled
- LHCHxEN:
  - 0: The associated channel is disabled.
  - 1: The associated channel is enabled.
If 2PH is set to ‘1’, only CH1 parameter is used.

### 7.6.25 LHCH1IADJ Register
LHCH1IADJ register programs the 8-bit IADJ DAC for channel-1. The settings in this register are applied when LH pin is set high. If LHCH1IADJ ≤ 8, the channel-1 is turned off. The DAC output can be set from 85 mV (code 9) to 2.4 V (code 255).

**Table 27. LHCH1IADJ Register**

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>18h</td>
<td>LHCH1IADJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

### 7.6.26 LHCH2IADJ Register
LHCH2IADJ register programs the 8-bit IADJ DAC for channel-2. The settings in this register are applied when LH pin is set high. If LHCH2IADJ ≤ 8, the channel-2 is turned off. The DAC output can be set from 85 mV (code 9) to 2.4 V (code 255).

**Table 28. LHCH2IADJ Register**

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>19h</td>
<td>LHCH2IADJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

If 2PH is set to ‘1’, only CH1 parameter is used.

### 7.6.27 LHCH1PWML Register
LHCH1PWML register sets the 8 LSBs of the PWM-width on a 10-bit counter for channel-1. The settings in this register are applied when LH pin is set high.

**Table 29. LHCH1PWML Register**

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Ah</td>
<td>LHCH1PWML</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

### 7.6.28 LHCH1PWMH Register
LHCH1PWMH register sets the 2 MSBs of the PWM-width on a 10-bit counter for channel-1. The settings in this register are applied when LH pin is set high.

**Table 30. LHCH1PWMH Register**

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Bh</td>
<td>LHCH1PWMH</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>RSVD</td>
<td>LSVD</td>
<td>LSVD</td>
<td>00000000</td>
</tr>
</tbody>
</table>

### 7.6.29 LHCH2PWML Register
LHCH2PWML register sets the 8 LSBs of the PWM-width on a 10-bit counter for channel-2. The settings in this register are applied when LH pin is set high.

**Table 31. LHCH2PWML Register**

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Ch</td>
<td>LHCH2PWML</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>

If 2PH is set to ‘1’, only CH1 parameter is used.

### 7.6.30 LHCH2PWMH Register
LHCH2PWMH register sets the 2 MSBs of the PWM-width on a 10-bit counter for channel-2. The settings in this register are applied when LH pin is set high.
If 2PH is set to ‘1’, only CH1 parameter is used.

### 7.6.31 LHILIM Register

LHILIM register configures the ILIM event counter and the $V_{ILIM(THR)}$ of channel-1 and channel-2. The settings in this register are applied when LH pin is set high.

#### Table 33. LHILIM Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Eh</td>
<td>LHILIM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00001111</td>
</tr>
</tbody>
</table>

LHILIM-counter counts the number of ILIM fault events before disabling the associated channel completely or initiating the ILIM Fault Timer.

- LHCHxILIMCNT:
  00: ILIM event counter threshold = 1.
  01: ILIM event counter threshold = 4.
  10: ILIM event counter threshold = 16.
  11: ILIM event counter threshold = 32.

- The current limit threshold voltage of the associated channel is set by LHCHxILIM:
  00: $V_{ILIM(THR)} = 75$ mV.
  01: $V_{ILIM(THR)} = 100$ mV.
  10: $V_{ILIM(THR)} = 150$ mV.
  11: $V_{ILIM(THR)} = 250$ mV.

### 7.6.32 LHIFT Register

LHIFT register determines the maximum count value of a 6-bit counter used for the ILIM Fault Timer. The clock for the ILIM Fault Timer is the CHx_CLK. The settings in this register are applied when LH pin is set high.

#### Table 34. LHIFT Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Fh</td>
<td>LHIFT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00001010</td>
</tr>
</tbody>
</table>

- LHCHxIFT:
  00: ILIM Fault Timer maximum count = 4.
  01: ILIM Fault Timer maximum count = 8.
  10: ILIM Fault Timer maximum count = 16.
  11: ILIM Fault Timer maximum count = 32.

If 2PH is set to ‘1’, only CH1 parameters are used and only ILIM Fault Timer 1 is active. In this case, ILIM Fault Timer-1 affects both channels.

### 7.6.33 LHMFT Register

LHMFT register determines the maximum count value of a 14-bit counter, used for the Main Fault Timer. The clock for the MFT is the CHx_CLK. The settings in this register are applied when LH pin is set high.

#### Table 35. LHMFT Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>20h</td>
<td>LHMFT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10011001</td>
</tr>
</tbody>
</table>
• LHCHxMFT:
  0000: Main Fault Timer maximum count = 0 (Main Fault Timer is disabled).
  0001: Main Fault Timer maximum count = 1000.
  0010: Main Fault Timer maximum count = 1500.
  0100: Main Fault Timer maximum count = 2500.
  0101: Main Fault Timer maximum count = 3000.
  0110: Main Fault Timer maximum count = 3500.
  0111: Main Fault Timer maximum count = 4000.
  1000: Main Fault Timer maximum count = 5000.
  1001: Main Fault Timer maximum count = 6000.
  1010: Main Fault Timer maximum count = 7000.
  1011: Main Fault Timer maximum count = 8000.
  1100: Main Fault Timer maximum count = 10000.
  1101: Main Fault Timer maximum count = 12000.
  1110: Main Fault Timer maximum count = 14000.
  1111: Main Fault Timer maximum count = 16383.

If 2PH is set to ‘1’, only CH1 parameters are used and only Fault Timer 1 is active. In this case, Fault Timer 1 affects both channels.

7.6.34 LHFEN1 Register

LHFEN1 register determines which of the faults shown in Table 36 are enabled. If a fault enable is set to ‘1’, it is enabled and it will affect the operation of the associated channel. The faults that are disabled will not affect the CHx fault pin output. The settings in this register are applied when LH pin is set high.

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>21h</td>
<td>LHFEN1</td>
<td>LCH2RFEN</td>
<td>LCH1RFEN</td>
<td>LCH2FB</td>
<td>LCH1FB</td>
<td>LCH2OV</td>
<td>LCH1OV</td>
<td>LCH2UV</td>
<td>LCH1UV</td>
<td>00111100</td>
</tr>
</tbody>
</table>

• LHCHxRFEN:
  0: Disables the CHxUV fault from affecting channel operation before or during the Soft-Start ramp. In CV mode, CHx ILIM neither triggers the IFT, nor turns off the channel before or during the Soft-Start ramp. Note that the cycle-by-cycle current limit is still active.
  1: All the enabled faults are active before or during the Soft-Start ramp.
• LHCHxFBOEN: if set to ‘1’, FB pin open fault is enabled. There are no associated fault read bits for these faults.
• LHCHxOVEN: if set to ‘1’, output over-voltage fault is enabled. CH2OV fault is disabled if 2PH bit is set to ‘1’.
• LHCHxUVEN: if set to ‘1’, output under-voltage fault is enabled. CH2UV fault is disabled if 2PH bit is set to ‘1’.

If 2PH is set to ‘1’, only CH1 parameter is used.

7.6.35 LHFEN2 Register

LHFEN2 register determines which of the faults shown in Table 37 are enabled. If a fault enable is set to ‘1’, it is enabled and it will affect the operation of the associated channel. The faults that are disabled will not affect the CHx fault pin output. The settings in this register are applied when LH pin is set high.

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>22h</td>
<td>LHFEN2</td>
<td>RSVD</td>
<td>RSVD</td>
<td>LCH2OCEN</td>
<td>LCH1OCEN</td>
<td>LCH2ILI</td>
<td>LCH1ILI</td>
<td>LCH2ISOEN</td>
<td>LCH1ISOEN</td>
<td>00001111</td>
</tr>
</tbody>
</table>
• LHCHxOCEN: if set to '1', output over-current fault is enabled.
• LHCHxILIMEN: if set to '1', ILIM fault is enabled.
• LHCHxISOEN: if set to '1', ISN open pin fault is enabled.

If 2PH is set to '1', only CH1 parameter is used.

7.6.36 LHFLATEN Register

LHFLATEN register determines which of the faults shown in Table 38 are latched faults. A latched fault turns off the channel. In this case, to turn on the channel back on, the CHxEN should be set to '1' in Table 3 via a SPI write command. The settings in this register are applied when LH pin is set high.

Table 38. LHFLATEN Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>23h</td>
<td>LHFLATEN</td>
<td>LHCH2ILI MFL</td>
<td>LHCH1ILI MFL</td>
<td>LHCH2O CFL</td>
<td>LHCH1O CFL</td>
<td>LHCH2OV FL</td>
<td>LHCH1OV FL</td>
<td>LHCH2UV FL</td>
<td>LHCH1UV FL</td>
<td>00000000</td>
</tr>
</tbody>
</table>

• LHCHxILIMFL: if set to '1', ILIM fault is set to a latched fault.
• LHCHxOCFL: if set to '1', output over-current fault is set to a latched fault.
• LHCHxOVFL: if set to '1', output over-voltage fault is set to a latched fault.
• LHCHxUVFL: if set to '1', output under-voltage fault is set to a latched fault.

If 2PH is set to '1', only CH1 parameter is used.

7.6.37 LHOV Register

LHCHxOV register programs a 3-bit DAC to set the OV threshold relative to the VFBREF. The settings in this register are applied when LH pin is set high.

Table 39. LHOV Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>24h</td>
<td>LHOV</td>
<td>RSVD</td>
<td>LHCH2OV2:0</td>
<td>RSVD</td>
<td>LHCH1OV2:0</td>
<td>00100010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• LHCHxOV:
  000: \( OV_{THR} = VFB_{REF} \times (1.000). \)
  001: \( OV_{THR} = VFB_{REF} \times (1.025). \)
  010: \( OV_{THR} = VFB_{REF} \times (1.050). \)
  011: \( OV_{THR} = VFB_{REF} \times (1.075). \)
  100: \( OV_{THR} = VFB_{REF} \times (1.100). \)
  101: \( OV_{THR} = VFB_{REF} \times (1.125). \)
  110: \( OV_{THR} = VFB_{REF} \times (1.150). \)
  111: \( OV_{THR} = VFB_{REF} \times (1.200). \)

If 2PH is set to '1', only CH1 parameter is used.

7.6.38 CAL Register

The CAL register includes calibration bits for the switch current sense circuitry.

Table 40. CAL Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>25h</td>
<td>CAL</td>
<td>CH2CAL2:0</td>
<td>CH2GOF</td>
<td>CH1CAL2:0</td>
<td>CH1GOF</td>
<td>00000000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHxCAL: Each channel has three calibration bits, which adds 2.5 mV of offset per bit (2.5 mV to 17.5 mV) to the switch current sense voltage threshold. The calibration bits can decrease the offset mismatch between the switch current sense of the two channels and improve the current sharing in two phase applications.

CHxGOFF: This bit turns off the associated channel, when set to "1".

7.6.39  RESET Register

Writing 0xC3 to the RESET register resets all writable registers to their default values. This register is write-only and reads from this register return 0. Note that a RESET command does not reset the PC bit in Table 20 to its power-on default value of ‘1’.

Table 41. RESET Register

<table>
<thead>
<tr>
<th>ADDR</th>
<th>REGISTER</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
<th>DEFAULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>26h</td>
<td>RESET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>00000000</td>
</tr>
</tbody>
</table>
8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI’s customers are responsible for determining suitability of components for their purposes. Customers must validate and test their design implementation to confirm system functionality.

8.1 Application Information General Design Considerations

The TPS92682-Q1 can be configured both in CC and CV mode. In both cases the following general design procedures are applicable.

8.1.1 Switching Frequency, $f_{SW}$

To set the switching frequency for each channel, refer to Oscillator section.

8.1.2 Duty Cycle Considerations

The switch duty cycle, $D$, defines the converter operation and is a function of the input and output voltages. In steady state, the duty cycle is derived using the expression:

Boost:

$$D = \frac{V_O - V_{IN}}{V_O}$$  \hspace{1cm} (9)

Buck-Boost:

$$D = \frac{V_O}{V_O + V_{IN}}$$  \hspace{1cm} (10)

The minimum duty cycle, $D_{MIN}$, and maximum duty cycle, $D_{MAX}$, are calculated by substituting maximum input voltage, $V_{IN\,(MAX)}$, and the minimum input voltage, $V_{IN\,(MIN)}$, respectively in the previous expressions. The minimum duty cycle achievable by the device is determined by the leading edge blanking period and the switching frequency. The maximum duty cycle is limited by the internal oscillator to 90% (typ) to allow for minimum off-time. It is necessary for the operating duty cycle to be within the operating limits of the device to ensure closed-loop regulation over the specified input and output voltage range.

8.1.3 Main Power MOSFET Selection

The power MOSFET is required to sustain the maximum switch node voltage, $V_{SW}$, and switch RMS current derived based on the converter topology. TI recommends a drain voltage $V_{DS}$ rating of at least 10% greater than the maximum switch node voltage to ensure safe operation.

The worst case MOSFET RMS current for Boost and Buck-Boost topology depends on the maximum output power, $P_{O\,(MAX)}$, and is calculated as follows:

$$I_{Q\,(RMS)} = \frac{P_{O\,(MAX)}}{V_{IN\,(MIN)}} \times \sqrt{1 - \frac{V_{IN\,(MIN)}}{V_{O\,(MIN)}}}$$  \hspace{1cm} (11)

Select a MOSFET with low total gate charge, $Q_g$, to minimize gate drive and switching losses.

8.1.4 Rectifier Diode Selection

A Schottky diode (when used as a rectifier) provides the best efficiency due to its low forward voltage drop and near-zero reverse recovery time. TI recommends a diode with a reverse breakdown voltage, $V_{D\,(BR)}$, greater than or equal to MOSFET drain-to-source voltage, $V_{DS}$, for reliable performance. It is important to understand the leakage current characteristics of the Schottky diode, especially at high operating temperatures as it impacts the overall converter operation and efficiency.

The diode power rating and package is selected based on the calculated current, the ambient temperature and the maximum allowable temperature rise.
Application Information General Design Considerations (continued)

8.1.5 Switch Current Sense Resistor

The switch current sense resistor, $R_{IS}$, is used to implement peak current mode control and to set the peak switch current limit. The value of $R_{IS}$ is selected to protect the main switching MOSFET under fault conditions. The $R_{IS}$ can be calculated based on peak inductor current, $I_{L(PK)}$, and switch current limit threshold, $V_{ILIM(THR)}$.

$$R_{IS} = \frac{V_{ILIM(THR)}}{1.2 \times I_{L(PK)}}$$

(12)

In Equation 12 20% margin is considered for transient conditions.

8.1.6 Slope Compensation

The magnitude of internal artificial ramp, $V_{SLP}$, is set by the ISLOPE register shown in Table 7. The slope of the artificial ramp is $V_{SLP}/T_{SW}$, where $T_{SW}$ is the switching period. Equation 13 shows a choice of $V_{SLP}$, which is sufficient for the stability of the Boost or Buck-Boost topologies over the entire range of duty-cycle $D$. In practice, slightly smaller $V_{SLP}$ can be selected for a given application. The value of $V_{SLP}$ in Equation 13 is determined by the inductor $L$, the switch current sense resistor $R_{IS}$, output voltage $V_{O}$, and the switching period $T_{SW}$.

$$V_{SLP} \geq \frac{V_{O}}{2 \times L} \times R_{IS} \times T_{SW}$$

(13)

8.1.7 Soft-Start

As described in Soft-Start section, the ramp can be programmed using the SOFTSTART Register. The soft-start time, $t_{SS}$, is the time for the internal digital ramp to complete the 256 counts (from 0-V to 2.8-V typ). Program the SOFTSTART Register with a $SSx_{DIV}$ that is found using Equation 14. The maximum time, $t_{SS}$, for each channel is related to the maximum value of $SSx_{DIV}$ in Table 9.

$$SSx_{DIV} \geq \frac{t_{SS} \times T_{SW}}{256}$$

(14)

8.2 Application Information CC Mode

The TPS92682-Q1 controller, when configured in CC mode, is suitable for implementing step-up or step-down LED driver topologies including BOOST, BUCK-BOOST, SEPIC, etc. This section presents the design process for the BOOST and BUCK-BOOST converters. The expressions derived for the BUCK-BOOST topology can be altered to select components for a 1:1 coupled-inductor SEPIC converter. The design procedure can be easily adapted for FLYBACK and similar converter topologies.
8.2.1 Inductor Selection

The choice of inductor sets the continuous conduction mode (CCM) and discontinuous conduction mode (DCM) boundary condition. Therefore, one approach of selecting the inductor value is by deriving the relationship between the output power corresponding to CCM-DCM boundary condition, $P_{O(BDRY)}$, and inductance, $L$. This approach ensures CCM operation in battery-powered LED driver applications that are required to support different LED string configurations with a wide range of programmable LED current set points. The CCM-DCM boundary condition can be estimated either based on the lowest LED current and the lowest output voltage requirements for a given application or as a fraction of maximum output power, $P_{O(MAX)}$.

\[
P_{O(BDRY)} \leq I_{LED(MIN)} \times V_{O(MIN)}
\]  
(15)

\[
\frac{P_{O(MAX)}}{4} \leq P_{O(BDRY)} \leq \frac{P_{O(MAX)}}{2}
\]  
(16)
Application Information CC Mode (continued)

Boost:
\[
L = \frac{V_{IN}^2}{2 \times P_{O(BDRY)} \times f_{SW}} \times \left(1 - \frac{V_{IN}}{V_O}\right)
\]  
(17)

Buck-Boost:
\[
L = \frac{1}{2 \times P_{O(BDRY)} \times f_{SW} \times \left(\frac{1}{V_O} + \frac{1}{V_{IN}}\right)^2}
\]  
(18)

Select inductor with saturation current rating greater than the peak inductor current, \(I_{L(PK)}\), at the maximum operating temperature.

Boost:
\[
I_{L(PK)} = P_{O(MAX)} \times \frac{V_{IN(MIN)}}{2 \times L \times f_{SW}} \times \left(1 - \frac{V_{IN(MIN)}}{V_{O(MAX)}}\right)
\]
(19)

Buck-Boost:
\[
I_{L(PK)} = P_{O(MAX)} \times \left(\frac{1}{V_O} + \frac{1}{V_{IN(MIN)}}\right) + \frac{V_{O(MIN)} \times V_{IN(MIN)}}{2 \times L \times f_{SW} \times (V_{O(MIN)} + V_{IN(MIN)})}
\]
(20)

8.2.2 Output Capacitor Selection

The output capacitors are required to attenuate the discontinuous or large ripple output current, and achieve the desired peak-to-peak LED current ripple, \(\Delta i_{LED(PP)}\). The capacitor value depends on the total series resistance of the LED string, \(r_D\), and the switching frequency, \(f_{SW}\). The capacitance required for the target LED ripple current can be calculated based on following equations.

Boost:
\[
C_{OUT} = \frac{I_{LED(MAX)}}{\Delta i_{LED(PP)} \times f_{SW} \times r_D \times \left(1 - \frac{V_{IN(MIN)}}{V_{O(MAX)}}\right)}
\]
(21)

Buck-Boost:
\[
C_{OUT} = \frac{I_{LED(MAX)} \times V_{O(MIN)}}{\Delta i_{LED(PP)} \times f_{SW} \times r_D \times \left(V_{O(MIN)} + V_{IN(MIN)}\right)}
\]
(22)

When choosing the output capacitors, it is important to consider the ESR and the ESL characteristics as they directly impact the LED current ripple. Ceramic capacitors are the best choice due to their low ESR, high ripple current rating, long lifetime, and good temperature performance. When selecting ceramic capacitors, it is important to consider the derating factors associated with higher temperature and the DC bias operating conditions. TI recommends an X7R dielectric with voltage rating greater than maximum LED stack voltage. An aluminum electrolytic capacitor can be used in parallel with ceramic capacitors to provide bulk energy storage. The aluminum capacitors must have necessary RMS current and temperature ratings to ensure prolonged operating lifetime. The minimum allowable RMS output capacitor current rating, \(I_{COUT(RMS)}\), can be approximated as:

Boost and Buck-Boost:
\[
I_{COUT(RMS)} = I_{LED} \times \sqrt{\frac{D_{MAX}}{1 - D_{MAX}}}
\]
(23)
8.2.3 Input Capacitor Selection

The input capacitor, $C_{\text{IN}}$, reduces the input voltage ripple and stores energy to supply input current during input voltage or PWM dimming transients. The series inductor in the Boost and SEPIC topologies provides continuous input current and requires a smaller input capacitor to achieve desired input voltage ripple, $\Delta V_{\text{IN(PP)}}$. The Buck-Boost and Flyback topologies have discontinuous input current and require a larger capacitor to achieve the same input voltage ripple. Based on the switching frequency, $f_{\text{SW}}$, and the maximum duty cycle, $D_{\text{MAX}}$, the input capacitor value can be calculated for each channel as follows:

**Boost:**

$$C_{\text{IN}} = \frac{V_{\text{IN(MIN)}}}{8L \times f_{\text{SW}} \times \Delta V_{\text{IN(PP)}} \times \left(1 - \frac{V_{\text{IN(MIN)}}}{V_{O(\text{MAX})}}\right)}$$

**Buck-Boost:**

$$C_{\text{IN}} = \frac{P_{\text{O(MAX)}}}{f_{\text{SW}} \times \Delta V_{\text{IN(PP)}} \times V_{\text{IN(MIN)}}}$$

X7R dielectric-based ceramic capacitors are the best choice due to their low ESR, high ripple current rating, and good temperature performance. For applications using PWM dimming, TI recommends large bulk capacitors in addition and in parallel to the ceramic capacitors to minimize the voltage deviation due to large input current transients generated in conjunction with the rising and falling edges of the LED current.

Decouple VIN pin with a 0.1-µF ceramic capacitor, placed as close as possible to the device, and optionally in series with a 10-Ω resistor to create a 160-kHz low-pass filter.

![VIN Filter](image)

**Figure 51. VIN Filter**

8.2.4 Programming LED Current

The LED current can be programmed to match the LED string configuration by writing an 8-bit value to the \textbf{CH1IADJ Register} and \textbf{CH2IADJ Register}. The Equation 26 shows the relation between the programmed LED current $I_{\text{LED}}$, the register CHxIADJ, and the LED current sense resistor $R_{\text{CS}}$.

$$I_{\text{LED}} = \frac{\text{CHxIADJ} \times 2.4}{14 \times R_{\text{CSx}} \times 255}$$

8.2.5 Feedback Compensation

The loop gain $T(s)$ is the product of the converter transfer function $G_{ivc}(s)$ (Equation 27) and the feedback transfer function $G_{c}(s)$.

Using a first-order approximation, the converter transfer function can be modeled as a single pole created by the output capacitor and the LED string dynamic resistance, $r_{\text{D}}$. In the boost and buck-boost topologies, the transfer function has a right half-plane zero created by the inductor, and the DC output current $I_{\text{LED}}$. The ESR of the output capacitor is neglected in this analysis.

$$G_{ivc}(s) = \frac{I_{\text{LED}}}{V_{\text{COMP}}} = G_{0} \times \left(1 - \frac{s}{\omega_{z}}\right) \times \left(1 + \frac{s}{\omega_{p}}\right)$$

\textbf{Table 42} summarizes the expression for the small-signal model parameters.
Application Information CC Mode (continued)

Table 42. Small-Signal Model Parameters for CC Operation

<table>
<thead>
<tr>
<th></th>
<th>DC GAIN ( (G_0) )</th>
<th>POLE FREQUENCY ( (\omega_p) )</th>
<th>ZERO FREQUENCY ( (\omega_z) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boost</td>
<td>( \frac{(1-D) \times V_o}{R_{IS} \times (V_o + (D \times I_{LED}))} )</td>
<td>( \frac{V_o + (D \times I_{LED})}{V_o \times r_d \times C_{OUT}} )</td>
<td>( \frac{V_o \times (1-D)^2}{L \times I_{LED}} )</td>
</tr>
<tr>
<td>Buck-Boost</td>
<td>( \frac{(1-D) \times V_o}{R_{IS} \times (V_o + (D \times f_d \times I_{LED}))} )</td>
<td>( \frac{V_o + (D \times r_d \times I_{LED})}{V_o \times f_d \times C_{OUT}} )</td>
<td>( \frac{V_o \times (1-D)^2}{D \times L \times I_{LED}} )</td>
</tr>
</tbody>
</table>

The feedback transfer function includes the current sense resistor and the loop compensation of the transconductance amplifier. A compensation network at the output of the error amplifier is used to configure loop gain and phase characteristics. A simple capacitor, \( C_{COMP} \), from COMPx to GND (as shown in Figure 52) provides integral compensation and creates a pole at the origin. Alternatively, a network of \( R_{COMP}, C_{COMP} \), and \( C_{HF} \), shown in Figure 53, can be used to implement Proportional-Integral (PI) compensation to create a pole at the origin, a low-frequency zero, and a high-frequency pole.

The feedback transfer function is defined as follows.

Feedback transfer function with integral compensation:

\[
G_c (s) = \frac{\hat{I}_{COMP}}{I_{LED}} = \frac{14 \times g_M \times R_{CS}}{s \times C_{COMP}}
\]  

Feedback transfer function with proportional integral compensation:

\[
G_c (s) = \frac{\hat{I}_{COMP}}{I_{LED}} = \frac{14 \times g_M \times R_{CS}}{s \times (C_{COMP} + C_{HF})} \times \frac{1 + s \times R_{COMP} \times C_{COMP}}{1 + s \times R_{COMP} \times (C_{COMP} + C_{HF})}
\]  

The pole at the origin minimizes output steady-state error. High bandwidth is achieved with the PI compensator by introducing a phase lead using a low-frequency zero. Use the following expressions to calculate the compensation network.

- **BOOST and BUCK-BOOST with Integral Compensator:**
  \[
  C_{COMP} = \frac{20 \times g_M \times R_{CS} \times G_0}{\omega_p}
  \]  

- **BOOST and BUCK-BOOST with Proportional-Integral Compensator:**

![Figure 52. Integral Compensator](image)

![Figure 53. Proportional Integral Compensator](image)
\[ C_{\text{COMP}} = \frac{14 \times g_m \times R_{CS} \times G_0}{\sqrt{\omega_p \times \omega_z}} \]  
(31)

\[ C_{\text{HF}} < \frac{C_{\text{COMP}}}{100} \]  
(32)

\[ R_{\text{COMP}} = \frac{1}{\omega_p \times C_{\text{COMP}}} \]  
(33)

The above compensation values are calculated to provide reasonable phase margin (> 45°) and bandwidth. In practice, the above values can be modified for desired dynamic performance (for example: PWM dimming rise/fall-time or over/under-shoot).

### 8.2.6 Overvoltage and Undervoltage Protection

In BOOST and SEPIC topologies, the Overvoltage threshold is programmed using a resistor divider, \( R_{FBx1} \) and \( R_{FBx2} \), from the output voltage \( V_O \) to GND. If the LEDs are referenced to a potential other than GND, as in the BUCK-BOOST, the output voltage is sensed and translated to ground by using a PNP transistor and level-shift resistors, as shown in Figure 50 for the channel-2. The Overvoltage turn-off threshold, \( V_{O(OV)} \), is:

**Boost:**

\[ V_{O(OV)} = V_{OV(THR)} \times \left( \frac{R_{FB1} + R_{FB2}}{R_{FB1}} \right) \]  
(34)

**Buck and Buck-Boost:**

\[ V_{O(OV)} = V_{OV(THR)} \times \frac{R_{FB2}}{R_{FB1}} + 0.7 \]  
(35)

In CC mode, \( V_{OV(THR)} = 1.24 \text{ V (typ)} \), when CHxOV register is set to 000.

The Overvoltage hysteresis, \( V_{OV(HYS)} \) is:

\[ V_{OV(HYS)} = I_{OV(HYS)} \times R_{FB2} \]  
(36)

where \( I_{OV(HYS)} \) is 20 µA (typ).

The corresponding undervoltage fault threshold, \( V_{O(UV)} \) is:

\[ V_{O(UV)} = 0.05 \times \frac{R_{FB1} + R_{FB2}}{R_{FB1}} \]  
(37)

### 8.2.7 Series P-Channel MOSFET Selection

In the applications with PWM dimming, the device requires a P-channel MOSFET placed in series with the LED load. Select a P-channel MOSFET with gate-to-source voltage rating of 10-V or higher and with a drain-to-source breakdown voltage rating greater than the output voltage. Ensure that the drain current rating of the P-channel MOSFET exceeds the programmed LED current by at least 10%.

It is important to consider the FET input capacitance and on-resistance as it impacts the accuracy and efficiency of the LED driver. TI recommends a FET with lower input capacitance and gate charge to minimize the errors caused by rise and fall times when PWM dimming at low duty cycles is applied.

### 8.3 Typical Application CV Mode

The TPS92682-Q1 controller, when configured in CV mode, is suitable for implementing step-up voltage regulator topologies including BOOST, SEPIC, etc. The device can also be configured in 2-phase mode for efficiency optimization and reduced input and output current ripple. This section presents the design process for the BOOST voltage regulator. The design procedure can be easily adapted for other converter topologies, like 1:1 coupled-inductor SEPIC converter.
Figure 54. Two Channel BOOST Voltage Regulator (CV mode)
8.3.1 Inductor Selection

The choice of the inductors in CV BOOST is highly dependent on the efficiency and the form-factor targets. One parameter that affects these specifications is the desired inductor current ripple. A common first choice for the inductor current ripple, $\Delta i_{L-PP}$, is 50% of the nominal inductor current $I_L$.

$$L = \frac{V_{IN} \times (V_O - V_{IN})}{\Delta i_{L-PP} \times V_O \times f_{SW}}$$

where $M = V_O/V_{IN}$.

BOOST voltage regulators can be configured to operate in Discontinuous Conduction Mode (DCM) to achieve higher efficiency at light load. The condition to operate in DCM vs CCM are shown in the following equations:

CCM Operation:

$$P_O > \frac{V_{IN}^2 \times (V_O - V_{IN})}{2 \times V_O \times L \times f_{SW}}$$

DCM Operation:

$$P_O \leq \frac{V_{IN}^2 \times (V_O - V_{IN})}{2 \times V_O \times L \times f_{SW}}$$
Typical Application CV Mode (continued)

8.3.2 Output Capacitor Selection

The output capacitors are required to attenuate the discontinuous output current of the BOOST converter, as well as decreasing the output voltage under- and over-shoot during load transient. The capacitance required for the target output peak-to-peak ripple is provided in the following equations:

For one-phase operation:

\[ C_{\text{OUT}} = \left( 1 - \frac{V_{\text{IN(MIN)}}}{V_{\text{O(MAX)}}} \right) \times \frac{I_{\text{OUT(MAX)}}}{\Delta V_{\text{O-PP}} \times f_{\text{SW}}} \]  \hspace{1cm} (41)

For two-phase operation, \( f_{\text{SW}} \) in Equation 41 must be substituted with twice of the switching frequency.

When choosing the output capacitors, it is important to consider the ESR and the ESL characteristics as they directly impact the output voltage ripple. Ceramic capacitors are the best choice due to their low ESR, high ripple current rating, long lifetime, and good temperature performance. When selecting ceramic capacitors, it is important to consider the derating factors associated with higher temperature and the DC bias operating conditions. TI recommends an X7R dielectric with voltage rating greater than maximum output voltage, \( V_{\text{OUT}} \). An aluminum electrolytic capacitor can be used in parallel with ceramic capacitors to provide bulk energy storage. The aluminum capacitors must have necessary RMS current and temperature ratings to ensure prolonged operating lifetime. The minimum allowable RMS output capacitor current rating, \( I_{\text{COUT(RMS)}} \), can be approximated as:

\[ I_{\text{COUT(RMS)}} = I_{\text{OUT}} \times \sqrt{\frac{D_{\text{MAX}}}{1 - D_{\text{MAX}}}} \]  \hspace{1cm} (42)

8.3.3 Input Capacitor Selection

The input capacitors for one-phase CV BOOST can be obtained in the same way found in Equation 24 for CC mode.

For two-phase operation, the input capacitor can be obtained as shown in Equation 43.

\[ C_{\text{IN}} = \frac{V_{\text{IN(MIN)}}}{8 \times (L / 2) \times (2xf_{\text{SW}})^2 \times \Delta V_{\text{IN(PP)}}} \times \left( 1 - \frac{V_{\text{IN(MIN)}}}{V_{\text{O(MAX)}}} \right) \]  \hspace{1cm} (43)

8.3.4 Programming Output Voltage \( V_{\text{OUT}} \)

The output voltage \( V_{\text{OUT}} \) can be programmed using the feedback resistors and by writing an 8-bit value to the CH1IADJ Register and CH2IADJ Register. The Equation 44 shows the relation between the programmed \( V_{\text{OUT}} \), the register CHxIADJ, and the feedback resistors.

\[ V_{\text{OUT}} = \left( 1 + \frac{R_{\text{FB2}}}{R_{\text{FB1}}} \right) \times \frac{\text{CHxIADJ} \times 2.4}{255} \]  \hspace{1cm} (44)

8.3.5 Feedback Compensation

The loop gain \( T(s) \) is the product of the converter transfer function \( G_{\text{VVC}}(s) \) and the feedback transfer function \( G_{\text{C}}(s) \). The TPS92682-Q1 device, when configured as a BOOST voltage regulator is normally followed by a second stage switching converter, which acts as a power sink load. In this case the converter transfer function, \( G_{\text{VVC}}(s) \), can be approximated as shown in Equation 45. The \( G_{\text{VVC}}(s) \) has a low frequency pole, \( \omega_{\text{P1}} \), and a high frequency pole, \( \omega_{\text{P2}} \), when the converter operates in CCM. In DCM the \( \omega_{\text{P2}} \) can be ignored. In a BOOST topology, the transfer function has a right half-plane zero.

\[ G_{\text{VVC}}(s) = \frac{\dot{V}_{\text{O}}}{\dot{V}_{\text{COMP}}} = G_0 \times \left( \frac{1 - \frac{S}{\omega_{Z}}}{1 + \frac{S}{\omega_{\text{P1}}} \times \frac{\frac{S}{\omega_{\text{P2}}}}{1}} \right) \]  \hspace{1cm} (45)
Typical Application CV Mode (continued)

Table 43 summarizes the expressions for the small-signal model parameters of a BOOST converter operating in CCM or DCM.

### Table 43. Small-Signal Model Parameters for CV BOOST

<table>
<thead>
<tr>
<th>BOOST Topology</th>
<th>( G_0 )</th>
<th>( \omega_{p1} )</th>
<th>( \omega_{p2} )</th>
<th>( \omega_{Z} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCM</td>
<td>( \frac{F_m \times V_O}{R_{IS} \times (V_{IN} + F_m \times V_O \times V_O^2)} )</td>
<td>( \frac{V_{IN} \times C_{OUT} \times \left( V_{IN} / (F_m \times V_O + F_v) \right)}{V_O} )</td>
<td>( \frac{F_m \times V_O}{L} )</td>
<td>( \frac{V_{IN}^2}{P_O \times L} )</td>
</tr>
<tr>
<td>DCM</td>
<td>( \frac{2 \times (V_O - V_{IN}) \times V_O}{V_{IN} \times V_C} )</td>
<td>( \frac{V_{IN} \times I_O}{V_O \times (V_O - V_{IN}) \times C_{OUT}} )</td>
<td>( \infty )</td>
<td>( \pi \times f_{SW} )</td>
</tr>
</tbody>
</table>

In Table 43, \( F_m \) is the compensation ramp gain, \( F_v \) is the \( V_O \) feedback gain, \( I_O \) is the DC output current, and \( V_C \) is the DC compensation voltage. In a BOOST topology:

\[
F_m = \frac{R_{IS}}{V_{SLP}} \quad (46)
\]

\[
F_v = \frac{V_{IN}^2}{2 \times L \times f_{SW} \times V_O^2} \quad (47)
\]

\[
V_C = R_{IS} \times \frac{2 \times I_O \times (V_O - V_{IN})}{L \times f_{SW}} \times \left( \frac{L \times f_{SW}}{F_m \times V_{IN}} + 1 \right) \quad (48)
\]

The feedback transfer function includes the voltage divider gain (\( H_{FB} = R_{FB1}/(R_{FB1} + R_{FB2}) \)) and the transconductance amplifier gain. A compensation network at the output of the error amplifier is used to configure loop gain and phase characteristics. In CV BOOST application, a Proportional-Integral (PI) compensation is recommended. A network of \( R_{COMP} \), \( C_{COMP} \), and \( C_{HF} \), shown in Figure 56, can be used to implement PI compensation to create a pole at the origin, a low-frequency zero, and a high-frequency pole.

The feedback transfer function is defined as follows.

Feedback transfer function with proportional integral compensation:

\[
G_C(s) = \frac{\ddot{V}_{COMP}}{\dot{V}_O} = \frac{g_m \times H_{FB}}{s \times (C_{COMP} + C_{HF})} \times \frac{1 + \frac{s \times R_{COMP} \times C_{COMP}}{1 + \frac{s \times R_{COMP} \times \left( C_{COMP} \times C_{HF} \right)}}}{1 + \frac{s \times R_{COMP} \times \left( C_{COMP} \times C_{HF} \right)}} \quad (49)
\]
Figure 56. Proportional Integral Compensator

The pole at the origin minimizes output steady-state error. High bandwidth is achieved with the PI compensator by introducing a phase lead using a low-frequency zero.

PI compensator component values can be found by selecting a reasonable bandwidth and phase-margin. It is recommended to select a bandwidth of $\omega_C$ smaller than the RHP zero $\omega_Z$ by a factor of $K_C$ in the range of 5 to 10. Assuming $\omega_C = \omega_Z / K_C$ and $\omega_C >> \omega_{P1}$:

$$R_{COMP} = \frac{\omega_Z}{K_C \times g_M \times G_0 \times H_{FB} \times \omega_{P1}}$$  \hspace{1cm} (50)

The compensator zero, generated by the $R_{COMP}$ and $C_{COMP}$ is recommended to be placed far below the bandwidth $\omega_C$ and above $\omega_{P1}$ to provide adequate phase-margin. It is recommended to set the low-frequency zero of the compensator as follows:

$$\frac{1}{C_{COMP} \times R_{COMP}} = K_P \times \omega_{P1}$$  \hspace{1cm} (51)

where $K_P$ is a factor in the range of 1 to 5. From Equation 51 and Equation 50, $C_{COMP}$ can be found.

$$C_{HF} < \frac{C_{COMP}}{100}$$  \hspace{1cm} (52)

8.3.6 Overvoltage and Undervoltage Protection

In CV mode, the output Overvoltage level is set in $OV$ Register as a percentage above the programmed regulated value of $V_{OUT}$.

The Overvoltage hysteresis, $V_{OV(HYS)}$ is:

$$V_{OV(HYS)} = I_{OV(HYS)} \times R_{FB2}$$  \hspace{1cm} (53)

where $I_{OV(HYS)}$ is 20 µA (typ).

The corresponding undervoltage fault threshold, $V_{O(UV)}$ is:

$$V_{O(UV)} = 0.05 \times \frac{R_{FB1} + R_{FB2}}{R_{FB1}}$$  \hspace{1cm} (54)
8.4 Typical Application CC Mode

Figure 57 shows the schematic for a dual channel, high side current sense, Boost and Buck-Boost LED driver with PFET dimming. In this application the Channel-1 of the device is configured as Boost and the Channel-2 as Buck-Boost.

![Schematic diagram of CC Mode LED Driver, BOOST and Buck-Boost](image-url)
8.4.1 CC Boost Design Requirements

Table 44 shows the design parameters for the boost LED driver application.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT CHARACTERISTICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{IN}</td>
<td>Input voltage range</td>
<td>7</td>
<td>14</td>
<td>18</td>
<td>V</td>
</tr>
<tr>
<td>OUTPUT CHARACTERISTICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{F(LED)}</td>
<td>LED forward voltage</td>
<td>2.8</td>
<td>3.2</td>
<td>3.6</td>
<td>V</td>
</tr>
<tr>
<td>N_{LED}</td>
<td>Number of LEDs in series</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{O}</td>
<td>Output voltage LED+ to LED−</td>
<td>33.6</td>
<td>38.4</td>
<td>43.2</td>
<td>V</td>
</tr>
<tr>
<td>I_{LED}</td>
<td>Output current</td>
<td>350</td>
<td>550</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>RR_{LED}</td>
<td>LED current ripple ratio</td>
<td>4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f_{D}</td>
<td>LED string resistance</td>
<td>3</td>
<td></td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>P_{O(MAX)}</td>
<td>Maximum output power</td>
<td>25</td>
<td></td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>f_{PWM}</td>
<td>PWM dimming frequency</td>
<td>400</td>
<td></td>
<td>Hz</td>
<td></td>
</tr>
<tr>
<td>SYSTEMS CHARACTERISTICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_{O(BDRY)}</td>
<td>Output power at CCM-DCM boundary condition</td>
<td>8</td>
<td></td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>\Delta V_{IN(PP)}</td>
<td>Input voltage ripple</td>
<td>20</td>
<td></td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>V_{O(OV)}</td>
<td>Output Overvoltage protection threshold</td>
<td>50</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V_{O(HYS)}</td>
<td>Output Overvoltage protection hysteresis</td>
<td>2.4</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>f_{DM}</td>
<td>Dither Modulation Frequency</td>
<td>400</td>
<td>600</td>
<td>Hz</td>
<td></td>
</tr>
<tr>
<td>f_{SW}</td>
<td>Switching frequency</td>
<td>400</td>
<td></td>
<td>kHz</td>
<td></td>
</tr>
</tbody>
</table>

8.4.2 CC Boost Detailed Design Procedure

In the following section the detailed design procedure for the CC BOOST LED driver is provided.

8.4.2.1 Calculating Duty Cycle

From Equation 9 and the input and output characteristics in Table 44, we can solve for D_TYP, D_MAX, and D_MIN.

\[ D_{TYP} = 0.64 \]
\[ D_{MAX} = 0.84 \]
\[ D_{MIN} = 0.46 \]

8.4.2.2 Setting Switching Frequency

For the default division factor of 2 in SWDIV Register and from Equation 1, the R_T value for f_{SW} = 400kHz can be obtained:

\[ R_T = \frac{10^{12}}{12.5 \times SW_{DIV} \times f_{SW}} \]
\[ R_T = 100 \, \text{k}\Omega \] (55)

8.4.2.3 Setting Dither Modulation Frequency

The dither modulation frequency can be set using FM Register in Equation 2. For the dither modulation frequency of less than 600 Hz, the FM_{FREQ} must be set to 0101, which corresponds to a division factor of 1536 and sets FM = 521 Hz.
8.4.2.4 **Inductor Selection**

The inductor is selected to meet the CCM-DCM boundary power requirement, $P_{O(BDRY)}$. In most applications, $P_{O(BDRY)}$ is set to be 1/3 of the maximum output power, $P_{O(MAX)}$. The inductor value is calculated for typical input voltage, $V_{IN(TYP)}$, and output voltage, $V_{O(TYP)}$. From Equation 17, the inductor $L$ is calculated to be:

\[ L \geq 19.5 \ \mu H \]

The value of $L = 22 \ \mu H$ is selected for this application.

Ensure that the inductor saturation current rating is greater than $1.2 \times I_{L(PK)}$ found from Equation 19:

\[ I_{L(PK)} = 3.9 \ \text{A} \]

8.4.2.5 **Output Capacitor Selection**

The specified peak-to-peak LED current ripple, $\Delta i_{LED(PP)}$, is:

\[ \Delta i_{LED(PP)} = R R_{LED} \times I_{LED(MAX)} = 22 \ \text{mA} \]

The output capacitance required to achieve the target LED current ripple can be obtained from Equation 21. The resulting capacitance value is calculated to be: $C_{OUT} \geq 18.4 \ \mu F$.

Four 4.7 \mu F 100 V ceramic capacitors are used in parallel to achieve a combined required output capacitance.

8.4.2.6 **Input Capacitor Selection**

The input capacitor is required to reduce switching noise conducted through the input terminal and to reduce the input impedance of the LED driver. Equation 24 is used to calculate the required capacitance of $C_{IN} \geq 10 \ \mu F$ to limit peak-to-peak input voltage ripple, $\Delta v_{IN(PP)}$, to 20 mV.

Two 4.7 \mu F, 50 V ceramic capacitors are used in parallel to achieve the combined input capacitance of 9.4 \mu F. As shown in Figure 57, additional 33 \mu F 50 V electrolytic capacitor and more ceramic capacitors are also used at the input terminal to further decrease the over- and undershoot of $V_{IN}$ during PWM dimming.

8.4.2.7 **Main N-Channel MOSFET Selection**

Ensure that the MOSFET ratings exceed the maximum output voltage and RMS switch current.

\[ V_{DS} = V_{O(OV)} \times 1.1 = 55 \ \text{V} \]

The maximum RMS switch current can be found from Equation 11 to be 3.9 A.

An N-channel MOSFET with a voltage rating of 100 V and a current rating of more than 4 A is required for this design.

8.4.2.8 **Rectifier Diode Selection**

Select a diode with a reverse breakdown voltage, $V_{D(BR)}$, greater than or equal to MOSFET drain-to-source voltage, $V_{DS}$, for reliable performance.

The DC current rating of the diode rectifier for the Boost LED driver must be greater than $I_{LED(MAX)}$.

8.4.2.9 **Setting $I_{LED}$ and Selecting $R_{CS}$**

The LED current can be programmed by writing an 8-bit value to the CH1IADJ Register, and as described in Programming LED Current.

The value of the current sense resistor, $R_{CS}$, can be selected to result in the $I_{LED(MAX)}$ for the maximum programmed value of 255 in the CHxIADJ register.

\[ R_{CS} = \frac{2.4}{14 \times I_{LED(MAX)}} \]

Substituting $I_{LED(MAX)} = 0.55 \ \text{A}$ in Equation 56 results in $R_{CS} = 0.31 \ \Omega$. A current sense value of 0.3 \Omega is selected for this design.
8.4.2.10 Setting Switch Current Limit

As shown in Equation 12, the switch current limit is determined by the switch current sense resistor, \( R_{IS} \), and the switch current threshold. For \( V_{LIM(THR)} = 250 \text{ mV} \) and \( 1.2 \times I_{L(PK)} = 4.7 \text{ A} \), \( R_{IS} \leq 53 \text{ m}\Omega \). A standard sense resistor of \( R_{IS} = 40 \text{ m}\Omega \) is selected for this application.

8.4.2.11 Slope Compensation

The recommended slope compensation magnitude can be obtained from Equation 13, \( V_{SLP} \geq 100 \text{ mV} \).

The \( V_{SLP} \) can be programmed in ISLOPE Register. The ISLOPE =011 is selected, which corresponds with \( V_{SLP} = 150 \text{ mV} \).

8.4.2.12 Compensator Parameters

Proportional-Integral Compensator is selected for this design. The compensator component can be obtained from Equation 31, Equation 32 and Equation 33:
\[
\begin{align*}
C_{COMP} &= 33 \text{ nF} \\
C_{HF} &= 3.3 \text{ nF} \\
R_{COMP} &= 715 \Omega 
\end{align*}
\]

It is be noted that the above compensator components are fine-tuned to provide improved transient performance in PWM dimming.

8.4.2.13 Overvoltage Protection

The output Overvoltage level is programmed using a resistor divider, \( R_{FB2} \) and \( R_{FB1} \), from the output voltage, \( V_O \), to GND. \( R_{FB2} \) can be calculated from the \( V_{OV(HYS)} = 2.4 \text{ V} \) and Equation 36:
\[
R_{FB2} = 120 \text{ k}\Omega.
\]

\( R_{FB1} \) can be calculated from Equation 34 and the required value of \( V_{O(OV)} = 50 \text{ V} \):
\[
R_{FB1} = 3 \text{ k}\Omega.
\]

8.4.2.14 Series P-Channel MOSFET Selection

In applications with PWM dimming, the device requires a P-channel MOSFET placed in series with the LED load. Select a P-channel MOSFET with a gate-to-source voltage rating of 10-V or higher and with a drain-to-source breakdown voltage rating greater than the output voltage. Ensure that the drain current rating of the P-channel MOSFET exceeds the programmed LED current by at least 10%. It is important to consider the FET input capacitance and on-resistance as it impacts the accuracy and efficiency of the LED driver. TI recommends a FET with lower input capacitance and gate charge to minimize the errors caused by rise and fall times when PWM dimming at low duty cycles is applied.

8.4.3 CC Buck-Boost Design Requirements

Buck-Boost LED drivers provide the flexibility needed in applications, where the load voltage (LED string voltage) maybe less or more than the input battery voltage or the application supports multiple LED load configurations. For such applications, it is necessary to modify the design procedure presented to account for the wider range of output voltage and LED current specifications. Table 45 shows the design parameters for the Buck-Boost (BtB) LED driver application.

<table>
<thead>
<tr>
<th>Table 45. Design Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARAMETER</td>
</tr>
<tr>
<td>INPUT CHARACTERISTICS</td>
</tr>
<tr>
<td>( V_{IN} )</td>
</tr>
<tr>
<td>OUTPUT CHARACTERISTICS</td>
</tr>
<tr>
<td>( V_{F(LED)} )</td>
</tr>
<tr>
<td>( N_{LED} )</td>
</tr>
<tr>
<td>( V_O )</td>
</tr>
</tbody>
</table>
Table 45. Design Parameters (continued)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{LED}</td>
<td>Output current</td>
<td>200</td>
<td>500</td>
<td>1200</td>
<td>mA</td>
</tr>
<tr>
<td>RR_{LED}</td>
<td>LED current ripple ratio</td>
<td>7.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r_{D}</td>
<td>LED string resistance</td>
<td>0.8</td>
<td>1.5</td>
<td>2.3</td>
<td>Ω</td>
</tr>
<tr>
<td>P_{O(MAX)}</td>
<td>Maximum output power</td>
<td></td>
<td>12</td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>f_{PWM}</td>
<td>PWM dimming frequency</td>
<td>400</td>
<td></td>
<td></td>
<td>Hz</td>
</tr>
</tbody>
</table>

**SYSTEMS CHARACTERISTICS**

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{O(BDRY)}</td>
<td>Output power at CCM-DCM boundary condition</td>
<td>3.5</td>
<td></td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>\Delta v_{IN(PP)}</td>
<td>Input voltage ripple</td>
<td>100</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>V_{O(OV)}</td>
<td>Output Overvoltage protection threshold</td>
<td>40</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>V_{O(HYS)}</td>
<td>Output Overvoltage protection hysteresis</td>
<td>3</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>f_{DM}</td>
<td>Dither Modulation Frequency</td>
<td>400</td>
<td>600</td>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td>f_{SW}</td>
<td>Switching frequency</td>
<td>400</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
</tbody>
</table>

8.4.4 CC Buck-Boost Detailed Design Procedure

In the following section the detailed design procedure for the CC Buck-Boost LED driver is provided.

8.4.4.1 Calculating Duty Cycle

From Equation 10 and the input and output characteristics in Table 45, we can solve for D_{TYP}, D_{MAX}, and D_{MIN}.

D_{TYP} = 0.58
D_{MAX} = 0.82
D_{MIN} = 0.32

8.4.4.2 Setting Switching Frequency

The R_{T} value that sets the internal clock is calculated from Equation 55 in CC Boost Detailed Design Procedure. For the default division factor of 2 in SWDIV Register, the value for f_{SW} = 400kHz can be obtained.

8.4.4.3 Setting Dither Modulation Frequency

Frequency modulation is shared between both channels of the TPS92682-Q1. As a result, the same frequency modulation is applied to both Boost and Buck-Boost LED drivers.

8.4.4.4 Inductor Selection

The inductor is selected to meet the CCM-DCM boundary power requirement, P_{O(BDRY)}. Typically, the boundary condition is set to enable CCM operation at the lowest possible operating power. The inductor value is calculated for typical input voltage, V_{IN(TYP)}, and output voltage, V_{O(TYP)}. From Equation 18, the inductor L is calculated to be:

L = 23.4 µH

The value of L = 22 µH is selected for this application.

Ensure that the inductor saturation current rating is greater than the 1.2 \times I_{L(PK)} found from Equation 20:

I_{L(PK)} = 3.4 A

8.4.4.5 Output Capacitor Selection

The specified peak-to-peak LED current ripple, \Delta i_{LED(PP)}, is:

\Delta i_{LED(PP)} = RR_{LED} \times I_{LED(MAX)} = 90 mA

The output capacitance required to achieve the target LED current ripple can be obtained from Equation 22. The resulting capacitance value is calculated to be C_{OUT} ≥ 24.2 µF.
Five 4.7 µF 100 V ceramic capacitors are used in parallel to achieve a combined required output capacitance.

### 8.4.4.6 Input Capacitor Selection

The input capacitor is required to reduce switching noise conducted through the input terminal and to reduce the input impedance of the LED driver. Equation 25 is used to calculate the required capacitance of \( C_{IN} \geq 43 \, \mu F \) to limit peak-to-peak input voltage ripple, \( \Delta V_{IN(PP)} \), to 100 mV.

Four 10 µF, 50 V ceramic capacitors are used in parallel to achieve a combined input capacitance of 40 µF. As shown in Figure 57, additional 33 µF 50 V electrolytic capacitor and more ceramic capacitors are also used at the input terminal to further decrease the over- and undershoot of \( V_{IN} \) during PWM dimming.

### 8.4.4.7 Main N-Channel MOSFET Selection

Maximum transistor voltage rating must exceed the following:

\[
V_{DS} = 1.2 \times (V_{O(OV)} + V_{IN(MAX)}) = 70 \, V
\]

The maximum RMS switch current can be found from Equation 11 to be 2.3 A.

An N-channel MOSFET with a voltage rating of 100 V and a current rating of more than 3 A is required for this design.

### 8.4.4.8 Rectifier Diode Selection

Select a diode with a reverse breakdown voltage, \( V_{D(BR)} \), greater than or equal to MOSFET drain-to-source voltage, \( V_{DS} \), for reliable performance.

The DC current rating of the diode rectifier for the Buck-Boost LED driver must be greater than \( I_{LED(MAX)} \).

### 8.4.4.9 Setting \( I_{LED} \) and Selecting \( R_{CS} \)

The LED current can be programmed by writing an 8-bit value to the \( CH2IADJ \) Register, and as described in Programming LED Current.

The value of the current sense resistor, \( R_{CS} \), can be selected to result in the \( I_{LED(MAX)} \) for the maximum programmed value of 255 in the CHxIADJ register.

Substituting \( I_{LED(MAX)} = 1.2 \, A \) in Equation 56 results in \( R_{CS} = 0.14 \, \Omega \). A current sense value of 0.1 \( \Omega \) is selected for this design.

### 8.4.4.10 Setting Switch Current Limit

As shown in Equation 12, the switch current limit is determined by the switch current sense resistor, \( R_{IS} \), and the switch current threshold. For \( V_{ILIM(THR)} = 250 \, mV \) and \( 1.2 \times I_{L(PK)} = 4 \, A \), \( R_{IS} \leq 62 \, m\Omega \). A standard sense resistor of \( R_{IS} = 60 \, m\Omega \) is selected in this design.

### 8.4.4.11 Slope Compensation

The recommended slope compensation magnitude can be obtained from Equation 13, \( V_{SLP} \geq 100 \, mV \).

The \( V_{SLP} \) can be programmed in ISLOPE Register. The ISLOPE =011 is selected, which corresponds with \( V_{SLP} = 150 \, mV \).

### 8.4.4.12 Compensator Parameters

An integral compensator can be selected for this design. The \( C_{COMP} \) can be calculated from Equation 30:

\[
C_{COMP} = 100 \, nF
\]

A proportional integral compensator can be used to achieve higher bandwidth and improved transient performance. However, it is necessary to experimentally tune the compensator parameters over the entire operating range to ensure stable operation.

### 8.4.4.13 Overvoltage Protection

The output Overvoltage level is programmed using \( R_{FB2} \) and \( R_{FB1} \). \( R_{FB2} \) can be calculated from the \( V_{OV(HYS)} = 3 \, V \) and Equation 36:
\[ R_{FB2} = 150 \, \text{k}\Omega. \]

\[ R_{FB1} \] can be calculated from Equation 35 and the required value of \( V_{O(OV)} = 40 \, \text{V} \):

\[ R_{FB1} = 4.75 \, \text{k}\Omega. \]

### 8.4.5 PWM Dimming Consideration

A 60-V, 2-A P-channel FET is used to achieve series FET PWM dimming.

### 8.4.6 Application Curves

The following waveform curves are for the Boost and the Buck-Boost LED drivers. Channel-1 of the TPS92682-Q1 is configured as a Boost LED driver and the Channel-2 as a Buck-Boost.
CH1: Boost $I_{LED}$ current
CH2: Buck-Boost $I_{LED}$ current
CH3: Boost LED+ voltage (12×LED)
CH4: Buck-Boost LED+ voltage (6×LED)

Figure 62. Buck-Boost PWM Dimming, Switch Current

CH1: Boost $I_{LED}$ current
CH3: Boost LED+ voltage (12×LED)
CH4: CH4: COMP1-PIN voltage

Figure 63. Boost LED Open Fault

CH3: FB2/OV2 PIN voltage
CH4: COMP2 PIN voltage

Figure 64. Buck-Boost LED Open Fault

CH1: Boost $I_{LED}$ current
CH3: Buck-Boost LED+ voltage
CH4: Boost $V_{SW}$ voltage

Figure 65. Buck-Boost LED Open Fault

CH1: Boost $I_{LED}$ current
CH2: Buck-Boost $I_{LED}$ current
CH3: Buck-Boost LED+ voltage
CH4: Buck-Boost $V_{SW}$ voltage

Figure 66. Boost Output Short Fault

Figure 67. Buck-Boost Output Short Fault
### Figure 68. Boost Conducted EMI Scan with FM

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Level</th>
<th>QPK</th>
<th>Att</th>
<th>RBW 120 kHz</th>
<th>MT</th>
<th>1s</th>
<th>PREAMP ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>108.000000 MHz</td>
<td>4.89 dBµV</td>
<td></td>
<td>0 dB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Limit Check 1 MHz: PASS
- Line C2SP4: PASS
- Line C2SP6: PASS
- Line C2SP2: PASS

Start 150.0 kHz, Stop 108.0 MHz

12×LED, I_{LED} = 560 mA

### Figure 69. Buck-Boost Conducted EMI Scan with FM

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Level</th>
<th>QPK</th>
<th>Att</th>
<th>RBW 120 kHz</th>
<th>MT</th>
<th>1s</th>
<th>PREAMP ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>108.000000 MHz</td>
<td>5.73 dBµV</td>
<td></td>
<td>0 dB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Limit Check 1 MHz: PASS
- Line C2SP4: PASS
- Line C2SP6: PASS
- Line C2SP2: PASS
- Line C2SP5: PASS

Start 150.0 kHz, Stop 108.0 MHz

6×LED, I_{LED} = 700 mA
8.5 Typical Application CV Mode

Figure 70 shows the schematic for a two-phase Boost Constant Voltage (CV) regulator.

![Schematic diagram of a two-phase Boost CV regulator](image-url)

**Figure 70. CV Mode Two-Phase BOOST**
8.5.1 CV Design Requirements

Table 46 shows the design parameters for the CV two-phase boost.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT CHARACTERISTICS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{IN}$</td>
<td>Input voltage range</td>
<td>8</td>
<td>14</td>
<td>28</td>
<td>V</td>
</tr>
<tr>
<td>$I_{IN(MAX)}$</td>
<td>Maximum input current</td>
<td>10</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OUTPUT CHARACTERISTICS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{O}$</td>
<td>Output voltage</td>
<td>50</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{O(MAX)}$</td>
<td>Maximum output current</td>
<td>2</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{O(MAX)}$</td>
<td>Maximum output power</td>
<td>100</td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SYSTEMS CHARACTERISTICS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR</td>
<td>Peak Ratio: peak to average inductor current at $P_{OUT(MAX)}$, $I_{L(PK)}/I_{L}$</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta V_{IN(PP)}$</td>
<td>Input voltage ripple</td>
<td>10</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta V_{OUT(PP)}$</td>
<td>Output voltage ripple</td>
<td>50</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{O(OV)}$</td>
<td>Output Overvoltage protection threshold</td>
<td>55</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{O(V(HYS))}$</td>
<td>Output Overvoltage protection hysteresis</td>
<td>2.0</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f_{DM}$</td>
<td>Dither Modulation Frequency</td>
<td>400</td>
<td>600</td>
<td>Hz</td>
<td></td>
</tr>
<tr>
<td>$f_{SW}$</td>
<td>Switching frequency</td>
<td>200</td>
<td>kHz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.5.2 Detailed Design Procedure

In the following section the detailed design procedure for the two-phase CV Boost is provided.

8.5.2.1 Calculating Duty Cycle

From Equation 9 and the input and output characteristics in Table 46, we can solve for $D_{TYP}$, $D_{MAX}$, and $D_{MIN}$.

$D_{TYP} = 0.72$

$D_{MAX} = 0.84$

$D_{MIN} = 0.44$

8.5.2.2 Setting Switching Frequency

Assuming the division factor of 4 in $SWDIV$ Register and from Equation 1, the $R_T$ value for the $f_{SW} = 200kHz$ can be obtained:

$$R_T = \frac{10^{12}}{12.5 \times SWDIV \times f_{SW}}$$

$R_T = 100 \, k\Omega$

8.5.2.3 Setting Dither Modulation Frequency

The dither modulation frequency can be set using $FM$ Register in Equation 2. For the dither modulation frequency of less than 600 Hz, the $FM_{FREQ}$ must be set to 0101, which corresponds to a division factor of 1536 and sets $FM = 521$ Hz.

8.5.2.4 Inductor Selection

The inductor is selected to meet the peak-to-peak inductor current ripple at $P_{OUT(MAX)}$. The inductor current ripple, $\Delta i_{L,PP}$, can be obtained from the $PR = I_{L(PK)}/I_{L}$ at $P_{OUT(MAX)}$:

$$\Delta i_{L,PP} = 2 \times (PR - 1) \times \frac{P_{O(MAX)}}{V_{IN}}$$

(58)
In Equation 58, it is important to note that the $P_{\text{OUT(MAX)}}$ is the maximum output power per phase, 50 W in this design.

The value of $\Delta i_{L-PP}$ is calculated for typical input voltage, $V_{\text{IN(TYP)}}$. From Equation 38, the inductor L is calculated to be:

$L \geq 17 \, \mu\text{H}$

The value of $L = 15 \, \mu\text{H}$ is selected for this application.

Ensure that the inductor saturation current rating is greater than $1.1 \times I_{L(PK)} = 6.5 \, \text{A}$ ($I_{L(PK)}$ is calculated with 90% CV BOOST efficiency assumption).

### 8.5.2.5 Output Capacitor Selection

The output capacitors are required to attenuate the discontinuous output current of the BOOST converter, as well as decreasing the output voltage under- and over-shoot during load transient. The total required output capacitor, $C_{\text{OUT}}$, can be found from Equation 41, where $f_{\text{SW}}$ is replaced with $2 \times 200 \, \text{kHz} = 400 \, \text{kHz}$ for two-phase operation.

$C_{\text{OUT}} \geq 84 \, \mu\text{F}$.

10 × 4.7 $\mu\text{F}$ 100 V ceramic capacitors are used in parallel, at the output of each phase, to achieve a combined required output capacitance. It is important to note that the CV Boost output capacitor also plays an important role in decreasing the output under and over-shoot voltage during load transient.

### 8.5.2.6 Input Capacitor Selection

The input capacitor is required to reduce switching noise conducted through the input terminal and to reduce the input impedance of the CV Boost. Equation 43 is used to calculate the required capacitance of $C_{\text{IN}} \geq 70 \, \mu\text{F}$ to limit peak-to-peak input voltage ripple, $\Delta V_{\text{IN(PP)}}$, to 10 mV.

Eight 10 $\mu\text{F}$, 50 V ceramic capacitors are used in parallel to achieve a combined input capacitance of 80 $\mu\text{F}$. As shown in Figure 70, an additional 33 $\mu\text{F}$ 50 V electrolytic capacitor and a 1-$\mu\text{H}$ inductor are also used at the input terminal. The electrolytic capacitor is used to further decrease over- and undershoot during load transient. The input inductor is used to decrease the switching noise and improve EMI performance.

### 8.5.2.7 Main N-Channel MOSFET Selection

Ensure that the MOSFET ratings exceed the maximum output voltage and RMS switch current.

$V_{\text{DS}} = V_{O(OV)} \times 1.1 = 61 \, \text{V}$

The maximum RMS switch current can be found from Equation 11, where $P_{\text{O(MAX)}}$ is replaced by half of the total maximum output power for two-phase operation.

An N-channel MOSFET with a voltage rating of 100 V and a current rating of more than 7 A is required for this design.

### 8.5.2.8 Rectifier Diode Selection

Select a diode with a reverse breakdown voltage, $V_{D(BR)}$, greater than or equal to MOSFET drain-to-source voltage, $V_{\text{DS}}$, for reliable performance.

The DC current rating of the diode rectifier for the Boost LED driver must be greater than half of the total output current, $I_{O(MAX)} = 2 \, \text{A}$.

### 8.5.2.9 Programming $V_{\text{OUT}}$

The output voltage $V_{\text{OUT}}$ can be programmed using the feedback resistors and by writing an 8-bit value to the CH1IADJ Register and CH2IADJ Register. The Equation 26 shows the relation between the programmed $V_{\text{OUT}}$, the register CHxIADJ, and the feedback resistors.

It is recommended to set the ratio of the feedback resistors $R_{\text{FB2}}/R_{\text{FB1}}$ such that for the maximum CHxIADJ = 255, $V_{\text{OUT}}$ does not increase above the maximum desired limit (e.g. $V_{O(LIM)} = 60 \, \text{V}$).

In this design for $V_{O(LIM)} = 60 \, \text{V}$, $R_{\text{FB2}}/R_{\text{FB1}} = 24$. 
In this design, CHxIADJ is set to the value of 212 to achieve $V_O = 50$ V, for the $R_{FB2}/R_{FB1} = 24$.

### 8.5.2.10 Setting Switch Current Limit

As shown in Equation 12, the switch current limit is determined by the switch current sense resistor, $R_{IS}$, and the switch current threshold. For $V_{ILIM(THR)} = 100$ mV and $I_{L(PK)} = 6$ A, $R_{IS} \leq 16$ mΩ. A standard sense resistor of $R_{IS} = 10$ mΩ is selected for this application.

The maximum power loss introduced by $R_{IS}$ can be found from Equation 59, to be 0.45 W.

$$P_{RIS-Loss} = R_{IS} \times (I_{Q(RMS)})^2$$  \hspace{1cm} (59)

### 8.5.2.11 Slope Compensation

The recommended slope compensation magnitude can be obtained from Equation 13, $V_{SLP} \geq 100$ mV.

In CV mode for $R_{IS}$ values smaller than 20 mΩ, it is recommended to use $V_{SLP} \geq 250$ mV for better noise immunity.

The $V_{SLP}$ can be programmed in ISLOPE Register. The ISLOPE =101 is selected, which corresponds with $V_{SLP} = 250$ mV.

### 8.5.2.12 Compensator Parameters

Proportional-Integral Compensator is selected for this design. The compensator component can be obtained from Equation 50, Equation 51 and Equation 52:

$C_{COMP} = 33$ nF
$C_{HF} = 100$ pF
$R_{COMP} = 15$ kΩ

It is noted that the above compensator components are fine-tuned to provide improved load transient performance.

### 8.5.2.13 Overvoltage Protection

In CV mode, the output Overvoltage level is set in OV Register as a percentage above the programmed regulated value of $V_{OUT}$. For $V_{O(OV)} = 55$ V, OV Register is set to 10%, which corresponds with CHxOV = 100.

$R_{FB2}$ can be calculated from the $V_{OV(HYS)} = 2$ V and from Equation 53:

$R_{FB2} = 100$ kΩ.

$R_{FB1}$ can be calculated from the ratio of $R_{FB2}/R_{FB1} = 24$, found in VOUT setting.

$R_{FB1} = 4.12$ kΩ.
8.5.3 Application Curves

The following waveform curves are for the two-phase CV Boost.

**Figure 71. Normal Operation, P_{OUT} = 50 W**
- CH1: Phase-1 V_{SW} voltage
- CH2: Phase-2 V_{SW} voltage
- CH3: CV Boost V_{OUT}

**Figure 72. Load Transient**
- CH2: I_{OUT}, 0.2 A to 2 A transient
- CH3: CV Boost V_{OUT}

**Figure 73. Startup, SOFTSTART = 0111**
- CH1: V_{COMP1} pin
- CH3: CV Boost V_{OUT}

**Figure 74. Startup, SOFTSTART = 1111**
- CH1: V_{COMP1} pin
- CH3: CV Boost V_{OUT}
9 Power Supply Recommendations

This device is designed to operate from an input voltage supply range between 4.5 V and 65 V. The input could be a car battery or another pre-regulated power supply. If the input supply is located more than a few inches from the TPS92682-Q1 device, additional bulk capacitance or an input filter may be required in addition to the ceramic bypass capacitors to address noise and EMI concerns.

10 Layout

10.1 Layout Guidelines

- The performance of the switching regulator depends as much on the layout of the PCB as the component selection. Following a few simple guidelines maximizes noise rejection and minimizes the generation of EMI within the circuit.

- Discontinuous currents are the most likely to generate EMI. Therefore, take care when routing these paths. The main path for discontinuous current in the device using a buck regulator topology contains the input capacitor, \( \text{C}_{\text{IN}} \), the recirculating diode, \( \text{D} \), the N-channel MOSFET, \( \text{Q1} \), and the sense resistor, \( \text{R}_{\text{IS}} \). In the TPS92682-Q1 device using a boost regulator topology, the discontinuous current flows through the output capacitor \( \text{C}_{\text{OUT}} \), diode, \( \text{D} \), N-channel MOSFET, \( \text{Q1} \), and the current sense resistor, \( \text{R}_{\text{IS}} \). When using a buck-boost regulator topology, implement the layout of both input and output loops carefully. Make sure that these loops are as small as possible. In order to minimize parasitic inductance, ensure that the connection between all the components are short and thick. In particular, make the switch node (where \( L \), \( D \), and \( Q1 \) connect) just large enough to connect the components. To minimize excessive heating, large copper pours can be placed adjacent to the short current path of the switch node.

- Route the CSP and CSN together with kelvin connections to the current sense resistor with traces as short as possible. If needed, use common mode and differential mode noise filters to attenuate switching and diode reverse recovery noise from affecting the internal current sense amplifier.

- Because the COMPx, ISPx, ISNx, and FBx pins are all high-impedance inputs that may couple external noise, ensure that the loops containing these nodes are minimized whenever possible.

- In some applications, the LED or LED array can be far away from the TPS92682-Q1 device, or on a separate PCB connected by a wiring harness. When an output capacitor is used and the LED array is large or separated from the rest of the regulator, place the output capacitor close to the LEDs to reduce the effects of parasitic inductance on the AC impedance of the capacitor.

- The TPS92682-Q1 device has an exposed thermal pad to aid power dissipation. Adding several vias under the exposed pad helps conduct heat away from the device. The junction-to-ambient thermal resistance varies with application. The most significant variables are the area of copper in the PCB and the number of vias under the exposed pad. The integrity of the solder connection from the device exposed pad to the PCB is...
Layout Guidelines (continued)

Critical. Excessive voids greatly decrease the thermal dissipation capacity.

10.2 Layout Example

Figure 77 shows a layout example for a CC boost LED driver, which is connected to the channel-1 of the TPS92682-Q1.

Figure 77. CC Boost Layout Example
11 Device and Documentation Support

11.1 Receiving Notification of Documentation Updates
To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on Alert me to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.2 Community Resources
The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community.* Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.3 Trademarks
E2E is a trademark of Texas Instruments.

11.4 Electrostatic Discharge Caution
This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

11.5 Glossary
**SLYZ022 — TI Glossary.**
This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information
The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.
### PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan</th>
<th>Lead finish/Ball material</th>
<th>MSL Peak Temp</th>
<th>Op Temp (°C)</th>
<th>Device Marking</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS92682QDAPRQ1</td>
<td>PREVIEW</td>
<td>HTSSOP</td>
<td>DAP</td>
<td>32</td>
<td>2000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>NIPDAU</td>
<td>Level-3-260C-168 HR</td>
<td>-40 to 125</td>
<td>TPS92682Q</td>
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<tr>
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<td>VQFN</td>
<td>RHM</td>
<td>32</td>
<td>3000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
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<td>Level-3-260C-168 HR</td>
<td>-40 to 125</td>
<td>TPS92682Q</td>
<td>Samples</td>
</tr>
</tbody>
</table>

---

(1) The marketing status values are defined as follows:

- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBSOLETE**: TI has discontinued the production of the device.

(2) **RoHS**: TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as “Pb-Free”.

- **RoHS Exempt**: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green**: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) **MSL, Peak Temp**: The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.
**TAPE AND REEL INFORMATION**

*All dimensions are nominal*

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<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0 (mm)</th>
<th>B0 (mm)</th>
<th>K0 (mm)</th>
<th>P1 (mm)</th>
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<td>8.0</td>
<td>12.0</td>
<td>Q2</td>
</tr>
</tbody>
</table>

**TAPE DIMENSIONS**

A0  Dimension designed to accommodate the component width
B0  Dimension designed to accommodate the component length
K0  Dimension designed to accommodate the component thickness
W   Overall width of the carrier tape
P1  Pitch between successive cavity centers

**REEL DIMENSIONS**

Reel Diameter
Reel Width (W1)

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**

Q1, Q2, Q3, Q4

Pocket Quadrants
Sprocket Holes
User Direction of Feed
## TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
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<td>35.0</td>
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</tbody>
</table>
Images above are just a representation of the package family, actual package may vary. Refer to the product data sheet for package details.
NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.
NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).

5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
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