

# TPS40170 4.5-V to 60-V, Wide-Input Synchronous PWM Buck Controller

## 1 Features

- New, similar products available:
  - [LM5145](#) 75-V synchronous buck controller with wide input voltage and duty cycle ranges
  - [LM5146](#) 100-V synchronous buck DC/DC controller with wide duty-cycle range
- Wide input voltage range from 4.5 V to 60 V
- Reference voltage of 600 mV with 1% accuracy
- Programmable UVLO and hysteresis
- Voltage mode control with voltage feed forward
- Programmable frequency between 100 kHz and 600 kHz
- Bi-directional -frequency synchronization with primary and secondary option
- Low-side FET sensing overcurrent protection and high-side FET sensing short-circuit protection with integrated thermal compensation
- Programmable closed loop soft-start
- Supports pre-biased outputs
- Thermal shutdown at 165°C with hysteresis
- Voltage tracking
- Power good
- ENABLE with 1-μA low current shutdown
- LDO output of 8.0 V and 3.3 V
- Integrated Bootstrap Diode
- 20-Pin 3.5 mm × 4.5 mm VQFN (RGY) package
- Create a [Custom Design with WEBENCH® Tools](#)

## 2 Applications

- POL modules
- Wide input voltage, high-power density DC - DC converters for industrial, networking, and telecom equipment

## 3 Description

TPS40170 is a full-featured, synchronous PWM buck controller that operates at an input voltage between 4.5 V and 60 V and is optimized for

high-power density, high-reliability DC-DC converter applications. The controller implements voltage-mode control with input voltage feed-forward compensation that enables instant response to input voltage change. The switching frequency is programmable from 100 kHz to 600 kHz.

The TPS40170 has a complete set of system protection and monitoring features such as programmable undervoltage lockout (UVLO), programmable overcurrent protection (OCP) by sensing the low-side FET, selectable short-circuit protection (SCP) by sensing the high-side FET and thermal shutdown. The ENABLE pin allows for system shutdown in a low-current (1 μA typical) mode. The controller supports pre-biased output, provides an open-drain PGOOD signal, and has closed-loop soft-start, output voltage tracking and adaptive dead-time control.

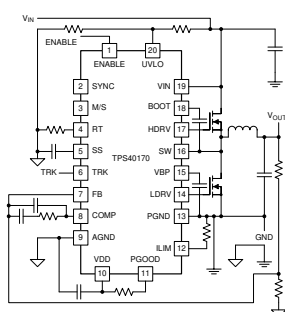
TPS40170 provides accurate output voltage regulation through 1% ensured accuracy. Additionally, the controller implements a novel scheme of bi-directional synchronization with one controller acting as the primary and other downstream controllers acting as secondaries synchronized to the primary in-phase or 180° out-of-phase. Secondary controllers can be synchronized to an external clock within ±30% of the free-running switching frequency.

New products ([LM5145](#) and [LM5146](#)) offer reduced BOM cost, higher efficiency, and reduced design size among many other features.

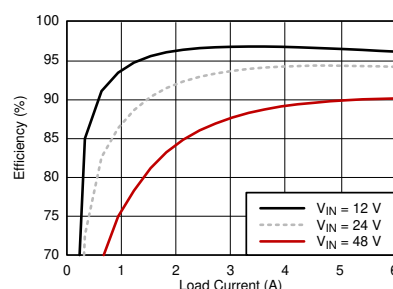
### Package Information

| PART NUMBER | PACKAGE <sup>(1)</sup> | PACKAGE SIZE <sup>(2)</sup> |
|-------------|------------------------|-----------------------------|
| TPS40170    | RGY (VQFN, 20)         | 4.50 mm × 3.50 mm           |

- (1) For all available packages, see [Section 10](#).
- (2) The package size (length × width) is a nominal value and includes pins, where applicable.



**Simplified Application**



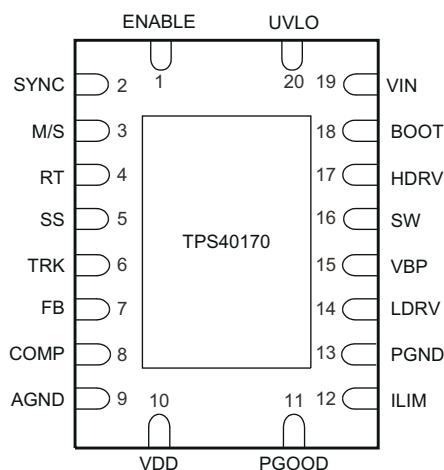
**Efficiency vs Load Current**



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## 4 Pin Configuration and Functions



**Figure 4-1. RGY PACKAGE, QFN-20 (Top View)**

**Table 4-1. Pin Functions**

| PIN    |     | TYPE<br>(1) | DESCRIPTION   |
|--------|-----|-------------|---|
| NAME   | NO. |             |   |
| AGND   | 9   | —           | Analog signal ground. This pin must be electrically connected to power ground PGND externally.  |
| BOOT   | 18  | O           | Boot capacitor node for high-side FET gate driver. The boot capacitor is connected from this pin to SW.   |
| COMP   | 8   | O           | Output of the internal error amplifier. The feedback loop compensation network is connected from this pin to the FB pin.  |
| ENABLE | 1   | I           | This pin must be high for the device to be enabled. If this pin is pulled low, the device is put in a low-power consumption shutdown mode.  |
| FB     | 7   | I           | Negative input to the error amplifier. The output voltage is fed back to this pin through a resistor divider network.   |
| HDRV   | 17  | O           | Gate driver output for the high-side FET.   |
| ILIM   | 12  | I           | A resistor from this pin to PGND sets the overcurrent limit. This pin provides source current used for overcurrent protection threshold setting.  |
| LDRV   | 14  | O           | Gate driver output for the low-side FET. Also, a resistor from this pin to PGND sets the multiplier factor to determine short-circuit current limit. If no resistor is present the multiplier defaults to 7 times the ILIM pin voltage.   |
| M/S    | 3   | I           | Primary or secondary mode selector pin for frequency synchronization. This pin must be tied to VIN for primary mode. In the secondary mode this pin must be tied to AGND or left floating. If the pin is tied to AGND, the device synchronizes with a 180° phase shift. If the pin is left floating, the device synchronizes with a 0° phase shift. |
| PGND   | 13  | —           | Power ground. This pin must externally connect to the AGND at a single point.   |
| PGOOD  | 11  | O           | Power good indicator. This pin is an open-drain output pin and a 10 kΩ pull-up resistor is recommended to be connected between this pin and VDD.  |
| RT     | 4   | I           | A resistor from this pin to AGND sets the oscillator frequency. Even if operating in secondary mode, it is required to have a resistor at this pin to set the free running switching frequency.   |
| SS     | 5   | I           | Soft-start. A capacitor must be connected at this pin to AGND. The capacitor value sets the soft-start time.  |
| SW     | 16  | I           | This pin must connect to the switching node of the synchronous buck converter. The high-side and low-side FET current sensing are also done from this node.   |
| SYNC   | 2   | I/O         | Synchronization. This is a bi-directional pin used for frequency synchronization. In the primary mode, it is the SYNC output pin. In the secondary mode, it is a SYNC input pin. If unused, this pin can be left open.  |
| TRK    | 6   | I           | Tracking. External signal at this pin is used for output voltage tracking. This pin goes directly to the internal error amplifier as a positive reference. The lesser of the voltages between $V_{TRK}$ and the internal 600 mV reference sets the output voltage. If not used, this pin must be pulled up to VDD.                                  |
| UVLO   | 20  | I           | Undervoltage lockout. A resistor divider on this pin from VIN to AGND can be used to set the UVLO threshold.  |

**Table 4-1. Pin Functions (continued)**

| PIN  |     | TYPE<br>(1) | DESCRIPTION  |
|------|-----|-------------|--|
| NAME | NO. |             |  |
| VBP  | 15  | O           | 8 V regulated output for gate driver. A ceramic capacitor with a value from 1 $\mu$ F to 10 $\mu$ F must be connected from this pin to PGND and placed close to this pin.  |
| VDD  | 10  | O           | 3.3 V regulated output. A ceramic by-pass capacitor with a value from 0.1 $\mu$ F to 1 $\mu$ F must be connected from this pin to AGND and placed close to this pin.   |
| VIN  | 19  | I           | Input voltage for the controller which is also the input voltage for the DC/DC converter. A ceramic by-pass capacitor with a value from 0.1 $\mu$ F to 1 $\mu$ F must be connected from this pin to PGND and placed close to this pin. |

(1) I = input, O = output

## 5 Specifications

### 5.1 Absolute Maximum Ratings

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

|                                |  | MIN             | MAX                   | UNIT |
|--------------------------------|--|-----------------|-----------------------|------|
| Input voltage                  | VIN  | –0.3            | 62                    | V    |
|                                | M/S  | –0.3            | VIN                   |      |
|                                | UVLO   | –0.3            | 16                    |      |
|                                | SW   | –5              | V <sub>VIN</sub>      |      |
|                                | SW (for duration less than 200 ns)                                   | –10             | V <sub>VIN</sub>      |      |
|                                | BOOT   |                 | V <sub>SW</sub> + 8.8 |      |
| Output voltage                 | HDRV   | V <sub>SW</sub> | BOOT                  | V    |
|                                | BOOT-SW, HDRV-SW (differential from BOOT or HDRV to SW)              | –0.3            | 8.8                   |      |
|                                | VBP, LDRV, COMP, RT, ENABLE, PGOOD, SYNC                             | –0.3            | 8.8                   |      |
|                                | VDD, FB, TRK, SS, ILIM   | –0.3            | 3.6                   |      |
|                                | AGND-PGND, PGND-AGND   | 200             | 200                   | mV   |
|                                | PowerPAD to AGND (must be electrically connected external to device) |                 | 0                     |      |
| Lead Temperature               |  |                 | 260                   | °C   |
| Operating junction temperature | T <sub>J</sub>   | –40             | 125                   | °C   |

### 5.2 Handling Ratings

|                    |                         |  | MIN | MAX  | UNIT |
|--------------------|-------------------------|--|-----|------|------|
| T <sub>stg</sub>   | Storage temperature     |  | –55 | 150  | °C   |
| V <sub>(ESD)</sub> | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup>              |     | 2000 | V    |
|                    |                         | Charged device model (CDM), per JEDEC specification JESD22-C101, all pins <sup>(2)</sup> |     | 1000 |      |

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 5.3 Recommended Operating Conditions

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

|                 |                                      | MIN | MAX | UNIT |
|-----------------|--------------------------------------|-----|-----|------|
| V <sub>IN</sub> | Input voltage                        | 4.5 | 60  | V    |
| T <sub>J</sub>  | Operating junction temperature range | –40 | 125 | °C   |

## 5.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |  | TPS40170 | UNIT |
|-------------------------------|--|----------|------|
|                               |  | RGY      |      |
|                               |  | 20 PINS  |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 35.0     | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case(top) thermal resistance     | 36.7     |      |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 12.6     |      |
| Ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 0.4      |      |
| Ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 12.7     |      |
| R <sub>θJC(bot)</sub>         | Junction-to-case(bottom) thermal resistance  | 3.1      |      |

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

Unless otherwise stated, these specifications apply for  $-40^{\circ}\text{C} \leq T_J \leq 125^{\circ}\text{C}$ ,  $V_{\text{VIN}}=12\text{ V}$

## 5.5 Electrical Characteristics

| PARAMETER                       |  | TEST CONDITIONS   | MIN  | TYP  | MAX  | UNIT |
|---------------------------------|--|---|------|------|------|------|
| INPUT SUPPLY                    |  |   |      |      |      |      |
| V <sub>VIN</sub>                | Input voltage range                                |   | 4.5  |      | 60   | V    |
| I <sub>SD</sub>                 | Shutdown current                                   | V <sub>ENABLE</sub> < 100 mV  |      | 1    | 2.5  | μA   |
| I <sub>Q</sub>                  | Operating current, drivers not switching           | V <sub>ENABLE</sub> ≥ 2 V, f <sub>SW</sub> = 300 kHz                                      |      |      | 4.5  | mA   |
| ENABLE                          |  |   |      |      |      |      |
| V <sub>DIS</sub>                | ENABLE pin voltage to disable the device           |   |      |      | 100  | mV   |
| V <sub>EN</sub>                 | ENABLE pin voltage to enable the device            |   | 600  |      |      |      |
| I <sub>ENABLE</sub>             | ENABLE pin source current                          |   |      |      | 300  | nA   |
| 8-V AND 3.3-V REGULATORS        |  |   |      |      |      |      |
| V <sub>BP</sub>                 | 8 V regulator output voltage                       | V <sub>ENABLE</sub> ≥ 2 V, 8.2 V < V <sub>IN</sub> ≤ 60 V, 0 mA < I <sub>IN</sub> < 20 mA | 7.8  | 8.0  | 8.3  | V    |
| V <sub>DO</sub>                 | 8 V regulator dropout voltage, V <sub>IN-BP</sub>  | 4.5 < V <sub>IN</sub> ≤ 8.2 V, V <sub>EN</sub> ≥ 2.0 V, I <sub>IN</sub> = 10 mA           |      | 110  | 200  | mV   |
| V <sub>VDD</sub>                | 3.3 V regulator output voltage                     | V <sub>ENABLE</sub> ≥ 2 V, 4.5 V < V <sub>IN</sub> ≤ 60 V, 0 mA < I <sub>IN</sub> < 5 mA  | 3.22 | 3.30 | 3.42 | V    |
| FIXED AND PROGRAMMABLE UVLO     |  |   |      |      |      |      |
| V <sub>UVLO</sub>               | Programmable UVLO ON voltage (at UVLO pin)         | V <sub>ENABLE</sub> ≥ 2 V   | 878  | 900  | 919  | mV   |
| I <sub>UVLO</sub>               | Hysteresis current out of UVLO pin                 | V <sub>ENABLE</sub> ≥ 2 V , UVLO pin > V <sub>UVLO</sub>                                  | 4.06 | 5.00 | 6.20 | μA   |
| V <sub>BP (ON)</sub>            | VBPTurn-on voltage                                 | V <sub>ENABLE</sub> ≥ 2 V, UVLO pin > V <sub>UVLO</sub>                                   | 3.85 |      | 4.40 | V    |
| V <sub>BP (OFF)</sub>           | VBPTurn-off voltage                                |   | 3.60 |      | 4.05 |      |
| V <sub>BP (HYS)</sub>           | VBPUVLO Hysteresis voltage                         |   |      | 180  |      | 400  |
| REFERENCE                       |  |   |      |      |      |      |
| V <sub>REF</sub>                | Reference voltage (+ input of the error amplifier) | T <sub>J</sub> = 25°C, 4.5 V < V <sub>IN</sub> ≤ 60 V                                     | 594  | 600  | 606  | mV   |
|                                 |  | −40°C ≤ T <sub>J</sub> ≤ 125°C, 4.5 V < V <sub>IN</sub> ≤ 60 V                            | 591  | 600  | 609  |      |
| OSCILLATOR                      |  |   |      |      |      |      |
| f <sub>SW</sub>                 | Switching frequency                                | Range (typical)   | 100  |      | 600  | kHz  |
|                                 |  | R <sub>RT</sub> = 100 kΩ, 4.5 V <V <sub>IN</sub> ≤ 60 V                                   | 90   | 100  | 110  |      |
|                                 |  | R <sub>RT</sub> = 31.6 kΩ, 4.5 V <V <sub>IN</sub> ≤ 60 V                                  | 270  | 300  | 330  |      |
|                                 |  | R <sub>RT</sub> = 14.3 kΩ, 4.5 V <V <sub>IN</sub> ≤ 60 V                                  | 540  | 600  | 660  |      |
| V <sub>VALLEY</sub>             | Valley voltage                                     |   | 0.7  | 1    | 1.2  | V    |
| K <sub>PWM</sub> <sup>(1)</sup> | PWM Gain (V <sub>IN</sub> / V <sub>RAMP</sub> )    | 4.5 V < V <sub>IN</sub> ≤ 60 V  | 14   | 15   | 16   | V/V  |
| PWM AND DUTY CYCLE              |  |   |      |      |      |      |

## 5.5 Electrical Characteristics (continued)

| PARAMETER  |  | TEST CONDITIONS   | MIN  | TYP  | MAX             | UNIT |
|--|--|---|------|------|-----------------|------|
| t <sub>ON(min)</sub> <sup>(1)</sup>                | Minimum controlled pulse   | V <sub>IN</sub> = 4.5 V, f <sub>SW</sub> = 300 kHz                                |      | 100  | 150             | ns   |
|  |  | V <sub>IN</sub> = 12 V, f <sub>SW</sub> = 300 kHz                                 |      | 75   | 100             |      |
|  |  | V <sub>IN</sub> = 60 V, f <sub>SW</sub> = 300 kHz                                 |      | 50   | 80              |      |
| t <sub>OFF(max)</sub> <sup>(1)</sup>               | Minimum OFF time   | V <sub>IN</sub> = 12 V, f <sub>SW</sub> = 300 kHz                                 |      | 170  | 250             |      |
| D <sub>MAX</sub> <sup>(1)</sup>                    | Maximum duty cycle   | f <sub>SW</sub> = 100 kHz, 4.5 V < V <sub>IN</sub> ≤ 60 V                         | 95%  |      |                 |      |
|  |  | F <sub>SW</sub> = 300 kHz, 4.5 V < V <sub>IN</sub> ≤ 60 V                         | 91%  |      |                 |      |
|  |  | f <sub>SW</sub> = 600 kHz, 4.5 V < V <sub>IN</sub> ≤ 60 V                         | 82%  |      |                 |      |
| ERROR AMPLIFIER                                    |  |   |      |      |                 |      |
| GBWP <sup>(1)</sup>                                | Gain bandwidth product   |   | 7    | 10   | 13              | MHz  |
| A <sub>OL</sub> <sup>(1)</sup>                     | Open-loop gain   |   | 80   | 90   | 95              | dB   |
| I <sub>IB</sub>                                    | Input bias current   |   |      |      | 100             | nA   |
| I <sub>EAOP</sub>                                  | Output source current  | V <sub>FB</sub> = 0 V   | 2    |      |                 | mA   |
| I <sub>EAOM</sub>                                  | Output sink current  | V <sub>FB</sub> = 1 V   | 2    |      |                 |      |
| PROGRAMMABLE SOFT-START                            |  |   |      |      |                 |      |
| I <sub>SS(source,start)</sub>                      | Soft-start source current at V <sub>SS</sub> < 0.5 V                                     | V <sub>SS</sub> = 0.25 V  | 42   | 52   | 62              | μA   |
| I <sub>SS(source,normali)</sub>                    | Soft-start source current at V <sub>SS</sub> > 0.5 V                                     | V <sub>SS</sub> = 1.5 V   | 9.3  | 11.6 | 13.9            |      |
| I <sub>SS(sink)</sub>                              | Soft-start sink current  | V <sub>SS</sub> = 1.5 V   | 0.77 | 1.05 | 1.33            |      |
| V <sub>SS(fltH)</sub>                              | SS pin HIGH voltage during fault (OC or thermal) reset timing                            |   | 2.38 | 2.50 | 2.61            | V    |
| V <sub>SS(fltL)</sub>                              | SS pin LOW voltage during fault (OC or thermal) reset timing                             |   | 235  | 300  | 375             | mV   |
| V <sub>SS(steady_state)</sub>                      | SS pin voltage during steady-state   |   | 3.25 | 3.30 | 3.50            | V    |
| V <sub>SS(offst)</sub>                             | Initial offset voltage from SS pin to error amplifier input                              |   | 525  | 650  | 775             | mV   |
| TRACKING   |  |   |      |      |                 |      |
| V <sub>TRK(ctrl)</sub> <sup>(1)</sup>              | Range of TRK which overrides V <sub>REF</sub>  | 4.5 V < V <sub>IN</sub> ≤ 60 V  | 0    |      | 600             | mV   |
| SYNCHRONIZATION (PRIMARY/SECONDARY)                |  |   |      |      |                 |      |
| V <sub>MSTR</sub>                                  | M/S pin voltage in primary mode  |   | 3.9  |      | V <sub>IN</sub> | V    |
| V <sub>SLV(0)</sub>                                | M/S pin voltage in secondary 0 deg mode  |   | 1.25 |      | 1.75            |      |
| V <sub>SLV(180)</sub>                              | M/S pin voltage in secondary 180 deg mode  |   | 0    |      | 0.75            |      |
| I <sub>SYNC(in)</sub>                              | SYNC pin pull-down current   | M/S configured as secondary- 0 degrees or secondary-180 degrees                   | 8    | 11   | 14              | μA   |
| V <sub>SYNC(in_high)</sub>                         | SYNC pin input high-voltage level  |   | 2    |      |                 | V    |
| V <sub>SYNC(in_low)</sub>                          | SYNC pin input low-voltage level   |   |      |      | 0.8             |      |
| t <sub>SYNC(high_min)</sub>                        | Minimum SYNC high pulse-width  |   | 40   | 50   |                 | ns   |
| t <sub>SYNC(low_min)</sub>                         | Minimum SYNC low pulse-width   |   | 40   | 50   |                 |      |
| GATE DRIVERS                                       |  |   |      |      |                 |      |
| R <sub>HDHI</sub>                                  | High-side driver pull-up resistance  | C <sub>LOAD</sub> = 2.2 nF, I <sub>DRV</sub> = 300 mA                             | 1.37 | 2.64 | 3.50            | Ω    |
| R <sub>HDLO</sub>                                  | High-side driver pull-down resistance  |   | 1.08 | 2.40 | 3.35            |      |
| R <sub>LDHI</sub>                                  | Low-side driver pull-up resistance   |   | 1.37 | 2.40 | 3.20            |      |
| R <sub>LDLO</sub>                                  | Low-side driver pull-down resistance   |   | 0.44 | 1.10 | 1.70            |      |
| t <sub>NON-OVERLAP1</sub>                          | Time delay between HDRV fall and LDRV rise   | C <sub>LOAD</sub> = 2.2 nF,   |      | 50   |                 | ns   |
| t <sub>NON-OVERLAP2</sub>                          | Time delay between HDRV rise and LDRV fall   | V <sub>HDRV</sub> = 2 V, V <sub>LDRV</sub> = 2 V                                  |      | 60   |                 |      |
| OVERCURRENT PROTECTION (LOW-SIDE MOSFET SENSING)   |  |   |      |      |                 |      |
| I <sub>ILIM</sub>                                  | ILIM pin source current  | 4.5 V < V <sub>IN</sub> < 60 V, T <sub>J</sub> = 25°C                             | 9.00 | 9.75 | 10.45           | μA   |
| I <sub>ILIM(ss)</sub>                              | ILIM pin source current during Soft-start  |   |      | 15   |                 |      |
| I <sub>ILIM, Tc</sub> <sup>(1)</sup>               | Temperature coefficient of ILIM current  | 4.5 V < V <sub>IN</sub> < 60 V  |      | 1400 |                 | ppm  |
| V <sub>ILIM</sub> <sup>(1)</sup>                   | ILIM pin voltage operating range   | 4.5 V < V <sub>IN</sub> < 60 V  | 50   |      | 300             | mV   |
| OCP <sub>TH</sub>                                  | Overcurrent protection threshold (Voltage across low-side FET for detecting overcurrent) | R <sub>ILIM</sub> = 10 kΩ, I <sub>ILIM</sub> = 10 μA (V <sub>ILIM</sub> = 100 mV) | −110 | −100 | −84             |      |
| SHORT CIRCUIT PROTECTION HIGH-SIDE MOSFET SENSING) |  |   |      |      |                 |      |

## 5.5 Electrical Characteristics (continued)

| PARAMETER                            |   | TEST CONDITIONS  | MIN  | TYP  | MAX  | UNIT |
|--------------------------------------|---|--|------|------|------|------|
| V <sub>LDRV(max)</sub>               | LDRV pin maximum voltage during calibration   | R <sub>LDRV</sub> = open                                 |      | 300  | 360  | mV   |
| A <sub>OC3</sub>                     | Multiplier factor to set the SCP based on OCP level setting at the ILIM pin                           | R <sub>LDRV</sub> = 10 kΩ                                | 2.75 | 3.20 | 3.60 | V/V  |
| A <sub>OC7</sub>                     |   | R <sub>LDRV</sub> = open                                 | 6.40 | 7.25 | 7.91 |      |
| A <sub>OC15</sub>                    |   | R <sub>LDRV</sub> = 20 kΩ                                | 13.9 | 16.4 | 18.0 |      |
| THERMAL SHUTDOWN                     |   |  |      |      |      |      |
| T <sub>SD,set</sub> <sup>(1)</sup>   | Thermal shutdown set threshold  | 4.5 V < V <sub>IN</sub> < 60 V                           | 155  | 165  | 175  | °C   |
| T <sub>SD,reset</sub> <sup>(1)</sup> | Thermal shutdown reset threshold  |  | 125  | 135  | 145  |      |
| T <sub>hyst</sub> <sup>(1)</sup>     | Thermal shutdown hysteresis   |  | 30   |      |      |      |
| POWERGOOD                            |   |  |      |      |      |      |
| V <sub>OV</sub>                      | FB pin voltage upper limit for power good   | 4.5 V < V <sub>IN</sub> < 60 V                           | 627  | 647  | 670  | mV   |
| V <sub>UV</sub>                      | FB pin voltage lower limit for power good   |  | 527  | 552  | 570  |      |
| V <sub>PG,HYST</sub>                 | Power good hysteresis voltage at FB pin   |  | 8.5  | 20.0 | 32.0 |      |
| V <sub>PG(out)</sub>                 | PGOOD pin voltage when FB pin voltage > V <sub>OV</sub> or < V <sub>UV</sub> , I <sub>PGD</sub> =2 mA |  |      |      | 100  |      |
| V <sub>PG(np)</sub>                  | PGOOD pin voltage when device power is removed  | V <sub>IN</sub> is open, 10 kΩ to V <sub>EXT</sub> = 5 V |      | 1    | 1.5  | V    |
| BOOT DIODE                           |   |  |      |      |      |      |
| V <sub>DFWD</sub>                    | Bootstrap diode forward voltage   | I = 20 mA  | 0.5  | 0.7  | 0.9  | V    |
| R <sub>BOOT-SW</sub>                 | Discharge resistor from BOOT to SW  |  |      | 1    |      | MΩ   |

(1) Specified by design. Not production tested.

## 5.6 Typical Characteristics

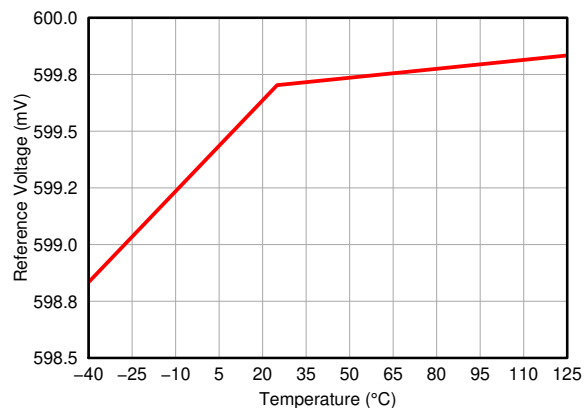


Figure 5-1. Reference Voltage vs. Junction Temperature

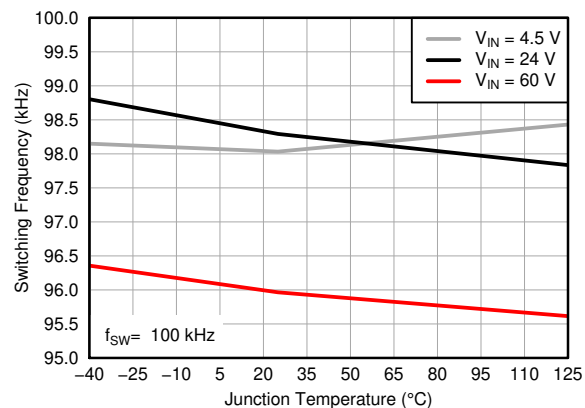


Figure 5-2. Switching Frequency vs. Junction Temperature ( $f_{SW} = 100 \text{ kHz}$ )

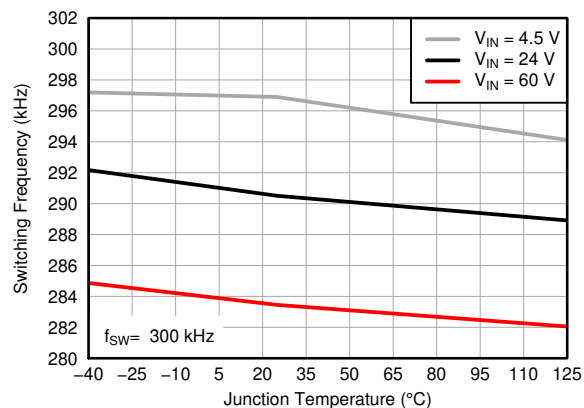


Figure 5-3. Switching Frequency vs. Junction Temperature ( $f_{SW} = 300 \text{ kHz}$ )

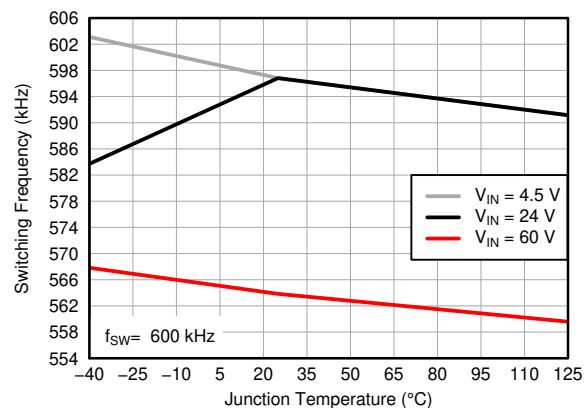


Figure 5-4. Switching Frequency vs. Junction Temperature ( $f_{SW} = 600 \text{ kHz}$ )

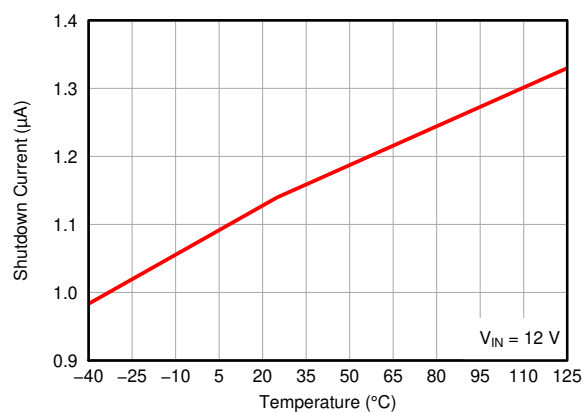


Figure 5-5. Shutdown Current vs. Junction Temperature

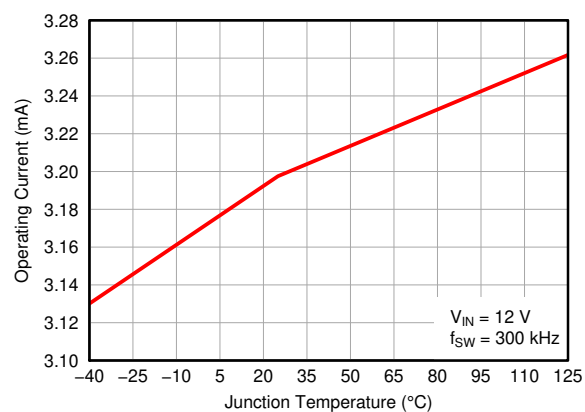


Figure 5-6. Operating Current vs. Junction Temperature



## 5.6 Typical Characteristics (continued)

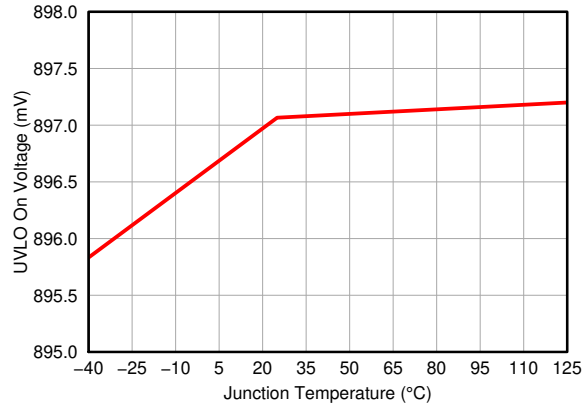


Figure 5-7. UVLO Pin On Voltage vs. Junction Temperature

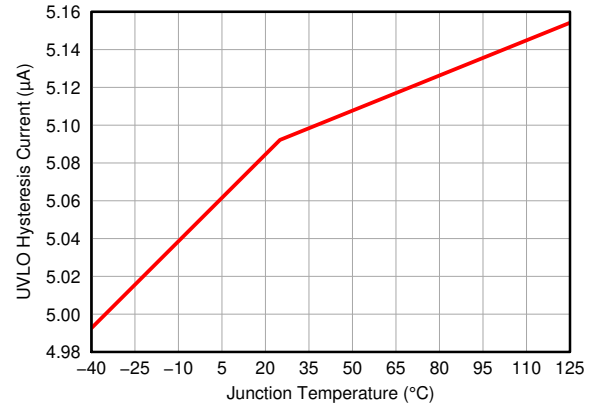


Figure 5-8. UVLO Pin Hysteresis Current vs. Junction Temperature

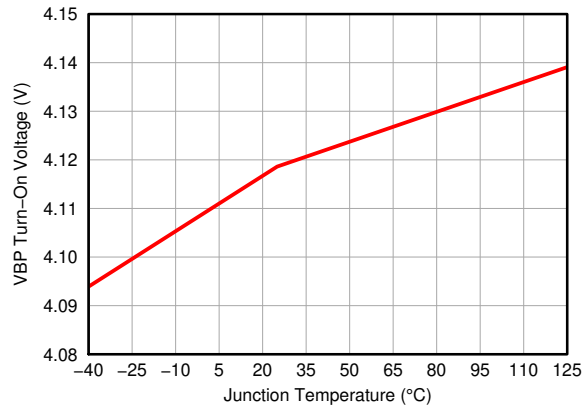


Figure 5-9. VBP Turn-On Voltage vs. Junction Temperature

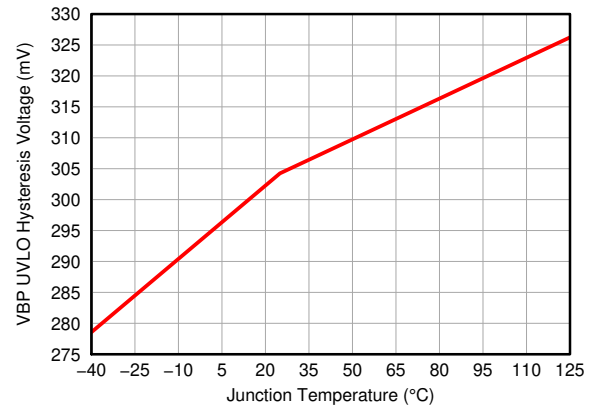


Figure 5-10. VBP UVLO Hysteresis Voltage

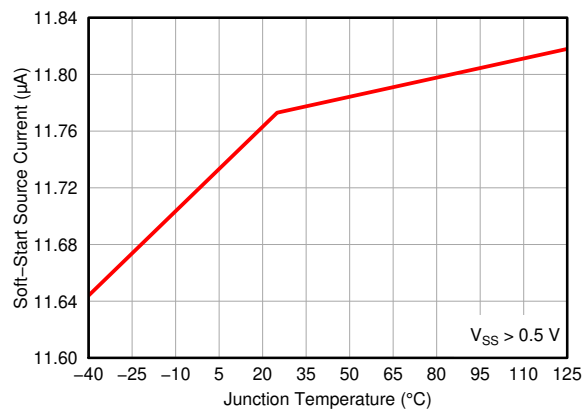


Figure 5-11. Soft-Start Source Current vs. Junction Temperature ( $V_{SS} > 0.5$  V)

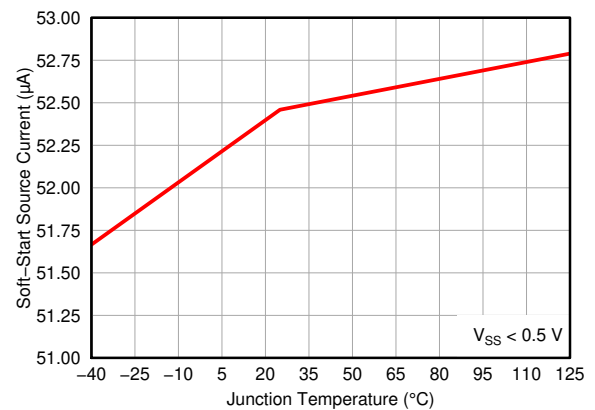


Figure 5-12. Soft-Start Source Current vs. Junction Temperature ( $V_{SS} < 0.5$  V)

## 5.6 Typical Characteristics (continued)

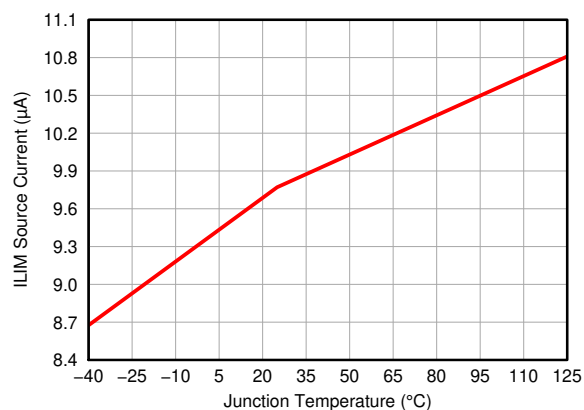


Figure 5-13. ILIM Source Current vs. Junction Temperature

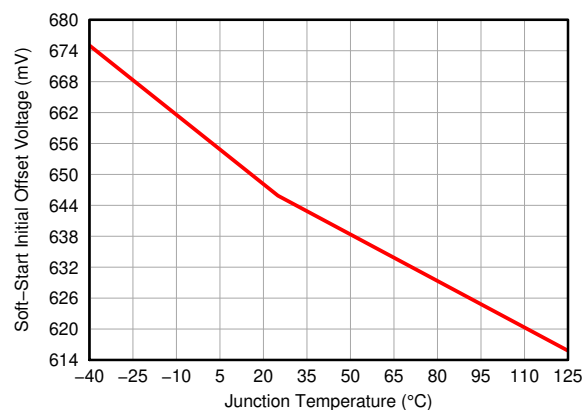


Figure 5-14. Soft-Start Initial Offset Voltage vs. Junction Temperature

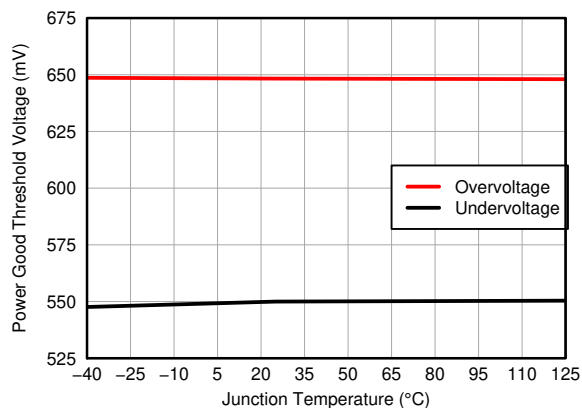


Figure 5-15.  $V_{OV}/V_{UV}$  Power Good Threshold Voltage

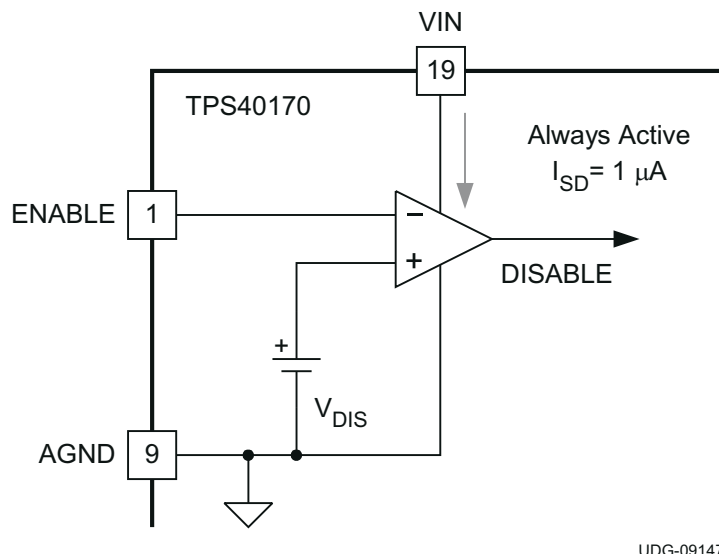


## 6.3 Feature Description

### 6.3.1 LDO Linear Regulators and Enable

The TPS40170 has two internal low-drop-out (LDO) linear regulators. One has a nominal output voltage of  $V_{VBP}$  and is present at the VBP pin. This is the voltage that is mainly used for the gate-driver output. The other linear regulator has an output voltage of  $V_{VDD}$  and is present at the VDD pin. This voltage can be used in external low-current logic circuitry. The maximum allowable current drawn from the VDD pin must not exceed 5 mA.

The TPS40170 has a dedicated device enable pin (ENABLE). This simplifies user level interface design because no multiplexed functions exist. If the ENABLE pin of the TPS40170 is higher than  $V_{EN}$ , then the LDO regulators are enabled. To ensure that the LDO regulators are disabled, the ENABLE pin must be pulled below  $V_{DIS}$ . By pulling the ENABLE pin below  $V_{DIS}$ , the device is completely disabled and the current consumption is very low (nominally, 1  $\mu$ A). Both LDO regulators are actively discharged when the ENABLE pin is pulled below  $V_{DIS}$ . A functionally equivalent circuit to the enable circuitry on the TPS40170 is shown in Figure 6-1.



**Figure 6-1. TPS40170 Enable Functional Block**

The ENABLE pin must not be allowed to float. If the ENABLE function is not needed for the design, then it is suggested that the ENABLE pin be pulled up to  $V_{IN}$  by a high value resistor ensuring that the current into the ENABLE pin does not exceed 10  $\mu$ A. If it is not possible to meet this clamp current requirement, then it is suggested that a resistor divider from  $V_{IN}$  to GND be used to connect to ENABLE pin. The resistor divider must be such that the ENABLE pin must be higher than  $V_{EN}$  and lower than 8 V.

#### Note

To avoid potential erroneous behavior of the enable function, the ENABLE signal applied must have a minimum slew rate of 20 V/s.

### 6.3.2 Input Undervoltage Lockout (UVLO)

The TPS40170 has both fixed and programmable input undervoltage lockout (UVLO). In order for the device to turn ON, all of the following conditions must be met:

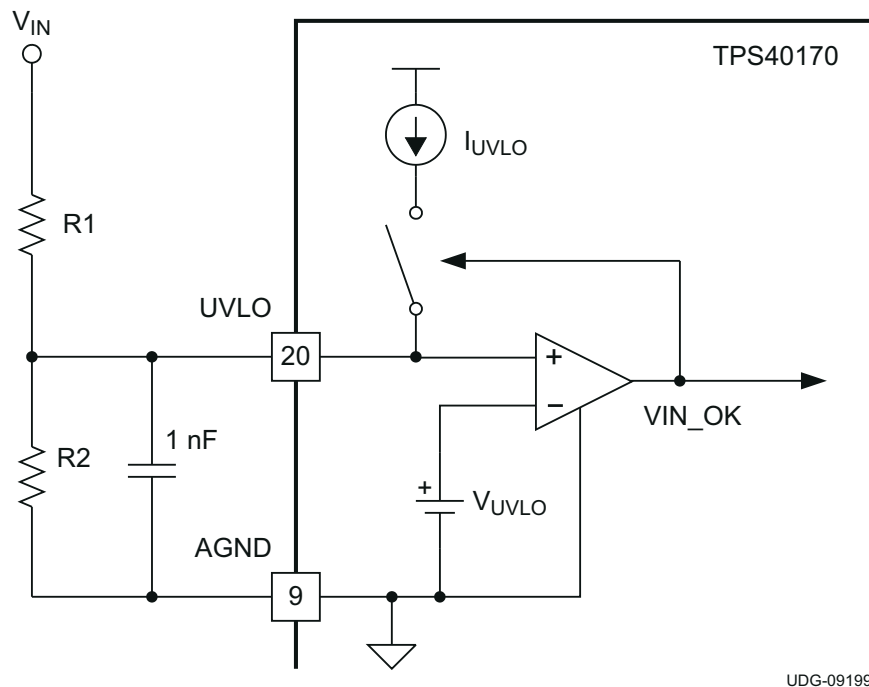
- The ENABLE pin voltage must be greater than  $V_{EN}$
- The VBP voltage (at VBP pin) must be greater than  $V_{BP(on)}$
- The UVLO pin must be greater than  $V_{UVLO}$

In order for the device to turn OFF, any one of the following conditions must be met:

- The ENABLE pin voltage must be less than  $V_{DIS}$

- The VBP voltage (at VBP pin) must be less than  $V_{BP(off)}$
- The UVLO pin must be less than  $V_{UVLO}$

Programming the input UVLO can be accomplished using the UVLO pin. A resistor divider from the input voltage ( $V_{IN}$  pin) to GND sets the UVLO level. After the input voltage reaches a value that meets the  $V_{UVLO}$  level at the UVLO pin, then a small hysteresis current,  $I_{UVLO}$  at the UVLO pin is switched in. The programmable UVLO function is shown in Figure 6-2.



**Figure 6-2. UVLO Functional Block Schematic**

### 6.3.2.1 Equations for Programming the Input UVLO:

Components R1 and R2 represent external resistors for programming UVLO and hysteresis and can be calculated in Equation 1 and Equation 2 respectively.

$$R_1 = \frac{V_{ON} - V_{OFF}}{I_{UVLO}} \quad (1)$$

$$R_2 = R_1 \times \frac{V_{UVLO}}{(V_{ON} - V_{UVLO})} \quad (2)$$

where

- $V_{ON}$  is the desired turn-on voltage of the converter
- $V_{OFF}$  is the desired turn-off voltage for the converter
- $I_{UVLO}$  is the hysteresis current generated by the device, 5.0  $\mu A$  (typ)
- $V_{UVLO}$  is the UVLO pin threshold voltage, 0.9 V (typ)

### Note

If the UVLO pin is connected to a voltage greater than 0.9 V, the programmable UVLO is disabled and the device defaults to an internal UVLO ( $V_{BP(on)}$  and  $V_{BP(off)}$ ). For example, the UVLO pin can be connected to VDD or the VBP pin to disable the programmable UVLO function.

A 1 nF ceramic by-pass capacitor must be connected between the UVLO pin and GND.

### 6.3.3 Oscillator and Voltage Feed-Forward

TPS40170 implements an oscillator with input-voltage feed-forward compensation that enables instant response to input voltage changes. Figure 6-3 shows the oscillator timing diagram for the TPS40170. The resistor from the RT pin to GND sets the free running oscillator frequency. The voltage  $V_{RT}$  on the RT pin is made proportional to the input voltage (see Equation 3).

$$V_{RT} = \frac{V_{IN}}{K_{PWM}} \quad (3)$$

where

- $K_{PWM} = 15$

The resistor at the RT pin sets the current in the RT pin. The proportional current charges an internal 100-pF oscillator capacitor. The ramp voltage on this capacitor is compared with the RT pin voltage,  $V_{RT}$ . After the ramp voltage reaches  $V_{RT}$ , the oscillator capacitor is discharged. The ramp that is generated by the oscillator (which is proportional to the input voltage) acts as voltage feed-forward ramp to be used in the PWM comparator.

The time between the start of the discharging oscillator capacitor and the start of the next charging cycle is fixed at 170 ns (typical). During the fixed discharge time, the PWM output is maintained as OFF. This is the minimum OFF-time of the PWM output.

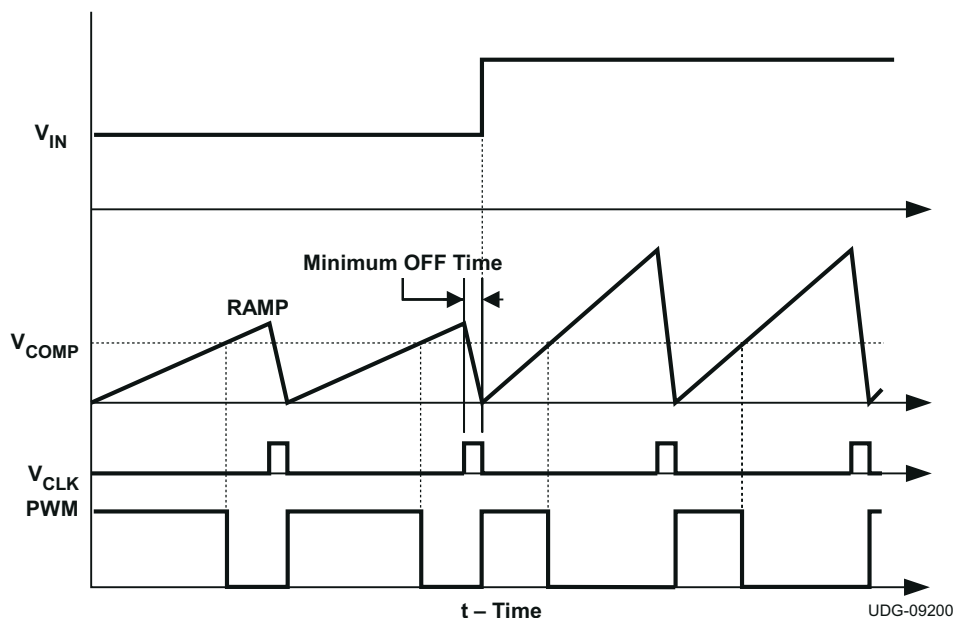


Figure 6-3. Feed-Forward Oscillator Timing Diagram

### 6.3.3.1 Calculating the Timing Resistance ( $R_{RT}$ )

$$R_{RT} = \left( \frac{10^4}{f_{SW}} \right) - 2(k\Omega) \quad (4)$$

where

- $f_{SW}$  is the switching frequency in kHz
- $R_{RT}$  is the resistor connected from RT pin to GND in k $\Omega$

#### Note

The switching frequency can be adjusted between 100 kHz and 600 kHz. The maximum switching frequency before skipping pulses is determined by the input voltage, output voltage, FET resistances, DCR of the inductor, and the minimum on time of the TPS40170. Use [Equation 5](#) to determine the maximum switching frequency. For further details, please see analog design journal, [Understanding output voltage limitations of DC/DC buck converters](#).

$$f_{SW(max)} = \frac{V_{OUT(min)} + (I_{OUT(min)} \times (R_{DS2} + R_{LOAD}))}{t_{ON(min)} \times (V_{IN(max)} - I_{OUT(min)} \times (R_{DS1} - R_{DS2}))} \quad (5)$$

where

- $f_{SW(max)}$  is the maximum switching frequency
- $V_{OUT(min)}$  is the minimum output voltage
- $V_{IN(max)}$  is the maximum input voltage
- $I_{OUT(min)}$  is the minimum output current
- $R_{DS1}$  is the high-side FET resistance
- $R_{DS2}$  is the low-side FET resistance
- and  $R_{LOAD}$  is the inductor series resistance

### 6.3.4 Overcurrent Protection and Short-Circuit Protection (OCP and SCP)

The TPS40170 has the capability to set a two-level overcurrent protection. The first level of overcurrent protection (OCP) is the normal overload setting based on low-side MOSFET voltage sensing. The second level of protection is the heavy overload setting such as short-circuit based on the high-side MOSFET voltage sensing. This protection takes effect immediately. The second level is termed short-circuit protection (SCP).

The OCP level is set by the ILIM pin voltage. A current ( $I_{ILIM}$ ) is sourced into the ILIM pin from which a resistor  $R_{ILIM}$  is connected to GND. Resistor  $R_{ILIM}$  sets the first level of overcurrent limit. The OCP is based on the low-side FET voltage at the switch-node (SW pin) when the LDRV is ON after a blanking time, which is the product of inductor current and low-side FET turn-on resistance  $R_{DS(on)}$ . The voltage is inverted and compared to ILIM pin voltage. If it is greater than the ILIM pin voltage, then a 3-bit counter inside the device increments the fault-count by 1 at the start of the next switching cycle. Alternatively, if it is less than the ILIM pin voltage, then the counter inside the device decrements the fault-count by 1. When the fault-count reaches 7, an overcurrent fault (OC\_FAULT) is declared and both the HDRV and LDRV are turned OFF. The resistor  $R_{ILIM}$  can be calculated by the following [Equation 6](#).

$$R_{ILIM} = \frac{I_{OC} \times R_{DS(on)}}{I_{ILIM}} = \frac{I_{OC} \times R_{DS(on)}}{9.0\mu A} \quad (6)$$

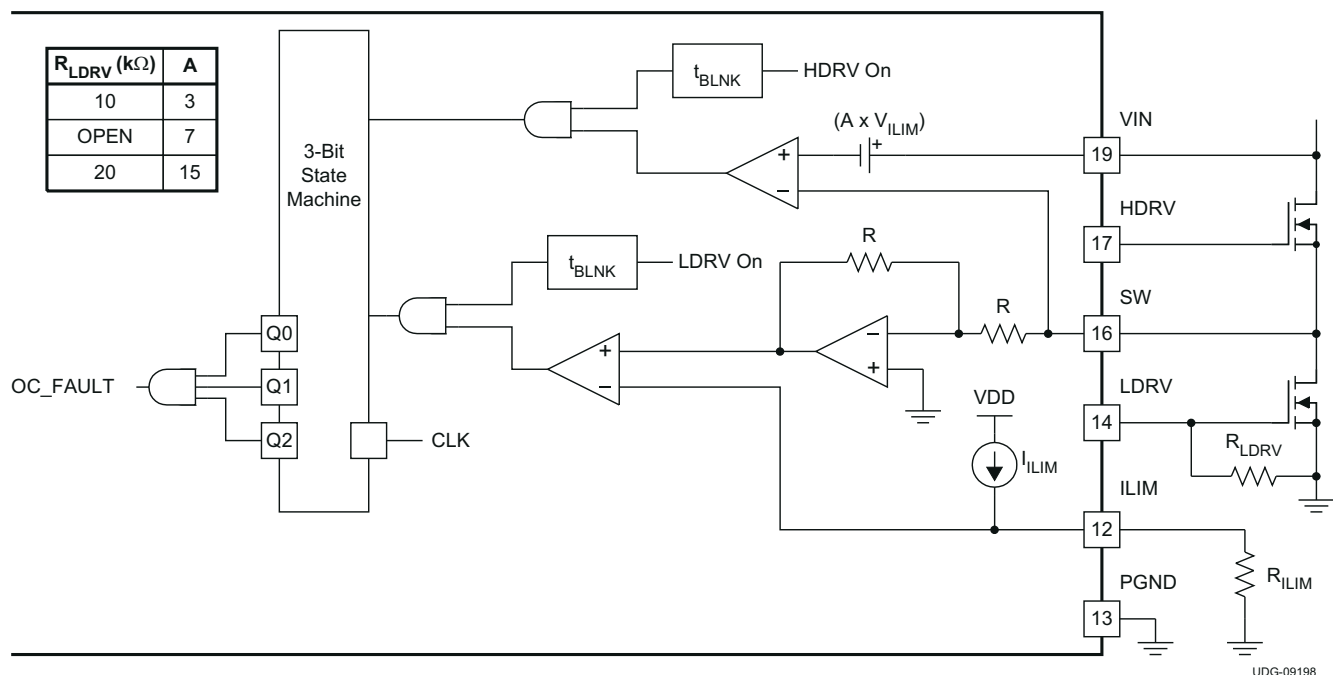
The SCP level is set by a multiple of the ILIM pin voltage. The multiplier has three discrete values, 3, 7 or 15 times, which can be selected by respectively choosing a 10-k $\Omega$ , open circuit, or 20 k $\Omega$  resistor from LDRV pin to

GND. This multiplier AOC information is translated during the  $t_{CAL}$  time, which starts after the enable and UVLO conditions are met.

The SCP is based on sensing the high-side FET voltage drop from  $V_{VIN}$  to  $V_{SW}$  when the HDRV is ON after a blanking time, which is product of inductor current and high-side FET turn-on resistance  $R_{DS(on)}$ . The voltage is compared to the product of multiplier and the ILIM pin voltage. If it exceeds the product, then the fault-count is immediately set to 7 and the OC\_FAULT is declared. The HDRV is terminated immediately without waiting for the duty cycle to end. When an OC\_FAULT is declared, both the HDRV and LDRV are turned OFF. The appropriate multiplier (A), can be selected using Equation 7.

$$A = \frac{I_{SC} \times R_{DS(on)HS}}{I_{OC} \times R_{DS(on)LS}} \quad (7)$$

Figure 6-4 shows the functional block of the two-level overcurrent protection.



**Figure 6-4. OCP and SCP Protection Functional Block Diagram**

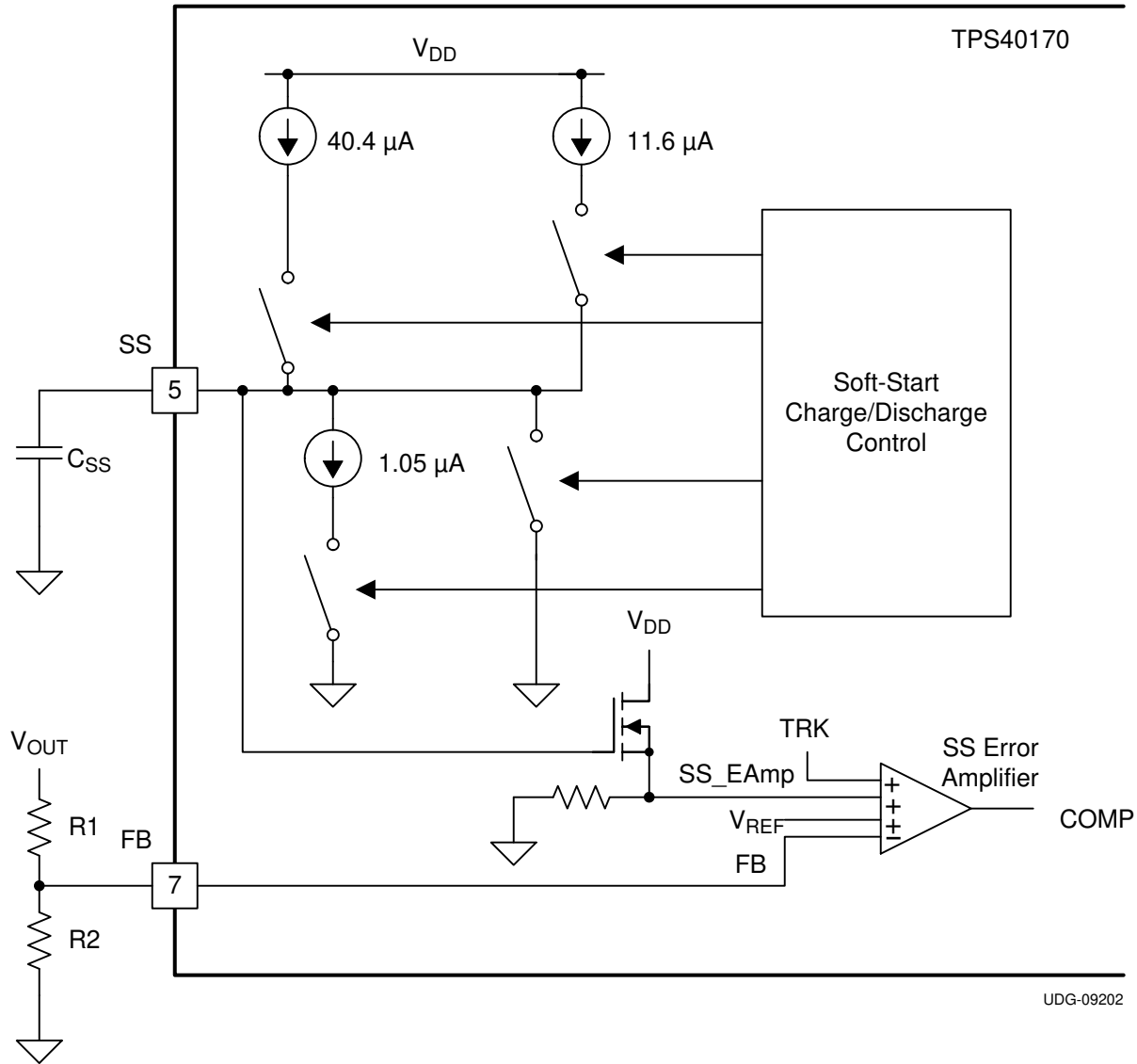
#### Note

Both OCP and SCP are based on low-side and high-side MOSFET voltage sensing at the SW node. Excessive ringing on the SW node can have negative impact on the accuracy of OCP and SCP. Adding an RC snubber from the SW node to GND helps minimize the potential impact.

### 6.3.5 Soft-Start and Fault-Logic

A capacitor from the SS pin to GND defines the SS time,  $t_{SS}$ . The TPS40170 enters into soft-start immediately after completion of the overcurrent calibration. The SS pin goes through the device internal level-shifter circuit before reaching one of the positive inputs of the error amplifier. The SS pin must reach approximately 0.65 V before the input to the error amplifier begins to rise above 0 V. To charge the SS pin from 0 V to 0.65 V faster, at the beginning of the soft-start in addition to the normal charging current, (11.6  $\mu$ A, typ.), an extra charging current (40.4  $\mu$ A, typ.) is switched-in to the SS pin. As the SS capacitor reaches 0.5 V, the extra charging current is turned off and only the normal charging current remains. Figure 6-5 shows the soft-start function block.





**Figure 6-5. Soft-Start Schematic Block**

As the SS pin voltage approaches 0.65 V, the positive input to the error amplifier begins to rise (see [Figure 6-6](#)). The output of the error amplifier (the COMP pin) starts rising. The rate of rise of the COMP voltage is mainly limited by the feedback loop compensation network. After  $V_{COMP}$  reaches the valley of the PWM ramp, the switching begins. The output is regulated to the error amplifier input through the FB pin in the feedback loop. After the FB pin reaches the 600 mV reference voltage, the feedback node is regulated to the reference voltage,  $V_{REF}$ . The SS pin continues to rise and is clamped to  $V_{DD}$ .

The SS pin is discharged through an internal switch during the following conditions:

- Input (VIN) undervoltage lock out UVLO pin less than  $V_{UVLO}$
- Overcurrent protection calibration time ( $t_{CAL}$ )
- VBP less than threshold voltage ( $VBP_{(off)}$ )

Because it is discharged through an internal switch, the discharging time is relatively fast compared with the discharging time during the fault restart which is discussed in the [Soft-Start During Overcurrent Fault](#) section.

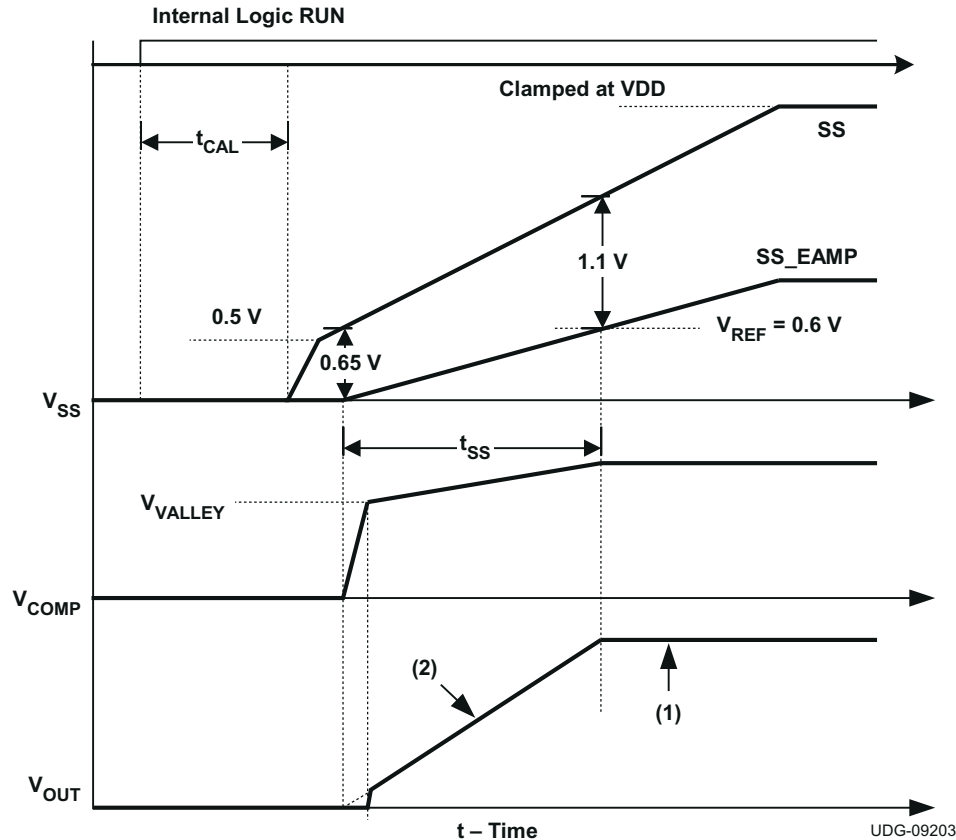


Figure 6-6. Soft-Start Waveforms

**Note**

Referring to Figure 6-6

- (1) VREF dominates the positive input of the error amplifier
- (2) SS\_EAMP dominates the positive input of the error amplifier

For  $0 < V_{SS\_EAMP} < V_{REF}$ 

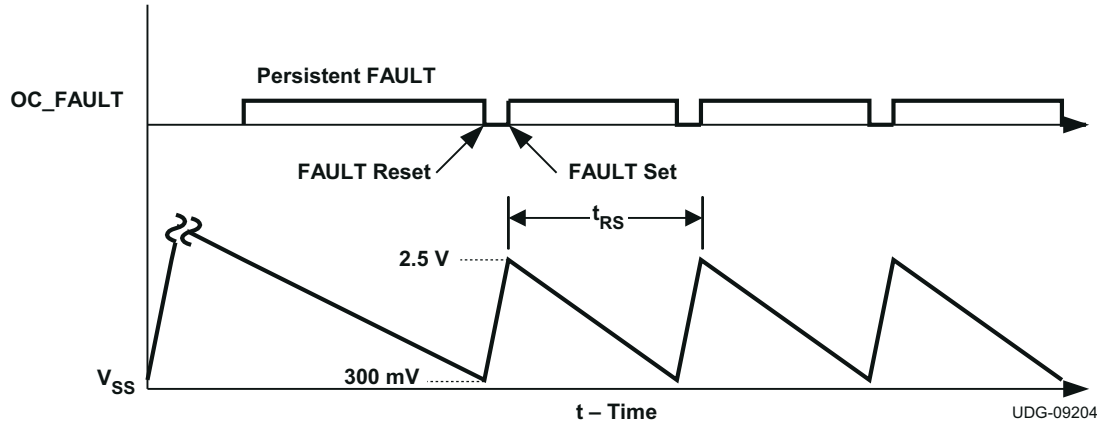
$$V_{OUT} = V_{SS(EAMP)} \times \frac{(R1+R2)}{R2} \quad (8)$$

For  $V_{SS\_EAMP} > V_{REF}$ 

$$V_{OUT} = V_{REF} \times \frac{(R1+R2)}{R2} \quad (9)$$

**6.3.5.1 Soft Start During Overcurrent Fault**

The soft-start block also has a role to controls the fault-logic timing. If an overcurrent fault (OC\_FAULT) is declared, the soft-start capacitor is discharged internally through the device by a small current  $I_{SS(sink)}$  (1.05  $\mu$ A, typ.). After the SS pin capacitor is discharged to below  $V_{SS(fft,low)}$  (300 mV, typ.), the soft-start capacitor begins charging again. If the fault is persistent, a fault is declared which is determined by the overcurrent protection state machine. If the soft-start capacitor is below  $V_{SS(fft,high)}$  (2.5 V, typ.), then the soft-start capacitor continues to charge until it reaches  $V_{SS(fft,high)}$  before a discharge cycle is initiated. This ensures that the re-start time-interval is always constant. Figure 6-7 shows the restart timing.



**Figure 6-7. Overcurrent Fault Restart Timing**

**Note**

For the feedback to be regulated to the SS\_EAMP voltage, the TRK pin must be pulled up high directly or through a resistor to VDD.

### 6.3.5.2 Equations for Soft Start and Restart Time

The soft-start time ( $t_{SS}$ ) is defined as the time taken for the internal SS\_EAMP node to go from 0 V to the 0.6 V,  $V_{REF}$  voltage. The SS\_EAMP starts rising as the SS pin goes beyond 0.65 V. The offset voltage between the SS and the SS\_EAMP starts increasing as the SS pin voltage starts rising. [Soft-Start Waveforms](#), shows that the SS time can be defined as the time taken for the SS pin voltage to change by 1.05 V (see [Equation 10](#)).

The restart time ( $t_{RS}$ ) is defined in [Equation 11](#) as the time taken for the soft-start capacitor ( $C_{SS}$ ) to discharge from 2.5 V to 0.3 V and to then recharge up to 2.5 V.

$$C_{SS} = \frac{t_{SS}}{0.09} \quad (10)$$

$$t_{RS} \approx 2.28 \times C_{SS} \quad (11)$$

where

- $C_{SS}$  is the soft-start capacitance in nF
- $t_{SS}$  is the soft-start time in ms
- $t_{RS}$  is the re-start time in ms

**Note**

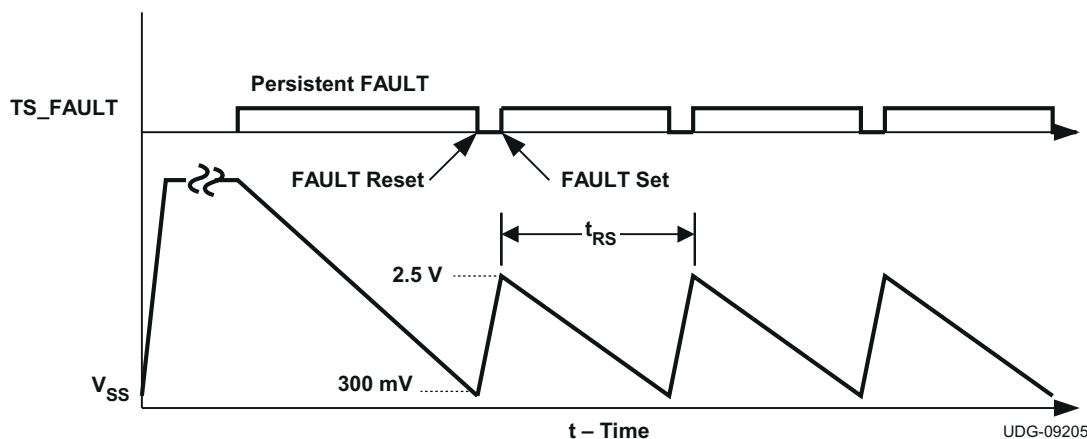
During soft-start ( $V_{SS} < 2.5$  V), the overcurrent protection limit is 1.5 times normal overcurrent protection limit. This allows higher output capacitance to fully charge without activating overcurrent protection.

### 6.3.6 Overtemperature Fault

[Figure 6-8](#) shows the overtemperature protection scheme. If the junction temperature of the device reaches the thermal shutdown limit of  $t_{SD(set)}$  (165°C, typical) and SS charging is completed, an overtemperature FAULT is declared. The soft-start capacitor begins to be discharged. During soft-start discharging period, the PWM switching is terminated; therefore, both HDRV and LDRV are driven low, turning off both MOSFETs.

The soft-start capacitor begins to charge and overtemperature fault is reset whenever the soft-start capacitor is discharged below  $V_{SS(ft,low)}$  (300 mV, typical). During each restart cycle, PWM switching is turned on. When

SS is fully charged, PWM switching is terminated. These restarts repeat until the temperature of the device has fallen below the thermal reset level,  $t_{SD(reset)}$  (135°C typical). PWM switching continues and system returns to normal regulation.



**Figure 6-8. Overtemperature Fault Restart Timing**

The soft-start timing during overtemperature fault is the same as the soft-start timing during overcurrent fault. See the [Equations for Soft Start and Restart Time](#) section.

### 6.3.7 Tracking

The TRK pin is used for output voltage tracking. The output voltage is regulated so that the FB pin equals the lowest of the internal reference voltage ( $V_{REF}$ ) or the level-shifted SS pin voltage ( $SS_{EAMP}$ ) or the TRK pin voltage. After the TRK pin goes above the reference voltage, then the output voltage is no longer governed by the TRK pin, but it is governed by the reference voltage.

If the voltage tracking function is used, then it must be noted that the SS pin capacitor must remain connected as the SS pin and is also used for FAULT timing. For proper tracking using the TRK pin, the tracking voltage must be allowed to rise only after  $SS_{EAMP}$  has exceeded  $V_{REF}$ , so that there is no possibility of the TRK pin voltage being higher than the  $SS_{EAMP}$  voltage. From [Soft-Start Waveforms](#), for  $SS_{EAMP} = 0.6$  V, the SS pin voltage is typically 1.7 V.

The maximum slew rate on the TRK pin must be determined by the output capacitance and feedback loop bandwidth. A higher slew rate can possibly trip overcurrent protection.

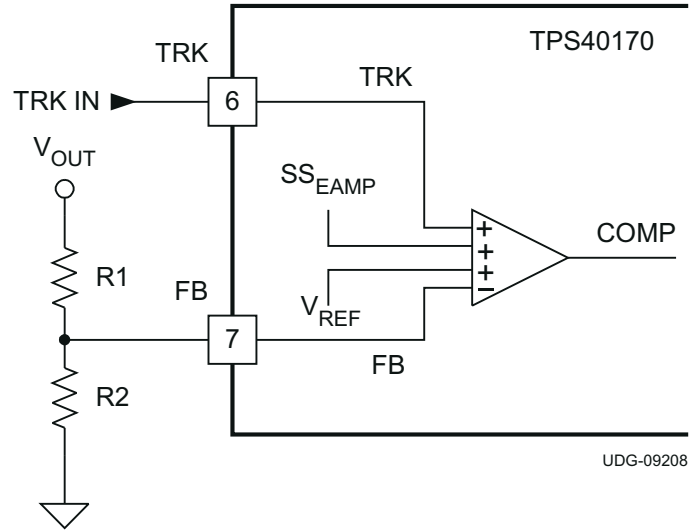
[Figure 6-9](#) shows the tracking functional block. For  $SS_{EAMP}$  voltages greater than TRK pin voltage, the  $V_{OUT}$  is given by [Equation 12](#) and [Equation 13](#).

For  $0\text{ V} < V_{\text{TRK}} < V_{\text{REF}}$

$$V_{\text{OUT}} = V_{\text{TRK}} \times \frac{(R_1 + R_2)}{R_2} \quad (12)$$

For  $V_{\text{TRK}} > V_{\text{REF}}$

$$V_{\text{OUT}} = V_{\text{REF}} \times \frac{(R_1 + R_2)}{R_2} \quad (13)$$



**Figure 6-9. Tracking Functional Block**

There are three potential applications for the tracking function.

- simultaneous voltage tracking
- ratiometric voltage tracking
- sequential startup mode

The tracking function configurations and waveforms are shown in [Figure 6-10](#), [Figure 6-12](#), and [Figure 6-14](#) respectively.

In simultaneous voltage tracking shown in [Figure 6-10](#), tracking signals,  $V_{\text{TRK1}}$  and  $V_{\text{TRK2}}$ , of two modules, POL1 and POL2, start up at the same time and their output voltages  $V_{\text{OUT1}}$  initial and  $V_{\text{OUT2}}$  initial are approximately the same during initial startup. Because  $V_{\text{TRK1}}$  and  $V_{\text{TRK2}}$  are less than  $V_{\text{REF}}$  (0.6 V, typical), [Equation 12](#) is used. As a result, components selection must meet [Equation 14](#).

$$\left( \frac{(R_1 + R_2)}{R_1} \right) \times V_{\text{TRK1}} = \left( \frac{(R_3 + R_4)}{R_3} \right) \times V_{\text{TRK2}} \Rightarrow \frac{R_5}{R_6} = \left( \frac{\left( \frac{R_1}{(R_1 + R_2)} \right)}{\left( \frac{R_3}{(R_3 + R_4)} \right)} - 1 \right) \quad (14)$$

After the lower output voltage setting reaches output voltage  $V_{\text{OUT1}}$  set point, where  $V_{\text{TRK1}}$  increases above  $V_{\text{REF}}$ , the output voltage of the other one ( $V_{\text{OUT2}}$ ) continues increasing until it reaches its own set point, where  $V_{\text{TRK2}}$  increases above  $V_{\text{REF}}$ . At that time, [Equation 13](#) is used. As a result, the resistor settings must meet [Equation 15](#) and [Equation 16](#).

$$V_{\text{OUT1}} = \left( \frac{(R_1 + R_2)}{R_1} \right) \times V_{\text{REF}} \quad (15)$$

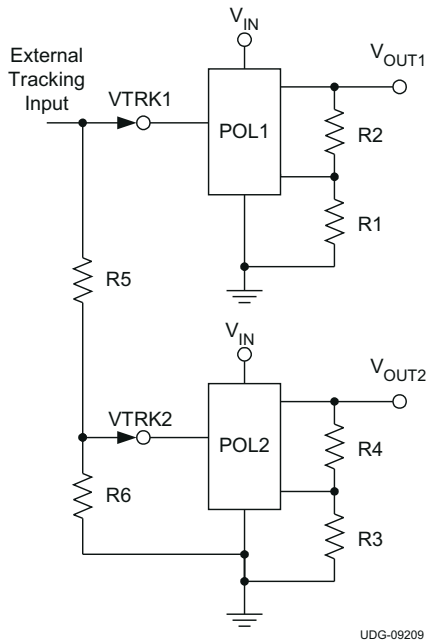
$$V_{\text{OUT2}} = \left( \frac{(R_3 + R_4)}{R_3} \right) \times V_{\text{REF}} \quad (16)$$

[Equation 14](#) can be simplified into [Equation 17](#) by replacing with [Equation 15](#) and [Equation 16](#).

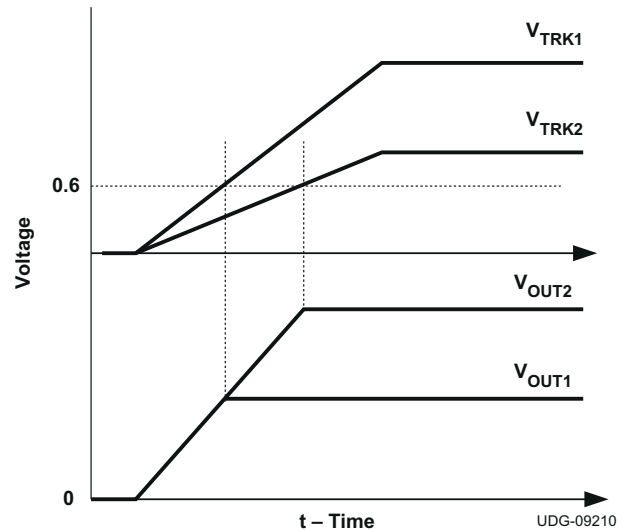
$$\left(\frac{R_5}{R_6}\right) = \left(\left(\frac{V_{OUT2}}{V_{OUT1}}\right) - 1\right) \quad (17)$$

If 5 V =  $V_{OUT2}$  and 2.5 V =  $V_{OUT1}$  are required, according to Equation 15, Equation 16 and Equation 17, the selected components can be as following:

- $R_5 = R_6 = R_4 = R_2 = 10 \text{ k}\Omega$
- $R_1 = 3.16 \text{ k}\Omega$
- $R_3 = 1.37 \text{ k}\Omega$

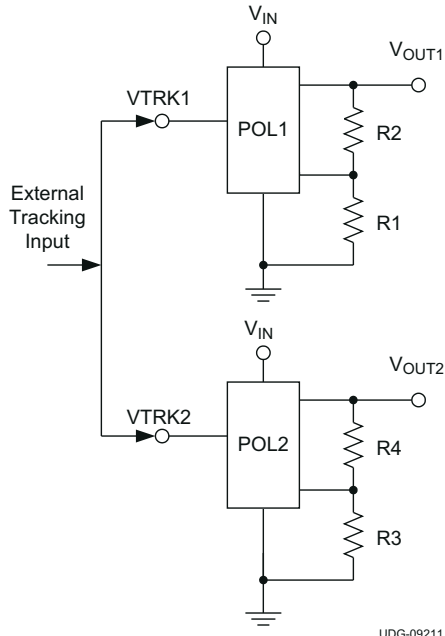


**Figure 6-10. Simultaneous Voltage Tracking Schematic**

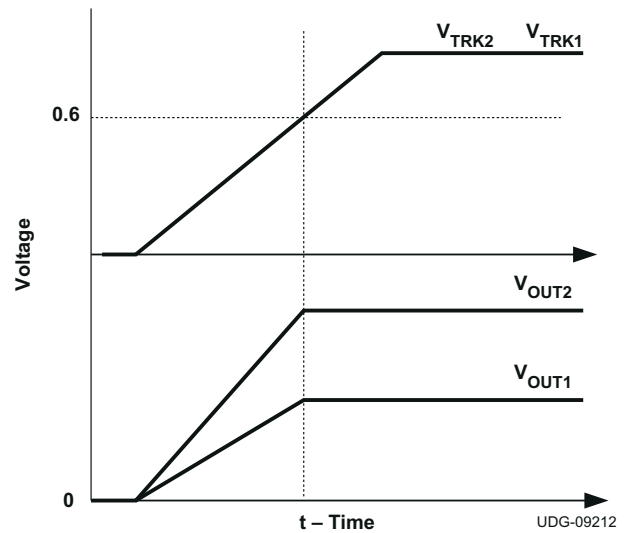


**Figure 6-11. Simultaneous Voltage Tracking Waveform**

In ratiometric voltage tracking shown in Figure 6-12, the two tracking voltages,  $V_{TRK1}$  and  $V_{TRK2}$ , for two modules, POL1 and POL2, are the same. Their output voltage,  $V_{OUT1}$  and  $V_{OUT2}$ , are different with different voltage divider  $R_2/R_1$  and  $R_4/R_3$ .  $V_{OUT1}$  and  $V_{OUT2}$  increase proportionally and reach their output voltage set points at about the same time.

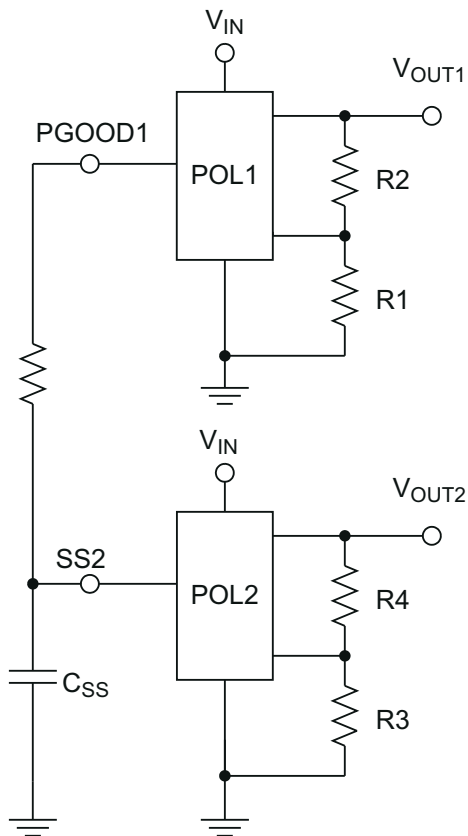


**Figure 6-12. Ratiometric Voltage Tracking Schematic**

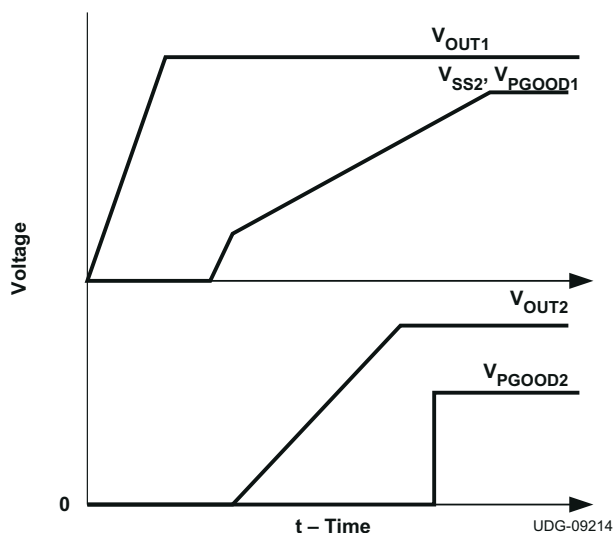


**Figure 6-13. Ratiometric Voltage Tracking Waveform**

Sequential start-up is shown in [Figure 6-14](#). During start-up of the first module, POL1, PGOOD1 is pulled to low. Because PGOOD1 is connected to soft-start SS2 of the second module, POL2, is not able to charge its soft-start capacitor. After output voltage  $V_{OUT1}$  of POL1 reaches its setting point, PGOOD1 is released. POL2 starts charging its soft-start capacitor. Finally, output voltage  $V_{OUT2}$  of POL2 reaches its setting point.



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**Figure 6-14. Sequential Start-Up Schematic****Figure 6-15. Sequential Start-Up Waveform****Note**

The TRK pin has high impedance, so it is a noise sensitive terminal. If the tracking function is used, TI recommends a small RC filter at the TRK pin to filter out high-frequency noise.

If the tracking function is not used, the TRK pin must be pulled up directly or through a resistor (with a value between 10 kΩ and 100 kΩ) to VDD.

**6.3.8 Adaptive Drivers**

The drivers for the external high-side and low-side MOSFETs are capable of driving a gate-to-source voltage,  $V_{BP}$ . The LDRV driver for the low-side MOSFET switches between  $V_{BP}$  and PGND, while the HDRV driver for the high-side MOSFET is referenced to SW and switches between BOOT and SW. The drivers have non-overlapping timing that is governed by an adaptive delay circuit to minimize body diode conduction in the synchronous rectifier.

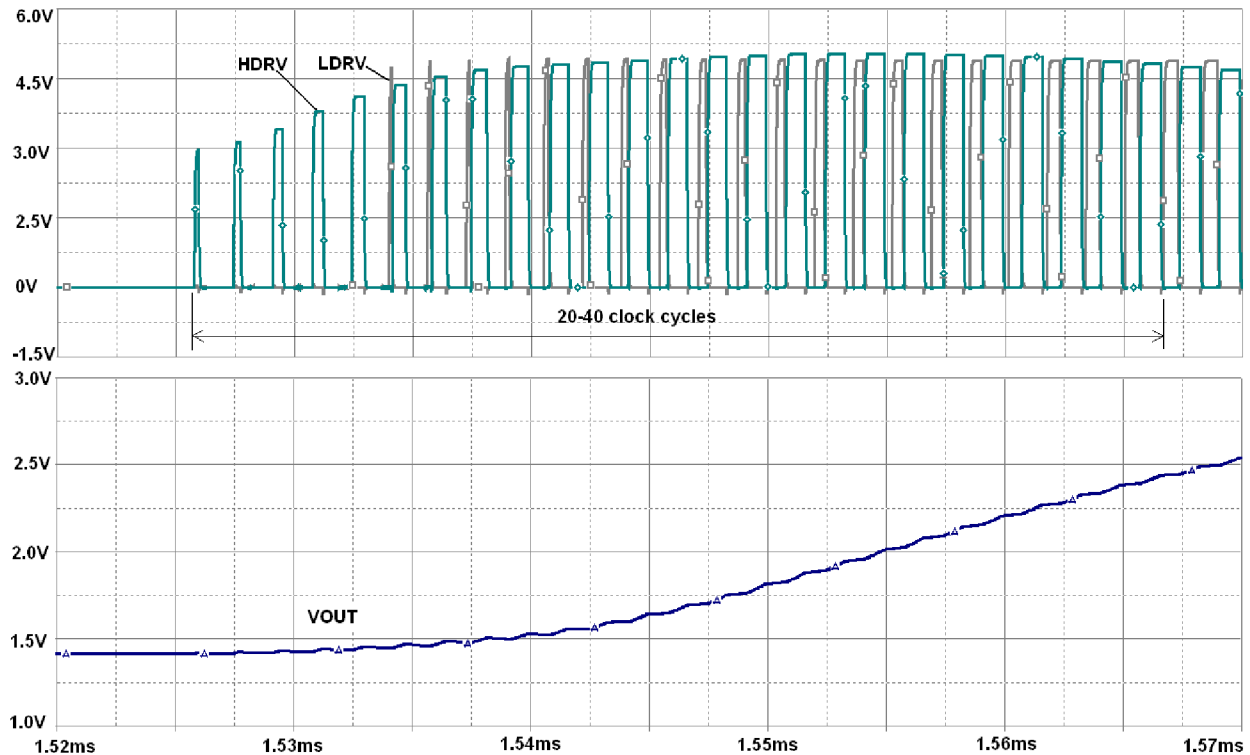
**6.3.9 Start-Up into Pre-Biased Output**

The TPS40170 contains a circuit to prevent current from being pulled out of the output during startup in case the output is pre-biased. When the soft-start commands a voltage higher than the pre-bias level (internal soft-start becomes greater than feedback voltage  $[V_{FB}]$ ), the controller slowly activates synchronous rectification by starting the first LDRV pulses with a narrow on-time (see [Figure 6-16](#)), where:

- $V_{IN} = 5\text{ V}$
- $V_{OUT} = 3.3\text{ V}$
- $V_{PRE} = 1.4\text{ V}$
- $f_{SW} = 300\text{ kHz}$
- $L = 0.6\text{ }\mu\text{H}$



It then increments the on-time on a cycle-by-cycle basis until it coincides with the time dictated by (1-D), where D is the duty cycle of the converter. This scheme prevents the initial sinking of the pre-bias output, and ensures that the output voltage ( $V_{OUT}$ ) starts and ramps up smoothly into regulation and the control loop is given time to transition from pre-biased startup to normal mode operation with minimal disturbance to the output voltage. The time from the start of switching until the low-side MOSFET is turned on for the full (1-D) interval is between approximately 20 and 40 clock cycles.



**Figure 6-16. Start-Up Switching Waveform during Pre-Biased Condition**

If the output is pre-biased to a voltage higher than the voltage commanded by the reference, then the PWM switching does not start.

#### Note

When output is pre-biased at  $V_{PRE-BIAS}$ , that voltage also applies to the SW node during start-up. When the pre-bias circuitry commands the first few high-side pulses before the first low-side pulse is initiated, the gate voltage for the high-side MOSFET is as described in [Equation 18](#). Alternatively, If pre-bias level is high, it is possible that SCP can be tripped due to high turn-on resistance of the high-side MOSFET with low gate voltage. After tripped, the device resets and then attempts to re-start. The device can not be able to start up until output is discharged to a lower voltage level by either an active load or through feedback resistors.

In the case of a high pre-bias level, a low gate-threshold voltage rated device is recommended for the high-side MOSFET and increasing the SCP level also helps alleviate the problem.

$$V_{GATE(hs)} = (V_{BP} - V_{DFWD} - V_{PRE-BIAS}) \quad (18)$$

where

- $V_{\text{GATE(hs)}}$  is the gate voltage for the high-side MOSFET
- $V_{\text{BP}}$  is the BP regulator output
- $V_{\text{DFWD}}$  is bootstrap diode forward voltage

### 6.3.10 Power Good (PGOOD)

The TPS40170 provides an indication that the output voltage of the converter is within the specified limits of the regulation as measured at the FB pin. The PGOOD pin is an open-drain signal and pulls low when any condition exists that can indicate that the output of the supply can be out of regulation. These conditions include:

- $V_{\text{FB}}$  is not within the PGOOD threshold limits.
- Soft-start is active, that is, SS pin voltage is below  $V_{\text{SS,FLT,HIGH}}$  limit.
- An undervoltage condition exists for the device.
- An overcurrent or short-circuit fault is detected.
- An overtemperature fault is detected.

Figure 6-17 shows a situation where no fault is detected during the start-up, (the normal PGOOD situation). The figure shows that PGOOD goes high  $t_{\text{PGD}}$  (20  $\mu\text{s}$ , typical) after all the conditions (listed above) are met.

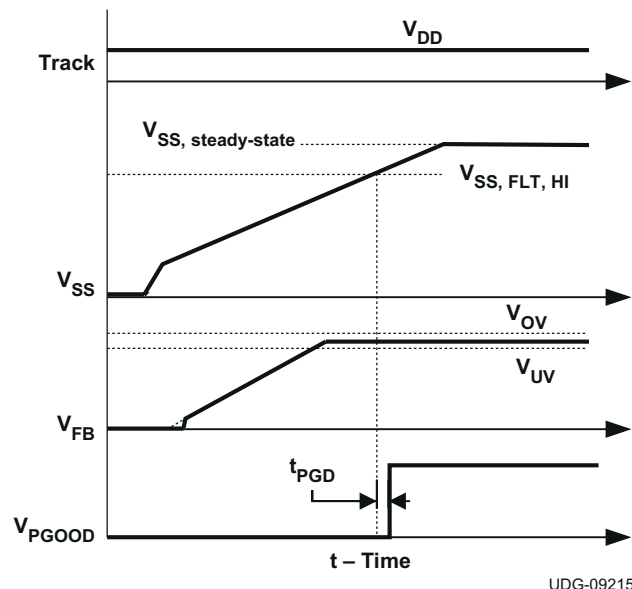


Figure 6-17. PGOOD Signal

When there is no power to the device, PGOOD is not able to pull close to GND if an auxiliary supply is used for the power good indication. In this case, a built-in resistor connected from drain to gate on the PGOOD pulldown device allows the PGOOD pin to operate like as a diode to GND.

### 6.3.11 PGND and AGND

TPS40170 provides separate signal ground (AGND) and power ground (PGND) pins. PGND is primarily used for gate driver ground return. AGND is an internal logic signal ground return. These two ground signals are internally loosely connected by two anti-parallel diodes. PGND and AGND must be electrically connected externally.

## 6.4 Device Functional Modes

### 6.4.1 Frequency Synchronization

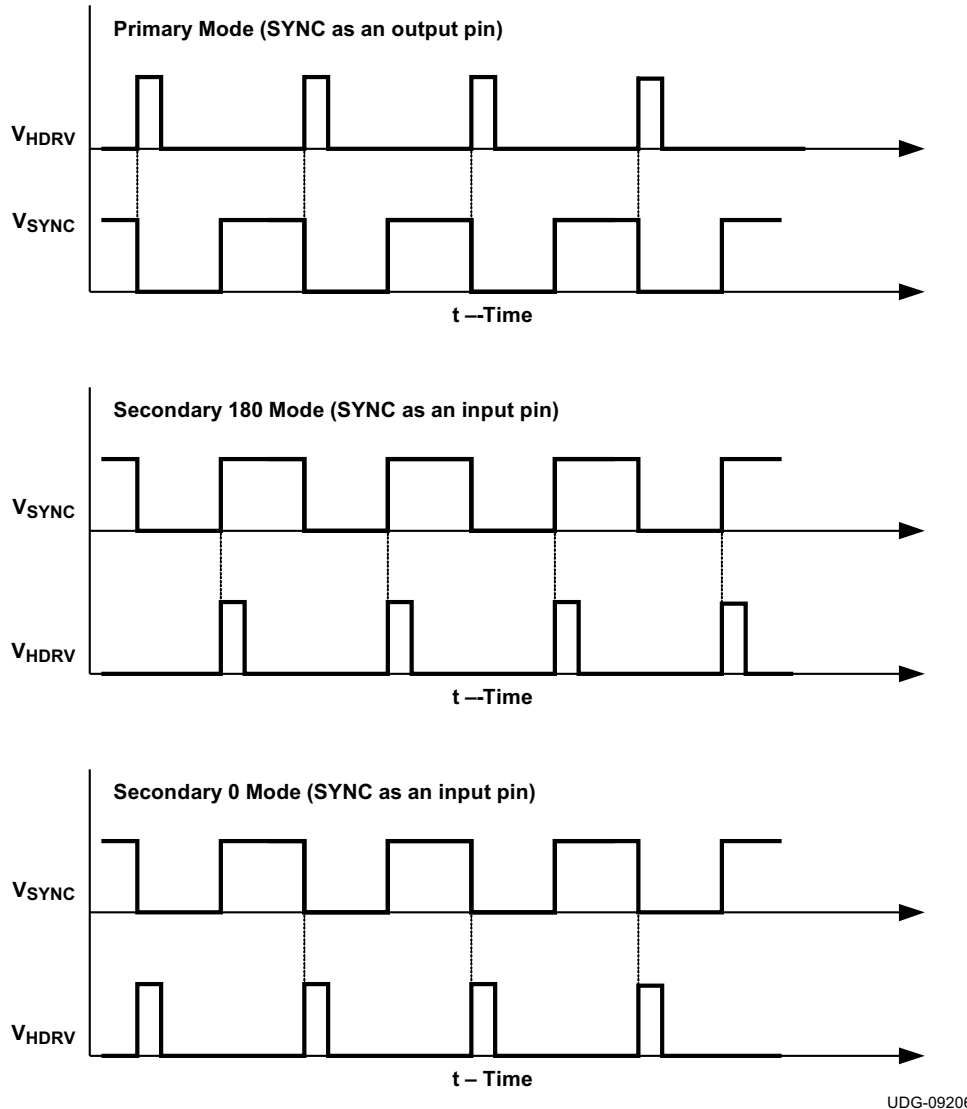
The TPS40170 has three modes.

- **Primary mode:** In this mode the primary/secondary selector pin, (M/S) is connected to VIN. The SYNC pin emits a stream of pulses at the same frequency as the PWM switching frequency. The pulse stream at the

SYNC pin is at 50% duty cycle and the same amplitude as  $V_{VBP}$ . Also, the falling edge of the voltage on SYNC pin is synchronized with the rising edge of the HDRV.

- **Secondary-180° mode:** In this mode the M/S pin is connected to GND. The SYNC pin of the TPS40170 accepts a synchronization clock signal, and the HDRV is synchronized with the rising edge of the incoming synchronization clock.
- **Secondary-0° mode:** In this mode, the M/S pin is left open. The SYNC pin of the TPS40170 accepts a synchronization clock signal, and the HDRV is synchronized with the falling edge of the incoming synchronization clock.

The two secondary modes can be synchronized to an external clock through the SYNC pin. They are shown in Figure 6-18. The synchronization frequency must be within  $\pm 30\%$  of its programmed free running frequency.

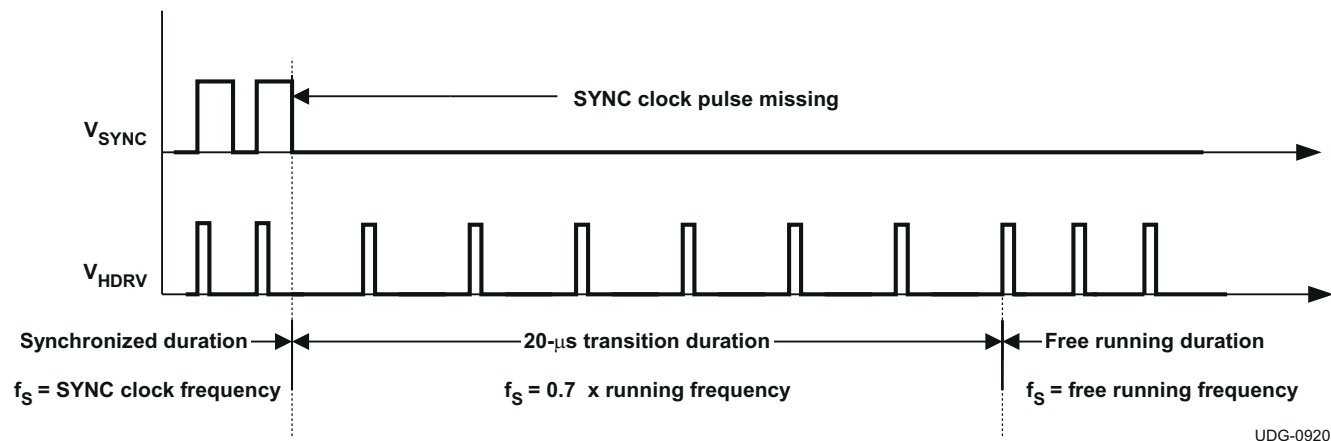


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**Figure 6-18. Frequency Synchronization Waveforms In Different Modes**

TPS40170 provides a smooth transition for the SYNC clock signal loss at secondary mode. In secondary mode, a synchronization clock signal is provided externally through the SYNC pin to the device. The switching frequency is synchronized to the external SYNC clock signal. If for some reason the external clock signal is missing, the device switching frequency is automatically overridden by a transition frequency which is 0.7

times its programmed free running frequency. This transition time is approximately 20  $\mu$ s. After that, the device switching frequency is changed to its programmed free running frequency. Figure 6-19 shows this process.



**Figure 6-19. Transition for Sync Clock Signal Missing (For Secondary-180 Mode)**

#### Note

When the device is operating in the primary mode with duty ratio around 50%, PWM jittering can occur. Always configure the device into the secondary mode by either connecting the M/S pin to GND or leaving it floating if primary mode is not used.

When an external SYNC clock signal is used for synchronization, limit maximum slew rate of the clock signal to 10 V/ $\mu$ s to avoid potential PWM jittering and connect the SYNC pin to the external clock signal via a 5-k $\Omega$  resistor.

### 6.4.2 Operation Near Minimum VIN ( $V_{VIN} \leq 4.5$ V)

The TPS40170 is designed to operate with input voltages above 4.5 V. With voltages below 4.5 V if the EN pin is above its 600-mV turn-on threshold the VDD and VBP internal regulators are active. These regulators operate in drop out and output the highest voltage possible for the given VIN. The EN pin voltage must be below 100 mV to disable the VDD and VBP regulators. Switching is disabled while the VBP output voltage is below the VBP turn-on voltage of 4.4-V maximum. When there is sufficient VIN voltage to regulate the VBP voltage above 4.4 V the final condition for switching to begin is the UVLO pin voltage must be above its 900 mV typical threshold. After all three conditions are met the TPS40170 begins switching and the soft-start sequence is initiated. The device starts at the soft-start time determined by the external capacitance at the SS/TR pin. If a design requires operation near the minimum VIN voltage, due to lower VBP voltage when operating in dropout, lower gate threshold MOSFETs are recommended.

## 7 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, as well as validating and testing their design implementation to confirm system functionality.

### 7.1 Application Information

The wide input TPS40170 controller can function in a very wide range of applications. The WEBENCH software uses an iterative design procedure and accesses a comprehensive database of components when generating a design. This section presents a simplified discussion of the design process.

#### 7.1.1 Bootstrap Resistor

A small resistor in series with the bootstrap capacitor reduces the turn-on speed of the high-side MOSFET, thereby reducing the rising edge ringing of the SW node and reduces short through induced by  $dv/dt$ . A bootstrap resistor value that is too large delays the turn-on time of the high-side switch and can trigger an apparent SCP fault.

#### 7.1.2 SW Node Snubber Capacitor

Observable voltage ringing at the SW node is caused by fast switching edges and parasitic inductance and capacitance. If the ringing results in excessive voltage on the SW node, or erratic operation of the converter, an RC snubber can be used to dampen the ringing and ensure proper operation over the full load range. See design example.

#### 7.1.3 Input Resistor

The TPS40170 has a wide input voltage range which allows for the device input to share power source with power stage input. Power stage switching noise can pollute the device power source if the layout is not adequate in minimizing noise. It can trigger short-circuit fault. If so, adding a small resistor between the device input and power stage input is recommended. This resistor composites an RC filter with the device input capacitor and filter out the switching noise from power stage. See R1 in the design example.

#### 7.1.4 LDRV Gate Capacitor

Power device selection is important for proper switching operation. If the low-side MOSFET has low gate capacitance  $C_{GS}$  (if  $C_{GS} < C_{GD}$ ), there is a risk of short-through induced by high  $dv/dt$  at switching node (See reference[1]) during high-side turned-on. If this happens, add a small capacitance between LDRV and GND. See design example.

### 7.2 Typical Application

This example describes the design process for a very wide input (10 V to 60 V) to a regulated 5 V output at a load current of 6 A. The schematic shown in [Figure 7-1](#) is configured for the design parameters provided in [Table 7-1](#). Alternatively the WEBENCH software can be used to generate a complete design with the TPS40170.

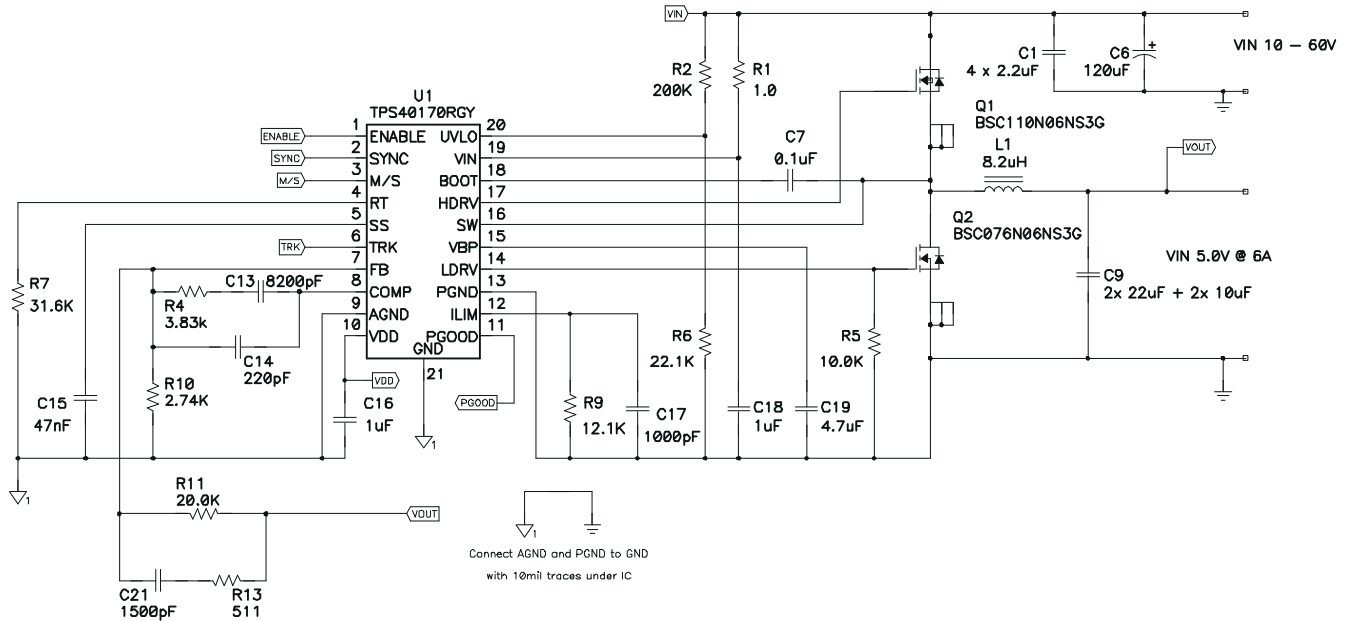


Figure 7-1. Typical Design Application

## 7.2.1 Design Requirements

Table 7-1. Design Requirements

| PARAMETER               |                                  | TEST CONDITIONS                                | MIN | NOM | MAX  | UNIT            |
|-------------------------|----------------------------------|--|-----|-----|------|-----------------|
| V <sub>IN</sub>         | Input voltage                    |  | 10  |     | 60   | V               |
| V <sub>IN(ripple)</sub> | Input ripple                     | I <sub>OUT</sub> = 6 A                         |     |     | 0.5  |                 |
| V <sub>OUT</sub>        | Output voltage                   | 0 A ≤ I <sub>OUT</sub> ≤ 20 A                  | 4.8 | 5.0 | 5.2  |                 |
|                         | Line regulation                  | 10 V ≤ V <sub>IN</sub> ≤ 60 V                  |     |     | 0.5% |                 |
|                         | Load regulation                  | 0 A ≤ I <sub>OUT</sub> ≤ 6 A                   |     |     | 0.5% |                 |
| V <sub>RIPPLE</sub>     | Output ripple                    | I <sub>OUT</sub> = 6 A                         |     |     | 100  | mV              |
| V <sub>OVER</sub>       | Output overshoot                 | ΔI <sub>OUT</sub> = 2.5 A                      |     | 250 |      |                 |
| V <sub>UNDER</sub>      | Output undershoot                | ΔI <sub>OUT</sub> = -2.5 A                     |     | 250 |      |                 |
| I <sub>OUT</sub>        | Output current                   | 10 V ≤ V <sub>IN</sub> ≤ 60 V                  | 0   |     | 6    | A               |
| t <sub>SS</sub>         | Soft-start time                  | V <sub>IN</sub> = 24 V                         |     | 4   |      | ms              |
| I <sub>SCP</sub>        | Short-circuit current trip point |  | 8   |     |      | A               |
| η                       | Efficiency                       | V <sub>IN</sub> = 24 V, I <sub>OUT</sub> = 6 A |     | 94% |      |                 |
| f <sub>SW</sub>         | Switching frequency              |  |     | 300 |      | kHz             |
| Size                    |                                  |  |     |     | 1.5  | in <sup>2</sup> |

## 7.2.2 Detailed Design Procedure

$$C_{OUT(min)} = \frac{(I_{TRAN(max)})^2 \times L}{V_{OUT} \times V_{OVER}} = \frac{(3)^2 \times 8.2 \mu H}{5 \times 250 mV} = 59 \mu F \quad (19)$$

With a minimum capacitance, the maximum allowable ESR is determined by the maximum ripple voltage and is approximated [Equation 20](#).

$$ESR_{MAX} = \frac{V_{RIPPLE(tot)} - V_{RIPPLE(cap)}}{I_{RIPPLE}} = \frac{V_{RIPPLE(tot)} - \left( \frac{I_{RIPPLE}}{8 \times C_{OUT} \times f_{SW}} \right)}{I_{RIPPLE}} = \frac{100mV - \left( \frac{1.86A}{8 \times 59\mu F \times 300kHz} \right)}{1.86A} = 47m\Omega \quad (20)$$

Two 1210, 22  $\mu$ F, 16 V X7R ceramic capacitors plus two 0805 10  $\mu$ F, 16 V X7R ceramic capacitors are selected to provide more than 59  $\mu$ F of minimum capacitance (including tolerance and DC bias derating) and less than 47 m $\Omega$  of ESR (parallel ESR of approximately 4 m $\Omega$ ).

### 7.2.2.1 Custom Design with WEBENCH® Tools

[Click here](#) to create a custom design using the WEBENCH Power Designer.

1. Start by entering your  $V_{IN}$ ,  $V_{OUT}$  and  $I_{OUT}$  requirements.
2. Optimize your design for key parameters like efficiency, footprint and cost using the optimizer dial and compare this design with other possible solutions from Texas Instruments.
3. WEBENCH Power Designer provides you with a customized schematic along with a list of materials with real time pricing and component availability.
4. In most cases, you will also be able to:
  - Run electrical simulations to see important waveforms and circuit performance,
  - Run thermal simulations to understand the thermal performance of your board,
  - Export your customized schematic and layout into popular CAD formats,
  - Print PDF reports for the design, and share your design with colleagues.

### 7.2.2.2 List of Materials

**Table 7-2. Design Example List of Materials**

| REFERENCE DESIGNATOR | QTY  | VALUE                    | DESCRIPTION                                   | SIZE   | PART NUMBER        | MANUF     |
|----------------------|------|--------------------------|---|--------|--------------------|-----------|
| C1                   | 4    | 2.2 $\mu$ F              | Capacitor, Ceramic, 100 V, X7R, 15%           | 1210   | Std                | Std       |
| C6                   | 1    | 120 $\mu$ F              | Capacitor, Aluminum, 63 V, 20%, KZE Series    | 0.315" | KZE63VB121M10X16LL | Chemi-con |
| C7                   | 1    | 0.1 $\mu$ F              | Capacitor, Ceramic, 50 V, X7R, 15%            | 603    | Std                | Std       |
| C9                   | 2 ea | 22 $\mu$ F<br>10 $\mu$ F | Capacitor, Ceramic, 16 V, X7R, 15%            | 1210   | Std                | Std       |
| C13                  | 1    | 8200 pF                  | Capacitor, Ceramic, 50 V, X7R, 15%            | 603    | Std                | Std       |
| C14                  | 1    | 220 pF                   | Capacitor, Ceramic, 50 V, X7R, 15%            | 603    | Std                | Std       |
| C15                  | 1    | 47 nF                    | Capacitor, Ceramic, 50 V, X7R, 15%            | 603    | Std                | Std       |
| C16                  | 1    | 1 $\mu$ F                | Capacitor, 1 6V, X7R, 15%                     | 603    | Std                | Std       |
| C17                  | 1    | 1000 pF                  | Capacitor, Ceramic, 50 V, X7R, 15%            | 603    | Std                | Std       |
| C18                  | 1    | 1 $\mu$ F                | Capacitor, Ceramic, 100 V, X7R, 15%           | 1206   | Std                | Std       |
| C19                  | 1    | 4.7 $\mu$ F              | Capacitor, Ceramic, 16 V, X5R, 15%            | 805    | Std                | Std       |
| C21                  | 1    | 1500 pF                  | Capacitor, Ceramic, 50 V, X7R, 15%            | 603    | Std                | Std       |
| L1                   | 1    | 8.2 $\mu$ H              | Inductor, SMT, 10 A, 16 m $\Omega$            | 0.51"² | IHLP5050FDER8R2M01 | Vishay    |
| Q1                   | 1    |                          | MOSFET, N-channel, 60 V, 50 A, 11 m $\Omega$  |        | BSC110N06NS3G      | Infineon  |
| Q2                   | 1    |                          | MOSFET, N-channel, 60 V, 50 A, 7.6 m $\Omega$ |        | BSC076N06NS3G      | Infineon  |
| R10                  | 1    | 2.74 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R4                   | 1    | 3.83 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R5                   | 1    | 10.0 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R9                   | 1    | 12.1 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R11                  | 1    | 20.0 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R6                   | 1    | 22.1 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R7                   | 1    | 31.6 k $\Omega$          | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |
| R2                   | 1    | 200 k $\Omega$           | Resistor, Chip, 1/16W, 1%                     | 603    | Std                | R603      |

**Table 7-2. Design Example List of Materials (continued)**

| REFERENCE DESIGNATOR | QTY | VALUE  | DESCRIPTION   | SIZE | PART NUMBER | MANUF             |
|----------------------|-----|--------|---|------|-------------|-------------------|
| R13                  | 1   | 511 kΩ | Resistor, Chip, 1/16W, 1%                             | 603  | Std         | R603              |
| U1                   |     |        | IC, 4.5 V - 60 V wide input sync. PWM buck controller |      | TPS40170RGY | Texas Instruments |

**7.2.2.3 Select a Switching Frequency**

To maintain acceptable efficiency and meet minimum on-time requirements, a 300 kHz switching frequency is selected.

**7.2.2.4 Inductor Selection (L1)**

Synchronous buck power inductors are typically sized for approximately 20-40% peak-to-peak ripple current ( $I_{RIPPLE}$ ). Given this target ripple current, the required inductor size can be calculated in Equation 21.

$$L \approx \frac{V_{IN(max)} - V_{OUT}}{0.3 \times I_{OUT}} \times \frac{V_{OUT}}{V_{IN(max)}} \times \frac{1}{f_{SW}} = \frac{60V - 5V}{0.3 \times 6A} \times \frac{5V}{60V} \times \frac{1}{300kHz} = 8.5\mu H \quad (21)$$

Selecting a standard 8.2 μH inductor value, solving for  $I_{RIPPLE} = 1.86$  A.

The RMS current through the inductor is approximated by Equation 22.

$$I_{L(rms)} = \sqrt{\left(I_{L(avg)}\right)^2 + \frac{1}{12} \times (I_{RIPPLE})^2} = \sqrt{(I_{OUT})^2 + \frac{1}{12} \times (I_{RIPPLE})^2} = \sqrt{(6)^2 + \frac{1}{12} \times (1.86)^2} = 6.02A \quad (22)$$

**7.2.2.5 Output Capacitor Selection (C9)**

The selection of the output capacitor is typically driven by the output transient response. The Equation 23 and Equation 24 overestimate the voltage deviation to account for delays in the loop bandwidth and can be used to determine the required output capacitance:

$$V_{OVER} < \frac{I_{TRAN}}{C_{OUT}} \times \Delta T = \frac{I_{TRAN}}{C_{OUT}} \times \frac{I_{TRAN} \times L}{V_{OUT}} = \frac{(I_{TRAN})^2 \times L}{V_{OUT} \times C_{OUT}} \quad (23)$$

$$V_{UNDER} < \frac{I_{TRAN}}{C_{OUT}} \times \Delta T = \frac{I_{TRAN}}{C_{OUT}} \times \frac{I_{TRAN} \times L}{(V_{IN} - V_{OUT})} = \frac{(I_{TRAN})^2 \times L}{(V_{IN} - V_{OUT}) \times C_{OUT}} \quad (24)$$

If  $V_{IN(min)} > 2 \times V_{OUT}$ , use overshoot to calculate minimum output capacitance. If  $V_{IN(min)} < 2 \times V_{OUT}$ , use undershoot to calculate minimum output capacitance.

**7.2.2.6 Peak Current Rating of Inductor**

With output capacitance, it is possible to calculate the charge current during start-up and determine the minimum saturation current rating for the inductor. The start-up charging current is approximated in Equation 25.

$$I_{CHARGE} = \frac{V_{OUT} \times C_{OUT}}{t_{SS}} = \frac{5V \times (2 \times 22\mu F + 2 \times 10\mu F)}{4ms} = 0.08A \quad (25)$$

$$I_{L(peak)} = I_{OUT(max)} + \left(\frac{1}{2} \times I_{RIPPLE}\right) + I_{CHARGE} = 6A + \frac{1}{2} \times 1.86A + 0.08A = 7.01A \quad (26)$$

An IHLP5050FDER8R2M01 8.2 μH is selected. This 10-A, 16-mΩ inductor exceeds the minimum inductor ratings in a 13 mm × 13 mm package.



### 7.2.2.7 Input Capacitor Selection (C1, C6)

The input voltage ripple is divided between capacitance and ESR. For this design  $V_{\text{RIPPLE(cap)}} = 400 \text{ mV}$  and  $V_{\text{RIPPLE(ESR)}} = 100 \text{ mV}$ . The minimum capacitance and maximum ESR are estimated by:

$$C_{\text{IN(min)}} = \frac{I_{\text{LOAD}} \times V_{\text{OUT}}}{V_{\text{RIPPLE(cap)}} \times V_{\text{IN}} \times f_{\text{SW}}} = \frac{6 \text{ A} \times 5 \text{ V}}{400 \text{ mV} \times 10 \text{ V} \times 300 \text{ kHz}} = 25 \mu\text{F} \quad (27)$$

$$\text{ESR}_{\text{MAX}} = \frac{V_{\text{RIPPLE(esr)}}}{I_{\text{LOAD}} + \frac{1}{2} \times I_{\text{RIPPLE}}} = \frac{100 \text{ mV}}{6.93 \text{ A}} = 14.4 \text{ m}\Omega \quad (28)$$

The RMS current in the input capacitors is estimated in [Equation 29](#).

$$I_{\text{RMS(cin)}} = I_{\text{LOAD}} \times \sqrt{D \times (1-D)} = 6 \text{ A} \times \sqrt{0.5 \times (1-0.5)} = 3.0 \text{ A} \quad (29)$$

To achieve these values, four 1210, 2.2  $\mu\text{F}$ , 100 V, X7R ceramic capacitors plus a 120  $\mu\text{F}$  electrolytic capacitor are combined at the input. This provides a smaller size and overall cost than 10 ceramic input capacitors or an electrolytic capacitor with the ESR required.

**Table 7-3. Inductor Summary**

| PARAMETER            |                                  | VALUE | UNIT          |
|----------------------|----------------------------------|-------|---------------|
| L                    | Inductance                       | 8.2   | $\mu\text{H}$ |
| $I_{\text{L(rms)}}$  | RMS current (thermal rating)     | 6.02  | A             |
| $I_{\text{L(peak)}}$ | Peak current (saturation rating) | 7.01  | A             |

### 7.2.2.8 MOSFET Switch Selection (Q1, Q2)

Using the J/K method for MOSFET optimization, apply [Equation 30](#) through [Equation 33](#).

High-side gate (Q1):

$$J = (10)^{-9} \times \left( \frac{V_{\text{IN}} \times I_{\text{OUT}}}{I_{\text{DRIVE}}} + \frac{Q_{\text{G}}}{Q_{\text{SW}}} \times V_{\text{DRIVE}} \right) \times f_{\text{SW}} \quad (\text{W/nC}) \quad (30)$$

$$K = (10)^{-3} \left( (I_{\text{OUT}})^2 + \frac{1}{12} \times (I_{\text{P-P}})^2 \right) \times \left( \frac{V_{\text{OUT}}}{V_{\text{IN}}} \right) \quad (\text{W/m}\Omega) \quad (31)$$

Low-side gate (Q2):

$$K = (10)^{-3} \left( (I_{\text{OUT}})^2 + \frac{1}{12} \times (I_{\text{P-P}})^2 \right) \times \left( 1 - \frac{V_{\text{OUT}}}{V_{\text{IN}}} \right) \quad (\text{W/m}\Omega) \quad (32)$$

$$J = 10^{-9} \left( \frac{V_{\text{FD}} \times I_{\text{OUT}}}{I_{\text{DRIVE}}} + \frac{Q_{\text{G}}}{Q_{\text{SW}}} \times V_{\text{DRIVE}} \right) \times f_{\text{SW}} \quad (\text{W/nC}) \quad (33)$$

Optimizing for 300 kHz, 24 V input, 5 V output at 6 A, calculate ratios of 5.9 m $\Omega$ /nC and 0.5 m $\Omega$ /nC for the high-side and low-side FETS respectively. BSC110N06NS2 (Ratio 1.2) and BSC076N06NS3 (Ratio 0.69) MOSFETS are selected.

### 7.2.2.9 Timing Resistor (R7)

The switching frequency is programmed by the current through  $R_{RT}$  to GND. The  $R_{RT}$  value is calculated using Equation 34.

$$R_{RT} = \frac{(10)^4}{f_{SW}} - 2k\Omega = \frac{(10)^4}{300kHz} - 2 = 31.3k\Omega \approx 31.6k\Omega \quad (34)$$

### 7.2.2.10 UVLO Programming Resistors (R2, R6)

The UVLO hysteresis level is programmed by R2 using Equation 35.

$$R_{UVLO(hys)} = \frac{V_{UVLO(on)} - V_{UVLO(off)}}{I_{UVLO}} = \frac{9V - 8V}{5.0\mu A} = 200k\Omega \quad (35)$$

$$R_{UVLO(set)} > R_{UVLO(hys)} \left( \frac{V_{UVLO(max)}}{V_{UVLO\_ON(min)} - V_{UVLO(max)}} \right) = 200k\Omega \left( \frac{0.919V}{(9.0V - 0.919V)} \right) = 22.7k\Omega \approx 22.1k\Omega \quad (36)$$

### 7.2.2.11 Boot-Strap Capacitor (C7)

A bootstrap capacitor with a value between 0.1  $\mu F$  and 0.22  $\mu F$  must be placed between the BOOT pin and the SW pin. It must be 10 times higher than MOSFET gate capacitance. To ensure proper charging of the high-side FET gate, limit the ripple voltage on the boost capacitor to less than 250 mV.

$$C_{BOOST} = \frac{Q_{G1}}{V_{BOOT(ripple)}} = \frac{25nC}{250mV} = 100nF \quad (37)$$

### 7.2.2.12 VIN Bypass Capacitor (C18)

Place a capacitor with a value of 1.0  $\mu F$ . Select a capacitor with a value from 0.1  $\mu F$  to 1.0  $\mu F$ , X5R or better ceramic bypass capacitor for VIN as specified in [Recommended Operating Conditions](#). For this design a 1.0- $\mu F$ , 100-V, X7R capacitor has been selected.

### 7.2.2.13 VBP Bypass Capacitor (C19)

Select a capacitor with a value from 1.0  $\mu F$  to 10  $\mu F$ , X5R or better ceramic bypass capacitor for VBP as specified in [Recommended Operating Conditions](#). It must be at least 10 times higher than the bootstrap capacitance. For this design a 4.7- $\mu F$ , 16-V capacitor has been selected.

### 7.2.2.14 VDD Bypass Capacitor (C16)

Select a capacitor with a value between 0.1  $\mu F$  and 1  $\mu F$ , X5R or better ceramic bypass capacitor for VDD as specified in [Recommended Operating Conditions](#). For this design a 1- $\mu F$ , 16-V capacitor has been selected.

### 7.2.2.15 SS Timing Capacitor (C15)

The soft-start capacitor provides smooth ramp of the error amplifier reference voltage for controlled start-up. The soft-start capacitor is selected by using Equation 38.

$$C_{SS} = \frac{t_{SS}}{0.09} = \frac{4ms}{0.09} = 44nF \approx 47nF \quad (38)$$

### 7.2.2.16 ILIM Resistor (R9, C17)

The TPS40170 use the negative drop across the low-side FET at the end of the "OFF" time to measure the inductor current. Allowing for 30% over the minimum current limit for transient recovery and 20% rise in  $R_{DS(on)Q2}$  for self-heating of the MOSFET, the voltage drop across the low-side FET at current limit is given by Equation 39.

$$V_{OC} = \left( (1.3 \times I_{OCP(min)}) + \left( \frac{1}{2} \times I_{RIPPLE} \right) \right) \times 1.25 \times R_{DS(on)G2} = (1.3 \times 8 \text{ A} + \frac{1}{2} \times 1.86 \text{ A}) \times 1.25 \times 7.6 \text{ m}\Omega = 107.6 \text{ mV} \quad (39)$$

The internal current limit temperature coefficient helps compensate for the MOSFET  $R_{DS(on)}$  temperature coefficient, so the current limit programming resistor is selected by [Equation 40](#).

$$R_{ILIM} = \frac{V_{OC}}{I_{OCSET(min)}} = \frac{107.6 \text{ mV}}{9.0 \mu\text{A}} = 12.0 \text{ k}\Omega \approx 12.1 \text{ k}\Omega \quad (40)$$

A 1000 pF capacitor is placed in parallel to improve noise immunity of the current limit set-point.

#### 7.2.2.17 SCP Multiplier Selection (R5)

The TPS40170 controller uses a multiplier ( $A_{OC}$ ) to translate the low-side over-current protection into a high-side  $R_{DS(on)}$  pulse-by-pulse short-circuit protection. Ensure that [Equation 41](#) is true.

$$A_{OC} > \frac{I_{OCP(min)} + \left( \frac{1}{2} \times I_{RIPPLE} \right)}{I_{OCP(min)} + \left( \frac{1}{2} \times I_{RIPPLE} \right)} \times \frac{R_{DS(on)Q1}}{R_{DS(on)Q2}} = \frac{8 \text{ A} + \frac{1}{2} \times 1.86 \text{ A}}{8 \text{ A} + \frac{1}{2} \times 1.86 \text{ A}} \times \frac{11 \text{ m}\Omega}{7.6 \text{ m}\Omega} = 1.45 \quad (41)$$

$A_{OC} = 3$  is selected as the next greater  $A_{OC}$ . The value of R5 is set to 10 k $\Omega$ .

#### 7.2.2.18 Feedback Divider (R10, R11)

The TPS40170 controller uses a full operational amplifier with an internally fixed 0.6 V reference. The value of R11 is selected between 10 k $\Omega$  and 50 k $\Omega$  for a balance of feedback current and noise immunity. With the value of R11 set to 20 k $\Omega$ , the output voltage is programmed with a resistor divider given by [Equation 42](#).

$$R10 = \frac{V_{FB} \times R11}{(V_{OUT} - V_{FB})} = \frac{0.600 \text{ V} \times 20.0 \text{ k}\Omega}{(5.0 \text{ V} - 0.600 \text{ V})} = 2.73 \text{ k}\Omega \approx 2.74 \text{ k}\Omega \quad (42)$$

#### 7.2.2.19 Compensation: (R4, R13, C13, C14, C21)

Using the TPS40k Loop Stability Tool for a 60 kHz bandwidth and a 50° phase margin with an R11 value of 20.0 k $\Omega$ , the following values are obtained. The tool is available from the TI website, [SLUC263](#).

- C21 = C1 = 1500 pF
- C13 = C2 = 8200 pF
- C14 = C3 = 220 pF
- R13 = R2 = 511  $\Omega$
- R4 = R3 = 3.83 k $\Omega$

## 7.2.3 Application Curves

Figure 7-2 shows an input from 10 V to 60 V for an output of 5.0 V at 6 A, efficiency graph for this design. Figure 7-3 shows an input of 24 V for an output of 5.0 V at 6 A, loop response where  $V_{IN} = 24$  V and  $I_{OUT} = 6$  A, yielding 58-kHz bandwidth, 51° phase margin. Figure 7-4 shows the output ripple 20 mV/div, 2  $\mu$ s/div, 20-MHz bandwidth.

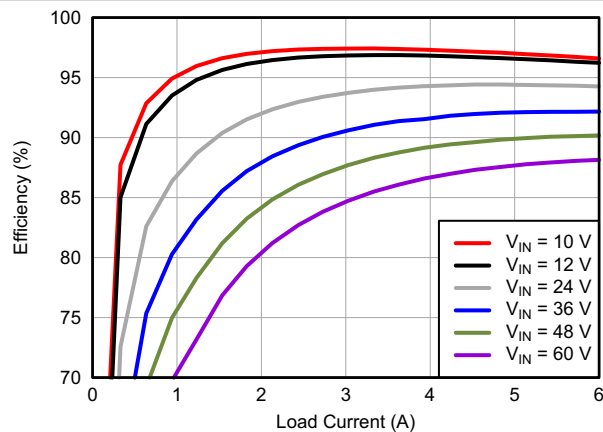


Figure 7-2. Efficiency vs. Load Current

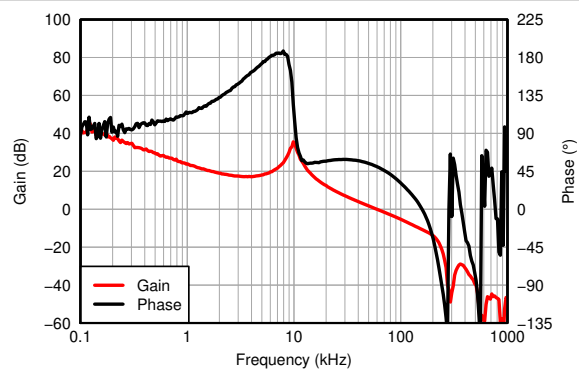


Figure 7-3. Loop Response

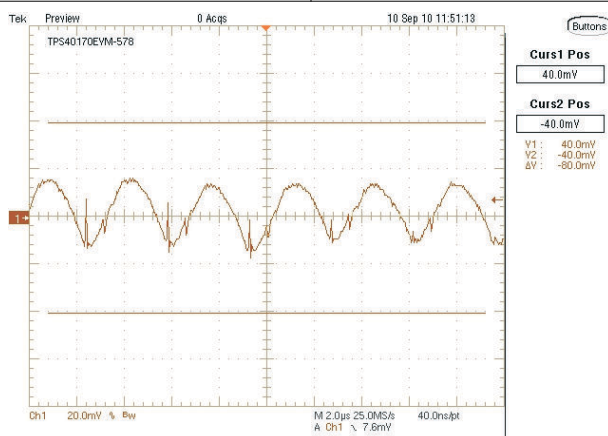


Figure 7-4. Output Ripple Waveform

## 7.3 Power Supply Recommendations

The TPS40170 is designed for operation from an input voltage supply range between 4.5 V and 60 V. Good regulation of this input supply is essential. If the input supply is more distant than a few inches from the TPS40170 and the buck power stage, the circuit can require additional bulk capacitance in addition to ceramic bypass capacitors. An electrolytic capacitor with a value of 120  $\mu$ F is a typical choice.

## 7.4 Layout

### 7.4.1 Layout Guidelines

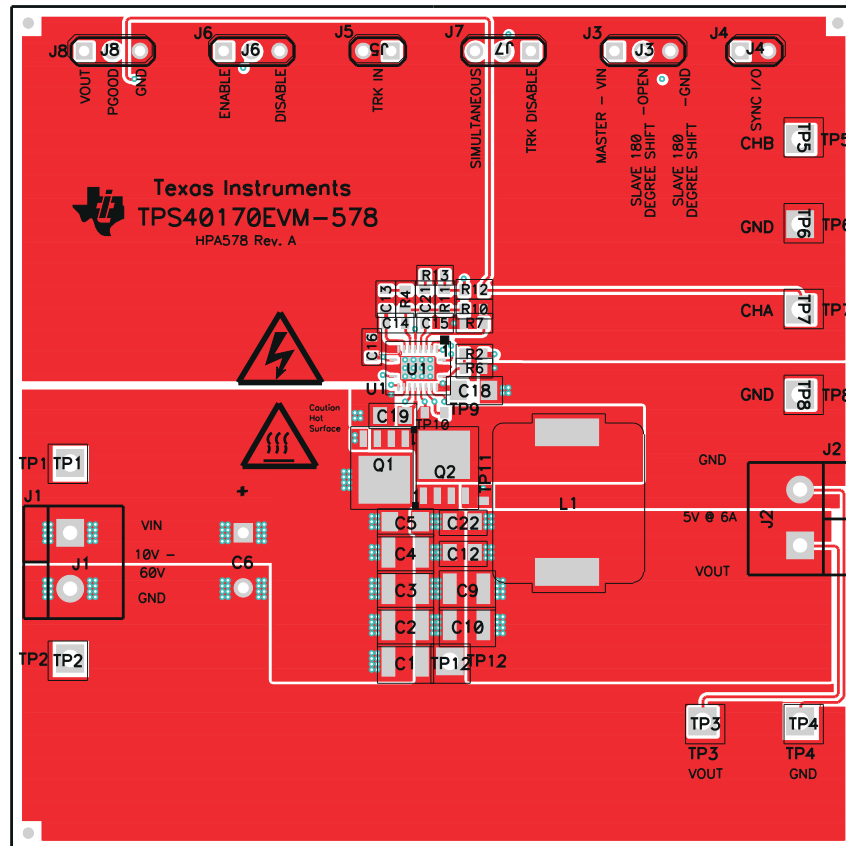
**Top Copper, Viewed From Top** illustrates an example layout. For the controller, it is important to carefully connect noise sensitive signals such as RT, SS, FB, and comp as close to the IC as possible and connect to AGND as shown. The PowerPad must be connected to any internal PCB ground planes using multiple vias directly under the IC. The AGND and PGND must be connected at a single point.

When using high-performance FETs such as NexFET™ from Texas Instruments, careful attention to the layout is required. Minimize the distance between positive node of the input ceramic capacitor and the drain pin of the control (high-side) FET. Minimize the distance between the negative node of the input ceramic capacitor and the source pin of the synchronization (low-side) FET. Because of the large gate drive, smaller gate charge, and

faster turn-on times of the high-performance FETs, it is recommended to use a minimum of 4, 10  $\mu$ F ceramic input capacitors such as TDK #C3216X5R1A106M. Ensure the layout allows a continuous flow of the power planes.

The layout of the HPA578 EVM is shown in [Top Copper, Viewed From Top](#) through [Internal Layer 2, Viewed from Top](#) for reference.

### 7.4.2 Layout Example



**Figure 7-5. Top Copper, Viewed From Top**

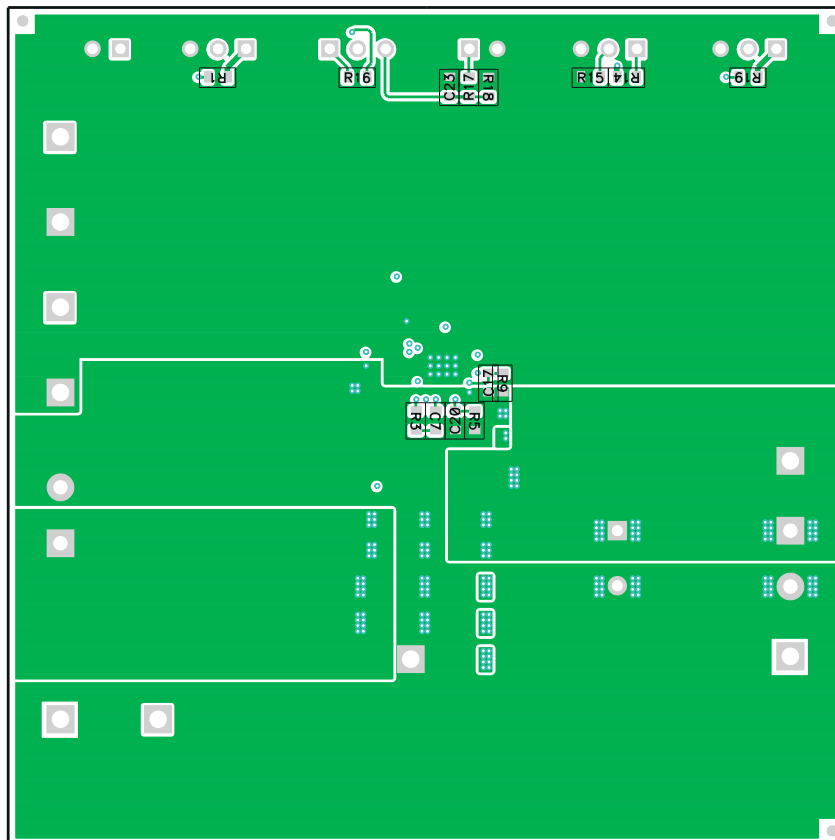
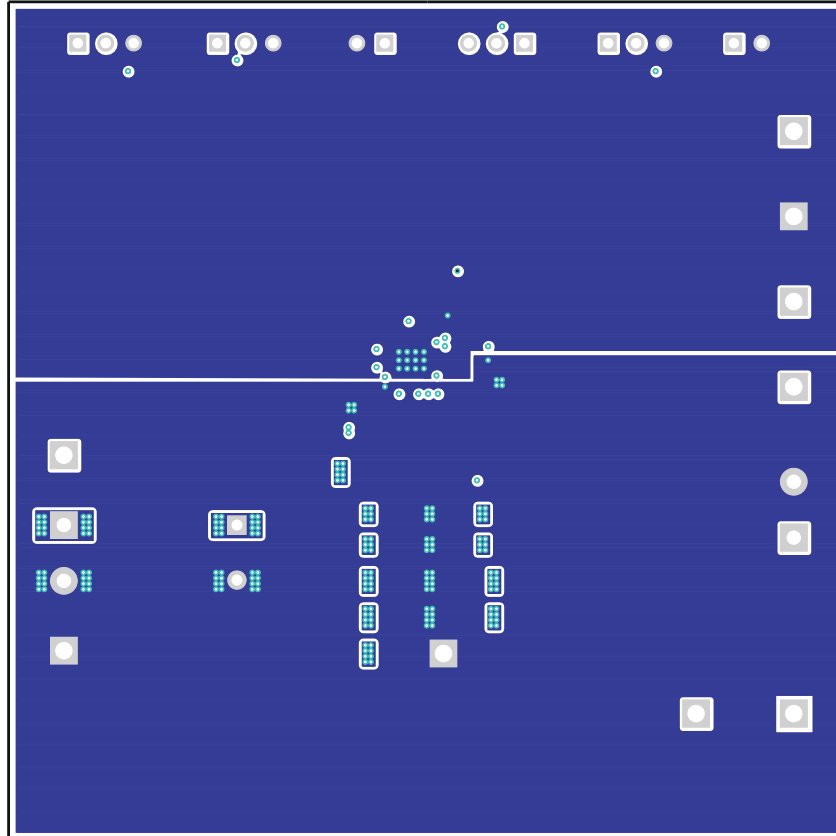


Figure 7-6. Bottom Copper, Viewed From Bottom



**Figure 7-7. Internal Layer 1, Viewed from Top**

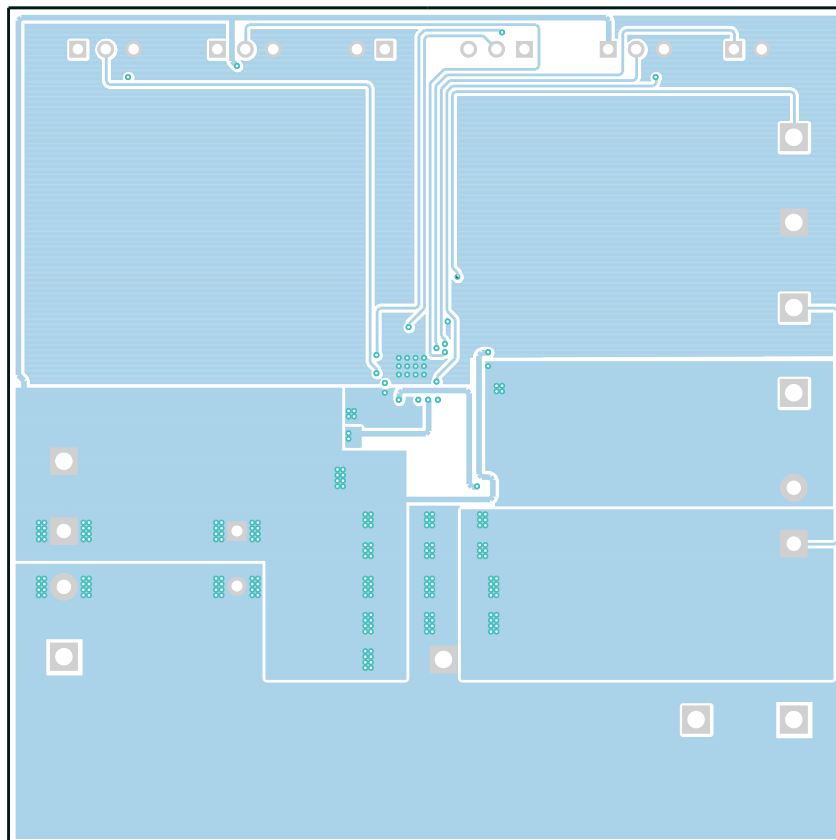


Figure 7-8. Internal Layer 2, Viewed from Top



## 8 Device and Documentation Support

### 8.1 Device Support

#### 8.1.1 Third-Party Products Disclaimer

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#### 8.1.2 Development Support

##### 8.1.2.1 Custom Design with **WEBENCH®** Tools

[Click here](#) to create a custom design using the WEBENCH Power Designer.

1. Start by entering your  $V_{IN}$ ,  $V_{OUT}$  and  $I_{OUT}$  requirements.
2. Optimize your design for key parameters like efficiency, footprint and cost using the optimizer dial and compare this design with other possible solutions from Texas Instruments.
3. WEBENCH Power Designer provides you with a customized schematic along with a list of materials with real time pricing and component availability.
4. In most cases, you will also be able to:
  - Run electrical simulations to see important waveforms and circuit performance,
  - Run thermal simulations to understand the thermal performance of your board,
  - Export your customized schematic and layout into popular CAD formats,
  - Print PDF reports for the design, and share your design with colleagues.

#### 8.1.3 Related Devices

The following device has characteristics similar to the TPS40170 and can be of interest.

| DEVICE                   | DESCRIPTION                            |
|--------------------------|--|
| <a href="#">TPS40057</a> | Wide Input Synchronous Buck Controller |

### 8.2 Documentation Support

#### 8.2.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, [Understanding output voltage limitations of DC/DC buck converters](#) analog design journal

### 8.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). Click on *Notifications* 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.

### 8.4 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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## 8.6 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.

## 8.7 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

## 9 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| <b>Changes from Revision B (December 2014) to Revision C (November 2023)</b>  | <b>Page</b>        |
|---|--------------------|
| • Added new, similar product introduction in the <i>Features</i> section.....   | <a href="#">1</a>  |
| • Updated the numbering format for tables, figures, and cross-references throughout the document.....   | <a href="#">1</a>  |
| • Changed all instances of legacy terminology to primary and secondary.....   | <a href="#">1</a>  |
| • Added new, similar product introduction in the <i>Description</i> section.....  | <a href="#">1</a>  |
| • Changed from BODY SIZE to PACKAGE SIZE and added a table note to the <i>Package Information</i> table.....  | <a href="#">1</a>  |
| <hr/>   |                    |
| <b>Changes from Revision A (November 2013) to Revision B (December 2014)</b>  | <b>Page</b>        |
| • Added Handling Ratings table, Feature Description section, Device Functional Modes, Application and Implementation section, Power Supply Recommendations section, Layout section, Device and Documentation Support section, and Mechanical, Packaging, and Orderable Information section..... | <a href="#">3</a>  |
| <hr/>   |                    |
| <b>Changes from Revision * (March 2011) to Revision A (November 2013)</b>   | <b>Page</b>        |
| • Deleted Ordering Information table. Replaced with Package Option Addenda inserted after the last page of this data sheet. ....  | <a href="#">3</a>  |
| • Added clarity to .....  | <a href="#">16</a> |
| • Added significant clarity to and corrected typographic errors in DESIGN EXAMPLE .....   | <a href="#">32</a> |

## 10 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

| Orderable part number        | Status<br>(1) | Material type<br>(2) | Package   Pins  | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------|---------------|----------------------|-----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">TPS40170RGYR</a> | Active        | Production           | VQFN (RGY)   20 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| TPS40170RGYR.A               | Active        | Production           | VQFN (RGY)   20 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| TPS40170RGYR.B               | Active        | Production           | VQFN (RGY)   20 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| <a href="#">TPS40170RGYT</a> | Active        | Production           | VQFN (RGY)   20 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| TPS40170RGYT.A               | Active        | Production           | VQFN (RGY)   20 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| TPS40170RGYT.B               | Active        | Production           | VQFN (RGY)   20 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| TPS40170RGYTG4.A             | Active        | Production           | VQFN (RGY)   20 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |
| TPS40170RGYTG4.B             | Active        | Production           | VQFN (RGY)   20 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | 40170               |

(1) **Status:** For more details on status, see our [product life cycle](#).

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

(4) **Lead finish/Ball material:** Parts 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.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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**OTHER QUALIFIED VERSIONS OF TPS40170 :**

- Automotive : [TPS40170-Q1](#)
- Enhanced Product : [TPS40170-EP](#)

**NOTE:** Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects
- Enhanced Product - Supports Defense, Aerospace and Medical Applications

## TAPE AND REEL INFORMATION



\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS40170RGYR | VQFN         | RGY             | 20   | 3000 | 330.0              | 12.4               | 3.8     | 4.8     | 1.6     | 8.0     | 12.0   | Q1            |
| TPS40170RGYT | VQFN         | RGY             | 20   | 250  | 180.0              | 12.4               | 3.8     | 4.8     | 1.6     | 8.0     | 12.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device       | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS40170RGYR | VQFN         | RGY             | 20   | 3000 | 356.0       | 356.0      | 35.0        |
| TPS40170RGYT | VQFN         | RGY             | 20   | 250  | 210.0       | 185.0      | 35.0        |

## GENERIC PACKAGE VIEW

**RGY 20**

**VQFN - 1 mm max height**

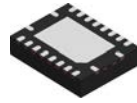
3.5 x 4.5, 0.5 mm pitch

PLASTIC QUAD FGLATPACK - NO LEAD

This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



4225264/A



4225320/A 09/2019

#### 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.

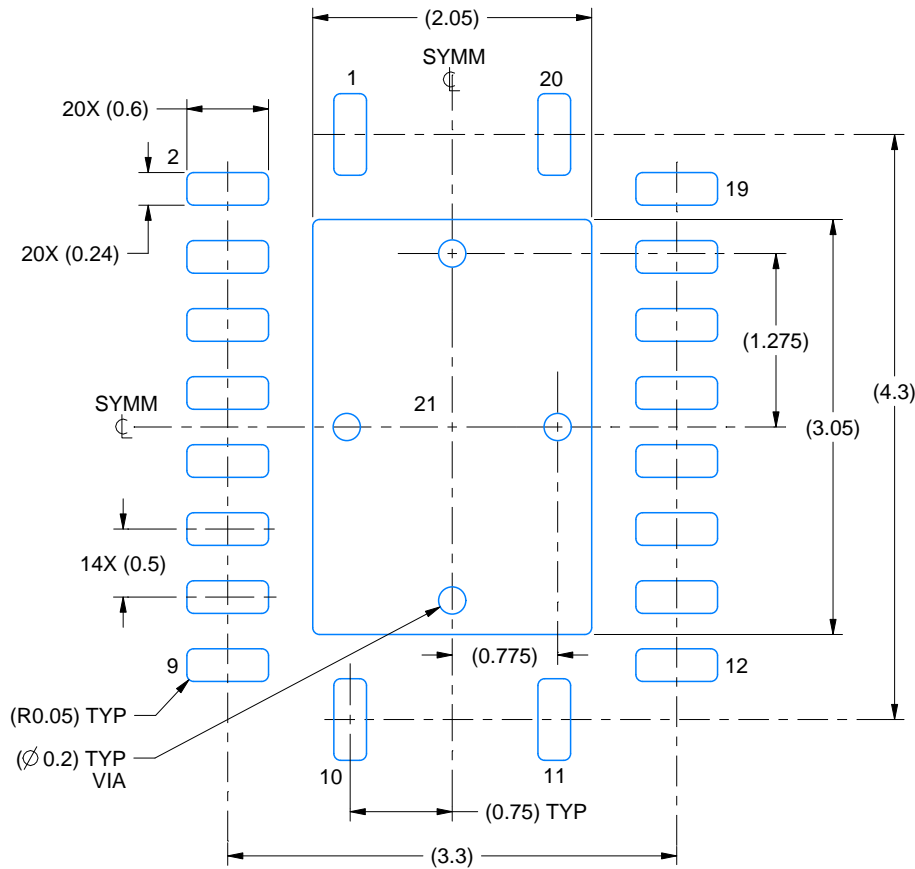


# EXAMPLE BOARD LAYOUT

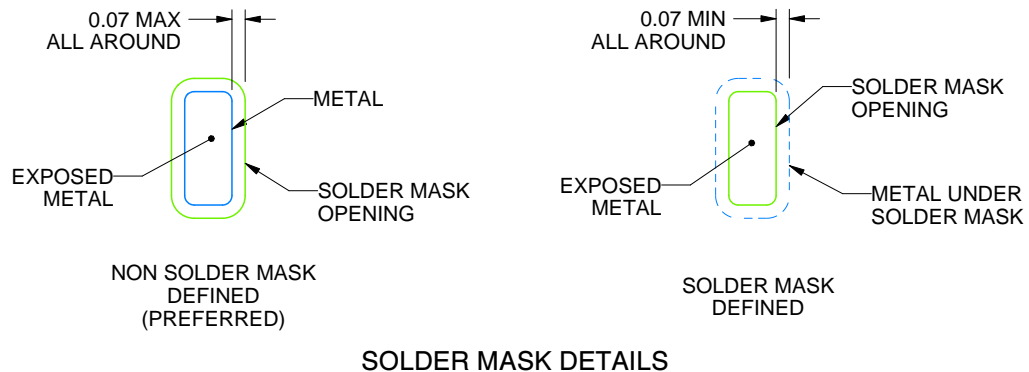
RGY0020A

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:18X



SOLDER MASK DETAILS

4225320/A 09/2019

NOTES: (continued)

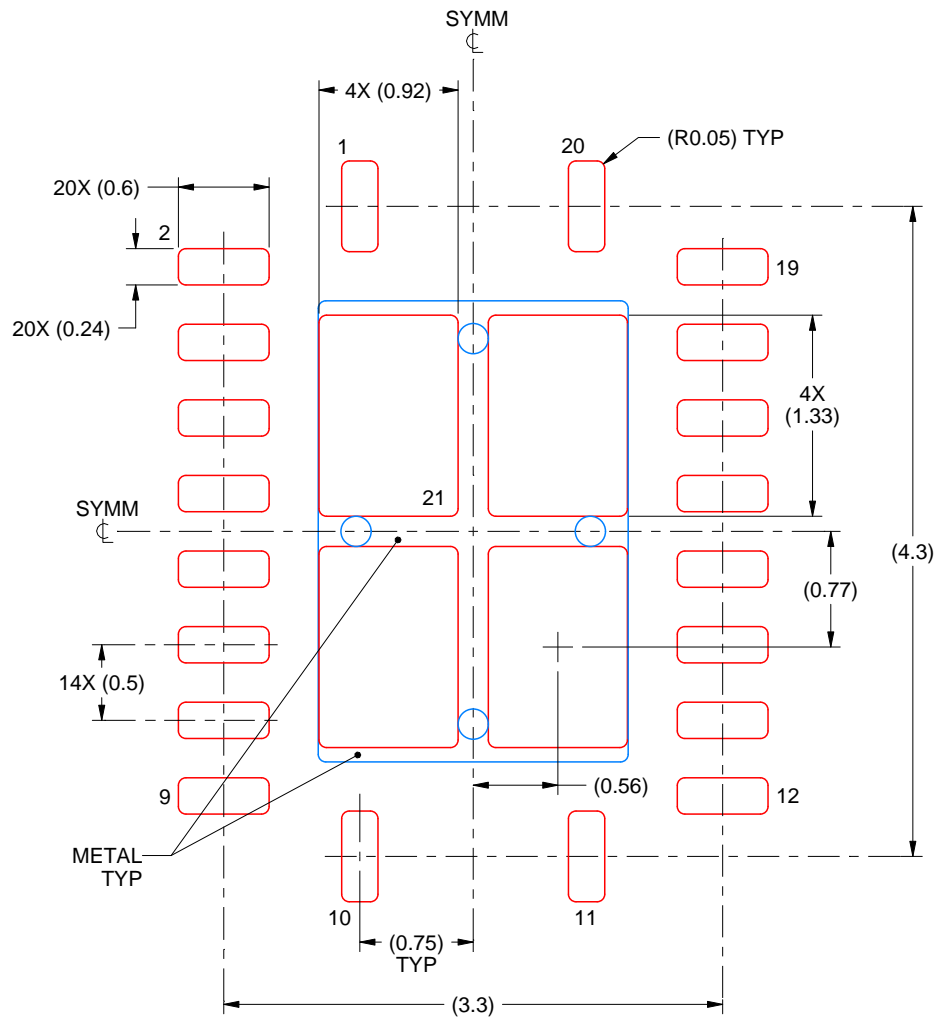
- This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).
- Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

# EXAMPLE STENCIL DESIGN

RGY0020A

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



**SOLDER PASTE EXAMPLE**  
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 21  
78% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE  
SCALE:20X

4225320/A 09/2019

NOTES: (continued)

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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