# 4.5-V TO 60-V WIDE-INPUT SYNCHRONOUS PWM BUCK CONTROLLER

**Check for Samples: TPS40170-EP**

## FEATURES

- **Wide-Input Voltage Range from 4.5 V to 60 V**
- **600-mV Reference Voltage With 1% Accuracy**
- **Programmable UVLO and Hysteresis**
- **Voltage-Mode Control With Voltage Feed-Forward**
- **Programmable Frequency Between 100 kHz and 600 kHz**
- **Bidirectional Frequency Synchronization With Master/Slave 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**
- **8-V and 3.3-V LDO Output**
- **Integrated Bootstrap Diode**
- **20-Pin 3.5-mm × 4.5-mm QFN (RGY) Package**

## APPLICATIONS

- **POL Modules**
- **Wide Input Voltage, High-Power-Density DC/DC Converter**

## SUPPORTS DEFENSE, AEROSPACE, AND MEDICAL APPLICATIONS

- **Controlled Baseline**
- **One Assembly and Test Site**
- **One Fabrication Site**
- **Available in Military (–55°C to 125°C) Temperature Range**
- **Extended Product Life Cycle**
- **Extended Product-Change Notification**
- **Product Traceability**

## 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 an 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 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 within 1% accuracy. Additionally, the controller implements a novel scheme of bidirectional synchronization with one controller acting as the master and other downstream controllers acting as slaves, synchronized to the master in-phase or 180° out-of-phase. Slave controllers can be synchronized to an external clock within ±30% of the free-running switching frequency.

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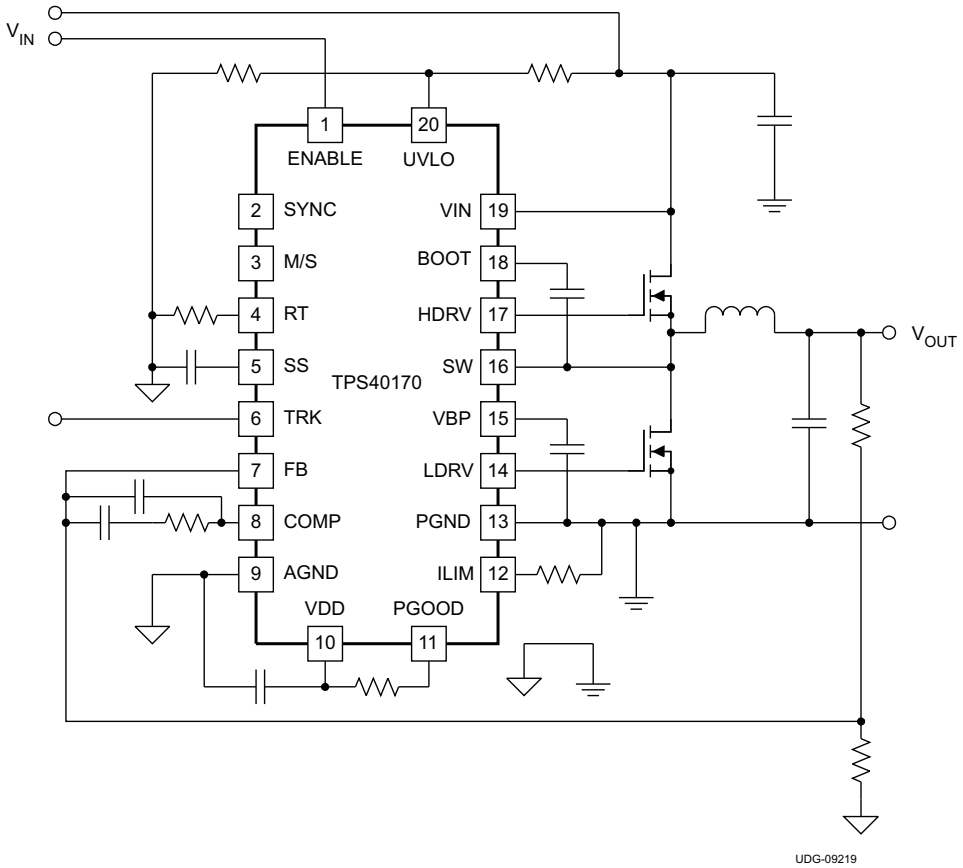
## SIMPLIFIED APPLICATION




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.

### ORDERING INFORMATION(1)

| $T_J$ | PACKAGE | PINS | TRANSPORT MEDIA | QUANTITY | DEVICE NUMBER | TOP-SIDE MARKING | VID NUMBER |
|---|---|---|---|---|---|---|---|
| –55°C to 125°C | QFN | 20 | Tape and reel | 250 | TPS40170MRGYTEP | PZYM | V62/13607-01XE |

(1) For the most current package and ordering information see the *Package Option Addendum* at the end of this document, or see the TI web site at www.ti.com.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## ABSOLUTE MAXIMUM RATINGS(1)

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

| | | VALUE | | |
|---|---|---|---|---|
| | | MIN | MAX | UNIT |
| Input voltage | VIN | –0.3 | 62 | V |
| | M/S | –0.3 | VIN | |
| | UVLO | –0.3 | 16 | |
| | SW | –5 | VIN | |
| | BOOT | | $V_{SW}$ + 8.8 | |
| Output voltage | HDRV | $V_{SW}$ | 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 | |
| Grounding | AGND-PGND, PGND-AGND | -200 | 200 | mV |
| | PowerPAD to AGND (must be electrically connected external to device) | | 0 | |
| Electrostatic discharge (ESD) | Human-body model (HBM) | | 1 | kV |
| | Charged-device model (CDM) | | 1 | kV |
| Absolute maximum junction temperature | $T_J$ | -55 | 125 | °C |
| Storage temperature | $T_{stg}$ | –55 | 150 | °C |

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

## THERMAL INFORMATION

| THERMAL METRIC(1) | | TPS40170-EP RGY 20 PINS | UNITS |
|---|---|---|---|
| $\theta_{JA}$ | Junction-to-ambient thermal resistance(2) | 35.4 | °C/W |
| $\theta_{JCtop}$ | Junction-to-case (top) thermal resistance(3) | 38.1 | |
| $\theta_{JB}$ | Junction-to-board thermal resistance(4) | 10.8 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter(5) | 0.5 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter(6) | 10.9 | |
| $\theta_{JCbot}$ | Junction-to-case (bottom) thermal resistance(7) | 4.3 | |

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.
(2) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
(3) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
(4) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
(5) The junction-to-top characterization parameter, $\psi_{JT}$, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining $\theta_{JA}$, using a procedure described in JESD51-2a (sections 6 and 7).
(6) The junction-to-board characterization parameter, $\psi_{JB}$, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining $\theta_{JA}$ , using a procedure described in JESD51-2a (sections 6 and 7).
(7) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

## RECOMMENDED OPERATING CONDITIONS

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

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{IN}$ | Input voltage | 4.5 | | 60 | V |

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## ELECTRICAL CHARACTERISTICS

These specifications apply for –55ºC ≤ $T_J$ ≤ +125ºC, $V_{VIN}$ = 12 V, unless otherwise noted.

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **INPUT SUPPLY** | | | | | | |
| $V_{VIN}$ | Input voltage range | | 4.5 | | 60 | V |
| $I_{SD}$ | Shutdown current | $V_{ENABLE}$ < 100 mV | | 1 | 2.5 | µA |
| $I_{QQ}$ | Operating current, drivers not switching | $V_{ENABLE}$ ≥ 2 V, $f_{SW}$ = 300 kHz | | | 4.5 | mA |
| **ENABLE** | | | | | | |
| $V_{DIS}$ | ENABLE pin voltage to disable the device | | | | 100 | mV |
| $V_{EN}$ | ENABLE pin voltage to enable the device | | 600 | | | mV |
| $I_{ENABLE}$ | ENABLE pin source current | | | | 410 | nA |
| **8-V AND 3.3-V REGULATORS** | | | | | | |
| $V_{VBP}$ | 8-V regulator output voltage | $V_{ENABLE}$ ≥ 2 V, 8.2 V < $V_{VIN}$ ≤ 60 V, 0 mA < $I_{IN}$ < 20 mA | 7.8 | 8.0 | 8.35 | V |
| $V_{DO}$ | 8-V regulator dropout voltage, $V_{VIN-VVBP}$ | 4.5 < $V_{VIN}$ ≤ 8.2 V, $V_{EN}$ ≥ 2 V, $I_{IN}$ = 10 mA | | 110 | 210 | mV |
| $V_{VDD}$ | 3.3-V regulator output voltage | $V_{ENABLE}$ ≥ 2 V, 4.5 V < $V_{VIN}$ ≤ 60 V, 0 mA < $I_{IN}$ < 5 mA | 3.2 | 3.3 | 3.42 | V |
| **FIXED AND PROGRAMMABLE UVLO** | | | | | | |
| $V_{UVLO}$ | Programmable UVLO ON voltage (at UVLO pin) | $V_{ENABLE}$ ≥ 2 V | 878 | 900 | 920 | mV |
| $I_{UVLO}$ | Hysteresis current out of UVLO pin | $V_{ENABLE}$ ≥ 2 V , UVLO pin > $V_{UVLO}$ | 4 | 5 | 6.2 | µA |
| $VBP_{ON}$ | VBP turnon voltage | $V_{ENABLE}$ ≥ 2 V, UVLO pin > $V_{UVLO}$ | 3.8 | | 4.4 | V |
| $VBP_{OFF}$ | VBP turnoff voltage | | 3.55 | | 4.1 | |
| $VBP_{HYS}$ | VBP UVLO Hysteresis voltage | | 175 | | 400 | mV |
| **REFERENCE** | | | | | | |
| $V_{REF}$ | Reference voltage (+ input of the error amplifier) | $T_J$ = 25°C, 4.5 V < $V_{VIN}$ ≤ 60 V | 594 | 600 | 606 | mV |
| | | –55°C ≤ $T_J$ ≤ 125ºC, 4.5 V < $V_{VIN}$ ≤ 60 V | 585 | 600 | 610 | |
| **OSCILLATOR** | | | | | | |
| $f_{SW}$ | Switching frequency | Range (typical) | 100 | | 600 | kHz |
| | | $R_{RT}$ = 100 kΩ, 4.5 V <$V_{VIN}$ ≤ 60 V | 85 | 100 | 115 | |
| | | $R_{RT}$ = 31.6 kΩ, 4.5 V <$V_{VIN}$ ≤ 60 V | 270 | 300 | 335 | |
| | | $R_{RT}$ = 14.3 kΩ, 4.5 V <$V_{VIN}$ ≤ 60 V | 540 | 600 | 670 | |
| $V_{VALLEY}$ | Valley voltage | | 0.7 | 1 | 1.25 | V |
| $K_{PWM}$ | PWM gain ($V_{VIN}$ / $V_{RAMP}$) | 4.5 V < $V_{VIN}$ ≤ 60 V | 14 | 15 | 16 | V/V |
| **PWM AND DUTY CYCLE** | | | | | | |
| $t_{ON(min)}$ | Minimum controlled pulse | $V_{VIN}$ = 4.5 V, $f_{SW}$ = 300 kHz | | 100 | 160 | ns |
| | | $V_{VIN}$ = 12 V, $f_{SW}$ = 300 kHz | | 75 | 130 | |
| | | $V_{VIN}$ = 60 V, $f_{SW}$ = 300 kHz | | 50 | 80 | |
| $t_{OFF(max)}$ | Minimum OFF time | $V_{VIN}$ = 12V, $f_{SW}$ = 300 kHz | | 170 | 250 | ns |
| $D_{MAX}$ | Maximum duty cycle | $f_{SW}$ = 100 kHz, 4.5 V < $V_{VIN}$ ≤ 60 V | 95% | | | |
| | | $F_{SW}$ = 300 kHz, 4.5 V < $V_{VIN}$ ≤ 60 V | 90% | | | |
| | | $f_{SW}$ = 600 kHz, 4.5 V < $V_{VIN}$ ≤ 60 V | 82% | | | |


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## ELECTRICAL CHARACTERISTICS (continued)

These specifications apply for –55ºC ≤ $T_J$ ≤ +125ºC, $V_{VIN}$ = 12 V, unless otherwise noted.

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **ERROR AMPLIFIER** | | | | | | |
| GBWP (1) | Gain bandwidth product | | 7 | 10 | 13 | MHz |
| $A_{OL}$ (1) | Open-loop gain | | 80 | 90 | 95 | dB |
| $I_{IB}$ | Input bias current | | | | 135 | nA |
| $I_{EAOP}$ | Output source current | $V_{VFB}$ = 0 V | 1.8 | | | mA |
| $I_{EAOM}$ | Output sink current | $V_{VFB}$ = 1 V | 1.9 | | | mA |
| **PROGRAMMABLE SOFT START** | | | | | | |
| $I_{SS(source,start)}$ | Soft-start source current at $V_{SS}$ < 0.5 V | $V_{SS}$ = 0.25 V | 42 | 52 | 62 | µA |
| $I_{SS(source,normal)}$ | Soft-start source current at $V_{SS}$ > 0.5 V | $V_{SS}$ = 1.5 V | 9.2 | 11.6 | 13.9 | µA |
| $I_{SS(sink)}$ | Soft-start sink current | $V_{SS}$ = 1.5 V | 0.7 | 1.05 | 1.36 | µA |
| $V_{SS(fltH)}$ | SS pin HIGH voltage during fault (OC or thermal) reset timing | | 2.38 | 2.5 | 2.65 | V |
| $V_{SS(fltL)}$ | SS pin LOW voltage during fault (OC or thermal) reset timing | | 235 | 300 | 375 | mV |
| $V_{SS(steady\_state)}$ | SS pin voltage during steady-state | | 3.2 | 3.3 | 3.55 | V |
| $V_{SS(offst)}$ | Initial offset voltage from SS pin to error amplifier input | | 525 | 650 | 790 | mV |
| **TRACKING** | | | | | | |
| $V_{TRK(ctrl)}$ | Range of TRK which overrides $V_{REF}$ | 4.5 V < $V_{IN}$ ≤ 60 V | 0 | | 600 | mV |
| **SYNCHRONIZATION (MASTER/SLAVE)** | | | | | | |
| $V_{MSTR}$ | M/S pin voltage in master mode | | 3.9 | | VIN | V |
| $V_{SLV(0)}$ | M/S pin voltage in slave 0º mode | | 1.26 | | 1.74 | V |
| $V_{SLV(180)}$ | M/S pin voltage in slave 180º mode | | 0 | | 0.74 | V |
| $I_{SYNC(in)}$ | SYNC pin pulldown current | M/S configured as slave- 0º or slave-180º | 8 | 11 | 14.5 | µA |
| $V_{SYNC(in\_high)}$ | SYNC pin input high-voltage level | | 2 | | | V |
| $V_{SYNC(in\_low)}$ | SYNC pin input low-voltage level | | | | 0.8 | V |
| $t_{SYNC(high\_min)}$ | Minimum SYNC high pulse duration | | 40 | | | ns |
| $t_{SYNC(low\_min)}$ | Minimum SYNC low pulse duration | | 40 | | | ns |
| **GATE DRIVERS** | | | | | | |
| $R_{HDHI}$ | High-side driver pullup resistance | $C_{LOAD}$ = 2.2 nF, $I_{DRV}$ = 300 mA, $T_J$ = –55°C to 125°C | 1.37 | 2.64 | 4 | Ω |
| $R_{HDLO}$ | High-side driver pulldown resistance | | 1 | 2.4 | 4 | Ω |
| $R_{LDHI}$ | Low-side driver pullup resistance | | 1.25 | 2.4 | 4 | Ω |
| $R_{LDLO}$ | Low-side driver pulldown resistance | | 0.44 | 1.1 | 1.7 | Ω |
| $t_{NON-OVERLAP1}$ | Time delay between HDRV fall and LDRV rise | $C_{LOAD}$ = 2.2 nF, $V_{HDRV}$ = 2 V, $V_{LDRV}$ = 2 V | | 50 | | ns |
| $t_{NON-OVERLAP2}$ | Time delay between HDRV rise and LDRV fall | | | 60 | | ns |
| **OVERCURRENT PROTECTION (LOW-SIDE MOSFET SENSING)** | | | | | | |
| $I_{ILIM}$ | ILIM pin source current | 4.5 V < $V_{IN}$ < 60 V, $T_J$ = 25°C | 9 | 9.75 | 11 | µA |
| | | 4.5 V < $V_{IN}$ < 60 V, $T_J$ = –55°C to 125°C | 6.9 | | 12 | µA |
| $I_{ILIM,(ss)}$ | ILIM pin source current during soft-start | 4.5 V < $V_{IN}$ < 60 V, $T_J$ = 25°C | | 15 | | µA |
| $I_{ILIM,\ Tc}$ | Temperature coefficient of ILIM current | 4.5 V < $V_{IN}$ < 60 V | | 1400 | | ppm |
| $V_{ILIM}$ | ILIM pin voltage operating range | 4.5 V < $V_{IN}$ < 60 V | 50 | | 300 | mV |
| $OCP_{TH}$ | Overcurrent protection threshold (voltage across low-side FET for detecting overcurrent) | $R_{ILIM}$ = 10 kΩ, $I_{ILIM}$ = 10 µA ($V_{ILIM}$ = 100 mV) | –110 | –100 | –84 | mV |
| **SHORT CIRCUIT PROTECTION HIGH-SIDE MOSFET SENSING)** | | | | | | |
| $V_{LDRV(max)}$ | LDRV pin maximum voltage during calibration | $R_{LDRV}$ = open | | 300 | 360 | mV |
| $A_{OC3}$ | Multiplier factor to set the SCP based on OCP level setting at the ILIM pin | $R_{LDRV}$ = 10 kΩ | 2.75 | 3.2 | 3.6 | V/V |
| $A_{OC7}$ | | $R_{LDRV}$ = open | 6.3 | 7.25 | 7.91 | V/V |
| $A_{OC15}$ | | $R_{LDRV}$ = 20 kΩ | 13.5 | 16.4 | 18 | V/V |

(1) Ensured by design at -40°C < $T_J$ < 125°C, not production tested.

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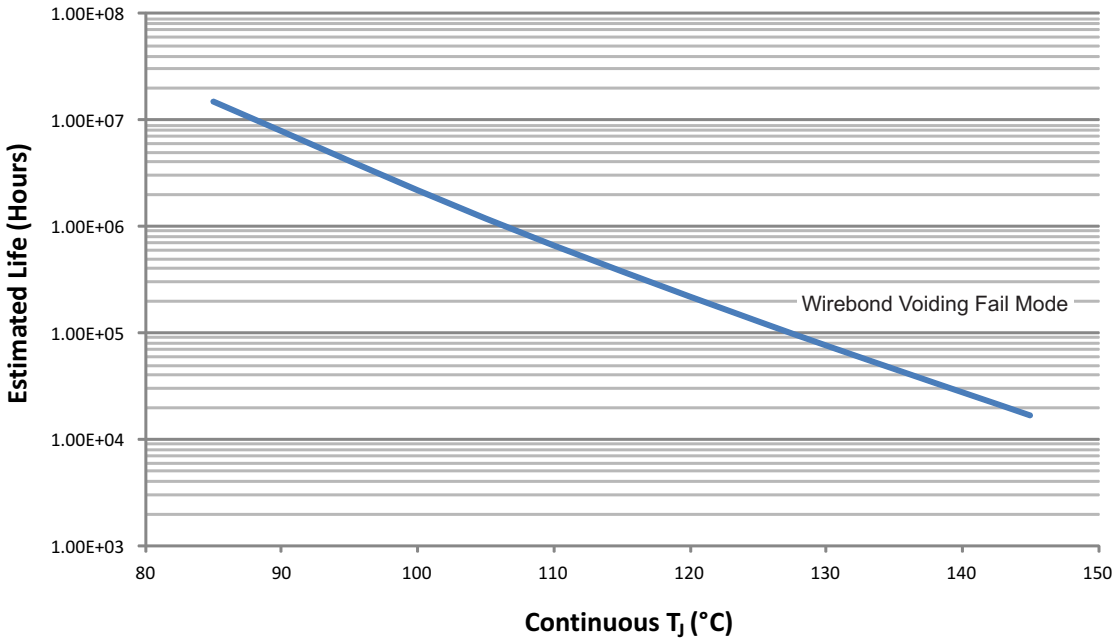
## ELECTRICAL CHARACTERISTICS (continued)

These specifications apply for –55ºC ≤ $T_J$ ≤ +125ºC, $V_{VIN}$ = 12 V, unless otherwise noted.

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **THERMAL SHUTDOWN** | | | | | | |
| $T_{SD,set}$ (2) | Thermal shutdown set threshold | 4.5 V < $V_{VIN}$ < 60 V | 155 | 165 | 175 | °C |
| $T_{SD,reset}$ (2) | Thermal shutdown reset threshold | | 125 | 135 | 145 | °C |
| $T_{hyst}$ | Thermal shutdown hysteresis | | | 30 | | °C |
| **POWER GOOD** | | | | | | |
| $V_{OV}$ | FB pin voltage upper limit for power good | 4.5 V < $V_{VIN}$ < 60 V | 620 | 647 | 675 | mV |
| $V_{UV}$ | FB pin voltage lower limit for power good | | 520 | 552 | 575 | |
| $V_{PG,HYST}$ | Power good hysteresis voltage at FB pin | | 8.4 | 20 | 33 | |
| $V_{PG(out)}$ | PGOOD pin voltage when FB pin voltage > $V_{OV}$ or < $V_{UV}$, $I_{PGD}$ = 2 mA | | | | 100 | mV |
| $V_{PG(np)}$ | PGOOD pin voltage when device power is removed | $V_{VIN}$ is open, 10-kΩ to $V_{EXT}$ = 5 V | | 1 | 1.5 | V |
| **BOOT DIODE** | | | | | | |
| $V_{DFWD}$ | Bootstrap diode forward voltage | I = 20 mA | 0.5 | 0.7 | 1 | V |
| $R_{BOOT-SW}$ | Discharge resistor from BOOT to SW | | | 1 | | MΩ |

(2) Ensured by design, not production tested.




(1) See datasheet for absolute maximum and minimum recommended operating conditions.

(2) Enhanced plastic product disclaimer applies.

**Figure 1. TPS40170-EP Derating Chart**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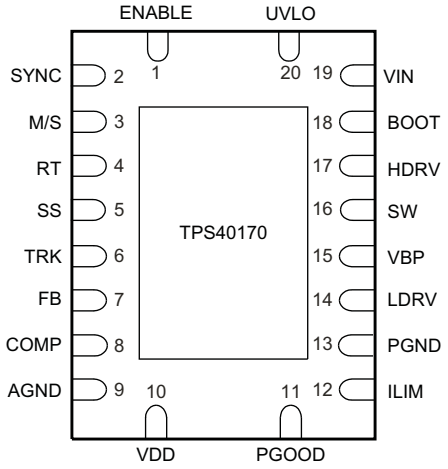
## DEVICE INFORMATION

**RGY PACKAGE**
**QFN-20**
**(Top View)**




## PIN FUNCTIONS

| PIN | | I/O | 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 the 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 the short-circuit current limit. If no resistor is present, the multiplier defaults to 7 times the ILIM pin voltage. |
| M/S | 3 | I | Master- or slave-mode selector pin for frequency synchronization. This pin must be tied to VIN for master mode. In the slave 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 pullup 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 slave 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 from 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 bidirectional pin used for frequency synchronization. In the master mode, it is the SYNC output pin. In the slave 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 should be pulled up to VDD. |

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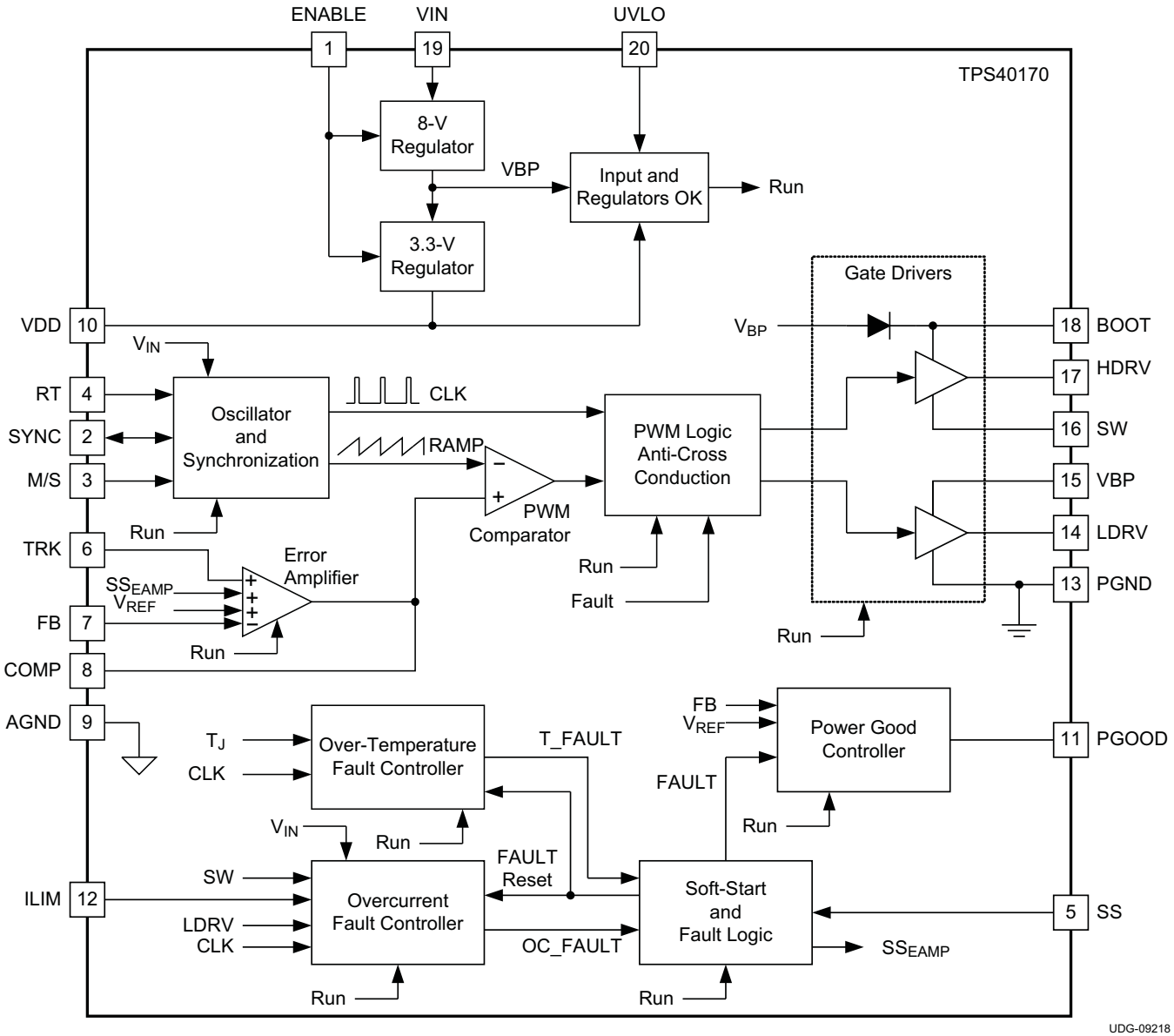
**PIN FUNCTIONS (continued)**

| PIN | | I/O | DESCRIPTION |
|---|---|---|---|
| NAME | NO. | | |
| UVLO | 20 | I | Undervoltage lockout. A resistor divider on this pin from VIN to AGND can be used to set the UVLO threshold. |
| VBP | 15 | O | 8-V regulated output for gate driver. A ceramic capacitor with a value between 1 µF and 10 µF must be connected from this pin to PGND |
| VDD | 10 | O | 3.3-V regulated output. A ceramic bypass capacitor with a value between 0.1 µF and 1 µF must be connected between this pin and the AGND pin and placed closely to this pin. |
| VIN | 19 | I | Input voltage for the controller, which is also the input voltage for the dc-dc converter. A 1-µF bypass capacitor from this pin to AGND must be added and placed closed to VIN. |

## DEVICE BLOCK DIAGRAM





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## TYPICAL CHARACTERISTICS

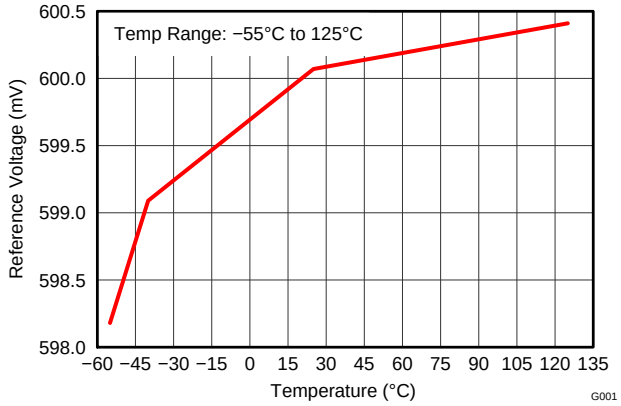


**Figure 2. Reference Voltage vs Junction Temperature**

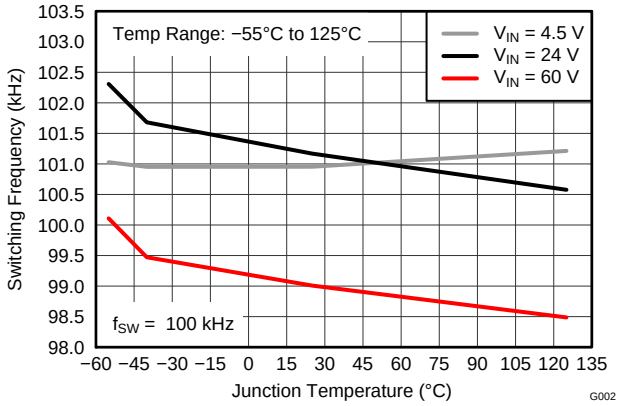


**Figure 3. Switching Frequency vs Junction Temperature ($f_{SW}$ = 100 kHz)**

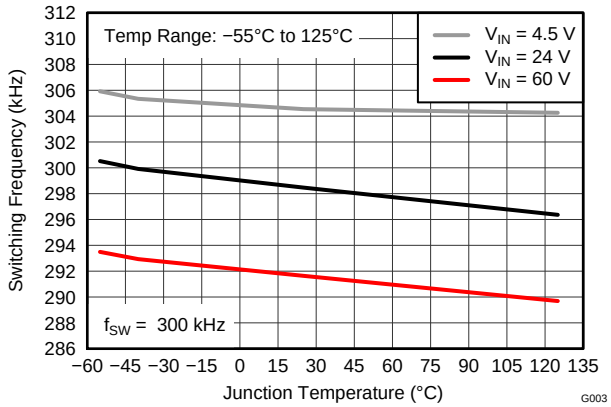


**Figure 4. Switching Frequency vs Junction Temperature ($f_{SW}$ = 300 kHz)**

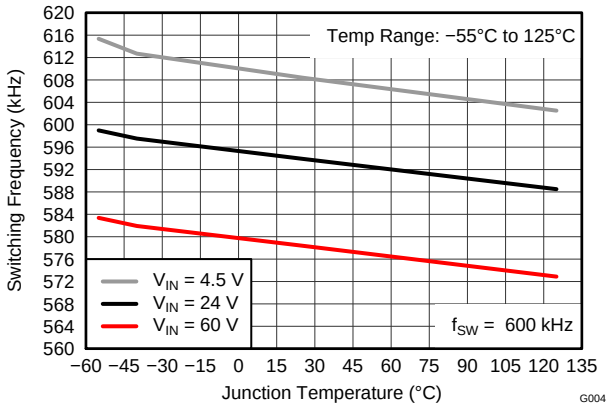


**Figure 5. Switching Frequency vs Junction Temperature ($f_{SW}$ = 600 kHz)**

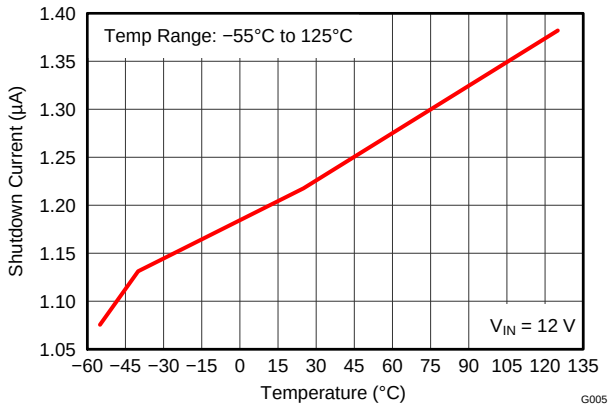


**Figure 6. Shutdown Current vs Junction Temperature**

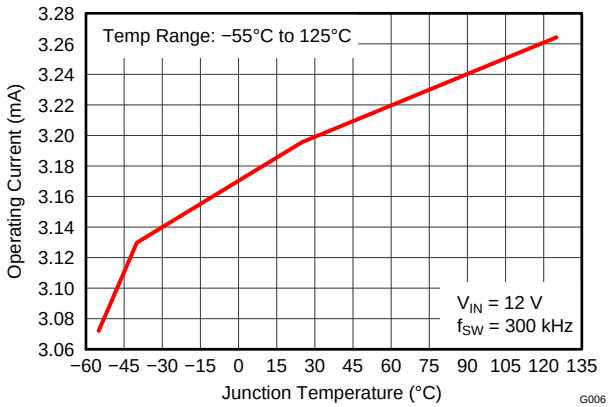


**Figure 7. Operating Current vs Junction Temperature**

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## TYPICAL CHARACTERISTICS (continued)

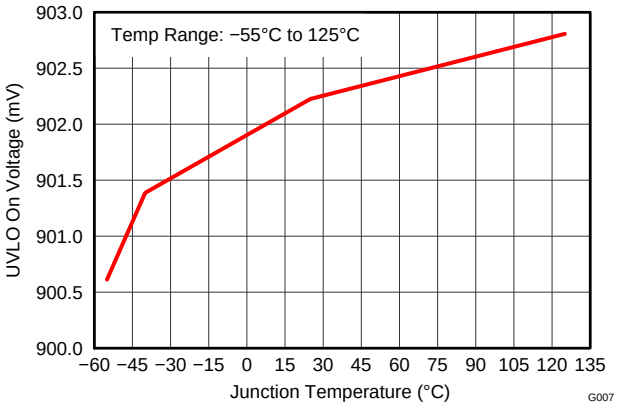


**Figure 8. UVLO On Voltage vs Junction Temperature**

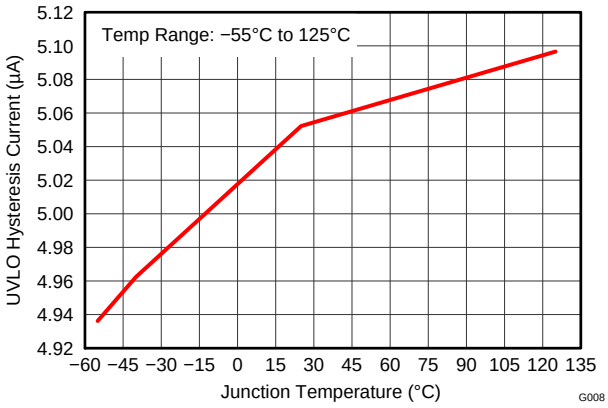


**Figure 9. UVLO Hysteresis Current vs Junction Temperature**

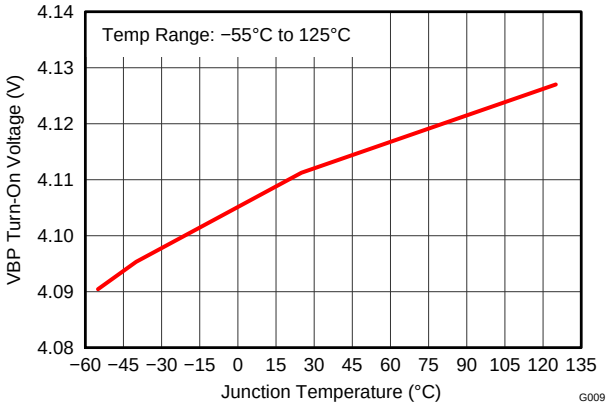


**Figure 10. VBP Turnon Voltage vs Junction Temperature**

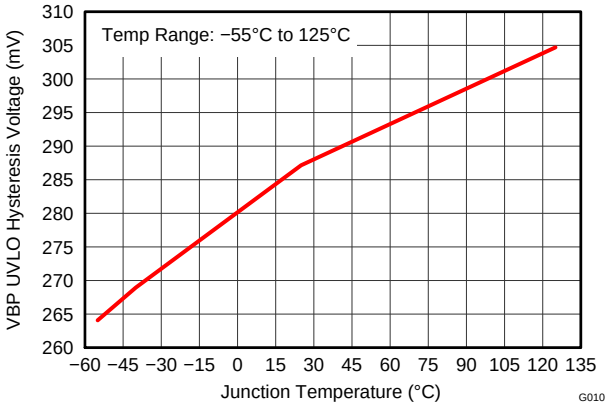


**Figure 11. VBP UVLO Hysteresis Voltage**

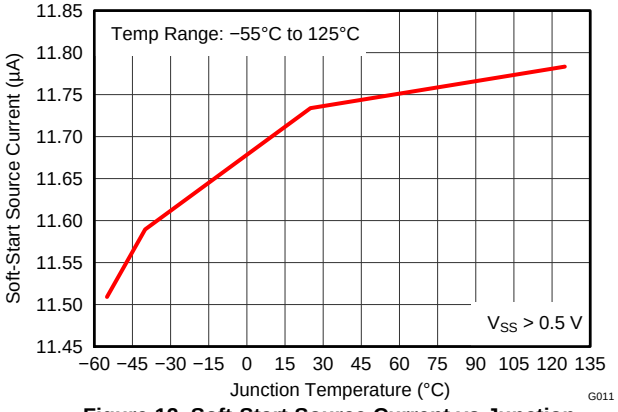


**Figure 12. Soft-Start Source Current vs Junction Temperature ($V_{SS}$ > 0.5 V)**

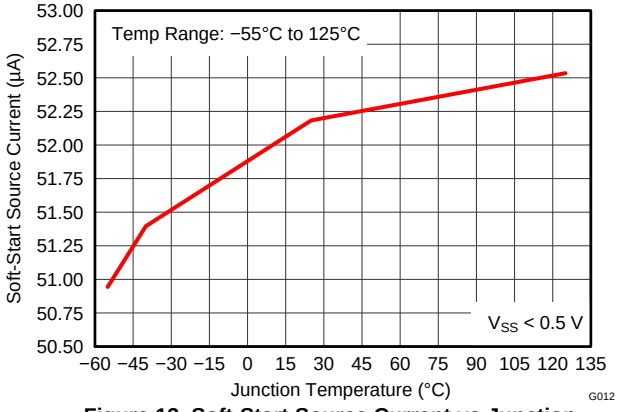


**Figure 13. Soft-Start Source Current vs Junction Temperature ($V_{SS}$ < 0.5 V)**


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## TYPICAL CHARACTERISTICS (continued)

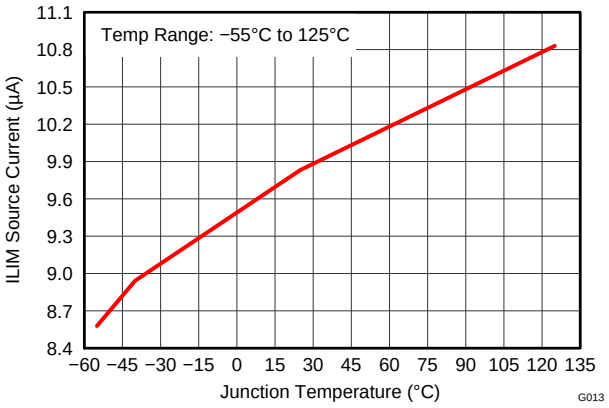


**Figure 14. ILIM Source Current vs Junction Temperature**

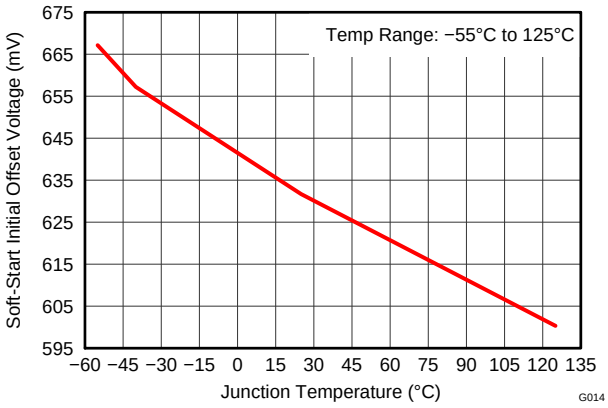


**Figure 15. Soft-Start Initial Offset Voltage vs Junction Temperature**

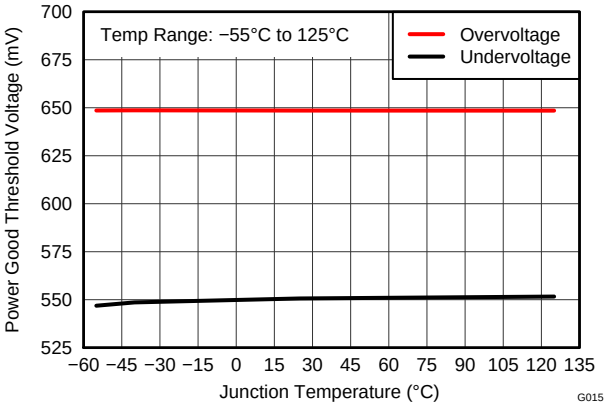


**Figure 16. $V_{OV}/V_{UV}$ Power Good Threshold Voltage**

# APPLICATION INFORMATION

## FUNCTIONAL DESCRIPTION

The TPS40170 is a synchronous PWM buck controller that accepts a wide range of input voltages from 4.5 V to 60 V and features voltage-mode control with input-voltage feed-forward compensation. The switching frequency is programmable from 100 kHz to 600 kHz.

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

The TPS40170 provides accurate output voltage regulation within 1% accuracy.

Additionally, the controller implements a novel scheme of bidirectional synchronization with one controller acting as the master and other downstream controllers acting as slaves, synchronized to the master in-phase or 180° out-of-phase. Slave controllers can be synchronized to an external clock within ±30% of the internal switching frequency.

### LDO Linear Regulators and Enable

The TPS40170 has two internal low-dropout (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 µA). 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 17.

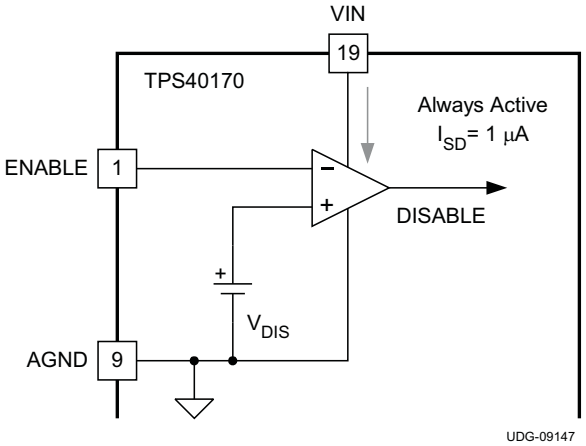


**Figure 17. TPS40170 ENABLE Functional Block**

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 VIN by a high-value resistor, ensuring that the current into the ENABLE pin does not exceed 10 µA. If it is not possible to meet this clamp current requirement, then it is suggested that a resistor divider from VIN to GND be used to connect to ENABLE pin. The resistor divider should be such that the ENABLE pin is higher than $V_{EN}$ and lower than 8 V.


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**NOTE**

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

### 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 $V_{VBP(on)}$.
- 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 the VBP pin) must be less than $V_{VBP(off)}$.
- 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 (VIN pin) to GND sets the UVLO level. Once 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 18.

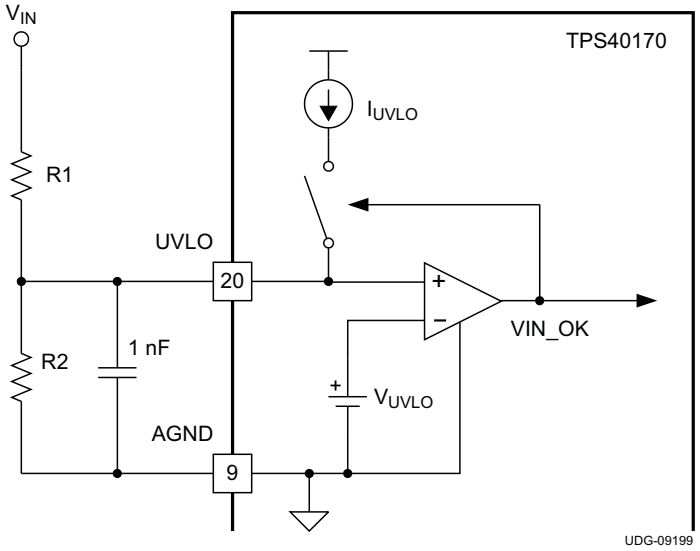


**Figure 18. UVLO Functional Block Schematic**

### *Equations for Programming the Input UVLO:*

Components R1 and R2 represent external resistors for programming UVLO and hysteresis; their values 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 turnon voltage of the converter.
- $V_{OFF}$ is the desired turnoff voltage for the converter.
- $I_{UVLO}$ is the hysteresis current generated by the device, 5 µA (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 ($V_{VBP(on)}$ and $V_{VBP(off)}$). For example, the UVLO pin can be connected to VDD or the VBP pin to disable the programmable UVLO function.

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

### Oscillator and Voltage Feed-Forward

TPS40170 implements an oscillator with input-voltage feed-forward compensation that enables instant response to input voltage changes. Figure 19 shows the oscillator timing diagram for the TPS40170. The resistor from the RT pin to GND sets the free-running oscillator frequency. Voltage $V_{RT}$ on the RT pin is made proportional to the input voltage (see Equation 3).

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

where

- K = 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, $V_{RT}$. Once 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.


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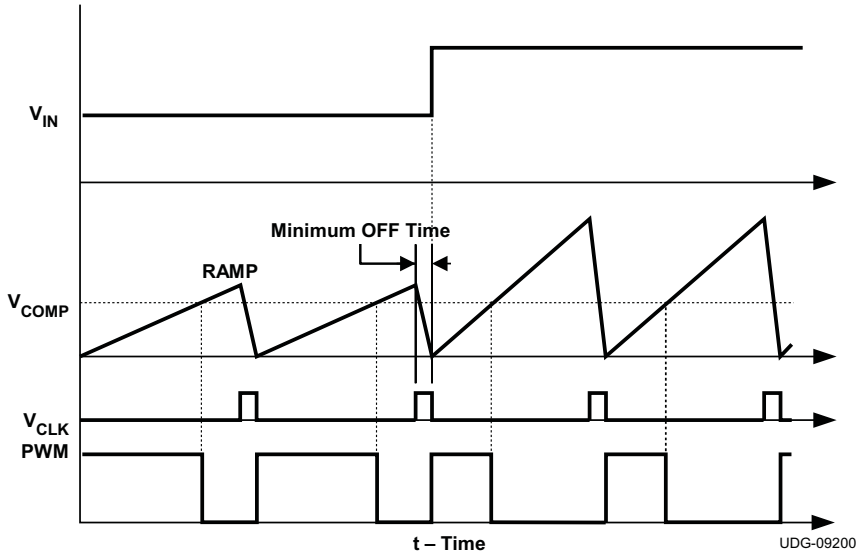


**Figure 19. Feed-Forward Oscillator Timing Diagram**

### *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 kΩ.

**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, see application note SLYT293.

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

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.
- $R_{LOAD}$ is the inductor series resistance.

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### 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 LDRV is ON after a blanking time, which is the product of inductor current and low-side FET turnon 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. Resistor $R_{ILIM}$ can be calculated by Equation 6.

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

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 choosing a 10-kΩ, open-circuit, or 20-kΩ resistor, respectively, from the 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 HDRV is ON after a blanking time, which is product of inductor current and high-side FET turnon resistance $R_{DS(on)}$. The voltage is compared to the product of the multiplier and the ILIM pin voltage. If the voltage exceeds the product, then the fault-count is immediately set to 7 and the OC_FAULT is declared. 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.

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

Figure 20 is a functional block diagram of the two-level overcurrent protection.

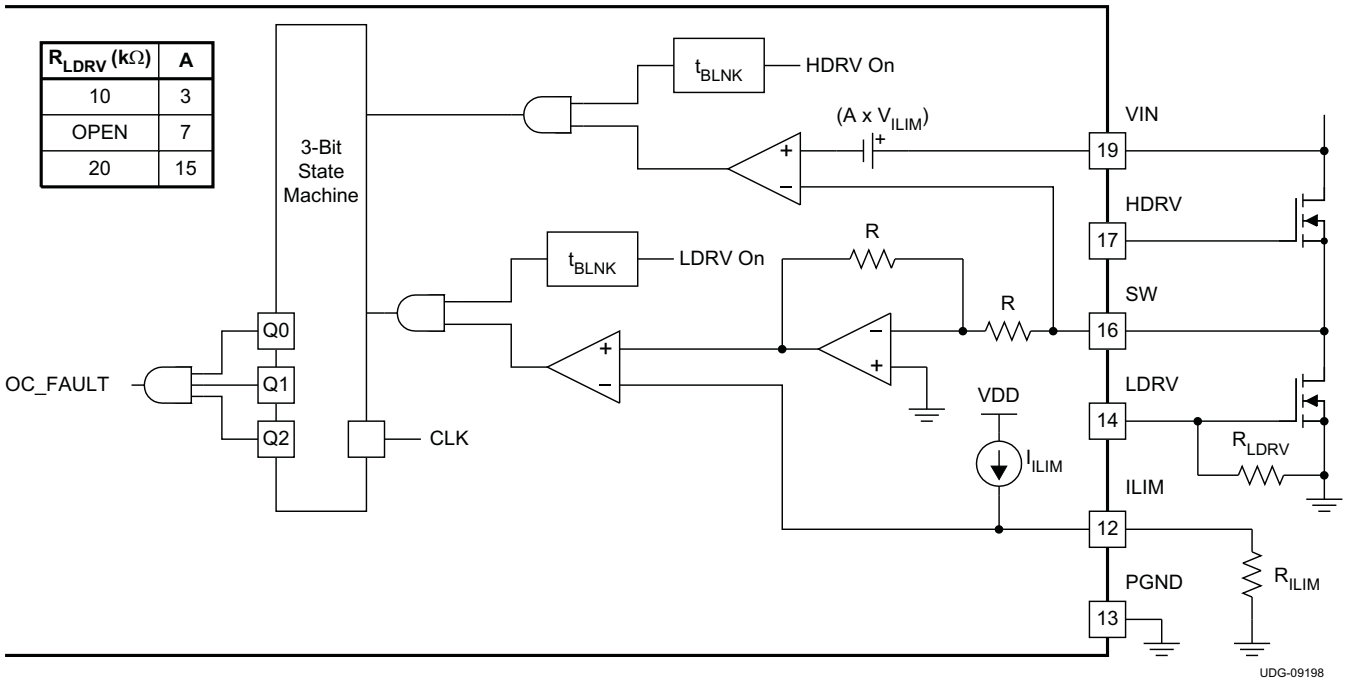


**Figure 20. OCP and SCP Protection Functional Block Diagram**


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**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 a negative impact on the accuracy of OCP and SCP. Adding an R-C snubber from the SW node to GND helps minimize the potential impact.

### 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 internal level-shifter circuit of the device 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, an extra charging current (40.4 µA, typ.) is switched-in to the SS pin at the beginning of the soft-start in addition to the normal charging current (11.6 µA, typ.). As the SS capacitor reaches 0.5 V, the extra charging current is turned off and only the normal charging current remains. Figure 21 shows the soft-start function block.

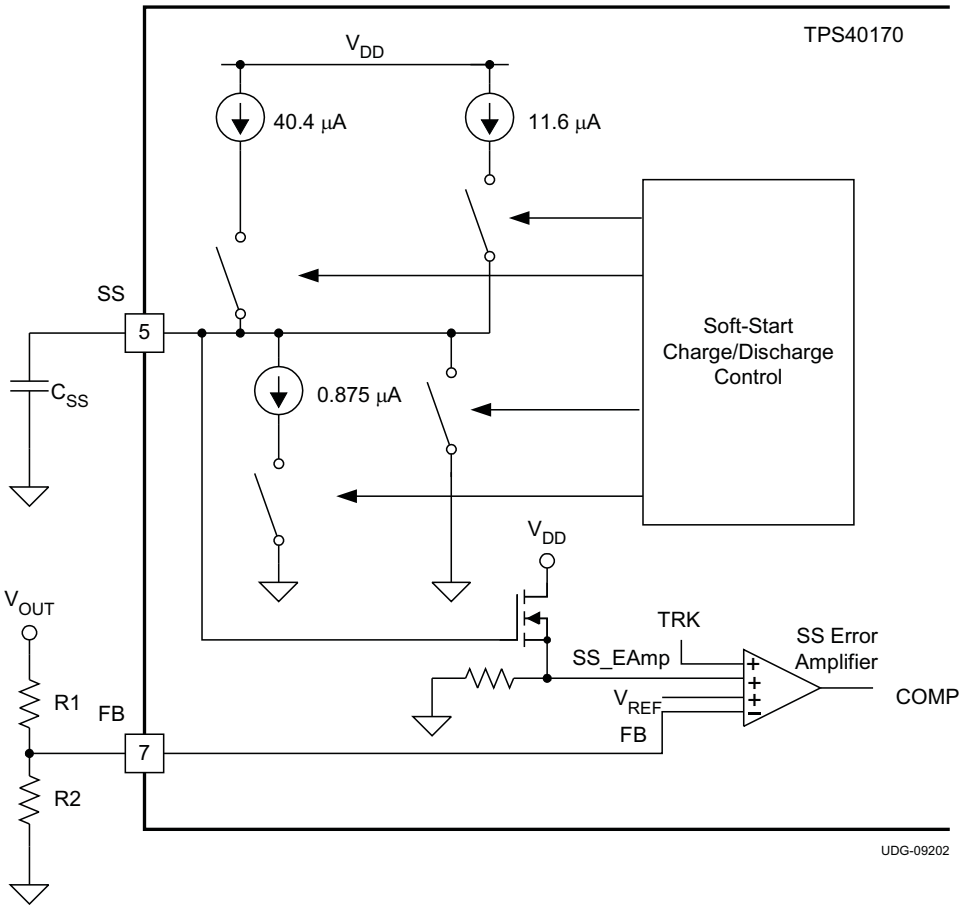


**Figure 21. Soft-Start Schematic Block**

As the SS pin voltage approaches 0.65 V, the positive input to the error amplifier begins to rise (see Figure 22). 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. Once $V_{COMP}$ reaches the $V_{valley}$ of the PWM ramp, the switching begins. The output is regulated to the error amplifier input through the FB pin in the feedback loop. Once 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 VDD.

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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 ($V_{BP(off)}$)

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.

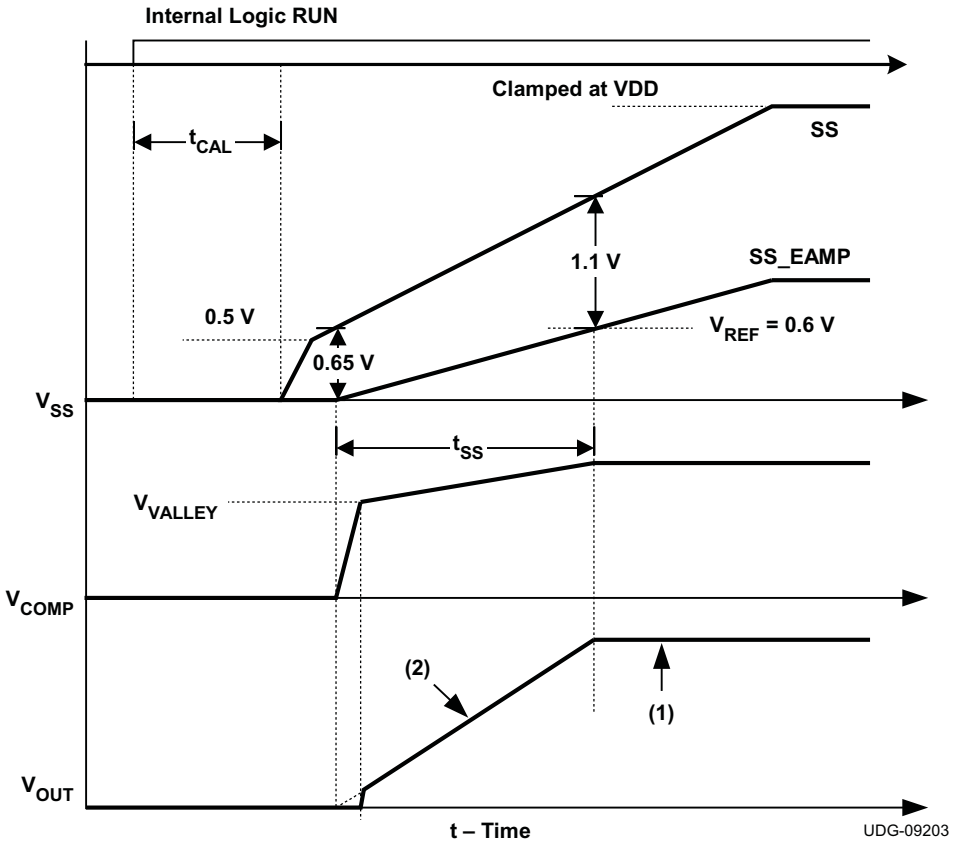


**Figure 22. Soft-Start Waveforms**

**NOTE**

Referring to Figure 22

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

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


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### *Soft-Start During Overcurrent Fault*

The soft-start block also has a role to control 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 µA, typ.). Once the SS pin capacitor is discharged to below $V_{SS(flt,low)}$ (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 $V_{SS(flt,high)}$ (2.5 V, typ.), then the soft-start capacitor continues to charge until it reaches $V_{SS(flt,high)}$ before a discharge cycle is initiated. This ensures that the re-start time-interval is always constant. Figure 23 shows the restart timing.

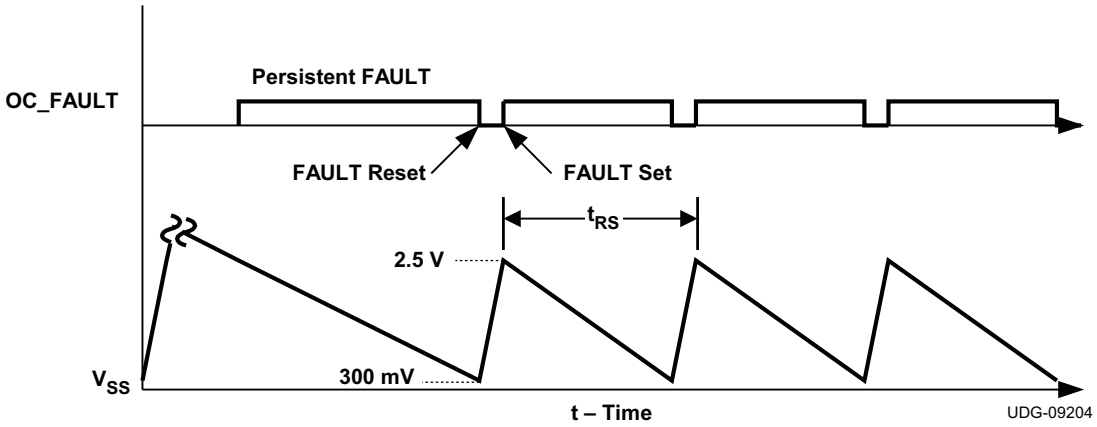


**Figure 23. Overcurrent Fault Restart Timing**

**NOTE**

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

### *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. SS_EAMP starts rising as the SS pin goes beyond 0.65 V. The offset voltage between SS and SS_EAMP starts increasing as the SS pin voltage starts rising. Figure 22 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).

$$C_{SS} = \frac{t_{SS}}{0.09} \tag{10}$$

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.

$$t_{RS} \approx 2.28 \times C_{SS} \tag{11}$$

where

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

**NOTE**

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

## Overtemperature Fault

Figure 24 shows the over temperature protection scheme. If the junction temperature of the device reaches the thermal shutdown limit of $t_{SD(set)}$ (165°C, typ) 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 an overtemperature fault is reset whenever the soft-start capacitor is discharged below $V_{SS(flt,low)}$ (300 mV, typ.). 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 typ). PWM switching continues and the system returns to normal regulation.

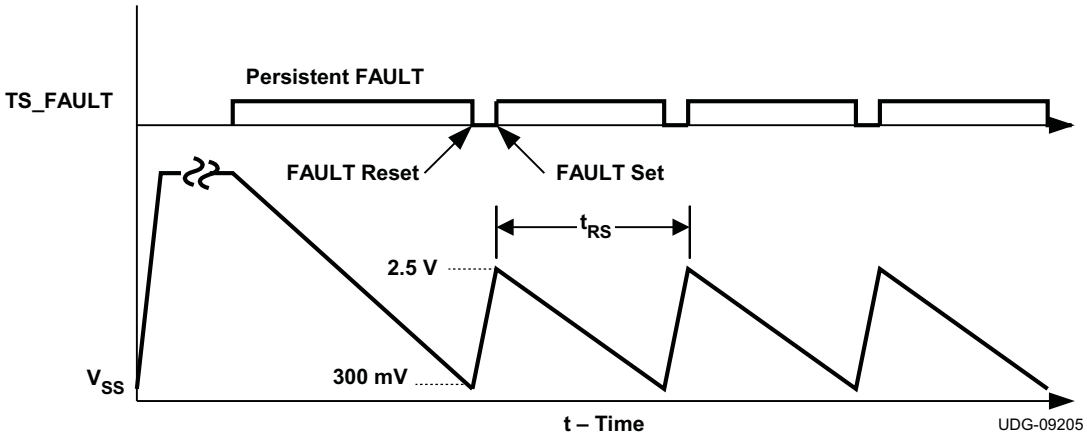


**Figure 24. Overtemperature Fault Restart Timing**

The soft-start timing during an overtemperature fault is the same as the soft-start timing during an overcurrent fault. See the *Equations for Soft-Start and Restart Time* section.


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## Frequency Synchronization

The TPS40170 has three modes.

- **Master mode**: In this mode, the master- or slave-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 of 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 HDRV.
- **Slave–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 HDRV is synchronized with the rising edge of the incoming synchronization clock.
- **Slave–0° mode**: In this mode, the M/S pin is left open. The SYNC pin of the TPS40170 accepts a synchronization clock signal, and HDRV is synchronized with the falling edge of the incoming synchronization clock.

The two slave modes can be synchronized to an external clock through the SYNC pin. They are shown in Figure 25. The synchronization frequency should be within ±30% of its programmed free-running frequency.

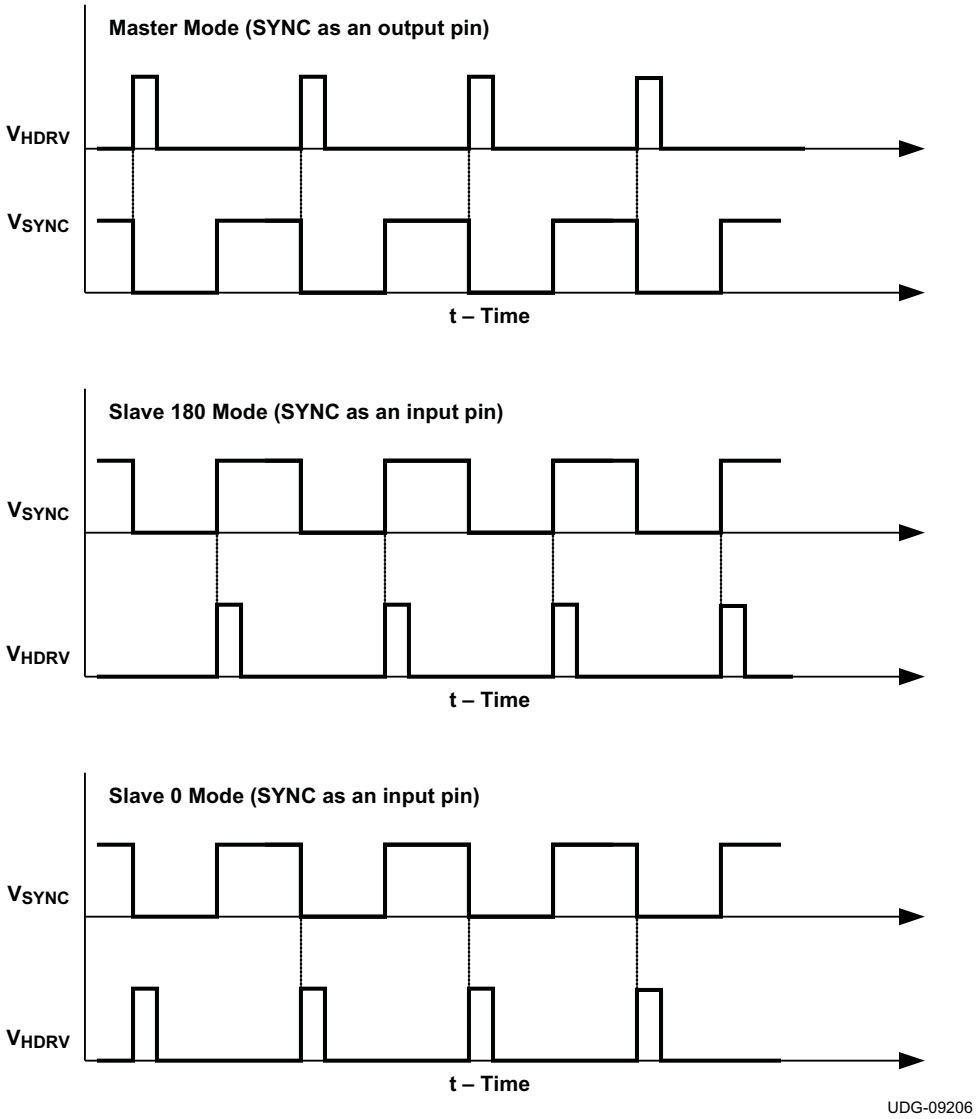


**Figure 25. Frequency Synchronization Waveforms in Different Modes**

TPS40170 provides a smooth transition for the SYNC clock-signal loss in slave mode. In slave 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 µs. After that, the device switching frequency is changed to its programmed free-running frequency. Figure 26 shows this process.

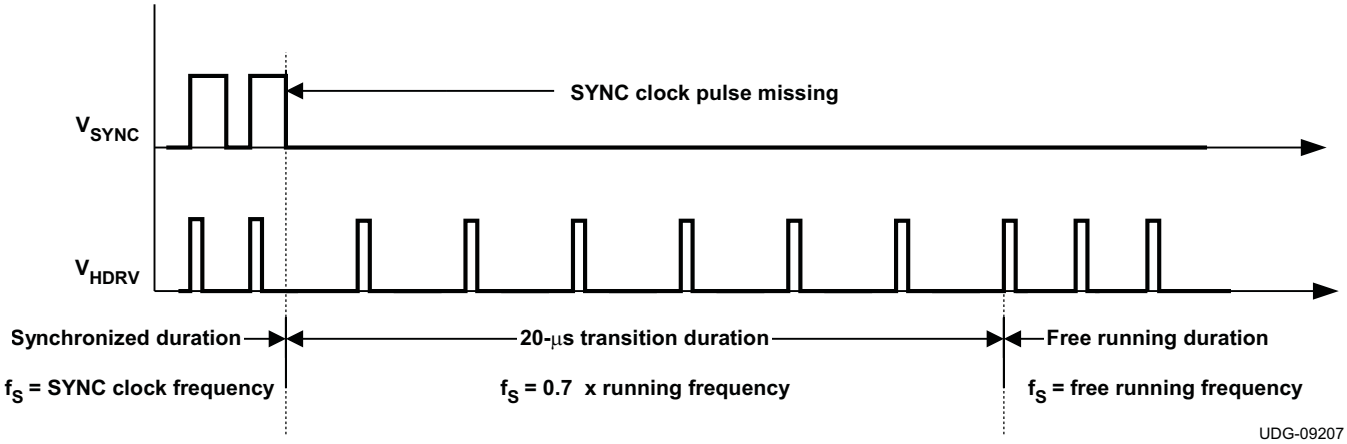


**Figure 26. Transition for SYNC Clock Signal Missing (for Slave–180º Mode)**

**NOTE**

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

When the external SYNC clock signal is used for synchronization, limit the maximum slew rate of the clock signal to 10 V/µs to avoid potential PWM jittering,and connect the SYNC pin to the external clock signal via a 5-kΩ resistor.


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## 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. Once 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 should be noted that the SS pin capacitor must remain connected to SS pin and is also used for FAULT timing. For proper tracking using the TRK pin, the tracking voltage should 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 Figure 22, for $SS_{EAMP}$ = 0.6 V, the SS pin voltage is typically 1.7 V.

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

Figure 27 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 $0\ V < V_{TRK} < V_{REF}$

$$V_{OUT} = V_{TRK} \times \frac{(R1 + R2)}{R2} \quad (12)$$

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

$$V_{OUT} = V_{REF} \times \frac{(R1 + R2)}{R2} \quad (13)$$

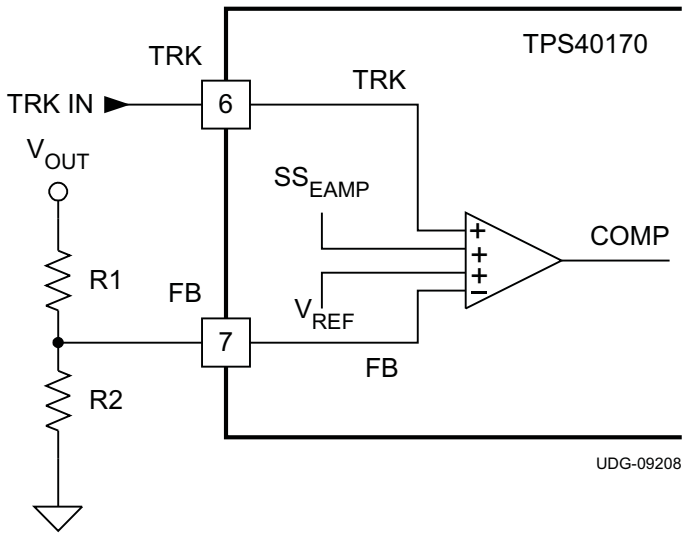


**Figure 27. Tracking Functional Block**

There are three potential applications for the tracking function.

- Simultaneous voltage tracking
- Ratiometric voltage tracking
- Sequential start-up mode

The tracking function configurations and waveforms are shown in Figure 28, Figure 29,Figure 30,Figure 31,Figure 32, andFigure 33 respectively.

In simultaneous voltage tracking, shown in Figure 28, tracking signals VTRK1 and VTRK2 of two modules, POL1 and POL2, start up at the same time, and their output voltages VOUT1initial and VOUT2initial are approximately the same during initial startup. Because VTRK1 and VTRK2 are less than $V_{REF}$ (0.6 V, typ.), Equation 12 is used. As a result, components selection should meet Equation 14.

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

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

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

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

Equation 14 can be simplified into Equation 17 by substituting terms from Equation 15 and Equation 16.

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

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 follows:

- $R_5 = R_6 = R_4 = R_2$ =10 kΩ
- $R_1$ = 3.16 kΩ
- $R_3$ = 1.37 kΩ

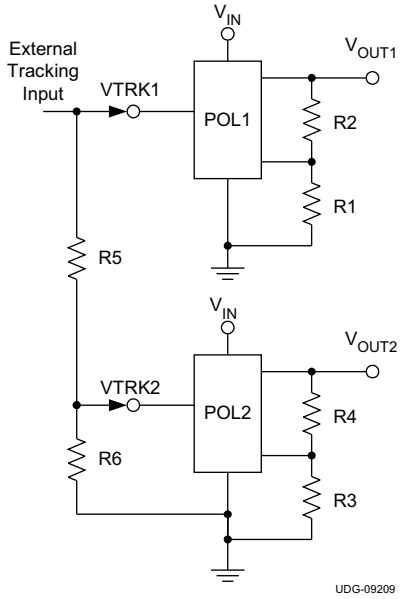


**Figure 28. Simultaneous Voltage-Tracking Schematic**

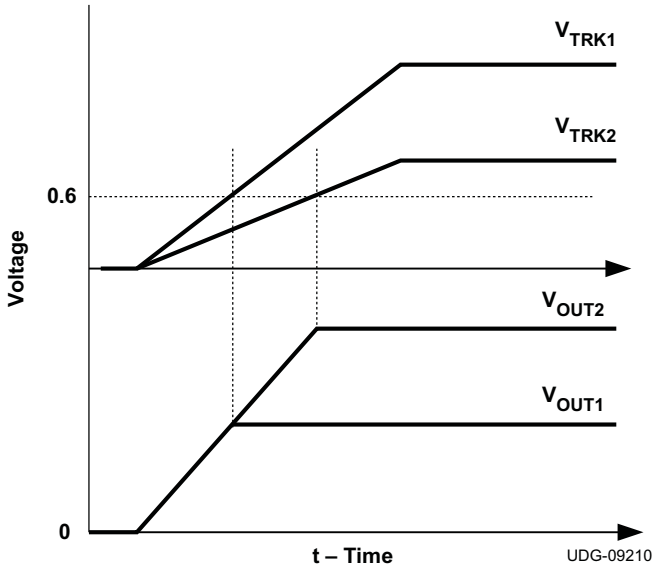


**Figure 29. Simultaneous Voltage-Tracking Waveform**


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In ratiometric voltage tracking as shown in Figure 30, the two tracking voltages, VTRK1 and VTRK2, for two modules, POL1 and POL2, are the same. Their output voltages, VOUT1 and VOUT2, are different with different voltage dividers, R2–R1 and R4–R3. VOUT1 and VOUT2 increase proportionally and reach their output voltage set points at about the same time.

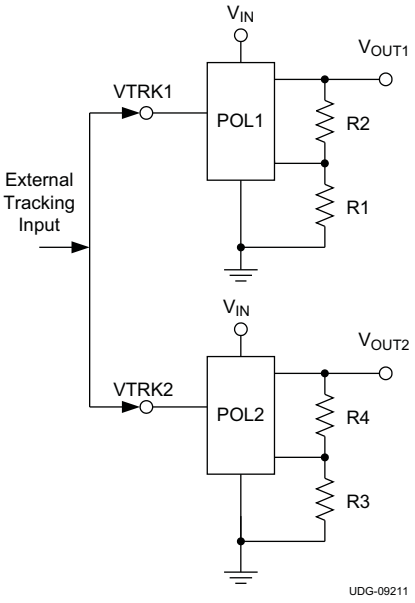


**Figure 30. Ratiometric Voltage-Tracking Schematic**

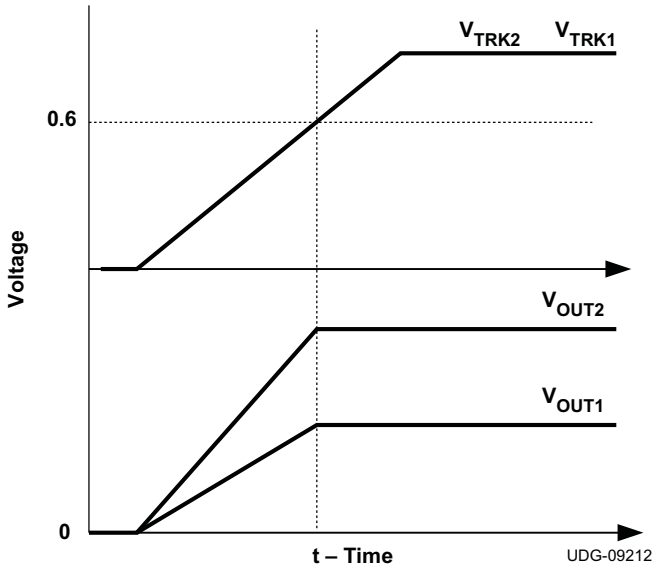


**Figure 31. Ratiometric Voltage-Tracking Waveform**

Sequential start-up is shown in Figure 32. During start-up of the first module, POL1, its 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 VOUT1 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.

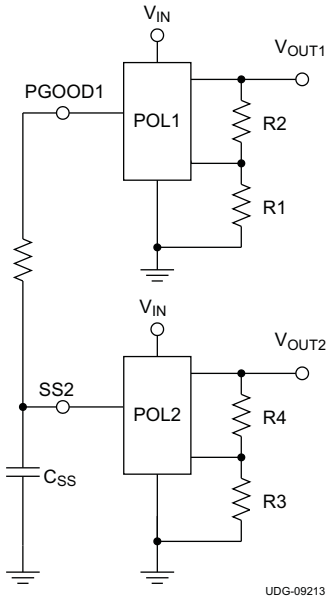


**Figure 32. Sequential Start-Up Schematic**

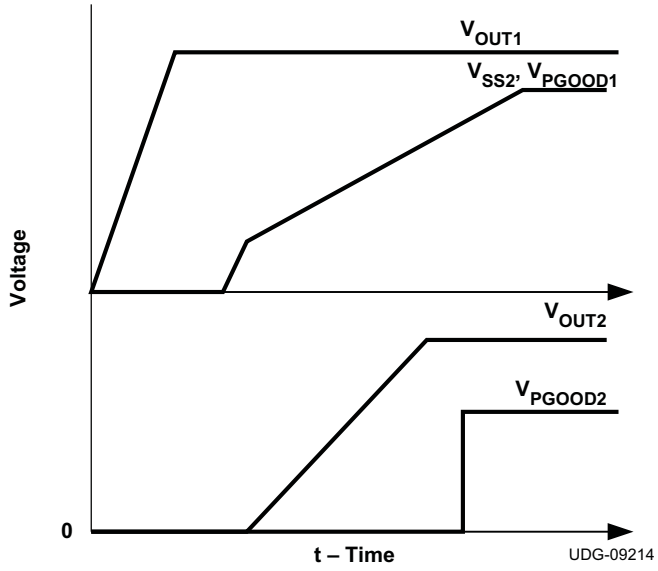


**Figure 33. Sequential Start-Up Waveform**

**NOTE**

The TRK pin has high impedance, so it is a noise-sensitive terminal. If the tracking function is used, a small R-C filter is recommended 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.


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## Adaptive Drivers

The drivers for the external high-side and low-side MOSFETs are capable of driving a gate-to-source voltage, $V_{VBP}$. The LDRV driver for the low-side MOSFET switches between VBP 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.

## 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 [$V_{VFB}$]), the controller slowly activates synchronous rectification by starting the first LDRV pulses with a narrow on-time (see Figure 34), where:

- $V_{IN}$ = 5 V
- $V_{OUT}$ = 3.3 V
- $V_{PRE}$ = 1.4 V
- $f_{SW}$ = 300 kHz
- L = 0.6 µH

LDRV pulses 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.

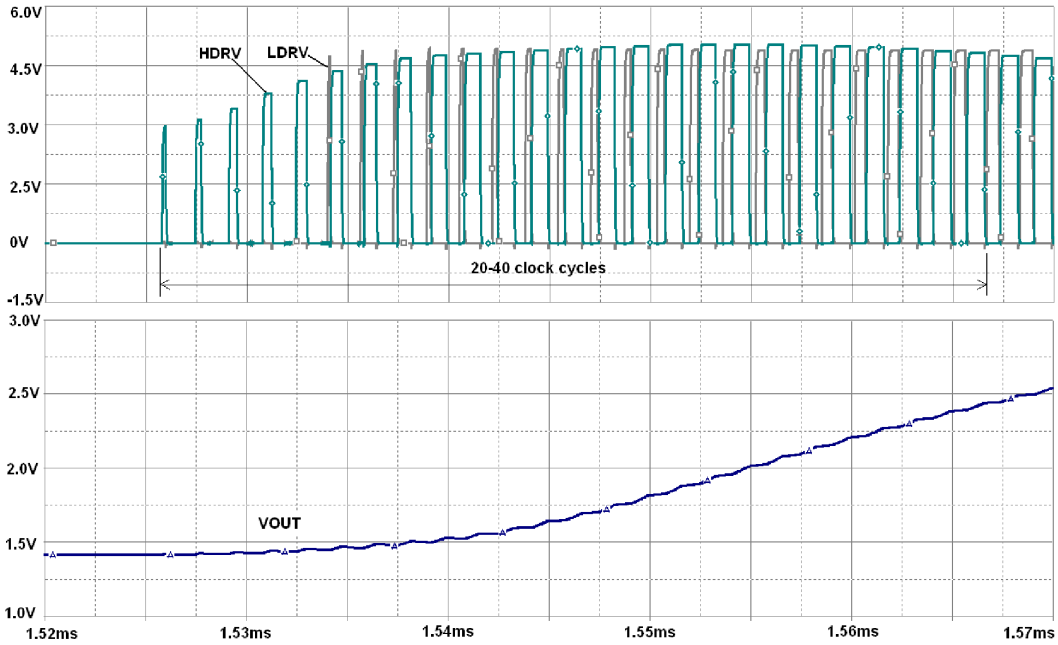


**Figure 34. Start-Up Switching Waveform During Pre-Biased Condition**

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

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**NOTE**

When output is pre-biased at $V_{PREBIAS}$, 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 the pre-bias level is high, it is possible that SCP can be tripped due to high the turnon resistance of the high-side MOSFET with low gate voltage. Once tripped, the device resets and then attempts to restart. The device may not be able to start up until the output is discharged to a lower voltage level either by 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.

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

where

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


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## Power Good (PGOOD)

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

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

Figure 35 shows a situation where no fault is detected during the start-up, (the normal PGOOD situation). It shows that PGOOD goes high $t_{PGD}$ (20 µs, typ.) after all the conditions (previously listed) are met.

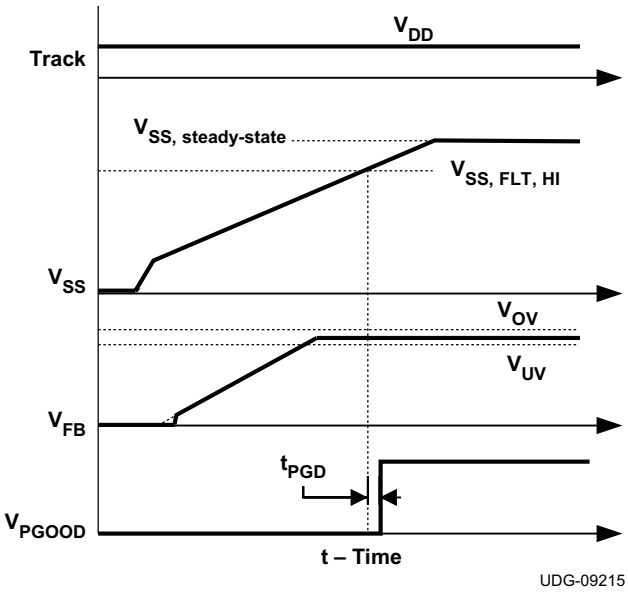


**Figure 35. PGOOD Signal**

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 as a diode to GND.

## PGND and AGND

**NOTE**

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.

## Bootstrap Capacitor

A bootstrap capacitor with a value between 0.1 µF and 0.22 µF must be placed between the BOOT pin and the SW pin. It should be 10 times higher than MOSFET gate capacitance.

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## Bypass and Filtering

In an integrated circuit, supply bypassing is important for jitter-free operation. To decrease noise in the converter, ceramic bypass capacitors must be placed as close to the package as possible.

1. VIN to GND: use a 0.1-µF ceramic capacitor.
2. BP to GND: use a 1-µF to 10-µF ceramic capacitor. It should be 10 times greater than the bootstrap capacitance.
3. VDD to GND: use a 0.1-µF to 1-µF ceramic capacitor .

## Design Hints

### Bootstrap Resistor

A small resistor in series with the bootstrap capacitor reduces the turnon time of the internal MOSFET, thereby reducing the rising edge ringing of the SW node and reducing shoot-through induced by dv/dt. A bootstrap resistor value that is too large delays the turnon time of the high-side switch and may trigger an apparent SCP fault. See the *Design Examples* section.

### 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 R-C snubber may be used to dampen the ringing and ensure proper operation over the full load range. See the *Design Examples* section.

### Input Resistor

The TPS40170 has a wide input-voltage range, which allows for the device input to share a power source with the power-stage input. Power-stage switching noise may pollute the device power source if the layout is not adequate in minimizing noise. Power-stage switching noise may trigger a short-circuit fault. If so, adding a small resistor between the device input and power-stage input is recommended. This resistor, together with the device input capacitor, composes an R-C filter that filters out the switching noise from power stage. See the *Design Examples* section.

### LDRV Gate Capacitor

Power-device selection is important for proper switching operation. If the low-side MOSFET has low gate capacitance Cgs (if Cgs < Cgd), there is a risk of short-through induced by high dv/dt at the switching node (See reference[1]) during high-side turnon. If this happens, add a small capacitance between LDRV and GND. See the *Design Examples* section.


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## DESIGN EXAMPLES

### Introduction

The wide-input TPS40170 controller can function in a very wide range of applications. This example describes the design process for a very wide-input (10 V to 60 V) to regulated 5-V output at a load current of 6 A. The design parameters are provided in Table 1.

**Table 1. Design Example Parameters**

| PARAMETER | | TEST CONDITIONS | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Input voltage | | 10 | | 60 | V |
| $V_{IN(ripple)}$ | Input ripple | $I_{OUT}$ = 6 A | | | 0.5 | V |
| $V_{OUT}$ | Output voltage | 0 A ≤ $I_{OUT}$ ≤ 20 A | 4.8 | 5 | 5.2 | V |
| | Line regulation | 10 V ≤ $V_{IN}$ ≤ 60 V | | | 0.5% | |
| | Load regulation | 0 A ≤ $I_{OUT}$ ≤ 6 A | | | 0.5% | |
| $V_{RIPPLE}$ | Output ripple | $I_{OUT}$ = 6 A | | | 100 | mV |
| $V_{OVER}$ | Output overshoot | $\Delta I_{OUT}$ = 2.5 A | | 250 | | mV |
| $V_{UNDER}$ | Output undershoot | $\Delta I_{OUT}$ = -2.5 A | | 250 | | mV |
| $I_{OUT}$ | Output current | 10 V ≤ $V_{IN}$ ≤ 60 V | 0 | | 6 | A |
| $t_{SS}$ | Soft-start time | $V_{IN}$ = 24 V | | 4 | | ms |
| $I_{SCP}$ | Short circuit current trip point | | 8 | | | A |
| η | Efficiency | $V_{IN}$ = 24 V, $I_{OUT}$ = 6 A | | 94% | | |
| $f_{SW}$ | Switching frequency | | | 300 | | kHz |
| | Size | | | | 1.5 | $in^2$ |

### Design Procedure

#### Select A Switching Frequency

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

#### Inductor Selection (L1).

Synchronous buck power inductors are typically sized for approximately 20%–40% of peak-to-peak ripple current ($I_{RIPPLE}$). Given this target ripple current, the required inductor size can be calculated in Equation 19.

$$L \approx \frac{V_{IN(max)} - V_{OUT}}{0.3 \times I_{OUT}} \times \frac{V_{OUT}}{V_{IN(max)}} \times \frac{1}{f_{SW}} = \frac{60\,V - 5\,V}{0.3 \times 6\,A} \times \frac{5\,V}{60\,V} \times \frac{1}{300\,kHz} = 8.5\,\mu H \quad (19)$$

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 20.

$$I_{L(rms)} = \sqrt{\left(I_{L(avg)}\right)^2 + \left(\tfrac{1}{12} \times I_{RIPPLE}\right)^2} = \sqrt{\left(I_{OUT}\right)^2 + \left(\tfrac{1}{12} \times I_{RIPPLE}\right)^2} = \sqrt{(6)^2 + \tfrac{1}{12} \times (1.86)^2} = 6.02\,A \quad (20)$$

#### Output Capacitor Selection (C9)

The selection of the output capacitor is typically driven by the output transient response. Equation 21 and Equation 22 overestimate the voltage deviation to account for delays in the loop bandwidth and can be used to determine the required output capacitance:

$$V_{OVER} < \frac{I_{TRAN}}{C_{OUT}} \times \Delta T = \frac{I_{TRAN}}{C_{OUT}} \times \frac{I_{TRAN} \times L}{V_{OUT}} = \frac{\left(I_{TRAN}\right)^2 \times L}{V_{OUT} \times C_{OUT}} \quad (21)$$

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$$V_{UNDER} < \frac{I_{TRAN}}{C_{OUT}} \times \Delta T = \frac{I_{TRAN}}{C_{OUT}} \times \frac{I_{TRAN} \times L}{(V_{IN} - V_{OUT})} = \frac{(I_{TRAN})^2 \times L}{(V_{IN} - V_{OUT}) \times C_{OUT}} \quad (22)$$

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.

$$C_{OUT(min)} = \frac{(I_{TRAN(max)})^2 \times L}{V_{OUT} \times V_{OVER}} = \frac{(3)^2 \times 8.2\,\mu H}{5 \times 250\,mV} = 59\,\mu F \quad (23)$$

With a minimum capacitance, the maximum allowable ESR is determined by the maximum ripple voltage and is approximated by Equation 24.

$$ESR_{MAX} = \frac{V_{RIPPLE(tot)} - V_{RIPPLE(cap)}}{I_{RIPPLE}} = \frac{V_{RIPPLE(tot)} - \left(\frac{I_{RIPPLE}}{8 \times C_{OUT} \times f_{SW}}\right)}{I_{RIPPLE}} = \frac{100\,mV - \left(\frac{1.86\,A}{8 \times 59\,\mu F \times 300\,kHz}\right)}{1.86\,A} = 47\,m\Omega \quad (24)$$

Two 1210, 22-µF, 16-V X7R ceramic capacitors plus two 0805 10-µF, 16-V X7R ceramic capacitors are selected to provide more than 59 µF of minimum capacitance (including tolerance and dc bias derating) and less than 47 mΩ of ESR (parallel ESR of approximately 4 mΩ).

### 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 by Equation 25.

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

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

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

### Input Capacitor Selection (C1, C6)

The input voltage ripple is divided between capacitance and ESR. For this design, VRIPPLE(cap) = 400 mV and VRIPPLE(ESR) = 100 mV. The minimum capacitance and maximum ESR are estimated by:

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

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

The rms current in the input capacitors is estimated in Equation 29.

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

To achieve these values, four 1210, 2.2-µF, 100-V, X7R ceramic capacitors plus a 120-µF 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 2. Inductor Summary**

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


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### MOSFET Switch Selection (Q1, Q2)

Using the J/K method for MOSFET optimization, apply Equation 30 through Equation 33.

High-side gate (Q1):

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

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

Low-side gate (Q2):

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

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

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

### 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.

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

### UVLO Programming Resistors (R2, R6)

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

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

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

### Bootstrap Capacitor (C7)

To ensure proper charging of the high-side FET gate, limit the ripple voltage on the boost capacitor to less than 250 mV.

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

### VIN Bypass Capacitor (C18)

Place a capacitor with a value of 1 µF. Select a capacitor with a value between 0.1 µF and 1.0 µF, X5R or better ceramic bypass capacitor for VIN as specified in Table 3 . For this design, a 1.0-µF, 100 V, X7R capacitor has been selected.

### VBP Bypass Capacitor (C19)

Select a capacitor with a value between 1 µF and 10 µF, X5R or better ceramic bypass capacitor for BP as specified in Table 3. For this design a 4.7-µF, 16 V capacitor has been selected.

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### SS Timing Capacitor (C15)

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

$$C_{SS} = \frac{t_{SS}}{0.09} = \frac{4\,ms}{0.09} = 44\,nF \approx 47\,nF \tag{38}$$

### ILIM Resistor (R19, C17)

The TPS40170 uses 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 a 20% rise in $R_{DS(on)Q2}$ for self-heating of the MOSFET, the voltage drop across the low-side FET at the current limit is given by Equation 39.

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

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.

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

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

### SCP Multiplier Selection (R5)

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

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

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

### 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 kΩ and 50 kΩ for a balance of feedback current and noise immunity. With the value of R11 set to 20 kΩ, the output voltage is programmed with a resistor divider given by Equation 42.

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

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

Using the TPS40k Loop Stability Tool for a 60-kHz bandwidth and a 50° phase margin with an R10 value of 20 kΩ, the following values are obtained. The tool is available from the TI Web site, Literature Number SLUC263 .

- C21 = C1 = 1500 pF
- C13 = C2 = 8200 pF
- C14 = C3 = 220 pF
- R13 = R2 = 511 Ω
- R4 = R3 = 3.83 kΩ


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## Typical Performance Characteristics

Figure 36 shows an efficiency graph for this design with 10-V to 60-V input and 5-V at 6-A output. Figure 37 shows a 24-V to 5-V at 6-A loop response, where $V_{IN}$ = 24 V and $I_{OUT}$ = 6 A, yielding 58-kHz bandwidth, 51° phase margin. Figure 38 shows the output ripple 20 mV/div, 2 µs/div, 20 MHz bandwidth.

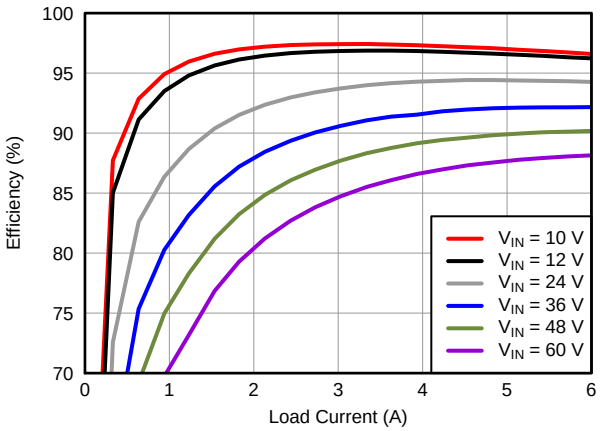


**Figure 36. Efficiency vs Load Current**

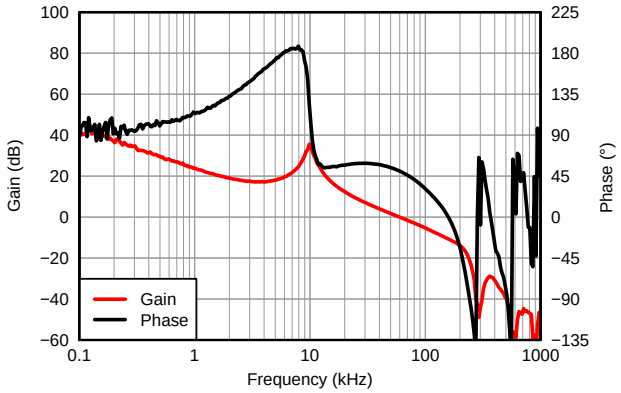


**Figure 37. Loop Response**

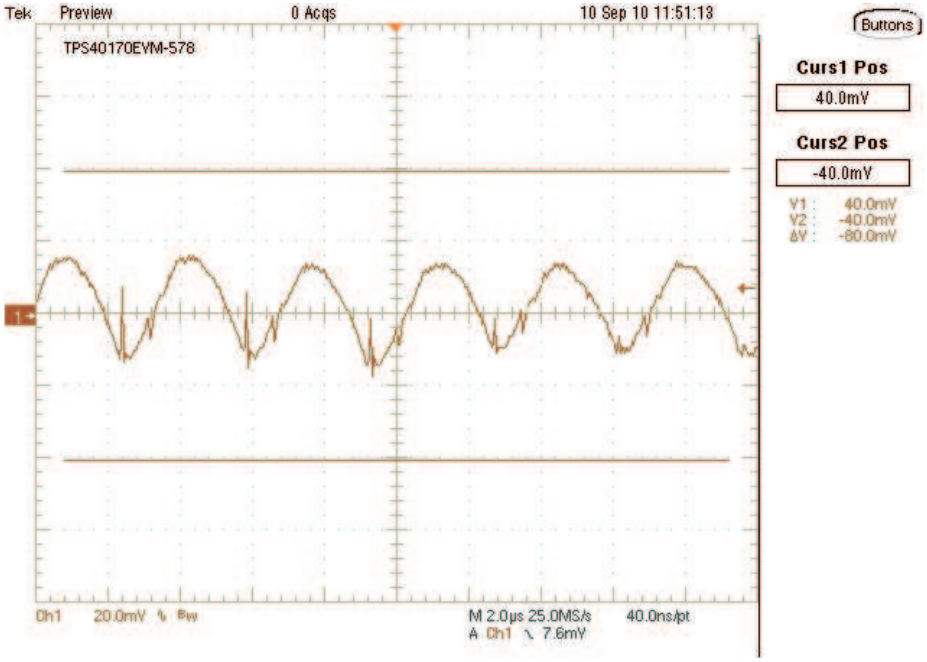


**Figure 38. Output Ripple Waveform**

## Schematic

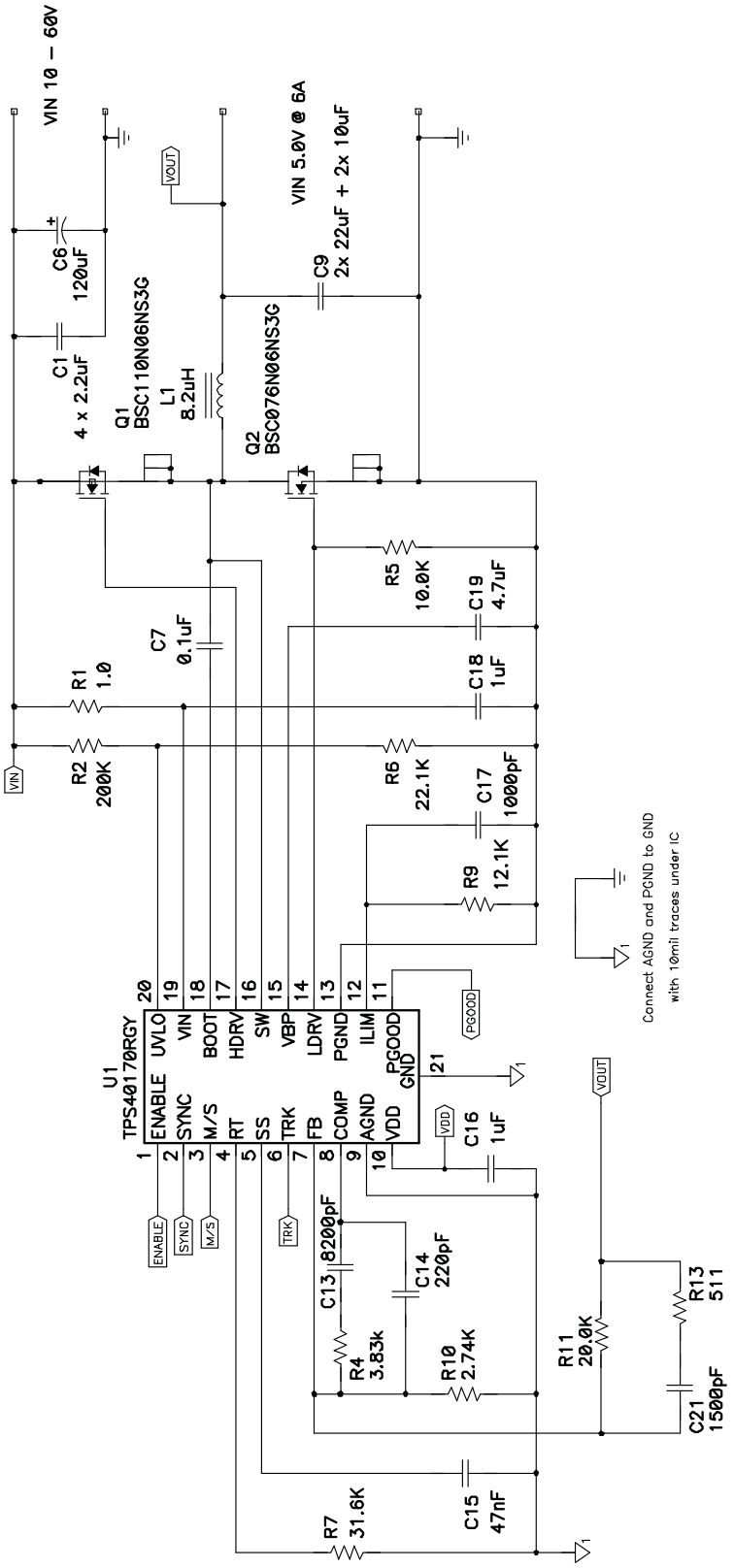


**Figure 39. Design Example Application**


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## List of Materials

**Table 3. Design Example List of Materials**

| REFERENCE DESIGNATOR | QTY | VALUE | DESCRIPTION | SIZE | PART NUMBER | MANUF |
|---|---|---|---|---|---|---|
| C1 | 4 | 2.2 µF | Capacitor, ceramic, 100-V, X7R, 15% | 1210 | Std | Std |
| C6 | 1 | 120 µF | Capacitor, aluminum, 63-V, 20%, KZE series | 0.315 inch (0.8 cm) | KZE63VB121M10X16LL | Chemi-con |
| C7 | 1 | 0.1 µF | Capacitor, ceramic, 50-V, X7R, 15% | 603 | Std | Std |
| C9 | 2 ea | 22 µF<br>10 µF | 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 µF | Capacitor, 16-V, X7R, 15% | 603 | Std | Std |
| C17 | 1 | 1000 pF | Capacitor, ceramic, 50-V, X7R, 15% | 603 | Std | Std |
| C18 | 1 | 1 µF | Capacitor, ceramic, 100-V, X7R, 15% | 1206 | Std | Std |
| C19 | 1 | 4.7 µF | 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 µH | Inductor, SMT, 10-A, 16-mΩ | 0.51 $inch^2$ (1.3 $cm^2$) | IHLP5050FDER8R2M01 | Vishay |
| Q1 | 1 | | MOSFET, N-channel, 60-V, 50-A, 11-mΩ | | BSC110N06NS3G | Infineon |
| Q2 | 1 | | MOSFET, N-channel, 60-V, 50-A, 7.6-mΩ | | BSC076N06NS3G | Infineon |
| R10 | 1 | 2.74 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R4 | 1 | 3.83 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R5 | 1 | 10.0 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R9 | 1 | 12.1 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R11 | 1 | 20.0 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R6 | 1 | 22.1 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R7 | 1 | 31.6 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| R2 | 1 | 200 kΩ | Resistor, chip, 1/16W, 1% | 603 | Std | R603 |
| 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 | | TPS40170-Q1RGY | Texas Instruments |

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## Layout Recommendations

Figure 40 illustrates an example layout. For the controller, it is important to connect carefully noise-sensitive signals such as RT, SS, FB, and COMP as close to the IC as possible and connect to AGND as shown. The thermal pad should be connected to any internal PCB ground planes using multiple vias directly under the IC. AGND and PGND should be connected at a single point.

When using high-performance FETs such as NexFET™ power MOSFETs from Texas Instruments, careful attention to the layout is required. Minimize the distance between the 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 syncronization (low-side) FET. Becasue of the large gate drive, smaller gate charge, and faster turnon times of the high-performance FETs, it is recommended to use a minimum of four 10-µF 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 Figure 40 through Figure 43 for reference.

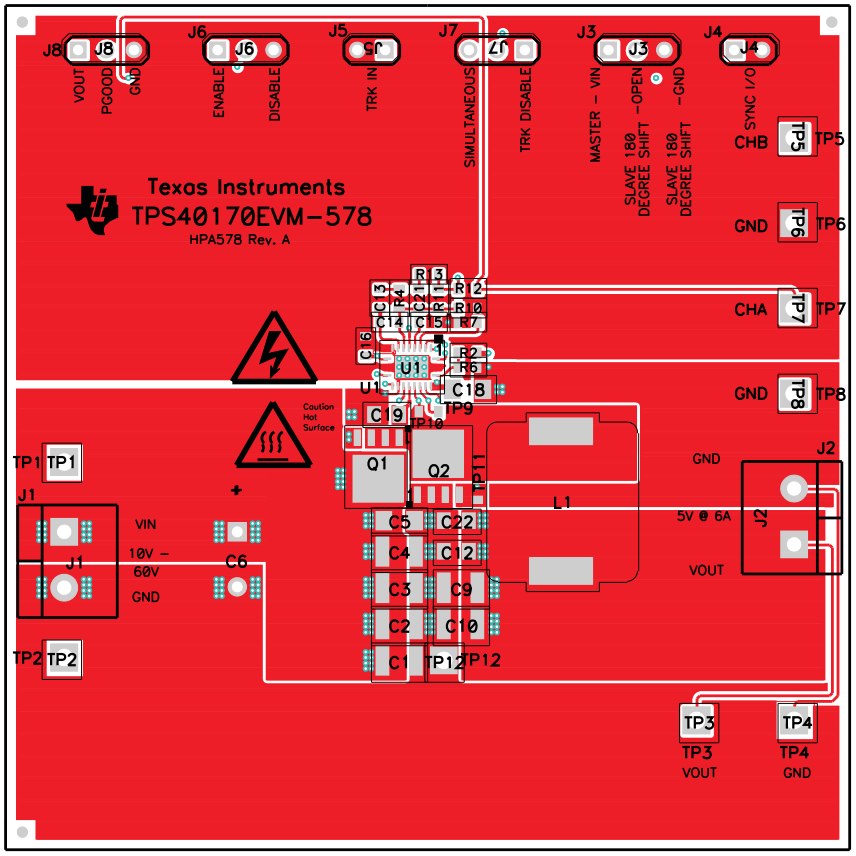


**Figure 40. Top Copper, Viewed From Top**


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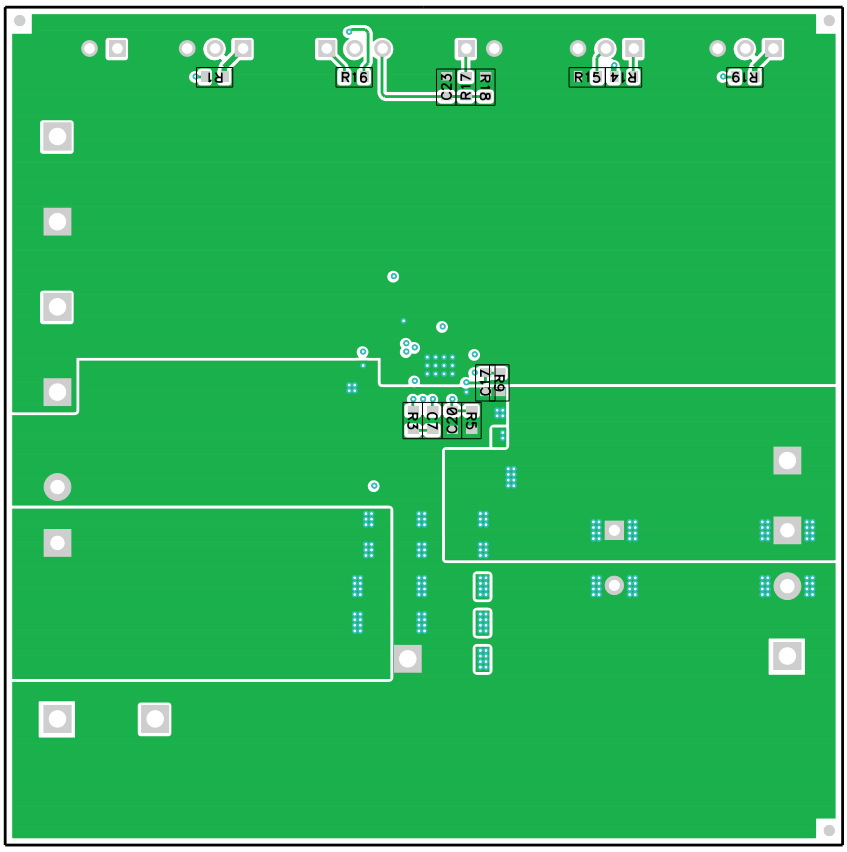


**Figure 41. Bottom Copper, Viewed From Bottom**

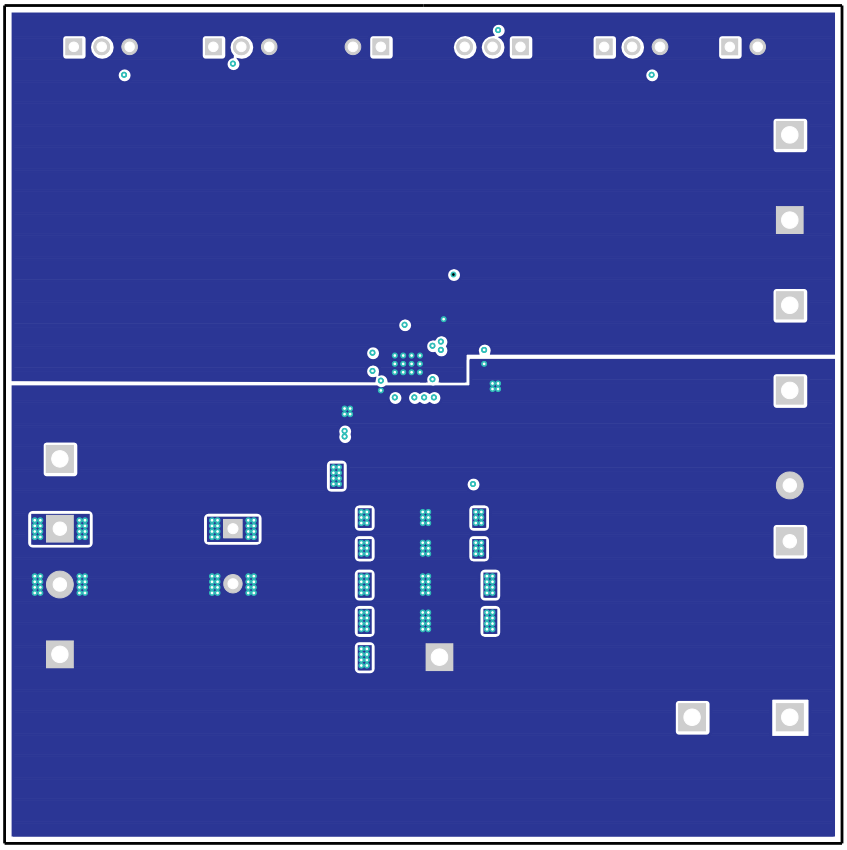

**Figure 42. Internal Layer 1, Viewed From Top**


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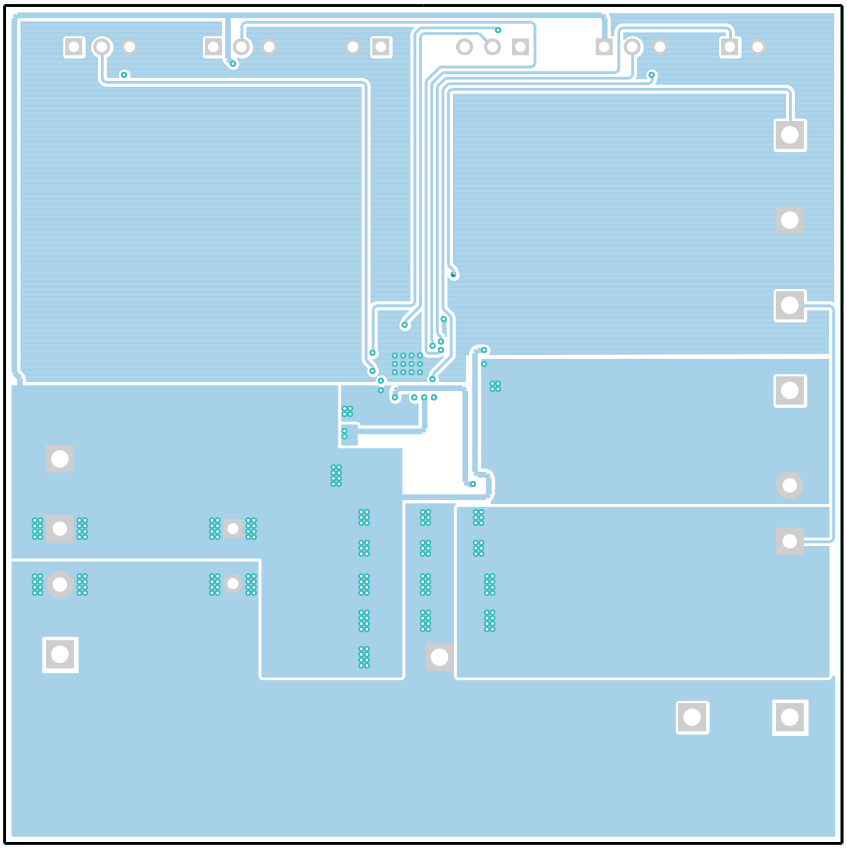

**Figure 43. Internal Layer 2, Viewed From Top**

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## ADDITIONAL REFERENCES

1. Steve Mappus, *DV/DT Immunity Improved in Synchronous Buck Converters*. July, 2005, Power Electronics Technology.

## RELATED DEVICES

The following devices have characteristics similar to the TPS40170 and may be of interest.

| DEVICE | DESCRIPTION | TI LITERATURE NUMBER |
|---|---|---|
| TPS40057 | Wide-input synchronous buck controller | SLUS593 |


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## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS40170MRGYTEP | ACTIVE | VQFN | RGY | 20 | 250 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -55 to 125 | PZYM | Samples |
| V62/13607-01XE | ACTIVE | VQFN | RGY | 20 | 250 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -55 to 125 | PZYM | Samples |

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

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

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

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

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**OTHER QUALIFIED VERSIONS OF TPS40170-EP :**

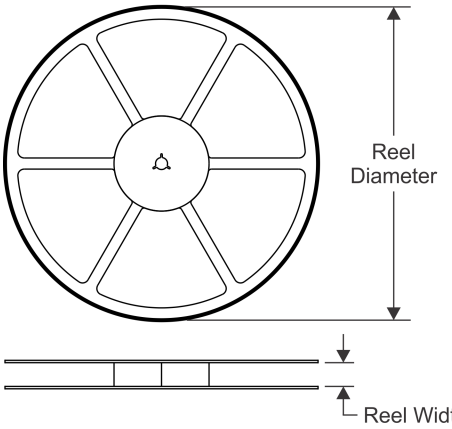
- Catalog: TPS40170
- Automotive: TPS40170-Q1

NOTE: Qualified Version Definitions:

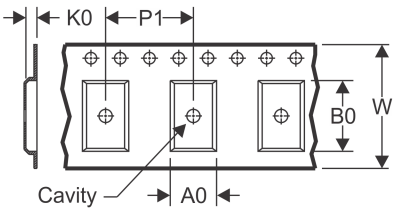
- Catalog - TI's standard catalog product
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

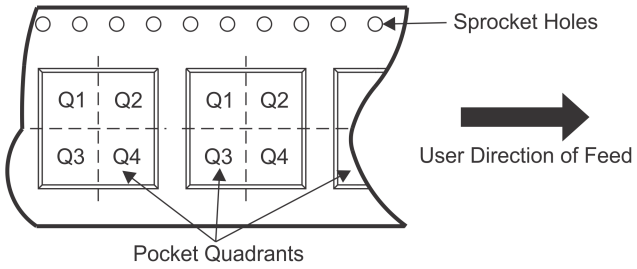



**TAPE DIMENSIONS**




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

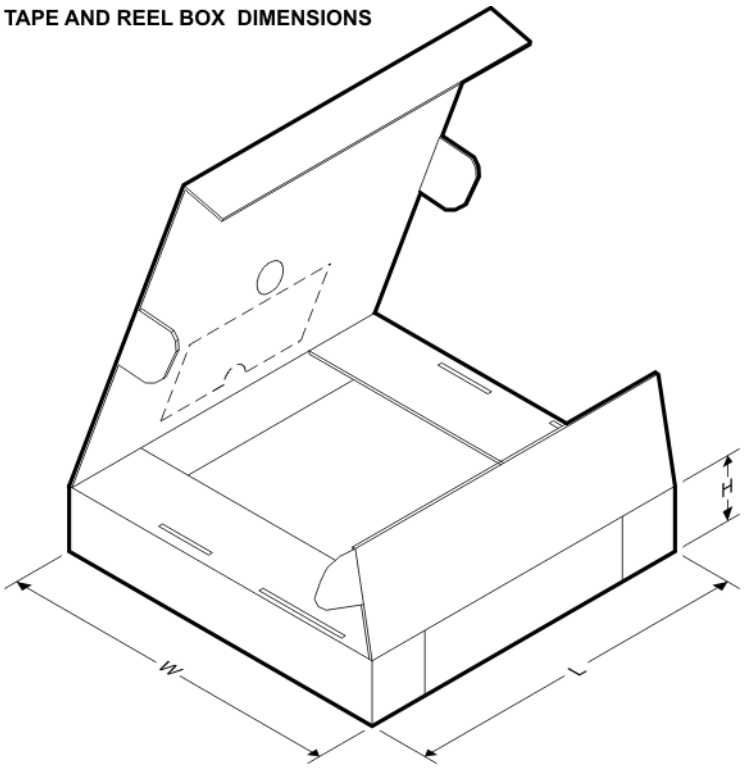
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS40170MRGYTEP | 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) |
|---|---|---|---|---|---|---|---|
| TPS40170MRGYTEP | VQFN | RGY | 20 | 250 | 210.0 | 185.0 | 35.0 |

# GENERIC PACKAGE VIEW

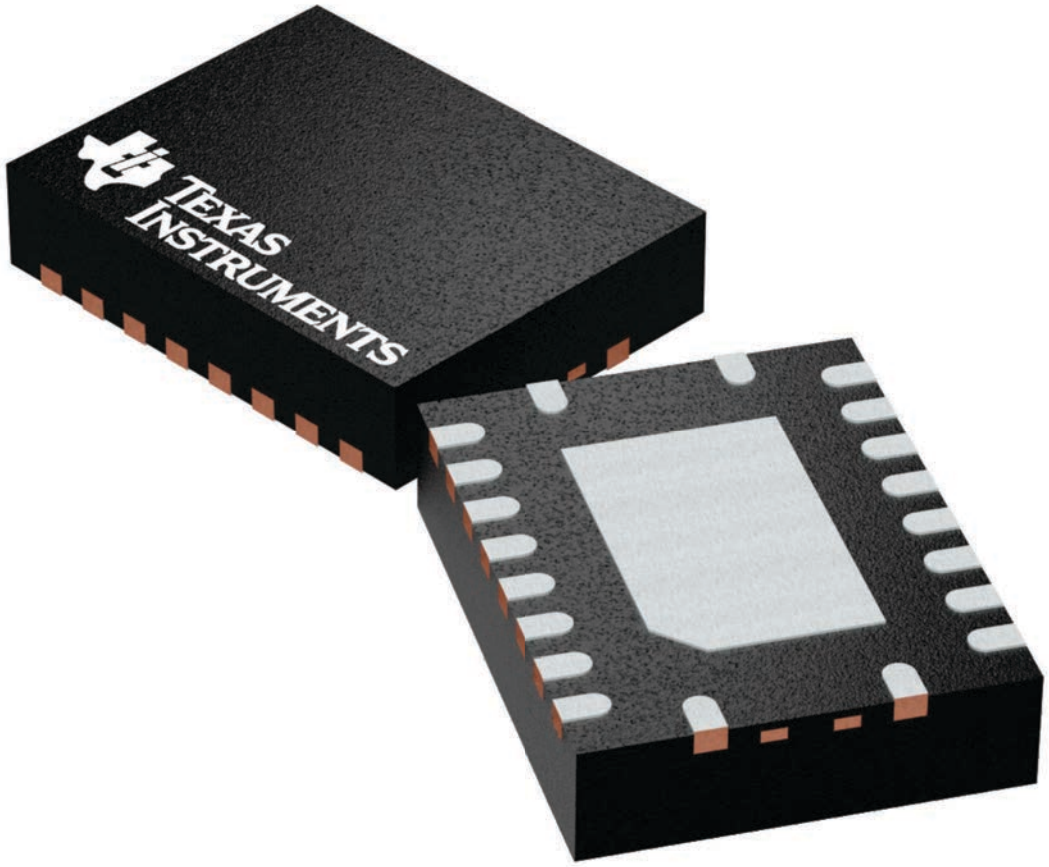
## RGY 20

## 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.



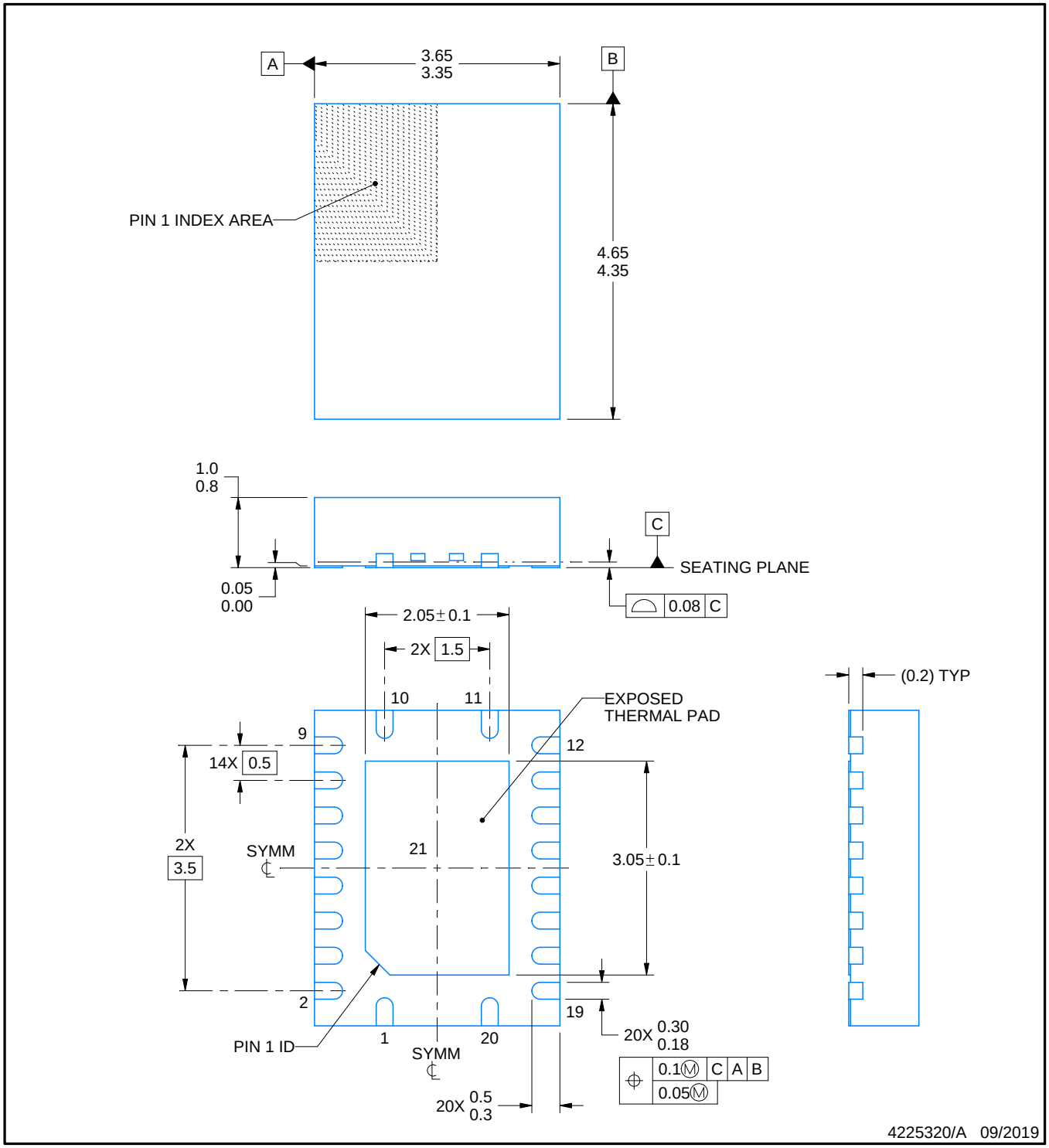

4225264/A

# PACKAGE OUTLINE

## RGY0020A

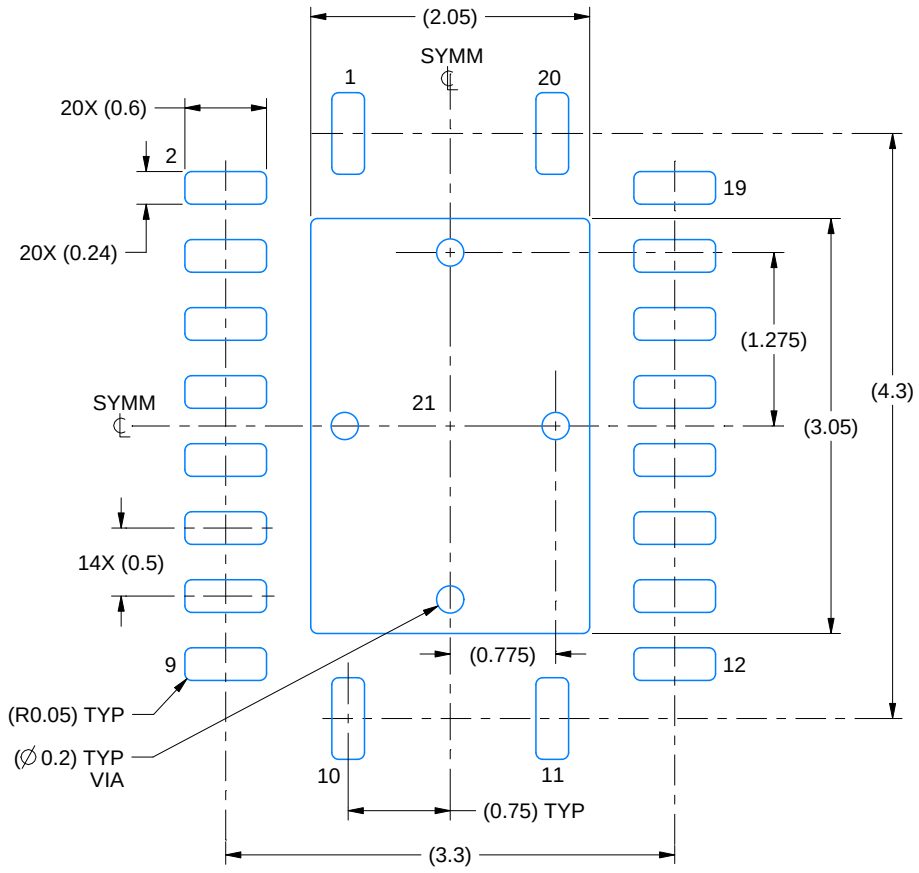
## VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD

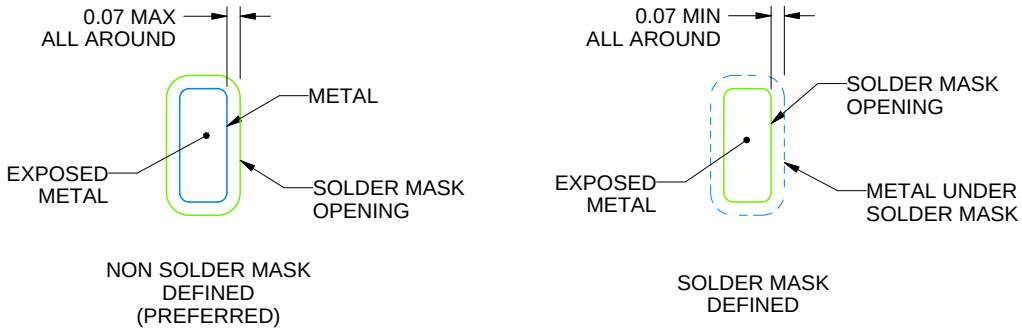



NOTES:

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.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:18X




SOLDER MASK DETAILS

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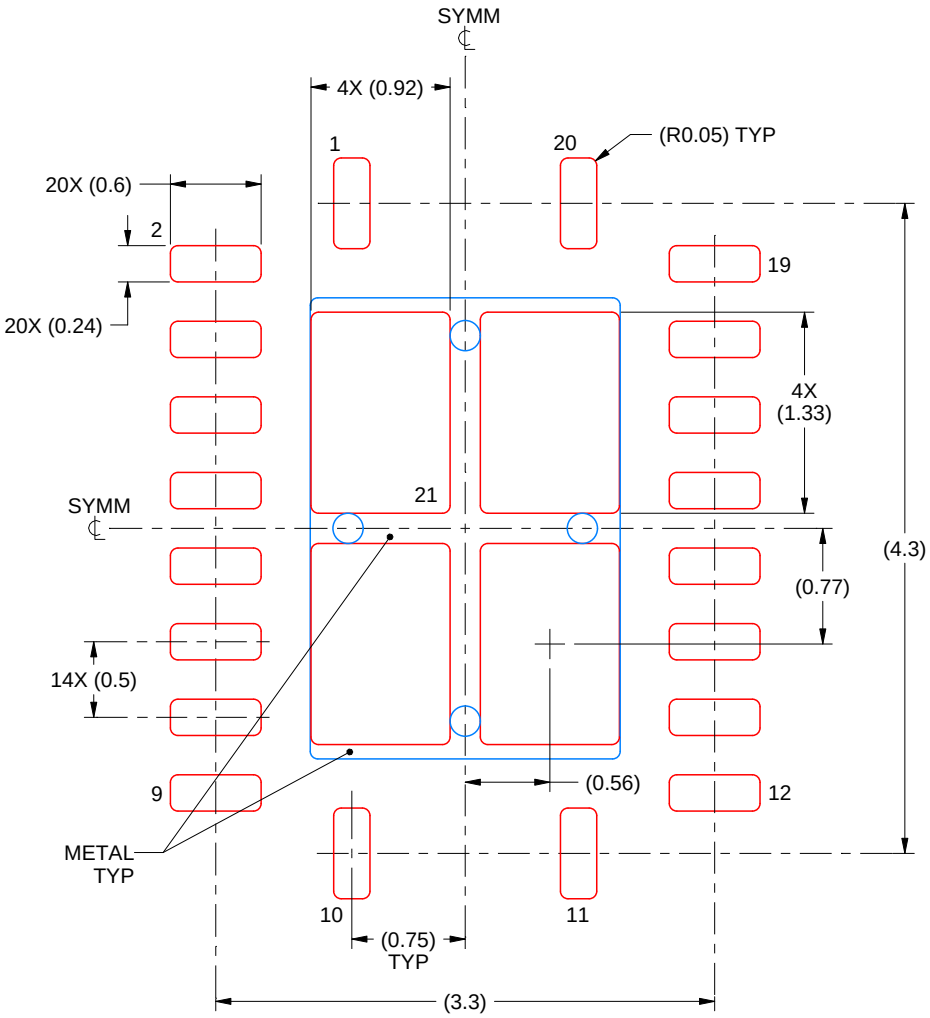
NOTES: (continued)

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




SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

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

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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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