

TPS53321 5A降圧型レギュレータ、スイッチャ内蔵

1 特長

- 96%の最大効率
- 5Aの連続出力電流
- すべてMLCCの出力コンデンサをサポート
- SmoothPWM™自動スキップ Eco-Mode™によって軽負荷時の効率を向上
- 軽負荷と重負荷の両方で効率を最適化
- 電圧モード制御
- マスタ/スレーブのインターリーブ動作をサポート
- 公称周波数の±20%まで同期
- 2.9Vから6Vまでの変換電圧範囲
- ディセーブル時のソフトストップ出力放電
- 出力電圧は0.6V～0.84V×V_{IN}の間で可変
- 過電流、過電圧、過熱保護
- 小型の3mm×3mm、16ピンQFNパッケージ
- オープン・ドレインのパワー・グッド・インジケータ
- 内部ブートストラップ・スイッチ
- 低いR_{DS(on)}: 3.3V入力で24mΩ、5V入力で19mΩ
- プリバイアス・スタートアップをサポート

2 アプリケーション

- 5V降圧型レール
- 3.3V降圧型レール

3 概要

TPS53321は、合計16個の部品で、200mm²のPCB領域に、完全に統合されたV_{IN} = 3V～5Vの同期FETコンバータ・ソリューションを実現します。低いオン抵抗と、TI独自のSmoothPWM™スキップ・モード動作により、96%のピーク効率、100mAの軽負荷で90%超の効率が得られます。22μFのセラミック出力コンデンサを2個使用するだけで、電力密度の高い5Aソリューションを構築できます。

TPS53321は、1.1MHzのスイッチング周波数、SKIPモード動作のサポート、プリバイアスのスタートアップ、内部ソフトスタート、出力ソフト放電、内部VBSTスイッチ、パワー・グッド、EN/入力UVLO、過電流、過電圧、低電圧、過熱保護の機能があり、すべてセラミックの出力コンデンサをサポートしています。2.9V～3.5Vの電源電圧と、2.9V～6Vの変換電圧に対応し、出力電圧は0.6V～0.84V×V_{IN}の範囲で調整可能です。

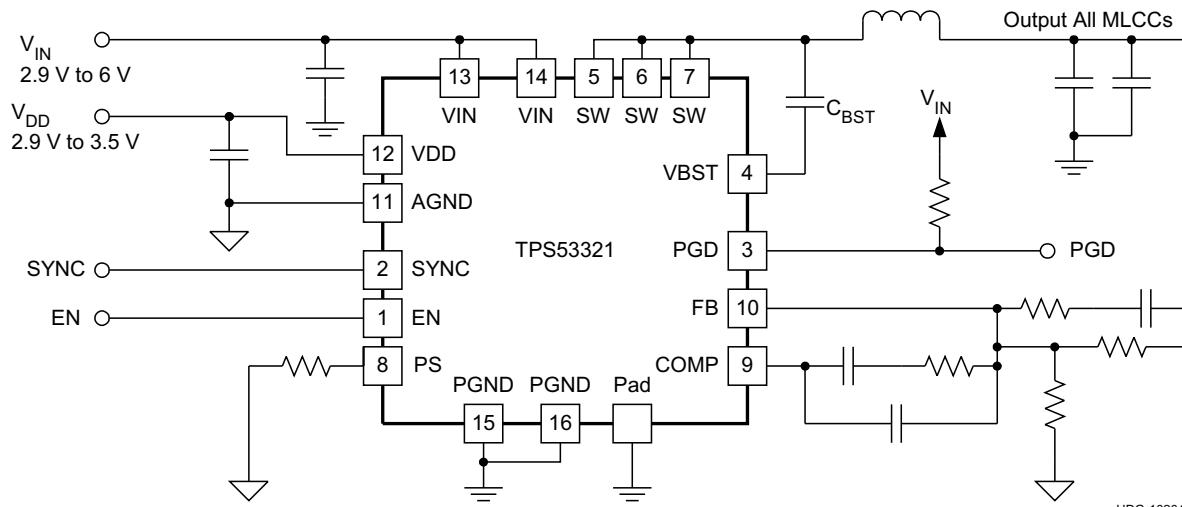
TPS53321は3mm×3mmの16ピンQFNパッケージ(Green RoHS準拠、鉛フリー)で供給され、-40°C～85°Cで動作します。

製品情報⁽¹⁾

| 型番 | パッケージ | 本体サイズ(公称) |
|----------|----------|---------------|
| TPS53321 | QFN (16) | 3.00mm×3.00mm |

(1) 提供されているすべてのパッケージについては、データシートの末尾にある注文情報を参照してください。

代表的なアプリケーション回路



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English Data Sheet: SLUSAFA3

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4 改訂履歴

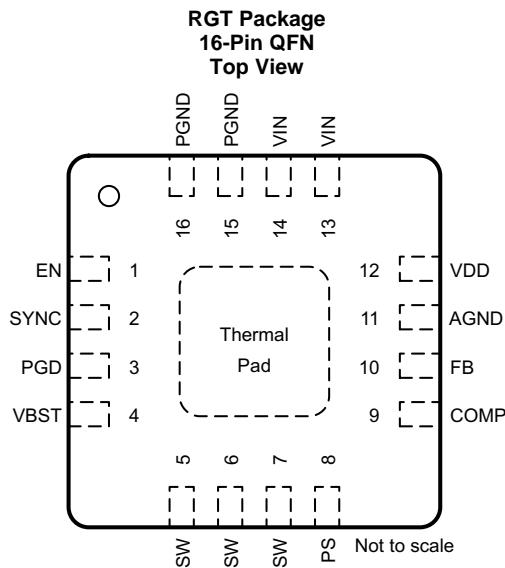
資料番号末尾の英字は改訂を表しています。その改訂履歴は英語版に準じています。

2010年12月発行のものから更新

Page

| | |
|--|----|
| • 「ESD定格」表、「機能説明」セクション、「デバイスの機能モード」セクション、「アプリケーションと実装」セクション、「電源に関する推奨事項」セクション、「レイアウト」セクション、「デバイスおよびドキュメントのサポート」セクション、「メカニカル、パッケージ、および注文情報」セクション 追加 | 1 |
| • データシートの末尾にあるPOAを参照し、「注文情報」表を削除 | 1 |
| • Deleted Lead temperature, 1.6 mm (1/16 inch) from case for 10 seconds: 300°C | 4 |
| • Deleted Package Dissipation Ratings table | 5 |
| • Added Thermal Information table | 5 |
| • Changed R2 value in Typical 3.3-V Input Application Circuit Diagram From: 4.02 kΩ To: 2.67 kΩ | 12 |
| • Changed R2 value in Master and Slave Configuration Schematic From: 4.02 kΩ To: 2.67 kΩ | 16 |
| • Changed R12 value in Master and Slave Configuration Schematic From: 2.67 kΩ To: 4.02 kΩ | 16 |

5 Pin Configuration and Functions



Pin Functions

| PIN | | TYPE ⁽¹⁾ | DESCRIPTION |
|-----|------|---------------------|--|
| NO. | NAME | | |
| 1 | EN | I | Enable. Internally pulled up to VDD with a 1.35-MΩ resistor. |
| 2 | SYNC | B | Synchronization signal for input interleaving. Master SYNC pin sends out 180° out-of-phase signal to slave SYNC. SYNC frequency must be within ±20% of slave nominal frequency. |
| 3 | PGD | O | Power good output flag. Open-drain output. Pull up to an external rail through a resistor. |
| 4 | VBST | P | Supply input for high-side MOSFET (bootstrap terminal). Connect capacitor from this pin to SW terminal. |
| 5 | SW | B | Output inductor connection to integrated power devices |
| 6 | SW | B | Output inductor connection to integrated power devices |
| 7 | SW | B | Output inductor connection to integrated power devices |
| 8 | PS | I | Mode configuration pin (with 10-µA current): Connecting to ground: FCCM slave Pulled high or floating (internal pulled high): FCCM master Connect a 24.3-kΩ resistor to GND: DE slave Connect a 57.6-kΩ resistor to GND: HEF mode Connect a 105-kΩ resistor to GND : reserved mode Connect a 174-kΩ resistor to GND: DE master |
| 9 | COMP | O | Error amplifier compensation terminal. Type III compensation method is recommended for stability. |
| 10 | FB | I | Voltage feedback. Also used for OVP, UVP, and PGD determination. |
| 11 | AGND | G | Device analog ground terminal |
| 12 | VDD | P | Input bias supply for analog functions |
| 13 | VIN | P | Gate driver supply and power conversion voltage input |
| 14 | VIN | P | Gate driver supply and power conversion voltage input |
| 15 | PGND | P | IC power GND terminal |
| 16 | PGND | P | IC power GND terminal |

(1) B = Bidirectional, G = Ground, I = Input, O = Output, P = Supply

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾

| | | MIN | MAX | UNIT |
|---------------------------------------|--------------------------|-------------------------|------|------|
| Input voltage | VIN, EN | −0.3 | 7 | V |
| | VBST | −0.3 | 17 | |
| | VBST(with respect to SW) | −0.3 | 7 | |
| | FB, PS, VDD | −0.3 | 3.7 | |
| Output voltage | SW | DC | −0.3 | V |
| | | Pulse < 20 ns, E = 5 μJ | −3 | |
| | PGD | −0.3 | 7 | |
| | COMP, SYNC | −0.3 | 3.7 | |
| | PGND | −0.3 | 0.3 | |
| Junction temperature, T _J | | −40 | 150 | °C |
| Ambient temperature, T _A | | −40 | 85 | °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, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

6.2 ESD Ratings

| | | VALUE | UNIT |
|--------------------|-------------------------|--|-------|
| V _(ESD) | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾ | ±2000 |
| | | Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾ | ±500 |

(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.

6.3 Recommended Operating Conditions

| | | MIN | NOM | MAX | UNIT |
|----------------|--------------------------|------|-----|------|------|
| Input voltage | VIN | 2.9 | | 6 | V |
| | VDD | 2.9 | 3.3 | 3.5 | |
| | VBST | −0.1 | | 13.5 | |
| | VBST(with respect to SW) | −0.1 | | 6 | |
| | EN | −0.1 | | 6 | |
| | FB, PS | −0.1 | | 3.5 | |
| Output voltage | SW | −1 | | 6.5 | V |
| | PGD | −0.1 | | 6 | |
| | COMP, SYNC | −0.1 | | 3.5 | |
| | PGND | −0.1 | | 0.1 | |
| T _J | Junction temperature | −40 | | 125 | °C |

6.4 Thermal Information

| THERMAL METRIC ⁽¹⁾ | | TPS53321 | UNIT |
|-------------------------------|--|-----------|------|
| | | RGT (QFN) | |
| | | 16 PINS | |
| R _{θJA} | Junction-to-ambient thermal resistance | 42.8 | °C/W |
| R _{θJC(top)} | Junction-to-case (top) thermal resistance | 51.3 | °C/W |
| R _{θJB} | Junction-to-board thermal resistance | 16 | °C/W |
| Ψ _{JT} | Junction-to-top characterization parameter | 0.7 | °C/W |
| Ψ _{JB} | Junction-to-board characterization parameter | 16 | °C/W |
| R _{θJC(bot)} | Junction-to-case (bottom) thermal resistance | 4.4 | °C/W |

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

6.5 Electrical Characteristics

over recommended free-air temperature range, V_{IN} = 3.3 V, V_{VDD} = 3.3 V, and PGND = GND (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT | |
|---|---|--|--------|-------|------|----|
| SUPPLY: VOLTAGE, CURRENTS, and UVLO | | | | | | |
| V _{IN} | VIN supply voltage | Nominal input voltage range | 2.9 | 6 | V | |
| I _{VINSDN} | VIN shutdown current | EN = LO | | 3 | µA | |
| V _{UVLO} | VIN UVLO threshold | Ramp up, EN = HI | | 2.8 | V | |
| V _{UVLOHYS} | VIN UVLO hysteresis | VIN UVLO Hysteresis | | 130 | mV | |
| V _{DD} | Internal circuitry supply voltage | Nominal 3.3-V input voltage range | 2.9 | 3.3 | 3.5 | V |
| I _{DDSDN} | VDD shutdown current | EN = LO | | 5 | µA | |
| I _{DD} | Standby current | EN = HI, no switching | | 2.2 | 3.5 | mA |
| V _{DDUVLO} | 3.3-V UVLO threshold | Ramp up, EN = HI | | 2.8 | V | |
| V _{DDUVLOHYS} | 3.3-V UVLO hysteresis | | | 75 | mV | |
| VOLTAGE FEEDBACK LOOP: VREF AND ERROR AMPLIFIER | | | | | | |
| V _{VREF} | VREF | Internal precision reference voltage | 0.6 | | V | |
| TOLV _{REF} | VREF Tolerance | 0°C ≤ T _A ≤ 85°C | -1% | 1% | | |
| | | -40°C ≤ T _A ≤ 85°C | -1.25% | 1.25% | | |
| UGBW ⁽¹⁾ | Unity gain bandwidth | | 14 | | MHz | |
| A _{OL} ⁽¹⁾ | Open-loop gain | | 80 | | dB | |
| I _{FBINT} | FB input leakage current | Sourced from FB pin | | 30 | nA | |
| I _{EA} MAX ⁽¹⁾ | Output sinking and sourcing current | C _{COMP} = 20 pF | | 5 | mA | |
| SR ⁽¹⁾ | Slew rate | | | 5 | V/µs | |
| OCP: OVERCURRENT AND ZERO CROSSING | | | | | | |
| I _{OCPL} | Overcurrent limit on upper FET | When I _{OUT} exceeds this threshold for 4 consecutive cycles. V _{IN} =3.3 V, V _{OUT} =1.5 V with 1-µH inductor, T _A = 25°C | 6 | 6.5 | 7 | A |
| I _{OCPH} | One time overcurrent latch off on the lower FET | Immediately shuts down when sensed current reach this value. V _{IN} =3.3 V, V _{OUT} =1.5 V with 1-µH inductor, T _A = 25°C | 6.25 | 6.8 | 7.35 | A |
| t _{HICCUP} | Hiccup time interval | | 12.5 | 14.5 | 16.5 | ms |
| V _{ZXOFF} ⁽¹⁾ | Zero crossing comparator internal offset | PGND – SW, skip mode | -4.5 | -3 | -1.5 | mV |
| PROTECTION: OVP, UVP, PGD, AND INTERNAL THERMAL SHUTDOWN | | | | | | |
| V _{OVP} | Ovoltage protection threshold voltage | Measured at FB w/r/t VREF | 114% | 117% | 120% | |
| V _{UVP} | Undervoltage protection threshold voltage | Measured at FB w/r/t VREF | 80% | 83% | 86% | |

(1) Ensured by design. Not production tested.

Electrical Characteristics (continued)

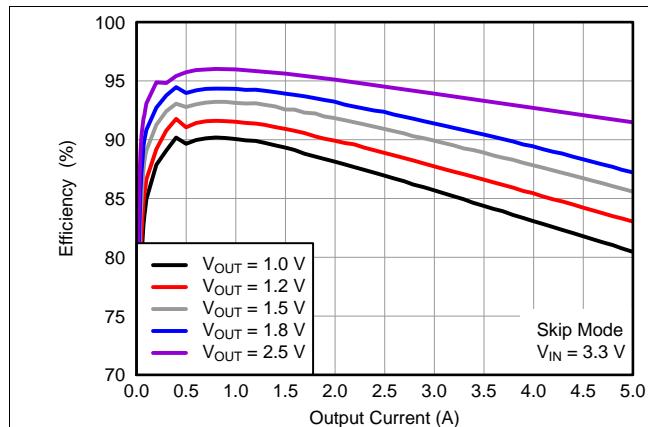
over recommended free-air temperature range, $V_{IN} = 3.3$ V, $V_{VDD} = 3.3$ V, and $PGND = GND$ (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--|--|--|------|------------|------|
| V_{PGDL} | PGD low threshold | Measured at FB w/r/t VREF | 80% | 83% | 86% |
| V_{PGDU} | PGD upper threshold | Measured at FB w/r/t VREF | 114% | 117% | 120% |
| $V_{INMINPG}$ | Minimum V_{IN} voltage for valid PGD at start-up | Measured at V_{IN} with 1-mA (or 2-mA) sink current on PGD pin at start-up | 1 | | V |
| $THSD^{(1)}$ | Thermal shutdown | Latch off controller, attempt soft-stop | 130 | 140 | 150 |
| $THSD_{HYS}^{(1)}$ | Thermal shutdown hysteresis | Controller restarts after temperature has dropped | 40 | | °C |
| LOGIC PINS: I/O VOLTAGE AND CURRENT | | | | | |
| V_{PGPD} | PGD pulldown voltage | Pulldown voltage with 4-mA sink current | 0.2 | 0.4 | V |
| I_{PGLK} | PGD leakage current | Hi-Z leakage current, apply 3.3-V in off state | -2 | 0 | 2 |
| R_{ENPU} | Enable pullup resistor | | 1.35 | | MΩ |
| V_{ENH} | EN logic high threshold | | 1.1 | 1.18 | 1.3 |
| V_{ENHYS} | EN hysteresis | | 0.18 | 0.24 | V |
| PS_{THS} | PS mode threshold voltage | Level 1 to level 2 ⁽²⁾ | 0.12 | V | |
| | | Level 2 to level 3 | 0.4 | | |
| | | Level 3 to level 4 | 0.8 | | |
| | | Level 4 to level 5 | 1.4 | | |
| | | Level 5 to level 6 | 2.2 | | |
| I_{PS} | PS source | 10-µA pullup current when enabled | 8 | 10 | 12 |
| f_{SYNCSL} | Slave SYNC frequency range | Versus nominal switching frequency | -20% | 20% | |
| PW_{SYNC} | SYNC low pulse width | | 110 | | ns |
| I_{SYNC} | SYNC pin sink current | $T_A = 25^\circ C$ | 10 | | µA |
| $V_{SYNCTHS}^{(1)}$ | SYNC threshold | Falling edge | 1 | | V |
| $V_{SYNCHYS}^{(1)}$ | SYNC hysteresis | | 0.5 | | V |
| BOOT STRAP: VOLTAGE AND LEAKAGE CURRENT | | | | | |
| I_{VBSTLK} | VBST leakage current | $V_{IN} = 3.3$ V, $V_{VBST} = 6.6$ V, $T_A = 25^\circ C$ | | 1 | µA |
| TIMERS: SS, FREQUENCY, RAMP, ON-TIME AND I/O TIMING | | | | | |
| t_{SS_1} | Delay after EN asserting | EN = HI, master or HEF mode | 0.2 | | ms |
| t_{SS_2} | Delay after EN asserting | EN = HI, slave waiting time | 0.5 | | ms |
| t_{SS_3} | Soft-start ramp-up time | Rising from $V_{SS} = 0$ V to $V_{SS} = 0.6$ V | 0.4 | | ms |
| $t_{PGDENDLY}$ | PGD start-up delay time | Rising from $V_{SS} = 0$ V to $V_{SS} = 0.6$ V, from V_{SS} reaching 0.6 V to V_{PGD} going high | 1.2 | | ms |
| t_{OVPDLY} | Ovoltage protection delay time | Time from FB out of +20% of VREF to OVP fault | 1 | 1.7 | 2.5 |
| t_{UVPDLY} | Undervoltage protection delay time | Time from FB out of -20% of VREF to UVP fault | 11 | | µs |
| f_{SW} | Switching frequency control | FCCM | 0.99 | 1.1 | 1.21 |
| | Ramp amplitude ⁽¹⁾ | $2.9 \text{ V} < V_{IN} < 6.0 \text{ V}$ | | $V_{IN}/4$ | V |
| $t_{MIN(off)}$ | Minimum OFF time | FCCM or DE mode | 100 | 140 | ns |
| | | HEF mode | 175 | 250 | |
| D_{MAX} | Maximum duty cycle, FCCM and DE mode | $f_{SW} = 1.1 \text{ MHz}, 0^\circ C \leq T_A \leq 85^\circ C$ | 84% | 89% | |
| | Maximum duty cycle, HEF mode | $f_{SW} = 1.1 \text{ MHz}, 0^\circ C \leq T_A \leq 85^\circ C$ | 75% | 81% | |
| R_{SFTSTP} | Soft-discharge transistor resistance | $V_{EN} = \text{Low}, V_{IN} = 3.3 \text{ V}, V_{OUT} = 0.5 \text{ V}$ | 60 | | Ω |

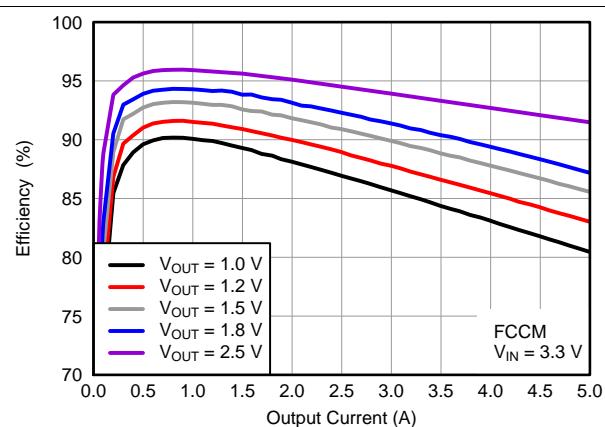
(2) See PS pin description for levels.

6.6 Typical Characteristics

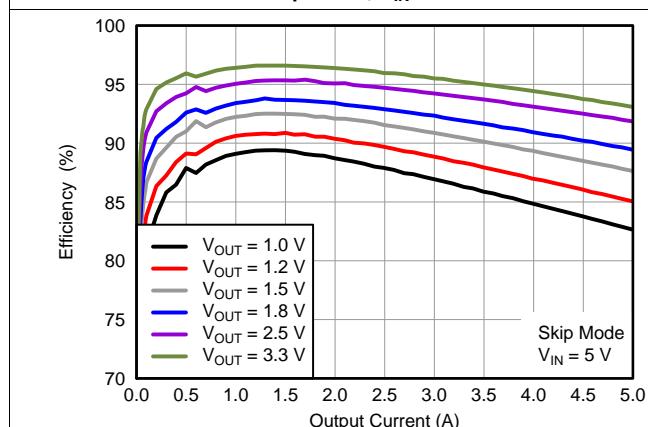
Inductor PCMC065T-1R0 (1 μ H, 5.6 m Ω) is used.



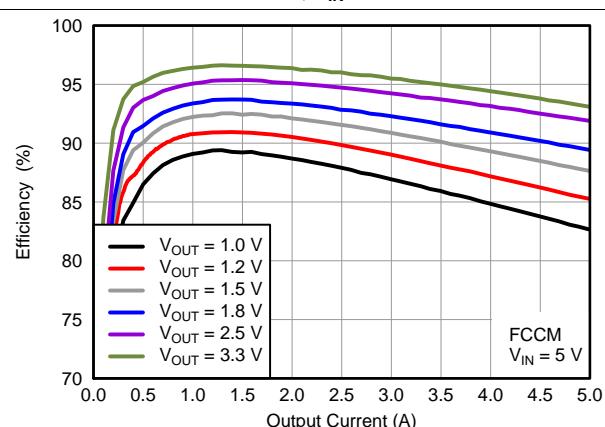
**Figure 1. Efficiency vs Output Current,
Skip Mode, $V_{IN} = 3.3$ V**



**Figure 2. Efficiency vs Output Current,
FCCM, $V_{IN} = 3.3$ V**



**Figure 3. Efficiency vs Output Current,
Skip Mode, $V_{IN} = 5$ V**



**Figure 4. Efficiency vs Output Current,
FCCM, $V_{IN} = 5$ V**

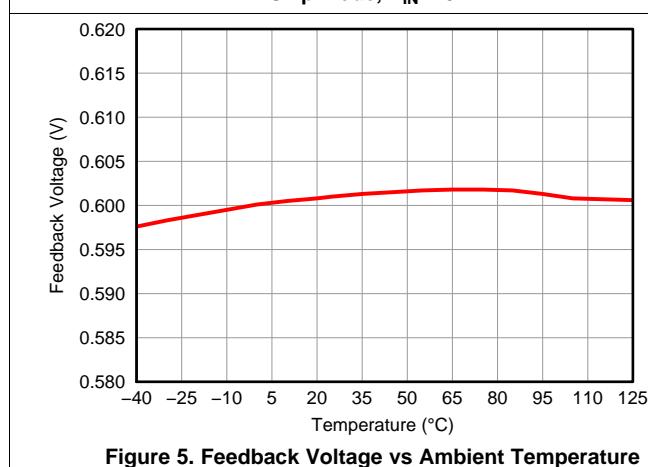


Figure 5. Feedback Voltage vs Ambient Temperature

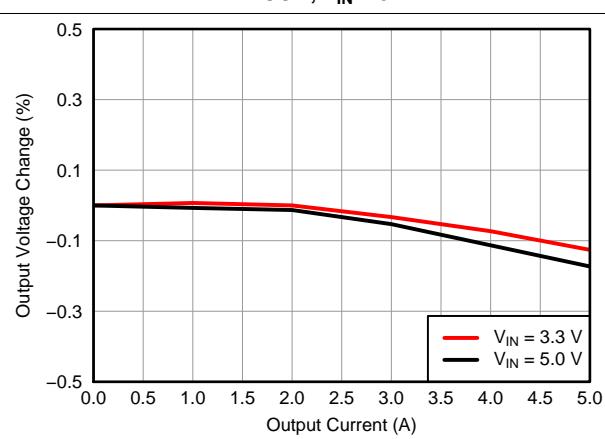


Figure 6. Output Voltage Change vs Output Current

Typical Characteristics (continued)

Inductor PCMC065T-1R0 (1 μ H, 5.6 m Ω) is used.

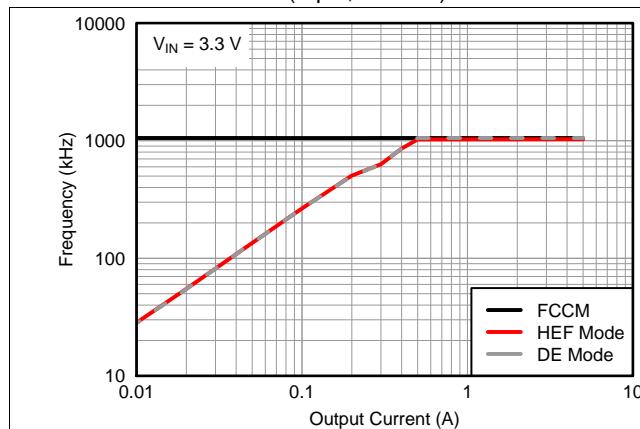


Figure 7. Frequency vs Output Current at $V_{IN} = 3.3$ V

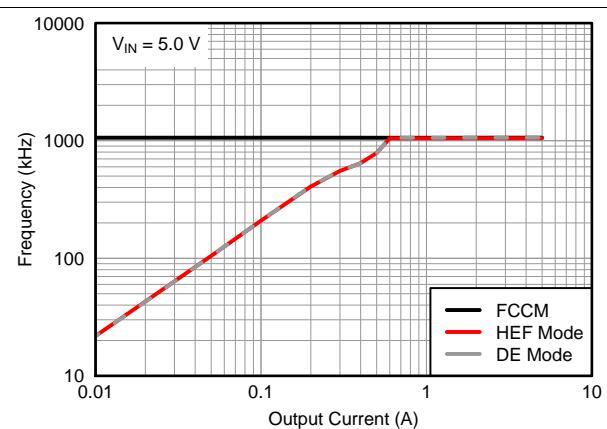


Figure 8. Frequency vs Output Current at $V_{IN} = 5$ V

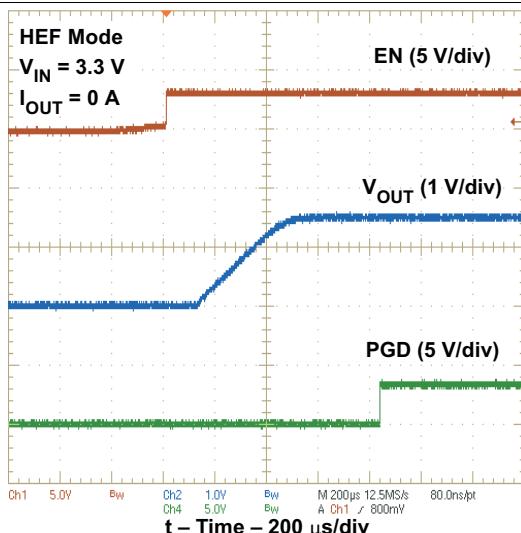


Figure 9. Normal Start-Up Waveform

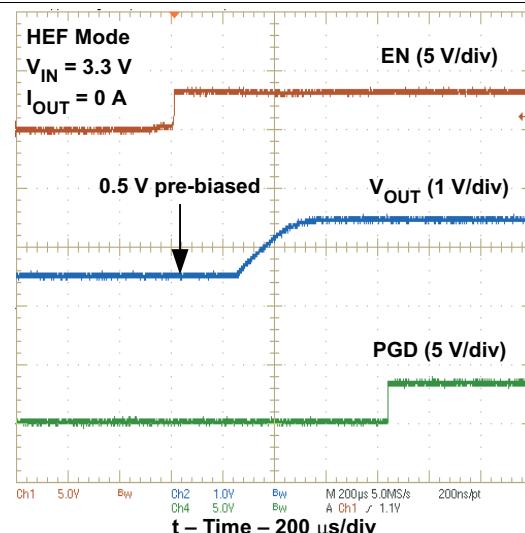


Figure 10. Prebias Start-Up Waveform

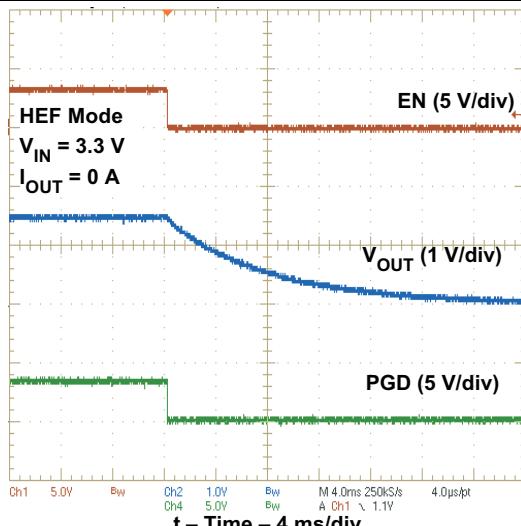


Figure 11. Soft-Stop Waveform

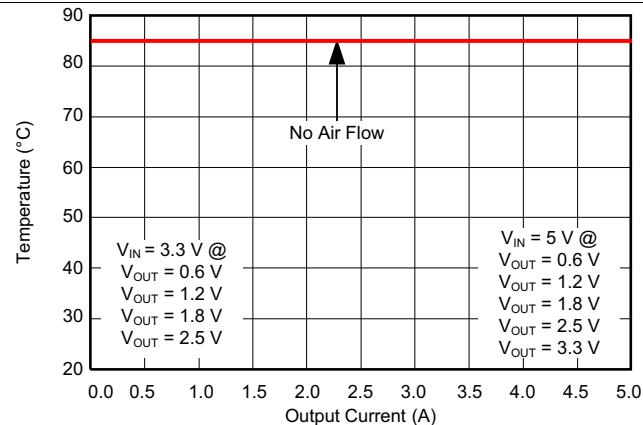


Figure 12. Safe Operating Area

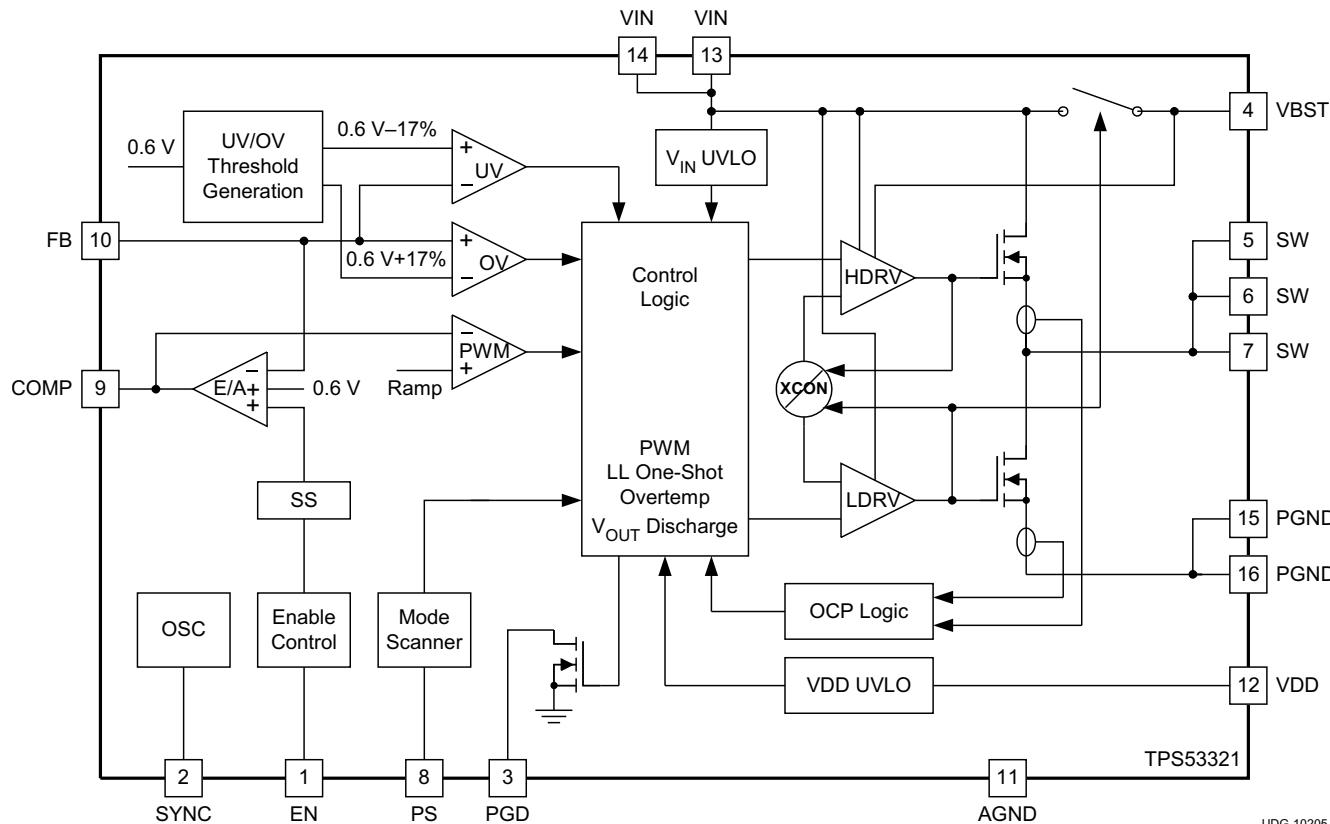
7 Detailed Description

7.1 Overview

The TPS53321 is a high-efficiency switching regulator with two integrated N-channel MOSFETs and is capable of delivering up to 5 A of load current. The TPS53321 provides output voltage between 0.6 V and $0.84 \times V_{IN}$ from 2.9 V to 6 V wide input voltage range.

This device employs five operation modes to fit various application requirements. The *master or slave* mode enables a two-phase interleaved operation to reduce input ripple. The *skip* mode operation provides reduced power loss and increases the efficiency at light load. The unique, patented PWM modulator enables smooth light load to heavy load transition while maintaining fast load transient.

7.2 Functional Block Diagram



UDG-10205

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7.3 Feature Description

7.3.1 Soft Start

The soft-start function reduces the inrush current during the start up sequence. A slow-rising reference voltage is generated by the soft-start circuitry and sent to the input of the error amplifier. When the soft-start ramp voltage is less than 600 mV, the error amplifier uses this ramp voltage as the reference. When the ramp voltage reaches 600 mV, the error amplifier switches to a fixed 600-mV reference. The typical soft-start time is 400 μ s.

7.3.2 Power Good

The TPS53321 monitors the voltage on the FB pin. If the FB voltage is between 83% and 117% of the reference voltage, the power good signal remains high. If the FB voltage falls outside of these limits, the internal open-drain output pulls the power good pin (PGD) low.

Feature Description (continued)

During start-up, V_{IN} must be higher than 1 V to have valid power good logic, and the power good signal is delayed for 1.2 ms after the FB voltage falls to within the power good limits. There is also 10- μ s delay during the shutdown sequence.

7.3.3 Undervoltage Lockout (UVLO) Protection

The TPS53321 provides undervoltage lockout (UVLO) protection for both power input (V_{IN}) and bias input (V_{DD}) voltage. If either of them is lower than the UVLO threshold voltage minus the hysteresis, the device shuts off. When the voltage rises above the threshold voltage, the device restarts. The typical UVLO rising threshold is 2.8 V for both V_{IN} and V_{DD} . A hysteresis voltage of 130 mV for V_{IN} and 75 mV for V_{DD} is also provided to prevent glitch.

7.3.4 Overcurrent Protection

The TPS53321 continuously monitors the current flowing through the high-side and the low-side MOSFETs. If the current through the high-side FET exceeds 6.5 A, the high-side FET turns off and the low-side FET turns on until the next PWM cycle. An overcurrent (OC) counter starts to increment each occurrence of an overcurrent event. The converter shuts down immediately when the OC counter reaches four. The OC counter resets if the detected current is less 6.5 A after an OC event.

Another set of overcurrent circuitry monitors the current flowing through low-side FET. If the current through the low-side FET exceeds 6.8 A, the overcurrent protection is enabled and immediately turns off both the high-side and the low-side FETs and shuts down the converter. The device is fully protected against overcurrent during both on-time and off-time. The device attempts to restart after a hiccup delay of 14.5 ms (typical). If the overcurrent condition clears before restart, the device starts up normally.

7.3.5 Overvoltage Protection

The TPS53321 monitors the voltage divided feedback voltage to detect overvoltage and undervoltage conditions. When the feedback voltage is greater than 117% of the reference, the high-side MOSFET turns off and the low-side MOSFET turns on. The output voltage then drops until it reaches the undervoltage threshold. At that point the low-side MOSFET turns off and the device enters a high-impedance state.

7.3.6 Undervoltage Protection

When the feedback voltage is lower than 83% of the reference voltage, the undervoltage protection timer starts. If the feedback voltage remains lower than the undervoltage threshold voltage after 10 μ s, the device turns off both the high-side and the low-side MOSFETs and goes into a high-impedance state. The device attempts to restart after a hiccup delay of 14.5 ms (typical).

7.3.7 Overtemperature Protection

The TPS53321 continuously monitors the die temperature. If the die temperature exceeds the threshold value (140°C typical), the device shuts off. When the device temperature falls to 40°C below the overtemperature threshold, it restarts and returns to normal operation.

7.3.8 Output Discharge

When the enable pin is low, the TPS53321 discharges the output capacitors through an internal MOSFET switch between SW and PGND while high-side and low-side MOSFETs remain off. The typical discharge switch ON-resistance is 60 Ω . This function is disabled when V_{IN} is less than 1 V.

7.3.9 Master and Slave Operation and Synchronization

Two TPS53321 can operate interleaved when configured as master and slave. The SYNC pins of the two devices are connected together for synchronization. In CCM, the master device sends the 180° out-of-phase pulse to the slave device through the SYNC pin, which determines the leading edge of the PWM pulse. If the slave device does not receive the SYNC pulse from the master device or if the SYNC connection is broken during operation, the slave device continues to operate using its own internal clock.

Feature Description (continued)

In DE mode, the master and slave switching node does not synchronize to each other if either one of them is operating in DCM. When both master and slave enter CCM, the switching nodes of the master and the slave synchronize to each other.

The SYNC pin of the slave device can also connect to external clock source within $\pm 20\%$ of the 1.1-MHz switching frequency. The falling edge of the SYNC triggers the rising edge of the PWM signal.

7.4 Device Functional Modes

7.4.1 Operation Modes

The TPS53321 offers five operation modes determined by the PS pin connections listed in [Table 1](#).

Table 1. Operation Mode Selection

| PS PIN CONNECTION | OPERATION MODE | AUTO-SKIP AT LIGHT LOAD | MASTER/SLAVE SUPPORT |
|---------------------------|----------------|-------------------------|----------------------|
| GND | FCCM Slave | — | Slave |
| 24.3 k Ω to GND | DE Slave | Yes | Slave |
| 57.6 k Ω to GND | HEF Mode | Yes | — |
| 174 k Ω to GND | DE Master | Yes | Master |
| Floating or pulled to VDD | FCCM Master | — | Master |

In *forced continuous conduction mode* (FCCM), the high-side FET is ON during the on-time and the low-side FET is ON during the off-time. The switching is synchronized to the internal clock thus the switching frequency is fixed.

In *diode emulation* (DE) mode, the high-side FET is ON during the on-time and low-side FET is ON during the off-time until the inductor current reaches zero. An internal zero-crossing comparator detects the zero crossing of inductor current from positive to negative. When the inductor current reaches zero, the comparator sends a signal to the logic control and turns off the low-side FET.

When the load is increased, the inductor current is always positive and the zero-crossing comparator does not send a zero-crossing signal. The converter enters into *continuous conduction mode* (CCM) when no zero-crossing is detected for two consecutive PWM pulses. The switching synchronizes to the internal clock and the switching frequency is fixed.

In *high-efficiency* (HEF) mode, the operation is the same as DE mode at light load. However, the converter does not synchronize to the internal clock during CCM. Instead, the PWM modulator determines the switching frequency.

7.4.2 Eco-Mode™ Light-Load Operation

In skip modes (DE and HEF) when the load current is less than one-half of the inductor peak current, the inductor current becomes negative by the end of off-time. During light load operation, the low-side MOSFET is turned off when the inductor current reaches zero. The energy delivered to the load per switching cycle is increased compared to the normal PWM mode operation and the switching frequency is reduced. The switching loss is reduced, thereby improving efficiency.

In both DE and HEF mode, the switching frequency is reduced in discontinuous conduction mode (DCM). When the load current is 0 A, the minimum switching frequency is reached. The difference between V_{VBST} and V_{SW} must be maintained at a value higher than 2.4 V.

7.4.3 Forced Continuous Conduction Mode (FCCM)

When the PS pin is grounded or greater than 2.2 V, the TPS53321 is operating in *forced continuous conduction mode* in both light-load and heavy-load conditions. In this mode, the switching frequency remains constant over the entire load range, making it suitable for applications that require tight control of switching frequency at a cost of lower efficiency at light load.

8 Application and Implementation

NOTE

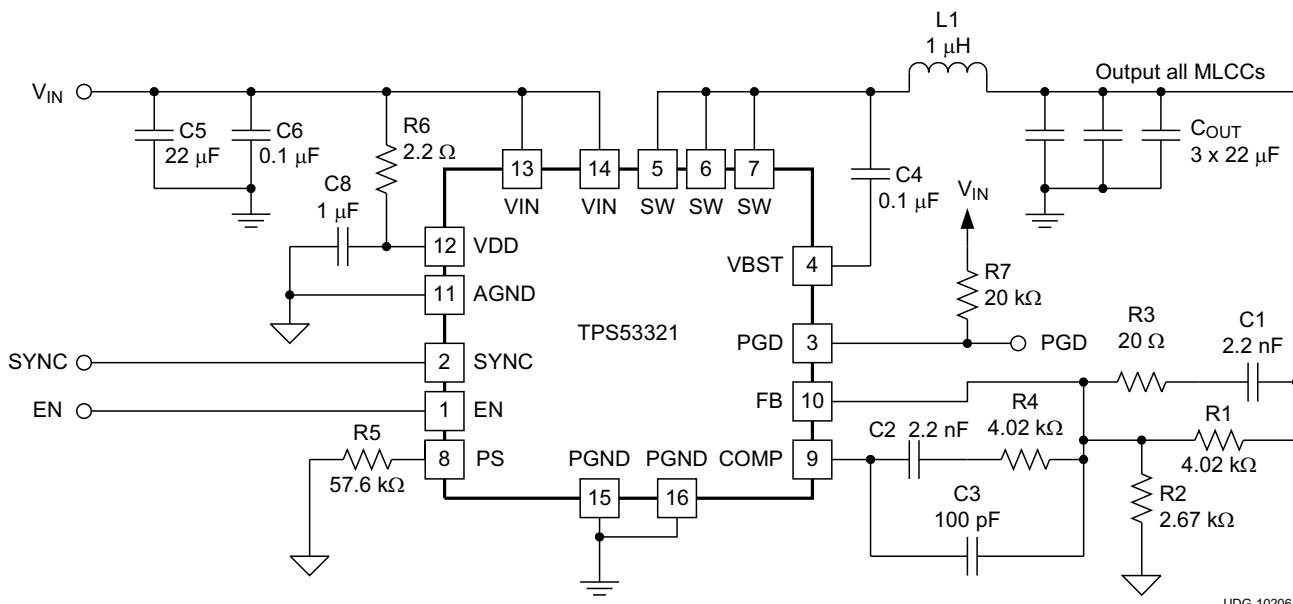
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation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

8.1 Application Information

The TPS53321 device is a high-efficiency synchronous-buck converter. The device suits low output voltage point-of-load applications with 5-A or lower output current in computing and similar digital consumer applications.

8.2 Typical Application

This design example describes a voltage-mode, 5-A synchronous buck converter with integrated MOSFETs. The device provides a fixed 1.5-V output at up to 5 A from a 3.3-V input bus.



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Figure 13. Typical 3.3-V Input Application Circuit Diagram

8.2.1 Design Requirements

Table 2 lists the design specifications for this application example.

Table 2. TPS53321 Design Example Specifications

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|------------------------------|------------------------|-----|------|-----|------|
| INPUT CHARACTERISTICS | | | | | |
| Input voltage, VIN | Vin | 2.9 | 3.3 | 6 | V |
| Maximum input current | Vin = 3.3 V, 1.5 V/5 A | | 2.67 | | A |
| No load input current | Vin = 3.3 V, 1.5 V/0 A | | 12.5 | | mA |

Typical Application (continued)

Table 2. TPS53321 Design Example Specifications (continued)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|-------------------------------|--|--------|-----|-------|--------------------|
| OUTPUT CHARACTERISTICS | | | | | |
| Output voltage, V_o | | 1.485 | 1.5 | 1.515 | V |
| Output voltage regulation | Line regulation | 0.1% | | | |
| | Load regulation | 1% | | | |
| Output voltage ripple | $V_{in} = 3.3\text{ V}, 1.5\text{ V}/0\text{ A}$ to 5 A | | | 20 | mV_{pp} |
| Output load current | | 0 | | 5 | A |
| Output over current | | | 6.5 | | A |
| OUTPUT CHARACTERISTICS | | | | | |
| Switching frequency | Fixed | 1.1 | | | MHz |
| 1.5-V full load efficiency | $V_{in} = 3.3\text{ V}, 1.5\text{ V}/5\text{ A}$ | 85.94% | | | |
| | $V_{in} = 5\text{ V}, 1.5\text{ V}/5\text{ A}$ | 87% | | | |
| Operating temperature | | 25 | | | $^{\circ}\text{C}$ |

8.2.2 Detailed Design Procedure

8.2.2.1 Determine the Value of R_1 and R_2

The output voltage is programmed by the voltage-divider resistor, R_1 and R_2 shown in [Figure 13](#). R_1 is connected between the FB pin and the output, and R_2 is connected between the FB pin and GND. The recommended value for R_1 is from $1\text{ k}\Omega$ to $5\text{ k}\Omega$. Determine R_2 using equation in [Equation 1](#).

$$R_2 = \frac{0.6}{V_{OUT} - 0.6} \times R_1 \quad (1)$$

8.2.2.2 Choose the Inductor

The inductance value must be determined to give the ripple current of approximately 20% to 40% of maximum output current. The inductor ripple current is determined by [Equation 2](#).

$$I_{L(\text{ripple})} = \frac{1}{L \times f_{SW}} \times \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{V_{IN}} \quad (2)$$

The inductor also requires low DCR to achieve good efficiency, as well as enough room above peak inductor current before saturation.

8.2.2.3 Choose the Output Capacitor(s)

The output capacitor selection is determined by output ripple and transient requirement. When operating in CC mode, the output ripple has three components calculated with [Equation 3](#) through [Equation 6](#).

$$V_{\text{RIPPLE}} = V_{\text{RIPPLE}(C)} + V_{\text{RIPPLE}(ESR)} + V_{\text{RIPPLE}(ESL)} \quad (3)$$

$$V_{\text{RIPPLE}(C)} = \frac{I_{L(\text{ripple})}}{8 \times C_{\text{OUT}} \times f_{SW}} \quad (4)$$

$$V_{\text{RIPPLE}(ESR)} = I_{L(\text{ripple})} \times ESR \quad (5)$$

$$V_{\text{RIPPLE}(ESL)} = \frac{V_{IN} \times ESL}{L} \quad (6)$$

When ceramic output capacitors are used, the ESL component is usually negligible. In the case when multiple output capacitors are used, ESR and ESL must be the equivalent of ESR and ESL of all the output capacitor in parallel.

When operating in DCM, the output ripple is dominated by the component determined by capacitance. It also varies with load current and can be expressed as shown in [Equation 7](#).

$$V_{\text{RIPPLE}(\text{DCM})} = \frac{(\alpha \times I_{\text{L}(\text{ripple})} - I_{\text{OUT}})^2}{2 \times C_{\text{OUT}} \times f_{\text{SW}} \times I_{\text{L}(\text{ripple})}}$$

where

- α is the DCM on-time coefficient and can be expressed in [Equation 8](#) (typical value 1.25)

$$\alpha = \frac{t_{\text{ON}(\text{DCM})}}{t_{\text{ON}(\text{CCM})}} \quad (8)$$

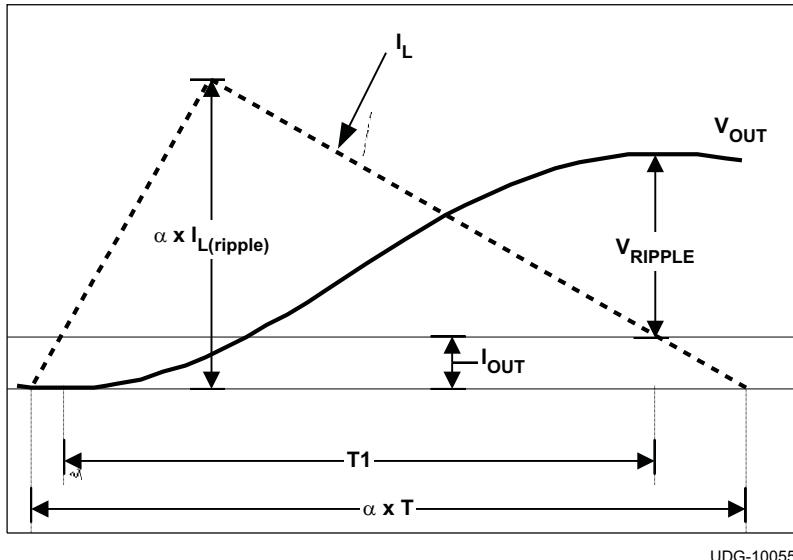


Figure 14. DCM V_{OUT} Ripple Calculation

8.2.2.4 Choose the Input Capacitor

The selection of input capacitor must be determined by the ripple current requirement. The ripple current generated by the converter must be absorbed by the input capacitors as well as the input source. The RMS ripple current from the converter can be expressed in [Equation 9](#).

$$I_{\text{IN}(\text{ripple})} = I_{\text{OUT}} \times \sqrt{D \times (1-D)}$$

where

- D is the duty cycle and can be expressed as shown in [Equation 10](#)

$$D = \frac{V_{\text{OUT}}}{V_{\text{IN}}} \quad (10)$$

To minimize the ripple current drawn from the input source, sufficient input decoupling capacitors must be placed close to the device. The ceramic capacitor is recommended because it provides low ESR and low ESL. The input voltage ripple can be calculated as shown in [Equation 11](#) when the total input capacitance is determined.

$$V_{\text{IN}(\text{ripple})} = \frac{I_{\text{OUT}} \times D}{f_{\text{SW}} \times C_{\text{IN}}} \quad (11)$$

8.2.2.5 Compensation Design

The TPS53321 uses voltage mode control. To effectively compensate the power stage and ensure fast transient response, Type III compensation is typically used.

The control to output transfer function can be described in [Equation 12](#).

$$G_{CO} = 4 \times \frac{1 + s \times C_{OUT} \times ESR}{1 + s \times \left(\frac{L}{DCR + R_{LOAD}} + C_{OUT} \times (ESR + DCR) \right) + s^2 \times L \times C_{OUT}} \quad (12)$$

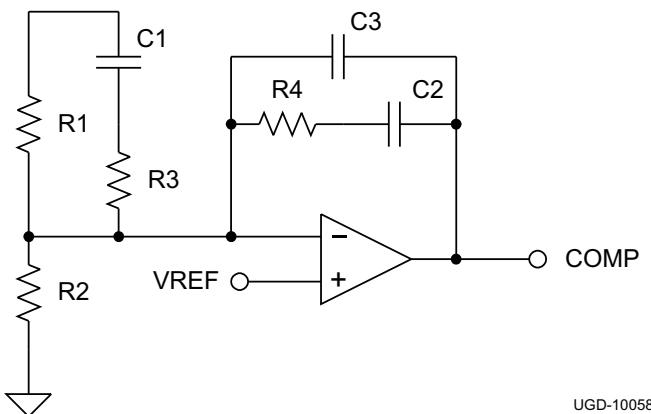
The output L-C filter introduces a double pole which can be calculated as shown in [Equation 13](#).

$$f_{DP} = \frac{1}{2 \times \pi \times \sqrt{L \times C_{OUT}}} \quad (13)$$

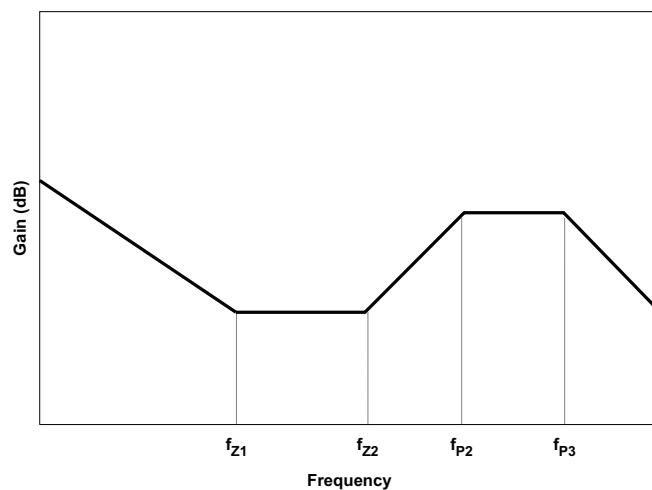
The ESR zero can be calculated as shown in [Equation 14](#).

$$f_{ESR} = \frac{1}{2 \times \pi \times ESR \times C_{OUT}} \quad (14)$$

[Figure 15](#) and [Figure 16](#) show the configuration of Type III compensation and typical pole and zero locations. [Equation 16](#) through [Equation 20](#) describe the compensator transfer function and poles and zeros of the Type III network.



UGD-10058



UDG-10057

Figure 15. Type III Compensation Network Configuration Schematic

Figure 16. Type III Compensation Gain Plot and Zero/Pole Placement

$$G_{EA} = \frac{(1 + s \times C_1 \times (R_1 + R_3))(1 + s \times R_4 \times C_2)}{(s \times R_1 \times (C_2 + C_3)) \times (1 + s \times C_1 \times R_3) \times \left(1 + s \times R_4 \frac{C_2 \times C_3}{C_2 + C_3}\right)} \quad (15)$$

$$f_{z1} = \frac{1}{2 \times \pi \times R_4 \times C_2} \quad (16)$$

$$f_{z2} = \frac{1}{2 \times \pi \times (R_1 + R_3) \times C_1} \approx \frac{1}{2 \times \pi \times R_1 \times C_1} \quad (17)$$

$$f_{p1} = 0 \quad (18)$$

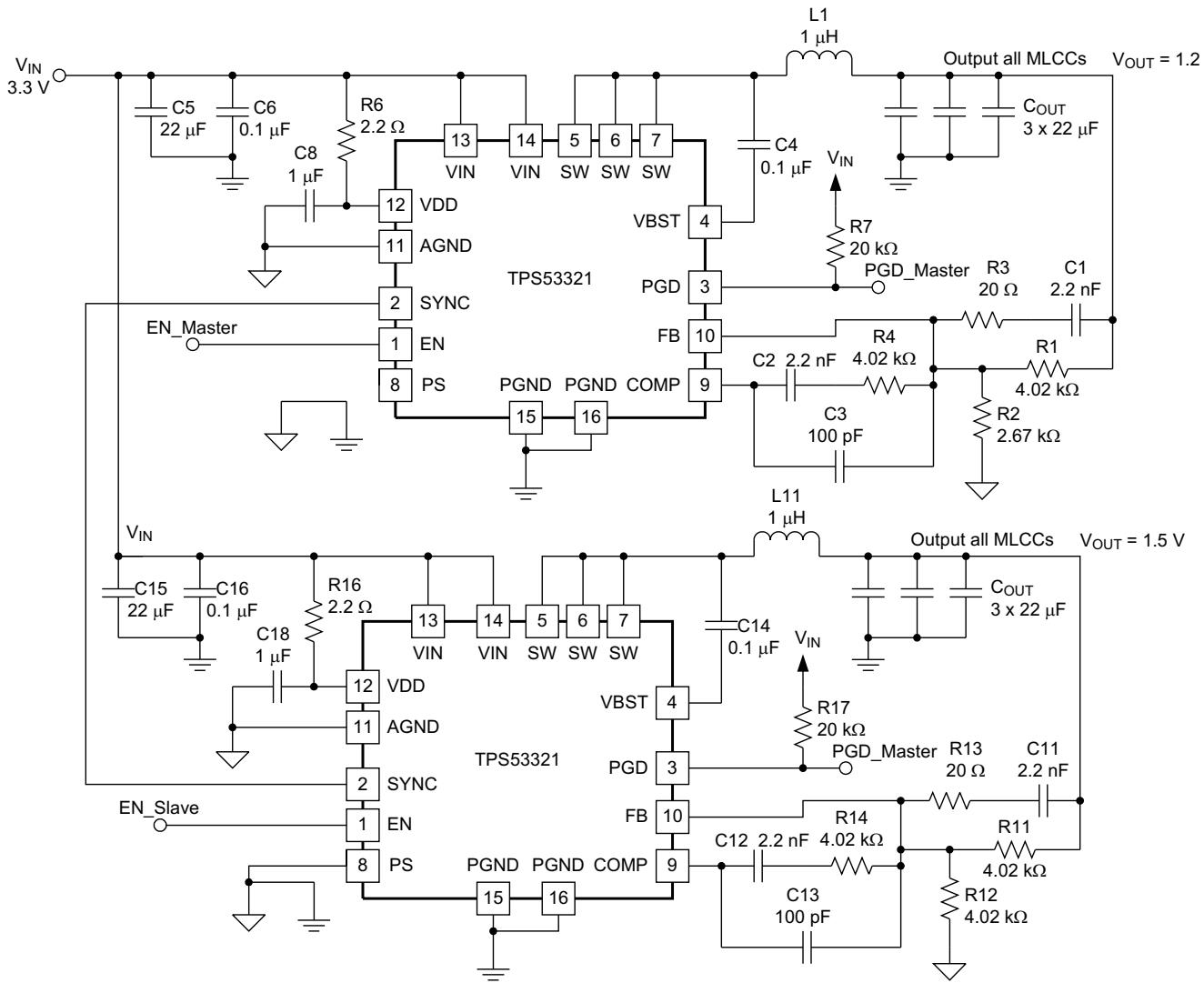
$$f_{p2} = \frac{1}{2 \times \pi \times R_3 \times C_1} \quad (19)$$

$$f_{p3} = \frac{1}{2 \times \pi \times R_4 \times \left(\frac{C_2 \times C_3}{C_2 + C_3}\right)} \approx \frac{1}{2 \times \pi \times R_4 \times C_3} \quad (20)$$

The two zeros can be placed near the double pole frequency to cancel the response from the double pole. One pole can be used to cancel ESR zero, and the other non-zero pole can be placed at half switching frequency to attenuate the high frequency noise and switching ripple. Suitable values can be selected to achieve a compromise between high phase margin and fast response. A phase margin higher than 45 degrees is required for stable operation.

For DCM operation, a C3 between 56 pF and 150 pF is recommended for output capacitance between 20 μ F to 200 μ F.

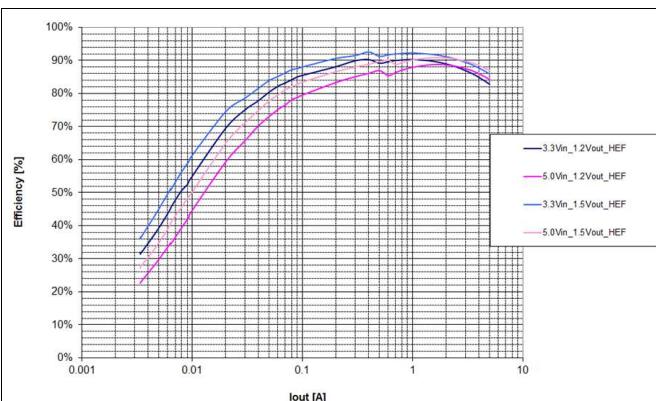
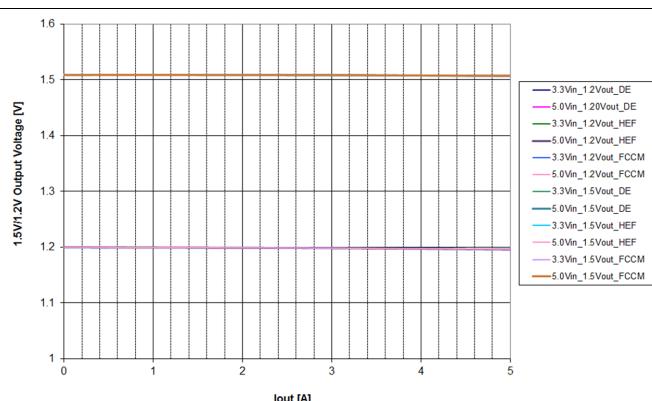
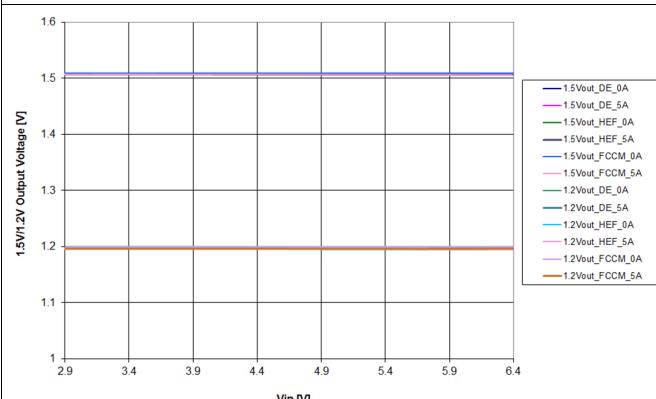
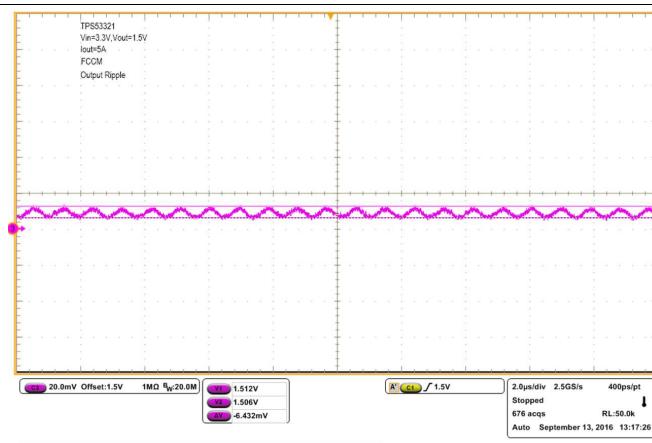
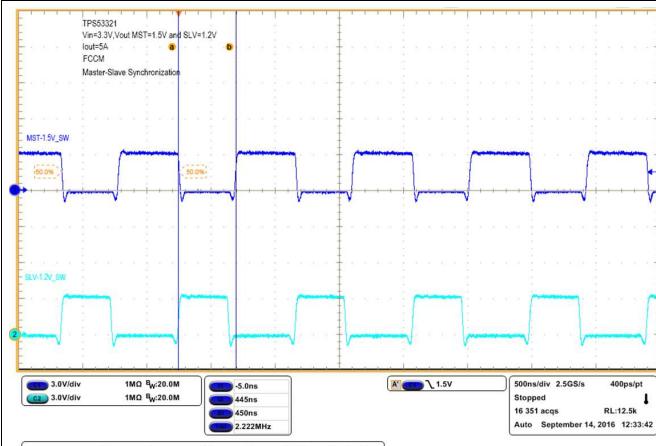
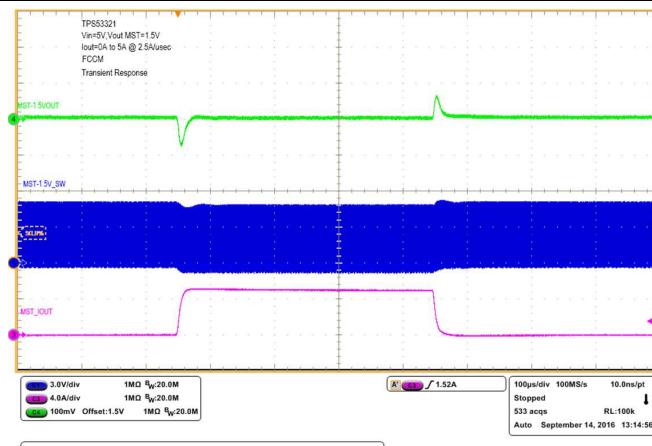
Figure 17 shows the master and slave configuration schematic for a design with a 3.3-V input.

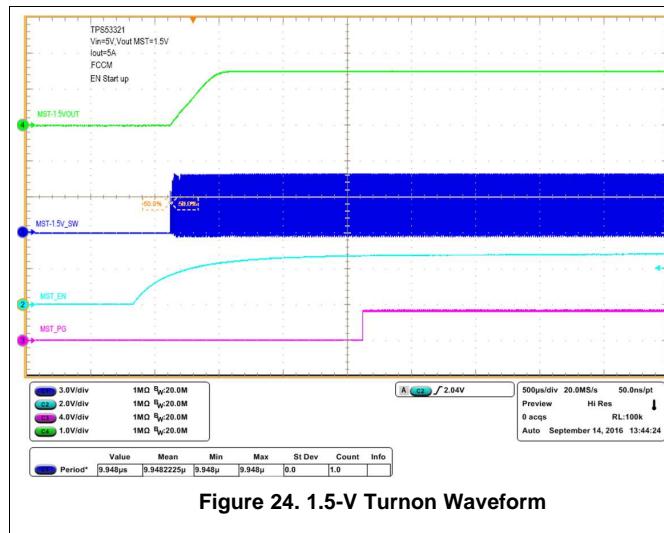
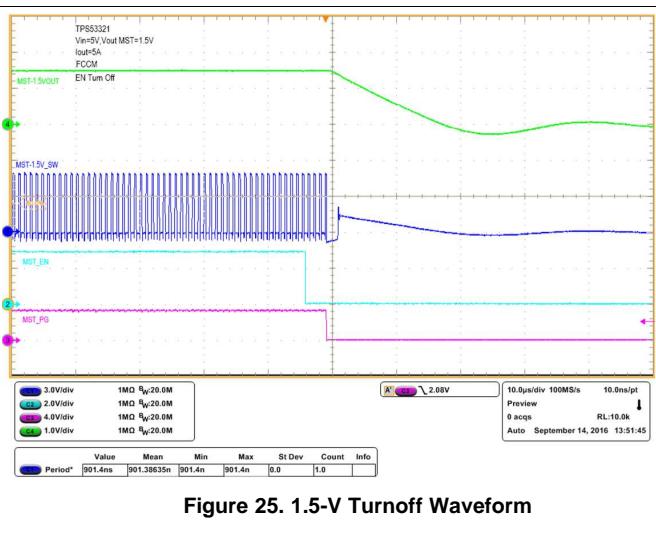


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Figure 17. Master and Slave Configuration Schematic

8.2.3 Application Curves


Figure 18. Efficiency

Figure 19. Load Regulation

Figure 20. Line Regulation

Figure 21. 1.5-V Output Ripple

Figure 22. Master-Slave 180° Synchronization

Figure 23. 1.5-V Output Transient


Figure 24. 1.5-V Turnon Waveform

Figure 25. 1.5-V Turnoff Waveform

9 Power Supply Recommendations

The TPS53321 devices are designed to operate from an input voltage supply range between 2.9 V and 6 V (2.9 V to 3.5 V biased). This input supply must be well regulated. Proper bypassing of input supplies and internal regulators is also critical for noise performance, as is PCB layout and grounding scheme. See the recommendations in [Layout](#).

10 Layout

10.1 Layout Guidelines

Good layout is essential for stable power supply operation. Follow these guidelines for a clean PCB layout:

- Separate the power ground and analog ground planes. Connect them together at one location.
- Use four vias to connect the thermal pad to power ground.
- Place VIN and VDD decoupling capacitors as close to the device as possible.
- Use wide traces for V_{IN} , V_{OUT} , PGND, and SW. These nodes carry high current and also serve as heat sinks.
- Place feedback and compensation components as close to the device as possible.
- Keep analog signals (FB, COMP) away from noisy signals (SW, SYNC, VBST).
- See TPS53321 evaluation module for a layout example.

Figure 26 shows an example layout for the TPS53321.

10.2 Layout Example

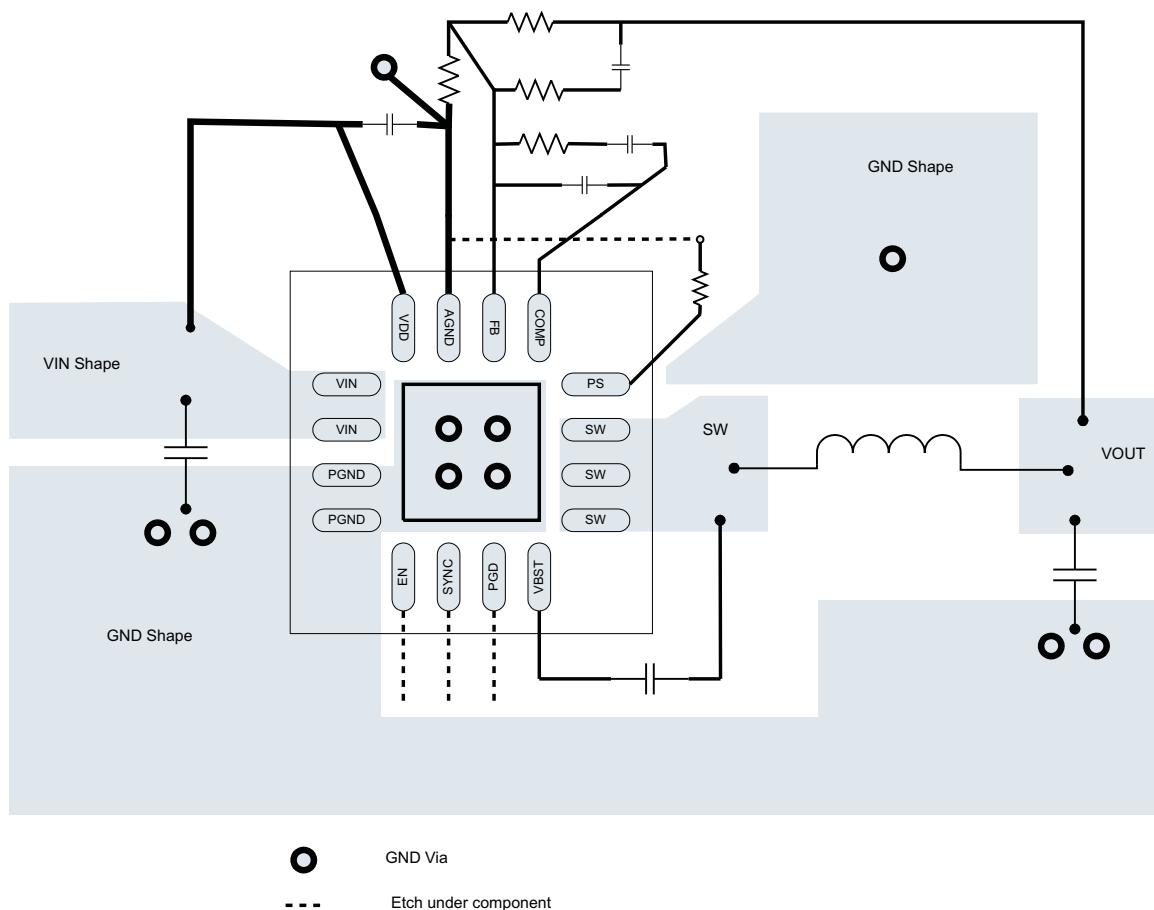


Figure 26. TPS53321 Layout Example

11 デバイスおよびドキュメントのサポート

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11.5 Glossary

[SLY022 — TI Glossary](#).

This glossary lists and explains terms, acronyms, and definitions.

12 メカニカル、パッケージ、および注文情報

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PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package Pins | Package qty Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|-----------------------|---------------|----------------------|-----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| TPS53321RGTR | Active | Production | VQFN (RGT) 16 | 3000 LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 3321 |
| TPS53321RGTR.B | Active | Production | VQFN (RGT) 16 | 3000 LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 3321 |
| TPS53321RGTT | Active | Production | VQFN (RGT) 16 | 250 SMALL T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 3321 |
| TPS53321RGTT.B | Active | Production | VQFN (RGT) 16 | 250 SMALL T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 3321 |

⁽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.

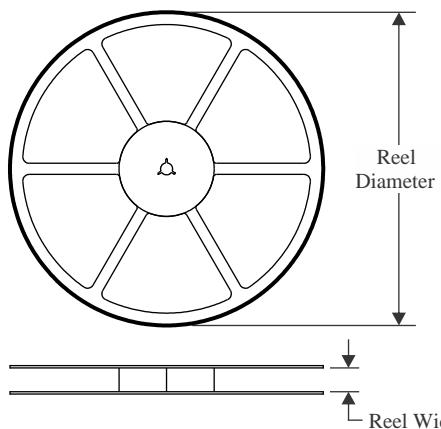
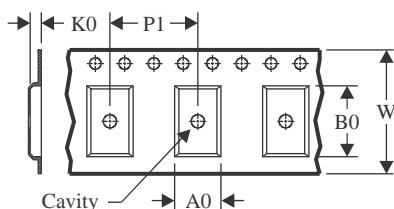
⁽⁵⁾ **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will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

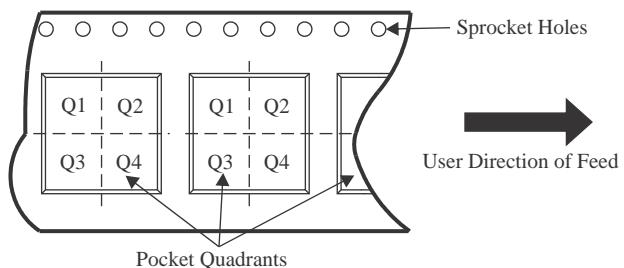
Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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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 |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS53321RGTR | VQFN | RGT | 16 | 3000 | 330.0 | 12.4 | 3.3 | 3.3 | 1.1 | 8.0 | 12.0 | Q2 |
| TPS53321RGTT | VQFN | RGT | 16 | 250 | 180.0 | 12.4 | 3.3 | 3.3 | 1.1 | 8.0 | 12.0 | Q2 |

TAPE AND REEL BOX DIMENSIONS


*All dimensions are nominal

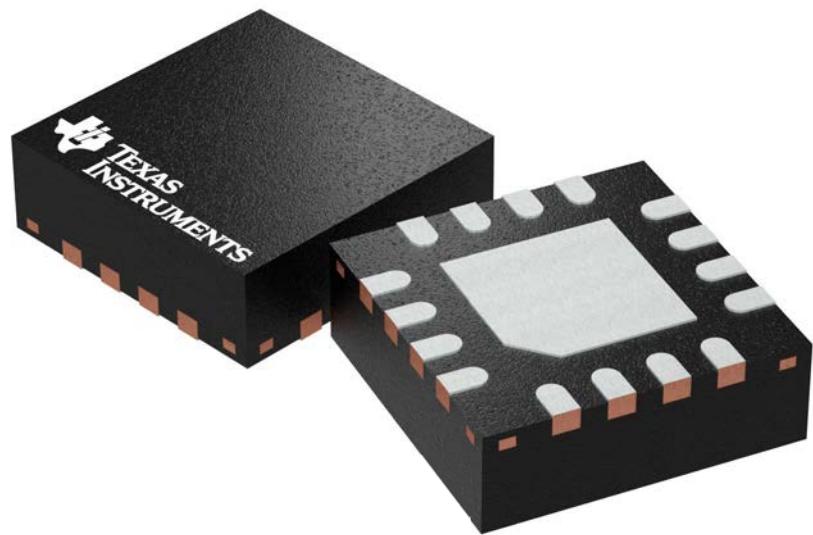
| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS53321RGTR | VQFN | RGT | 16 | 3000 | 367.0 | 367.0 | 35.0 |
| TPS53321RGTT | VQFN | RGT | 16 | 250 | 210.0 | 185.0 | 35.0 |

GENERIC PACKAGE VIEW

RGT 16

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD

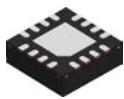


Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

4203495/I

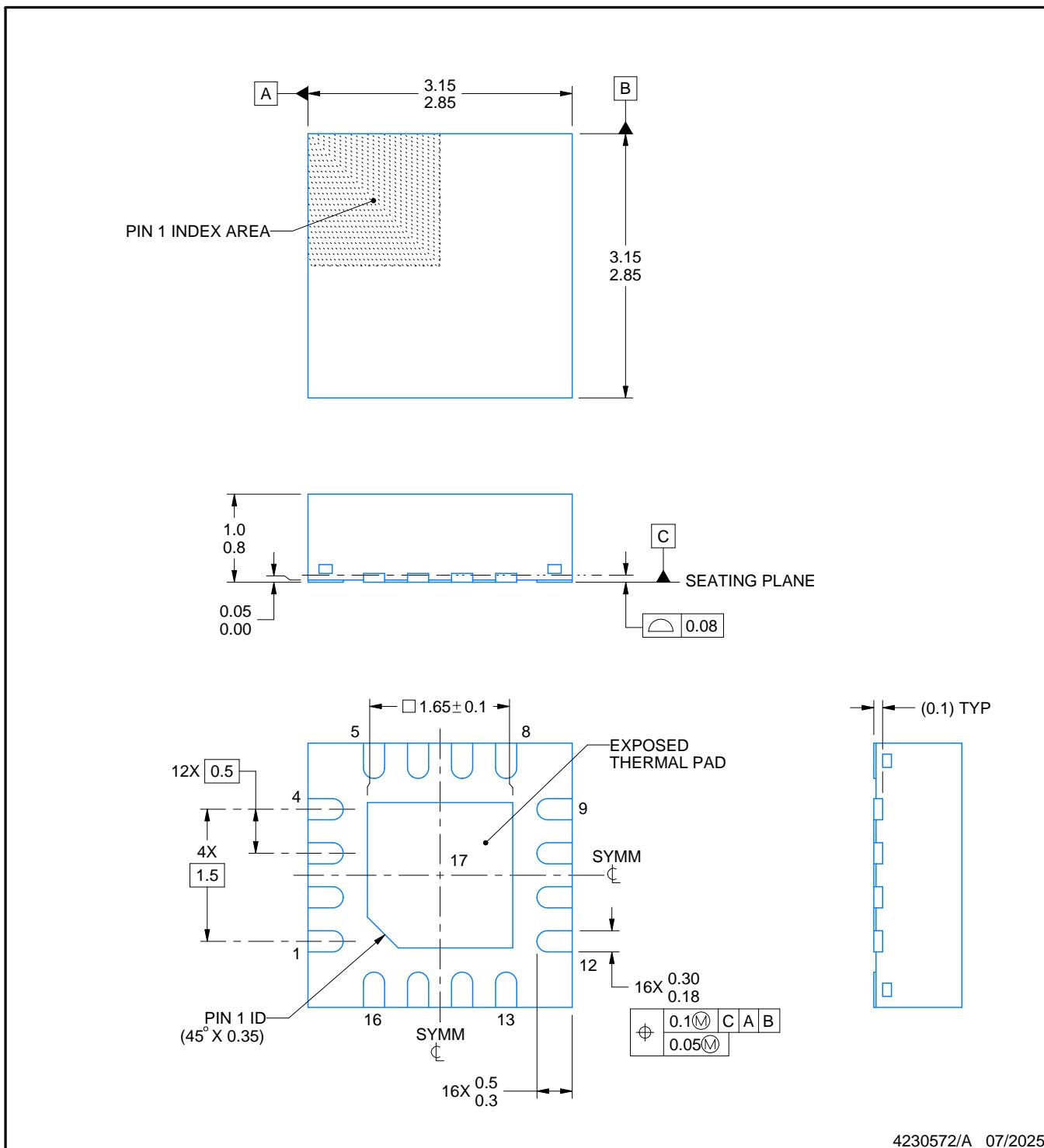
PACKAGE OUTLINE

RGT0016F



VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



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NOTES:

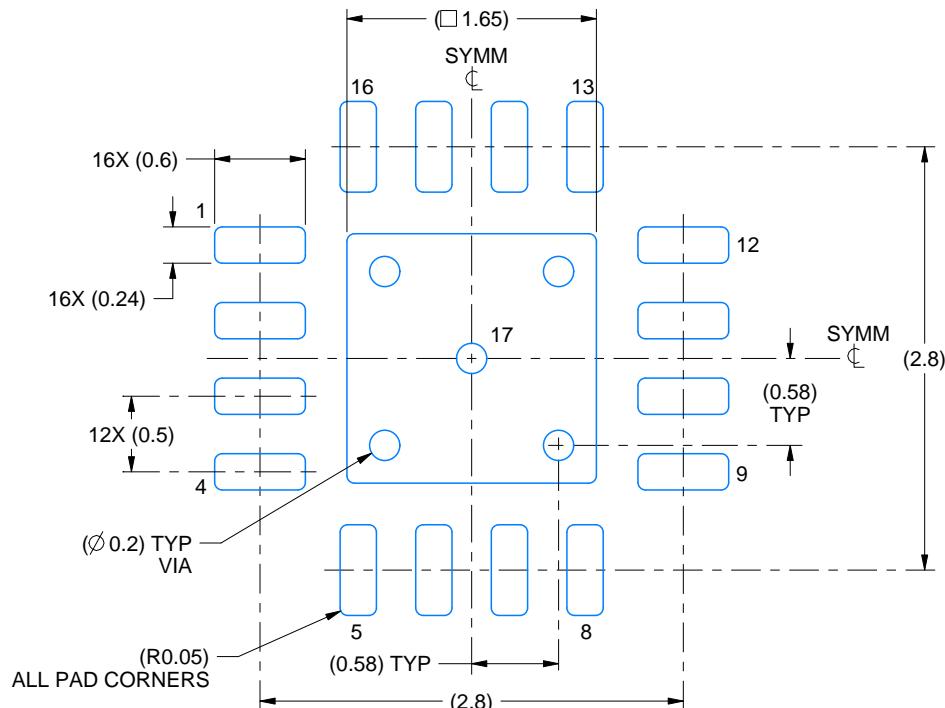
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

EXAMPLE BOARD LAYOUT

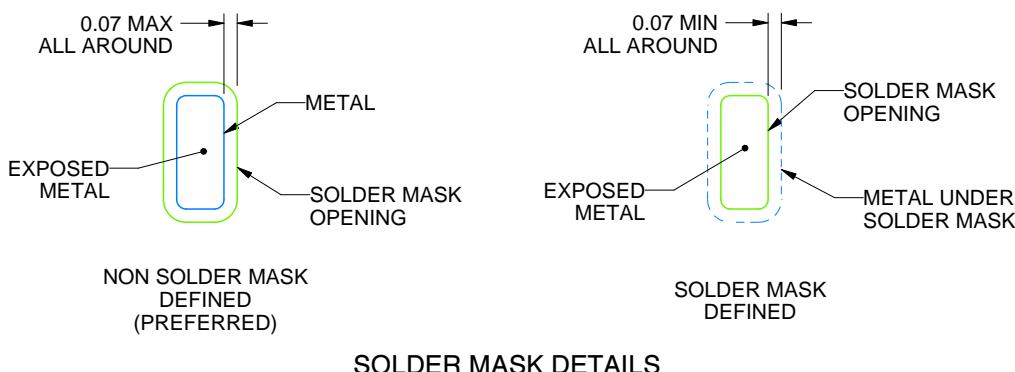
RGT0016F

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:20X



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NOTES: (continued)

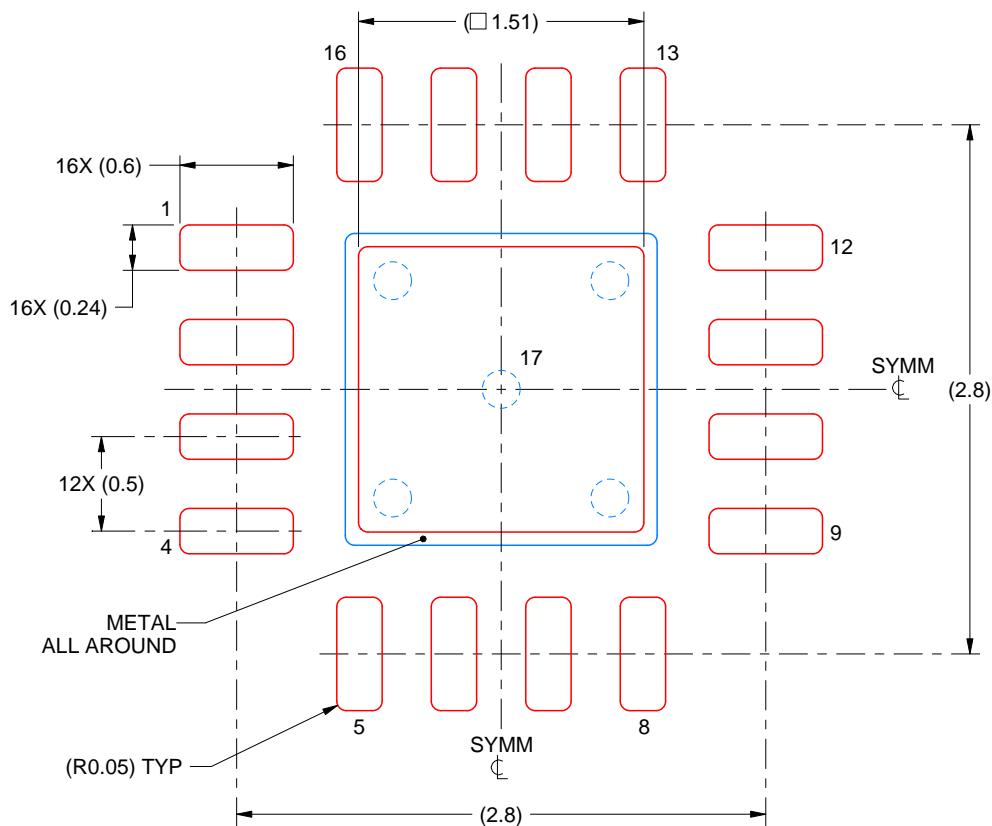
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown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

EXAMPLE STENCIL DESIGN

RGT0016F

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



SOLDER PASTE EXAMPLE BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 17:
84% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:25X

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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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