

LM5166 3V~65V入力、500mAの同期整流降圧コンバータ、超低 I_Q

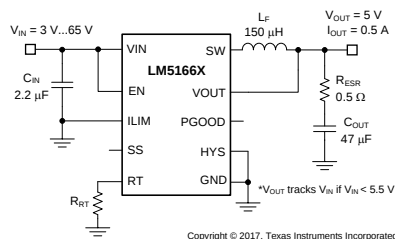
1 特長

- 広い入力電圧範囲: 3V~65V
- 無負荷時の静止電流: 9.7 μ A
- 接合部温度範囲: -40°C~150°C
- 固定(3.3V、5V)または可変 V_{OUT} のオプション
- EN55022/CISPR 22 EMI標準に準拠
- 1 Ω のPFET降圧スイッチを内蔵
 - 100%デューティ・サイクルに対応し、低いドロップアウト電圧を実現
- 0.5 Ω のNFET同期整流器を内蔵
 - 外部ショットキー・ダイオードが不要
- ピーク電流制限をプログラム可能:
 - 500mA、300mA、200mA負荷
- PFMまたはCOTモードの動作を選択可能
- 内部基準電圧: 1.223V $\pm$ 1.2%
- 最高600kHzのスイッチング周波数
- 内部または外部で変更可能な900 μ sのソフトスタート時間
- ダイオード・エミュレーションおよびパルス・スキップにより軽負荷時の非常に高い効率を実現
- ループ補償やブートストラップ部品が不要
- 高精度でヒステリシス付きのイネーブル/入力UVLO
- オープン・ドレインのパワー・グッド・インジケータ
- ヒステリシス付きのサーマル・シャットダウン保護
- LM5165とピン互換
- 10ピンの3mm $\times$ 3mm VSONパッケージ
- WEBENCH[®] Power Designerを使用してカスタム・レギュレータ設計を作成

2 アプリケーション

- ファクトリ/ビルディング・オートメーション
- 車載用およびバッテリー駆動のアプリケーション
- 高電圧LDOの代替品
- 低消費電力のバイアス電源

一般的なCOTモードのアプリケーション



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3 概要

LM5166は小型で使いやすい、3V~65Vで超低 I_Q の同期整流降圧コンバータで、広い範囲の入力電圧と負荷電流にわたって高い効率を維持します。ハイサイドとローサイドのパワーMOSFETが搭載されており、3.3Vまたは5Vの固定出力電圧、または可変出力電圧で、最大500mAの出力電流を供給できます。このコンバータは、実装を簡素化し、同時に対象アプリケーションに合わせて性能を最適化できるよう設計されています。軽負荷時の効率を最適化するにはパルス周波数変調(PFM)モードを、ほぼ一定の周波数で動作するためにはコンスタント・オン・タイム(COT)制御方式を使用できます。いずれの制御方式にもループ補償は必要なく、非常に優れたラインおよび負荷過渡応答と、大きな降圧変換率について短いPWMオン時間を実現します。

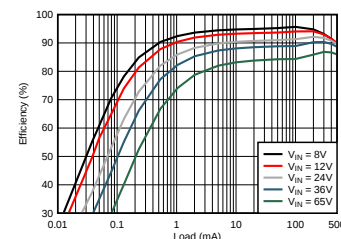
ハイサイドのPチャネルMOSFETは100%デューティ・サイクルで動作可能なため、最低のドロップアウト電圧を実現し、ゲート駆動用のブートストラップ・コンデンサが必要ありません。また、電流制限の設定ポイントを変更可能で、特定の負荷電流の要件に応じてインダクタの選択を最適化できます。スタートアップ時間の選択や変更には、最小遅延(ソフトスタートなし)、内部的に固定(900 μ s)、コンデンサを使用して外部でソフトスタートをプログラムのオプションを選択できます。オープン・ドレインのPGOODインジケータは、シーケンシング、フォルト報告、出力電圧監視に使用できます。LM5166は0.5mmピン・ピッチの10ピンVSONパッケージで供給されます。

製品情報⁽¹⁾

型番	出力	パッケージ
LM5166	可変	VSON (10)
LM5166X	5V固定	
LM5166Y	3.3V固定	

(1) 利用可能なすべてのパッケージについては、この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。

一般的なCOTモードのアプリケーションの効率



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4 改訂履歴

Revision A (December 2016) から Revision B に変更

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•	データシートのテキストを最新のTIDドキュメントおよび翻訳標準に合わせて更新	1
•	WNBENCHリスト項目の言語を変更、コンテンツを追加し、WEBENCHへのリンクをデータシートに追加	1
•	LM5166XおよびLM5166Y出力バージョンをデータシートに追加	1
•	「製品情報」表の本体サイズ(NOM)列を、出力バージョンに置き換え	1
•	一般的なCOTモードのアプリケーション回路を固定5V出力に変更	1
•	Changed the EN absolute maximum voltage from ($V_{VIN} + 0.3 V$) to 68 V	4
•	Deleted note 5 under the <i>Absolute Maximum Ratings</i> table	4
•	Changed the EN max operating voltage from V_{VIN} to 65 V	4
•	Removed note 2 under the <i>Recommended Operating Conditions</i>	4
•	Changed the I_{FB} maximum from: 100 nA to: 25 nA	5
•	Added 図 13 and 図 14	8
•	Modified the <i>Functional Block Diagram</i> graphic	14
•	Changed $R_{DS(ON)1}$ to $R_{DS(ON)2}$ in 式 3	17
•	Updated 式 12	19
•	Added a link to TI Design TIDA-01395 to the <i>Typical Applications</i> section	26
•	Changed Design 3 to a 3.3-V fixed output, LM5166Y	35
•	Added a new part number to C_{IN} ref description	35
•	Added a new part number to L_F ref description	38
•	Added the <i>Design 5: 12-V, 300-mA COT Converter Operating from 24-V or 48-V Input</i> section to <i>Typical Applications</i> ...	41
•	Changed the <i>PCB Layout</i> and <i>PCB Layout Guidelines</i> section names to <i>Layout</i> and <i>Layout Guidelines</i>	44
•	「ドキュメントのサポート」セクションにコンテンツを追加	47

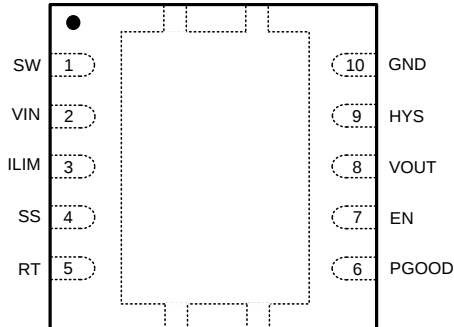
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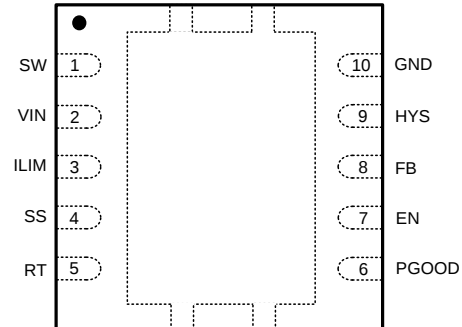
•	データシートの状態を製品プレビューから量産データに変更	1
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5 Pin Configuration and Functions

**LM5166X and LM5166Y Fixed Output DRC Package
10-Pin VSON
Top View**



**LM5166 Adjustable Output DRC Package
10-Pin VSON
Top View**



Pin Functions

PIN		I/O ⁽¹⁾	DESCRIPTION
NO.	NAME		
1	SW	P	Switching node that is internally connected to the drain of the PFET buck switch (high side) and the drain of the NFET synchronous rectifier (low side). Connect to the buck inductor.
2	VIN	P	Regulator supply input pin to high-side power MOSFET and internal bias rail LDO. Connect to input supply and input filter capacitor C _{IN} . The path from the VIN pin to the input capacitor must be as short as possible.
3	ILIM	I	Programming pin for current limit. Connecting the appropriate resistance from the ILIM pin to GND selects one of the three current limit options. The available current limit options are detailed in 表 3.
4	SS	I	Programming pin for the soft-start delay. If a 100-kΩ resistor is connected from the SS pin to GND, the internal soft-start circuit is disabled and the FB comparator reference steps immediately from zero to full value when the regulator is enabled by the EN input. If the SS pin is left open, the internal soft-start circuit ramps the FB reference from zero to full value in 900 μs. If a capacitor is connected from the SS pin to GND, the soft-start time can be set longer than 900 μs.
5	RT	I	Mode select and on-time programming pin for Constant On-Time control. Connect a resistor from the RT pin to GND to program the on-time and hence switching frequency. Short RT to GND to select PFM (pulse frequency modulation) operation.
6	PGOOD	O	Power Good output flag pin. PGOOD is connected to the drain of an NFET that holds the pin low when either FB or VOUT is not in regulation. Use a 10-kΩ to 100-kΩ pullup resistor to system voltage rail or VOUT (no higher than 12 V).
7	EN	I	Input pin of the precision enable / UVLO comparator. The regulator is enabled when the EN pin voltage is greater than 1.22 V.
8	VOUT or FB	I	Feedback input to the voltage regulation loop for the LM5166 Adjustable Output version, or a VOUT pin connects the internal feedback resistor divider to the regulator output voltage for the fixed 3.3-V or 5-V options. The FB pin connects the internal feedback comparator to an external resistor divider for the adjustable voltage option, and the reference for the FB pin comparator is 1.223 V.
9	HYS	O	Drain of internal NFET that is turned off when the EN input is greater than the EN pin threshold. External resistors from HYS to EN and GND program the input UVLO threshold and hysteresis.
10	GND	G	Regulator ground return.
—	PAD	P	Connect to GND pin and system ground on PCB. Path to C _{IN} must be as short as possible.

(1) P = Power, G = Ground, I = Input, O = Output.

6 Specifications

6.1 Absolute Maximum Ratings

Over the recommended operating junction temperature range of -40°C to 150°C (unless otherwise noted).⁽¹⁾⁽²⁾

		MIN	MAX	UNIT
VIN, EN to GND		-0.3	68	V
SW to GND		-0.7	$V_{\text{VIN}} + 0.3$	V
	20-ns transient	-3		
PGOOD, VOUT ⁽³⁾ to GND		-0.3	16	V
HYS to GND		-0.3	7	V
ILIM, SS, RT, FB ⁽⁴⁾ to GND		-0.3	3.6	V
Maximum junction temperature, T_J		-40	150	$^{\circ}\text{C}$
Storage temperature, T_{stg}		-55	150	$^{\circ}\text{C}$

- (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.
- (2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and specifications.
- (3) Fixed output setting.
- (4) Adjustable output setting.

6.2 ESD Ratings

		VALUE	UNIT
$V_{\text{(ESD)}}$ Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	± 2000	V
	Charged device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	± 1000	

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

Over the recommended operating junction temperature range of -40°C to 150°C (unless otherwise noted).⁽¹⁾

		MIN	NOM	MAX	UNIT
Input voltages	VIN	3		65	V
	EN	-0.3		65	
	PGOOD	-0.3		12	
	HYS	-0.3		5.5	
Output current	I_{OUT}	0		500	mA
Temperature	Operating junction temperature	-40		150	$^{\circ}\text{C}$

- (1) Operating Ratings are conditions under which the device is intended to be functional. For specifications and test conditions, see *Electrical Characteristics*.

6.4 Thermal Information

THERMAL METRIC ⁽¹⁾		LM5166	UNIT
		DRC (VSON)	
		10 PINS	
$R_{\theta\text{JA}}$	Junction-to-ambient thermal resistance	49.1	$^{\circ}\text{C/W}$
$R_{\theta\text{JC(top)}}$	Junction-to-case (top) thermal resistance	57.2	$^{\circ}\text{C/W}$
$R_{\theta\text{JB}}$	Junction-to-board thermal resistance	26.6	$^{\circ}\text{C/W}$
Ψ_{JT}	Junction-to-top characterization parameter	0.8	$^{\circ}\text{C/W}$
Ψ_{JB}	Junction-to-board characterization parameter	23.8	$^{\circ}\text{C/W}$
$R_{\theta\text{JC(bot)}}$	Junction-to-case (bottom) thermal resistance	4.8	$^{\circ}\text{C/W}$

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

6.5 Electrical Characteristics

Typical values correspond to $T_J = 25^\circ\text{C}$. Minimum and maximum limits are based on $T_J = -40^\circ\text{C}$ to $+125^\circ\text{C}$. $V_{IN} = 12\text{ V}$ (unless otherwise noted).⁽¹⁾⁽²⁾

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I _{Q-SD}	VIN DC supply current, shutdown	V _{EN} = 0 V, T _J = 25°C		4	6	μA
I _{Q-SLEEP}	VIN DC supply current, no load	V _{FB} = 1.5 V, T _J = 25°C		9.7	15	μA
I _{Q-SLEEP-VINMAX}	VIN DC supply current, no load	V _{FB} = 1.5 V, V _{VIN} = 65 V, T _J = 25°C		10	15	μA
I _{Q-ACTIVE-PFM}	VIN DC supply current, active	PFM mode, R _{RT} = 0 Ω, R _{SS} = 100 kΩ		205		μA
I _{Q-ACTIVE-COT}	VIN DC supply current, active	COT mode, R _{RT} = R _{SS} = 100 kΩ		320		μA
POWER SWITCHES						
R _{DS(on)1}	High-side MOSFET R _{DS(on)}	I _{SW} = −100 mA		0.93		Ω
R _{DS(on)2}	Low-side MOSFET R _{DS(on)}	I _{SW} = 100 mA		0.48		Ω
CURRENT LIMITING						
I _{HS_LIM1}	High-side peak current limit threshold	See 表 3	1125	1250	1375	mA
I _{HS_LIM2}			675	750	825	
I _{HS_LIM3}			440	500	560	
I _{LS_LIM1}	Low-side valley current limit threshold	See 表 3		415		mA
I _{LS_LIM2}				315		
REGULATION COMPARATOR						
V _{VOUT5}	VOUT 5-V DC setpoint	LM5166X	4.9	5.0	5.1	V
V _{VOUT3.3}	VOUT 3.3-V DC setpoint	LM5166Y	3.23	3.3	3.37	V
I _{VOUT}	VOUT pin input current	V _{VOUT} = 5 V, LM5166X		7		μA
		V _{VOUT} = 3.3 V, LM5166Y		3.8		
V _{FB1}	Lower FB regulation threshold (PFM and COT)	Adjustable VOUT version	1.208	1.223	1.238	V
V _{FB2}	Upper FB regulation threshold (PFM)		1.218	1.233	1.248	V
I _{FB}	FB pin input bias current	V _{FB} = 1 V			25	nA
FB _{HYS-PFM}	FB comparator PFM hysteresis	PFM mode		10		mV
FB _{HYS-COT}	FB comparator dropout hysteresis	COT mode		4		mV
FB _{LINE-REG}	FB threshold variation over line	V _{VIN} = 3 V to 65 V		0.005		%/V
V _{OUT_{LINE-REG}}	VOUT threshold variation over line	LM5166X, V _{VIN} = 6 V to 65 V LM5166Y, V _{VIN} = 4.5 V to 65 V		0.005		%/V
POWER GOOD						
UVT _{RISE}	PGOOD comparator	V _{FB} rising relative to V _{FB1} threshold		94%		
UVT _{FALL}		V _{FB} falling relative to V _{FB1} threshold		87%		
R _{PGOOD}	PGOOD on-resistance	V _{FB} = 1 V		80	200	Ω
V _{INMIN-PGOOD}	Minimum required VIN for valid PGOOD	V _{VIN} falling I _{PGOOD} = 0.1 mA, V _{PGOOD} < 0.5 V		1.2	1.65	V
I _{PGOOD}	PGOOD off-state leakage	V _{FB} = 1.2 V, V _{PGOOD} = 5.5 V		10	100	nA
ENABLE / UVLO						
V _{IN-ON}	Turnon threshold	V _{VIN} rising	2.60	2.75	2.95	V
V _{IN-OFF}	Turnoff threshold	V _{VIN} falling	2.35	2.45	2.60	V
V _{EN-ON}	EN turnon threshold	V _{EN} rising	1.163	1.22	1.276	V
V _{EN-OFF}	EN turnoff threshold	V _{EN} falling	1.109	1.144	1.178	V

(1) All hot and cold limits are specified by correlating the electrical characteristics to process and temperature variations and applying statistical process control.

(2) The junction temperature (T_J in $^\circ\text{C}$) is calculated from the ambient temperature (T_A in $^\circ\text{C}$) and power dissipation (P_D in Watts) as follows:
 $T_J = T_A + (P_D \cdot \theta_{JA})$ where θ_{JA} (in $^\circ\text{C}/\text{W}$) is the package thermal impedance provided in [Thermal Information](#).

Electrical Characteristics (continued)

Typical values correspond to $T_J = 25^\circ\text{C}$. Minimum and maximum limits are based on $T_J = -40^\circ\text{C}$ to $+125^\circ\text{C}$. $V_{IN} = 12\text{ V}$ (unless otherwise noted).⁽¹⁾⁽²⁾

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{EN-HYS}	EN hysteresis			76		mV
V_{EN-SD}	EN shutdown threshold	V_{EN} falling	0.3	0.6		V
R_{HYS}	HYS on-resistance	$V_{EN} = 1\text{ V}$		80	200	Ω
I_{HYS}	HYS off-state leakage	$V_{EN} = 1.5\text{ V}$, $V_{HYS} = 5.5\text{ V}$		10	100	nA
SOFT-START						
I_{SS}	Soft-start charging current	$V_{SS} = 1\text{ V}$		10		μA
T_{SS-INT}	Soft-start rise time	SS floating		900		μs
THERMAL SHUTDOWN						
T_{J-SD}	Thermal shutdown threshold			170		$^\circ\text{C}$
$T_{J-SD-HYS}$	Thermal shutdown hysteresis			10		$^\circ\text{C}$

6.6 Switching Characteristics

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
T_{ON-MIN}	Minimum on-time			180		ns
T_{ON1}	On-time	16 k Ω from RT to GND		280		ns
T_{ON2}	On-time	75 k Ω from RT to GND		1150		ns

6.7 Typical Characteristics

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.

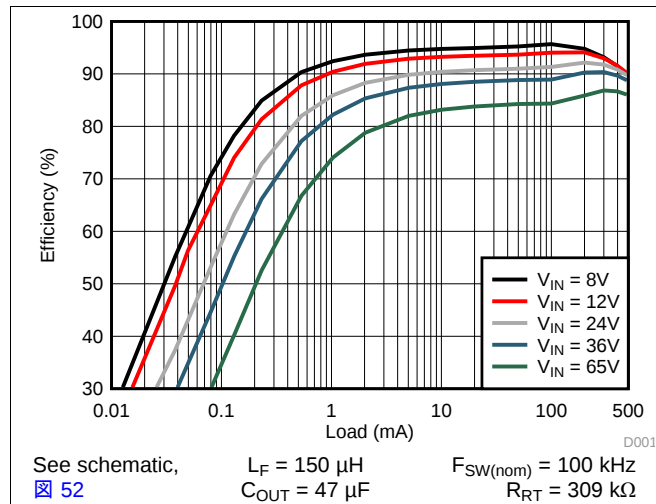


Figure 1. Converter Efficiency: 5 V, 500 mA, COT

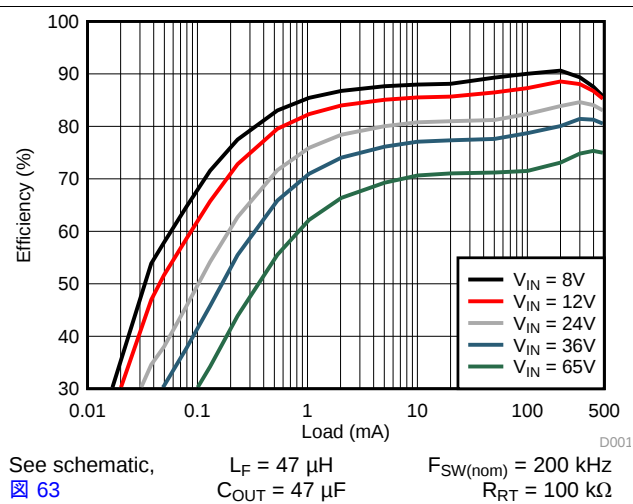


Figure 2. Converter Efficiency: 3.3 V, 500 mA, COT

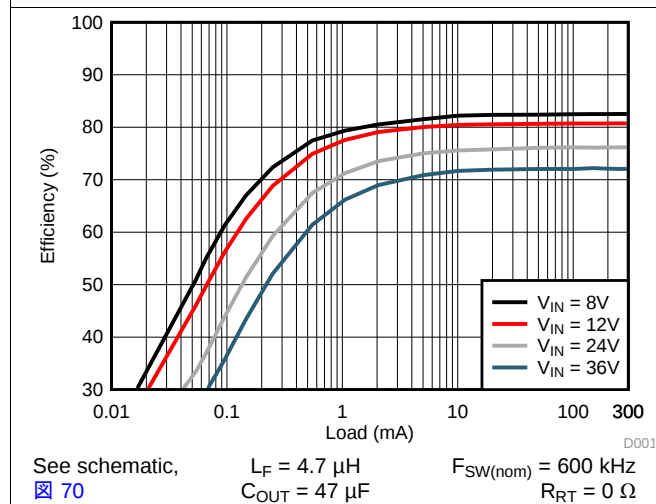


Figure 3. Converter Efficiency: 3.3 V, 300 mA, PFM

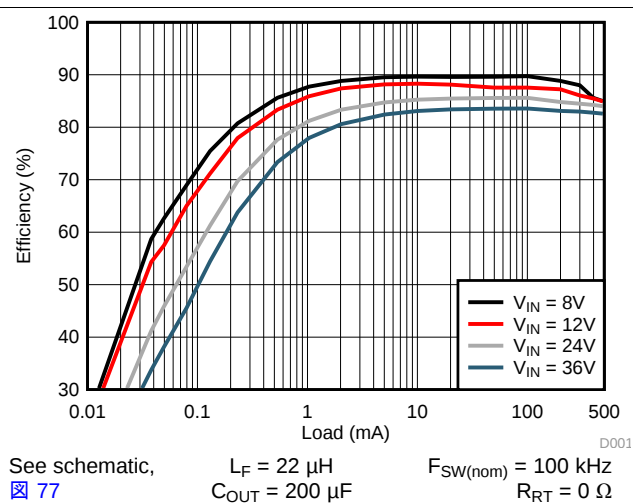


Figure 4. Converter Efficiency: 5 V, 500 mA, PFM

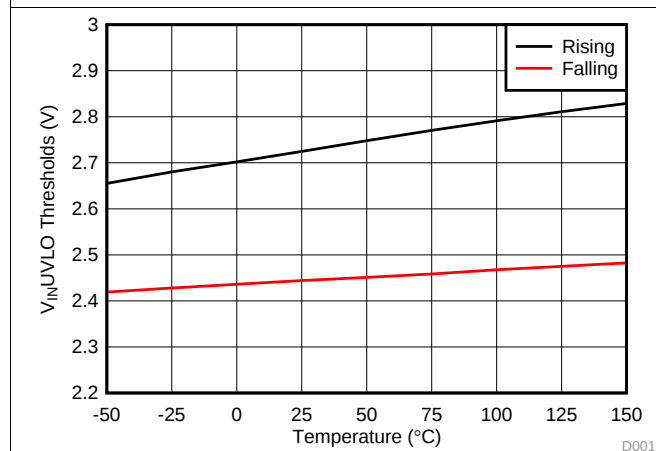


Figure 5. Internal V_{IN} UVLO Voltage vs Temperature

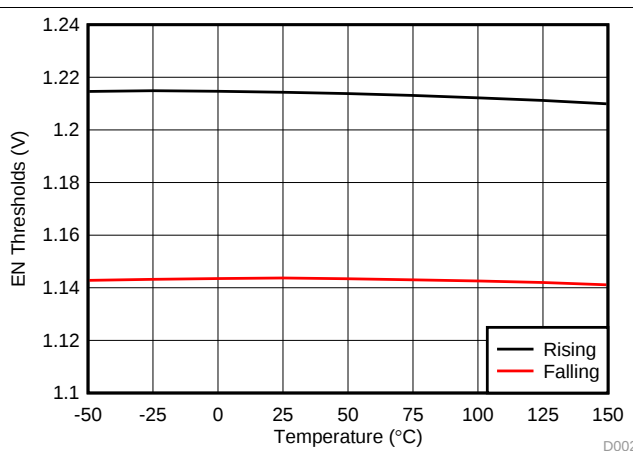


Figure 6. Enable Threshold Voltage vs Temperature

Typical Characteristics (continued)

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.

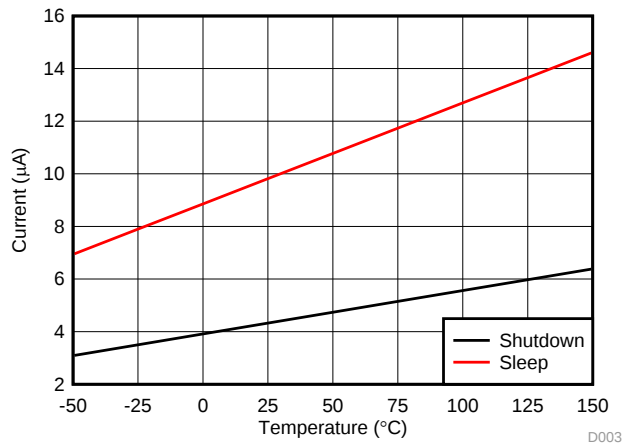


FIG 7. V_{IN} Sleep and Shutdown Supply Current vs Temperature

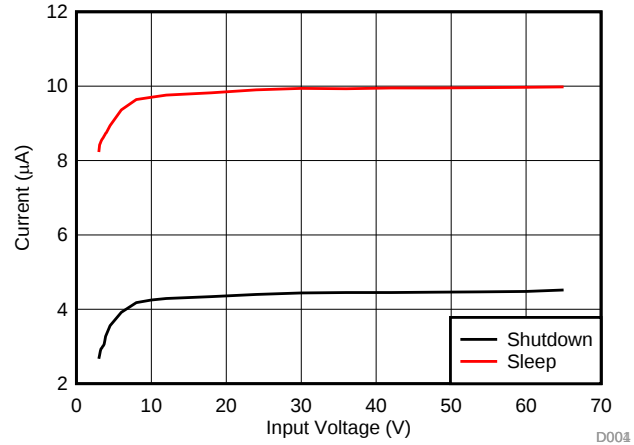
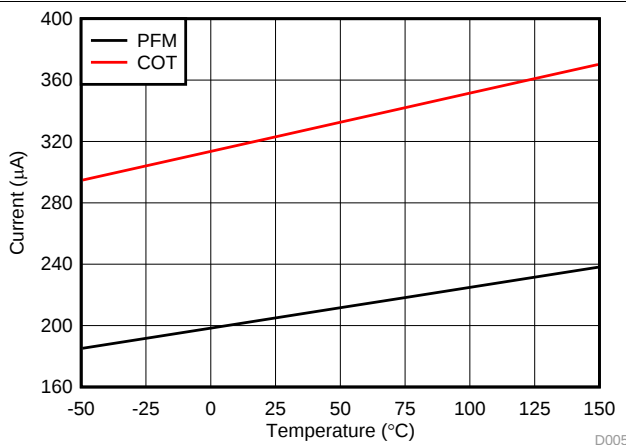
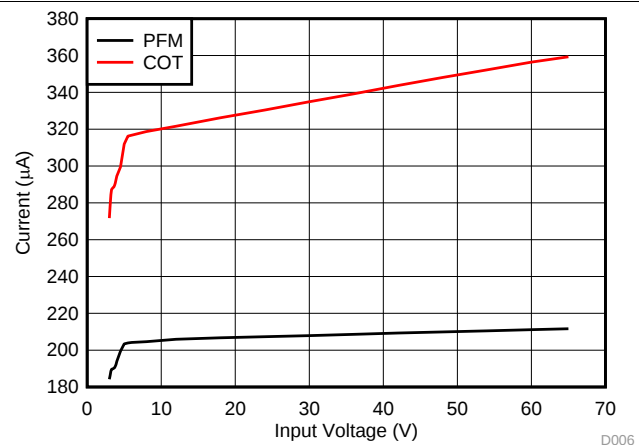


FIG 8. V_{IN} Sleep and Shutdown Supply Current vs Input Voltage



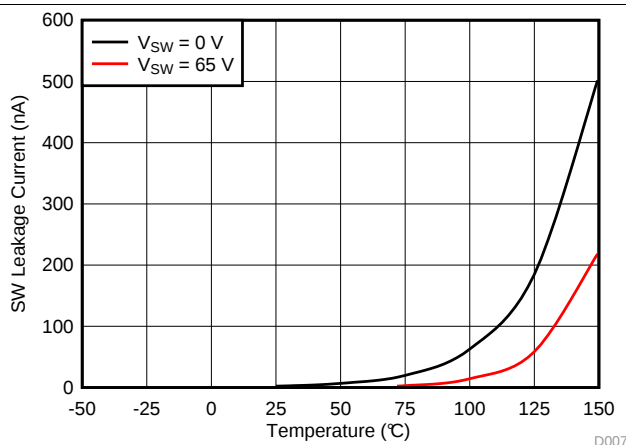
$R_{RT} = 100\text{ k}\Omega$

FIG 9. V_{IN} Active Mode Supply Current vs Temperature



$R_{RT} = 100\text{ k}\Omega$

FIG 10. V_{IN} Active Mode Supply Current vs Input Voltage



$V_{VIN} = 65\text{ V}$

FIG 11. SW Pin Leakage Current vs Temperature

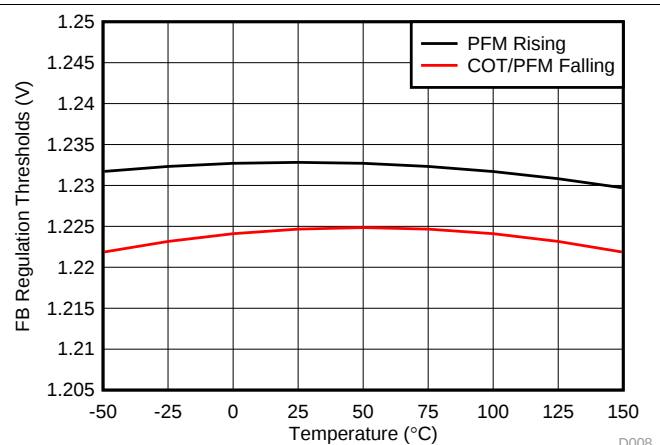
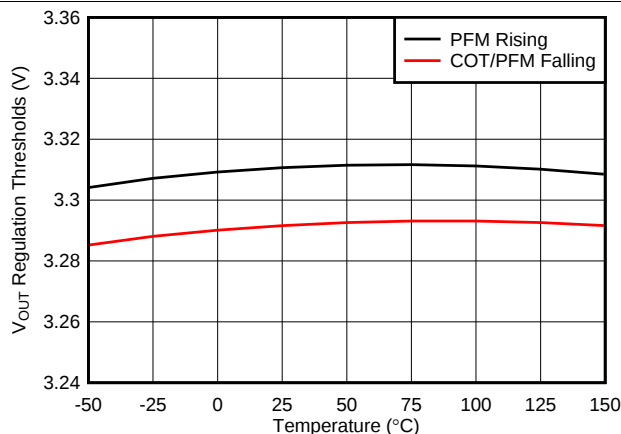


FIG 12. Feedback Comparator Threshold Voltage vs Temperature

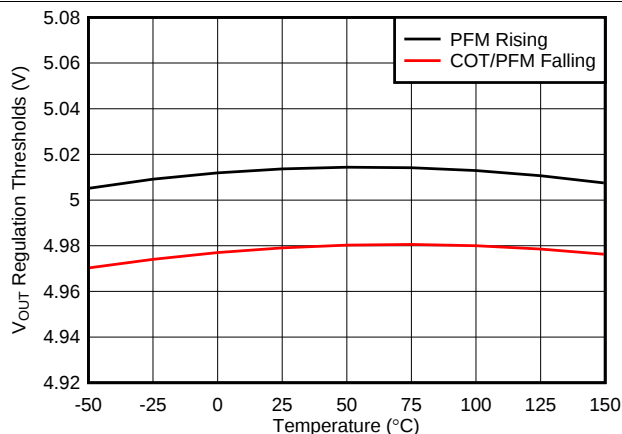
Typical Characteristics (continued)

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.



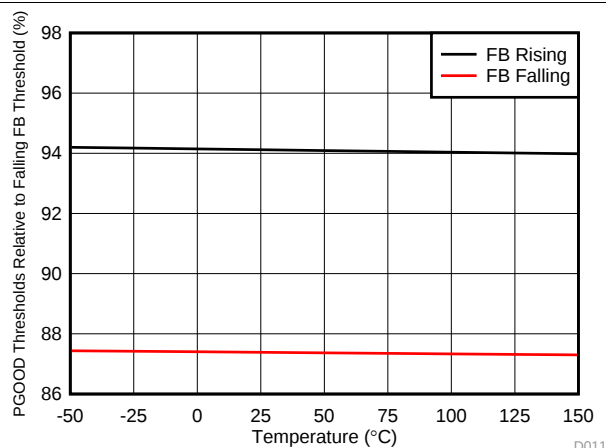
LM5166Y

FIG 13. VOUT Regulation Thresholds vs Temperature



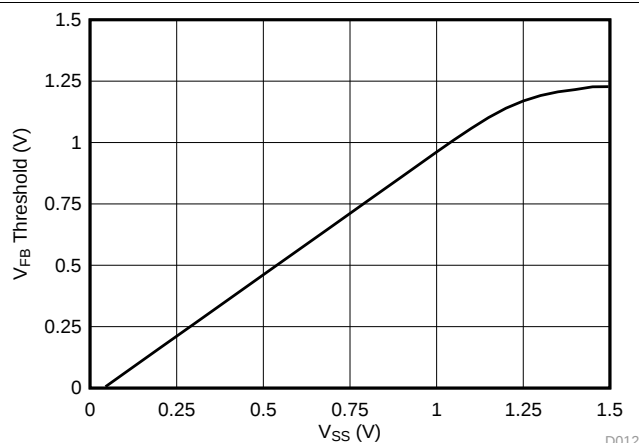
LM5166X

FIG 14. VOUT Regulation Thresholds vs Temperature



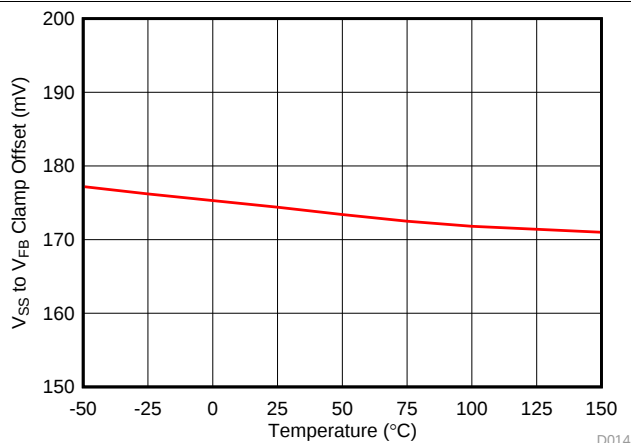
D011

FIG 15. PGOOD Thresholds vs Temperature



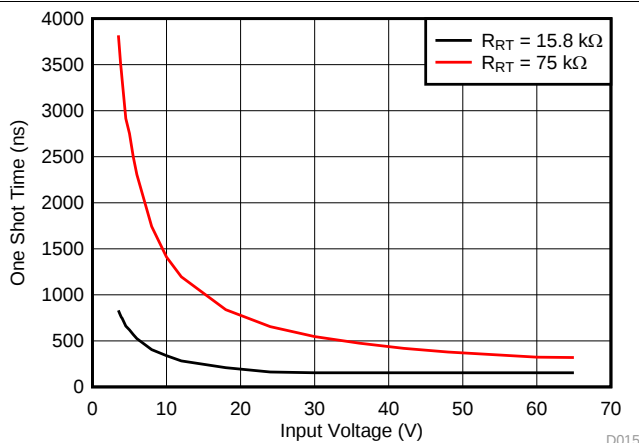
D012

FIG 16. Feedback Voltage vs Soft-Start Voltage



D014

FIG 17. Soft-Start to Feedback Clamp Offset vs Temperature



D015

FIG 18. COT One-Shot Timer T_{ON} vs Input Voltage

Typical Characteristics (continued)

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.

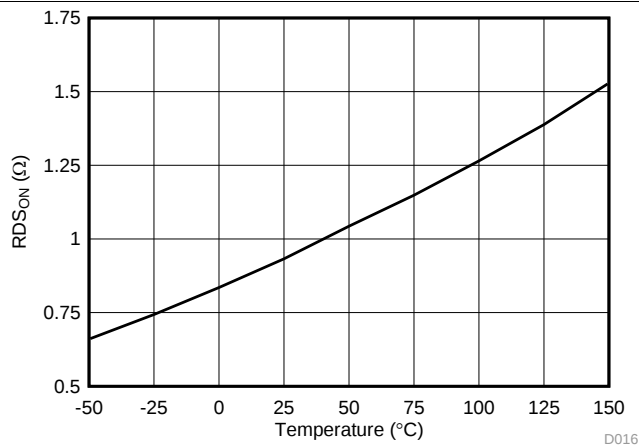


图 19. High-Side MOSFET On-State Resistance vs Temperature

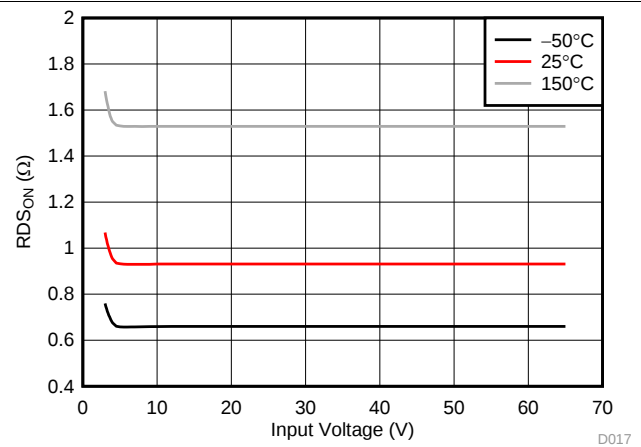


图 20. High-Side MOSFET On-State Resistance vs Input Voltage

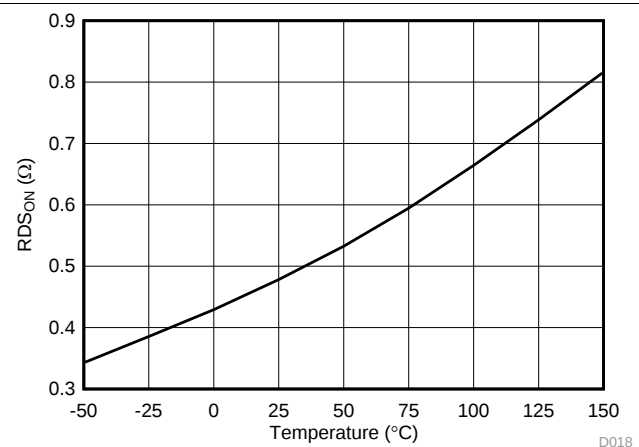


图 21. Low-Side MOSFET On-State Resistance vs Temperature

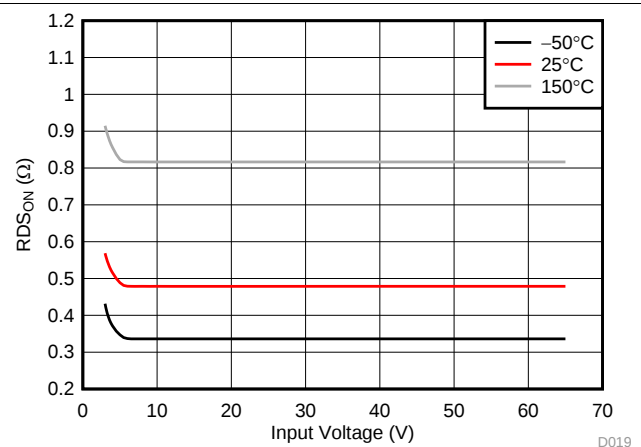


图 22. Low-Side MOSFET On-State Resistance vs Input Voltage

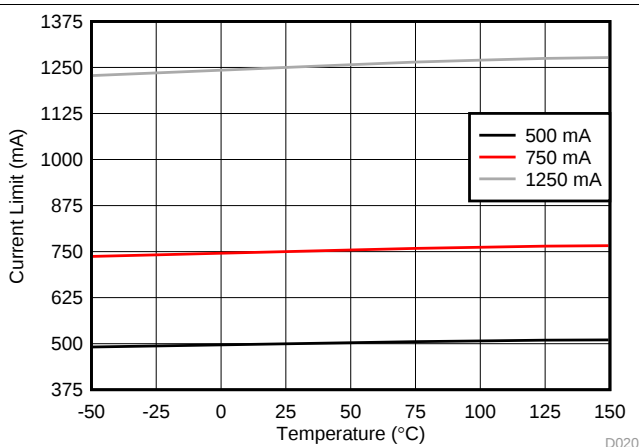


图 23. High-Side Peak Current Limit vs Temperature

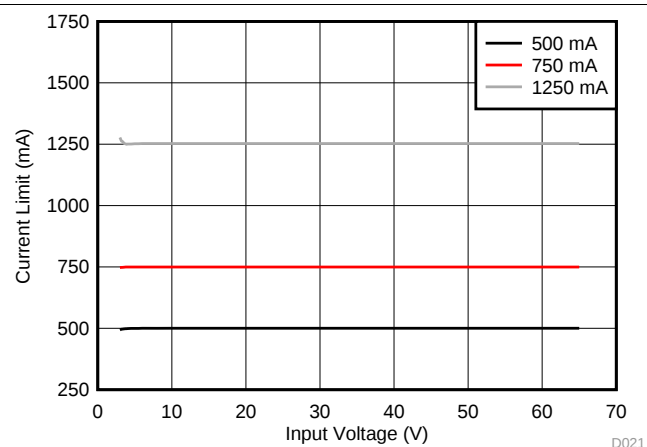


图 24. High-Side Peak Current Limit vs Input Voltage

Typical Characteristics (continued)

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.

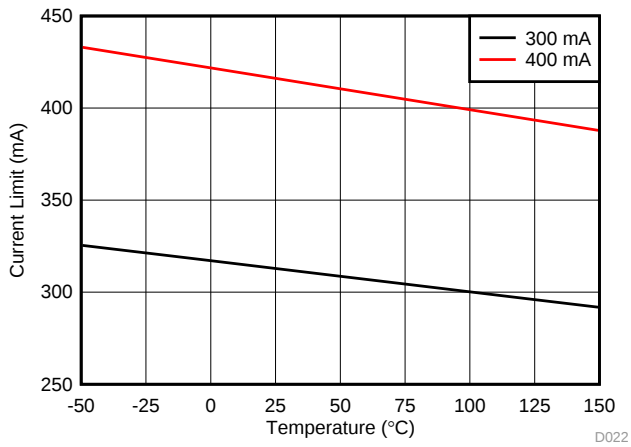


图 25. Low-Side Valley Current Limit vs Temperature

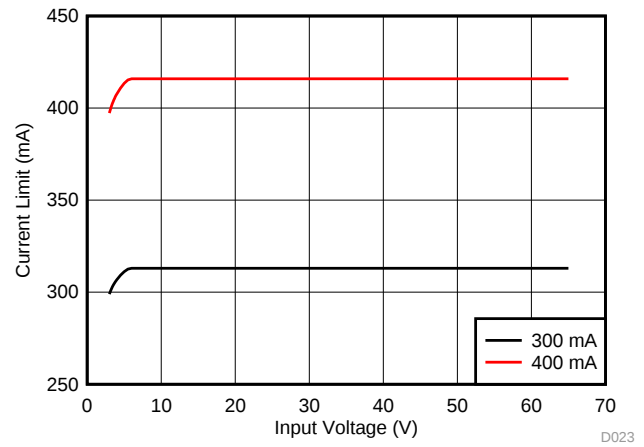


图 26. Low-Side Valley Current Limit vs Input Voltage

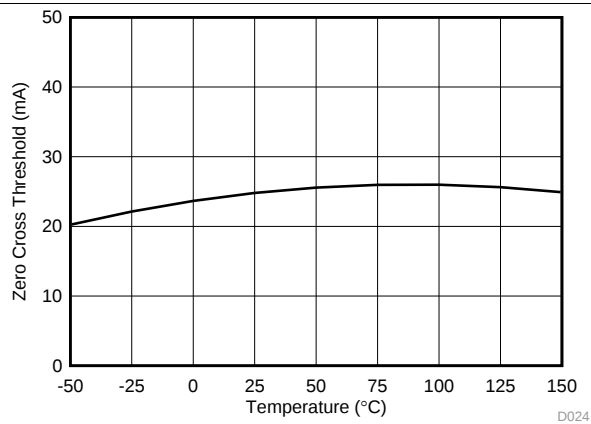


图 27. Zero-Cross Current Threshold vs Temperature

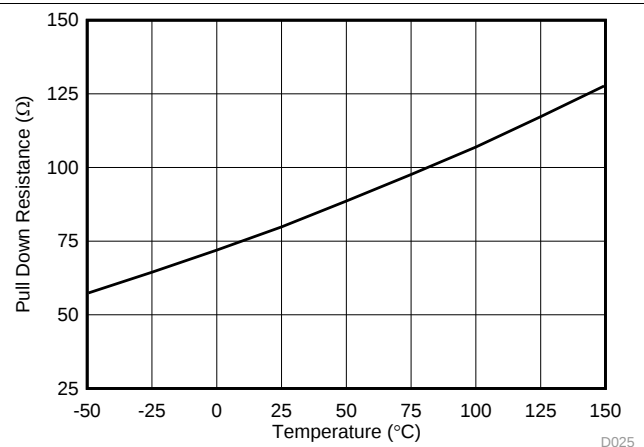
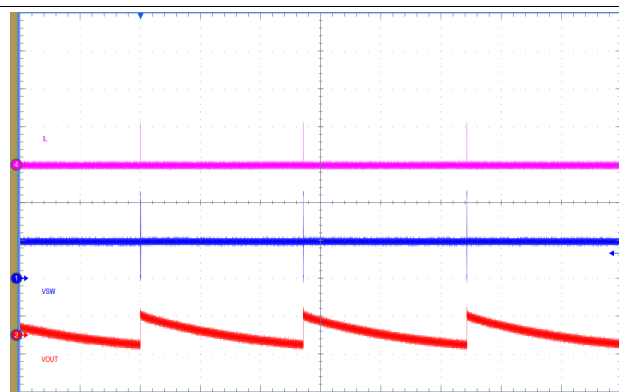
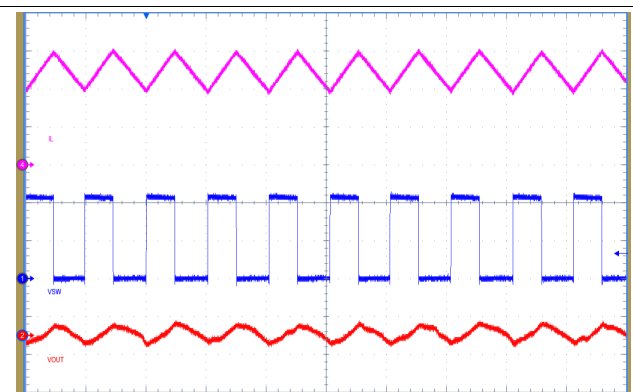


图 28. PGOOD and HYS Pulldown $R_{DS(on)}$ vs Temperature



Time Scale: 20 ms/Div
CH1: V_{SW} , 5 V/Div
CH2: V_{OUT} , 50 mV/Div
CH4: I_L , 200 mA/Div

图 29. No-Load Switching Waveforms, COT, Type 2



Time Scale: 10 μs/Div
CH1: V_{SW} , 5 V/Div
CH2: V_{OUT} , 50 mV/Div
CH4: I_L , 200 mA/Div

图 30. Full Load Switching Waveforms, COT, Type 2

Typical Characteristics (continued)

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.

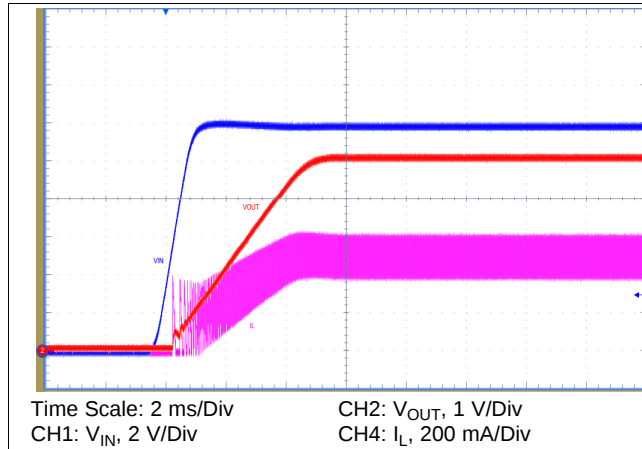


图 31. Full-Load Start-Up, COT, Type 2

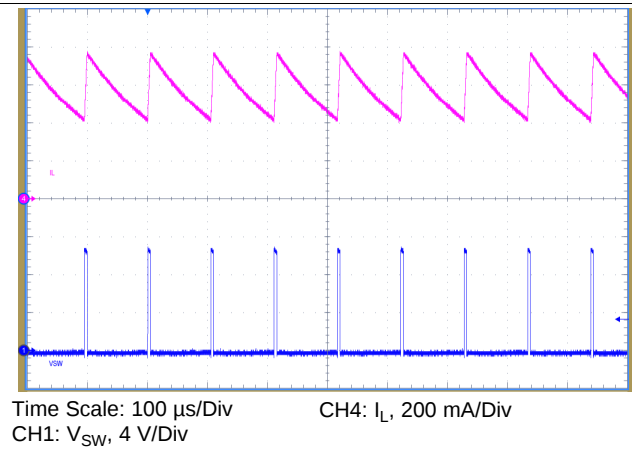


图 32. Short Circuit, COT, Type 2

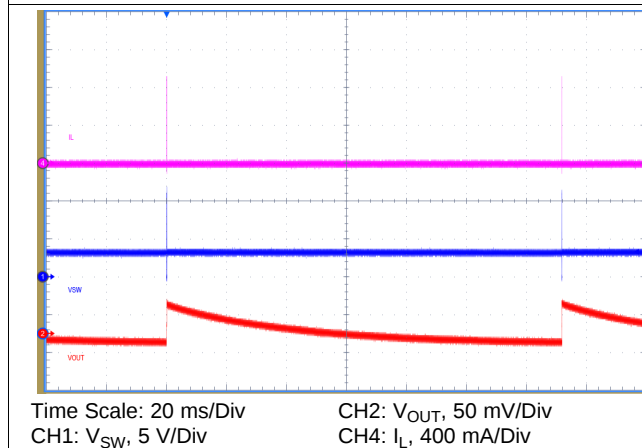


图 33. No-Load Switching Waveforms
PFM Mode, $I_{LIM} = 750\text{ mA}$

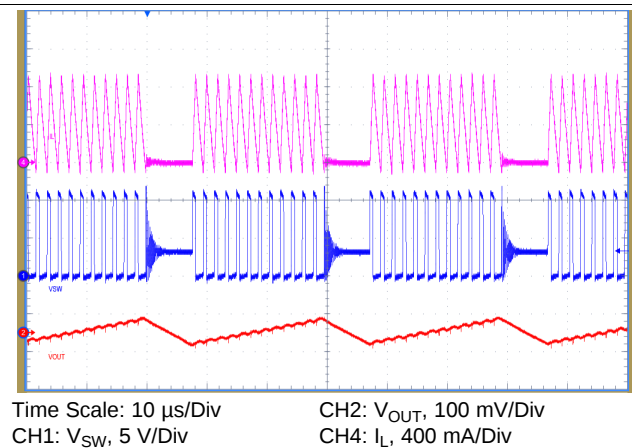


图 34. Full-Load Switching Waveforms
PFM Mode, $I_{LIM} = 750\text{ mA}$

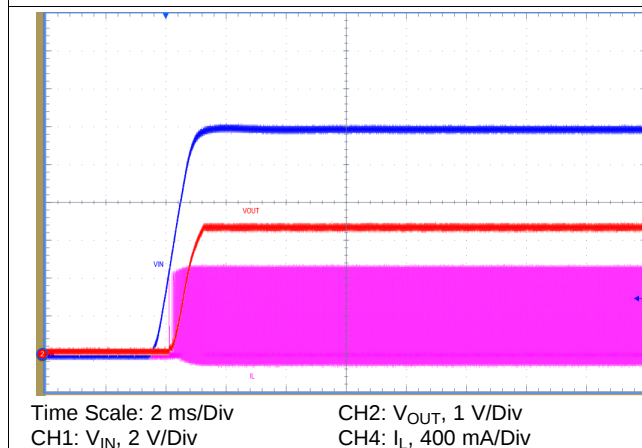


图 35. Full-Load Start-Up, PFM, $I_{LIM} = 750\text{ mA}$

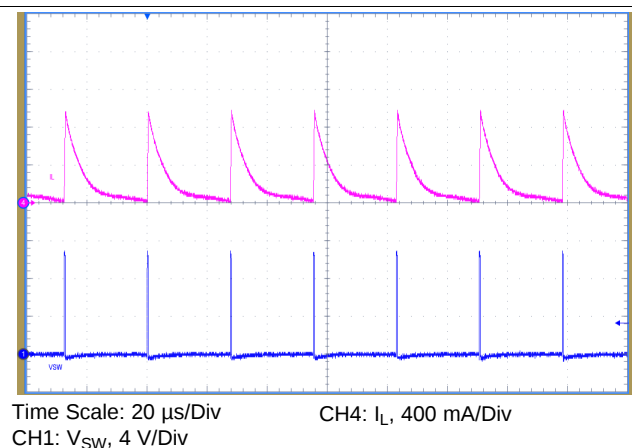
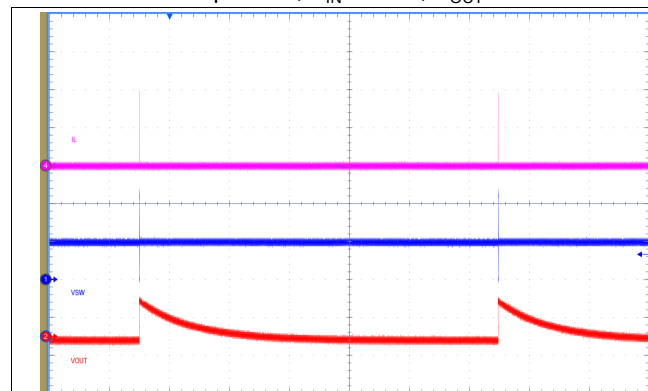


图 36. Short Circuit, PFM, $I_{LIM} = 750\text{ mA}$

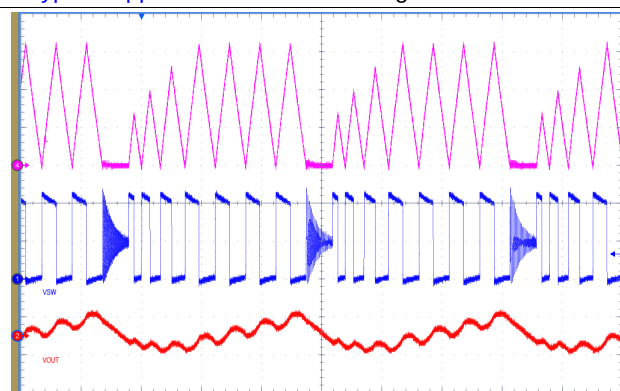
Typical Characteristics (continued)

Unless otherwise specified, $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$. Please refer to [Typical Applications](#) for circuit designs.



Time Scale: 50 ms/Div
CH1: V_{SW} , 5 V/Div
CH2: V_{OUT} , 50 mV/Div
CH4: I_L , 400 mA/Div

图 37. No-Load Switching Waveforms
PFM Mode, $I_{LIM} = 1.25\text{ A}$, Modulated



Time Scale: 20 μ s/Div
CH1: V_{SW} , 5 V/Div
CH2: V_{OUT} , 100 mV/Div
CH4: I_L , 400 mA/Div

图 38. Full-Load Switching Waveforms
PFM Mode, $I_{LIM} = 1.25\text{ A}$, Modulated

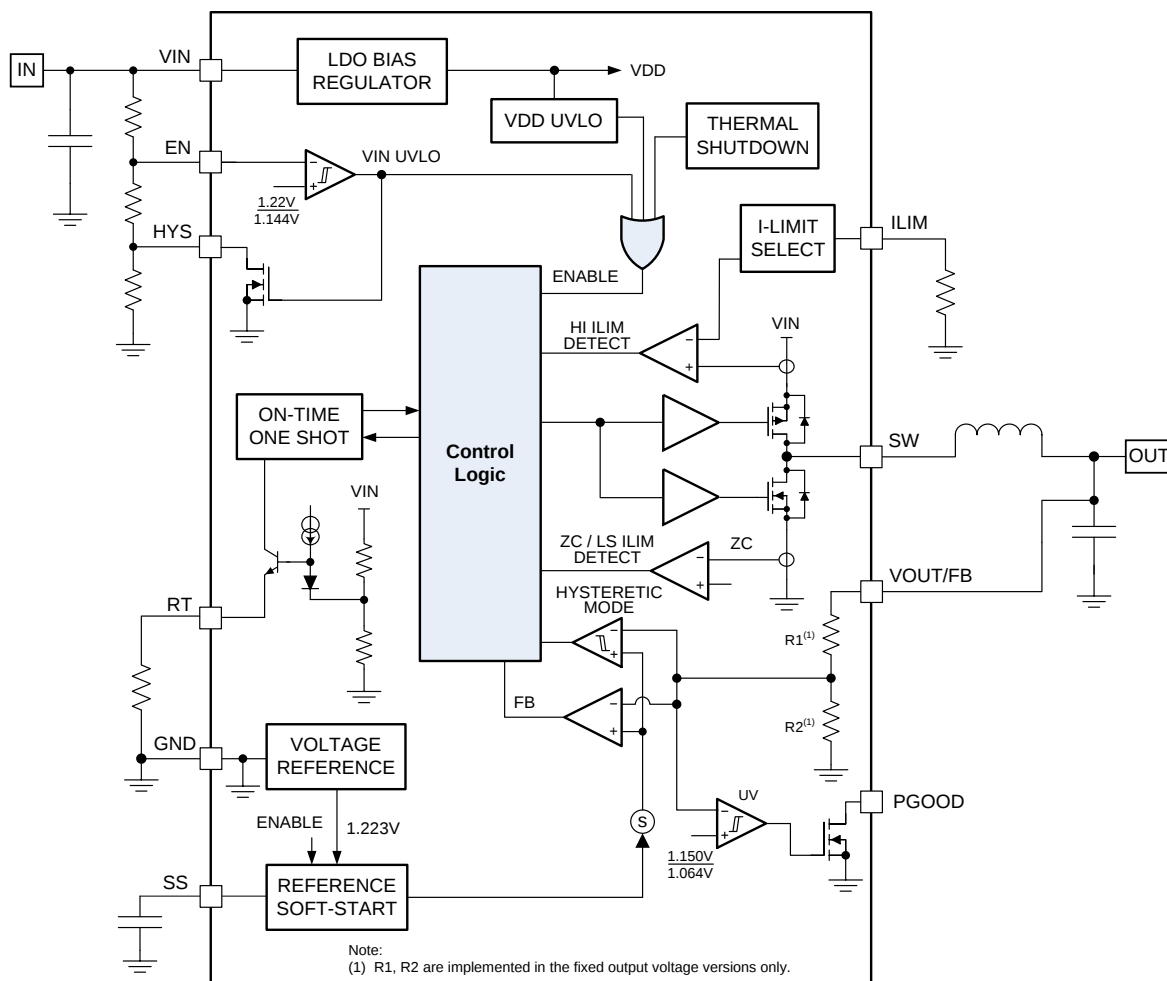
7 Detailed Description

7.1 Overview

The LM5166 regulator is an easy-to-use synchronous buck DC-DC converter that operates from a supply voltage ranging from 3 V to 65 V. The device is intended for step-down conversions from 5-V, 12-V, 24-V, and 48-V unregulated, semi-regulated, and fully-regulated supply rails. With integrated high-side and low-side power MOSFETs, the LM5166 delivers up to 500-mA DC load current with exceptional efficiency and ultra-low input quiescent current in a very small solution size. Designed for simple implementation, a choice of operating modes offers flexibility to optimize its usage according to the target application. Fixed-frequency, constant on-time (COT) operation with discontinuous conduction mode (DCM) at light loads is ideal for low-noise, high current, high current, fast transient load requirements. Alternatively, pulse frequency modulation (PFM) mode, complemented by an adjustable current limit, achieves ultra-high light-load efficiency performance. Control loop compensation is not required with either operating mode, which reduces design time and external component count.

The LM5166 incorporates other features for comprehensive system requirements, including an open-drain Power Good circuit for power-rail sequencing and fault reporting, internally-fixed or externally-adjustable soft start, monotonic start-up into prebiased loads, precision enable with customizable hysteresis for programmable line undervoltage lockout (UVLO), and thermal shutdown with automatic recovery. These features enable a flexible and easy-to-use platform for a wide range of applications. The pin arrangement is designed for simple and optimized PCB [Layout](#), requiring only a few external components.

7.2 Functional Block Diagram



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7.3 Feature Description

7.3.1 Integrated Power MOSFETs

The LM5166 is a step-down buck converter with integrated high-side PMOS buck switch and low-side NMOS synchronous switch. During the high-side MOSFET on-time, the SW voltage V_{SW} swings up to approximately V_{IN} , and the inductor current increases with slope $(V_{IN} - V_{OUT})/L_F$. When the high-side MOSFET is turned off by the control logic, the low-side MOSFET turns on after a fixed dead time. Inductor current flows through the low-side MOSFET with slope $-V_{OUT}/L_F$. Duty cycle D is defined as T_{ON}/T_{SW} , where T_{ON} is the high-side MOSFET conduction time and T_{SW} is the switching period.

7.3.2 Selectable PFM or COT Mode Converter Operation

Depending on how the RT pin is connected, the LM5166 operates in PFM or COT mode. With the RT pin tied to GND, the device operates in PFM mode. An R_{RT} resistor connected between the RT and GND pins enables COT control and sets the desired switching frequency as defined by 式 4. 図 39 and 図 40 show converter schematics for PFM and COT modes of operation.

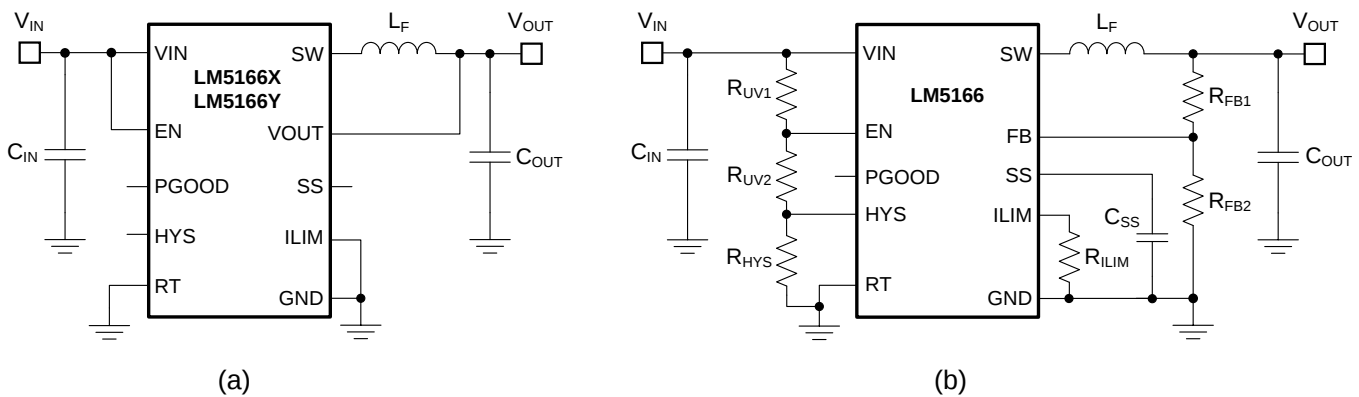


图 39. PFM Mode Converter Schematics: (a) Fixed Output Voltage of 5 V or 3.3 V, (b) Adjustable Output Voltage With Programmable Soft Start, Current Limit, and UVLO

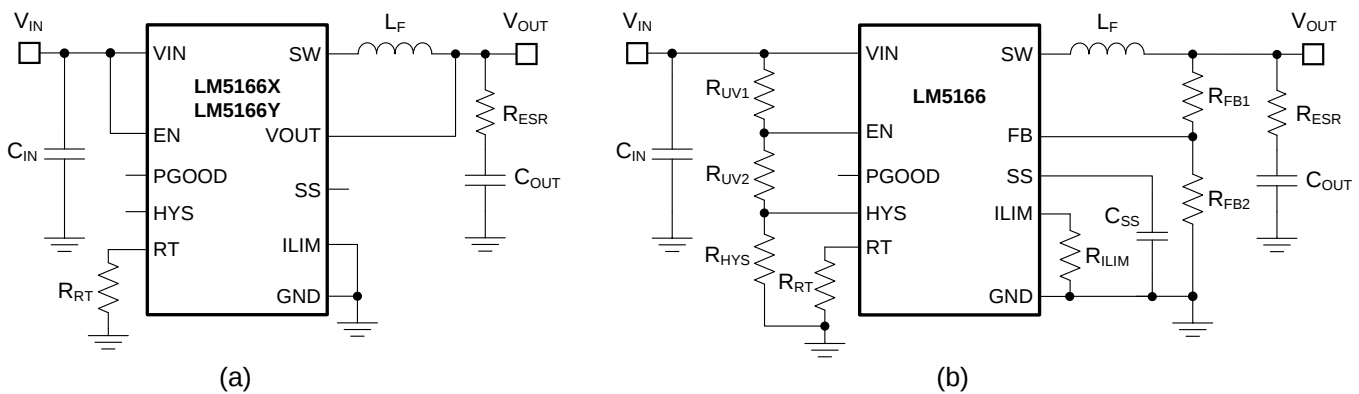


图 40. COT Mode Converter Schematics: (a) Fixed Output Voltage of 5 V or 3.3 V, (b) Adjustable Output Voltage With Programmable Soft Start, Current Limit, and UVLO

Feature Description (continued)

7.3.2.1 PFM Mode Operation

In PFM mode, the LM5166 behaves as a hysteretic voltage regulator operating in boundary conduction mode. The output voltage is regulated between upper and lower threshold levels according to the PFM feedback comparator hysteresis of 10 mV. [Figure 41](#) shows the relevant output voltage and inductor current waveforms. The LM5166 provides the required switching pulses to recharge the output capacitor to the upper threshold, followed by a sleep period where most of the internal circuits are disabled. The load current is supported by the output capacitor during this time, and the LM5166 current consumption reduces to 9.7 μA . The sleep period duration depends on load current and output capacitance.

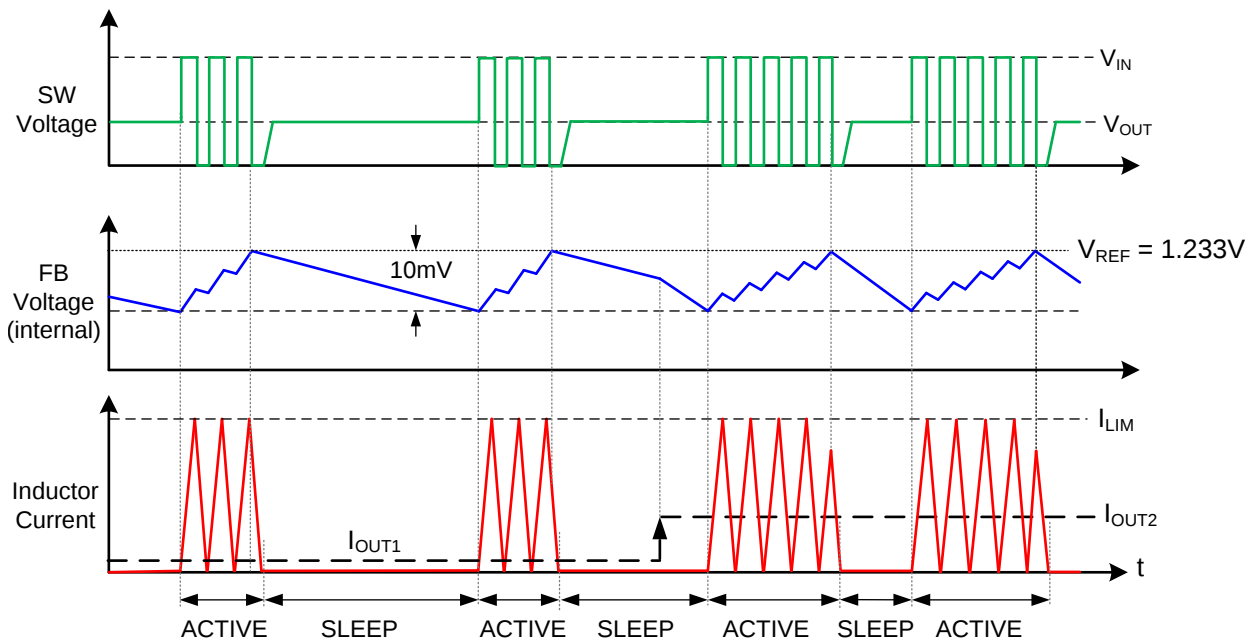


Figure 41. PFM Mode Output Voltage and Inductor Current Representative Waveforms

When operating in PFM mode at given input and output voltages, the chosen filter inductance dictates the PFM pulse frequency as

$$F_{\text{SW(PFM)}} = \frac{V_{\text{OUT}}}{L_F \cdot I_{\text{PK(PFM)}}} \cdot \left(1 - \frac{V_{\text{OUT}}}{V_{\text{IN}}} \right)$$

where

- $I_{\text{PK(PFM)}}$ is one of the programmable levels for peak current limit. See [Adjustable Current Limit](#) for more detail. (1)

One of the supported ILIM settings enables a function that modulates the peak current threshold levels during the first three switching cycles of each active period as illustrated in [Figure 42](#). This function improves efficiency under most application conditions at the expense of slightly degraded load transient response.

Feature Description (continued)

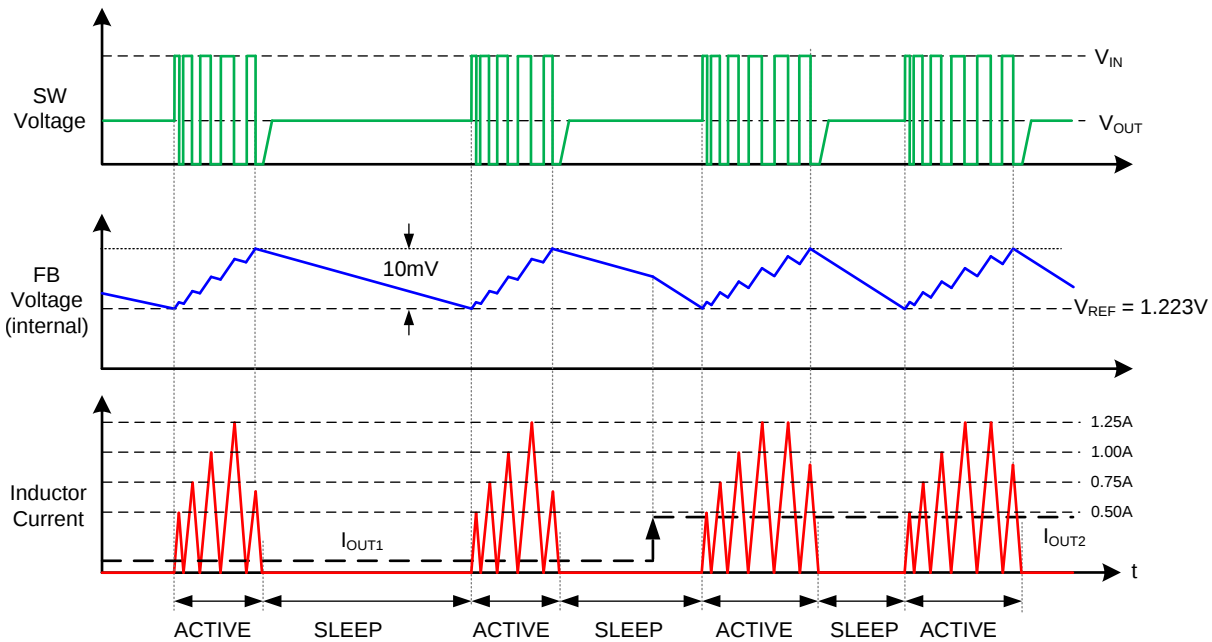


FIG 42. PFM Mode With Modulated I_{LIM} , Output Voltage and Inductor Current Representative Waveforms

As expected, the choice of mode and switching frequency represents a compromise between conversion efficiency, quiescent current, and passive component size. Lower switching frequency implies reduced switching losses (including gate charge losses, transition losses, and so forth) and higher overall efficiency. Higher switching frequency, on the other hand, implies smaller LC output filter and hence, a more compact design. Lower inductance also helps transient response and reduces the inductor DCR conduction loss. The ideal switching frequency in a given application is a tradeoff and thus is determined on a case-by-case basis. It relates to the input voltage, output voltage, most frequent load current level(s), external component choices, and circuit size requirement. At light loads, the PFM converter has a relatively longer sleep time interval and thus operates at lower input quiescent current levels.

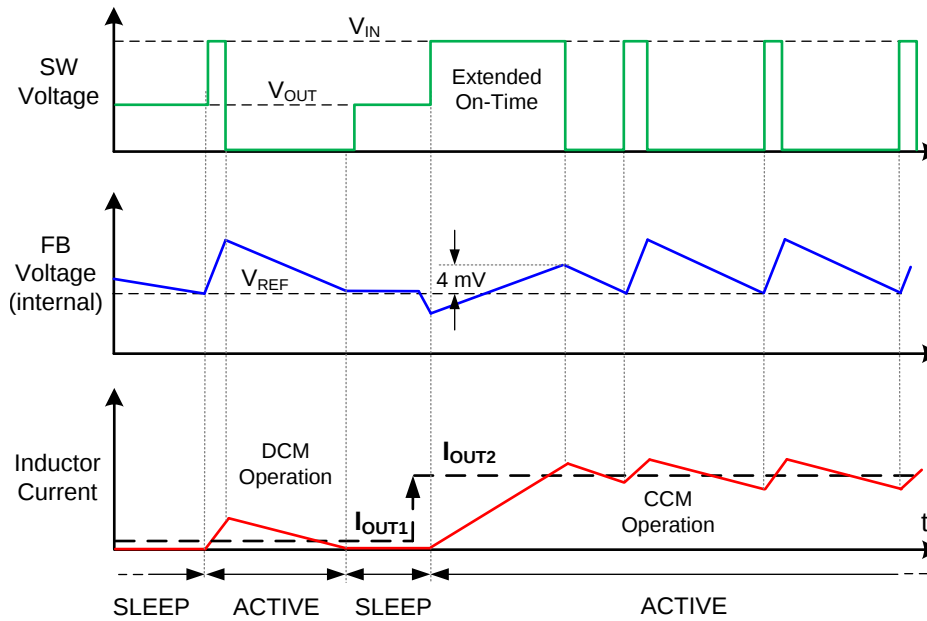
7.3.2.2 COT Mode Operation

In COT mode, the LM5166-based converter turns on the high-side MOSFET with constant on-time that adapts to V_{IN} , as defined by 式 2, to operate with nearly fixed switching frequency when in continuous conduction mode (CCM). The high-side MOSFET turns on when the feedback voltage (V_{FB}) falls below the reference voltage. The regulator control loop maintains a constant output voltage by adjusting the PWM off-time as defined with 式 3. For stable operation, the feedback voltage must decrease monotonically in phase with the inductor current during the off-time as explained in [Ripple Generation Methods](#).

$$t_{ON}[ns] = \frac{175 \cdot R_{RT}[k\Omega]}{V_{IN}} \quad (2)$$

$$t_{OFF} = \frac{L_F \cdot \Delta I_{L(nom)}}{V_{OUT} + (R_{DCR} + R_{DS(on)2}) \cdot I_{OUT}} \quad (3)$$

Diode emulation mode (DEM) prevents negative inductor current, and pulse skipping maintains high efficiency at light load currents by decreasing the effective switching frequency. The COT-controlled LM5166 waveforms in CCM and DEM are shown in 图 43.

Feature Description (continued)

图 43. COT Mode Feedback Voltage and Inductor Current Representative Waveforms

The required on-time adjust resistance for a particular frequency (in CCM) is given in 式 4 and tabulated in 表 1. The maximum programmable on-time is 15 μ s.

$$R_{RT}[\text{k}\Omega] = \frac{V_{OUT}[\text{V}]}{F_{SW}[\text{kHz}]} \cdot \frac{10^4}{1.75} \quad (4)$$

表 1. On-Time Adjust Resistance (E96 EIA Values) for Various Switching Frequencies and Output Voltages⁽¹⁾

F_{SW} (kHz)	R_{RT} (k Ω)			
	$V_{OUT} = 1.8 \text{ V}$	$V_{OUT} = 3.3 \text{ V}$	$V_{OUT} = 5 \text{ V}$	$V_{OUT} = 12 \text{ V}$
100	102	187	287	681
200	51.1	95.3	143	340
300	34	63.4	95.3	226
400	25.5	47.5	71.5	169
500	20.5	37.4	57.6	137
600	16.9	31.6	47.5	115

(1) For a more precise adjustment of the switching frequency consider 式 2 and 式 3. The *LM5166 Quickstart Calculator* estimates and plots the switching frequency as a function of load current.

7.3.2.2.1 Ripple Generation Methods

In the Constant-On-Time (COT) control scheme, the on-time is terminated by a one-shot, and the off-time is terminated by the feedback voltage (V_{FB}) falling below the reference voltage (V_{FB1}). Therefore, for stable operation, the feedback voltage must decrease monotonically in phase with the inductor current during the off-time. Furthermore, this change in feedback voltage (V_{FB}) during the off-time must be large enough to dominate any noise present at the feedback node.

表 2. Ripple Generation Methods

TYPE	SCHEMATIC	CALCULATION
Type 1 Lowest Cost		$R_{ESR} \geq \frac{20mV \cdot V_{OUT}}{V_{FB1} \cdot \Delta I_{L(nom)}} \quad (5)$ $R_{ESR} \geq \frac{V_{OUT}}{2 \cdot V_{IN} \cdot F_{SW} \cdot C_{OUT}} \quad (6)$
Type 2 Reduced Ripple		$R_{ESR} \geq \frac{20mV}{\Delta I_{L(nom)}} \quad (7)$ $R_{ESR} \geq \frac{V_{OUT}}{2 \cdot V_{IN} \cdot F_{SW} \cdot C_{OUT}} \quad (8)$ $C_{FF} \geq \frac{1}{2\pi \cdot F_{SW} \cdot (R_{FB1} \parallel R_{FB2})} \quad (9)$
Type 3⁽¹⁾ Lowest Ripple		$C_A \geq \frac{10}{F_{SW} \cdot (R_{FB1} \parallel R_{FB2})} \quad (10)$ $R_A C_A \leq \frac{(V_{IN(nom)} - V_{OUT}) \cdot T_{ON} (@V_{IN(nom)})}{20mV} \quad (11)$ $C_B \geq \frac{T_{TR-Settling}}{3 \cdot R_{FB1}} \quad (12)$

(1) Lin, Min and others, "Frequency Domain Analysis of Fixed On-Time With Bottom Detection Control for Buck Converter," IEEE IECON 2010, pp. 481–485.

表 2 presents three different methods for generating appropriate voltage ripple at the feedback node. Type 1 ripple generation method uses a single resistor, designated R_{ESR} , in series with the output capacitor. The generated voltage ripple has two components:

- Capacitive ripple caused by the inductor ripple current charging and discharging the output capacitor.
- Resistive ripple caused by the inductor ripple current flowing in the output capacitor ESR and series resistance R_{ESR} .

The capacitive ripple component is out of phase with the inductor current. As a result, the capacitive ripple does not decrease monotonically during the off-time. The resistive ripple component is in phase with the inductor current and decreases monotonically during the off-time. The resistive ripple must exceed the capacitive ripple at the output (V_{OUT}) for stable operation. If this condition is not satisfied, unstable switching behavior is observed in COT converters, with multiple on-time bursts in close succession followed by a long off-time. 式 5 and 式 6 define the value of the R_{ESR} resistor that ensures the required amplitude and phase of the ripple at the feedback node.

Type-2 ripple generation method uses a C_{FF} capacitor in addition to the R_{ESR} resistor. As the output voltage ripple is directly AC-coupled by C_{FF} to the feedback node, the R_{ESR} value and ultimately the output voltage ripple are reduced by a factor of V_{OUT} / V_{FB1} .

Type-3 ripple generation method uses an RC network consisting of R_A and C_A , and the switch node (SW) voltage to generate a triangular ramp. This triangular ramp is then AC-coupled into the feedback node (FB) with capacitor C_B . Because this circuit does not use the output voltage ripple, it is suited for applications where low output voltage ripple is critical. Application note [AN-1481 Controlling Output Ripple & Achieving ESR Independence in Constant On-Time Regulator Designs](#) provides additional details on this topic.

7.3.2.2 COT Mode Light-Load Operation

Diode emulation mode (DEM) operation occurs when the low-side MOSFET switches off as the inductor valley current reaches zero. Here, the load current is less than half of the peak-to-peak inductor current ripple in CCM. Turning off the low-side MOSFET at zero current reduces switching loss, and preventing negative current conduction reduces conduction loss. In DEM, the duration that both high-side and low-side MOSFETs remain off progressively increases as load current decreases.

7.3.3 Low Dropout Operation and 100% Duty Cycle Mode

Using $R_{DS(on)1}$ and $R_{DS(on)2}$ for the high-side and low-side MOSFET on-state resistances, respectively, and R_{DCR} for the inductor DC resistance, the duty cycle in COT (CCM) or PFM mode is given by 式 13.

$$D = \frac{V_{OUT} + (R_{DS(on)2} + R_{DCR}) \cdot I_{OUT}}{V_{IN} - (R_{DS(on)1} - R_{DS(on)2}) \cdot I_{OUT}} \approx \frac{V_{OUT}}{V_{IN}} \quad (13)$$

The LM5166 provides a low input voltage to output voltage dropout by engaging the high-side MOSFET at 100% duty cycle. In COT operation, the extended on-time mode seamlessly increases the duty cycle during low dropout conditions or load-step transients. The buck switch on-time extends based on the requirement that the FB voltage exceeds the internal 4-mV FB comparator hysteresis during any COT mode on-time. The on-time (and duty cycle) are extended as needed at low input voltage conditions until the FB voltage reaches the upper threshold. 100% duty cycle operation is eventually reached as the input voltage decreases to a level near the output voltage setpoint. Very low dropout voltages can be achieved with 100% duty cycle and a low DCR inductor.

Note that PFM mode operation provides a natural transition to 100% duty cycle if needed during low input voltage conditions. If the input-to-output voltage difference is very low, the inductor current increases to a level determined by the load and may not reach the peak current threshold required to turn off the buck switch.

Use 式 14 to calculate the minimum input voltage to maintain output regulation at 100% duty cycle.

$$V_{IN(min)} = V_{OUT} + I_{OUT} \cdot (R_{DS(on)1} + R_{DCR}) \quad (14)$$

7.3.4 Adjustable Output Voltage (FB)

Three voltage feedback settings are available. The fixed 3.3-V and 5-V versions include internal feedback resistors that sense the output directly through the VOUT pin, and the adjustable voltage option senses the output through an external resistor divider connected from the output to the FB pin.

The LM5166 voltage regulation loop regulates the output voltage by maintaining the FB voltage equal to the internal reference voltage (V_{FB1}). A resistor divider programs the ratio from output voltage V_{OUT} to FB. For a target V_{OUT} setpoint, calculate R_{FB2} based on the selected R_{FB1} by 式 15.

$$R_{FB2} = \frac{1.223V}{V_{OUT} - 1.223V} \cdot R_{FB1} \quad (15)$$

R_{FB1} in the range of 100 k Ω to 1 M Ω is recommended for most applications. A larger R_{FB1} consumes less DC current, which is necessary if light-load efficiency is critical. However, R_{FB1} larger than 1 M Ω is not recommended as the feedback path becomes more susceptible to noise. Larger feedback resistances generally require more careful feedback path PCB layout. It is important to route the feedback trace away from the noisy area of the PCB. For more PCB layout recommendations, see [Layout](#).

7.3.5 Adjustable Current Limit

The LM5166 protects the system from overload conditions using cycle-by-cycle current limiting of the peak inductor current. The current sensed in the high-side MOSFET is compared to the current limit threshold set by the ILIM pin (see [表 3](#)). Current is sensed after a 120-ns leading-edge blanking time following the high-side MOSFET turnon. The propagation delay of the current limit comparator is 80 ns, typical.

表 3. Current Limit Thresholds

MODE OF OPERATION	R_{ILIM} (k Ω)	TYPICAL I_{HS_LIM} (mA)	TYPICAL I_{LS_LIM} (mA)	$I_{OUT(max)}$ (mA)
COT Mode	0	750	415	500
	$\geq 100^{(1)}$	500	315	300
PFM Mode	0	1250	N/A	500
	24.9	1250 ⁽²⁾	N/A	500
	56.2	750	N/A	300
	$\geq 100^{(1)}$	500	N/A	200

- (1) For this current limit threshold selection, the ILIM pin may also be left open instead of using a 100-k Ω or greater resistor.
- (2) This I_{LIM} setting enables a function that modulates the I_{LIM} levels during the first three switching cycles as illustrated in [图 42](#).

Note that in PFM mode, the inductor current ramps from zero to the chosen peak threshold every switching cycle. Consequently, the maximum output current is equal to half the peak inductor current. The output current capability in COT mode is higher and equal to the peak current threshold minus one-half the inductor ripple current. The ripple current is determined by the input and output voltages and the chosen inductance and switching frequency.

7.3.6 Precision Enable (EN) and Hysteresis (HYS)

The precision EN input supports adjustable input undervoltage lockout (UVLO) with hysteresis programmed independently through the HYS pin for application specific power-up and power-down requirements. EN connects to the input of a comparator with 76-mV hysteresis. The reference input of the comparator is connected to a 1.22-V bandgap reference. An external logic signal can be used to drive EN input to toggle the output on and off for system sequencing or protection. The simplest way to enable operation is to connect EN directly to VIN. This allows self-start-up of the LM5166 when V_{IN} is within its valid operating range.

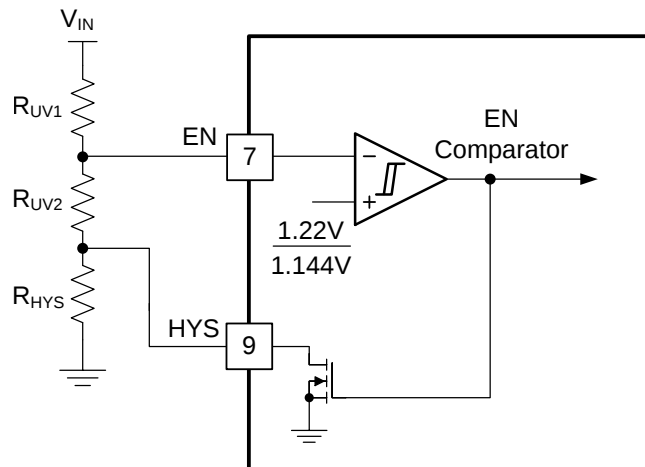


图 44. Input Voltage UVLO Using EN and HYS

However, many applications benefit from using a resistor divider R_{UV1} and R_{UV2} as shown in [Figure 44](#) to establish a precision UVLO level. Adding R_{HYS} and the connection to the HYS pin increases the voltage hysteresis as needed.

The input UVLO voltages are calculated using [Equation 16](#) and [Equation 17](#).

$$V_{IN(on)} = 1.22V \cdot \left(1 + \frac{R_{UV1}}{R_{UV2}} \right) \quad (16)$$

$$V_{IN(off)} = 1.144V \cdot \left(1 + \frac{R_{UV1}}{R_{UV2} + R_{HYS}} \right) \quad (17)$$

The LM5166 enters a low I_Q shutdown mode when EN is pulled below an NPN transistor base-emitter voltage drop (approximately 0.6 V at room temperature). If EN is below this hard shutdown threshold, the internal LDO regulator powers off and the internal bias supply rail collapses, turning off the bias currents of the LM5166.

7.3.7 Power Good (PGOOD)

The LM5166 has a built-in PGOOD flag to indicate whether the output voltage is within a regulation window. The PGOOD signal can be used for start-up sequencing of downstream converters, as shown in [Figure 45](#), or fault protection. PGOOD is an open-drain output that requires a pullup resistor to a DC supply (12 V maximum). Typical range of pullup resistance is 10 kΩ to 100 kΩ. If necessary, use a resistor divider to decrease the PGOOD pin voltage from a higher pullup rail.

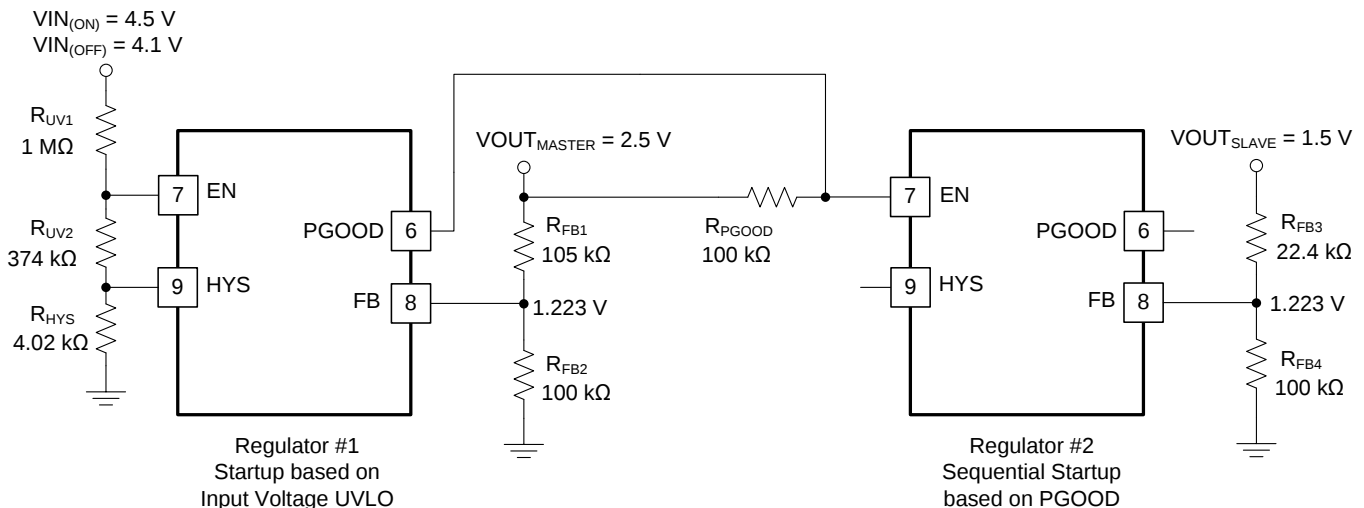


Figure 45. Master-Slave Sequencing Implementation Using PGOOD and EN

When the FB voltage exceeds 94% of the internal reference V_{FB1} , the PGOOD switch turns off and PGOOD will be pulled high. If the FB voltage falls below 87% of V_{FB1} , the PGOOD switch turns on, and PGOOD pulls low to indicate *power bad*. The rising edge of PGOOD has a built-in noise filter delay of 5 μs.

7.3.8 Configurable Soft Start (SS)

The LM5166 has a flexible and easy-to-use start-up control through the SS pin. A soft-start feature prevents inrush current impacting the LM5166 and its supply when power is first applied. Soft start is achieved by slowly ramping up the target regulation voltage when the device is enabled or powered up. Selectable and adjustable soft-start timing options include minimum delay (no soft-start), 900-μs internally fixed soft-start, and an externally-adjustable soft start.

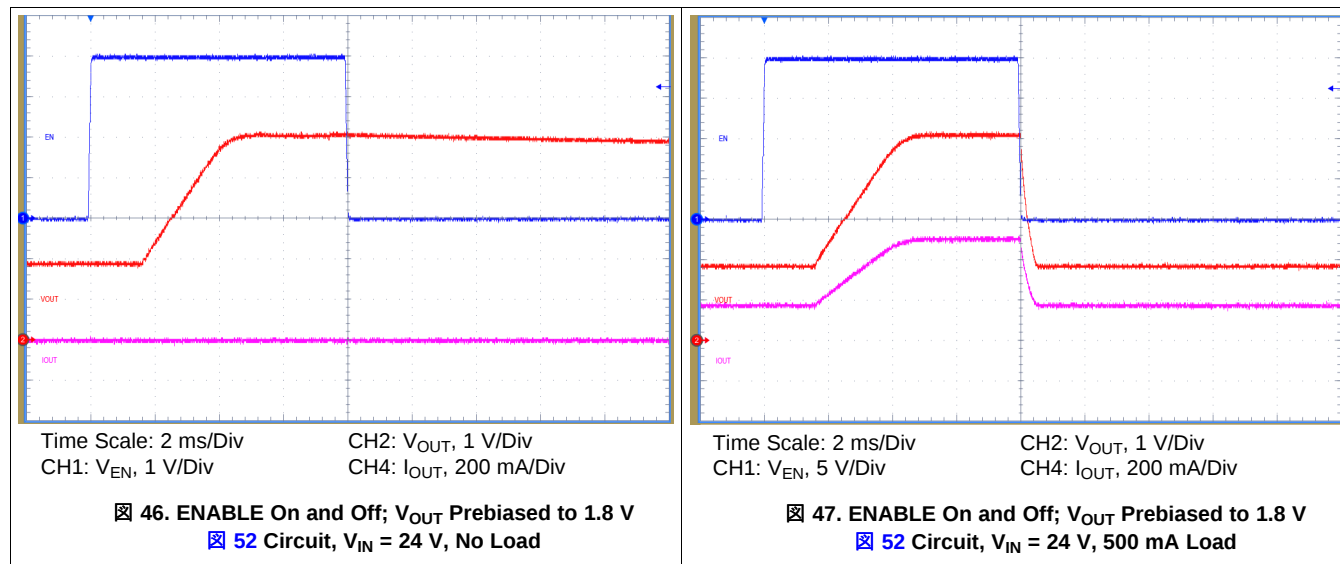
The simplest way to use the LM5166 is to leave the SS pin open circuit for a 900-μs soft-start time. The LM5166 will employ the internal soft-start control ramp and start-up to the regulated output voltage. In applications with a large amount of output capacitors, higher V_{OUT} , or other special requirements, extend the soft-start time by connecting an external capacitor C_{SS} from SS to GND. Longer soft-start time further reduces the supply current needed to charge the output capacitors. An internal current source ($I_{SS} = 10 \mu A$) charges C_{SS} and generates a ramp to control the ramp rate of the output voltage. For a desired soft-start time t_{SS} , the C_{SS} capacitance is:

$$C_{SS} [nF] = 8.1 \cdot t_{SS} [ms] \quad (18)$$

C_{SS} is discharged by an internal 80-Ω FET when V_{OUT} is shutdown by EN, UVLO, or thermal shutdown.

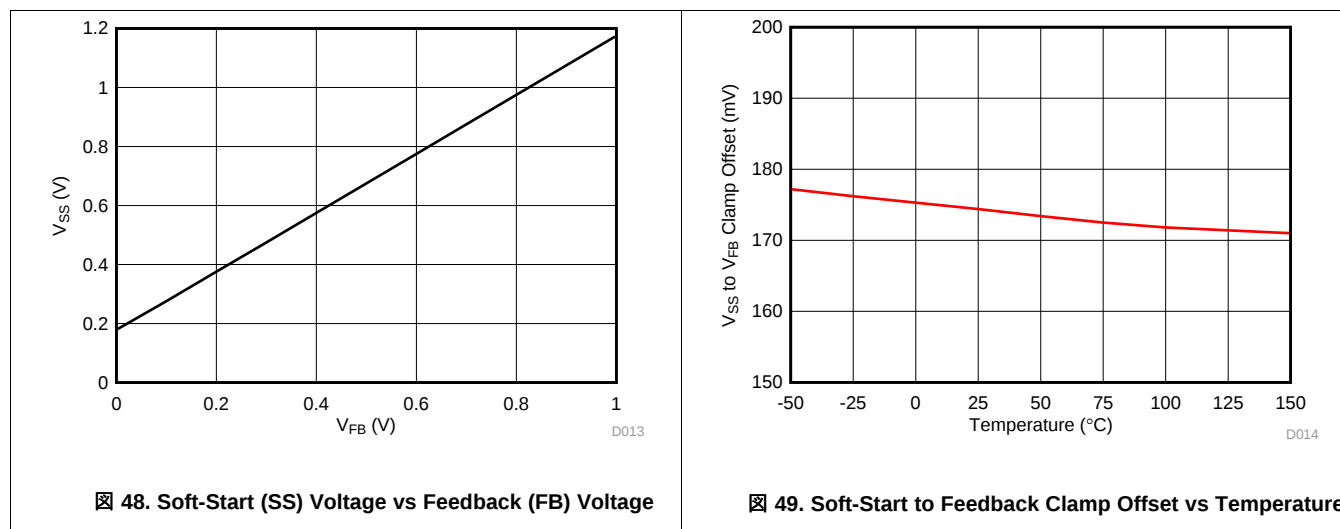
It is desirable in some applications for the output voltage to reach its nominal setpoint in the shortest possible time. Connecting a 100-kΩ resistor from SS to GND disables the soft-start circuit of the LM5166, and the LM5166 operates in current limit during start-up to rapidly charge the output capacitance.

Diode emulation mode (DEM) of the LM5166 prevents negative inductor current enabling monotonic start-up under prebiased output conditions. With a prebiased output voltage, the LM5166 waits until the soft-start ramp allows regulation above the prebiased voltage and then follows the soft-start ramp to the regulation setpoint as shown in [Figure 46](#) and [Figure 47](#).

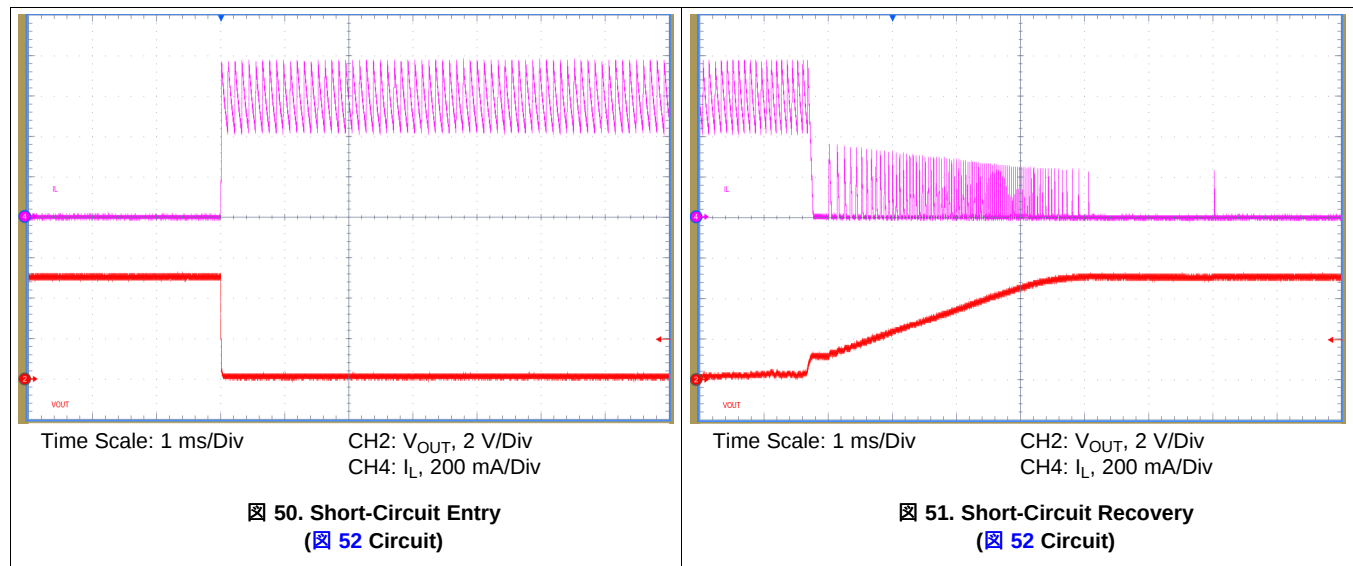


7.3.9 Short-Circuit Operation

The LM5166 features a clamping circuit that clamps the SS voltage about 175 mV above the FB voltage (see [Figure 48](#) and [Figure 49](#)). The circuit is enabled in COT mode and only works when an external soft-start capacitor is connected.



In case of an overload event such as an output short circuit, the clamping circuit discharges the soft-start capacitor. When the short is removed, the FB voltage quickly rises until it reaches the level of the SS pin. Then, the recovery continues under the soft-start capacitor control. [Fig 50](#) and [Fig 51](#) show short-circuit entry and recovery waveforms.



7.3.10 Thermal Shutdown

Thermal shutdown is a built-in self protection to limit junction temperature and prevent damage related to overheating. Thermal shutdown turns off the device when the junction temperature exceeds 170°C typically to prevent further power dissipation and temperature rise. Junction temperature decreases during thermal shutdown, and the LM5166 restarts when the junction temperature falls to 160°C.

7.4 Device Functional Modes

7.4.1 Shutdown Mode

The EN pin provides ON / OFF control for the LM5166. When V_{EN} is below 0.3 V, the device is in shutdown mode. Both the internal LDO and the switching regulator are off. The quiescent current in shutdown mode drops to 4 μ A (typical) at $V_{IN} = 12$ V. The LM5166 also includes undervoltage protection of the internal bias LDO. If the internal bias supply voltage is below the UV threshold level, the switching regulator remains off.

7.4.2 Standby Mode

The internal bias LDO has a lower enable threshold than the switching regulator. When V_{EN} is above 0.6 V and below the precision enable threshold (1.22 V typically), the internal LDO is on and regulating. The precision enable circuitry is turned on if the LDO output is above the bias rail UV threshold. The switching action and output voltage regulation are disabled in the standby mode.

7.4.3 Active Mode – COT

The LM5166 is in active mode when V_{EN} is above the precision enable threshold and the internal bias rail is above its UV threshold level. In COT active mode, the LM5166 operates in one of three modes depending on the load current:

1. CCM with fixed switching frequency when the load current is more than half of the peak-to-peak inductor current ripple;
2. Pulse skipping and diode emulation mode when load current is less than half of the peak-to-peak inductor current ripple of CCM operation;
3. Extended on-time mode when V_{IN} is nearly equal to V_{OUT} (dropout) and during load step transients.

7.4.4 Sleep Mode – COT

The LM5166 is in COT sleep mode when V_{EN} and V_{IN} are above their relevant threshold levels, FB has exceeded its upper hysteresis level, and the output capacitor is sourcing the load current. In COT sleep mode, the LM5166 operates with very low quiescent current (9.7 μ A typical). There is a 2- μ s wake-up delay from sleep to active modes.

7.4.5 Active Mode – PFM

The LM5166 is in PFM active mode when V_{EN} and V_{IN} are above their relevant thresholds, FB has fallen below the lower hysteresis level, and boundary conduction mode switching is recharging the output capacitor to the upper hysteresis level.

7.4.6 Sleep Mode – PFM

The LM5166 is in PFM sleep mode when V_{EN} and V_{IN} are above their relevant threshold levels, FB has exceeded the upper hysteresis level, and the output capacitor is sourcing the load current. In PFM sleep mode, the LM5166 operates with very low quiescent current (9.7 μ A typical). There is a 2- μ s wake-up delay from sleep to active modes.

8 Applications and Implementation

注

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 LM5166 only requires a few external components to convert from a wide range of supply voltages to a fixed output voltage. To expedite and streamline the process of designing a LM5166-based converter, a comprehensive [LM5166 Quickstart Calculator](#) is available for download to assist the designer with component selection for a given application. [WEBENCH®](#) online software is also available to generate complete designs, leveraging iterative design procedures and access to comprehensive component databases. The following sections discuss the design procedure for both COT and PFM converters using specific circuit design examples.

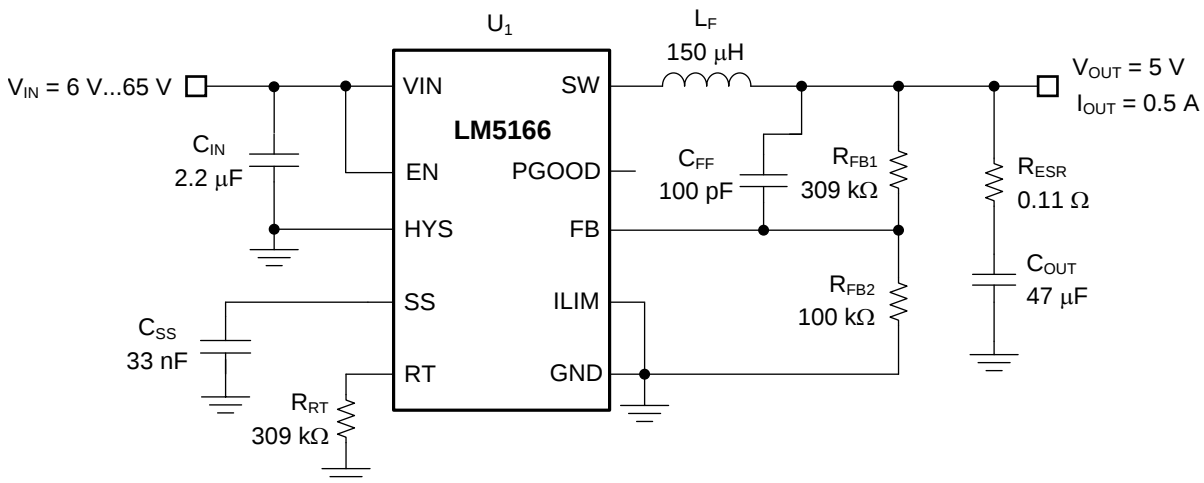
The LM5166 integrates several optional features to meet system design requirements, including precision enable, UVLO, programmable soft start, programmable switching frequency in COT mode, adjustable current limit, and PGOOD indicator. Each application incorporates these features as needed for a more comprehensive design. The application circuits detailed below show LM5166 configuration options suitable for several application use cases. Please see the [LM5166EVM-C50A](#) and [LM5166EVM-C33A](#) EVM user's guides for more detail.

8.2 Typical Applications



For step-by-step design procedure, circuit schematics, bill of materials, PCB files, simulation and test results of an LM5166-powered implementation, refer to [24-V AC Power Stage with Wide \$V_{IN}\$ Converter and Battery Gauge for Smart Thermostat](#) reference design.

8.2.1 Design 1: Wide V_{IN} , Low I_Q , High-Efficiency COT Converter Rated at 5 V, 500 mA



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图 52. Schematic for Design 1 With $V_{IN(nom)} = 24\text{ V}$, $V_{OUT} = 5\text{ V}$, $I_{OUT(max)} = 500\text{ mA}$, $F_{SW(nom)} = 100\text{ kHz}$

8.2.1.1 Design Requirements

The target efficiency is 90% for loads above 10 mA based on a nominal input voltage of 24 V and an output voltage of 5 V. The required input voltage range is 6 V to 65 V. The LM5166 is chosen to deliver a 5-V output voltage. The switching frequency is set at 100 kHz. The output voltage soft-start time is 4 ms. The required components are listed in [表 4](#).

表 4. List of Components for Design 1⁽¹⁾

COUNT	REF DES	DESCRIPTION	PART NUMBER	MFR
1	C _{IN}	Capacitor, Ceramic, 2.2 μ F, 100 V, X7R, 10%, 1210	GRM32ER72A225KA35L	Murata
1	C _{OUT}	Capacitor, Ceramic, 47 μ F, 10 V, X7R, 10%, 1210	GRM32ER71A476KE15L	Murata
1	C _{SS}	Capacitor, Ceramic, 33 nF, 16 V, X7R, 10%, 0402	Std	Std
1	C _{FF}	Capacitor, Ceramic, 100 pF, 50 V, X7R, 10%, 0402	Std	Std
1	L _F	Inductor, 150 μ H, 0.240 Ω typ, 1.4 A Isat, 5 mm max	7447714151	Würth
		Inductor, 150 μ H, 0.285 Ω typ, 1.12 A Isat, 5.1 mm max	CDRH105RNP-151NC	Sumida
1	R _{RT}	Resistor, Chip, 309 k Ω , 1/16W, 1%, 0402	Std	Std
1	R _{FB1}	Resistor, Chip, 309 k Ω , 1/16W, 1%, 0402	Std	Std
1	R _{ESR}	Resistor, Chip, 0.11 Ω , 1/16W, 1%, 0402	Std	Std
1	R _{FB2}	Resistor, Chip, 100 k Ω , 1/16W, 1%, 0402	Std	Std
1	U ₁	LM5166, Synchronous Buck Converter, VSON-10, ADJ	LM5166DRCR	TI

(1) See [デベロッパー・ネットワークの製品に関する免責事項](#).

8.2.1.2 Detailed Design Procedure

8.2.1.2.1 Custom Design With WEBENCH® Tools

[Click here](#) to create a custom design using the LM5166 device with the WEBENCH® Power Designer.

1. Start by entering the input voltage (V_{IN}), output voltage (V_{OUT}), and output current (I_{OUT}) requirements.
2. Optimize the design for key parameters such as efficiency, footprint, and cost using the optimizer dial.
3. Compare the generated design with other possible solutions from Texas Instruments.

The WEBENCH Power Designer provides a customized schematic along with a list of materials with real-time pricing and component availability.

In most cases, these actions are available:

- Run electrical simulations to see important waveforms and circuit performance
- Run thermal simulations to understand board thermal performance
- Export customized schematic and layout into popular CAD formats
- Print PDF reports for the design, and share the design with colleagues

Get more information about WEBENCH tools at www.ti.com/WEBENCH.

8.2.1.2.2 Feedback Resistors – R_{FB1}, R_{FB2}

While the 5-V fixed output version of the LM5166 is suitable here, the adjustable version is chosen to provide the user with the option to trim or margin the output voltage if needed. The feedback resistor divider network comprises the upper feedback resistor R_{FB1} and lower feedback resistor R_{FB2}. Select R_{FB1} of 309 k Ω to minimize quiescent current and improve light-load efficiency in this application. With the desired output voltage setpoint of 5 V and $V_{FB} = 1.223$ V, calculate the resistance of R_{FB2} using [式 15](#) as 100.1 k Ω . Choose the closest available standard value of 100 k Ω for R_{FB2}. See [Adjustable Output Voltage \(FB\)](#) for more details.

8.2.1.2.3 Switching Frequency – R_T

The switching frequency of a COT-configured LM5166 is set by the on-time programming resistor at the RT pin. Using [式 4](#), a standard 1% resistor of 309 k Ω gives a switching frequency of 92 kHz. Including the inductor R_{DCR} and R_{DS(on)2} in the calculation of t_{OFF} ([式 3](#)) gives an adjusted F_{SW} of 101 kHz at 500 mA. The [LM5166 Quickstart Calculator](#) estimates and plots the switching frequency as a function of load current.

Note that at very low duty cycles, the minimum controllable on-time of the high-side MOSFET, T_{ON(min)}, of 180 ns may affect choice of switching frequency. In CCM, T_{ON(min)} limits the voltage conversion step-down ratio for a given switching frequency. The minimum controllable duty cycle is given by [式 19](#).

$$D_{MIN} = T_{ON(min)} \cdot F_{SW} \quad (19)$$

Given a fixed $T_{ON(min)}$, it follows that higher switching frequency implies a larger minimum controllable duty cycle. Ultimately, the choice of switching frequency for a given output voltage affects the available input voltage range, solution size, and efficiency. The maximum supply voltage for a given $T_{ON(min)}$ before switching frequency reduction occurs is given by 式 20.

$$V_{IN(max)} = \frac{V_{OUT}}{T_{ON(min)} \cdot F_{SW}} \quad (20)$$

8.2.1.2.4 Filter Inductance – L_F

The inductor ripple current (assuming CCM operation) and peak inductor current are given respectively by 式 21 and 式 22.

$$\Delta I_L = \frac{V_{OUT}}{F_{SW} \cdot L_F} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (21)$$

$$I_{L(peak)} = I_{OUT(max)} + \frac{\Delta I_L}{2} \quad (22)$$

For most applications, choose the inductance such that the inductor ripple current, ΔI_L , is between 30% and 60% of the rated load current at nominal input voltage. Calculate the inductance using 式 23.

$$L_F = \frac{V_{OUT}}{F_{SW} \cdot \Delta I_{L(nom)}} \cdot \left(1 - \frac{V_{OUT}}{V_{IN(nom)}}\right) \quad (23)$$

Choosing a 150- μ H inductor in this design results in 295-mA peak-to-peak ripple current at nominal input voltage of 24 V, equivalent to 59% of the 500-mA rated load current. The peak inductor current at maximum input voltage of 65 V is 675 mA, which is sufficiently below the LM5166 peak current limit of 750 mA.

Check the inductor datasheet to ensure that the inductor saturation current is well above the current limit setting of a particular design. Ferrite designs have low core loss and are preferred at high switching frequencies, so design goals can then concentrate on copper loss and preventing saturation. However, ferrite core materials exhibit a hard saturation characteristic – the inductance collapses abruptly when the saturation current is exceeded. This results in an abrupt increase in inductor ripple current, higher output voltage ripple, not to mention reduced efficiency and compromised reliability. Note that inductor saturation current generally decreases as the core temperature increases.

8.2.1.2.5 Output Capacitors – C_{OUT}

Select the output capacitor to limit the capacitive voltage ripple at the converter output. This is the sinusoidal ripple voltage that arises from the triangular ripple current flowing in the capacitor. Select an output capacitance using 式 24 to limit the capacitive voltage ripple component to 0.5% of the output voltage.

$$C_{OUT} \geq \frac{\Delta I_{L(nom)}}{8 \cdot F_{SW} \cdot \Delta V_{OUT}} \quad (24)$$

Substituting $\Delta I_{L(nom)}$ of 295 mA and ΔV_{OUT} of 25 mV gives C_{OUT} greater than 16 μ F. Mindful of the voltage coefficient of ceramic capacitors, select a 47- μ F, 10-V capacitor with a high-quality dielectric.

8.2.1.2.6 Ripple Generation Network – R_{ESR} , C_{FF}

For this design, the Type 2 ripple generation method is selected as it offers a good balance between cost and output voltage ripple. For other methods, see [Ripple Generation Methods](#).

Select a series resistor, R_{ESR} , such that sufficient ripple in phase with the inductor current ripple appears at the feedback node, FB, using 式 7 and 式 8. Select a feedforward capacitor, C_{FF} , using 式 9.

With $\Delta I_{L(nom)}$ of 295 mA at the nominal input voltage of 24 V, the required R_{ESR} is 0.11 Ω . The required feedforward capacitance, C_{FF} , is 100 pF. Calculate the total output voltage ripple in CCM using 式 25.

$$\Delta V_{OUT} = \Delta I_{L(nom)} \cdot \sqrt{R_{ESR}^2 + \left(\frac{1}{8 \cdot F_{SW} \cdot C_{OUT}}\right)^2} \quad (25)$$

8.2.1.2.7 Input Capacitor – C_{IN}

An input capacitor is necessary to limit the input ripple voltage while providing switching-frequency AC current to the buck power stage. To minimize the parasitic inductance in the switching loop, position the input capacitors as close as possible to the VIN and GND pins of the LM5166. The input capacitors conduct a trapezoidal-wave current of peak-to-peak amplitude equal to the output current. It follows that the resultant capacitive component of AC ripple voltage is a triangular waveform. Together with the ESR-related ripple component, the peak-to-peak input ripple voltage amplitude is given by 式 26.

$$\Delta V_{IN} = \frac{I_{OUT} \cdot D \cdot (1-D)}{F_{SW} \cdot C_{IN}} + I_{OUT} \cdot R_{ESR} \quad (26)$$

The input capacitance required for a particular load current, based on an input voltage ripple specification of ΔV_{IN} , is given by 式 27.

$$C_{IN} \geq \frac{I_{OUT} \cdot D \cdot (1-D)}{F_{SW} \cdot (\Delta V_{IN} - I_{OUT} \cdot R_{ESR})} \quad (27)$$

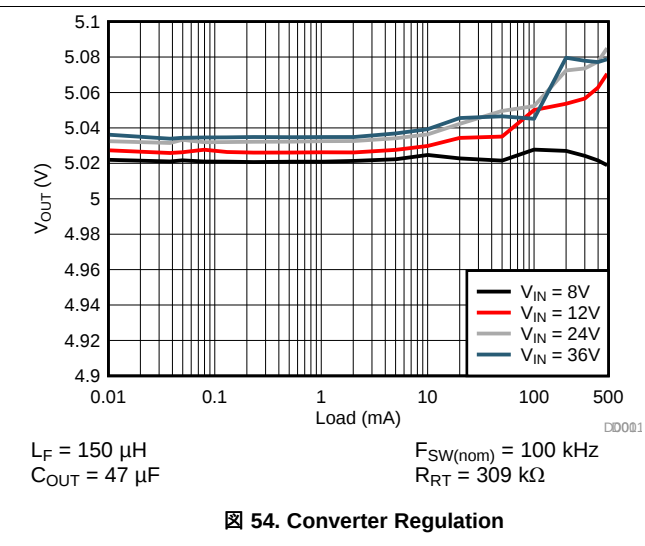
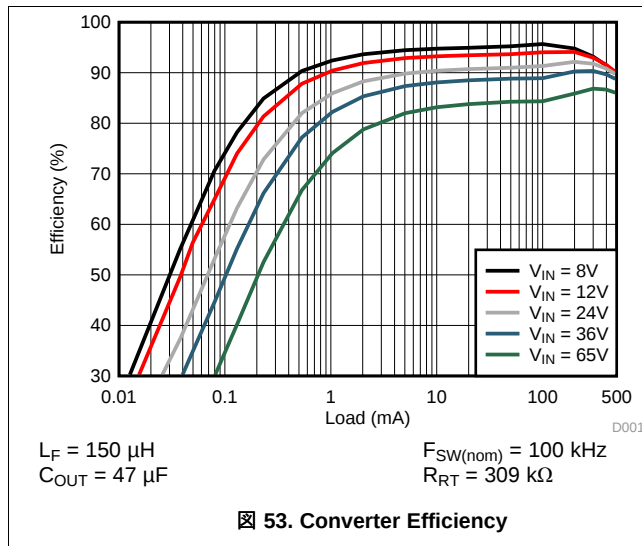
The recommended high-frequency input capacitance is 2.2 μ F or higher and should be a high-quality ceramic component with sufficient voltage rating. Based on the voltage coefficient of ceramic capacitors, choose a voltage rating of twice the maximum input voltage. Additionally, some bulk capacitance is required if the LM5166 circuit is not located within approximately 5 cm from the input voltage source. This capacitor provides damping to the resonance associated with parasitic inductance of the supply lines and high-Q ceramics.

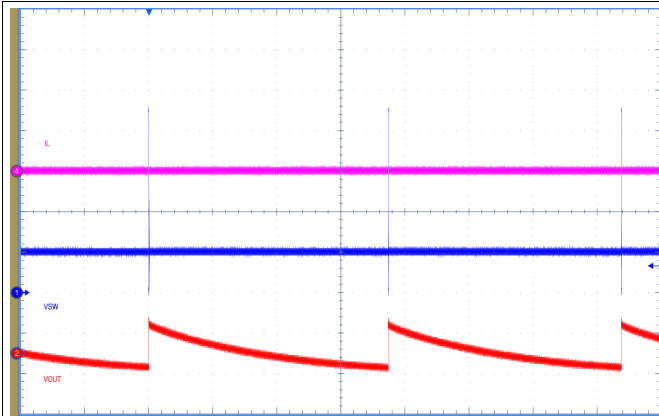
8.2.1.2.8 Soft-Start Capacitor – C_{SS}

Connect an external soft-start capacitor for a specific soft-start time. In this example, select a soft-start capacitance of 33 nF based on 式 18 to achieve a soft-start time of 4 ms.

8.2.1.2.9 Application Curves

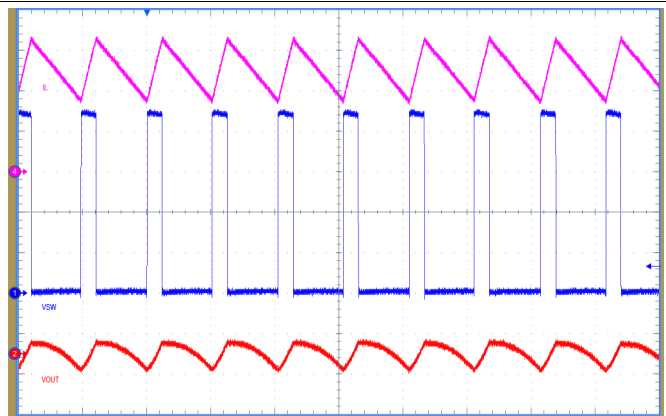
Unless otherwise stated, application performance curves were taken at T_A = 25°C.





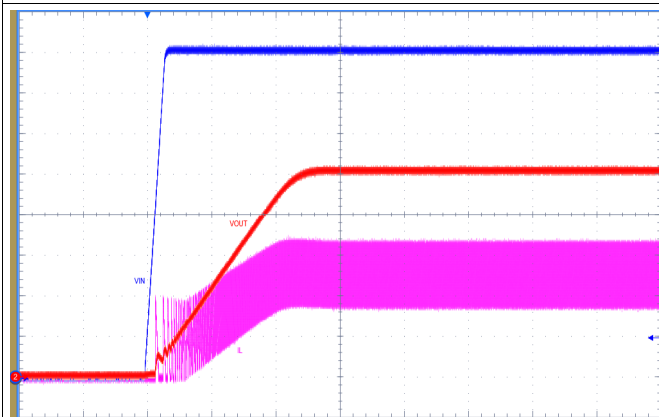
Time Scale: 20 ms/Div
CH1: V_{SW} , 5 V/Div
CH2: V_{OUT} , 50 mV/Div
CH4: I_L , 200 mA/Div

图 55. No-Load Switching Waveforms, $V_{IN} = 24$ V



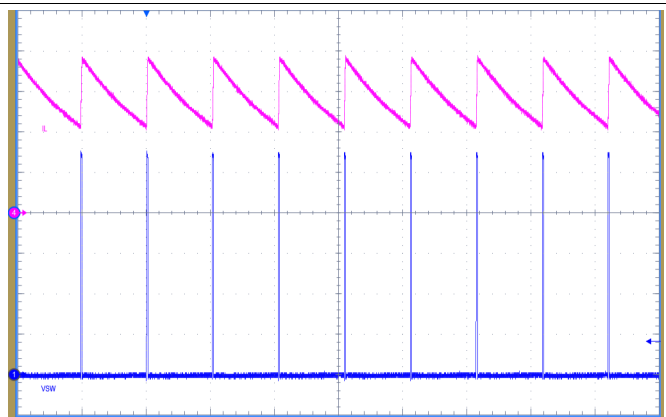
Time Scale: 10 μs/Div
CH1: V_{SW} , 5 V/Div
CH2: V_{OUT} , 50 mV/Div
CH4: I_L , 200 mA/Div

图 56. Full-Load Switching Waveforms, $V_{IN} = 24$ V



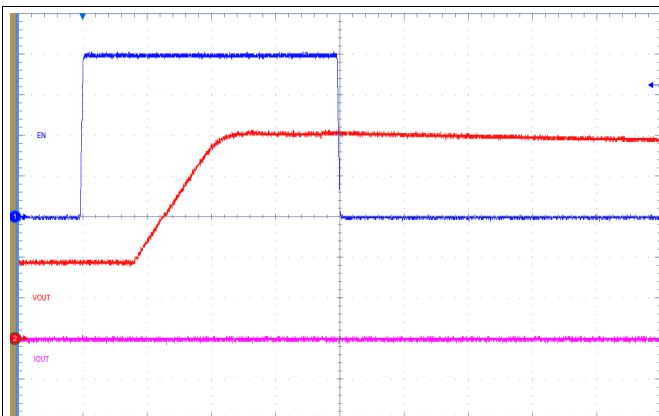
Time Scale: 2 ms/Div
CH1: V_{IN} , 3 V/Div
CH2: V_{OUT} , 1 V/Div
CH4: I_L , 200 mA/Div

图 57. Full-Load Start-Up, $V_{IN} = 24$ V



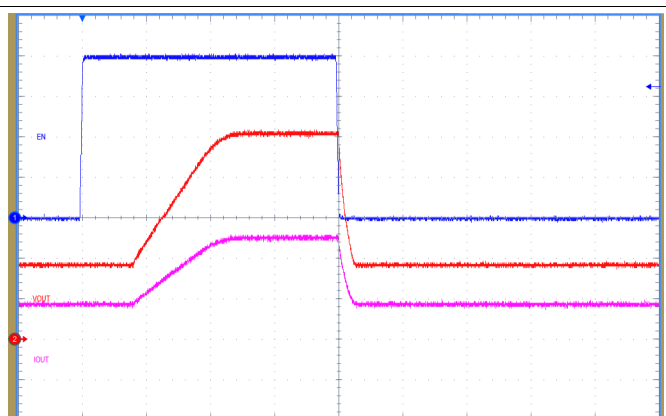
Time Scale: 100 μs/Div
CH1: V_{SW} , 4 V/Div
CH4: I_L , 200 mA/Div

图 58. Short Circuit, $V_{IN} = 24$ V



Time Scale: 2 ms/Div
CH1: V_{EN} , 1 V/Div
CH2: V_{OUT} , 1 V/Div
CH4: I_{OUT} , 200 mA/Div

图 59. ENABLE On and Off; V_{OUT} Prebiased to 1.8 V
 $V_{IN} = 24$ V, No Load



Time Scale: 2 ms/Div
CH1: V_{EN} , 5 V/Div
CH2: V_{OUT} , 1 V/Div
CH4: I_{OUT} , 200 mA/Div

图 60. ENABLE On and Off; V_{OUT} Prebiased to 1.8 V
 $V_{IN} = 24$ V, 500 mA Load

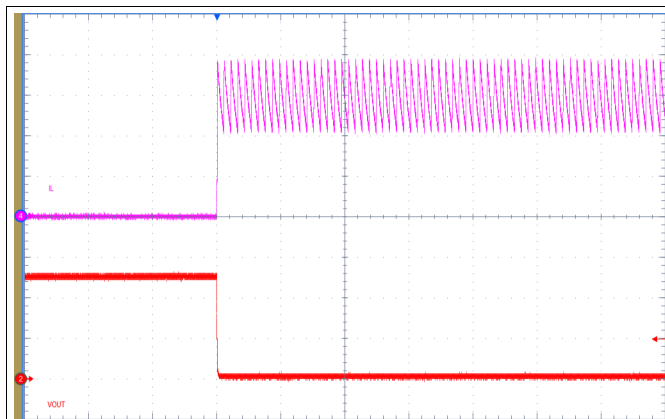


図 61. Short-Circuit Entry

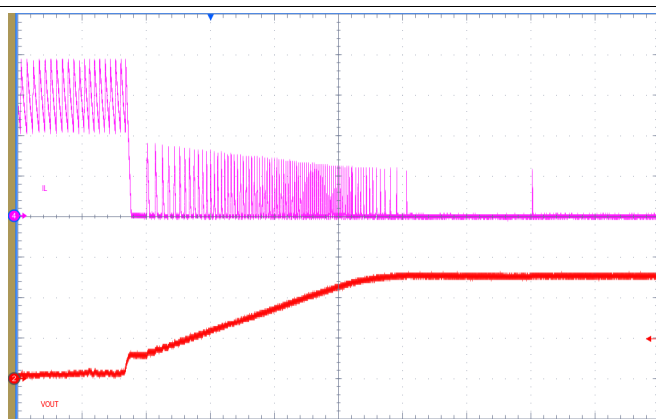
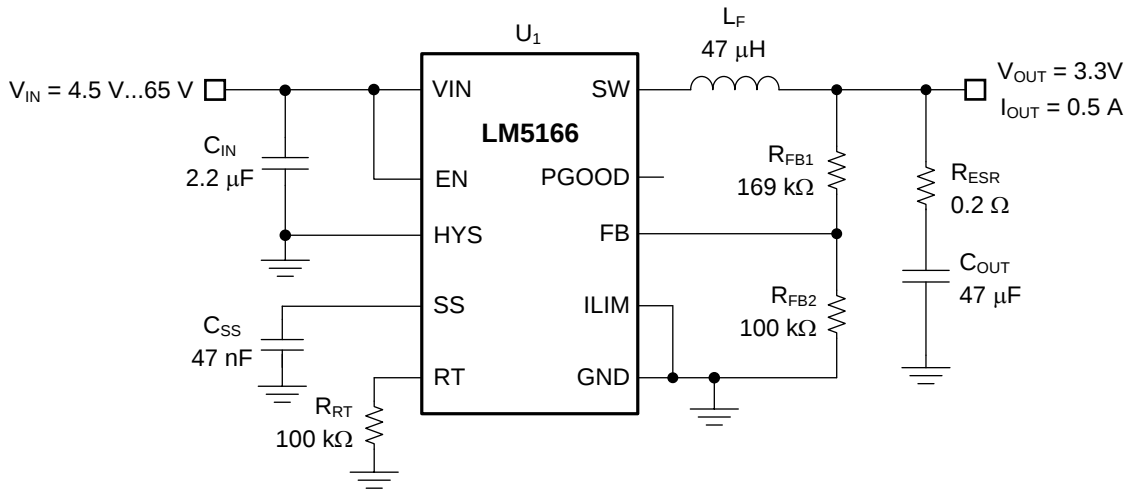


図 62. Short-Circuit Recovery

8.2.2 Design 2: Wide V_{IN} , Low I_Q COT Converter Rated at 3.3 V, 500 mA



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図 63. Schematic for Design 2 With $V_{IN(nom)} = 12\text{ V}$, $V_{OUT} = 3.3\text{ V}$, $I_{OUT(max)} = 500\text{ mA}$, $F_{SW(nom)} = 200\text{ kHz}$

8.2.2.1 Design Requirements

The target efficiency is 85% for loads above 10 mA based on a nominal input voltage of 12 V and an output voltage of 3.3 V. The required input voltage range is 4.5 V to 65 V. The LM5166 is chosen to deliver a 3.3-V output voltage. The switching frequency is set at 200 kHz. The output voltage soft-start time is 4 ms. The required components are listed in 表 5.

表 5. List of Components for Design 2⁽¹⁾

COUNT	REF DES	DESCRIPTION	PART NUMBER	MFR
1	C _{IN}	Capacitor, Ceramic, 2.2 μF, 100 V, X7R, 10%, 1210	GRM32ER72A225KA35L	Murata
1	C _{OUT}	Capacitor, Ceramic, 47 μF, 10 V, X7R, 10%, 1210	GRM32ER71A476KE15L	Murata
1	C _{SS}	Capacitor, Ceramic, 47 nF, 16 V, X7R, 10%, 0402	Std	Std
1	L _F	Inductor, 47 μH, 0.245 Ω max, 1.2 A Isat, 3.5 mm max	LPS6235-473MR	Coilcraft
		Inductor, 47 μH, 0.315 Ω typ, 1.3 A Isat, 2.8 mm max	74404063470	Würth
1	R _{RT}	Resistor, Chip, 100 kΩ, 1/16W, 1%, 0402	Std	Std
1	R _{FB1}	Resistor, Chip, 169 kΩ, 1/16W, 1%, 0402	Std	Std
1	R _{ESR}	Resistor, Chip, 0.2 Ω, 1/16W, 1%, 0402	Std	Std
1	R _{FB2}	Resistor, Chip, 100 kΩ, 1/16W, 1%, 0402	Std	Std
1	U ₁	LM5166, Synchronous Buck Converter, VSON-10, ADJ	LM5166DRCR	TI

(1) See デベロッパー・ネットワークの製品に関する免責事項.

8.2.2.2 Detailed Design Procedure

8.2.2.2.1 Feedback Resistors – R_{FB1}, R_{FB2}

The output voltage of the LM5166 is externally adjustable using a resistor divider network. The divider network comprises the upper feedback resistor R_{FB1} and lower feedback resistor R_{FB2}. Select R_{FB1} of 169 kΩ to minimize quiescent current and improve light-load efficiency in this application. With the desired output voltage setpoint of 3.3 V and $V_{FB} = 1.223\text{ V}$, calculate the resistance of R_{FB2} using 式 15 as 100.1 kΩ. Choose the closest available standard value of 100 kΩ for R_{FB2}. See Adjustable Output Voltage (FB) for more detail.

8.2.2.2.2 Switching Frequency – R_T

The switching frequency of a COT-configured LM5166 is set by the on-time programming resistor at the R_T pin. Using 式 4, a standard 1% resistor of 100 k Ω gives a switching frequency of 190 kHz. Including the inductor R_{DCR} and $R_{DS(on)2}$ in the calculation of t_{OFF} (式 3) gives an adjusted F_{SW} of 215 kHz at 500 mA. The LM5166 [Quick-Start Design Tool](#) estimates and plots the switching frequency as a function of load current.

Note that at very low duty cycles, the minimum controllable on-time of the high-side MOSFET, $T_{ON(min)}$, of 180 ns may affect choice of switching frequency. In CCM, $T_{ON(min)}$ limits the voltage conversion step-down ratio for a given switching frequency. The minimum controllable duty cycle is given by 式 19.

Given a fixed $T_{ON(min)}$, it follows that higher switching frequency implies a larger minimum controllable duty cycle. Ultimately, the choice of switching frequency for a given output voltage affects the available input voltage range, solution size, and efficiency. The maximum supply voltage for a given $T_{ON(min)}$ before switching frequency reduction occurs is given by 式 20.

8.2.2.2.3 Filter Inductance – L_F

The inductor ripple current (assuming CCM operation) and peak inductor current are given respectively by 式 21 and 式 22. For most applications, choose an inductance such that the inductor ripple current, ΔI_L , is between 30% and 60% of the rated load current at nominal input voltage. Calculate the inductance using 式 23.

Choosing a 47- μ H inductor in this design results in 275-mA peak-to-peak ripple current at nominal input voltage of 12 V, equivalent to 55% of the 500-mA rated load current. The peak inductor current at maximum input voltage of 65 V is 694 mA, which is sufficiently below the LM5166 peak current limit of 750 mA.

8.2.2.2.4 Output Capacitors – C_{OUT}

Select the output capacitor to limit the capacitive voltage ripple at the converter output. This is the sinusoidal ripple voltage that arises from the triangular ripple current flowing in the capacitor. Select an output capacitance using 式 24 to limit the capacitive voltage ripple component to 0.5% of the output voltage.

Substituting $\Delta I_{L(nom)}$ of 275 mA and ΔV_{OUT} of 25 mV gives C_{OUT} greater than 11 μ F. Mindful of the voltage coefficient of ceramic capacitors, select a 47- μ F, 10-V capacitor with a high-quality dielectric.

8.2.2.2.5 Ripple Generation Network – R_{ESR}

For this design, the Type 1 ripple generation method is selected as it only requires a single external component. For other schemes, see [Ripple Generation Methods](#).

Select a series resistor, R_{ESR} , using 式 5 and 式 6 such that sufficient ripple in phase with the SW node voltage appears at the feedback node, FB. With $\Delta I_{L(nom)}$ of 275 mA at the nominal input voltage of 12 V, the required R_{ESR} is 0.2 Ω . Calculate the total output voltage ripple in CCM using 式 25.

8.2.2.2.6 Input Capacitor – C_{IN}

An input capacitor is necessary to limit the input ripple voltage while providing switching-frequency AC current to the buck power stage. To minimize the parasitic inductance in the switching loop, position the input capacitors as close as possible to the VIN and GND pins of the LM5166. The input capacitors conduct a trapezoidal-wave current of peak-to-peak amplitude equal to the output current. It follows that the resultant capacitive component of AC ripple voltage is a triangular waveform. Together with the ESR-related ripple component, the peak-to-peak input ripple voltage amplitude is given by 式 26. The input capacitance required for a particular load current, based on an input voltage ripple specification of ΔV_{IN} , is given by 式 27.

The recommended high-frequency capacitance is 2.2 μ F or higher and should be a high-quality ceramic with sufficient voltage rating. Based on the voltage coefficient of ceramic capacitors, choose a voltage rating of twice the maximum input voltage. Additionally, some bulk capacitance is required if the LM5166 circuit is not located within approximately 5 cm from the input voltage source. This capacitor provides damping to the resonance associated with parasitic inductance of the supply lines and high-Q ceramics.

8.2.2.2.7 Soft-Start Capacitor – C_{SS}

Connect an external soft-start capacitor for a specific soft-start time. In this example, select a soft-start capacitance of 47 nF based on 式 18 to achieve a soft-start time of 6 ms.

8.2.2.2.8 Application Curves

Unless otherwise stated, application curves were taken at $T_A = 25^\circ\text{C}$.

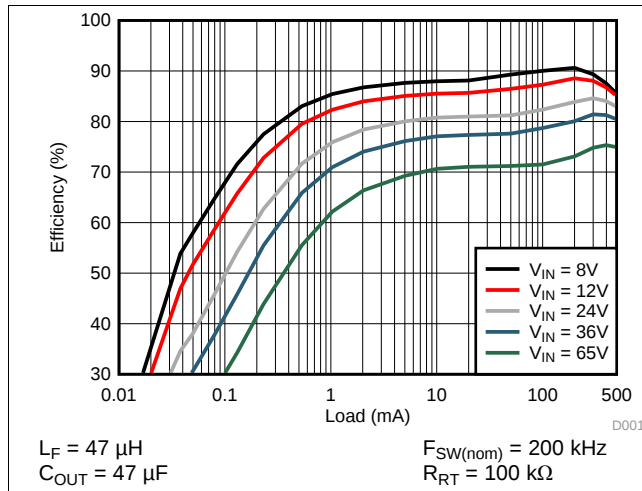


图 64. Converter Efficiency

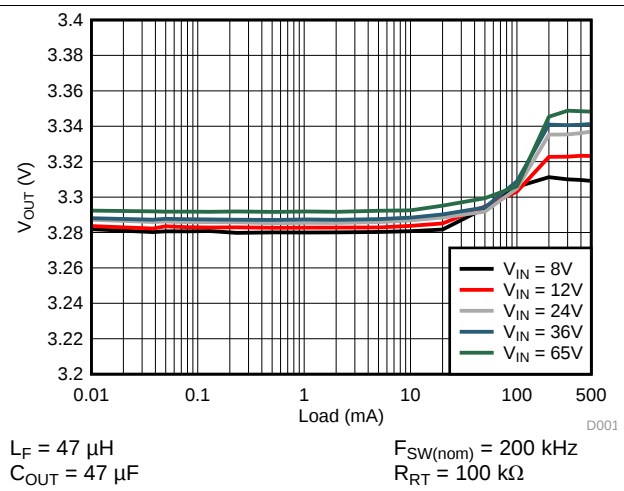


图 65. Converter Regulation

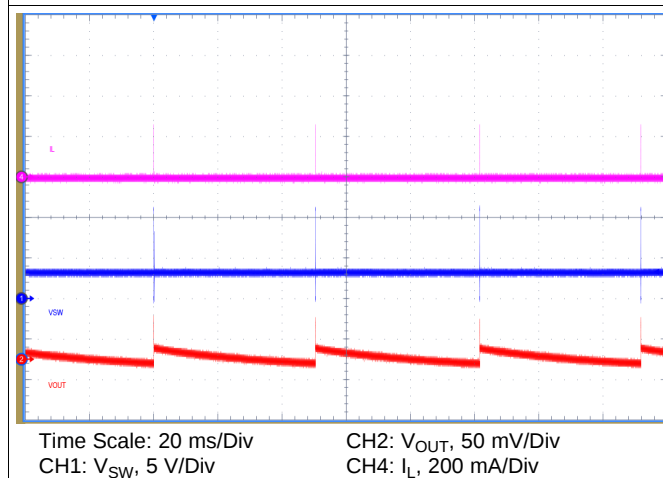


图 66. No-Load Switching Waveforms

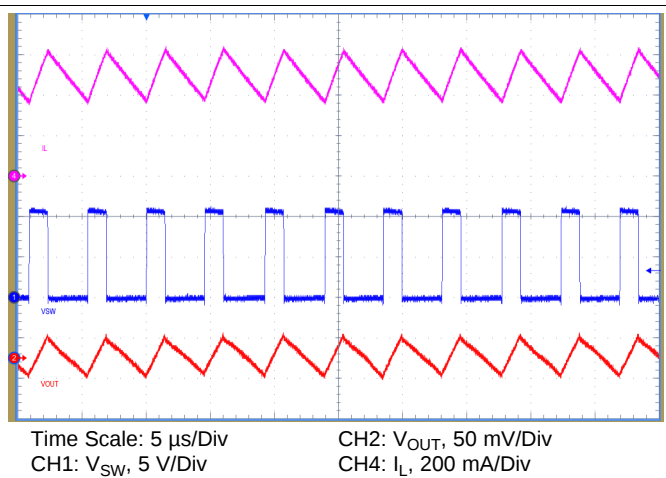


图 67. Full-Load Switching Waveforms

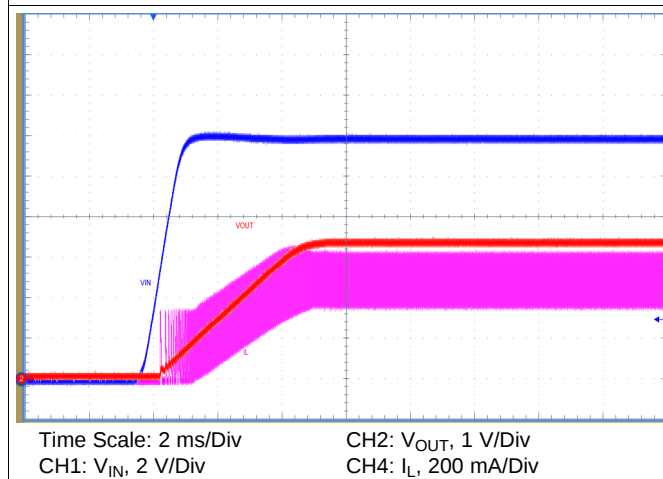


图 68. Full-Load Start-Up

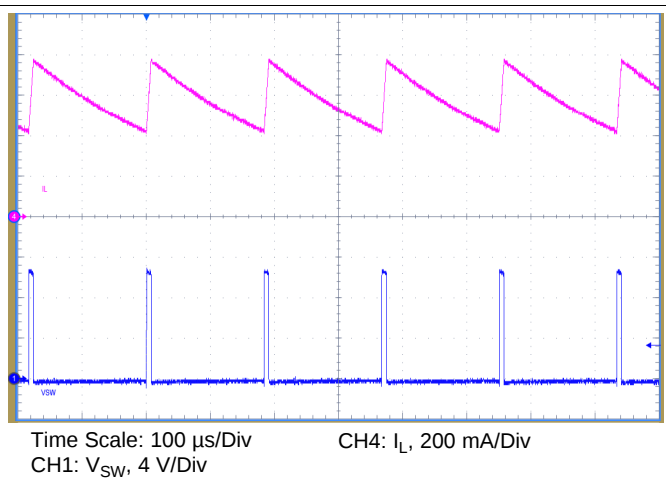
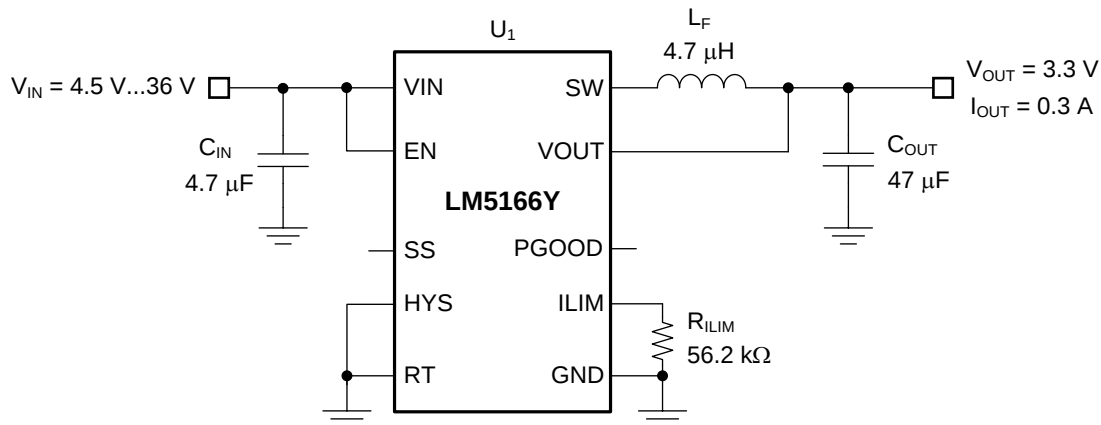


图 69. Short Circuit

8.2.3 Design 3: High-Density PFM Converter Rated at 3.3 V, 0.3 A



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図 70. Schematic for Design 3 With $V_{IN(nom)} = 24\text{ V}$, $V_{OUT} = 3.3\text{ V}$, $I_{OUT(max)} = 0.3\text{ A}$, $F_{SW(nom)} = 600\text{ kHz}$

8.2.3.1 Design Requirements

The target efficiency is 75% for loads above 10 mA based on a nominal input voltage of 24 V, an output voltage of 3.3 V, with the emphasis on small solution size. The required input voltage range is 4.5 V to 36 V. The LM5166 has an internally-set soft-start time of 900 μs and an adjustable peak current limit threshold. The required components are listed in 表 6.

表 6. List of Components for Design 3⁽¹⁾

COUNT	REF DES	DESCRIPTION	PART NUMBER	MFR
1	CIN	Capacitor, Ceramic, 4.7 μF , 50 V, X7R, 10%, 1206	GRM31CR71H475MA12L	Murata
			885012208094	Würth
1	COUT	Capacitor, Ceramic, 47 μF , 6.3 V, X5R, 10%, 1206	GRM31CR60J476KE19	Murata
1	LF	Inductor, 4.7 μH , 0.18 Ω typ, 2.2 A Isat, 1.2 mm max	TFM252012ALMA4R7TMAA	TDK
		Inductor, 4.7 μH , 0.3 Ω typ, 2.1 A Isat, 1.2 mm max	Würth	Würth
1	RILIM	Resistor, Chip, 56.2 k Ω , 1/16W, 1%, 0402	Std	Std
1	U1	LM5166Y, Synchronous Buck Converter, VSON-10, 3.3-V Fixed	LM5166YDRCR	TI

(1) See [デベロッパー ネットワークの製品に関する免責事項](#).

8.2.3.2 Detailed Design Procedure

8.2.3.2.1 Peak Current Limit Setting – R_{ILIM}

Install a 56.2-k Ω resistor from ILIM to GND to select a 750-mA peak current limit threshold setting to meet the rated output current of 300 mA in PFM. See [Adjustable Current Limit](#) for more detail.

8.2.3.2.2 Switching Frequency – L_F

Tie RT to GND to select PFM mode of operation. The inductor, input voltage, output voltage and peak current determine the pulse switching frequency of a PFM-configured LM5166. For a given input voltage, output voltage and peak current, the inductance of L_F sets the switching frequency when the output is in regulation. Use 式 28 to select an inductance of 4.7 μH based on the target PFM converter switching frequency of 600 kHz at 24-V input.

$$L_F = \frac{V_{OUT}}{F_{SW(PFM)} \cdot I_{PK(PFM)}} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}} \right) \quad (28)$$

$I_{PK(PFM)}$ in this example is the peak current limit setting of 750 mA plus the inductor current overshoot resulting from the 80-ns peak current comparator delay, t_{ILIM_delay} . An additional constraint on the inductance is the 180-ns minimum on-time of the high-side MOSFET. Therefore, to keep the inductor current well controlled, choose an inductance that is larger than $L_{F(min)}$ using 式 29 where $V_{IN(max)}$ is the maximum input supply voltage for the application, t_{ILIM_delay} is 80 ns, $t_{ON(min)}$ is 180 ns, the maximum current limit threshold, $I_{LIM(max)}$, is 825 mA, and the maximum allowed peak inductor current, $I_{L(max)}$, is 1.6 A.

$$L_{F(min)} = \text{Max} \left(\frac{V_{IN(max)} \cdot t_{ON(min)}}{I_{L(max)}}, \frac{V_{IN(max)} \cdot t_{ILIM_delay}}{I_{L(max)} - I_{LIM(max)}} \right) \quad (29)$$

Choose an inductor with saturation current rating above the peak current limit setting, and allow for derating of the saturation current at the highest expected operating temperature.

8.2.3.2.3 Output Capacitors – C_{OUT}

The output capacitor, C_{OUT} , filters the inductor's ripple current and stores energy to meet the load current requirement when the LM5166 is in sleep mode. The output ripple has a base component of amplitude $V_{OUT}/123$ related to the typical feedback comparator hysteresis in PFM. The wake-up time from sleep to active mode adds a ripple voltage component that is a function of the output current. Approximate the total output ripple by 式 30.

$$\Delta V_{OUT} = \left(\frac{I_{PK(PFM)}}{2} + I_{OUT} \right) \cdot \frac{1\mu s}{C_{OUT}} + \frac{V_{OUT}}{123} \quad (30)$$

Also, the output capacitance must be large enough to accept the energy stored in the inductor without a large deviation in output voltage. Setting this voltage change equal to 1% of the output voltage results in a C_{OUT} requirement defined with 式 31.

$$C_{OUT} \geq 50 \cdot L_F \cdot \left(\frac{I_{PK(PFM)}}{V_{OUT}} \right)^2 \quad (31)$$

In general, select the capacitance of C_{OUT} to limit the output voltage ripple at full load current, ensuring that it is rated for worst-case RMS ripple current given by $I_{RMS} = I_{PK(PFM)}/2$. In this design example, select a 47- μ F, 6.3-V capacitor with a high-quality dielectric.

8.2.3.2.4 Input Capacitor – C_{IN}

The input capacitor, C_{IN} , filters the triangular current waveform of the high-side MOSFET (see 图 89). To prevent large ripple voltage, use a low-ESR ceramic input capacitor sized for the worst-case RMS ripple current given by $I_{RMS} = I_{OUT}/2$. In this design example, choose a 2.2- μ F, 50-V ceramic input capacitor with a high-quality dielectric.

8.2.3.2.5 Application Curves

Unless otherwise stated, application curves were taken at $T_A = 25^\circ\text{C}$.

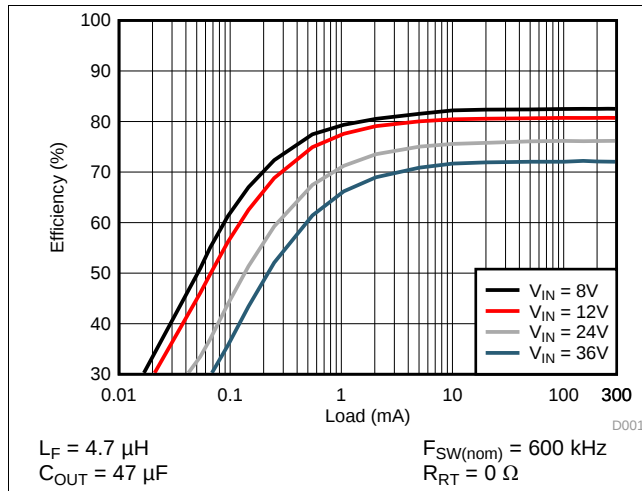


图 71. Converter Efficiency

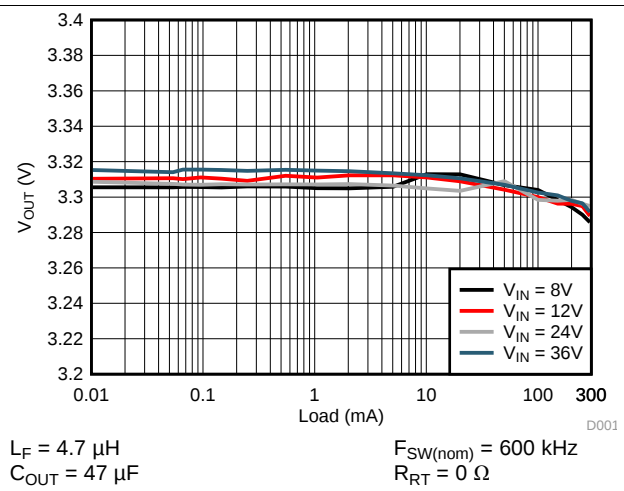


图 72. Converter Regulation

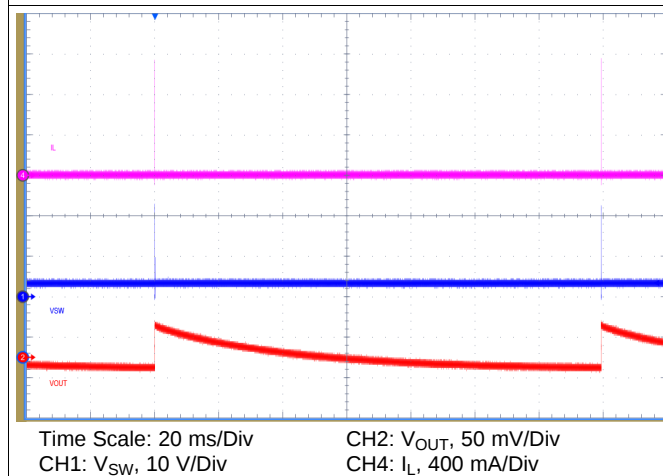


图 73. No-Load Switching Waveforms, $V_{IN} = 24 \text{ V}$

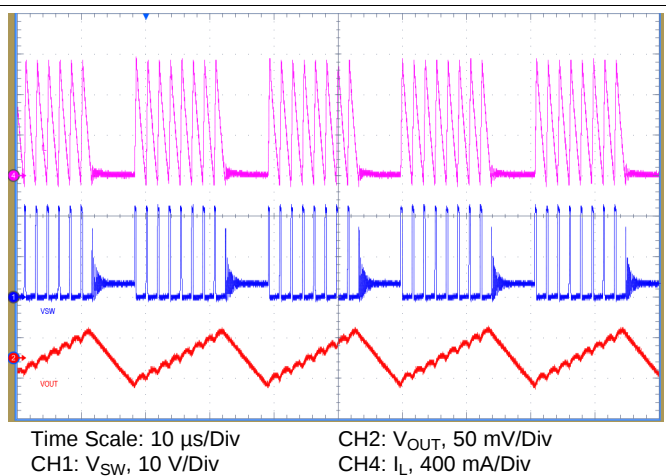


图 74. Full-Load Switching Waveforms, $V_{IN} = 24 \text{ V}$

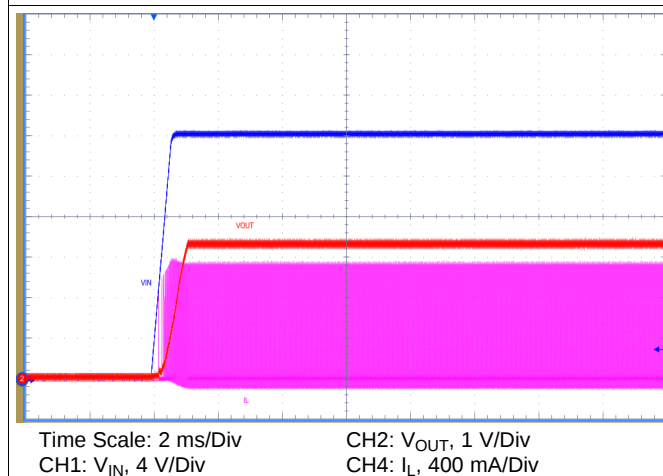


图 75. Full-Load Start-Up, $V_{IN} = 24 \text{ V}$

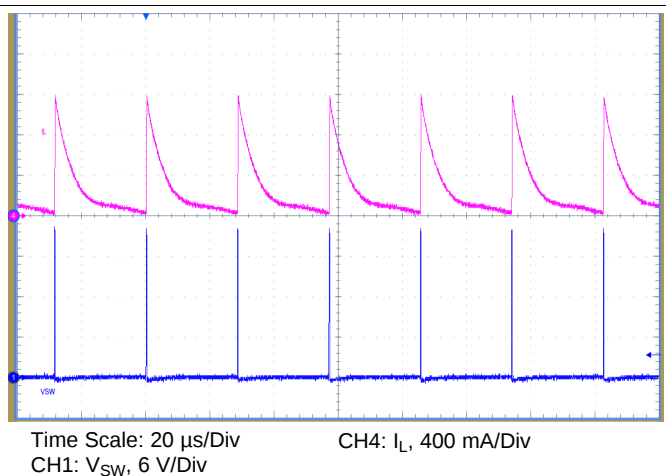
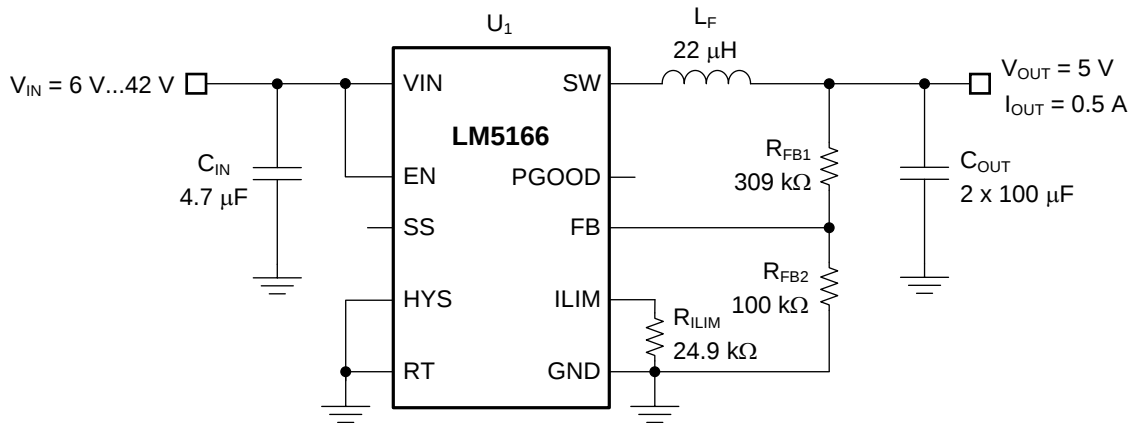


图 76. Short Circuit, $V_{IN} = 24 \text{ V}$

8.2.4 Design 4: Wide V_{IN} , Low I_Q PFM Converter Rated at 5 V, 500 mA



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图 77. Schematic for Design 4 With $V_{IN(nom)} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$, $I_{OUT(max)} = 500\text{ mA}$, $F_{SW(nom)} = 100\text{ kHz}$

8.2.4.1 Design Requirements

The target efficiency is 85% for loads above 1 mA based on a nominal input voltage of 12 V, an output voltage of 5 V. The required input voltage range is 6 V to 42 V. The LM5166 has an internally-set soft-start time of 900 μs and an adjustable peak current limit threshold. The required components are listed in 表 7.

表 7. List of Components for Design 4⁽¹⁾

COUNT	REF DES	DESCRIPTION	PART NUMBER	MFR
1	C_{IN}	Capacitor, Ceramic, 4.7 μF , 50 V, X7R, 20%, 1206	GRM31CR71H475MA12L	Murata
			C3216X7R1H475M160AC	TDK
2	C_{OUT}	Capacitor, Ceramic, 100 μF , 10 V, X5R, 10%, 1210	GRM32ER61A107ME20K	Murata
1	L_F	Inductor, 22 μH , 0.145 Ω max, 1.7 A Isat, 3.5 mm max	LPS6235-223MR	Coilcraft
		Inductor, 22 μH , 0.2 Ω max, 2.3 A Isat, 3 mm max	CMLB063T-220MS	Cyntec
1	R_{ILIM}	Resistor, Chip, 24.9 k Ω , 1/16W, 1%, 0402	Std	Std
1	R_{FB1}	Resistor, Chip, 309 k Ω , 1/16W, 1%, 0402	Std	Std
1	R_{FB2}	Resistor, Chip, 100 k Ω , 1/16W, 1%, 0402	Std	Std
1	U_1	LM5166, Synchronous Buck Converter, VSON-10, ADJ	LM5166DRCR	TI

(1) See [デベロッパー・ネットワークの製品に関する免責事項](#).

8.2.4.2 Detailed Design Procedure

8.2.4.2.1 Feedback Resistors – R_{FB1} , R_{FB2}

The output voltage of the LM5166 is externally adjustable using a resistor divider network. The divider network comprises the upper feedback resistor R_{FB1} and lower feedback resistor R_{FB2} . Select R_{FB1} of 309 k Ω to minimize quiescent current and improve light-load efficiency in this application. With the desired output voltage setpoint of 5 V and $V_{FB} = 1.223\text{ V}$, calculate the resistance of R_{FB2} using 式 15 as 99.5 k Ω . Choose the closest available standard value of 100 k Ω for R_{FB2} . See [Adjustable Output Voltage \(FB\)](#) for more detail.

8.2.4.2.2 Peak Current Limit Setting – R_{ILIM}

Install a 24.9-k Ω resistor from ILIM to GND to select a 1.25-A peak current limit threshold setting with modulated ILIM function to meet the rated output current of 500 mA and the efficiency target. See [Adjustable Current Limit](#) for more detail.

8.2.4.2.3 Switching Frequency – L_F

Tie RT to GND to select PFM mode of operation. The inductor, input voltage, output voltage and peak current determine the pulse switching frequency of a PFM-configured LM5166. For a given input voltage, output voltage and peak current, the inductance of L_F sets the switching frequency when the output is in regulation. Use 式 28 to select an inductance of 22 μ H based on the target PFM converter switching frequency of 100 kHz at 12-V input.

$I_{PK(PFM)}$ in this example is the peak current limit setting of 1.25 A plus the inductor current overshoot resulting from the 80-ns peak current comparator delay. An additional constraint on the inductance is the 180-ns minimum on-time of the high-side MOSFET. Therefore, to keep the inductor current well controlled, choose an inductance that is larger than $L_{F(min)}$ using 式 29.

Choose an inductor with saturation current rating above the peak current limit setting, and allow for derating of the saturation current at the highest expected operating temperature.

8.2.4.2.4 Output Capacitors – C_{OUT}

The output capacitor, C_{OUT} , filters the ripple current of the inductor and stores energy to meet the load current requirement when the LM5166 is in sleep mode. The output ripple has a base component of amplitude $V_{OUT}/123$ related to the typical feedback comparator hysteresis in PFM. The wake-up time from sleep to active mode adds a ripple voltage component that is a function of the output current. Approximate the total output ripple by 式 30.

Also, the output capacitance must be large enough to accept the energy stored in the inductor without a large deviation in output voltage. Setting this voltage change equal to 1% of the output voltage results in a C_{OUT} requirement defined with 式 31.

In general, select the capacitance of C_{OUT} to limit the output voltage ripple at full load current, ensuring that it is rated for worst-case RMS ripple current given by $I_{RMS} = I_{PK(PFM)}/2$. In this design example, select two 100- μ F, 10-V capacitors with a high-quality dielectric.

8.2.4.2.5 Input Capacitor – C_{IN}

The input capacitor, C_{IN} , filters the triangular current waveform of the high-side MOSFET (see 图 89). To prevent large ripple voltage, use a low-ESR ceramic input capacitor sized for the worst-case RMS ripple current given by $I_{RMS} = I_{OUT}/2$. In this design example, choose a 4.7- μ F, 50-V ceramic input capacitor with a high-quality dielectric.

8.2.4.3 Application Curves

Unless otherwise stated, application curves were taken at $T_A = 25^\circ\text{C}$.

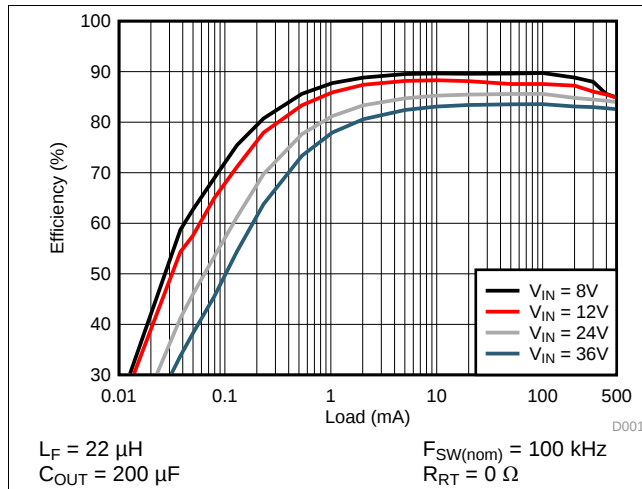


图 78. Converter Efficiency

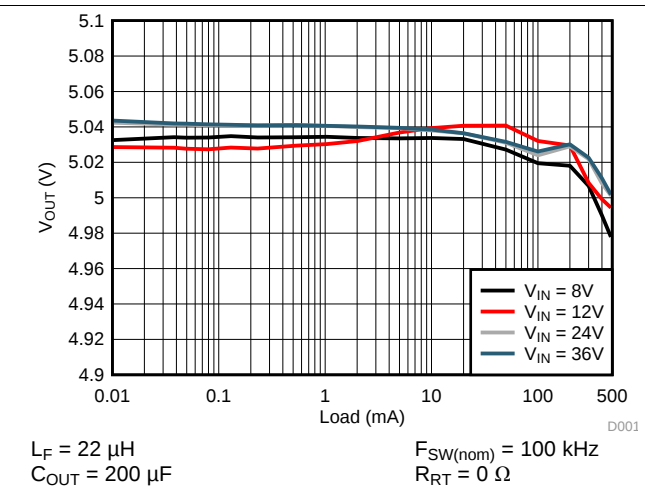


图 79. Converter Regulation

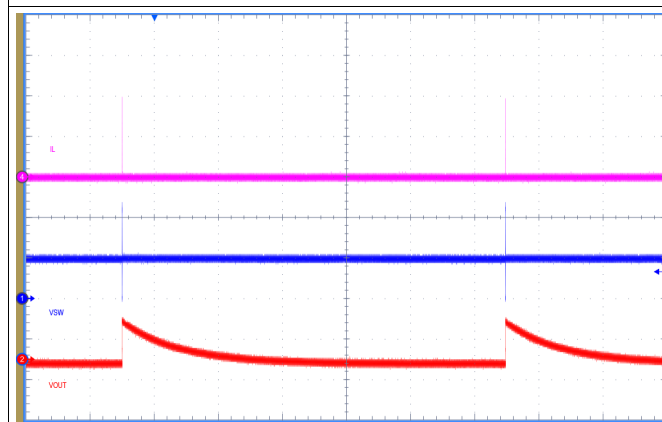


图 80. No-Load Switching Waveforms

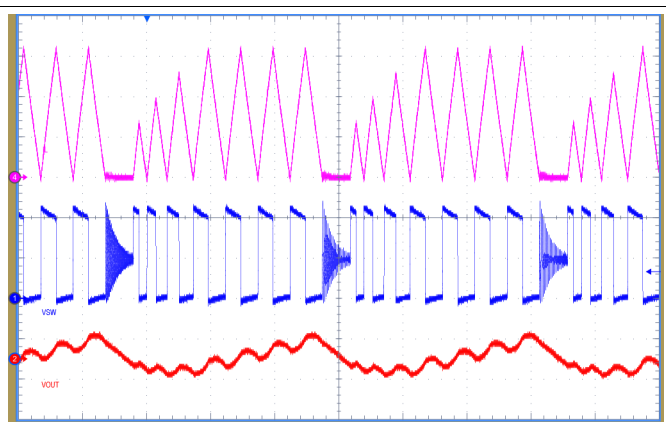


图 81. Full-Load Switching Waveforms

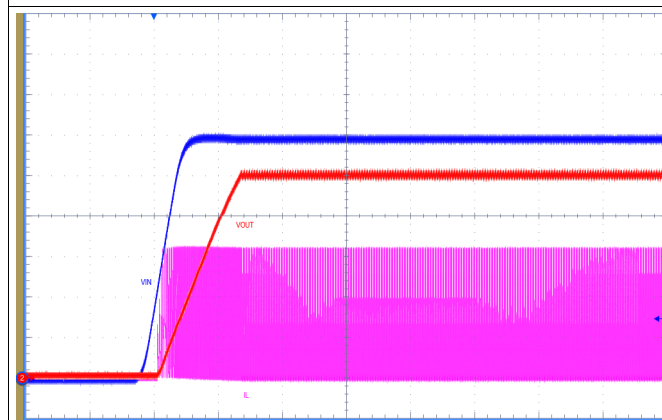


图 82. Full-Load Start-Up

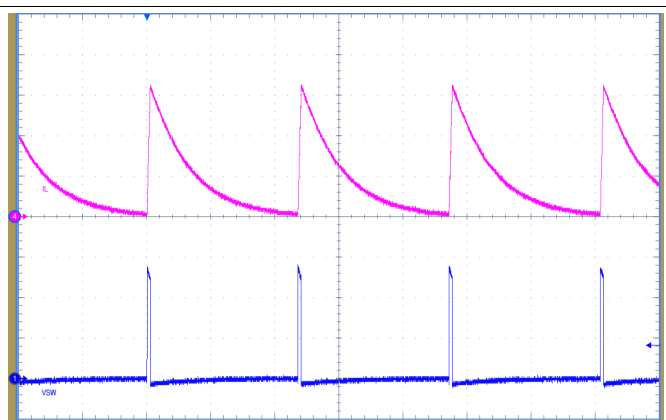
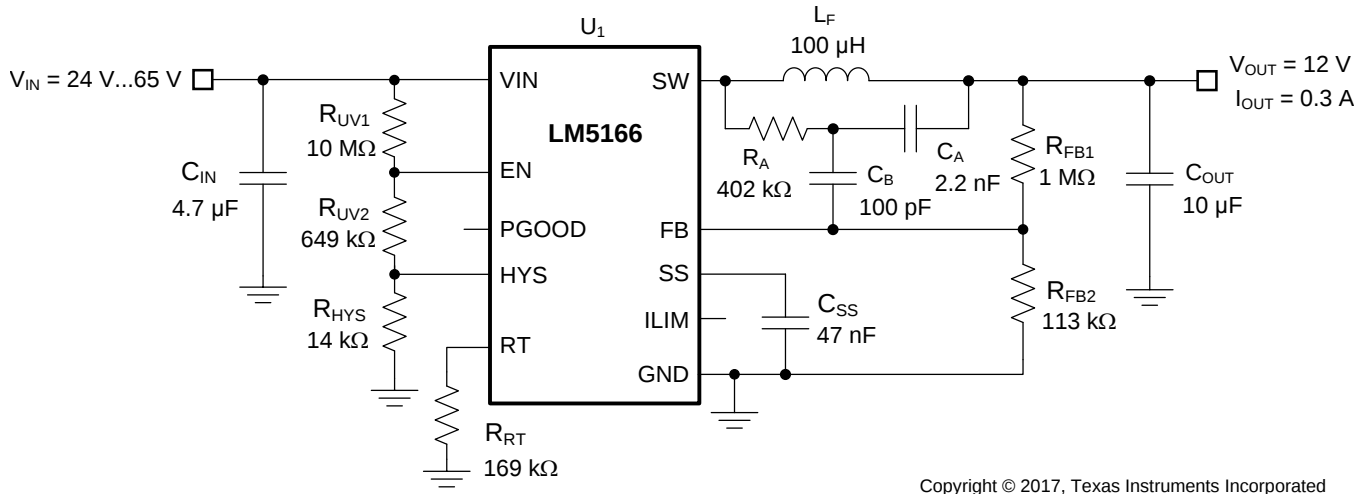


图 83. Short Circuit

8.2.5 Design 5: 12-V, 300-mA COT Converter Operating From 24-V or 48-V Input

The schematic diagram of 12-V, 300-mA COT converter is given in 図 84.



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図 84. Schematic for Design 5 With $V_{OUT} = 12\text{ V}$, $I_{OUT(max)} = 300\text{ mA}$, $F_{SW(nom)} = 400\text{ kHz}$

8.2.5.1 Design Requirements

The full-load efficiency specifications are 93% and 89% based on input voltages of 24 V and 48 V, respectively, and an output voltage setpoint of 12 V. The input voltage range is 24 V to 65 V, with UVLO turnon and turnoff at 20 V and 18 V, respectively. The output voltage setpoint is established by feedback resistors, R_{FB1} and R_{FB2} . The required components are listed in 表 8.

表 8. List of Components for Design 5⁽¹⁾

REF DES	QTY	SPECIFICATION	VENDOR	PART NUMBER
C_{IN}	1	4.7 μF , 100 V, X7S, 1210	Murata	GRM31CR71H475MA12L
		4.7 μF , 80 V, X7R, 1210	Murata	GRM32ER71K475KE14L
C_{OUT}	1	10 μF , 25 V, X7R, 1206	Murata	GRM31CR71E106MA12L
			TDK	C3216X7R1E106M
			Würth	885012208069
L_F	1	100 $\mu\text{H} \pm 20\%$, 0.54 A, 375 m Ω maximum DCR, 6 $\times$ 6 $\times$ 3.5 mm	Coilcraft	LPS6235-104MRC
R_A	1	402 k Ω , 1%, 0402	Std	Std
R_{FB1}	1	1 M Ω , 1%, 0402	Std	Std
R_{FB2}	1	113 k Ω , 1%, 0402	Std	Std
R_{UV1}	1	10 M Ω , 1%, 0603	Std	Std
R_{UV2}	1	649 k Ω , 1%, 0402	Std	Std
R_{HYS}	1	14 k Ω , 1%, 0402	Std	Std
R_{RT}	1	169 k Ω , 1%, 0402	Std	Std
C_A	1	2.2 nF, 25 V, X7R, 0402	Std	Std
C_B	1	100 pF, 50 V, NP0, 0402	Std	Std
C_{SS}	1	47 nF, 16 V, X7R, 0402	Std	Std
U_1	1	LM5166 Synchronous Buck Converter, VSON-10, 3 mm $\times$ 3 mm	TI	LM5166DRCR

(1) See デベロッパー・ネットワークの製品に関する免責事項.

8.2.5.2 Detailed Design Procedure

The component selection procedure for this design is quite similar to that of COT designs 1 and 2.

8.2.5.2.1 Peak Current Limit Setting – R_{ILIM}

Leave the ILIM pin open circuit to select the 500-mA peak current limit setting for a rated output current of 300 mA. See [表 3](#).

8.2.5.2.2 Switching Frequency – R_{RT}

Using [式 4](#), select a standard 1% resistor value of 169 k Ω to set a switching frequency of 400 kHz.

8.2.5.2.3 Inductor – L_F

Choosing a 100- μ H inductor in this design results in 150-mA peak-to-peak ripple current at an input voltage of 24 V, equivalent to 50% of the 300-mA rated load current. A larger ripple current design results in improved light-load efficiency. The peak inductor current at maximum input voltage of 65 V is 424 mA, which is sufficiently below the LM5166 peak current limit of 500 mA. Select an inductor with saturation current rating well above the peak current limit setting, and allow for derating of the saturation current at the highest expected operating temperature.

8.2.5.2.4 Input and Output Capacitors – C_{IN} , C_{OUT}

Choose a 4.7- μ F, 80-V or 100-V ceramic input capacitor with 1210 footprint. Such a capacitor is typically available in X7S or X7R dielectric. Based on [式 24](#), select a 10- μ F, 25-V ceramic output capacitor with X7R dielectric and 1206 footprint.

8.2.5.2.5 Feedback Resistors – R_{FB1} , R_{FB2}

Select R_{FB1} of 1 M Ω to minimize quiescent current and improve light-load efficiency in this application. With the desired output voltage setpoint of 12 V and $V_{FB} = 1.223$ V, calculate the resistance of R_{FB2} using [式 15](#) as 113.5 k Ω . Choose the closest available standard value of 113 k Ω for R_{FB2} . See [Adjustable Output Voltage \(FB\)](#) for more detail.

8.2.5.2.6 Ripple Generation Network – R_A , C_A , C_B

Select the ripple injection circuit components R_A and C_A values using [式 10](#) and [式 11](#). Choose capacitor C_B using [式 12](#) based on a target transient response settling time of 300 μ s.

8.2.5.2.7 Undervoltage Lockout Setpoint – R_{UV1} , R_{UV2} , R_{HYS}

Adjust the undervoltage lockout (UVLO) using an externally-connected resistor divider network of R_{UV1} , R_{UV2} , and R_{HYS} . The UVLO has two thresholds, one for power up when the input voltage is rising and one for power down or brownouts when the input voltage is falling. The EN rising threshold for the LM5166 is 1.22 V.

Rearranging [式 16](#) and [式 17](#), the expressions to calculate R_{UV2} and R_{HYS} are as follows:

$$R_{UV2} = \frac{V_{EN(on)}}{V_{IN(on)} - V_{EN(on)}} \cdot R_{UV1} \quad (32)$$

$$R_{HYS} = \frac{V_{EN(off)}}{V_{IN(off)} - V_{EN(off)}} \cdot R_{UV1} - R_{UV2} \quad (33)$$

Choose R_{UV1} as 10 M Ω to minimize input quiescent current. Given the desired input voltage UVLO thresholds of 20 V and 18 V, calculate the resistance of R_{UV2} and R_{HYS} as 649 k Ω and 14 k Ω , respectively. See [Precision Enable \(EN\) and Hysteresis \(HYS\)](#) for more detail.

8.2.5.2.8 Soft Start – C_{SS}

Install a 47-nF capacitor from SS to GND for a soft-start time of 6 ms.

8.2.5.3 Application Curves

Unless otherwise stated, application curves were taken at $T_A = 25^\circ\text{C}$.

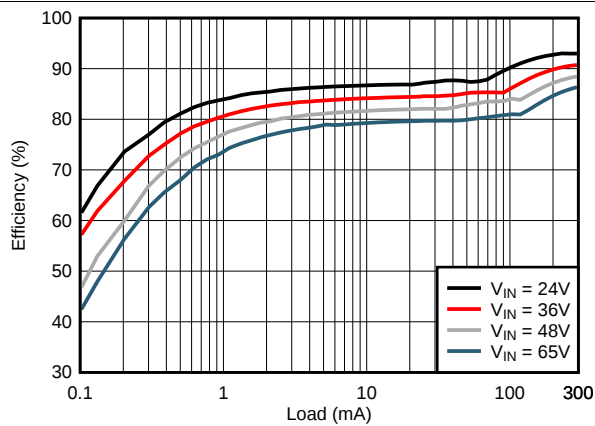


图 85. Converter Efficiency

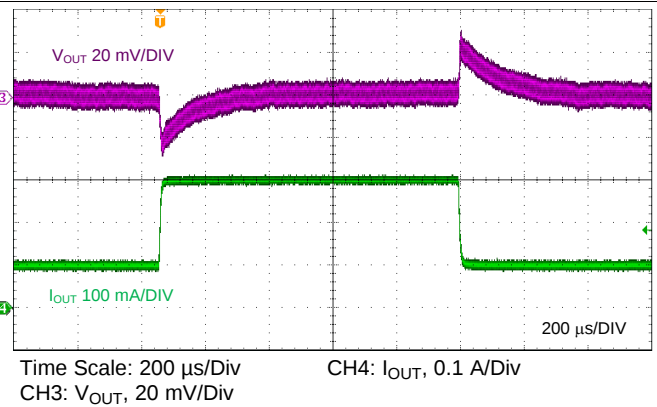


图 86. Load Transient Waveforms, 100 mA to 300 mA

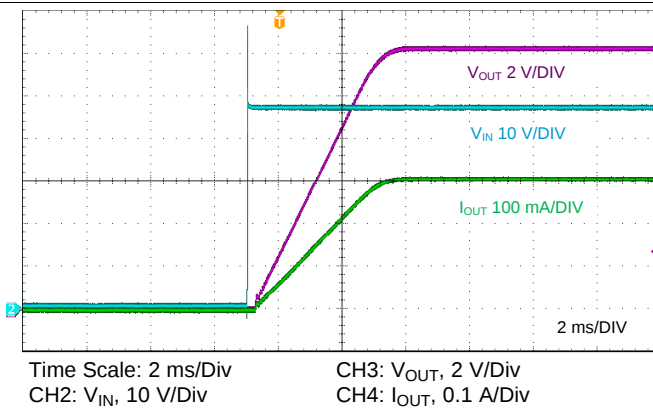


图 87. Start-up Waveforms

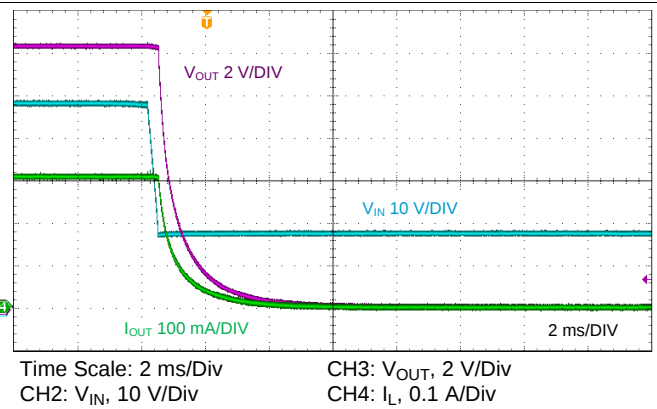


图 88. Shutdown Waveforms

9 Power Supply Recommendations

The LM5166 is designed to operate from an input voltage supply range between 3 V and 65 V. This input supply should be able to withstand the maximum input current and maintain a voltage above 3 V. Ensure that the impedance of the input supply rail is low enough that an input current transient does not cause a high enough drop at the LM5166 supply voltage to create a false UVLO fault triggering and system reset. If the input supply is placed more than a few inches from the LM5166 converter, additional bulk capacitance may be required in addition to the ceramic bypass capacitors. A 10- μ F electrolytic capacitor is a typical choice for this function, whereby the capacitor ESR provides a level of damping against input filter resonances. A typical ESR of 0.5 Ω provides enough damping for most input circuit configurations.

10 Layout

The performance of any switching converter depends as much upon PCB layout as it does the component selection. The following guidelines are provided to assist with designing a PCB with the best power conversion performance, thermal performance, and minimized generation of unwanted EMI.

10.1 Layout Guidelines

PCB layout is a critical portion of good power supply design. There are several paths that conduct high slew-rate currents or voltages that can interact with stray inductance or parasitic capacitance to generate noise and EMI or degrade the power supply performance.

1. To help eliminate these problems, bypass the VIN pin to GND with a low-ESR ceramic bypass capacitor with a high-quality dielectric. Place C_{IN} as close as possible to the LM5166 VIN and GND pins. Grounding for both the input and output capacitors should consist of localized top-side planes that connect to the GND pin and GND PAD.
2. Minimize the loop area formed by the input capacitor connections to the VIN and GND pins.
3. Locate the inductor close to the SW pin. Minimize the area of the SW trace or plane to prevent excessive capacitive coupling.
4. Tie the GND pin directly to the power pad under the device and to a heat-sinking PCB ground plane.
5. Use a ground plane in one of the middle layers as noise shielding and heat dissipation path.
6. Have a single-point ground connection to the plane. Route the ground connections for the feedback, soft-start, and enable components to the ground plane. This prevents any switched or load currents from flowing in analog ground traces. If not properly handled, poor grounding results in degraded load regulation or erratic output voltage ripple behavior.
7. Make V_{IN} , V_{OUT} and ground bus connections as wide as possible. This reduces any voltage drops on the input or output paths of the converter and maximizes efficiency.
8. Minimize trace length to the FB pin. Place both feedback resistors, R_{FB1} and R_{FB2} , close to the FB pin. Place C_{FF} (if needed) directly in parallel with R_{FB1} . If output setpoint accuracy at the load is important, connect the V_{OUT} sense at the load. Route the V_{OUT} sense path away from noisy nodes and preferably through a layer on the other side of a shielding layer.
9. The RT pin is sensitive to noise. Thus, locate the R_{RT} resistor as close as possible to the device and route with minimal lengths of trace. The parasitic capacitance from RT to GND must not exceed 20 pF.
10. Provide adequate heat sinking for the LM5166 to keep the junction temperature below 150°C. For operation at full rated load, the top-side ground plane is an important heat-dissipating area. Use an array of heat-sinking vias to connect the exposed pad to the PCB ground plane. If the PCB has multiple copper layers, these thermal vias must also be connected to inner layer heat-spreading ground planes.

10.1.1 Compact PCB Layout for EMI Reduction

Radiated EMI generated by high di/dt components relates to pulsing currents in switching converters. The larger area covered by the path of a pulsing current, the more electromagnetic emission is generated. The key to minimizing radiated EMI is to identify the pulsing current path and minimize the area of that path.

The critical switching loop of the buck converter power stage in terms of EMI is denoted in [Figure 89](#). The topological architecture of a buck converter means that a particularly high di/dt current path exists in the loop comprising the input capacitor and the integrated MOSFETs of the LM5166, and it becomes mandatory to reduce the parasitic inductance of this loop by minimizing the effective loop area.

Layout Guidelines (continued)

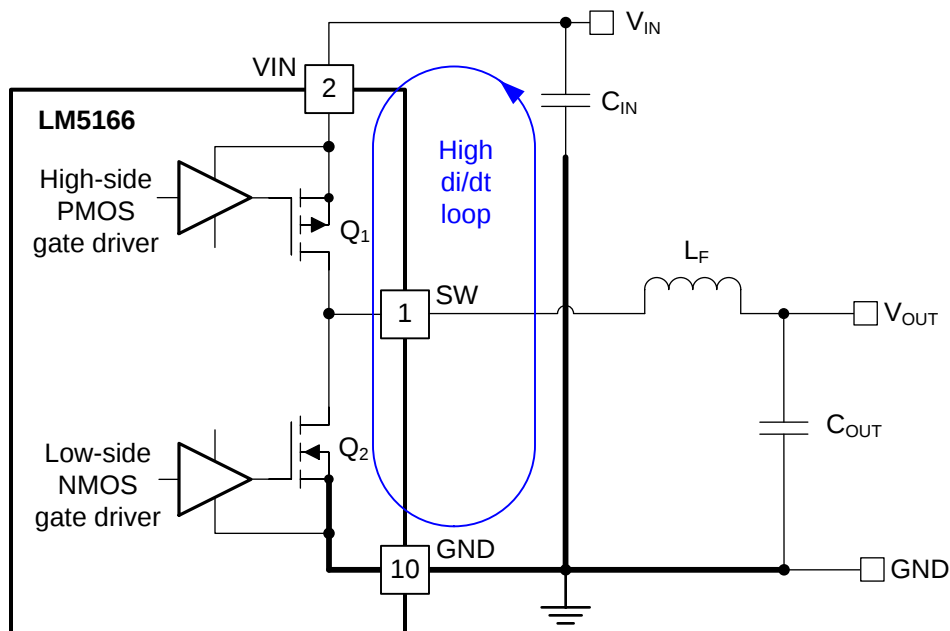


图 89. DC-DC Buck Converter With Power Stage Circuit Switching Loops

The input capacitor provides the primary path for the high di/dt components of the high-side MOSFET's current. Placing a ceramic capacitor as close as possible to the V_{IN} and GND pins is the key to EMI reduction. Keep the trace connecting SW to the inductor as short as possible and just wide enough to carry the load current without excessive heating. Use short, thick traces or copper pours (shapes) for current conduction path to minimize parasitic resistance. Place the output capacitor close to the V_{OUT} side of the inductor, and connect the capacitor's return terminal to the GND pin and exposed PAD of the LM5166.

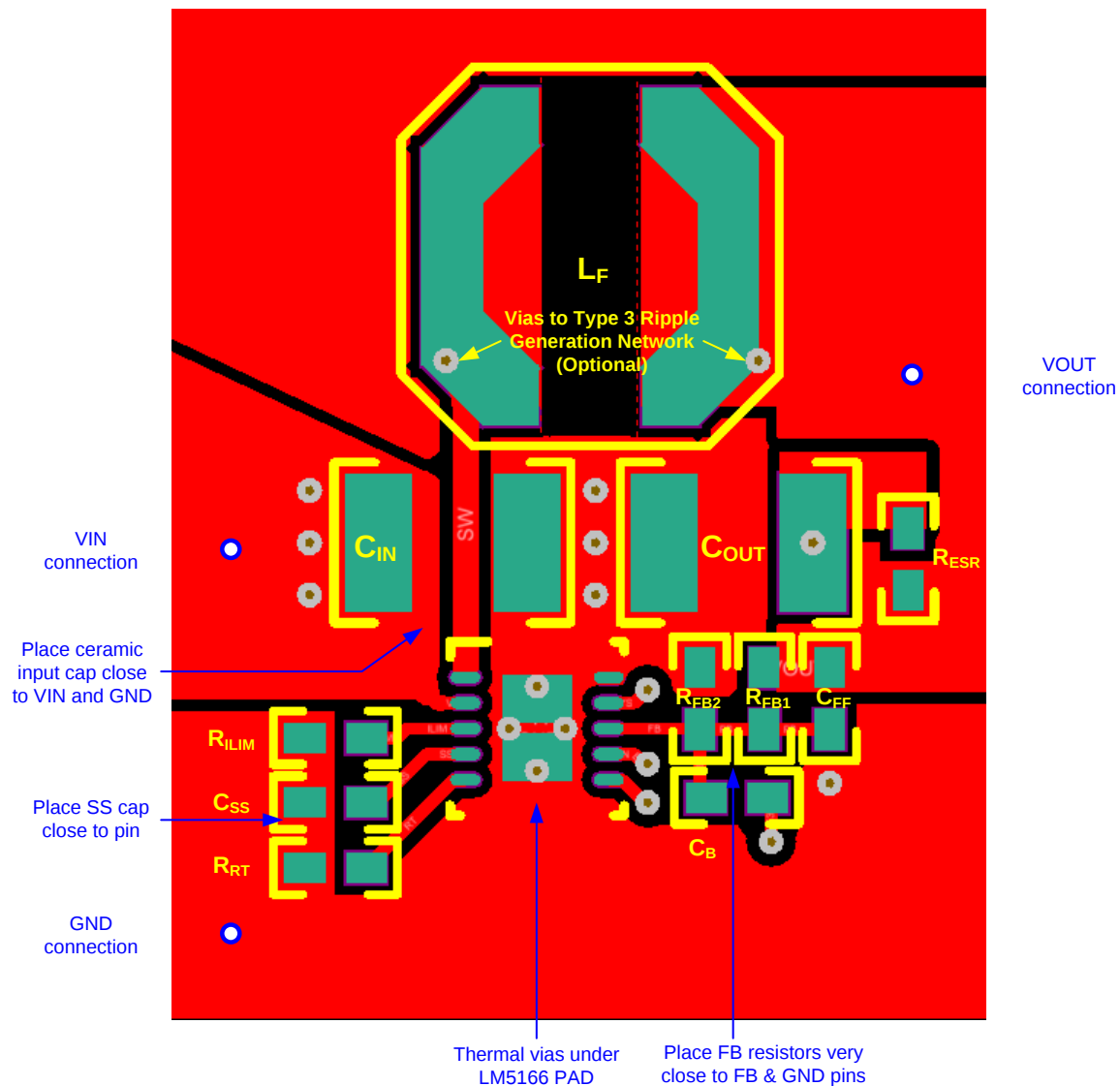
10.1.2 Feedback Resistors

For the adjustable output voltage version of the LM5166, reduce noise sensitivity of the output voltage feedback path by placing the resistor divider close to the FB pin, rather than close to the load. This reduces the trace length of FB signal and noise coupling. The FB pin is the input to the feedback comparator, and as such is a high impedance node sensitive to noise. The output node is a low impedance node, so the trace from V_{OUT} to the resistor divider can be long if a short path is not available.

Route the voltage sense trace from the load to the feedback resistor divider, keeping away from the SW node, the inductor and V_{IN} to avoid contaminating the feedback signal with switch noise, while also minimizing the trace length. This is most important when high feedback resistances, greater than 100 k Ω , are used to set the output voltage. Also, route the voltage sense trace on a different layer from the inductor, SW node and V_{IN} , such that there is a ground plane that separates the feedback trace from the inductor and SW node copper polygon. This provides further shielding for the voltage feedback path from switching noise sources.

10.2 Layout Example

 90 shows an example layout for the PCB top layer of a 4-layer board with essential components placed on the top side. The bottom layer features optional Type 3 ripple generation components (R_A and C_A), and R_{UV1} , R_{UV2} , and R_{HYS} resistors.



 90. LM5166 Single-Sided PCB Layout Example

11 デバイスおよびドキュメントのサポート

11.1 デバイス・サポート

11.1.1 デベロッパー・ネットワークの製品に関する免責事項

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11.1.2 開発サポート

- LM5166 [クイックスタート・カリキュレータ](#)
- LM5166 [シミュレーション・モデル](#)
- TIのリファレンス・デザイン・ライブラリについては、[TIDesigns](#)を参照してください。
- TIのWEBENCH設計環境については、[WEBENCH®設計センター](#)を参照してください。

11.1.3 WEBENCH®ツールによるカスタム設計

[ここをクリック](#)すると、WEBENCH® Power Designerにより、LM5166デバイスを使用するカスタム設計を作成できます。

1. 最初に、入力電圧(V_{IN})、出力電圧(V_{OUT})、出力電流(I_{OUT})の要件を入力します。
2. オプティマイザのダイヤルを使用して、効率、占有面積、コストなどの主要なパラメータについて設計を最適化します。
3. 生成された設計を、テキサス・インスツルメンツが提供する他のソリューションと比較します。

WEBENCH Power Designerでは、カスタマイズされた回路図と部品リストを、リアルタイムの価格と部品の在庫情報と併せて参照できます。

ほとんどの場合、次の操作を実行可能です。

- 電氣的なシミュレーションを実行し、重要な波形と回路の性能を確認する。
- 熱シミュレーションを実行し、基板の熱特性を把握する。
- カスタマイズされた回路図やレイアウトを、一般的なCADフォーマットでエクスポートする。
- 設計のレポートをPDFで印刷し、同僚と設計を共有する。

WEBENCHツールの詳細は、www.ti.com/WEBENCHでご覧になれます。

11.2 ドキュメントのサポート

- 『[LM5166EVM-C50A EVMユーザー・ガイド](#)』(SNVU485)
- 『[LM5166EVM-C33A EVMユーザー・ガイド](#)』(SNVU544)
- 『[低 \$I_Q\$ の同期整流降圧コンバータにより可能になるインテリジェントなフィールド・センサ・アプリケーション](#)』(SLYT671)
- 『[低EMI降圧コンバータによるBLE接続性付きのマルチバリアブル・センサ・トランスミッタの駆動](#)』(SLYT693)
- 『[COT降圧コンバータ用の理想的なリップル生成ネットワークの選択](#)』(SNVA776)
- TI Designs
 - TIDA-01395 『[スマート・サーモスタット用の 24V AC 電力段、 \$V_{IN}\$ の広いコンバータとバッテリー・ゲージ付き](#)』(TIDUCW0)
 - TIDA-01358 『[スマート・サーモスタット用の 24V AC 電力段、 \$V_{IN}\$ の広いコンバータとバッテリー・バックアップ付き](#)』(TIDUCE1)
 - TIPD215 『[アダプティブ電力管理採用、1W未満、クワッド・チャネル、アナログ出力モジュールのリファレンス・デザイン](#)』(TIDUCV5)
 - TIDA-00666 『[Bluetooth® Low Energy接続を搭載し、4~20mA電流ループで駆動されるフィールド・トランスミッタ](#)』(TIDUC27)
- Industrial Strengthブログ
 - 「産業用アプリケーションでのスマート・センサ・トランスミッタの電源供給」
 - 「産業向けの堅牢な設計 - 第1部」
 - 「ビルディング・オートメーションの動向: 予知保全」
 - 「ビルディング・オートメーションの動向: センサの接続によりユーザに快適な環境を実現」
- ホワイト・ペーパー

ドキュメントのサポート (continued)

- 『コスト効率の優れた、要求の厳しいアプリケーション用の広 V_{IN} 、低EMIの同期整流降圧回路の評価』(SLYY104)
- 『AN-2162: DC/DCコンバータから伝導されるEMIでの簡単な成功』(SNVA489)
- 『車載用クランキング・シミュレータ・ユーザー・ガイド』(SLVU984)
- 『新しい熱測定基準の使用』(SBVA025)
- 『半導体とICパッケージの熱指標』(SPRA953)

11.3 ドキュメントの更新通知を受け取る方法

ドキュメントの更新についての通知を受け取るには、ti.comのデバイス製品フォルダを開いてください。右上の隅にある「通知を受け取る」をクリックして登録すると、変更されたすべての製品情報に関するダイジェストを毎週受け取れます。変更の詳細については、修正されたドキュメントに含まれている改訂履歴をご覧ください。

11.4 コミュニティ・リソース

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

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設計サポート TIの設計サポート役に立つE2Eフォーラムや、設計サポート・ツールをすばやく見つけることができます。技術サポート用の連絡先情報も参照できます。

11.5 商標

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WEBENCH is a registered trademark of Texas Instruments.

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11.6 静電気放電に関する注意事項



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静電気放電はわずかな性能の低下から完全なデバイスの故障に至るまで、様々な損傷を与えます。高精度の集積回路は、損傷に対して敏感であり、極めてわずかなパラメータの変化により、デバイスに規定された仕様に適合しなくなる場合があります。

11.7 Glossary

[SLYZ022](#) — 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

以降のページには、メカニカル、パッケージ、および注文に関する情報が記載されています。この情報は、そのデバイスについて利用可能な最新のデータです。このデータは予告なく変更されることがあり、ドキュメントが改訂される場合もあります。本データシートのブラウザ版を使用されている場合は、画面左側の説明をご覧ください。

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)
LM5166DRCR	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166DRCR.A	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166DRCRG4	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166DRCRG4.A	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166DRCT	Active	Production	VSON (DRC) 10	250 SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166DRCT.A	Active	Production	VSON (DRC) 10	250 SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166DRCT.B	Active	Production	VSON (DRC) 10	250 SMALL T&R	-	NIPDAU	Level-2-260C-1 YEAR	-40 to 150	5166
LM5166XDRCR	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	Call TI Nipdau	Level-1-260C-UNLIM	-40 to 150	5166X
LM5166XDRCR.A	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	Call TI	Level-1-260C-UNLIM	-40 to 150	5166X
LM5166XDRCR.B	Active	Production	VSON (DRC) 10	3000 LARGE T&R	-	Call TI	Level-1-260C-UNLIM	-40 to 150	5166X
LM5166XDRCT	Active	Production	VSON (DRC) 10	250 SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166X
LM5166XDRCT.A	Active	Production	VSON (DRC) 10	250 SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166X
LM5166YDRCR	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y
LM5166YDRCR.A	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y
LM5166YDRCR.B	Active	Production	VSON (DRC) 10	3000 LARGE T&R	-	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y
LM5166YDRCRG4	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y
LM5166YDRCRG4.A	Active	Production	VSON (DRC) 10	3000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y
LM5166YDRCT	Active	Production	VSON (DRC) 10	250 SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y
LM5166YDRCT.A	Active	Production	VSON (DRC) 10	250 SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 150	5166Y

⁽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



*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
LM5166DRCR	VSON	DRC	10	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166DRCRG4	VSON	DRC	10	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166DRCT	VSON	DRC	10	250	180.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166XDRCR	VSON	DRC	10	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166XDRCR	VSON	DRC	10	250	180.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166YDRCR	VSON	DRC	10	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166YDRCRG4	VSON	DRC	10	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
LM5166YDRCT	VSON	DRC	10	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)
LM5166DRCR	VSON	DRC	10	3000	346.0	346.0	33.0
LM5166DRCRG4	VSON	DRC	10	3000	346.0	346.0	33.0
LM5166DRCT	VSON	DRC	10	250	210.0	185.0	35.0
LM5166XDRCR	VSON	DRC	10	3000	335.0	335.0	25.0
LM5166XDRCT	VSON	DRC	10	250	182.0	182.0	20.0
LM5166YDRCR	VSON	DRC	10	3000	335.0	335.0	25.0
LM5166YDRCRG4	VSON	DRC	10	3000	335.0	335.0	25.0
LM5166YDRCT	VSON	DRC	10	250	182.0	182.0	20.0

GENERIC PACKAGE VIEW

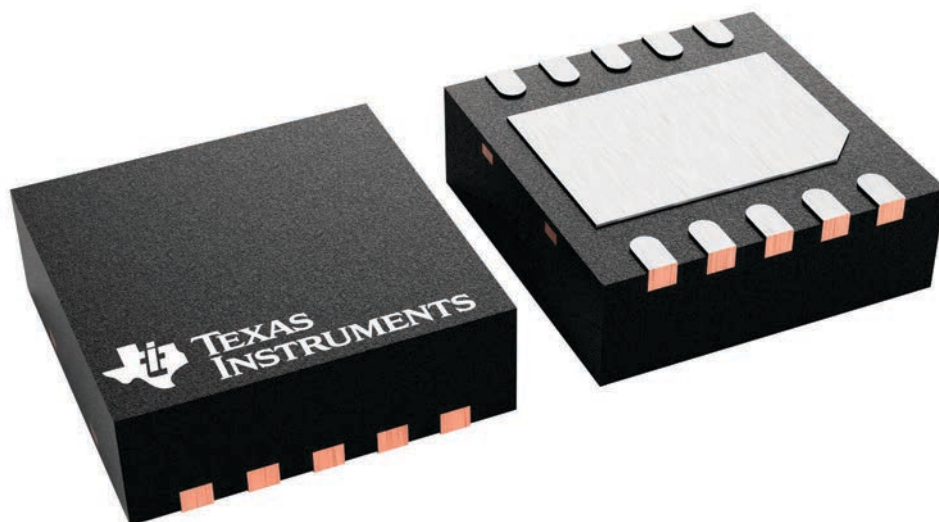
DRC 10

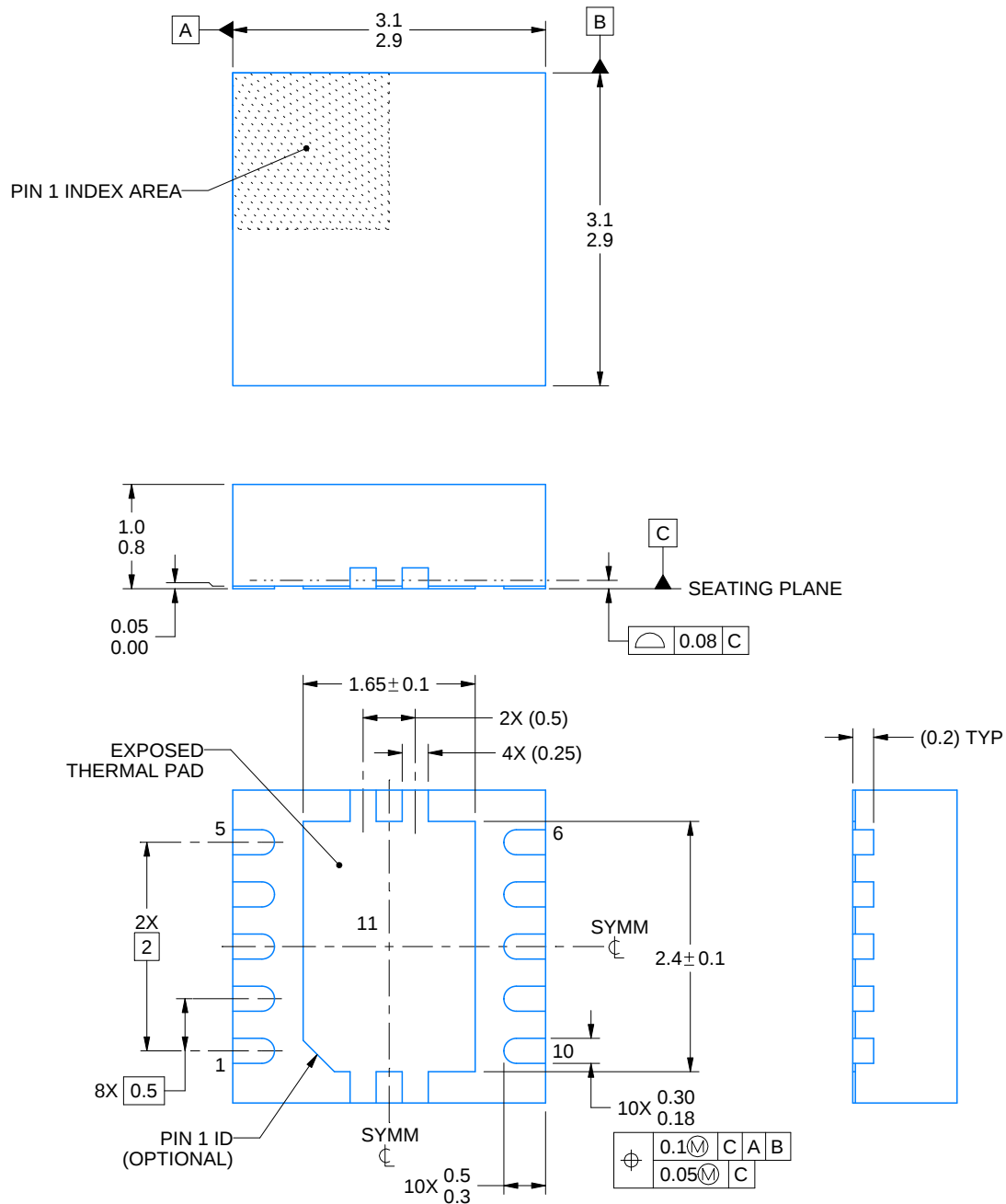
VSON - 1 mm max height

3 x 3, 0.5 mm pitch

PLASTIC SMALL OUTLINE - NO LEAD

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





4218878/B 07/2018

NOTES:

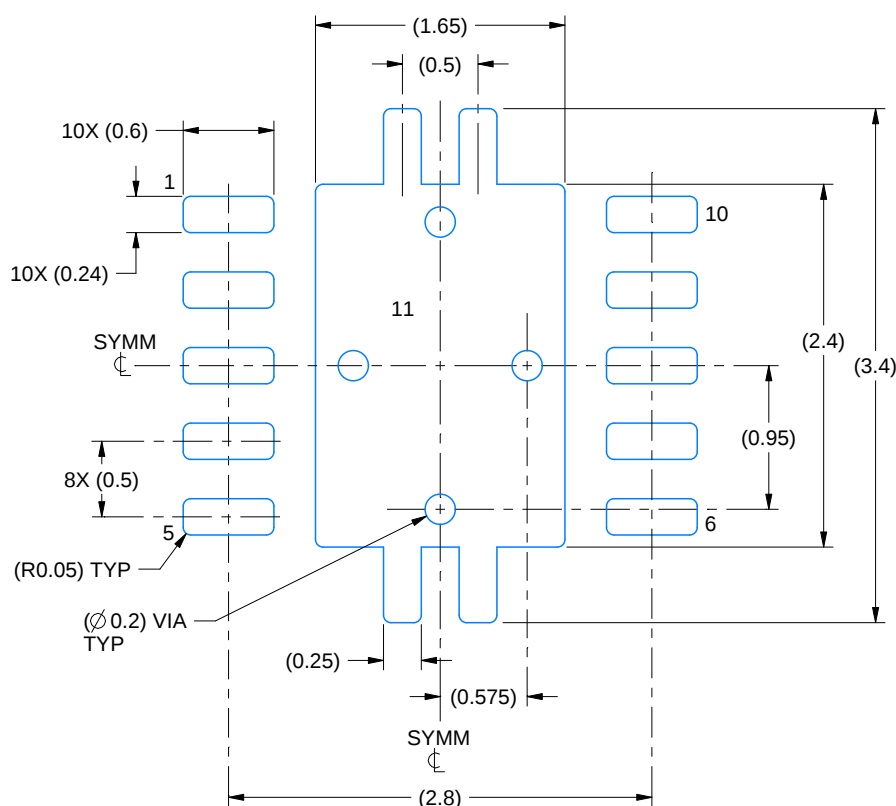
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical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

EXAMPLE BOARD LAYOUT

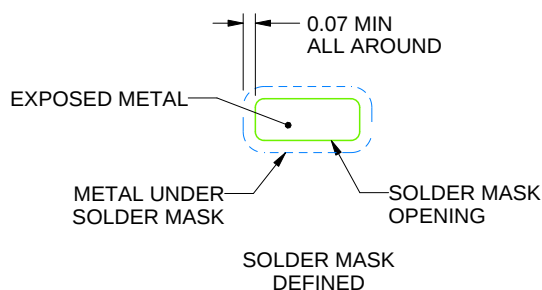
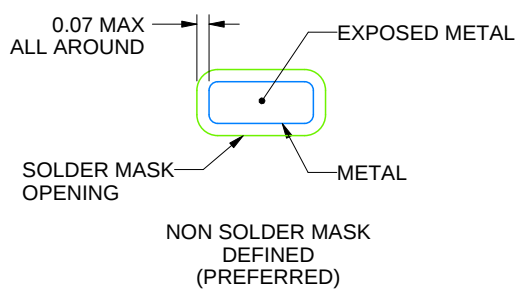
DRC0010J

VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:20X



SOLDER MASK DETAILS

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NOTES: (continued)

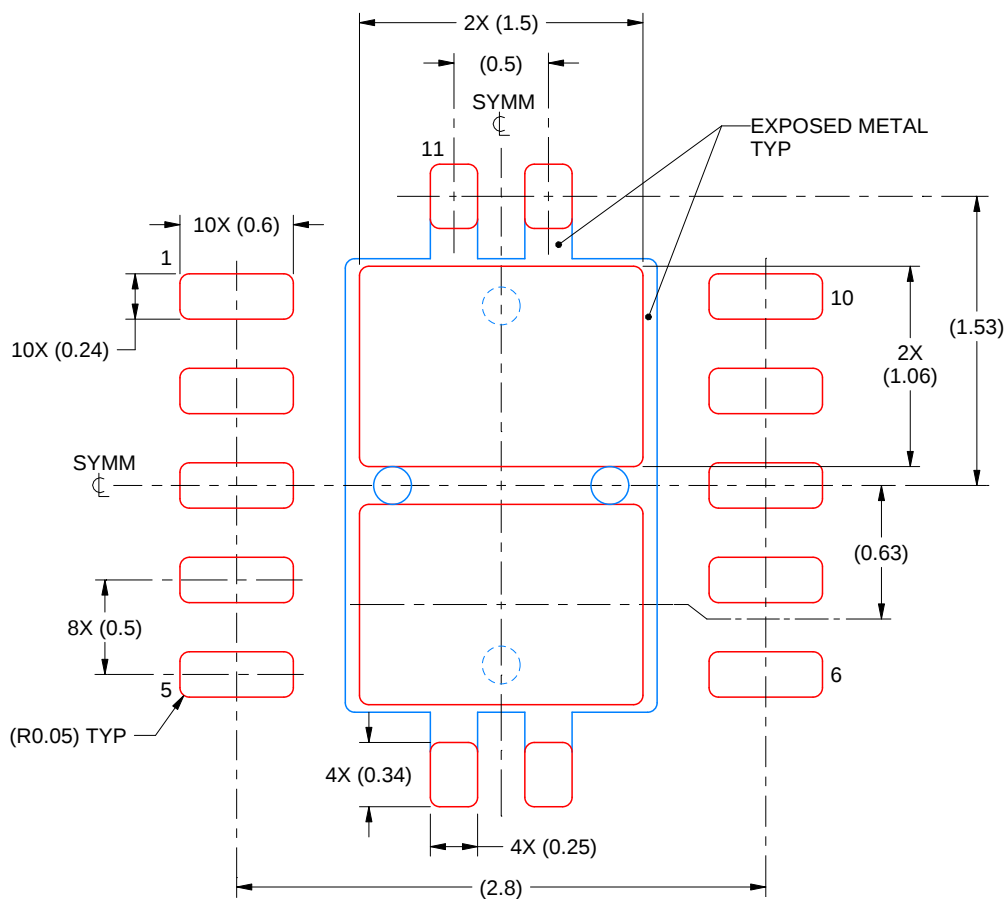
- This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/sluea271).
- Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

EXAMPLE STENCIL DESIGN

DRC0010J

VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 11:
80% PRINTED SOLDER COVERAGE BY AREA
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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