LM2595 SIMPLE SWITCHER®電力コンバータ、150kHz 1A降圧型電圧レギュレータ

1 特長

- 3.3V、5V、12V、および可変出力電圧バージョン
- 可変タイプの出力電圧範囲は1.2Vから最大37V、入力と負荷の全条件で±4%の許容誤差
- TO-220およびTO-263表面実装パッケージで供給
- 1Aの出力負荷電流を保証
- 最大40Vの入力電圧範囲
- 4個の外付け部品で動作可能
- 優れたラインおよび負荷レギュレーション仕様
- 150kHz固定周波数の内部オシレータ
- TTLシャットダウン機能
- 低消費電力のスタンバイ・モード、I_Qの標準値85µA
- 高効率
- 容易に入手可能な標準インダクタ使用
- サーマル・シャットダウンおよび電流制限保護

2 アプリケーション

- シンプルな高効率降圧型(バック)レギュレータ
- リニア・レギュレータ用の高効率プリレギュレータ
- オンボード・スイッチング・レギュレータ
- 反転型コンバータ

3 概要

LM2595シリーズのレギュレータは、降圧型(バック)スイッチング・レギュレータのすべてのアクティブ機能を内蔵したモノリシックICで、優れたラインおよび負荷レギュレーションで1Aの負荷を駆動できます。3.3V、5V、12Vの固定出力電圧と、可変出力電圧のバージョンがあります。

これらのレギュレータは、必要な外部コンポーネントの数が最小限で、簡単に使用でき、内部的な周波数補償と固定周波数発振器が内蔵されています。

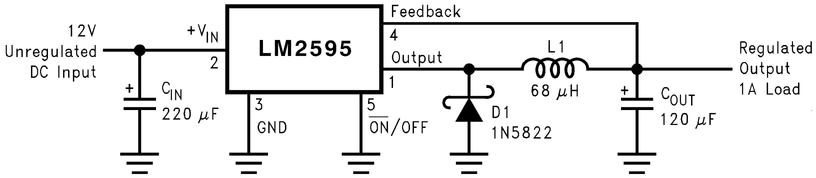
LM2595シリーズは 150kHzのスイッチング周波数で動作するため、低周波数で動作するスイッチング・レギュレータに比べて、サイズの小さなフィルタ部品を使用できます。標準的な5ピンのTO-220パッケージで、いくつかの異なるリードフォーミング品で供給されるほか、5ピンのTO-263表面実装パッケージでも供給されます。一般に、出力電圧が12V未満で、周囲温度が50℃未満なら、ヒートシンクは必要ありません。

製品情報(1)

型番	パッケージ	本体サイズ(公称)
LM2595	TO-263 (5)	10.16mm×8.42mm
	TO-220 (5)	14.986mm×10.16mm

(1) 提供されているすべてのパッケージについては、巻末の注文情報を参照してください。

代表的なアプリケーション



(固定出力電圧バージョン)

目次

4 改訂履歴

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

Revision B (April 2013) から Revision C に変更 **Page**

- 「*ESD定格*」の表、「*機能説明*」セクション、「*デバイスの機能モード*」セクション、「*アプリケーションと実装*」セクション、「*電源に関する推奨事項*」セクション、「*レイアウト*」セクション、「*デバイスおよびドキュメントのサポート*」セクション、「*メカニカル、パッケージ、および注文情報*」セクションを追加 ... 1
- 設計用ソフトウェア*Switchers Made Simple*への言及をすべて削除 ... 1
- Removed NEB package from data sheet ... 4

Revision A (April 2013) から Revision B に変更 **Page**

- Changed layout of National Semiconductor Data Sheet to TI format ... 32

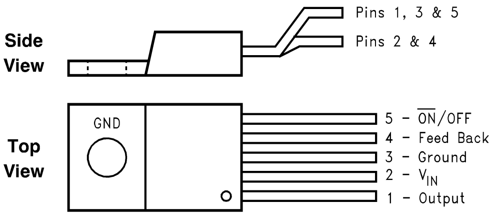
5 概要（続き）

LM2595シリーズでの使用に最適な標準インダクタをいくつかのメーカーから入手できます。このため、スイッチング電源の設計が大幅に簡素化されます。

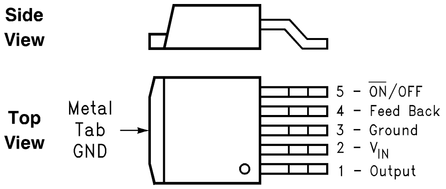
また、入力電圧と出力負荷のあらゆる条件において、出力電圧について±4%、オシレータ周波数について±15%の許容誤差が保証されています。外部シャットダウン機能を内蔵しており、スタンバイ電流は標準値で85µAです。自己保護機能として、出力スイッチのための2段階周波数低下電流制限回路と、異常時でも完全に保護動作が保証される過熱シャットダウン機能を備えています。

6 Pin Configuration and Functions

NDH Package
5–Pin TO-220
Top View



KTT Package
5-Pin TO-263
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	Output	O	Internal switch. The voltage at this pin switches between (+V_{IN} − V_{SAT}) and approximately –0.5 V, with a duty cycle of approximately V_{OUT}/V_{IN}. To minimize coupling to sensitive circuitry, the PCB copper area connected to this pin must be kept to a minimum.
2	+V_{IN}	I	This is the positive input supply for the IC switching regulator. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching currents needed by the regulator.
3	Ground	—	Circuit ground.
4	Feedback	I	Senses the regulated output voltage to complete the feedback loop.
5	$\overline{\text{ON}}$/OFF	I	Allows the switching regulator circuit to be shut down using logic level signals, thus dropping the total input supply current to approximately 85 µA. Pulling this pin below a threshold voltage of approximately 1.3 V turns the regulator on, and pulling this pin above 1.3 V (up to a maximum of 25 V) shuts the regulator down. If this shutdown feature is not needed, the $\overline{\text{ON}}$/OFF pin can be wired to the ground pin or it can be left open, in either case the regulator is in the ON condition.

7 Specifications

7.1 Absolute Maximum Ratings (1)(2)

			MIN	MAX	UNIT
Maximum supply voltage				45	V
$\overline{\text{ON}}$/OFF pin input voltage			–0.3	25	V
Feedback pin voltage			–0.3	25	V
Output voltage to ground (steady-state)				–1	V
Power dissipation			Internally limited		
Lead temperature	KTT package	Vapor phase (60 sec)		215	°C
		Infrared (10 sec)		245	
	NDH package (soldering, 10 sec)			260	
Maximum junction temperature				150	°C
Storage temperature, T_{stg}			–65	150	°C

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

(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±2000	V

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

7.3 Recommended Operating Conditions

	MIN	MAX	UNIT
Supply voltage	4.5	40	V
Temperature range, T_J	–40	125	°C

7.4 Thermal Information

THERMAL METRIC (1)			LM2595		UNIT
			KTT (TO-263)	NDH (TO-220)	
			5 PINS	5 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance (2)(3)	Printed-circuit board with 1-oz copper area of approximately 1 in^2	—	50	°C/W
		Printed-circuit board with 0.5 in^2 of 1-oz copper area	50	—	
		Printed-circuit board with 2.5 in^2 of 1-oz copper area	30	—	
		Double-sided, printed-circuit board with 3 in^2 of 1-oz copper area	20	—	
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance		2	2	°C/W

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

(2) The package thermal impedance is calculated in accordance to JESD 51-7.

(3) Thermal resistances were simulated on a 4-layer, JEDEC board

7.5 Electrical Characteristics – 3.3 V

Specifications are for T_J = 25°C (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS(3) (see Figure 35 for test circuit)							
V_{OUT}	Output voltage	4.75 V ≤ V_{IN} ≤ 40 V, 0.1 A ≤ I_{LOAD} ≤ 1 A	T_J = 25°C	3.168	3.3	3.432	V
			Over full operating temperature range	3.135		3.465	
η	Efficiency	V_{IN} = 12 V, I_{LOAD} = 1 A			78%		

(1) All limits specified at room temperature and temperature extremes. All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2595 is used as shown in the Figure 35 test circuit, system performance is shown in the test conditions column.

7.6 Electrical Characteristics – 5 V

Specifications are for T_J = 25°C (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS(3) (see Figure 35 for test circuit)							
V_{OUT}	Output voltage	7 V ≤ V_{IN} ≤ 40 V, 0.1 A ≤ I_{LOAD} ≤ 1 A	T_J = 25°C	4.8	5	5.2	V
			Over full operating temperature range	4.75		5.25	
η	Efficiency	V_{IN} = 12 V, I_{LOAD} = 1 A			82%		

(1) All limits specified at room temperature and temperature extremes. All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2595 is used as shown in the Figure 35 test circuit, system performance is shown in the test conditions column.

7.7 Electrical Characteristics – 12 V

Specifications are for T_J = 25°C (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN(1)	TYP(2)	MAX(1)	UNIT
SYSTEM PARAMETERS(3) (see Figure 35 for test circuit)							
V_{OUT}	Output voltage	15 V ≤ V_{IN} ≤ 40 V, 0.1 A ≤ I_{LOAD} ≤ 1 A	T_J = 25°C	11.52	12	12.48	V
			Over full operating temperature range	11.4		12.6	
η	Efficiency	V_{IN} = 25 V, I_{LOAD} = 1 A			90%		

(1) All limits specified at room temperature and temperature extremes. All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2595 is used as shown in the Figure 35 test circuit, system performance is shown in the test conditions column.

7.8 Electrical Characteristics – Adjustable

Specifications are for T_J = 25°C (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN[1]	TYP[2]	MAX[1]	UNIT
SYSTEM PARAMETERS[3] (see Figure 35 for test circuit)							
V_{FB}	Feedback voltage	4.5 V ≤ V_{IN} ≤ 40 V, 0.1 A ≤ I_{LOAD} ≤ 1 A			1.23		V
		V_{OUT} programmed for 3 V, circuit of Figure 35	T_J = 25°C	1.193		1.267	
			Over full operating temperature range	1.18		1.28	
η	Efficiency	V_{IN} = 12 V, V_{OUT} = 3 V, I_{LOAD} = 1 A			78%		

(1) All limits specified at room temperature and temperature extremes. All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) External components such as the catch diode, inductor, input and output capacitors, and voltage programming resistors can affect switching regulator system performance. When the LM2595 is used as shown in the Figure 35 test circuit, system performance is shown in the test conditions column.

7.9 Electrical Characteristics – All Output Voltage Versions

Specifications are for T_J = 25°C, I_{LOAD} = 200 mA, V_{IN} = 12 V for the 3.3-V, 5-V, and adjustable versions, and V_{IN} = 24 V for the 12-V version (unless otherwise noted).

PARAMETER		TEST CONDITIONS		MIN[1]	TYP[2]	MAX[1]	UNIT
DEVICE PARAMETERS							
I_b	Feedback bias current	Adjustable version only, V_{FB} = 1.3 V	T_J = 25°C		10	50	nA
			Over full operating temperature range			100	
f_O	Oscillator frequency[3]	T_J = 25°C		127	150	173	kHz
		Over full operating temperature range		110		173	
V_{SAT}	Saturation voltage	I_{OUT} = 1 A, T_J = 25°C[4][5]			1	1.2	V
		Over full operating temperature range				1.3	
DC	Max duty cycle (ON)[5]				100%		
	Min duty cycle (OFF)[6]				0%		
I_{CL}	Current limit	Peak current[4][5]	T_J = 25°C	1.2	1.5	2.4	A
			Over full operating temperature range	1.15		2.6	
I_L	Output leakage current	Output = 0 V[4][6][7]				50	µA
		Output = −1 V			2	15	mA
I_Q	Quiescent current[6]				5	10	mA
I_{STBY}	Standby quiescent current	$\overline{\text{ON}}$/OFF pin = 5 V (OFF)[7]	T_J = 25°C		85	200	µA
			Over full operating temperature range			250	
$\overline{\text{ON}}$/OFF CONTROL (see Figure 35 for test circuit)							
	$\overline{\text{ON}}$/OFF pin logic input				1.3		V
V_{IH}	Threshold voltage, high	Regulator ON, over full operating temperature range				0.6	V
V_{IL}	Threshold voltage, low	Regulator OFF, over full operating temperature range		2			V
I_H	$\overline{\text{ON}}$/OFF pin input current, high	V_{LOGIC} = 2.5 V (regulator OFF)			5	15	µA
I_L	$\overline{\text{ON}}$/OFF pin input current, low	V_{LOGIC} = 0.5 V (regulator ON)			0.02	5	µA

(1) All limits specified at room temperature and temperature extremes. All room temperature limits are 100% production tested. All limits at temperature extremes are specified via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level (AOQL).
(2) Typical numbers are at 25°C and represent the most likely norm.
(3) The switching frequency is reduced when the second stage current limit is activated. The amount of reduction is determined by the severity of current overload.
(4) No diode, inductor or capacitor connected to output pin.
(5) Feedback pin removed from output and connected to 0 V to force the output transistor switch ON.
(6) Feedback pin removed from output and connected to 12 V for the 3.3-V, 5-V, and adjustable versions, and 15 V for the 12-V version, to force the output transistor switch OFF.
(7) V_{IN} = 40 V.

7.10 Typical Characteristics

Circuit of Figure 35

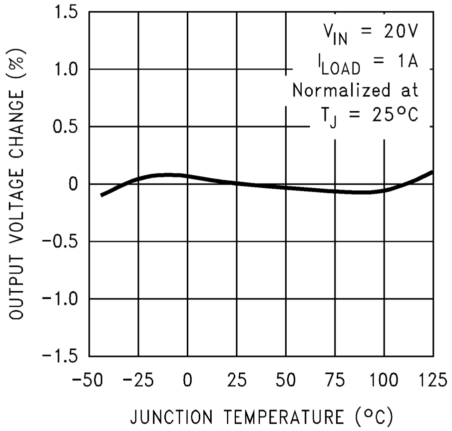


Figure 1. Normalized Output Voltage

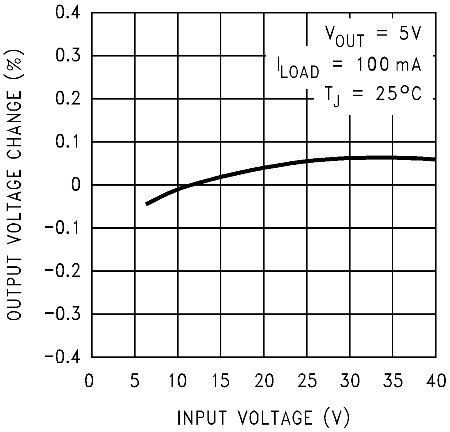


Figure 2. Line Regulation

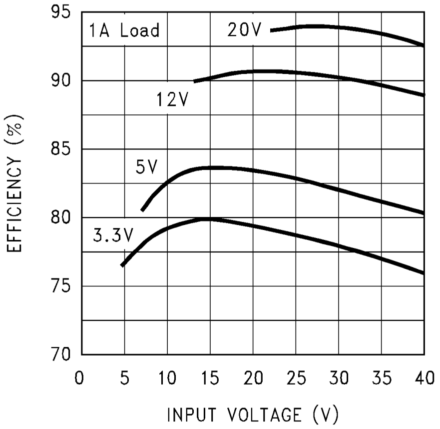


Figure 3. Efficiency

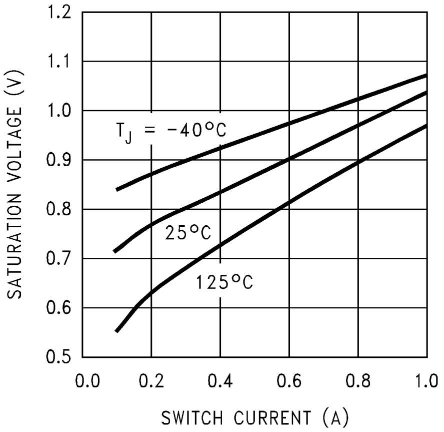


Figure 4. Switch Saturation Voltage

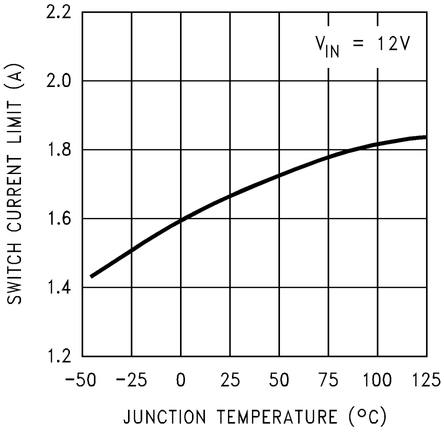


Figure 5. Switch Current Limit

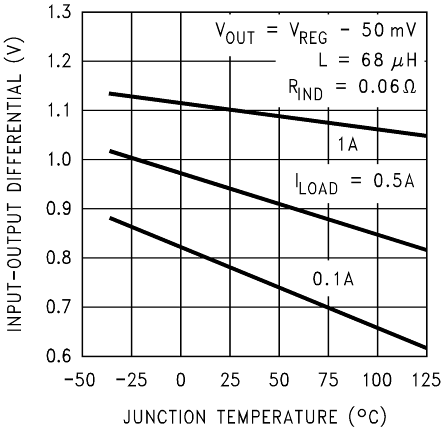


Figure 6. Dropout Voltage

Typical Characteristics (continued)

Circuit of Figure 35

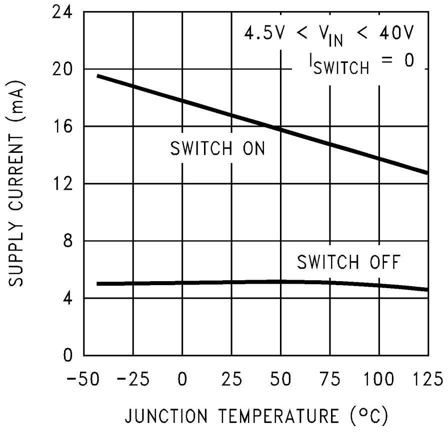


Figure 7. Operating Quiescent Current

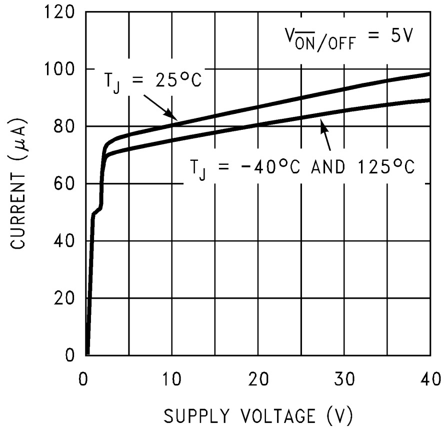


Figure 8. Shutdown Quiescent Current

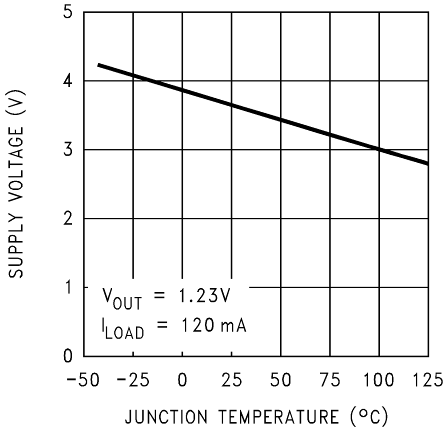


Figure 9. Minimum Operating Supply Voltage

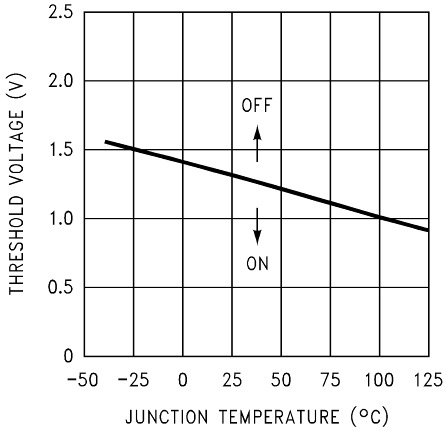


Figure 10. $\overline{ON}$ /OFF Threshold Voltage

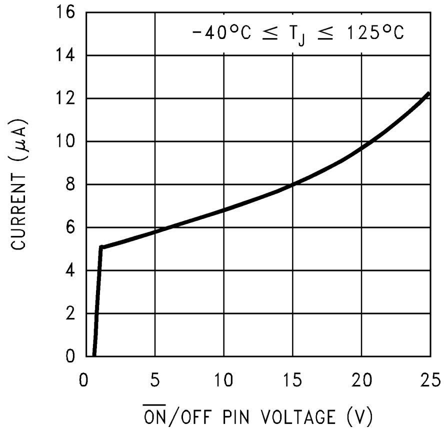


Figure 11. $\overline{ON}$/OFF Pin Current (Sinking)

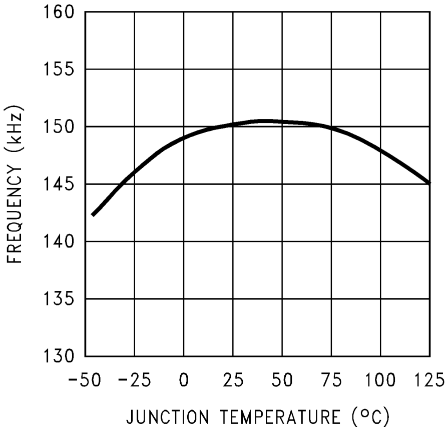


Figure 12. Switching Frequency

Typical Characteristics (continued)

Circuit of Figure 35

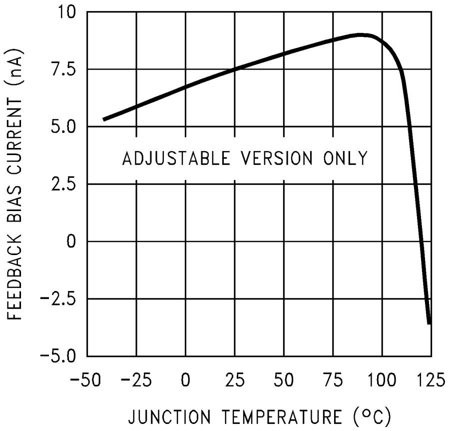


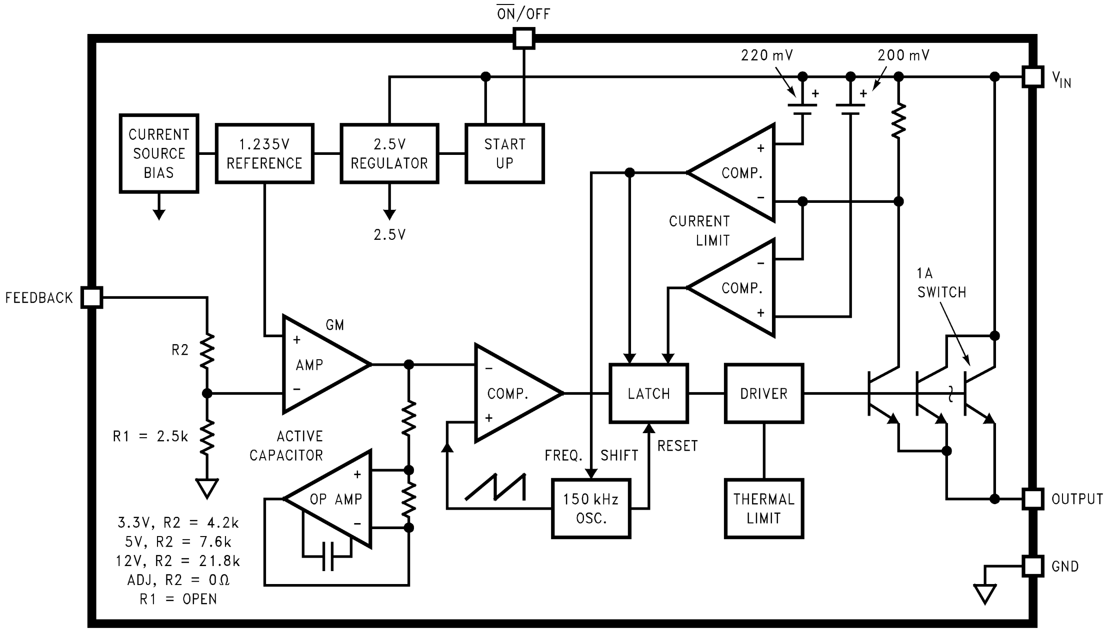
Figure 13. Feedback Pin Bias Current

8 Detailed Description

8.1 Overview

The LM2595 SIMPLE SWITCHER® regulator is an easy-to-use, nonsynchronous step-down DC-DC converter with a wide input voltage range up to 40 V. The regulator is capable of delivering up to 1-A DC load current with excellent line and load regulation. These devices are available in fixed output voltages of 3.3-V, 5-V, 12-V, and an adjustable output version. The family requires few external components, and the pin arrangement was designed for simple, optimum PCB layout.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Delayed Start-Up

The circuit in Figure 14 uses the $\overline{\text{ON}}$/OFF pin to provide a time delay between the time the input voltage is applied and the time the output voltage comes up (only the circuitry pertaining to the delayed start up is shown). As the input voltage rises, the charging of capacitor C1 pulls the $\overline{\text{ON}}$/OFF pin high, keeping the regulator off. Once the input voltage reaches its final value and the capacitor stops charging, the resistor R2 pulls the $\overline{\text{ON}}$/OFF pin low, thus allowing the circuit to start switching. Resistor R_1 is included to limit the maximum voltage applied to the $\overline{\text{ON}}$/OFF pin (maximum of 25 V), reduces power supply noise sensitivity, and also limits the capacitor, C1, discharge current. When high input ripple voltage exists, avoid long delay time, because this ripple can be coupled into the $\overline{\text{ON}}$/OFF pin and cause problems.

This delayed start-up feature is useful in situations where the input power source is limited in the amount of current it can deliver. It allows the input voltage to rise to a higher voltage before the regulator starts operating. Buck regulators require less input current at higher input voltages.

Feature Description (continued)

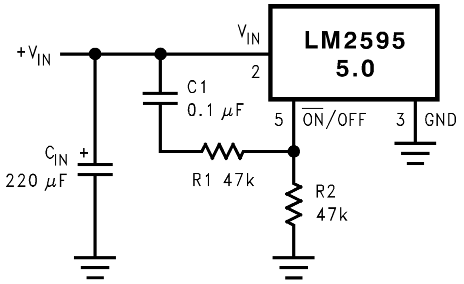


Figure 14. Delayed Start-Up

8.3.2 Undervoltage Lockout

Some applications require the regulator to remain off until the input voltage reaches a predetermined voltage. Figure 15 shows an undervoltage lockout feature applied to a buck regulator, while Figure 16 and Figure 17 apply the same feature to an inverting circuit. The circuit in Figure 16 features a constant threshold voltage for turnon and turnoff (Zener voltage plus approximately one volt). If hysteresis is required, the circuit in Figure 17 has a turnon voltage which is different than the turnoff voltage. The amount of hysteresis is approximately equal to the value of the output voltage. If Zener voltages greater than 25 V are used, an additional 47-kΩ resistor is required from the $\overline{\text{ON}}$/OFF pin to the ground pin to stay within the 25-V maximum limit of the $\overline{\text{ON}}$/OFF pin.

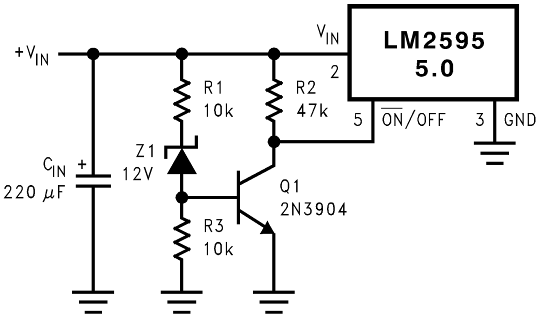
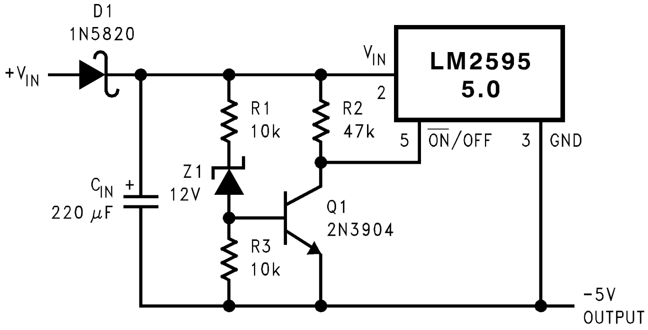


Figure 15. Undervoltage Lockout for Buck Regulator

8.3.3 Inverting Regulator

The circuit in Figure 18 converts a positive input voltage to a negative output voltage with a common ground. The circuit operates by bootstrapping the regulator's ground pin to the negative output voltage, then grounding the feedback pin, the regulator senses the inverted output voltage and regulates it.



This circuit has an $\overline{\text{ON}}$/OFF threshold of approximately 13 V.

Figure 16. Undervoltage Lockout for Inverting Regulator

Feature Description (continued)

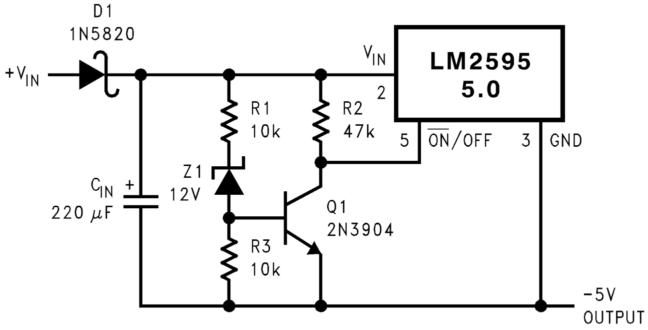
This example uses the LM2595 5-V version to generate a −5-V output, but other output voltages are possible by selecting other output voltage versions, including the adjustable version.

Because this regulator topology can produce an output voltage that is either greater than or less than the input voltage, the maximum output current greatly depends on both the input and output voltage. Figure 19 provides a guide as to the amount of output load current possible for the different input and output voltage conditions.

The maximum voltage appearing across the regulator is the absolute sum of the input and output voltage, and this must be limited to a maximum of 40 V. For example, when converting 20 V to −12 V, the regulator would see 32 V between the input pin and ground pin. The LM2595 has a maximum input voltage spec of 40 V.

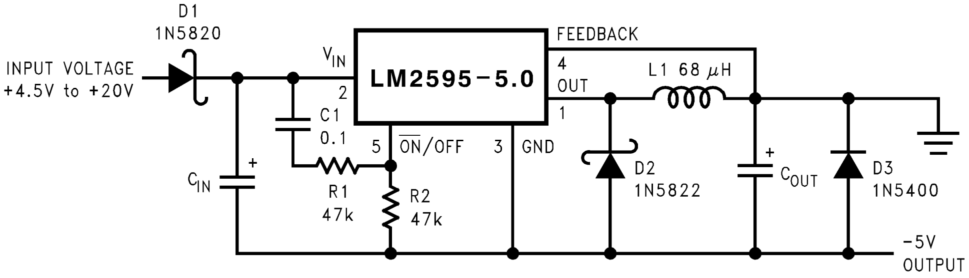
Additional diodes are required in this regulator configuration. Diode D1 is used to isolate input voltage ripple or noise from coupling through the C_{IN} capacitor to the output, under light or no load conditions. Also, this diode isolation changes the topology to closely resemble a buck configuration thus providing good closed loop stability. TI recommends a Schottky diode for low input voltages (because of its lower voltage drop), but for higher input voltages, a fast recovery diode could be used.

Without diode D3, when the input voltage is first applied, the charging current of C_{IN} can pull the output positive by several volts for a short period of time. Adding D3 prevents the output from going positive by more than a diode voltage.



This circuit has hysteresis.
Regulator starts switching at V_{IN} = 13 V
Regulator stops switching at V_{IN} = 8 V

Figure 17. Undervoltage Lockout With Hysteresis For Inverting Regulator



C_{IN} – 220-µF, 25-V tantalum Sprague 595D
120-µF, 50-V electrolytic Panasonic HFQ
C_{OUT} – 22-µF, 20-V tantalum Sprague 595D
120-µF, 25-V electrolytic Panasonic HFQ

Figure 18. Inverting −5-V Regulator With Delayed Start-Up

Feature Description (continued)

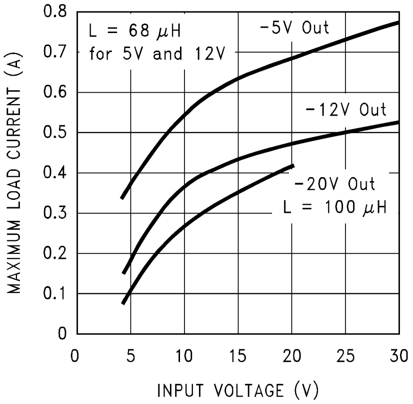


Figure 19. Inverting Regulator Typical Load Current

Because of differences in the operation of the inverting regulator, the standard design procedure is not used to select the inductor value. In the majority of designs, a 68-µH, 1.5-A inductor is the best choice. Capacitor selection is narrowed down to just a few values. Using the values shown in Figure 18 will provide good results in the majority of inverting designs.

This type of inverting regulator can require relatively large amounts of input current when starting up, even with light loads. Input currents as high as the LM2595 current limit (approximately 1.5 A) are required for at least 2 ms or more, until the output reaches its nominal output voltage. The actual time depends on the output voltage and the size of the output capacitor. Input power sources that are current limited or sources that can not deliver these currents without getting loaded down, may not work correctly. Because of the relatively high start-up currents required by the inverting topology, the delayed start-up feature (C1, R_1 and R_2) shown in Figure 18 is recommended. By delaying the regulator start-up, the input capacitor is allowed to charge up to a higher voltage before the switcher begins operating. A portion of the high input current required for start-up is now supplied by the input capacitor (C_{IN}). For severe start up conditions, the input capacitor can be made much larger than normal.

8.3.4 Inverting Regulator Shutdown Methods

Using the $\overline{\text{ON}}$/OFF pin in a standard buck configuration is simple. To turn the regulator ON, pull the $\overline{\text{ON}}$/OFF pin below 1.3 V (at 25°C referenced to ground). To shut the regulator OFF, pull the $\overline{\text{ON}}$/OFF pin above 1.3 V. With the inverting configuration, some level shifting is required, because the ground pin of the regulator is no longer at ground, but is now setting at the negative output voltage level. Two different shutdown methods for inverting regulators are shown in Figure 20 and Figure 21.

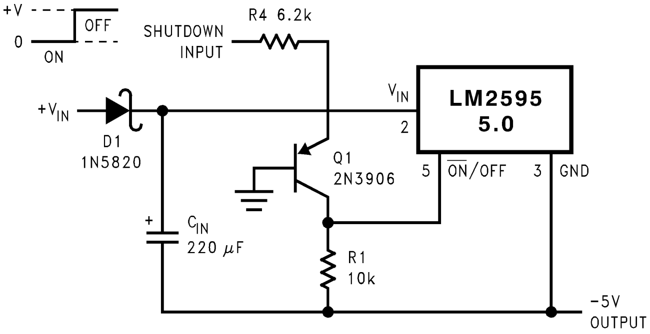


Figure 20. Inverting Regulator Ground Referenced Shutdown

Feature Description (continued)

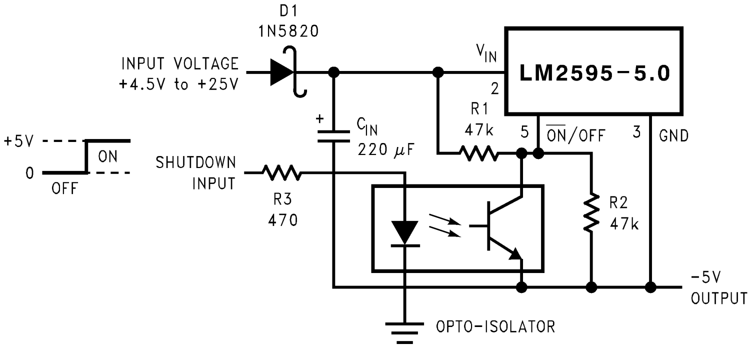


Figure 21. Inverting Regulator Ground Referenced Shutdown Using Opto Device

8.4 Device Functional Modes

8.4.1 Discontinuous Mode Operation

The selection guide chooses inductor values suitable for continuous mode operation, but for low current applications or high input voltages, a discontinuous mode design may be a better choice. Discontinuous mode would use an inductor that would be physically smaller, and would need only one half to one third the inductance value required for a continuous mode design. The peak switch and inductor currents will be higher in a discontinuous design, but at these low load currents (400 mA and below), the maximum switch current will still be less than the switch current limit.

Discontinuous operation can have voltage waveforms that are considerably different than a continuous design. The output pin (switch) waveform can have some damped sinusoidal ringing present (see *Typical Characteristics*). This ringing is normal for discontinuous operation, and is not caused by feedback loop instabilities. In discontinuous operation, there is a period of time where neither the switch nor the diode are conducting, and the inductor current has dropped to zero. During this time, a small amount of energy can circulate between the inductor and the switch/diode parasitic capacitance causing this characteristic ringing. Normally this ringing is not a problem, unless the amplitude becomes great enough to exceed the input voltage, and even then, there is very little energy present to cause damage.

Different inductor types and/or core materials produce different amounts of this characteristic ringing. Ferrite core inductors have very little core loss and therefore produce the most ringing. The higher core loss of powdered iron inductors produce less ringing. If desired, a series RC could be placed in parallel with the inductor to dampen the ringing.

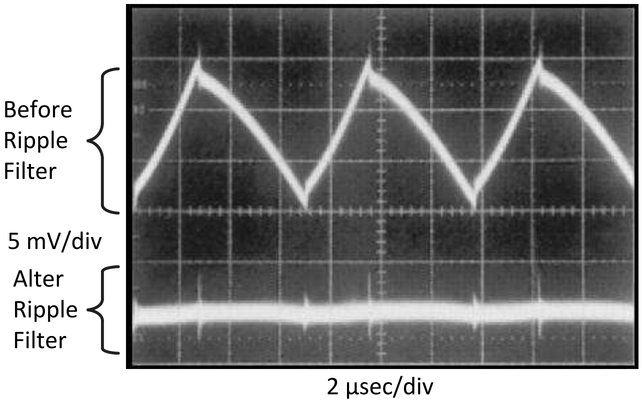


Figure 22. Post Ripple Filter Waveform

9 Application and Implementation

NOTE

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

9.1 Application Information

9.1.1 Input Capacitor (C_{IN})

A low ESR aluminum or tantalum bypass capacitor is required between the input pin and ground pin. The capacitor must be placed near the regulator using short leads. This capacitor prevents large voltage transients from appearing at the input, and provides the instantaneous current required each time the switch turns on.

The important parameters for the Input capacitor are the voltage rating and the RMS current rating. Because of the relatively high RMS currents flowing in a buck regulator's input capacitor, this capacitor must be chosen for its RMS current rating rather than its capacitance or voltage ratings, although the capacitance value and voltage rating are directly related to the RMS current rating.

The RMS current rating of a capacitor could be viewed as a capacitor's power rating. The RMS current flowing through the capacitors internal ESR produces power which causes the internal temperature of the capacitor to rise. The RMS current rating of a capacitor is determined by the amount of current required to raise the internal temperature approximately 10°C above an ambient temperature of 105°C. The ability of the capacitor to dissipate this heat to the surrounding air will determine the amount of current the capacitor can safely sustain. Capacitors that are physically large and have a large surface area will typically have higher RMS current ratings. For a given capacitor value, a higher voltage electrolytic capacitor will be physically larger than a lower voltage capacitor, and thus be able to dissipate more heat to the surrounding air, and therefore will have a higher RMS current rating.

The consequences of operating an electrolytic capacitor above the RMS current rating is a shortened operating life. The higher temperature speeds up the evaporation of the capacitor's electrolyte, resulting in eventual failure.

Selecting an input capacitor requires consulting the manufacturer's data sheet for maximum allowable RMS ripple current. For a maximum ambient temperature of 40°C, a general guideline would be to select a capacitor with a ripple current rating of approximately 50% of the DC load current. For ambient temperatures up to 70°C, a current rating of 75% of the DC load current would be a good choice for a conservative design. The capacitor voltage rating must be at least 1.25 times greater than the maximum input voltage, and often a much higher voltage capacitor is required to satisfy the RMS current requirements.

Figure 23 shows the relationship between an electrolytic capacitor value, its voltage rating, and the RMS current it is rated for. These curves were obtained from the Nichicon *PL* series of low-ESR, high-reliability electrolytic capacitors designed for switching regulator applications. Other capacitor manufacturers offer similar types of capacitors, but always check the capacitor data sheet.

Standard electrolytic capacitors typically have much higher ESR numbers, lower RMS current ratings and typically have a shorter operating lifetime.

Because of their small size and excellent performance, surface-mount solid tantalum capacitors are often used for input bypassing, but several precautions must be observed. A small percentage of solid tantalum capacitors can short if the inrush current rating is exceeded. This can happen at turnon when the input voltage is suddenly applied, and of course, higher input voltages produce higher inrush currents. Several capacitor manufacturers do a 100% surge current testing on their products to minimize this potential problem. If high turn on currents are expected, it may be necessary to limit this current by adding either some resistance or inductance before the tantalum capacitor, or select a higher voltage capacitor. As with aluminum electrolytic capacitors, the RMS ripple current rating must be sized to the load current.

Application Information (continued)

9.1.2 Feedforward Capacitor (C_{FF}) for Adjustable Output Voltage Version Only

A feedforward capacitor, C_{FF}, shown across R2 in Table 1 is used when the output voltage is greater than 10 V or when C_{OUT} has a very low ESR. This capacitor adds lead compensation to the feedback loop and increases the phase margin for better loop stability.

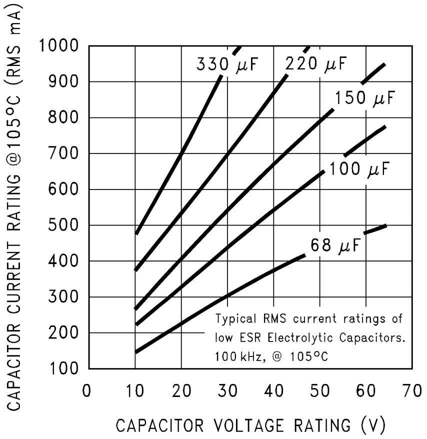


Figure 23. RMS Current Ratings for Low ESR Electrolytic Capacitors (Typical)

9.1.3 Output Capacitor (C_{OUT})

An output capacitor is required to filter the output and provide regulator loop stability. Low impedance or low ESR Electrolytic or solid tantalum capacitors designed for switching regulator applications must be used. When selecting an output capacitor, the important capacitor parameters are the 100-kHz Equivalent Series Resistance (ESR), the RMS ripple current rating, voltage rating, and capacitance value. For the output capacitor, the ESR value is the most important parameter.

The output capacitor requires an ESR value that has an upper and lower limit. For low output ripple voltage, a low ESR value is required. This value is determined by the maximum allowable output ripple voltage, typically 1% to 2% of the output voltage. But if the selected capacitor's ESR is extremely low, there is a possibility of an unstable feedback loop, resulting in an oscillation at the output. Using the capacitors listed in the tables, or similar types, will provide design solutions under all conditions.

If very low output ripple voltage (less than 15 mV) is required, see *Output Voltage Ripple and Transients* for a post ripple filter.

An aluminum electrolytic capacitor's ESR value is related to the capacitance value and its voltage rating. In most cases, higher voltage electrolytic capacitors have lower ESR values (see Figure 24). Often, capacitors with much higher voltage ratings may be required to provide the low ESR values required for low output ripple voltage.

The output capacitor for many different switcher designs often can be satisfied with only three or four different capacitor values and several different voltage ratings. See Table 5 and Table 7 for typical capacitor values, voltage ratings, and manufacturer's capacitor types.

Electrolytic capacitors are not recommended for temperatures below −25°C. The ESR rises dramatically at cold temperatures and typically rises 3X at −25°C and as much as 10X at −40°C (see Figure 25).

Solid tantalum capacitors have a much better ESR specifications for cold temperatures and are recommended for temperatures below −25°C.

Application Information (continued)

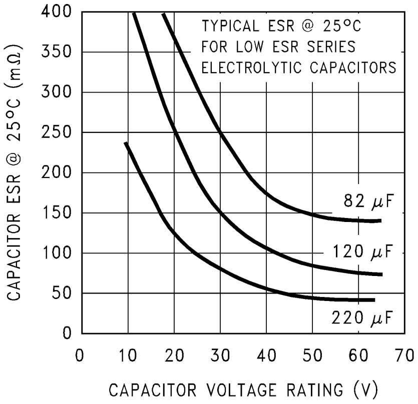


Figure 24. Capacitor ESR vs Capacitor Voltage Rating (Typical Low ESR Electrolytic Capacitor)

Table 1. Output Capacitor and Feedforward Capacitor Selection Table

OUTPUT VOLTAGE (V)	THROUGH-HOLE OUTPUT CAPACITOR			SURFACE-MOUNT OUTPUT CAPACITOR		
	PANASONIC HFQ SERIES (µF/V)	NICHICON PL SERIES (µF/V)	FEEDFORWARD CAPACITOR	AVX TPS SERIES (µF/V)	SPRAGUE 595D SERIES (µF/V)	FEEDFORWARD CAPACITOR
9	180/25	180/25	1.5 nF	100/16	180/16	1.5 nF
12	120/25	120/25	1.5 nF	68/20	120/20	1.5 nF
15	120/25	120/25	1.5 nF	68/20	100/20	1.5 nF
24	82/35	82/35	1 nF	33/25	33/35	220 pF
28	82/50	82/50	1 nF	10/35	33/35	220 pF

9.1.4 Catch Diode

Buck regulators require a diode to provide a return path for the inductor current when the switch turns off. This must be a fast diode and must be placed close to the LM2595 using short leads and short printed circuit traces.

Because of their very fast switching speed and low forward voltage drop, Schottky diodes provide the best performance, especially in low output voltage applications (5 V and lower). Ultra-fast recovery, or high-efficiency rectifiers are also a good choice, but some types with an abrupt turnoff characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series are much too slow and must not be used.

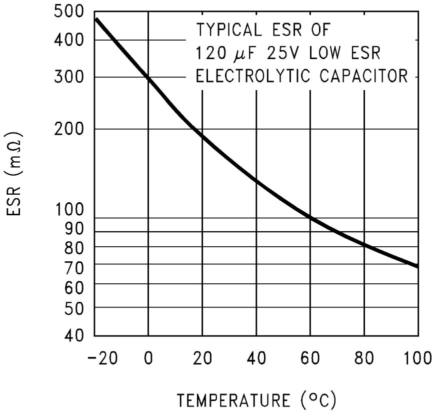


Figure 25. Capacitor ESR Change vs Temperature

Table 2. Diode Selection Table

VR	1-A DIODES				3-A DIODES			
	SURFACE MOUNT		THROUGH HOLE		SURFACE MOUNT		THROUGH HOLE	
	SCHOTTKY	ULTRA FAST RECOVERY	SCHOTTKY	ULTRA FAST RECOVERY	SCHOTTKY	ULTRA FAST RECOVERY	SCHOTTKY	ULTRA FAST RECOVERY
20 V	SK12	All of these diodes are rated to at least 50 V	1N5817	All of these diodes are rated to at least 50 V		All of these diodes are rated to at least 50 V	1N5820	All of these diodes are rated to at least 50 V
			SR102		SK32		SR302	
							MBR320	
30 V	SK13		1N5818				1N5821	
	MBRS130		SR103		SK33		MBR330	
			11DQ03				31DQ03	
	SK14						1N5822	
40 V	MBRS140		1N5819		SK34		SR304	
	10BQ040		SR104		MBRS340		MBR340	
	10MQ040	MURS120	11DQ04	MUR120	30WQ04	MURS320	31DQ04	MUR320
50 V	MBRS160	10BF10	SR105		SK35	30WF10	SR305	30WF10
or	10BQ050		MBR150		MBR360		MBR350	
More	10MQ060		11DQ05		30WQ05		31DQ05	

9.1.5 Inductor Selection

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulators performance and requirements. Most switcher designs will operate in the discontinuous mode when the load current is low.

The LM2595 (or any of the Simple Switcher family) can be used for both continuous or discontinuous modes of operation.

In many cases the preferred mode of operation is the continuous mode. This mode offers greater output power, lower peak switch, inductor and diode currents, and can have lower output ripple voltage. However, the continuous mode requires larger inductor values to keep the inductor current flowing continuously, especially at low output load currents and/or high input voltages.

To simplify the inductor selection process, an inductor selection guide (nomograph) was designed (see Figure 27 through Figure 30). This guide assumes that the regulator is operating in the continuous mode, and selects an inductor that will allow a peak-to-peak inductor ripple current to be a certain percentage of the maximum design load current. This peak-to-peak inductor ripple current percentage is not fixed, but is allowed to change as different design load currents are selected. (See Figure 26.)

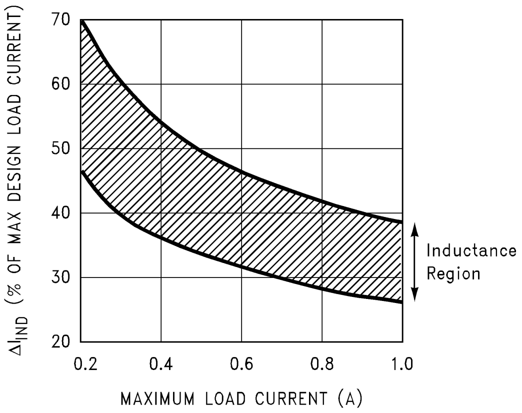


Figure 26. ΔI_{IND}, Peak-to-Peak Inductor Ripple Current (as a Percentage of the Load Current) vs Load Current

By allowing the percentage of inductor ripple current to increase for low load currents, the inductor value and size can be kept relatively low.

When operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage), with the average value of this current waveform equal to the DC output load current.

Inductors are available in different styles such as pot core, toroid, E-core, bobbin core, and so forth, as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin, rod or stick core, consists of wire wound on a ferrite bobbin. This type of construction makes for an inexpensive inductor; however, because the magnetic flux is not completely contained within the core, it generates more Electro-Magnetic Interference (EMl). This magnetic flux can induce voltages into nearby printed circuit traces, thus causing problems with both the switching regulator operation and nearby sensitive circuitry, and can give incorrect scope readings because of induced voltages in the scope probe (see *Open Core Inductors*).

When multiple switching regulators are placed on the same PCB, open core magnetics can cause interference between two or more of the regulator circuits, especially at high currents. A toroid or E-core inductor (closed magnetic structure) must be used in these situations.

The inductors listed in the selection chart include ferrite E-core construction for Schott, ferrite bobbin core for Renco and Coilcraft, and powdered iron toroid for Pulse Engineering.

Exceeding an inductor's maximum current rating may cause the inductor to overheat because of the copper wire losses, or the core may saturate. If the inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This can cause the switch current to rise very rapidly and force the switch into a cycle-by-cycle current limit, thus reducing the DC output load current. This can also result in overheating of the inductor and/or the LM2595. Different inductor types have different saturation characteristics, and this must be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

For continuous mode operation, see the inductor selection graphs in Figure 27 through Figure 30

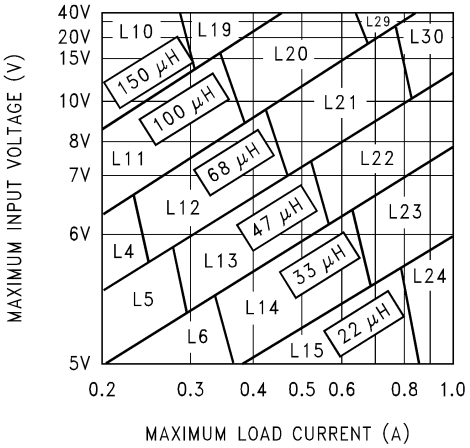


Figure 27. LM2595 3.3-V

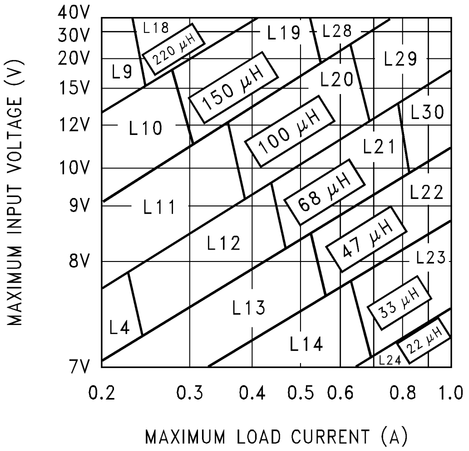


Figure 28. LM2595 5-V

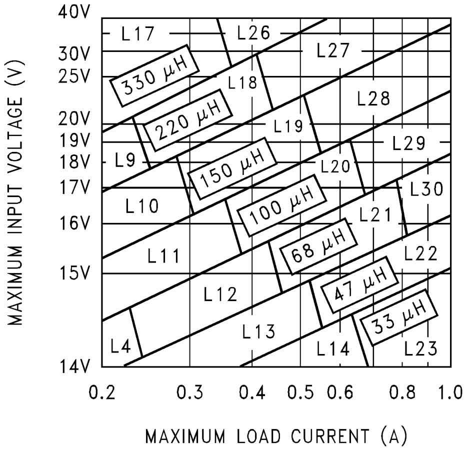


Figure 29. LM2595 12-V

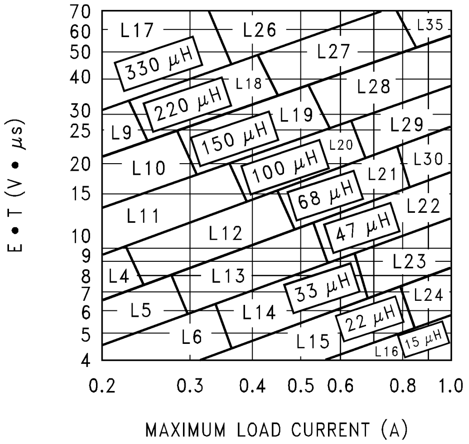


Figure 30. LM2595 Adjustable Voltage

Table 3. Inductor Manufacturer's Part Numbers

	INDUCTANCE (µH)	CURRENT (A)	RENCO		PULSE ENGINEERING		COILCRAFT
			THROUGH HOLE	SURFACE MOUNT	THROUGH HOLE	SURFACE MOUNT	SURFACE MOUNT
L4	68	0.32	RL-1284-68-43	RL1500-68	PE-53804	PE-53804-S	DO1608-68
L5	47	0.37	RL-1284-47-43	RL1500-47	PE-53805	PE-53805-S	DO1608-473
L6	33	0.44	RL-1284-33-43	RL1500-33	PE-53806	PE-53806-S	DO1608-333
L9	220	0.32	RL-5470-3	RL1500-220	PE-53809	PE-53809-S	DO3308-224
L10	150	0.39	RL-5470-4	RL1500-150	PE-53810	PE-53810-S	DO3308-154
L11	100	0.48	RL-5470-5	RL1500-100	PE-53811	PE-53811-S	DO3308-104
L12	68	0.58	RL-5470-6	RL1500-68	PE-53812	PE-53812-S	DO3308-683
L13	47	0.70	RL-5470-7	RL1500-47	PE-53813	PE-53813-S	DO3308-473
L14	33	0.83	RL-1284-33-43	RL1500-33	PE-53814	PE-53814-S	DO3308-333
L15	22	0.99	RL-1284-22-43	RL1500-22	PE-53815	PE-53815-S	DO3308-223
L16	15	1.24	RL-1284-15-43	RL1500-15	PE-53816	PE-53816-S	DO3308-153
L17	330	0.42	RL-5471-1	RL1500-330	PE-53817	PE-53817-S	DO3316-334
L18	220	0.55	RL-5471-2	RL1500-220	PE-53818	PE-53818-S	DO3316-224
L19	150	0.66	RL-5471-3	RL1500-150	PE-53819	PE-53819-S	DO3316-154
L20	100	0.82	RL-5471-4	RL1500-100	PE-53820	PE-53820-S	DO3316-104
L21	68	0.99	RL-5471-5	RL1500-68	PE-53821	PE-53821-S	DO3316-683
L22	47	1.17	RL-5471-6	—	PE-53822	PE-53822-S	DO3316-473
L23	33	1.40	RL-5471-7	—	PE-53823	PE-53823-S	DO3316-333
L24	22	1.70	RL-1283-22-43	—	PE-53824	PE-53824-S	DO3316-223
L26	330	0.80	RL-5471-1	—	PE-53826	PE-53826-S	DO5022P-334
L27	220	1.00	RL-5471-2	—	PE-53827	PE-53827-S	DO5022P-224
L28	150	1.20	RL-5471-3	—	PE-53828	PE-53828-S	DO5022P-154
L29	100	1.47	RL-5471-4	—	PE-53829	PE-53829-S	DO5022P-104
L30	68	1.78	RL-5471-5	—	PE-53830	PE-53830-S	DO5022P-683
L35	47	2.15	RL-5473-1	—	PE-53935	PE-53935-S	—

9.1.6 Output Voltage Ripple and Transients

The output voltage of a switching power supply operating in the continuous mode will contain a sawtooth ripple voltage at the switcher frequency, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is a function of the inductor sawtooth ripple current and the ESR of the output capacitor. A typical output ripple voltage can range from approximately 0.5% to 3% of the output voltage. To obtain low ripple voltage, the ESR of the output capacitor must be low; however, caution must be exercised when using extremely low ESR capacitors because they can affect the loop stability, resulting in oscillation problems. If very low output ripple voltage is required (less than 20 mV), TI recommends a post ripple filter (see Figure 32). The inductance required is typically between 1 μH and 5 μH, with low DC resistance, to maintain good load regulation. A low ESR output filter capacitor is also required to assure good dynamic load response and ripple reduction. The ESR of this capacitor may be as low as desired, because it is out of the regulator feedback loop. Figure 22 shows a typical output ripple voltage, with and without a post ripple filter.

When observing output ripple with a scope, it is essential that a short, low inductance scope probe ground connection be used. Most scope probe manufacturers provide a special probe terminator which is soldered onto the regulator board, preferably at the output capacitor. This provides a very short scope ground, thus eliminating the problems associated with the 3 inch ground lead normally provided with the probe, and provides a much cleaner and more accurate picture of the ripple voltage waveform.

The voltage spikes are caused by the fast switching action of the output switch and the diode, the parasitic inductance of the output filter capacitor, and its associated wiring. To minimize these voltage spikes, the output capacitor must be designed for switching regulator applications, and the lead lengths must be kept very short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

When a switching regulator is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current increases or decreases, the entire sawtooth current waveform also rises and falls. The average value (or the center) of this current waveform is equal to the DC load current.

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will smoothly change from a continuous to a discontinuous mode of operation. Most switcher designs (regardless how large the inductor value is) will be forced to run discontinuous if the output is lightly loaded. This is a perfectly acceptable mode of operation.

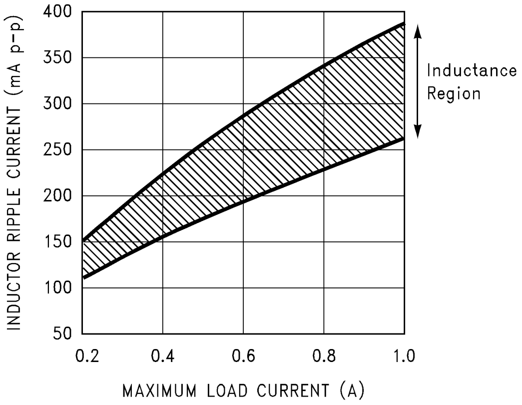


Figure 31. Peak-to-Peak Inductor Ripple Current vs Load Current

In a switching regulator design, knowing the value of the peak-to-peak inductor ripple current (ΔI_{IND}) can be useful for determining a number of other circuit parameters. Parameters such as, peak inductor or peak switch current, minimum load current before the circuit becomes discontinuous, output ripple voltage and output capacitor ESR can all be calculated from the peak-to-peak ΔI_{IND}. When the inductor nomographs shown in Figure 27 through Figure 30 are used to select an inductor value, the peak-to-peak inductor ripple current can immediately be determined. Figure 31 shows the range of (ΔI_{IND}) that can be expected for different load currents. Figure 31 also shows how the peak-to-peak inductor ripple current (ΔI_{IND}) changes from the lower border to the upper border (for a given load current) within an inductance region. The upper border represents a higher input voltage, while the lower border represents a lower input voltage (see *Inductor Selection*).

These curves are only correct for continuous mode operation, and only if the inductor selection guides are used to select the inductor value

Consider the following example:

V_{OUT} = 5 V, maximum load current of 800 mA

V_{IN} = 12 V (nominal) varying between 10 V and 14 V

The selection guide in Figure 28 shows that the vertical line for a 0.8-A load current and the horizontal line for the 12-V input voltage intersect approximately midway between the upper and lower borders of the 68-µH inductance region. A 68-µH inductor allows a peak-to-peak inductor current (ΔI_{IND}) to flow as a percentage of the maximum load current. Referring to Figure 31, follow the 0.8-A line approximately midway into the inductance region, and read the peak-to-peak inductor ripple current (ΔI_{IND}) on the left hand axis (approximately 300 $mA_{p\text{-}p}$).

As the input voltage increases to 14 V, it approaches the upper border of the inductance region, and the inductor ripple current increases. Figure 31 shows that for a load current of 0.8 A, the peak-to-peak inductor ripple current (ΔI_{IND}) is 300 mA with 12-V in, and can range from 340 mA at the upper border (14-V in) to 225 mA at the lower border (10-V in).

Once the ΔI_{IND} value is known, the following formulas can be used to calculate additional information about the switching regulator circuit.

1. Peak Inductor or peak switch current $= \left(I_{LOAD} + \frac{\Delta I_{IND}}{2}\right) = \left(0.8A + \frac{0.30}{2}\right) = 0.95A$
2. Minimum load current before the circuit becomes discontinuous $= \frac{\Delta I_{IND}}{2} = \frac{0.3}{2} = 0.15A$
3. Output Ripple Voltage = (ΔI_{IND}) × (ESR of C_{OUT})
   = 0.30 A × 0.16 Ω = 48 $mV_{p\text{-}p}$
4. ESR of C_{OUT}
   $$= \frac{\text{Output Ripple Voltage } (\Delta V_{OUT})}{\Delta I_{IND}}$$
   $$= \frac{0.048V}{0.30A} = 0.16\Omega$$

9.1.7 Open Core Inductors

Another possible source of increased output ripple voltage or unstable operation is from an open core inductor. Ferrite bobbin or stick inductors have magnetic lines of flux flowing through the air from one end of the bobbin to the other end. These magnetic lines of flux will induce a voltage into any wire or PCB copper trace that comes within the inductor's magnetic field. The strength of the magnetic field, the orientation and location of the PC copper trace to the magnetic field, and the distance between the copper trace and the inductor determine the amount of voltage generated in the copper trace. Another way of looking at this inductive coupling is to consider the PCB copper trace as one turn of a transformer (secondary) with the inductor winding as the primary. Many millivolts can be generated in a copper trace placed near an open core inductor, which can cause stability problems or high output ripple voltage problems.

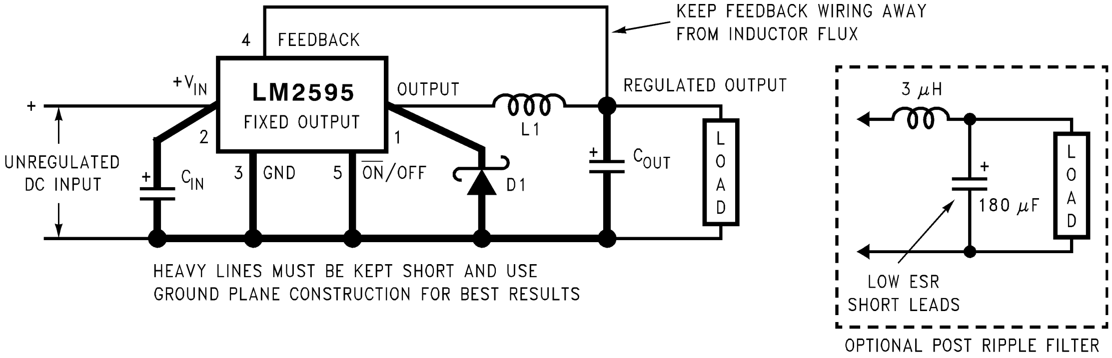
If unstable operation is seen, and an open core inductor is used, it is possible that the location of the inductor with respect to other PC traces may be the problem. To determine if this is the problem, temporarily raise the inductor away from the board by several inches and then check circuit operation. If the circuit now operates correctly, then the magnetic flux from the open core inductor is causing the problem. Substituting a closed core inductor such as a torroid or E-core will correct the problem, or re-arranging the PC layout may be necessary. Magnetic flux cutting the IC device ground trace, feedback trace, or the positive or negative traces of the output capacitor must be minimized.

Sometimes, placing a trace directly beneath a bobbin inductor will provide good results, provided it is exactly in the center of the inductor (because the induced voltages cancel themselves out). However, if the trace is off center, then problems could arise. If flux problems are present, even the direction of the inductor winding can make a difference in some circuits.

This discussion on open core inductors is not to frighten users, but to alert them on what kind of problems to watch out for. Open core bobbin or *stick* inductors are an inexpensive, simple way of making a compact, efficient inductor, and they are used by the millions in many different applications.

9.2 Typical Applications

9.2.1 Series Buck Regulator (Fixed Output)



C_{IN} – 120-µF, 50-V, aluminum electrolytic Nichicon, *PL Series*
C_{OUT} – 120-µF, 25-V aluminum electrolytic Nichicon, *PL Series*
D1 – 3-A, 40-V Schottky rectifier, 1N5822
L1 – 100-µH, L29

Figure 32. Fixed Output Voltage Versions

9.2.1.1 Design Requirements

Table 4 lists the parameters for this design example.

Table 4. Example Parameters

PARAMETER	EXAMPLE VALUE
Regulated output voltage (3.3 V, 5 V or 12 V), V_{OUT}	5 V
Maximum DC input voltage, V_{IN}(max)	12 V
Maximum load current, I_{LOAD}(max)	1 A

9.2.1.2 Detailed Design Procedure

9.2.1.2.1 Inductor Selection (L1)

1. Select the correct inductor value selection guide from Figure 27, Figure 28, or Figure 29 (output voltages of 3.3 V, 5 V, or 12 V respectively).

   Use the inductor selection guide for the 5-V version shown in Figure 28.
2. From the inductor value selection guide, identify the inductance region intersected by the maximum input voltage line and the maximum load current line. Each region is identified by an inductance value and an inductor code (LXX).

   From the inductor value selection guide shown in Figure 28, the inductance region intersected by the 12-V horizontal line and the 1-A vertical line is 68 µH, and the inductor code is L30.
3. Select an appropriate inductor from the manufacturer's part numbers listed in Table 3.

   The inductance value required is 68 µH. See row L30 of Table 3 and choose an inductor part number from any of the manufactures (in most instance, both through-hole and surface-mount inductors are available).

9.2.1.2.2 Output Capacitor Selection (C_{OUT})

1. In the majority of applications, low ESR (Equivalent Series Resistance) electrolytic capacitors between 47 µF and 330 µF and low ESR solid tantalum capacitors between 56 µF and 270 µF provide the best results. This capacitor must be placed close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 330 µF.
2. To simplify the capacitor selection procedure, see Table 5 for quick design component selection. This table contains different input voltages, output voltages, and load currents, and lists various inductors and output

capacitors that will provide the best design solutions.

From Table 5, place the 5-V output voltage section. In the load current column, choose the load current line that is closest to the current required in the application; for this example, use the 1-A line. In the maximum input voltage column, select the line that covers the input voltage required in the application; in this example, use the 15-V line. The rest of this line shows the recommended inductors and capacitors that will provide the best overall performance.

The capacitor list contains both through-hole electrolytic and surface-mount tantalum capacitors from four different capacitor manufacturers. TI recommends using both the manufacturers and the manufacturer's series listed in Table 5.

In this example, aluminum electrolytic capacitors from several different manufacturers are available with the range of ESR numbers required:

- 220-µF, 25-V Panasonic HFQ Series
- 220-µF, 25-V Nichicon PL Series

3. The capacitor voltage rating for electrolytic capacitors must be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are required to satisfy the low ESR requirements for low output ripple voltage.

   For a 5-V output, a capacitor voltage rating at least 7.5 V or more is required. But, in this example, even a low ESR, switching grade, 220-µF, 10-V aluminum electrolytic capacitor would exhibit approximately 225 mΩ of ESR (see Figure 24 for the ESR versus voltage rating). This amount of ESR would result in relatively high output ripple voltage. To reduce the ripple to 1% of the output voltage, or less, a capacitor with a higher voltage rating (lower ESR) must be selected. A 16-V or 25-V capacitor will reduce the ripple voltage by approximately half.

9.2.1.2.3 Catch Diode Selection (D1)

1. The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode must have a current rating equal to the maximum current limit of the LM2595. The most stressful condition for this diode is an overload or shorted output condition.

   See Table 2. In this example, a 3-A, 20-V, 1N5820 Schottky diode will provide the best performance, and will not be overstressed even for a shorted output.
2. The reverse voltage rating of the diode must be at least 1.25 times the maximum input voltage.
3. This diode must be fast (short reverse recovery time) and must be placed close to the LM2595 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and must be the first choice, especially in low output voltage applications. Ultra-fast recovery, or high-efficiency rectifiers also provide good results. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N5400 series must not be used because they are too slow.

9.2.1.2.4 Input Capacitor (C_{IN})

A low ESR aluminum or tantalum bypass capacitor is required between the input pin and ground pin to prevent large voltage transients from appearing at the input. This capacitor must be placed close to the IC using short leads. In addition, the RMS current rating of the input capacitor must be selected to be at least ½ the DC load current. The capacitor manufacturer's data sheet must be checked to assure that this current rating is not exceeded. Figure 23 shows typical RMS current ratings for several different aluminum electrolytic capacitor values.

The important parameters for the input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 12 V, an aluminum electrolytic capacitor with a voltage rating greater than 18 V (1.5 × V_{IN}) is necessary. The next higher capacitor voltage rating is 25 V.

For an aluminum electrolytic, the capacitor voltage rating must be approximately 1.5 times the maximum input voltage. Exercise caution if solid tantalum capacitors are used (see *Input Capacitor (C_{IN})* on input capacitor). The tantalum capacitor voltage rating must be 2 times the maximum input voltage and TI recommends that they be surge current tested by the manufacturer.

The RMS current rating requirement for the input capacitor in a buck regulator is approximately ½ the DC load current. In this example, with a 1-A load, a capacitor with a RMS current rating of at least 500 mA is required. Figure 23 can be used to select an appropriate input capacitor. From the curves, place the 25-V line and note which capacitor values have RMS current ratings greater than 500 mA. Either a 180-µF or 220-µF, 25-V capacitor could be used.

Use caution when using ceramic capacitors for input bypassing, because it may cause severe ringing at the V_{IN} pin.

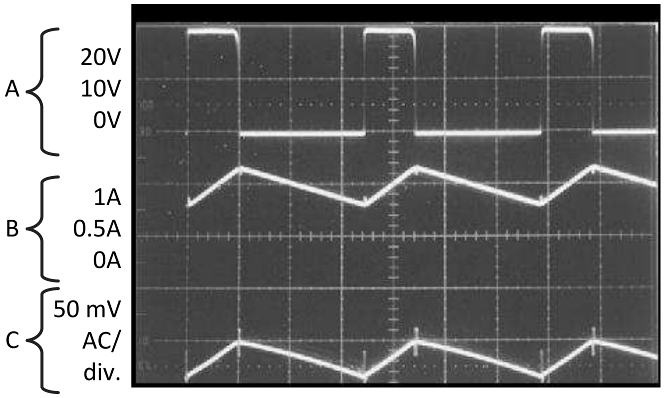
For a through-hole design, a 220-µF, 25-V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. Other types or other manufacturers' capacitors can be used provided the RMS ripple current ratings are adequate.

For surface-mount designs, solid tantalum capacitors can be used, but exercise caution with regard to the capacitor surge current rating (see *Input Capacitor (C_{IN})* on input capacitors). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

Table 5. LM2595 Fixed Voltage Quick Design Component Selection Table

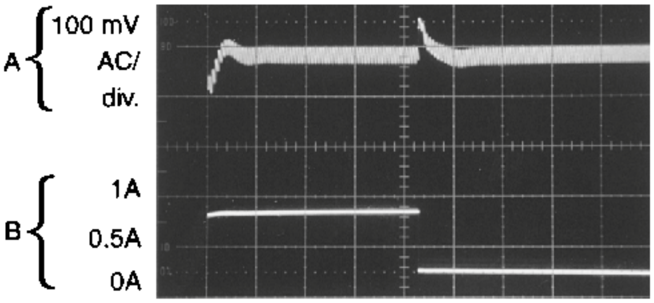
CONDITIONS			INDUCTOR		OUTPUT CAPACITOR			
					THROUGH-HOLE ELECTROLYTIC		SURFACE-MOUNT TANTALUM	
OUTPUT VOLTAGE (V)	LOAD CURRENT (A)	MAX INPUT VOLTAGE (V)	INDUCTANCE (µH)	INDUCTOR (#)	PANASONIC HFQ SERIES (µF/V)	NICHICON PL SERIES (µF/V)	AVX TPS SERIES (µF/V)	SPRAGUE 595D SERIES (µF/V)
3.3	1	5	22	L24	330/16	330/16	220/10	330/10
		7	33	L23	270/25	270/25	220/10	270/10
		10	47	L31	220/25	220/35	220/10	220/10
		40	68	L30	180/35	220/35	220/10	180/10
		6	47	L13	220/25	220/16	220/10	220/10
	0.5	10	68	L21	150/35	150/25	100/16	150/16
		40	100	L20	150/35	82/35	100/16	100/20
5	1	8	33	L28	330/16	330/16	220/10	270/10
		10	47	L31	220/25	220/25	220/10	220/10
		15	68	L30	180/35	180/35	220/10	150/16
		40	100	L29	180/35	120/35	100/16	120/16
		9	68	L21	180/16	180/16	220/10	150/16
	0.5	20	150	L19	120/25	1200/25	100/16	100/20
		40	150	L19	100/25	100/25	68/20	68/25
12	1	15	47	L31	220/25	220/25	68/20	120/20
		18	68	L30	180/35	120/25	68/20	120/20
		30	150	L36	82/25	82/25	68/20	100/20
		40	220	L35	82/25	82/25	68/20	68/25
		15	68	L21	180/25	180/25	68/20	120/20
	0.5	20	150	L19	82/25	82/25	68/20	100/20
		40	330	L26	56/25	56/25	68/20	68/25

9.2.1.3 Application Curves



V_{IN} = 20 V, V_{OUT} = 5 V, I_{LOAD} = 1 A
L = 68 μH, C_{OUT} = 120 μF, C_{OUT} ESR = 100 mΩ
A: Output pin voltage, 10 V/div.
B: Inductor current, 0.5 A/div.
C: Output ripple voltage, 50 mV/div.
Horizontal time base: 2 μs/div.

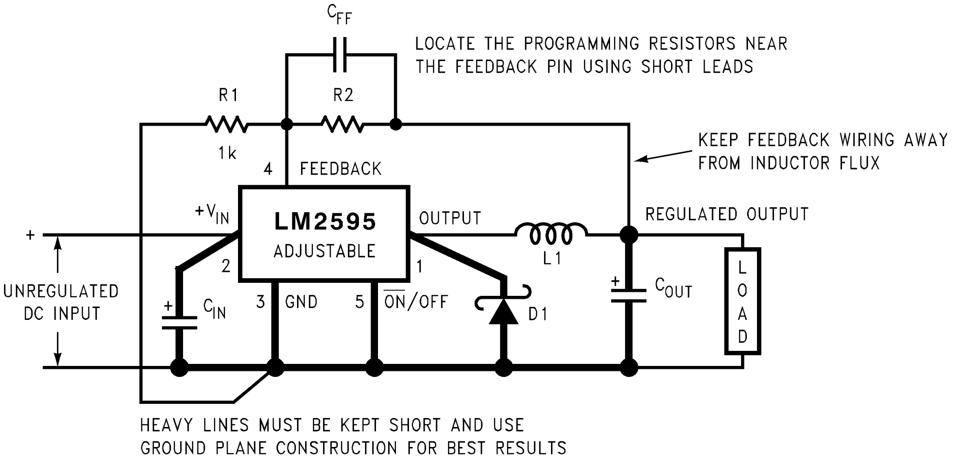
Figure 33. Continuous Mode Switching Waveforms



V_{IN} = 20 V, V_{OUT} = 5 V, I_{LOAD} = 250 mA to 750 mA
L = 68 μH, C_{OUT} = 120 μF, C_{OUT} ESR = 100 mΩ
A: Output voltage, 100 mV/div. (AC)
B: 250-mA to 750-mA load pulse
Horizontal time base: 100 μs/div.

Figure 34. Load Transient Response for Continuous Mode

9.2.2 Series Buck Regulator (Adjustable Output)



LOCATE THE PROGRAMMING RESISTORS NEAR THE FEEDBACK PIN USING SHORT LEADS

KEEP FEEDBACK WIRING AWAY FROM INDUCTOR FLUX

HEAVY LINES MUST BE KEPT SHORT AND USE GROUND PLANE CONSTRUCTION FOR BEST RESULTS

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

Select R_1 to be approximately 1 kΩ, use a 1% resistor for best stability.

C_{IN} – 120-μF, 50-V aluminum electrolytic Nichicon, *PL Series*
C_{OUT} – 120-μF, 25-V aluminum electrolytic Nichicon, *PL Series*
D1 – 3-A, 40-V Schottky rectifier, 1N5822
L1 – 100-μH, L29
R_1 – 1-kΩ, 1%
C_{FF} – See *Feedforward Capacitor (C_{FF})*

Figure 35. Adjustable Output Voltage Versions

9.2.2.1 Design Requirements

Table 6 lists the parameters for this design example.

Table 6. Example Parameters

PARAMETER	EXAMPLE VALUE
Regulated output voltage, V_{OUT}	20 V
Maximum input voltage, V_{IN}(max)	28 V
Maximum load current, I_{LOAD}(max)	1 A
Switching frequency, F	Fixed at a nominal 150 kHz

9.2.2.2 Detailed Design Procedure

9.2.2.2.1 Programming Output Voltage

Select the R_1 and R_2.

Use Equation 1 to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23\text{V} \tag{1}$$

Select a value for R_1 between 240 Ω and 1.5 kΩ in Equation 2. The lower resistor values minimize noise pickup in the sensitive feedback pin (for the lowest temperature coefficient and the best stability with time, use 1% metal film resistors).

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) \tag{2}$$

Select R_1 to be 1 kΩ, 1%. Solve for R_2 in Equation 3.

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1\text{k}\left(\frac{20\text{V}}{1.23\text{V}} - 1\right) \tag{3}$$

R_2 = 1k (16.26 − 1) = 15.26k, closest 1% value is 15.4 kΩ.

R_2 = 15.4 kΩ.

9.2.2.2.2 Inductor Selection (L1)

1. Calculate the inductor Volt • microsecond constant E • T (V • µs) with Equation 4.

$$E \bullet T = (V_{IN} - V_{OUT} - V_{SAT}) \bullet \frac{V_{OUT} + V_D}{V_{IN} - V_{SAT} + V_D} \bullet \frac{1000}{150\text{ kHz}} (\text{V} \bullet \mu\text{s})$$

   where
   - V_{SAT} = internal switch saturation voltage = 1 V
   - and V_D = diode forward voltage drop = 0.5 V (4)

   Calculate the inductor Volt • microsecond constant (E • T) with Equation 5.

$$E \bullet T = (28 - 20 - 1) \bullet \frac{20 + 0.5}{28 - 1 + 0.5} \bullet \frac{1000}{150} (\text{V} \bullet \mu\text{s})$$
$$E \bullet T = (7) \bullet \frac{20.5}{27.5} \bullet 6.67\ (\text{V} \bullet \mu\text{s}) = 34.8\ (\text{V} \bullet \mu\text{s}) \tag{5}$$

2. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the Inductor Value Selection Guide shown in Figure 30.

   E • T = 34.8 (V • µs)
3. On the horizontal axis, select the maximum load current.

   I_{LOAD}(max) = 1 A
4. Identify the inductance region intersected by the E • T value and the Maximum Load Current value. Each region is identified by an inductance value and an inductor code (LXX).

   From the inductor value selection guide shown in Figure 30, the inductance region intersected by the 35 (V • µs) horizontal line and the 1-A vertical line is 100 µH, and the inductor code is L29.
5. Select an appropriate inductor from the manufacturers' part numbers listed in Table 3.

   From the table in Table 3, place line L29, and select an inductor part number from the list of manufacturers' part numbers.

9.2.2.2.3 Output Capacitor Selection (C_{OUT})

1. In the majority of applications, low ESR electrolytic or solid tantalum capacitors between 47 µF and 330 µF provide the best results. This capacitor must be placed close to the IC using short capacitor leads and short copper traces. Do not use capacitors larger than 330 µF. See section on C_{OUT} in *Output Capacitor Selection (C_{OUT})*.
2. To simplify the capacitor selection procedure, refer to the quick design table shown in Table 7. This table contains different output voltages, and lists various output capacitors that will provide the best design solutions.

   From the quick design table shown in Table 7, place the output voltage column. From that column, place the output voltage closest to the output voltage in the application. In this example, select the 24-V line. Under the output capacitor section, select a capacitor from the list of through-hole electrolytic or surface-mount tantalum types from four different capacitor manufacturers. TI recommends using both the manufacturers and the manufacturers' series listed in the table.

   In this example, through-hole aluminum electrolytic capacitors from several different manufacturers are available:
   - 82-µF, 35-V Panasonic HFQ Series
   - 82-µF, 35-V Nichicon PL Series
3. The capacitor voltage rating must be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are required to satisfy the low ESR requirements needed for low output ripple voltage.

   For a 20-V output, a capacitor rating of at least 30 V or more is required. In this example, either a 35-V or 50-V capacitor would work. A 35-V rating was chosen, although a 50-V rating could also be used if a lower output ripple voltage is required.

   Other manufacturers or other types of capacitors may also be used, provided the capacitor specifications (especially the 100-kHz ESR) closely match the types listed in Table 7. Refer to the capacitor manufacturers' data sheet for this information.

9.2.2.2.4 Feedforward Capacitor (C_{FF})

For output voltages greater than approximately 10 V, an additional capacitor is required. The compensation capacitor is typically between 50 pF and 10 nF, and is wired in parallel with the output voltage setting resistor, R_2. It provides additional stability for high output voltages, low input or output voltages, or very low ESR output capacitors, such as solid tantalum capacitors. Use Equation 6 to calculate C_{FF}.

$$C_{FF} = \frac{1}{31 \times 10^3 \times R_2} \tag{6}$$

This capacitor type can be ceramic, plastic, silver mica, and so forth (because of the unstable characteristics of ceramic capacitors made with Z5U material, they are not recommended).

The table shown in Table 7 contains feedforward capacitor values for various output voltages. In this example, a 1-nF capacitor is required.

9.2.2.2.5 Catch Diode Selection (D1)

1. The catch diode current rating must be at least 1.3 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode must have a current rating equal to the maximum current limit of the LM2595. The most stressful condition for this diode is an overload or shorted output condition. See Table 2.
2. The reverse voltage rating of the diode must be at least 1.25 times the maximum input voltage. Schottky diodes provide the best performance, and in this example a 3-A, 40-V, 1N5822 Schottky diode is a good choice.
3. This diode must be fast (short reverse recovery time) and must be placed close to the LM2595 using short leads and short printed circuit traces. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and must be the first choice, especially in low output voltage applications. Ultra-fast recovery or high-efficiency rectifiers are also good choices, but some types with an abrupt turnoff characteristic may cause instability or EMI problems. Ultra-fast recovery diodes typically have reverse recovery times of 50 ns or less. Rectifiers such as the 1N4001 series must not be used because they are too slow. The 3-A diode rating is more than adequate and will not be overstressed even for a shorted output.

9.2.2.2.6 Input Capacitor (C_{IN})

A low ESR aluminum or tantalum bypass capacitor is required between the input pin and ground to prevent large voltage transients from appearing at the input. In addition, the RMS current rating of the input capacitor must be selected to be at least ½ the DC load current. The capacitor manufacturer's data sheet must be checked to assure that this current rating is not exceeded. Figure 23 shows typical RMS current ratings for several different aluminum electrolytic capacitor values.

The important parameters for the input capacitor are the input voltage rating and the RMS current rating. With a nominal input voltage of 28 V, an aluminum electrolytic aluminum electrolytic capacitor with a voltage rating greater than 42 V (1.5 × V_{IN}) is required. Because the next higher capacitor voltage rating is 50 V, a 50-V capacitor must be used. The capacitor voltage rating of (1.5 × V_{IN}) is a conservative guideline, and can be modified somewhat if desired.

This capacitor must be placed close to the IC using short leads and the voltage rating must be approximately 1.5 times the maximum input voltage.

The RMS current rating requirement for the input capacitor of a buck regulator is approximately ½ the DC load current. In this example, with a 1-A load, a capacitor with a RMS current rating of at least 500 mA is required.

Figure 23 can be used to select an appropriate input capacitor. From the curves, place the 50-V line and note which capacitor values have RMS current ratings greater than 500 mA. Either a 100-µF or 120-µF, 50-V capacitor could be used.

If solid tantalum input capacitors are used, TI recommends that they be surge current tested by the manufacturer. See caution when using a high dielectric constant ceramic capacitor for input bypassing, because it may cause severe ringing at the V_{IN} pin.

For a through-hole design, a 120-µF, 50-V electrolytic capacitor (Panasonic HFQ series or Nichicon PL series or equivalent) would be adequate. Other types or other manufacturers' capacitors can be used provided the RMS ripple current ratings are adequate.

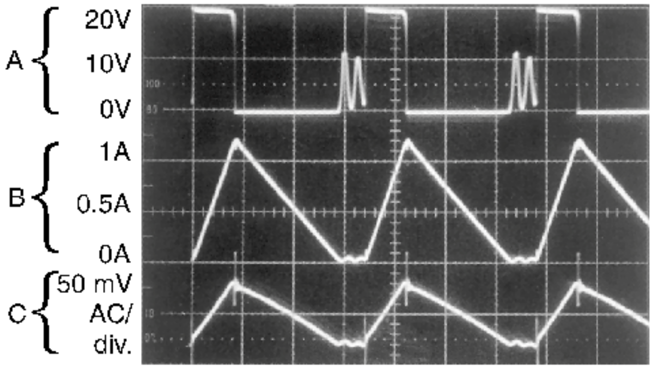
For surface-mount designs, solid tantalum capacitors can be used, but caution must be exercised with regard to the capacitor surge current rating (see *Input Capacitor (C_{IN})* or input capacitors in this data sheet). The TPS series available from AVX, and the 593D series from Sprague are both surge current tested.

To further simplify the buck regulator design procedure, TI is making available computer design software to be used with the SIMPLE SWITCHER line of switching regulators.

Table 7. Output Capacitor and Feedforward Capacitor Selection Table

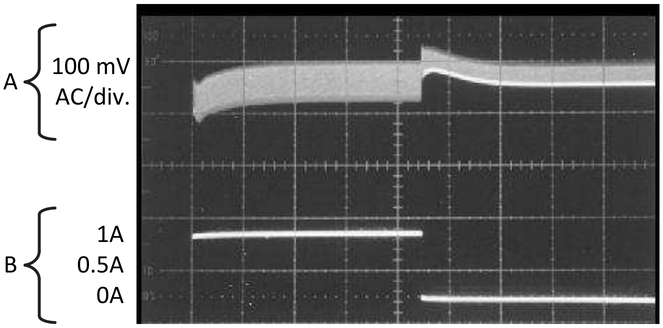
OUTPUT VOLTAGE (V)	THROUGH-HOLE ELECTROLYTIC OUTPUT CAPACITOR			SURFACE-MOUNT TANTALUM OUTPUT CAPACITOR		
	PANASONIC HFQ SERIES (µF/V)	NICHICON PL SERIES (µF/V)	FEEDFORWARD CAPACITOR	AVX TPS SERIES (µF/V)	SPRAGUE 595D SERIES (µF/V)	FEEDFORWARD CAPACITOR
1.2	330/50	330/50	0	330/6.3	330/6.3	0
4	220/25	220/25	4.7 nF	220/10	220/10	4.7 nF
6	220/25	220/25	3.3 nF	220/10	220/10	3.3 nF
9	180/25	180/25	1.5 nF	100/16	180/16	1.5 nF
12	120/25	120/25	1.5 nF	68/20	120/20	1.5 nF
15	120/25	120/25	1.5 nF	68/20	100/20	1.5 nF
24	82/35	82/35	1 nF	33/25	33/35	220 pF
28	82/50	82/50	1 nF	10/35	33/35	220 pF

9.2.2.3 Application Curves



V_{IN} = 20 V, V_{OUT} = 5 V, I_{LOAD} = 600 mA
L = 22 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ
A: Output pin voltage, 10 V/div.
B: Inductor current 0.5 A/div.
C: Output ripple voltage, 50 mV/div.
Horizontal time base: 2 µs/div.

Figure 36. Discontinuous Mode Switching Waveforms



V_{IN} = 20 V, V_{OUT} = 5 V, I_{LOAD} = 250 mA to 750 mA
L = 22 μH, C_{OUT} = 220 μF, C_{OUT} ESR = 50 mΩ
A: Output voltage, 100 mV/div. (AC)
B: 250-mA to 750-mA load pulse
Horizontal time base: 200 µs/div.

Figure 37. Load Transient Response for Discontinuous Mode

10 Power Supply Recommendations

The LM2595 is designed to operate from an input voltage supply up to 40 V. This input supply must be well regulated and able to withstand maximum input current and maintain a stable voltage.

11 Layout

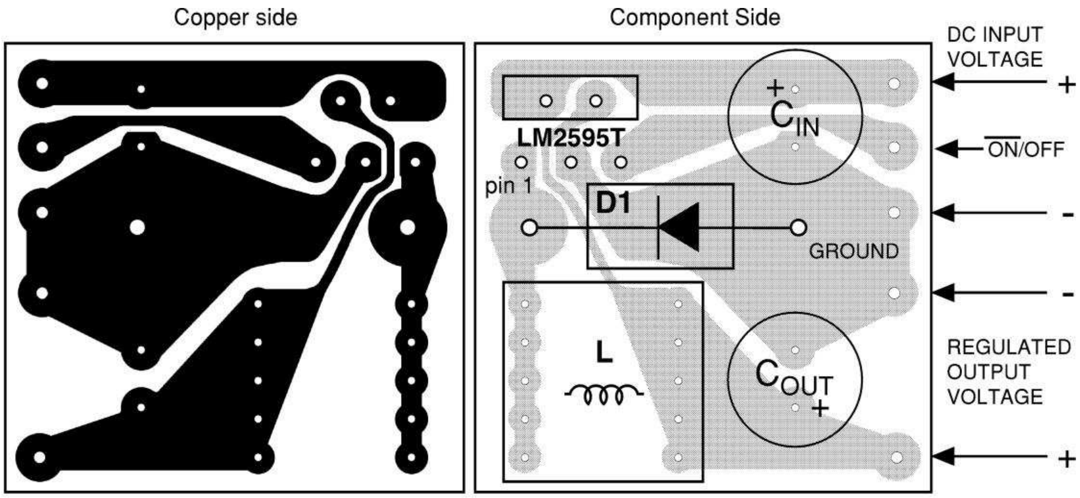
11.1 Layout Guidelines

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance can generate voltage transients which can cause problems. For minimal inductance and ground loops, the wires indicated by heavy lines must be wide printed circuit traces and must be kept as short as possible. For best results, external components must be placed as close to the switcher IC as possible using ground plane construction or single point grounding.

If open core inductors are used, take special care regarding the location and positioning of this type of inductor. Allowing the inductor flux to intersect sensitive feedback, IC groundpath and C_{OUT} wiring can cause problems.

When using the adjustable version, take special care regarding the location of the feedback resistors and the associated wiring. Physically place both resistors near the IC, and route the wiring away from the inductor, especially an open core type of inductor (see *Open Core Inductors* for more information).

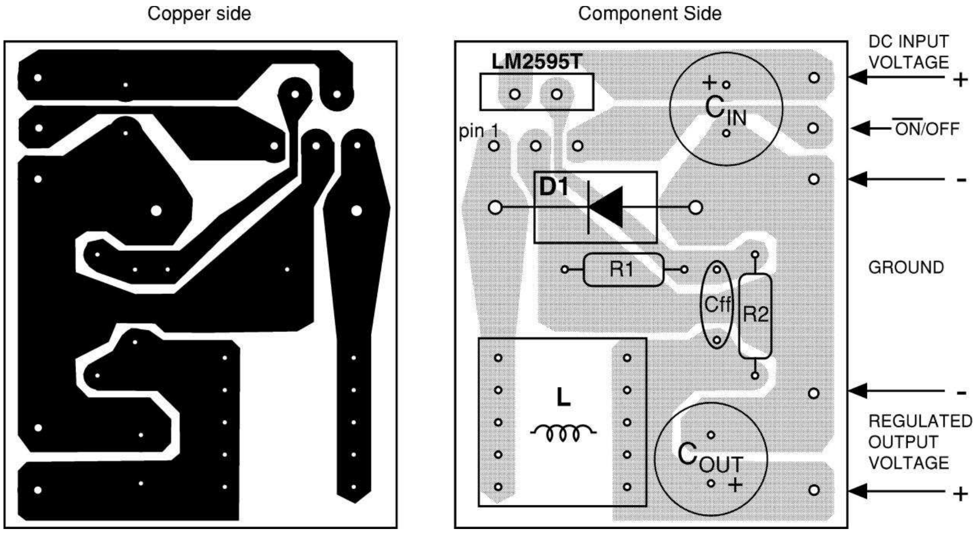
11.2 Layout Examples



C_{IN} – 150-µF, 50-V aluminium electrolytic Nichicon, *PL series*
C_{OUT} – 120-µF, 25-V aluminium electrolytic Nichicon, *PL series*
D1 – 3-A, 40-V Schottky rectifier, 1N5822
L1 – 68-µH, L30, Schottky, through-hole

Figure 38. Typical Through-Hole PCB Layout, Fixed Output (1X Size)

Layout Examples (continued)



C_{IN} – 150-µF, 50-V aluminium electrolytic Nichicon, *PL series*
C_{OUT} – 120-µF, 25-V aluminium electrolytic Nichicon, *PL series*
D1 – 3-A, 40-V Schottky rectifier, 1N5822
L1 – 68-µH, L30, Schottky through-hole
R1 – 1-kΩ, 1%
R2 – Use formula in *Detailed Design Procedure*
C_{FF} – See Table 7

Figure 39. Typical Through-Hole PCB Layout, Adjustable Output (1X Size)

11.3 Thermal Considerations

The LM2595 is available in two packages: a 5-pin TO-220 (NDH) and a 5-pin surface-mount TO-263 (KTT).

The TO-220 package can be used without a heat sink for ambient temperatures up to approximately 50°C (depending on the output voltage and load current). Figure 40 shows the LM2595T junction temperature rises above ambient temperature for different input and output voltages. The data tor these curves was taken with the LM2595T (TO-220 package) operating as a switching regulator in an ambient temperature of 25°C (still air). These temperature rise numbers are all approximate and there are many factors that can affect these temperatures. Higher ambient temperatures require some heat sinking, either to the PCB or a small external heat sink.

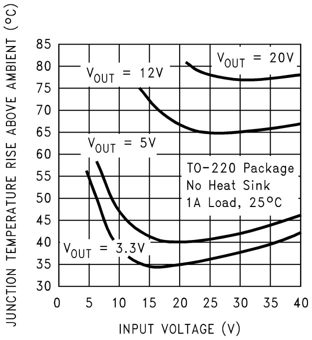
The TO-263 surface-mount package tab is designed to be soldered to the copper on a printed-circuit board (PCB). The copper and the board are the heat sink for this package and the other heat producing components, such as the catch diode and inductor. The PCB copper area that the package is soldered to must be at least 0.4 in^2, and ideally must have 2 or more square inches of 2 oz (0.0028 in) copper. Additional copper area improves the thermal characteristics, but with copper areas greater than approximately 3 in^2, only small improvements in heat dissipation are realized. If further thermal improvements are required, TI recommends using double sided or multilayer PCB with large copper areas.

Figure 41 show the LM2595S (TO-263 package) junction temperature rise above ambient temperature with a 1-A load for various input and output voltages. This data was taken with the circuit operating as a buck switching regulator with all components mounted on a PCB to simulate the junction temperature under actual operating conditions. This curve can be used for a quick check for the approximate junction temperature for various conditions, but be aware that there are many factors that can affect the junction temperature.

For the best thermal performance, wide copper traces and generous amounts of PCB copper must be used in the board layout. (One exception to this is the output (switch) pin, which must not have large areas of copper.) Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and moving air lowers the thermal resistance even further.

Thermal Considerations (continued)

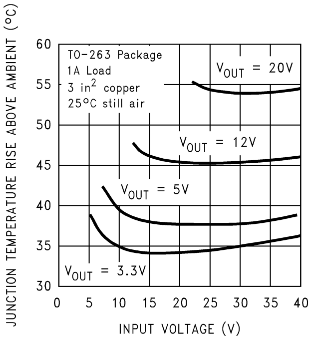
Package thermal resistance and junction temperature rise numbers are all approximate, and there are many factors that will affect these numbers. Some of these factors include board size, shape, thickness, position, location, and even board temperature. Other factors are, trace width, total printed-circuit copper area, copper thickness, single- or double-sided multilayer board, and the amount of solder on the board. The effectiveness of the PCB to dissipate heat also depends on the size, quantity, and spacing of other components on the board, as well as whether the surrounding air is still or moving. Furthermore, some of these components such as the catch diode will add heat to the PCB and the heat can vary as the input voltage changes. For the inductor, depending on the physical size, type of core material, and the DC resistance, it could either act as a heat sink taking heat away from the board, or it could add heat to the board.



CIRCUIT DATA FOR TEMPERATURE RISE CURVE
TO-220 PACKAGE (NDH)

Capacitors	Through-hole electrolytic
Inductor	Through-hole, 68-µH Schottky
Diode	Through-hole, 3-A, 40-V Schottky
PCB	3 square inches, single-sided 2-oz copper (0.0028″)

Figure 40. Junction Temperature Rise, TO-220



CIRCUIT DATA FOR TEMPERATURE RISE CURVE
TO-263 PACKAGE (KTT)

Capacitors	Surface-mount tantalum, molded *D* size
Inductor	Surface-mount, 68-µH, Schottky
Diode	Surface-mount, 3-A, 40-V, Schottky
PCB	3 square inches, single-sided 2-oz copper (0.0028″)

Figure 41. Junction Temperature Rise, TO-263

12 デバイスおよびドキュメントのサポート

12.1 コミュニティ・リソース

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12.4 Glossary

SLYZ022 — *TI Glossary*.

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

13 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。これらの情報は、指定のデバイスに対して提供されている最新のデータです。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 Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM2595S-12/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	RoHS-Exempt & Green	SN	Level-3-245C-168 HR	-40 to 125	LM2595S -12 P+	Samples
LM2595S-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	RoHS-Exempt & Green	SN	Level-3-245C-168 HR		LM2595S -3.3 P+	Samples
LM2595S-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	RoHS-Exempt & Green	SN	Level-3-245C-168 HR		LM2595S -5.0 P+	Samples
LM2595S-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	45	RoHS-Exempt & Green	SN	Level-3-245C-168 HR		LM2595S -ADJ P+	Samples
LM2595SX-12/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	RoHS-Exempt & Green	SN	Level-3-245C-168 HR	-40 to 125	LM2595S -12 P+	Samples
LM2595SX-3.3/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	RoHS-Exempt & Green	SN	Level-3-245C-168 HR		LM2595S -3.3 P+	Samples
LM2595SX-5.0/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	RoHS-Exempt & Green	SN	Level-3-245C-168 HR		LM2595S -5.0 P+	Samples
LM2595SX-ADJ/NOPB	ACTIVE	DDPAK/ TO-263	KTT	5	500	RoHS-Exempt & Green	SN	Level-3-245C-168 HR		LM2595S -ADJ P+	Samples
LM2595T-12/NOPB	ACTIVE	TO-220	NDH	5	45	RoHS & Green	SN	Level-1-NA-UNLIM	-40 to 125	LM2595T -12 P+	Samples
LM2595T-3.3/NOPB	ACTIVE	TO-220	NDH	5	45	RoHS & Green	SN	Level-1-NA-UNLIM		LM2595T -3.3 P+	Samples
LM2595T-5.0/NOPB	ACTIVE	TO-220	NDH	5	45	RoHS & Green	SN	Level-1-NA-UNLIM		LM2595T -5.0 P+	Samples
LM2595T-ADJ/NOPB	ACTIVE	TO-220	NDH	5	45	RoHS & Green	SN	Level-1-NA-UNLIM		LM2595T -ADJ P+	Samples

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

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

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

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

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

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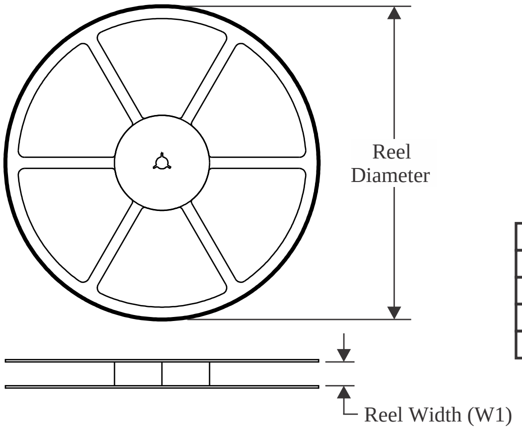
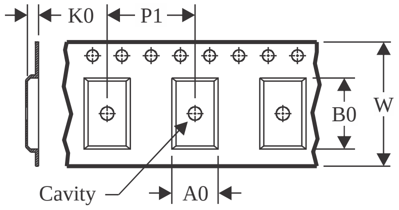
TAPE AND REEL INFORMATION

REEL DIMENSIONS

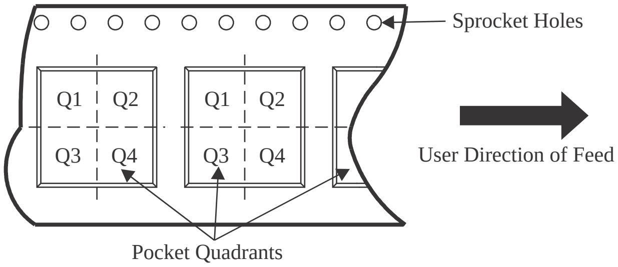


TAPE DIMENSIONS



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

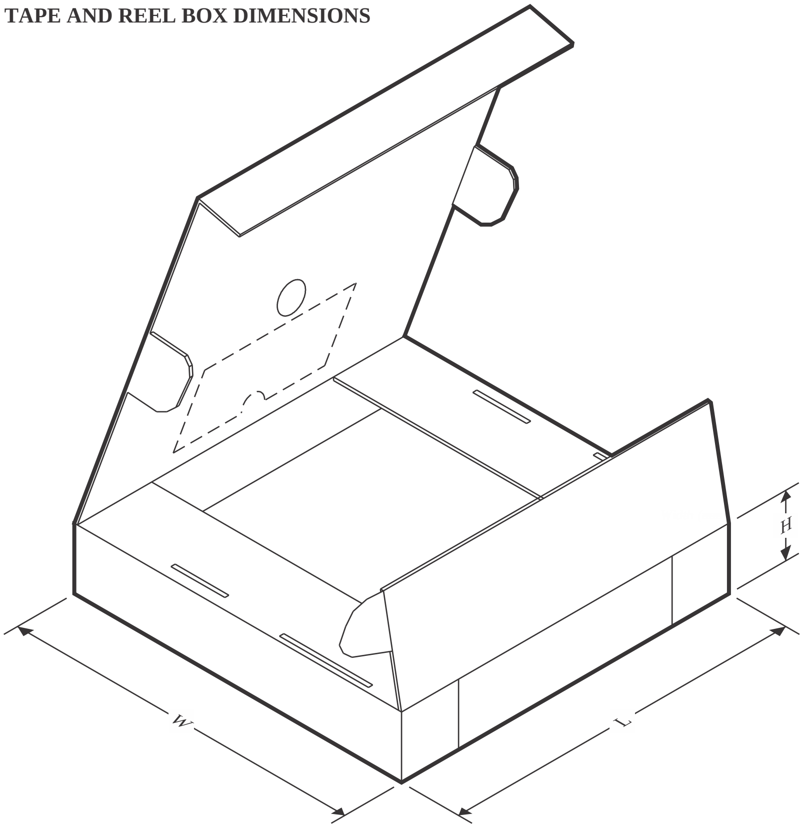
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM2595SX-12/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2595SX-3.3/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2595SX-5.0/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2
LM2595SX-ADJ/NOPB	DDPAK/ TO-263	KTT	5	500	330.0	24.4	10.75	14.85	5.0	16.0	24.0	Q2

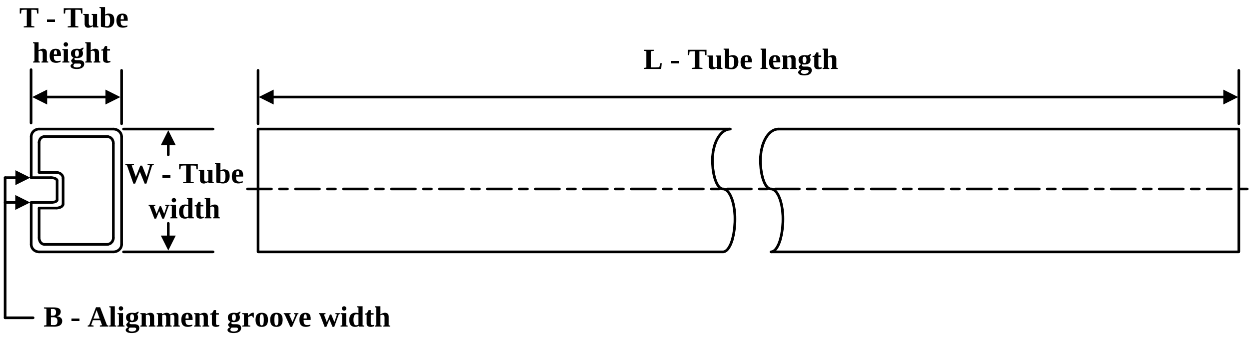
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM2595SX-12/NOPB	DDPAK/TO-263	KTT	5	500	356.0	356.0	45.0
LM2595SX-3.3/NOPB	DDPAK/TO-263	KTT	5	500	356.0	356.0	45.0
LM2595SX-5.0/NOPB	DDPAK/TO-263	KTT	5	500	356.0	356.0	45.0
LM2595SX-ADJ/NOPB	DDPAK/TO-263	KTT	5	500	356.0	356.0	45.0

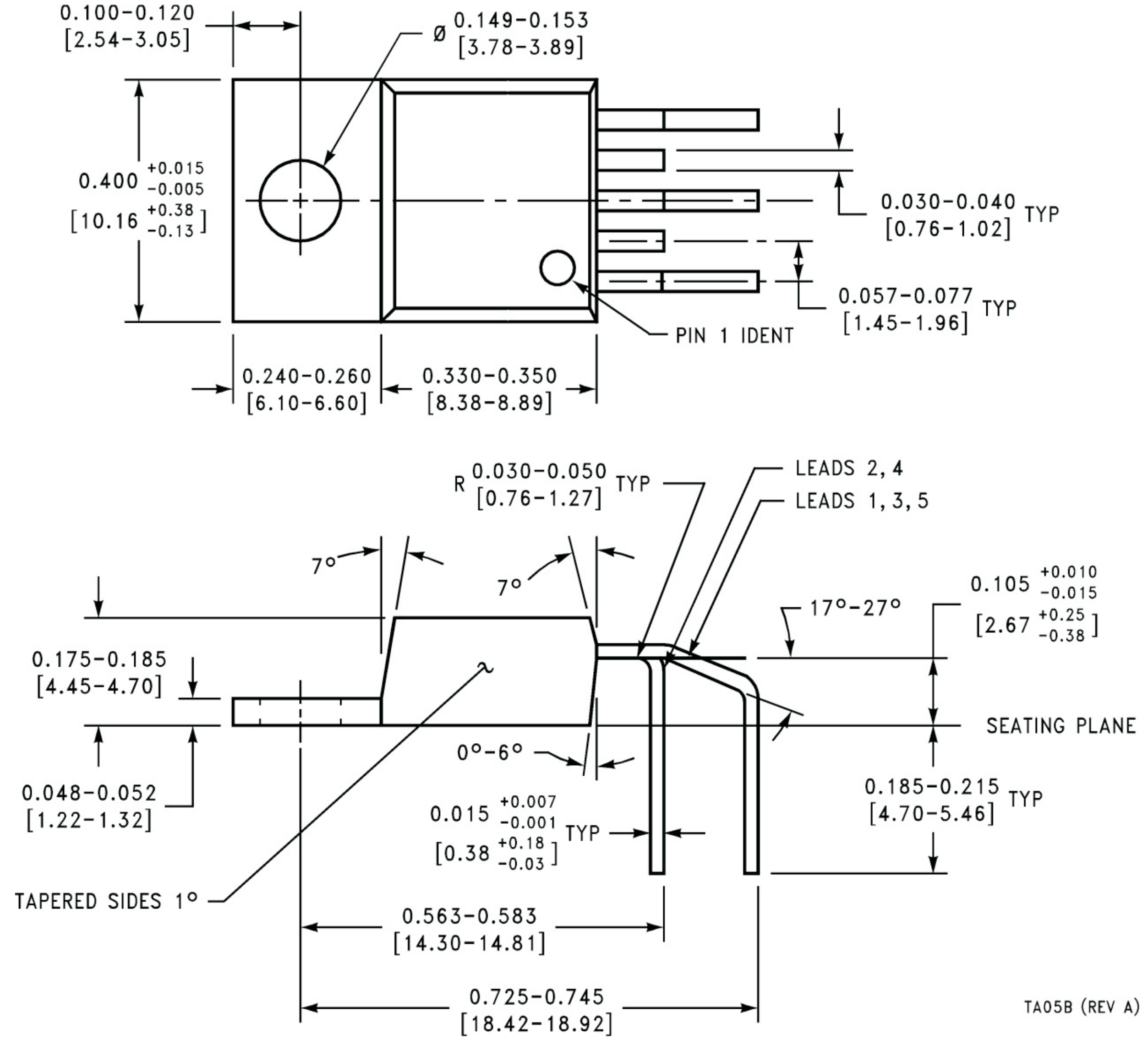
TUBE



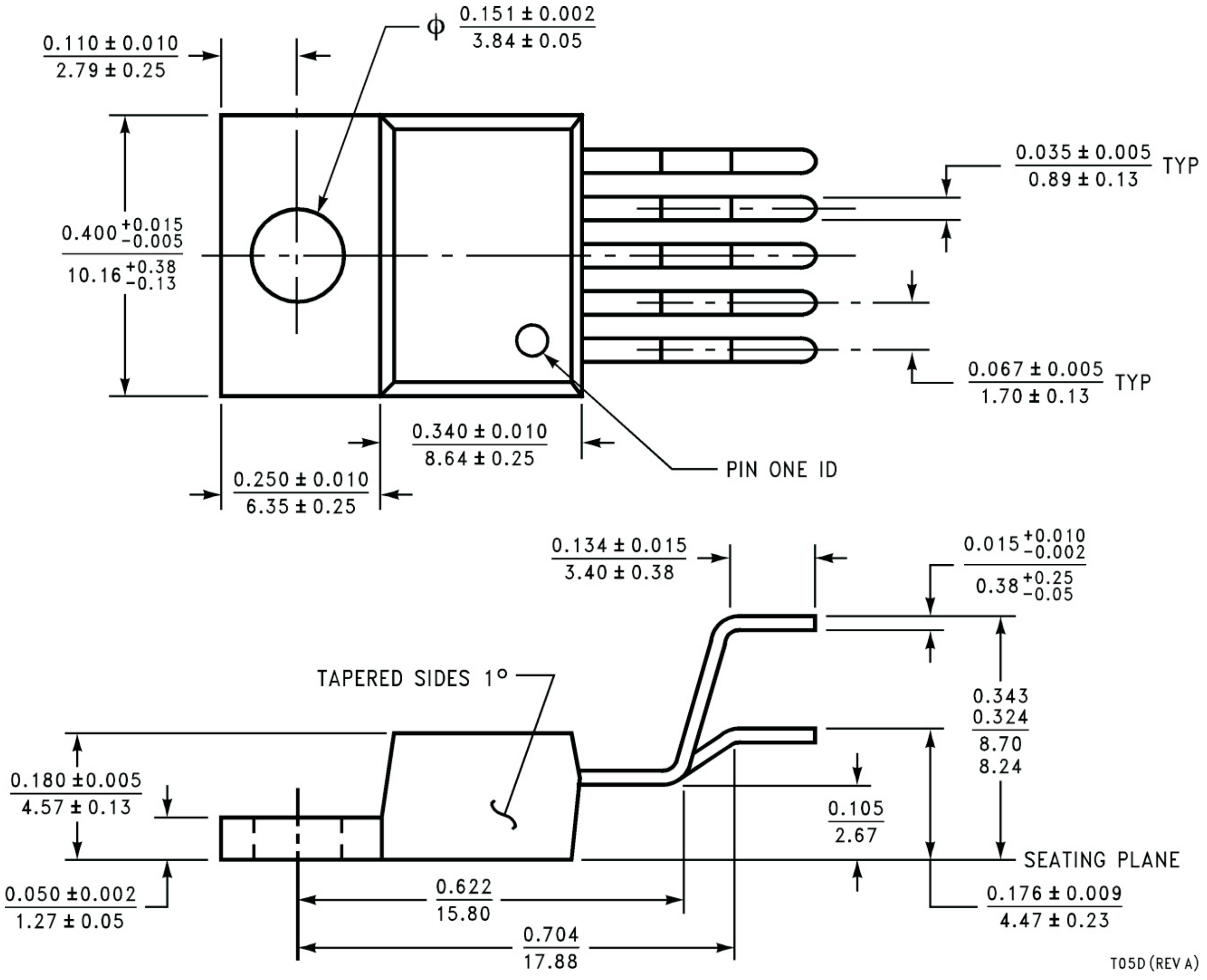
*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (µm)	B (mm)
LM2595S-12/NOPB	KTT	TO-263	5	45	502	25	8204.2	9.19
LM2595S-3.3/NOPB	KTT	TO-263	5	45	502	25	8204.2	9.19
LM2595S-5.0/NOPB	KTT	TO-263	5	45	502	25	8204.2	9.19
LM2595S-ADJ/NOPB	KTT	TO-263	5	45	502	25	8204.2	9.19
LM2595T-12/NOPB	NDH	TO-220	5	45	502	30	30048.2	10.74
LM2595T-3.3/NOPB	NDH	TO-220	5	45	502	30	30048.2	10.74
LM2595T-5.0/NOPB	NDH	TO-220	5	45	502	30	30048.2	10.74
LM2595T-ADJ/NOPB	NDH	TO-220	5	45	502	30	30048.2	10.74

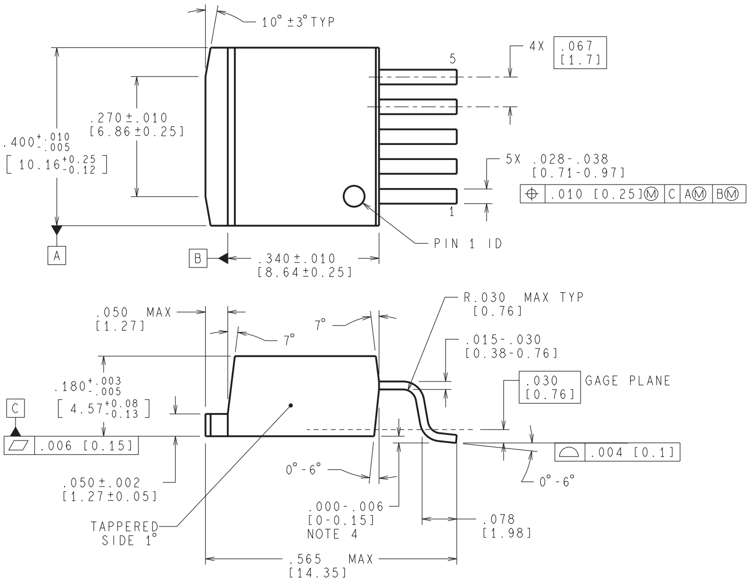
NEB0005B

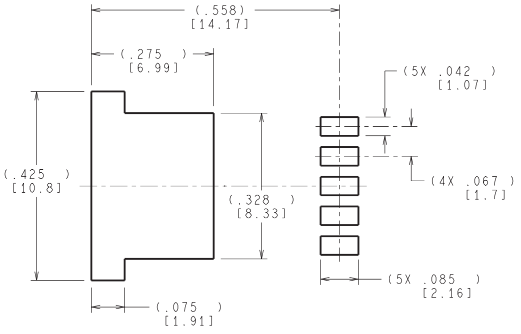

0.100-0.120
[2.54-3.05]
Ø 0.149-0.153
[3.78-3.89]
0.400 +0.015 -0.005
[10.16 +0.38 -0.13]
0.030-0.040 TYP
[0.76-1.02]
0.057-0.077 TYP
[1.45-1.96]
PIN 1 IDENT
0.240-0.260
[6.10-6.60]
0.330-0.350
[8.38-8.89]
R 0.030-0.050 TYP
[0.76-1.27]
LEADS 2, 4
LEADS 1, 3, 5
7°
7°
0.105 +0.010 -0.015
[2.67 +0.25 -0.38]
17°-27°
0.175-0.185
[4.45-4.70]
SEATING PLANE
0°-6°
0.048-0.052
[1.22-1.32]
0.185-0.215 TYP
[4.70-5.46]
0.015 +0.007 -0.001 TYP
[0.38 +0.18 -0.03]
TAPERED SIDES 1°
0.563-0.583
[14.30-14.81]
0.725-0.745
[18.42-18.92]
TA05B (REV A)

NDH0005D

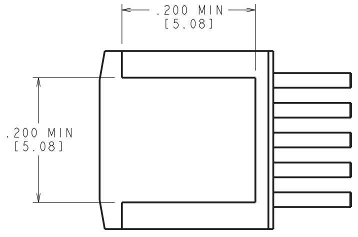

0.110 ± 0.010
2.79 ± 0.25
ϕ 0.151 ± 0.002
3.84 ± 0.05
0.035 ± 0.005 TYP
0.89 ± 0.13
0.400 +0.015 −0.005
10.16 +0.38 −0.13
0.067 ± 0.005 TYP
1.70 ± 0.13
0.340 ± 0.010
8.64 ± 0.25
PIN ONE ID
0.250 ± 0.010
6.35 ± 0.25
0.134 ± 0.015
3.40 ± 0.38
0.015 +0.010 −0.002
0.38 +0.25 −0.05
TAPERED SIDES 1°
0.343
0.324
8.70
8.24
0.180 ±0.005
4.57 ± 0.13
0.105
2.67
SEATING PLANE
0.050 ±0.002
1.27 ± 0.05
0.622
15.80
0.176 ± 0.009
4.47 ± 0.23
0.704
17.88
T05D (REV A)

KTT0005B





LAND PATTERN RECOMMENDATION



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