TEXAS INSTRUMENTS
LM22678, LM22678-Q1
ZHCS538M – SEPTEMBER 2008 – REVISED OCTOBER 2020

采用易用封装的 LM22678/-Q1 42V、5A SIMPLE SWITCHER® 降压稳压器

1 特性

- 推出的新产品：LM61460 3V 至 36V、6A 低 EMI 同步转换器
- 宽输入电压范围：4.5V 至 42V
- 内部补偿电压模式控制
- 与低 ESR 陶瓷电容器一起工作时运行稳定
- 100mΩ N 沟道 MOSFET
- 输出电压选项：
  -可调节（输出电压最低为 1.285V）
  -5.0（输出电压固定为 5V）
- ±1.5% 反馈基准电压精度
- 500kHz 开关频率
- –40°C 至 125°C 的工作结温范围
- 精密使能引脚
- 集成式自举二极管
- 集成软启动
- 完全支持 WEBENCH®
- LM22678-Q1 是一款汽车级产品，符合 AEC-Q100 1 级标准（工作结温范围为 –40°C 至 +125°C）
- PFM（外露焊盘）封装

2 应用

- 工业分布式电源应用
- 测试和测量
- 电器
- 通用宽输入电压应用

3 说明

LM22678 开关稳压器可使用最少的外部组件来提供实现高效高压降压稳压器所需的全部功能。这款稳压器易于使用，且集成有一个 42V N 沟道 MOSFET 开关，可提供高达 5A 的负载电流。并且特有出色的线路和负载调节以及高效率 (> 90%)。电压模式控制提供较短的最小接通时间，从而实现了输入和输出电压间的最宽比率。内部环路补偿意味着用户无需承担计算环路补偿组件的枯燥工作。这款稳压器提供有 5V 固定输出和可调输出电压两种选项。500kHz 的开关频率使得小型外部组件的使用成为可能并可实现良好的瞬态响应。精密使能输入可简化稳压器控制和系统电源排序。在关断模式下，稳压器流耗只有 25μA（典型值）。内置软启动功能（典型值 500μs）节省了外部组件。LM22678 器件还内置有热关断和限流功能，可防止器件发生意外过载。

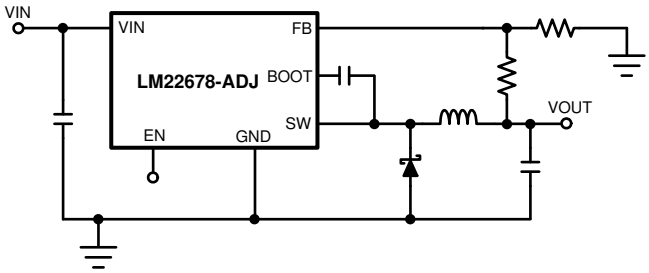
新产品 LM61460 可以提高效率、降低待机静态电流并提升 EMI 性能。请参阅器件比较表进行比较。开始使用 LM61460 进行 WEBENCH 设计

LM22678 器件是德州仪器 (TI) SIMPLE SWITCHER® 系列产品。SIMPLE SWITCHER 概念使用最少量的外部组件和德州仪器 (TI) WEBENCH 设计工具提供了一套易于使用的完整设计。为了简化设计，TI 的 WEBENCH 工具包含诸如外部组件计算、电气模拟、散热模拟以及内置电路板等特性。

器件信息

器件型号	封装(1)	封装尺寸（标称值）
LM22678	TO-263 (7)	10.16mm x 9.85mm
LM22678-Q1		

(1) 如需了解所有可用封装，请参阅数据表末尾的可订购产品附录。



简化版应用电路原理图

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4 Revision History

注：以前版本的页码可能与当前版本的页码不同

Changes from Revision L (November 2014) to Revision M (October 2020)	Page
• 向*特性* 部分添加了 LM61460 项目符号	1
• 更新了整个文档的表、图和交叉参考的编号格式。	1
• 将标题从*具有多种特性的 LM22678/-Q1 42V、5A SIMPLE SWITCHER® 降压稳压器* 更改为*采用易用封装的 LM22678/-Q1 42V、5A SIMPLE SWITCHER® 降压稳压器*	1

Changes from Revision K (March 2013) to Revision L (November 2014)	Page
• 添加了*引脚配置和功能* 部分、*处理等级* 表、*特性说明* 部分、*器件功能模式*、*应用和实施* 部分、*电源相关建议* 部分、*布局* 部分、*器件和文档支持* 部分以及*机械、封装和可订购信息* 部分	1
• Deleted *Inverting Regulator Application*	14

5 Pin Configuration and Functions

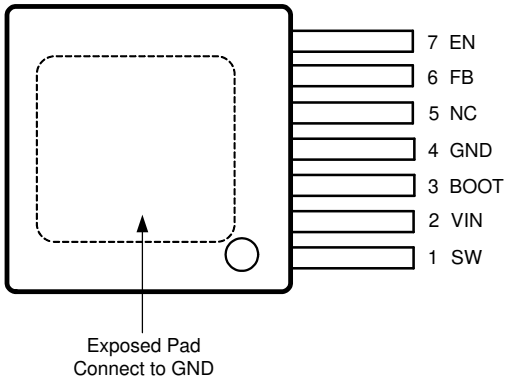


图 5-1. 7-Pin PFM Package (Top View)

表 5-1. Pin Functions

PIN		TYPE	DESCRIPTION	APPLICATION INFORMATION
NAME	NO.			
BOOT	3	I	Bootstrap input	Provides the gate voltage for the high-side NFET.
EN	7	I	Enable input	Used to control regulator start-up and shutdown. See 节 7.3.1.
EP	EP	—	Exposed pad	Connect to ground. Provides thermal connection to PCB. See 节 8.
FB	6	I	Feedback input	Feedback input to the regulator
GND	4	—	Ground input to regulator; system common	System ground pin
NC	5	—	Not connected	Pin is not electrically connected inside chip. Pin does function as thermal conductor.
SW	1	O	Switch pin	Switching output of regulator
VIN	2	I	Input voltage	Supply input to the regulator

6 Specifications

6.1 Absolute Maximum Ratings

	MIN	MAX	UNIT(1) (2)
VIN to GND		43	V
EN Pin Voltage	–0.5	6	V
SW to GND (3)	-5	V_{IN}	V
BOOT Pin Voltage		V_{SW} + 7	V
FB Pin Voltage	–0.5	7	V
Power Dissipation	Internally Limited		
Junction Temperature(4)		150	°C

(1) *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur, including inoperability and degradation of device reliability and/or performance. Functional operation of the device and/or non-degradation at the Absolute Maximum Ratings or other conditions beyond those indicated in the 节 *6.4* is not implied. The Recommended Operating Conditions indicate conditions at which the device is functional and should not be operated beyond such conditions.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.
(3) The absolute-maximum specification of the ‘SW to GND’ applies to dc voltage. An extended negative voltage limit of –10 V applies to a pulse of up to 50 ns.
(4) For soldering specifications, refer to the application report *Absolute Maximum Ratings for Soldering* (SNOA549).

6.2 Handling Ratings: LM22678

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		–65	150	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1)	–2	2	kV

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

6.3 Handling Ratings: LM22678-Q1

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		–65	150	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per AEC Q100-002(1)	–2	2	kV

(1) AEC Q100-002 indicates HBM stressing is done in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.4 Recommended Operating Conditions

		MIN	MAX	UNIT
V_{IN}	Supply Voltage	4.5	42	V
	Junction Temperature Range	–40	125	°C

6.5 Thermal Information

THERMAL METRIC(1) (2)		LM22678, LM22678-Q1	UNIT
		NDR	
		7 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	22	°C/W

(1) For more information about traditional and new thermal metrics, see the application report *IC Package Thermal Metrics* (SPRA953).
(2) The value of $R_{\theta JA}$ for the PFM package of 22°C/W is valid if package is mounted to 1 square inch of copper. The $R_{\theta JA}$ value can range from 20 to 30°C/W depending on the amount of PCB copper dedicated to heat transfer. See application note AN-1797 (SNVA328) for more information.

6.6 Electrical Characteristics

Typical values represent the most likely parametric norm at $T_A = T_J = 25°C$, and are provided for reference purposes only. Unless otherwise specified: $V_{IN} = 12$ V.

PARAMETER		TEST CONDITIONS	MIN(1)	TYP(2)	MAX(1)	UNIT
LM22678-5.0						
V_{FB}	Feedback Voltage	V_{IN} = 8 V to 42 V	4.925	5.0	5.075	V
		V_{IN} = 8 V to 42 V, –40°C ≤ T_J ≤ 125°C	4.9		5.1	
LM22678-ADJ						
V_{FB}	Feedback Voltage	V_{IN} = 4.7 V to 42 V	1.266	1.285	1.304	V
		V_{IN} = 4.7 V to 42 V, –40°C ≤ T_J ≤ 125°C	1.259		1.311	
ALL OUTPUT VOLTAGE VERSIONS						
I_Q	Quiescent Current	V_{FB} = 5 V		3.4		mA
		V_{FB} = 5 V, –40°C ≤ T_J ≤ 125°C			6	
I_{STDBY}	Standby Quiescent Current	EN Pin = 0 V		25	40	µA
I_{CL}	Current Limit		6.0	7.1	8.4	A
		–40°C ≤ T_J ≤ 125°C	5.75		8.75	
I_L	Output Leakage Current	V_{IN} = 42 V, EN Pin = 0 V, V_{SW} = 0 V		0.2	2	µA
		V_{SW} = –1 V		0.1	3	µA
$R_{DS(ON)}$	Switch On-Resistance			0.1	0.14	Ω
		–40°C ≤ T_J ≤ 125°C			0.2	
f_O	Oscillator Frequency			500		kHz
		–40°C ≤ T_J ≤ 125°C	400		600	
T_{OFFMIN}	Minimum Off-time			200		ns
		–40°C ≤ T_J ≤ 125°C	100		300	
T_{ONMIN}	Minimum On-time			100		ns
I_{BIAS}	Feedback Bias Current	V_{FB} = 1.3 V (ADJ Version Only)		230		nA
V_{EN}	Enable Threshold Voltage	Falling		1.6		V
		Falling, –40°C ≤ T_J ≤ 125°C	1.3		1.9	
V_{ENHYST}	Enable Threshold Hysteresis			0.6		V
I_{EN}	Enable Input Current	EN Input = 0 V		6		µA
T_{SD}	Thermal Shutdown Threshold			150		°C

(1) MIN and MAX limits are 100% production tested at 25°C. Limits over the operating temperature range are ensured through correlation using Statistical Quality Control (SQC) methods. Limits are used to calculate TI's Average Outgoing Quality Level (AOQL).
(2) Typical values represent most likely parametric norms at the conditions specified and are not ensured.

6.7 Typical Characteristics

V_{in} = 12 V, T_J = 25°C (unless otherwise specified)

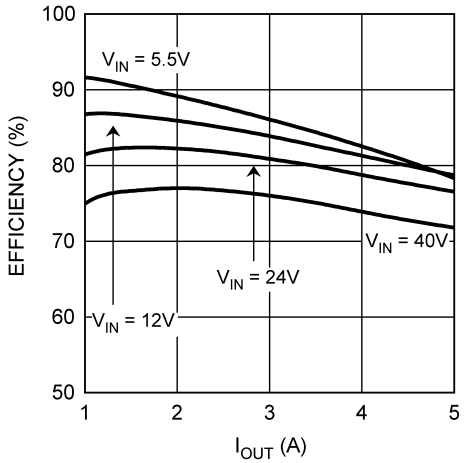


图 6-1. Efficiency vs I_{OUT} and V_{IN}, V_{OUT} = 3.3 V

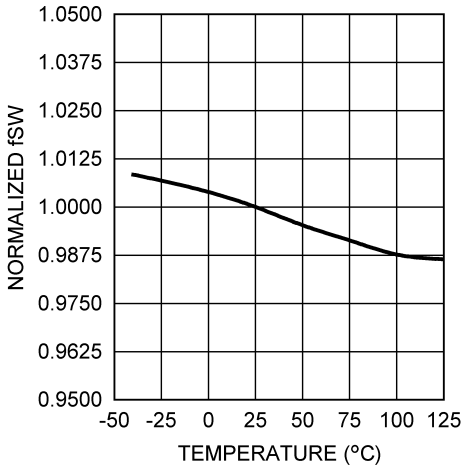


图 6-2. Normalized Switching Frequency vs Temperature

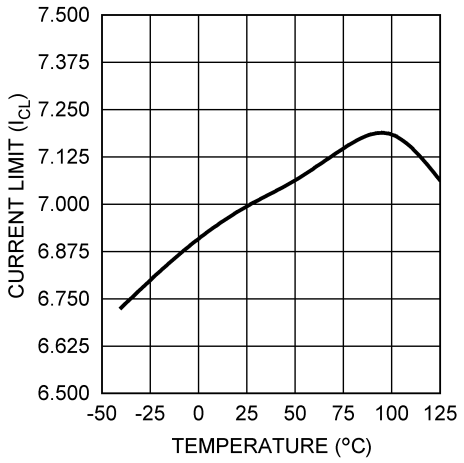


图 6-3. Current Limit vs Temperature

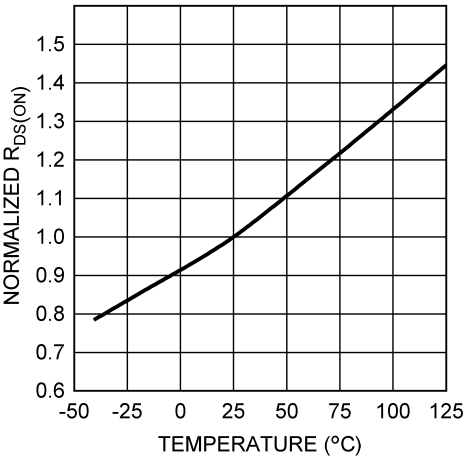


图 6-4. Normalized $R_{DS(ON)}$ vs Temperature

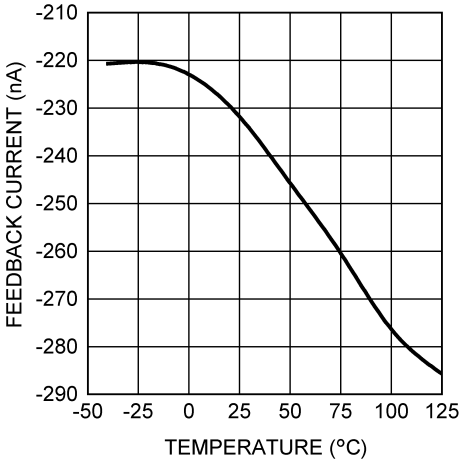


图 6-5. Feedback Bias Current vs Temperature

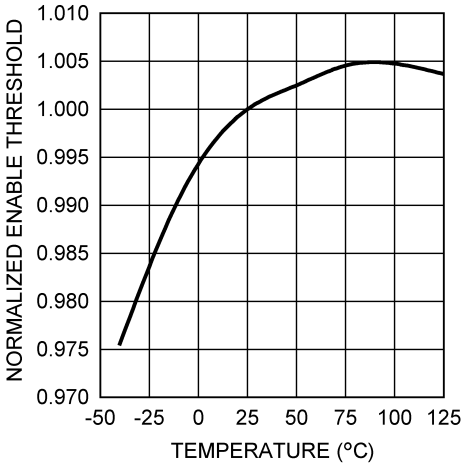


图 6-6. Normalized Enable Threshold Voltage vs Temperature

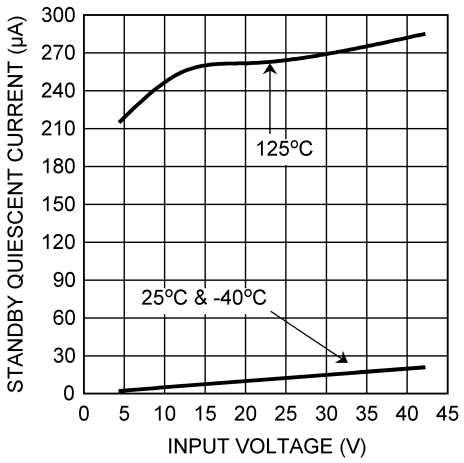


图 6-7. Standby Quiescent Current vs Input Voltage

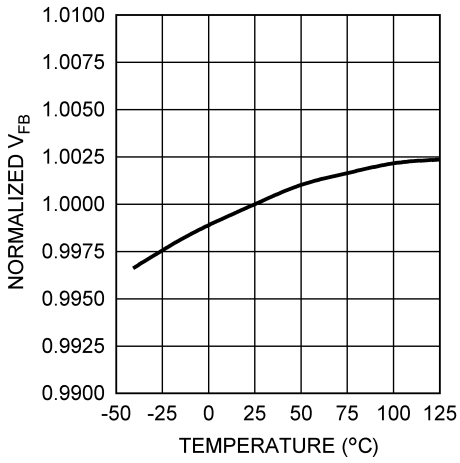


图 6-8. Normalized Feedback Voltage vs Temperature

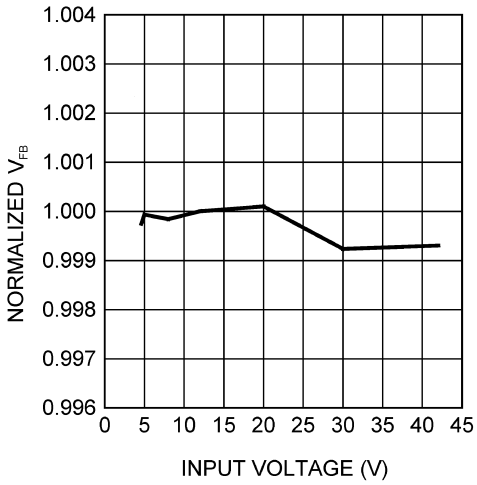


图 6-9. Normalized Feedback Voltage vs Input Voltage

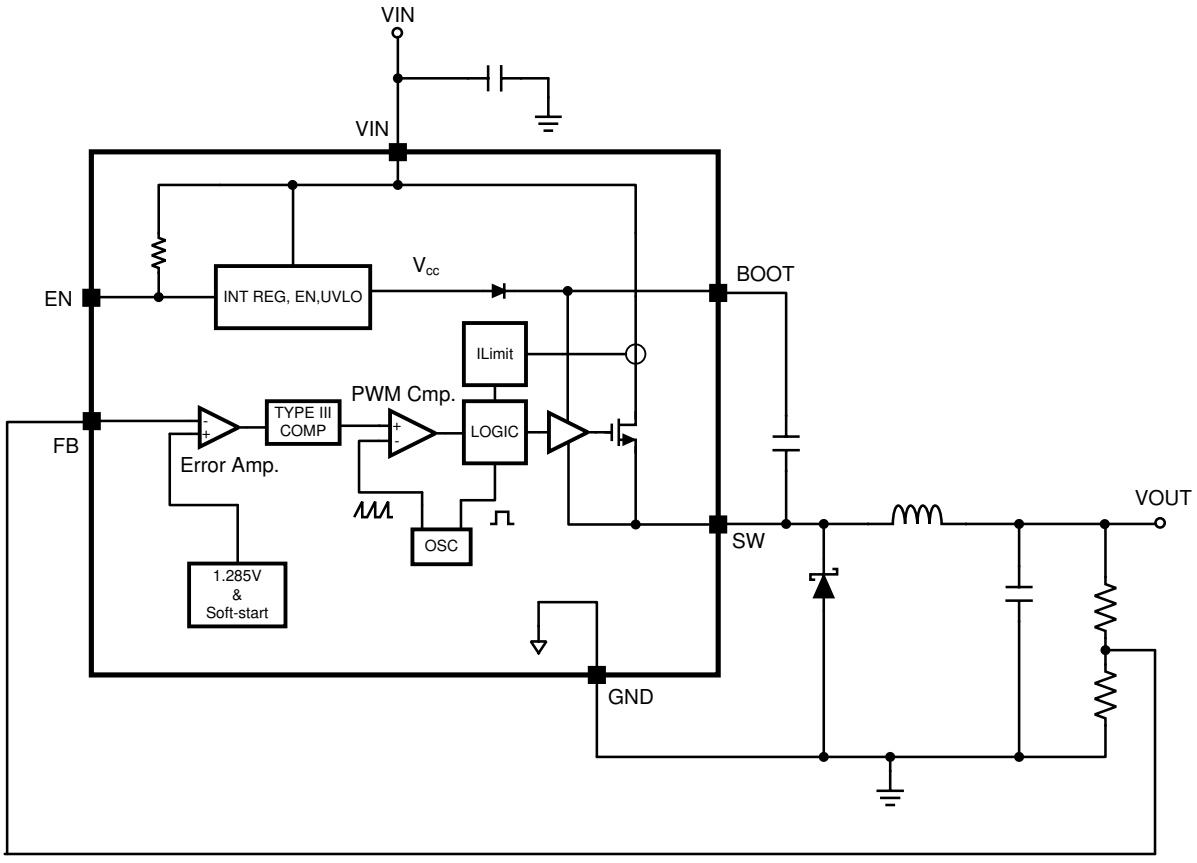
7 Detailed Description

7.1 Overview

The LM22678 incorporates a voltage mode constant frequency PWM architecture. In addition, input voltage feedforward is used to stabilize the loop gain against variations in input voltage. This allows the loop compensation to be optimized for transient performance. The power MOSFET, in conjunction with the diode, produces a rectangular waveform at the switch pin, which swings from about zero volts to VIN. The inductor and output capacitor average this waveform to become the regulator output voltage. By adjusting the duty cycle of this waveform, the output voltage can be controlled. The error amplifier compares the output voltage with the internal reference and adjusts the duty cycle to regulate the output at the desired value.

The internal loop compensation of the -ADJ option is optimized for outputs of 5 V and below. If an output voltage of 5 V or greater is required, the -5.0 option can be used with an external voltage divider. The minimum output voltage is equal to the reference voltage, that is, 1.285 V (typ).

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Precision Enable and UVLO

The precision enable input (EN) is used to control the regulator. The precision feature allows simple sequencing of multiple power supplies with a resistor divider from another supply. Connecting this pin to ground or to a voltage less than 1.6 V (typ.) will turn off the regulator. The current drain from the input supply, in this state, is 25 µA (typ.) at an input voltage of 12 V. The EN input has an internal pullup of about 6 µA. Therefore, this pin can be left floating or pulled to a voltage greater than 2.2 V (typ) to turn the regulator on. The hysteresis on this input is about 0.6 V (typ.) above the 1.6-V (typ.) threshold. When driving the enable input, the voltage must never exceed the 6-V absolute maximum specification for this pin.

Although an internal pullup is provided on the EN pin, it is good practice to pull the input high when this feature is not used, especially in noisy environments. This can most easily be done by connecting a resistor between VIN and the EN pin. The resistor is required because the internal zener diode at the EN pin will conduct for voltages above about 6 V. The current in this zener must be limited to less than 100 µA. A resistor of 470 kΩ will limit the current to a safe value for input voltages as high 42 V. Smaller values of resistor can be used at lower input voltages.

The LM22678 device also incorporates an input undervoltage lockout (UVLO) feature. This prevents the regulator from turning on when the input voltage is not great enough to properly bias the internal circuitry. The rising threshold is 4.3 V (typ.) while the falling threshold is 3.9 V (typ.). In some cases, these thresholds can be too low to provide good system performance. The solution is to use the EN input as an external UVLO to disable the part when the input voltage falls below a lower boundary. This is often used to prevent excessive battery discharge or early turnon during start-up. This method is also recommended to prevent abnormal device operation in applications where the input voltage falls below the minimum of 4.5 V. 图 7-1 shows the connections to implement this method of UVLO. 方程式 1 and 方程式 2 can be used to determine the correct resistor values.

$$R_{ENT} = R_{ENB} \cdot \left(\frac{V_{off}}{V_{EN}} - 1 \right) \tag{1}$$

$$V_{on} = V_{off} \cdot \left(\frac{V_{EN} + V_{ENHYST}}{V_{EN}} \right) \tag{2}$$

where

- V_{off} is the input voltage where the regulator shuts off.
- V_{on} is the voltage where the regulator turns on.

Due to the 6-µA pullup, the current in the divider should be much larger than this. A value of 20 kΩ, for R_{ENB} is a good first choice. Also, a zener diode may be needed between the EN pin and ground, in order to comply with the absolute maximum ratings on this pin.

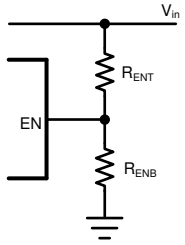


图 7-1. External UVLO Connections

7.3.2 Soft Start

The soft-start feature allows the regulator to gradually reach steady-state operation, thus reducing start-up stresses. The internal soft-start feature brings the output voltage up in about 500 µs. This time is fixed and cannot be changed. Soft start is reset any time the part is shut down or a thermal overload event occurs.

7.3.3 Bootstrap Supply

The LM22678 device incorporates a floating high-side gate driver to control the power MOSFET. The supply for this driver is the external bootstrap capacitor connected between the BOOT pin and SW. A good quality 10-nF ceramic capacitor must be connected to these pins with short, wide PCB traces. One reason the regulator imposes a minimum off-time is to ensure that this capacitor recharges every switching cycle. A minimum load of about 5 mA is required to fully recharge the bootstrap capacitor in the minimum off-time. Some of this load can be provided by the output voltage divider, if used.

7.3.4 Internal Loop Compensation

The LM22678 has internal loop compensation designed to provide a stable regulator over a wide range of external power stage components.

The internal compensation of the -ADJ option is optimized for output voltages below 5 V. If an output voltage of 5 V or greater is needed, the -5.0 option with an external resistor divider can be used.

Ensuring stability of a design with a specific power stage (inductor and output capacitor) can be tricky. The LM22678 stability can be verified using the WEBENCH Designer online circuit simulation tool at WEBENCH Designer. A quick start spreadsheet can also be downloaded from the online product folder.

The complete transfer function for the regulator loop is found by combining the compensation and power stage transfer functions. The LM22678 has internal type III loop compensation, as detailed in 图 7-2. This is the approximate "straight line" function from the FB pin to the input of the PWM modulator. The power stage transfer function consists of a dc gain and a second order pole created by the inductor and output capacitor or capacitors. Due to the input voltage feedforward employed in the LM22678, the power stage dc gain is fixed at 20 dB. The second order pole is characterized by its resonant frequency and its quality factor (Q). For a first pass design, the product of inductance and output capacitance should conform to 方程式 3.

$$L \cdot C_{out} \approx 1.1 \times 10^{-9} \tag{3}$$

Alternatively, this pole should be placed between 1.5 kHz and 15 kHz and is determined by 方程式 4.

$$F_o = \frac{1}{2\pi \cdot \sqrt{L \cdot C_{out}}} \tag{4}$$

The Q factor depends on the parasitic resistance of the power stage components and is not typically in the control of the designer. Of course, loop compensation is only one consideration when selecting power stage components (see 节 8 for more details).

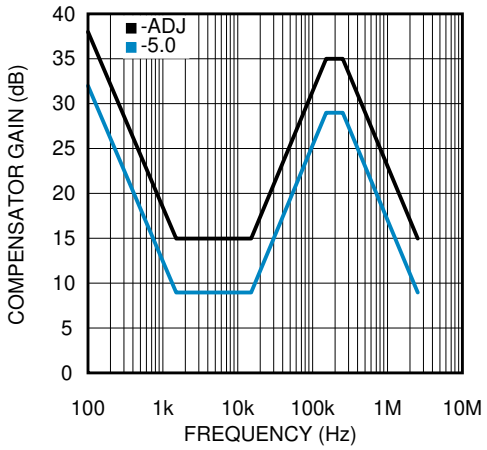


图 7-2. Compensator Gain

In general, hand calculations or simulations can only aid in selecting good power stage components. Good design practice dictates that load and line transient testing should be done to verify the stability of the application. Also, Bode plot measurements should be made to determine stability margins. *AN-1889 How to Measure the Loop Transfer Function of Power Supplies* (SNVA364) shows how to perform a loop transfer function measurement with only an oscilloscope and function generator.

7.4 Device Functional Modes

7.4.1 Shutdown Mode

The EN pin provides electrical ON and OFF control for the LM22678 device. When VEN is below 1.6 V, the device is in shutdown mode. The current drain from the input supply, in this state, is 25 µA (typ) at an input voltage of 12 V. The EN input has an internal pullup of about 6 µA. The LM22678 also incorporates an input undervoltage lockout (UVLO) feature. This prevents the regulator from turning on when the input voltage is not great enough to properly bias the internal circuitry. The rising threshold is 4.3 V (typ.) while the falling threshold is 3.9 V (typ.).

7.4.2 Active Mode

The LM22678 device is in active mode when VEN is above the precision enable threshold and its input voltage is above its UVLO level. The simplest way to enable the LM22678 is to connect the EN pin to VIN through a resistor. A resistor of 470 kΩ will limit the current to a safe value for input voltages as high 42 V.

7.4.3 Current Limit

The LM22678 device has current limiting to prevent the switch current from exceeding safe values during an accidental overload on the output. This peak current limit is found in 节 *6.6* under the heading of I_{CL}. The maximum load current that can be provided, before current limit is reached, is determined from 方程式 5.

$$I_{out}|_{max} \approx I_{CL} - \frac{(V_{in} - V_{out})}{2 \cdot L \cdot F_{sw}} \cdot \frac{V_{out}}{V_{in}} \quad (5)$$

where

- L is the value of the power inductor.

When the LM22678 device enters current limit, the output voltage will drop and the peak inductor current will be fixed at I_{CL} at the end of each cycle. The switching frequency will remain constant while the duty cycle drops. The load current will not remain constant, but will depend on the severity of the overload and the output voltage.

For very severe overloads "short-circuit", the regulator changes to a low frequency current foldback mode of operation. The frequency foldback is about 1/5 of the nominal switching frequency. This will occur when the

current limit trips before the minimum on-time has elapsed. This mode of operation is used to prevent inductor current "run-away", and is associated with very low output voltages when in overload. 方程式 6 can be used to determine what level of output voltage will cause the part to change to low frequency current foldback.

$$V_x \leq V_{in} \cdot F_{sw} \cdot T_{on} \cdot 1.8 \tag{6}$$

where

- F_{sw} is the normal switching frequency.
- V_{in} is the maximum for the application.

If the overload drives the output voltage to less than or equal to V_x, the part will enter current foldback mode. If a given application can drive the output voltage to $\leqslant V_x$, during an overload, then a second criterion must be checked. 方程式 7 determines the maximum input voltage, when in this mode, before damage occurs.

$$V_{in} \leq \frac{V_{sc} + 0.4}{T_{on} \cdot F_{sw} \cdot 0.36} \tag{7}$$

where

- V_{sc} is the value of output voltage during the overload.
- F_{sw} is the normal switching frequency.

备注

If the input voltage should exceed this value while in foldback mode, the regulator, diode, or both can be damaged.

It is important to note that the voltages in these equations are measured at the inductor. Normal trace and wiring resistance will cause the voltage at the inductor to be higher than that at a remote load. Therefore, even if the load is shorted with zero volts across its terminals, the inductor will still see a finite voltage. It is this value that should be used for V_x and V_{sc} in the calculations. In order to return from foldback mode, the load must be reduced to a value much lower than that required to initiate foldback. This load "hysteresis" is a normal aspect of any type of current limit foldback associated with voltage regulators.

The safe operating area, when in short circuit mode, is shown in 图 7-3. Operating points below and to the right of the curve represent safe operation.

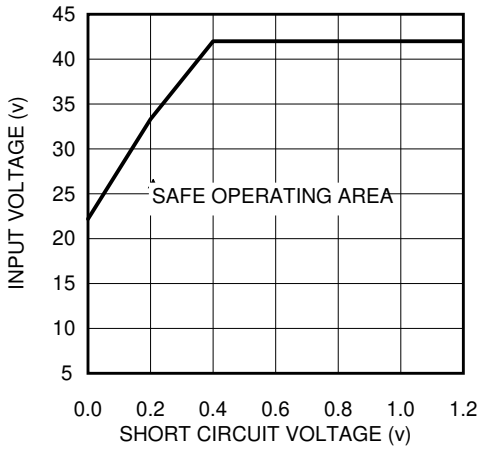


图 7-3. SOA

7.4.4 Thermal Protection

Internal thermal-shutdown circuitry protects the LM22678 should the maximum junction temperature be exceeded. This protection is activated at about 150°C, with the result that the regulator will shut down until the temperature drops below about 135°C.

7.4.5 Duty-Cycle Limits

Ideally, the regulator would control the duty cycle over the full range of zero to one. However due to inherent delays in the circuitry, there are limits on both the maximum and minimum duty cycles that can be reliably controlled. This in turn places limits on the maximum and minimum input and output voltages that can be converted by the LM22678. A minimum on-time is imposed by the regulator to correctly measure the switch current during a current limit event. A minimum off-time is imposed in order the re-charge the bootstrap capacitor. 方程式 8 can be used to determine the approximate maximum input voltage for a given output voltage.

$$V_{in}|_{max} \approx \frac{V_{out} + 0.4}{T_{on} \cdot F_{sw} \cdot 1.8} \tag{8}$$

where

- F_{sw} is the switching frequency.
- T_{ON} is the minimum on-time.

Both values can be found in 节 6.6.

The worst case occurs at the lowest output voltage. If the input voltage found in 方程式 8 is exceeded, the regulator will skip cycles; thus, effectively lowering the switching frequency. The consequences of this are higher output voltage ripple and a degradation of the output voltage accuracy.

The second limitation is the maximum duty cycle before the output voltage will "dropout" of regulation. 方程式 9 can be used to approximate the minimum input voltage before dropout occurs.

$$V_{in}|_{min} \approx \frac{V_{out} + 0.4 + I_{out} \cdot R_L}{1 - T_{off} \cdot F_{sw} \cdot 1.8} + I_{out} \cdot R_{dson} \tag{9}$$

where

- The values of T_{OFF} and $R_{DS(ON)}$ are found in 节 6.6.

The worst case here occurs at the highest load. In this equation, R_L is the dc inductor resistance. Of course, the lowest input voltage to the regulator must not be less than 4.5 V (typ.).

8 Application and Implementation

备注

以下应用部分的信息不属于 TI 组件规范，TI 不担保其准确性和完整性。客户应负责确定 TI 组件是否适用于其应用。客户应验证并测试其设计，以确保系统功能。

8.1 Application Information

The LM22678 device is a step down dc-to-dc regulator. It is typically used to convert a higher dc voltage to a lower dc voltage with a maximum output current of 5 A. 节 *8.2.1.2* can be used to select components for the LM22678. Alternately, the WEBENCH software may be used to generate complete designs. When generating a design, the WEBENCH software utilizes iterative design procedure and accesses comprehensive databases of components. Go to WEBENCH Designer for more details. This section presents a simplified discussion of the design process.

8.1.1 Output Voltage Divider Selection

For output voltages between about 1.285 V and 5 V, the -ADJ option should be used, with an appropriate voltage divider as shown in 图 8-1. 方程式 10 can be used to calculate the resistor values of this divider.

$$R_{FBT} = \left[\frac{V_{out}}{1.285} - 1\right] \cdot R_{FBB} \tag{10}$$

A good value for R_{FBB} is 1 kΩ. This will help to provide some of the minimum load current requirement and reduce susceptibility to noise pick-up. The top of R_{FBT} should be connected directly to the output capacitor or to the load for remote sensing. If the divider is connected to the load, a local high-frequency bypass should be provided at that location.

For output voltages of 5 V, the -5.0 option should be used. In this case no divider is needed and the FB pin is connected to the output. The approximate values of the internal voltage divider are as follows: 7.38 kΩ from the FB pin to the input of the error amplifier and 2.55 kΩ from there to ground.

Both the -ADJ and -5.0 options can be used for output voltages greater than 5 V, by using the correct output divider. As mentioned in 节 *7.3.4*, the -5.0 option is optimized for output voltages of 5 V. However, for output voltages greater than 5 V, this option may provide better loop bandwidth than the -ADJ option, in some applications. If the -5.0 option is to be used at output voltages greater than 5 V, 方程式 11 should be used to determine the resistor values in the output divider.

$$R_{FBT} = \frac{R_{FBB} \cdot (V_{out} - 5)}{5 + R_{FBB} \cdot 5 \times 10^{-4}} \tag{11}$$

Again, a value of R_{FBB} of about 1 kΩ is a good first choice.

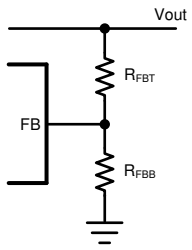


图 8-1. Resistive Feedback Divider

A maximum value of 10 kΩ is recommended for the sum of R_{FBB} and R_{FBT} to maintain good output voltage accuracy for the -ADJ option. A maximum of 2 kΩ is recommended for the -5.0 option. For the -5.0 option, the total internal divider resistance is typically 9.93 kΩ.

In all cases the output voltage divider should be placed as close as possible to the FB pin of the LM22678 device; because this is a high impedance input and is susceptible to noise pick-up.

8.1.2 Power Diode

A Schottky-type power diode is required for all LM22678 applications. Ultra-fast diodes are not recommended and may result in damage to the IC due to reverse recovery current transients. The near ideal reverse recovery characteristics and low forward voltage drop of Schottky diodes are particularly important for high input voltage and low output voltage applications common to the LM22678 device. The reverse breakdown rating of the diode should be selected for the maximum V_{IN}, plus some safety margin. A good rule of thumb is to select a diode with a reverse voltage rating of 1.3 times the maximum input voltage.

Select a diode with an average current rating at least equal to the maximum load current that will be seen in the application.

8.2 Typical Applications

8.2.1 Typical Buck Regulator Application

图 8-2 shows an example of converting an input voltage range of 5.5 V to 42 V, to an output of 3.3 V at 5 A.

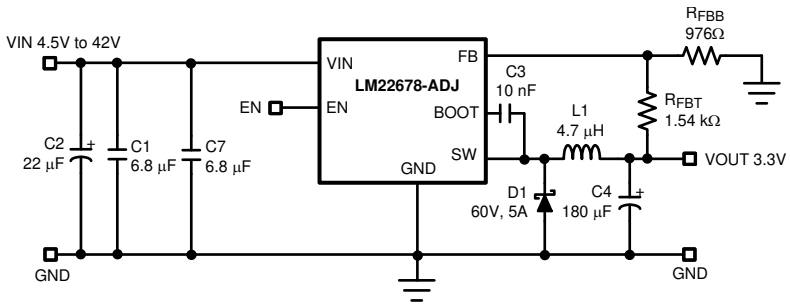


图 8-2. Typical Buck Regulator Application

8.2.1.1 Design Requirements

DESIGN PARAMETERS	EXAMPLE VALUE
Driver Supply Voltage (VIN)	4.5 to 42 V
Output Voltage (VOUT)	3.3 V
R_{FBT}	Calculated based on R_{FBB} and V_{REF} of 1.285 V.
R_{FBB}	1 kΩ to 10 kΩ
I_{OUT}	5 A

8.2.1.2 Detailed Design Procedure

8.2.1.2.1 External Components

The following guidelines should be used when designing a step-down (buck) converter with the LM22678 device.

8.2.1.2.1.1 Inductor

The inductor value is determined based on the load current, ripple current, and the minimum and maximum input voltages. To keep the application in continuous conduction mode (CCM), the maximum ripple current, I_{RIPPLE}, should be less than twice the minimum load current. The general rule of keeping the inductor current peak-to-peak ripple around 30% of the nominal output current is a good compromise between excessive output voltage

ripple and excessive component size and cost. Using this value of ripple current, the value of inductor (L) is calculated using 方程式 12.

$$L = \frac{(V_{in} - V_{out}) \cdot V_{out}}{0.3 \cdot I_{out} \cdot F_{sw} \cdot V_{in}} \tag{12}$$

where

- F_{sw} is the switching frequency.
- V_{in} should be taken at its maximum value, for the given application.

方程式 12 provides a guide to select the value of the inductor L; the nearest standard value will then be used in the circuit.

Once the inductor is selected, the actual ripple current can be determined by 方程式 13.

$$\Delta I = \frac{(V_{in} - V_{out}) \cdot V_{out}}{L \cdot F_{sw} \cdot V_{in}} \tag{13}$$

Increasing the inductance will generally slow down the transient response but reduce the output voltage ripple. Reducing the inductance will generally improve the transient response but increase the output voltage ripple.

The inductor must be rated for the peak current, I_{PK}, in a given application, to prevent saturation. During normal loading conditions, the peak current is equal to the load current plus 1/2 of the inductor ripple current.

During an overload condition, as well as during certain load transients, the controller can trip current limit. In this case the peak inductor current is given by I_{CL}, found in 节 6.6. Good design practice requires that the inductor rating be adequate for this overload condition.

备注

If the inductor is not rated for the maximum expected current, it can saturate resulting in damage to the LM22678, the power diode, or both.

8.2.1.2.2 Input Capacitor

The input capacitor selection is based on both input voltage ripple and RMS current. Good quality input capacitors are necessary to limit the ripple voltage at the VIN pin while supplying most of the regulator current during switch on-time. Low-ESR ceramic capacitors are preferred. Larger values of input capacitance are desirable to reduce voltage ripple and noise on the input supply. This noise can find its way into other circuitry, sharing the same input supply, unless adequate bypassing is provided. A very approximate formula for determining the input voltage ripple is shown in 方程式 14.

$$V_{ri} \approx \frac{I_{out}}{4 \cdot F_{sw} \cdot C_{in}} \tag{14}$$

where

- V_{ri} is the peak-to-peak ripple voltage at the switching frequency.

Another concern is the RMS current passing through this capacitor. 方程式 15 determines an approximation to this current.

$$I_{rms} \approx \frac{I_{out}}{2} \tag{15}$$

The capacitor must be rated for at least this level of RMS current at the switching frequency.

All ceramic capacitors have large voltage coefficients, in addition to normal tolerances and temperature coefficients. To help mitigate these effects, multiple capacitors can be used in parallel to bring the minimum capacitance up to the desired value. This can also help with RMS current constraints by sharing the current among several capacitors. Many times it is desirable to use an electrolytic capacitor on the input, in parallel with the ceramics. The moderate ESR of this capacitor can help to damp any ringing on the input supply caused by long power leads. This method can also help to reduce voltage spikes that may exceed the maximum input voltage rating of the LM22678 device.

It is good practice to include a high frequency bypass capacitor as close as possible to the LM22678 device. This small case size, low ESR ceramic capacitor should be connected directly to the VIN and GND pins with the shortest possible PCB traces. Values in the range of 0.47 µF to 1 µF are appropriate. This capacitor helps to provide a low impedance supply to sensitive internal circuitry. It also helps to suppress any fast noise spikes on the input supply that may lead to increased EMI.

8.2.1.2.3 Output Capacitor

The output capacitor is responsible for filtering the output voltage and supplying load current during transients. Capacitor selection depends on application conditions as well as ripple and transient requirements. Best performance is achieved with a parallel combination of ceramic capacitors and a low-ESR SP™ or POSCAP™ type. Very low ESR capacitors such as ceramics reduce the output ripple and noise spikes, while higher value electrolytics or polymer provide large bulk capacitance to supply transients. Assuming very low ESR, 方程式 16 determines an approximation to the output voltage ripple.

$$V_{ro} \approx \frac{(V_{in} - V_{out}) \cdot V_{out}}{8 \cdot V_{in}} \cdot \frac{1}{F_{sw}^2 \cdot L \cdot C_{out}} \tag{16}$$

Typically, a total value of 100 µF or greater is recommended for output capacitance.

In applications with V_{out} less than 3.3 V, it is critical that low-ESR output capacitors are selected. This will limit potential output voltage overshoots as the input voltage falls below the device normal operating range.

8.2.1.2.4 Bootstrap Capacitor

The bootstrap capacitor between the BOOT pin and the SW pin supplies the gate current to turn on the N-channel MOSFET. The recommended value of this capacitor is 10 nF and should be a good quality, low-ESR ceramic capacitor. In some cases, it can be desirable to slow down the turnon of the internal power MOSFET in order to reduce EMI. This can be done by placing a small resistor in series with the C_{boot} capacitor. Resistors in the range of 10 Ω to 50 Ω can be used. This technique should only be used when absolutely necessary, because it will increase switching losses and thereby reduce efficiency.

8.2.1.3 Application Curves

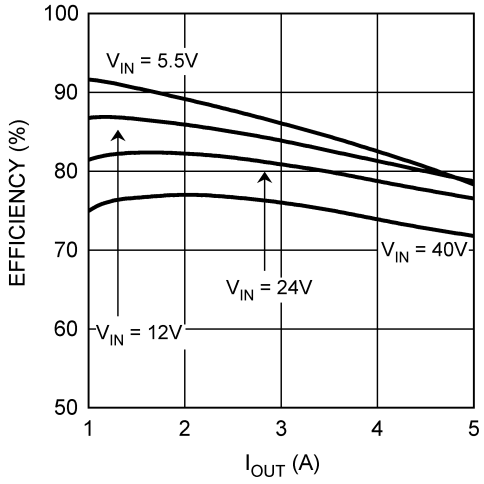


图 8-3. Efficiency vs I_{OUT} and V_{IN}, V_{OUT} = 3.3 V

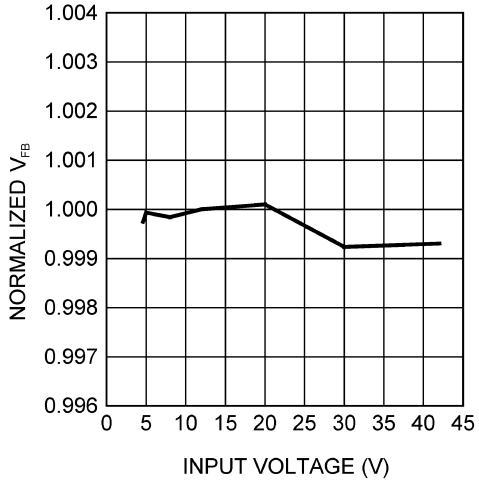


图 8-4. Normalized Feedback Voltage vs Input Voltage

Power Supply Recommendations

The LM22678 device is designed to operate from an input voltage supply range between 4.5 V and 42 V. This input supply should be well regulated and able to withstand maximum input current and maintain a stable voltage. The resistance of the input supply rail should be low enough that an input current transient does not cause a high enough drop at the LM22678 supply voltage that can cause a false UVLO fault triggering and system reset. If the input supply is located more than a few inches from the LM22678 device, additional bulk capacitance may be required in addition to the ceramic bypass capacitors. The amount of bulk capacitance is not critical, but a 47 µF or 100 µF electrolytic capacitor is a typical choice.

9 Layout

9.1 Layout Guidelines

Board layout is critical for the proper operation of switching power supplies. First, the ground plane area must be sufficient for thermal dissipation purposes. Second, appropriate guidelines must be followed to reduce the effects of switching noise. Switch mode converters are very fast switching devices. In such cases, the rapid increase of input current combined with the parasitic trace inductance generates unwanted L di/dt noise spikes. The magnitude of this noise tends to increase as the output current increases. This noise may turn into electromagnetic interference (EMI) and can also cause problems in device performance. Therefore, care must be taken in layout to minimize the effect of this switching noise.

The most important layout rule is to keep the ac current loops as small as possible. 图 9-1 shows the current flow in a buck converter. The top schematic shows a dotted line which represents the current flow during the FET switch on-state. The middle schematic shows the current flow during the FET switch off-state.

The bottom schematic shows the currents referred to as ac currents. These ac currents are the most critical because they are changing in a very short time period. The dotted lines of the bottom schematic are the traces to keep as short and wide as possible. This will also yield a small loop area reducing the loop inductance. To avoid functional problems due to layout, review the PCB layout example. Best results are achieved if the placement of the LM22678 device, the bypass capacitor, the Schottky diode, R_{FBB}, R_{FBT}, and the inductor are placed as shown in 图 9-1. In the layout shown, R1 = R_{FBB} and R2 = R_{FBT}. It is also recommended to use 2 oz copper boards or heavier to help thermal dissipation and to reduce the parasitic inductances of board traces. See *AN-1229 SIMPLE SWITCHER® PCB Layout Guidelines* (SNVA054) for more information.

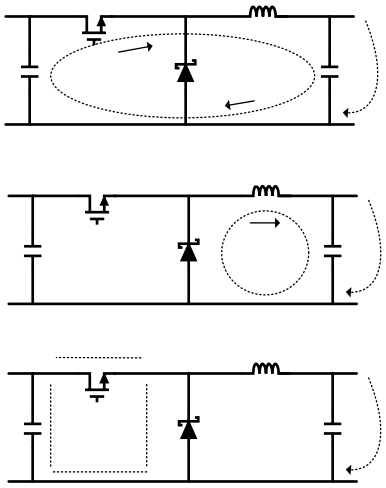


图 9-1. Current Flow in a Buck Application

9.2 Layout Example

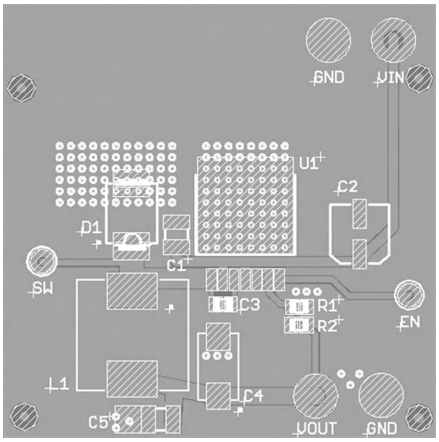


图 9-2. LM22678 Layout Example

9.3 Thermal Considerations

The components with the highest power dissipation are the power diode and the power MOSFET internal to the LM22678 regulator. The easiest method to determine the power dissipation within the LM22678 is to measure the total conversion losses then subtract the power losses in the diode and inductor. The total conversion loss is the difference between the input power and the output power. An approximation for the power diode loss is shown in 方程式 17.

$$P_D = I_{out} \cdot V_D \cdot \left[1 - \frac{V_{out}}{V_{in}}\right] \quad (17)$$

where

- V_D is the diode voltage drop.

An approximation for the inductor power is determined by 方程式 18.

$$P_L = I_{out}^2 \cdot R_L \cdot 1.1 \quad (18)$$

where

- R_L is the dc resistance of the inductor.

The 1.1 factor is an approximation for the ac losses.

The regulator has an exposed thermal pad to aid power dissipation. Adding multiple vias under the device to the ground plane will greatly reduce the regulator junction temperature. Selecting a diode with an exposed pad will also aid the power dissipation of the diode. The most significant variables that affect the power dissipation of the regulator are output current, input voltage and operating frequency. The power dissipated while operating near the maximum output current and maximum input voltage can be appreciable. The junction-to-ambient thermal resistance of the LM22678 will vary with the application. The most significant variables are the area of copper in the PC board, the number of vias under the IC exposed pad and the amount of forced air cooling provided. A large continuous ground plane on the top or bottom PCB layer will provide the most effective heat dissipation. The integrity of the solder connection from the IC exposed pad to the PC board is critical. Excessive voids will greatly diminish the thermal dissipation capacity. The junction-to-ambient thermal resistance of the LM22678 PFM package is specified in 节 6.6. See *AN-2020 Thermal Design By Insight, Not Hindsight* (SNVA419) for more information.

10 Device and Documentation Support

10.1 Documentation Support

10.1.1 Related Documentation

- *AN-2020 Thermal Design By Insight, Not Hindsight* (SNVA419)
- *AN-1229 SIMPLE SWITCHER® PCB Layout Guidelines* (SNVA054)
- *AN-1892 LM22677 Evaluation Board* (SNVA366)
- *AN-1889 How to Measure the Loop Transfer Function of Power Supplies* (SNVA364)

10.2 支持资源

TI E2E™ 支持论坛是工程师的重要参考资料，可直接从专家获得快速、经过验证的解答和设计帮助。搜索现有解答或提出自己的问题可获得所需的快速设计帮助。

链接的内容由各个贡献者“按原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的《使用条款》。

10.3 接收文档更新通知

要接收文档更新通知，请导航至 ti.com 上的器件产品文件夹。点击 *订阅更新* 进行注册，即可每周接收产品信息更改摘要。有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

10.4 静电放电警告

静电放电 (ESD) 会损坏这个集成电路。德州仪器 (TI) 建议通过适当的预防措施处理所有集成电路。如果不遵守正确的处理和安装程序，可能会损坏集成电路。

ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

10.5 术语表

TI 术语表	本术语表列出并解释了术语、首字母缩略词和定义。

Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable 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
LM22678QTJ-5.0/NOPB	ACTIVE	TO-263	NDR	7	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-5.0	Samples
LM22678QTJ-ADJ/NOPB	ACTIVE	TO-263	NDR	7	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-ADJ	Samples
LM22678QTJE-5.0/NOPB	ACTIVE	TO-263	NDR	7	250	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-5.0	Samples
LM22678QTJE-ADJ/NOPB	ACTIVE	TO-263	NDR	7	250	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-ADJ	Samples
LM22678TJ-5.0/NOPB	ACTIVE	TO-263	NDR	7	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-5.0	Samples
LM22678TJ-ADJ/NOPB	ACTIVE	TO-263	NDR	7	1000	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-ADJ	Samples
LM22678TJE-5.0/NOPB	ACTIVE	TO-263	NDR	7	250	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-5.0	Samples
LM22678TJE-ADJ/NOPB	ACTIVE	TO-263	NDR	7	250	RoHS & Green	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-ADJ	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.

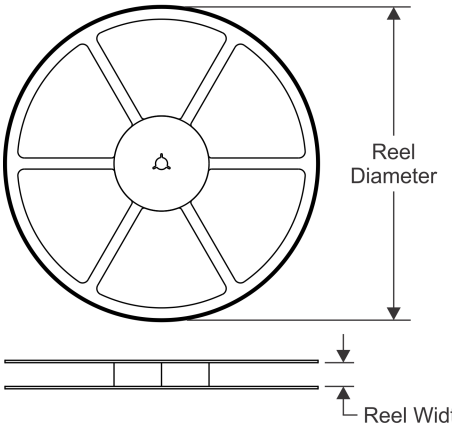
(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(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.

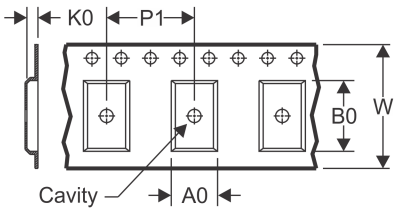
(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

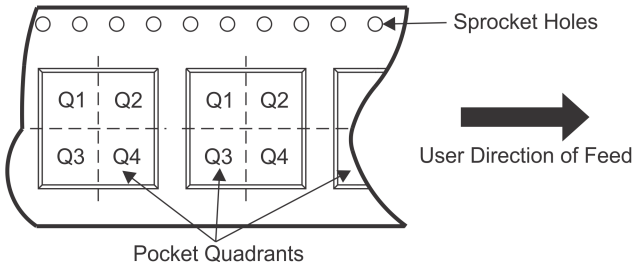


TAPE DIMENSIONS



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

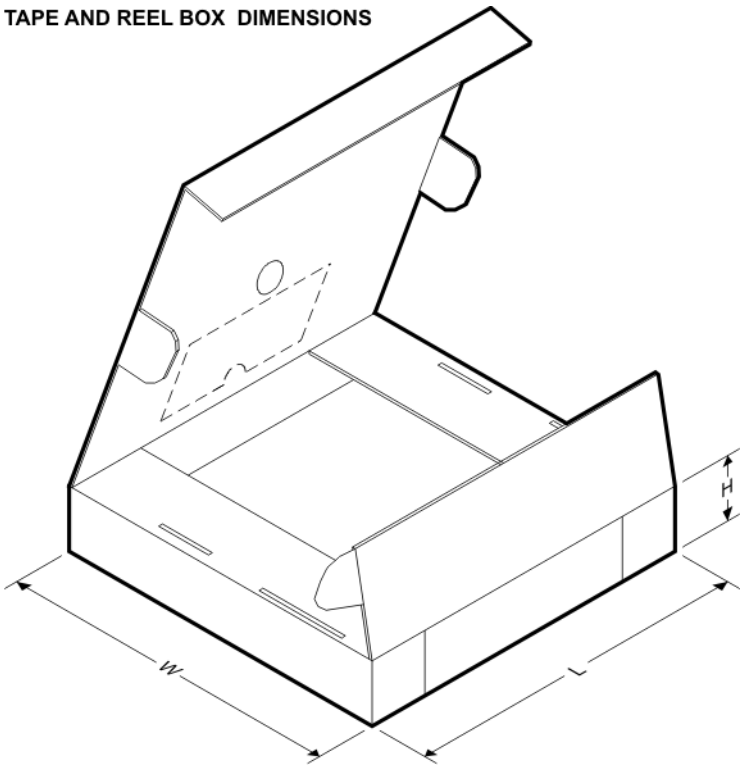
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
LM22678QTJ-5.0/NOPB	TO-263	NDR	7	1000	330.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678QTJ-ADJ/NOPB	TO-263	NDR	7	1000	330.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678QTJE-5.0/NOPB	TO-263	NDR	7	250	178.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678QTJE-ADJ/NOPB	TO-263	NDR	7	250	178.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678TJ-5.0/NOPB	TO-263	NDR	7	1000	330.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678TJ-ADJ/NOPB	TO-263	NDR	7	1000	330.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678TJE-5.0/NOPB	TO-263	NDR	7	250	178.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2
LM22678TJE-ADJ/NOPB	TO-263	NDR	7	250	178.0	24.4	10.6	15.4	2.45	12.0	24.0	Q2

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

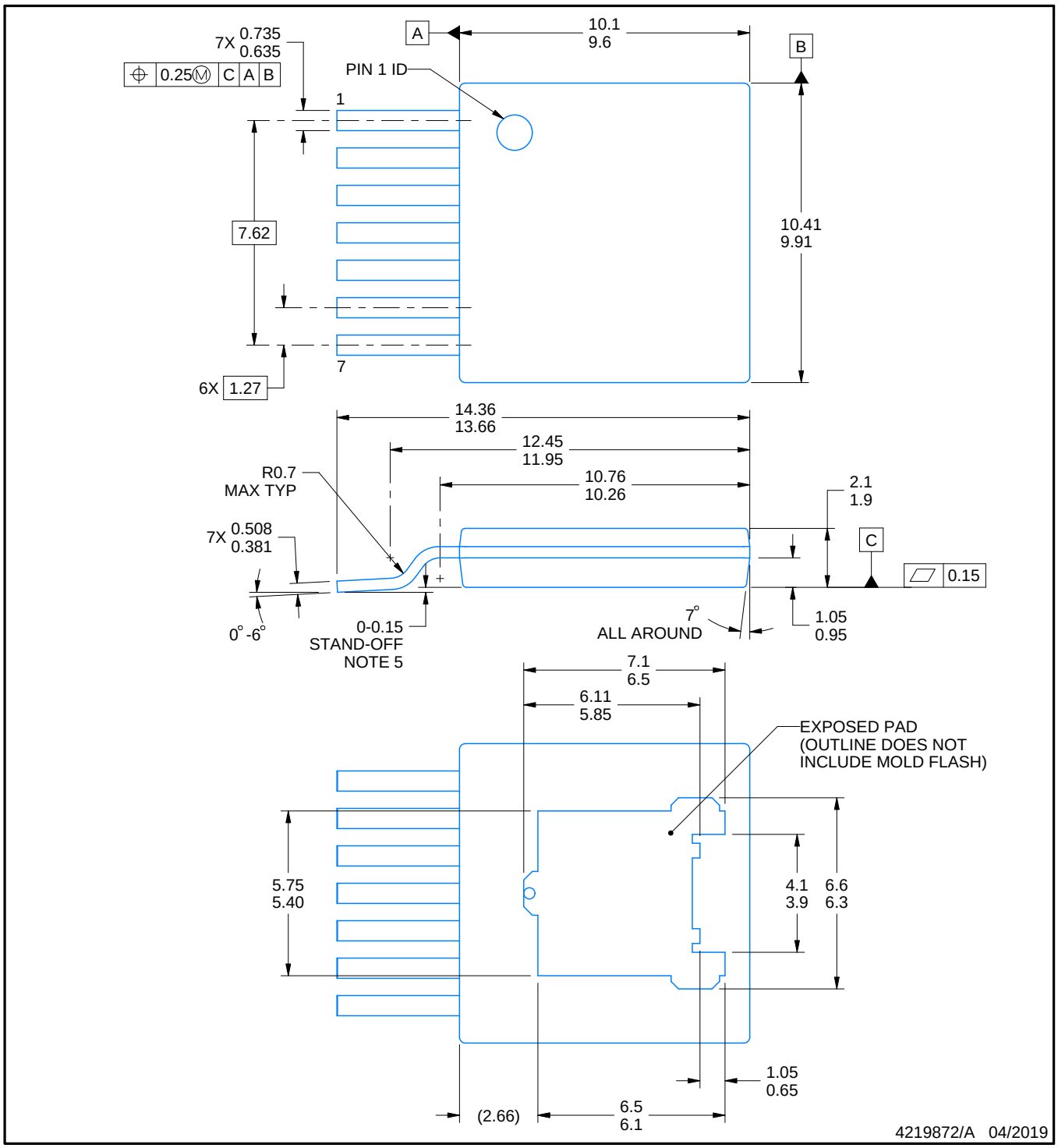
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM22678QTJ-5.0/NOPB	TO-263	NDR	7	1000	367.0	367.0	35.0
LM22678QTJ-ADJ/NOPB	TO-263	NDR	7	1000	367.0	367.0	35.0
LM22678QTJE-5.0/NOPB	TO-263	NDR	7	250	210.0	185.0	35.0
LM22678QTJE-ADJ/NOPB	TO-263	NDR	7	250	210.0	185.0	35.0
LM22678TJ-5.0/NOPB	TO-263	NDR	7	1000	367.0	367.0	35.0
LM22678TJ-ADJ/NOPB	TO-263	NDR	7	1000	367.0	367.0	35.0
LM22678TJE-5.0/NOPB	TO-263	NDR	7	250	210.0	185.0	35.0
LM22678TJE-ADJ/NOPB	TO-263	NDR	7	250	210.0	185.0	35.0

PACKAGE OUTLINE

NDR0007A

TO-263 - 2.25 mm max height

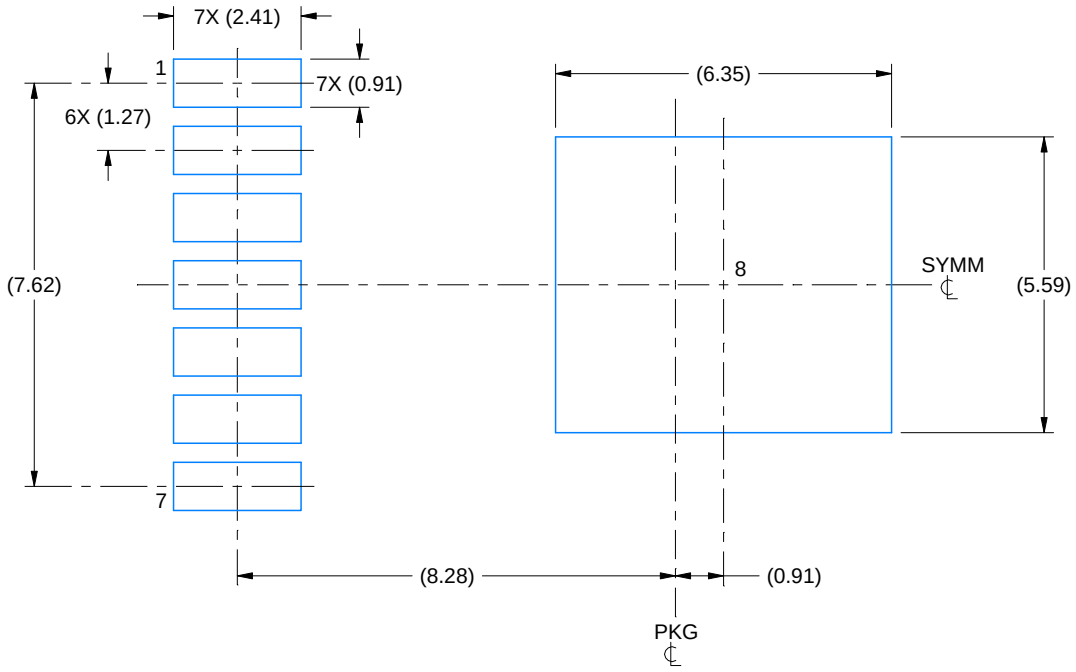
TO-263

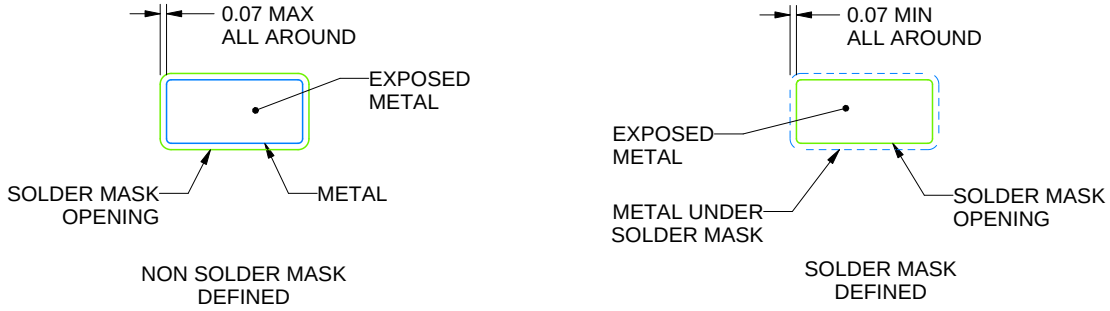


NOTES:

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. Features may not exist and shape may vary per different assembly sites.
4. Reference JEDEC registration TO-279B.
5. Under all conditions, leads must not be above Datum C

TO-263





SOLDER MASK DETAILS

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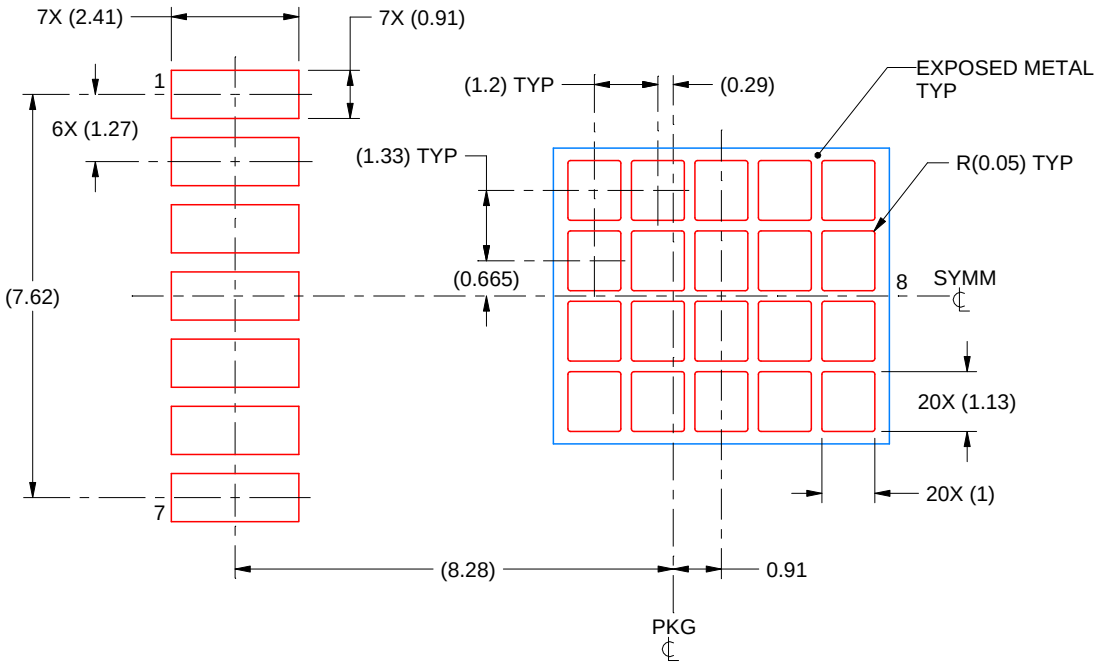
NOTES: (continued)

6. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature numbers SLMA002(www.ti.com/lit/slm002) and SLMA004 (www.ti.com/lit/slma004).
7. Vias are optional depending on application, refer to device data sheet. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD
64% PRINTED SOLDER COVERAGE BY AREA
SCALE:7X

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NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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