LM22678/-Q1 42-V, 5-A SIMPLE SWITCHER® Step-Down Voltage Regulator With Easy-to-Use Package

1 Features

- New product available: LM61460 3-V to 36-V, 6-A low EMI synchronous converter
- Wide input voltage range: 4.5 V to 42 V
- Internally compensated voltage mode control
- Stable with low-ESR ceramic capacitors
- 100-mΩ N-channel MOSFET
- Output voltage options:
  -ADJ (outputs as low as 1.285 V)
  -5.0 (output fixed to 5 V)
- ±1.5% Feedback reference accuracy
- Switching frequency of 500 kHz
- –40°C to 125°C Operating junction temperature range
- Precision enable pin
- Integrated bootstrap diode
- Integrated soft start
- Fully WEBENCH® enabled
- LM22678-Q1 is an automotive-grade product that is AEC-Q100 grade 1 qualified (–40°C to +125°C operating junction temperature)
- PFM (exposed pad) package

2 Applications

- Industrial distributed power applications
- Test and measurement
- Appliances
- General-purpose wide V_{IN} applications

3 Description

The LM22678 switching regulator provides all of the functions necessary to implement an efficient high-voltage step-down (buck) regulator using a minimum of external components. This easy-to-use regulator incorporates a 42-V N-channel MOSFET switch that can provide up to 5 A of load current. Excellent line and load regulation along with high efficiency (> 90%) are featured. Voltage mode control offers short minimum on-time, allowing the widest ratio between input and output voltages. Internal loop compensation means that the user is free from the tedious task of calculating the loop compensation components. Fixed 5-V output and adjustable output voltage options are available. A switching frequency of 500 kHz allows for small external components and good transient response. A precision enable input allows simplification of regulator control and system power sequencing. In shutdown mode the regulator draws only 25 µA (typical). Built-in soft-start (500 µs, typical) saves external components. The LM22678 device also has built-in thermal shutdown, and current limiting to protect against accidental overloads.

The new product, LM61460, offers higher efficiency, lower stand-by quiescent current, and improved EMI performance. See the device comparison table to compare.Start WEBENCH design with LM61460

The LM22678 device is a member of Texas Instruments' SIMPLE SWITCHER® family. The SIMPLE SWITCHER concept provides for an easy-to-use complete design using a minimum number of external components and the TI WEBENCH design tool. TI's WEBENCH tool includes features such as external component calculation, electrical simulation, thermal simulation, and Build-It boards for easy design-in.

Device Information

PART NUMBER	PACKAGE[1]	BODY SIZE (NOM)
LM22678	TO-263 (7)	10.16 mm x 9.85 mm
LM22678-Q1		

(1) For all available packages, see the orderable addendum at the end of the data sheet.
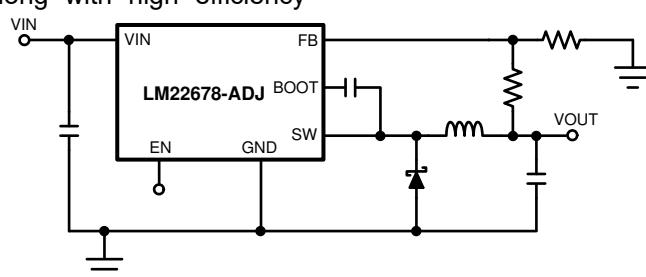

Simplified Application Schematic

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4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision L (November 2014) to Revision M (October 2020)   **Page**

- Added LM61460 bullet to the *Features* 1
- Updated the numbering format for tables, figures and cross-references throughout the document...................1
- Changed title from *LM22678/-Q1 42-V, 5-A SIMPLE SWITCHER® Step-Down Voltage Regulator With Features* to *LM22678/-Q1 42-V, 5-A SIMPLE SWITCHER® Step-Down Voltage Regulator With Easy to Use Package* 1

Changes from Revision K (March 2013) to Revision L (November 2014)   **Page**

- Added *Pin Configuration and Functions* section, *Handling Rating* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section 1
- Deleted *Inverting Regulator Application* 14

5 Pin Configuration and Functions
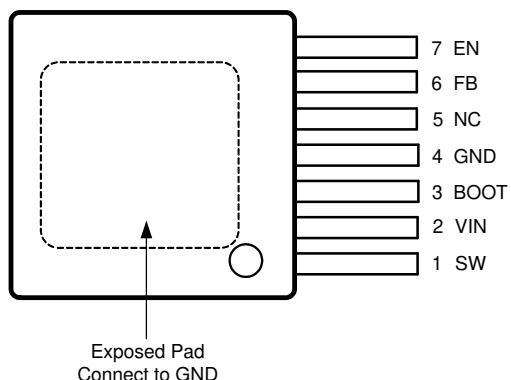
Figure 5-1. 7-Pin PFM Package (Top View)

Table 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 *Section 7.3.1*.
EP	EP	—	Exposed pad	Connect to ground. Provides thermal connection to PCB. See *Section 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 *Section 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)
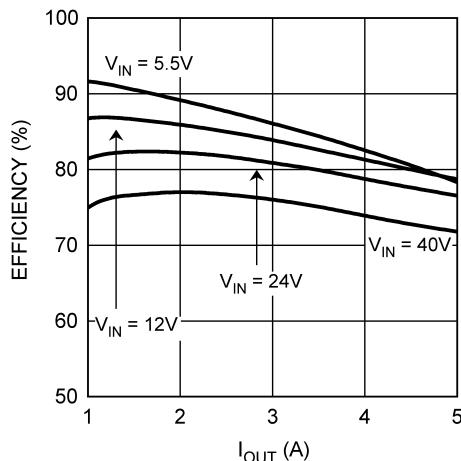
Figure 6-1. Efficiency vs I_{OUT} and V_{IN}, V_{OUT} = 3.3 V
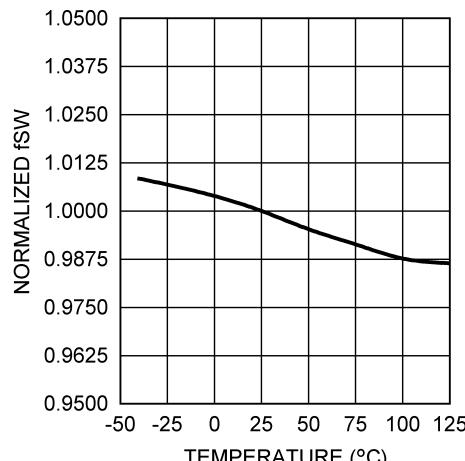
Figure 6-2. Normalized Switching Frequency vs Temperature
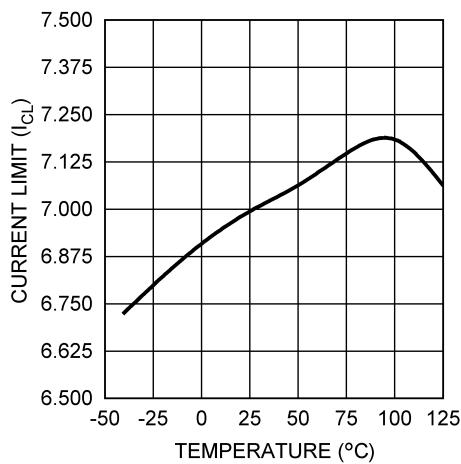
Figure 6-3. Current Limit vs Temperature
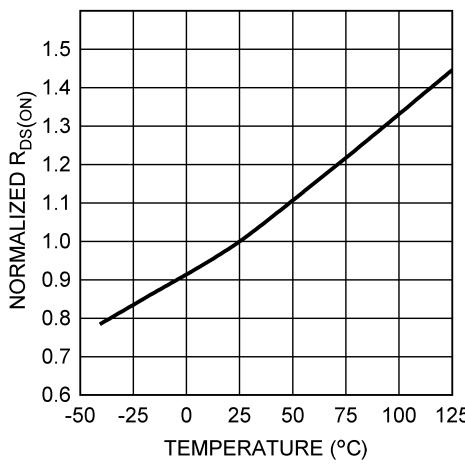
Figure 6-4. Normalized $R_{DS(ON)}$ vs Temperature
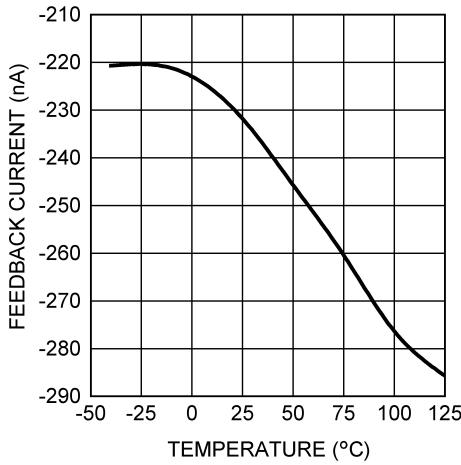
Figure 6-5. Feedback Bias Current vs Temperature
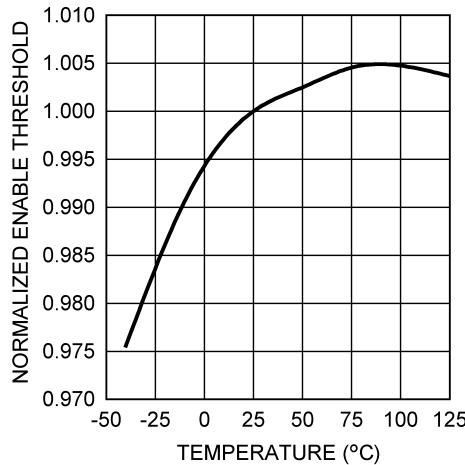
Figure 6-6. Normalized Enable Threshold Voltage vs Temperature

Product Folder Links: *LM22678 LM22678-Q1*
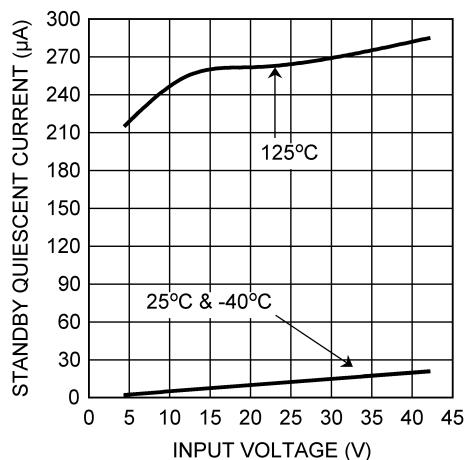
Figure 6-7. Standby Quiescent Current vs Input Voltage
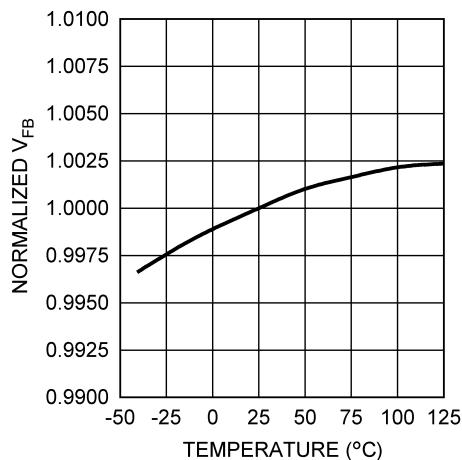
Figure 6-8. Normalized Feedback Voltage vs Temperature
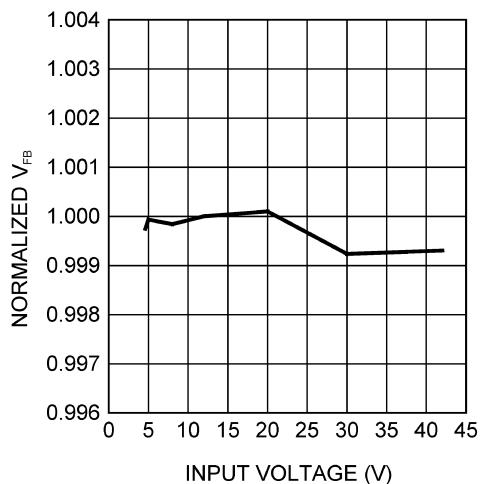
Figure 6-9. Normalized Feedback Voltage vs Input Voltage

Product Folder Links: *LM22678 LM22678-Q1*

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
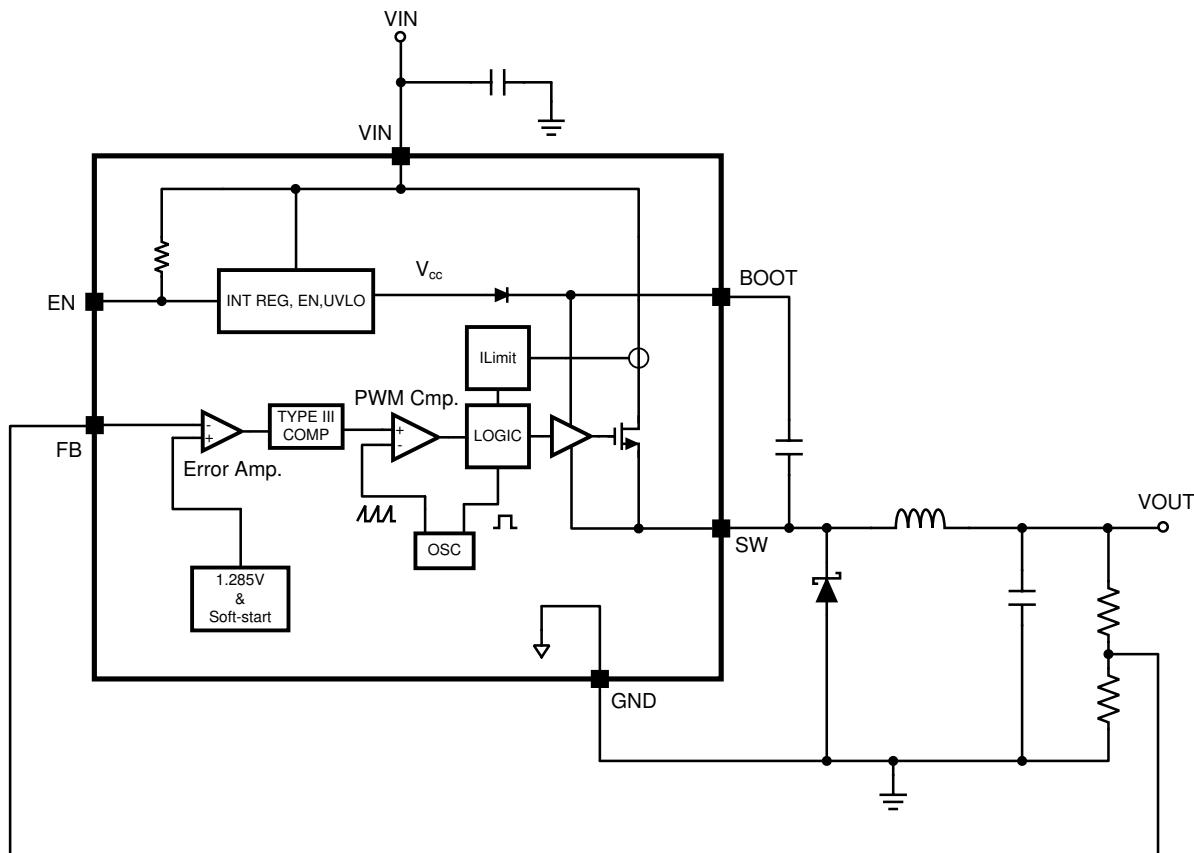
7.3 Feature Description

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. Figure 7-1 shows the connections to implement this method of UVLO. Equation 1 and Equation 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.
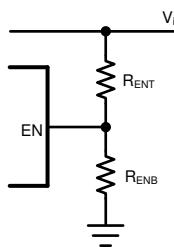
Figure 7-1. External UVLO Connections

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 Figure 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 Equation 3.

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

(3)

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

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

(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 *Section 8* for more details).
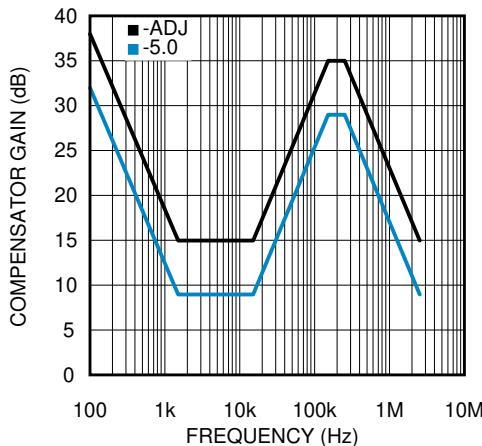
Figure 7-2. Compensator Gain

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 *Section 6.6* under the heading of I_{CL}. The maximum load current that can be provided, before current limit is reached, is determined from Equation 5.

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

(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. Equation 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 $\leq V_x$, during an overload, then a second criterion must be checked. Equation 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.

Note

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 Figure 7-3. Operating points below and to the right of the curve represent safe operation.


Figure 7-3. SOA

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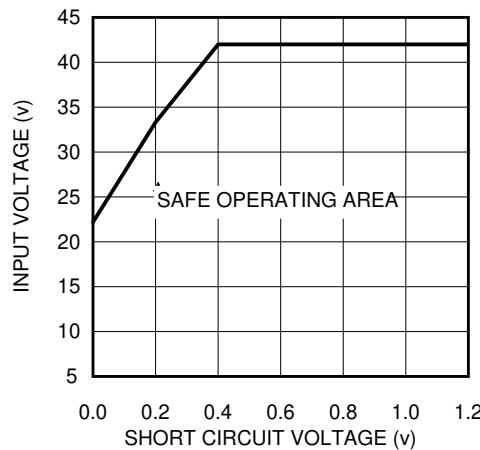
7.4.4 Thermal Protection

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. Equation 8 can be used to determine the approximate maximum input voltage for a given output voltage.

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

(8)

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

Both values can be found in *Section 6.6*.

The worst case occurs at the lowest output voltage. If the input voltage found in Equation 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. Equation 9 can be used to approximate the minimum input voltage before dropout occurs.

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

(9)

where
- The values of T_{OFF} and $R_{DS(ON)}$ are found in *Section 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

Note

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

8.1 Application Information

The 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. *Section 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 Figure 8-1. Equation 10 can be used to calculate the resistor values of this divider.

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

(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 *Section 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, Equation 11 should be used to determine the resistor values in the output divider.

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

(11)

Again, a value of R_{FBB} of about 1 kΩ is a good first choice.
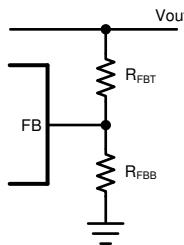
Figure 8-1. Resistive Feedback Divider

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

Figure 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.
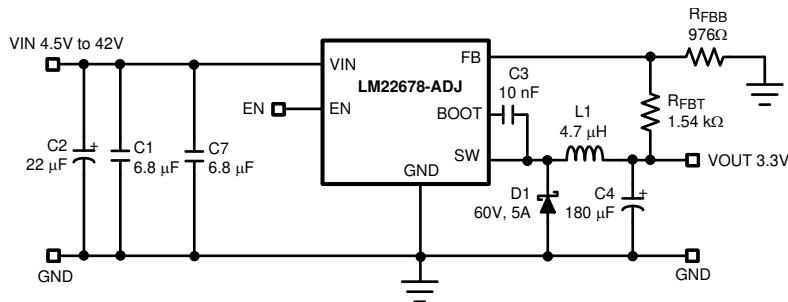

Figure 8-2. Typical Buck Regulator Application

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 Equation 12.

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

(12)

where

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

Equation 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 Equation 13.

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

(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 *Section 6.6*. Good design practice requires that the inductor rating be adequate for this overload condition.

Note

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 Equation 14.

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

(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. Equation 15 determines an approximation to this current.

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

(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, Equation 16 determines an approximation to the output voltage ripple.

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

(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
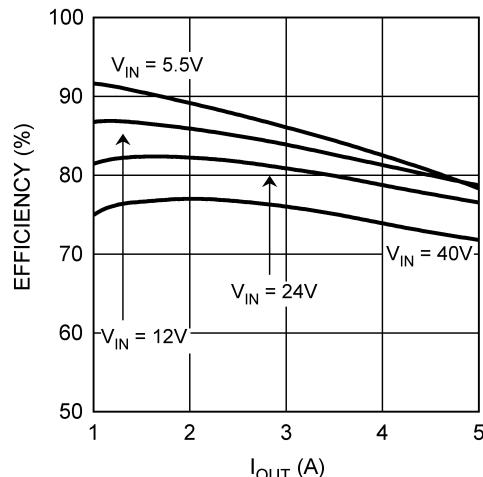
Figure 8-3. Efficiency vs I_OUT and V_IN, V_OUT = 3.3 V
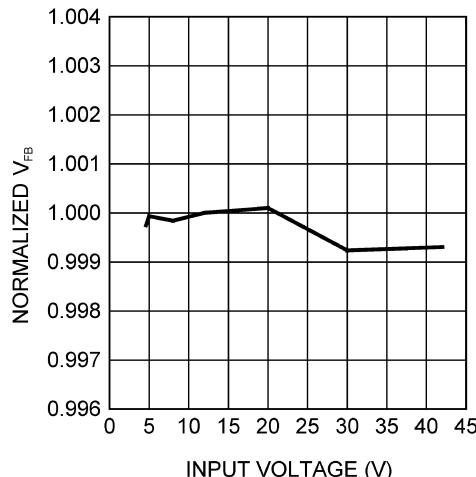
Figure 8-4. Normalized Feedback Voltage vs Input Voltage

Product Folder Links: *LM22678 LM22678-Q1*

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. Figure 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 Figure 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.
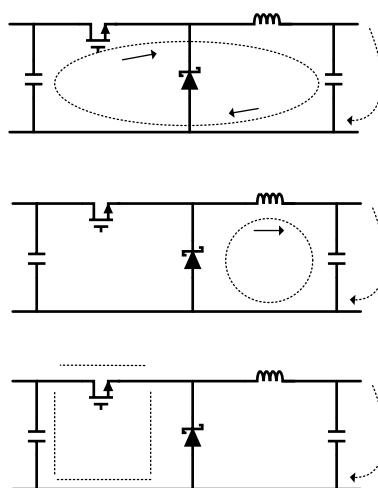
Figure 9-1. Current Flow in a Buck Application

9.2 Layout Example
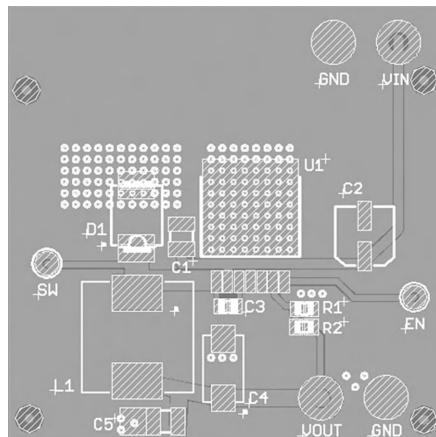
Figure 9-2. LM22678 Layout Example

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 Equation 17.

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

(17)

where

- V_D is the diode voltage drop.

An approximation for the inductor power is determined by Equation 18.

$$P_L = I_{out}^2 \cdot R_L \cdot 1.1$$

(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 *Section 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 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

10.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Subscribe to updates* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

10.4 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

10.5 Glossary

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

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 part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
LM22678QTJ-5.0/NO.A	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-5.0
LM22678QTJ-5.0/NO.B	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	-	Call TI	Call TI	-40 to 125	
LM22678QTJ-5.0/NOPB	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-5.0
LM22678QTJ-ADJ/NO.A	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-ADJ
LM22678QTJ-ADJ/NOPB	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-ADJ
LM22678QTJE-5.0/NO.A	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-5.0
LM22678QTJE-5.0/NOPB	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-5.0
LM22678QTJE-ADJ/NO.A	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-ADJ
LM22678QTJE-ADJ/NOPB	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 QTJ-ADJ
LM22678TJ-5.0/NOPB	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-5.0
LM22678TJ-5.0/NOPB.A	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-5.0
LM22678TJ-ADJ/NOPB	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-ADJ
LM22678TJ-ADJ/NOPB.A	Active	Production	TO-263 (NDR) | 7	1000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-ADJ
LM22678TJE-5.0/NO.A	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-5.0
LM22678TJE-5.0/NOPB	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-5.0
LM22678TJE-ADJ/NO.A	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-ADJ
LM22678TJE-ADJ/NOPB	Active	Production	TO-263 (NDR) | 7	250 | SMALL T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	LM22678 TJ-ADJ

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

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

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

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

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

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF LM22678, LM22678-Q1 :

- Catalog : LM22678

- Automotive : LM22678-Q1

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION

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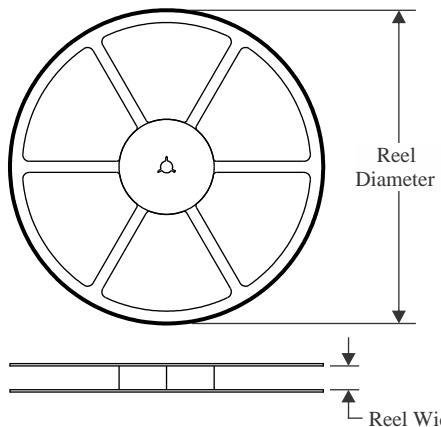
TAPE DIMENSIONS
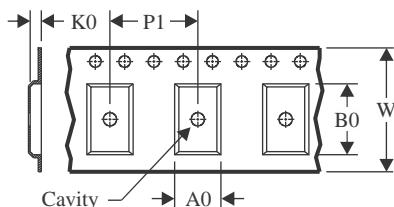
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE
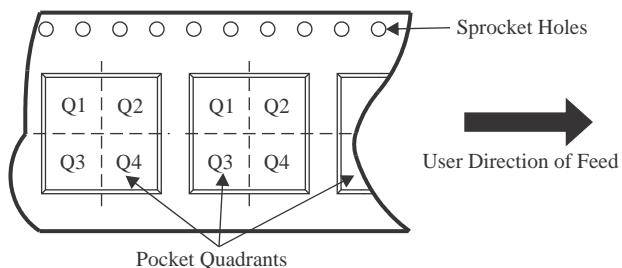
*All dimensions are nominal

| Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
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

7X $\dfrac{0.735}{0.635}$

$\oplus$ | 0.25 Ⓜ | C | A | B

A | $\dfrac{10.1}{9.6}$ | B

PIN 1 ID

1

7.62

$\dfrac{10.41}{9.91}$

7

6X | 1.27

$\dfrac{14.36}{13.66}$

$\dfrac{12.45}{11.95}$

$\dfrac{10.76}{10.26}$

R0.7 MAX TYP

$\dfrac{2.1}{1.9}$

7X $\dfrac{0.508}{0.381}$

C

$\boxed{\diagdown}$ | 0.15

0°-6°

0-0.15 STAND-OFF NOTE 5

7° ALL AROUND

$\dfrac{1.05}{0.95}$

$\dfrac{7.1}{6.5}$

$\dfrac{6.11}{5.85}$

EXPOSED PAD (OUTLINE DOES NOT INCLUDE MOLD FLASH)

$\dfrac{5.75}{5.40}$

$\dfrac{4.1}{3.9}$ $\dfrac{6.6}{6.3}$

$\dfrac{1.05}{0.65}$

(2.66)

$\dfrac{6.5}{6.1}$
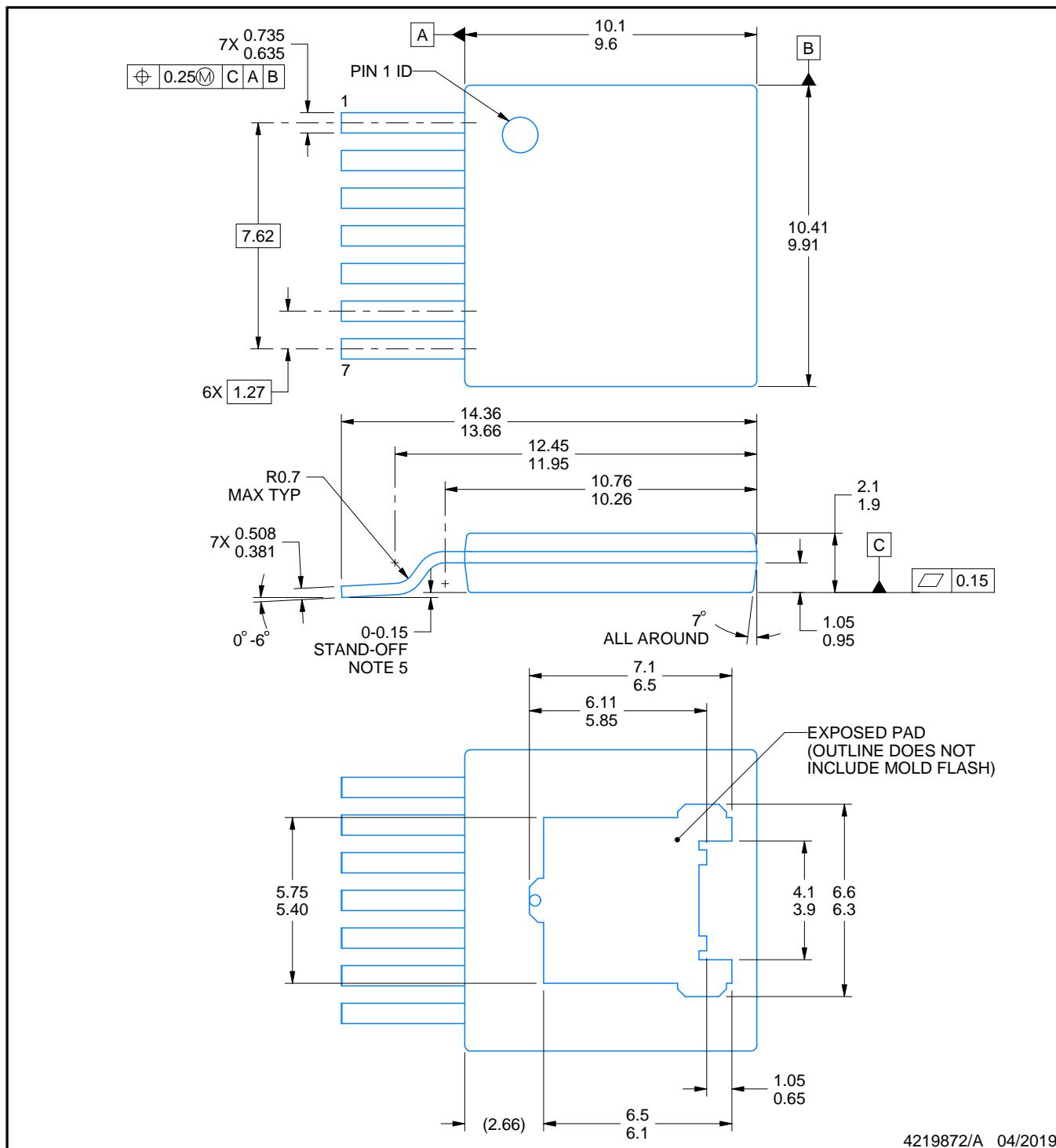
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NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. 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

7X (2.41)

7X (0.91)

1

6X (1.27)

(6.35)

(7.62)

8

SYMM

(5.59)

7

(8.28)

(0.91)

PKG

0.07 MAX
ALL AROUND

EXPOSED
METAL

SOLDER MASK
OPENING

METAL

NON SOLDER MASK
DEFINED

0.07 MIN
ALL AROUND

EXPOSED
METAL

SOLDER MASK
OPENING

METAL UNDER
SOLDER MASK

SOLDER MASK
DEFINED

SOLDER MASK DETAILS

4219872/A   04/2019
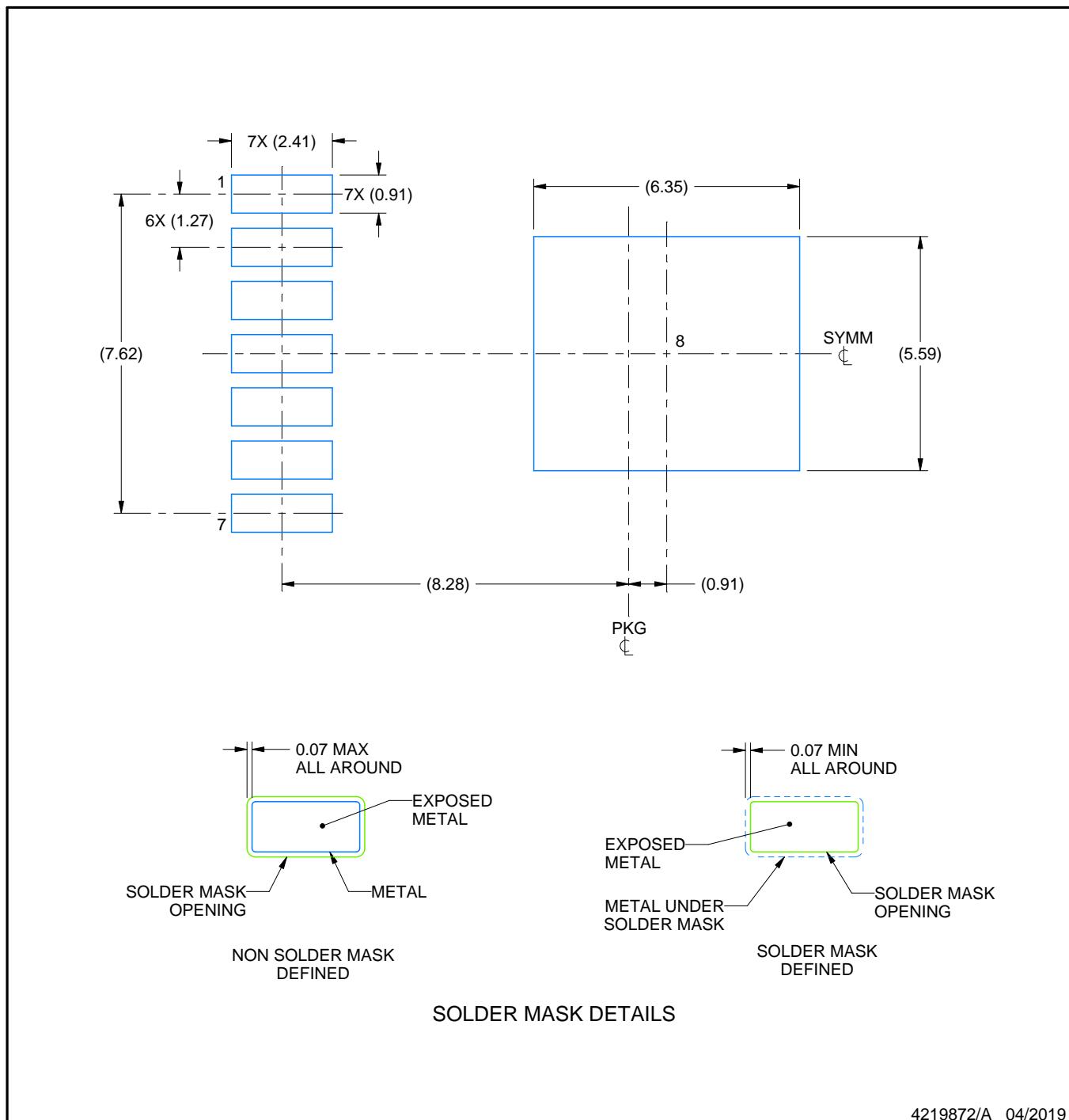
NOTES: (continued)

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.

7X (2.41)

7X (0.91)

1

6X (1.27)

(1.2) TYP

(0.29)

EXPOSED METAL
TYP

(1.33) TYP

R(0.05) TYP

(7.62)

(0.665)

8   SYMM
℄

20X (1.13)

7

20X (1)

(8.28)

0.91

PKG
℄
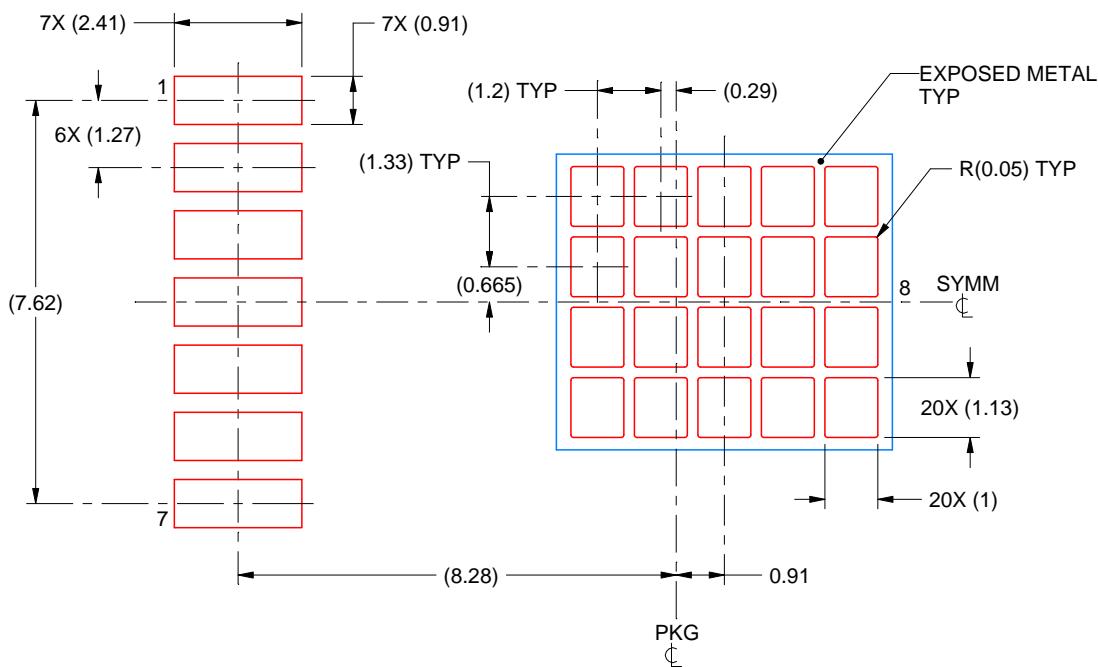
SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

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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