

TMP815 Variable-Speed Single-Phase Full-Wave Fan-Motor Predriver

1 Features

- Single-Phase Full-Wave Driving Predriver
 - Low Saturation Drive Using External P-channel Devices at Top and N-channel Devices in Bottom in H-bridge Configuration Enables High-Efficiency Low-Power Consumption Drive
- Variable Speed Control Possible With External PWM Input
 - Separately Excited Upper Direct PWM ($f = 30$ kHz) Control Method Ensures Quiet Speed Control
- Current Limiter Circuit Incorporated
 - Chopper Type Current Limiting Made at Start-up and During Lock
- Reactive Current Cut Circuit Incorporated
 - Reactive Current Before Phase Change Is Cut to Enable Silent and Low-Consumption Drive
- Minimum-Speed Setting Pin
 - Minimum Speed Can be Set With External Resistor
- Soft-Start Setting Pin
- Lock Protection and Automatic Reset Circuits Incorporated

- Rotation Speed Detection (FG) and Lock Detection (RD) Output
- Thermal Shutdown Circuit Incorporated

2 Applications

- Server Fans
- Appliance Fans

3 Description

The TMP815 device is a single-phase bipolar driving motor predriver with a variable-speed function that is compatible with an external PWM signal. A highly efficient and quiet variable-drive fan motor with low-power consumption can be achieved with few external parts.

This device is best suited for driving of the servers requiring large air flow and large current or the fan motors of consumer appliances.

Device Information ⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TMP815	TSSOP (PW)	4.40 mm × 5.00 mm

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

Simplified Schematic

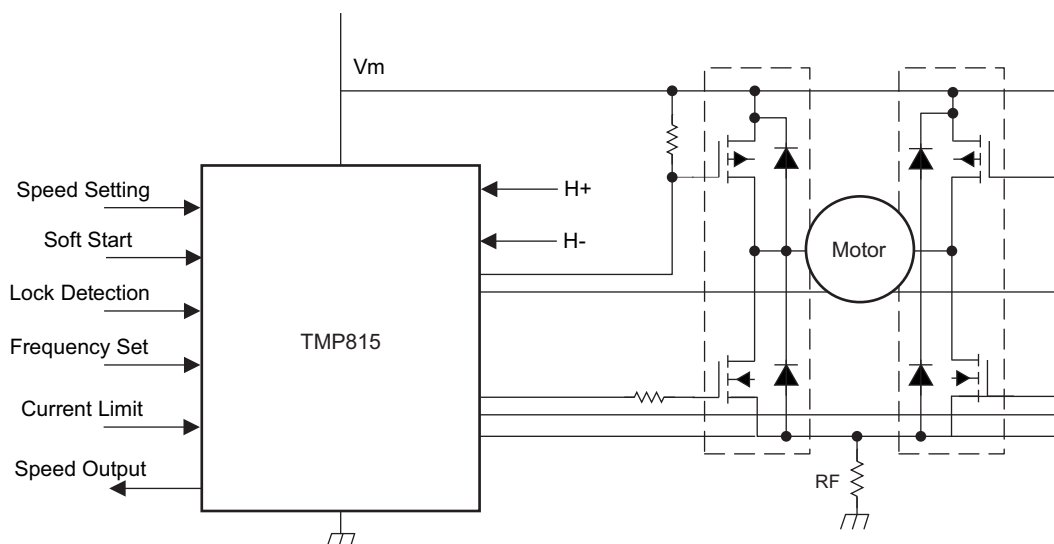


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4 Revision History

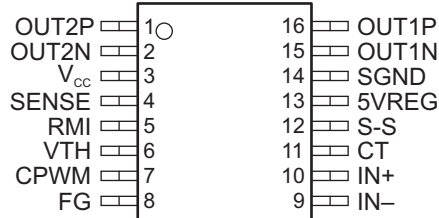
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (May 2015) to Revision B	Page
Changed the <i>Operating free-air temperature</i> from (-30 to 95 °C) to (-40 to 125 °C) in the <i>Recommended Operating Conditions</i> table and added characterization data for the new temperature range in the <i>Electrical Characteristics</i> table	4

Changes from Original (May 2009) to Revision A	Page
Added <i>ESD Ratings</i> table, <i>Feature Description</i> section, <i>Device Functional Modes</i>, <i>Application and Implementation</i> section, <i>Power Supply Recommendations</i> section, <i>Layout</i> section, <i>Device and Documentation Support</i> section, and <i>Mechanical, Packaging, and Orderable Information</i> section	1

5 Pin Configuration and Functions

**PW Package
16-Pin TSSOP
Top View**



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
OUT2P	1	O	Upper-side driver output
OUT2N	2	O	Lower-side driver output
V _{CC}	3		Power supply For the power stabilization capacitor on the signal side (see *2 in Figure 5), use the capacitance of 1 μ F or more. Connect V _{CC} and GND with a thick and short pattern. For the power stabilization capacitor on the power side (see *3 in Figure 5), use the capacitance of 1 μ F or more. Connect the power supply on the power side and GND with a thick and short pattern.
SENSE	4	I	Current limiting detection (see *8 in Figure 5) When the pin voltage exceeds 0.2 V, the current is limited, and the operation enters the lower regeneration mode. Connect to GND if not used.
RMI	5	I	Minimum speed setting (see *6 in Figure 5) If the device power supply is likely to be turned off first when the pin is used with external power supply, insert a current limiting resistor to prevent inflow of large current (also applies to VTH terminal). Connect to 5VREG with a pullup resistor if not used.
VTH	6	I	Speed control (see *7 in Figure 5) For control with pulse input, insert a current limiting resistor and use the pin with a frequency of 20 kHz to 100 kHz (TI recommends 20 kHz to 50 kHz). For the control method, see Figure 2 . Connect to GND if not used (at full speed).
CPWM	7	O	Connection to capacitor for generation of PWM basic frequency (see *5 in Figure 5) CP = 220 pF causes oscillation at f = 30 kHz, which is the basic frequency of PWM. As this is also used for the current limiting canceling signal, be sure to connect the capacitor even when speed control is not used.
FG	8	O	Rotation speed detection pin (see *9 in Figure 5) This is an open-collector output, which can detect the rotation speed from the FG output according to the phase change over. Keep this pin open when not used.
IN–	9	I	Hall input (see *4 in Figure 5)
IN+	10	I	Hall input. Make connecting traces as short as possible to prevent carrying of noise. To further limit noise, insert a capacitor between IN+ and IN–. The Hall input circuit is a comparator having a hysteresis of 15 mV. Also includes a soft-switch section with ± 30 -mV input-signal differential voltage. TI recommends that the Hall input level is a minimum of 100 mV _{p-p} .
CT	11	O	Connection to the lock detection capacitor (see *10 in Figure 5) The constant current charge and discharge circuits cause locking when the pin voltage rises to 3 V and unlocking when pin voltage falls to 1.1 V. Connect to GND when not used (when locking is not necessary).
S-S	12	I	Connection to the soft-start setting capacitor (see *11 in Figure 5) Connect the capacitor between S-S and 5VREG to set the soft-start time, according to the capacitance that is chosen (see Figure 3 and Figure 4). Connect to GND when not used.
5VREG	13	O	5-V regulator output
SGND	14		System ground (see *1 in Figure 5) Connection to the control-circuit power-supply system
OUT1N	15	O	Lower-side driver output
OUT1P	16	O	Upper-side driver output

6 Specifications

6.1 Absolute Maximum Ratings

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

			MIN	MAX	UNIT
V _{CC}	Supply voltage			18	V
V _{OUT}	Output voltage	OUT1P, OUT1N, OUT2P, OUT2N		18	V
I _{OUT}	Continuous output current	OUT1N, OUT2N		–20	mA
		OUT1P, OUT2P		20	
V _{VTH} V _{RMI}	Input voltage	VTH, RMI		7	V
V _{S-S}	Input/output voltage	S-S		7	V
V _{FG}	Output voltage	FG		19	V
I _{FG}	Continuous output current	FG		10	mA
I _{SVREG}	Continuous output current	5VREG		–20	mA
T _{stg}	Storage temperature		–65	150	°C

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

6.2 ESD Ratings

		VALUE	UNIT
V _(ESD)	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins ⁽¹⁾	±2500	V
	Charged device model (CDM), per JEDEC specification JESD22-C101, all pins ⁽²⁾	±1000	

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

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

6.3 Recommended Operating Conditions

T_A = 25°C

		MIN	MAX	UNIT
V _{CC}	Supply voltage	6	16	V
V _{VTH}	VTH input voltage	0	5	V
V _{RMI}	RMI input voltage	0	5	V
V _{ICM}	Hall input common phase input voltage	0.2	3	V
T _A	Operating free-air temperature	–40	125	°C

6.4 Thermal Information

THERMAL METRIC ⁽¹⁾		TMP815	UNIT
		PW (TSSOP)	
		16 PINS	
R _{θJA}	Junction-to-ambient thermal resistance	108	°C/W
R _{θJC(top)}	Junction-to-case (top) thermal resistance	94.2	°C/W
R _{θJB}	Junction-to-board thermal resistance	31.5	°C/W
ψ _{JT}	Junction-to-top characterization parameter	38.9	°C/W
ψ _{JB}	Junction-to-board characterization parameter	1.9	°C/W
R _{θJC(bot)}	Junction-to-case (bottom) thermal resistance	38.3	°C/W

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

6.5 Electrical Characteristics

 $V_{CC} = 12\text{ V}$, $T_A = 25^\circ\text{C}$ (unless otherwise noted)

PARAMETER			TEST CONDITIONS		MIN	TYP	MAX	UNIT
V _{5VREG}	Output voltage	5VREG	I _{5VREG} = −5 mA	T _A = 25°C	4.8	4.95	5.1	V
				T _A = −40°C to +125°C			5.2	
V _{LIM}	Current limiting voltage	SENSE	T _A = 25°C		185	200	215	mV
			T _A = −40°C to +125°C				250	
V _{CPWMH}	High-level output voltage	CPWM			2.8	3	3.2	V
V _{CPWML}	Low-level output voltage				0.9	1.1	1.3	V
I _{CPWM1}	Charge current		V _{CPWM} = 0.5 V		24	30	36	μA
I _{CPWM2}	Discharge current		V _{CPWM} = 3.5 V		21	27	33	μA
f _{PWM}	Oscillation frequency		CP = 220 pF			30		kHz
V _{CTH}	High-level output voltage	CT			2.8	3	3.2	V
V _{CTL}	Low-level output voltage				0.9	1.1	1.3	V
I _{CT1}	Charge current				1.6	2	2.5	μA
I _{CT2}	Discharge current				0.16	0.2	0.25	μA
R _{CT}	Charge/discharge current ratio				8	10	12	
I _{S-S}	Discharge current	S-S	V _{S-S} = 1 V		0.4	0.5	0.6	μA
V _{ONH}	High-level output voltage	OUT_N	I _{OH} = −10 mA		V _{CC} − $\frac{1}{1}$ V _{CC} − 0.85			V
V _{ONL}	Low-level output voltage		I _{OL} = 10 mA	T _A = 25°C	0.9			1
		T _A = −40°C to +125°C					1.05	
V _{OPL}	Low-level output voltage	OUT_P	I _{OL} = 10 mA			0.5	0.65	V
V _{HN}	Hall input sensitivity	IN+, IN-	IN+, IN− differential voltage (including offset and hysteresis)			±10	±20	mV
V _{FG}	Low-level output voltage	FG	I _{FG} = 5 mA	T _A = 25°C	0.15			0.3
				T _A = −40°C to +125°C				0.41
I _{FGL}	Output leakage current		V _{FG} = 19 V				20	μA
I _{VTH} I _{RMI}	Bias current	VTH, RMI	V _{CPWM} = V _{VTH} = V _{RMI} = 2 V, V _{CT} = 0 V				0.1	μA
I _{CC}	Supply current	V _{CC}	During drive		4	7.5	9.5	mA
			During lock protection		4	7.5	9.5	

6.6 Typical Characteristics

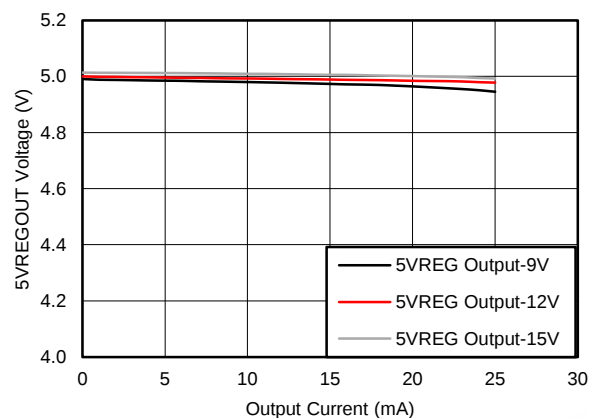


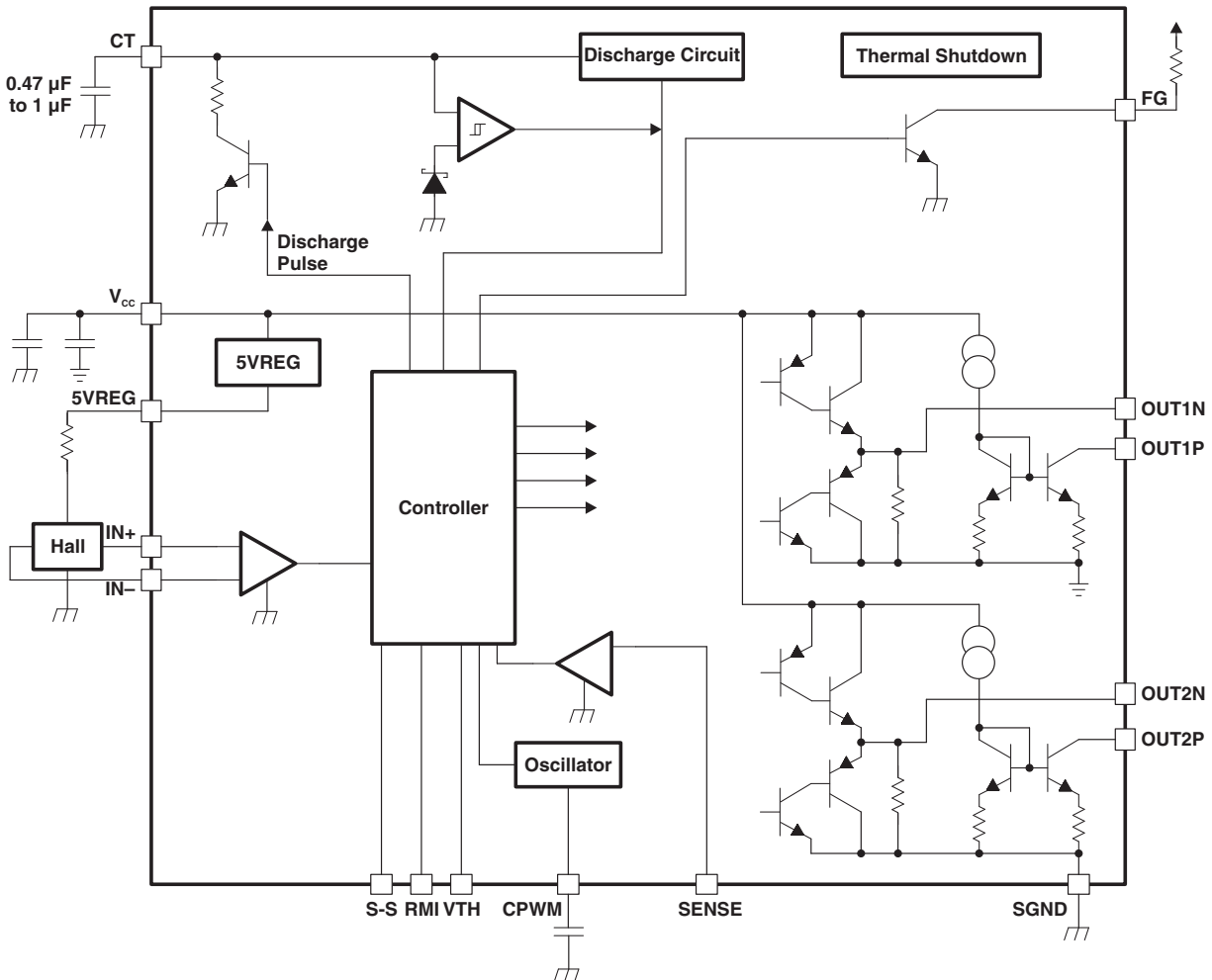
Figure 1. 5VREG Output Voltage (V) vs Output Current (mA)

7 Detailed Description

7.1 Overview

The TMP815 device is a single phase bipolar predriver which uses the hall sensor and speed control inputs for driving the single phase motor connected through the H Bridge. The predriver outputs are designed for driving top side P-channel and bottom side N-channel FETs in the bridge. Multiple protections like overcurrent, soft start, speed control, lock detect, speed feedback and minimum speed are incorporated in the device.

7.2 Functional Block Diagram

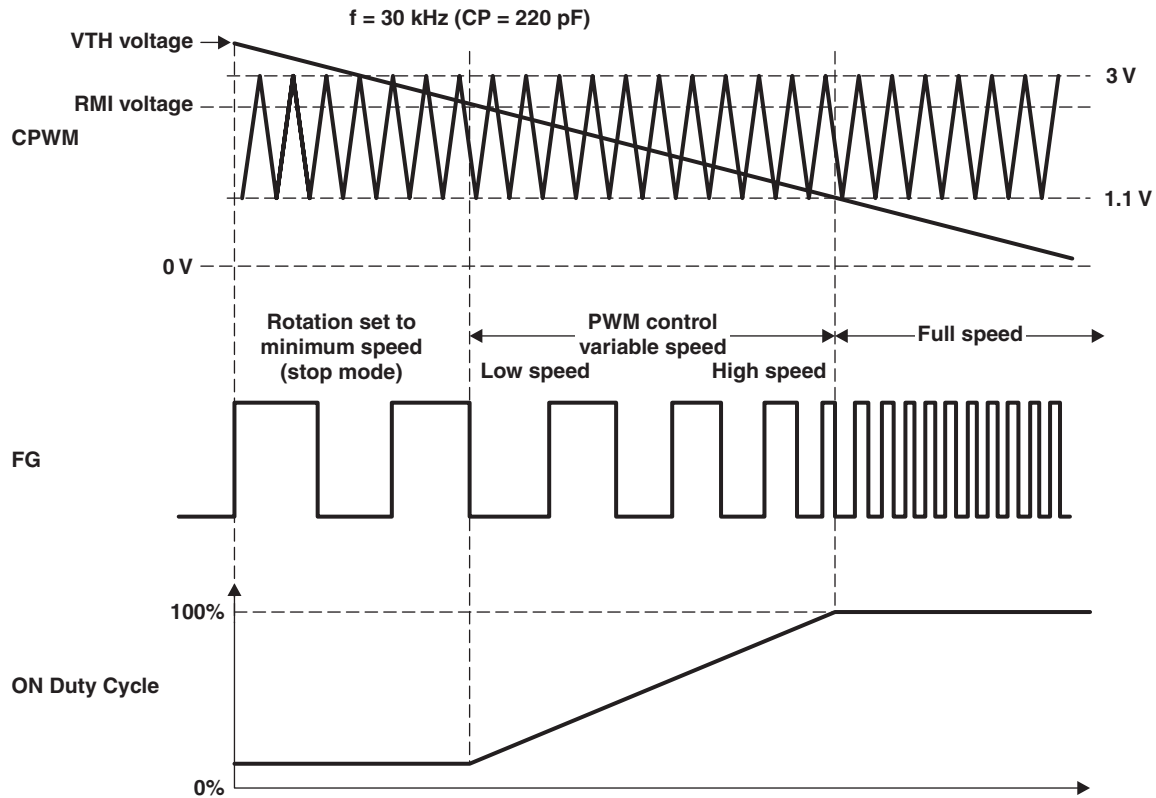


7.3 Feature Description

7.3.1 Speed Control

The speed control functionality is obtained by VTH pin of the device. For pulsed inputs, the user can supply a 20-kHz to 100-kHz frequency input (20 kHz to 50 kHz recommended) on the pin with a current limiting resistor in between.

If not used, this pin needs to be connected to ground for full speed.



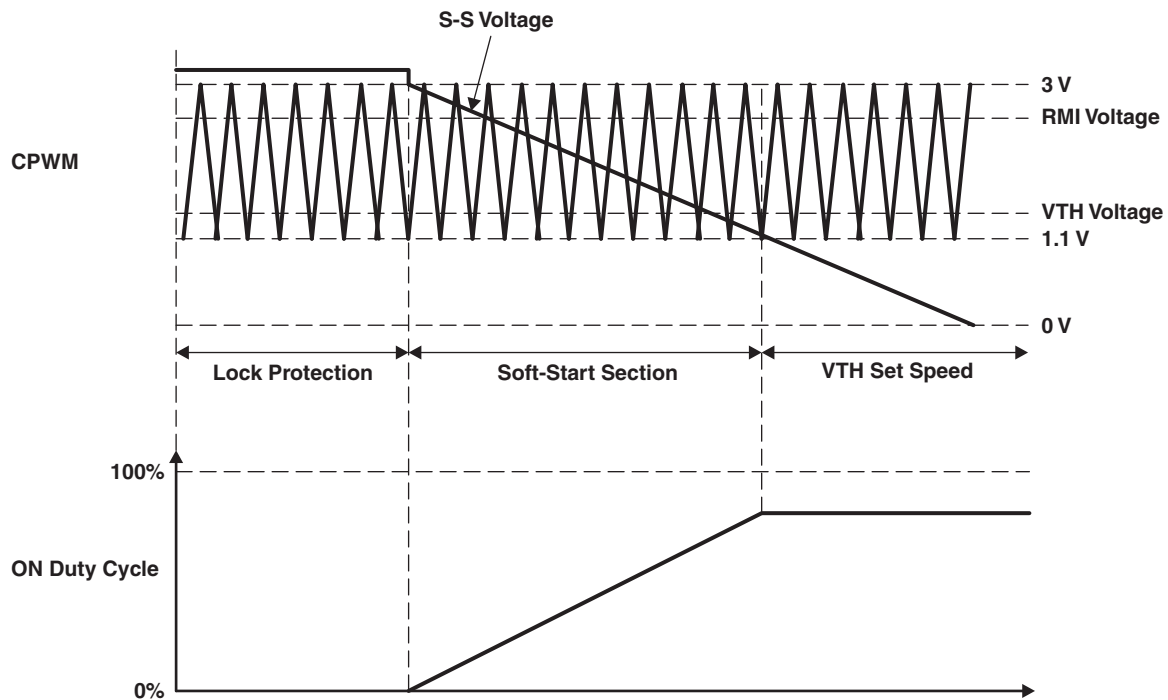
- Minimum speed setting (stop) mode. The low speed fan rotation occurs at the minimum speed set with the RMI pin. When the minimum speed is not set (RMI pin pulled up to 5VREG), the motor stops.
- Low ↔ high-speed. PWM control is made by comparing the CPWM oscillation voltage (1.1 V ↔ 3 V) and VTH voltage. Both upper and lower output TRs are turned ON when the VTH voltage is low. The upper output TR is turned OFF when the VTH voltage is high, regenerating the coil current in the lower TR. Therefore, as the VTH voltage decreases, the output on duty cycle increases, causing an increase in the coil current, raising the motor rotation speed. The rotation speed can be monitored with the FG output.
- Full-speed mode. The full-speed mode becomes effective with the VTH voltage of 1.65 V or less. (VTH must be equal to GND when the speed control is not used.)
- PWM-IN input disconnection mode. The full-speed mode becomes effective when the VTH voltage is 1.1 V or less. Set VTH = GND when the speed control is not used.

Figure 2. Speed Control Timing

7.3.2 Soft-Start

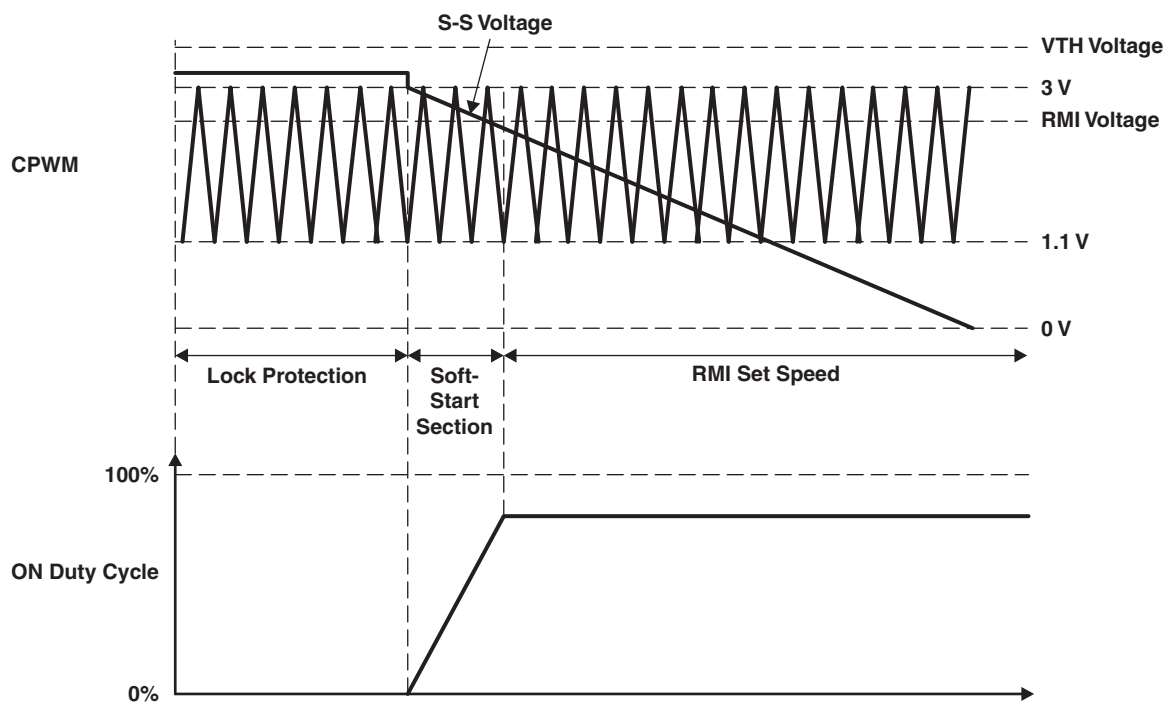
The speed control functionality is obtained by S-S pin of the device. Connection to the soft-start setting capacitor (see [Figure 5](#)) is through this pin. Connect the capacitor between S-S and 5VREG to set the soft-start time, according to the capacitance that is chosen (see [Figure 3](#) and [Figure 4](#)). If the soft-start feature is not intended to be used, then the this pin needs to be connected to ground.

Feature Description (continued)



Adjust the S-S pin voltage gradient by means of the capacitance of the oscillator between the S-S pin and 5VREG. Recommended capacitance is 0.1 μ F to 1 μ F.

Figure 3. Soft-Start Timing ($V_{VTH} < V_{RMI}$)



Adjust the S-S pin voltage gradient by means of the capacitance of the oscillator between the S-S pin and 5VREG. Recommended capacitance is 0.1 μ F to 1 μ F.

Figure 4. Soft-Start Timing ($V_{VTH} > V_{RMI}$)

Feature Description (continued)

7.3.3 Lock Detection

When the rotor is locked by external means or load conditions, The lock detection feature helps to protect the circuit by not allowing the current to rise beyond control. A hiccup mechanism is also provided. The lock detection is enabled by a connection to the lock detection capacitor (see *10 in [Figure 5](#)) The constant current charge and discharge circuits cause drive stop when the pin voltage rises to 3 V and unlocking the drive when pin voltage falls to 1.1 V. If lock detection feature is not desired in the application, this pin needs to be connected to ground.

7.3.4 Current Limit

Current limit resistor is connected in a return path of H Bridge connection. This input is connected to the SENSE pin where the Current is limited when the voltage across this resistor crosses 200-mV threshold. The device enters in lower regeneration mode (see *8 in [Figure 5](#)) If not used, this pin needs to be connected to ground.

7.3.5 Minimum Speed Setting

Minimum speed setting (see *6 in [Figure 5](#)) feature is use with the RMI pin in the device. Connect to 5VREG with a pullup resistor if not used.

7.3.6 Speed Output

The speed of the motor while running can be observed at the FG pin which is an open collector output and needs to be pulled high for using it.

7.3.7 Drive Frequency Selection

The P channel switches in the device are switched with higher frequency whose duty cycle is decided by the speed control input. The frequency of the operation can be decided by the capacitor connected at the CPWM pin. As this is used also for the current limiting canceling signal, be sure to connect the capacitor even when speed control is not used.

7.4 Device Functional Modes

Table 1. Drive Lock Truth Table ^{(1) (2)}

IN–	IN+	CT	OUT1P	OUT1N	OUT2P	OUT2N	FG	MODE
H	L	L	L	L	OFF	H	L	OUT1 → 2 drive
L	H	L	OFF	H	L	L	OFF	OUT2 → 1 drive
H	L	H	OFF	L	OFF	H	L	Lock protection
L	H	H	OFF	H	OFF	L	OFF	

(1) For VTH, RMI, and S-S pins, see [Figure 2](#).

(2) CPWM = H, VTH = RMI = S-S = L

Table 2. Speed Control Truth Table ^{(1) (2)}

VTH, RMI	CPWM	IN–	IN+	OUT1P	OUT1N	OUT2P	OUT2N	MODE
L	H	H	L	L	L	OFF	H	OUT1 → 2 Drive
L	H	L	H	OFF	H	L	L	OUT2 → 1 Drive
H	L	H	L	OFF	L	OFF	H	Regeneration mode
H	L	L	H	OFF	H	OFF	L	

(1) For VTH, RMI, and S-S pins, see [Figure 2](#).

(2) CT = S-S = L

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 TMP815 device needs few external components for the features described in [Feature Description](#) . The device needs a 1- μ F or greater capacitor connected at VCC. The device generates 5-V regulated output which can be used for pullups in the circuit as well as the Hall sensor.

Figure 5 shows the typical application diagram.

Figure 5. 12-V Sample Application Circuit

- Input Voltage: 6 to 16 V
- VCC capacitor: 1 μ F or more
- H Bridge top side: P-channel FETs
- H Bridge bottom side: N-channel FETs

Typical Application (continued)

8.2.2 Detailed Design Procedure

Pins:

- CPWM Capacitor: 220 pF for 30-kHz switching or appropriate.
- VTH Pin connected to Ground for Full speed or supplied with pulsed input
- RMI Pin Pulled high to 5VREG output or external connection if required
- 5VREG connected to Hall Sensor. Hall sensor differential inputs connected to IN+ and IN-
- Current sense resistor connected to SENSE pin or GND.
- CT connected to Lock Detection capacitor (0.47 uF or calculated values) or to GND
- Drive outputs connected to the Gates of the H bridge switches.
- Pull up on FG.

Power Supply:

- Make sure the power supply has set with sufficient current limit at the decided at the motor voltage.

Build the circuit with the recommended connections at the pins.

Test the motor circuit with hardware connected to it.

8.2.3 Application Curves

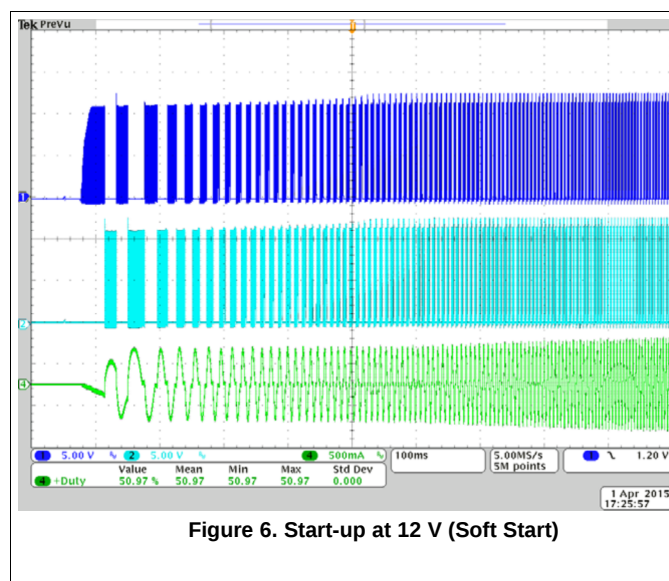


Figure 6. Start-up at 12 V (Soft Start)

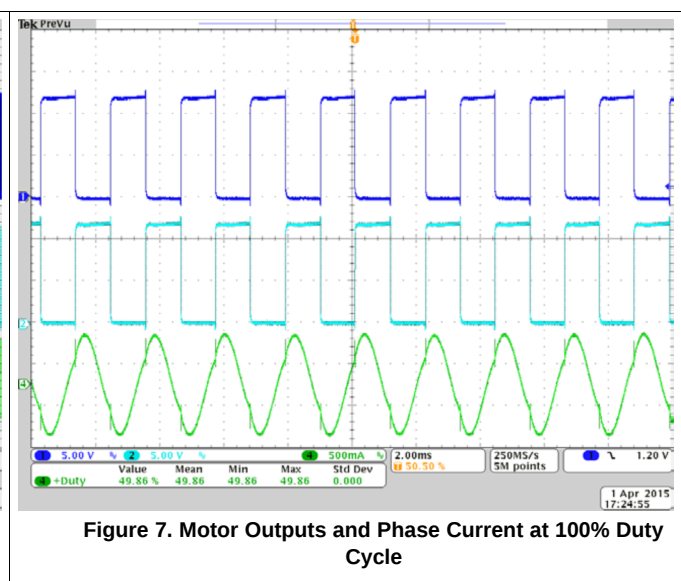


Figure 7. Motor Outputs and Phase Current at 100% Duty Cycle

Typical Application (continued)

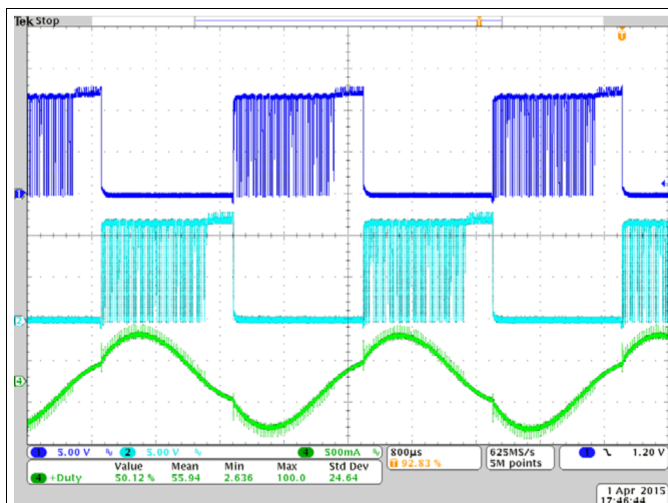


Figure 8. Motor Outputs and Phase Current at Duty Cycle < 100%

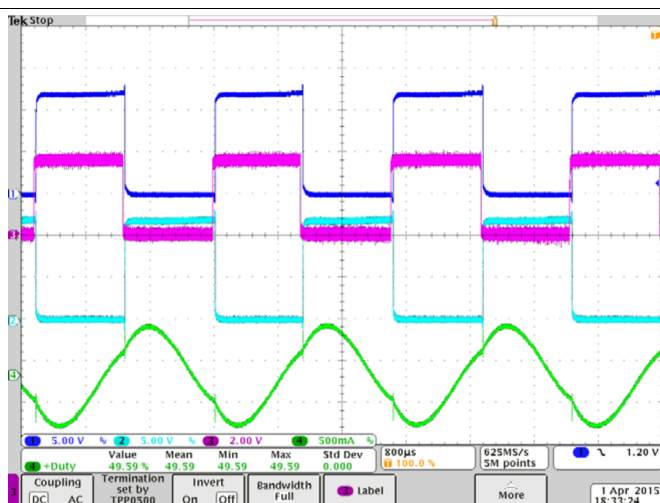


Figure 9. Motor Outputs and Phase Currents at 100% Duty Cycle and With Hall Sensor Data

9 Power Supply Recommendations

For testing purposes, a current limited source can be connected with voltage from 6 to 16 V on printed-circuit-board. Use a 1- μ F capacitor (minimum) to take care of load transient requirements.

10 Layout

10.1 Layout Guidelines

Connect 1- μ F capacitor or greater between VCC and SGND with short traces.

Connect a capacitor between IN+ and IN- for noise reduction picked from Hall sensors.

Keep S-S, CT and CPWM capacitor near the device.

10.2 Layout Example

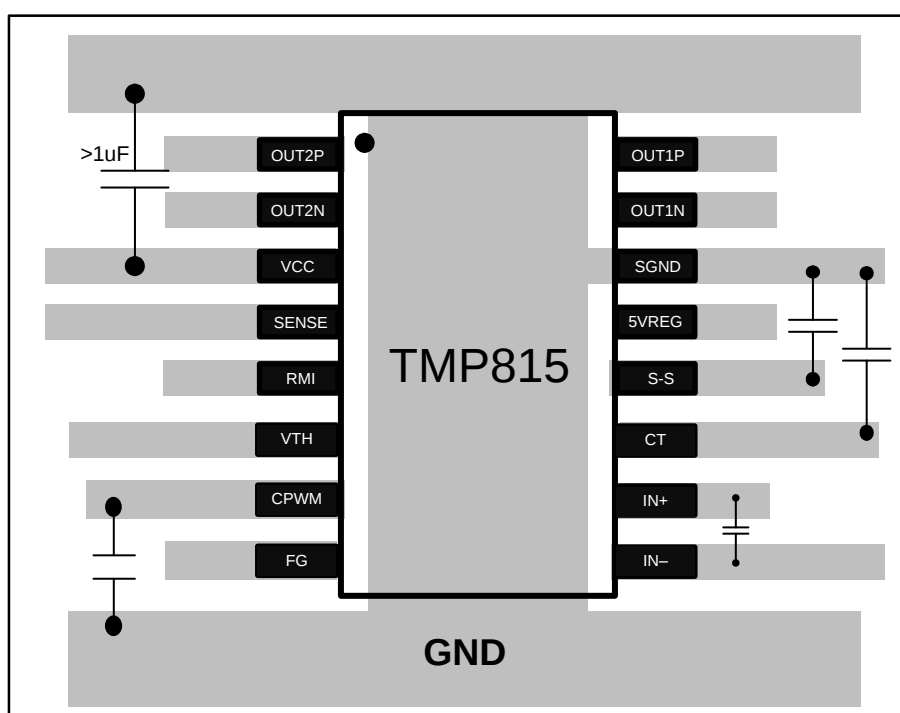


Figure 10. Recommended Layout Example

11 Device and Documentation Support

11.1 Community Resource

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

TI E2E™ Online Community *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

Design Support *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

11.2 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.3 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.4 Glossary

[SLYZ022](#) — *TI Glossary*.

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

12 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)
TMP815PWR	Last Time Buy	Production	TSSOP (PW) 16	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	TMP815
TMP815PWR.A	NRND	Production	TSSOP (PW) 16	2000 LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 85	TMP815

⁽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.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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.

TAPE AND REEL INFORMATION



*All dimensions are nominal

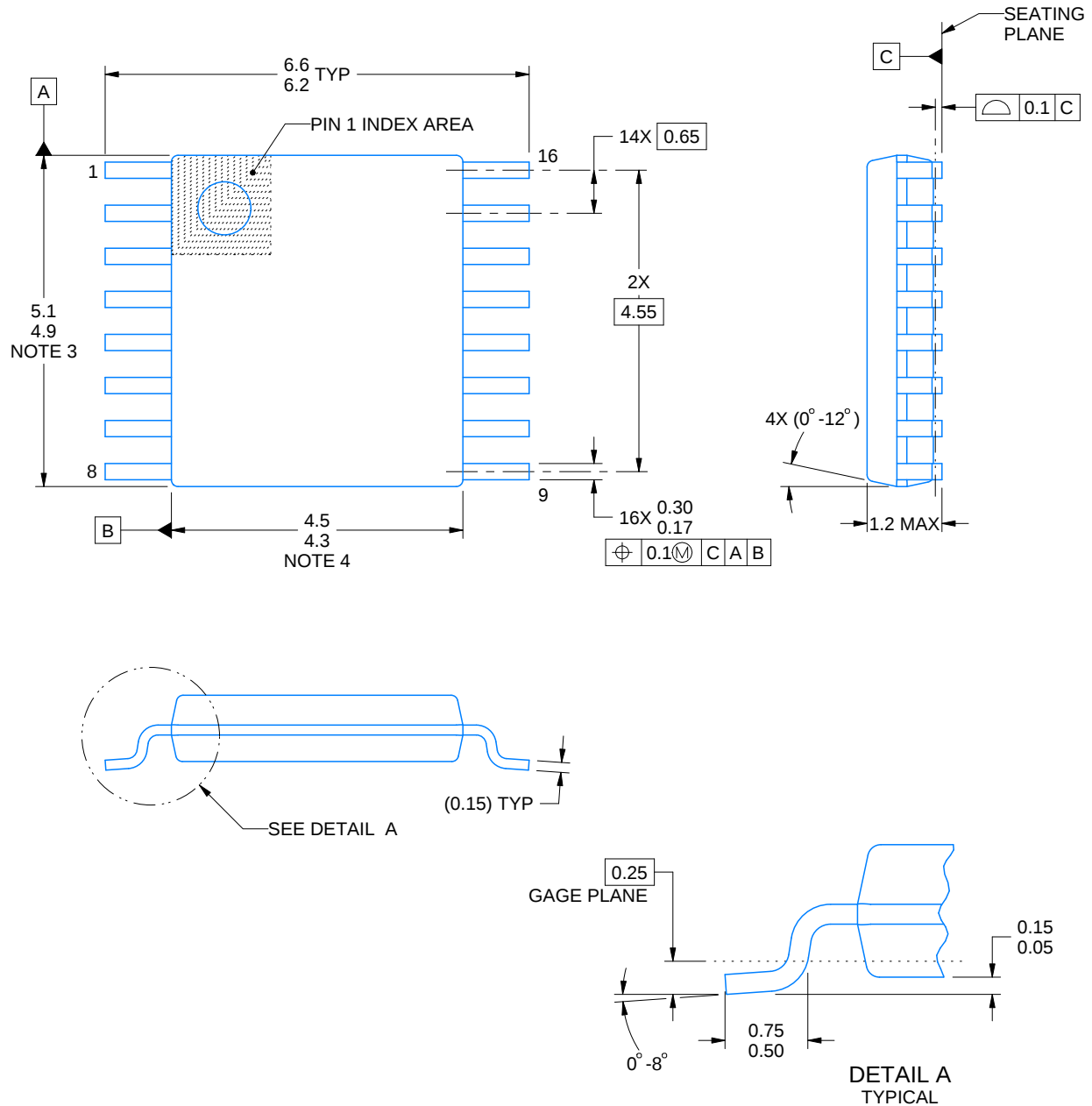
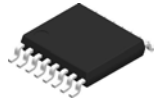
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TMP815PWR	TSSOP	PW	16	2000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TMP815PWR	TSSOP	PW	16	2000	353.0	353.0	32.0



4220204/B 12/2023

NOTES:

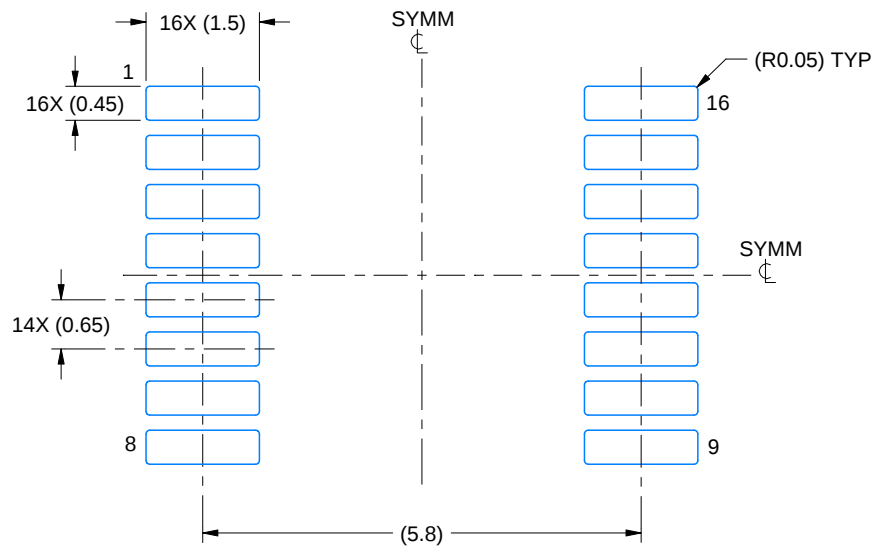
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153.

EXAMPLE BOARD LAYOUT

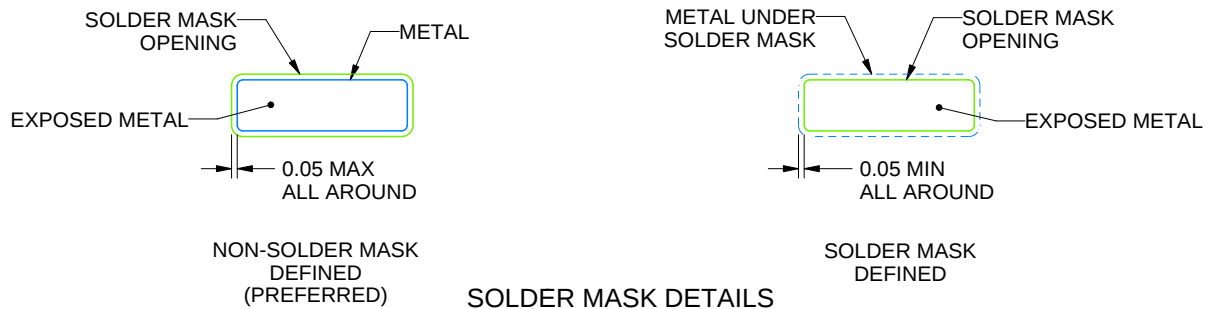
PW0016A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 10X



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NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

PW0016A

TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE: 10X

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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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