TMI8421 Stepper Motor Controller IC

FEATURES

- 6-V to 35-V Operating Supply Voltage Range
- 2-A Maximum Drive Current at 24 V and T_A=25℃
- PWM Microstepping Stepper Motor Driver
  – Built-In Microstepping Indexer
  – Up to 1/16 Microstepping
- Multiple Decay Modes
  – Slow Decay
  – Mixed Decay
- Simple STEP/DIR Interface
- Low Current Sleep Mode
- Built-In 5-V Reference Output
- Protection Features
  – Overcurrent Protection (OCP)
  – Thermal Shutdown (TSD)
  – VM Undervoltage Lockout (UVLO)
  – Fault Condition Indication Pin (nFAULT)
- Small Package and Footprint
  – QFN5x5-28L

APPLICATIONS

- Automatic Teller Machines
- Video Security Cameras
- Printers and Scanners
- Money Handing Machines
- Office Automation Machines
- Gaming Machines
- Factory Automation
- Robotics

GENERAL DESCRIPTION

The TMI8421 is a complete microstepping motor driver with built-in translator for easy operation. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth-, and sixteenth-step modes, with an output drive capacity of up to 35 V and ±2 A. Simply inputting one pulse on the STEP input drives the motor one microstep.

During stepping operation, the chopping control in the TMI8421 automatically selects the current decay mode, Slow or Mixed. In Mixed decay mode, the device is set initially to a fast decay for a proportion of the fixed off-time, then to a slow decay for the remainder of the off-time. Mixed decay current control results in reduced audible motor noise, increased step accuracy, and reduced power dissipation, Internal synchronous rectification control circuitry is provided to improve power dissipation during PWM operation.

Internal circuit protection includes: thermal shutdown , undervoltage lockout (UVLO), and crossover-current protection. Fault conditions are indicated on nFAULT. Special power-on sequencing is not required.

The TMI8421 is supplied in a surface-mount QFN package(ES), 5 x 5 mm, with a nominal overall package height of 0.90 mm and an exposed pad for enhanced thermal dissipation. It is lead (Pb) free(suffix-T), with 100% matte tin plated leadframes.

TYPICAL APPILCATION

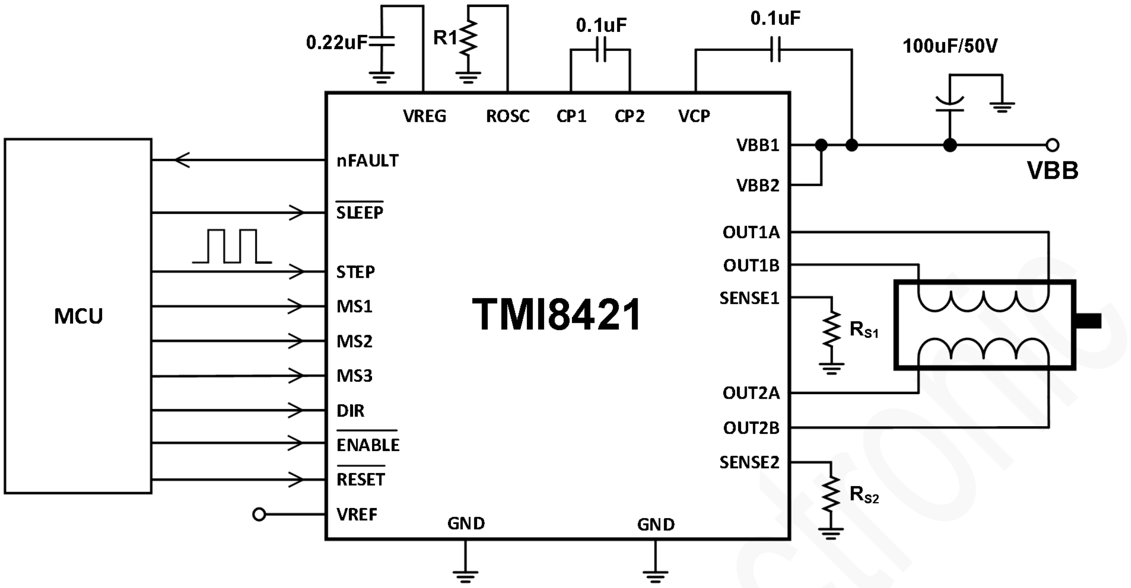


Figure 1. Basic Application Circuit

ABSOLUTE MAXIMUM RATINGS (Note 1)

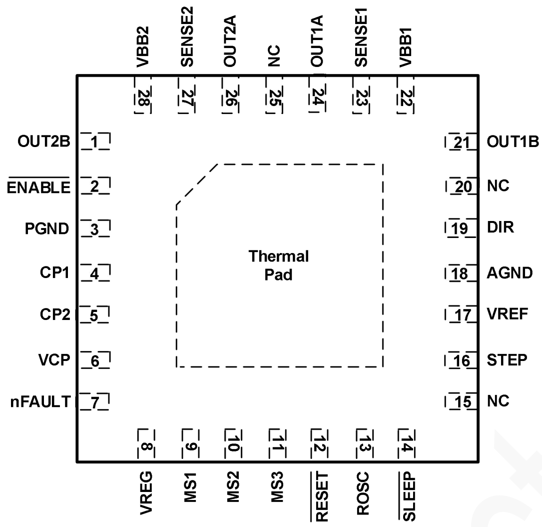
Parameter	Min	Max	Unit
Power supply voltage (VBB)	-0.3	45	V
Logic input voltage	-0.3	5.5	V
Reference input voltage (VREF)	-0.3	5.5	V
Continuous motor drive output current	0	2	A
Operating ambient temperature	-40	85	°C
T_J, operating virtual junction temperature (Note 2)	-40	150	°C
Storage temperature	-60	150	°C

ESD RATING

Items	Description	Value	Unit
V_{ESD}	Human Body Model for all pins	±2000	V

JEDEC specification JS-001

PACKAGE/ORDER INFORMATION



QFN5x5-28L (Top view)

TMI8421/XXXXX (TMI8421: Device Code, XXXXX: Inside Code) for TMI8421

Part Number	Package	Top mark	Quantity/ Reel
TMI8421	QFN5x5-28L	TMI8421 XXXXX	5000/盘

The TMI8421 device is Pb-free and RoHS compliant.

PIN FUNCTIONS

PIN			Function
Number	Name	I/O(1)	
3, 18	GND	-	Device ground.
22	VBB1	-	Bridge 1 power supply. Connect a 0.1μF bypass capacitor to ground, as well as a sufficient bulk capacitance rated for VBB1.
28	VBB2	-	Bridge 2 power supply. Connect a 0.1μF bypass capacitor to ground, as well as a sufficient bulk capacitance rated for VBB2.
8	VREG	O	Regulator decoupling terminal. Connect a 0.22μF ceramic capacitor to ground.
4	CP1	IO	Charge pump flying capacitor.
5	CP2	IO	Charge pump flying capacitor.
6	VCP	IO	High-side gate drive voltage. Connect a 0.1μF ceramic capacitor to VBB.
7	nFAULT	OD	Fault. Logic low when in fault condition (overtemp, overcurrent).
2	$\overline{\text{ENABLE}}$	I	Logic high to disable device outputs and indexer operation, logic low to enable. Internal pulldown.

PIN FUNCTIONS (Continued)

PIN			Function
Number	Name	I/O(1)	
14	$\overline{SLEEP}$	I	Sleep mode input. Logic high to enable device, logic low to enter low-power sleep mode. Internal pulldown.
12	$\overline{RESET}$	I	Reset input. Logic low sets the translator to a predefined Home state(shown in Figures 3 through 7), and turns off all the FET outputs. All STEP inputs are ignored until the logic is set to high. Internal pulldown.
16	STEP	I	Rising edge causes the indexer to move one step. Internal pulldown.
19	DIR	I	Direction input. Level sets the direction of stepping. Internal pulldown.
9	MS1	I	Microstep mode(1/2/3). MS1 - MS3 set the step mode - full, 1/2, 1/4, 1/8 or 1/16 step. Internal pulldown.
10	MS2	I	
11	MS3	I	
13	ROSC	O	Timing set. Externally programmable Fixed Off-Time.
17	VREF	I	Current set reference input.
23	SENSE1	IO	Bridge 1 ground / Isense. Connect to current sense resistor for bridge 1.
27	SENSE2	IO	Bridge 2 ground / Isense. Connect to current sense resistor for bridge 2.
24	OUT1A	O	Bridge 1 output A .
21	OUT1B	O	Bridge 1 output B.
26	OUT2A	O	Bridge 2 output A .
1	OUT2B	O	Bridge 2 output B .
15, 20, 25	NC	NC	Not connected.

(1) Directions: I = input, O = output, OZ = tri-state output, OD = open-drain output, IO = input/output

RECOMMENDED OPERATING CONDITIONS

Items	Description	Min	Max	Unit
VBB	Power supply voltage range	6.0	35	V
VREF	VREF input voltage	1	4	V

(1) All VBB pins must be connected to the same supply voltage.

(2) Operational at VREF between 0V and 1V, but accuracy is degraded.

ELECTRICAL CHARACTERISTICS

T_A =25°C (unless otherwise noted)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNIT
POWER SUPPLY						
VBB operating voltage	V_{BB}	Operating	6	-	35	V
VBB operating supply current	I_{VBB}	VBB = 24V, f_{PWM} < 50kHz			4	mA
		Operating, outputs disabled			2	mA
VBB sleep mode supply current	I_{VBBQ}	Sleep Mode			5	uA
VREG voltage	V_{REG}	I_O = 0 to 1 mA, VBB = 24V, T_J = 25°C		5		V
LOGIC-LEVEL INPUTS(SLEEP, RESET, EN, MS1, MS2, MS3, STEP, DIR)						
Input low voltage	V_{IL}				0.7	V
Input high voltage	V_{IH}		1.5		5.5	V
Input hysteresis	V_{HYS}			0.25		V
Input low current	I_{IL}	VIN = 0V	–20	<1	20	μA
Input high current	I_{IH}	VIN = 5V		50		μA
Internal pulldown resistance	R_{PD}	Pull down to GND		100		kΩ
OPEN-DRIN OUTPUTS(nFAULT)						
Output low voltage	V_{OL}	I_{OD} = 5mA			0.7	V
Output high leakage current	I_{OZ}	V_{OD} = 5V			1	μA
MOTOR DRIVER						
HS FET on resistance	$R_{DS(ON)}$	VBB = 24V, I_O = 1.5A		300		mΩ
LS FET on resistance	$R_{DS(ON)}$	VBB = 24V, I_O = 1.5A		300		mΩ
Body diode forward voltage	V_D	I_O = 1.5 A		0.9	1.2	V
Current sense blanking time	t_{BLANK}			3		μs
Fixed Off-Time	t_{OFF}	OSC = 5V or GND	20	30	40	μs
		R_{OSC} = 25 kΩ	23	30	37	μs
Rise time	t_{RISE}	OUTx rising 10% to 90%	15		70	ns
Fall time	t_{FALL}	OUTx falling 90% to 10%	25		45	ns
Dead time	t_{DEAD}		100	475	800	ns
CURRENT CONTROL						
Reference input voltage	V_{REF}		0		4	V
Reference input current	I_{REF}		-3		3	μA
Current trip-level error	err_I	V_{REF} = 2 V, $\%I_{TripMAX}$ = 38.27%			±15	%
		V_{REF} = 2 V, $\%I_{TripMAX}$ = 70.71%			±5	%
		V_{REF} = 2 V, $\%I_{TripMAX}$ = 100.00%			±5	%
Current sense amplifier gain	A_{ISENSE}	Reference only		8		V/V

ELECTRICAL CHARACTERISTICS (Continued)

T_A = 25°C, over recommended operating conditions (unless otherwise noted)

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNIT
PROTECTION CIRCUITS						
VBB undervoltage lockout	V_{UVLO_fall}	VBB falls until UVLO triggers			4.7	V
	V_{UVLO_rise}	VBB rises until operation recovers	4.9			V
VBB undervoltage hysteresis	V_{UVLO_HYS}			0.15		V
Overcurrent protection trip level	I_{OCP}			4.0		A
Thermal shutdown temperature	T_{SD} (Note 3)			165		℃
Thermal shutdown hysteresis	T_{HYS} (Note 3)			15		℃

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: T_J is calculated from the ambient temperature T_A and power dissipation P_D according to the following formula: $T_J = T_A + P_D \times \theta_{JA}$. The maximum allowable continuous power dissipation at any ambient temperature is calculated by $P_{D(MAX)} = (T_{J(MAX)} - T_A)/\theta_{JA}$.

Note 3: Thermal shutdown threshold and hysteresis are guaranteed by design.

Functional Description

Overview

The TMI8421 can be powered with a supply voltage between 6 V and 35 V and is capable of providing an output current up to 2 A full-scale.

The TMI8421 is a complete microstepping motor driver with a built-in translator for easy operation with minimal control lines. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth, and sixteenth-step modes. The currents in each of the two output full-bridges and all of the N-channel DMOS FETs are regulated with fixed off-time PWM (pulse-width modulated) control circuitry.

At each step, the current for each full-bridge is set by the value of its external current sense resistor (R_{S1} and R_{S2}), a reference voltage (VREF), and the output voltage of its DAC (which in turn is controlled by the output of the translator). At power-on or reset, the translator sets the DACs and the phase current polarity to the initial Home state (shown in Figures 3 through 7), and the current regulator to Mixed decay mode for both phases. When a step command signal occurs on the STEP input, the translator automatically sequences the DACs to the next level and current polarity. (See Table 2 for the current-level sequence.) The microstep resolution is set by the combined effect of the MSx inputs, as shown in Table 1.

When stepping, if the new output levels of the DACs are lower than their previous output levels, then the decay mode for the active full-bridge is set to Mixed. If the new output levels of the DACs are higher than or equal to their previous levels, then the decay mode for the active full-bridge is set to Slow. This automatic current decay selection improves microstepping performance by reducing the distortion of the current waveform that results from the back EMF of the motor.

Microstep Select (MSx)

The microstep resolution is set by the voltage on logic inputs MSx, as shown in Table 1. The MS1, MS2 and MS3 pins have a 100 kΩ pull-down resistance. When changing the step mode, the change does not take effect until the next STEP rising edge. If the step mode is changed without a translator reset, and absolute position must be maintained, it is important to change the step mode at a step position that is common to both step modes in order to avoid missing steps. When the device is powered down, or reset due to TSD or an overcurrent event, the translator is set to the home position which is by default common to all step modes.

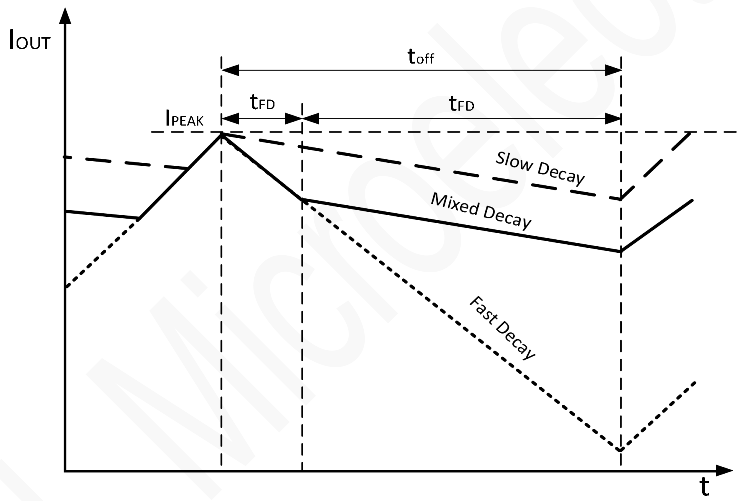
Table 1. Microstepping Resolution Truth Table

MS1	MS2	MS3	Microstep Resolution	Excitation Mode
L	L	L	Full Step	2 Phase
H	L	L	Half Step	1-2 Phase
L	H	L	Quarter Step	W1-2 Phase
H	H	L	Eighth Step	2W1-2 Phase
H	H	H	Sixteenth Step	4W1-2 Phase
L	L	H	Full Step	2 Phase
H	L	H	Half Step	1-2 Phase
L	H	H	Quarter Step	W1-2 Phase

Mixed Decay Operation

The bridge operates in Mixed decay mode, at power-on and reset, and during normal running according to the ROSC configuration and the step sequence, as shown in Figures 3 through 7. During Mixed decay mode, when the trip point is reached, the TMI8421 initially goes into a fast decay interval for 31.25% of the off-time, t_{OFF}. After that, it switches to slow decay for the remainder of t_{OFF}. A timing diagram for this feature appears in Figure 2.

Typically, mixed decay is only necessary when the current in the winding is going from a higher value to a lower value as determined by the state of the translator. For most loads, automatically selected mixed decay is convenient because it minimizes ripple when the current is rising and prevents missed steps when the current is falling. For some applications where microstepping at very low speeds is necessary, the lack of back EMF in the winding causes the current to increase in the load quickly, resulting in missed steps. By pulling the ROSC pin to ground, mixed decay is set to be active 100% of the time, for both rising and falling currents, and prevents missed steps . If this is not an issue, it is recommended that automatically selected mixed decay be used, because it will produce reduced ripple currents. Refer to the Fixed Off-Time section for details.



Symbol	Characteristic
t_{off}	Device fixed off-time
I_{PEAK}	Maximum output current
t_{SD}	Slow decay interval
t_{FD}	Fast decay interval
I_{OUT}	Device output current

Figure 2: Current Decay Modes Timing Chart

Low Current Microstepping

Intended for applications where the minimum on-time prevents the output current from regulating to the programmed current level at low current steps. To prevent this, the device can be set to operate in Mixed decay mode on both rising and falling portions of the current waveform. This feature is implemented by shorting the ROSC pin to ground. In this state, the off-time is internally set to 30 μs.

Step Input

A low-to-high transition on the STEP input sequences the translator and advances the motor one increment. The translator controls the input to the DACs and the direc- tion of current flow in each winding. The size of the increment is determined by the combined state of the MSx inputs.

Current Regulation

Each full-bridge is con- trolled by a fixed off-time PWM current control circuit that limits the load current to a desired value, I_{TRIP}. Initially, a diagonal pair of source and sink FET outputs are enabled and current flows through the motor winding and the current sense resistor, R_{Sx}. When the voltage across R_{Sx} equals the DAC output voltage, the current sense comparator resets the PWM latch. The latch then turns off the appropriate source driver and initiates a fixed off time decay mode.

The maximum value of current limiting is set by the selection of RSx and the voltage at the VREF pin. The transconductance func- tion is approximated by the maximum value of current limiting, $I_{TripMAX}$ (A), which is set by

$$I_{TripMAX} = V_{REF} / (8 \times R_S)$$

where R_S is the resistance of the sense resistor (Ω) and V_{REF} is the input voltage on the VREF pin (V).

The DAC output reduces the V_{REF} output to the current sense comparator in precise steps, such that

$$I_{trip} = (\%I_{TripMAX} / 100) \times I_{TripMAX}$$

(See Table 2 for $\%I_{TripMAX}$ at each step.)

It is critical that the maximum rating (0.5 V) on the SENSE1 and SENSE2 pins is not exceeded.

Fixed Off-Time

The internal PWM current control circuitry uses a one-shot circuit to control the duration of time that the DMOS FETs remain off. The off time, t_{OFF}, is determined by the ROSC terminal. The ROSC terminal has three settings:

1. ROSC tied to 5V：off-time internally set to 30 μs; decay mode is automatic Mixed decay except when in full step where decay mode is set to Slow decay.

2. ROSC tied directly to ground：off-time internally set to 30 μs; current decay is set to Mixed decay for both increasing and decreasing currents for all step modes.

3. ROSC through a resistor to ground：off-time is determined by the following formula, the decay mode is automatic Mixed decay for all step modes except full-step which is set to Slow decay.

$$t_{OFF} \approx R_{OSC} / 825$$

Where t_{OFF} is in μs.
Where Toff is in microseconds.
ROSC is allowed in the range 5kΩ to 80kΩ.

VBB Undervoltage Lockout (UVLO)

If at any time the voltage on the VBB pin falls below the undervoltage lockout threshold voltage, all FETs in the H-bridge will be disabled. Operation resumes when VBB rises above the UVLO threshold.

Overcurrent Protection (OCP)

An analog current limit circuit on each FET limits the current through the FET by removing the gate drive. If this analog current limit persists for longer than the OCP time, all FETs in the H-bridge will be disabled and the nFAULT pin will be driven low. The device will remain disabled until either SLEEP pin is applied, or VBB is removed and re-applied.

Overcurrent conditions on both high and low side devices; that is, a short to ground, supply, or across the motor winding will all result in an overcurrent shutdown. Note that overcurrent protection does not use the current sense circuitry used for PWM current control, and is independent of the ISENSE resistor value or VREF voltage.

Thermal Shutdown (TSD)

If the die temperature exceeds safe limits, all FETs in the H-bridge will be disabled and the nFAULT pin will be driven low. Once the die temperature has fallen to a safe level operation will automatically resume.

Application Curves

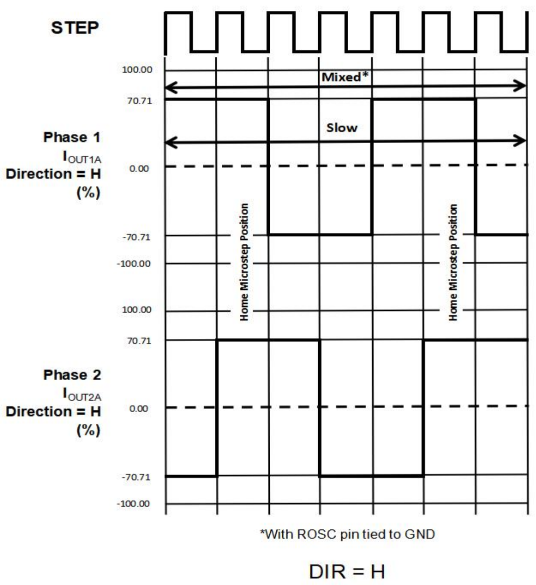


Figure 3: Decay Modes for Full-Step Increments

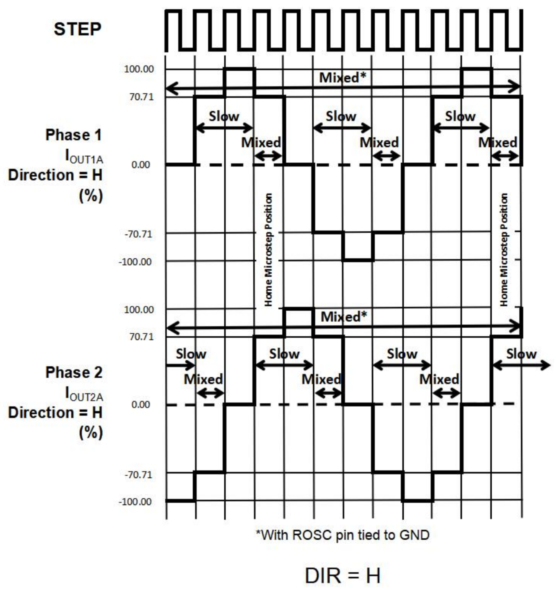


Figure 4: Decay Modes for Half-Step Increments

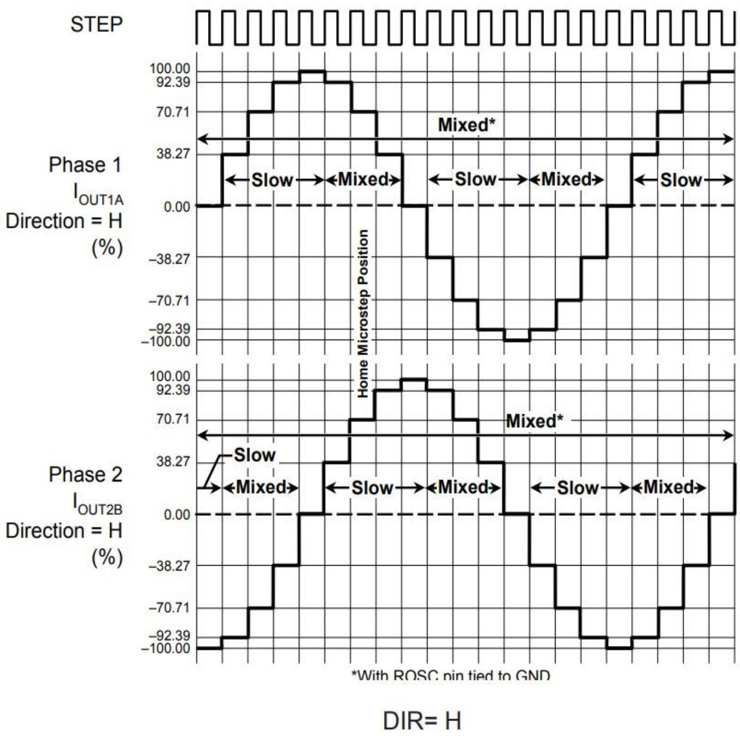


Figure 5: Decay Modes for Quarter-Step Increments

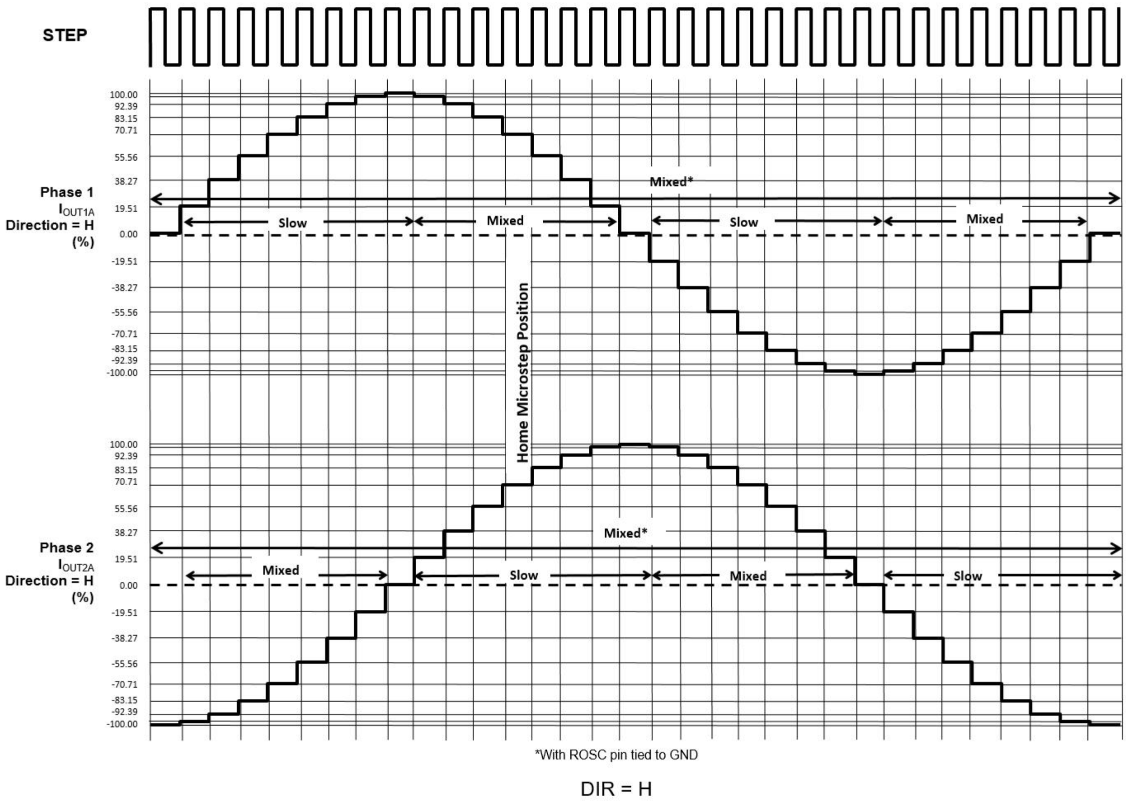


Figure 6: Decay Modes for Eighth-Step Increments

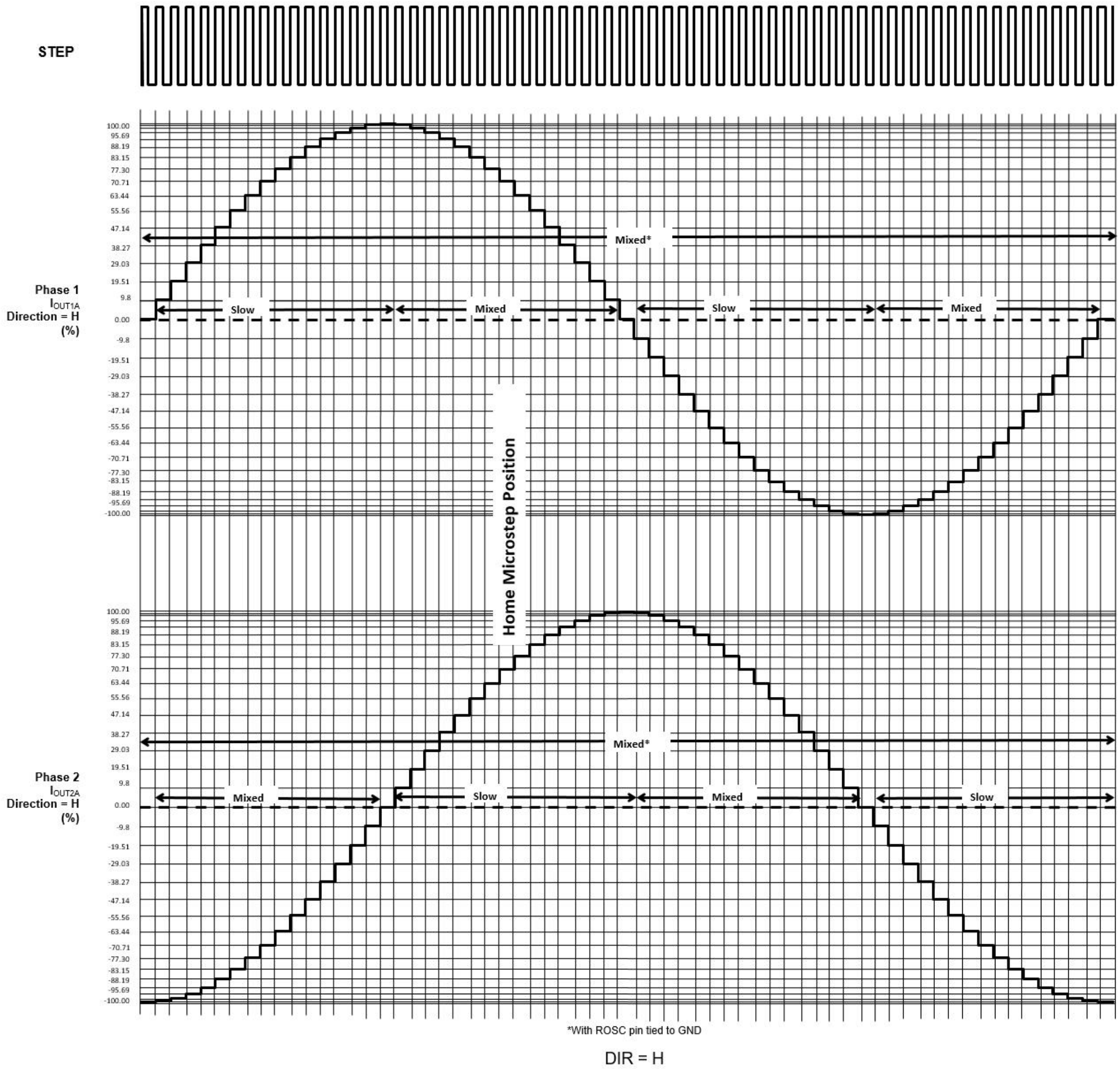


Figure 7: Decay Modes for Sixteenth-Step Increments

Table 2: Step Sequencing Settings

Home microstep position at Step Angle 45°; DIR = H

Full Step #	Half Step #	1/4 Step #	1/8 Step #	1/16 Step #	Phase1 Current [% $I_{tripMax}$] (%)	Phase2 Current [% $I_{tripMax}$] (%)	Step Angle (°)
	1	1	1	1	100.00	0.00	0.0
				2	99.52	9.80	5.6
			2	3	98.08	19.51	11.3
				4	95.69	29.03	16.9
		2	3	5	92.39	38.27	22.5
				6	88.19	47.14	28.1
			4	7	83.15	55.56	33.8
				8	77.30	63.44	39.4
1	2	3	5	9	70.71	70.71	45.0
				10	63.44	77.30	50.6
			6	11	55.56	83.15	56.3
				12	47.14	88.19	61.9
		4	7	13	38.27	92.39	67.5
				14	29.03	95.69	73.1
			8	15	19.51	98.08	78.8
				16	9.80	99.52	84.4
	3	5	9	17	0.00	100.00	90.0
				18	–9.80	99.52	95.6
			10	19	–19.51	98.08	101.3
				20	–29.03	95.69	106.9
		6	11	21	–38.27	92.39	112.5
				22	–47.14	88.19	118.1
			12	23	–55.56	83.15	123.8
				24	–63.44	77.30	129.4
2	4	7	13	25	–70.71	70.71	135.0
				26	–77.30	63.44	140.6
			14	27	–83.15	55.56	146.3
				28	–88.19	47.14	151.9
		8	15	29	–92.39	38.27	157.5
				30	–95.69	29.03	163.1
			16	31	–98.08	19.51	168.8
				32	–99.52	9.80	174.4

Table 2: Step Sequencing Settings(Continued)

Home microstep position at Step Angle 45°; DIR = H

Full Step #	Half Step #	1/4 Step #	1/8 Step #	1/16 Step #	Phase1 Current [% $I_{tripMax}$] (%)	Phase2 Current [% $I_{tripMax}$] (%)	Step Angle (°)
	5	9	17	33	–100.00	0.00	180.0
				34	–99.52	–9.80	185.6
			18	35	–98.08	–19.51	191.3
				36	–95.69	–29.03	196.9
		10	19	37	–92.39	–38.27	202.5
				38	–88.19	–47.14	208.1
			20	39	–83.15	–55.56	213.8
				40	–77.30	–63.44	219.4
3	6	11	21	41	–70.71	–70.71	225.0
				42	–63.44	–77.30	230.6
			22	43	–55.56	–83.15	236.3
				44	–47.14	–88.19	241.9
		12	23	45	–38.27	–92.39	247.5
				46	–29.03	–95.69	253.1
			24	47	–19.51	–98.08	258.8
				48	–9.80	–99.52	264.4
	7	13	25	49	0.00	–100.00	270.0
				50	9.80	–99.52	275.6
			26	51	19.51	–98.08	281.3
				52	29.03	–95.69	286.9
		14	27	53	38.27	–92.39	292.5
				54	47.14	–88.19	298.1
			28	55	55.56	–83.15	303.8
				56	63.44	–77.30	309.4
4	8	15	29	57	70.71	–70.71	315.0
				58	77.30	–63.44	320.6
			30	59	83.15	–55.56	326.3
				60	88.19	–47.14	331.9
		16	31	61	92.39	–38.27	337.5
				62	95.69	–29.03	343.1
			32	63	98.08	–19.51	348.8
				64	99.52	–9.80	354.4

APPLICATION INFORMATION

Application information

The TMI8421 can be used to control a bipolar stepper motor. The STEP interface controls the outputs and current control can be implemented with the internal current regulation circuitry. Detailed fault reporting is provided with the internal protection circuits and nFAULT pin.

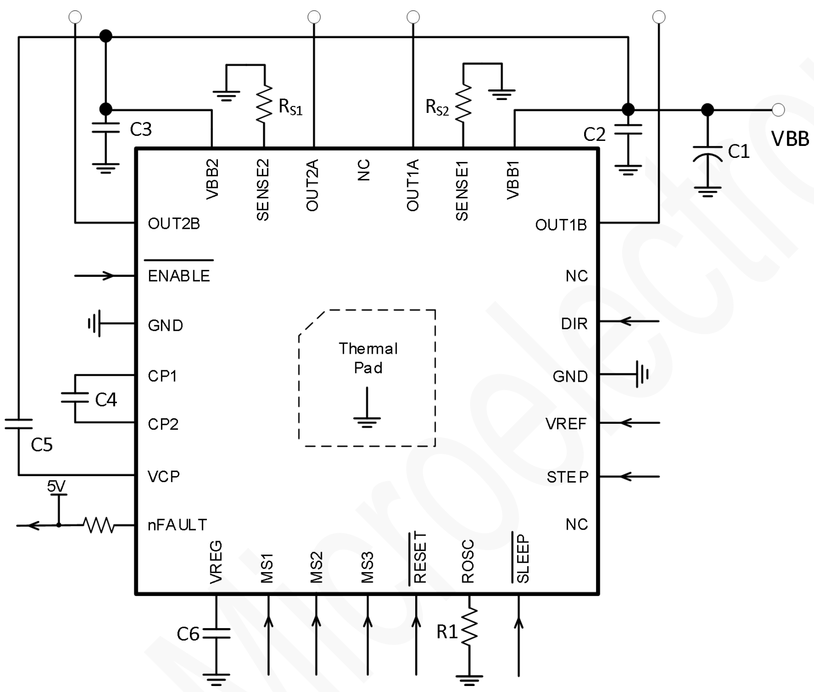


Figure 8. TMI8421 Typical Application

Block Diagram

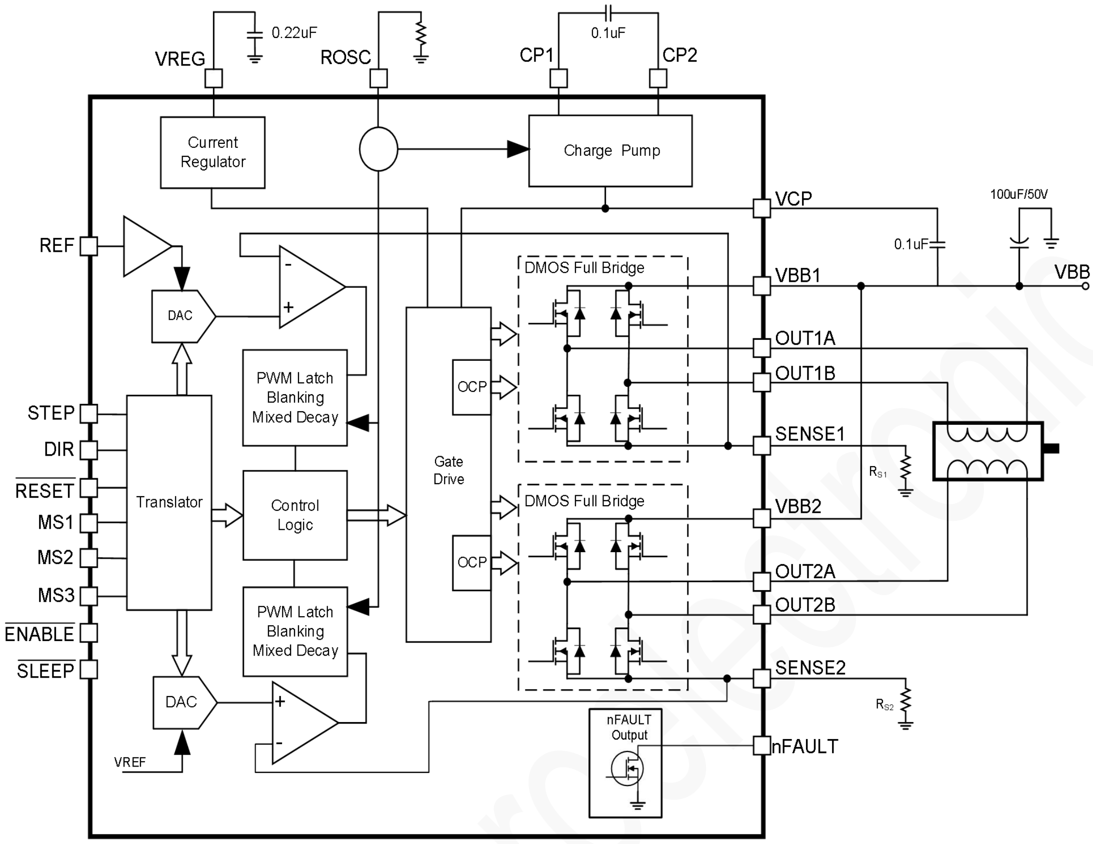
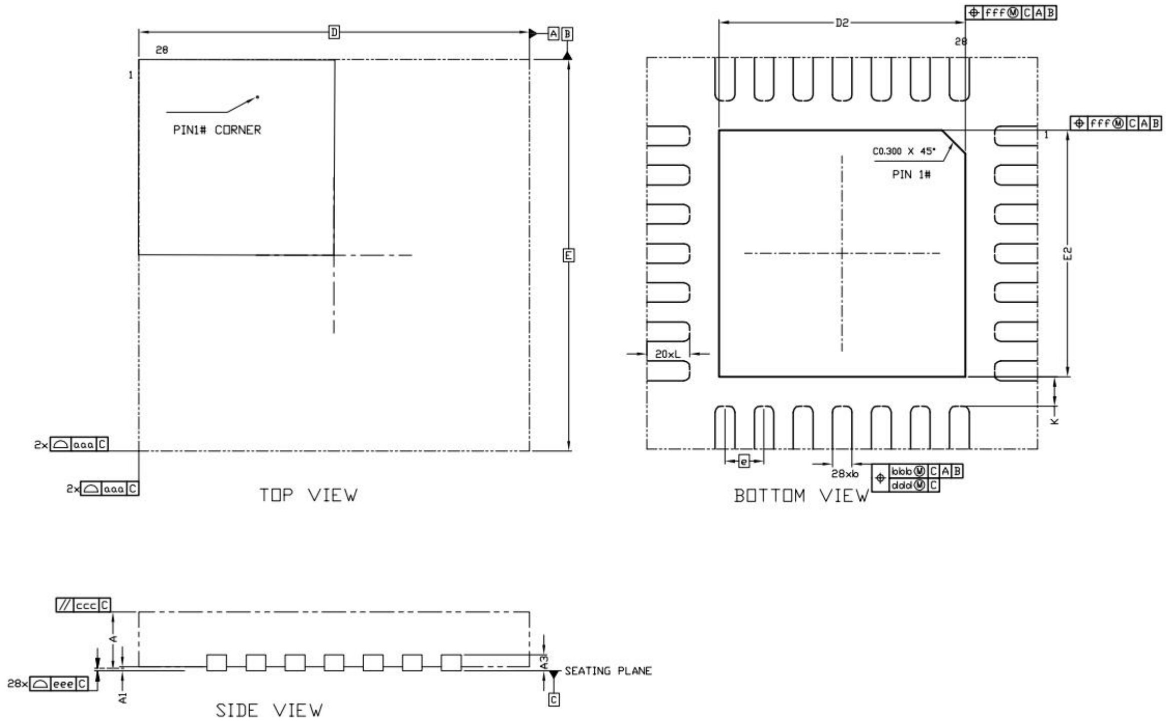


Figure 9. TMI8421 Block Diagram

PACKAGE INFORMATION

QFN5x5-28L



Unit: mm

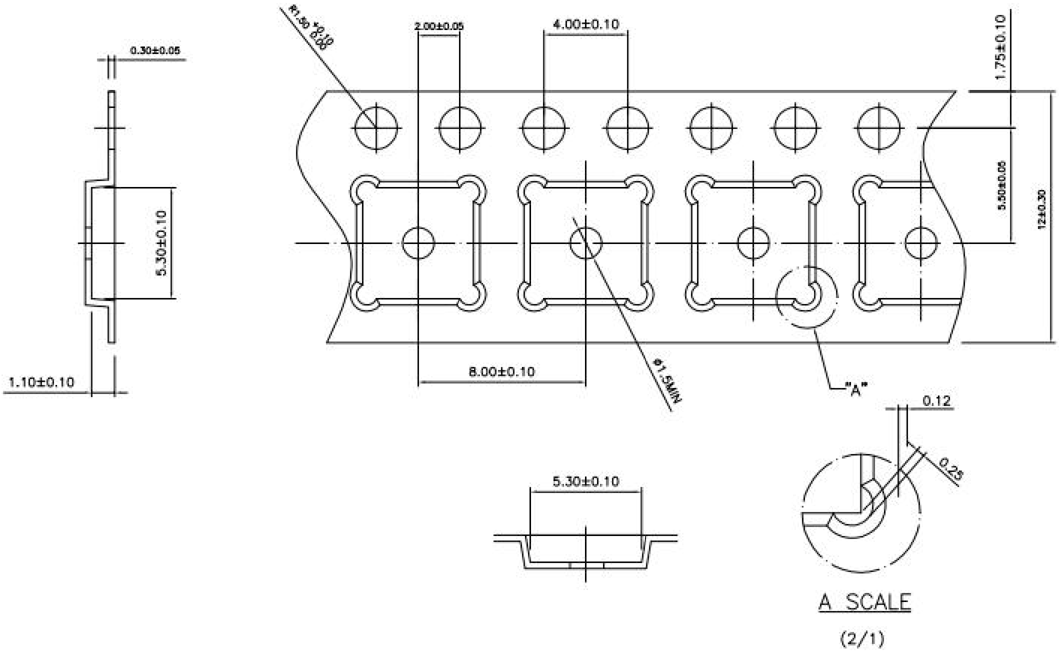
Symbol	Dimensions In Millimeters			Symbol	Dimensions In Millimeters		
	Min	NOM	Max		Min	NOM	Max
A	0.70	0.75	0.80	e	0.50BSC		
	0.80	0.85	0.90	L	0.50	0.55	0.60
A1	0	0.02	0.05	K	0.20	-	-
A3	-	0.20 REF	-	aaa	0.10		
b	0.18	0.25	0.30	bbb	0.10		
D	5.00BSC			ccc	0.10		
E	5.00BSC			ddd	0.05		
D2	3.05	3.15	3.25	eee	0.08		
E2	3.05	3.15	3.25	fff	0.10		

Note:

1) All dimensions are in millimeters.
2) Package length does not include mold flash, protrusion or gate burr.
3) Package width does not include inter lead flash or protrusion.
4) Lead popularity (bottom of leads after forming) shall be 0.10 millimeters max.
5) Pin 1 is lower left pin when reading top mark from left to right.

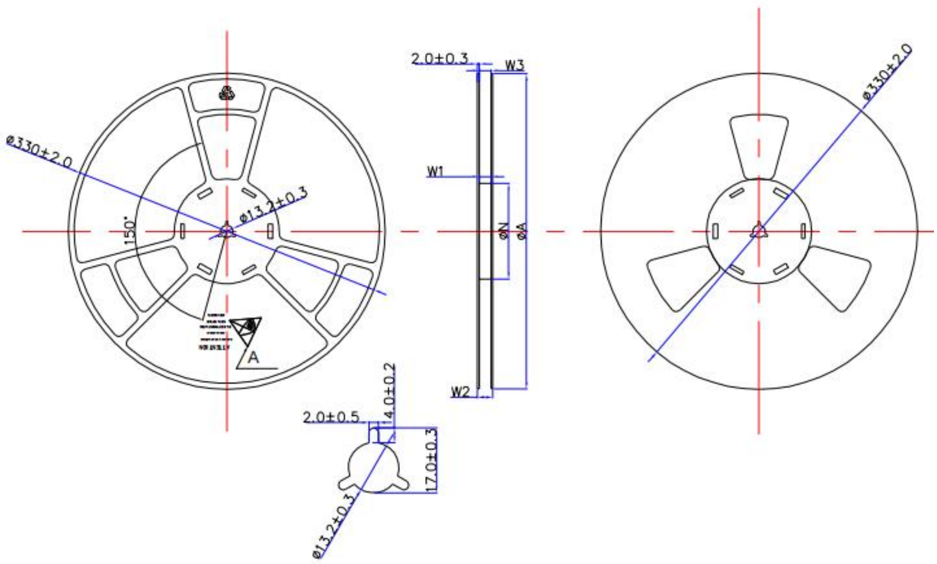
TAPE AND REEL INFORMATION

TAPE DIMENSIONS: QFN5x5-28L



Symbol	Dimensions	Symbol	Dimensions	Symbol	Dimensions	Symbol	Dimensions
A0	6.70±0.10	θ	5° TYP	E	1.75±0.10	D1	1.55MIN
B0	10.05±0.10	t	0.30±0.05	F	7.50±0.10	P0	0.30±0.10
K0	1.50±0.10	W	16.00±0.30	P2	2.00±0.10	10P0	40.00±0.20
K1	1.35±0.10	P	8.00±0.10	D	1.50±0.10		

REEL DIMENSIONS: QFN5x5-28L



Unit: mm

Ø A	Ø N	W1(+2/0)	W2(Max)	W2(Max)
330±2.0	100±1.0	12.4	18.4	11.9/15.4

Note:

1) All Dimensions are in Millimeter
2) Quantity of Units per Reel is 5000
3) MSL level is level 3.

Important Notification

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