Contents

Appendix A. Bill Of Materials (BOM)

Bill Of Materials			
Concept	Quantity	Unit cost	Total cost
608ZZ Radial bearing	2	0,98 €	1,96 €
Belt pulley	2	2,05 €	4,10 €
Coupling 5 to 8 mm	2	2,15 €	4,30 €
DIN125 M3	14	0,05 €	0,70 €
DIN125 M5	4	0,05 €	0,20 €
DIN125 M8	4	0,05 €	0,20 €
DIN912 M3x10	60	0,10 €	6,00 €
DIN912 M3x12	18	0,10 €	1,80 €
DIN912 M3x18	2	0,10 €	0,20 €
DIN912 M3x6	10	0,10 €	1,00 €
DIN912 M4x25	16	0,10 €	1,60 €
DIN912 M5x10	4	0,10 €	0,40 €
DIN913 M3x30	4	0,10 €	0,40 €
DIN934 M3	36	0,05 €	1,80 €
DIN934 M4	16	0,05 €	0,80 €
DIN934 M8	4	0,05 €	0,20 €
Endstop	3	3,45 €	10,35 €
IGUS JFM-0810-038	6	0,55 €	3,30 €
IGUS JFM-0810-06	8	0,55 €	4,40 €
LM8 Linear bearing	8	1,23 €	9,84 €
Magnet	8	1,10 €	8,80 €
SY42STH47-1684A_Real Colors (curt)	4	6,23 €	24,92 €
Selfoil 4-8-12-2-10	6	0,32 €	1,92 €
Selfoil 4-8-12-2-4	6	0,37 €	2,22 €
Z-axis spring	2	0,34 €	0,68 €
Pololu DRV8825	3	5,32 €	15,96 €
Arduino Mega	1	30,00 €	30,00 €
Condensador 100uF	4	0,20 €	0,80 €
Power supply	1	6,67 €	6,67 €
Push button	3	0,40 €	1,20 €
Electronic cable	1	4,00 €	4,00 €
Conector DC	1	1,13 €	1,13 €
Interruptor DC	1	1,45 €	1,45 €
Methacrylte	1	41,30 €	41,30 €
Laser cutting	1	12,32 €	12,32 €
PLA plastic (coil)	1	15,00 €	15,00 €
PLA-A002-001 (Side Profile)	2	-	-
PLA-A002-002 (Aluminum Sheet)	1	-	-
PLA-A002-003 (Large Support)	2	-	-

PLA-A003-001 (Wall A)	2	-	-
PLA-A003-002 (Wall B Middle)	1	-	-
PLA-A003-002 (Wall B)	2	-	-
PLA-A003-003 (Container Wall A)	2	-	-
PLA-A003-004 (Container Wall B)	2	-	-
PLA-A003-005 (Container Floor)	1	-	-
PLA-A003-006 (Container Wall A ext)	2	-	-
PLA-A003-007 (Container Wall B ext)	2	-	-
PLA-A003-008 (Funnel Wall B)	2	-	-
PLA-A003-009 (Funnel Joint Mirrored)	2	-	-
PLA-A003-009 (Funnel Joint)	2	-	-
PLA-A003-010 (Container Holder Mirrored)	1	-	-
PLA-A003-010 (Container Holder)	1	-	-
PLA-A003-010 (Funnel Wall A)	2	-	-
PLA-A004-001 (Bottom Surface)	2	-	-
PLA-A004-002 (Foam)	2	-	-
PLA-A004-003 (Top Surface)	2	-	-
PLA-A004-004 (Rod Bar M8)	2	-	-
PLA-A004-005 (Smooth Bar)	4	-	-
PLA-A004-006 (Mid Surface)	1	-	-
PLA-A004-007 (Z Lower Clamp)	2	-	-
PLA-A004-008 (Z Motion Idler)	2	-	-
PLA-A004-009 (Z Upper Clamp)	2	-	-
PLA-A004-011 (Platform Spacer)	8	-	-
REC-A001-001 (Cylinder)	1	-	-
REC-A001-002 (Pulley)	2	-	-
REC-A001-003 (Clamp)	2	-	-
REC-A001-004 (Clip A)	8	-	-
REC-A001-006 (Clip B)	8	-	-
REC-A001-009 (Fixed Belt Support)	2	-	-
REC-A001-010 (Fixed Belt Support Mirrored)	1	-	-
REC-A001-011 (Fixed Belt Support Slotted)	1	-	-
REC-A001-012 (Fixed belt)	2	-	-
REC-A001-013 (Endstop Spacer)	3	-	-
REC-A001-013 (Motor belt)	2	-	-
REC-A001-014 (Endstop Nut Holder)	5	-	-
REC-A002-001 (Pulley Spacer)	8	-	-
REC-A002-002 (Pulley Nut Holder)	6	-	-
REC-A003-001 (Tensile Pulley Nut Holder)	2	-	-
REC-A004-001 (Bolt Support)	4	-	-
		Total	221,92 €

Appendix B. Electronics

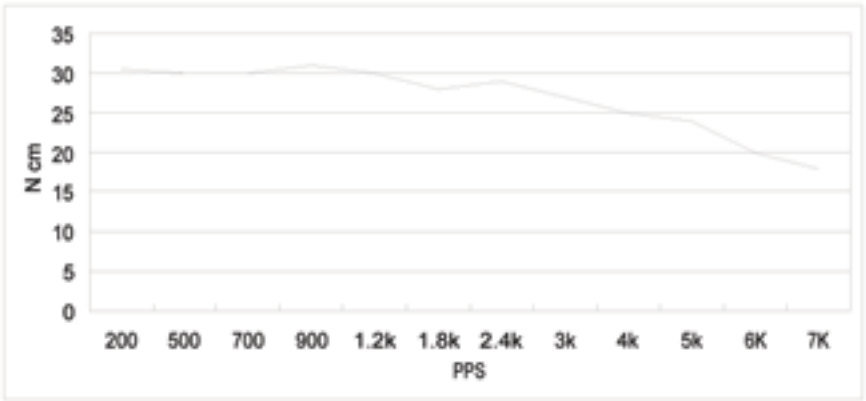
Steppers

HIGH TORQUE HYBRID STEPPING MOTOR SPECIFICATIONS

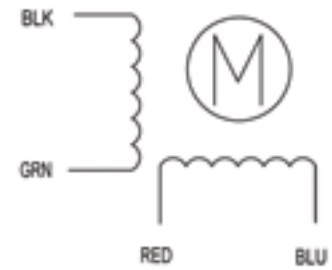
General specifications		Electrical specifications	
Step Angle (°)	1.8	Rated Voltage (V)	2.8
Temperature Rise (°C)	80 Max (rated current,2 phase on)	Rated Current (A)	1.68
Ambient temperature (°C)	-20～+50	Resistance Per Phase (±10%Ω)	1.65 (25°C)
Number of Phase	2	Inductance Per Phase (±20%mH)	2.8
Insulation Resistance	100MΩ, Min (500VDC)	Holding Torque (Kg.cm)	4.4
Insulation Class	Class B	Detent Torque (g.cm)	200
Max.radial force (N)	28 (20mm from the flange)	Rotor Inertia (g. cm²)	68
Max.axial force (N)	10	Weight (Kg)	0.365

● Pull out torque curve:

VOLTAGE: 24VDC, CONSTANT CURRENT: 1.68A, HALF STEP

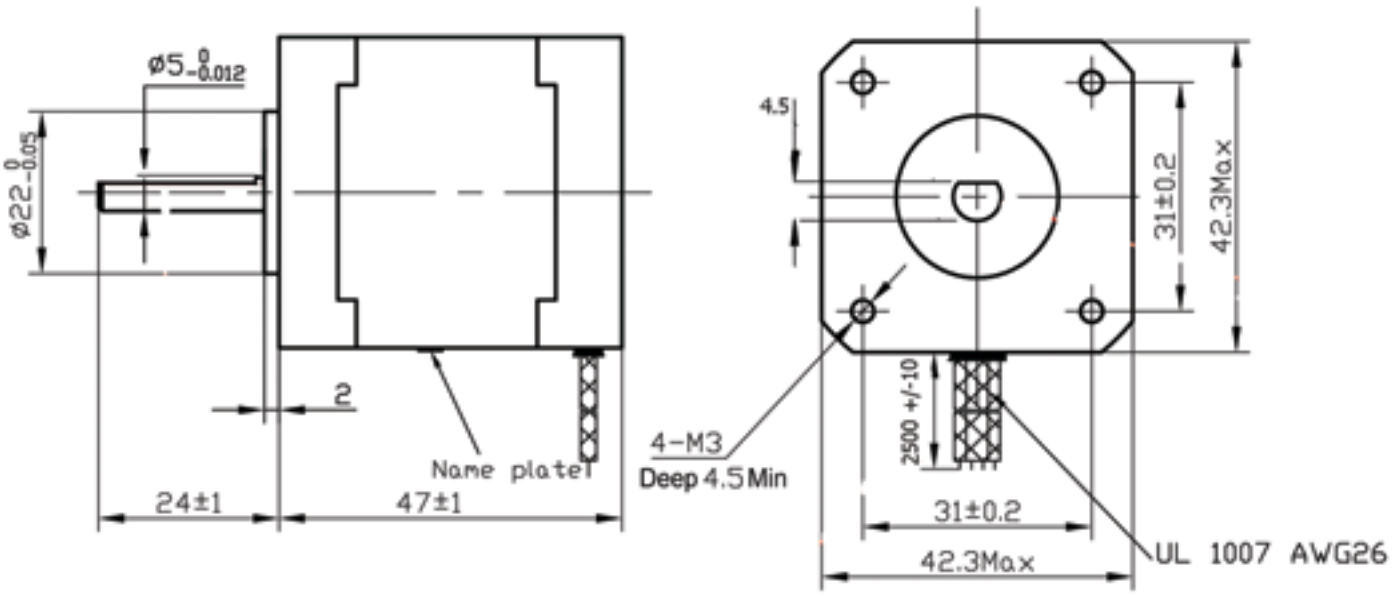


● Wiring Diagram:



● Dimensions:

(unit=mm)



REV	REVISIONS	DESCRIPTION	BY	DATE
DRAW				
CHECK				
APPROVE				

SY42STH47-1684A

Unit 1 Sovereign Business Park,
Willis Way,
Poole,
Dorset,
United Kingdom
BH15 3TB
www.zappautomation.com
enquiries@zappautomation.com

Motor Drivers

DRV8825 Stepper Motor Controller IC

1 Features

- PWM Microstepping Stepper Motor Driver
  - Built-In Microstepping Indexer
  - Up to 1/32 Microstepping
- Multiple Decay Modes
  - Mixed Decay
  - Slow Decay
  - Fast Decay
- 8.2-V to 45-V Operating Supply Voltage Range
- 2.5-A Maximum Drive Current at 24 V and T_A = 25°C
- Simple STEP/DIR Interface
- Low Current Sleep Mode
- Built-In 3.3-V Reference Output
- Small Package and Footprint
- Protection Features
  - Overcurrent Protection (OCP)
  - Thermal Shutdown (TSD)
  - VM Undervoltage Lockout (UVLO)
  - Fault Condition Indication Pin (nFAULT)

2 Applications

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

3 Description

The DRV8825 provides an integrated motor driver solution for printers, scanners, and other automated equipment applications. The device has two H-bridge drivers and a microstepping indexer, and is intended to drive a bipolar stepper motor. The output driver block consists of N-channel power MOSFET's configured as full H-bridges to drive the motor windings. The DRV8825 is capable of driving up to 2.5 A of current from each output (with proper heat sinking, at 24 V and 25°C).

A simple STEP/DIR interface allows easy interfacing to controller circuits. Mode pins allow for configuration of the motor in full-step up to 1/32-step modes. Decay mode is configurable so that slow decay, fast decay, or mixed decay can be used. A low-power sleep mode is provided which shuts down internal circuitry to achieve very low quiescent current draw. This sleep mode can be set using a dedicated nSLEEP pin.

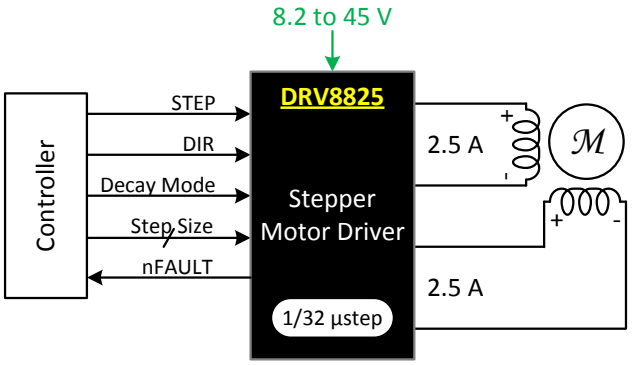
Internal shutdown functions are provided for overcurrent, short circuit, under voltage lockout and over temperature. Fault conditions are indicated via the nFAULT pin.

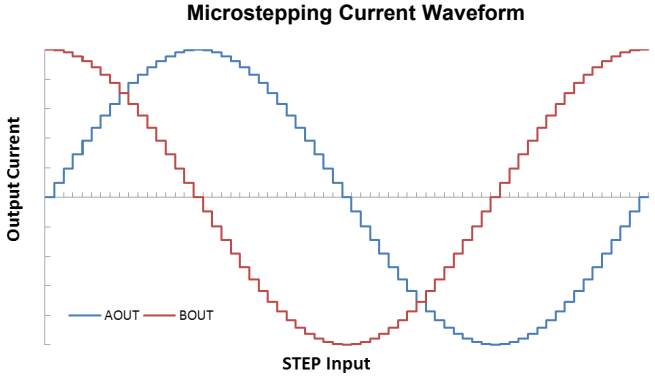
Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
DRV8825	HTSSOP (28)	9.70 mm × 6.40 mm

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

4 Simplified Schematic





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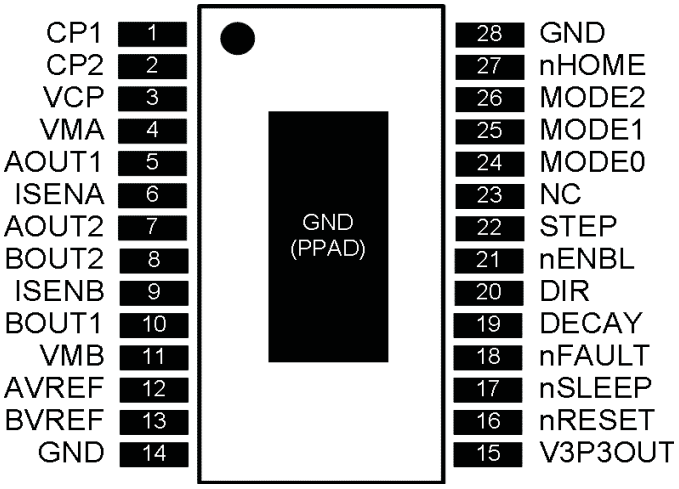
5 Revision History

Changes from Revision E (August 2013) to Revision F **Page**

- Added new sections and reordered data sheet to fit new TI flow ... 1
- Updated pin descriptions ... 3
- Added power supply ramp rate and updated ISENSEx pin voltage in *Absolute Maximum Ratings* ... 4
- Updated V_{IL} voltage minimum and typical in *Electrical Characteristics* ... 6
- Updated I_{IN} and t_{DEG} in *Electrical Characteristics* ... 6

6 Pin Configuration and Functions



Pin Functions

PIN		I/O(1)	DESCRIPTION	EXTERNAL COMPONENTS OR CONNECTIONS
NAME	NO.			
POWER AND GROUND				
CP1	1	I/O	Charge pump flying capacitor	Connect a 0.01-µF 50-V capacitor between CP1 and CP2.
CP2	2	I/O	Charge pump flying capacitor	
GND	14, 28	—	Device ground	
VCP	3	I/O	High-side gate drive voltage	Connect a 0.1-µF 16-V ceramic capacitor and a 1-MΩ resistor to VM.
VMA	4	—	Bridge A power supply	Connect to motor supply (8.2 to 45 V). Both pins must be connected to the same supply, bypassed with a 0.1-µF capacitor to GND, and connected to appropriate bulk capacitance.
VMB	11	—	Bridge B power supply	
V3P3OUT	15	O	3.3-V regulator output	Bypass to GND with a 0.47-µF 6.3-V ceramic capacitor. Can be used to supply VREF.
CONTROL				
AVREF	12	I	Bridge A current set reference input	Reference voltage for winding current set. Normally AVREF and BVREF are connected to the same voltage. Can be connected to V3P3OUT.
BVREF	13	I	Bridge B current set reference input	
DECAY	19	I	Decay mode	Low = slow decay, open = mixed decay, high = fast decay. Internal pulldown and pullup.
DIR	20	I	Direction input	Level sets the direction of stepping. Internal pulldown.
MODE0	24	I	Microstep mode 0	MODE0 through MODE2 set the step mode - full, 1/2, 1/4, 1/8/ 1/16, or 1/32 step. Internal pulldown.
MODE1	25	I	Microstep mode 1	
MODE2	26	I	Microstep mode 2	
NC	23	—	No connect	Leave this pin unconnected.
nENBL	21	I	Enable input	Logic high to disable device outputs and indexer operation, logic low to enable. Internal pulldown.
nRESET	16	I	Reset input	Active-low reset input initializes the indexer logic and disables the H-bridge outputs. Internal pulldown.
nSLEEP	17	I	Sleep mode input	Logic high to enable device, logic low to enter low-power sleep mode. Internal pulldown.
STEP	22	I	Step input	Rising edge causes the indexer to move one step. Internal pulldown.
STATUS				
nFAULT	18	OD	Fault	Logic low when in fault condition (overtemp, overcurrent)

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

Pin Functions (continued)

PIN		I/O[1]	DESCRIPTION	EXTERNAL COMPONENTS OR CONNECTIONS
NAME	NO.			
nHOME	27	OD	Home position	Logic low when at home state of step table
OUTPUT				
AOUT1	5	O	Bridge A output 1	Connect to bipolar stepper motor winding A. Positive current is AOUT1 → AOUT2
AOUT2	7	O	Bridge A output 2	
BOUT1	10	O	Bridge B output 1	Connect to bipolar stepper motor winding B. Positive current is BOUT1 → BOUT2
BOUT2	8	O	Bridge B output 2	
ISENA	6	I/O	Bridge A ground / Isense	Connect to current sense resistor for bridge A.
ISENB	9	I/O	Bridge B ground / Isense	Connect to current sense resistor for bridge B.

7 Specifications

7.1 Absolute Maximum Ratings[1][2]

		MIN	MAX	UNIT
$V_{(VMx)}$	Power supply voltage	–0.3	47	V
	Power supply ramp rate		1	V/µs
	Digital pin voltage	–0.5	7	V
$V_{(xVREF)}$	Input voltage	–0.3	4	V
	ISENSEx pin voltage[3]	–0.8	0.8	V
	Peak motor drive output current, t < 1 µs		Internally limited	A
	Continuous motor drive output current[4]	0	2.5	A
	Continuous total power dissipation	See *Thermal Information*		
T_J	Operating junction temperature range	–40	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to network ground terminal.
(3) Transients of ±1 V for less than 25 ns are acceptable
(4) Power dissipation and thermal limits must be observed.

7.2 Handling Ratings

			MIN	MAX	UNIT
T_{stg}	Storage temperature range		–60	150	°C
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins[1]	–2000	2000	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins[2]	–500	500	

(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.

7.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
$V_{(VMx)}$	Motor power supply voltage range[1]	8.2		45	V
$V_{(VREF)}$	VREF input voltage[2]	1		3.5	V
I_{V3P3}	V3P3OUT load current	0		1	mA

(1) All V_M pins must be connected to the same supply voltage.
(2) Operational at VREF between 0 to 1 V, but accuracy is degraded.

7.4 Thermal Information

THERMAL METRIC(1)		DRV8825 PWP 28 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance(2)	31.6	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance(3)	15.9	
$R_{\theta JB}$	Junction-to-board thermal resistance(4)	5.6	
ψ_{JT}	Junction-to-top characterization parameter(5)	0.2	
ψ_{JB}	Junction-to-board characterization parameter(6)	5.5	
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance(7)	1.4	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.
(2) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
(3) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
(4) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
(5) The junction-to-top characterization parameter, ψ_{JT}, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA}, using a procedure described in JESD51-2a (sections 6 and 7).
(6) The junction-to-board characterization parameter, ψ_{JB}, estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA} , using a procedure described in JESD51-2a (sections 6 and 7).
(7) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

7.5 Electrical Characteristics

over operating free-air temperature range of –40°C to 85°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
POWER SUPPLIES						
I_{VM}	VM operating supply current	$V_{(VMx)}$ = 24 V		5	8	mA
I_{VMQ}	VM sleep mode supply current	$V_{(VMx)}$ = 24 V		10	20	µA
V3P3OUT REGULATOR						
V_{3P3}	V3P3OUT voltage	IOUT = 0 to 1 mA	3.2	3.3	3.4	V
LOGIC-LEVEL INPUTS						
V_{IL}	Input low voltage		0		0.7	V
V_{IH}	Input high voltage		2.2		5.25	V
V_{HYS}	Input hysteresis		0.3	0.45	0.6	V
I_{IL}	Input low current	VIN = 0	–20		20	µA
I_{IH}	Input high current	VIN = 3.3 V			100	µA
R_{PD}	Internal pulldown resistance			100		kΩ
nHOME, nFAULT OUTPUTS (OPEN-DRAIN OUTPUTS)						
V_{OL}	Output low voltage	I_O = 5 mA			0.5	V
I_{OH}	Output high leakage current	V_O = 3.3 V			1	µA
DECAY INPUT						
V_{IL}	Input low threshold voltage	For slow decay mode			0.8	V
V_{IH}	Input high threshold voltage	For fast decay mode	2			V
I_{IN}	Input current		–40		40	µA
R_{PU}	Internal pullup resistance (to 3.3 V)			130		kΩ
R_{PD}	Internal pulldown resistance			80		kΩ
H-BRIDGE FETS						
$R_{DS(ON)}$	HS FET on resistance	$V_{(VMx)}$ = 24 V, I_O = 1 A, T_J = 25°C		0.2		Ω
		$V_{(VMx)}$ = 24 V, I_O = 1 A, T_J = 85°C		0.25	0.32	
	LS FET on resistance	$V_{(VMx)}$ = 24 V, I_O = 1 A, T_J = 25°C		0.2		
		$V_{(VMx)}$ = 24 V, I_O = 1 A, T_J = 85°C		0.25	0.32	
I_{OFF}	Off-state leakage current		–20		20	µA
MOTOR DRIVER						
f_{PWM}	Internal current control PWM frequency			30		kHz
t_{BLANK}	Current sense blanking time			4		µs
t_R	Rise time		30		200	ns
t_F	Fall time		30		200	ns
PROTECTION CIRCUITS						
V_{UVLO}	VM undervoltage lockout voltage	$V_{(VMx)}$ rising		7.8	8.2	V
I_{OCP}	Overcurrent protection trip level		3			A
t_{DEG}	Overcurrent deglitch time			3		µs
t_{TSD}	Thermal shutdown temperature	Die temperature	150	160	180	°C
CURRENT CONTROL						
I_{REF}	xVREF input current	$V_{(xVREF)}$ = 3.3 V	–3		3	µA
V_{TRIP}	xISENSE trip voltage	$V_{(xVREF)}$ = 3.3 V, 100% current setting	635	660	685	mV
ΔI_{TRIP}	Current trip accuracy (relative to programmed value)	$V_{(xVREF)}$ = 3.3 V, 5% current setting	–25%		25%	
		$V_{(xVREF)}$ = 3.3 V, 10% to 34% current setting	–15%		15%	
		$V_{(xVREF)}$ = 3.3 V, 38% to 67% current setting	–10%		10%	
		$V_{(xVREF)}$ = 3.3 V, 71% to 100% current setting	–5%		5%	
A_{ISENSE}	Current sense amplifier gain	Reference only		5		V/V

7.6 Timing Requirements

			MIN	MAX	UNIT
1	f_{STEP}	Step frequency		250	kHz
2	$t_{WH(STEP)}$	Pulse duration, STEP high	1.9		µs
3	$t_{WL(STEP)}$	Pulse duration, STEP low	1.9		µs
4	$t_{SU(STEP)}$	Setup time, command before STEP rising	650		ns
5	$t_{H(STEP)}$	Hold time, command after STEP rising	650		ns
6	t_{ENBL}	Enable time, nENBL active to STEP	650		ns
7	t_{WAKE}	Wakeup time, nSLEEP inactive high to STEP input accepted		1.7	ms

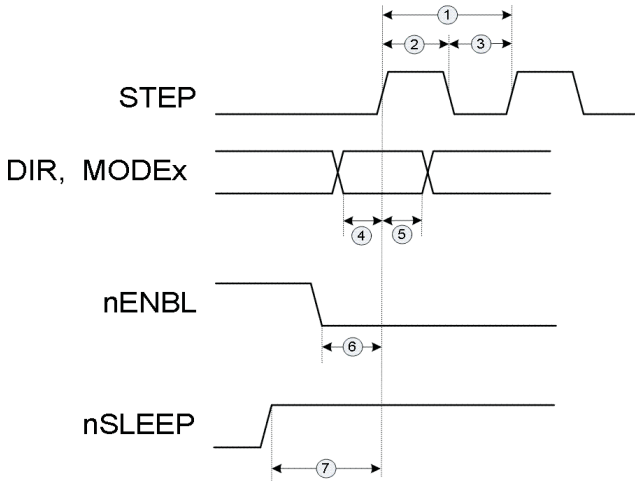


Figure 1. Timing Diagram

7.7 Typical Characteristics

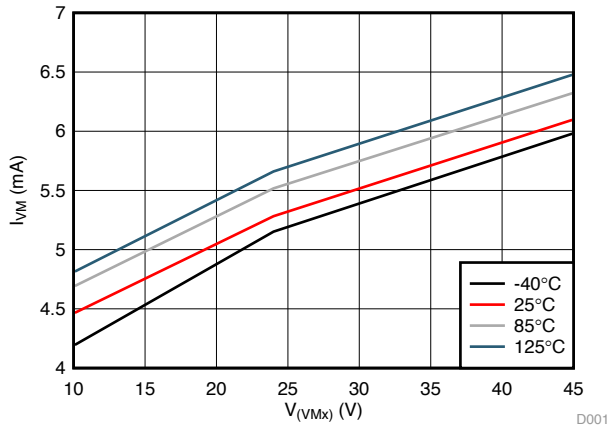


Figure 2. I_{VMx} vs $V_{(VMx)}$

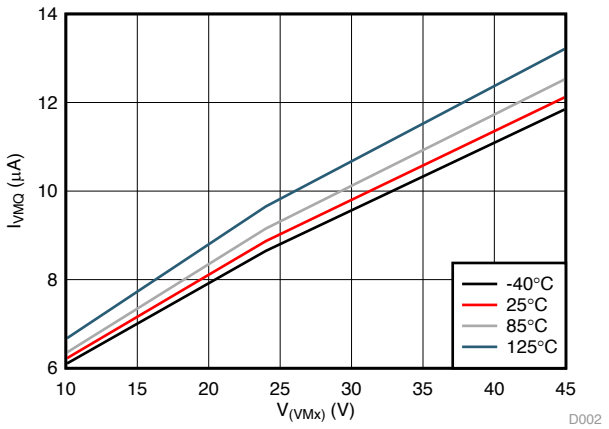


Figure 3. I_{VMxQ} vs $V_{(VMx)}$

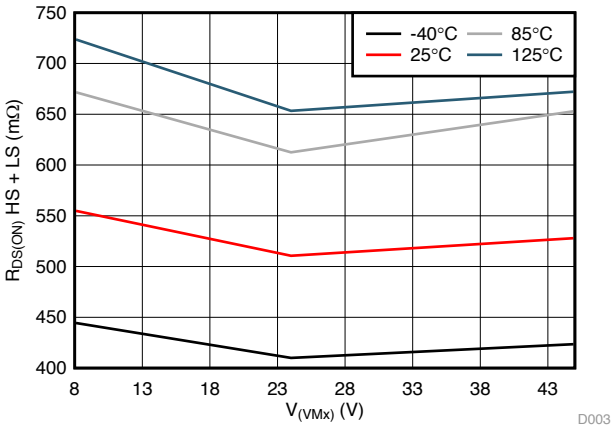


Figure 4. $R_{DS(ON)}$ vs $V_{(VMx)}$

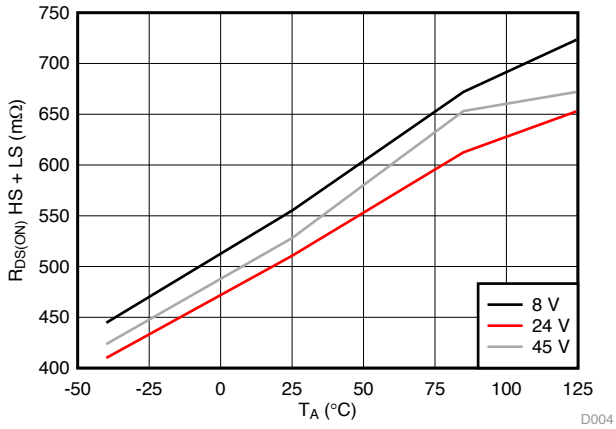


Figure 5. $R_{DS(ON)}$ vs Temperature

8 Detailed Description

8.1 Overview

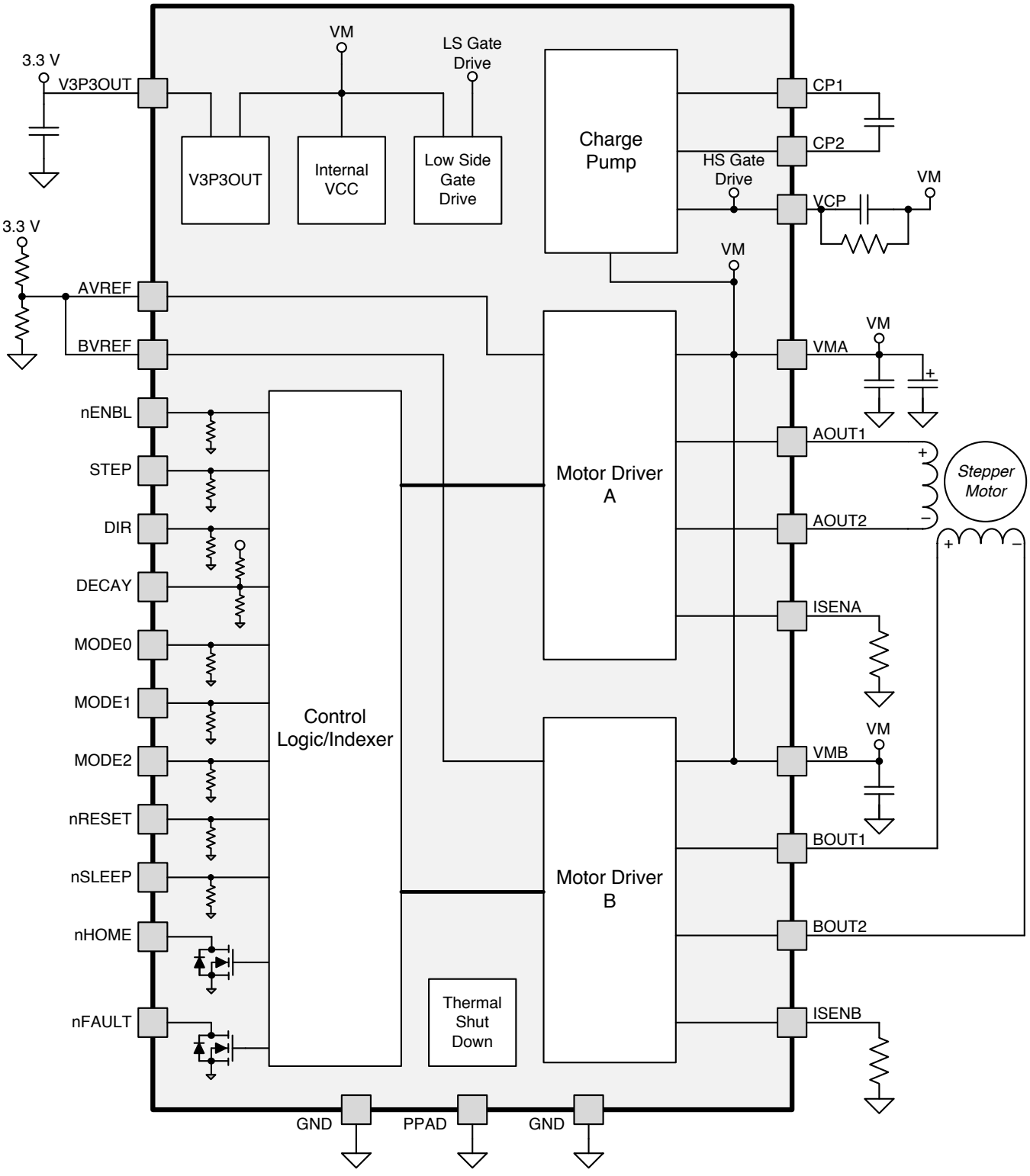
The DRV8825 is an integrated motor driver solution for bipolar stepper motors. The device integrates two NMOS H-bridges, current sense, regulation circuitry, and a microstepping indexer. The DRV8825 can be powered with a supply voltage between 8.2 and 45 V and is capable of providing an output current up to 2.5 A full-scale.

A simple STEP/DIR interface allows for easy interfacing to the controller circuit. The internal indexer is able to execute high-accuracy microstepping without requiring the processor to control the current level.

The current regulation is highly configurable, with three decay modes of operation. Depending on the application requirements, the user can select fast, slow, and mixed decay.

A low-power sleep mode is included which allows the system to save power when not driving the motor.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 PWM Motor Drivers

The DRV8825 contains two H-bridge motor drivers with current-control PWM circuitry. Figure 6 shows a block diagram of the motor control circuitry.

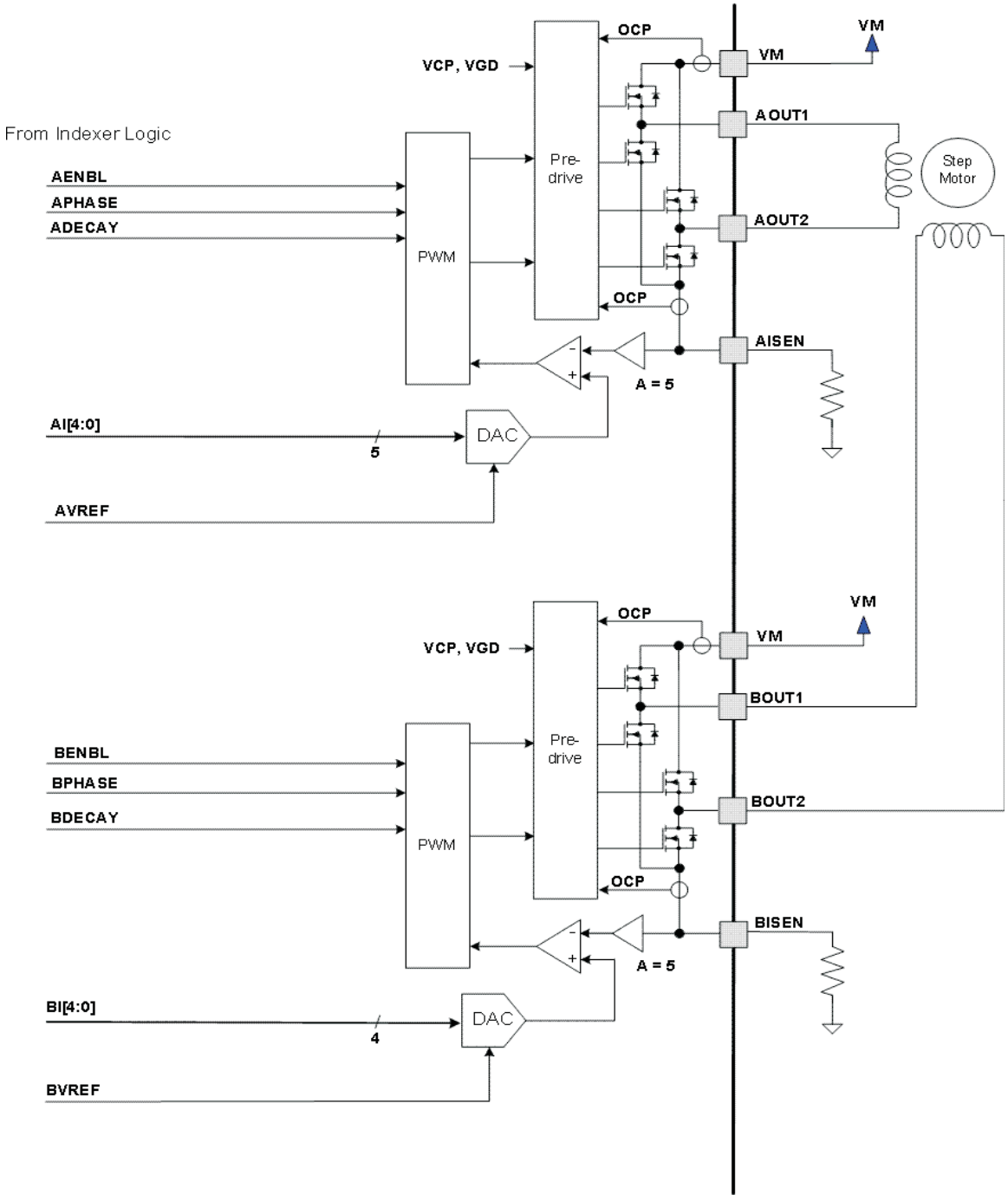


Figure 6. Motor Control Circuitry

Note that there are multiple VM motor power supply pins. All VM pins must be connected together to the motor supply voltage.

Feature Description (continued)

8.3.2 Current Regulation

The current through the motor windings is regulated by a fixed-frequency PWM current regulation, or current chopping. When an H-bridge is enabled, current rises through the winding at a rate dependent on the DC voltage and inductance of the winding. Once the current hits the current chopping threshold, the bridge disables the current until the beginning of the next PWM cycle.

In stepping motors, current regulation is used to vary the current in the two windings in a semi-sinusoidal fashion to provide smooth motion.

The PWM chopping current is set by a comparator which compares the voltage across a current sense resistor connected to the xISEN pins, multiplied by a factor of 5, with a reference voltage. The reference voltage is input from the xVREF pins.

The full-scale (100%) chopping current is calculated in Equation 1.

$$I_{CHOP} = \frac{V_{(xREF)}}{5 \times R_{ISENSE}} \quad (1)$$

Example:

If a 0.25-Ω sense resistor is used and the VREFx pin is 2.5 V, the full-scale (100%) chopping current will be 2.5 V / (5 x 0.25 Ω) = 2 A.

The reference voltage is scaled by an internal DAC that allows fractional stepping of a bipolar stepper motor, as described in the microstepping indexer section below.

8.3.3 Decay Mode

During PWM current chopping, the H-bridge is enabled to drive current through the motor winding until the PWM current chopping threshold is reached. This is shown in Figure 7 as case 1. The current flow direction shown indicates positive current flow.

Once the chopping current threshold is reached, the H-bridge can operate in two different states, fast decay or slow decay.

In fast decay mode, once the PWM chopping current level has been reached, the H-bridge reverses state to allow winding current to flow in a reverse direction. As the winding current approaches 0, the bridge is disabled to prevent any reverse current flow. Fast decay mode is shown in Figure 7 as case 2.

In slow decay mode, winding current is recirculated by enabling both of the low-side FETs in the bridge. This is shown in Figure 7 as case 3.

Feature Description (continued)

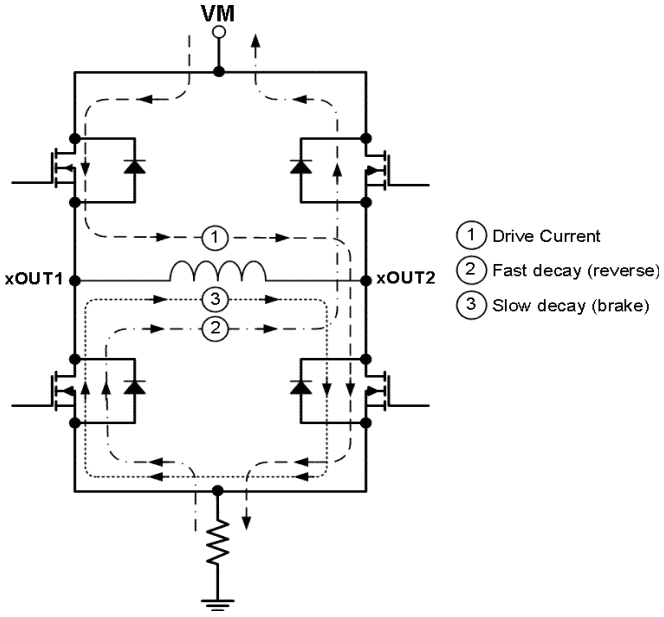


Figure 7. Decay Mode

The DRV8825 supports fast decay, slow decay and a mixed decay mode. Slow, fast, or mixed decay mode is selected by the state of the DECAY pin; logic low selects slow decay, open selects mixed decay operation, and logic high sets fast decay mode. The DECAY pin has both an internal pullup resistor of approximately 130 kΩ and an internal pulldown resistor of approximately 80 kΩ. This sets the mixed decay mode if the pin is left open or undriven.

Mixed decay mode begins as fast decay, but at a fixed period of time (75% of the PWM cycle) switches to slow decay mode for the remainder of the fixed PWM period. This occurs only if the current through the winding is decreasing (per the indexer step table); if the current is increasing, then slow decay is used.

8.3.4 Blanking Time

After the current is enabled in an H-bridge, the voltage on the xISEN pin is ignored for a fixed period of time before enabling the current sense circuitry. This blanking time is fixed at 3.75 µs. Note that the blanking time also sets the minimum on time of the PWM.

8.3.5 Microstepping Indexer

Built-in indexer logic in the DRV8825 allows a number of different stepping configurations. The MODE0 through MODE2 pins are used to configure the stepping format as shown in Table 1.

Table 1. Stepping Format

MODE2	MODE1	MODE0	STEP MODE
0	0	0	Full step (2-phase excitation) with 71% current
0	0	1	1/2 step (1-2 phase excitation)
0	1	0	1/4 step (W1-2 phase excitation)
0	1	1	8 microsteps/step
1	0	0	16 microsteps/step
1	0	1	32 microsteps/step
1	1	0	32 microsteps/step
1	1	1	32 microsteps/step

Table 2 shows the relative current and step directions for different settings of MODEx. At each rising edge of the STEP input, the indexer travels to the next state in the table. The direction is shown with the DIR pin high; if the DIR pin is low the sequence is reversed. Positive current is defined as xOUT1 = positive with respect to xOUT2.

Note that if the step mode is changed while stepping, the indexer will advance to the next valid state for the new MODEx setting at the rising edge of STEP.

The home state is 45°. This state is entered at power-up or application of nRESET. This is shown in Table 2 by the shaded cells. The logic inputs DIR, STEP, nRESET, and MODEx have internal pulldown resistors of 100 kΩ.

Table 2. Relative Current and Step Directions

1/32 STEP	1/16 STEP	1/8 STEP	1/4 STEP	1/2 STEP	FULL STEP 70%	WINDING CURRENT A	WINDING CURRENT B	ELECTRICAL ANGLE
1	1	1	1	1		100%	0%	0
2						100%	5%	3
3	2					100%	10%	6
4						99%	15%	8
5	3	2				98%	20%	11
6						97%	24%	14
7	4					96%	29%	17
8						94%	34%	20
9	5	3	2			92%	38%	23
10						90%	43%	25
11	6					88%	47%	28
12						86%	51%	31
13	7	4				83%	56%	34
14						80%	60%	37
15	8					77%	63%	39
16						74%	67%	42
17	9	5	3	2	1	71%	71%	45
18						67%	74%	48
19	10					63%	77%	51
20						60%	80%	53
21	11	6				56%	83%	56
22						51%	86%	59
23	12					47%	88%	62
24						43%	90%	65
25	13	7	4			38%	92%	68
26						34%	94%	70
27	14					29%	96%	73
28						24%	97%	76
29	15	8				20%	98%	79
30						15%	99%	82
31	16					10%	100%	84
32						5%	100%	87
33	17	9	5	3		0%	100%	90
34						–5%	100%	93
35	18					–10%	100%	96
36						–15%	99%	98
37	19	10				–20%	98%	101
38						–24%	97%	104
39	20					–29%	96%	107

Table 2. Relative Current and Step Directions (continued)

1/32 STEP	1/16 STEP	1/8 STEP	1/4 STEP	1/2 STEP	FULL STEP 70%	WINDING CURRENT A	WINDING CURRENT B	ELECTRICAL ANGLE
40						–34%	94%	110
41	21	11	6			–38%	92%	113
42						–43%	90%	115
43	22					–47%	88%	118
44						–51%	86%	121
45	23	12				–56%	83%	124
46						–60%	80%	127
47	24					–63%	77%	129
48						–67%	74%	132
49	25	13	7	4	2	–71%	71%	135
50						–74%	67%	138
51	26					–77%	63%	141
52						–80%	60%	143
53	27	14				–83%	56%	146
54						–86%	51%	149
55	28					–88%	47%	152
56						–90%	43%	155
57	29	15	8			–92%	38%	158
58						–94%	34%	160
59	30					–96%	29%	163
60						–97%	24%	166
61	31	16				–98%	20%	169
62						–99%	15%	172
63	32					–100%	10%	174
64						–100%	5%	177
65	33	17	9	5		–100%	0%	180
66						–100%	–5%	183
67	34					–100%	–10%	186
68						–99%	–15%	188
69	35	18				–98%	–20%	191
70						–97%	–24%	194
71	36					–96%	–29%	197
72						–94%	–34%	200
73	37	19	10			–92%	–38%	203
74						–90%	–43%	205
75	38					–88%	–47%	208
76						–86%	–51%	211
77	39	20				–83%	–56%	214
78						–80%	–60%	217
79	40					–77%	–63%	219
80						–74%	–67%	222
81	41	21	11	6	3	–71%	–71%	225
82						–67%	–74%	228
83	42					–63%	–77%	231
84						–60%	–80%	233
85	43	22				–56%	–83%	236
86						–51%	–86%	239

Table 2. Relative Current and Step Directions (continued)

1/32 STEP	1/16 STEP	1/8 STEP	1/4 STEP	1/2 STEP	FULL STEP 70%	WINDING CURRENT A	WINDING CURRENT B	ELECTRICAL ANGLE
87	44					–47%	–88%	242
88						–43%	–90%	245
89	45	23	12			–38%	–92%	248
90						–34%	–94%	250
91	46					–29%	–96%	253
92						–24%	–97%	256
93	47	24				–20%	–98%	259
94						–15%	–99%	262
95	48					–10%	–100%	264
96						–5%	–100%	267
97	49	25	13	7		0%	–100%	270
98						5%	–100%	273
99	50					10%	–100%	276
100						15%	–99%	278
101	51	26				20%	–98%	281
102						24%	–97%	284
103	52					29%	–96%	287
104						34%	–94%	290
105	53	27	14			38%	–92%	293
106						43%	–90%	295
107	54					47%	–88%	298
108						51%	–86%	301
109	55	28				56%	–83%	304
110						60%	–80%	307
111	56					63%	–77%	309
112						67%	–74%	312
113	57	29	15	8	4	71%	–71%	315
114						74%	–67%	318
115	58					77%	–63%	321
116						80%	–60%	323
117	59	30				83%	–56%	326
118						86%	–51%	329
119	60					88%	–47%	332
120						90%	–43%	335
121	61	31	16			92%	–38%	338
122						94%	–34%	340
123	62					96%	–29%	343
124						97%	–24%	346
125	63	32				98%	–20%	349
126						99%	–15%	352
127	64					100%	–10%	354
128						100%	–5%	357

8.3.6 nRESET, nENBL, and nSLEEP Operation

The nRESET pin, when driven active low, resets internal logic, and resets the step table to the home position. It also disables the H-bridge drivers. The STEP input is ignored while nRESET is active.

The nENBL pin is used to control the output drivers and enable/disable operation of the indexer. When nENBL is low, the output H-bridges are enabled, and rising edges on the STEP pin are recognized. When nENBL is high, the H-bridges are disabled, the outputs are in a high-impedance state, and the STEP input is ignored.

Driving nSLEEP low will put the device into a low power sleep state. In this state, the H-bridges are disabled, the gate drive charge pump is stopped, the V3P3OUT regulator is disabled, and all internal clocks are stopped. In this state all inputs are ignored until nSLEEP returns inactive high. When returning from sleep mode, some time (approximately 1 ms) needs to pass before applying a STEP input, to allow the internal circuitry to stabilize. Note that nRESET and nENABL have internal pulldown resistors of approximately 100 kΩ. The nSLEEP pin has an internal pulldown resistor of 1 MΩ. nSLEEP and nRESET signals need to be driven to logic high for device operation.

8.3.7 Protection Circuits

The DRV8825 is fully protected against undervoltage, overcurrent, and overtemperature events.

8.3.7.1 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 remains disabled until either nRESET pin is applied, or VM is removed and reapplied.

Overcurrent conditions on both high-side and low-side devices; that is, a short to ground, supply, or across the motor winding 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 I_{SENSE} resistor value or xVREF voltage.

8.3.7.2 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. After the die temperature has fallen to a safe level, operation automatically resumes.

8.3.7.3 Undervoltage Lockout (UVLO)

If at any time the voltage on the VM pins falls below the UVLO threshold voltage, all circuitry in the device will be disabled and internal logic will be reset. Operation will resume when $V_{(VMx)}$ rises above the UVLO threshold.

8.4 Device Functional Modes

8.4.1 STEP/DIR Interface

The STEP/DIR interface provides a simple method for advancing through the indexer table. For each rising edge on the STEP pin, the indexer travels to the next state in the table. The direction it moves in the table is determined by the input to the DIR pin. The signals applied to the STEP and DIR pins should not violate the timing diagram specified in Figure 1.

8.4.2 Microstepping

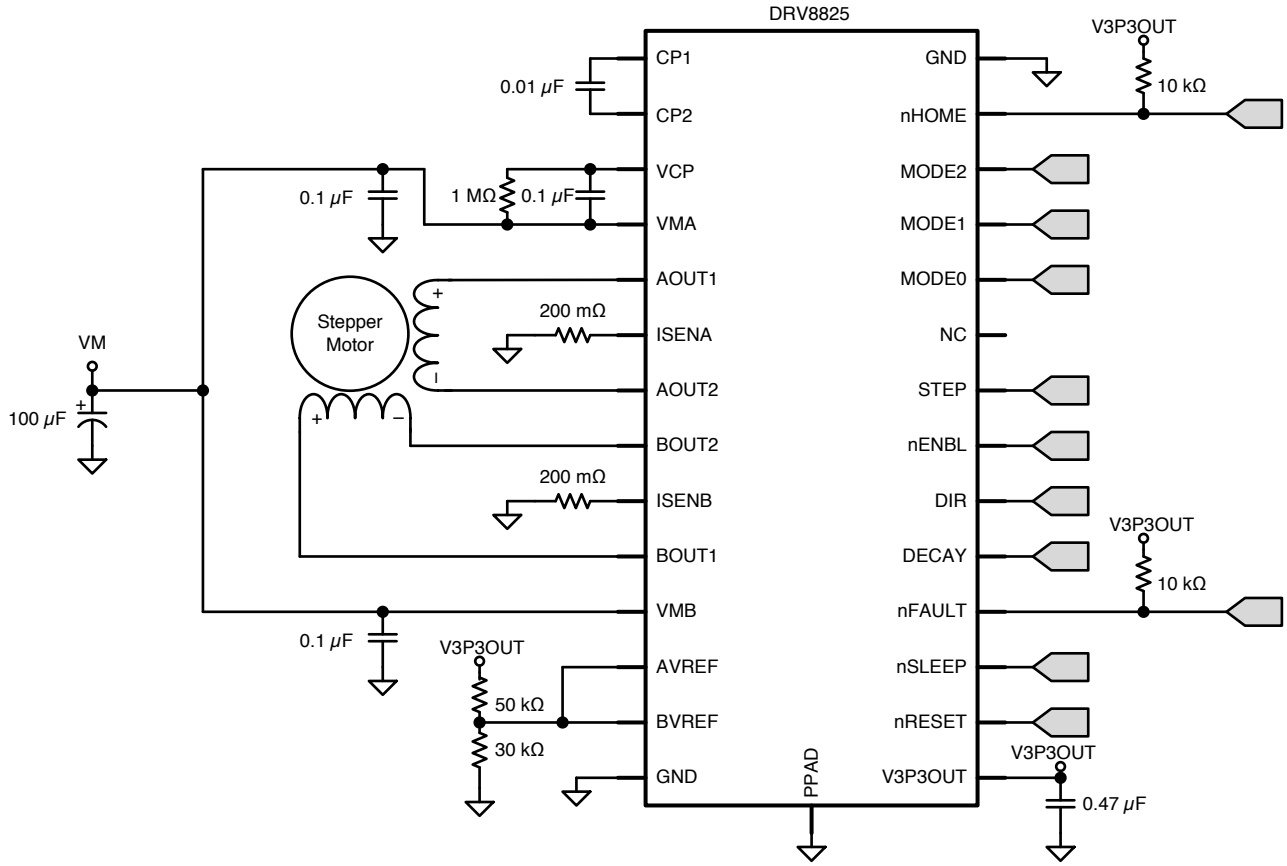
The microstepping indexer allows for a variety of stepping configurations. The state of the indexer is determined by the configuration of the three MODE pins (refer to Table 1 for configuration options). The DRV8825 supports full step up to 1/32 microstepping.

9 Application and Implementation

9.1 Application Information

The DRV8825 is used in bipolar stepper control. The microstepping motor driver provides additional precision and a smooth rotation from the stepper motor. The following design is a common application of the DRV8825.

9.2 Typical Application



9.2.1 Design Requirements

Design Parameter	Reference	Example Value
Supply Voltage	VM	24 V
Motor Winding Resistance	RL	3.9 Ω
Motor Winding Inductance	IL	2.9 mH
Motor Full Step Angle	θstep	1.8°/step
Target Microstepping Level	nm	8 µsteps per step
Target Motor Speed	v	120 rpm
Target Full-Scale Current	IFS	1.25 A

9.2.2 Detailed Design Procedure

9.2.2.1 Stepper Motor Speed

The first step in configuring the DRV8825 requires the desired motor speed and microstepping level. If the target application requires a constant speed, then a square wave with frequency f_{step} must be applied to the STEP pin.

If the target motor startup speed is too high, the motor will not spin. Make sure that the motor can support the target speed or implement an acceleration profile to bring the motor up to speed.

For a desired motor speed (v), microstepping level (n_m), and motor full step angle (θ_{step}),

$$f_{step}\,(\mu steps/second) = \frac{v\left(\frac{rotations}{minute}\right) \times 360\left(\frac{^\circ}{rotation}\right) \times n_m\left(\frac{\mu steps}{step}\right)}{60\left(\frac{seconds}{minute}\right) \times \theta_{step}\left(\frac{^\circ}{step}\right)} \quad (2)$$

$$f_{step}\,(\mu steps/second) = \frac{120\left(\frac{rotations}{minute}\right) \times 360\left(\frac{^\circ}{rotation}\right) \times 8\left(\frac{\mu steps}{step}\right)}{60\left(\frac{seconds}{minute}\right) \times 1.8\left(\frac{^\circ}{step}\right)} \quad (3)$$

θ_{step} can be found in the stepper motor data sheet or written on the motor itself.

For the DRV8825, the microstepping level is set by the MODE pins and can be any of the settings in Table 1. Higher microstepping will mean a smoother motor motion and less audible noise, but will increase switching losses and require a higher f_{step} to achieve the same motor speed.

9.2.2.2 Current Regulation

In a stepper motor, the set full-scale current (I_{FS}) is the maximum current driven through either winding. This quantity depends on the xVREF analog voltage and the sense resistor value (R_{SENSE}). During stepping, I_{FS} defines the current chopping threshold (I_{TRIP}) for the maximum current step. The gain of DRV8825 is set for 5 V/V.

$$I_{FS}\,(A) = \frac{xVREF\,(V)}{A_v \times R_{SENSE}\,(\Omega)} = \frac{xVREF\,(V)}{5 \times R_{SENSE}\,(\Omega)} \quad (4)$$

To achieve I_{FS} = 1.25 A with R_{SENSE} of 0.2 Ω, xVREF should be 1.25 V.

9.2.2.3 Decay Modes

The DRV8825 supports three different decay modes: slow decay, fast decay, and mixed decay. The current through the motor windings is regulated using a fixed-frequency PWM scheme. This means that after any drive phase, when a motor winding current has hit the current chopping threshold (I_{TRIP}), the DRV8825 will place the winding in one of the three decay modes until the PWM cycle has expired. Afterward, a new drive phase starts.

The blanking time, t_{BLANK}, defines the minimum drive time for the current chopping. I_{TRIP} is ignored during t_{BLANK}, so the winding current may overshoot the trip level.

9.2.3 Application Curves

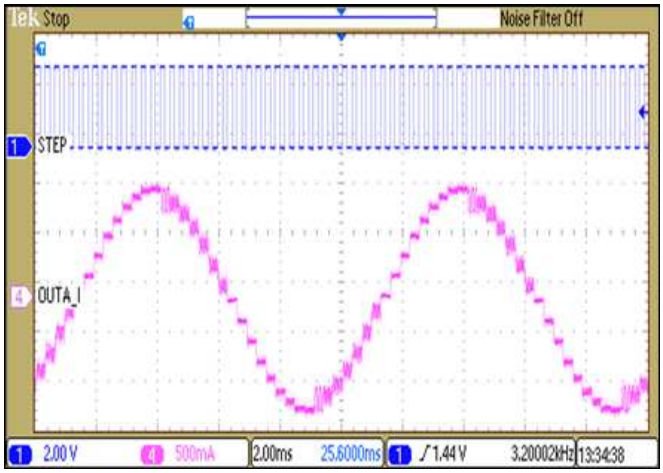


Figure 8. Microstepping Current (Phase A) vs STEP Input, Mixed Decay

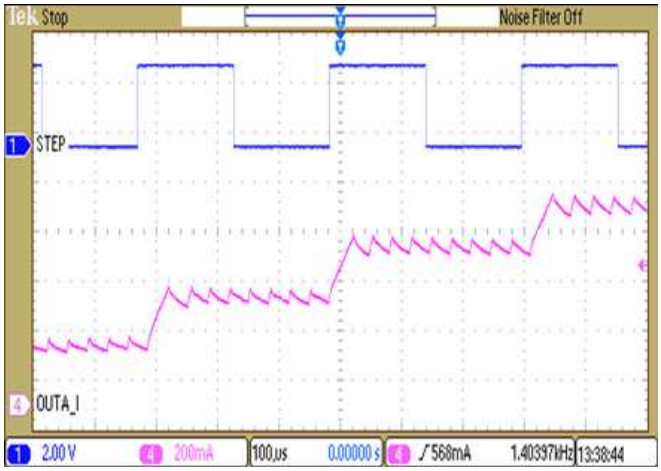


Figure 9. Microstepping Current (Phase A) vs STEP Input, Slow Decay on Increasing Steps

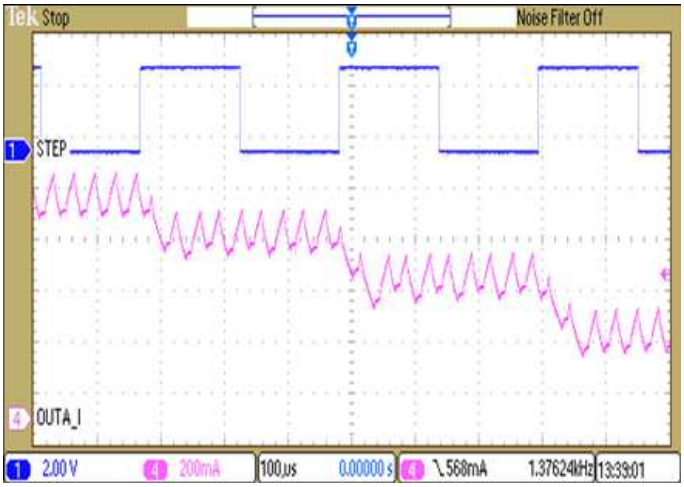


Figure 10. Microstepping Current (Phase A) vs STEP Input, Mixed Decay on Decreasing Steps

10 Power Supply Recommendations

The DRV8825 is designed to operate from an input voltage supply (VMx) range between 8.2 and 45 V. Two 0.1-µF ceramic capacitors rated for VMx must be placed as close as possible to the VMA and VMB pins respectively (one on each pin). In addition to the local decoupling caps, additional bulk capacitance is required and must be sized accordingly to the application requirements.

10.1 Bulk Capacitance

Bulk capacitance sizing is an important factor in motor drive system design. It is dependent on a variety of factors including:

- Type of power supply
- Acceptable supply voltage ripple
- Parasitic inductance in the power supply wiring
- Type of motor (brushed DC, brushless DC, stepper)
- Motor startup current
- Motor braking method

The inductance between the power supply and motor drive system will limit the rate current can change from the power supply. If the local bulk capacitance is too small, the system will respond to excessive current demands or dumps from the motor with a change in voltage. You should size the bulk capacitance to meet acceptable voltage ripple levels.

The data sheet generally provides a recommended value but system level testing is required to determine the appropriate sized bulk capacitor.

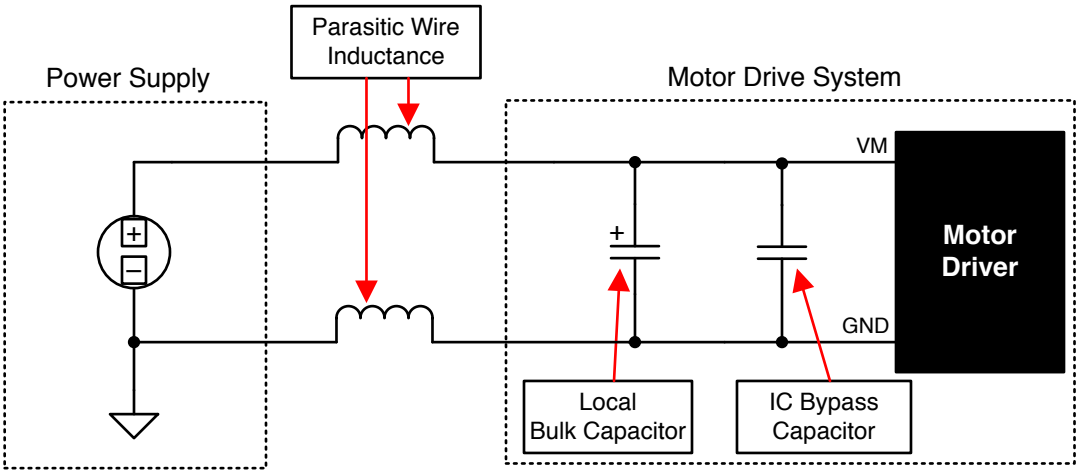


Figure 11. Setup of Motor Drive System With External Power Supply

10.2 Power Supply and Logic Sequencing

There is no specific sequence for powering-up the DRV8825. It is okay for digital input signals to be present before VMx is applied. After VMx is applied to the DRV8825, it begins operation based on the status of the control pins.

11 Layout

11.1 Layout Guidelines

The VMA and VMB pins should be bypassed to GND using low-ESR ceramic bypass capacitors with a recommended value of 0.1-µF rated for VMx. This capacitor should be placed as close to the VMA and VMB pins as possible with a thick trace or ground plane connection to the device GND pin.

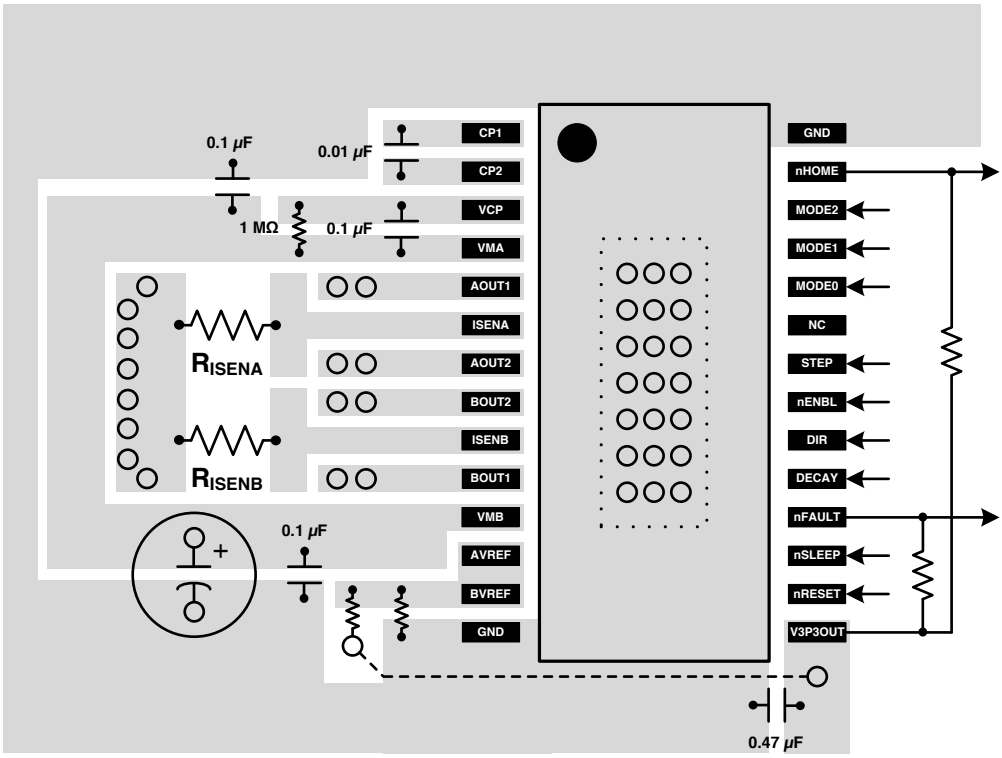
The VMA and VMB pins must be bypassed to ground using an appropriate bulk capacitor. This component may be an electrolytic and should be located close to the DRV8825.

A low-ESR ceramic capacitor must be placed in between the CPL and CPH pins. TI recommends a value of 0.01-µF rated for VMx. Place this component as close to the pins as possible.

A low-ESR ceramic capacitor must be placed in between the VMA and VCP pins. TI recommends a value of 0.1-µF rated for 16 V. Place this component as close to the pins as possible. Also, place a 1-MΩ resistor between VCP and VMA.

Bypass V3P3 to ground with a ceramic capacitor rated 6.3 V. Place this bypass capacitor as close to the pin as possible

11.2 Layout Example



11.3 Thermal Protection

The DRV8825 has thermal shutdown (TSD) as described above. If the die temperature exceeds approximately 150°C, the device will be disabled until the temperature drops to a safe level.

Any tendency of the device to enter TSD is an indication of either excessive power dissipation, insufficient heatsinking, or too high an ambient temperature.

11.3.1 Power Dissipation

Power dissipation in the DRV8825 is dominated by the power dissipated in the output FET resistance, or $R_{DS(ON)}$. Average power dissipation when running a stepper motor can be roughly estimated by Equation 5.

Thermal Protection (continued)

$$P_{TOT} = 4 \times R_{DS(ON)} \times \left(I_{OUT(RMS)}\right)^2 \quad (5)$$

where P_{TOT} is the total power dissipation, $R_{DS(ON)}$ is the resistance of each FET, and $I_{OUT(RMS)}$ is the RMS output current being applied to each winding. $I_{OUT(RMS)}$ is equal to the approximately 0.7x the full-scale output current setting. The factor of 4 comes from the fact that there are two motor windings, and at any instant two FETs are conducting winding current for each winding (one high-side and one low-side).

The maximum amount of power that can be dissipated in the device is dependent on ambient temperature and heatsinking.

Note that $R_{DS(ON)}$ increases with temperature, so as the device heats, the power dissipation increases. This must be taken into consideration when sizing the heatsink.

11.3.2 Heatsinking

The PowerPAD™ package uses an exposed pad to remove heat from the device. For proper operation, this pad must be thermally connected to copper on the PCB to dissipate heat. On a multi-layer PCB with a ground plane, this can be accomplished by adding a number of vias to connect the thermal pad to the ground plane. On PCBs without internal planes, copper area can be added on either side of the PCB to dissipate heat. If the copper area is on the opposite side of the PCB from the device, thermal vias are used to transfer the heat between top and bottom layers.

For details about how to design the PCB, refer to TI application report SLMA002, "PowerPAD™ Thermally Enhanced Package" and TI application brief SLMA004, *PowerPAD™ Made Easy*, available at www.ti.com.

In general, the more copper area that can be provided, the more power can be dissipated. It can be seen that the heatsink effectiveness increases rapidly to about 20 cm^2, then levels off somewhat for larger areas.

12 Device and Documentation Support

12.1 Trademarks

PowerPAD is a trademark of Texas Instruments.

12.2 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.

12.3 Glossary

SLYZ022 — *TI Glossary*.

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

13 Mechanical, Packaging, and Orderable Information

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

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
DRV8825PWP	ACTIVE	HTSSOP	PWP	28	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	DRV8825	Samples
DRV8825PWPR	ACTIVE	HTSSOP	PWP	28	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	DRV8825	Samples

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

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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

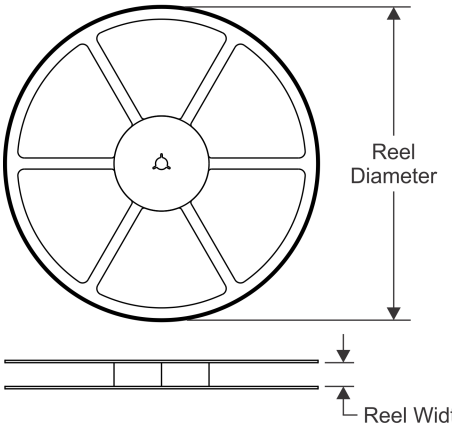
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

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

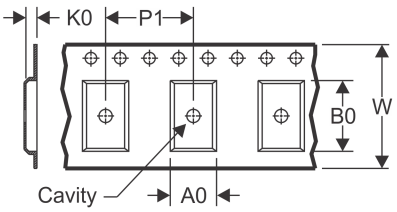
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

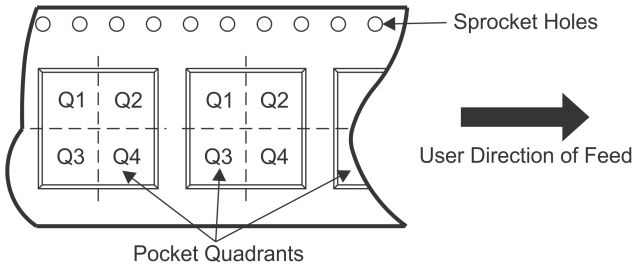


TAPE DIMENSIONS



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

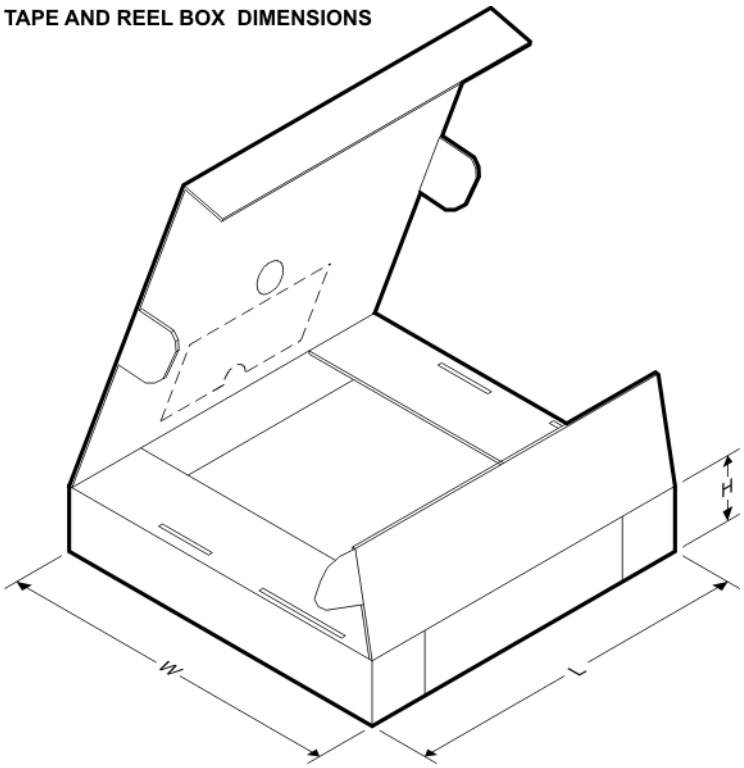
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
DRV8825PWPR	HTSSOP	PWP	28	2000	330.0	16.4	6.9	10.2	1.8	12.0	16.0	Q1

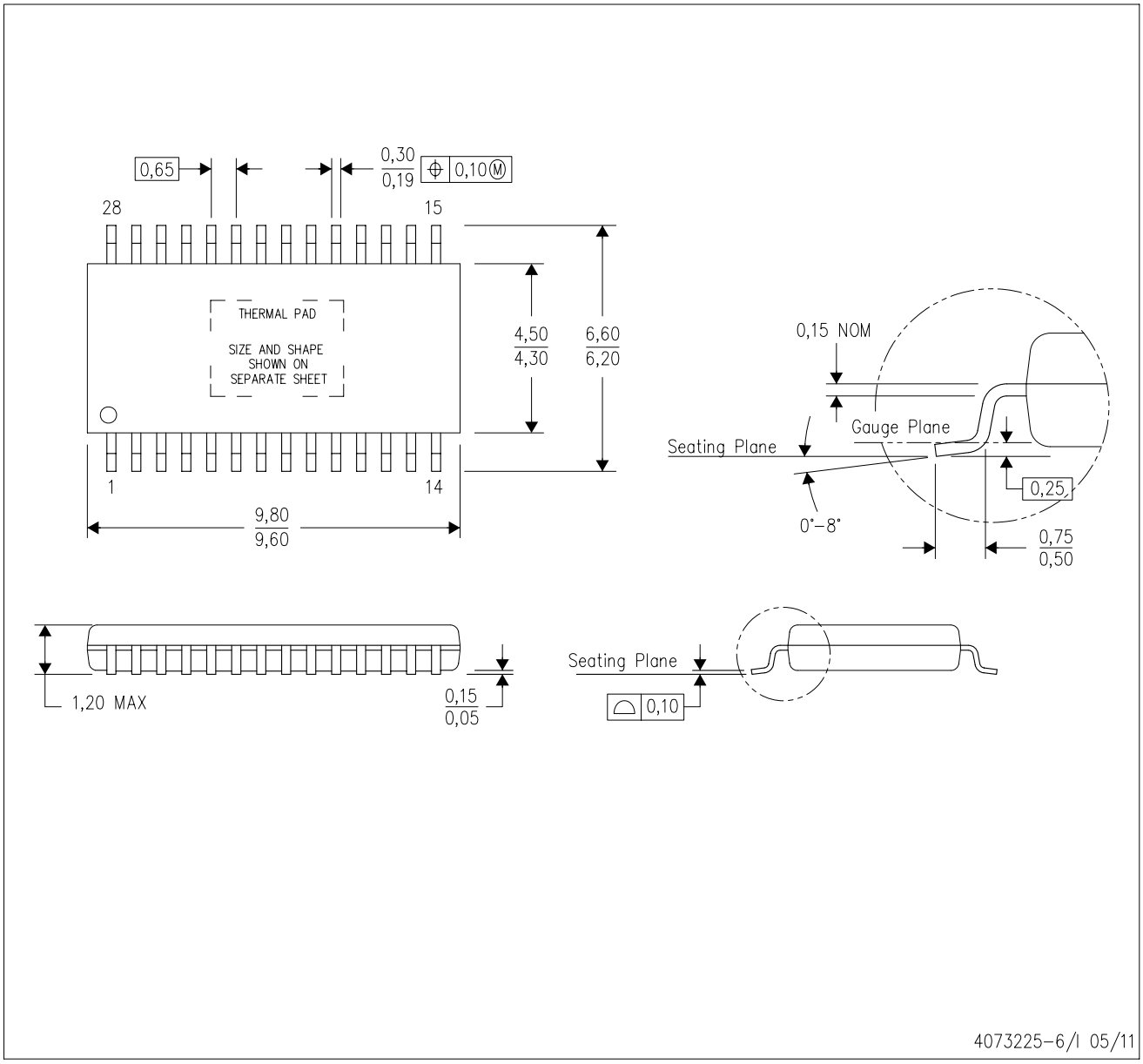
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
DRV8825PWPR	HTSSOP	PWP	28	2000	367.0	367.0	38.0

PWP (R–PDSO–G28) PowerPAD™ PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusions. Mold flash and protrusion shall not exceed 0.15 per side.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <http://www.ti.com>.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
E. Falls within JEDEC MO–153

PowerPAD is a trademark of Texas Instruments.

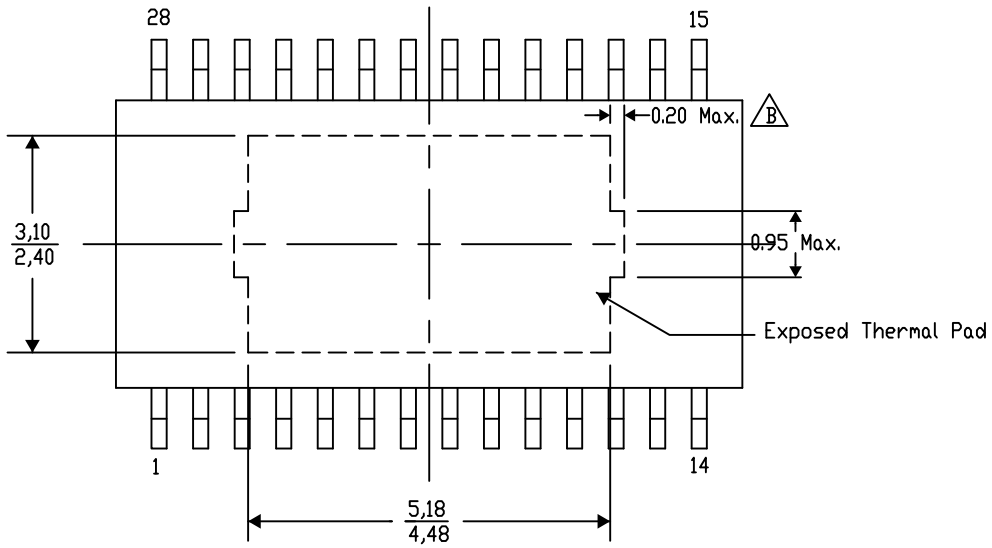
PWP (R–PDSO–G28) PowerPAD™ SMALL PLASTIC OUTLINE

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the PCB. After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Top View

Exposed Thermal Pad Dimensions

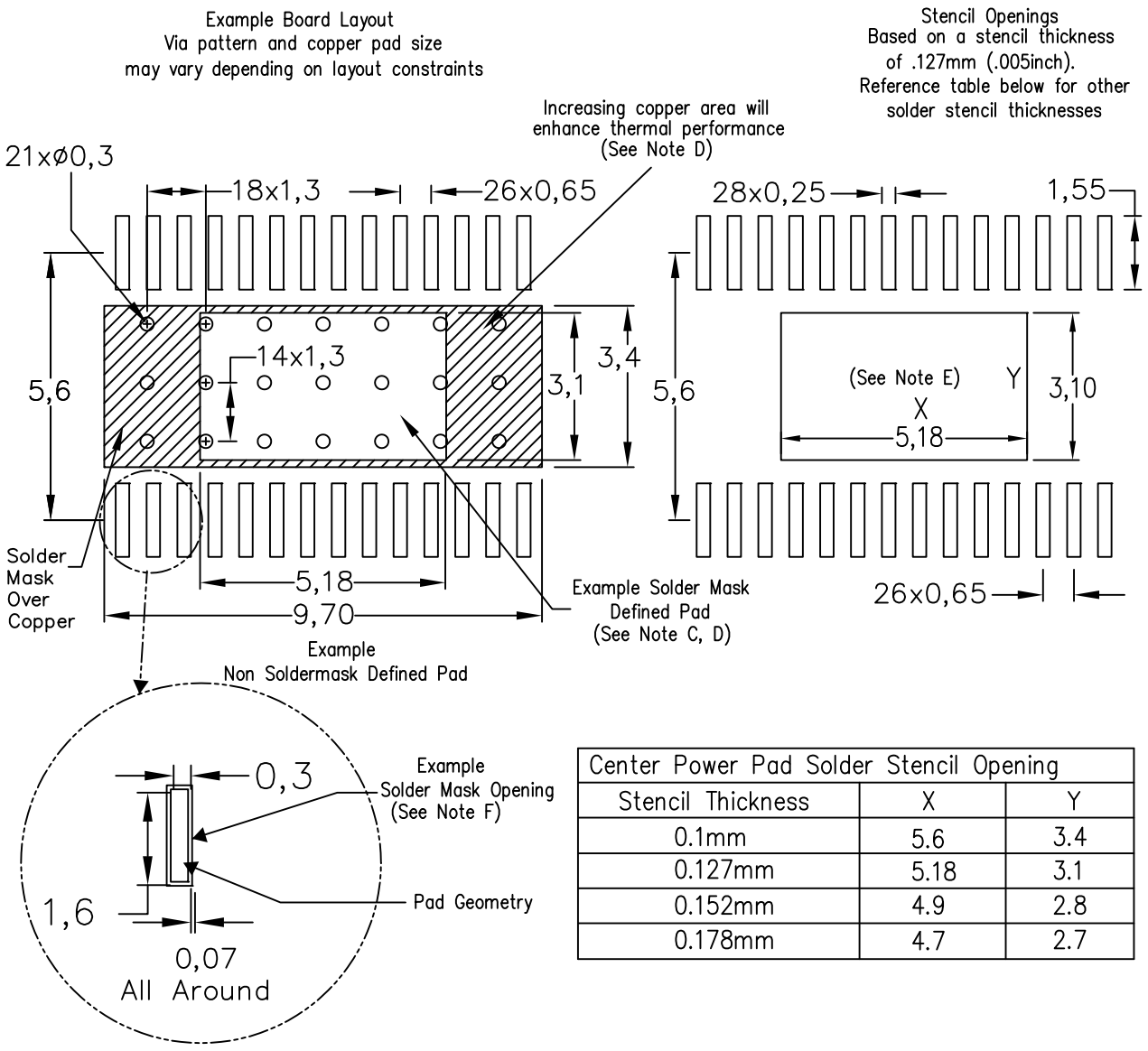
4206332–38/AH 11/13

NOTE: A. All linear dimensions are in millimeters

B. Exposed tie strap features may not be present.

PowerPAD is a trademark of Texas Instruments

PWP (R–PDSO–G28) PowerPAD™ PLASTIC SMALL OUTLINE



Center Power Pad Solder Stencil Opening		
Stencil Thickness	X	Y
0.1mm	5.6	3.4
0.127mm	5.18	3.1
0.152mm	4.9	2.8
0.178mm	4.7	2.7

4207609–22/T 08/13

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002, SLMA004, and also the Product Data Sheets.
E. For specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http://www.ti.com>. Publication IPC–7351 is recommended for alternate designs. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil
F. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Firmware source code

```
#include <AccelStepper.h>
#include <MultiStepper.h>

// Variable declaration

// Arduino Pins
const int recoater1                 = 12; //STEP
const int recoater2                 = 13; //DIR
const int printzone1                = 10; //STEP
const int printzone2                = 11; //DIR
const int pow_feeding1              = 8; //STEP
const int pow_feeding2              = 9;//DIR
const int rec_stop                  = 24;
const int printzone_stop            = 23;
const int pow_feeding_stop          = 26;
const int layer_button              = 50;
const int home_button               = 48;
const int set_up_button             = 46;
const int powder_cleaning_button    = 44;
const int part_extracting_button    = 42;
const int cilynder_button           = 40;

//Motor steps
const int steps_rec                 = 800;
const int steps_pla                 = 800;

// Speed to 0 position in mm/s
const long speed_to_0       = 80;
const long recoater_speed_0 = 30;

//Geometrical data
const long bar_coarse       = 1.25;   //In mm
const long recoater_move    = 115;    //In mm

//Printing data
const long layer_thickness    = 1;    //In mm
const long feeding_thickness  = 2;    //In mm
const long recoater_speed     = 30; //In mm/s
const long platforms_speed    = 20;   //In mm/s
const long motor_pulley_teeth = 20;   //Teeth
const long belt_teeth         = 5;    //Teeth/cm
const long set_up_z           = 20;   //Feeding z start in mm

//Variable Calculations
const    long    mspeed_to_0                                    =
(speed_to_0/bar_coarse)*(steps_pla/60);                              //steps/s
const        long        mrecoater_speed_0                      =
(recoater_speed_0*10*belt_teeth/motor_pulley_teeth)*(steps_rec/60);
//steps/s
const      long      mrecoater_speed                            =
(recoater_speed*10*belt_teeth/motor_pulley_teeth)*(steps_rec/60);
//steps/s
const       long       mplatforms_speed                        =
(platforms_speed/bar_coarse)*(steps_pla/60);
//steps/s
```

```
      const      long      steps_recoater                                    =
belt_teeth/motor_pulley_teeth*recoater_move/10;
//Steps
      const      long      steps_printzone                                   =
steps_pla*(layer_thickness/bar_coarse);                                 //Steps
      const      long      steps_feeding                                     =
steps_pla*(feeding_thickness/bar_coarse);                               //Steps
      const  long  steps_feeding_setup  =  steps_pla*(set_up_z/bar_coarse);
//Steps

      //Powder_cleaning variables
      const    long    cleaning_thickness                                 =    5;
//In mm
      const    long    cleaning_steps                                     =
steps_pla*(cleaning_thickness/bar_coarse);
//Steps
      const      long      cleaning_recoater_speed             =       80;
//In mm/s
      const            long           mcleaning_recoater_speed            =
(cleaning_recoater_speed*10*belt_teeth/motor_pulley_teeth)*(steps_rec/60);
//steps/s

      // Steppers initialization
      AccelStepper recoater(1, recoater1, recoater2);
      AccelStepper printzone(1, printzone1, printzone2);
      AccelStepper pow_feeding(1, pow_feeding1, pow_feeding2);


      void setup() {
        recoater.setAcceleration(3000);
        printzone.setAcceleration(1000);
        pow_feeding.setAcceleration(1000);
        pinMode(layer_button,INPUT);
        pinMode(home_button,INPUT);
        pinMode(set_up_button,INPUT);
        pinMode(powder_cleaning_button,INPUT);
        pinMode(part_extracting_button,INPUT);
        pinMode(cilynder_button,INPUT);
        pinMode(rec_stop,INPUT);
        pinMode(printzone_stop,INPUT);
        pinMode(pow_feeding_stop,INPUT);
      }

      void loop(){

        if (digitalRead(layer_button)==HIGH) {
          layer();
        }

        if (digitalRead(home_button)==HIGH) {
          home_();
        }

        if (digitalRead(set_up_button)==HIGH) {
          set_up();
        }

        if (digitalRead(powder_cleaning_button)==HIGH){
```

```
    powder_cleaning();
  }

  if (digitalRead(part_extracting_button)==HIGH){
    part_extraction();
  }

  if (digitalRead(cilynder_button)==HIGH){
    cylinder();
  }
}


//home_ sets all the steppers to its initial position
void home_(){

  printzone.setMaxSpeed(mspeed_to_0);
  pow_feeding.setMaxSpeed(mspeed_to_0);
  recoater.setMaxSpeed(mrecoater_speed_0);
  printzone.setSpeed(-mspeed_to_0);
  pow_feeding.setSpeed(-mspeed_to_0);
  recoater.setSpeed(-mrecoater_speed_0);

  while  (digitalRead(rec_stop)==HIGH){
    recoater.runSpeed();
  }
  recoater.setCurrentPosition(0);
  while  (digitalRead(printzone_stop)==HIGH){
    printzone.runSpeed();
  }
  printzone.setCurrentPosition(0);
   while  (digitalRead(pow_feeding_stop)==HIGH){
    pow_feeding.runSpeed();
  }
  pow_feeding.setCurrentPosition(0);
}



//layer move the platforms and the recoater to spread one powder layer
void layer(){

  printzone.setMaxSpeed(mplatforms_speed);
  pow_feeding.setMaxSpeed(mplatforms_speed);
  recoater.setMaxSpeed(mrecoater_speed);

  printzone.runToNewPosition(steps_printzone);
  pow_feeding.runToNewPosition(-steps_feeding);
  delay(500);
  recoater.runToNewPosition(steps_recoater);

  delay(1000);
  recoater.runToNewPosition(0);
}



//set_up moves the platforms and the recoater to the initial printing
```

```
position to add the powder on the powder platform
      void set_up(){

        home_();
        delay(1000);
        pow_feeding.setMaxSpeed(mspeed_to_0);
        pow_feeding.runToNewPosition(steps_feeding_setup);
      }


      //powder_cleaning extracts most of the powder from the powder platform
and throws it to the waste container
      void powder_cleaning(){

        recoater.setMaxSpeed(mcleaning_recoater_speed);
        pow_feeding.setMaxSpeed(mspeed_to_0);

        while  (digitalRead(pow_feeding_stop)==HIGH){
          pow_feeding.runToNewPosition(cleaning_steps);
          delay(500);
          recoater.runToNewPosition(steps_recoater);
          delay(500);
          recoater.runToNewPosition(0);
          delay(500);
        }
      }


      //part_extraction lifts up the printingzone platform to extract the
printed part
      void part_extraction(){

        printzone.setMaxSpeed(mplatforms_speed);
        while  (digitalRead(printzone_stop)==HIGH){
          printzone.runSpeed();
        }
      }


      //cylinder moves the recoating cylinder forward and backwards if
rquired
      void cylinder(){

        recoater.setMaxSpeed(mrecoater_speed);
        recoater.runToNewPosition(steps_recoater);
        delay(500);
        recoater.runToNewPosition(0);
```

Appendix C. TRL

Summary of the Technology Readiness Level Calculation

Project Name:	Selective Laser Sintering test bench	**Project Manager:**	Roger Uceda
Date TRL Calculated:	02-oct-15		

Go to next report

Glossary

TRL Summary	2	3

Green Set Point:	100%	Yellow Set Point:	75%

1	2	3	4	5	6	7	8	9

Questions marked Not Applicable

Level	Question
	No questions marked as Not Applicable

Summary of questions based on answers provided

TRL	HW/SW?	% Complete	Applicable Question
1	B	100	Do rough calculations support the concept?
	B	100	Do basic principles (physical, chemical, mathematical) support the concept?
	S	100	Does it appear the concept can be supported by software?
	S	100	Are the software requirements known in general terms?
	B	100	Do paper studies confirm basic scientific principles of new technology?
	S	100	Have mathematical formulations of concepts been developed?
	S	100	Have the basic principles of a possible algorithm been formulated?
	B	100	Has a scientific methodology or approach been developed?
100% Complete			As expected, level 1 is completed as the SLS physical principles have been already tested.
2	B	100	Has potential system or component applications been identified?
	B	100	Have paper studies confirmed system or component application feasibility?
	B	100	Has an apparent design solution been identified?
	H	100	Have the basic components of the technology been identified?
	B	100	Has the user interface been defined?
	H	100	Have technology or system components been at least partially characterized?
	H	100	Have performance predictions been documented for each component?
	S	100	Has preliminary software coding that confirms basic principles been documented?
	B	100	Has a functional requirements generation process been initiated?
	H	100	Does preliminary analysis confirm basic scientific principles?
	S	100	Have experiments validating the concept been performed with synthetic data?
	B	100	Are basic scientific principles confirmed with analytical studies?
	B	100	Do all individual parts of the technology work separately? (No real attempt at integration)
	S	100	Is the hardware that the software will be hosted on available?
	B	100	Are output devices available?

100% Complete			The application of the technology has been already formulated

3	H	100	Have predictions of components of technology capability been validated?
	S	100	Have analytical studies verified performance predictions and produced algorithms?
	H	100	Can all science applicable to the technology be modeled or simulated?
	S	100	Is outline of software algorithms documented?
	H	100	Do experiments/M&S validate performance predictions of technology capability?
	S	100	Does preliminary coding verify that software can satisfy an operational requirement?
	B	100	Do experiments verify feasibility of application of technology?
	H	100	Do experiments/M&S validate performance predictions of components of technology capability?
	B	100	Have cross-technology effects (if any) been identified?
	B	100	Do paper studies indicate that technology or system components can be integrated?
	B	100	Are the technology/system performance metrics established?
	S	100	Have technology/system performance characteristics been confirmed with representative data sets?
	S	100	Do algorithms run successfully in a laboratory environment, possibly on a surrogate processor?
	S	100	Has inventory of available software that does similar tasks been completed?
	B	100	Has scientific feasibility of proposed technology been fully demonstrated?
	B	100	Does analysis of present technologies show that proposed technology/system fills a capability gap?
	S	0	Has existing software been examined for possible reuse?
94,11764 70588235 % Complete			Some of the level 3 requirments have to be analyzed on the project

4	B	100	Does draft system architecture plan exist?
	S	100	Do stand-alone modules align with preliminary system architecture plan?
	B	100	Does technology demonstrate basic functionality in simplified environment?
	S	100	Have ad hoc integration of functions or modules been demonstrated?
	B	0	Have cross-technology effects (if any) been fully identified and documented?
	H	0	Has acceptance testing of individual components been performed?
	H	0	Has performance of components and interfaces between components been demonstrated?
	B	0	Have end user technology/system requirements been documented?
	H	0	Does breadboard demonstrate functionality of all components?
	S	0	Have algorithms been converted to pseudocode?
	S	0	Has analysis of data requirements and formats been completed?
	H	0	Has component compatibility been demonstrated?
	B	0	Have performance characteristics been demonstrated in a laboratory environment?
	S	0	Does prototype solve synthetic full-scale problems or process fully representative data sets?
	S	0	Have all functions or modules been demonstrated in a laboratory environment?
	B	0	Have low-fidelity assessments of system integration and engineering been completed?
25% Complete			Level 4 has to be devoloped during the project.

5	B	0	Have cross-technology effects (if any) been fully identified, analyzed, and documented?
	B	0	Have internal system interface requirements been documented?
	B	0	Have external interfaces been documented?
	B	0	Has analysis of internal interface requirements been completed?
	B	0	Does the breadboard have realistic interfaces?
	S	0	Is coding of individual functions/modules completed?
	B	0	Can all system specifications be simulated and validated within a laboratory environment?
	H	0	Has a brassboard been developed?
	B	0	Is the laboratory environment high-fidelity?
	S	0	Have functions been integrated into modules?
	B	0	Have individual component functions been verified through testing?
	S	0	Have system modules been debugged?
	S	0	Has integration of modules/functions been demonstrated in a laboratory environment?
	S	0	Have algorithms been run on a processor that can be fielded in an operational environment?
	B	0	Have objective and threshold operational requirements been developed?
	B	0	Has a Product Breakdown Structure been developed?

0%
Complete

6	B	0	Have system integration issues been addressed?
	B	0	Is the operational environment fully known?
	B	0	Have performance characteristics been verified in a simulated operational environment?
	B	0	Has prototype been tested in a simulated operational environment?
	B	0	Has system been tested in realistic environment outside the laboratory?
	B	0	Has an inventory of external interfaces been completed?
	S	0	Has analysis of timing constraints been completed with satisfactory results?
	S	0	Has analysis of database structures and interfaces been completed?
	S	0	Does the prototype functionally handle realistic problems?
	S	0	Have software algorithms been integrated with existing systems?
	S	0	Has functionality of integrated modules been tested?
	S	0	Is software documentation available?
	B	0	Has engineering feasibility been fully demonstrated?

0%
Complete

7	H	0	Can unavailable system components be simulated using modeling and simulation?
	B	0	Have all interfaces been tested individually under stressed and anomalous conditions?
	S	0	Do algorithms run on processor(s) in an operational environment?
	B	0	Has technology or system been tested in a relevant environment?
	H	0	Are available components representative of production components?
	B	0	Has operational testing of technology/system in relevant environment been completed?
	B	0	Has fully integrated prototype been demonstrated in actual or simulated operational environment?

0%
Complete

8	B	0	Are all technology/system components form, fit, and function compatible?
	B	0	Is technology/system form, fit, and function compatible with operational environment?
	B	0	Has technology/system form, fit, and function been demonstrated in operational environment?
	S	0	Has software been thoroughly debugged?
	B	0	Is technical Developmental Test and Evaluation (DT&E) successfully completed?

0%
Complete

9	B	0	Does technology/system function as defined in Operational Concept document?
	B	0	Has technology/system has been deployed in intended operational environment?
	B	0	Has technology/system been fully demonstrated?
	B	0	Has Operational Test and Evaluation (OT&E) been successfully completed?

0%
Complete