

DRV5012 Ultra-Low-Power Digital-Latch Hall-Effect Sensor

1 Features

- Industry-Leading Low-Power Consumption
- Pin-Selectable Sampling Rate:
 - SEL = Low: 20 Hz Using 1.3 μA (1.8 V)
 - SEL = High: 2.5 kHz Using 142 μA (1.8 V)
- 1.65- to 5.5-V Operating V_{CC} Range
- High Magnetic Sensitivity: ± 2 mT (Typical)
- Robust Hysteresis: 4 mT (Typical)
- Push-Pull CMOS Output
- Small and Thin X2SON Package
- -40°C to $+85^{\circ}\text{C}$ Operating Temperature Range

2 Applications

- Brushless DC Motor Sensors
- Incremental Rotary Encoding:
 - Motor Speed
 - Mechanical Travel
 - Fluid Measurement
 - Knob Turning
 - Wheel Speed
- Portable Medical Devices
- E-Locks, E-Bikes, Motorized Blinds
- Flow Meters
- Contactless Activation

3 Description

The DRV5012 device is an ultra-low-power digital-latch Hall effect sensor with a pin-selectable sampling rate.

When a south magnetic pole is near the top of the package and the B_{OP} threshold is exceeded, the device drives a low voltage. The output stays low until a north pole is applied and the B_{RP} threshold is crossed, which causes the output to drive a high voltage. Alternating north and south poles are required to toggle the output, and integrated hysteresis separates B_{OP} and B_{RP} to provide robust switching.

Using an internal oscillator, the DRV5012 device samples the magnetic field and updates the output at a rate of 20 Hz or 2.5 kHz, depending on the SEL pin. This dual-bandwidth feature can allow systems to monitor changes in movement while using minimal power.

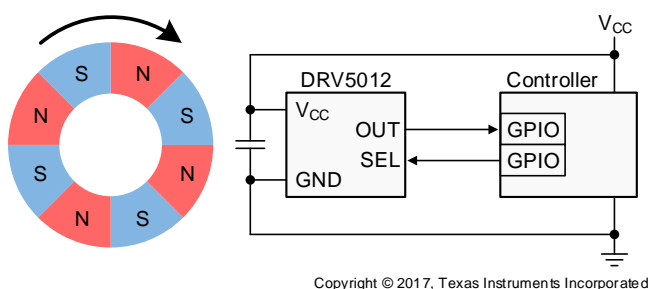
The device operates from a V_{CC} range of 1.65 V to 5.5 V, and is packaged in a small X2SON.

Device Information⁽¹⁾

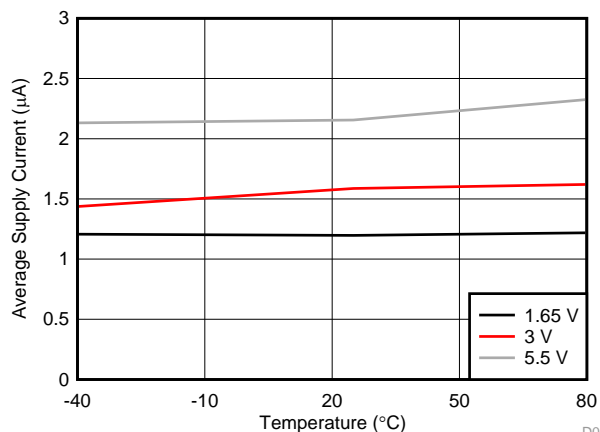
PART NUMBER	PACKAGE	BODY SIZE (NOM)
DRV5012	X2SON (4)	1.10 mm x 1.40 mm

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

Typical Schematic



Current Consumption in 20-Hz Mode



D016



Table of Contents

1 Features	1	7.4 Device Functional Modes.....	10
2 Applications	1	8 Application and Implementation	11
3 Description	1	8.1 Application Information.....	11
4 Revision History	2	8.2 Typical Applications	11
5 Pin Configuration and Functions	3	8.3 Do's and Don'ts.....	15
6 Specifications	3	9 Power Supply Recommendations	16
6.1 Absolute Maximum Ratings	3	10 Layout	16
6.2 ESD Ratings	3	10.1 Layout Guidelines	16
6.3 Recommended Operating Conditions.....	4	10.2 Layout Example	16
6.4 Thermal Information	4	11 Device and Documentation Support	17
6.5 Electrical Characteristics.....	5	11.1 Device Support.....	17
6.6 Magnetic Characteristics.....	5	11.2 Receiving Notification of Documentation Updates	17
6.7 Typical Characteristics.....	6	11.3 Community Resources.....	17
7 Detailed Description	7	11.4 Trademarks	17
7.1 Overview	7	11.5 Electrostatic Discharge Caution.....	17
7.2 Functional Block Diagram	7	11.6 Glossary	17
7.3 Feature Description.....	7	12 Mechanical, Packaging, and Orderable Information	17

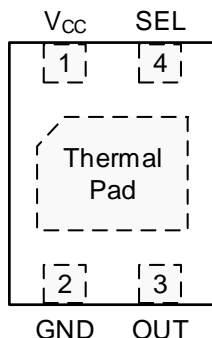
4 Revision History

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

DATE	REVISION	NOTES
August 2017	*	Initial release.

5 Pin Configuration and Functions

DMR Package
4-Pin X2SON With Exposed Thermal Pad
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
GND	2	—	Ground reference
OUT	3	O	Push-pull CMOS output. Drives a V_{CC} or ground level.
SEL	4	I	CMOS input that selects the sampling rate: a low voltage sets 20 Hz; a high voltage sets 2.5 kHz.
V_{CC}	1	—	1.65-V to 5.5-V power supply. TI recommends connecting this pin to a ceramic capacitor to ground with a value of at least 0.1 μ F.
Thermal Pad	PAD	—	No-connect. This pin should be left floating or tied to ground. It should be soldered to the board for mechanical support.

6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Power supply voltage	V_{CC}	-0.3	5.5	V
Power supply voltage slew rate	V_{CC}	Unlimited		V / μ s
Output voltage	OUT	-0.3	$V_{CC} + 0.3$	V
Output current	OUT	-5	5	mA
Input voltage	SEL	-0.3	$V_{CC} + 0.3$	V
Magnetic flux density, B_{MAX}		Unlimited		T
Junction temperature, T_J		105		$^{\circ}$ C
Storage temperature, T_{stg}		-65	150	$^{\circ}$ 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
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	± 6000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	± 750	

- (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

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

		MIN	MAX	UNIT
V_{CC}	Power supply voltage (VCC)	1.65	5.5	V
V_O	Output voltage (OUT)	0	V_{CC}	V
I_O	Output current (OUT)	-5	5	mA
V_I	Input voltage (SEL)	0	V_{CC}	V
T_A	Operating ambient temperature	-40	85	°C

6.4 Thermal Information

THERMAL METRIC ⁽¹⁾	DRV5012	UNIT	
	DMR (X2SON)		
	4 PINS		
$R_{\theta JA}$	Junction-to-ambient thermal resistance	159	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	77	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	102	°C/W
ψ_{JT}	Junction-to-top characterization parameter	0.9	°C/W
ψ_{JB}	Junction-to-board characterization parameter	100	°C/W

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

6.5 Electrical Characteristics

for $V_{CC} = 1.65\text{ V}$ to 5.5 V , over operating free-air temperature range (unless otherwise noted)

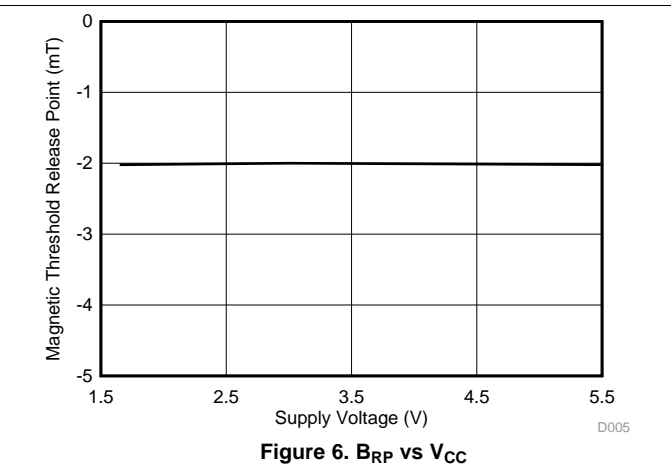
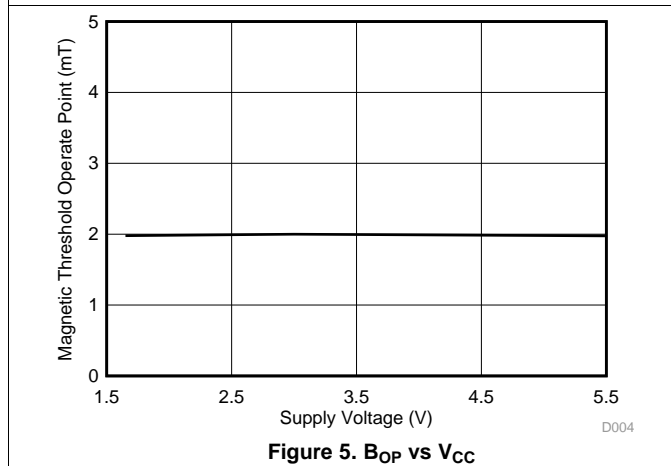
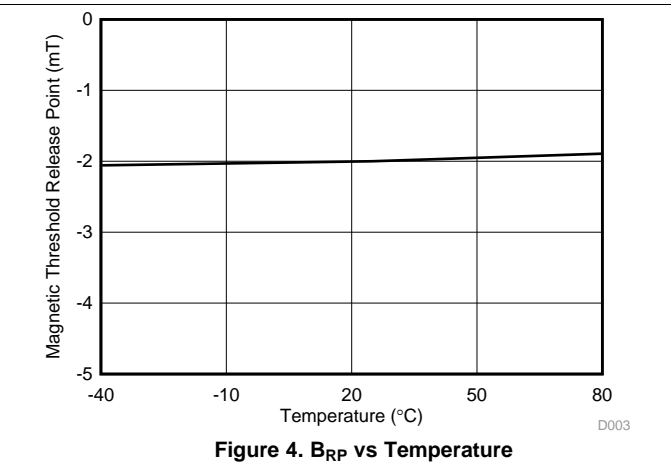
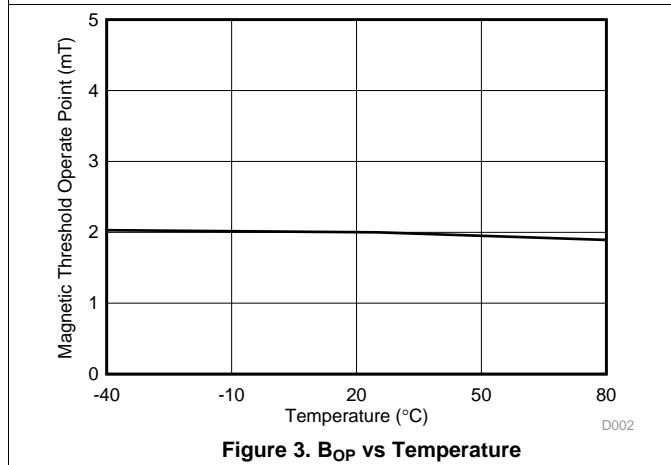
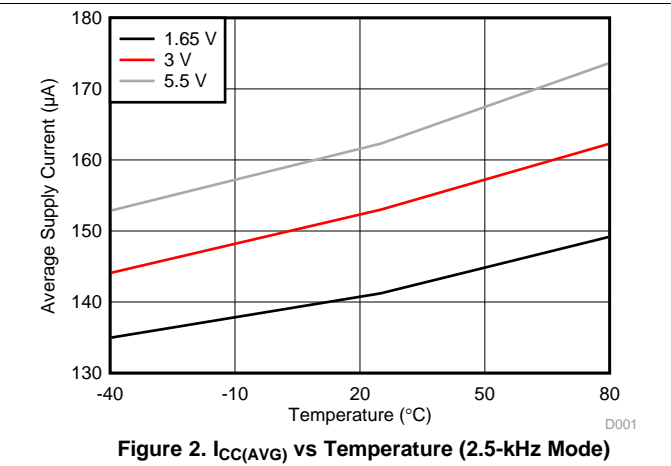
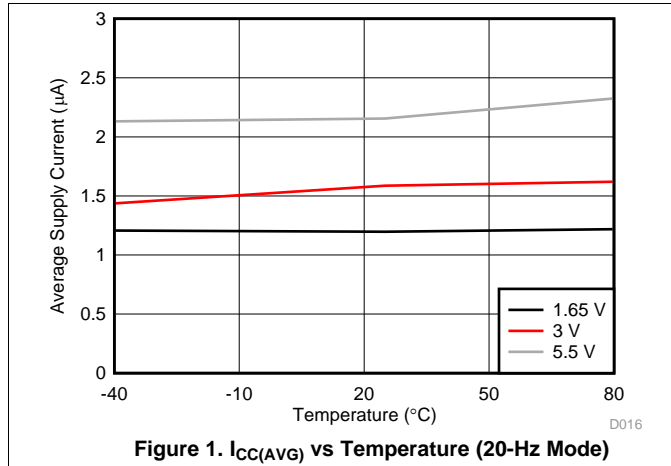
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OUT pin						
V_{OH}	High-level output voltage	$I_{OUT} = -1\text{ mA}$	$V_{CC} - 0.35$	$V_{CC} - 0.1$		V
V_{OL}	Low-level output voltage	$I_{OUT} = 1\text{ mA}$		0.1	0.3	V
SEL pin						
V_{IH}	High-level input voltage	$V_{CC} = 1.65\text{ to }2.5\text{ V}$	$0.8 \times V_{CC}$			V
		$V_{CC} = 2.5\text{ to }5.5\text{ V}$	2			
V_{IL}	Low-level input voltage			$0.15 \times V_{CC}$		V
I_{IH}	High-level input leakage current	$SEL = V_{CC}$		1		nA
I_{IL}	Low-level input leakage current	$SEL = 0\text{ V}$		1		nA
DYNAMIC CHARACTERISTICS						
f_s	Frequency of magnetic sampling	$SEL = \text{Low}$	13.3	20	37	Hz
		$SEL = \text{High}$	1665	2500	4700	
t_s	Period of magnetic sampling	$SEL = \text{Low}$	27	50	75	ms
		$SEL = \text{High}$	0.21	0.4	0.6	
$I_{CC(AVG)}$	Average current consumption	$V_{CC} = 1.8\text{ V}$	$SEL = \text{Low}$	1.3		μA
			$SEL = \text{High}$	142		
		$V_{CC} = 3\text{ V}$	$SEL = \text{Low}$	1.6	3.3	
			$SEL = \text{High}$	153	370	
		$V_{CC} = 5\text{ V}$	$SEL = \text{Low}$	2		
			$SEL = \text{High}$	160		
$I_{CC(PK)}$	Peak current consumption		2	2.7	mA	
t_{ON}	Power-on time (see Figure 11)			55	100	μs
t_{ACTIVE}	Active time period (see Figure 11)			40		μs

6.6 Magnetic Characteristics

for $V_{CC} = 1.65\text{ V}$ to 5.5 V , over operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
B_{OP}	Magnetic threshold operate point (see Figure 9)		0.6	2	3.3	mT
B_{RP}	Magnetic threshold release point (see Figure 9)		-3.3	-2	-0.6	mT
B_{HYS}	Magnetic hysteresis: $ B_{OP} - B_{RP} $		2	4		mT

6.7 Typical Characteristics



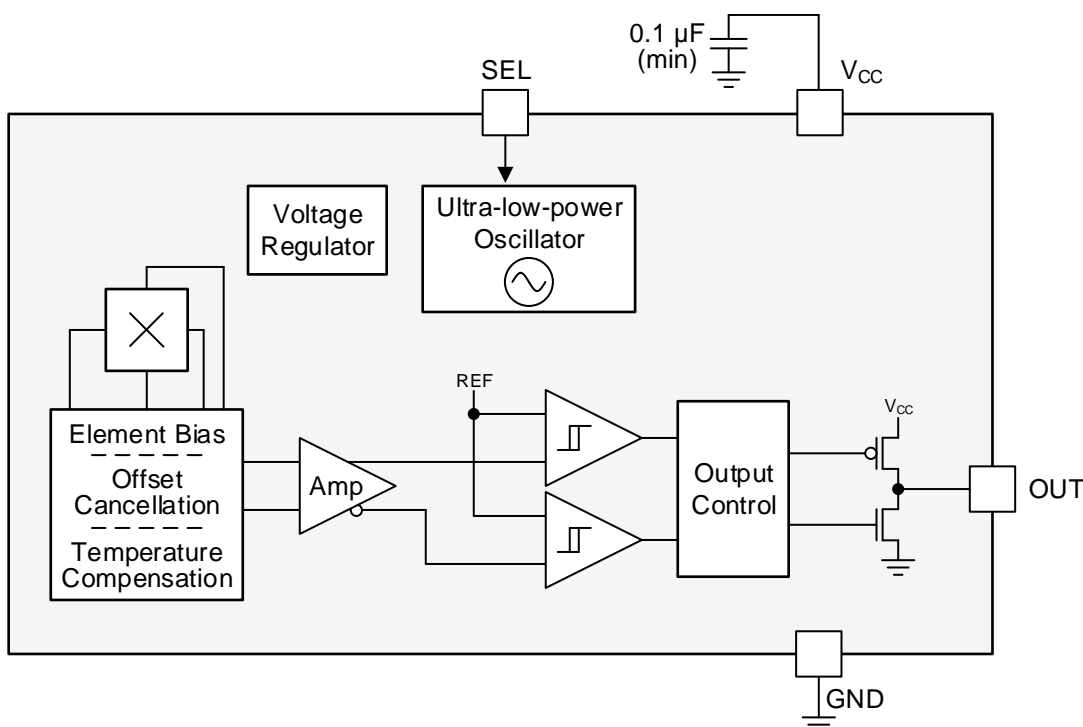
7 Detailed Description

7.1 Overview

The DRV5012 device is a magnetic sensor with a digital output that latches the most recent pole measured. Applying a south magnetic pole near the top of the package causes the output to drive low, a north pole causes the output to drive high, and the absence of a magnetic field causes the output to continue to drive the previous state, whether low or high.

The device integrates a Hall effect element, analog signal conditioning, and a low-frequency oscillator that enables ultra-low average power consumption. By operating from a 1.65-V to 5.5-V supply, the device periodically measures magnetic flux density, updates the output, and enters a low-power sleep state. A logic input pin, SEL, sets the sampling frequency to 20 Hz or 2.5 kHz with a tradeoff in power consumption.

7.2 Functional Block Diagram



Copyright © 2017, Texas Instruments Incorporated

7.3 Feature Description

7.3.1 Magnetic Flux Direction

The DRV5012 device is sensitive to the magnetic field component that is perpendicular to the top of the package (as shown in Figure 7).

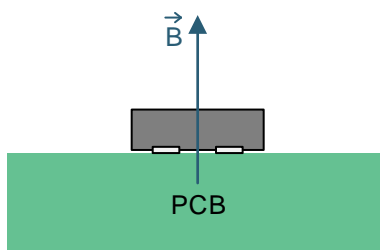


Figure 7. Direction of Sensitivity

Feature Description (continued)

Magnetic flux that travels from the bottom to the top of the package is considered positive in this data sheet. This condition exists when a south magnetic pole is near the top of the package. Magnetic flux that travels from the top to the bottom of the package results in negative millitesla values.

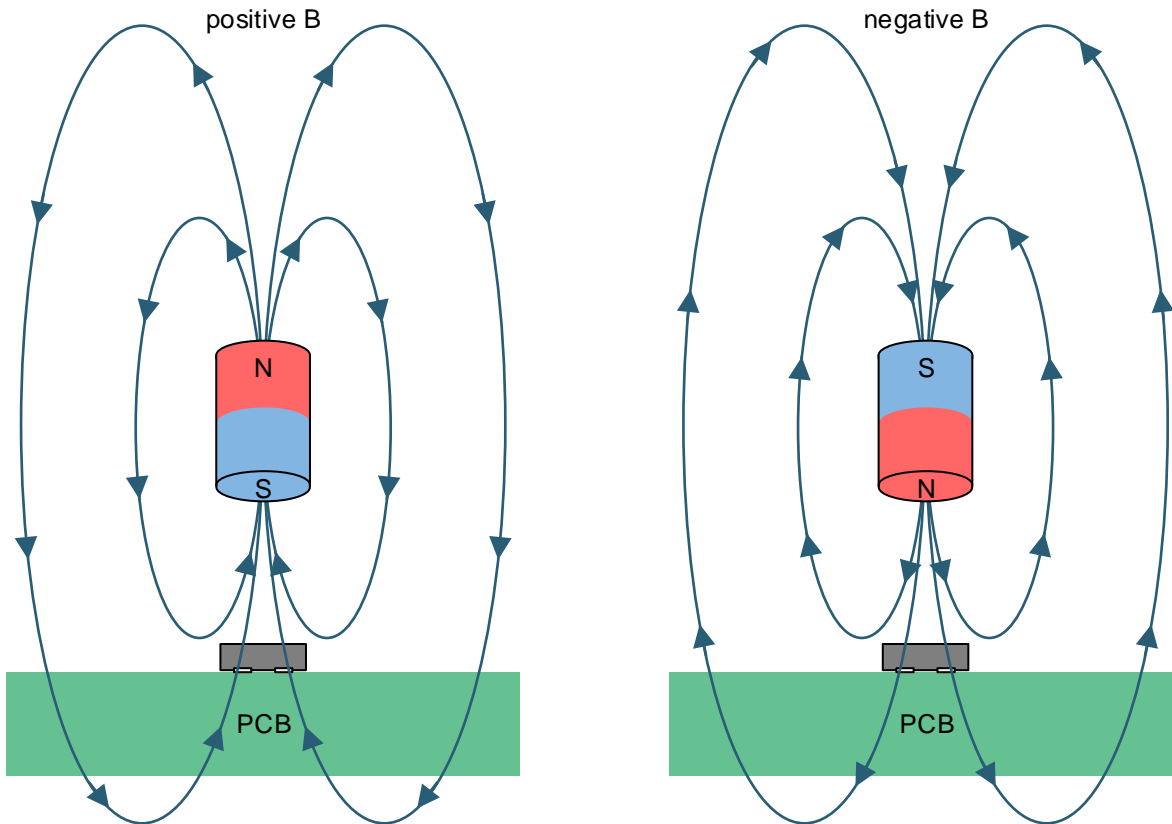


Figure 8. Flux Direction Polarity

7.3.2 Magnetic Response

Figure 9 shows the device functionality and hysteresis.

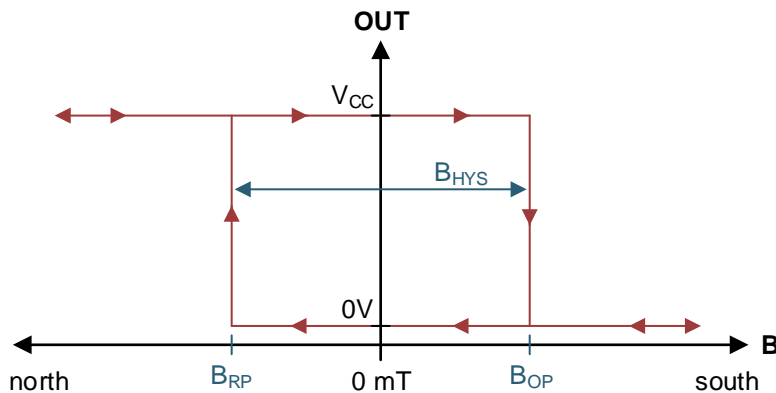


Figure 9. Device Functionality

Feature Description (continued)

7.3.3 Output Driver

The device features a push-pull CMOS output that can drive a V_{CC} or ground level.

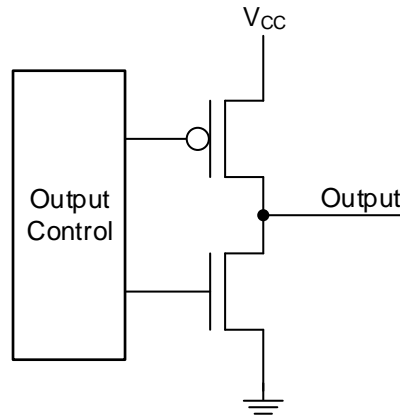


Figure 10. Push-Pull Output (Simplified)

7.3.4 Sampling Rate

When the DRV5012 device powers up, it measures the first magnetic sample and sets the output within the t_{ON} time. The output is latched, and the device enters an ultra-low-power sleep state. After each t_s time has passed, the device measures a new sample and updates the output if necessary. If the magnetic field does not change between periods, the output also does not change.

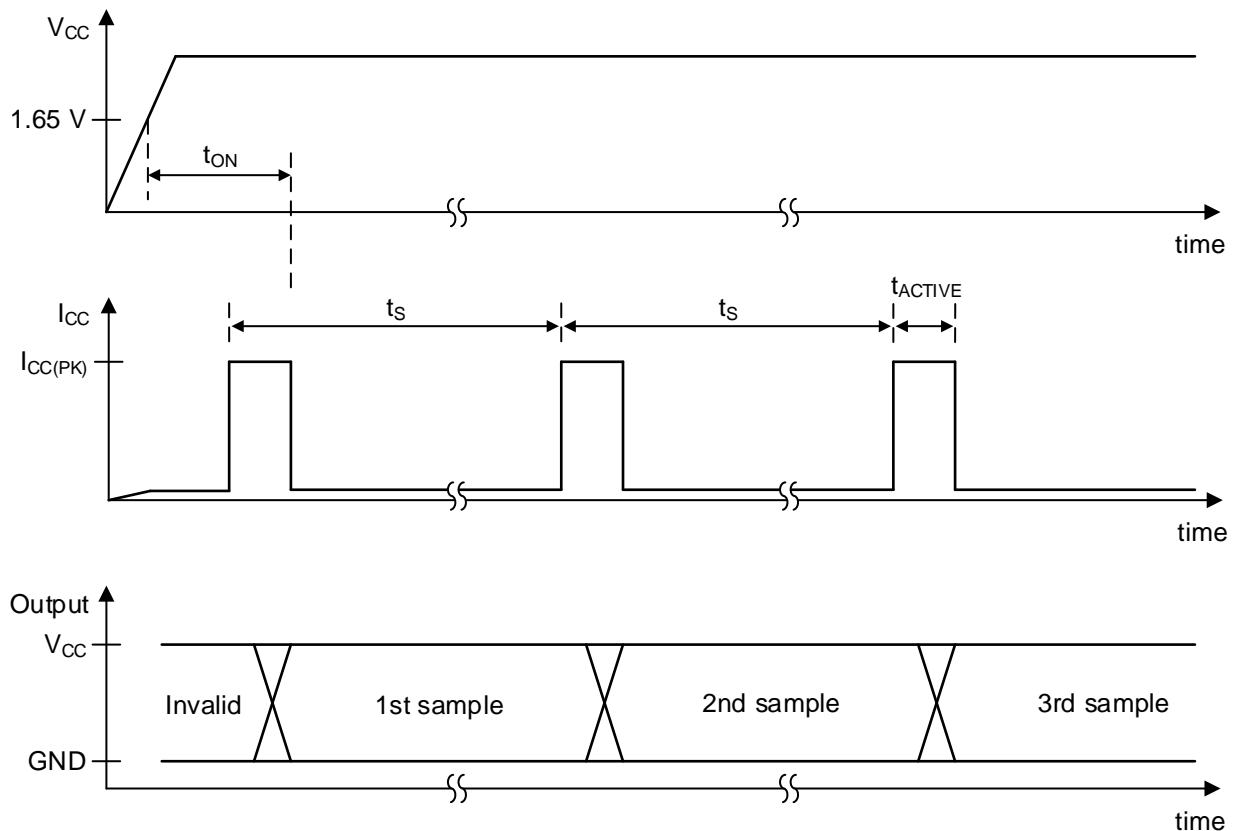


Figure 11. Timing Diagram

Feature Description (continued)

7.3.5 SEL Pin

The SEL pin is a CMOS input that selects between two sampling rates. When the pin is low, the device samples at 20 Hz and uses low power. When the pin is high, the device samples at 2500 Hz and uses more power. The SEL pin can be tied directly high or low, or it can be changed during device operation. If the SEL voltage changes, the device detects the new voltage during the next t_{ACTIVE} time.

7.3.6 Hall Element Location

The sensing element inside the device is in the center of the package when viewed from the top. [Figure 12](#) shows the tolerances and side-view dimensions.

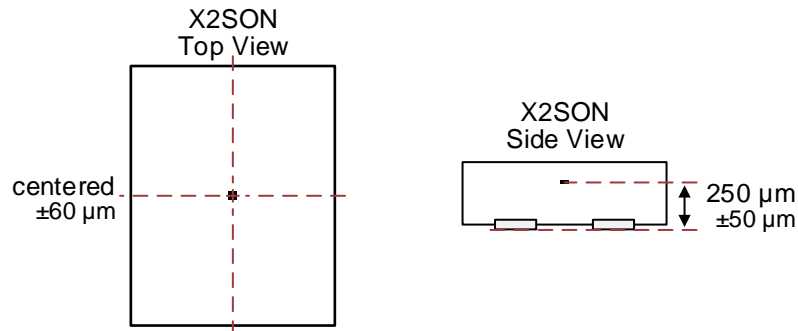


Figure 12. Hall Element Location

7.4 Device Functional Modes

The DRV5012 device has two operating modes, 20 Hz and 2.5 kHz, as set by the SEL pin. In both cases the [Recommended Operating Conditions](#) must be met.

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.

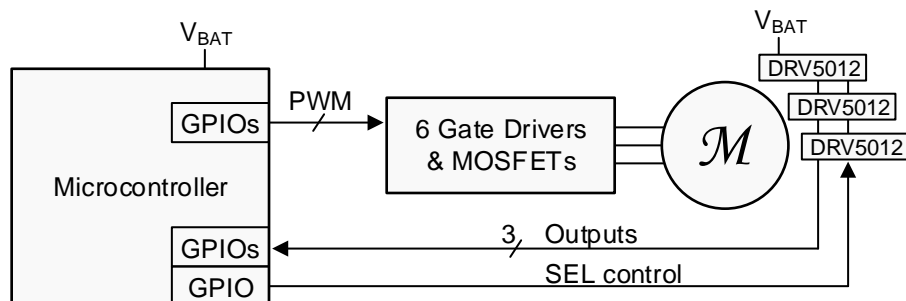
8.1 Application Information

The DRV5012 device is typically used in rotary applications for brushless DC (BLDC) motor sensors or incremental rotary encoding.

To ensure reliable functionality, the magnet should apply a flux density at the sensor greater than the maximum B_{OP} and less than the minimum B_{RP} thresholds. It is good practice to add additional margin to account for mechanical tolerance, temperature effects, and magnet variation.

8.2 Typical Applications

8.2.1 BLDC Motor Sensors Application



Copyright © 2017, Texas Instruments Incorporated

Figure 13. BLDC Motor System

8.2.1.1 Design Requirements

For this design example, use the parameters listed in [Table 1](#).

Table 1. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
Number of motor phases	3
Motor RPM	3000
Number of magnet poles on the rotor	6
Magnetic material	Bonded Neodymium
Peak magnetic flux density at the Hall sensors	±15 mT
Battery voltage range (V_{BAT})	2 to 3.5 V

8.2.1.2 Detailed Design Procedure

Three-phase brushless DC motors often use 3 Hall effect latch devices to measure the electrical angle of the rotor and tell the controller how to drive the 3 wires. These wires connect to electromagnet windings, which generate magnetic fields that apply forces to the permanent magnets on the rotor.

The 3 Hall sensors should be spaced across the printed-circuit board (PCB) so that they are 120° electrical degrees apart. This configuration creates six 3-bit states with equal time duration for each electrical cycle, which consists of 1 north and 1 south magnetic pole. From the center of the motor axis, the number of degrees each sensor should be spaced equals $2 / [\text{number of poles}] \times 120^\circ$. In this design example, 1 sensor is placed at 0°, 1 sensor is placed 40° rotated, and 1 sensor is placed 80° rotated. Alternatively, a 3x degree offset can be added or subtracted to any sensor, meaning the third sensor could alternatively be placed at $80^\circ - (3 \times 40^\circ) = -40^\circ$.

While an ideal BLDC motor would energize the phases at the exact correct times, the DRV5012 device introduces variable lag because of the sampling architecture that achieves low power. An acceptable amount of lag can be measured by the sampling time error as a percentage of the electrical period. This design example uses 3000 RPM, which is 50 revolutions per second. Each revolution has 6 poles (3 electrical cycles), so the electrical frequency is 150 Hz, a period of 6.7 ms. The DRV5012 device in 2.5 kHz mode has a sampling period of 0.4 ms, which is 6% of the electrical period. Generally, the maximum timing error should be kept under 10% to ensure the BLDC motor spins, and timing error can reduce motor efficiency.

When the motor in this example is not driven, the SEL pins of the DRV5012 devices are set to a low voltage, and the sensor outputs are monitored for changes. If a change occurs, the microcontroller wakes the system into a higher power state and takes other appropriate action.

8.2.1.3 Application Curve

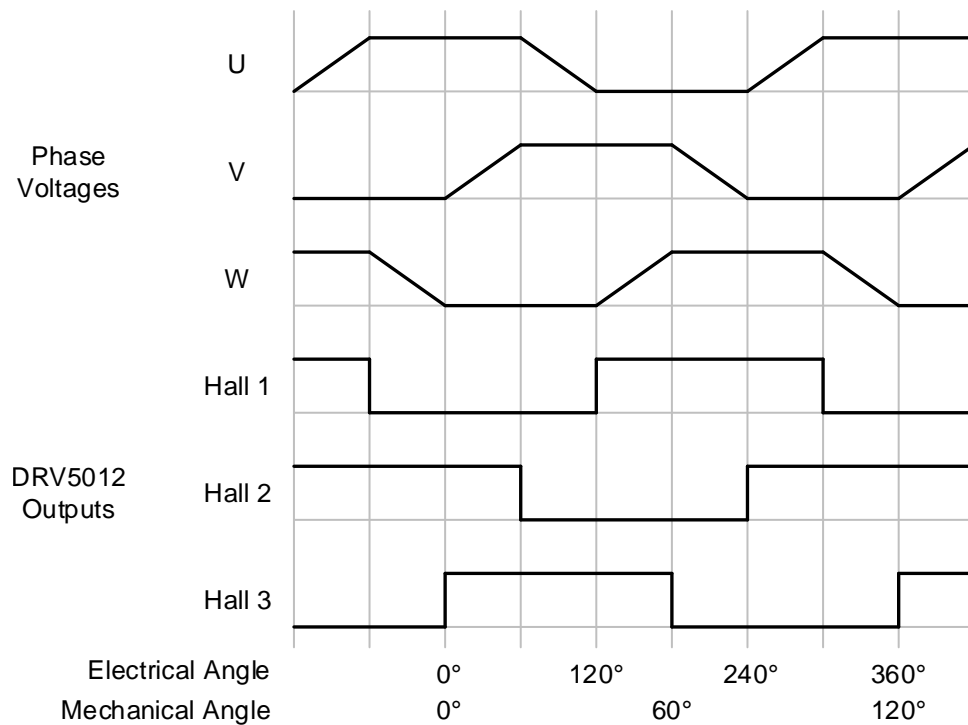
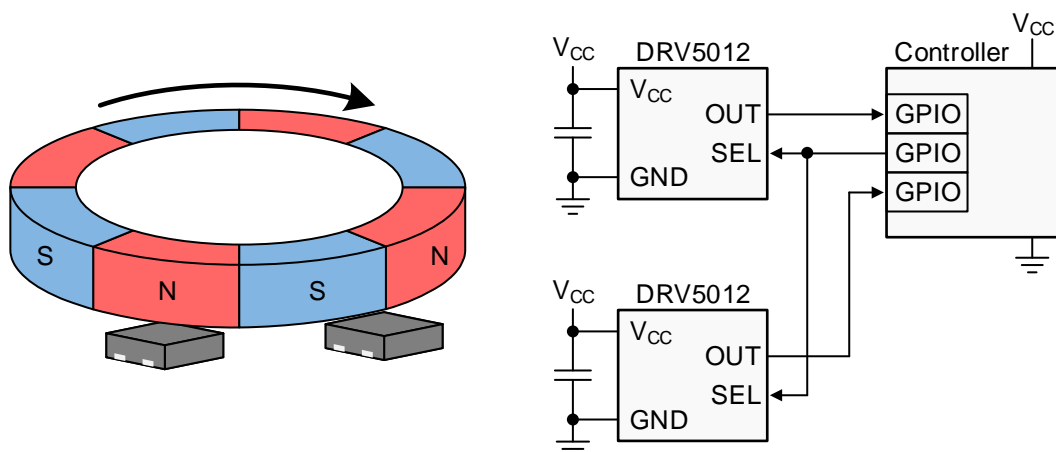


Figure 14. 3-Phase BLDC Motor Phase Voltages and Hall Signals

8.2.2 Incremental Rotary Encoding Application



Copyright © 2017, Texas Instruments Incorporated

Figure 15. Incremental Rotary Encoding System

8.2.2.1 Design Requirements

For this design example, use the parameters listed in [Table 2](#).

Table 2. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
RPM range	0 to 4000
Number of magnet poles	8
Magnetic material	Ferrite
Air gap above the Hall sensors	2.5 mm
Peak magnetic flux density at the sensors	±7 mT

8.2.2.2 Detailed Design Procedure

Incremental encoders are used on knobs, wheels, motors, and flow meters to measure relative rotary movement. By attaching a ring magnet to the rotating component and placing a DRV5012 device nearby, the sensor generates voltage pulses as the magnet turns. If directional information is also needed (clockwise versus counterclockwise), a second DRV5012 device can be added with a phase offset, and then the order of transitions between the two signals describes the direction.

Creating this phase offset requires spacing the two sensors apart on the PCB, and an ideal 90° quadrature offset is attained when the sensors are separated by half the length of each magnet pole, plus any integer number of pole lengths. [Figure 15](#) shows this configuration, as the sensors are 1.5 pole lengths apart. One of the sensors changes its output every $360^\circ / 8 \text{ poles} / 2 \text{ sensors} = 22.5^\circ$ of rotation. For reference, the TI Design [TIDA-00480](#) uses a 66-pole magnet with changes every 2.7°.

Because the DRV5012 device periodically samples the magnetic field, there is a limit to the maximum rotational speed that can be measured. Generally, the device sampling rate should be faster than 2 times the number of poles per second. In this design example, the maximum speed is 4000 RPM, which involves 533 poles per second. The DRV5012 has a minimum sampling frequency of 1665 Hz (when the SEL pin is high), which is approximately 3×533 poles per second.

In systems where the sensor sampling rate is close to 2 times the number of poles per second, most of the samples will measure a magnetic field that is significantly lower than the peak value, since the peaks only occur when the sensor and pole are perfectly aligned. In this case, margin should be added by applying a stronger magnetic field that has peaks significantly higher than the maximum B_{OP} of the DRV5012 device.

8.2.2.3 Application Curve

Two signals in quadrature provide movement and direction information. Each 2-bit state has unique adjacent 2-bit states for clockwise and counterclockwise.

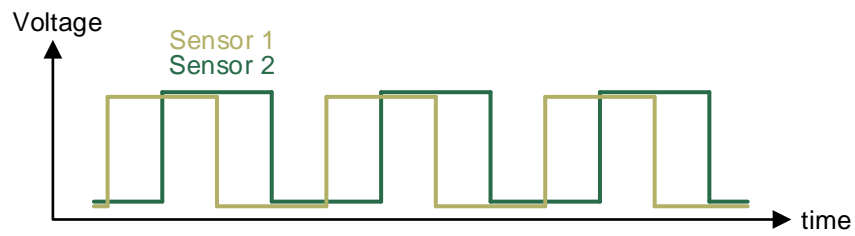


Figure 16. 2-bit Quadrature Output

8.3 Do's and Don'ts

Because the Hall element is sensitive to magnetic fields that are perpendicular to the top of the package, a correct magnet orientation must be used for the sensor to detect the field. Figure 17 shows correct and incorrect orientations when using a ring magnet.

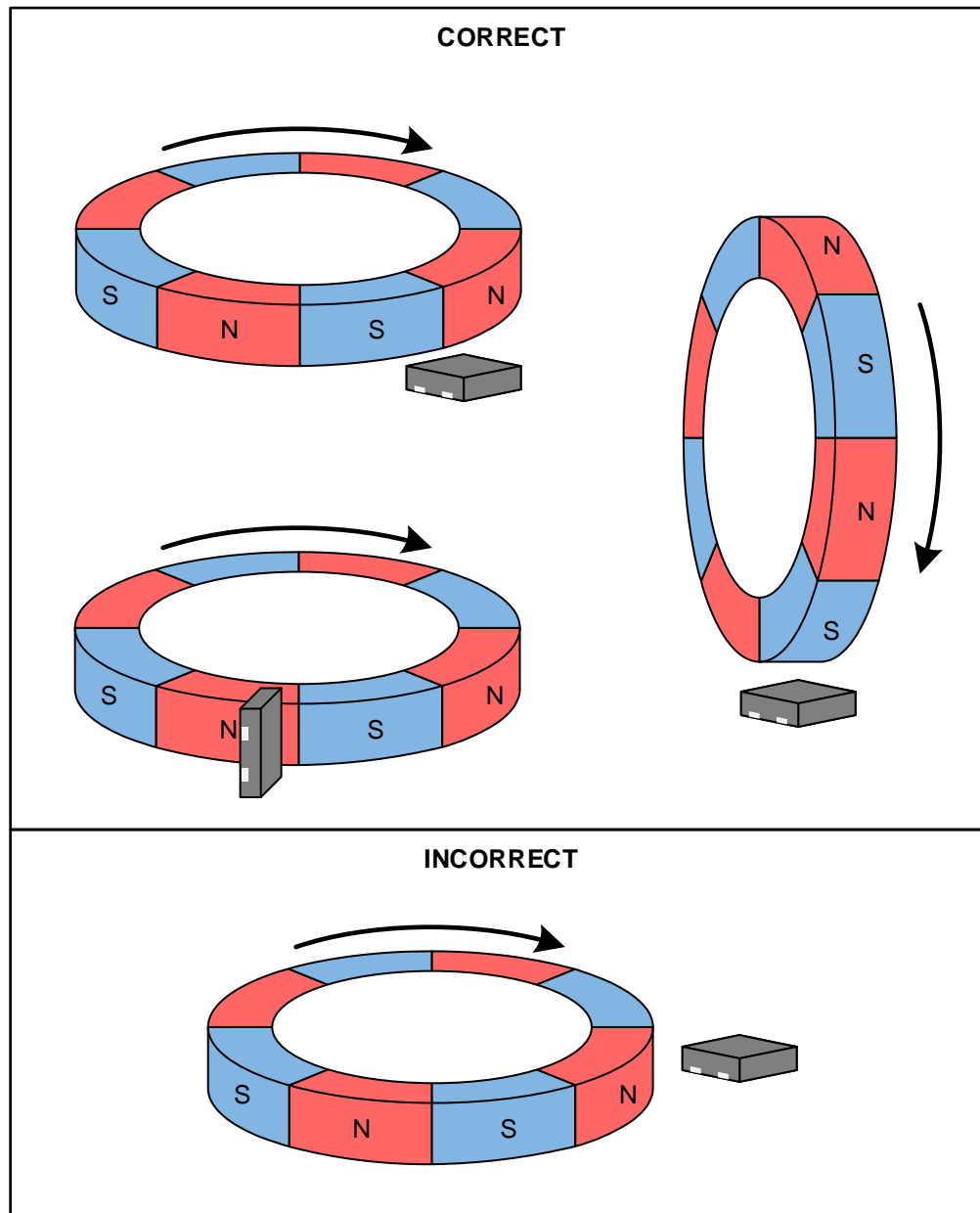


Figure 17. Correct and Incorrect Magnet Orientations

9 Power Supply Recommendations

The DRV5012 device is powered from 1.65-V to 5.5-V DC power supplies. A decoupling capacitor close to the device must be used to provide local energy with minimal inductance. TI recommends using a ceramic capacitor with a value of at least 0.1 μF .

10 Layout

10.1 Layout Guidelines

Magnetic fields pass through most nonferromagnetic materials with no significant disturbance. Embedding Hall effect sensors within plastic or aluminum enclosures and sensing magnets on the outside is common practice. Magnetic fields also easily pass through most PCBs, which makes placing the magnet on the opposite side possible.

10.2 Layout Example

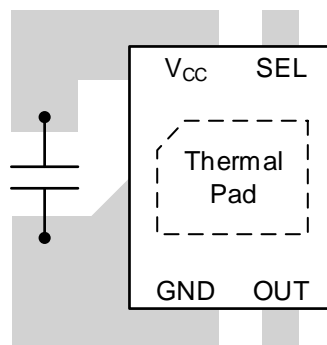


Figure 18. Layout Example

11 Device and Documentation Support

11.1 Device Support

11.1.1 Development Support

For additional design reference, refer to the [Automotive Hall Sensor Rotary Encoder TI Design \(TIDA-00480\)](#).

11.2 Receiving Notification of Documentation Updates

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

11.3 Community Resources

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.

11.4 Trademarks

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

11.5 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.

11.6 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 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
DRV5012AEDMRR	PREVIEW	X2SON	DMR	4	3000	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	2AE	
DRV5012AEDMRT	PREVIEW	X2SON	DMR	4	250	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	2AE	

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

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

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

(6) Lead/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.

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.

IMPORTANT NOTICE

Texas Instruments Incorporated (TI) reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

TI's published terms of sale for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>) apply to the sale of packaged integrated circuit products that TI has qualified and released to market. Additional terms may apply to the use or sale of other types of TI products and services.

Reproduction of significant portions of TI information in TI data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such reproduced documentation. Information of third parties may be subject to additional restrictions. Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyers and others who are developing systems that incorporate TI products (collectively, "Designers") understand and agree that Designers remain responsible for using their independent analysis, evaluation and judgment in designing their applications and that Designers have full and exclusive responsibility to assure the safety of Designers' applications and compliance of their applications (and of all TI products used in or for Designers' applications) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to their applications, Designer has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any applications that include TI products, Designer will thoroughly test such applications and the functionality of such TI products as used in such applications.

TI's provision of technical, application or other design advice, quality characterization, reliability data or other services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using TI Resources in any way, Designer (individually or, if Designer is acting on behalf of a company, Designer's company) agrees to use any particular TI Resource solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

Designer is authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNER AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Unless TI has explicitly designated an individual product as meeting the requirements of a particular industry standard (e.g., ISO/TS 16949 and ISO 26262), TI is not responsible for any failure to meet such industry standard requirements.

Where TI specifically promotes products as facilitating functional safety or as compliant with industry functional safety standards, such products are intended to help enable customers to design and create their own applications that meet applicable functional safety standards and requirements. Using products in an application does not by itself establish any safety features in the application. Designers must ensure compliance with safety-related requirements and standards applicable to their applications. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

TI may expressly designate certain products as completing a particular qualification (e.g., Q100, Military Grade, or Enhanced Product). Designers agree that it has the necessary expertise to select the product with the appropriate qualification designation for their applications and that proper product selection is at Designers' own risk. Designers are solely responsible for compliance with all legal and regulatory requirements in connection with such selection.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer's non-compliance with the terms and provisions of this Notice.