High Stability, Low Noise Vibration Rejecting Yaw Rate Gyro

Preliminary Technical Data

ADXRS646

FEATURES

Complete rate gyroscope on a single chip
Z-axis (yaw rate) response
8°/hour bias stability
0.01°/√second angle random walk
High vibration rejection over wide frequency
Measurement range extendable to a maximum of ±450°/s
10,000 g powered shock survivability
Ratiometric to referenced supply
6 V single-supply operation
−40°C to +105°C operation
Self-test on digital command
Ultrasmall and light (<0.15 cc, <0.5 gram)
Temperature sensor output
RoHS compliant

APPLICATIONS

Industrial applications
Severe Mechanical Environments
Platform stabilization

GENERAL DESCRIPTION

The ADXRS646 is a complete angular rate sensor (gyroscope) that uses the Analog Devices, Inc. patented high volume BiMOS surface-micromachining process to make a complete gyro on one chip. An advanced, differential, quad sensor design rejects the influence of linear acceleration and vibration, enabling the ADXRS646 to offer rate sensing in harsh environments where shock and vibration are present.

The output signal, RATEOUT (1B, 2A), is a voltage proportional to angular rate about the axis normal to the top surface of the package. The measurement range is a minimum of ±250°/s. The output is ratiometric with respect to a provided reference supply. Other external capacitors are required for operation.

A temperature output is provided for compensation techniques. Two digital self-test inputs electromechanically excite the sensor to test proper operation of both the sensor and the signal conditioning circuits. The ADXRS646 is available in a 7 mm × 7 mm × 3 mm BGA chip-scale package.

FUNCTIONAL BLOCK DIAGRAM

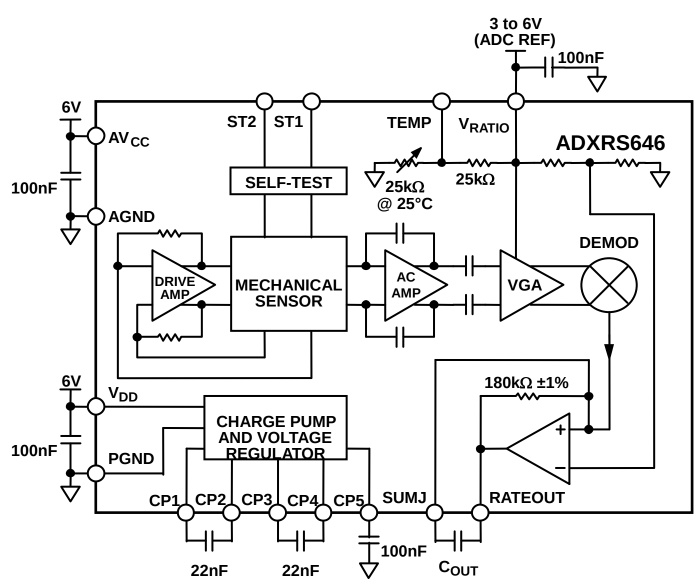

Figure 1. Block Diagram

Rev. PrA
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SPECIFICATIONS

All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

T_A = 25°C, V_S = AV_{CC} = V_{DD} = 6 V, V_{RATIO} = AV_{CC}, angular rate = 0°/sec, bandwidth = 80 Hz (C_{OUT} = 0.01 µF), I_{OUT} = 100 µA, ±1 *g*, unless otherwise noted.

Table 1.

Parameter	Conditions	Min	Typ	Max	Unit
SENSITIVITY[1]	Clockwise rotation is positive output				
Measurement Range[2]	Full-scale range over specifications range	±250	±300		°/sec
Initial and Over Temperature	−40°C to +105°C	8.5	9	9.5	mV/°/sec
Temperature Drift[3]			±2		%
Nonlinearity	Best fit straight line		0.01		% of FS
NULL[1]					
Null	−40°C to +105°C	2.7	3.0	3.3	V
Calibrated Null[7]	−40°C to +105°C		±0.1		°/sec
Temperature Drift	−40°C to +105°C		±1		°/sec
Linear Acceleration Effect	Any axis		0.015		°/sec/*g*
Vibration Rectification	25g RMS, 50Hz to 5kHz		0.0001		$°/s/g^2$
NOISE PERFORMANCE					
Rate Noise Density	T_A ≤ 25°C		0.01		°/sec/√Hz
Rate Noise Density	T_A ≤ 105°C		0.015		°/sec/√Hz
Resolution Floor	T_A = 25°C 1 minute to 1 hour in-run		8		°/hr
FREQUENCY RESPONSE					
Bandwidth[4]	±3dB user adjustable up to		1000		Hz
Sensor Resonant Frequency		16	18	20	kHz
SELF-TEST[1]					
ST1 RATEOUT Response	ST1 pin from Logic 0 to Logic 1		-50		°/sec
ST2 RATEOUT Response	ST2 pin from Logic 0 to Logic 1		50		°/sec
ST1 to ST2 Mismatch[5]		-5	±2	5	%
Logic 1 Input Voltage		4			V
Logic 0 Input Voltage				2	V
Input Impedance	To common	40	50	100	kΩ
TEMPERATURE SENSOR[1]					
V_{OUT} at 25°C	Load = 10 MΩ	2.8	2.9	3.0	V
Scale Factor[6]	25°C, V_{RATIO} = 5 V		10		mV/°C
Load to V_S			25		kΩ
Load to Common			25		kΩ
TURN-ON TIME[7]	Power on to ±0.5°/s of final with CP5 = 100nF			50	ms
OUTPUT DRIVE CAPABILITY					
Current Drive	For rated specifications			200	µA
Capacitive Load Drive				1000	pF
POWER SUPPLY					
Operating Voltage (V_S)		5.75	6.00	6.25	V
Quiescent Supply Current			4		mA
TEMPERATURE RANGE					
Specified Performance		−40		+105	°C

[1] Parameter is linearly ratiometric with V_{RATIO}.
[2] Measurement range is the maximum range possible, including output swing range, initial offset, sensitivity, offset drift, and sensitivity drift at 5 V supplies.
[3] From +25°C to −40°C or +25°C to +105°C.
[4] Adjusted by external capacitor, C_{OUT}. Reducing bandwidth below 0.01 Hz does not result in further noise improvement.
[5] Self-test mismatch is described as (ST2 + ST1)/((ST2 − ST1)/2).
[6] Scale factor for a change in temperature from 25°C to 26°C. V_{TEMP} is ratiometric to V_{RATIO}. See the Temperature Output and Calibration section for more information.
[7] Based on characterization

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Acceleration (Any Axis, 0.5 ms)	
Unpowered	10,000 *g*
Powered	10,000 *g*
V_{DD}, AV_{CC}	−0.3 V to +6.6 V
V_{RATIO}	AV_{CC}
ST1, ST2	AV_{CC}
Output Short-Circuit Duration (Any Pin to Common)	Indefinite
Operating Temperature Range	−55°C to +125°C
Storage Temperature Range	−65°C to +150°C

Stresses above those listed under the Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Drops onto hard surfaces can cause shocks of greater than 10,000 *g* and can exceed the absolute maximum rating of the device. Care should be exercised in handling to avoid damage.

RATE SENSITIVE AXIS

This is a Z-axis rate-sensing device (also called a yaw rate-sensing device). It produces a positive going output voltage for clockwise rotation about the axis normal to the package top, that is, clockwise when looking down at the package lid.

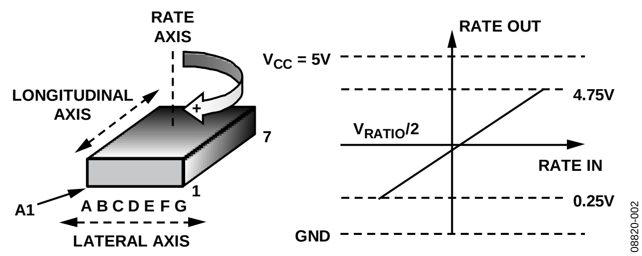
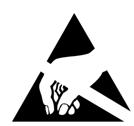


Figure 2. RATEOUT Signal Increases with Clockwise Rotation

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

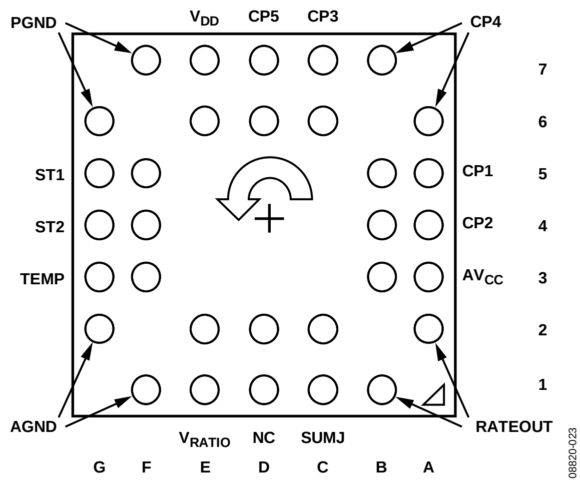


Figure 3. Pin Configuration

Table 3. Pin Function Descriptions

Pin No.	Mnemonic	Description
6D, 7D	CP5	HV Filter Capacitor, 100nF.
6A, 7B	CP4	Charge Pump Capacitor, 22 nF.
6C, 7C	CP3	Charge Pump Capacitor, 22 nF.
5A, 5B	CP1	Charge Pump Capacitor, 22 nF.
4A, 4B	CP2	Charge Pump Capacitor, 22 nF.
3A, 3B	AV_{CC}	Positive Analog Supply.
1B, 2A	RATEOUT	Rate Signal Output.
1C, 2C	SUMJ	Output Amp Summing Junction.
1D, 2D	NC	Do Not Connect.
1E, 2E	V_{RATIO}	Reference Supply for Ratiometric Output.
1F, 2G	AGND	Analog Supply Return.
3F, 3G	TEMP	Temperature Voltage Output.
4F, 4G	ST2	Self-Test for Sensor 2.
5F, 5G	ST1	Self-Test for Sensor 1.
6G, 7F	PGND	Charge Pump Supply Return.
6E, 7E	V_{DD}	Positive Charge Pump Supply.

TYPICAL PERFORMANCE CHARACTERISTICS

N > 1000 for all histograms, unless otherwise noted

Figure 4. Null Bias Error at 25°C

Figure 5. Null Drift Over Temperature

Figure 6. Null Output Over Temperature, Device Soldered on PCB

Figure 7. Sensitivity Error at 25°C

Figure 8. Sensitivity Drift Over Temperature

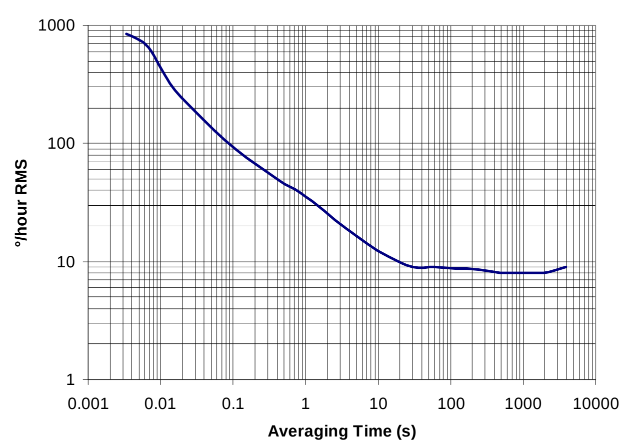


Figure 9. Typical Root Allan Deviation at 25°C vs. Averaging Time

THEORY OF OPERATION

The ADXRS646 operates on the principle of a resonator gyro. Figure 10 shows a simplified version of one of four polysilicon sensing structures. Each sensing structure contains a dither frame that is electrostatically driven to resonance. This produces the necessary velocity element to produce a Coriolis force when experiencing angular rate. The ADXRS646 is designed to sense a Z-axis (yaw) angular rate.

When the sensing structure is exposed to angular rate, the resulting Coriolis force couples into an outer sense frame, which contains movable fingers that are placed between fixed pickoff fingers. This forms a capacitive pickoff structure that senses Coriolis motion. The resulting signal is fed to a series of gain and demodulation stages that produce the electrical rate signal output. The quad sensor design rejects linear and angular acceleration, including external *g*-forces and vibration. This is achieved by mechanically coupling the four sensing structures such that external *g*-forces appear as common-mode signals that can be removed by the fully differential architecture implemented in the ADXRS646.

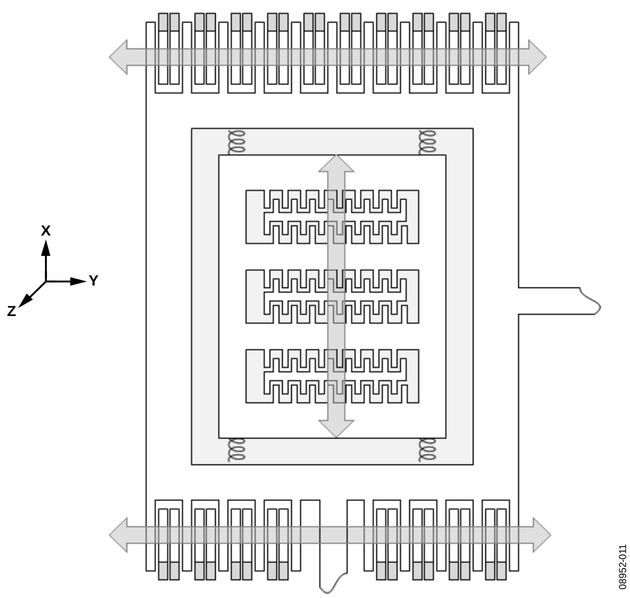


Figure 10. Simplified Gyro Sensing Structure – One Corner

The electrostatic resonator requires 21V for operation. Because only 6V are typically available in most applications, a charge pump is included on chip. If an external 21V supply is available, the two capacitors on CP1 to CP4 can be omitted, and this supply can be connected to CP5 (Pin 6D, Pin 7D). CP5 should not be grounded when power is applied to the ADXRS646. No damage occurs, but under certain conditions, the charge pump may fail to start up after the ground is removed without first removing power from the ADXRS646.

SETTING BANDWIDTH

External Capacitor C_{OUT} is used in combination with the on-chip R_{OUT} resistor to create a low-pass filter to limit the bandwidth of the ADXRS646 rate response. The −3 dB frequency set by R_{OUT} and C_{OUT} is

$$f_{OUT} = 1/(2 \times \pi \times R_{OUT} \times C_{OUT})$$

and can be well controlled because R_{OUT} has been trimmed during manufacturing to be 180 kΩ ± 1%. Any external resistor applied between the RATEOUT pin (1B, 2A) and SUMJ pin (1C, 2C) results in

$$R_{OUT} = (180\ \text{k}\Omega \times R_{EXT})/(180\ \text{k}\Omega + R_{EXT})$$

In general, an additional filter (in either hardware or software) is added to attenuate high frequency noise arising from demodulation spikes at the 18 kHz resonant frequency of the gyro. An R/C output filter consisting of a 3.3k series resistor and 22nF shunt capacitor (2.2kHz pole) is recommended. Figure 11. Power Spectral Density Output With and Without Additional Output Filtering shows the effect of adding a this filter to the output of an ADXRS646 set to 2000Hz bandwidth

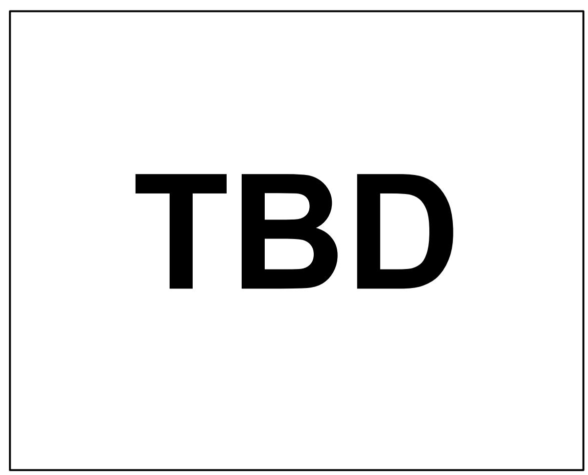


Figure 11. Power Spectral Density Output With and Without Additional Output Filtering

TEMPERATURE OUTPUT AND CALIBRATION

It is common practice to temperature-calibrate gyros to improve their overall accuracy. The ADXRS646 has a temperature proportional voltage output that provides input to such a calibration method. The temperature sensor structure is shown in Figure . The temperature output is characteristically nonlinear, and any load resistance connected to the TEMP output results in decreasing the TEMP output and its temperature coefficient. Therefore, buffering the output is recommended.

The voltage at TEMP (3F, 3G) is nominally 2.9 V at 25°C, and V_{RATIO} = 6 V. The temperature coefficient is ~10 mV/°C at 25°C. Although the TEMP output is highly repeatable, it has only modest absolute accuracy.

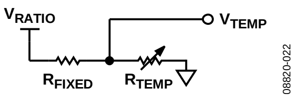


Figure 12. Temperature Sensor Structure

SUPPLY RATIOMETRICITY

The AD646's RATEOUT, ST1, ST2, and TEMP signals are ratiometric to the V_{RATIO} voltage, i.e., the null voltage, rate sensitivity, and temperature outputs are proportional to V_{RATIO}. So, it is most easily used with a supply-ratiometric ADC which results in self cancellation of errors due to minor supply variations. There is some small, usually negligible, error due to non-ratiometric behavior. Note that, in order to guarantee full rate range, V_{RATIO} should not be greater than AV_{CC}

NULL ADJUSTMENT

The nominal 3.0 V null is for a symmetrical swing range at RATEOUT (1B, 2A). However, a nonsymmetric output swing may be suitable in some applications. Null adjustment is possible by injecting a suitable current to SUMJ (1C, 2C). Note that supply disturbances may reflect some null instability. Digital supply noise should be avoided, particularly in this case.

SELF-TEST FUNCTION

The ADXRS646 includes a self-test feature that actuates each of the sensing structures and associated electronics in the same manner, as if subjected to angular rate. It is activated by standard logic high levels applied to Input ST1 (5F, 5G), Input ST2 (4F, 4G), or both. ST1 causes the voltage at RATEOUT to change about −0.5 V, and ST2 causes an opposite change of +0.5 V. The self-test response follows the viscosity temperature dependence of the package atmosphere, approximately 0.25%/°C.

Activating both ST1 and ST2 simultaneously is not damaging. ST1 and ST2 are fairly closely matched (±2%), but actuating both simultaneously may result in a small apparent null bias shift proportional to the degree of self-test mismatch.

ST1 and ST2 are activated by applying a voltage equal to V_{RATIO} to the ST1 pin and the ST2 pin. The voltage applied to ST1 and ST2 must never be greater than AV_{CC}.

CONTINUOUS SELF-TEST

The on-chip integration of the ADXRS646 gives it higher reliability than is obtainable with any other high volume manufacturing method. Also, it is manufactured under a mature BiMOS process that has field-proven reliability. As an additional failure detection measure, power-on self-test can be performed. However, some applications may warrant continuous self-test while sensing rate. Details outlining continuous self-test techniques are also available in the AN-768 Application Note.

MODIFYING THE MEASUREMENT RANGE

The ADXRS646 scale factor can be reduced to extend the measurement range to as much as ±450°/s by adding a single 225kΩ resistor between the RATEOUT and SUMJ. If an external resistor is added between RATEOUT and SUMJ C_{OUT} must be proportionally increased to maintain correct bandwidth.

MECHANICAL PERFORMANCE

The ADXRS646 excellent vibration rejection is demonstrated in the graphs below. Figure 13 shows the ADXRS646 output response with and without 15g RMS 50Hz to 5kHz of random vibration. Bandwidth of the gyro was limited to 1600Hz. Performance is similar regardless of the direction of input vibration.

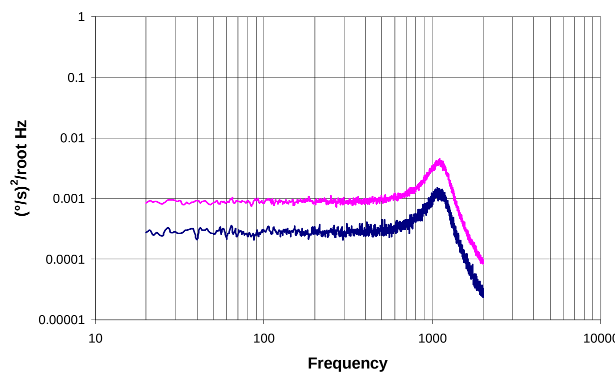


Figure 13. ADXRS646 Output Response With and Without Random Vibration (15g RMS, 50Hz to 5kHz)

Figure 14 demonstrates the ADXRS646 DC bias response to 5g Sine vibration over the 20Hz to 5kHz range. As can be seen, there are no sensitive frequencies present and vibration rectification is vanishingly small. As in the previous example gyro bandwidth was set to 1600Hz.

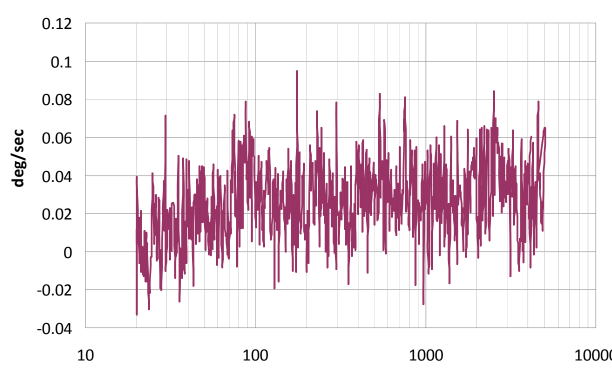


Figure 14. ADXRS646 Sine Vibration Output Response (5g, 20Hz to 5kHz)

OUTLINE DIMENSIONS

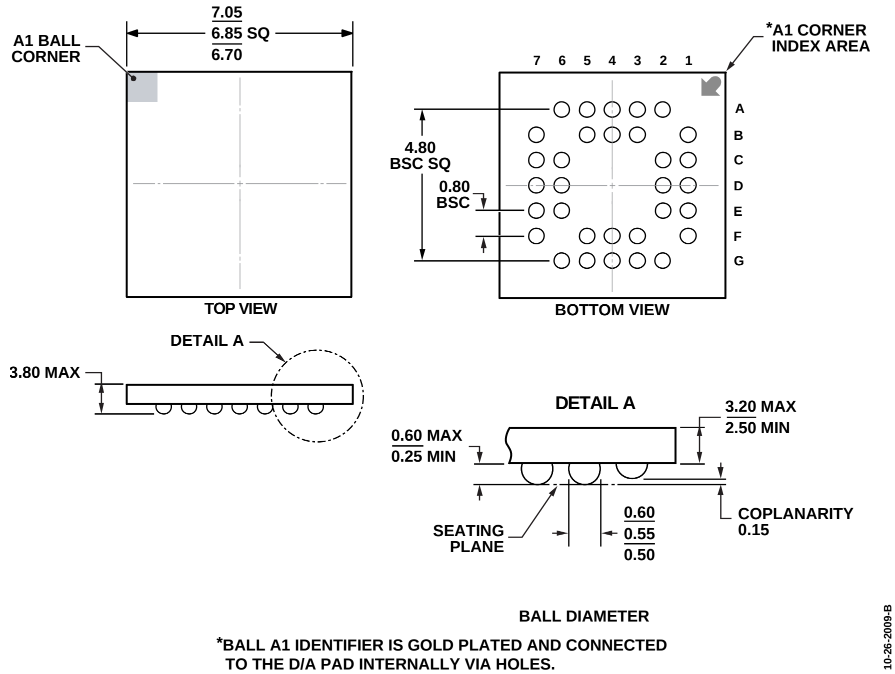


Figure 15. 32-Lead Ceramic Ball Grid Array [CBGA]
(BC-32-3)
Dimensions shown in millimeters

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option
ADXRS646BBGZ	−40°C to +105°C	32-Lead Ceramic Ball Grid Array [CBGA]	BC-32-3
ADXRS646BBGZ-RL	−40°C to +105°C	32-Lead Ceramic Ball Grid Array [CBGA]	BC-32-3
ADXRS646TBGZ-EP	−55°C to +105°C	32-Lead Ceramic Ball Grid Array [CBGA]	BC-32-3
ADXRS646TBGZ-EP-RL	−55°C to +105°C	32-Lead Ceramic Ball Grid Array [CBGA]	BC-32-3
EVAL-ADXRS646Z		Evaluation Board	

[1] Z = RoHS Compliant Part.

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